My Troubleshooting Textbook

by Max Robinson

Chapter 10 Things That Have Never Worked.

Chapter 0

Review of Fundamentals.

In order to understand the material in this book, the reader must understand certain fundamentals of electricity and electronics. The teaching of these fundamentals is far beyond the scope of this book. This chapter is merely a review. If the reader is not familiar with any of what is presented in this chapter, it is strongly urged that he or she supplement his or her knowledge by studying Electronics for Physicists.

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0.1 DC CIRCUITS.

Kirchhoff's voltage law states that the algebraic sum of all voltage drops around a closed loop is equal to zero.

Kirchhoff's current law states that the algebraic sum of all currents flowing into a node is equal to zero.

The consequences of these laws for series circuits are a) the sum of all voltage rises is equal to the sum of all voltage drops, and b) the current anywhere in a series circuit is equal to the current anywhere else in the same circuit.

The consequences of Kirchhoff's laws for parallel circuits are a) the sum of all upward flowing currents is equal to the sum of all downward flowing currents, and b) the voltage across any element in the circuit is equal to the voltage across any other element in the same circuit.

Ohm's law states the relationship between voltage, current and resistance in an electric circuit.

$$V = I \times R \qquad \text{(Eq. 0.1)}$$

$$I = V/R \qquad \text{(Eq. 0.2)}$$

$$R = V/I \qquad \text{(Eq. 0.3)}$$

where V is voltage in volts, I is current in amperes and R is resistance in ohms.

To properly apply Ohm's law it is necessary to use the resistance of a particular resistor, the current through that same resistor and the voltage across that same resistor.

When resistors are connected in series the total resistance is

$$R_T = R_1 + R_2 + R_3 + \ldots + R_n$$

for any number of resistors in series.

When resistors are connected in parallel the equivalent resistance is

$$1/R_{eq} = 1/R_1 + 1/R_2 + 1/R_3 + \ldots + 1/R_n$$

for any number of resistors in parallel.

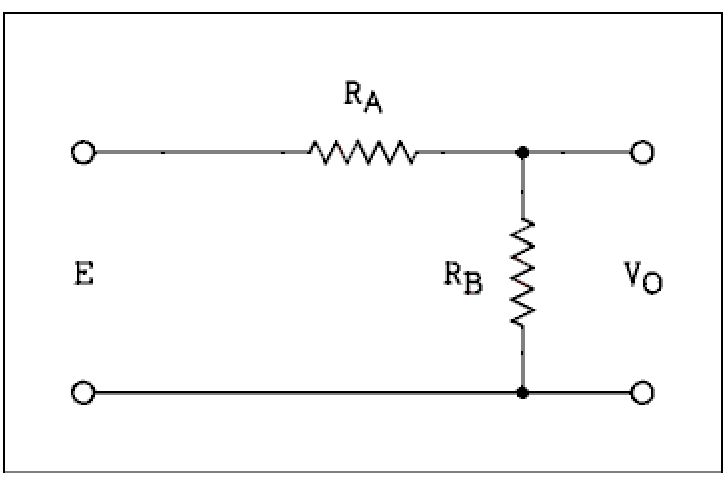

Figure 0.1, Voltage Divider Circuit.

For a verbal description click here.

Figure 0.1 is of a voltage divider. R_A and R_B may be the equivalent of other resistors in series and/or parallel. The output voltage Vo is given by

$$V_o = E\, R_B/(R_A + R_B) \qquad \text{(Eq. 0.4)}$$

Thevenin's theorem states that a network with output terminals and is of any level of complexity, using resistors, can be reduced to one ideal voltage source in series with a single resistance.

The ideal (Thevenin) voltage source is equal to the no- load output voltage of the original network.

The Thevenin resistance is equal to the resistance looking in at the terminals of the original network with all voltage sources replaced by shorts and all current sources replaced by opens.

Example 0.1.

Determine the Thevenin equivalent circuit of the network of figure 0.2.

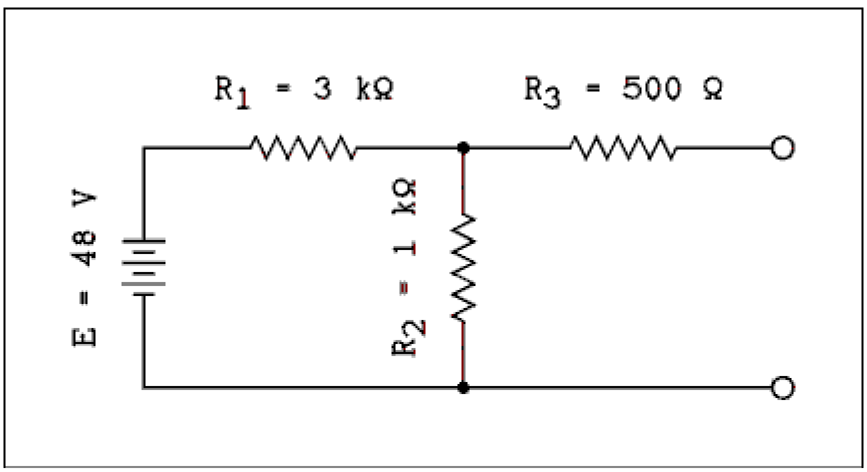

Figure 0.2, Circuit for Example 0.1.

For a verbal description click here.

Solution:

With no load connected to the output, there will be no voltage drop across R3. Therefore, the voltage across R2 will be the same as the output voltage. R1 and R2 make up a voltage divider. By equation 0.4 we have

V_o = 48 v x 1 k ohm / (3 k ohm + 1 k ohm) = 12 volts.

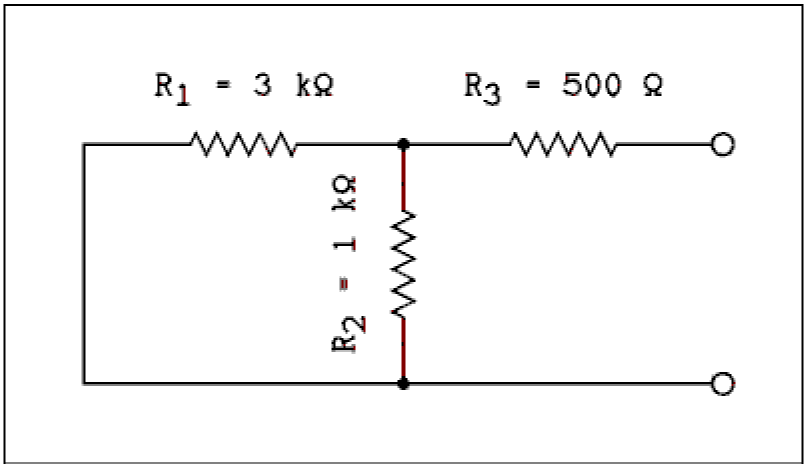

Figure 0.3, Network of Figure 0.2 with the voltage source replaced by a short.

For a verbal description click here.

If we replace the battery in figure 0.2 with a short and redraw the circuit we have the circuit of figure 0.3. The resistance looking in at the terminals is R1 in parallel with R2 and this combination in series with R_3. R_1 in parallel with R_2 is R_{12} = 1/(1/(1 k ohm) + 1/(3 k ohm)) = 750 ohm. Now adding R_3 in series we have 750 ohm + 500 ohm = 1250 ohm. The Thevenin equivalent circuit is shown in figure 0.4.

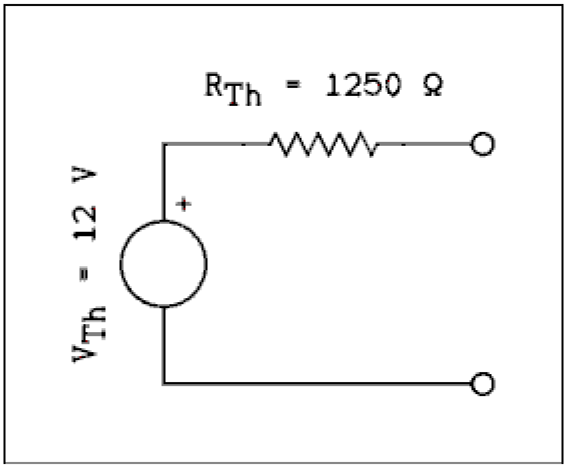

Figure 0.4, Thevenin's Equivalent Circuit of Figure 0.2.

For a verbal description click here.

There are many other methods of solving electric networks. A few of these are Norton's theorem, superposition theorem, loop equations, node equations and Y-delta transformation. If you do not understand these techniques, it will be necessary to take an introductory level course in electrical engineering.

RC Time Constant.

If a capacitor C is being charged or discharged through a resistor R the time constant is given by

$$T = R \times C \qquad \text{(Eq. 0.5)}$$

where T is time in seconds, R is resistance in ohms and C is capacitance in farads.

T is the time required for a charging capacitor to charge up to 63.2 percent of its final voltage or for a discharging capacitor to discharge to 36.8 percent of its starting voltage.

Theoretically a capacitor will never get fully charged or discharged. As a matter of practicality a capacitor is considered to be fully charged or discharged after 5 x T seconds have elapsed.

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0.2 AC CIRCUITS.

All of the laws and theorems which apply to DC also apply to AC. In theorems stated in words replace the word "resistance" by the word "impedance". In equations, replace the symbol R by the symbol Z where Z = R + jX or Z = Z /_ Theta

A capacitor is an open circuit for DC but has reactance for AC. The reactance of a capacitor is

$$X_C = 1 / (2 \times Pi \times f \times C) \qquad \text{(Eq. 0.6)}$$

where X_C is the reactance of the capacitor in ohms, f is the frequency in hertz and C is the capacitance in farads.

An inductor has a very low resistance for DC (ideally zero) but has reactance for AC. The reactance is given by

$$X_L = 2 \times Pi \times f \times L \qquad \text{(Eq. 0.7)}$$

where X_L is the reactance of the inductor in ohms, f is the frequency in hertz and L is the inductance in henrys.

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0.3 POWER SUPPLIES.

Power supplies serve the purpose of changing the 120 volt AC line voltage to one or more useful DC voltage(s).

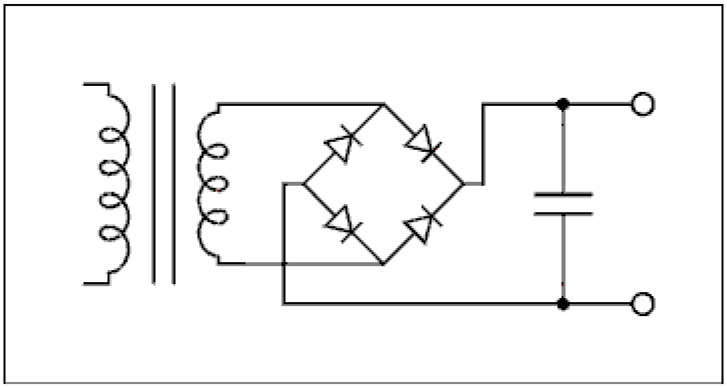

Figure 0.5, Full-Wave Bridge Rectifier Power Supply.

For a verbal description click here.

The circuit of a full-wave bridge rectifier is shown in figure 0.5. The no-load output voltage of this circuit is given by

$E_M = E_{AC}$ x Square Root (2) (Eq. 0.8)

where E_M is the no-load DC output voltage of the circuit and E_{AC} is the RMS AC voltage across the entire transformer secondary.

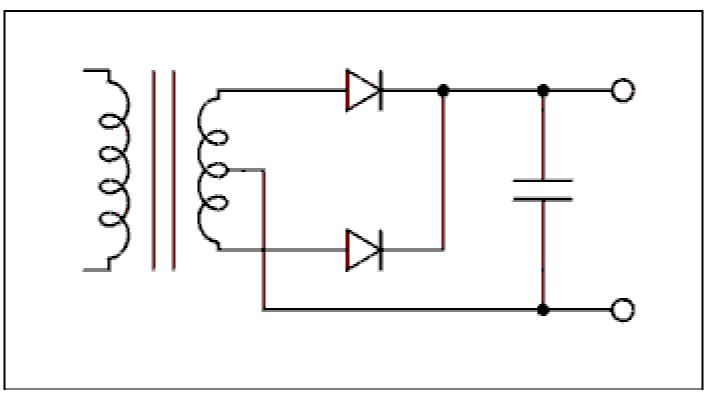

Figure 0.6, Full-Wave Center-Tapped Rectifier Power Supply.

For a verbal description click here.

The circuit of a full-wave center-tapped rectifier is shown in figure 0.6. The no-load voltage of this circuit is given by

$E_M = E_{AC}$ x Square Root (2)/2 (Eq. 0.9)

where E_M is the no-load DC output voltage of the circuit and E_{AC} is the RMS AC voltage across the entire transformer secondary.

The ripple output from a full-wave rectifier power Supply operating on 60 Hz is given by

$V_R = E_M$ / (200 x R_L x C (Eq 0.10)

where V_R is the peak to peak ripple voltage of the power supply, E_M is the no-load DC output voltage as given by equation 0.8 or 0.9, R_L is the equivalent load resistance on the power supply in ohms and C is the capacitance of the filter capacitor in farads.

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0.4 BIPOLAR TRANSISTOR FUNDAMENTALS.

All of the following discussion assumes the transistors are NPN. For PNP transistors, just reverse all voltages and currents.

A transistor has three terminals. They are called emitter, base and collector. Internally the transistor is made up of three alternating layers of semiconductor material, for example, NPN. The emitter is one of the N layers, the base is the P layer and the collector is the other N layer. This means that there are two P-N junctions, one between the emitter and base and the other between the collector and base.

The normal way of biasing a transistor is to forward bias the base-emitter junction and reverse bias the collector-base junction. For an NPN transistor this means to connect a current source between emitter and base so as to run current into the base, and connect a Thevenin circuit between emitter and collector such that the collector is positive and the Thevenin voltage source is greater than 0.6 volts. Figure 0.7 shows the biasing circuit.

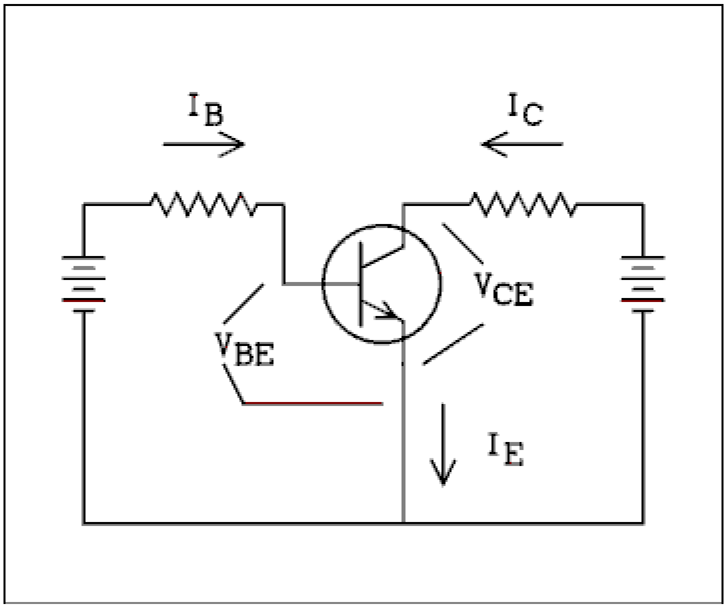

Figure 0.7, Ideal Biasing Circuit for an NPN Transistor.

For a verbal description click here.

The voltage between emitter and base VBE is about 0.65 volts. Some authors round this up to 0.7 while others round it down to 0.6 volts. Depending on the magnitude of the collector current the voltage between collector and emitter V_{CE} will be anywhere between 0.1 volts and V_{TH}.

If V_{CE} = 0.1 volts, the transistor is said to be in saturation. If $V_{CE} = V_{TH}$ the transistor is said to be in cutoff. If 0.1 volts $< V_{CE} < V_{TH}$ is true, the transistor is said to be in linear operation.

When the transistor is in linear operation the collector current is controlled by the base current. If the base current is zero, the collector current is zero because the collector base junction is reversed biased. As base current increases, the collector current increases. The current gain of the transistor is defined as follows.

$$\text{Beta} = I_C / I_B \qquad \text{(Eq. 0.11)}$$

Therefore,

$$I_C = \text{Beta} \times I_B \qquad \text{(Eq. 0.12)}$$

The emitter current is the sum of base and collector currents.

$$I_E = I_B + I_C \qquad \text{(Eq. 0.13)}$$

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0.5 BIPOLAR TRANSISTOR CIRCUITS.

Figure 0.8 gives a practical biasing circuit for an NPN transistor. It will be easier to analyze this circuit if we reduce the voltage divider in the base circuit to its Thevenin equivalent circuit. This has been done in figure 0.9.

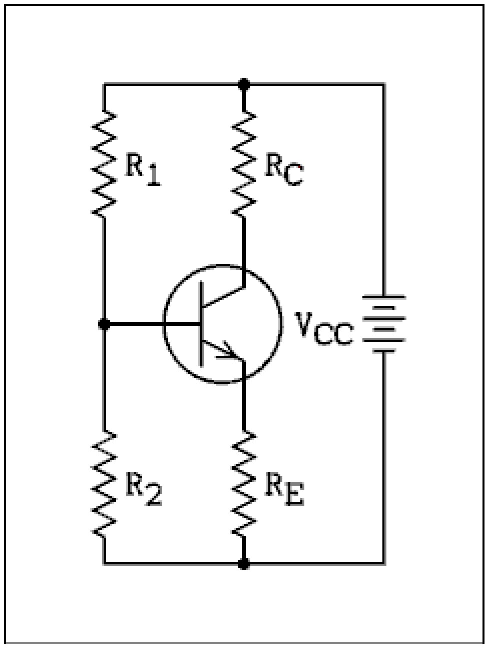

Figure 0.8, Transistor with Constant Voltage Biasing.

For a verbal description click here.

$$V_{BB} = V_{CC} \times R_2 / (R_1 + R_2)$$

And

$$R_B = (R_1 \times R_2) / (R_1 + R_2).$$

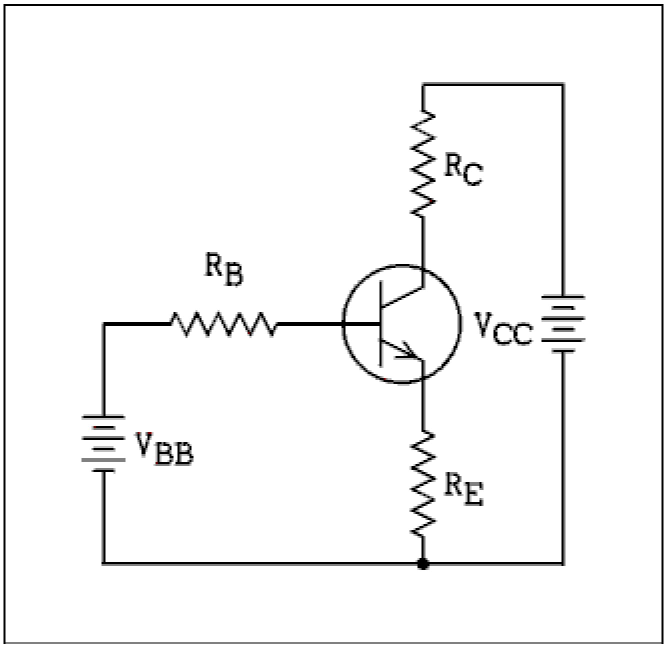

Figure 0.9, Constant Voltage Biasing Circuit with a Thevenin's equivalent circuit replacing the voltage divider in the base circuit.

For a verbal description click here.

If we write a loop equation around the base loop and substitute equations 0.12 and 0.13 we get this equation for the collector current.

Exact form $I_C = Beta\ (V_{BB} - V_{BE}) / (R_B + R_E\ (Beta + 1))$ (Eq. 0.14)

If Beta is large or guessed at, and it is usually both, the collector current becomes

First approximation $I_C = (V_{BB} - V_{BE}) / ((R_B/Beta) + R_E)$ Eq. 0.15

If R_B / Beta << R_E, as it sometimes is, the collector current becomes,

Second approximation $I_C = (V_{BB} - V_{BE}) / R_E$ (Eq. 0.16)

There are three ways of injecting and recovering signals in a transistor amplifier. These are common emitter, common collector (emitter follower) and common base.

Common Emitter Amplifier.

A common emitter amplifier is shown in figure 0.10. The common sides of the input and output are connected to the circuit ground. The emitter of the transistor is also connected to signal ground through a capacitor. The emitter is common to both input and output. The resistor on the right labeled R_{FS} is the input resistance of the Following Stage. The voltage gain of this circuit is

$$A_V = - Beta \times R_L / h_{ie} \qquad \text{(Eq. 0.17)}$$

where A_V is the voltage gain, Beta is as defined above, R_L is the parallel combination of all resistances connected to the collector of the transistor and h_{ie} is the input resistance of the transistor. h_{ie} is never given in transistor manuals. It can be found in manufacturers' data sheets but it varies quite a lot from one unit to the next, even of the same type number. As a very rough approximation h_{ie} = (1 volt) / I_C, this approximation is not good enough to get an equation number.

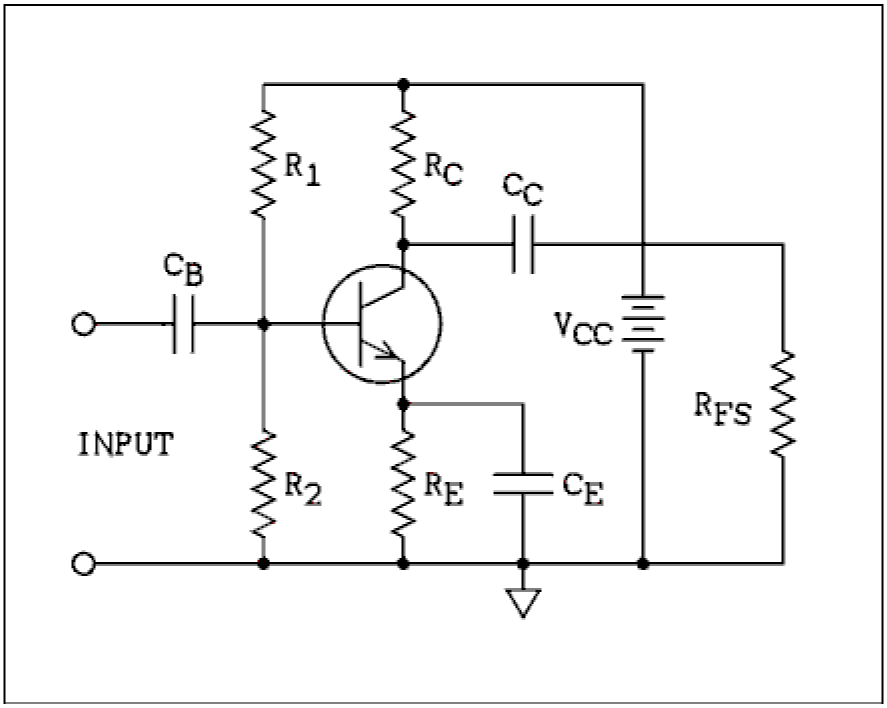

Figure 0.10, Common Emitter Amplifier Circuit.

For a verbal description click here.

The input impedance is equal to h_{ie} in parallel with the parallel combination of R1 and R2, The output impedance is equal to R_C.

If the emitter bypass capacitor is removed the gain becomes

$$A_V = - R_L / R_E \qquad \text{(Eq. 0.18)}$$

where R_L is as defined above and R_E is the emitter resistor.

The input resistance is R_{in} in parallel with R_B. R_{in} is given by

$$R_{in} = h_{ie} + Beta \times R_E \qquad \text{(Eq. 0.19)}$$

The term Beta x R_E is usually much greater than h_{ie} so the equation becomes

$$R_{in} = Beta \times R_E \qquad \text{(Eq. 0.20)}$$

The output impedance remains equal to R_C.

The upper frequency limit of an amplifier is considered to be the frequency at which the output is 3 db down from the output at medium frequencies. This is variously known as the upper frequency limit, the upper 3 db frequency, the upper corner frequency, the upper cutoff frequency or the bandwidth. We will symbolize this frequency by f_C.

$$f_C = 1 / (2 \times Pi \times R_l \times C) \qquad \text{(Eq. 0.21)}$$

where R_L is the parallel combination of R_C and all other resistances connected to the collector in ohms and C is the total capacitance from collector to ground in farads.

The Miller effect causes the input capacitance of an inverting amplifier to be much larger than the stray wiring capacitance. The Miller capacitance is given by

$$C_M = C_{BC} \times (1 - A_V) \qquad \text{(Eq. 0.22)}$$

where C_M is the Miller capacitance and C_{BC} is the capacitance between collector and base of the transistor including wiring capacitance. Remember that in an inverting amplifier A_V is a negative number.

Common Collector (Emitter-Follower) Amplifiers.

The circuit of a common collector amplifier is shown in figure 0.11. Equations 0.14 through 0.16 may be used to calculate the collector current of this circuit.

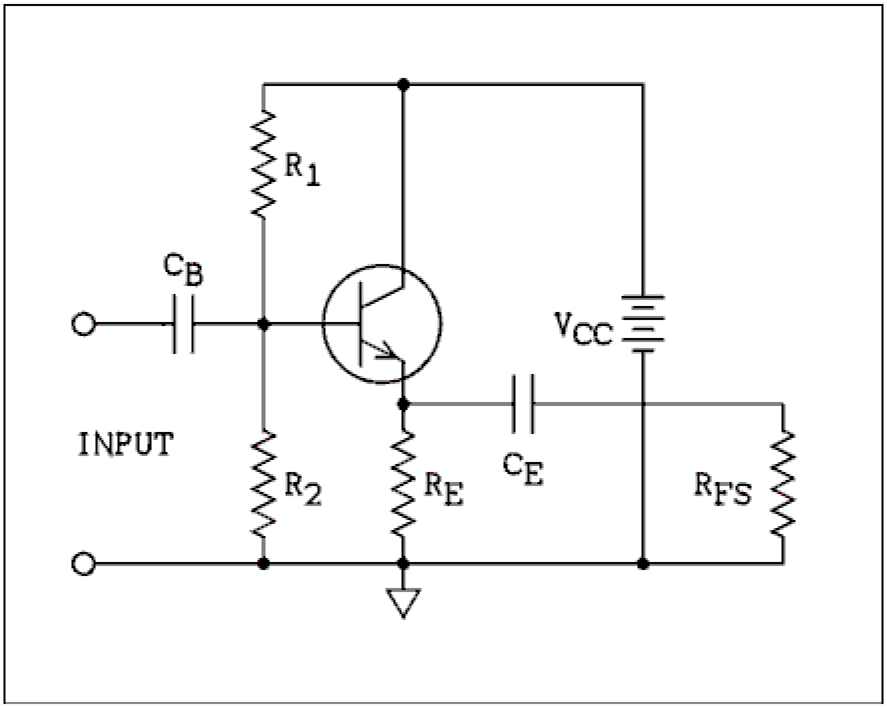

Figure 0.11, Common Collector (Emitter-Follower) Amplifier.

For a verbal description click here.

The voltage gain of this circuit is approximately equal to unity.

The input impedance of this circuit is the parallel combination of R_{in} in parallel with both R_1 and R_2.

$$R_{in} = \text{Beta} \times R_L \qquad \text{(Eq. 0.23)}$$

where R_L is the parallel combination of all resistors connected to the emitter of the transistor.

The output impedance of this circuit is R_E in parallel with R_{OUT}.

$$R_{OUT} = R_S / \text{Beta} \qquad \text{(Eq. 0.24)}$$

where R_S is the parallel combination of R_1, R_2 and R_g, the generator output resistance.

Because the voltage gain is very close to + 1, equation 0.22 tells us that the Miller capacitance CM is essentially zero. Do not get the mistaken impression that the input capacitance is zero. There is always stray wiring capacitance.

Common Base Amplifier.

The circuit of a common base amplifier is shown in figure 0.12. The voltage gain is given by equation 0.17. The input resistance is approximately equal to h_{ie} / Beta. The output impedance is equal to R_C.

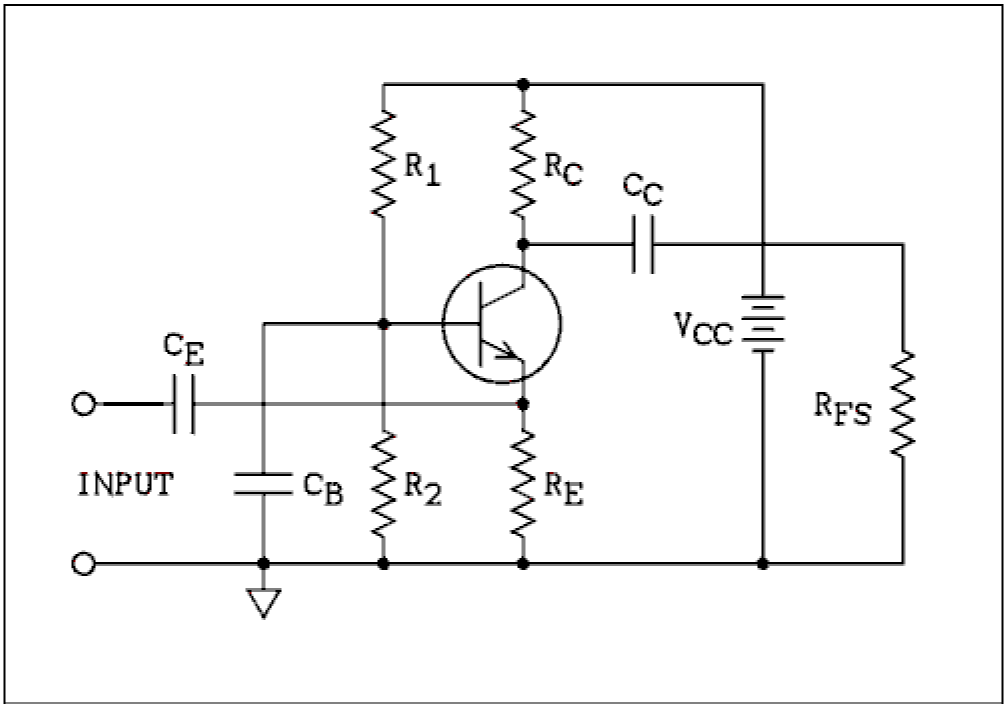

Figure 0.12, Common Base Amplifier.

For a verbal description click here.

The base of a transistor is physically between the emitter and collector. When the base is grounded (for AC), the base becomes an electrostatic shield between the emitter (input) and collector (output). Through careful circuit layout C_{EC} the capacitance between emitter and collector can be made very small (of the order of 0.1 pf).

A common base amplifier is noninverting. Equation 0.22 would actually give a negative input capacitance. This negative Miller capacitance will cancel with positive (real) stray circuit capacitance and it is possible to achieve a net zero input capacitance. Such an amplifier can have a very wide bandwidth.

Common base amplifiers are used as amplifiers in VHF and UHF receivers and as wide-band amplifiers in the vertical channel of oscilloscopes. When used in this application the power supplies are arranged so the base is at DC as well as AC ground. This permits a low impedance ground connection.

Feedback.

When feedback is applied to transistor amplifiers, the equations are derived in such a way as to allow for positive or negative feedback. To avoid contradictions with the Electronics for Physicists book the equation given here will not be the same as seen in other books but will be the same as in the afore mentioned book. The gain of an amplifier with feedback A' is given by

$$A' = A / (1 + A B) \qquad \text{(Eq. 0.25)}$$

where A is the gain of the amplifier without feedback and B is that fraction of the output signal which is fed back to the input.

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0.6 OPERATIONAL AMPLIFIERS.

An operational amplifier is an amplifier with a differential input and a very high gain. The frequency response of the amplifier has been tailored to prevent oscillation when negative feedback is applied to reduce the gain to unity.

A differential input consists of two inputs with respect to ground. If the same signal is applied to both inputs, the difference between the two inputs will be zero and the output of the amplifier will be zero, theoretically. There will be some small output. If two signals which are similar but not identical are applied, the amplifier will amplify the difference between the two signals.

If one input is grounded and a signal put into the other input, the amplifier will amplify that signal. If the signal is put into the noninverting input, the output will be of the same sign as the input signal. If the signal is put into the inverting input, the output will be of the opposite sign as the input signal.

If the inverting input is more positive than the noninverting input, the output will go negative. If the noninverting input is more positive than the inverting input, the output will go positive.

When we analyze operational amplifier circuits, the feedback is always assumed to be negative. The equation which results is

$$A' = A / (1 + A \times B) \qquad \text{(Eq. 0.26)}$$

The open loop gain A is entered as a positive number.

Equation 0.26 is seldom seen in connection with op amps because the open loop gain A is so large. The limit as A approaches infinity is,

$$A' = 1 / B \qquad \text{(Eq. 0.27)}$$

where B is that fraction of the output signal which is fed back to the input.

Equation 0.27 is based on the assumption that A x B is much greater than one. A x B may not always be much greater than one, especially at high frequencies.

The gain of an op amp falls off as frequency increases at the rate of 20 db per decade. The unity gain frequency of an op amp is given in its specifications. The gain A at any frequency f is given by

$$A = f_G / f \qquad \text{(Eq. 0.28)}$$

where f_G is the unity gain frequency of the op amp. If equation 0.28 gives a value greater than the specified DC gain, the DC gain is the gain at that frequency, not the result of equation 0.28.

In the case of a 741 op amp which has a unity gain bandwidth of 1 megahertz, the gain at 20 kilohertz is only 50. Common emitter amplifiers often have more gain than this.

If the gain is low due to frequency effects, equation 0.26 should be used instead of equation 0.27.

Figure 0.13 is the circuit of an inverting amplifier. For this circuit the value of B is given by

Inverting Amplifier. $$B = R_1 / R_2 \qquad \text{(Eq. 0.29)}$$

This equation gives the value of B to be used in equation 0.26 or 0.27. For best temperature stability R_3 should be equal to the parallel combination of R_1 and R_2.

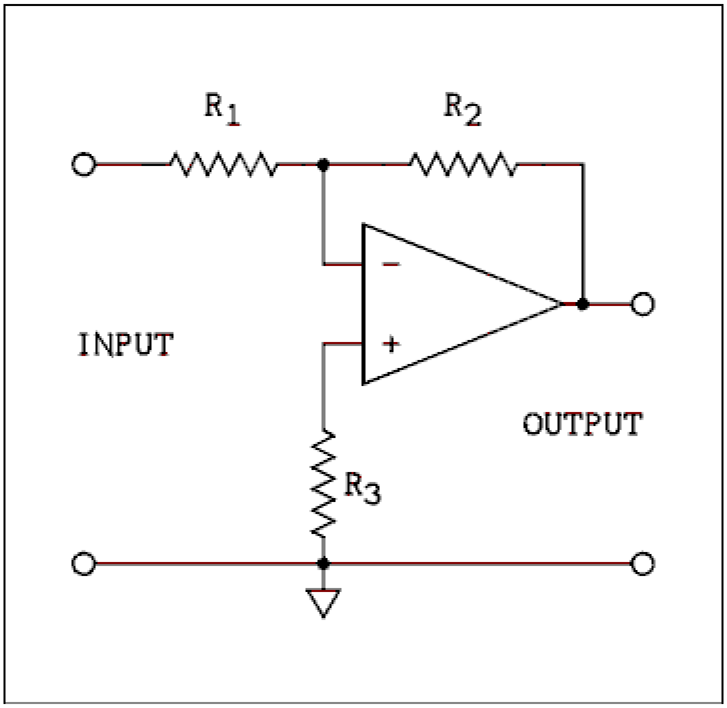

Figure 0.13, Inverting Amplifier with Op Amp.

For a verbal description click here.

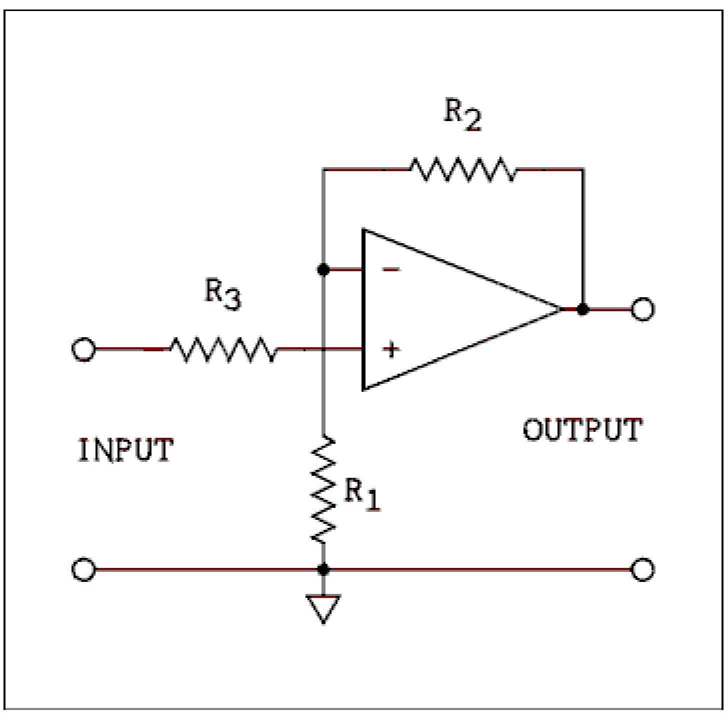

Figure 0.14, Noninverting Amplifier.

For a verbal description click here.

Figure 0.14 is the circuit of a noninverting amplifier. For this circuit the value of B is given by

Noninverting Amplifier. $B = R_1 / (R_1 + R_2)$ (Eq. 0.30)

This equation gives the value of B to be used in equation 0.26 or 0.27. For best temperature stability R_3 should be equal to the parallel combination of R_1 and R_2.

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0.7 FIELD EFFECT TRANSISTORS.

Junction FET.

A field effect transistor (FET) consist of a P-N junction on the side of a bar of silicon. The bar is known as the channel. One end of the channel is the Source, the other end is the Drain, and the other side of the P-N junction is the Gate. If the channel is N type semiconductor, the Gate is P type.

When the P-N junction of the Gate and channel is reversed biased a depletion region in the channel reduces its effective cross section area. This restricts current flow between the Source and Drain. The larger the reverse bias, the more the channel is restricted and the smaller the current between Source and Drain. The JFET (Junction Field Effect Transistor) is almost never used with the Gate to channel junction forward biased.

Note: In oscillators and class C amplifiers the gate is purposefully driven positive which causes rectification. The rectified voltage is negative which provides proper bias for an N channel FET. When a MOSFET is used, see below, a diode is connected from Gate to Source to accomplish the necessary rectification.

Metal Oxide Semiconductor FET (MOSFET).

Since the P-N junction is not normally forward biased, there is no need to have an actual P-N junction to create the depletion region. All that is needed is an electric field which can be created by a metallic plate. A small spot on the N type semiconductor is exposed to oxygen which creates a thin layer of silicon dioxide, hence the name. This thin glass layer is coated with metal which forms the gate. In operation an MOSFET acts almost the same as a JFET except that the gate can be driven positive for even higher conduction. Like its junction brother, the MOS FET is rarely operated in this condition. When used in an oscillator or a class C amplifier a diode is connected from Gate to Source to provide the necessary bias rectification. For convenience an N channel MOSFET is constructed on a P type substraight. This substraight is either internally connected to the Source, or is brought out to its own lead and the user must connect it to the most negative part of the circuit. This configuration is known as a depletion mode MOSFET.

The MOSFET can be made in another configuration. A lightly doped P region, part of the substraight, is placed between the Source and Drain. This does not allow conduction between them. When the Gate is biased positively the holes in the region between Source and Drain are repelled deeper into the substraight leaving electrons behind. This effectively turns this region from P to N type semiconductor which allows conduction. The more positive the Gate the more conduction there is between Source and Drain. This is known as an enhancement mode MOSFET.

In 1987 MOSFETs were used primarily for switching in logic circuits. They are still used for that but a new generation of MOSFETs has been developed which will stand up to very high voltage and power. In that respect they are as close to silicon tubes as can be.

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0.8 FET Circuits.

The junction FET is used most often as a source follower, analogous to the emitter follower, for a high impedance input and a low impedance output. The input impedance is the resistor from gate to ground and the capacitance is a very few pf. The output impedance is 1 over the transductance in parallel with the source resistor.

A special type of JFET known as a GASFET (Gallium Arsenide) is used as the low noise amplifier in satellite receivers.

High voltage MOSFETs are used in both analog and switching modes. The former includes but not limited to, * pass transistors in constant voltage and constant current power supplies, and output transistors in audio and servo amplifiers. The latter includes * switching power supplies, and variable speed drives for industrial electric motors.

* Have you ever read one of those terms of use things on the internet?

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0.9 Vacuum Tube Fundamentals.

A vacuum tube is constructed inside a glass envelope which is evacuated to a very high level. The envelope is usually cylindrical which is the reason for the name. The internal structure is usually cylindrical as well. The filament or heater runs down the center. If the tube is a filamentary type it serves as the cathode which emits electrons when heated. If the tube is a heater/cathode type the cylindrical cathode surrounds the heater but is electrically insulated from it. Next out is the control grid. If there are additional grids they surround the control grid. Everything is surrounded by the plate or anode and is coaxial.

Filament type tubes are the oldest type. In the golden age of tubes, 1950s, filament types were only used for very low power, used in portable radios, or high power, in radio transmitters. The heater/cathode type is by far the most common. They were used in radios, TV sets, audio amplifiers and a wide range of measurement and industrial equipment.

The minimum tube is a diode which consists of a cathode and anode. This is used primarily as a rectifier in power supplies and radio detectors.

Next higher is the triode, 3 element tube. (Note: The heater does not count when elements inside a tube are counted.) It consists of the cathode, control grid, and plate or anode. This type is favored by audio enthusiasts. Like the FET, the grid usually operates negative with respect to the cathode while the plate is positive.

Next higher on the totem pole is the tetrode which has two grids. The one closest to the cathode is the control grid and the outer one is known as the screen grid. The additional grid was added to serve as an electrostatic shield between the grid and plate. The control grid to plate capacitance caused RF amplifiers to oscillate and a means was needed to reduce this capacitance. The screen grid is made positive usually about equal to the plate or occasionally even higher. This type of tube has problems and very few true tetrodes were ever manufactured. There is a form of the tetrode in which a beam forming element was added between the screen grid and plate. It was connected to the cathode within the tube. This was done initially to avoid infringing on a patent but turned out to produce one of the best tubes ever made, the 6L6 and its many derivatives. The beam forming element suppressed secondary emission of electrons from the plate.

The pentode inserts a third grid between the screen grid and plate. This is also a method of suppressing secondary emission of electrons from the plate. It is called the suppressor grid. It is often brought out to a pin and the designer has to tie it to the cathode, or rarely, ground.

Toward the end of the golden age of tubes when there began to be significant competition from transistors, a type of tube was developed for use in car radios that would operate with no more than 12 volts on the plate. It was known as a space charge tube and was a pentode, but the control grid and screen grid were interchanged. The grid closest to the cathode was operated at 12 volts to get the electrons moving and the second grid was the control grid. The third grid served as a shield between the plate and control grid to prevent oscillation when the tube was used as a radio frequency amplifier.

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0.10 Tube Circuits.

The only circuits to be reviewed here are the resistance coupled amplifiers. Remember, this is only a refresher of knowledge you should already possess.

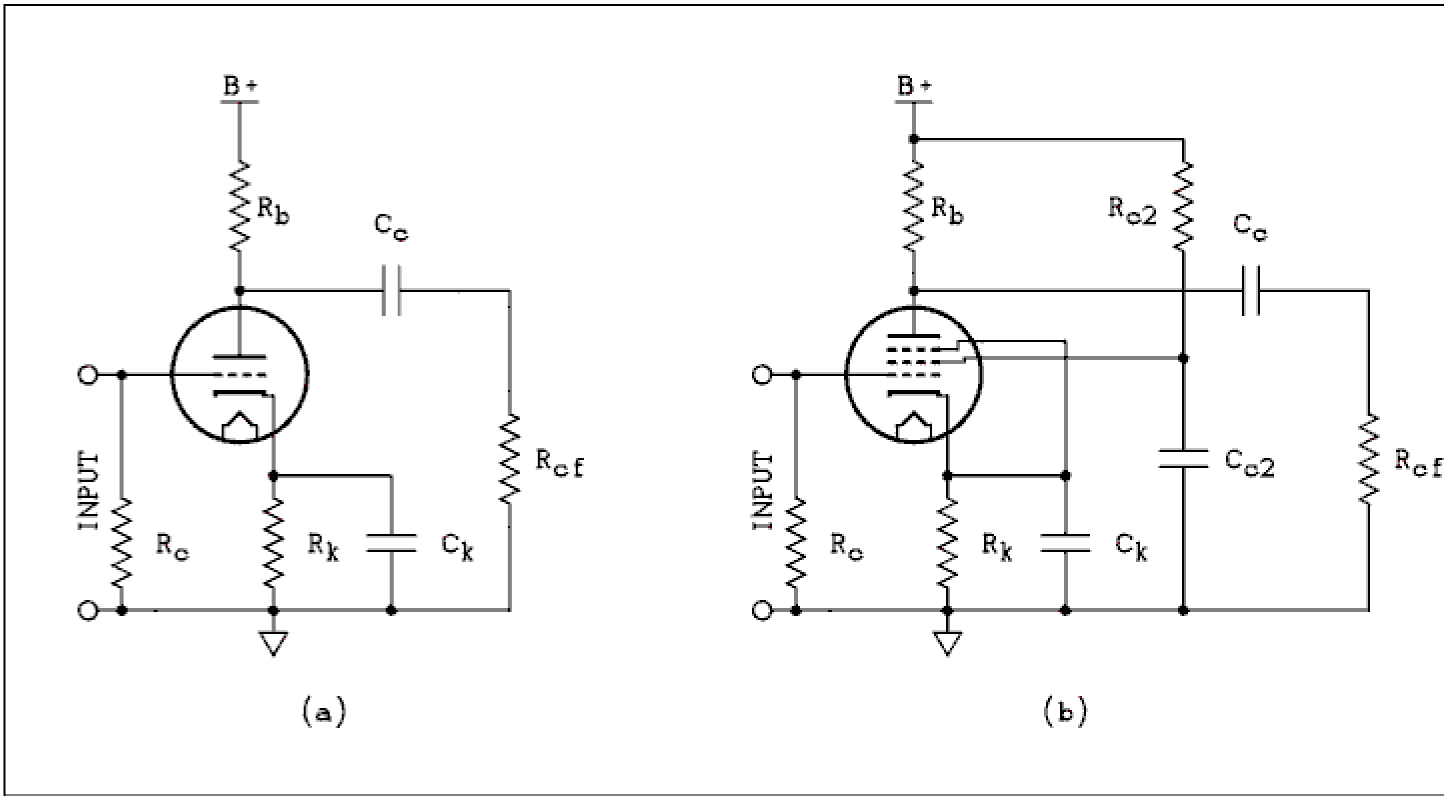

Figure 0.15 (a) Triode resistance coupled amplifier and (b) Pentode Resistance Coupled Amplifier.

For a verbal description click here.

The notation used is consistant with that used in resistance coupled amplifier tables found in the back of most tube manuals.

Figure 0.15a is a triode resistance coupled amplifier. The current flowing through R_k produces a voltage drop which makes the cathode positive with respect to ground. The grid is held at ground potential by R_c so the grid is negative with respect to the cathode. This is an audio frequency amplifier. C_k filters the AC component from the cathode voltage which if present would reduce the gain of the amplifier. Note: Sometimes C_k is deliberately omitted which reduces distortion along with reducing the gain.

The output of this amplifier circuit appears across R_{cf}. R_{cf} is the grid resistor of the following stage. It is assumed that this amplifier stage is sending its signal to another amplifier stage.

Figure 0.15b is a pentode amplifier stage. Pentode circuits give higher gain than triodes but have a higher parts count. Biasing works the same way as in the triode circuit. C_{c2} prevents reduction of the gain which would occur if AC signals were allowed to appear at the screen grid. This capacitor is never omitted. However, if the cathode bypass capacitor is omitted the screen grid bypass capacitor must be returned to the cathode instead of ground. Gain is higher and distortion lower than with C_{c2} returned to ground.

Chapter 1

Introduction to Troubleshooting.

using this book.

This text assumes you are on a first name basis with the material in the book "Electronics for Physicists". You should at the very least study through chapter 5 and preferably through chapter 6.

I can't force you to take my advice. All I can do is give and hope. If you run into trouble as you work your way through this book you may find that you need to stop and study "Electronics for Physicists". There is nothing wrong with parallel study of the two books but if you skim through the other book you may occasionally find you have missed some point and need to go back for more study. In the final analysis it's up to you. However you decide to do it I wish you luck.

Troubleshooting.

When people think of electronics troubleshooting, they may think of the TV repair person. However, the steadily increasing level of technology in consumer electronics and use of surface mount components and proprietary integrated circuits have made the cost of repairing TV sets and audio equipment so high that it is no longer economically feasible to repair failed units. This has turned us into a throw away society. "If it stops working just send it to the land fill and buy a new one".

Electronic troubleshooting in the modern world has moved from consumer electronics to other fields. these are:

1. Maintaining laboratory equipment used in industrial research and development laboratories.
2. Maintaining automated production equipment.
3. Working for a manufacturer to perform field service of laboratory or industrial equipment manufactured by the company.
4. Troubleshooting prototype equipment in an R and D lab.
5. Troubleshooting production equipment at the end of an assembly line.
6. Troubleshooting research and teaching laboratory equipment at a university, college, or secondary school system.
7. Individuals, who are most likely to be retired, who restore and repair antique electronic equipment for themselves and others.

8. DIYers and hams who build their own equipment from kits or scratch.

Number 6 was essentially half of the job I did for the university. The other half was teaching.

Engineering technologists are not necessarily overqualified for these positions.

Finding troubles in an electronic circuit is rather like figuring out "Who done it?" You are Sherlock Holmes. You have a number of seemingly unrelated clues and you have to figure out which part is defective.

In every defective circuit there are symptoms and causes. The most obvious symptom is "it doesn't work". When you open up the box, you may see a burned resistor. "Aha!" you will say, and you replace the resistor. When you turn the power on, the newly replaced resistor begins to get hot, smoke and burn up. The burned resistor was just another symptom, not a cause. There is another defect which caused the resistor to burn out.

A burned out transistor may be a cause or a symptom. The odds are in favor of it being a symptom.

Often the clues are more subtle than a scorched resistor. Nine times out of ten, there are no visible defects. When this happens it is necessary to make tests on the circuit.

At first, every part is suspect. As you make more tests, some parts are eliminated as suspects. As you gather more clues, the number of suspects is narrowed down until only one is left.

Holmes' first rule: When all other suspects have been eliminated, the one which remains, no matter how improbable, is the correct one. When you apply this rule, be sure that you have eliminated all other suspects.

Probability plays a very large role in troubleshooting. If you have narrowed down the suspects to two parts, and they are equally difficult to replace, replace the one which has the highest probability of being defective.

Ease of replacement will override the probability rule. If in the above situation one of the two parts is difficult to replace, and the other is easy, than replace the easiest one first. If that one is the trouble, you have saved yourself a lot of work. If the easy one is not the trouble, you haven't wasted very much work and you now know for sure that the "hard to replace" one is bad.

The first law of troubleshooting is check the easy things first. It is possible to gain a reputation as a miracle worker by always using this law.

You may be called in to "look at" a major piece of equipment for which there is no documentation. The thing to do is to check the power supply. If you are lucky, the supply will be a simple circuit consisting of a transformer, a rectifier and a filter capacitor. If the fault is in the supply, you can "do the impossible" and fix it.

The difficulty of any given troubleshooting job depends on the amount of documentation you have for the particular piece of equipment. The less documentation you have, the more difficult the task.

Troubleshooting a piece of equipment which has no documentation can be a formidable task at best. There are times when you can "give it a try" and times when it is best to just walk away. For example, the six-transistor radio uses a somewhat standard circuit. Regardless of the manufacturer or even the country of origin, the circuits used vary only slightly. If you are familiar with this circuit, don't hesitate to "have a go at it". The same applies to the standard 5 tube radio. On the other hand, if someone asks you to work on a video cassette recorder or a computer, check the line cord, the fuses and the power supply. If the simple things are all right, forget it! For cases in between these two extremes you will have to way the complexity of the device against your skills and make your own decision.

A situation which is frequently encountered is to have a detailed schematic diagram but no normal voltages or wave-forms. In this case you must deduce what the normal voltages will be, based on your knowledge of electronics.

Those problems which seemed so theoretical in the early courses will now come down to earth and take on reality. You will use Ohm's law, Kirchhoff's laws and all you have learned about transistors and operational amplifiers to figure out what normal voltages are.

Another way to get a reputation as a miracle worker is to overestimate the amount of time required to solve the problem. That one comes from Star Trek's Scotty.

There are two distinct kinds of troubleshooting. One is in a piece of equipment that has worked but suddenly stopped working. The other is less familiar and is in a piece of equipment that has never worked. This could be something produced in a research and development laboratory or something you built yourself. It is definitely harder to troubleshoot something that has never worked. The reason is that all the parts may be good but a design flaw is keeping it from performing its intended operation. In such a case you may or may not have the cooperation of the design engineers. They have egos which are wrapped up in the design. They are likely to be unwilling to admit that they have made a mistake.

Chapter 2   Test Equipment.

Chapter 2

Test Equipment.

Troubleshooting is impossible unless you have test equipment and know how to use it. In actual fact, someone who is very skilled can do more with a simple voltmeter than someone who has little skill and a workbench full of test equipment.

It is every bit as important to choose the right test instrument as it is to operate it correctly. If you try to use a VOM (volt-ohm-milliammeter) to measure voltages in high impedance circuits or an electronic multimeter to test a logic circuit, you will get nowhere fast. This chapter will discuss several of the most common pieces of test equipment and explain what they can and cannot do.

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2.1 The Volt-Ohm-Milliammeter (VOM).

The volt-ohm-milliammeter (VOM) has been around longer than any other test instrument. In spite of this it remains very popular. The reasons for its popularity are: reliability, portability, ruggedness and low cost.

By definition a VOM has no amplifying devices in it. It contains only resistors, a few diodes, perhaps one capacitor, some batteries and, of course, the meter movement.

As the name implies the VOM can measure voltage, current and resistance. Most VOMs will measure both AC and DC voltage while the current ranges are DC only. The internal batteries are used in measuring resistance. A VOM will not measure the reactance of an inductor or a capacitor.

Ranges and scales.

There is a great amount of confusion about the correct usage of the terms range and scale. They are NOT interchangeable and should never be used as such. The range expresses the limits or extent over which the meter can measure with a given setting of the controls. The scale refers to the graduations which the pointer moves across.

It is NOT correct to say "the meter is set to the 10 volt scale". It is correct to say "the meter is set to the 10 volt range".

It is correct to say "the scale reading is 5.3". Notice that there are no units given. The units and the power of ten by which the scale reading must be multiplied come from the setting of the range switch.

Reading the meter.

Even a very high-quality VOM will not give useful results if the operator does not interpret the reading correctly.

A typical VOM may have 8 voltage ranges, 6 current ranges and 5 resistance ranges. There are never separate scales for each range. It is necessary to multiply the scale reading by the correct power of ten to obtain the correct reading.

Example 2.1.

A VOM is set to the 2.5 volt range. There is no 0 to 2.5 scale but there is a 0 to 250 scale. The reading on this scale is 195. What is the voltage being indicated?

Solution:

The range switch is set to the 2.5 volt range (given), which means that the meter can measure voltages anywhere in the range of 0 to 2.5 volts. It is therefore impossible for the reading to be 195 volts. If the meter were indicating full scale (all the way to the right), it would be indicating 2.5 volts. Also, the pointer would be over the 250 mark on the scale. It is necessary to divide the scale reading by 100 to obtain the correct voltage reading. 195/100 = 1.95 volts, which is the correct reading.

Example 2.2.

A VOM is set to the 500 milliampere range and the scale indication is 27 on a 0 to 50 scale. What is the meter indicating?

Solution:

The 0 to 50 scale corresponds to the 0 to 500 milliampere range; therefore, the scale indication must be multiplied by 10 to obtain the correct reading. 27 times 10 = 270 milliamperes.

Notice that you do not multiply the range switch setting by the scale reading. You choose the scale which is related to the range switch setting by a power of 10 and multiply the scale reading by that power of 10 to obtain the reading.

Most experienced VOM users simply look at the scale, mentally put the decimal point in the right place and take the reading. As so often happens, the marvelous computer called the human mind makes all of these calculations without even thinking about them.

AC voltage.

All VOMs have AC voltage ranges. Because the meter movement will respond to DC only, two or more diodes are used to change the AC to DC. Because of the nonlinear voltage - current characteristic of a diode, the meter indication is not directly proportional to voltage. This nonlinearity is compensated for by the meter manufacturer printing nonlinear scales on the meter face. These special scales are almost always in red and clearly marked AC. These special scales only apply to the lowest one or two AC ranges of the meter. Be extra careful to always read the correct scale.

Input resistance.

A VOM does not have a fixed input resistance. It depends on the setting of the range switch. All VOMs have a sensitivity rating which is stated in ohms/volt (ohms per volt). To obtain the input resistance of a VOM, it is necessary to multiply the sensitivity by the setting of the range switch. The DC sensitivity of a Simpson 260 is 20,000 ohms/volt.

Example 2.3.

A Simpson 260 is set to the ten volt range and is indicating 5.1 volts. The sensitivity is 20,000 ohms/volt. What is the input resistance of the meter when set to this range?

Solution:

The voltage being indicated is extraneous information. The input resistance is the product of the range switch setting and the sensitivity. 10 volts times 20,000 ohms/volt = 200,000 ohms or 200 k ohms.

Example 2.4.

A Simpson 260 is set to the 10 volt AC range. The stated AC sensitivity is 5,000 ohms/volt. What is the input resistance?

Solution:

10 volts times 5,000 ohms/volt = 50,000 ohms or 50 k ohms.

It is a common mistake to multiply the scale reading by the sensitivity instead of the range switch setting. If that were so, the meter's resistance would be zero when its pointer was sitting on zero. The voltmeter would be a dead short and it would be impossible for a voltage to appear across it.

Voltage measurement and loading effect.

Whenever a voltmeter is connected to a circuit, the voltmeter draws current from the circuit and perturbs it. As you remember from fundamental circuit theory, every circuit can be reduced to a Thevenin equivalent. Figure 2.1 shows a voltmeter connected to such a circuit. A practical approximation for the percent error of a measurement is given by

$$\% \text{ error} = 100\,\% \times R_{Th} / R_M \qquad (2.1)$$

where R_{Th} is the Thevenin resistance of the circuit under test and R_M is the resistance of the meter as calculated in examples

2.3 and 2.4 above. This is simple enough to be estimated by a mental calculation as opposed to needing a calculator to work it out.

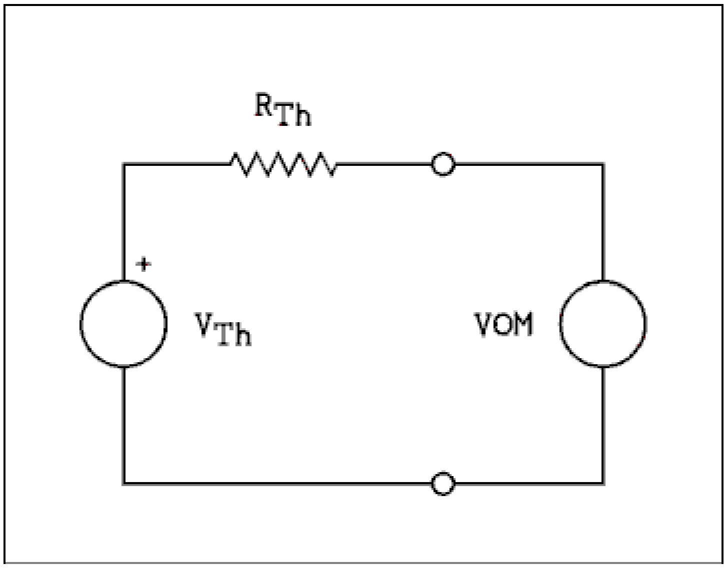

Figure 2.1 Voltmeter measuring output voltage of Thevenin circuit.

For a verbal description click here.

Typical accuracy for a VOM is approximately 2% of full scale. If we do not wish to perturb the voltage under test by any more than 2%, equation 2-1 tells us that RTH must be 0.02RM. For the conditions of example 2.3 RTH must be no larger than 4,000 ohms or 4 k ohms.

Example 2.5.

A Simpson 260 is set to the 10 volt AC range and is being used to measure voltages in a circuit. What is the maximum value the Thevenin resistance can have if the meter is to perturb the voltage by no more than 2 percent?

Solution:

Referring to example 2.4, the resistance of the meter is 50 k ohms. Solving equation 2-1 for RTH yields

$R_{Th} = R_M \times 0.02 = 50$ k ohms x 0.02 = 1 k ohm

A Simpson VOM which is set to the 10 volt AC range can only be used to measure voltage in circuits with Thevenin resistances from 0 to 1 k ohm.

Example 2.6.

A Simpson 260 is set to the 2.5 volt DC range and is being used to measure voltage in a circuit which has a Thevenin resistance of 5 k ohms. The DC sensitivity is 20 K ohms/volt. What is the percent by which the meter will perturb the measurement?

Solution:

The resistance of the meter on the 2.5 volt DC range is 2.5 V x 20 k ohms/V = 50 k ohms. From equation 2-1

% error = 100% x (5 k ohms)/(50 k ohms) = 10%

As you can see, a VOM can only be used to measure voltage in very low impedance circuits. In spite of this it remains a very popular test instrument.

Resistance measurement.

Measuring resistance with a VOM requires an extra step and a different method of interpreting the readings. Most people prefer to use a digital meter to measure resistance. If a VOM is the only meter available, you should know how to use it to measure resistance.

The scale for measuring resistance is not the same as the voltage and current scales. First of all, the zero is at the wrong end of the scale. There is a very good reason for that. The scale is also very nonlinear. This scale is always at the top of the meter and is clearly labeled "OHMS".

The circuitry within a VOM applies a voltage from a battery to the resistor under test and measures the current. Ohm's law tells us that I=V/R. This is a nonlinear function, which is the reason why the OHMS scale on the VOM is nonlinear.

The range switch is not marked the same for resistance ranges, as it is for voltage and current ranges. A typical set of resistance ranges are as found on the Simpson model 260 VOM. These ranges are RX1, RX100 and RX10,000. These are read

"Resistance times one", "Resistance times one hundred", and "Resistance times ten thousand".

This indicates that the scale reading is to be multiplied by the range switch setting.

Example 2.7.

A VOM is set to the RX1 range and the ohms scale is reading 12.5. What is the resistance being measured?

Solution:

To obtain the resistance, multiply the range switch setting by the scale reading. 12.5 times 1 = 12.5 ohms.

Example 2.8.

A VOM is set to the RX10,000 range and the scale is reading 1.6. What is the resistance being measured?

Solution:

1.6 multiplied by 10,000 = 16,000 ohms or 16 k ohms.

Adjusting the ohmmeter.

To make a resistance measurement, follow this procedure.

1. Set the range switch to the range you intend to use.
2. Clip the two test leads together.
3. Adjust the ZERO ADJUST knob on the VOM to bring the pointer over the zero mark on the ohms scale.
4. Unclip the leads from each other and clip them to the resistor to be tested.
5. Read the scale and multiply by the range switch setting.
6. If the pointer is far to the right or left of the scale, the reading will not be very accurate.
7. Every time you change ranges you must repeat steps 2 through 5.

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2.2 The Electronic Voltmeter.

An electronic voltmeter or electronic multimeter contains an amplifier circuit between the input terminals and the readout device. This amplifier has a very high input impedance and enables the meter to be used to measure voltages in much higher impedance circuits than a VOM can measure.

The first form of electronic voltmeter was the vacuum tube voltmeter VTVM. For several decades the VTVM was the most common instrument to be found on the test bench.

When the age of the semiconductor came upon us, the vacuum tubes in the VTVM were replaced by field effect transistors. The name FETVM was too clumsy to catch on. TVM (Transistor Voltmeter) never caught on either. The name EVM (Electronic Voltmeter) was never tried. Heath company tried SSVM for Solid State Voltmeter. I don't really know if that one caught on with other manufacturers. In this text we will use EVM as a generic term for an analog meter containing vacuum tubes or transistors.

The input resistance of an EVM (electronic voltmeter) is typically 10 megohms. More costly units have an input resistance of 100 or even 1000 megohms. unlike the VOM the input resistance is the same for AC and DC. Also, the resistance is constant on all ranges. An EVM loads the circuit under test in exactly the same way as any other meter. The only difference is that the circuit resistance can be higher before the error becomes significant.

One reads the EVM in exactly the same manner as the VOM. The terms "range" and "scale" have the same meanings and should be used the same. Remember, the range is the setting of the range switch and the scale is the set of markings on the meter face.

The resistance ranges may operate differently than on a VOM. If you are using an EVM you should consult the instruction manual for that meter to determine how to adjust and read the meter on the resistance ranges.

The AC Voltmeter.

Some EVMs are especially designed to measure AC with good accuracy over a wide range of frequencies. The lowest range on these meters is usually 1 millivolt. Such meters are clearly labeled as AC Voltmeters and will not give any reading if used to measure DC.

This is the only area where analog EVMs are still extensively used. A typical frequency range for an analog AC Voltmeter (AC only) is from 5 hertz to 4 megahertz. These meters are AC only, If you try to measure DC you will get no reading or one which makes no sense.

The input impedance of such a voltmeter is typically 10 megohms in parallel with 100 picofarads.

An AC Voltmeter is used in trouble shooting wide band amplifiers such as video amplifiers where frequencies exist to which VOMs, other EVMs and even DMMs (digital multimeters) cannot respond. The AC Voltmeter will also find uses in low-level audio equipment where signal levels are too low for other meters to indicate.

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2.3 The Digital Multimeter (DMM).

Except for AC-only models, the analog EVM has largely been replaced by the Digital Multimeter (DMM). The low cost and small size of digital circuitry and digital readouts have just about put the EVM out of business.

Digital Multimeters are smaller, lighter, cheaper and more accurate than their analog counterparts. It is no wonder why you almost never see an analog EVM anymore. The only area where DMMs are behind is in measuring AC over a wide range of frequencies. A typical frequency range for a DMM is 40 to 5,000 hertz although more expensive models will usually read accurately out to 20,000 hertz. A typical analog AC Voltmeter (AC only) may have a frequency range of 5 hertz to 4 megahertz. But when it comes to DC voltage, current and resistance, the DMM is unsurpassed.

Little thought is required to use a DMM. The measurement units V (volts), mV (millivolts), k ohms (kilohms), M ohms (megohms), etc. are usually indicated in the display window. The decimal point is always put in the right place. If the display window contains 1.364 k ohms or 103.8 uA, you have the measurement. What you see is what you get. Some DMMs even select the correct range automatically, removing almost all operator intervention in their operation.

The input resistance of most low cost DMMs is 10 megohms. Higher cost instruments may have input resistances of 100 or even 1000 megohms. DMMs load the circuit under test as do all voltmeters. Equation 2-1 applies.

Example 2.9.

A DMM which has an input resistance of 10 megohms is being used to measure voltage in a circuit where the Thevenin resistance is 100 kilohms. What is the percent error introduced by the meter loading the circuit?

Solution:

From equation 2-1

% error = (100 k ohms)/(10 M ohms) x 100% = 1%

Although 1% error is small by analog standards, it is large by digital standards. If you are making a measurement under the conditions of example 2.9, the meter will give you 3 or 4 significant digits, but you must remember that the reading is 1% low.

Correcting Measurements.

Digital meters give so many significant digits that most users will read the display and take it as absolutely correct. This is a very bad habit to get into. The meter reading should be mathematically corrected if the error given by equation 2-1 is greater than 1%.

Referring to figure 2.1 the Thevenin resistance of the circuit and the resistance of the meter make up a voltage divider. If we rearrange the voltage divider equation we have

$$V_{Th} = V_M \left((R_M + R_{Th})/R_M\right) \qquad (2.2)$$

where R_M is the resistance of the meter, R_{Th} is the Thevenin resistance of the circuit, V_M is the voltage being read on the meter and V_{Th} is the voltage across the terminals when the voltmeter is not present.

Example 2.10.

A DMM with an input resistance of 10 M ohms is being used to measure the voltage in a circuit where the Thevenin resistance is 220 k ohms. The meter reads 12.52 volts. What was the voltage before the meter was connected?

Solution:

Using equation 2.2 we have

V_{Th} = 12.52 v ((10 M ohms + 220 k ohms)/10 M ohms) = 12.80 volts.

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2.4 Choosing The Correct Test Meter.

It is important to use the correct meter for a given job. Using an inappropriate meter can at best give readings which are in error and at worst give nonsensical readings or even damage the meter.

Strong Electromagnetic Fields.

Making measurements in the presence of strong electromagnetic fields is a special but important case. Such fields are found around radio, television and radar transmitters, electrical substations and large electric generators or motors.

Modern day DMMs are housed in plastic cases. Plastic does not shield against electromagnetic fields. Many instruments have a shield consisting of a layer of metal foil which is coated with plastic to prevent shorting out the circuit board. This meager shield is totally inadequate to the job of preventing electromagnetic fields from entering the circuitry of the instrument.

Electromagnetic fields can so totally jam the circuits in a digital meter as to prevent it from working. Even if the meter appears to work, its readings will not be reliable. The circuits in an electronic analog meter (EVM) can be adversely affected by strong electromagnetic fields. Only the VOM has no internal devices which can be affected by these fields.

Meter Characteristics.

Table 2-1 summarizes the characteristics of the various types of meters.

The ranges listed in the table refer to full-scale ranges, not minimum measurement capability. For example, the VOM is listed as having DC current ranges from 50 microamps to 10 amps. That does not mean that 50 uA is the smallest current that can be measured; it means that the lowest range is 0 to 50 uA. The smallest current which can be measured with any reasonable accuracy is 5 uA.

Table 2.1.

Summary of Test Meter Characteristics.

3

Characteristic	VOM	EVM	DMM
DC Voltage Ranges	2.5 to 5000 V	1.0 to 1000 V	200 mV to 1000 V
DC Current Ranges	50 uA to 10 Amps	None	200 uA to 2 Amps
AC Voltage Ranges *	2.5 to 5000 V	1.0 to 1000 V 1 mV to 300 V	200 mV to 1000 V
AC Current Ranges	None	None	200 uA to 2 Amps
Frequency Ranges *	20 Hz to 20,000 Hz	20 Hz to 20,000 Hz 5 Hz to 4 MHz	40 Hz to 5,000 Hz

DC Input Resistance	20,000 Ohms/Volt	11 Megohms	10 Megohms
AC Input Resistance	5,000 Ohms/Volt	10 Megohms	10 Megohms
Resistance Ranges	RX1 to RX10,000	RX1 to RX1M	200 ohms to 20 M ohms
Accuracy	2%	2%	0.05%
Susceptibility to EMI	Not Very Susceptible	Somewhat Susceptible	Very Susceptible

EMI = Electromagnetic Interference.
* Data for AC-only electronic voltmeter.

When an EVM is set to the DC voltage range a 1 Megohm resistor is connected in series with the input at the probe tip. This is done either by using a special probe only for DC voltage or by a switch on the probe tip. The purpose for this resistor is to filter out AC including RF that might be present on the measured voltage or picked up by the leads. Many EVMs use a shielded lead after the resistor.

A few examples will give you some practice in choosing the correct meter for a given task.

Example 2.11.

You need to measure voltage, current and resistance in a laboratory and the accuracy needs to be as good as possible. What kind of meter would you use?

Solution:

EMI (electromagnetic interference) is not likely to be a problem in a laboratory setting. The need for accuracy indicates the use of a DMM (Digital Multimeter).

Example 2.12.

You need to measure AC voltages over a range of 2 to 10 volts and a frequency range of 20 to 20,000 hertz. The Thevenin resistance of the sources can be as high as 5 k ohms. There are no nearby sources of EMI. Which meter would you use?

Solution:

The frequency range of 20 to 20,000 hertz eliminates the DMM from consideration. A VOM set to the 10 volt AC range will have an input resistance of 5 k ohms/V x 10 v = 50 k ohms. The circuit resistance of 5 k ohms gives an error of (5 k ohms/50 k ohms) x 100% = 10%. The VOM is eliminated. That leaves us with some kind of EVM. An AC-only model would be preferable but an electronic multimeter would serve the purpose.

Example 2.13.

You need to measure AC voltage in the neighborhood of 2500 volts. Which meter would you use?

Solution:

The only meter with ranges above 1000 volts is the VOM.

Example 2.14.

You need to make measurements on an operating microwave oven. Which meter would you use?

Solution:

A microwave oven with its service covers removed is likely to be a strong source of EMI. The old reliable VOM is the instrument of choice here.

Example 2.15.

You need to measure voltages in the range of 0.5 to 3 volts at frequencies from 100 kHz to 1 MHz. Which meter would you use?

Solution:

While the voltage range might be accommodated by other meters, the frequency range dictates the use of an AC- only EVM.

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2.5 Analog Versus Digital Meters.

There are some who might say that the analog meter is on its way out, but they would be wrong. As mentioned earlier, the analog meter is almost immune to EMI (electromagnetic interference). In addition to this it is very good for showing changes in electrical quantities.

There are many cases in which an adjustment must be made for maximum or minimum current or voltage. While it is possible to use a digital readout for such an adjustment, an analog meter makes it much easier.

Suppose you are adjusting a control for a minimum current. When using an analog meter you do not actually read the scale of the meter. You watch the pointer moving to the left as you turn the control. When the pointer starts moving to the right, you reverse direction on the control and bring the pointer back to its left-most position. It is a matter of eye-hand coordination.

On the other, hand if you are using a digital readout to make the same adjustment, you do have to read the number on the display. As you make the adjustment you continuously read the number and do a comparison to the previous one. It's no longer a matter of eye-hand coordination; now the mind must remember a number and do calculations of sorts: "Is this number larger than or smaller than the other one?" This remembering and calculating takes more time and requires more mental effort than does eye-hand coordination.

"But wait a minute" I hear some of you saying. "What about bar graph displays?" Bar graph displays usually have ten elements which gives only 10% resolution. In tuning the output circuit of a radio transmitter the capacitor is adjusted for minimum amplifier current. This setting gives maximum power output and maximum efficiency of the amplifier. If a bar graph were used for this purpose the amplifier current would have to change by 10% of full-scale before any change could be detected by the operator. If a transmitter's output stage is operated 10% "off the dip" the output could be down by as much as 30% and the output amplifier could even be damaged.

This is but one example; there are many others in the field of electronics. It can be argued that there is no reason why a bar graph must be limited to ten elements. There is a reason, money. To match the resolution of an analog meter a bar graph would have to have at least 50 elements and 100 would be preferred. At the present state of the art, a 50 or 100 element bar graph readout is so costly as to be unfeasible. And don't forget that matter of EMI. Analog meter readouts will be with us for many years to come.

In service work there are many service adjustments which require making an adjustment for zero, minimum or maximum voltage or current. That is one of the strongest arguments for keeping a VOM on the service bench.

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2.6 The Oscilloscope.

Until the 1950s an oscilloscope was considered by many to be just a high tech toy. It was possible to look at the shape of electrical waves, but it was not possible to make any measurements. Looking at the waves is useful in some circumstances but, unless it is possible to measure the voltage and period of the wave, an oscilloscope is just a technical television set.

The technicians of those days had an oscilloscope calibrator of a sort. It was a source of square-wave voltage with "calibrated" dials on it for voltage and frequency. The idea was to switch from the wave being observed to the calibrator, match the voltage and frequency to that of the original wave and read the dials on the calibrator.

Enter the Tektronix company. Their first models had the calibrator built in and a convenient switch to select the input wave or the calibrator wave. Then one of their engineers asked the question, "Why not calibrate the scope the same way a voltmeter is calibrated, with ranges?" The rest, as they say, is history.

Today we take the calibrated oscilloscope for granted. I wonder how many students know that the scope began life as described above.

The instrument is known by several different names: "oscilloscope", "o'scope", "'scope", "scope" and one author referred to it as the "CRO" (cathode ray oscilloscope). Whatever else you may call it, call it the most useful instrument on the service bench.

What an Oscilloscope Can Do.

In addition to giving us a pretty picture show, an oscilloscope can measure voltage and time interval. A clever technician armed only with a scope and a decade resistance box can measure current and resistance as well.

The modern-day oscilloscope is very accurately calibrated in volts per division on the vertical axis and in seconds per division on the horizontal axis. The display is a visual display of instantaneous voltage versus time. Such displays can give information not available using any other instrument.

For example, ripple in a power supply can render circuits inoperative but may not show up on any test meter. The problem will be readily apparent on an oscilloscope.

The following is not intended as a thorough tutorial on "how to use an oscilloscope". That can only be done if the tutorial is written for a particular make and model of oscilloscope. It is assumed that the student is familiar with oscilloscope controls and operating procedure. This section should bring together all of the fragments of knowledge you have acquired in the past few years.

Reading An Oscilloscope.

It is as important to know how to read an oscilloscope as it is to know how to read any other test instrument.

To obtain the voltage between two points on a wave, it is necessary to perform the following steps: a) Measure the vertical distance between the two points (in divisions and fractions of a division). b) Multiply the distance by the setting of the volts/division range switch. c) If a times ten probe is being used, multiply the voltage by ten.

Example 2.16.

For a wave on the screen of a scope the distance between the positive peak and the negative peak is 5.6 divisions. The setting of the vertical range switch is 100 mv/div. A times one probe is being used. What is the peak to peak voltage of the wave?

Solution:

The peak to peak distance has been given as 5.6 divisions. 5.6 divisions times 100 mv/division = 560 millivolts or 0.56 volts. The use of a times one probe means that the voltage must be multiplied by one.

To obtain the time between two points on a wave, it is necessary to perform the following steps: a) Measure the horizontal distance between the two points (in divisions and fractions of a division). b) Multiply the distance by the setting of the time/division sweep range switch.

Example 2.17.

For a wave on the screen of a scope the distance between two successive positive going zero crossings is 8.3 divisions. The setting of the sweep range switch is 0.5 ms/div. A times ten probe is being used. What is the period of the wave?

Solution:

The fact that a times ten probe is being used has no effect on the time reading. The wavelength has been given as 8.3 divisions. 8.3 divisions times 0.5 ms/division = 4.15 milliseconds.

The Times Ten Probe.

The input impedance of almost all oscilloscopes is one megohm of resistance in parallel with 30 picofarads of capacitance. That presents problems.

The resistance portion means that if we want plus or minus 2% accuracy the highest Thevenin resistance a circuit could have is 20 k ohms. That would considerably restrict the use of a scope but that's not all.

Capacitance added in parallel with a circuit presents a load at higher frequencies and slows down the rise time of square-waves and pulses. In most cases, calculation of this effect is too complex to be worth the effort. The best approach is to make the capacitance as small as physically possible.

The input capacitance of the scope by itself would not be so bad but there is more.

If you have ever touched the input terminal of a scope, or connected an unshielded wire to the input of a scope, you know that there are signals in the air which can be picked up by the wire (or your body) and displayed on the scope. If you are trying to look at a 130 kHz triangular wave, you don't want 60 Hz mixed with it. That is what you can have if you don't use shielded cables to connect circuits under test to the input of an oscilloscope.

Shielded cable consists of two conductors separated by an insulator, the definition of a capacitor. Typical cable capacitance is 30 picofarads per foot of cable. Typical cable length is 4 feet. The input capacitance now becomes 4 ft. x (30 pf/ft.) + 30 pf = 150 pf.

150 picofarads has a reactance of 20 kilohms at a frequency of 53.1 kilohertz. That says that 150 pf is much too much to have in parallel with a test instrument.

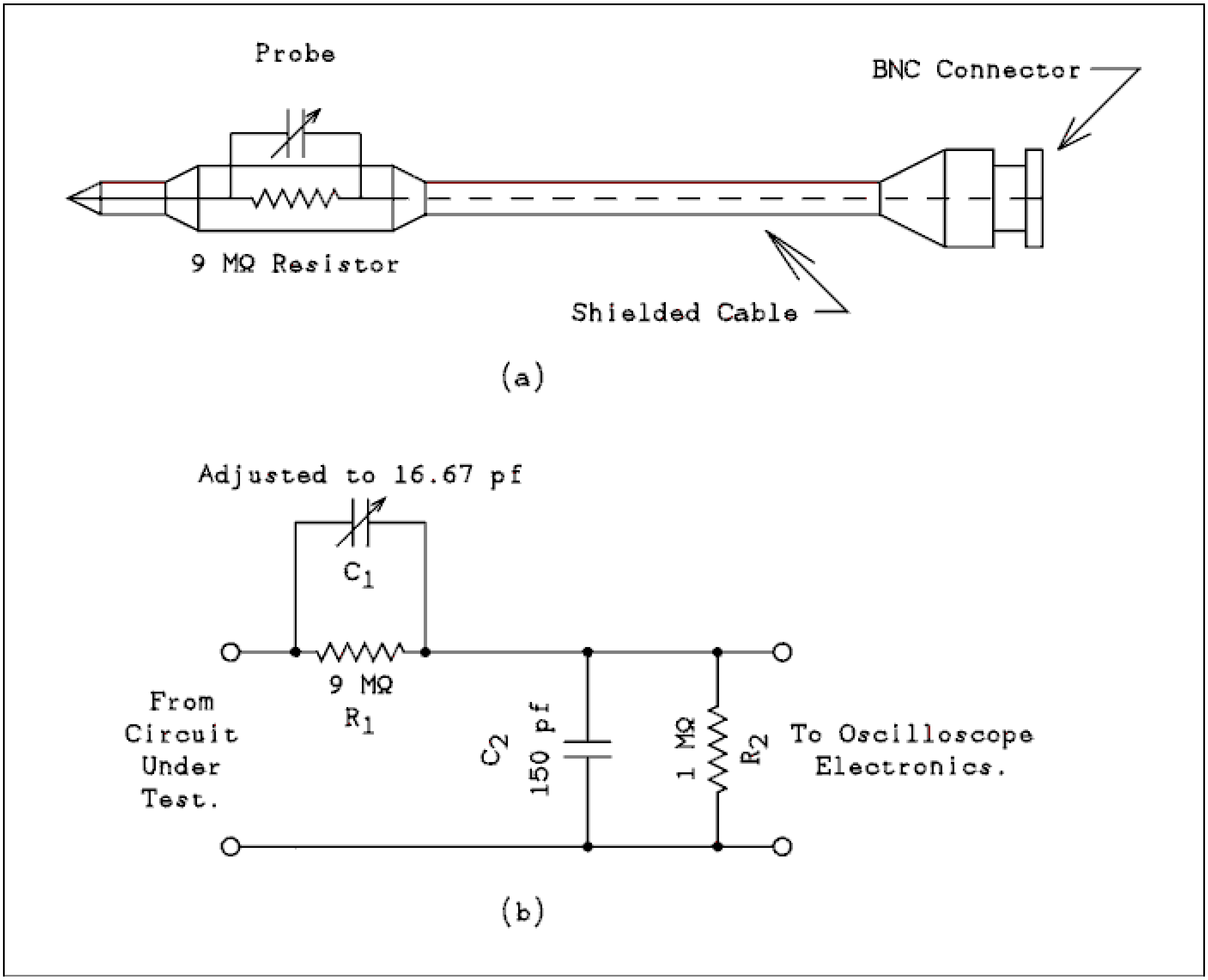


Figure 2.2 Schematic of X10 Probe.

For a verbal description click here.

It is possible to increase the input resistance and decrease the input capacitance of a scope by giving up some sensitivity. Figure 2.2(a) shows a drawing of a times ten probe and 2.2(b) the schematic diagram. The scope is presumed to have an input impedance of 1 M ohms resistor in parallel with a 30 pf capacitor. The variable capacitor in parallel with the 9 Megohm resistor would be physically inside the probe.

The frequency response of the circuit will be flat if

$$R1\ C1 = R2\ C2 \qquad (2.3)$$

is satisfied. Where R1 is the 9 Megohm resistor in the probe tip, C1 is the variable capacitor in the probe tip, R2 is the 1 M ohms resistor which represents the input resistance of the scope and C2 is the sum of the cable capacitance and the input capacitance of the scope 150 pf. If we solve equation 2.3 for C1 and plug in all known values, we have C1 = (1 M ohms x 150 pf)/(9 M ohms) = 16.7 pf. The effective input capacitance is C1 in series with C2 which is 15 pf. That's a lot better.

The effective input resistance is R1 in series with R2 which is 10 M ohms. That's also a lot better.

To sum it all up, by using a times ten probe the input resistance goes up by a factor of ten and the input capacitance goes down by a factor of ten. The voltage applied to the input of the scope is 1/10 of that applied to the probe tip.

Example 2.18.

The following information is obtained using an oscilloscope. Peak to peak voltage is 125 millivolts and period is 22 milliseconds. A times ten probe is being used. What are the actual voltage and period.

Solution:

The voltage is ten times what is measured, 125 mv x 10 = 1.25 volts. The times ten probe has no effect on the period measurement.

Adjusting the Times Ten Probe.

Before a times ten probe is used it must be adjusted to match the particular scope that is in use. As indicated in figure 2.2 the variable capacitor is in the probe tip but in some probes the adjustment is at the scope end of the probe cable. This is accomplished by making the capacitor at the probe tip a fixed value and a little larger than the theoretical value and placing a variable capacitor in parallel with the scope and cable capacitance, C2, placing it more conveniently at the scope end. Wherever it is it must be adjusted.

All oscilloscopes have a square-wave output which has been put there for exactly this purpose. If the probe has a switch to select X1 (times one) or X10 (times ten), be sure it is in the X10 position. Connect the probe tip to the square-wave output and adjust the controls on the scope to obtain a stable display of the square-wave.

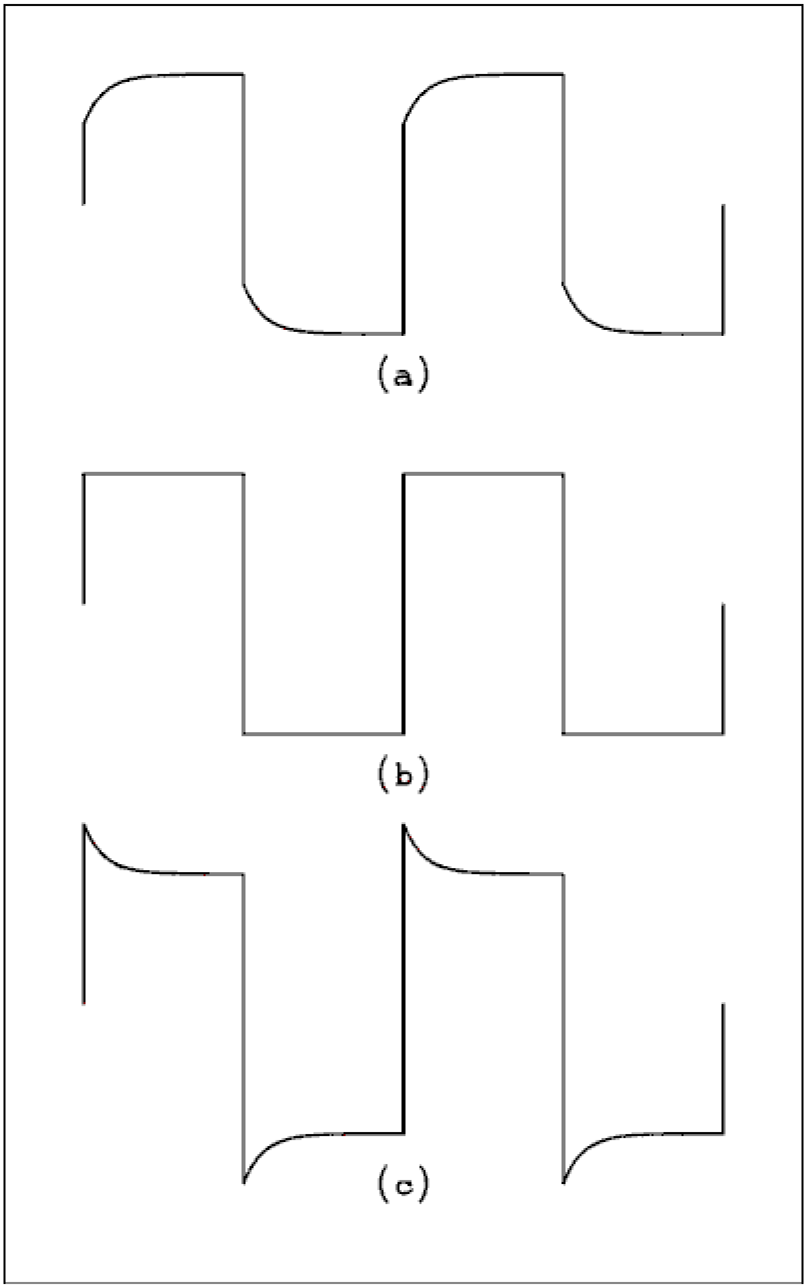


Figure 2.3 Square-wave for (a) undercompensated probe
(b) properly compensated probe and
(c) overcompensated probe.

For a verbal description click here.

If a screwdriver is required to adjust the probe, use a plastic one. Refer to figure 2.3. Figure 2.3a shows the condition of not enough capacitance, under compensation, while figure 2.3c shows the condition of too much capacitance, overcompensation. Figure 2.3b is just right, correct compensation. If it is not readily apparent how to adjust the probe, consult the instruction manual.

AC, DC and Ground.

All but the least expensive scopes have a switch located near the input connector which is labeled "AC DC GND" for AC, DC and ground.

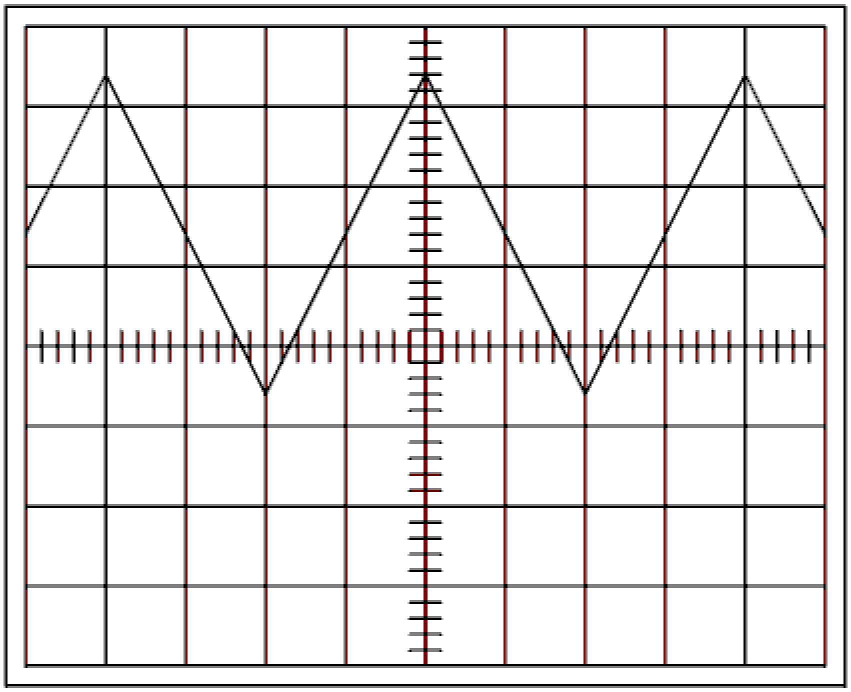
When this switch is set to the AC position, a capacitor is connected in series with the input to the scope. This capacitor will block DC from the input but will pass AC. The size of the capacitor is usually chosen so that the low frequency limit will be about 2 hertz. The upper frequency limit is set by the amplifiers in the scope and is uneffected by the setting of the switch.

In the DC position the scope responds to both AC and DC. The capacitor mentioned above is shorted out. The response of the scope is from DC (zero frequency) to the upper frequency limit of the scope. This makes it possible to use the scope to measure DC voltage the same as you would with a voltmeter.

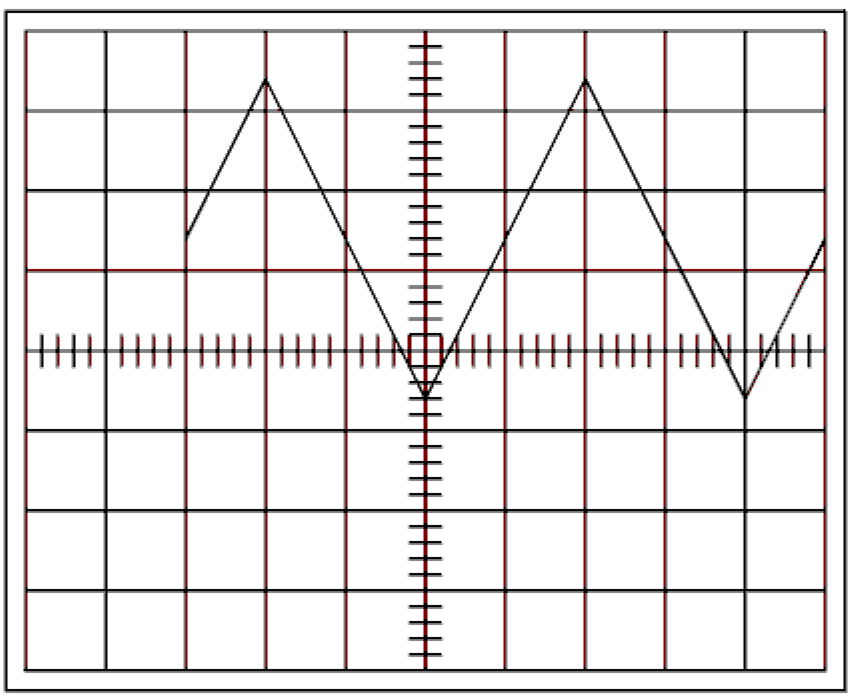
When the switch is set to the GND (ground) position the input to the vertical amplifier is grounded. The input resistance (as "seen" by the circuit under test) is not affected so that the circuit under test will not be damaged. In many measurements, especially those involving DC, it is essential to know where the trace would be if the input voltage to the scope were zero. Instead of disconnecting the probe, all that is necessary is to flip the input switch to the GND position, note the position of the trace (or use the positioning control to put it where you want it) and then flip the input switch back to DC or AC.

Example 2.19.

Figure 2.4 represents the display of a DC + AC voltage on an oscilloscope. When the input switch is set to ground, the trace is positioned one division up from the bottom of the screen, or at Y = -3 divisions. In figure 2.4a the scope operator has used the horizontal positioning control to set the most positive peak on the line of hash marks. In figure 2.4b the horizontal positioning control has been adjusted to put the least positive peak on the line of hash marks. This is what you would do if you were in a laboratory instead of reading a book. The settings of the scope controls are as follows: input switch to DC, Vertical range to 0.2 v/div and sweep range to 5 ms/div. A times ten probe is being used. What is: (a) the peak to peak voltage; (b) the voltage of the most positive peak; (c) the voltage of the least positive peak; and (d) the period of the wave?



(a)



(b)

Figure 2.4 Scope screens for Example 2.19.

For a verbal description click here.

Solution:

The only difference between figures 2.4a and 2.4b is that the horizontal positioning control has been changed. Figure 2.4a reveals that the most positive peak is 3.4 divisions above the center line and figure 2.4b reveals that the least positive peak is 0.6 divisions below the center line.

(a) The peak to peak distance of 3.4 div - (-0.6 div) = 4 divisions. 4 div x 0.2 v/div x 10 = 8 volts peak to peak.

(b) The voltage of the most positive peak is measured from the zero voltage line. As given, the zero volt line is one division up from the bottom of the screen or 3 divisions below the center line. The distance between zero volts and the most positive peak is 3.4 div - (-3 div) = 6.4 divisions. 6.4 div x 0.2 v/div x 10 = 12.8 volts.

(c) The distance between zero volts and the least positive peak is -0.6 div -(-3 div) = 2.4 divisions. 2.4 div x 0.2 v/div x 10 = 4.8 volts.

(d) We must use center line crossings in order to have the hash marks to read. Selecting two successive positive going center line crossings we have the wavelength as 4 divisions. The period is 4 div x 5 ms/div = 20 ms. The times ten probe has no effect on the time measurement.

Getting Best Accuracy.

Using modern oscilloscopes with some care it is possible to obtain accuracy equivalent to that of an analog meter. There are certain things you can do to maximize the accuracy of the measurement.

For voltage and period measurements keep the vertical deflection large. The large divisions are subdivided by the hash marks into 5 subdivisions. It is possible to mentally insert 4 sub-subdivisions between the hash marks. That means that the best resolution is 1/20 of a large division. That is the ideal case. In actual practice it is more likely that the best resolution is 1/10 of a large division.

If you only have a vertical deflection of one large division, the typical accuracy is about (0.1 div)/(1 div) x 100% = 10%. If the vertical deflection is about 6 large divisions the typical accuracy is about (0.1 div)/(6 div) x 100% = 1.7%. 2% accuracy is about the best to be expected.

For period measurements have several cycles on the screen. Also, measure from zero crossing to zero crossing, not peak to peak. The horizontal position of the rounded peak of a sine wave cannot be determined with any accuracy.

If the vertical deflection is large and there are several cycles on the screen, the zero-crossings will be almost vertical. Suppose you tried to measure the period from one positive peak to the next. You would be trying to determine the exact point of tangency of the curved peak of the wave to the scale, not an easy thing to do. When an almost vertical line crosses a horizontal scale it is easier to determine the exact point where the crossing takes place.

If you measure the time for four or five cycles, the accuracy of the measurement will be improved. If you measure the period of just one cycle, the distance will be rather small and the same argument will apply as for the vertical deflection. Measuring over several cycles increases the distance of the measurement and increases the accuracy.

Trigger Modes.

In olden days the horizontal sweep was generated by an oscillator with a sawtooth wave form. To get a stationary pattern on the screen it was necessary to synchronize the sweep oscillator with the input signal. Today's scopes use a triggered sweep instead of a synchronized sawtooth oscillator.

The key difference is that an oscillator keeps on running at approximately the same frequency even in the absence of an input signal. A triggered sweep begins when a trigger pulse is received, completes one cycle and then waits for the next trigger pulse before beginning the next cycle. If the trigger pulses stop, the sweep stops.

The "auto" mode is to keep a visible trace on the screen in the absence of an input signal. If you put the input switch in the GND position, you want the trace to be on the screen so you can see where it is. A special circuit senses that there are no trigger pulses and generates artificial trigger pulses. These pulses are removed when real pulses are present. Like any other automatic circuit it can sometimes get confused and cause the pattern on the screen to be unstable. When this happens, you should switch out of the auto mode. If you want to use the GND position on the input switch, you will have to put the trigger back into the auto mode. Someday it will occur to some engineer (who can do something about it) to cause the trigger circuits to go into the auto mode whenever the input switch is placed in the GND position.

The Slope switch selects whether the sweep will trigger on the positive going or negative going slope of the input wave.

The level control sets the voltage level at which the sweep will begin.

Trigger coupling modes come in a wide variety of shapes and sizes. A few of them are DC, AC slow, AC fast, AC lf, AC lf rej, (reject), TV, TVh, TVv, TVl and TVf. DC is a full spectrum coupling. It is used for slowly changing, infrequently occurring or DC restored video signals. AC slow and AC lf are for low frequency sine or sine like waves. AC fast and AC lf rej are for square-waves, pulses or high frequency sine waves. TV is a general television trigger mode. In some scopes the horizontal or vertical sync pulses are selected depending on the setting of the sweep range switch. TV h (horizontal) and TV l (line) select the horizontal sync pulses from the TV signal to be fed to the trigger circuits. TV v (vertical) and TV f (frame of field) select the vertical sync pulses.

For complete information you should consult the instruction manual for the particular scope you are using.

Measuring Current and Resistance Using a Scope.

Earlier it was mentioned in passing that it is possible to measure current and resistance using a scope. How is that possible? A decade resistance box would come in handy but all you really need are a few precision resistors.

Measuring current is easy and maybe some of you have figured that one out already. Simply place a resistor, say one ohm, in parallel with the input of the scope. The ranges on the vertical range switch become current ranges. For example, using a 1 ohm resistor the 100 mV/div range becomes 100 mA/div. The resistor should have sufficient wattage rating to carry the current being measured. Also remember that if the voltage drop becomes too great, you will perturb the circuit under test and the current measurement will be in error.

Measuring resistance requires a bit more ingenuity. All scopes have a square-wave signal output for compensating the probe. This output is used in the circuit of figure 2.5. Since one side of the circuit is connected to the scope's own ground it is not possible to measure the voltage across each resistor individually. Measure the voltage across the reference resistor RR and then measure the voltage across the series combination of RR and RX. This last voltage is of course the output voltage of the square-wave output. For best accuracy the voltage across the reference resistor should be about half of the square-wave output. The unknown resistance is given by

$$RX = RR\ (VS - VR)/VR \qquad (2.4)$$

where RX is the unknown resistance, RR is a known reference resistor, VS is the voltage of the square-wave source and VR is the measured voltage across the reference resistor.

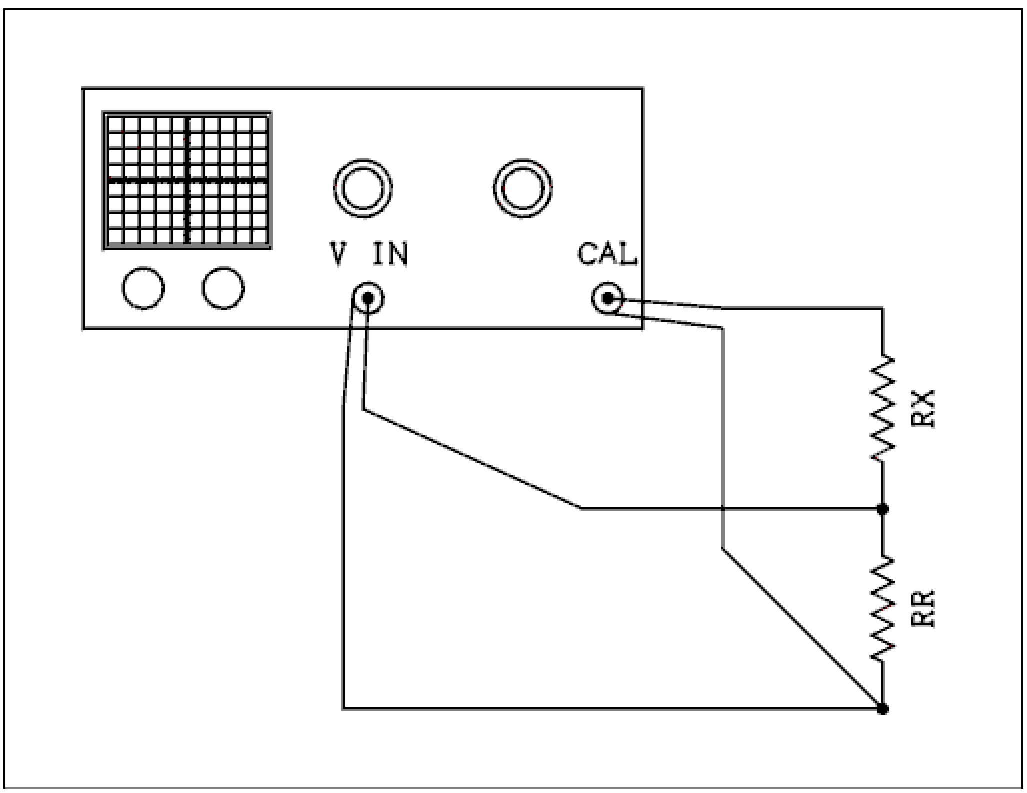


Figure 2.5 Resistance Measurement with an Oscilloscope.

For a verbal description click here.

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2.7 The Signal Tracer.

A signal tracer is an old instrument that was used primarily to troubleshoot radios back in the tube era. If you are interested in restoring Antique radios I strongly recommend that you buy or build one. The basic instrument was an audio amplifier and a speaker built into an instrument box. Some units such as the Heathkit T-4 also contained an eye tube. This seems to me to be just to dress up the instrument and serves little practical purpose. They are old enough to be considered antiques and if you buy one off eBay you will likely pay too much. Even if you have to buy all new parts you will likely pay less to build your own. Below is a practical circuit.

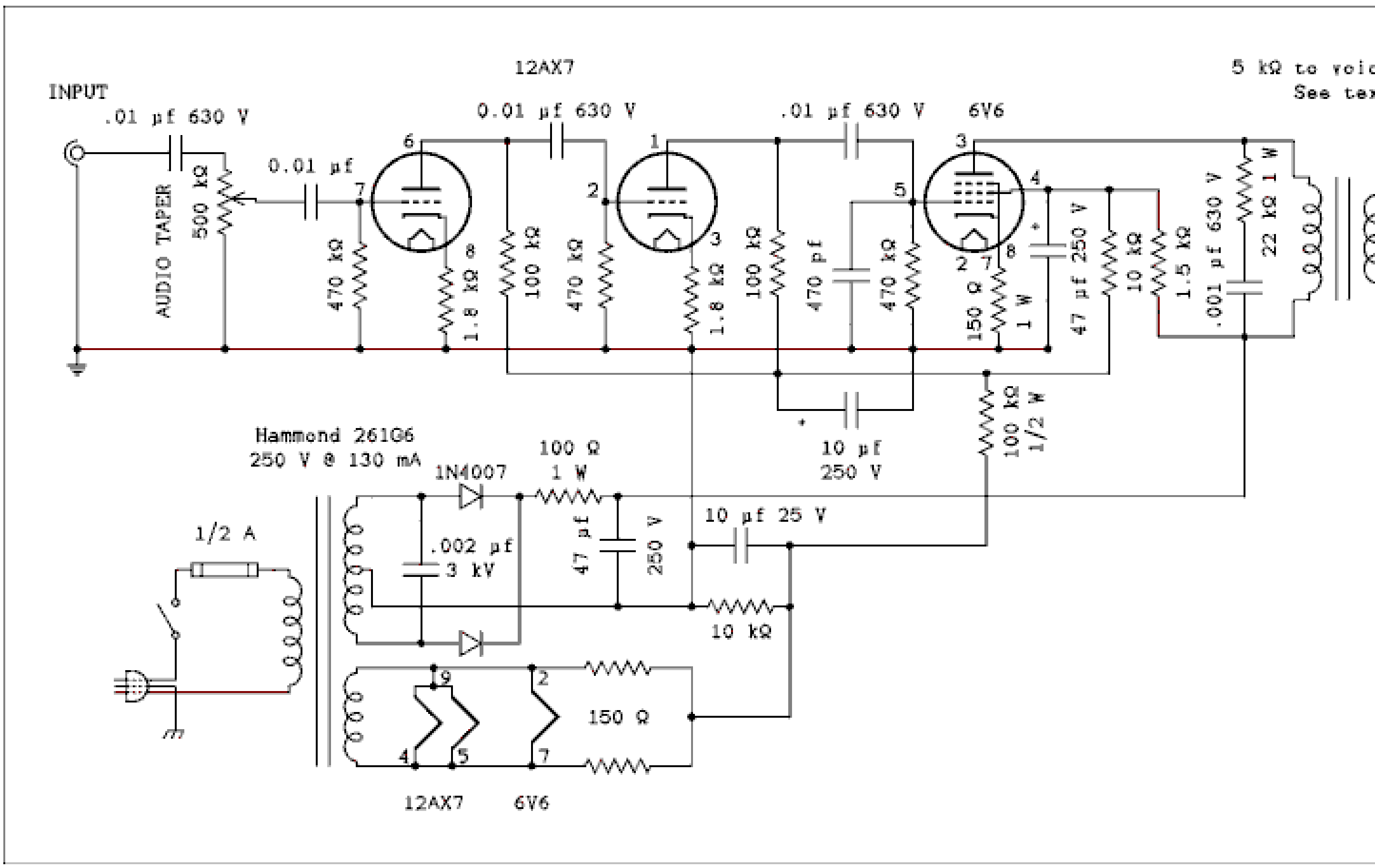

Figure 2.6 Signal Tracer.

For a verbal description click here.

The output transformer is a standard 5 k ohm to voice coil and may be scavenged from an all American 5 if desired. The power transformer has a higher current rating than needed but one just above it on the AES page which had a lower current range costs a dollar more. If desired you could use the extra current capacity to power experimental circuits.

If you prefer you can substitute a 6AQ5 for the 6V6. No component changes are necessary to change the tube. Remember that the pin numbers are different.

Oscillation.

It is very likely that this circuit will oscillate when there is nothing connected to the input and the volume control is turned up all the way. The 470 pf cap from the grid of the 6V6 to ground is meant to help but it won't prevent it completely. It will insure that it will be audible. My Heathkit T-4 and the amplifier in the combo power supply and amplifier do. It can be prevented by using a lot of shielding between the output tube and transformer and the 12AX7. It really doesn't hurt anything though.

As you can see this is nothing more than an audio amplifier with a whole lot of gain. It is useful for tracing signals through the audio section of a radio. A shielded probe should be used and a scope probe is a very good choice. Get one that has a times 1/times 10 switch on it. Of course you will have to mount a BNC connector on the tracer to make use of a scope probe.

Radio Frequencies and Intermediate Frequencies.

So how does one trace signals through the RF and IF stages of a radio? Here is how.

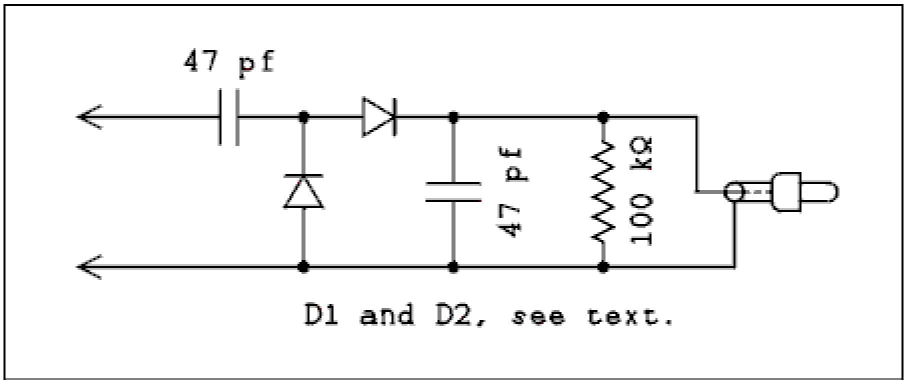

Figure 2.7 RF Probe for Signal Tracer.

For a verbal description click here.

You can use 1N4149 diodes if you want but performance will be much improved if you use germanium diodes instead. If you can get them or their equivalents 1N270 or 1N933 diodes will perform much better. If you can't get those 1N34A diodes will work just fine. The first capacitor in line should have a voltage rating of 500 volts because it will regularly come into contact with B+ voltages.

This probe has the advantage over the one supplied with the Heathkit T-4. It filters out low frequencies and responds only to frequencies higher than 50 kHz. In a departure from the usual quality Heath engineering the T-4 was supplied with a simple probe that didn't work very well. The manual admits this by saying that the probe should not be connected to the plate of a tube because all the operator will hear is 60 Hz hum from the power supply. Using this probe that will not be a problem.

The probe should be shielded to avoid the effects of hand capacitance but the metal shield should be covered with some kind of insulating material. It is not safe to work on a radio that has lethal voltages in it while holding a grounded probe in your hand.

Another use for the probe is to measure RF voltages. The DC output of the probe is very close to the peak to peak value of the input wave. If it is a good sine wave the RMS value of the wave is Vdc / (2 Square root of 2).

Also, do not be tempted to leave out the power transformer! Some of the radios you will be working on will be of the line connected chassis type and having two pieces of hot chassis equipment on your workbench is a catastrophe waiting to happen.

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2.8 Miscellaneous Test Equipment.

There are many different pieces of test equipment. Some are not well known. Some pieces of test equipment are designed to test one particular make and model of apparatus. These are usually referred to as "test sets" rather than test instruments. Test sets cannot be covered in a book such as this. They are issued to franchised service agencies and field service persons. Training in their use comes from the manufacturer.

Signal Sources.

Signal sources are used in the signal substitution or signal injection methods of testing to be covered in chapter 4 of this book.

There are three general categories of signal sources (more often called signal generators). They are 1) audio frequency, 2) radio frequency, and 3) pulse generators.

Audio frequency generators come in a wide variety of makes and models. The minimum acceptable frequency range is 20 to 20,000 hertz but most technicians prefer a range of 5 hertz to 1 megahertz. Generators are available which provide low distortion sine waves (.05% or less). The most familiar, however, is the function generator which provides sine, square and triangular waves. The distortion of the sine wave is usually in the range of 0.3% to 1%. A typical frequency range is from 1 hertz to 2 megahertz. The Thevenin output resistance of these generators is usually 50 ohms. Some function generators also provide outputs which are compatible with digital logic circuits. For details on operating procedure consult the instruction manual for the particular make and model you are using.

Radio frequency generators are further subdivided by the part of the radio spectrum they cover. For example a Hewlett-Packard model 606A is called an HF (high frequency) signal generator. It covers the range 50 kHz to 65 MHz. Granted, the HF spectrum is from 3 to 30 MHz but they didn't want to call it a "most of LF, MF, HF and part of VHF signal generator". As you can see from this example there is considerable overlap of AF (audio frequency) and RF (radio frequency) generators.

The one feature which distinguishes an RF generator from an AF generator is calibrated output voltage and power level. All RF generators worthy of the name use a combination of an output level meter and a well-calibrated attenuator to provide an output level which is known. The level is measured across a 50 ohm load and usually ranges from 0.1 microvolts to about 1 volt. Upper limits vary from one model to the next and can range from 0.2 volts to 3 volts.

Some high-priced AF generators may also have calibrated output levels, the minimum level usually about 1 millivolt. Only an RF generator will have a minimum output of 0.1 microvolts.

Pulse generators are used to stimulate logic circuits. They have outputs which are compatible with various integrated logic families such as TTL (transistor transistor logic), CMOS (complementary metal oxide semiconductor), ECL (emitter coupled logic) and others.

The pulse width and frequency are independently adjustable. There are frequently provisions for external triggering or triggering from the operation of a pushbutton switch.

Logic Probe.

A logic probe looks simple but can be quite complex. In general it has two indicator lights, one for a low logic level and the other for a high logic level. You might think that one light would do but if no lights are on, the probe is indicating an open circuit on its input.

If the logic probe is testing a pulse train of say 20 PPS (pulses per second) or higher, the lights will flash off and on too fast for the eye to perceive as flashes and they will look as if they are on continuously. A good logic probe will contain circuits which force the lights to flash slowly enough to be perceived as flashes.

Thus you have an unambiguous indication of logic low, logic high, open circuit or pulse train.

A logic probe must be compatible with the logic family with which it is being used.

Continuity Tester.

A continuity tester is a device which gives an indication when the resistance between its test leads falls below some preset value such as 100 ohms. The indication can be either visual or oral or both.

Many logic probes incorporate a continuity test mode.

Continuity testers are good for testing fuses, switches, line cords and even diodes. Although they are employed primarily by technicians who work on power or telephone circuits they can be a handy tool for the electronics technician as well.

Test Lamp.

A test lamp has the advantage over a voltmeter of being smaller and much less hassle to use. If the user desires to know if the voltage is present or absent, it is just what the doctor ordered.

In its most common form a test lamp is a neon lamp with a current limiting resistor in series with it. It may be housed in a small plastic cylinder and be equipped with a pocket clip. It will have two test leads emerging from it. The test lamp is used to check for the presence of AC line voltage.

You can also make your own test lamp. A six volt lamp makes an excellent quick tester for the presence of five volt power in a computer circuit.

AC Ammeter.

There is a class of AC ammeters which requires no direct connection to the circuit under test. They sense the magnetic field around a wire carrying AC. This magnetic field is directly proportional to the amount of current in the wire.

These meters have a spring loaded clamp which can be opened by squeezing a handle on the meter. The clamp is opened and allowed to close around, not on, the wire in which the current is to be measured.

The clamp must be placed around one wire. If you put the clamp around a lamp cord (two wires) the meter will read zero. The reason for this is each wire in the lamp cord is carrying current in the opposite direction to the other one. Because this is a series circuit, the current in each wire has the same magnitude. The two equal and opposite currents cancel each other out and there is no reading on the meter.

These meters are often called "amprobes" but Amprobe is a registered trademark.

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2.9 Instruction Manuals.

It is a common joke among technicians and engineers that, "When all else fails, read the instruction manual." This expresses the reluctance of most technical people to admit that they don't know something. There are, however, times when you should consult the instruction manual.

If you have encountered a familiar piece of equipment such as an oscilloscope, you may feel as if you know how to use a scope and don't need the manual. But if it is one of those new digital models (with no knobs, just push buttons) you will likely be sufficiently stumped to need some help.

If the equipment is unfamiliar you should by all means "read the book". There are only a few combinations of control settings which will work and an infinite number which will not work. The odds of hitting a working combination by random turning of knobs are vanishingly small.

Don't be ashamed to "read the book". There's no shame in that. No one was born all knowing.

Chapter 3   Failure Modes.

Chapter 3.

Failure Modes.

It is possible to spend an entire career studying the failure modes of electronic components. In this chapter we will cover only the electrical characteristics of failed components.

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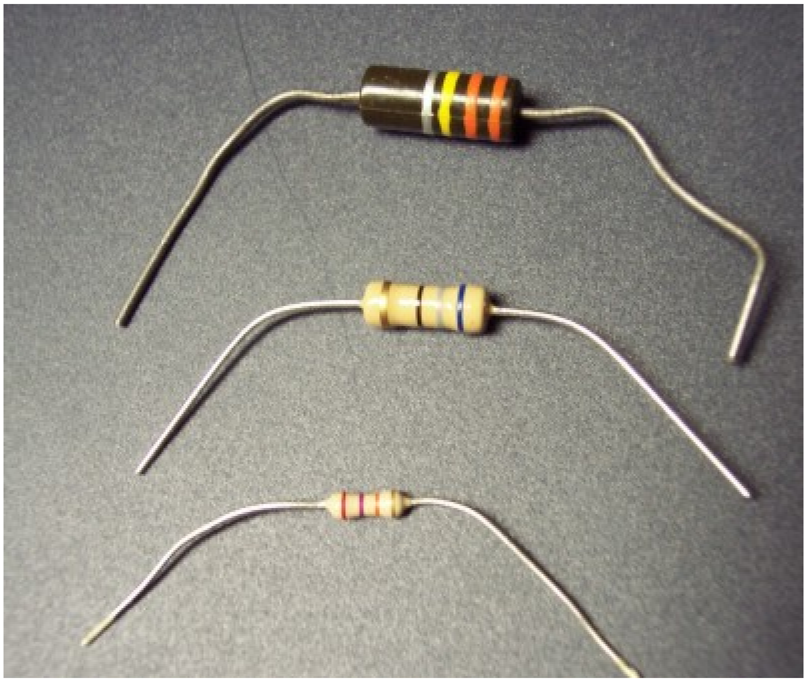
3.1 Generalized Failure Modes.

Electronic components usually fail in a specific way. That is a good thing; it makes the job of troubleshooting easier than it would be if components failed in random ways.

For example, capacitors almost always fail shorted while resistors almost never fail shorted. If there is a parallel combination of a resistor and a capacitor and the combination is found to be shorted, we can be almost certain that the capacitor is at fault.

The word "almost" appears in these statements because we are dealing with probability and there are no absolute certainties, only very high probabilities.

Resistors.



Picture 3.1 Example Resistors.

In the photo above the top resistor is a 330 k ohm 10% 1 watt carbon composition, the middle one is a 68 ohm 5% 1 watt carbon film, and at the bottom is a 27 k ohm 5% 1/4 watt carbon film resistor.

Components fail in the way they do because of the way they are constructed. Resistors are constructed in two main ways. One type is known as carbon composition. It is made by mixing up a concoction of finely powdered graphite, an equally finely powdered insulating material and some kind of glue. The brew is molded into a small cylinder and dried. The lead is in the form of a nail as shown in Figure 3.1.

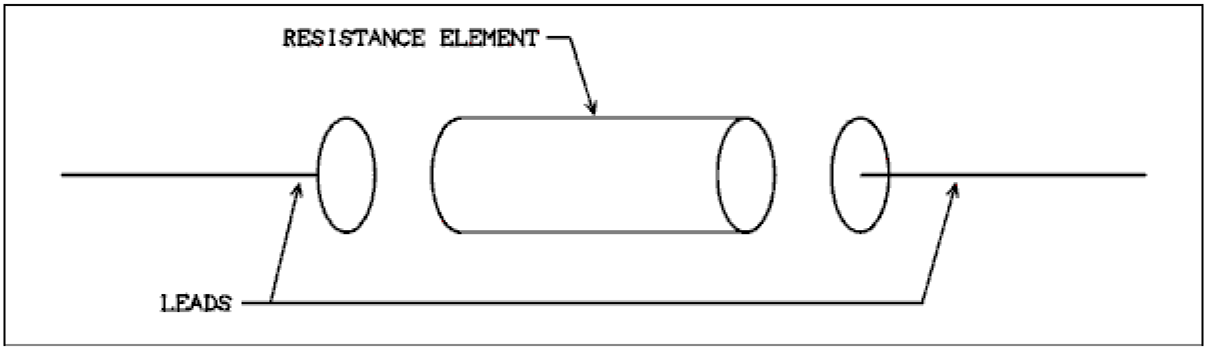


Figure 3.1 Construction of Carbon Composition Resistor.

For a verbal description click here.

The two leads are placed in contact with the ends of the cylinder and the assembly is encased in molded plastic. Color code bands are painted on the finished resistor. The force exerted by the lead's "head" against the end of the cylinder is the only connection between them. I have seen such resistors in which it was possible to rotate the resistor body on its leads. Needless to say the amplifier was very noisy especially when shaken.

The other type is carbon film or metal film. They are made by coating a ceramic or plastic cylinder with graphite or metal. Metal cups are placed over the ends of the cylinder and crimped in place to make good electrical contact with the film. The cups have leads attached as shown in figure 3.2.

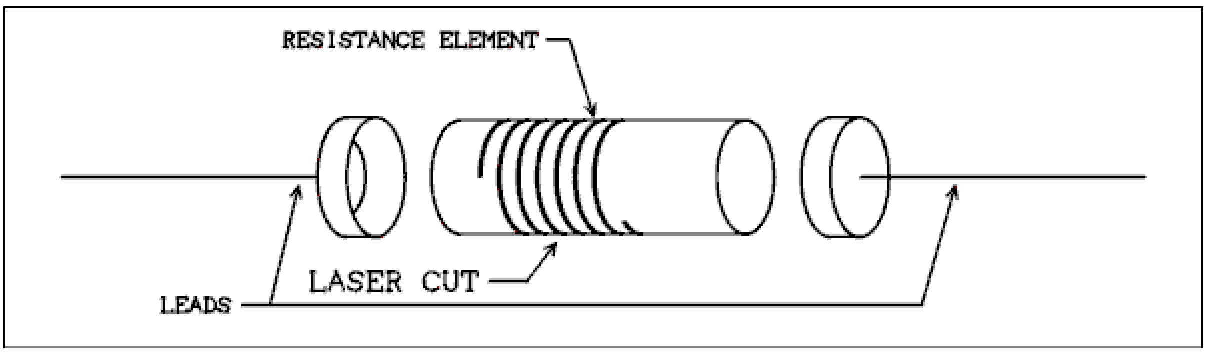


Figure 3.2 Construction of Film Resistor.

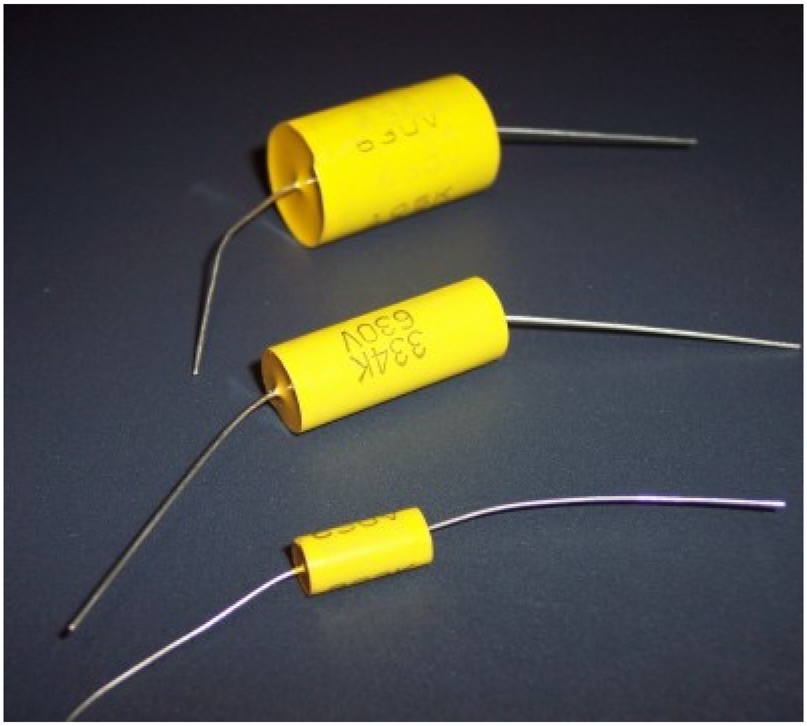
For a verbal description click here.

The assembly is then placed in a lathe where a laser starts cutting a helical path in the conductive coating turning it into a coil of conductor surrounding the insulating cylinder. The resistance is being measured continuously and when it reaches the desired value the laser is turned off and the resistor goes on to have its body encased in plastic. Color bands are then painted on. The end contacts are what gives these resistors their characteristic shape.

Carbon composition resistors can be reduced in value by excessive heat which turns some of the glue from the original mix into carbon. I have seen a 100 ohm resistor be reduced to 11 ohms by being burned to a crisp. However, this is rare. They usually increase in value with age and can totally fail open or become noisy as described above.

Film resistors are much more reliable because of the crimped connections. They hold their original value very well and rarely fail spontaneously. They can even remain very close to their value after some serious overheating.

Capacitors.



Picture 3.3 Example Capacitors.

Capacitors are constructed of two thin pieces of metal foil with a very thin insulator between them as shown in Figure 3.3.

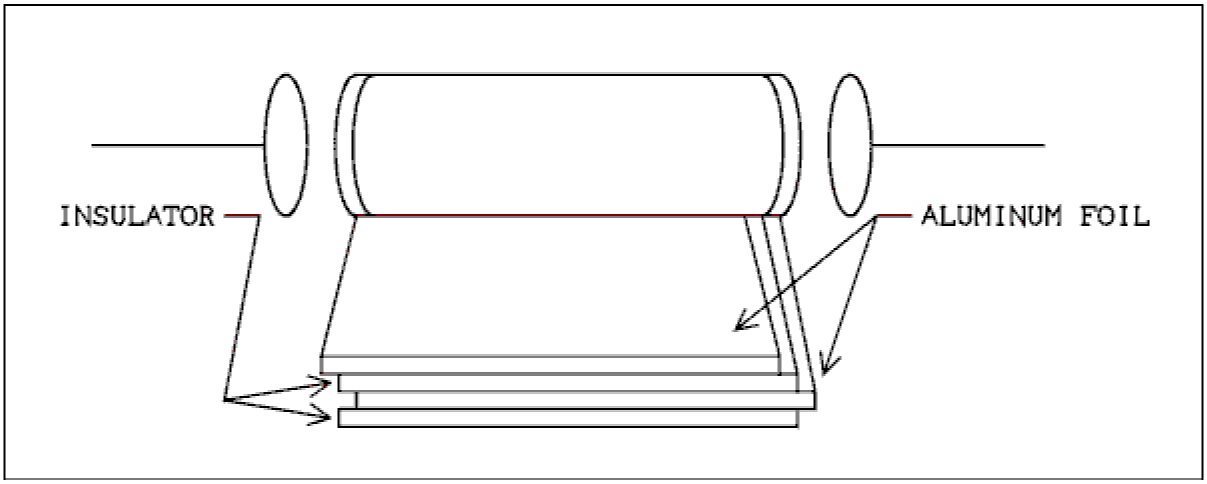


Figure 3.3 Construction of Plastic Film Capacitor.

For a verbal description click here.

Here the most likely failure is in the insulator, which will allow the two metal foils to touch, causing a short.

It is possible for the connection between the foil and the wire (which runs through the case to the outside world) to come loose causing an open circuit, but this is a low probability occurrence.

Capacitors are constructed by starting with a long strip of a sandwich consisting of a layer of aluminum foil, a thin film of plastic, another layer of foil and another layer of plastic film. The strip is rolled up to form a cylinder. The sandwich is made so that one of the foils sticks out slightly on one side and the other sticks out the other. Thus, the two foils are exposed one on each end. The connecting lead is made to resemble a nail. The head of the nail, where the hammer would hit it, is spot welded to the foil on the end of the cylinder. The whole thing is encased in plastic.

Transformers, Chokes, and other coils.

Components which consist of a coil of wire such as transformers, inductors and TV deflection yokes have two main failure modes. The wire can break or burn in two (probably due to a manufacturing flaw) causing an open circuit or the insulation on the wire can fail causing a short.

An open is quite easy to diagnose. Testing with an ohmmeter will show infinity on the defective winding.

A short may be a little more subtle. Unless the transformer is absolutely cooked the short is likely to be over one turn. One turn out of hundreds is not enough change in resistance to show up on a DC resistance measurement. In the case of a transformer when power is applied a high current will flow and if the fuse doesn't blow the transformer will get hot very quickly and emit a bubbling sound as wax or varnish inside begins to boil. There is no saving such a transformer. It must be replaced. In the case of a choke its inductance value will be reduced to a small fraction of its normal value. An inductance bridge or meter will be required to diagnose such a defect. In the case of a TV deflection yoke the picture will b askew and either the vertical or horizontal output tube will be overheating due to too much current. Possibly to the point of having its plate glowing red. The coil of a DC relay may not be effected by a shorted turn and may operate for decades undetected. On the other hand a shorted turn in the coil of an AC relay will cause it to draw too much current and also prevent enough magnetic field from being developed to close the contacts. In a few cases it may be possible to disassemble the relay and replace the coil. In most cases the entire relay must be replaced.

Semiconductors.

When semiconductor devices fail spontaneously, which is rare, they don't fail in a binary manner. What usually happens is that a lead which was welded to the crystal in the factory comes loose. Because there is no force to move the lead away from the crystal they will remain in contact, sort of. If the device is a transistor in a radio or amplifier the result will be static in the speaker. Shaking or slapping the radio or amplifier may or may not effect the crackling sound.

In a radio the bad transistor can usually be found by half splitting although you must be aware that changing impedance as the contact makes and breaks will change the load on the previous stage and cause the defect to appear at the output of the stage previous to the one with the defective transistor.

In a stereo amplifier the presents of negative feedback will cause the static to propagate around the entire feedback loop and no amount of signal tracing will locate the defective device. In such cases the only solution is to unsolder a component such as a resistor to open the feedback loop but BEWARE! In many stereo amplifiers the same feedback loop serves to stabilize the DC operating point as well as provide AC feedback for performance improvement. Opening such a loop will usually result in the output of the amplifier locking to one of the power supply rails. This could damage the amplifier giving you more defective parts to find and replace. In such a case try temporarily replacing the feedback resistor with two resistors in series, each half the value of the original. If there was a capacitor in parallel with the resistor temporarily remove it. Connect a capacitor from the junction of the two resistors to ground. The capacitor to ground should be of such a value that it forms a 10 second time constant with the parallel equivalent resistance of the two resistors. This allows the DC feedback to remain effective while the AC feedback is removed. It should now be possible to find the source of the noise by signal tracing.

When a semiconductor device fails as a result of some other component failure the semiconductor was destroyed by heat. When the silicon crystal is heated it eventually gets hot enough to melt. This results in a short between all leads of the device. As noted elsewhere in this text, the short can result in the current being so high that the wire leads or the crystal itself are burned away leaving an open circuit. Open is a secondary failure mode.

On rare occasions the semiconductor crystal will get just hot enough for the doping impurities to defuse in the crystal which will change the characteristics of the device. The usual result is that the breakdown voltage of junctions is reduced. Meaning that a transistor will no longer operate at the applied collector voltage or a diode will conduct somewhat in the reverse direction. If this rare failure mode occurs it may be very hard to find because it is so rare and is not expected. If the early breakdown does not finish off the device it may turn into a real dog. Transistors and diodes which appear to be good in an out of circuit test may still not work in the circuit.

Summary of Failure modes.

The failure modes of the most common components are summarized in table 3.1.

Table 3.1.

Summary of Failure Modes of a Few Electronic Components.

Component	High Probability Failure Mode(s)	Low Probability Failure Mode(s)
Resistor	Open Resistance value increased	Resistance value decreased
Capacitor, Film	Shorted Leaky (Effective parallel resistance too low)	Open

Cascading Failures.

Capacitor, Electrolytic	Shorted Leaky (Effective parallel resistance too low) Effective series resistance increased Open	
Inductor Transformer Relay coil Deflection yoke	Open Shorted	
Diode	Shorted	Open
Transistor	Base to Emitter short Base to Collector short Everything to everything short	Intermittently noisy Open
Operational Amplifier	Output shorted to one power supply rail	Low input resistance
Digital IC	Output shorted to ground or V+	
Vacuum Tube	Low cathode emission, (weak) Shorts between elements	Heater or filament open

Cascading Failures.

Failures can cascade. Consider the case of the simple power supply of figure 3.4. This is a typical circuit of those power supplies which are in plastic cases with AC plug prongs on them. These are often called "wall mounted" power supplies or wall warts. You will note that there are no fuses in the circuit.

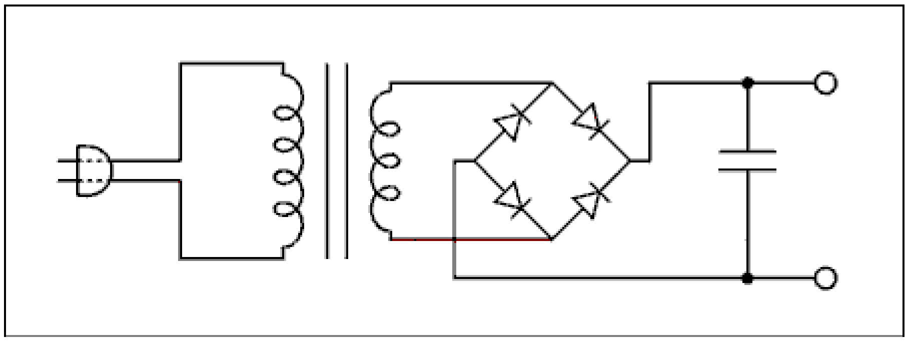


Figure 3.4 Schematic of Wall Wart.

For a verbal description click here.

Most recently made wall warts have some sort of fuse built into the transformer. This may be a current sensing or temperature sensing fuse. In either case it is a one time only operation and if it is burned out the entire wall wart must be replaced. The cost of obtaining a replacement transformer will most likely be about equal to the cost of a new wall wart.

If you have to repair a very old wall wart that has an unusual voltage making it impossible to replace you may have to saw it open and work on it. If so the paragraphs below will apply. These paragraphs will also apply to a power supply that is built with discrete components.

The failure could begin with a shorted filter capacitor. This causes the diodes in the bridge rectifier to overheat and eventually one or more will become shorted. This puts a very heavy load on the transformer causing it to overheat and develop shorted turns. This causes the transformer to draw even more current and get even hotter. The user may not know that anything is wrong until he or she smells the transformer burning and by then it is too late.

It is very common for failures to cascade in this manner. The first fault you find may be a symptom rather than a cause.

In the example of the power supply above, suppose that the transformer had been protected by a fuse. In that case the diodes would have likely shorted out anyway because of one of Murphy's laws, "An expensive semiconductor device protected by a fuse will protect the fuse by burning out first." Therefore, when the power supply comes to your service bench it will have a shorted filter capacitor and one or more shorted diodes. If you replace the faulty diodes and the fuse and apply power you will just burn out some more diodes and another fuse.

The table lists open semiconductors as a low probability occurrence. You may find open semiconductors in the normal course of service work. This most likely is a secondary failure mode.

In some circuits if a transistor shorts, an excessive amount of current can flow. This excessive current can cause the fine wires inside the transistor to melt, thus producing an open circuit. First the transistor shorts and second it burns open. That is a secondary failure mode.

Secondary failure modes are hard to predict in general because they depend on the circuit. In general if a secondary failure occurs, other components will be taken out as well.

The matter of secondary failures and cascading failures will be dealt with as they come up in specific circuits.

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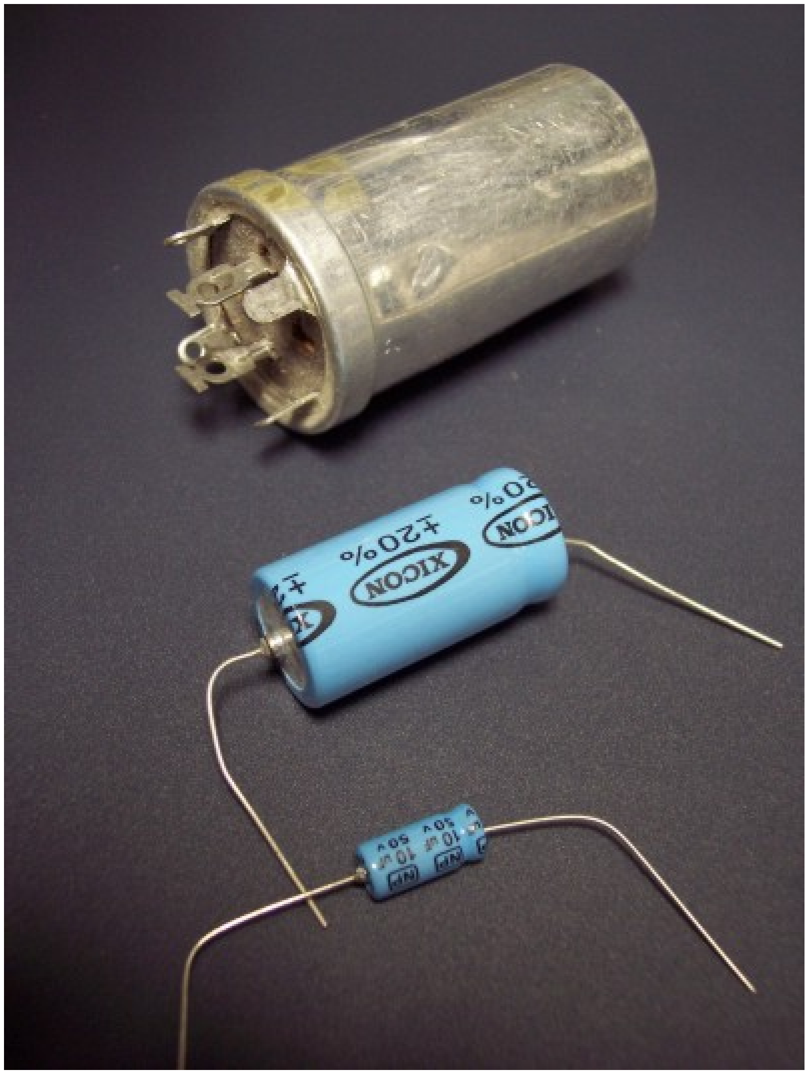
3.2 Electrolytic Capacitors.



Picture 3.5 3 Electrolytic Capacitors.

For a verbal description click here.

Electrolytic capacitors are unique enough to warrant a section of their own. In the picture above top is a two section can electrolytic. The negative end of both capacitors is connected to the can and the positive ends are brought out to the two large lugs. A capacitor of this type mounts in a special cutout made in the chassis in a factory or more often mounts on a mounting plate which has slots for the four smaller lugs that are around the edge of the bottom of the can. These capacitors are made with up to 4 separate capacitors in one unit.

Next is a single 450 volt capacitor that is used in tube circuits. Below that is a small 25 volt capacitor that is found in transistor circuits.

All of these capacitors have positive and negative terminals. Reversing the polarity can be catastrofic.

Electrolytic capacitors are an exception to the rule that capacitors rarely fail open. They are made similarly to conventional capacitors as described above but the insulator is a porous paper instead of plastic film. The paper is impregnated with an electrolyte usually an acid. During the manufacturing process each capacitor is connected to a current source. This causes a layer of aluminum oxide to form on the positive foil. As the voltage increases the oxide layer becomes thicker and the process is terminated when the voltage reaches about 1.5 times the intended working voltage. This process is known as forming the capacitor.

The paper is not the insulator, dielectric, of the capacitor, the oxide layer is. The aluminum foil is the positive plate, the oxide layer is the insulator and the electrolyte in the paper is the negative plate.

A common failure mode in equipment which has never worked is for the capacitor to be reverse polarized. Electrolytic capacitors are used in power supplies. If someone connects one backwards the capacitor will conduct a substantial direct current. This current heats up the capacitor interior and when it gets hot enough the water in the electrolyte turns to steam, pressure builds up inside the container and the capacitor literally explodes. The minimum sound is like a fire cracker but if the capacitor is large it can range up to a cherry bomb or a silver salute.

Other than the above electrolytic capacitors don't fail anymore often than plastic film capacitors as long as the equipment is in continuous use. Defective electrolytics are most often encountered by those who restore vintage electronics.

Electrolytics made 50 or more years ago probably weren't as well sealed as modern ones. They can dry out. With most of the water gone from the electrolyte the capacitance is reduced to a small fraction of its original value. Such capacitors are open and have to be replaced.

Another very common failure mode for electrolytic capacitors in vintage electronics equipment which has not been turned on for decades is to become unformed. The oxide layer has become very thin. If treated with care such capacitors can be reformed outside of the factory. The thing you must not do with vintage equipment is turn it on. The capacitors in the power supply will explode if the primary fuse doesn't blow first. Considerable damage can be done to other components, some of them difficult to find. More details can be found in a later chapter devoted to trouble shooting and restoring vintage electronics.

WARNING! Be sure to take the special precautions outlined below or you will wind up with a burned out meter. If you just connect the meter in series with a capacitor across a power supply, when the supply is turned on the charging current of the capacitor will be as much as an ampere and a sensitive milli amp or micro amp meter will be burned out.

The empirical formulas below tell you when to discard an electrolytic capacitor. In order to actually measure the leakage currents without destroying your meter here is what to do.

1. Connect a short across your meter and set it to a high current range.
2. Connect the meter in series with the capacitor you want to test.
3. Connect the combination across the power supply.
4. Turn on the power supply.
5. weight for 1 minute.
6. Remove the short from the meter.
7. Start switching to lower ranges until you can read the leakage.
8. Write down the value.
9. place the short back on the meter.
10. Turn off the power supply.
11. Discharge the capacitor by connecting a 10 k ohm 1 watt resistor across it for as long as it takes for the voltage to fall below 5 volts.
12. Disconnect everything.
13. Apply the formulas below to determine the state of your capacitor.

The current you measured above is termed the leakage current. In normal operation it does no harm but if it becomes too large the capacitor can fail violently as described above. A set of formulas which give the approximate leakage current are given below.

$$IL_{Min} = Sqrt(VC)/5$$

$$IL_{Max} = Sqrt(VC)/2$$

$$IL_{Worst\ Case} = Sqrt(VC)*6$$

IL is the leakage current, V is the rated voltage and C is the rated capacitance of the capacitor.
Note: Those familiar with basic electricity will remember that CV = Q, where Q is the charge stored in Coolums. This may be just a coincidence. I can't readily see how the square root of charge gives the leakage current. Dimensionally it gives meters times the square root of Newtons. This must be an empirical equation. It came from a capacitor manufacturer which is no longer in business.

The leakage current IL values for minimum, maximum, and worst case, are for newly manufactured capacitors. But if an older capacitor fails to reform to a current less than the worst case it should probably be discarded. Detailed reforming instructions will be given in the chapter on vintage equipment.

Here is an alternative method for testing an electrolytic capacitor using a voltmeter instead of a sensitive current meter.

1. Connect the capacitor in series with a resistor and the series combination across a power supply which is set to a voltage equal to the working voltage of the capacitor.
2. Set a voltmeter to a range just higher than the power supply voltage.
3. Connect the meter across the resistor. Start with a resistor having the value R = V / IL Where R is the resistance of the resistor for the initial test and IL is the expected leakage current from the above equations.
4. When the meter reading stops increasing turn off the power supply and discharge the capacitor.
5. Substitute a resistor having the value R = V / (10 x IL) If the capacitor is good the meter reading will rise to 90% of the power supply voltage.

The above test method will also serve to reform an electrolytic capacitor which has become unformed from prolonged disuse.

Effective Series Resistance, ESR.

Another common defect of electrolytic capacitors is for the effective series resistance to increase. All capacitors have some series resistance. It is as though there is a small resistor inside the case along with the capacitor. This resistor is in series. In film capacitors this resistance is very small being typically a fraction of an ohm. But in electrolytic capacitors the ESR can be significant. The usual cause is drying out of the electrolyte. A capacitor which is 20 years old may be slightly dried out causing an ESR of a few ohms. Depending on the application such a capacitor may not give any indication of trouble. A capacitor which is 50 years old may be so dried out that it's ESR is so high that it can no longer effectively bypass a cathode resistor or act as a filter in a power supply. It may show good on a capacitor tester and you may be able to measure its capacitance with a bridge but it just doesn't work right. Other 50 year old capacitors may be completely dried out and are effectively open. The later are usually enclosed in a cardboard tube and seeled with wax as opposed to being in metal cans. These wax seeled capacitors were used in all American 5 radios and give the symttom of a loud hum in the speaker after the tubes warm up.

Some testers and many bridges measure the D (dissipation) factor along with the capacitance. The dissipation factor is defined as

$$D = Rs / Xc$$

Where Rs is the effective series resistance, and Xc is the reactance of the capacitor calculated at the test frequency. Therefore,

$$Rs = D\ Xc$$

Substituting for Xc gives,

$$Rs = D / (2\ pi\ f\ C)$$

Where pi = 3.14159, f is the test frequency of the meter or bridge, and C is the capacitance in farads, not microfarads.

I know of no simple setup that will reliably measure ESR. One way might be to run up the frequency until Xc is less than an ohm then apply a current and measure the voltage. The problem is that the frequency may be so much higher than the normal operating frequency as to render the results meaningless. Substituting a known good capacitor is probably the only way to diagnose high ESR

Chapter 4 Troubleshooting Techniques.

Chapter 4

Troubleshooting Techniques.

Before we can begin troubleshooting, we must develop some techniques tools and rules. You may already know many of these rules but have never expressed them in words. Most are simple common sense.

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4.1 Check The Obvious First.

This seems so obvious that it should not need to be said. But time and time again, service personnel will overlook a pulled out plug, a blown fuse or even a burned out power indicator light.

Replace indicator and dial lights. If the power indicator is burned out the operator may assume that the equipment did not come on when the power switch was activated. You should replace lights even if you have not been asked to do so. Equipment operators appreciate it and will have good feelings about the equipment and the people who service it. This is more important than you might think. If the operator believes that the service personnel are doing a good job, there will be fewer complaints and better evaluations for the service people.

Be tactful. If you find something so simple that the operator could have corrected it, do not be insulting to the operator.

There is nothing to be gained and a great deal to be lost. If questioned by the operator, be as diplomatic as you can. Good relations between operating and service personnel are as important as the technical operation of the equipment itself.

Test for the presence of AC voltage. You may want to use a test lamp because it is quicker and easier than a voltmeter.

Test for the presence of DC voltage. Make sure that the power supplies are delivering the voltages and that they are getting to all of the circuit-boards in the unit.

Make sure the power supply voltages are correct and free of ripple. A sizable enough percentage of equipment failures are caused by the power supply to warrant always checking it first. As a friend Mike McCarty puts it, "The power supply is mama. If mama aint happy, aint nobody happy."

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4.2 Do Not Make Modifications.

There are two basic kinds of circuits to troubleshoot, circuits which used to work and stopped working, and circuits which have never worked.

If a circuit used to work, it is safe to assume that it came from the manufacturer with all component values correct for proper operation. As a service technician your job is to find the defective component and replace it. Modifying the circuit to correct the fault will probably result in performance not as good as when the equipment was new. Modifications also make the job of any technicians who come after you almost impossible. Don't start changing component values and rearranging circuitry; find the defective part and replace it.

As with any rule there are exceptions. One is obvious, if you are the owner of the equipment and you want to add a feature that was not part of the original design. Even so you should print or write clearly information about the modification on a gummed mailing label and stick it inside the chassis or cabinet. You may think you will own the equipment as long as you live but you aren't going to live forever. Eventually this beloved device will wind up in the hands of a stranger who will be helped if such a note is included. Making notations in the manual is not good enough. After you have gone on to the big ham shack in the sky chances are the manual will be tossed and the equipment sold at an estate sail.

Another exception is if the owner specifically asks for a modification. He or she may ask if you could add a phono jack so the RCA 45 could be played through the radio. Or someone may ask if the radio, phonograph, or TV set, could be equipped with a headphone jack for private listening.

When the equipment doesn't belong to you and the owner just wants it to work again, modifications are right out.

Don't start turning internal adjustments. If the equipment is just a little bit off from its specifications, recalibration may be what is needed. If the equipment just doesn't work, changing calibration settings isn't going to fix it. If you have turned every adjustment you can find, it will be difficult to know when you have replaced the defective part or parts. You can never be sure if the symptoms are caused by a defective part or the fact that every adjustment has been tinkered with. Resist the urge to tinker. Adjustable resistors and capacitors don't turn themselves.

I personally know of a case where this happened. A student worker was troubleshooting a Wavetech function generator. There must have been half a dozen trimmer pots on the circuit board. The first thing he did was to turn every screw. Then he started randomly replacing components. He finally gave up saying it couldn't be fixed. When it landed on my bench the first thing I did was to perform the adjustment procedure in the manual. It came into alignment and worked just fine. Somewhere along the line he had replaced the defective part but didn't know it because it was so far out of adjustment. So let me reiterate, don't turn any adjustments. They don't turn themselves and they are not the reason the instrument stopped working.

Circuits which have never worked are a slightly different story. An example of such a circuit could be an R and D (research and development) prototype. In such a case there may or may not be a defective component in the circuit. It may not be working because someone installed a resistor of the wrong value or a diode or transistor backward. In a case such as this you are justified in modifying the circuit.

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4.3 The Power Supply Section.

The power supply of any line operated electronic device is the first place you should look for trouble. As pointed out above the first thing is to check for normal voltages. However an often encountered symptom is "It blows fuses." In such a case the first step is to separate the power supply section from the rest of the device. This may be as easy as pulling a plug or two but may require unsoldering some wires. Once the supply has been separated from its load try another fuse. One exception to this is if the device uses vacuum tubes and one of them is a rectifier. Unplug the rectifier tube and make sure there is no bias supply that uses a selenium or silicon rectifier. Inspect the heater circuit to make sure there aren't any shorts. Then try another fuse. If it blows the transformer is most likely shorted and needs to be replaced.

If the transformer is good no matter if the device uses tubes or transistors, check for shorted diodes and filter capacitors. If the diodes and capacitors appear to be good but fuse blowing persists try the dim bulb test. Connect a low wattage, say 25 watt, tungsten light bulb in series with the power line. The bulb may light up at full intensity. You now have current flowing in the transformer, rectifier, and filter, components. Find out what is going on in the power supply before you switch to a higher wattage bulb. Check for heating of diodes and filter capacitors. Measure voltages with an oscilloscope if possible. If you find it necessary to go to a higher wattage bulb don't go above the rated current of the device. For example if the device specifications say normal line current is 2 amperes don't go above a 250 watt bulb.

This test may reveal that a diode is going into reverse breakdown at a lower voltage than required for the supply. Contrary to popular belief a diode is not completely binary in its failure. Overheating may reduce its reverse breakdown voltage. The cause of that overheating may be an electrolytic that passed an ohmmeter test but is conducting a direct current at a much lower voltage than it's normal operating voltage. Such a symptom is quite common in vintage equipment which has not been turned on for several decades. You may observe that the DC voltage across the filter capacitor is slowly increasing. If so let things run while occasionally checking the temperature of the capacitor. If the capacitor begins to heat change to a lower wattage bulb. What is happening is that the capacitor has become unformed from disuse and is being reformed. Reforming the capacitor may restore the unit to operation. If the capacitor refuses to reform to the necessary voltage it must be replaced. Even if it does reform after a few hours of dim bulb operation replacement is still recommended if at all possible.

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4.4 Half-splitting.

Many pieces of equipment are so designed that signals or data flow through them from one operational block to the next. In this case it is possible to apply a technique known as half-splitting.

In this procedure you check for the presence or absence of signal at a point halfway between input and output. If the signal is present, you know the trouble is in the second half. If the signal is absent, you know the trouble is in the first half. Then you split the defective half in half and check for signal. In a large system this procedure can save a lot of time over moving down the line checking each block or stage as you go.

Think of it as being similar to the old "guess the number" game. "I am thinking of a number between 1 and 1000. You make a guess and I will tell you if you are too high or too low." Your first logical guess would be 500. If I say "You're too low," your next guess would be 750, and so on. If your first guess was 1 and your next guess was 2, it would take a very long time to find the number unless I happened to be thinking of 3. If I am thinking of 998 it would take a very long time.

An example might be an AM radio. Although it may not be exactly half way, the volume control is a good place to start half-splitting. It is easy to find and test equipment is easy to connect. You are likely using a signal tracer or oscilloscope. Presents of audio means that the RF and IF sections are OK and the trouble is in the audio amplifier and speaker section. At this point the circuits are so simple it is impossible to distinguish between half-splitting and down the line testing.

All but the most elaborate console radios have only two stages in the audio section. So check between them, at the plate or collector of the power output and at the speaker.

If there is no audio at the volume control check to see if the local oscillator is running. Do not connect your scope probe directly to the oscillator grid in a tube radio. Connect to a low impedance point such as the cathode in a Hartley oscillator circuit. Transistor circuits operate at a low enough impedance that connecting to the base of the oscillator will not stop the circuit from oscillating.

There may be situations where half-splitting cannot be applied. One is an audio amplifier with negative feedback. Any trouble anywhere inside the loop will propagate around the loop and the signal will be out of whack everywhere. If the feedback is AC coupled only the loop can be opened up by unsoldering a resistor and maybe a capacitor. Then normal half splitting can be applied. In large and complex systems half-splitting usually can and should be employed.

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4.5 Signal Tracing.

One way in which half-splitting can be implemented is by signal tracing. In this technique a device which can detect the type of signals in the system is used to look for them.

When AM radios were about the only thing to be repaired, a device known as a signal tracer was on every service bench. The device was capable of responding to the signals in the RF (radio frequency), IF (intermediate frequency) or AF (audio frequency) stages of the radio. The "readout" of the signal tracer was a loudspeaker. Signal tracers are seldom seen these days and I know of only one company which is still manufacturing them. No such device is available for television signals.

A signal tracer for radios can easily be constructed. Any simple two tube single ended audio amplifier can be a signal tracer. Even one that already exists. Just attach a shielded probe to it such as a times 1 scope probe. If you use an existing amplifier it probably doesn't have a DC blocking capacitor in its input. One must be added before the amplifier is used as a signal tracer. Don't just say "I won't touch any high voltage. Someday you will make a mistake and touch a 300 volt point and "zap", there goes your amplifier especially if it is transistorized.

For checking IF and Rf circuitry all you need to do is add a simple AM detector as shown below.

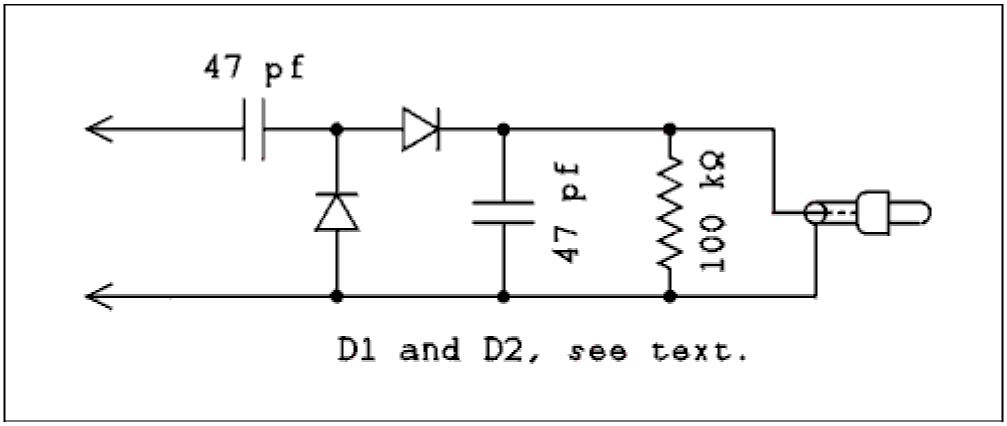

Figure 4.1 Circuit for a Simple AM Detector Probe.

For a verbal description click here.

Silicon diodes such as 1N4148 can be used but I don't recommend it. Improved performance can be had with 1N270 if you can get them. You stand a better chance of finding 1N34A diodes. Or the ECG or NTE equivalent.

This probe can be used to test for an AM signal on the plates or collectors of IF amplifiers, mixers, and RF amplifiers. When connected to an unmodulated source of RF the detector will deliver a DC voltage approximately equal to the peak to peak voltage of the source. The probe can be used in conjunction with a high impedance DC meter to tell if the local oscillator in a radio is operating.

In the age of CD players and computerized industrial control systems, signal tracing is usually accomplished using an oscilloscope. Of course the troubleshooter must know what the signal is supposed to look like in order to know if anything is wrong. Service manuals for most modern equipment contain actual photographs of scope traces to show what the signals are supposed to look like at various points in the system.

Signal Substitution.

Signal substitution is employed when the equipment being tested has been separated from its signal source. For example, suppose you are working on a stereo receiver but you don't have a turntable handy. You would use an AF generator to substitute for the magnetic pickup of the turntable. You would then employ the techniques of signal tracing to find the trouble.

Signal substitution should not be confused with signal injection. In signal substitution the signal generator is connected to the input of a piece of equipment instead of the device or equipment which normally goes there. The signal generator is left connected at the input throughout the testing procedure.

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4.6 Signal Injection.

Another way in which half-splitting can be implemented is by signal injection. It is employed when the equipment being tested has been separated from its signal source but its output device is present.

For example suppose you are troubleshooting the vertical amplifier of an oscilloscope. You could use a function generator to inject signals at various points in the vertical amplifier and watch for the signal to appear on the scope's screen.

***** WARNING *****

Few if any of today's signal generators have DC blocking capacitors in their outputs. The output impedance of most generators is 50 ohms. If you inject signals without using an external DC blocking capacitor, you could further damage the piece of equipment you are trying to fix and/or damage the signal generator.

It is necessary that the injected signal be compatible with the stage into which it is being injected. It will be of no use to inject the output from an RF generator into an audio stage or the output from an audio generator into an RF or IF stage.

Returning to our example of an AM radio you could start by injecting a signal at the volume control. If you don't hear the signal or it is very weak even with the generator's output turned up to full the trouble is in the audio section. Once again the circuit is so simple that there is little use in half-splitting beyond this point. If the audio signal generator you have does not have a DC blocking capacitor in its output you must use one. The simplest way is to hold one lead of a capacitor in the clip lead from the generator and use the other lead as a probe. It will usually help to shorten the leads of the capacitor. Start with the generator output set low and touch the probe to the plate or collector of the output device. Turn up the generator until you hear something. In a tube radio the sound will not be very loud even with the generator turned up to full. Turn the output down a bit and touch the grid or base of the output device. The sound should be loud with a low setting of the output. Move back to the grid or base of the first audio stage. The sound should be even louder. These statements would be true if there was no trouble in the audio section. Obviously there is so the sound will not be louder in one of the cases where it is supposed to be.

If the trouble is not in the audio section you need to work with the IF and RF sections. Set your RF signal generator to the frequency of the IF which in most cases will be 455 kHz but in car radios and some older radios may be 262.5 kHz. Remember to use a DC blocking capacitor. Touch the probe to the plate or collector of the last IF amplifier. You should hear a good loud signal with the generator set to about 0.1 volt. Move the generator to the base or grid of the same stage. Touch up the frequency of the generator to be sure it is tuned to the center of the IF band. The signal should be much louder. If the AGC in the radio is very good you might not perceive much of an increase. Don't be fooled by this. Turn down the output of the generator until the signal begins to get weak. Move the probe back to the plate or collector to confirm that the stage has a lot of gain.

The next logical thing to check is to see if the local oscillator is running. One of the least equipment intensive methods is to listen to the oscillator on another AM radio. Tune the other radio to a weak station in the top half of the AM band above 1000 kHz. Tune the radio you are troubleshooting about 455 kHz below the other one and if the oscillator is operating you will hear a beat, descending tone followed by an ascending tone, as you tune across the frequency. If you are working on a pocket transistor radio the two radios must be sitting one on top of the other for the oscillator signal from one to be picked up by the other.

Another way is to look with an oscilloscope. This is the only sure test for a transistor radio. When looking at the grid in a tube radio be sure to use a times 10 probe. Even so the frequency of the oscillator will be thrown off by several kHz.

Yet another way to confirm oscillation in a tube radio is to measure the DC voltage at the oscillator grid. If you have a genuine VTVM it will have a 1 meg ohm resistor in the DC probe. You should measure approximately -20 volts at the grid. This figure is very approximate and your mileage may very. If you measure only a fraction of a volt negative the oscillator is not running. If you only have a DMM you must use a 1 meg ohm resistor at the probe tip as described for a capacitor above. Touch the resistor to the grid. The reading will be approximately 10% low but you only want to determine if there is negative DC present at the grid. Its absolute value is not important.

If the oscillator is running but the radio is still not working you may be encountering a puzzling situation. You may be hearing stations when you touch your test probes to certain points in the radio but they go away when the probe is removed. This is most likely in a radio that has an RF amplifier stage. The trouble is there. If the radio does not have an RF stage this situation is still possible although the symptom was more likely to be that the radio would pick up very strong local stations but they sounded very weak. This would indicate trouble in the built in antenna or if the radio is very old and requires an external wire antenna the antenna transformer may be defective. You did remember to connect an external wire antenna to that old radio, didn't you?

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4.7 Disturbance Testing.

Disturbance testing can sometimes be employed in the absence of a signal generator. You may be familiar with one kind of disturbance testing. If you touch your finger to the phono input of a stereo amplifier you will hear a loud hum in the speaker. If you have ever used this effect to find out if the amplifier was working, you have engaged in disturbance testing for the purpose of troubleshooting.

The usual method of disturbance testing is to touch or scratch various points in the circuit with a screwdriver. It is sometimes helpful to touch a finger to the metal part of the screwdriver, but only in low voltage circuits.

If you are concerned about the hazard of electric shock (as you should always be), you can touch or scratch with one lead of a resistor while holding the other lead.

Disturbance testing should always be conducted with care because it is possible to destroy some MOSFETs (metal oxide semiconductor field effect transistors) by touching the gate terminal.

Back to the example of our radio. The impedance levels in a transistor radio are too low to effectively employ disturbance testing. You can test the audio section in a tube radio by touching the center terminal of the volume control. **CAUTION!** In most AC operated radios the on/off switch is shared with the volume control. The AC terminals for the on/off switch are on the back of the control. The audio terminals for the volume control are on the side. It is likely to be unhealthy to get them confused. Touch the center terminal on the side of the control and turn the volume up and down. You should hear the volume of the hum change. Note: If you aren't using a knob on the shaft but turning the bear metal shaft you will find that the hum will be considerably reduced when you touch the metal shaft. That's because you are grounding your body to the chassis of the radio and the signal that your body picks up as it acts as an antenna is not nearly as strong as when it is not grounded.

Disturbance testing on the IF amplifier is done by scratching on the grid terminal of the IF tube with the blade of a screwdriver. If this produces static in the speaker it is likely the IF amplifier is alright. And that takes us back to that pesky local oscillator again.

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4.8 Static Testing.

The "static" in static testing is static as in standing still, not static you hear on the radio. Static testing means testing the device with no signals present.

Static testing is further subdivided into two types, testing with power on and testing with power off.

Testing with power on usually means making DC voltage measurements. Voltage measurements are only meaningful if you know what the voltages are supposed to be. That implies that you need a voltage chart for the particular piece of equipment. If you are without such a chart, do not despair; later chapters in this book will cover how to reason from the circuit diagram what the voltages should be.

In any radio, tube or transistor, if it stops working chances are that some vital DC supply voltage is missing. While you may not be able to say if the voltage is high or low, if it is zero the tube isn't going to do much amplifying. In a tube radio check for plate and screen grid voltages. Odds are good this will lead you to the problem. In a transistor radio check to see that base emitter junctions are forward biased and that the collector is higher, in the absolute sense, than the base. Remember that most older transistor radios used PNP transistors which means that all voltages are reversed from the way we have become accustomed to thinking of them in NPN circuits.

Static testing with power off means making resistance measurements with an ohmmeter. Because the amplifying devices used today conduct current (from the ohmmeter battery) even when no power is applied (unlike vacuum tubes), resistance measurements are seldom used.

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4.9 Shotgunning.

The term "shotgunning" and the procedure which goes with it originated with the writer's father. The procedure is quite simple. "Find what stage the trouble is in and replace all of the parts in that stage. Resistors and capacitors are cheap" (and now so are transistors) "and time is money."

This philosophy does not work quite as well in the transistor age as it did in the vacuum tube age. One reason why this is true is because transistors have such a low input impedance. The trouble can be one stage later than you think it is. Another reason shotgunning doesn't work as well as it used to is because of the increased use of feedback in transistor circuits. This makes trouble propagate around the loop, making it very difficult to pinpoint the defective stage. Negative feedback can also defeat signal tracing and half-splitting.

Chapter 5   Faults in Power Supplies.

Chapter 5

Faults in Power Supplies.

With the exception of battery operated equipment everything has a power supply. When troubleshooting any piece of electronics the power supply is always the place to start.

The device containing the power supply may be a kit or DIY construction project that used old parts. It may be a piece of old electronics that has not been turned on in several decades.

There are also laboratory bench power supplies that may develop a fault and wind up on your bench.

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5.1 Rectifier-Filter Circuits.

WARNING: IF THE ELECTTRONIC ITEM HAS NOT BEEN TURNED ON FOR MANY YEARS, DON'T JUST PLUG IT IN AND TURN IT ON. Refer to the chapter on antique electronics equipment before attempting to troubleshoot such items.

Power supplies can range in complexity from simple transformer-rectifier-filter circuits to multi output with electronic voltage and current regulation. If the power supply is one of the latter the regulator circuits should be separated from the basic rectifier filter and the basic circuit tested separately.

Although a simple power supply has little to go wrong, as pointed out earlier in this book failures can cascade turning a simple problem into a more complex one.

An electrolytic capacitor used in a DIY project may have been taken from NOS (new old stock) and may not be formed up to its rated voltage. Such a capacitor may show good using an ohmmeter but will blow fuses and diodes when the power is turned on. Since the capacitors have never been put into use they should be tested at their rated voltage.

For a brief discussion on the construction of an electrolytic capacitor, how to test it, and its behavior in a circuit, refer back to 3.2 Electrolytic Capacitors.

For a discussion on testing a power supply which may have unformed electrolytic capacitors and how to reform them refer back to 4.3 The Power Supply Section.

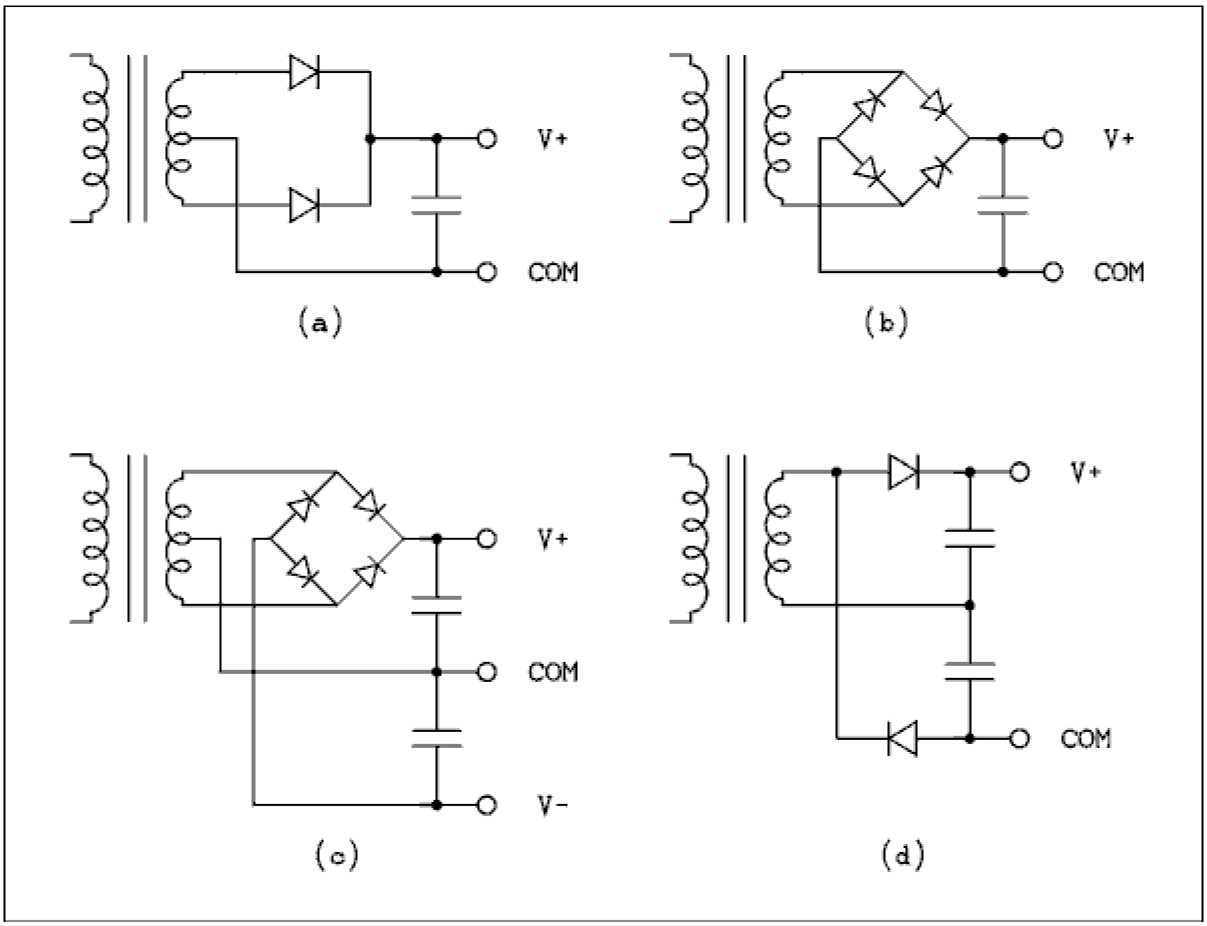

Figure 5.1, Four Most Common Rectifier-Filter Circuits.

For a verbal description click here.

Figure 5.1 shows the four rectifier-filter circuits you are most likely to encounter. The primary circuit showing connection to the power line, switch, and fuse have been omitted but will always be present in the device on your bench. Just for the record they are (a) full-wave center-tapped, (b) bridge, (c) dual voltage bridge, and (d) full-wave voltage doubler.

The terminal labeled "COM" (common) on each circuit may or may not be connected to the chassis of the work device. The positive terminal labeled "V+" could just as well be used as common to obtain a negative supply or a circuit could have its "COM" connected to the positive of another similar circuit to obtain more voltage. The circuit of Figure (c) could have the bottom or top terminal used as common to produce voltages of V+ and 2V+ or V- and 2V-.

If you have stripped the circuit down to one of these and it is found to be at fault the most likely symptom is blowing fuses. Resist the temptation to put in a bigger fuse. A good starting point is to use your ohmmeter to test the diodes. Most of the time a failed diode will be a really dead short, zero ohms. There will be parallel current paths through the other diodes and transformer secondary. If the power supply is low voltage high current the secondary may have a resistance of a small fraction of an ohm. In this case if two of the diodes are shorted it may appear as if all are shorted.

You will likely have to unsolder the diodes in order to test them. If even one defective diode is found you should replace all of them. All diodes in a rectifier should be of the same voltage and current rating. Diodes aren't all that expensive anyway.

Remember that one or more shorted diodes may be caused by a shorted or unformed electrolytic capacitor. After replacing the diodes and before plugging it in, use your bench power supply to attempt to apply the normal operating voltage across the outputs with the power supply being worked on unplugged. The bench power supply MUST be current limited.

WARNING!!! Most vacuum tube bench power supplies do not have current limiting. A resistor must be used to limit the current to a safe value for the bench power supply.

If the voltage will only come up to approximately 10% or 20% of operating voltage an unformed electrolytic capacitor is indicated.

In the case of Figure (c) the voltage may be applied to each half of the supply separately. This will localize the problem to one or the other of the circuits. If you carefully examine the circuit you will see that the bridge really consists of two full-wave center-tapped circuits like that of Figure (a). One is reversed from the other.

Silicon Diodes most often fail dead shorted. If the fuse does not blow quickly enough another diode may also go shorted and excessive current may burn one or both open. In either case the failure is binary and can be detected with an ohmmeter, even the ohmmeter section of a DMM. In higher voltage circuits the partial failure of reduced reverse breakdown voltage may be encountered. Such a failure mode is difficult to detect unless you have access to a curve tracer. In deed it may be difficult to tell the difference between such a diode failure and an unformed electrolytic capacitor. Unsoldering components for testing separately is the only way to resolve this ambiguity. If the capacitor test good up to its operating voltage the diodes should be shotgunned.

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5.2 Voltage and current Regulator Circuits.

5.2.0 How a voltage regulator works and what it does.

A voltage regulator has to hold the voltage constant as the voltage of the input varies and as the load current changes. The output voltage of a rectifier and filter capacitor is not constant. The line voltage can vary all over the place and then there is that ripple which is always present. Another application is in battery operated equipment. In many cases the designer of such equipment wants the voltage applied to the circuits to remain constant as the batteries run down. The battery voltage is set higher than the circuit needs and the regulator holds it constant until the voltage gets near the operating voltage. Special circuits usually warn the operator and/or turn off the equipment when the battery is so run down as to no longer operate the device.

Changing load current is another difficulty. We often use resistors to indicate the load on a power supply. The real load on a power supply is a transistor circuit and/or a small motor or two. The current drawn by a transistor circuit may change depending on what the circuit is and what it is doing at the moment. The current drawn by a motor changes as its mechanical load changes. So a regulator may have a lot to do.

A regulator can't increase the voltage applied to it. All it can do is reduce it. It regulates the voltage by reducing it by the amount required to hold it at some preset value. The difference between the regulator input and the output is called the regulator drop. Each type of regulator has it's minimum regulator drop. If the input voltage falls so low as to make the regulator drop less than the minimum the regulator will lose control and the output voltage will fall.

For example, a 12 volt regulator IC has a minimum drop of 2 volts. That means that the input voltage must be 14 volts or higher. It regulates just fine for input voltages anywhere from 14 to 40 volts. But if the input voltage falls to 13 volts the output voltage will fall to 11 volts and it will no longer be regulated. It will just be 2 volts less than the input, ripple and all. If the ripple valley falls below the minimum required the output voltage will acquire ripple as shown in the graph below.

A common fault in equipment that is older than 20 years is for the electrolytic filter capacitor(s) to dry out which reduces the effective capacitance value. In such a case the ripple amplitude will increase.

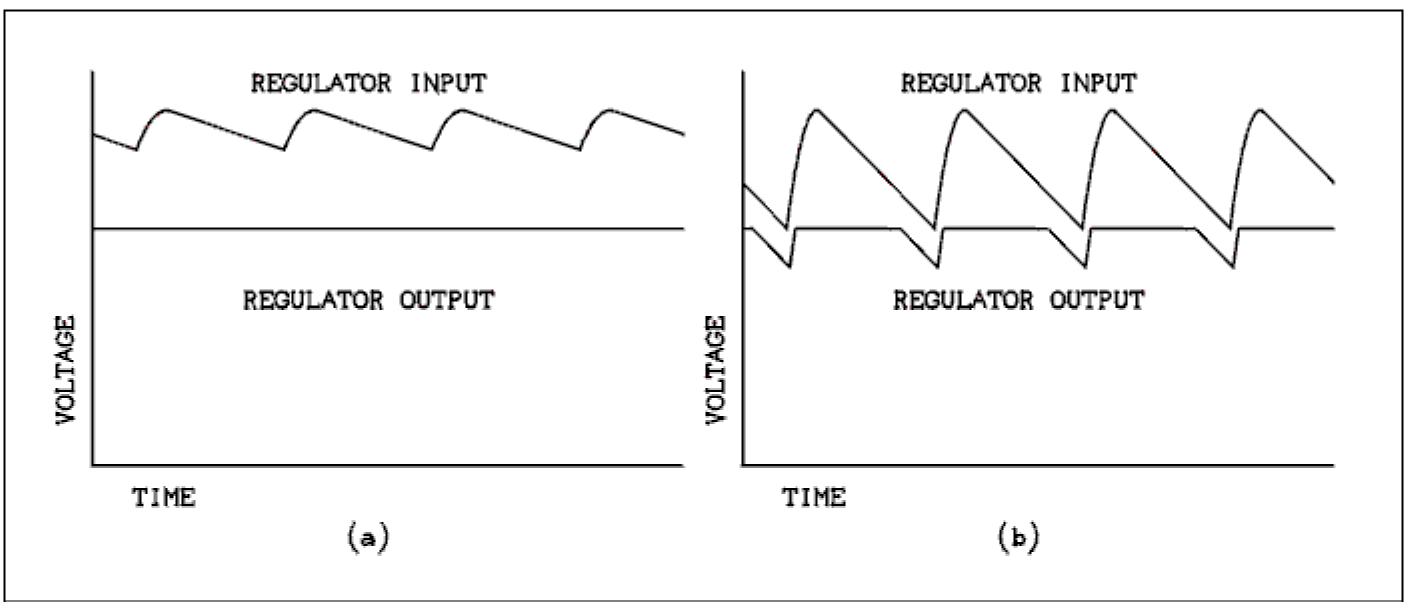

Figure 3.14 Input and output waves of a voltage regulator.

For a verbal description click here.

The upper wave is the output of a full wave rectifier with a capacitor filter. The lower wave is the output voltage of a voltage regulator. In (a) the input voltage is high enough that the regulator is able to do its job properly. In part (b) decreased capacitance has reduced the ripple valley so it is below the minimum required to maintain regulation. Note that the peak voltage is the same in both cases. This is the way ripple responds to decreased filter capacitance value or increased load current.

A measurement with a DC voltmeter is likely to indicate that the input voltage is high enough but the ripple valley is too low. Only an oscilloscope measurement will reveal this defect. This is one of the most overlooked problems in troubleshooting electronic devices.

5.2.1 Transistor Circuits.

If the basic rectifier filter section is working properly The problem is in the electronic regulator circuit. Beware of treating the symptom. Many power supplies I have opened up have revealed a burned or scorched resistor. Replacing this resistor will not fix the problem. The replacement will just burn out as the old one did. However, this will point you to the area of trouble.

A very basic voltage regulator circuit is shown in Figure 5.2.

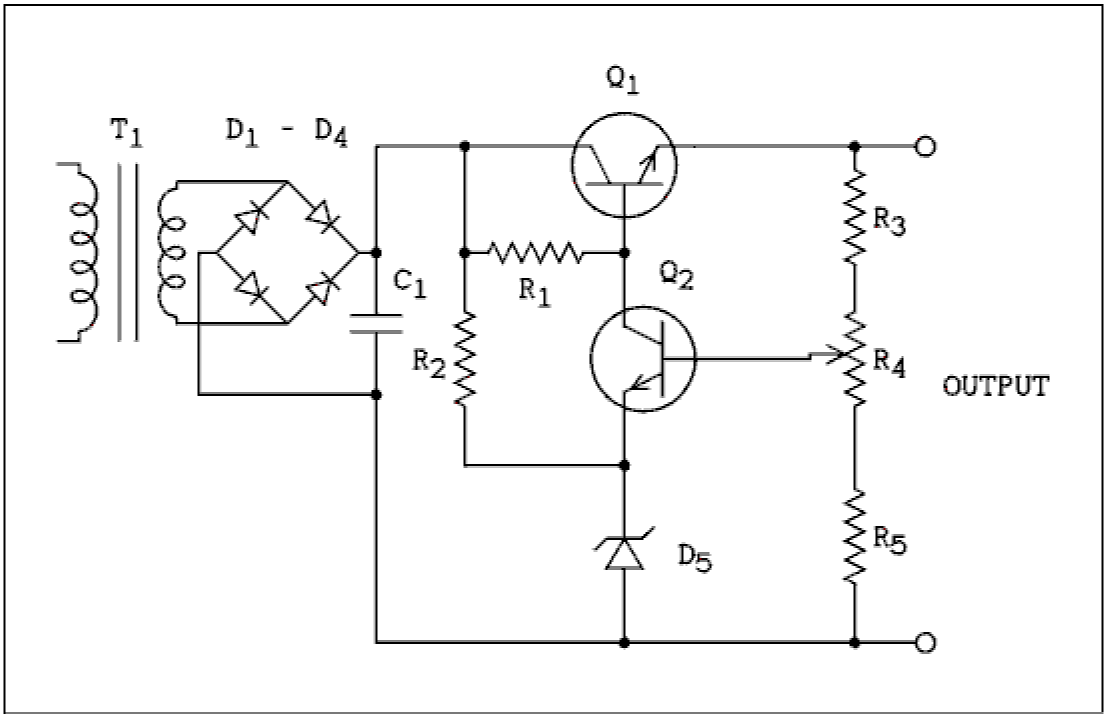

Figure 5.2, Simple Voltage Regulator Circuit.

For a verbal description click here.

This type of regulator would most likely be used as the internal power supply for some piece of lab equipment such as a signal generator. The voltage adjustment pot would be of the "set and forget" type. Bench power supplies require different circuitry so their voltage can be adjusted all the way to zero.

R2 supplies a current to the zener diode D5 which maintains a constant voltage at the emitter of Q2. R1 supplies current to the base of Q1 which without Q2 would hold Q1 in near saturation. The collector of Q2 can take current away from the base of Q1 reducing the voltage at the emitter of Q1. In the equilibrium condition the voltage at the emitter of Q1 is held constant by the circuit. Q1 is known as the pass transistor and Q2 is the error amplifier. The zener diode provides the reference voltage.

If the output voltage, emitter of Q1, tries to decrease due to an increase in load or a decrease in line voltage the voltage at the base of Q2 will decrease reducing the base current because the emitter voltage of Q2 is being held constant by the zener diode. This will also decrease the collector current of Q2. This allows the base current of Q1 to increase because the current through R1 divides between the collector of Q2 and the base of Q1. If the collector current of Q2 decreases the base current of Q1 will increase. This provides more current to the emitter of Q1 partially counteracting the original decrease in voltage at the emitter of Q1.

If Q1 shorts the output voltage will be stuck at maximum and cannot be changed by the setting of the pot.

If Q2 shorts the output voltage will be reduced to a value near that of the zener diode and can't be changed.

If D5 shorts the output voltage of the circuit will fall to a very low value. The control will still have some effect but the regulation will be vary poor.

If R2 opens the circuit will still appear to be working but the regulation will not be quite as good as it was before. The emitter current of Q2 is supplying current to the zener but it will not be as large and will vary quite a bit. As zener diodes aren't perfect a varying current will cause the voltage to vary somewhat.

If R1 opens the output voltage will fall to a very low value likely zero.

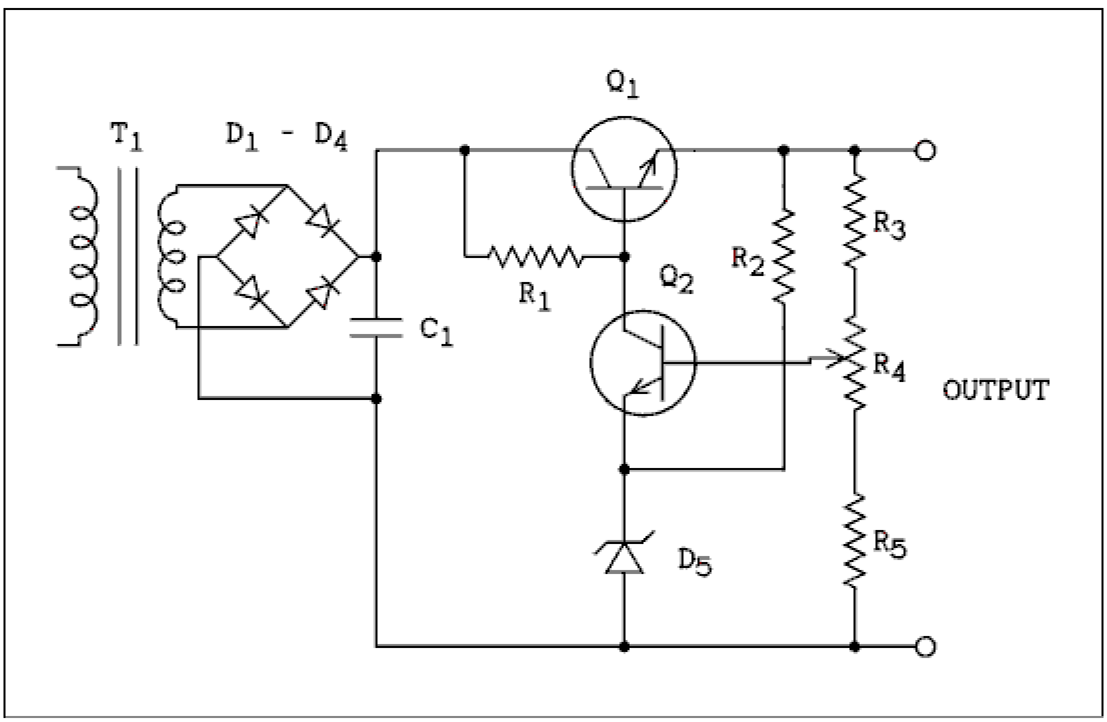

Figure 5.2b, Improved Simple Voltage Regulator Circuit.

For a verbal description click here.

Improved performance equivalent to using a current source instead of R2 can be achieved by simply moving the top end of R2 to the emitter of Q1 as shown in Figure 5.2B below. The value of R2 would have to be decreased somewhat but no additional components are required. Very small changes in the output voltage would have a very very small effect on the zener current and a very very very small effect on the zener diode voltage. The operating theory is not changed by this change.

General Operating Theory.

Q1 is the pass transistor and operates as an emitter follower amplifier. Such an amplifier has current gain. In high current power supplies Q1 is often a Darlington circuit.

Q2 is a voltage amplifier. It can be easily replaced by an operational amplifier. The emitter is the noninverting input and the base is the inverting input.

A zener diode is a zener diode and there isn't anything else that can replace it. There are IC devices known as voltage references but at their heart is a zener diode. An improvement that can be made to the zener part of the circuit would be to replace R2 with a current source. The circuit with all of these improvements is shown in Figure 5.3.

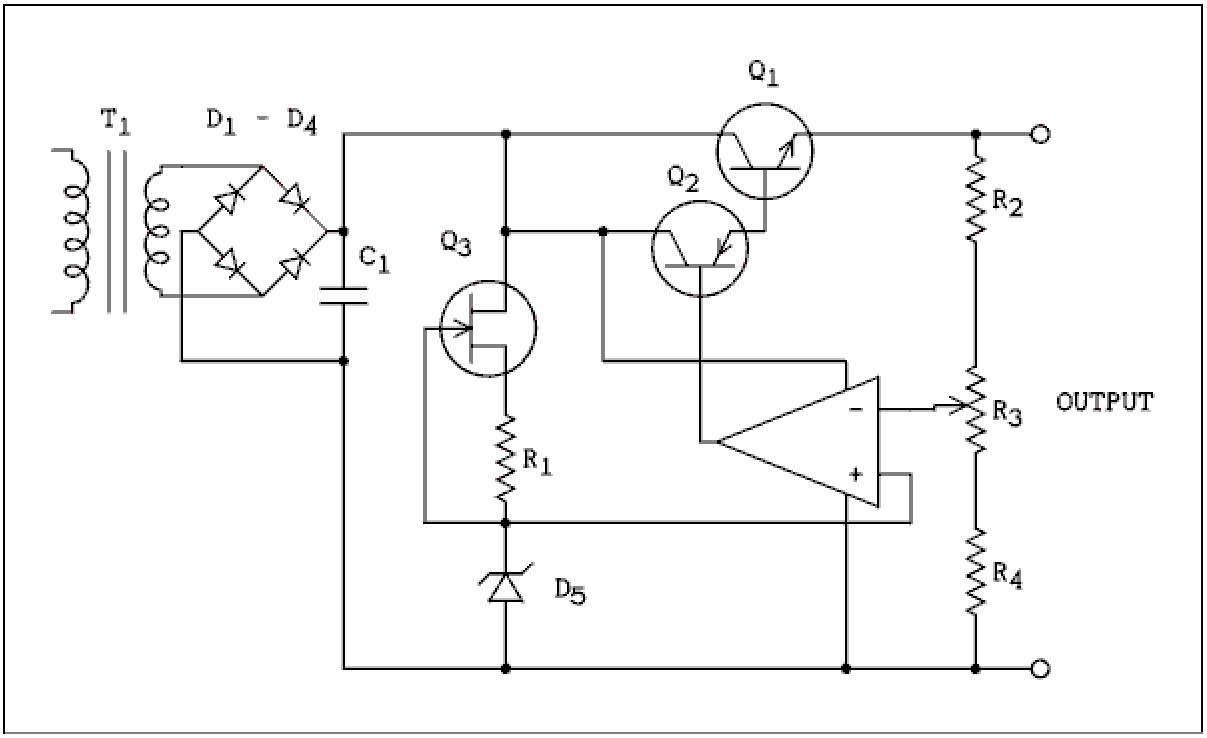

Figure 5.3, Improved Voltage Regulator Circuit.

For a verbal description click here.

Q3 and R1 form a constant current source for the zener diode. This isolates the zener current from changes in the input voltage. Because the zener diode is not perfect large changes in zener diode current can cause small changes in the voltage drop across the diode.

If the op amp has bipolar inputs the current into or out of the noninverting input will be only a few microamps. If an FET input op amp is used the current will be about 1 pico amp. In either case the current is insignificant compared to the current of several milliamps flowing in the zener diode. The circuit functions exactly as the one above except that the op amp has a much higher gain than a single transistor which makes the regulation much more accurate.

Troubleshooting this circuit is in many ways easier than the more primitive circuit of Figure 5.2. This circuit is somewhat limited in range of adjustment and may be a fixed voltage supply within a piece of complex equipment. In that case the pot is a setup adjustment which is not meant to be turned by the operator. Let me reiterate, DON'T CHANGE THE SETTING OF THE CONTROL.

If either Q1 or Q2 shorts the voltage will go up to maximum. It may be difficult to determine which one is at fault without removing them from the circuit and performing a junction test. One thing to try is measure the voltage from emitter to base of each one by connecting the voltmeter leads to those two points. If one of the transistors is good it will most likely have 0.6 volts between base and emitter. If you measure zero or 0.1 volts that transistor is most likely shorted.

If the op amp fails its output will be locked to either common or the positive input rail. This will cause the output to go to either zero or maximum voltage. If the voltage goes to maximum it may be difficult to tell the difference between a short in Q1 or Q2 from a short in the op amp. Once again measure the emitter base voltage on Q1 and Q2. If both are 0.6 volts the op amp is most likely shorted.

The failure mode of FETs is not easily predictable. The gate to channel junction can short in which case the drain current will go up to the zero bias value and stay there. This may or may not produce an over current condition in the zener and R1 large enough to cook either one. The power supply might operate for several years with this condition without any hint that anything is wrong. The conditions would be that the line regulation and ripple rejection would not be up to original specifications. The condition might show up as hum in a sensitive amplifier being powered by the regulator.

If the FET should develop a gate to source short the zener and R1 would be smoked.

If the FET develops an open drain or open source the zener voltage will drop to zero and so will the output voltage of the regulator.

Current limiting.

Figure 5.4 shows a current limiting circuit added to Figure 5.3.

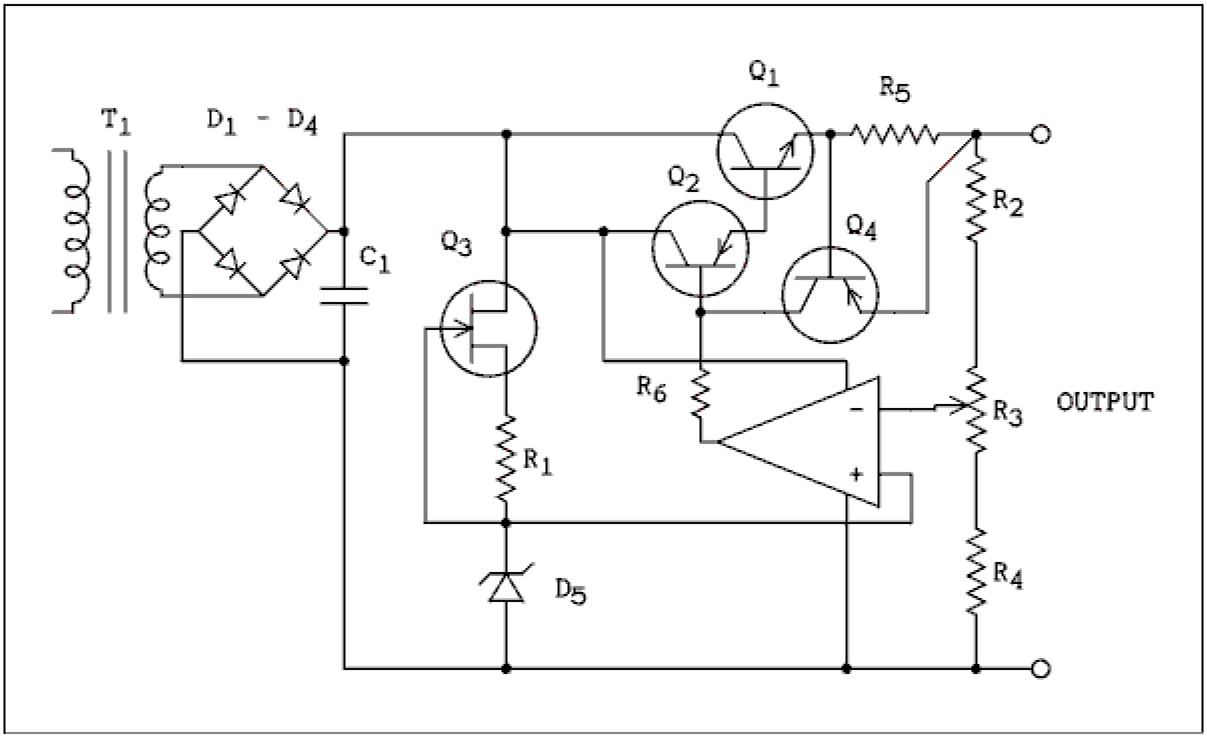

Figure 5.4, Improved Voltage Regulator Circuit with Current Limiting Added.

For a verbal description click here.

The ideal current limiter holds a constant voltage up to the current which is set by the value of R5 and the breakdown voltage of Q4. Once this current value has been reached the current does not increase by so much as a pico amp and the voltage of the regulator falls, to zero if necessary. The smaller the base current of Q2 is, the closer this current limiter will come to the ideal.

The circuit works as a voltage regulator as long as the voltage drop across R5 is less than the emitter base breakdown voltage of Q4. When the voltage drop across R5 reaches the breakdown voltage Q4 begins to conduct pulling base current away from Q2. R6 helps to isolate the output of the op amp from the base of Q2 so Q4 doesn't have to pull the output voltage of the op amp down.

With this circuit there would be some increase in current after limiting begins because as the voltage at the base of Q2 drops the current through R6 will increase. If Q1 and Q2 were replaced by a power FET R6 could be very large and the limiter would work quite well.

This circuit is a cascading failure waiting to happen. If the load develops a short the voltage will drop to zero but the maximum current will be flowing. If the heat sink on Q1 is not designed for this fault condition Q1 will overheat and eventually short out. When that happens the current will go up to a very large value and the voltage across R5 will exceed the emitter base breakdown voltage of Q4. This will cause the emitter base junction to short out and as the high current flows through the shorted junction the base will likely burn open. Q4 would not be a high power transistor but a small 250 mW transistor. With Q4 now burned away, R5 will smoke and burn up. As the high current continues to flow diodes in the rectifier will short out and the primary fuse will eventually blow, after most of the semiconductor devices have either shorted or melted open. Some parts in the electronics which was the load will probably be cooked as well. All in all this particular failure mode is a total disaster.

On the other hand if the heat sink was sized for continuous short circuit operation There shouldn't be any problems.

If this is a lab bench power supply the voltage and current should be fully adjustable. R5 can be a rheostat adjustable from the front panel.

If the power supply has a fixed output voltage and is part of a large device such as an oscilloscope or test set the current limit will also be fixed. Such an internal supply may also be equipped with current fold back as shown below to protect the power supply and circuitry connected to it in case of a short.

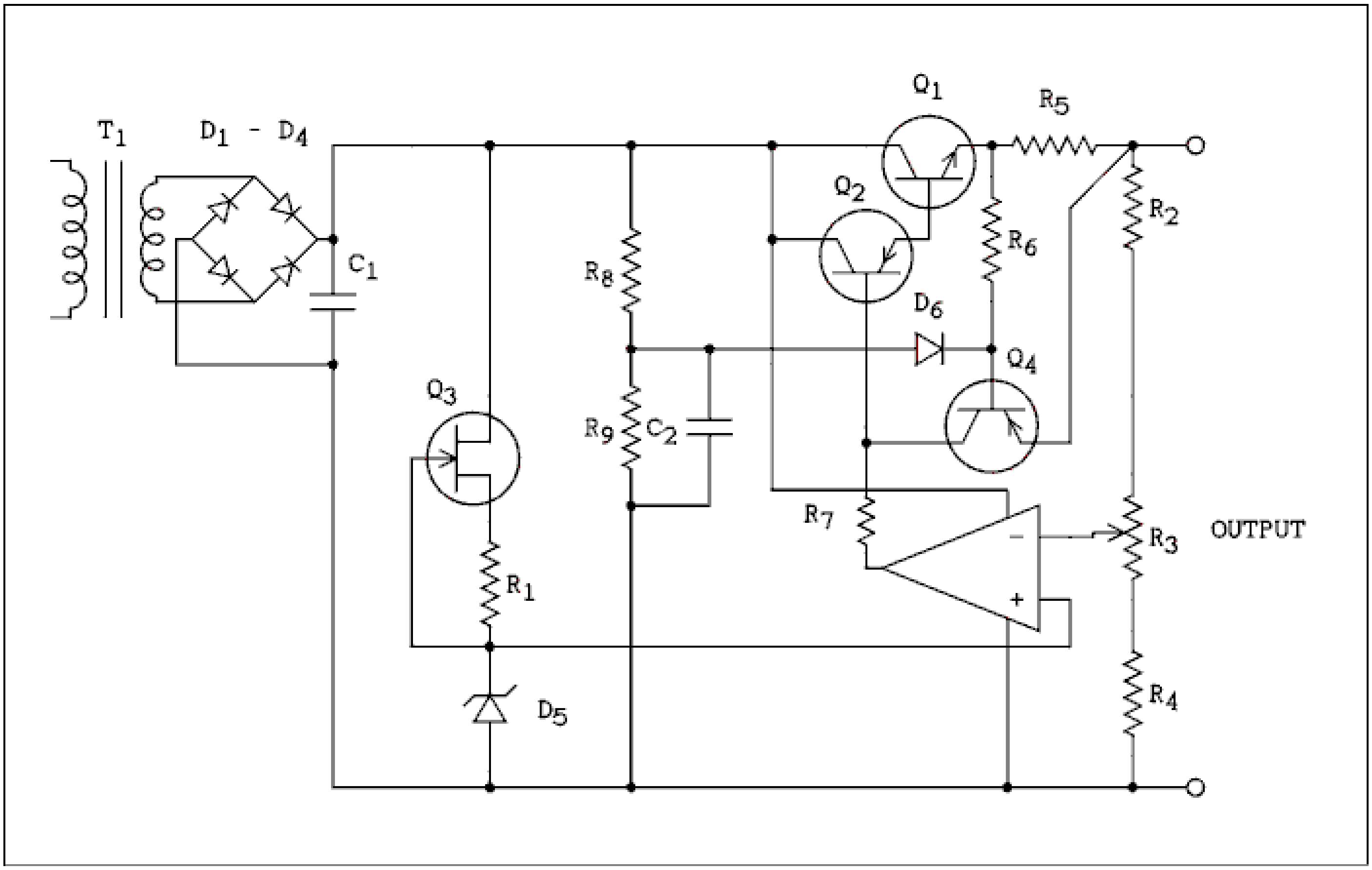

Figure 5.5, Voltage Regulator Circuit with Current Fold Back.

For a verbal description click here.

The fold back threshold is set by the voltage divider consisting of R8 and R9. C2 delays the voltage so the power supply can get started without going into fold back when the power is turned on.

In normal operation and when current limiting first begins D6 is reverse biased. As current limiting continues and the output voltage falls at some point D6 will become forward biased. This increases the base current of Q4 which takes even more current away from Q2. This shuts down Q2 and Q1 reducing the current to a small value.

If C2 should open the power supply most likely wouldn't come on. If C2 shorts or R8 opens, current fold back will be disabled. This is not likely to be discovered unless another failure brings attention to it.

If R9 should open the power supply will shut down. There will be an abnormally large current into the base of Q4. It may overheat and short, becoming a cascaded failure.

Floating the Error Amplifier.

You have noted in each of these circuits that the op amp power connections are between ground and the positive side of the rectifier-filter output. Op amp ICs typically have a maximum voltage of plus and minus eighteen volts. When using one of these ICs the highest allowable voltage of the filter output is 36 volts. The maximum regulator output voltage is several volts less than the filter output voltage so this limits the maximum voltage of the power supply. If the error amplifier is operated from an additional floating power supply the maximum output voltage is limited only by the maximum voltage of the pass transistor. An example is shown below.

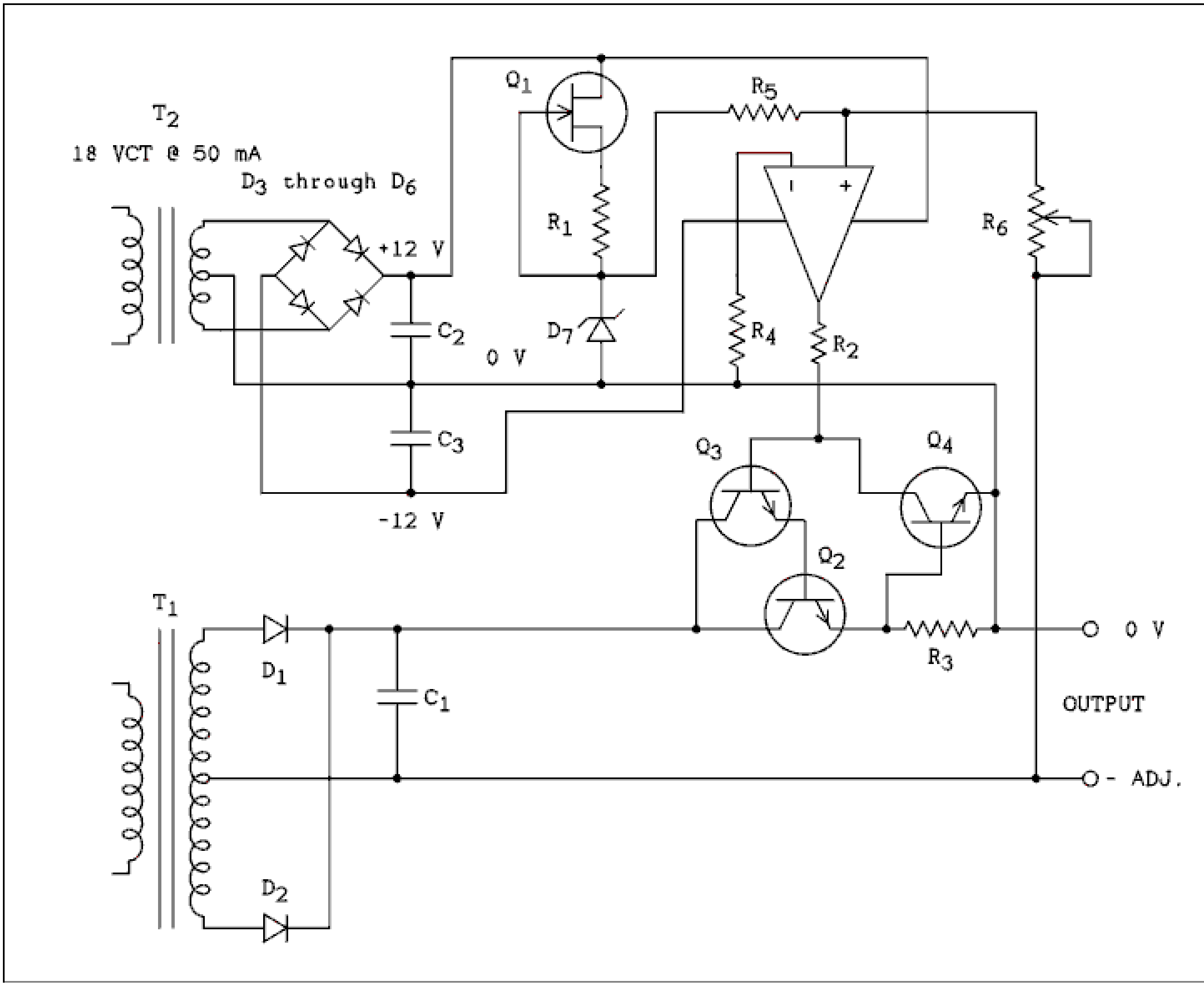

Figure 5.6, Voltage Regulator Circuit with Floating Error Amplifier.

For a verbal description click here.

Note that the center of the symmetrical supply for the op amp is connected to the positive output of the regulator. The voltage reference and the noninverting input are also returned to this point. An op amp will always set its output voltage to whatever is required to bring the inverting input to the same voltage as the noninverting input. Let's say that the reference zener diode is 6 volts, R5 is 12 k ohms, and R6 is set to 36 k ohms. The op amp is going to force the inverting input to be at zero volts because the noninverting input is at zero volts. That places 6 volts across R5 and makes the current through it 0.5 mA to the right. That current isn't going to go into the inverting input because it is a high impedance point, possibly an FET input. The current is flowing downward through R6. Now 0.5 mA in 36 k ohms gives a voltage of 18 volts. That's the answer. Nothing else to add or subtract.

This arrangement is often used in laboratory power supplies which employ switches to set the voltage. This can be precisely done because the voltage is directly proportional to the resistance. The most significant digit of the switches often selects taps on transformer T1 so the pass transistor, or tube, does not have to stand the maximum voltage of the power supply. If tubes are substituted for the pass transistor the output can go up to hundreds or even thousands of volts.

A common fault in power supplies such as this is for the switch contacts to become oxidized and make poor contact. Cleaning will usually fix this problem. One or more of the range resistors can open causing the power supply to work properly up to a certain voltage setting and then go to maximum.

The fact that the positive output is labeled as 0 volts does not mean this terminal is grounded or connected to the chassis. In deed, laboratory bench power supplies never have either side connected to the chassis. Schematics for these supplies will most likely have voltages labeled in this way because it makes trouble shooting much easier. Imagine if the voltages of the power supply operating from T2 were referenced from the negative output terminal (-ADJ.). Any faults in this part of the circuit would be much harder to figure out. If this circuit were a sub part of a large circuit either side might be grounded or neither side grounded.

IC Voltage Regulators.

The 723 voltage regulator remains popular and available even after 30 years. It is a 14 pin DIP that has all the elements of a voltage regulator inside. It will work at current levels of a few mA using its own internal pass transistor. If an external high power pass transistor is driven by the internal one in a darlington connection the little IC can handle an amp or more. After study of the above circuits the data sheet of the 723 will look very familiar.

The other IC regulators are those three terminal regulators. They come in a variety of voltages from 5 to 24 volts and there is one that is adjustable. They are current limited which can't be adjusted and thermally protected.

The latter can cause a fault which may be hard for the uninformed to find. If the regulator is air cooled and the air passage becomes clogged with dust as it is guaranteed to do, The regulator will overheat and shut down. As it is no longer dissipating power it will cool and turn back on. No reset is necessary. It may take several hours to heat up enough to shut down and only a few tens of minutes to recover. So, the equipment shuts down, you are called in, and about the time you arrive the IC has cooled enough to turn back on. If this did not repeat you could get the reputation of curing equipment by laying on of hands. But it is going to repeat again, and again, until you clean out the airway.

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5.2 Vacuum Tube Power Supplies.

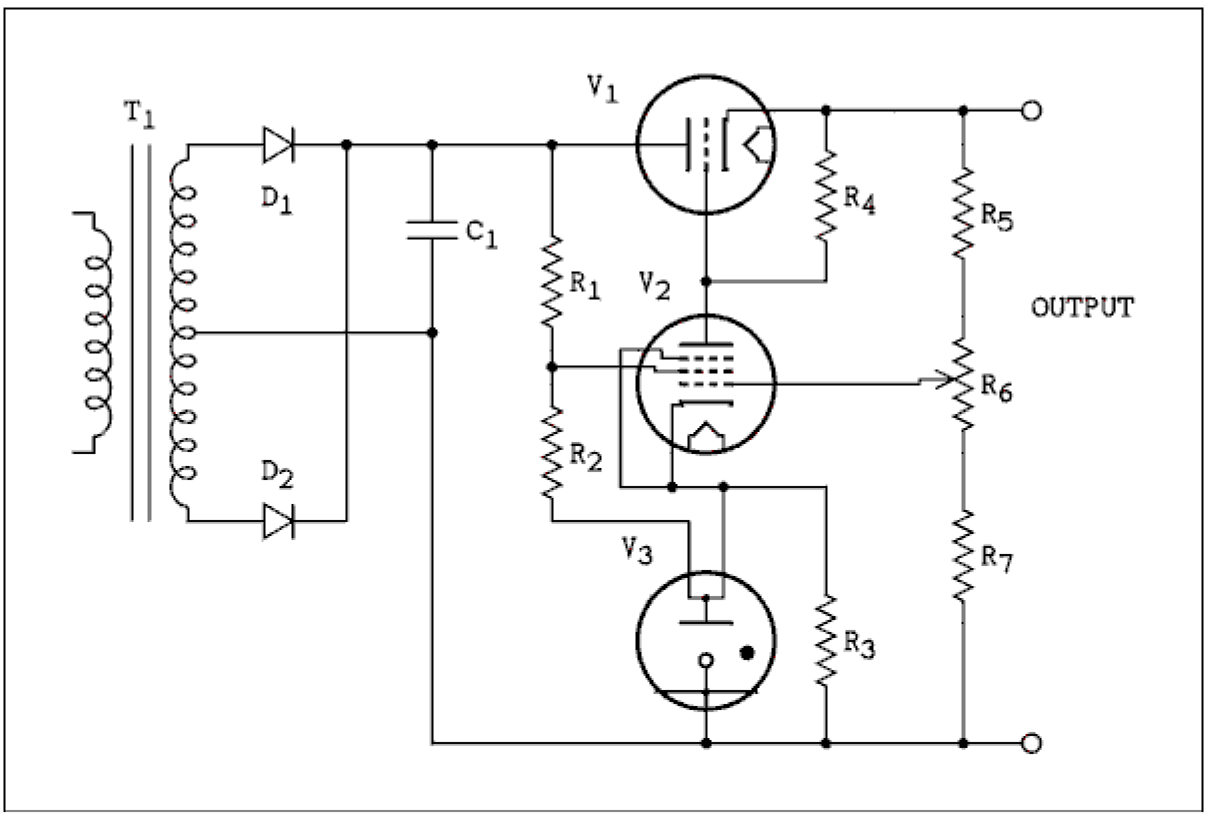

Figure 5.7, Vacuum Tube Voltage Regulator Circuit.

For a verbal description click here.

If this circuit seems familiar it should. Compare it with Figure 5.2. V3 is the voltage reference, V2 is the error amplifier, and V1 is the pass tube.

Isn't that funny? When I first learned transistors the analogy was drawn the other way. The circuit started out with tubes and they were replaced by transistors. Now when everyone is more familiar with transistors we have to start there and replace transistors with tubes. And now back to our regularly scheduled program.

V3 is a gas filled voltage regulator tube. They come in voltages of 75, 90, 105, and 150. They use the inert gasses with the exceptions of helium and radon. Each tube type uses a different gas. That was all we had before Clarence Zener did his thing.

R1 and R2 set the voltage on the screen grid of V2. This voltage will vary some and the more it varies the less gain the tube will have. The voltage divider is made as stiff as practical. The screen voltage is usually set between 1/2 and 2/3 of the supply voltage. R1 and R2 also provide the current for V3 the regulator tube. This tube requires a minimum of 5 mA to maintain the glow discharge and regulate the voltage. In order to insure that a brownout won't extinguish the VR tube a minimum current of 10 mA is usually set.

If the voltage at the output tries to decrease the voltage at the grid of V2 will change a bit in the negative direction. This will decrease the plate current of V2 because the cathode is held constant by the VR tube. A decrease in current through R4 will cause the voltage across it to decrease which will increase the current in V1 mostly counteracting the change.

The 7 pin miniature series of VR tubes has the anode connected to two pins and the cathode to three. This allows designers to protect the power supply against being operated with the Vr tube unplugged. In this circuit if V3 is unplugged while power is on the positive voltage will be removed from the cathode of V2. R3 will pull the cathode down close to common reducing the output voltage to near zero.

Unlike transistors tubes fail in a decided analog manner. Although there are occasionally catastrophic shorts the usual failure mode is for the cathode emission to become so low that the tube can no longer conduct enough current to do its job. The commonly used term for this is to describe the tube as weak. If V2 grows weak the output voltage will go high. It may still be possible to adjust it somewhat down from maximum but not all the way down.

If V1 grows weak the supply will still appear to work when lightly loaded, a small load current, but if loaded to its specified current the voltage will drop down and cannot be turned up to the desired value.

I have never known a VR tube to fail so I can't tell you how a failed tube behaves.

The output voltage of this circuit cannot be adjusted below the voltage of the VR tube plus about 50 volts. So a regulator built using a 105 volt tube would only come down to about 150 volts. Circuits of this kind are not used in bench power supplies but are frequently seen in fixed voltage regulators such as those found in Tektronix oscilloscopes, H P signal generators, etc.

Improved Voltage Regulator.

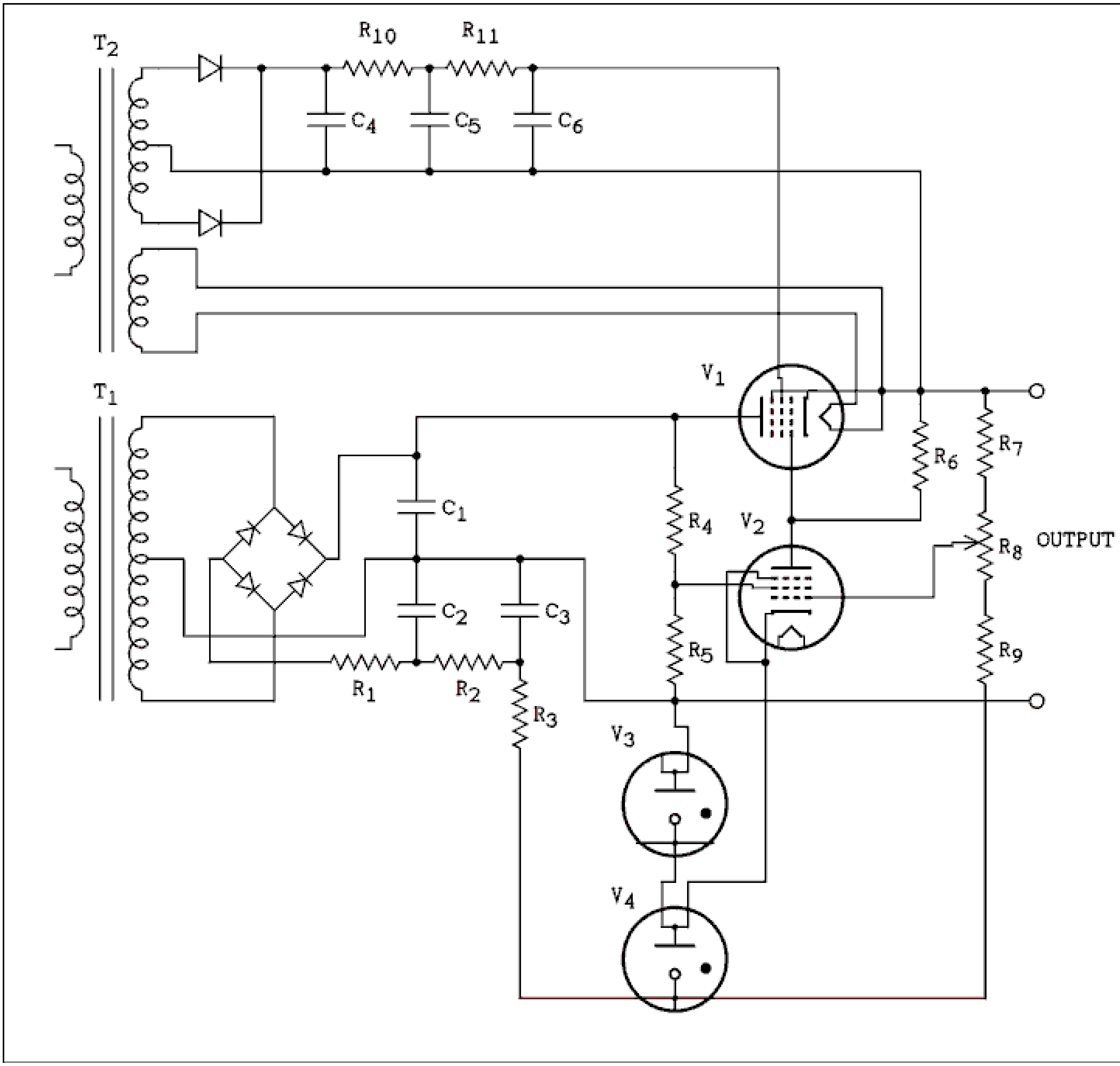

Figure 5.8, Improved Vacuum Tube Voltage Regulator Circuit.

For a verbal description click here.

This power supply circuit will go all the way to zero and even a little negative if R7 is not properly adjusted. R7 is usually a screwdriver adjusted rheostat. The cathode of the error amplifier, V2, is at a negative voltage and the negative end of the adjustment divider chain is held at twice that voltage.

This circuit will also go much closer to the voltage across C1 than the previous one. Figure 5.7 uses a triode but if the pentode in Figure 5.8 were to have its screen grid connected to its plate it would be triode connected. The floating power supply from T2 which is filtered by C4, R10, C5, R11, and C6, keeps the screen grid of the pass tube a constant voltage above its cathode which makes it behave as a pentode or beam tetrode. Any ripple on the screen supply will appear in the output of the regulator so it must be very well filtered.

Most power tubes have a maximum heater to cathode voltage of 200 volts. If the output of the regulator is to go higher than this the heater and its supply must be floating. The dot showing a connection from one side of the heater to the cathode of the pass tube is not a mistake.

The negative supply for the two seriesed VR tubes is derived from the negative half of the bridge on T1 and filtered by R1, C2, R2, and C3. R3 sets the current through the VR tubes and isolates them from C3. If a capacitor is placed in parallel with a VR tube it will form a relaxation oscillator just like the neon lamp type we used to build for science fair projects.

R1 dissipates more power than would be calculated based on the DC current. The output of the bridge rectifier has an AC component which has a peak to peak value equal to the peak value of half of the transformer secondary. Almost all of the AC component of current in R1 flows back to the center-tap through C2. Thus, R1 is carrying the DC plus the AC components of current. The power dissipated cannot be calculated without the use of calculus. Therefore it is recommended that this resistor be considered to be dissipating two or three times what the DC calculation yields.

Current Limiting?

I have never seen a vacuum tube power supply that was protected by a current limiting circuit. That is not to say they never existed, it's just that I have never seen one. My attempts to design such a circuit on paper have become very complicated and I doubt if they would work reliably. The only over current protection I have seen in a tube power supply is the obvious one of a fast acting fuse in series with the output or an over current relay. Think of an over current relay as being a self resetting circuitbreaker.

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5.3 Switching Mode Power Supplies.

The earliest switching mode power supplies were developed to improve the efficiency of the analog regulators shown above. Such regulators are likely to be 50 percent efficient or less. A more efficient circuit is shown below.

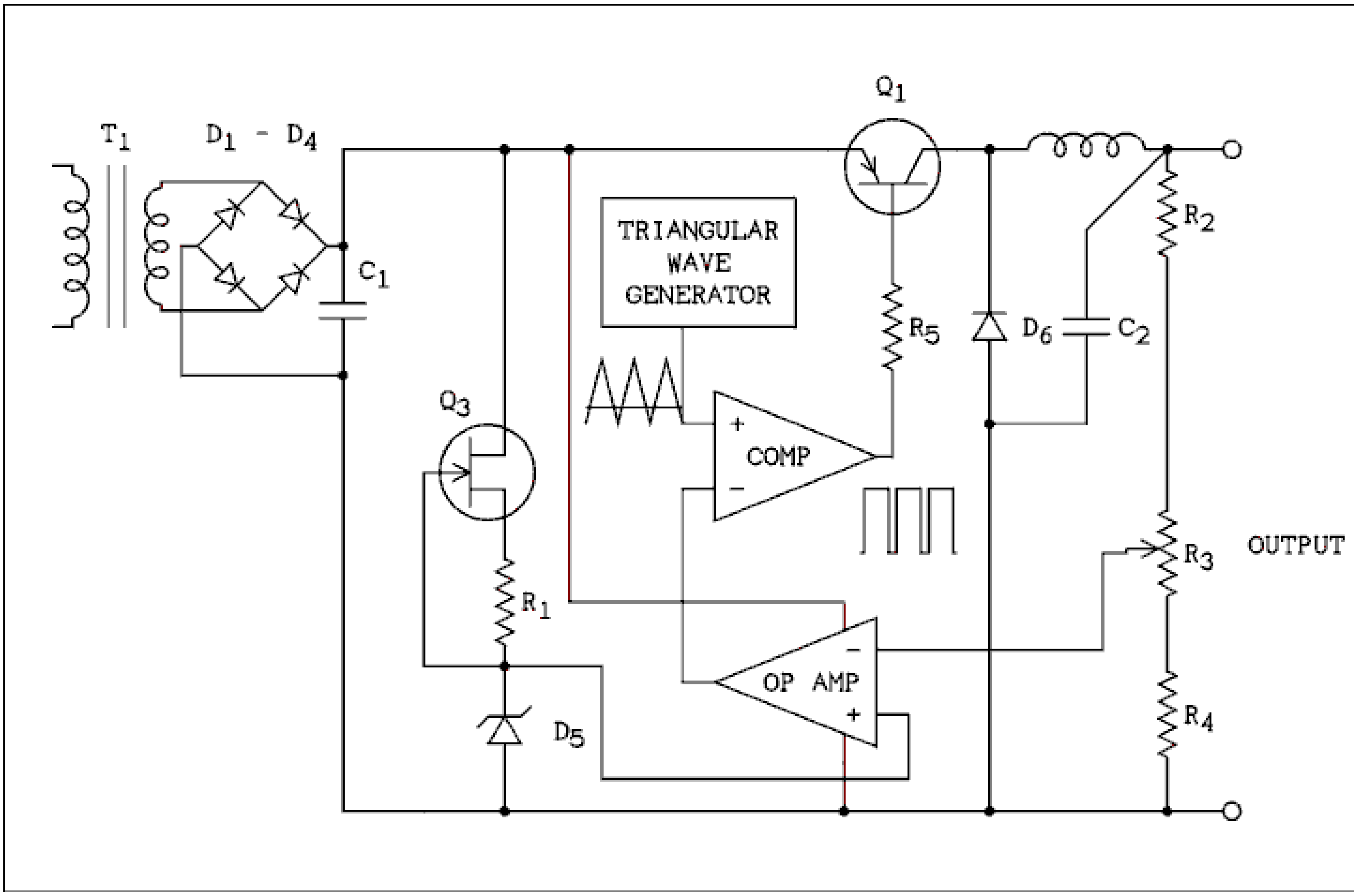

Figure 5.9, Early Switching Regulator Circuit.

For a verbal description click here.

The power connections to the triangular wave generator and comparator are not shown but they are assumed. If they were not present the circuit would not work.

Notice in the circuit above that the transistor is now a PNP. It acts as a switch not an analog amplifier. When the output level of the comparator which drives it is low Q1 is on. When the comparator output is high Q1 is off. When Q1 is off the power is zero. When it is on the voltage drop is small typically 0.1 to 0.5 volts depending on the current. The power is still very small for a current of 1 amp it can be as low as 250 mW.

The inductor and C2 smooth the output. When Q1 turns off the inductor produces a negative going pulse at its left end. D6 prevents this pulse from going to huge negative values that would burn out Q1.

A comparator is a device that compares two analog voltages and produces a binary output. If the noninverting input is higher than the inverting input the output is high. If the noninverting input is lower than the inverting input the output is low.

The triangular wave is applied to the inverting input. The horizontal line on the waveform is the assumed level of the noninverting input. The output wave is what would be produced.

Suppose that this is the equilibrium condition. If the load current increases the output voltage will decrease which will cause the output of the op amp to increase. The horizontal line on the triangular wave will move up and the negative pulses from the comparator will become wider. That means that Q1 will be on for a larger percentage of the time. This permits Q1 to deliver more current to the load and the output voltage will be maintained at almost the original value.

If Q1 shorts the output voltage goes up to maximum and won't come down. If either the op amp or comparator shorts to rail the output will go either to maximum or zero. If the triangular wave generator stops working the regulator circuit will seem to be working but the voltage will be bouncing up and down by some amount. Just how much and at what frequency cannot be predicted without knowing details about the regulator. It will likely be switching at a much lower rate and the output will have a definite triangular wave superimposed on the DC. Without the triangular wave generator the circuit will generate its own triangular waves.

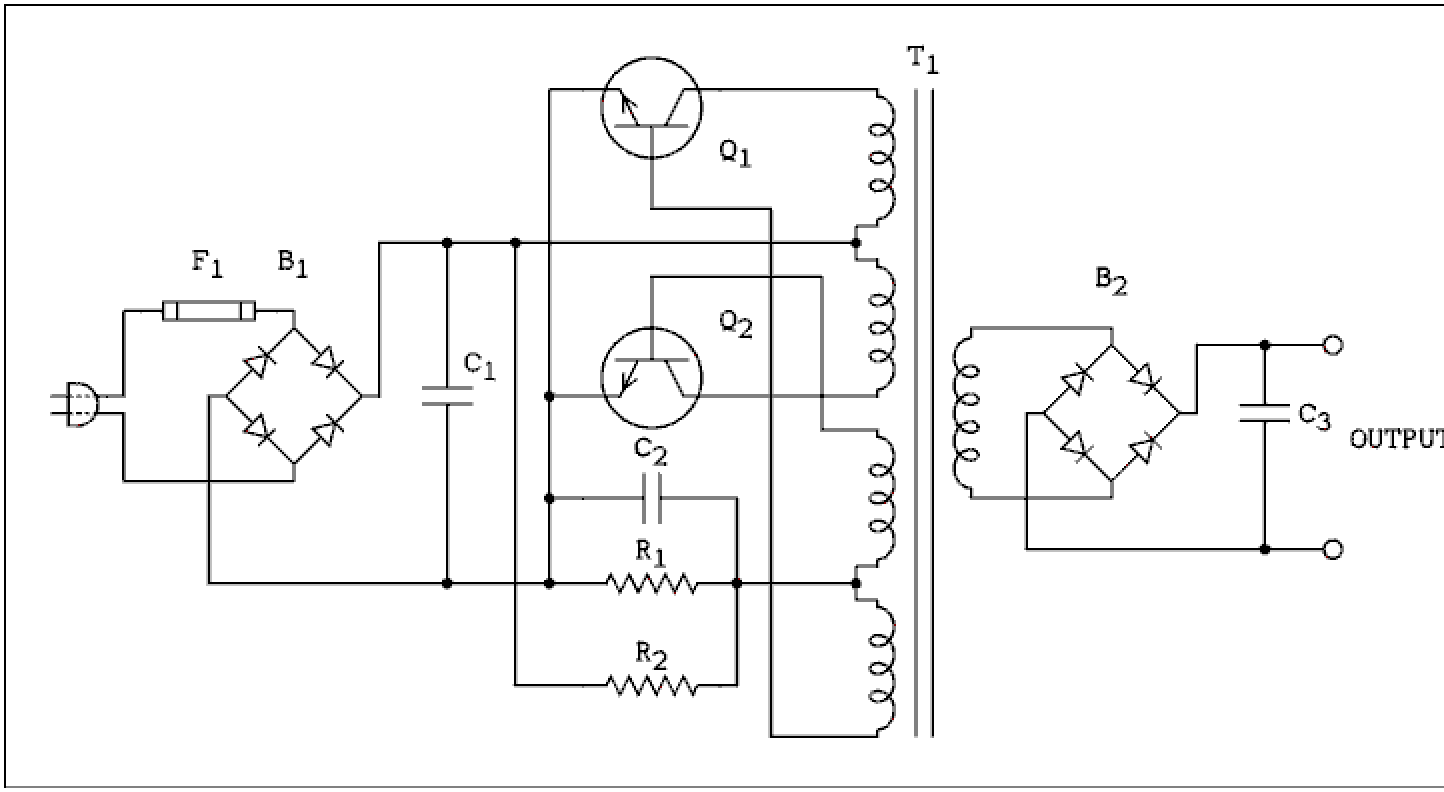

Figure 5.10, Isolated Switching Mode Power Supply Circuit.

For a verbal description click here.

The circuit above is not regulated but is strictly open loop. It's advantages are high efficiency, light weight, and small space.

The switching frequency is quite high to place it well above the range of human hearing. That means that the transformer needs very little iron and can be small and light. Because the transistors operate as switches they dissipate little power.

The high switching frequency and fast switching transistors used mean that the circuit produces strong harmonic frequencies well into the radio spectrum. In order to reduce this interference to below 1 microvolt the entire circuit would have to be placed in a cast iron box with multi section multi compartment filters on all leads passing through the wall of the box. This would mostly defeat the purpose of a switch mode power supply.

R2 slightly forward biases the base emitter junction of the two transistors to insure that oscillation will start spontaneously. After oscillation starts capacitor C2 builds up a negative charge and R1 limits the base current to a safe value. R1 also sets the maximum base current so if it should increase in value the output power of the supply would be somewhat down.

Chapter 6   Faults in Transistor Circuits.

Chapter 6.

Faults in Transistor Circuits.

Discrete transistor circuits are found in almost every area of electronics. Transistor circuitry is to be found in consumer, industrial, automotive and military electronics. The importance of knowing how to troubleshoot transistor circuits cannot be over-emphasized. In this chapter we will examine the minimal circuits that are the building blocks of larger circuits.

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6.1 Common Emitter Amplifiers.

One of the most common uses of transistors is to provide signal amplification. The most common amplifier configuration is the common emitter amplifier.

In this and following chapters we will refer to voltages at particular points. Everyone knows that there is no such thing as a voltage at a point, only voltages between two points. When we speak of a voltage at a point, the other point is assumed to be ground. Imagine that one lead of our voltmeter is connected to the ground point of the circuit. When we speak of the voltage at a point we are connecting the other lead of our voltmeter to that point. Thus the voltage at a point is the voltage between that point and ground.

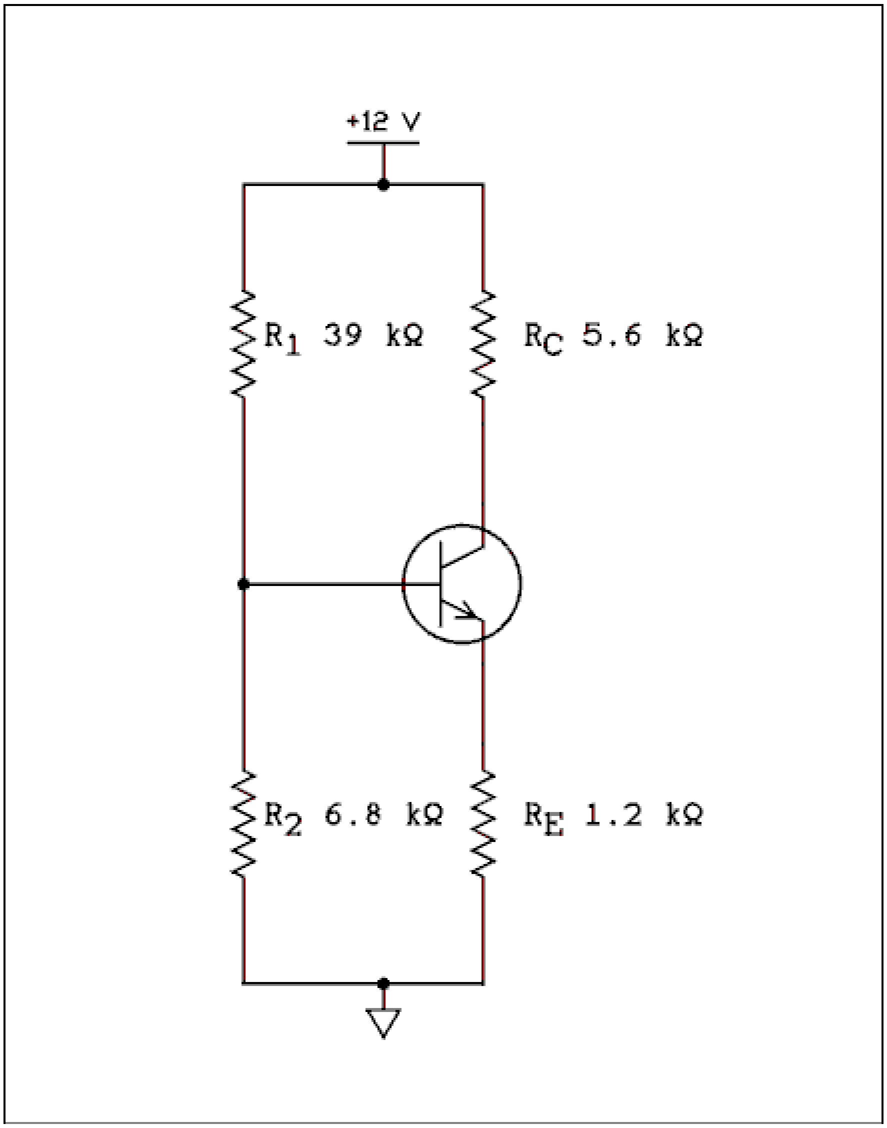

Figure 6.1 Constant Voltage Biasing.

For a verbal description click here.

Figure 6.1 is the circuit of the most popular method of biasing a common emitter amplifier. Typical voltages for this circuit would be VE (emitter to ground voltage) = 1.13 volts, VB (base to ground) = 1.73 volts, and VC (collector to ground) = 6.79 volts.

Suppose now that we observe the following voltages: VE = 1.5 volts, VB = 1.8 volts and VC = 12 volts.

The fact that VC = VCC indicates no voltage drop across the collector resistor and therefore no collector current. A shorted collector resistor can be ruled out because resistors rarely short.

VE - VB < 0.6 v could indicate a base-emitter short in the transistor, or could it? A base-emitter short would effectively place RE in parallel with R2. The parallel combination is (1.2 k ohms x 6.8 k ohms)/(1.2 k ohms + 6.8 k ohms) = 1.02 k ohms and the voltage divider equation gives a voltage at the base of 12 v x 1.02 k ohms /(1.02 k ohms + 39 k ohms) = 0.31 v. Since the measured voltage is 1.8 volts, a base to emitter short can be ruled out.

A short in the transistor involving the collector would make the collector and base voltages to be the same. Thus we can rule out a shorted transistor.

Because the voltage at the base is normal we can also rule out any trouble in R1 or R2.

If the collector resistor were open, the transistor collector would try to draw current and pull the collector voltage down to very near the emitter voltage. Thus we rule out the collector resistor.

After you have ruled out all other possibilities the one which remains is the answer. The emitter resistor open is the only thing not ruled out. Let us check the logic to see if it makes sense.

If the emitter resistor opens there can be no emitter current. With no emitter current there is also no collector current. No collector current means that there is no voltage drop across the collector resistor. Thus VC = VCC.

As a further consequence of no emitter current, the base-emitter junction will not be forward biased, VBE = 0.6 volts, which means that VE is closer than normal to VB. Since there is no base current, the voltage at the base will be normal or may increase slightly. All clues are consistent. The emitter resistor is open.

Suppose that we observe VE = 0, VB = 0 and VC = 12 volts. In this circuit there is no failure mode of the transistor which can make the base voltage zero. If R1 opens, there can be no current through R2 and no bias for the transistor. The transistor will be in cutoff; VE will be zero and VC = VCC. The answer must be R1 open.

Suppose we observe VE = 2.3 volts, VB = 2.9 volts and VC = 2.4 volts. There are two possibilities here, either the transistor is shorted (everything to everything) or the transistor is being driven into saturation. We will examine each possibility in turn.

If the transistor were shorted, the circuit would become that of figure 6.2. This places R1 in parallel with RC which is (39 k ohms x 5.6 k ohms)/(39 k ohms + 5.6 k ohms) = 4.90 k ohms and also R2 in parallel with RE (1.2 k ohms x 6.8 k ohms)/(1.2 k ohms + 6.8 k ohms) = 1.02 k ohms. The two parallel combinations make up a voltage divider. When we calculate the voltage we find 12 v x 1.02 k ohms /(1.02 k ohms + 4.90 k ohms) = 2.07 volts. If everything were shorted we should measure 2.07 volts at base, emitter and collector.

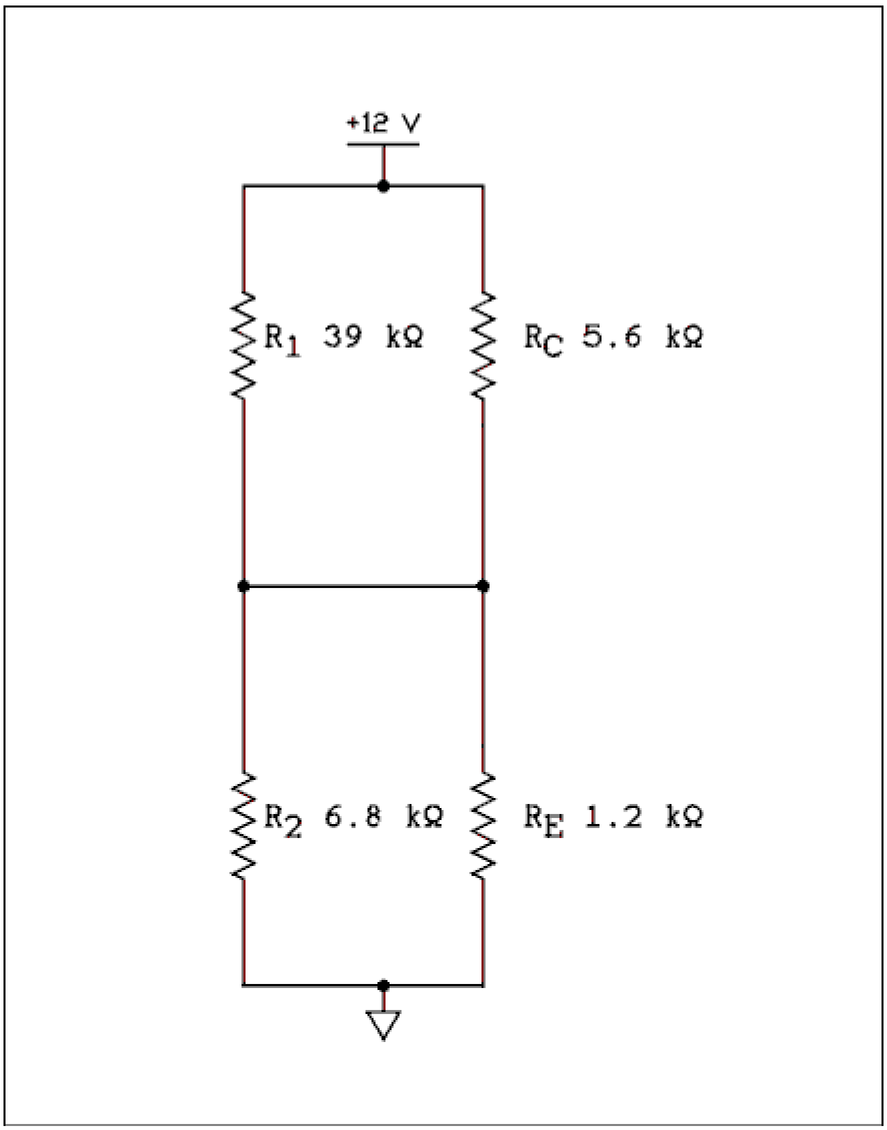

Figure 6.2 Figure 6.1 With a Shorted Transistor.

For a verbal description click here.

The only failure which could drive the transistor into saturation would be R2 open. If R2 opens, all of the current which flows through R1 will flow into the base of the transistor. We can calculate the base current as follows. From the voltage measurements above we see that the voltage at the base is approximately 3 volts. That leaves 9 volts to drop across R1. The current in R1 is 9 v / 39 k ohms = 230 microamps. If beta is 50 the collector current could be as high as 230 microamps x 50 = 11.5 mA. The resultant drop across RC is 11.5 mA x 5.6 k ohms = 64.4 volts. This is impossible! It is much greater than the power supply voltage. The transistor is in hard saturation. The fact that VB is different from VE is a strong (but not absolute) indication that the transistor is not shorted. It is time to shut down the power and make some ohmmeter tests.

Ohmmeters and Transistors.

Ohmmeters must be used on transistor circuits with some caution, not because of any danger of damage to the circuit but because of the danger of arriving at the wrong conclusion. Analog and digital ohmmeters work quite differently and you can be badly misled if you fail to understand the difference.

A digital ohmmeter applies a constant current source to the resistance under test and measures the voltage drop which results. Since the function V = I x R is linear, the scale is linear. The maximum voltage at full scale is 0.2 volts. This is not enough to forward bias a silicon P-N junction. What this means is that you cannot use a digital ohmmeter to test semiconductor devices. The meter will indicate over-range no matter what you do. You can use a digital ohmmeter to test resistors in transistor circuits without removing them from the circuit.

Many newer DMMs have a diode test position on the range switch. In this position the full-scale range is 2 volts (1.999) and a good P-N junction will indicate approximately 0.6 volts in the forward direction and over-range in the reverse direction.

An analog ohmmeter applies a voltage to the resistance under test and measures the current which flows. The ohmmeter scale is very nonlinear because I = E / R is nonlinear. The voltage applied is 1.5 volts on all but the RX10,000 range, where it is 9 volts. This voltage is sufficient to forward bias P-N junctions. You can use an analog ohmmeter to test transistors out of circuit.

In order to use an analog ohmmeter to test semiconductor devices you must know which lead of the ohmmeter is charged positively. In the case of the Simpson model 260 the terminal marked + is positive and the one marked "common" is negative. Many manufacturers are not as careful in designing their ohmmeter circuits. There are many analog ohmmeters on the market in which the terminal marked + is actually the negative side of the ohmmeter voltage source. The best way to find out is to use another test instrument to test the voltage at the ohmmeter terminals.

When you use an analog ohmmeter to test P-N junctions, you can determine if they are good, open or shorted.

When you connect the ohmmeter so as to forward bias the junction it will indicate a relatively low resistance. The actual value will be different on different ranges because a P-N junction does not obey Ohm's law.

When you connect the ohmmeter so as to reverse bias the junction the meter will indicate infinite resistance.

If a P-N junction is shorted the ohmmeter will show the same low resistance value in both directions. This value may range from 0 to a few ohms and will likely obey Ohm's law.

If the P-N junction is open it will indicate infinite resistance in both directions.

Example 6.1.

In the circuit of figure 6.3 the normal voltages are VE = 1.1 v, VB = 1.8 v and VC = 10.9 v. After the circuit develops a fault a low cost analog VOM is used to make the following voltage measurements: VE, VB and VC are all approximately 6 volts. What is wrong?

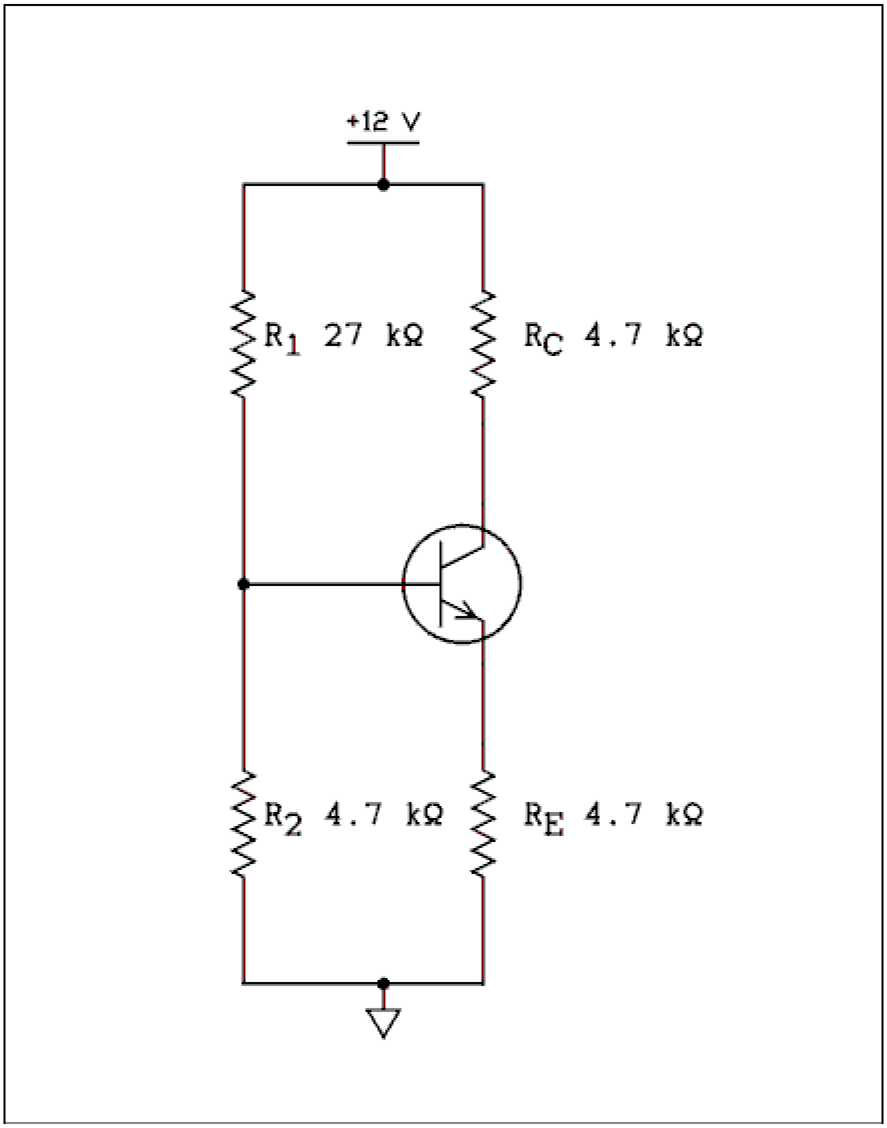

Figure 6.3 Circuit for Example 6.1.

For a verbal description click here.

Solution:

With all voltages being the same, our first conclusion might be that the transistor is totally shorted. If the transistor were shorted (everything to everything) the circuit of figure 6.4 would result. This fault places R1 in parallel with RC and R2 in parallel with RE. The two parallel combinations form a voltage divider across the power supply.

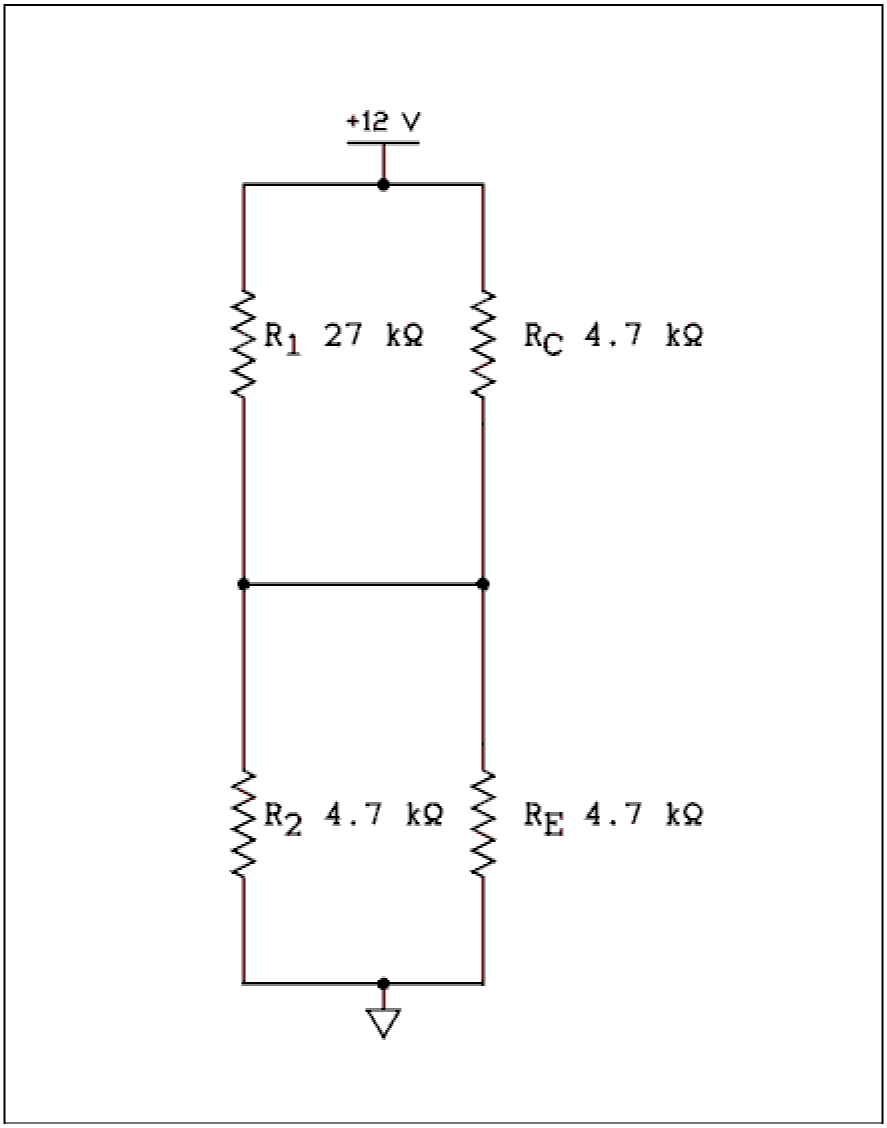

Figure 6.4 Figure 6.3 With a Shorted Transistor.

For a verbal description click here.

R1 in parallel with RC is (27 k ohms x 4.7 k ohms) / (27 k ohms + 4.7 k ohms) = 4.0 k ohms. R2 in parallel with RE is (4.7 k ohms x 4.7 k ohms) / (4.7 k ohms + 4.7 k ohms) = 2.35 k ohms. Applying the voltage divider equation gives VEBC = 12 v x 2.35 k ohms / (2.35 k ohms + 4.0 k ohms) = 4.44 volts. This seems rather far away from the measured value of 6 volts.

If R2 opened the circuit would become that of figure 6.5.

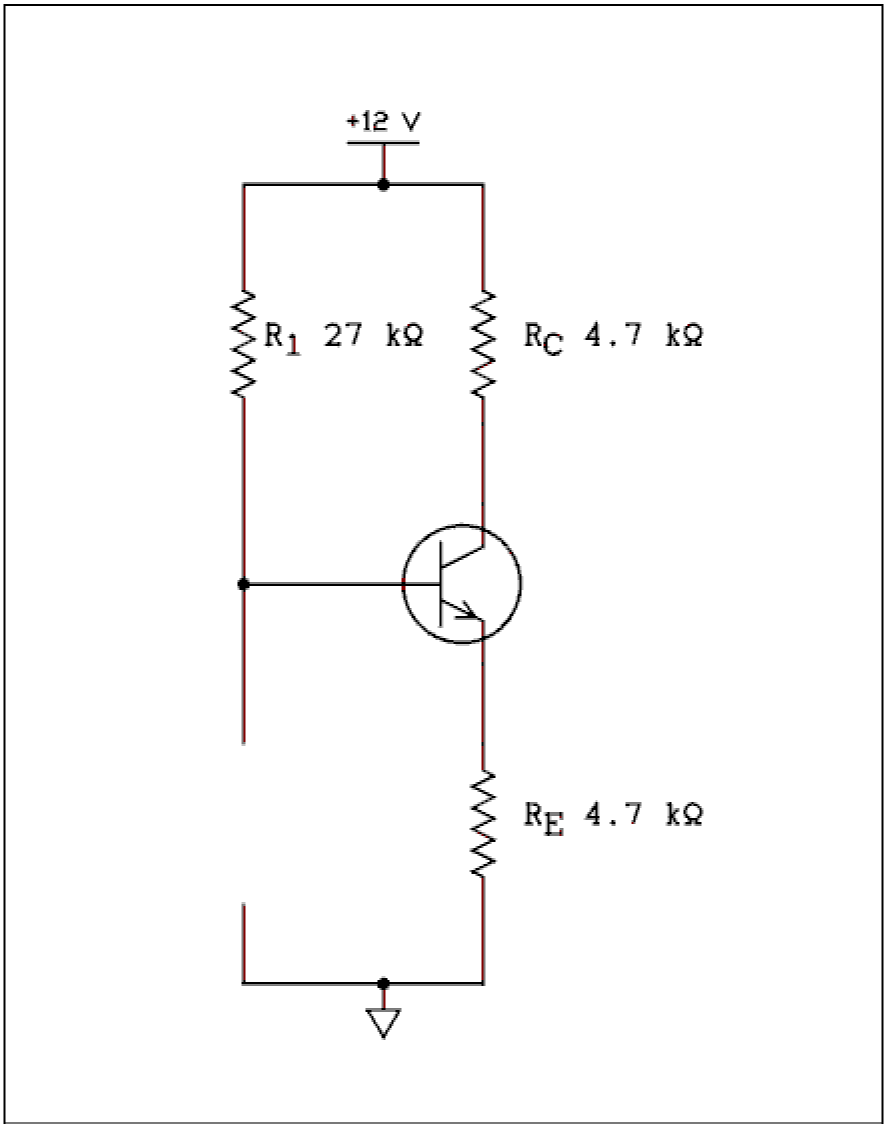

Figure 6.5 Figure 6.3 With R2 Open.

For a verbal description click here.

This would cause the transistor to be driven into hard saturation. The measured voltage indicates a drop of approximately 6 volts across R1. Since all of the current through R1 flows into the base of the transistor, the base current is 6 v / 27 k ohms = 220 microamps. Assuming 50 as a reasonable value for beta, the collector current could be as high as 50 x 220 microamps = 11 mA. If this current could flow through RC it would produce a voltage drop of 11 mA x 4.7 k ohms = 51.7 volts. This impossible voltage indicates that the transistor is in hard saturation. A transistor which is held in saturation has the equivalent circuit of figure 6.6.

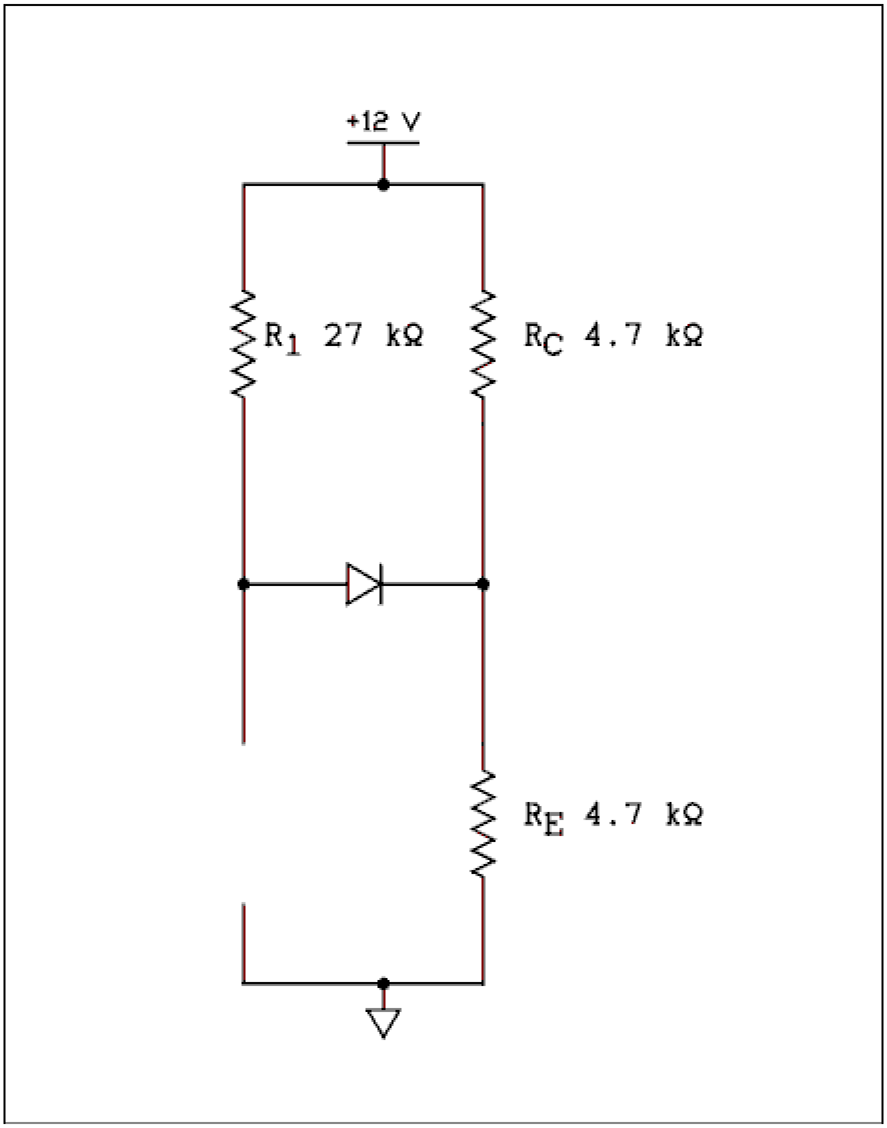

Figure 6.6 Equivalent Circuit of Figure 6.3 With R2 Open.

For a verbal description click here.

If we neglect the drop across the diode in figure 6.6, we have a voltage divider consisting of R1 in parallel with RC and the parallel combination is in series with RE. The voltage at all elements is VEBC = 12 v x 4.7 k ohms / (4.7 k ohms + 4.0 k ohms) = 6.48 volts.

The possibility that the transistor is shorted gives a voltage of 4.44 volts and the possibility that R2 is open gives 6.48 volts. The original measurement was approximately 6 volts. 6.48 is closer to 6 than 4.44 v; therefore, the answer must be that R2 is open. If the transistor is good, the voltage at the base would be 0.6 or 0.7 volts higher than that at the emitter. Since our cheap voltmeter did not show us this difference between 6 and 6.6 volts, it could not show us the difference between 6 and 6.48 volts.

Troubleshooting Without a Voltage Chart.

While the major manufacturers are very good about providing typical AC and DC voltage measurements, these companies can be counted on the fingers of one hand. There are dozens of medium sized and hundreds of small manufacturers who provide electronic equipment to industry and education. The owner's manuals provided by these lesser companies range from rough to downright primitive. A schematic diagram is about all you can expect. If you get a circuit board layout, consider yourself indeed fortunate. If you do get normal operating voltages, buy stock in the company while it is still cheap.

Small companies are often able to provide quality equipment at a lower price than a large company would ask. It is for this reason that you are likely to encounter such equipment in your career.

Suppose you are working on a piece of equipment from one of these smaller manufacturers and you measure the collector voltage of a transistor. You don't know any more after you make the measurement than you did before you made it. The reason is, of course, you don't know what the voltage is supposed to be.

If you are not given the voltages, you must calculate them yourself. Let us calculate the voltages in figure 6.1.

Note: If you follow the links below, use your back button to return here.

First, we will calculate the Thevenin equivalent of R1 and R2 in the base circuit from Equations 4.18 and 4.19. VBB = 12 v x 6.8 k ohms / (6.8 k ohms + 39 k ohms) = 1.78 volts. RB = 6.8 k ohms x 39 k ohms / (6.8 k ohms + 39 k ohms) = 5.79 k ohms.

If we don't know beta we can apply Equation 4.24.

Ic = (VBB - VBE)/RE = (1.78 v - 0.6 v)/1.2 k ohms = 0.983 mA.

We may want to use Equation 4.23. To do so we must make a guess as to the beta of the transistor. It will do little good to look up the transistor in a transistor manual. Values of beta even for transistors of the same type number can range from 25 to 250 and are listed as such in the manual.

Let us make a slightly pessimistic guess that the transistor's beta is 50.

Ic = (VBB - VBE)/(RE + RB/beta)

Ic = (1.78 v - 0.6 v)/(1.2 k ohms + 5.79 k ohms / 50) = 0.897 mA.

To calculate VE we must know IE. IE = IC (1 + Beta) / Beta
IE =0.897 (51/50) = 0.915 mA. VE = IE RE = 0.915 x 1200 = 1.098 Volts.

The voltage at the collector is equal to VCC - IC x RC. VC = 12 v - 0.897 mA x 5.6 k ohms = 6.98 volts.

Example 6.2.

In figure 6.3 change R1 to 270 k ohms and R2 to 82 k ohms. Calculate the values of VB, VE and VC.

Solution:

Let us calculate the Thevenin values for the voltage divider circuit of R1 and R2. VBB = 12 v x 82 k ohms / (270 k ohms + 82 k ohms) = 2.80 v. RB = 82 k ohms x 270 k ohms / (82 k ohms + 270 k ohms) = 62.9 k ohms.

Equation 4.24 depends on the voltage drop across RB being small. Because of the large value of RB in this problem we cannot ignore this voltage drop. We must use Equation 4.23.

IC = (VBB - VBE)/(RE + RB/beta)

IC = (2.80 v - 0.6 v)/(1.2 k ohms + 62.9 k ohms/50) = .895 mA.

VE = RE IC (Beta + 1) / Beta

VE = 1200 0.895 (51/50) = 1.095 volts.

The voltage at the base is VB = VE + 0.6 = 1.695 volts.

The voltage at the collector is equal to VCC - IC x RC. VC = 12 v - 0.895 mA x 5.6 k ohms = 6.99 volts.

By now you may be wondering if all of these calculations are worth the effort. You are likely thinking that you could change a resistor or transistor while someone else is making all of those calculations. Giving all of the details of a calculation in printed or written form always takes longer than it would on a calculator. An experienced person can finish the above calculations, using a pocket calculator, before the soldering iron gets hot.

Another way is to have a computer program that will perform the calculations and show the results. Such a program may be downloaded from this location. This program only works on windows computers in north America. Clicking on the link above will initiate download.

1. After clicking the link you will be asked if you want to open or save the file. Select save.
2. You can save it anywhere you want but remember where you saved it. I have a folder in My Documents named AAA as a place to put such files.
3. After download completes close the dialog box if you didn't check the box that says "Close this dialog box when download completes.
4. Open windows explorer and navigate to the folder where you downloaded the file. Select "Transistor_Q_Point.zip" in the left hand window and it will be unzipped and the three files it contains will display in the right hand window.
5. If "Transistor_Q_Point.zip" won't show in the left hand window, double click it in the right hand window. A new explorer window will open and three files will be displayed in it.
6. Double click "setup.exe" and the program will begin to install.
7. Accept all defaults unless you have a strong reason for doing otherwise.
8. When the installation is finished you will see the message "Transistor Q Point was successfully installed."

You will find that the program gives slightly different results from the calculations performed above. The computer program uses the exact equation which was derived in chapter 4 section 3 of Electronics for Physicists. Equation 4.22 is the most accurate and that was used in the program since there is no point in using approximations in a program. Most of the above results were obtained with equation 4.23 which neglects a Beta / (Beta + 1) term.

If your computer is not close to your workbench you may be very tempted by the process of "shotgunning" described in chapter 4 but beware. You can afford to fire the shotgun only once. If you fire it and miss, you could be in trouble with your supervisor or customer. There are faults which can be misleading as to which stage the trouble is in.

There are other faults which can occur in a common emitter circuit. These faults will be covered in sections 6.3 and 6.4.

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6.2 The Emitter-Follower's Fatal Flaw.

The fatal flaw in the emitter-follower is that the transistor can fail and the circuit can continue to function under some circumstances. A "tape output" on a stereo receiver might drive one tape deck but not another; a regulated power supply which is rated to deliver 500 mA will begin to current limit at 25 mA; an oscilloscope which, when new, had a bandwidth of 100 MHz, now has only a 30 MHz bandwidth. Faults involving the emitter-follower can be so subtle that they can go undiscovered for months or even years.

When an NPN transistor develops a base-emitter short it becomes equivalent to the circuit of figure 6.7.

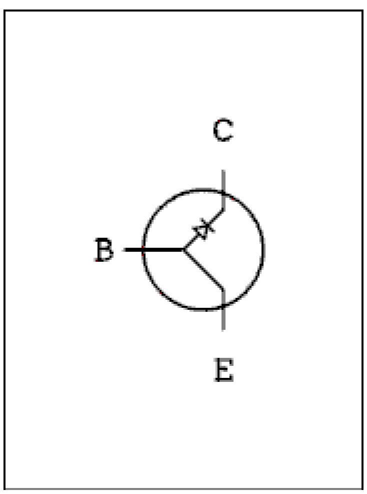

Figure 6.7 NPN Transistor with B to E Short.

For a verbal description click here.

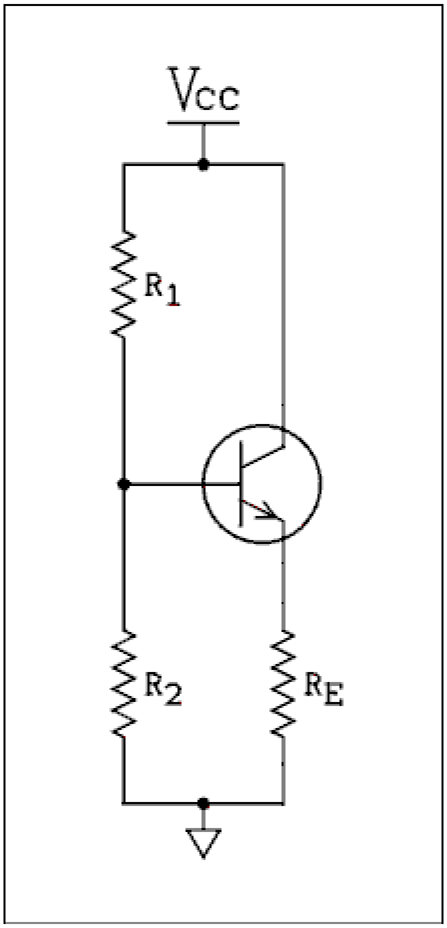

Figure 6.8 Emitter-Follower Circuit.

For a verbal description [click here.]

If we put this shorted transistor into the emitter-follower circuit of figure 6.8 the result is the circuit of figure 6.9.

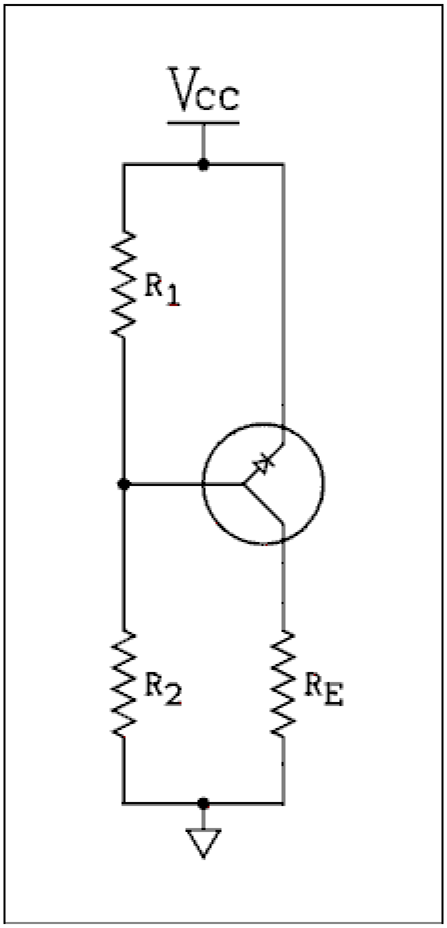

Figure 6.9 Emitter-Follower with Shorted NPN BJT.

For a verbal description click here.

The diode which was the base-collector junction in the former transistor is now just a diode. In the circuit of figure 6.9 it will always be reversed biased. We may leave out this reversed-biased diode and our former emitter-follower circuit now is that of figure 6.10.

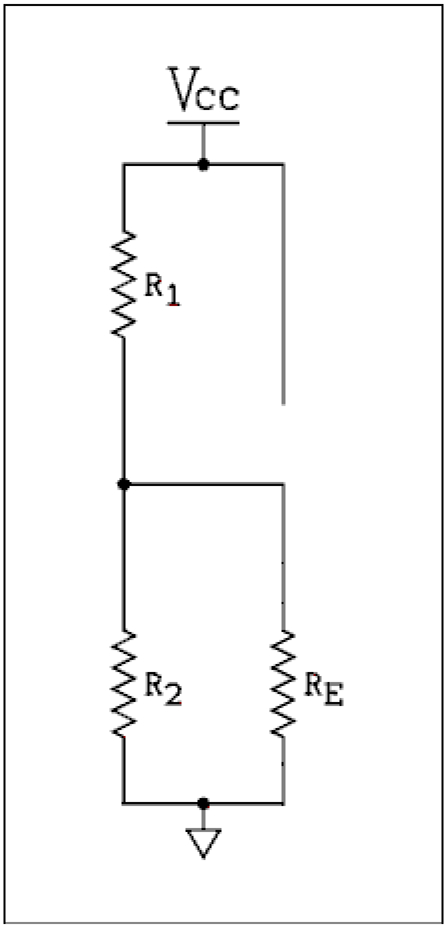

Figure 6.10 Equivalent Circuit of Emitter-Follower with Shorted BJT.

For a verbal description click here.

An emitter-follower has a voltage gain of approximately unity. The circuit of figure 6.10 has a voltage gain of unity, which is one of the reasons why the fault can be so hard to find. An emitter-follower has a current gain of approximately the beta of the transistor. The circuit of figure 6.10 has a current gain of less than unity, which is the reason it needs to be repaired.

Tape Output Buffer Amplifier.

Consider the AC coupled emitter-follower of figure 6.11. This circuit is often incorporated in the "tape output" circuit of stereo receivers or in the output circuit of tape decks or CD players. Although most tape decks have a high input impedance, occasionally one will come along which has a medium or even low input impedance. I happen to own one that has a 10 k ohm input resistance. If a consumer has more than one tape deck it is likely that "Y" connectors will be used to parallel the inputs of the decks on the one tape output. This is why the designer of the receiver put an emitter-follower in the tape output circuit.

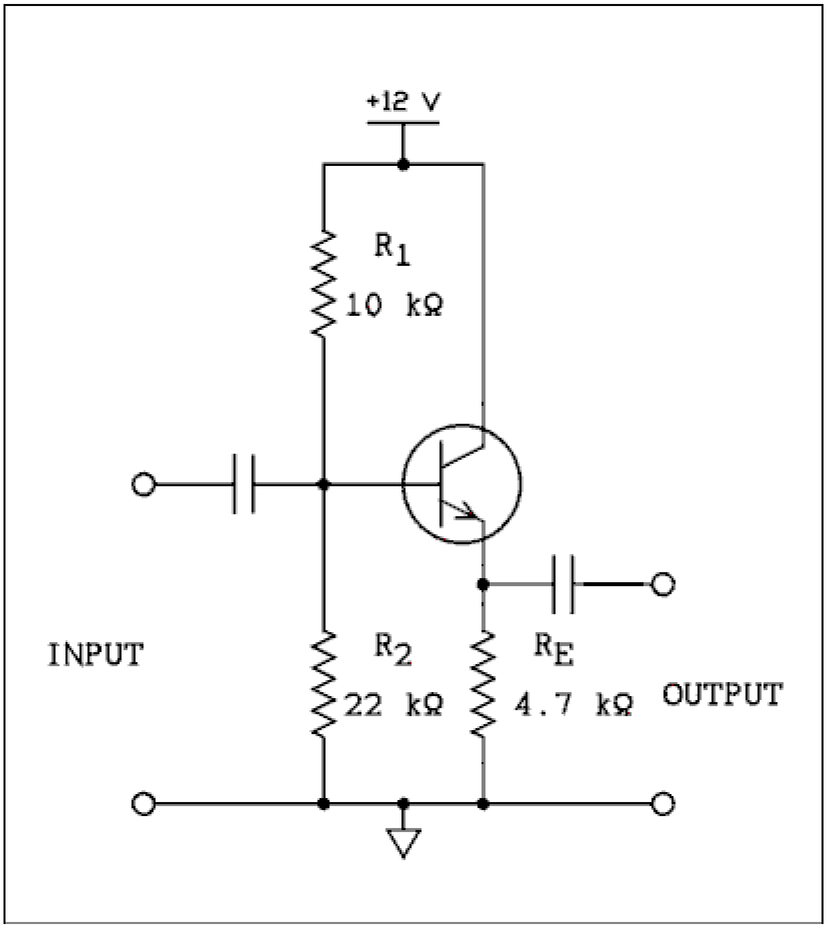

Figure 6.11 AC Coupled Emitter-Follower Circuit.

For a verbal description click here.

If the transistor in figure 6.11 develops a base-emitter short, the circuit will become that of figure 6.12. If the receiver is being used with one tape deck which has a high input impedance the fault may never be noticed. The fault may show up when the consumer tries to add another tape deck to the system.

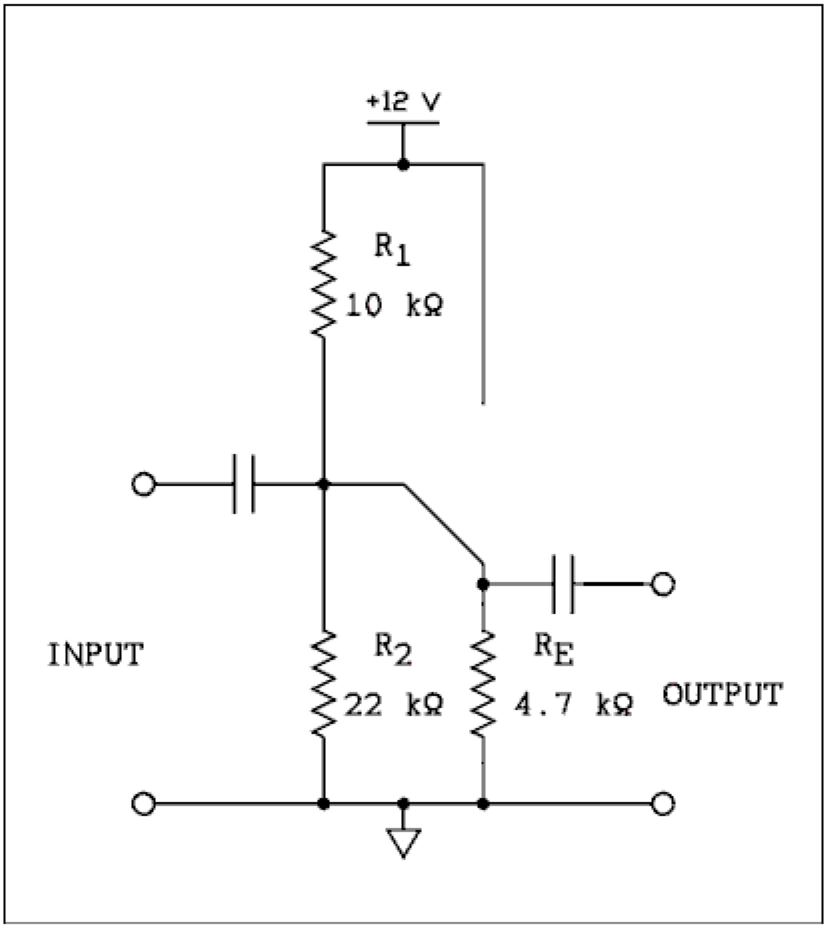

Figure 6.12 Emitter-follower with Base to Emitter Short.

For a verbal description click here.

The consumer will first blame the new tape deck. After being assured by the service technician that there is nothing wrong with the new deck, the receiver is likely to be the next item to appear on the service bench. The technician is unlikely to place any load on the tape outputs and the fault will not be found. The end result is an angry consumer who may never do business with that technician again.

A fault in an emitter-follower can be more easily found by DC analysis than by AC analysis. A typical set of DC voltages for the circuit of figure 6.11 is, VE = 7.3 volts and VB = 8.0 volts. Because the collector is connected directly to the +12 volt line the collector voltage will always be 12 volts. If the transistor develops a base to emitter short, R2 will be placed in parallel with RE and the equivalent resistance is (4.7 k ohms x 22 k ohms) / (4.7 k ohms + 22 k ohms) = 3.87 k ohms. The voltage divider now consists of a 10 k ohms and a 3.87 k ohms resistor. The voltage at base and emitter is 12 v x 3.87 k ohms / (3.87 k ohms + 10 k ohms) = 3.35 volts.

If measurement of DC voltages, (static testing), in an emitter-follower reveals voltages much lower than normal, you can bet your VOM that there is trouble in the circuit.

Wide Band Amplifier.

Now consider the circuit of figure 6.13. This circuit is typical of circuits found in the vertical amplifiers of oscilloscopes. These amplifiers are always differential or push-pull in configuration. The other half of the amplifier would be exactly like the half which is shown.

The emitter bypass capacitors have not been omitted from the drawing; there are none in the circuit. This introduces a large amount of emitter degeneration or negative feedback. Like all negative feedback this emitter degeneration increases the upper limit of frequency response. The designers are giving up gain to get increased bandwidth. The gain of the common emitter stages is approximately RC/RE.

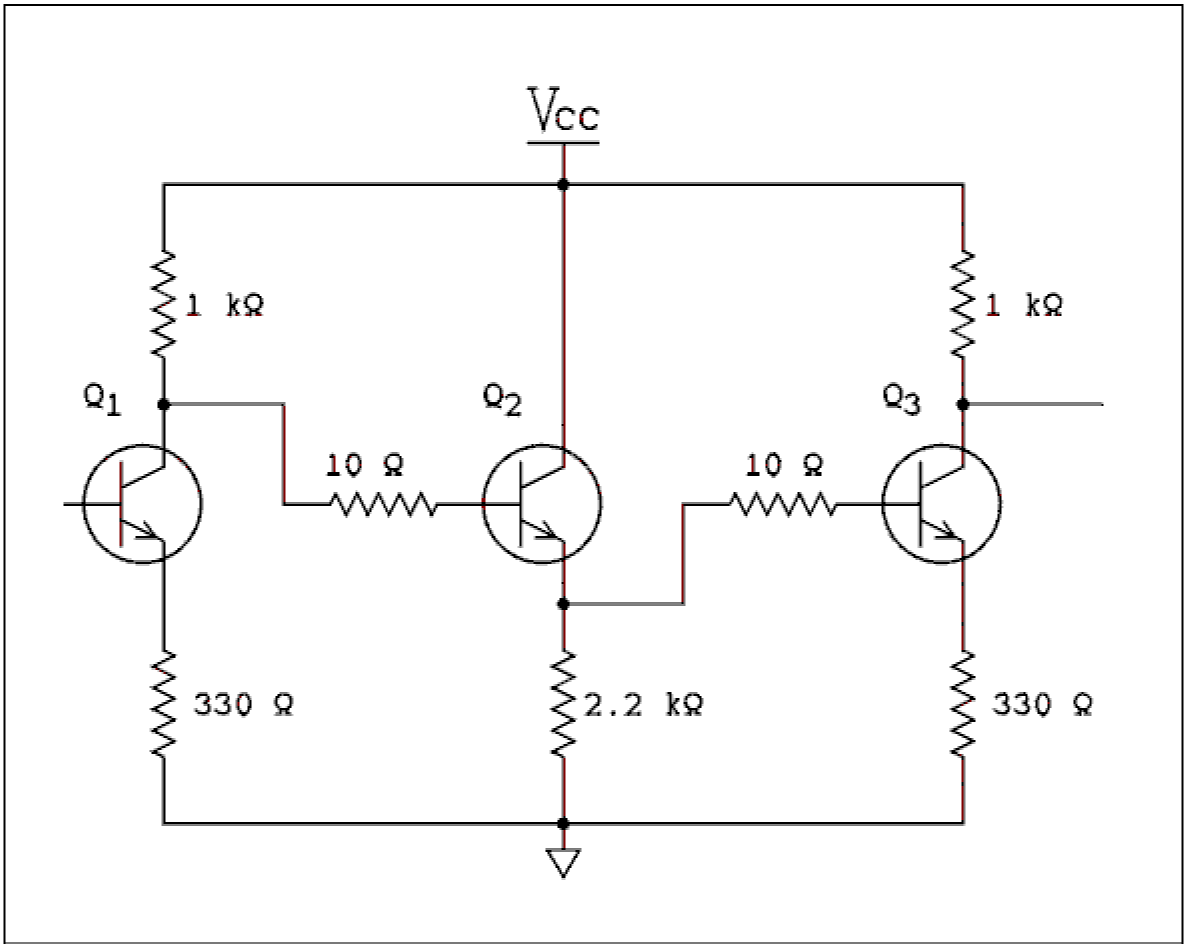

Figure 6.13 Wide Band Amplifier.

For a verbal description click here.

The emitter-follower Q2 would seem to be completely superfluous. The output impedance of the Q1 common emitter stage is the same as the collector resistor, 1 k ohms. The input impedance of the Q3 common emitter stage is approximately equal to RE x beta, or about 17 k ohms. A 1 k ohms source certainly does not need any help to drive a 17 k ohms load. If resistance was all there was to it then Q2 would be superfluous.

Two factors which control the upper frequency limit of an amplifier are the characteristics of the transistors and the capacitance in the circuit. Assuming that Q1, Q2 and Q3 are the best that money can by, the upper frequency limit of the Q1 stage will be determined by the total amount of capacitance from the collector of Q1 to ground. This capacitance is the output capacitance of Q1 and its printed circuitry, plus the input capacitance of the following stage.

If the following stage were a common emitter, this input capacitance would be made up of the input capacitance of the transistor plus the capacitance of the printed circuitry plus the Miller capacitance of the common emitter stage. If the stage following Q1 is an emitter-follower, there is no Miller capacitance. The purpose of the emitter-follower stage (Q2) is to isolate the Miller capacitance of Q3 from the output of Q1.

If Q2 develops a base-emitter short, the Miller capacitance of Q3 is no longer isolated from the output of Q1 and the frequency response of the amplifier will be impaired.

DC measurements may not reveal the fault because the emitter-follower is not doing any work at DC. The fault may show up if careful measurement is made of the base to emitter voltage of Q2 using a DMM. But even this measurement is not an ironclad guarantee of finding the trouble. It usually comes down to pulling the transistors from the board and testing them out of circuit.

If a scope with impaired frequency response comes to the bench of a technician who is unaware of this kind of fault, he or she may work for days and not find the cause. It may even get as far as recommending that the scope be junked.

Example 6.3.

In the circuit of figure 6.13 the output capacitance of the Q1 stage is 1 picofarad and the input capacitance of the Q2 stage is also 1 pf. The input capacitance of Q3 is 1 pf and the Miller capacitance is 4 pf. What are (a) the normal upper frequency limit of the amplifier and (b) the upper frequency limit if Q2 develops a base to emitter short?

Solution:

(a) When the circuit is operating normally the capacitance across R1 is 1 pf + 1 pf = 2 picofarads. fC = 1 / (2 x ã x R x C) = 1 / (6.28 x 1 k ohms x 2 pf) = 79.6 Mhz. (b) Even if Q2 is shorted its capacitance does not disappear. The total capacitance is now CT = CoQ1 + CiQ2 + CiQ3 + CmQ3 CT = 1 pf + 1 pf + 1 pf + 4 pf = 7 pf. The new corner frequency is fC = 1 / (6.28 x 7 pf x 1 k ohms) = 22.7 Mhz.

Regulated power supply.

You may not have realized it but the pass transistor in a regulated power supply is an emitter follower. The circuit of a simple adjustable voltage power supply is shown in figure 6.14. The diagram has been arranged in such a way as to emphasize the fact that the pass transistor is an emitter- follower.

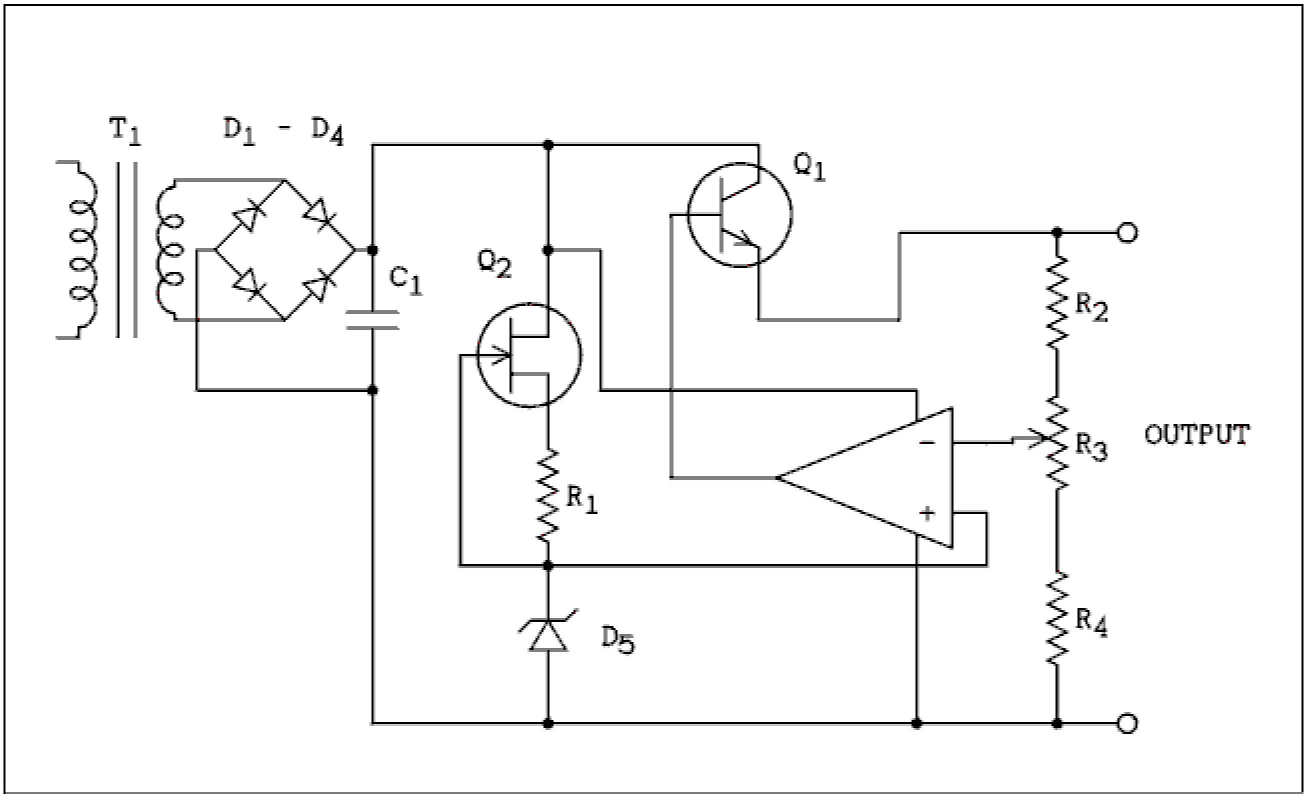

Figure 6.14 Regulated Power Supply.

For a verbal description click here.

Suppose that Q1 develops a base to emitter short. The circuit reduces to that of figure 6.15. This is just a noninverting amplifier whose gain is set by R1, R2, and R3. It is amplifying the voltage of the zener diode. That is all any regulated power supply does no matter how complex it may appear.

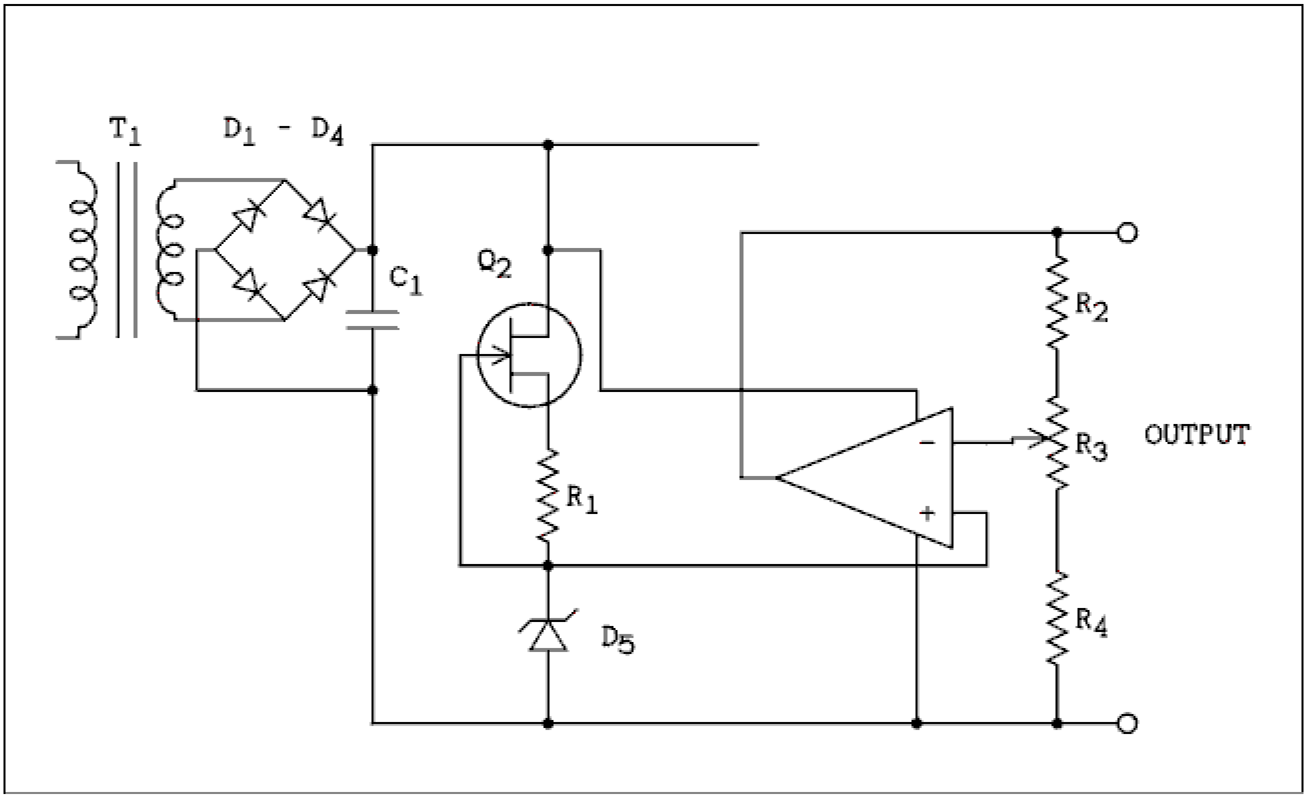

Figure 6.15 Regulated Power Supply After Q1 Develops a Base-Emitter Short.

For a verbal description click here.

If a power supply with a shorted pass transistor comes to your service bench you may wonder at first if it was operator trouble rather than equipment trouble. The output voltage comes up, it can be adjusted over its full range (assuming that the unit you are working on is adjustable) and the scope does not show any ripple. If you send it back to the lab with no further tests, it will be back on your bench within a day.

The output of a typical op amp (operational amplifier) will deliver about 25 mA. This is sufficient to supply current to the voltage adjust resistors and the power supply will function normally as long as there is no large load on the output.

When a power supply comes to your service bench you should always test the supply at its specified maximum current.

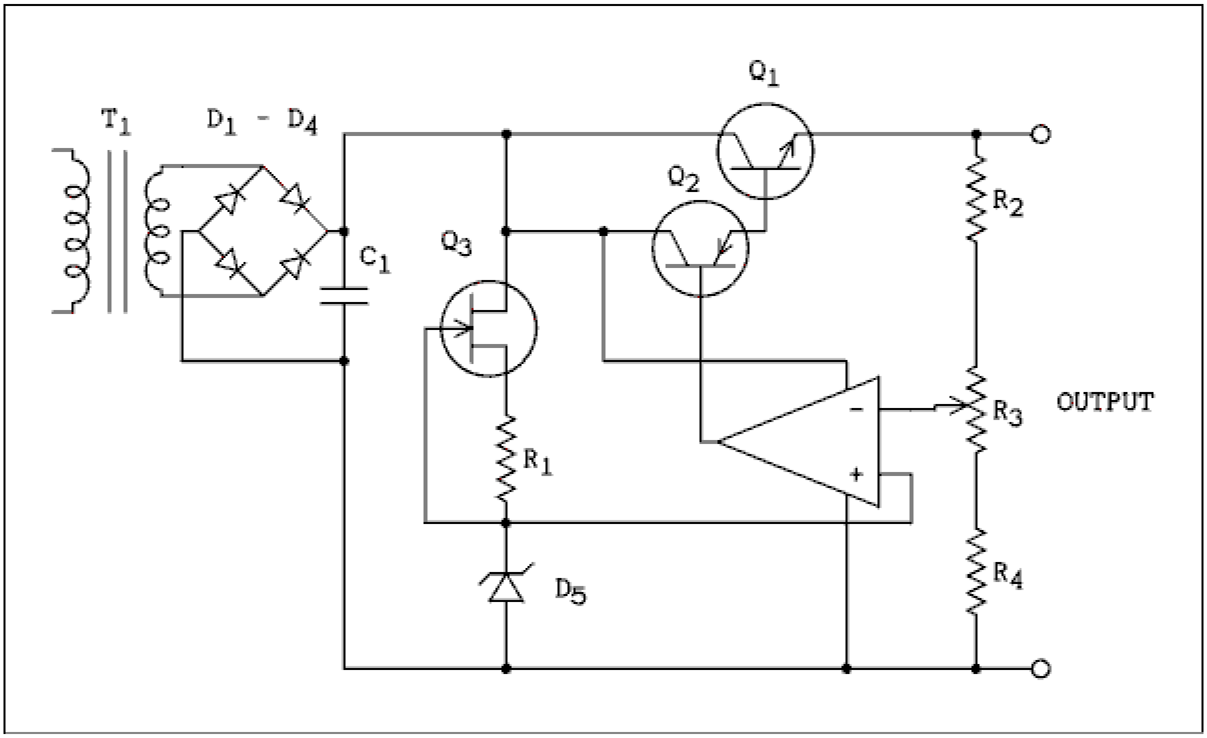

Figure 6.16 Regulated Power Supply with Darlington Pair.

For a verbal description click here.

Many regulated power supplies use a Darlington connected pair as the pass transistor, figure 6.16. If Q2 develops a base to emitter short the power supply will still work and will likely deliver an appreciable current, several hundred milliamperes. However, it will not perform up to its specified maximum current.

If Q1 develops a base to emitter short, Q2 will try to take over the duties of Q1. Q2 is not equipped with a large heat sink and will overheat very quickly. The power supply will seem to work normally for a short time and then catastrophically fail. Q2 will likely short everything to everything. The output voltage will go above specified maximum and stay there.

If both transistors in a Darlington pair have base to emitter shorts, the supply will be down to the bare op amp as shown in Figure 6.15. If you replace only one of the defective transistors you will create one of the situations described above.

The Cause of the Short.

You may be wondering how a base-emitter short can happen. The usual cause of any failure is difficult to pinpoint. Part of the fatal flaw in the emitter-follower is that it has its cause of failure built in.

Consider the circuit of figure 6.11 again. If there is no load connected to the output when the power is turned on, C2 will remain discharged. If the output is then shorted momentarily to ground, the capacitor will be charged through the emitter of the transistor. The pulse of current is short, but it can be several amperes in magnitude. This extremely large current pulse can burn out the base-emitter junction of a small transistor. The collector-base junction is larger in cross-section area and is usually not damaged.

It is possible to burn out the tape output buffer in a stereo receiver very easily. If the owner makes connections to the tape output with power turned on, the capacitor in the output will start out with no charge on it. In the process of connecting the cables it is possible to momentarily short the output and there goes the emitter-follower transistor. This is a documented and repeatable failure in a stereo receiver from a well known manufacturer.

A modification which will prevent burning out the transistor is to connect a resistor of about 470 k ohms from ground to the terminal marked "output" in figure 6.11. This will make sure that C2 gets charged even if there is nothing connected to the output. It is the charging of C2 through a dead short, not a resistor, which can destroy the transistor.

In the case of a power supply the pass transistors can be zapped if the power supply is forced to charge a large external capacitor each time the power supply is turned on. The current limiting circuits should prevent such damage but if it is a little slow to respond the pass transistors may experience a large amplitude current pulse.

We have cited only three uses of emitter-followers, there are many others. All are subject to the same kind of failure and all can be a little tricky to find.

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6.3 AC Coupled Amplifiers.

AC coupled amplifiers make up a significant percentage of amplifier circuits. They are used in audio, radio frequency and industrial applications.

An AC coupled amplifier is shown in figure 6.17. The emitter resistors are bypassed to increase the gain to the maximum. Capacitor C1 prevents whatever may be connected to the input from upsetting the base bias of Q1. C3 prevents the DC voltage at the collector of Q1 from upsetting the base bias of Q2 and C5 prevents the DC voltage at the collector of Q2 from reaching whatever is connected to the output.

DC Voltage Measurements.

If an emitter bypass capacitor shorts, the emitter voltage of that transistor will be zero. The voltage divider in the base will cause a very large base current to flow, which will drive the transistor into hard saturation. The typical voltages for a shorted bypass capacitor will be VE = 0 v, VB = 0.7 v and VC = 0.1 v.

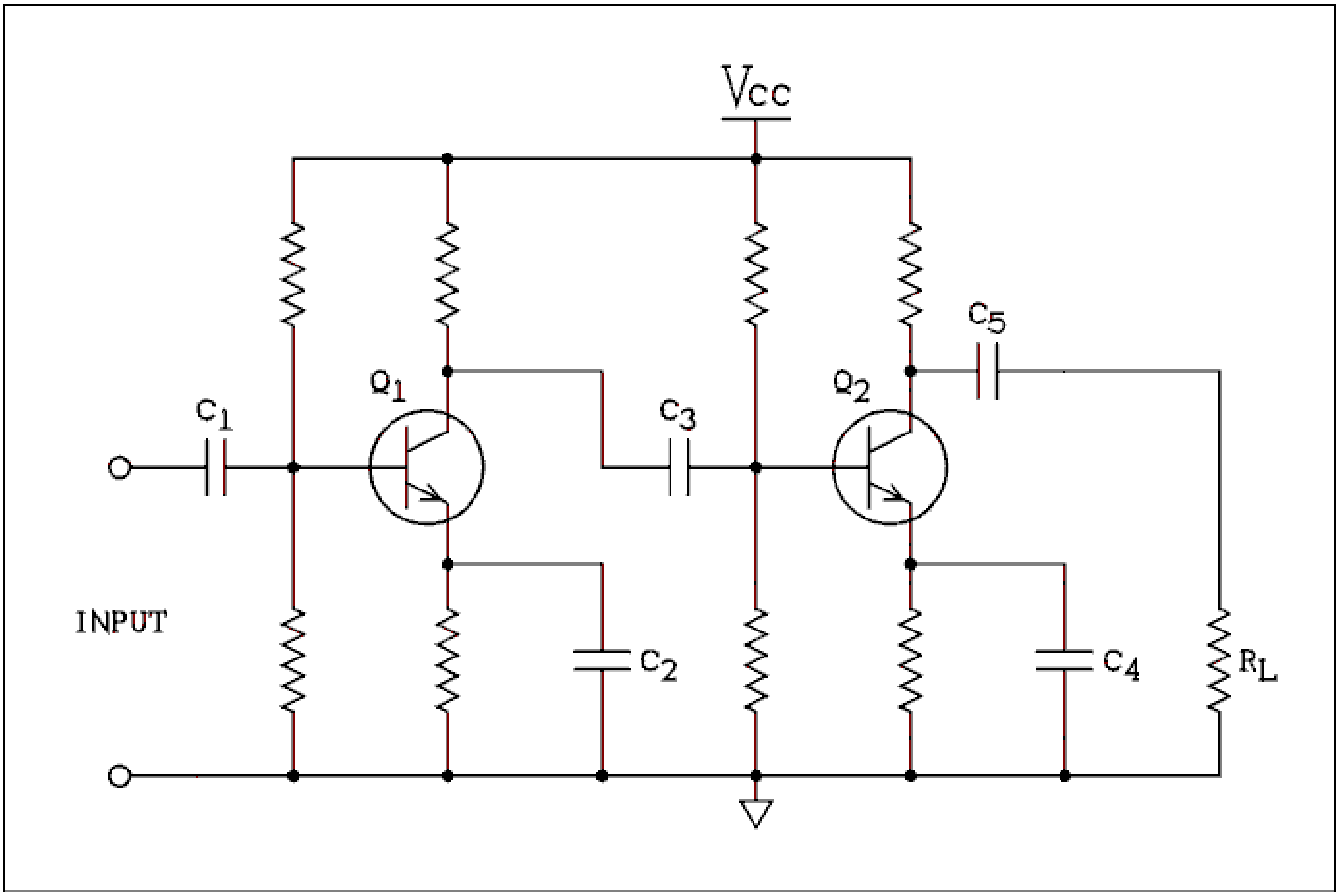

Figure 6.17 Two Stage Common Emitter Amplifier.

For a verbal description click here.

The results of a short in C1 are difficult to predict without knowing what is connected to the input. Suppose that a dynamic microphone is connected there. It is typical for a dynamic microphone to have a DC resistance of only a few tens of ohms. If C1 shorts, it will remove all bias from the base of Q1 and cause Q1 to be driven into cutoff. Typical voltages for this condition will be VE = 0 v, VB = 0 v and VC = VCC.

If C3 shorts, the result will depend on whether the voltage at the collector of Q1 is greater than or less than the voltage at the base of Q2. The two voltages will become equal and Q2 will be in either saturation or cutoff depending on whether VCQ1 is greater or less than VBQ2. Typical voltages cannot be given because they depend on the values of the resistors.

The effect of a short in C5 depends on what is connected to the output. If it were one side of a pair of headphones, the DC resistance would be very low, about 6 ohms. This would pull the collector voltage down and forward bias the base-collector junction. The transistor may not be damaged but it certainly will not amplify. Typical voltages would likely be VE = 0 v, VB = 0.7 v and VC = 0 volts.

AC Voltage Measurements.

If you are signal tracing instead of making static tests, you will see the signal suddenly disappear at the defect. A transistor which is in cutoff or saturation does not provide a signal path. Some types of faults can make you think that the trouble is in the stage ahead of where it actually is.

Suppose that Q2 in figure 6.17 develops a base-emitter short. The emitter is connected to ground through a capacitor. Because the base is shorted to the emitter, the base will be at AC ground potential. C3 also has a low reactance for AC and so the collector of Q1 is effectively shorted to ground for AC. The signal is no longer present at the collector of Q1 because it is shorted out by the series combination of C3, the base to emitter short in Q2 and C4.

When signal tracing, you would find signal at the base of Q1 and no signal at the collector of Q1. Your first conclusion would be that the trouble is in the Q1 stage. DC measurements would reveal that all in the Q1 stage is well. DC measurements in the Q2 stage will reveal the base to emitter short. This false clue is a very common phenomenon in transistor circuits.

A transistor which is being driven into hard saturation may appear as a short circuit to the signal. When the AC signal disappears, you must check the stage just after the point where the signal disappeared as well as the one where it disappeared.

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6.4 DC Coupled Amplifiers.

A DC coupled amplifier is one in which the stages are coupled together without using capacitors. Sometimes this is done because the amplifier must have gain all the way down to and including DC. Sometimes the reason is economics.

One of the miniature capacitors which are used in transistor circuits can cost 4 or 5 times as much as a resistor. The capacitors may even cost more than the transistors. Therefore, if it is possible to replace one capacitor with three resistors, the design engineer will do it. Even in circuits where the signals are AC only, it is very common to see groups of two, three or even four stages which are DC coupled.

A two-transistor DC coupled gain block is shown in figure 6.18. R4 is present to allow negative feedback to be applied to the emitter of Q1. If no feedback is to be connected, R4 can be replaced with a piece of wire. With R4 = 0, this circuit can provide the same amount of gain as the circuit of figure 6.17. The circuit of figure 6.18 with R4 = 0 does the same job with only 5 resistors and 3 capacitors, as opposed to 8 resistors and 5 capacitors for figure 6.17.

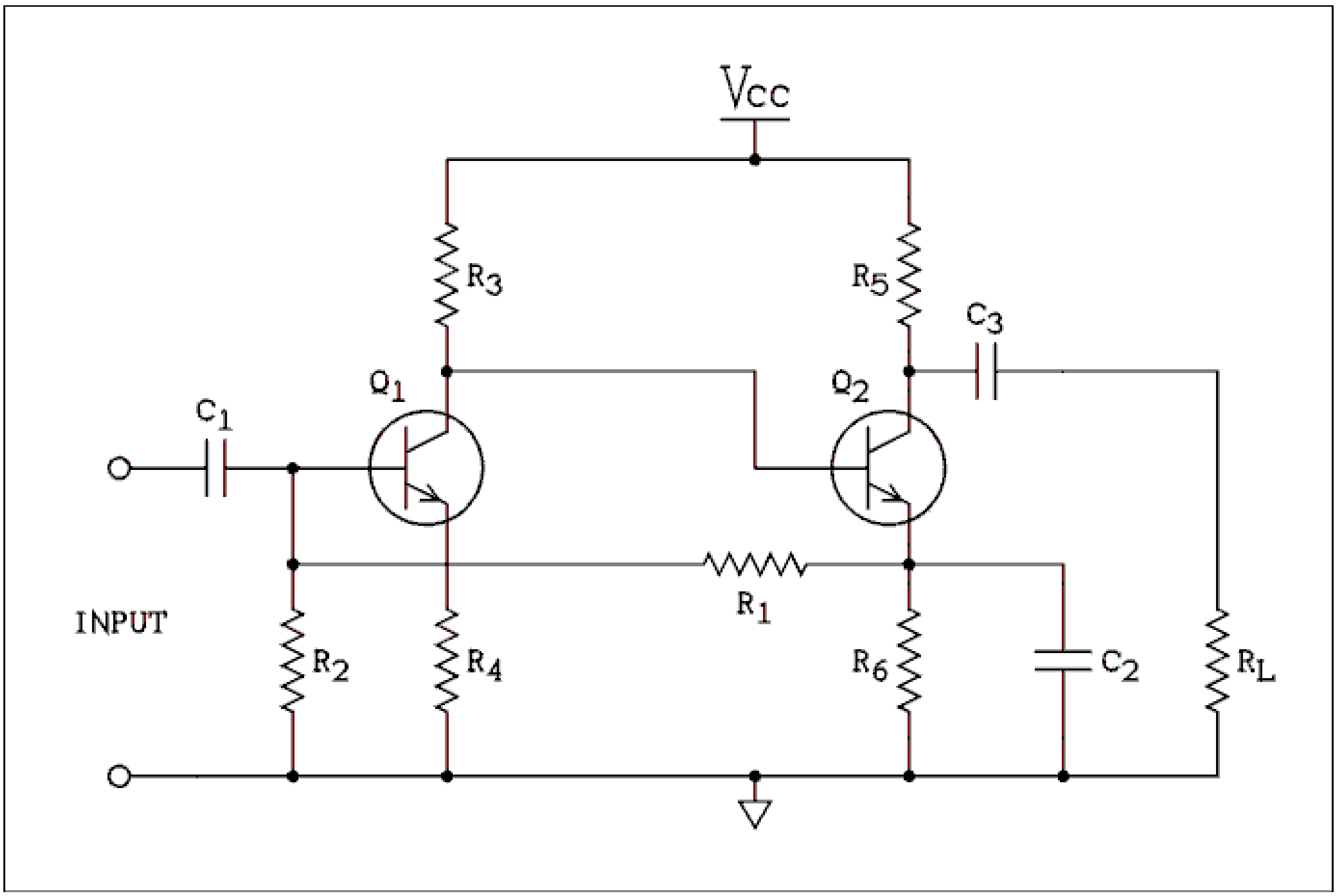

Figure 6.18 Two-stage DC Coupled Amplifier.

For a verbal description click here.

Operating point stabilization (DC feedback) is provided by R1 and R2 from the emitter of Q2 to the base of Q1. AC feedback along this path is prevented by C2, which bypasses AC signals at the emitter of Q2 to ground.

AC feedback is often added to this circuit by making R4 some low value, say 100 ohms, and coupling signal from the output back to the emitter of Q1.

If Q1 goes totally shorted, all of the voltages in the circuit will go nearly to zero except the collector of Q2, which will go up to VCC. The reason for this is as follows. When Q1 shorts out, all of its voltages will be equal to each other. R4, if it exists at all, is a low value and its voltage drop is very small. The short in Q1 will pull the base of Q2 down and send Q2 into cutoff.

If Q2 goes totally shorted, the emitter voltage of Q2 will remain normal, provided that R5 and R6 are not too low compared to R3. The DC feedback from the emitter of Q2 to the base of Q1 is responsible for this. The voltages at the collector and base of Q2 will be equal to the emitter voltage. The circuit with this defect will not provide gain for AC because C2 bypasses all signals to ground.

Example 6.4.

The normal voltage chart for the circuit of figure 6.18 is as follows.

	VE	VB	VC
Q1	0 v	0.6 v	4.0 v
Q2	3.4 v	4.0 v	8.3 v

A fault develops and the voltages become:

	VE	VB	VC
Q1	0 v	0.6 v	1.6 v

Q2	1.0 v	1.6 v	10.9 v

What is wrong?

Solution:

The transistors are not shorted because both have VB > VE and VC > VB. We conclude that both transistors are good. The voltage drop across R1 is 0.4 volts. This indicates that the current through R1 is not what it used to be. This could only be caused by R2 being open.

In example 6.4, the feedback is what causes the circuit to behave in the way it does. The voltage at the emitter of Q2 will be adjusted to whatever is necessary to make the voltage at the base of Q1 be 0.6 volts. As long as R1 and R2 are intact the emitter of Q2 adjusts to 3.4 v to forward bias Q1 by just the right amount. In this circuit you might assume that if R2 opened, the transistor would be driven into hard saturation. But if the base is receiving too much bias the collector voltage of Q1 will come down and the emitter voltage of Q2 will follow. The emitter of Q2 will assume whatever voltage is necessary to provide just the right amount of bias to the base of Q1.

This is another one of those circuits which will continue to work even with a defect, especially if there is AC feedback to the emitter of Q1. The circuit will function quite normally for small signals. On larger signals the positive peaks will be clipped off. This is because the voltage at the collector of Q2 (10.9 volts) can only go up to 12 volts but it can go down to about 1 volt.

If R3 opens there will be no current path from the collector of Q1 to VCC. The collector of Q1 which is also the base of Q2 will fall to its lowest possible potential. The voltages will be much the same as if Q1 had shorted, except if R4 is present, there will be absolutely no voltage drop across it because there is no current through it.

If R5 opened, the voltage at the collector of Q1 would fall until it became equal to the emitter voltage. All other voltages in the circuit may be normal, depending on the relative values of R3 and R6, because of the DC feedback through R1 and R2.

When R5 opens, R3 and R6 become a voltage divider with the base-emitter junction of Q2 acting as a forward biased diode. If R3 is much larger than R6 it will be unable to pull the voltage up to the normal emitter voltage. If the voltage divider of R3 and R6 can assume a voltage greater than the normal emitter voltage of Q2, the collector current of Q1 will pull the voltage down to the normal value.

Depending on the load impedance the circuit may still provide gain while adding some distortion. However, the sign of the gain will be changed. When the circuit is working normally it is a noninverting amplifier. When R5 opens, Q2 is no longer an inverting amplifier. With only Q1 doing any amplifying, the overall gain of the circuit is inverting. If this circuit is in the middle of a larger feedback loop the feedback can change from negative to positive.

If R6 opens, the emitter current of Q2 will be only that which flows through R1 and R2. The voltage at the collector of Q2 will rise to very nearly VCC. All other voltages in the circuit will be normal because of the regulating effect of the feedback.

Figure 6.19 shows a configuration involving an NPN and a PNP transistor. This circuit is stabilized by DC feedback from the tap on the collector resistor of Q2 which feeds back a portion of the output voltage to the emitter of Q1. The voltage at the node between R4 and R5 will adjust itself until Q1 has just the right collector current to provide just the right amount of bias to Q2.

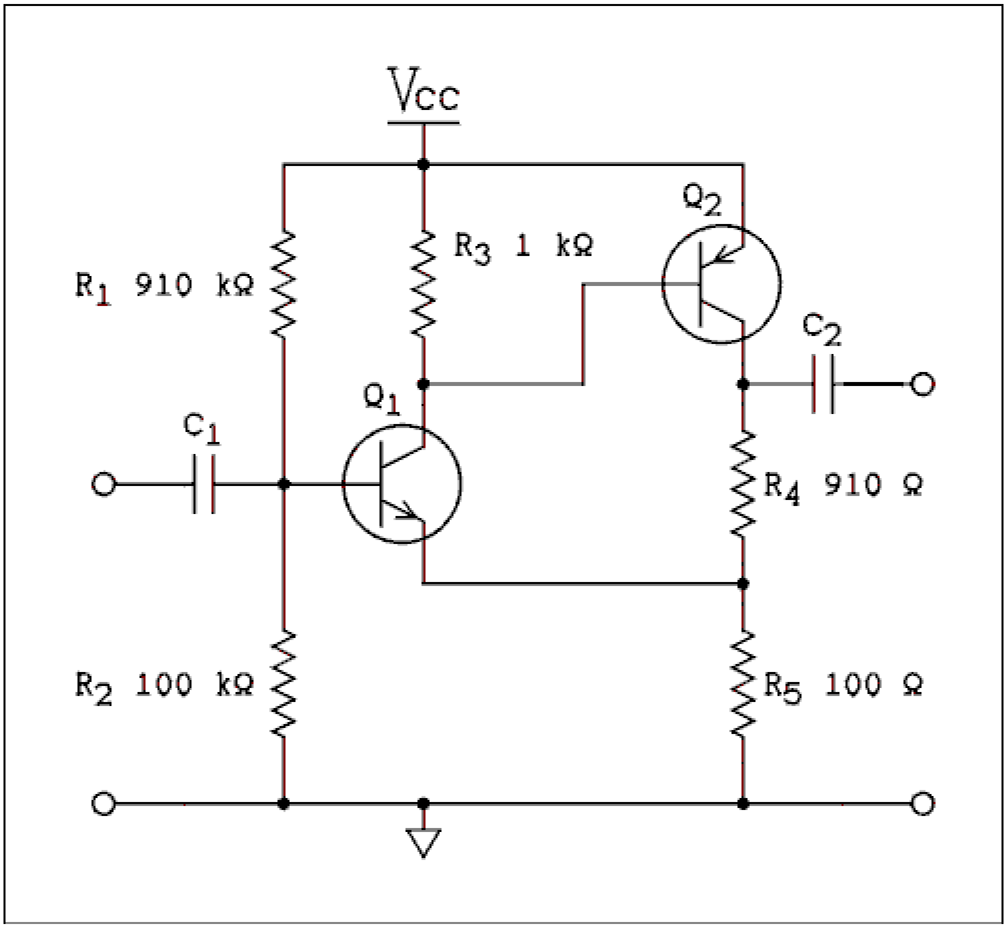

Figure 6.19 Complementary DC Coupled Amplifier.

For a verbal description click here.

The feedback path also passes AC. The gain of this circuit is set at 10. If higher gain is required, the variation of figure 6.20 may be used.

If Q1 in figure 6.19 shorts, it will effectively place a 100 ohm resistor from the base of Q2 to ground. This will unquestionably drive Q2 into hard saturation. The base current will be approximately 120 mA, assuming a 12 volt power supply. This excessive base current may destroy Q2 as well. In the circuit of figure 6.20 R4 will prevent excessive current from flowing and Q2 will likely survive.

In figure 6.19 if R2 opens, Q1 will receive constant current bias through R1. This will increase the collector current of Q1 and in turn increase the collector current of Q2, driving it into saturation. The voltage at the collector of Q2 will be 12 volts but the voltage at the emitter of Q1 will be higher than the expected value of 1.2 volts. The reason is the emitter current of Q1 has become significant compared to the current flowing through R4 and R5. In a test circuit with R2 open the emitter voltage of Q1 was 3 volts.

If R3 opens, the effect may never be noticed. A slight reduction of bandwidth at high signal levels will be the only observable effect.

If R5 opens, the voltage at the collector of Q2 will fall to about 0.6 volts. This is because the feedback in the circuit will try to keep Q1 biased just right. The base of Q1 is set at 1.2 volts by R1 and R2. In order to keep Q1 properly biased, the emitter voltage must be 0.6 volts. With R5 open the voltage drop across R4 is extremely small. Thus the collector of Q2 will be at 0.6 volts.

If R4 opens, the result will be to cause the collector current of Q1 to be very high. The opening of the current path to the collector of Q2 means that the emitter of Q1 must conduct all of the current which is flowing through the resistors to ground. Q1 cannot saturate because of the base- emitter junction of Q2 in its collector circuit. The collector voltage of Q2 will be VCC because it is in saturation and its collector resistor is open.

In figure 6.20 an additional resistor has been added to raise the impedance at the emitter of Q1. The emitter of Q1 is bypassed by C2 which removes all AC feedback. If some AC feedback is needed to lower the gain, a small amount of resistance may be inserted in series with C2.

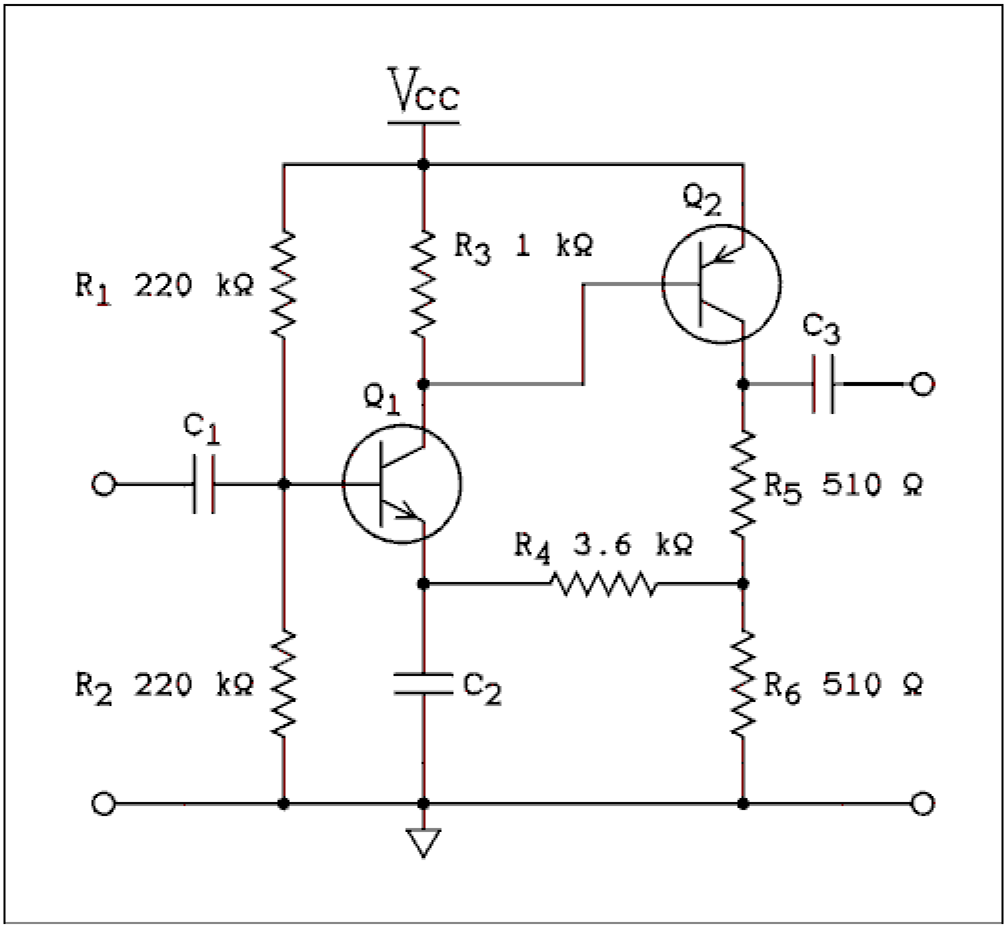

Figure 6.20 Complementary Amplifier Without AC Feedback.

For a verbal description [click here.]

If Q1 shorts, R4 will protect Q2 from being subjected to excessive base current, as was the case for figure 6.16.

In figure 6.20 if Q2 shorts, its collector voltage will become approximately 12 volts, which will increase the voltage applied to the emitter of Q1. The voltage at the base of Q1 is fixed by the voltage divider of R1 and R2. The short in Q2 will pull up the emitter voltage of Q1 to the point of reverse biasing the base-emitter junction of Q1. This will bias Q1 into cutoff.

If R1 opens, both transistors will be driven into cutoff and the voltage at the collector of Q2 will be zero. All other voltages will be what you would expect with both transistors in cutoff.

If R2 opens, both transistors will be in saturation. R4 in the emitter of Q1 will permit Q1 to make it into saturation.

If R3 opens, the effect will be quite noticeable. The collector current of Q1 will be reduced to equal the base current of Q2. This decreases the emitter current of Q1 which will cause the voltage drop across R4 to be reduced. Since the base voltage of Q1 is held nearly constant by the voltage divider of R1 and R2, the emitter voltage will change very little. The voltage at the node where R4, R5 and R6 join will increase. Calculations indicate and tests verify that for the given resistor values, Q2 will be biased into saturation.

If R6 opens, the voltages measured at the terminals of the transistors will change only very little. However, the voltage at the node connecting R4, R5 and R6 will rise from about 3 volts to become equal to the collector voltage of Q2 (about 6 volts). The blame is once again placed on that feedback which does its best to keep the circuit working no matter what is wrong. The circuit will adjust itself to properly bias Q1.

In actuality, both transistors are in cutoff. When a voltmeter is connected to the collector of Q2 it, the voltmeter, provides a load resistance to complete the current path. Both transistors are now conducting very small currents. An additional effect may be that the circuit which was previously dead may come to life (begin to amplify AC signals) when the voltmeter is connected and go dead again when the voltmeter is removed. This may lead one to a false conclusion that there is a loose connection in this part of the circuit.

If R5 opens, the result will be to place Q1 in saturation. The opening of the current path to the collector of Q2 means that the emitter of Q1 must conduct all of the current which is flowing through the resistors to ground. For almost any combination of resistor values this will put Q1 into saturation. When Q1 saturates, Q2 saturates.

Let us now return to a circuit which we looked at earlier, figure 6.13. In section 6.2 we discussed the effects of a short in Q2.

If Q1 shorted, the effect would be to place the emitter and collector resistors in series across the power supply. The collector voltage would be decreased. Q2 will pass this voltage through and decrease the bias on the base of Q3. This may or may not drive Q3 into cutoff. It will depend on the values of the resistors and the power supply voltages.

The following discussion will concern the effect of a total short in Q3. The same effect may well show up if Q1 were to short instead of Q3. Figure 6.13 does not show us what is driving the base of Q1. If it is an emitter follower, the effect would be the same. If it is a higher impedance source, the amplifier may simply go dead.

A total short in Q3 will convert it into a node connecting the emitter of Q2 to the bottom of R4 and the top of R5. While this does place quite a heavy load on Q2, the emitter follower could drive it.

Signals which are injected into the amplifier will come through even with a short in Q3. The gain of 3 which Q3 normally provides will become unity. That is a relatively small change.

The effect on phase shift is the one which will be most noticeable. A common emitter stage such as Q3 in normal operation inverts the input signal. A node connecting some resistors together provides no inversion. The amplifier shown in figure 6.13 is a noninverting amplifier with a gain of 9. When Q3 shorts, the amplifier becomes an inverting amplifier with a gain of 3.

Circuits such as figure 6.13 do not stand in isolation. A circuit such as this will be a small part of a much larger circuit. If the larger circuit has negative feedback, the loss of an inversion will cause this to become positive feedback.

If the feedback is AC coupled, the circuit will oscillate at some unpredictable frequency. If the entire feedback loop is DC coupled, the circuit will simply latch up at one extreme of voltage.

If the larger circuit is an electro-mechanical control system, the system will drive away from the proper point instead of towards it as it should. It will run to the mechanical limit where the limit switches will cause it to stop.

A small loss of gain inside a feedback loop can easily go unnoticed but a change of phase is very noticeable. An amplifier which oscillates or latches up or a control system which drives the wrong way can be a very puzzling situation.

Assume that the circuit of figure 6.13 is part of a sub-assembly which has been removed from a large system and taken to the repair shop. Because the circuit has been removed from its normal signal sources, signal substitution must be used for testing.

The diagram should indicate whether the amplifier unit is inverting or noninverting. The very first test should be to confirm that the phase of the amplifier is correct. If it is incorrect, some very careful testing will be necessary.

Set up the oscilloscope so it is triggered from the signal source. At each stage the scope will show the phase relationship between the input signal and the signal at the test point.

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6.5 Radio Frequency Amplifiers.

Radio frequencies are those that are higher than the audio band. It may surprise you to know that there is actually some overlap. The Omega Navigation system, no longer in operation, used a frequency range from 8 to 12 kHz. With the proper filtering to remove the power line frequency and its harmonics an audio amplifier could be connected to an antenna and some of these transmitters could be heard as they were switched on and off.

What distinguishes an RF (Radio Frequency) amplifier from an audio amplifier is that the former contains one or more LC resonant circuits to restrict the band of amplification to a narrow range of frequencies.

Common emitter amplifier.

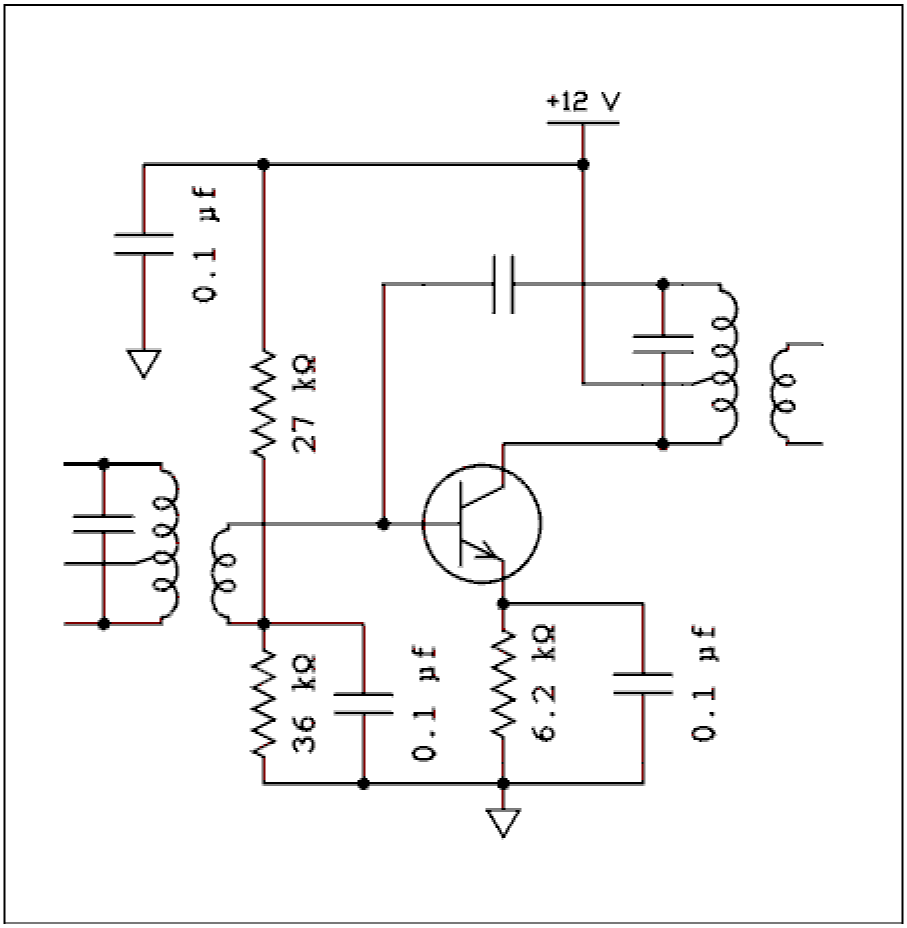

Figure 6.21 Typical IF Amplifier used in Pocket Radios.

For a verbal description click here.

This circuit is typical of the IF (intermediate frequency) amplifiers found in most transistor sets particularly those 6 transistor pocket radios. Transistors are low impedance devices and the input impedance is especially low. The tuned transformers have been designed to work with transistors operating at a supply voltage of from 9 to 12 volts.

The transistor is a triode device and as such has a significant amount of capacitance from input (base) to output (collector). In tubes this problem was solved by adding another grid but this is not possible in a transistor. Therefore an RF amplifier must be neutralized. Note that the Vcc is applied to a tap in the middle of the coil which is not in the exact center. This serves two purposes, one, the impedance between the tap and the near end is lower than the impedance across the entire coil. This prevents the low output impedance of the transistor from lowering the Q of the tuned circuit. Second, by connecting the coil as shown the phase of the voltage at the other end of the coil is 180 degrees out of phase with the voltage at the collector. By connecting a small capacitor, less than 10 pf, from this point back to the base the feedback through the collector to base capacitance of the transistor is canceled by an equal and opposite amount of feedback from the transformer through the capacitor to the base. This is a small ceramic capacitor and its failure is unheard of. If it were to open the amplifier would be likely to oscillate. If it were to short the transistor would be placed in saturation and the circuit would cease to amplify. If the IF strip uses AGC the positive bias is likely to be conducted along the AGC line making it difficult to isolate the problem to a particular stage.

KEEP YOUR SCREWDRIVER OUT OF THE TRANSFORMER ADJUSTING SLUGS!

If the radio or tuner isn't working it isn't because the adjustment screws turned themselves. The cause of the problem is a defective component not because the tuned circuits are mistuned. The only exception to this rule is if an uninformed owner tinkerer tightened up all the loose screws. Also the slugs are made of a material something akin to glass but not as hard. They are held in place by hardened paraffin and will not move easily. If you insert a metal screwdriver and start twisting the result will usually be a broken slug. If you can verify that alignment is necessary the IF transformers in question should be gently warmed under a heat lamp, with a hair dryer, or with a heat gun held a considerable distance away.

Open coils and open resistors are more likely than shorted capacitors since the capacitors are usually ceramic with voltage ratings of 50 volts and have a very low probability of failure. DC measurements around the circuit should find the fault. The same formula used in audio amplifiers may be used to calculate the voltages if they are not given.

Grounded or Common Base Amplifier.

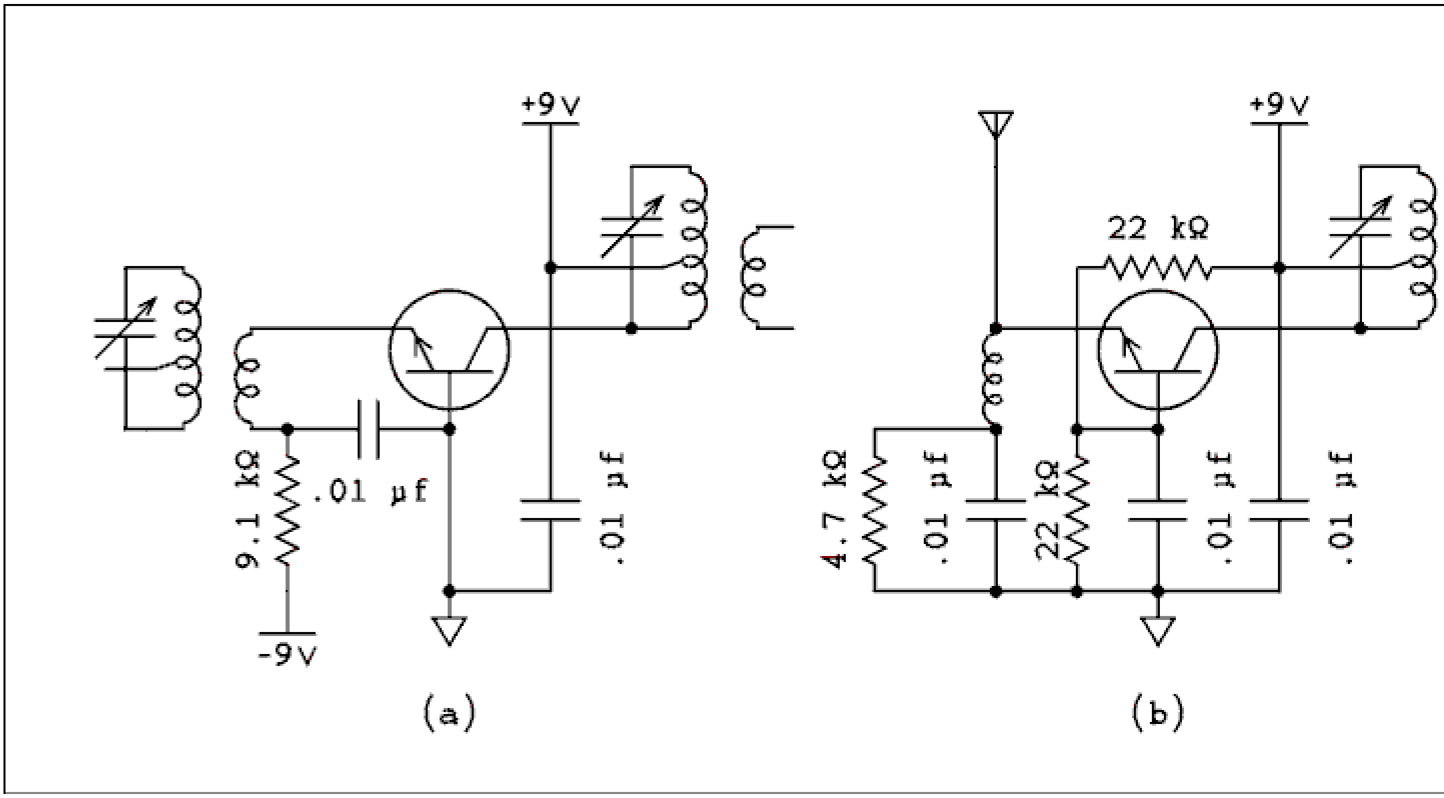

Figure 6.22 Two examples of grounded base amplifiers.

For a verbal description click here.

The transistor is constructed with the base physically between the collector and emitter. If the base could be grounded it would act as an electrostatic shield between the emitter and collector. When the emitter is used as the input element the impedance is quite low typically 25 millivolts divided by the emitter current. As you can see for an emitter current of 1 mA the input impedance is 25 ohms. This is a rather rough approximation and should not be used in the design of impedance matching circuits such as transformers or pi networks.

Actually grounding the base is most effective in preventing oscillation even at VHF. The circuit of Figure 6.22 (a) might be found in a short wave receiver or FM tuner. In an S W receiver there most certainly will be band switching which will complicate the schematic. If you examine the diagram carefully you will be able to tease out the basic circuitry.

Figure 6.22 (b) is a circuit often seen in portable FM radios. Because these radios use a single polarity power supply the transistor must be biased with the usual three resistor circuit which means that the base must be grounded through a capacitor rather than directly. The coil is a low Q RF choke which is tuned to the center of the FM band by circuit capacitance. The impedance at the base of a ¼ wave antenna is low which is a match for the input impedance of the amplifier. DC measurements should turn up a fault but connecting a voltmeter lead or oscilloscope probe may well make the circuit start oscillating. It may be necessary to connect a short across the collector coil to kill this oscillation in order to obtain good measurements.

Cascode Amplifier.

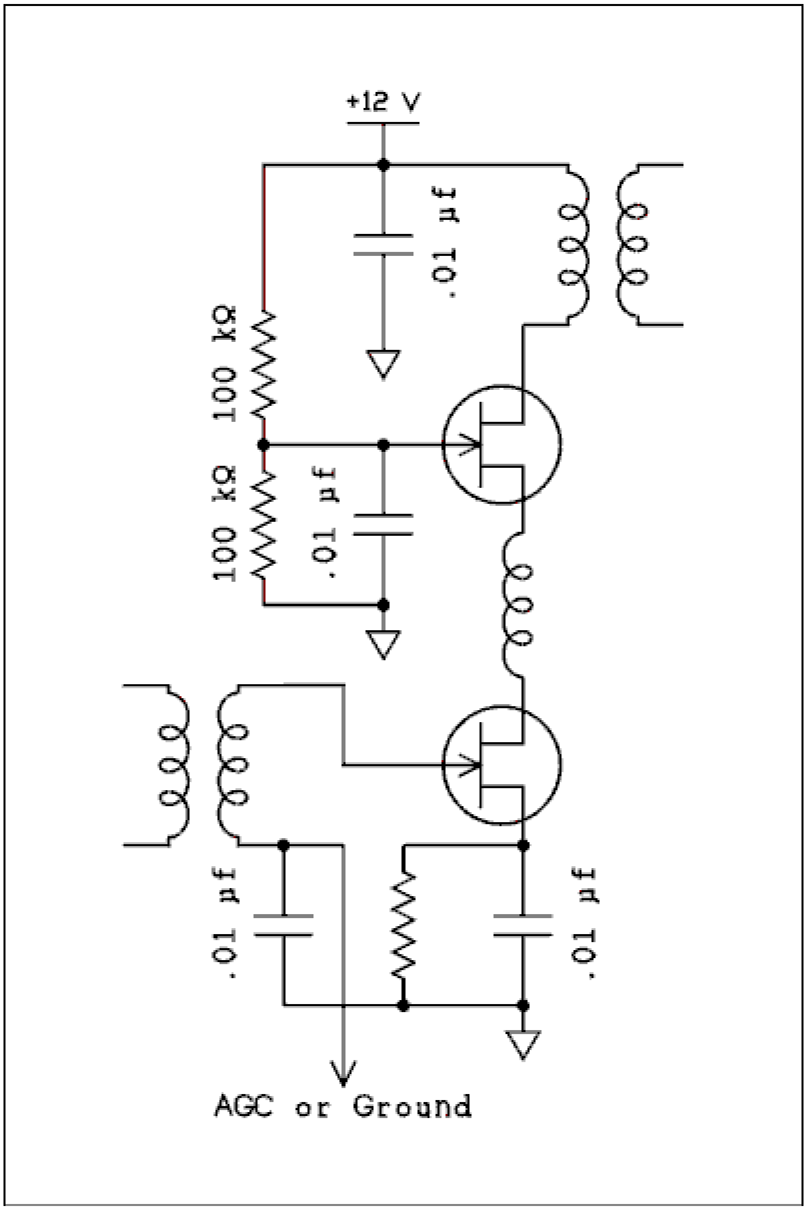

Figure 6.23 Cascode Amplifier sometimes found in Ham Radio Projects.

For a verbal description [click here.]

This circuit is used by amateur builders who don't know or didn't stop to think that a field effect transistor is not constructed like a triode tube. Proper operation of the circuit requires that the upper device have an electrostatic shield between the source and drain. FETs are not constructed in this way. The channel which has the source on one end and the drain on the other is a small bar of N type silicon. The gate is a small dot of P type silicon on one side of the channel. The gate is not physically between source and drain. For the depletion region to serve as an electrostatic shield it would have to occupy the entire cross section of the channel. That would place the FET in total cutoff and it would not function as an amplifier.

If you ever have to deal with such a circuit it will most likely come to you as a newly constructed device that has never worked. Slight detuning of the input and output tuned circuits may make it stable enough to use. The circuit is most likely to appear in fixed tuned converters so there is no tracking problem to deal with.

Probably the best cure is to break the "don't modify" rule and change the upper FET to an NPN BJT. I have used circuits of this kind and they are very stable because the grounded base of the BJT does act as an electrostatic shield in the same way as the grid of the triode did in the original tube circuit that the semiconductor version was borrowed from. If a low noise BJT is used the circuit should be just as quiet as it was with the FET. It should actually be quieter because it isn't oscillating.

A modified version of this circuit was used in the FM tuner section of the Heathkit AR-15. Instead of a series coil from the drain of the bottom fet to the source of the top fet the signal was coupled by a combination of magnetic and capacitive coupling. In addition a third winding on this transformer provided neutralization to the circuit. Clearly it took some engineering to make this circuit work well enough for use in a production product. The tuner front end came preassembled and factory aligned in the kit.

Servicing anything more complex than an IF amplifier in an AM receiver is usually beyond the capabilities of small shops and hobbyists and is best left to factory service centers. The reason is that the arrangement of leads and components effects the alignment and neutralization. Replacing a transistor in a VHF amplifier will certainly require the neutralization of the circuit to be readjusted. To do so usually requires a network analyzer which is a very expensive and complex piece of test equipment.

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6.6 Switching Circuits.

Although switching functions have largely been taken over by integrated logic, there are occasions on which a very small amount of switching circuitry is required. On such occasions the designer may elect to use discrete transistor logic.

Consider the circuit of figure 6.24. In logic terms This is a noninverting buffer. A "high" input will cause base current to flow in Q1 which will turn it on. When Q1 is on, its collector voltage will be about 0.1 volt ("low") and there will be no bias for the base of Q2. Q2 will be off and its collector voltage will be "high". If the input is "low" there will be no bias for the base of Q1 which will turn it off. With Q1 off, its collector will be "high" and there will be bias for the base of Q2, turning it on. When Q2 is on, its collector will be "low".

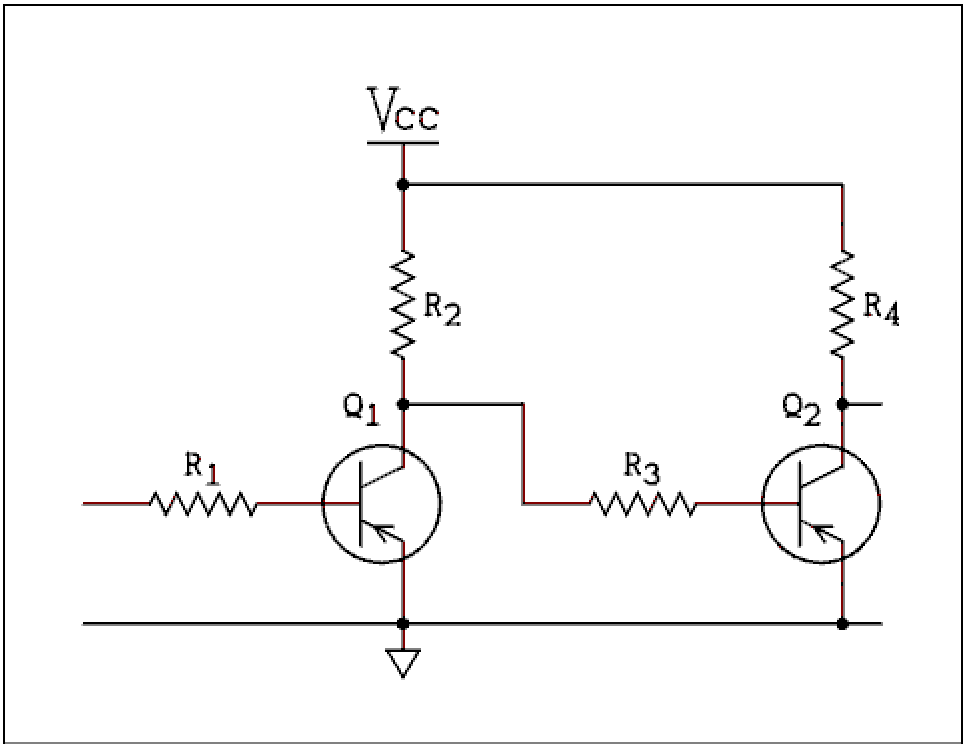

Figure 6.24 Discrete Noninverting Buffer.

For a verbal description click here.

If Q1 shorts, its collector will be "low" regardless of the state of the input. Q2 will be off and the output will be "high".

If Q2 shorts, its output will be "low" regardless of the state of Q1.

If R2 opens, the circuit would act the same as if Q1 had shorted. If R3 opens, changing logic levels would be observed at the collector of Q1 but Q2 would always be off and there would be a "high" at its collector.

Chapter 7 Transistorized Consumer Equipment.

Chapter 7.

Transistorized Consumer Equipment.

As you read in the foreword of this book it has been repurposed from a university textbook to a web publication whose target audience is more likely to be home experimenters and hobbyist. Therefore this chapter is about consumer grade electronics rather than exotic devices that may be found in a scientific research laboratory.

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7.1 Audio Amplifiers.

The term "audio amplifier" can cover a multitude of sins and in this section we shall cover the most important of them. There are thousands of variations on the basic audio amplifier so only a few representative samples can be given here.

Transformer Coupled Audio Amplifier.

The very first audio amplifiers employing transistors were designed as the audio section in transistor radios. Figure 7.1 is an example.

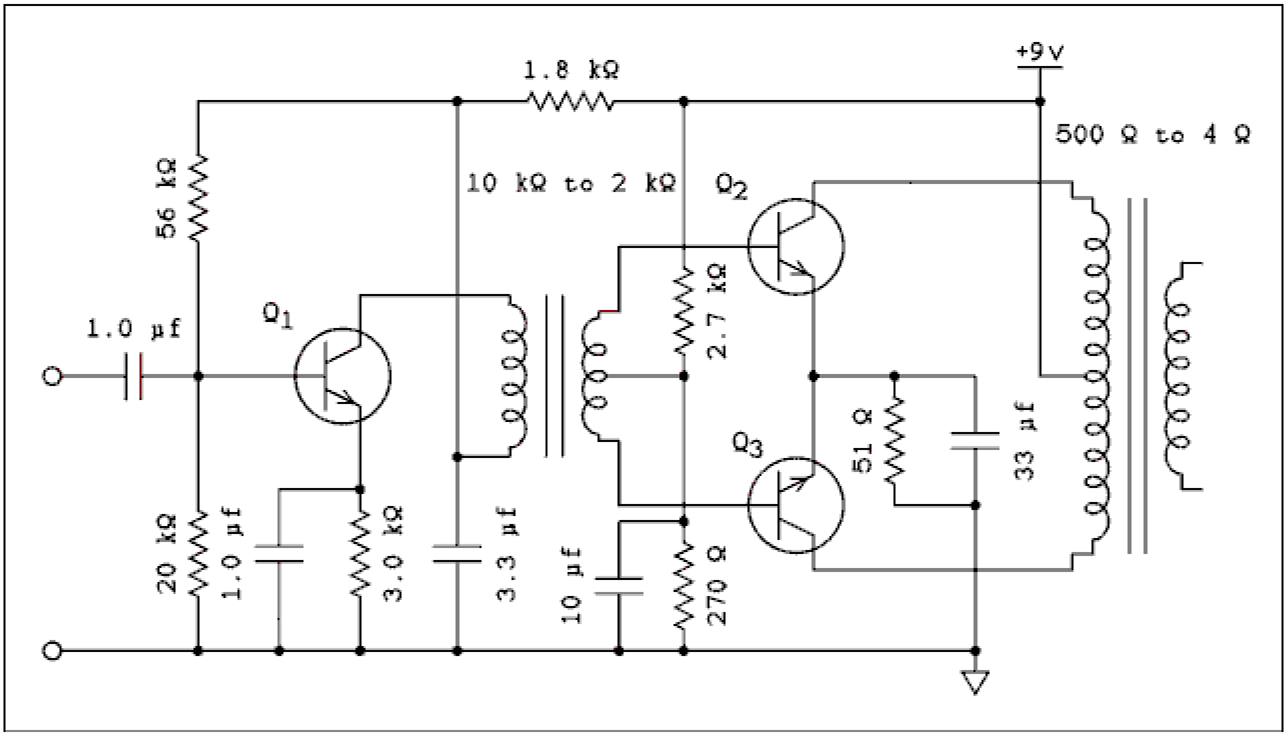

Figure 7.1 Transformer Coupled Audio Amplifier.

For a verbal description click here.

Although this circuit is very old dating back to the dawn of the transistor age it still exists in vintage radios and phonographs and is occasionally used in new equipment.

Transformer coupling was used because early transistors had low current gains. Transistors are current devices unlike tubes which are voltage devices. Note that both transformers are impedance step-down which translates to current step-up. Those transistors needed all the help they could get and the transformers provided it.

Note. The values given in the circuit are **NOT** from a vintage radio but have been designed to work with modern silicon transistors. If you were to construct this circuit using 2N3904s or any other small silicon NPN transistor it has a high probability of working and delivering approximately 250 mW, a little more on 12 volts.

Although the transistors are transformer coupled the failure analysis given in section 6.1 for the common emitter configuration mostly applies here. The main difference is that in the push-pull pair consisting of Q2 and Q3 the collector voltage will mostly be at Vcc for all failure modes except an open transformer winding. That case will be identical to that for an open collector resistor. For the single ended amplifier of Q1 the 1.8 k ohm resistor will be the collector load for DC and the failure modes will be almost the same. The upper base biasing resistor is effectively returned to the collector for DC but the effect of this will be small for a failure mode analysis.

In vintage equipment using germanium transistors there will be a thermistor in parallel with the resistor that is equivalent to the 270 ohm resistor. In most vintage circuits the capacitor across this resistor has been omitted. This omission likely slightly reduces power output and increases distortion. There was already so much distortion in these vintage circuits the designers probably felt that a little more wouldn't be noticed.

A variation of the transformer coupled amplifier was seen in line operated table radios from the mid 1970s onward. It came closest to being the transistor equivalent of the all American five tube radio.

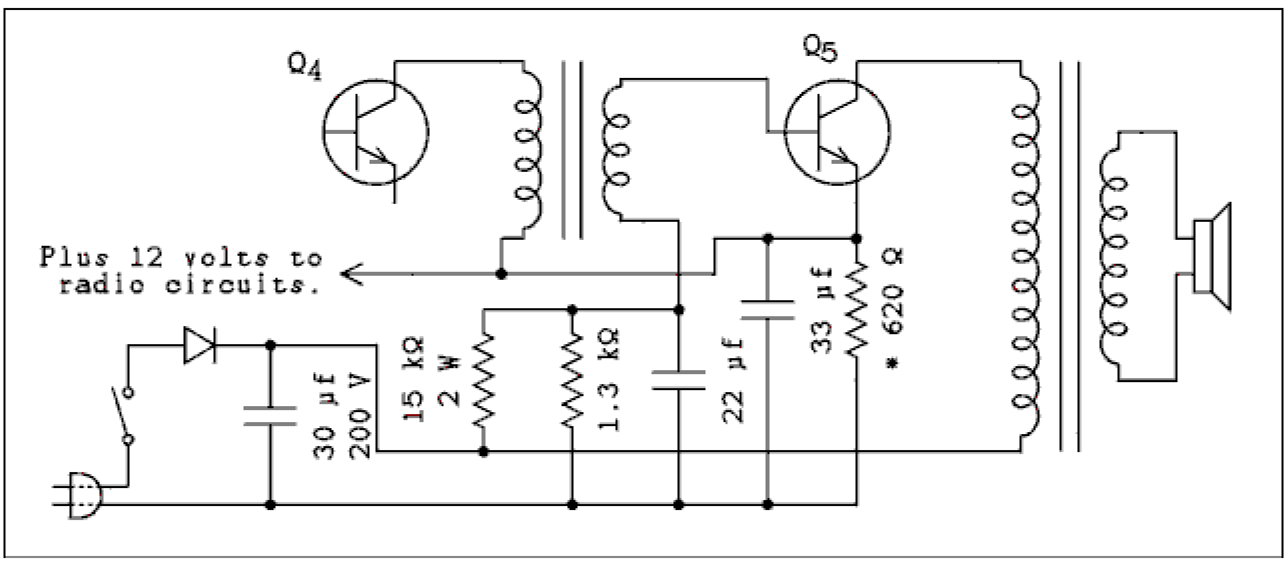

Figure 7.2 Line Operated Transformer Coupled Amplifier.

For a verbal description click here.

This circuit was made possible by the fact that high voltage power transistors had come down in price sufficiently to make the circuit practical. The output transformer would likely be a 5 k ohm to 4 ohm unit not unlike the ones used in tube radios.

The transistor would be mounted on a heat sink of some kind maybe the metal chassis of the radio.

The diode half wave rectifies the line voltage and the rectifier's output is filtered by the 30 uf capacitor. The ripple on the output is calculated by starting with the equation,

$i = C\, dV/dt$ (Eq 7.1)

First we mentally change the derivative to delta V / delta t and change the case of the current symbol, then solve the equation for dV.

$DV = Dt\, I/C$ (Eq 7.2)

Where DV is the change in voltage over a finite time, Dt is the time interval, I is the DC load current, and C is the capacitance of the capacitor in farads.

DV = 16 e-3 seconds x 20 mA/30 uf = 10.7 volts.

16 e-3 (16 milliseconds) is approximately the length of one cycle in north America.

The calculated peak of the 120 volt line voltage is 170 rounded to 3 digits. The calculated peak to peak ripple of 10.7 volts means that an average DC voltage of 165 volts is reasonable. This voltage value was used to design the transistor circuit. Because a transistor is a constant current device, similar to a pentode tube, voltage changes of 10 volts peak to peak will not produce any significant changes in collector current. The output transformer responds to changes in current so the hum level will be almost undetectable.

The voltage divider consisting of the 15 k ohm 2 watt and the 1.3 k ohm resistors form a voltage divider which places the base of Q5 at approximately 12.6 volts. The emitter will then be at 12 volts. The * 620 ohm resistor is the closest standard value that will produce 20 mA of emitter current in Q5. The resistor must be recalculated to account for the current drawn by the converter and IF stages of the radio. Let's say that the current drawn is 5 mA. Then the resistor has to conduct 15 mA to common to set the emitter current to 20 mA. The resistor value is given by 12 v / 15 mA = 800 ohms. The closest standard value is 820 ohms which means that the emitter and therefore the collector current of Q5 will be a shade low. In a real circuit the emitter voltage may be set a little higher and an additional RC filter stage inserted to ensure there will not be any positive feedback which could result in motorboating of the radio.

The above mention motorboating could be a fault of the circuit if the capacitor from the emitter of Q5 to ground were to develop a high effective series resistance (ESR).

If the emitter capacitor were to short Q5 would draw too much current, overheat, and short. This would apply the full line voltage peak to the converter and IF circuits thus cooking the entire radio and likely making it's repair uneconomical. Only a restorer of antiques would be interested in it after such a catastrophic failure.

Transformerless Amplifier.

Below is the circuit that was used for power amplifiers from the earliest days of transistors to some time in the early 70s.

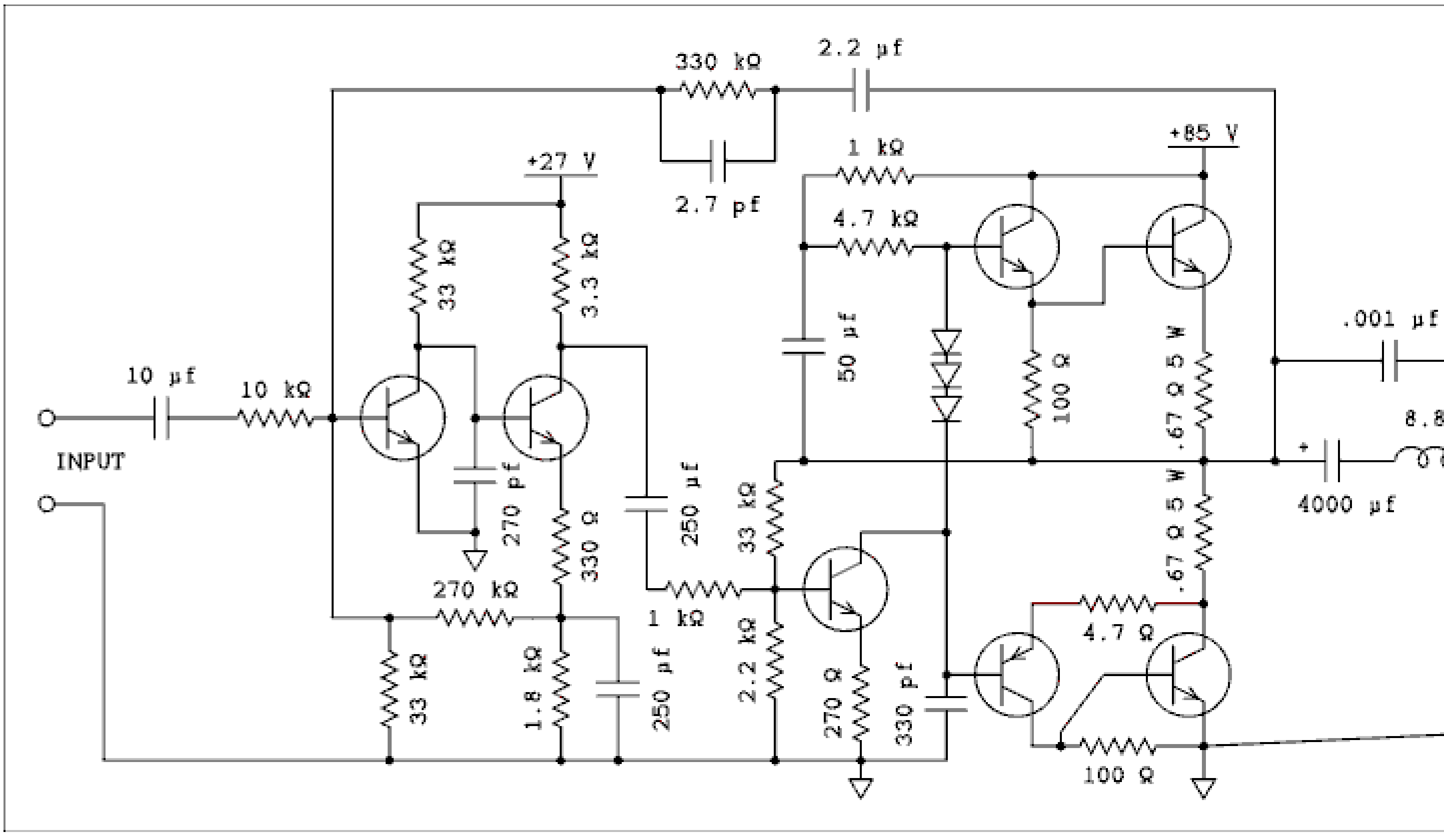

Figure 7.3 Transformerless Amplifier from the 1960s.

For a verbal description click here.

This circuit actually has 3 feedback loops. 1) An AC negative feedback loop around the entire amplifier from the positive side of the 4000 uf capacitor, which is often called the amplifier midpoint, through the 2.2 uf capacitor and the parallel combination of the 330 k ohm resistor and the 2.7 pf capacitor to the base of the first transistor. 2) A DC coupled negative feedback loop from the amplifier midpoint through a 33 k ohm resistor to the base of the transistor that would be Q3 if I had remembered to number them. 3) An AC coupled positive feedback loop from the amplifier midpoint through the 50 uf capacitor to the junction of the 1 k ohm and 4.7 k ohm resistors.

The first two transistors on the left are in a stabilized configuration identical to that of Figure 6.18. As pointed out in chapter 6 the failure of the second transistor's collector resistor can cause the phase of the amplifier to reverse while it does continue to amplify to some degree. This would change the negative feedback to positive and the amplifier will oscillate at some frequency, most likely high, possibly ultrasonic.

If ultrasonic the oscillation is likely to do serious damage to speakers before being detected. The output transistors would most likely blow.

The second feedback loop stabilizes the amplifier midpoint at 1/2 of the Vcc supply. If the 33 k ohm or the 270 k ohm resistor opens the midpoint will go up to very near Vcc. If the 2.2 k ohm resistor opens the midpoint will come down to be very close to zero. If the 250 uf capacitor between Q2 and Q3 shorts Q3 will be driven to high collector current and the amplifier midpoint will be reduced in voltage. I think the 1 k ohm resistor in series with the 250 uf capacitor is meant to reduce the effect of such a short to prevent damage to the rest of the amplifier.

Note there are three diodes in series with the collector of Q3. Note also that the base of the top darlington pair is connected above the diodes while the base of the lower complementary darlington pair is connected below the diodes. These diodes are to temperature compensate the idling current of the outputs. They are usually very near the heatsink or may even be thermally bonded to it. If one or more of these diodes shorts the effect might not be noticed for some time. It's main effect would be to reduce the idling current of the outputs likely to zero. The resultant distortion would be compensated for and covered up by the large amount of negative feedback. The user may perceive that the amplifier doesn't sound right but may not be able to put his finger on the problem.

If one of these diodes opens, all four transistors in the output stage as well as the two 0.67 ohm resistors are in for a cooking. If you replace the two resistors and four transistors without finding out what made them cook the replacements will cook just as the originals had.

If any one of the four transistors shorts it will most likely take the other three with it. This leaves the same symptom as an open diode but one of the four transistors shorting was the precipitating event. You are likely to find all four transistors open. That is because the initial short caused excessive current to flow which shorted another transistor and then the enormous amount of current melted the transistors open before the main fuse had time to blow. I have even seen the small leads on the driver transistors between the transistor header and the PC board burned in two. Repairing such an amplifier can be a game of Russian roulette. You replace all four transistors and the two resistors and check everything else you can think of, close your eyes and apply the power. The problem with this circuit and others like it is you can't fire it up with the expensive high power transistors removed. You have to put it all back together and hope.

The third feedback loop is more commonly known as bootstrapping. The 50 uf capacitor couples AC signal from the midpoint to the junction of the two resistors. The effect is to tremendously increase the effective value of the 4.7 k ohm resistor. As the mid point is driven up and down by AC signal the left end of the 4.7 k is also driven up and down. The voltage drop across the resistor is very nearly constant. Constant voltage means constant current. Instead of behaving like a resistor it behaves like a constant current source for the collector of Q3. This has the effect of increasing the gain of Q3 and reducing distortion in the three diodes. A short in the 50 uf capacitor would place the top transistors in cutoff which would allow the midpoint to be pulled down near zero. If the capacitor were to open the bootstrapping effect would be lost. This would increase the amount of distortion but the global feedback would tend to cover it up. Depending on how demanding a listener the owner is the amplifier might be brought in for service only to have the repair man say "It sounds alright to me." On the other hand the owner may not notice that anything is wrong and the problem could go undetected for years.

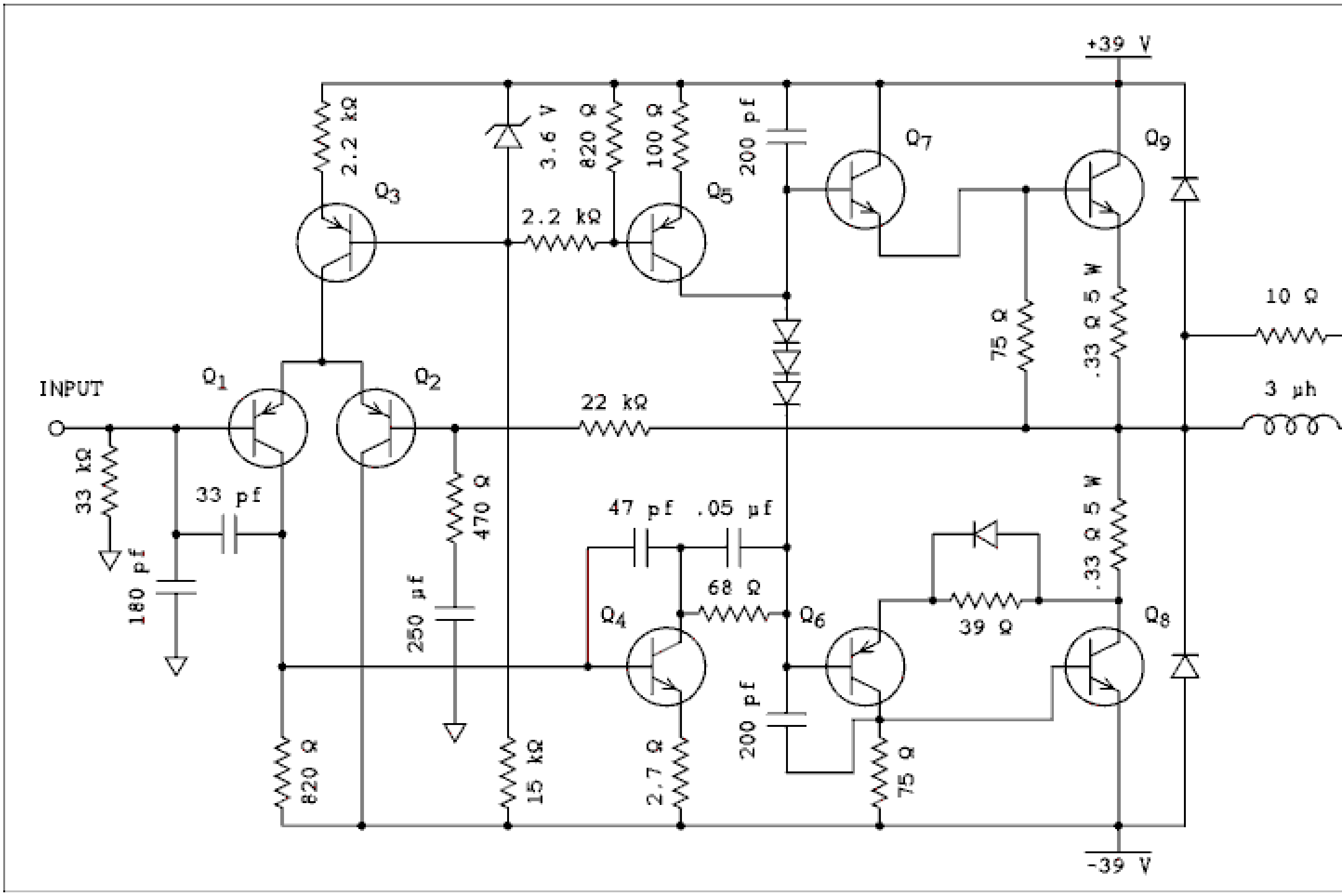

Figure 7.4 Improved Transformerless Amplifier from the 1970s.

For a verbal description click here.

Here is a circuit from the third decade of transistorized consumer equipment. Its main improvement is DC coupling throughout including the global feedback loop. Also a transistor (active) current source has replaced the bootstrapped resistor. The global negative feedback is applied to one base of a differential pair with input applied to the other. There is a current source in the emitters of the differential pair. It operates from symmetrical power supplies so the midpoint is held at zero. Almost any circuit fault will cause a large DC offset which can destroy a speaker system in pretty short order if there is no protective fuse.

The chief difficulty with this kind of circuit is that any fault anywhere will propagate around the feedback loop and every voltage will be out of whack. There are often clues. Say the midpoint is locked to the positive rail. You should find that the base of Q2 is more positive than the base of Q1. Because these are PNP transistors Q2 will be in cutoff and Q1 will be taking all of the current of the current source Q3. This will pull the collector of Q1 higher than normal and pull the base of Q4 higher, increasing its collector current. This will be trying to pull the three diodes down but it can't because the amplifier is at positive rail. The feedback is telling the amplifier to go negative but something is keeping it from it. It could be a short in any one of the three transistors Q5, Q7, Q9, or the 200 pf capacitor. Q4 could also be open causing this symptom.

This circuit suffers from many of the same problems as Figure 7.3 with the additional ones introduced by DC coupled feedback.

Both of these circuits have current limiting circuitry to protect the amplifier against a short in the speaker wiring. These circuits work in the same way as current limiting in a bench power supply. The voltage drop across the low ohm resistors in the output is sensed and if it exceeds a certain value the current supply to the bases of the power transistors is shut down.

Figure 7.5 is the circuit of Figure 7.3 with the protection circuitry added.

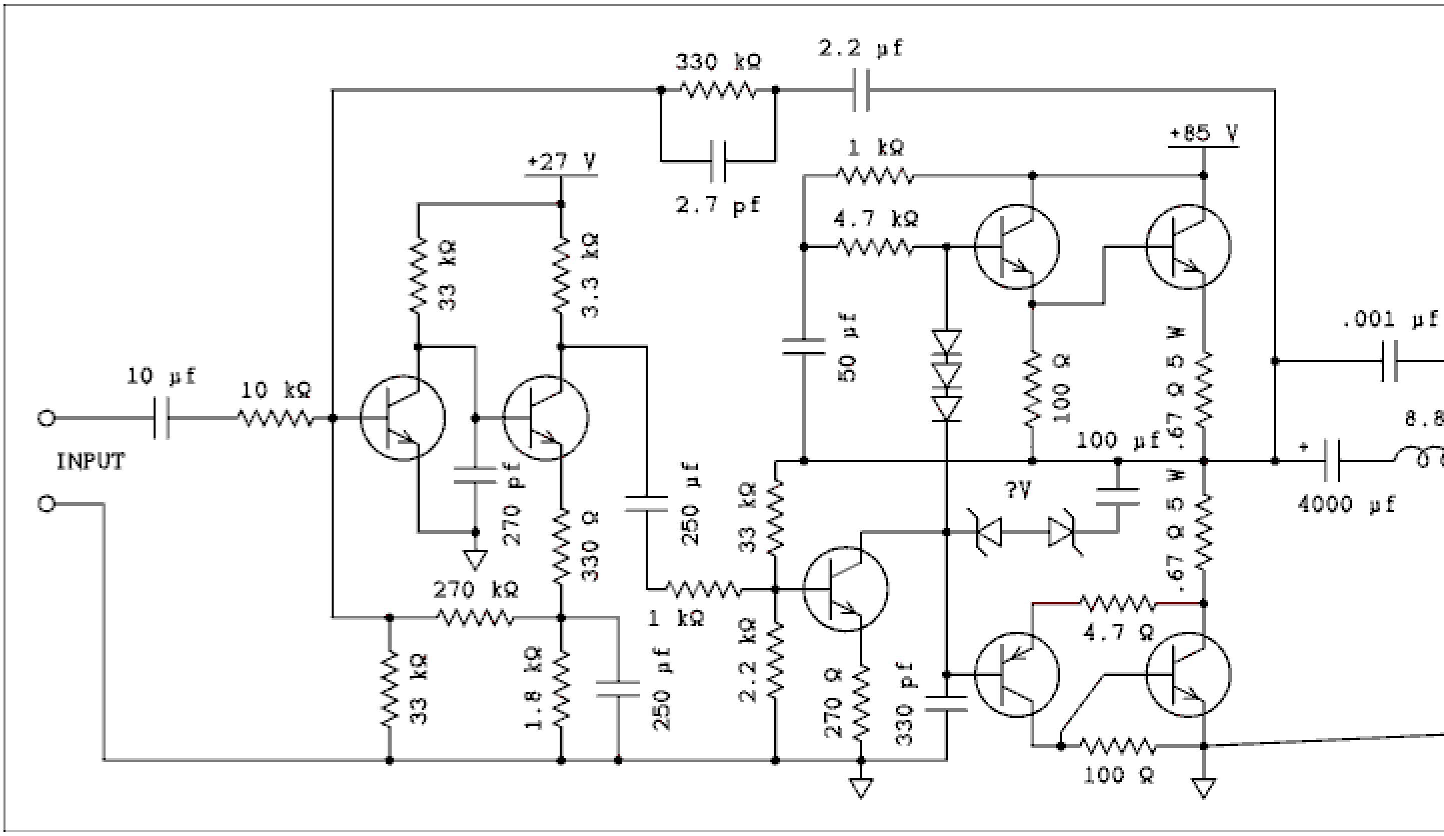

Figure 7.5 Figure 7.3 with protection circuitry added.

For a verbal description click here.

The added parts that make up the protection circuit may be hard to find. It consists of the series combination of two zener diodes connected anode to anode and a 100 uf capacitor. The literature I have for the amplifier does not reveal the voltage of the zener diodes. If a short is placed across the output the high current will cause a large AC voltage to be developed across each of the two 0.67 ohm resistors. This voltage also appears across the series combination of the two zener diodes and the capacitor.

Suppose there is a short and the input signal is telling the output to swing positively. The emitter of the top output will swing positive creating a larger than normal voltage drop across the top 0.67 ohm resistor. The positive going swing on the emitter of the top output transistor was caused by a positive going swing on the collector of Q3. Remember that there is a short on the amplifier output and the 4000 uf capacitor prevents any significant swing on the amplifier mid point. When the voltage across the 0.67 ohm resistor is large enough the left hand diode will go into zener breakdown and the right one into forward breakdown. This will prevent the voltage at the collector of Q3 from going any higher thus limiting the current to a safe value. When the output tries to swing negatively the lower 0.67 ohm resistor conducts a high current and the voltage at the collector of Q3 is negative going. The right hand diode goes into zener breakdown while the left hand one goes into forward breakdown. This prevents the collector of Q3 from going any more negative thus limiting the current.

Because the circuit of Figure 7.4 is dc coupled the current limiting circuitry must be DC coupled and somewhat more elaborate.

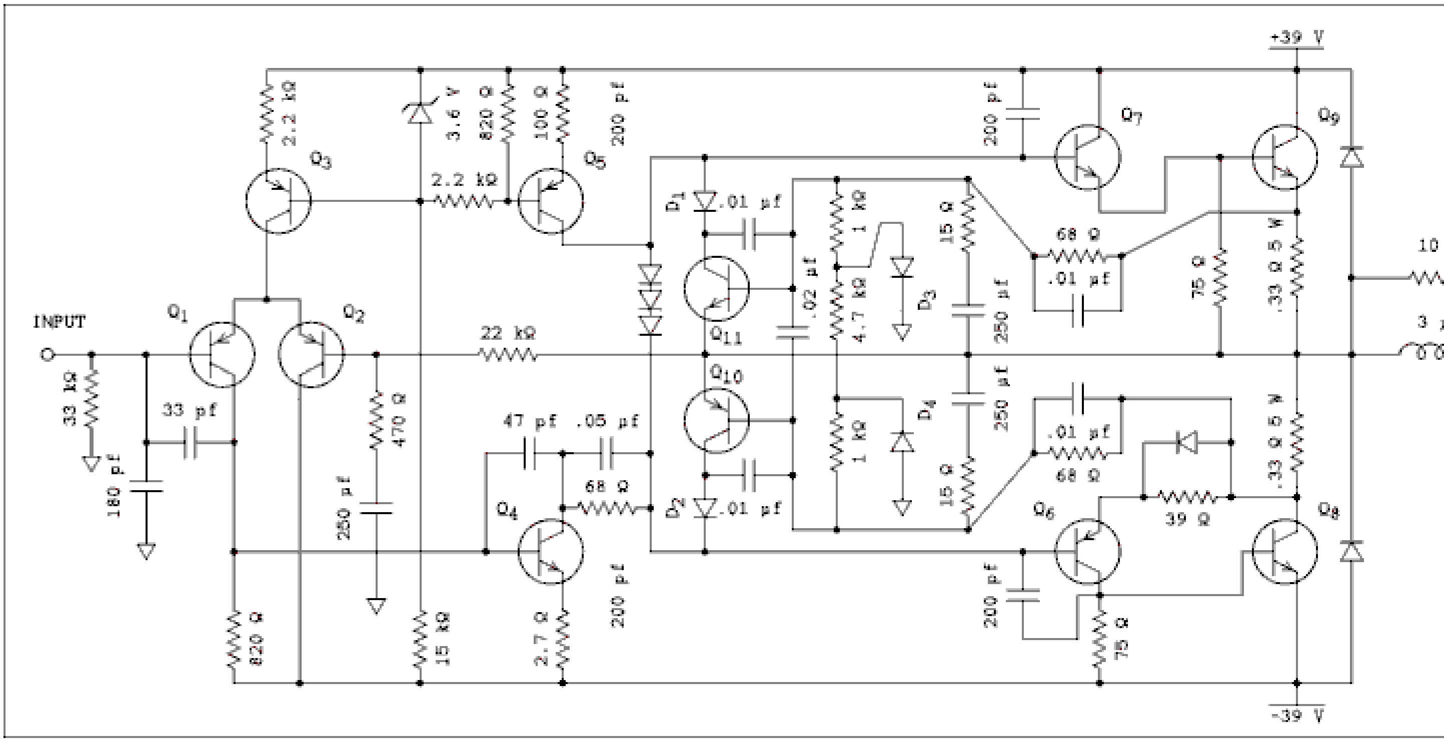

Figure 7.6 Figure 7.4 with protection circuitry added.

For a verbal description click here.

The limiting transistors are Q10 and Q11. Their emitters are connected to the amplifier midpoint. Diodes D1 and D2 disconnect the current limiting circuitry when no limiting is taking place. The connections from the top and bottom ends of the sense resistors may appear to be rather complicated but if you mentally strip it all away, basically the top of the top 0.33 ohm resistor connects to the base of Q11 and the bottom of the bottom 0.33 ohm resistor connects to the base of Q10. The network of resistors, capacitors, and diodes appears to serve the main purpose of preventing oscillation when current limiting is in effect.

On the positive half cycle if the load is drawing too much current Q11 is turned on and it's collector current takes current away from the base of Q7 reducing the output to a safe level. On the negative half cycle Q10 takes current away from Q6 limiting the current.

Stop the presses, it isn't quite that simple. Those two diodes D3 and D4 appear to add a lot of complexity but the limiter wouldn't work right without them. When there is no current limiting taking place everything is going up and down positive and negative with respect to ground. The drop across the 0.33 ohm resistors is small so the two 68 ohm resistors, the two .01 uf capacitors, the two 15 ohm resistors, the two 250 uf capacitors, (they are connected to the midpoint), the top end of the top 1 k ohm resistor, the bottom end of the bottom 1 k ohm resistor, Q10, Q11, and the three capacitors that are around Q10 and Q11, are all swinging up and down with the output signal.

But on the positive swing D3 is forward biased and holds the junction of the upper 1 k and the 4.7 k to near ground. This reverse biases the base emitter junction of Q11 which was already turned off but forward biases the base emitter junction of Q10 which turns it on. This might turn off Q6 and Q8 but they are already turned off. On the negative half cycle of normal output Q11 is turned on. This has no effect until current limiting kicks in.

If there is a short or too many speakers connected to the amplifier. Q11 will be turned on as explained above. If Q10 were not already on the voltage at the collector of Q5 would be pulled down which would turn on Q6 and Q8. Q4 and Q5 are both current sources so their voltage can be easily pulled around. This would bring about the destruction of Q6, Q7, Q8, and Q9, instead of protecting them. Q10 and Q11 being turned on at the same time prevents this from happening. The similar event occurs on the negative swing.

Current limiting circuitry is not likely to fail because it rarely if ever turns on. If prolonged current limiting should overheat either or both Q10 or Q11 causing it(them) to short the amplifier might appear to work at very low volume settings but distort at even moderate listening levels. Such a fault might be hard to find if you fail to check the current limiting components.

Integrated Circuit Amplifiers.

I recently had on my bench a home theater amplifier made by Sony. It had discrete complementary output transistors but the rest of the circuitry was inside a medium power integrated circuit. Fault detection circuits found a DC offset and would not connect the speakers while indicating an error on the front panel display. The offset was not large being about 1/4 of the Vcc and Vee supplies. The power transistors had normal values of Vbe indicating neither an open or short. My only alternative was to replace the IC. That turned out to fix it. Because of minimum order requirements I had to buy 3 of the ICs. Such is the plight of someone who does not operate a professional service shop.

Then there are those amplifiers that are one great big IC for each channel. Before ordering these expensive parts perform the "what is it being told to do" test. These are really nothing but high power op amps and they will be treated as such in this explanation. If the output is locked to the positive rail and the inverting input is more positive than the noninverting input the output is being told to go negative. If the output is locked to the negative rail and the inverting input is negative with respect to the noninverting input the output is being told to go positive. In either of these cases the op amp is not doing what it is being told to do so it must be defective.

On the other hand if the output is locked to the positive rail and the inverting input is negative with respect to the noninverting input the amplifier is being told to go positive. If the output is locked to the negative rail and the inverting input is more positive than the noninverting input the amplifier is being told to go negative. In either of these cases the amplifier is doing exactly what it is being told to do. The fault lies with the surrounding circuitry that is doing the telling. There are so many variations on these circuits that it is impossible to give any examples.

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7.2 Radios and tuners.

The All Japanese Six.

The 6 transistor radio which I shall call the All Japanese 6 (AJ6) uses 3 of its transistors in the audio section, another as the converter and the remaining two in the IF amplifier.

Note. The first transistors were mass produced by Texas Instruments and their engineers designed the first practical transistor radio. It was made under contract by a company in Illinois for a time. However as has happened so many times over the years since 1952 the Japanese were able to make it at less cost which drove American manufacturers out of the transistor radio business. Even though it isn't "all" Japanese I choose to call it the AJ6 in the same way as the 5 tube radio that really was all American was called the All American 5 (AA5). I do this with apologies to the states of Texas and Illinois.

One of my professors told the following joke. "Whenever an American company comes out with a new product, within one week the Russians have invented it first, and within two weeks the Japanese are making it cheaper." I have no knowledge of the USSR claiming to have invented the transistor radio first but there is no doubt that the Japanese did make it cheaper. Now it's the Chinese but that's another story for another time.

The diagrams below were obtained from this website. The diagrams have been redrawn to avoid any copyright problems.

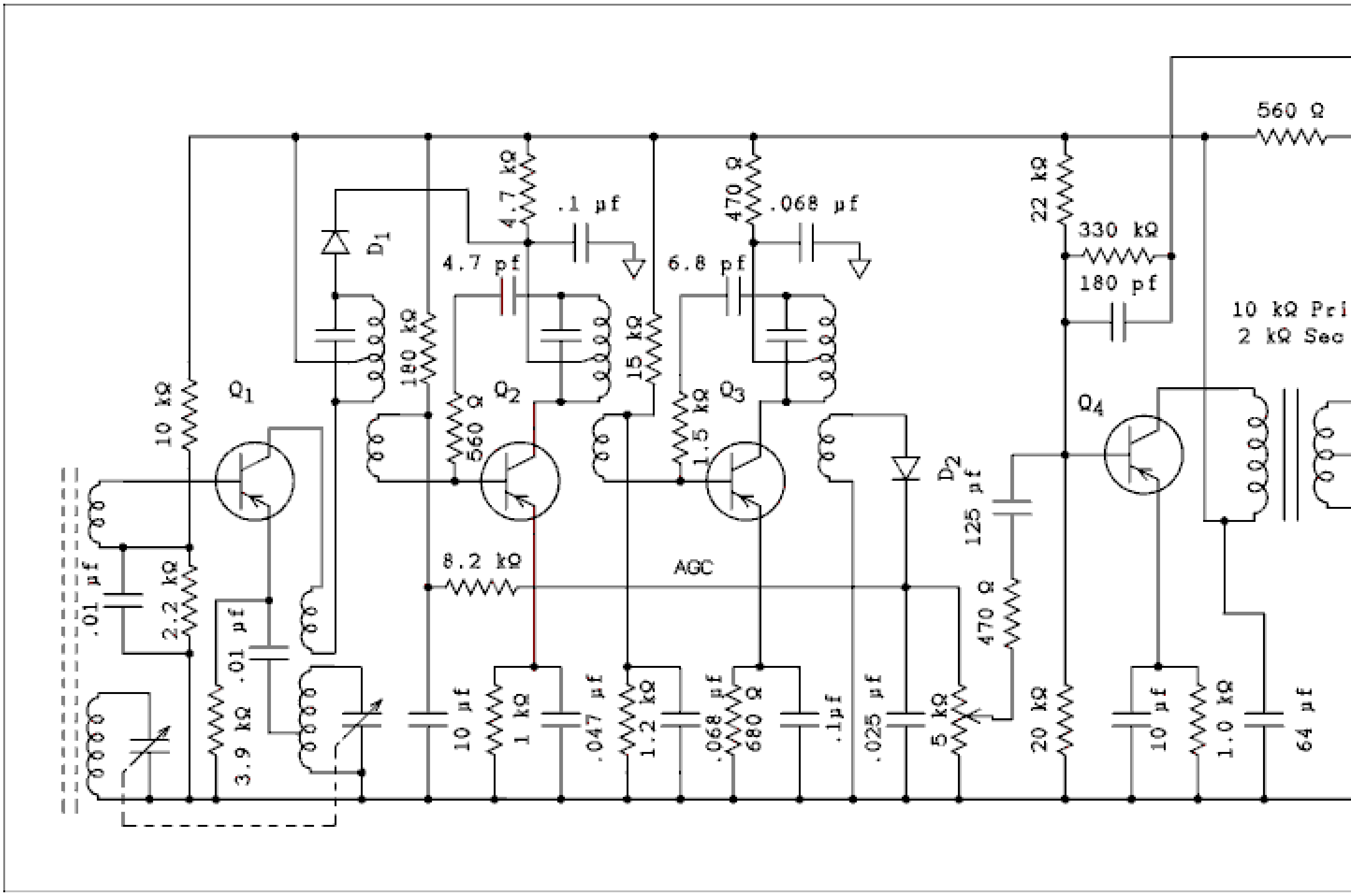

Figure 7.7 Voxson Model 762.

For a verbal description click here.

These diagrams give no clue as to the year of introduction. They all use germanium PNP transistors so the late 1950s or early 60s seems to be a good guess.

The Converter.

The station signal is picked up by the ferrite rod antenna and signal is coupled into the converter, Q1, by a coil that consists of a few turns wound between the turns of, or over, the grounded end of the main tuned winding. The transistor uses series fed constant voltage biasing. The 10 k ohm and 2.2 k ohm resistors provide the bias voltage to the transistor. The emitter resistor sets the collector current. The .01 uf capacitor keeps the low end of the base winding at RF ground.

In the collector of Q1 the tickler coil for the oscillator and the primary of the IF transformer are connected in series. Signal from the tickler coil is magnetically coupled to the resonant coil and a tap on this coil couples signal of the proper phase through the .01 uf capacitor to the emitter of Q1. The resonant coils of the ferrite antenna and the oscillator coil are tuned by the two sections of the tuning capacitor.

The IF (Intermediate Frequency) Amplifier.

The difference signal between the oscillator and station signal, 455 kHz, is coupled to the primary of the input IF transformer. Vcc is fed to the mid-tap on the IF transformer primary and the collector is connected to the end of the winding nearest the tap. This prevents the low impedance at the collector of Q1 from lowering the Q of the tuned circuit.

The function of D1 is unclear. Its anode is connected to the high impedance end of the primary of the input IF transformer while it's cathode is connected to the mid-tap on the interstage IF transformer. The Q point program tells us that the no signal collector current of Q2 is 212 microamps which gives a drop across the 4.7 k ohm resistor of approximately 1 volt. If a very strong nearby station were to be tuned in the peak RF voltage at the anode of D1 could exceed 1.1 volts but it is hard to say exactly what would happen. A strong signal would reduce the forward bias on Q2 bringing the voltage on the cathode of D1 closer to its DC anode voltage. The DC voltage at the mid-tap of the interstage transformer might be reduced which would reduce the gain of Q2 but the top end of the input transformer is a high impedance point which has many more turns between it and the mid-tap than there are between the collector end and the mid-tap. The cathode of the diode would have to drive the 4.7 k ohm resistor. It seems more likely that the signal on the primary of the input transformer would just be clipped distorting the modulated signal from the station.

The base winding of the input IF transformer couples signal to the base of Q2. Q2 is biased from the -9 volt line through a 180 k ohm resistor and AGC (automatic gain control) is applied through an 8.2 k ohm resistor. The AGC voltage is derived from the cathode of the detector D2 so it is positive going. This will reduce the collector current of Q2 reducing it's gain. This is the only point in the radio where closed loop AGC is applied. (Note. As speculated above the signal rectified by D1 may be forward gain control but it's function seems doubtful.) The primary function of the 4.7 k ohm resistor and 0.1 uf capacitor is to decouple the collector of Q2 from the minus nine volt line. The collector of Q3 is decoupled by the 470 ohm resistor and 0.068 uf capacitor.

The interstage IF transformer couples signal from the collector of Q2 to the base of Q3. The output IF transformer couples signal from the collector of Q3 to the detector, D2. The base of Q3 is biased by the voltage divider consisting of the 15 k ohm and 1.2 k ohm resistors. The 680 ohm resistor in the emitter sets the collector current. The 0.068 uf capacitor bypasses the cold end of the base winding on the interstage IF transformer and the 0.1 uf capacitor bypasses the emitter of Q3.

Both Q2 and Q3 are neutralized by the series combination of a resistor and small capacitor connected between the top of the IF transformer primary and the base. The use of a resistor is quite rare. Usually only a capacitor is seen. Early transistors had a substantial reverse voltage transfer ratio, h_{re}. This consisted of the capacitance between collector and base but also an electric field effect which altered the forward voltage drop across the base emitter junction as the collector voltage changed. The resistors apparently were used to neutralize the real part of h_{re} while the capacitors neutralized the imaginary part. This was evidently an example of thorough engineering which other companies found to be unnecessary. That would seem to point toward this being an early design. More about this when discussing figure 7.8.

Detector and AGC.

D2 half-wave rectifies the voltage on the secondary of the output IF transformer. The 0.025 uf capacitor smoothes out the 455 kHz ripple component while leaving the audio uneffected. The DC component which is proportional to the strength of the received station's signal is fed through an 8.2 k ohm resistor to the cold end of the base winding on the input IF transformer. A 10 uf capacitor filters out all audio from the AGC signal so just the strength of the station's signal will effect the gain of Q2. As the signal from the station gets stronger the DC voltage applied to the right end of the 8.2 k ohm resistor grows more positive. An increasing positive voltage reduces the bias on Q2 which reduces its collector current thus lowering its gain. Both the DC and audio are applied to the top of the 5 k ohm volume control. The signal from the wiper also contains a reduced version of the DC and audio. The 125 uf capacitor blocks the DC from the base of Q4.

The Audio Amplifier.

The base of Q4 is biased by the voltage divider consisting of the 22 k ohm and 20 k ohm resistors. The collector current of Q4 is set by the 1.2 k ohm resistor and this resistor is bypassed by the 10 uf capacitor. Signal from the collector of Q4 is coupled by the interstage audio transformer to the bases of Q5 and Q6. The low end of the primary of the interstage transformer is bypassed to ground by a 64 uf capacitor. This capacitor in conjunction with the 560 ohm resistor serves to decouple Q1 through Q4 from the effects of the audio power output transistors Q5 and Q6.

Q5 and Q6 have base bias applied through the secondary of the interstage transformer from the resistive voltage divider consisting of the 3.3 k ohm and 68 ohm resistors. Q5 and Q6 each have their own 10 ohm emitter resistors. This will provide some automatic collector current balancing effect not available if a single emitter resistor had been used for both transistors. Leaving these two resistors unbypassed also provides some negative feedback to the output stage. Signal from the collectors of Q5 and q6 is coupled by the output transformer to the speaker. The 220 ohm resistor and 0.047 uf capacitor roll off the high frequencies and stabilize the global negative feedback loop. This feedback is taken from the secondary of the output transformer back to the base of Q4 through the parallel combination of a 330 k ohm resistor and a 180 pf capacitor.

Comments.

The thoroughness of the neutralizing of the IF stages and the use of negative feedback in the audio section indicates that considerable thought was put into the design of this radio. It's hard to believe all that was used to drive a 2 inch speaker. Perhaps the design was lifted from an AC operated table radio with a larger speaker.

Another Example.

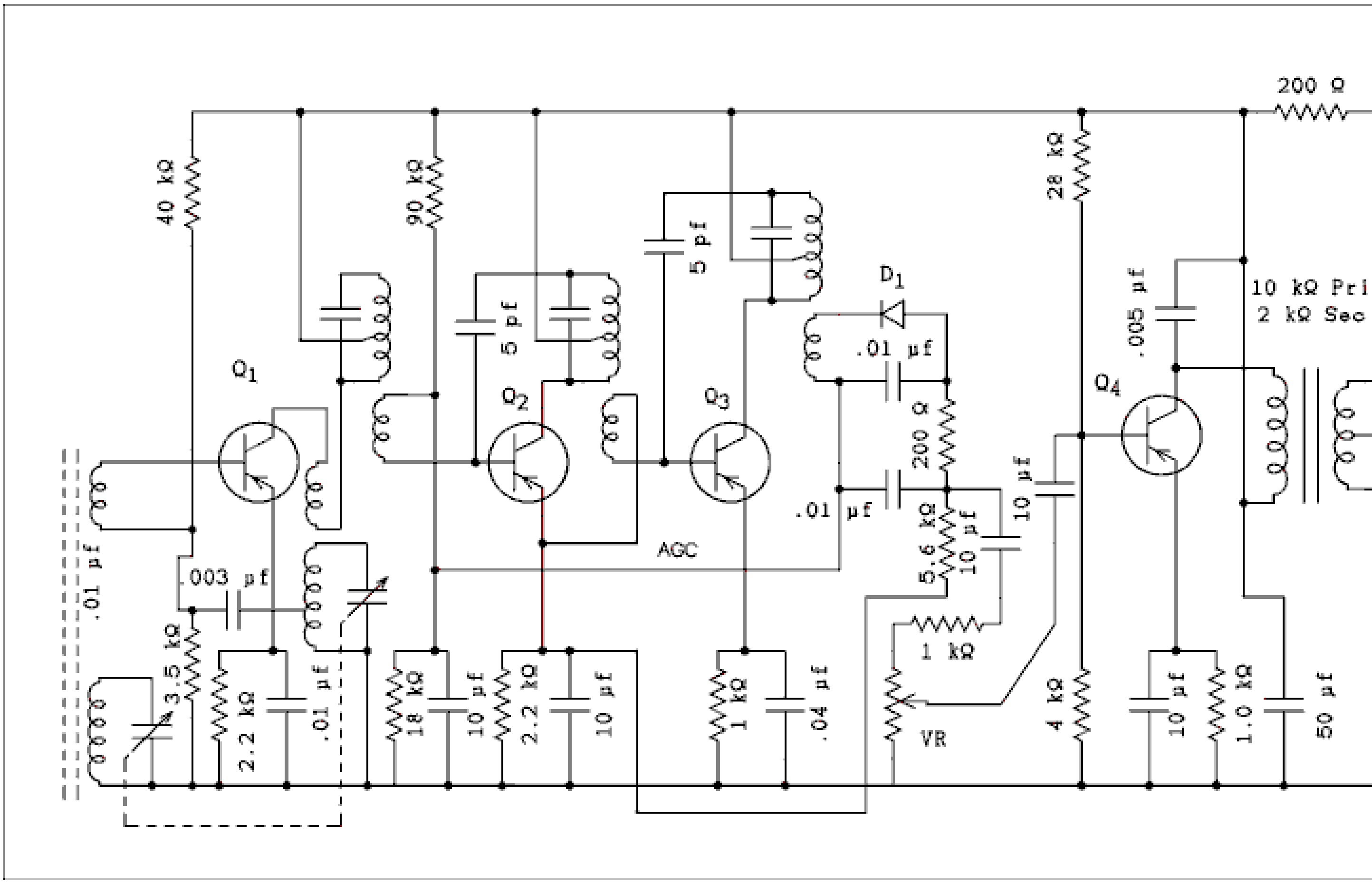

Figure 7.8 Sanyo Super-Six.

For a verbal description click here.

The converter.

This circuit is similar to the Voxson radio above but there are also notable differences. Feedback from the tuned winding of the oscillator coil is fed through a 0.003 uf capacitor to the cold end of the base winding on the ferrite rod antenna. This strikes me as a questionable design change because it is certain to result in a stronger signal from the local oscillator being radiated from the radio as compared to designs where the feedback is coupled to the emitter of the converter transistor. 4 of the 17 6 transistor radio circuits I found have oscillator feedback taken to the base of the converter transistor. The rest take the feedback to the emitter.

IF Amplifier.

Q2 and Q3 are neutralized by capacitors only which is far more typical of transistor radio designs. Also there is no decoupling for Q2 and Q3.

AGC.

The major difference is in the AGC system. The top of the output IF transformer secondary connects to the cathode of a diode D1 and the bottom connects to one end of a 0.01 uf capacitor. Instead of being connected to ground the bottom end of the winding is connected to the same voltage divider which biases the base of Q2. This divider consists of a 90 k ohm and an 18 k ohm resistor. This sets the base bias for Q2 as well as the reference for the detector at approximately -1.5 volts. This bias point is bypassed for both audio and Rf by a 10 uf capacitor.

The signal from the anode of the detector, D1, is partially filtered by the 0.01 uf capacitor which has its other end connected to the bottom of the IF secondary coil. Additional filtering is provided by the 200 ohm resistor and another 0.01 uf capacitor. At this point there is DC for AGC plus detected audio. The DC is filtered by a 5.6 k ohm resistor and the 10 uf capacitor in the emitter of Q2.

The AGC detector like any electrical source has two outputs. The positive side is the bottom end of the IF transformer secondary which is labeled AGC. The negative output is the bottom end of the 5.6 k ohm resistor. This source of DC is floating, not tied to ground anywhere, and is connected between the emitter and base of Q2. As the signal from the station becomes stronger the positive voltage applied between emitter and base becomes larger which takes away from the normal negative bias for a PNP transistor. The collector current of Q2 is reduced which reduces its gain. But in addition the voltage at the emitter becomes less negative.

Note that the bias for the base of Q3 instead of being derived from a voltage divider as in the circuit above, comes from the emitter of Q2. As the emitter voltage of Q2 becomes less negative so does the base voltage of Q3. This reduces its collector current which reduces its gain. AGC action in this radio would be much improved as compared to the one above because AGC is applied to both IF stages Q2 and Q3 instead of just to Q2.

Audio is coupled from the junction of the 200 ohm and 5.6 k ohm resistors through a 10 uf capacitor and a 1 k ohm resistor to the top of the volume control. This is labeled VR on the schematic and does not have an entry in the parts list. The wiper of the control feeds through another 10 uf capacitor to the base of Q4. Note that the designer of this radio took measures to keep DC levels off of the volume control. This reduces crackling when the control is rotated.

The Audio Amplifier.

The audio section has a few differences from the circuit above but is mostly similar. There is a 0.005 uf capacitor across the primary of the driver transformer. If the transformer is actually a 10k primary to 2k secondary the roll-off frequency is 3180 Hz which seems low even for a pocket radio. The 9 volt battery line is decoupled from the supply for Q1 through Q4 by a 200 ohm resistor and a 50 uf capacitor. The emitters of Q5 and Q6 are tied together and connected to ground through a single 10 ohm resistor. There is no negative feedback around the audio amplifier in this radio.

There is not a thermistor in either circuit selected as representative of 6 transistor radios. This may indicate that these are both early designs. Owners of radios of this type found they would stop playing if left on a beach blanket in the hot sun for several hours. The radios were found to be working upon arrival home. The problem was instability of the operating point of some of the transistors. The two most vulnerable stages were the converter, Q1, and the push-pull outputs, Q5 and Q6.

At elevated temperatures the transistor's current gain would increase causing it to go into saturation and stop oscillating. The cure for this was to make the parallel combination of the two biasing resistors in the base very approximately equal to the emitter resistor. This appears to have been done in both designs shown above. The result of an overheated push-pull pair was distorted sound and a quickly run down battery. As the transistors heated up their current gain would increase causing them to draw more current which heated them up more causing more current etc. etc. In line powered radios this runaway condition usually resulted in cooked transistors. In a battery powered radio a run down battery was usually the only result. Several repeats of this incident resulted in unhappy customers and eventually the engineers added the thermistor to compensate for wide temperature changes.

What can go wrong?

After the manufacturers made their radios able to work at the beach there really wasn't much left to go wrong. Low voltages and currents didn't put much stress on resistors, capacitors, and transistors. When a radio turned up at a service shop it was usually because of being dropped into the family swimming pool or overboard from the family boat. In such cases it was not economical to repair because the cost would exceed the price of anew radio. In deed by the late 60s a six transistor radio could be had for 5 or 6 dollars.

At this writing the very first transistor radios made in USA are 60 years old. If they haven't already these will soon become quite valuable as rare antiques and because there were so few made.

Meanwhile the transistor radios of today use the same ferrite antenna, tuning capacitor, and IF transformers, but the transistors have been incorporated into a 16 pin DIP. If a true 6 transistor radio lands on your bench it is most likely that the owner, sometimes you, wants it restored to operation for sentimental reasons. What voltage, current, and power, couldn't do to these radios, time has. The electrolytic capacitors will most certainly need to be replaced. In early transistors the mechanical connection between the leads and the germanium crystal wasn't very good and often failed. In most cases the radio will still play but the sound contains a most annoying crackling that is usually not effected by mechanical shock. Germanium transistors are available from specialty suppliers. A Google search should turn them up. I once went so far as to reengineer a transistor radio for silicon NPN transistors. It's not a job I would recommend to anyone.

The volume control in these radios is usually not the enclosed potentiometer we are accustomed to seeing in other equipment. The carbon element is glued to the circuit board and the wiping contact runs around it as the knob is turned. At the counter clockwise end of its rotation part of the wiper moves a contact opening the connection to the 9 volt battery. This leaves the carbon ring vulnerable to being damaged or at least getting dirty. Either one will result in a crackling sound when the control is rotated. If this occurs some control cleaner applied to the carbon ring will fix the problem. If the control has been damaged it will have to be replaced. The best source is probably another radio. I have no experience to offer on how to remove these rings.

Another source of crackling is the tuning capacitor. These capacitors are inside a plastic box and as far as I know opening the box is an irreversible process. To save space these capacitors have very thin layers of plastic between the plates. It is not unusual for the plastic to have worn through in a few places allowing the plates to make electrical contact. Replacing the capacitor is the only fix for this. Fortunately in most radios the tuning capacitor is easily removed and if you can obtain a matching capacitor, easily replaced.

As mentioned above the modern pocket radio contains a DIP IC instead of transistors. However, the tuning capacitor appears to have changed little if at all over the last 50 years. If all else fails, one of these IC radios could be a source of parts to repair an AJ-6.

Car Radios.

AM transistorized car radios are only slightly different from home AM radios. Three major differences are; They are with few exceptions tuned by variable inductors rather than variable capacitors, the intermediate frequency is 262.5 kHz, and the audio output is capable of delivering a watt or more. Much more in some cases. The FM stereo section is pretty standard.

The hardest part of repairing car radios is getting them out of the car and then back in after repair is complete. Modern low voltage high current power supplies are sufficient to power one while it is on the test bench. In some cases the speaker or speakers are mounted in another part of the car, such as in the door panels but any small set of speakers can be substituted for troubleshooting purposes.

One complaint may be that there is excessive ignition noise and alternator hum in the radio. This problem is very difficult to troubleshoot because it can't be tested outside of the car. In older radios power is fed into the radio through feed-through capacitors which in car radio parlance are known as spark plates. These are usually found in tube radios in an era when low impedance feed-through capacitors had not yet been developed. A spark plate is a square of metal which is connected to the hot power lead and insulated from the radio chassis with a sheet of mica. There is little to go wrong with such a device except corrosion at the point where the power lead connects to the plate. In modern transistorized radios feed-through capacitors will be found instead of the older technology.

AM/FM Stereo Car Radios.

This book is primarily aimed at those repairing or restoring vintage equipment so little time will be spent on this subject. Other than the differences noted above for AM radios there is virtually no difference between a car radio and a home AM/FM stereo receiver. With the exception of the 120 VAC power supply of course. High power car stereos require more supply voltage than the 12 volts of the car's electrical system. If only the available 12 volt supply were used the highest peak-to-peak voltage across the speaker would be approximately 22 volts using a bridge amplifier. Based on a 4 ohm speaker the power calculates out to about 15 watts. While this would be plenty for any sane person those car stereos that you can hear booming from 2 blocks away are running several hundred watts. To obtain that much power they have to use Vcc supplies of 50 or 100 volts. These comparatively high voltages are obtained from an inverter circuit which is basically a silicon version of the vibrators used in tube radios of old.

AM/FM Radios.

An AM/FM radio may be a portable, small table, clock radio, or car radio. Separate transistors are used for the AM and FM frontends. The low cost of transistors and high cost of switches is what makes this economically possible. Band switching is accomplished by switching on the Vcc to the frontend which is desired and switching off the Vcc to the other one. This can be done with a simple single pole double throw switch. Each mixer is coupled into the IF strip through the appropriate IF transformer. AM uses an intermediate frequency of 455 kHz while FM uses an intermediate frequency of 10.7 MHz.

In the IF strip the FM and AM IF transformers have their primaries and secondaries wired in series to the base or collector of each IF transistor. The highest frequency transformer, 10.7 MHz FM IF, is closest to the transistor. The AM IF usually needs only 2 stages and the signal is taken off for detection after passing through this many transistor stages. The FM signal usually needs a total of 4 stages so the IF strip continues with only 10.7 MHz transformers after the AM takeoff point. Some radios may only have a total of 3 IF stages. The last stage of the IF strip is overdriven to remove amplitude variations which contain no intelligence.

The FM signal is demodulated by a circuit known as a ratio detector. The circuit is shown below.

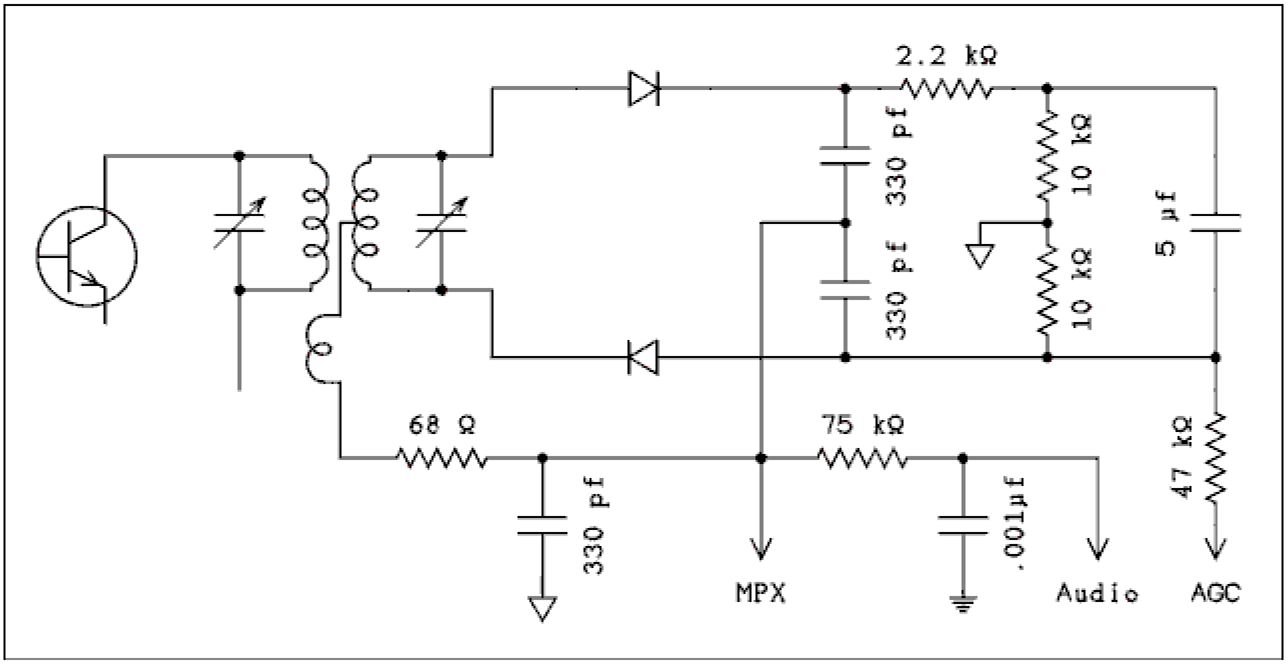

Figure 7.9 Ratio Detector.

For a verbal description click here.

There are three coils inside a discriminator transformer. (Note; even though the circuit is a ratio detector the transformer goes by the name of the other detector circuit which is a discriminator. The discriminator circuit is almost never used because of its poor AM rejection. But the transformer which is identical for both circuits still carries the name.) Now, where was I? Oh yes, 3 coils. The primary coil which is in the collector of the last IF transistor is tuned to the center of the FM IF, 10.7 MHz. The secondary which is center-tapped is also tuned to the center frequency. The third coil known as a tertiary winding is magnetically coupled to the primary but is untuned.

Imagine for a moment that the tertiary winding has no voltage across it. The voltages at the top and bottom of the secondary are 180 degrees out of phase with each other. There will be a positive voltage at the cathode of the top diode and a negative voltage at the anode of the bottom diode. The polarity of the DC voltages are determined by the direction of the diodes not by the phase of the RF signals. These voltages will be filtered by the 330 pf capacitors. These voltages will cause current to flow through the two 10 k ohm resistors. (Let's simplify the explanation by pretending that the 2.2 k ohm resistor doesn't exist. The imbalance it introduces can be compensated for by slightly off-tuning the secondary of the transformer.) As the junction of the two 10 k ohms is grounded the voltage at the center-tap will be zero. Without the tertiary winding it would stay like that regardless of the input frequency.

The current which is induced in the tertiary winding is in phase with the current which is induced in the secondary winding. That is because both currents are being induced from the primary winding.

The tertiary winding is untuned and it has a self resonant frequency which is much higher than 10.7 MHz. Thus it appears inductive and the voltage is leading the current induced in it by 90 degrees. The bottom of this winding is very nearly at ground potential so the voltage applied to the center-tap of the secondary leads the current by 90 degrees.

Because the secondary is tuned to resonance at 10.7 MHz the voltage from the center-tap to the top is in phase with the current and the voltage from the center-tap to the bottom is 180 degrees out of phase with the current. Let us say for the sake of argument that the RF voltages across the top half of the secondary, the bottom half of the secondary, and the tertiary winding are all equal in amplitude and equal 10 volts. This condition is shown in the phasor diagram in Figure 7.10(a).

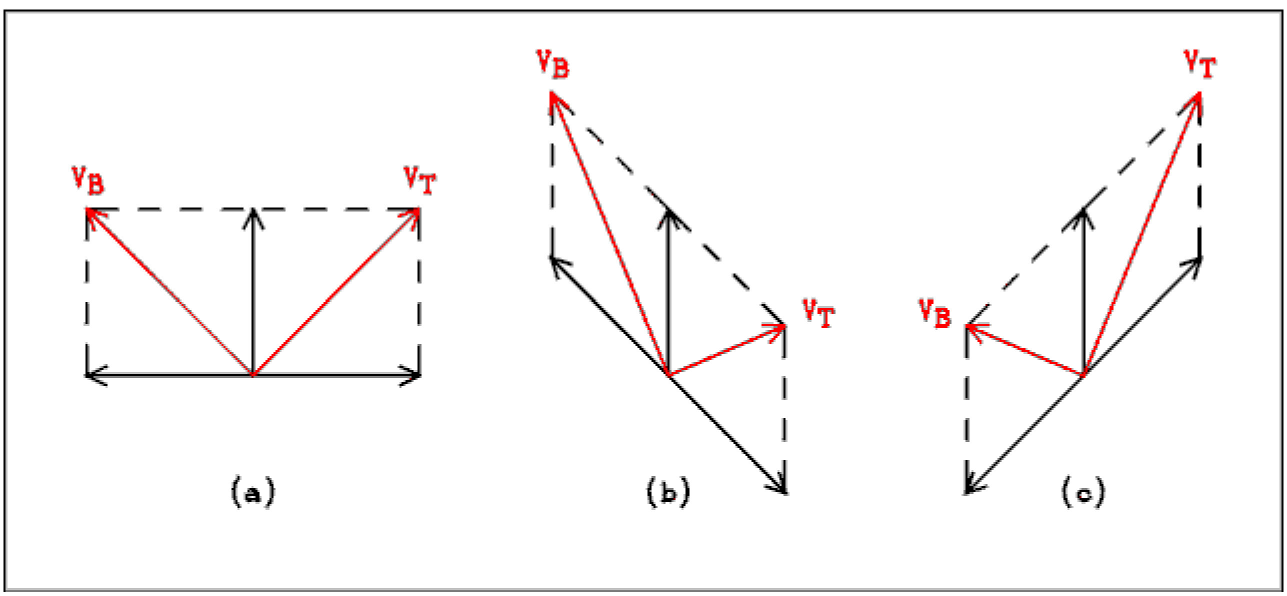

Figure 7.10 Phasor Diagrams of Discriminator Transformer Voltages.

For a verbal description click here.

The voltages across the tertiary winding and the top half of the secondary add as to the voltages across the tertiary and the bottom half of the secondary. This addition is shown in Figure 7.10(a). The voltage at the top of the secondary is 14.14 volts at an angle of 45 degrees while the voltage at the bottom of the secondary is 14.14 volts at an angle of 135 degrees. Note that both voltages still have equal amplitude although the relative phase angle has been altered. The diodes recover only amplitude information not phase information. Therefore the DC voltages at the cathode and anode of the top and bottom diodes respectively will be equal in value and opposite in sign. (+14.14 volts at the top and -14.14 volts at the bottom). Note that the DC and audio output from the detector is taken from the center-tap of the secondary. The tertiary winding has a minute amount of reactance at audio frequencies.

Now suppose that the frequency shifts upward. The phase of the voltage at the top end of the secondary will shift negatively because the resonant secondary now appears capacitive. Voltage lags current in a capacitive circuit so the phase will shift and let's say it shifted by -45 degrees as shown in figure 7.10(b). The voltage at the top of the secondary is now 7.653 volts at an angle of 22.5 degrees. The voltage at the bottom of the secondary is 18.478 volts at an angle of 112.5 degrees.

Remember that the two 10 k ohm resistors are holding the voltages across them equal and balanced to ground. Phasors represent the peak value so the voltage between the anode of the lower diode and the center-tap is 18.478 volts with the center-tap positive with respect to the diode anode. The voltage between the upper diode cathode and the center-tap is 7.653 volts with the cathode positive with respect to the center-tap. The total voltage is 26.131 volts. Each 10 k ohm resistor will have 13.0655 volts across it. The voltage at the center-tap will be 13.0655 v - 7.653 v = 5.4125 volts. Note that for an increase in frequency the output of the detector goes positive which is desirable for tuning meters and automatic frequency control (AFC).

When the frequency goes below center by the same amount it went above center the numbers are the same but all signs are reversed.

I wonder if anyone noticed the discrepancy with the numbers. When the incoming frequency is at the exact center the total voltage across the two 10 k ohm resistors was 28.28 volts and at a frequency that will give a 45 degree phase shift the voltage was 26.131 volts. If the voltage of the tertiary winding is decreased to 1 volt the total DC is 20.1 volts at center frequency and 20.05 volts at a frequency that gives a 45 degree phase shift. Decreasing the phase shift to 30 degrees gives 20.1 v and 20.08 v respectively. Reducing the phase shift and tertiary voltage reduces the amount of recovered audio. Clearly the designers of ratio detectors have to make some compromises to obtain a practical audio level and acceptable distortion.

There are no large currents or voltages in this circuit which reduces the probability of component failure. Resistors and capacitors can simply fail from old age. The most likely one to fail from this cause is the 5 µf capacitor which is a low voltage electrolytic. This capacitor in conjunction with the 2.2 k ohm resistor set the AM rejection. If the electrolytic should dry out and its value be reduced the AM rejection of the receiver will be considerably poorer than when the set was new. Do not assume that if 5 µf is good that 10 µf is better. The impedance and time constant of the circuit consisting of the 2.2 k ohm resistor and 5 µf capacitor in conjunction with the Q of the transformer secondary set the best value of AM rejection. Changing the value of the capacitor will reduce the AM rejection of the detector. In this particular case the substitution of a 4.7 µf capacitor would probably be acceptable especially since 5 µf capacitors are no longer made.

Note: In diagrams of the Ratio Detector you are likely to find in other textbooks the 2.2 k ohm resistor will be split between the top and bottom of the circuit. The designers of this circuit are taking the AGC voltage from the bottom end of the 5 µf cap. My best guess is that if there were a resistor between the diode and this cap there would be an additional RC time constant in the AGC loop which might render it unstable.

The two 10 k ohm resistors are 5% in table radios and are often 1% in High fi tuners. If one of them were to increase in value, a common result of old age, this would cause you to alter the tuning of the secondary of the discriminator transformer in an attempt to balance the circuit at center tuning. The effect of this would be to decrease the dynamic range of the detector possibly introducing a considerable amount of distortion.

If you think the detector is misaligned refer to the alignment procedure in the FM Tuner section below. References to the stereo light and tuning meter won't apply to a portable or table radio but the sound will be the same.

FM Tuners.

There is so much variation in circuitry among various tuners that it is impossible to give any detailed schematic diagrams. An FM tuner has the following sections. RF amplifier, Mixer and local oscillator, linear IF amplifier, limiting IF amplifier, FM detector, and stereo multiplex demodulator.

The RF amplifier operates in the frequency range between 88 and 108 MHz. The physical layout is even more critical than the component values. The simple act of bending a transistor to a more upright position could seriously degrade the performance of the tuner. If there is nothing wrong in the RF and mixer/oscillator section, don't touch it. If a transistor is burned out in this section and must be replaced your odds of ever getting it working again are small.

The linear section of the IF amplifier permits information for a signal level meter and AGC to be derived, usually from a simple diode detector.

The limiting section of the IF amplifier derives a signal which has a constant output level regardless of changes in the input signal. This is not done by AGC but by simple hard clipping. This is usually done within one or more integrated circuits. If the tuner is more than 20 years old these circuits may be very hard or impossible to find. Most all modern tuners use factory tuned LC filters or fixed tuned ceramic or crystal filters. In general such devices are not bothered by component replacement. Should one of these filters be found to be defective, and the tuner is old the chances of it playing again are small.

Detector Alignment.

CAUTION! Even high quality FM tuners in the transistor age use the same tiny transformers as their little brothers. The slugs in these have an obvious slot and they are very hard to turn. You may be tempted to use a metal screwdriver. DON'T DO IT! The slot will break out and the slug may brake into several pieces rendering the chances of a successful repair even lower. These slugs are held in place with paraffin. A little gentle warming with a hair dryer will permit them to be turned safely with an alignment tool.

Unless the tuner on your bench has been in the hands of someone who tightened up all the loose screws the IF and detector really won't need much if any alignment. In every old tuner I have seen the detector was slightly miss-aligned. You shouldn't need to turn the alignment slug more than 1/2 turn and more likely it will require less than a quarter turn.

The evidence for a misaligned detector is found by tuning across a strong local station which has only very weak signals nearby. When the detector is properly aligned you will observe three distinct listening peaks, not peaks on any meter. As you approach the signal you will begin to hear audio and it may not be distorted but it may be mixed with a little noise. The tuning meter will read quite low. As the tuning meter rises the sound will grow quite distorted. As you continue tuning the distortion will clear and the tuning meter will be at its peak. The stereo light will most likely come on. As you continue to tune the sound will once again grow distorted, the tuning meter will drop, and the stereo light will go out. The distortion will clear but the audio will be a bit noisy, and the tuning meter will read quite low.

A misaligned detector will give you two peaks and it may be ambiguous as to which one is the right one. Make small changes in the discriminator transformer or quadruture coil and tune across the station until you observe the signature of a properly aligned detector described above. If a symmetrical triple peak can't be obtained it may indicate trouble in the detector, or an IF that is seriously out of alignment.

Never adjust the detector for maximum noise when tuned off a station. You will adjust the detector so it won't detect FM at all but might detect AM if the limiters aren't to hard.

Stereo Demultiplexing.

Stereophonic, two channel, recordings have been transmitted on the radio since 1960. The method of transmission is compatible with monophonic, single channel, radios. This is done by a very clever method.

The two channels of the stereo audio signal are added together to form a signal called L + R, left added to right. This signal is modulated on the transmitter so any radio can pick it up. Then a signal that can tell a receiver with the proper hardware how to separate the mixed up channels is sent on frequencies that are above the range of human hearing. A monophonic radio may pick up these signals but they are not heard by the listener. The secret signal is made by subtracting the R signal from the L signal to give L - R. In the receiver the secret signal is added to the L + R signal and at the same time in a different circuit is subtracted from the L + R. This gives.

L + R + (L - R) = 2L

L + R - (L - R) = 2R

The factor 2 can actually be heard In many stereo receivers particularly early ones where the manufacturer did not compensate for them. When the receiver is switched to mono mode the sound grows softer.

The L - R or difference signal is it is often called has to be transmitted in such a way as to not cause any interference with the sum L + R signal. The signal is transmitted as double sideband suppressed carrier on a frequency of 38 kHz. The audio bandwidth is limited to 15 kHz so the double sideband signal occupies the band from 23 to 53 kHz.

Since the carrier has been suppressed it must be reinserted at the receiver and it must be in phase with the original carrier or the stereo signal will not be properly decoded. A 19 kHz pilot tone is sent to synchronize the oscillator that replaces the missing 38 kHz carrier.

So the whole composite stereo signal consisting of the baseband audio from 50 Hz to 15 kHz, the 19 kHz pilot tone, and the double sideband suppressed carrier from 23 to 53 kHz is sent to the frequency modulator in the transmitter. Preemphasis is applied to the two left and right channels independently before they are fed to the electronics that perform what has been described above.

Why is the 38 kHz carrier suppressed? The maximum carrier deviation that the FCC will allow on American broadcast stations is plus and minus 75 kHz. The mathematics of frequency modulation are far too complicated to go into here. To describe the effect, you can only squeeze in so much power into a carrier with a fixed deviation. The more you try to put in the less there is for the rest. A 38 kHz carrier would take considerable power away from the sum channel and require it to be modulated less to stay within FCC limits. An AM carrier does nothing but sit there and burn up power so it is suppressed. That makes much more modulation power available for the sum channel and the difference channel.

In receivers constructed using semiconductor technology the decoding is done by an IC with only a few external parts. The most popular seems to be the Motorola MC1310. A block diagram of the chip is shown in figure 7.11.

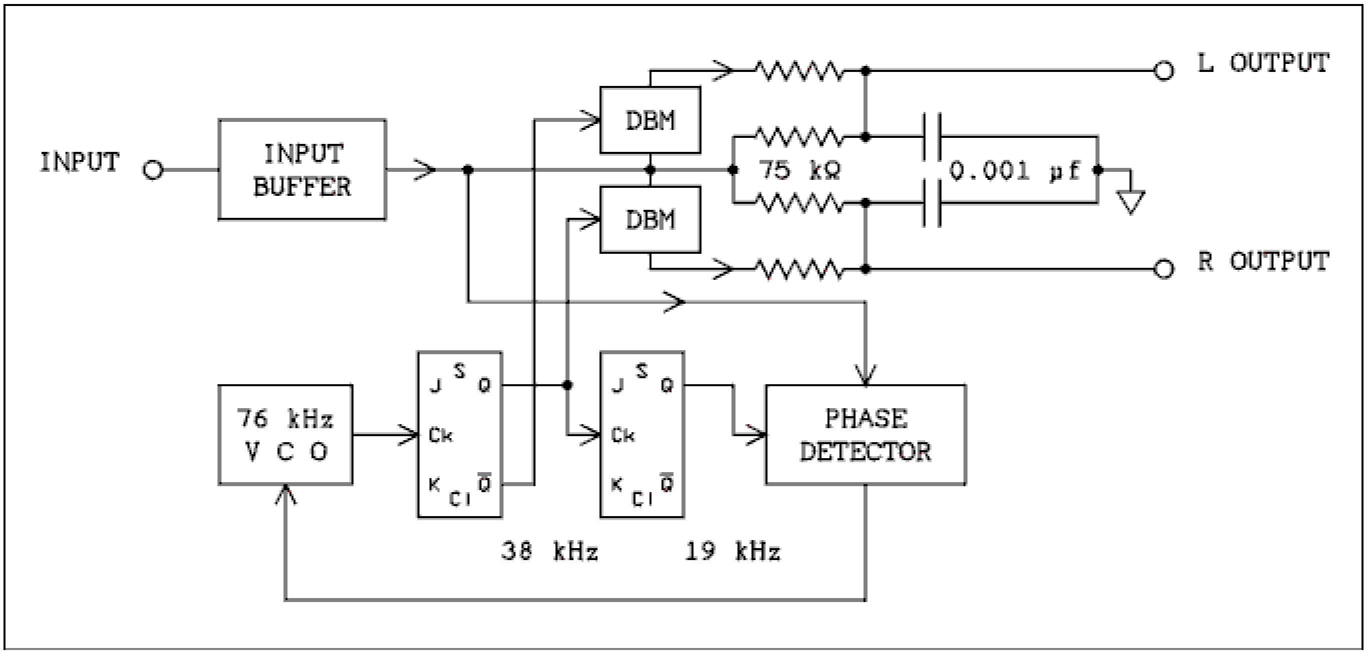

Figure 7.11 Block diagram of MC1310.

For a verbal description click here.

The input buffer provides a high input impedance to the chip while providing a low output impedance to drive all the internal circuitry. The entire composite stereo signal is applied to all internal circuit blocks and each one uses what it needs and ignores the rest. This eliminates the need for tuned circuits and LC filters.

The internal 38 kHz carrier is generated from the 19 kHz pilot by a phase locked loop. The 76 kHz VCO (voltage controlled oscillator) is divided by two by a JK flip-flop and then by two again by another flip-flop. This yields 19 kHz which is fed to the phase detector. The phase detector picks out the 19 kHz pilot tone and locks the VCO to it.

When the two input signals of a phase detector are at 90 degrees and the same frequency the DC output voltage is zero. When the two signals are in phase the output is positive and when the two are 180 degrees out of phase the output is negative.

The VCO is designed and adjusted so when the DC input voltage is zero its frequency is 76 kHz. When the voltage is negative the frequency is lower than 76 kHz and when the input voltage is positive the frequency is higher.

If the frequencies differ by say 1 Hz the output of the phase detector is 1 Hz. This will cause the VCO to be frequency modulated at 1 Hz and when it falls on 76 kHz the VCO will lock onto the pilot tone. The tuning range of the VCO is small so it won't lock onto musical notes in the program material.

The phase difference of the two 19 kHz signals is 90 degrees but at twice the frequency, namely 38 kHz the phase difference becomes 180 degrees. The 38 kHz signal between the two flip-flops is 180 degrees out of phase with the carrier that is required to recover the difference signal. A reversal in phase will flip the phase of the recovered difference signal. That is The difference signal will become -L + R. When the 38 kHz signal is fed to a DBM (doubly balanced mixer) it will use the 23 to 53 kHz double sideband signal to recover the -L + R signal which when combined with the composite signal through the two 75 k ohm resistors will derive the left channel. The not Q signal from the flip-flop is 180 degrees out of phase with the Q signal so when it is applied to another DBM it derives the L - R signal. When this signal is combined with the composite signal it derives the right channel signal.

What is a doubly balanced mixer?

Note: In the discussion below the terms sum frequency and difference frequency are used. Do not confuse these terms with the terms difference signal and sum signal. The sum signal is the L + R signal and the difference signal is the L - R signal. A sum frequency is a new frequency resulting from two frequencies being added together. A difference frequency is a new frequency resulting from two frequencies being subtracted one from the other. I promise to always say exactly what I mean and mean exactly what I say.

A DBM produces the sum and difference frequencies the same as any other mixer. If two signals of 6 kHz and 4.5 kHz are injected into a DBM the output is 1.5 kHz and 10.5 kHz. But the two original signals of 4.5 kHz and 6 kHz are canceled out by the circuitry and do not appear in the output. The truth is that the internal circuitry of the two DBMs is no different from the circuitry of the phase detector. They are the same circuit serving different functions. This makes chip manufacturing easier because it becomes a series of modules that are connected together before final packaging.

The 23 to 53 kHz double sideband signal combines with the 38 kHz signal to produce audio from 50 Hz to 15kHz which is the recovered difference signal. Also the original L + R sum signal combines with the 38 kHz signal to produce sum and difference frequencies which is a whole new set of frequencies in the range of 23 to 53 kHz. If the original difference signal were not canceled out by the DBM these frequencies would combine, beat together, to produce all sorts of weird effects.

The 76 kHz VCO is an RC controlled Multivibrator with the resistor and capacitor outside the IC. Part of the resistor is usually a trimmer resistor to set the frequency of the oscillator. The four 75 k ohm resistors are internal but the 0.001 uf capacitors must be supplied on the outside.

The output of the IC is not line level so gain stages must be provided before going to line output jacks. Many tuners have elaborate filters to make sure no frequencies above the audio band escape from the tuner. If the 19 or 38 kHz signals were to appear at the output with any appreciable amplitude they would beat with the bias oscillator in a tape recorder and produce beat frequencies, tones, in the audio band. These tones would not be heard when listening to the radio but would be heard in the recording.

What can go wrong?

If there is no output from the chip it is most likely bad and must be replaced. A possible symptom is that there is audio but it is monophonic, the same signal from both channels. This can be tested for without having to rely on your ears. Connect the two channels to the X and Y inputs of an oscilloscope and be sure the station you have tuned in is transmitting stereo program material. If the output is monaural the scope will show a straight line at 45 degrees to the horizontal. If the signal is stereo the scope will show all kinds of random circles and ellipses.

If the receiver is producing monaural try adjusting the trimmer pot in the frequency determining parts of the VCO. Many times this will fix the problem.

If one channel is dead check the gain stages that come after the demodulator chip.

If there is trouble in the filters and the user owns a tape recorder there may be beats in the recording that aren't heard in normal listening. Back to Fun with Transistors.
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7.3 Things You Should Leave Alone.

You should leave the following items alone.

1. VCRs.
2. CD Players.
3. DVD Players.
4. Flat screen TVs.

You may break the "leave it alone" rule if all four of these conditions are satisfied.

1. The item is not working at all.
2. It is out of warranty.
3. The service shop you took it to declined to work on it.
4. You own the item.

When you have nothing to lose there is no risk and you might just get it working. But don't make any bets or hold your breath.

So what to do if you decide to open it up and have a look. Before removing the screws or prying up the tabs check the back, or the manual, if you still have it, for a reset button.

Assuming you manage to get it open without doing too much damage trace the AC power line. You might find a fuse and most likely it will be a solder in type and won't be the kind you can walk into a Radio Shack and buy. If the fuse is blown don't replace it just yet. Fuses do occasionally blow all by themselves but it is rare.

Keep following the AC trail. Depending on the size of the device you may or may not find a power transformer. But eventually you will find one or more diodes and a filter capacitor. Check them for shorts.

After the rectifier and filter you may find either an analog voltage regulator or a switch mode power supply. At this point the problem usually becomes getting at the components to figure out what is there let alone test and replace them. If the designers were thoughtful enough to realize that this part of the unit is field repairable the circuit boards may come out easily.

If you get this far without finding any fault temporarily solder in a fuse clip and insert a standard fuse of the proper current rating. If it blows you haven't found the problem. If it doesn't start checking around on the net to find the proper replacement. If you can find a way to safely anchor the fuse clip so it is not hanging from the leads on the PC board you may decide to leave it in place.

CD and DVD players will have two power supply lines a positive and a negative with respect to ground. VCRs and TV sets will have a multitude of voltages available from the power supply. TV sets are most likely to have no line frequency transformer but a switch mode power supply after a bridge rectifier and filter capacitor.

DVD and CD players and VCRs can have mechanical problems which can be difficult to diagnose without special test sets supplied by the manufacturer. VCRs often have small spring loaded switches that are meant to detect trouble in the mechanism and shut off the power or reverse the action to prevent damage. These switches are often not of the best quality and they end up being the cause rather than the cure.

Often the wisest decision is to walk away particularly if the thing doesn't belong to you. In the words of the song, "You've got to know when to hold em and know when to fold em."

Chapter 8 Faults in Vacuum Tube Circuits.

Chapter 8.

Faults in Vacuum Tube Circuits.

A large segment of the electronics community considers vacuum tubes to be an obsolete and useless technology. Another large and growing segment considers them to be superior to transistors in many applications. To name just a few they are, musicians who play electric instruments, audiophiles, hams and SWLs, and hobbyist and experimenters.

Musicians and audiophiles prefer the sound of tubes over transistors. Hams and SWLs find that a tube receiver will outperform a transistor receiver of comparable complexity and price. Electronics hobbyist, especially the older ones, prefer the point to point wiring construction used in conjunction with tubes as opposed to the printed circuit boards of transistors.

Many items of tube equipment are more than 50 years old which qualifies them as antiques. If one of these items turns up on your service bench how it is treated depends on whether it has not been turned on for several decades or if it was in daily use and suddenly failed to operate. The latter case is covered in This chapter.

If an item is brought to your shop by a tearful owner who states that he or she used to listen to it at age six and asks you if you can make it work again even though it may have been stored in a damp basement or hot attic for the last 50 years you are definitely on the hot seat. Such an item requires special care. An entire chapter will be devoted to such items. There is bound to be some duplication between this chapter and the one concerning Antiques. However, this chapter is what it is.

For additional information on tube amplifier and radio circuits see The Fun with Tubes website. Also see Electronics for Physicists particularly chapter 4A.

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8.1 Audio Amplifiers.

The largest segment of the tube culture consists of musicians and audiophiles. The amplifiers they use differ in a few details but are basically the same.

Power Supplies.

Tube aficionados disagree on whether it is best to use a tube as the rectifier or silicon diodes. Tube rectifiers have a large internal voltage drop and the drop changes with current being drawn. When the power output stage is operating in class AB the power supply voltage will fall when the amplifier is delivering large amounts of power. The term applied to this is sag. Many musicians find the sound produced by sag to be desirable.

Silicon rectifiers do produce a small amount of sag but it is very much less than that occurring with a vacuum rectifier. Some extremist will state they can tell the difference between the sound of an amplifier using a tube rectifier and silicon even at low power. Personally, I don't believe them.

Whichever type of rectifier it has the power supply should always be checked first.

Heater Wiring and Schematics.

Tube heaters and filaments must be connected to a source of power or the tube will just sit there and not do a thing. Draftsmen have three basic ways of showing these connections.

The most obvious is to draw the lines from the power source to the tube. This is more likely to be seen in circuit diagrams showing filament type tubes rather then indirectly heated cathode tubes.

Another way to indicate heater connections is shown in Figure 8.0A. The letter X is used to indicate that the power source is indeed connected to the tube heater even though it is not shown with lines on the drawing.

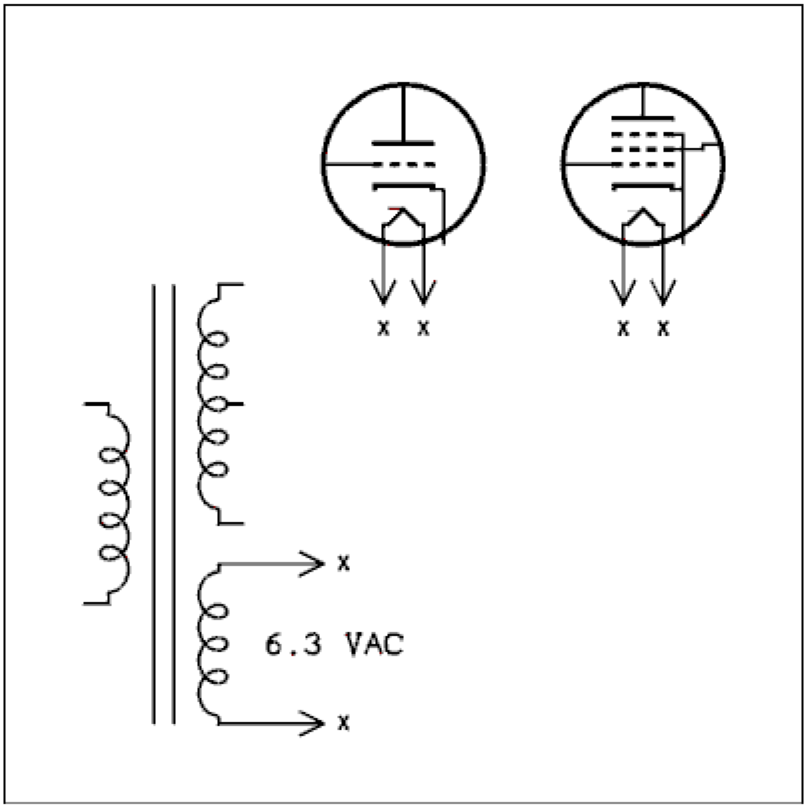

Figure 8.0.A Heater Connections Indicated By the Letter X.

For a verbal description click here.

The third way is to show the heaters separate from the tubes as shown in Figure 8.0B. In this method it is easier to show the heater connections in a duo triode such as the 12AX7. The circuit on the left shows parallel connection while the one on the right shows series connection.

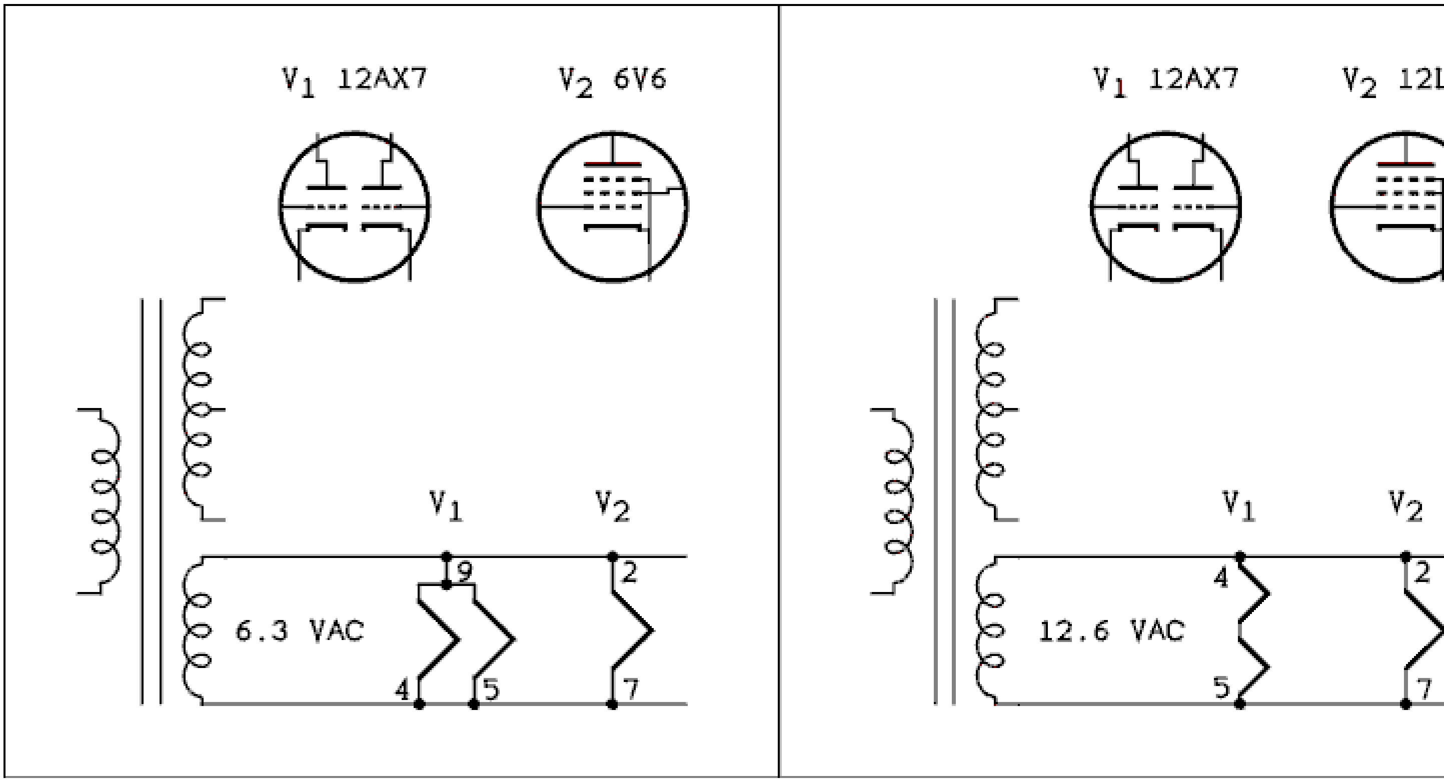

Figure 8.0.B Heater Connections Indicated By Removing the Heater From the Tube Symbol.

For a verbal description click here.

Single Ended Amplifier.

A single ended amplifier is about as simple as it gets. A typical example of a musical instrument amplifier is shown in Figure 8.1.

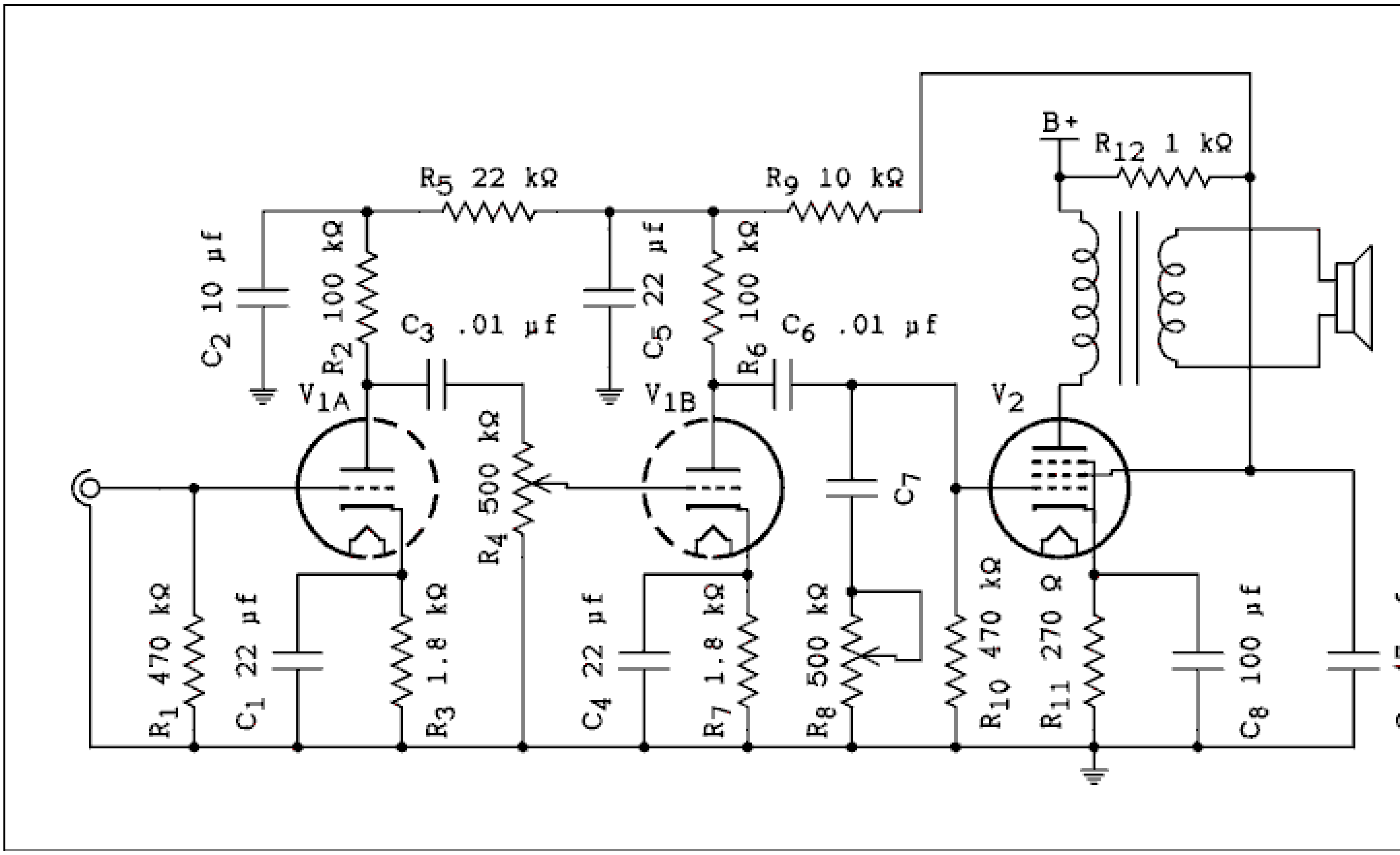

Figure 8.1 Single Ended Amplifier.

For a verbal description [click here.]

This would be a low power practice amplifier. V1 is a 12AX7 and V2 a 6V6. In another incarnation as a desk top amplifier for a portable CD player the V1A stage would be removed and the signal fed in at the top of the volume control. Another 6V6 would be added and the other half of the 12AX7 would be in the other channel.

A common fault in tube amplifiers is evidenced by the plate of the output tube, 6V6 in this case, glowing red hot. This is not a normal condition. There are two possible causes and they are both capacitors. If C8 shorts the grid bias on V2 will be reduced to zero and excessive plate current will flow. The other defect is for C6 to become leaky. This is a resistance in parallel with the capacitor and it doesn't take much leakage current to cause problems. A leakage current of 25 micro amps will approximately double the plate current of V2. This is an effective parallel resistance of 6 meg ohms.

If the amplifier is producing weak and distorted sound you may suspect a tube. Eliminate this fault by replacing both tubes with known good ones. If this fixes the problem go back to the old tubes one at a time to see which one is at fault.

If new tubes don't fix it look for a resistor that has increased in value or a leaky capacitor. These can usually be found by voltage measurements. Do not use a VOM for these measurements. The resistance of the VOM will severely load the high resistance voltage points. The plate voltages on those tubes with resistors in the plate circuit will be approximately from 1/2 to 3/4 of the voltage at the top end of the plate resistor. Grid voltages should always read zero or perhaps a few millivolts on the lowest range of a DMM.

Another fault that would silence the amplifier would be R5 or R9 open or C2 or C5 shorted. These will be evidenced by the voltage across either or both C2 and C5 being zero. If the voltages across C2 and C5 are zero the fault could be either C5 shorted or R9 open. An ohmmeter test with power off should find which is the fault.

If the voltage across C2 is zero this could be caused by C2 shorted or R5 open. The question can be resolved by the voltage across C5. If the voltage across C5 is higher than normal there is less current than normal flowing through R9. That points to R5 being open. If the voltage across C5 is lower than normal there is more current flowing through R9 than normal which points to C2 being shorted.

Unformed electrolytic capacitors are usually not found in new equipment. Faults unique to antique electronics will be covered in a chapter devoted to that sub class.

Negative Feedback. (NFB).

A musical instrument amplifier often does not employ negative feedback. NFB sharpens the overload corner so an amplifier without it will overload more gracefully than one that has it. Distortion which is anathema to audiophiles is often a desirable effect to a guitar player. But it needs to be a particular kind of distortion. Simple sharp clipping is usually undesirable.

If NFB were to be applied to this amplifier one side of the voice coil winding would be grounded and the other side connected through a resistor to the cathode of V1A. C4 would be removed or a 100 ohm resistor would be connected in series with it. The tone control circuit consisting of R8 and C7 would have to be removed. If the tone control were left in place the NFB would reduce its effect to the point of being almost unnoticeable.

Push-Pull Amplifiers.

To make a push-pull power output amplifier work properly the two grids must be driven by signals that are 180 degrees out of phase. That is accomplished through a circuit known as a phase inverter. Examples of the two major types of inverters are shown in Figure 8.2.

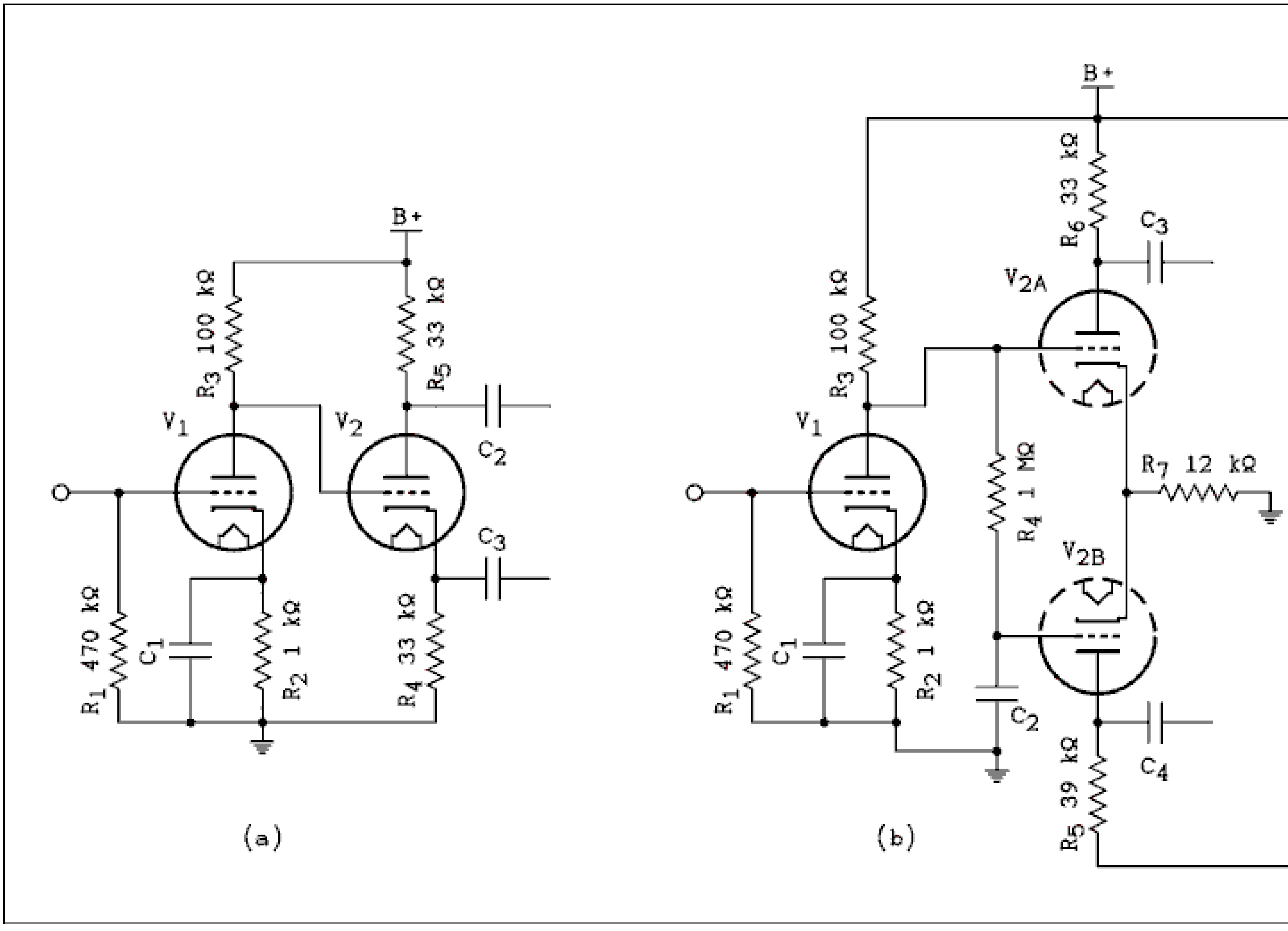

Figure 8.2 (a) Split Load Phase Inverter, (b) Long Tail Pair Phase Inverter.

For a verbal description click here.

Circuit (a) is known as a split load phase inverter. As shown it is often made with a low µ duo triode such as a 6SN7. Another variation uses a high µ triode for V1 and a low µ triode for V2. Yet a third variation connects a capacitor between the plate of V1 and the grid of V2. The V2 stage is biased the same way as the modified cathode follower shown in Figure 4A.17(b). All but the last variation can be upset by a change in the power supply voltage. A fault elsewhere in the amplifier could be responsible for a power supply voltage change and mislead the repair technician.

If the power supply voltage is correct check DC voltages around the circuit. The voltage at the plate of V1, also grid of V2, should be approximately 1/4 to 1/3 of the B+ supply. The voltage drops across R4 and R5 should be equal with the remainder of the B+ voltage dropped across V2. The capacitor across R2 may be omitted to permit negative feedback to be applied.

The circuit shown in Figure 8.2(b) is known as a long tail pair. V1 is usually a high µ triode while V2 is a medium or low µ duo triode. Signal is coupled directly from the plate of V1 to the grid of V2A. The signal is inverted and appears at the plate of V2A. Some of the signal is coupled from the cathode of V2A to the Cathode of V2B and then to the plate of V2B. In this signal path V2A acts as a cathode follower while V2B acts as a grounded grid amplifier. Both configurations do not invert the signal. The signal appears at the plate of V2B without being inverted. Thus the two signals at the two plates of V2 are 180 degrees out of phase. The signal path through V2A and V2B has slightly less gain than the signal path through V2A alone. The increased value of the plate load resistor on V2B, R5, compensates for the difference in gain. R4 makes certain that the voltages at the two grids of V2 are at the same DC potential. C2 grounds the grid of the grounded grid amplifier V2B. A very slight leak in C2 will imbalance the circuit and increase the distortion.

The voltage at the plate of V1 should not be too much greater than 1/4 of B+. The voltage drops across R5 and R6 should not differ by anymore than 20%. If there is a large imbalance it is most likely caused by R4 or C2.

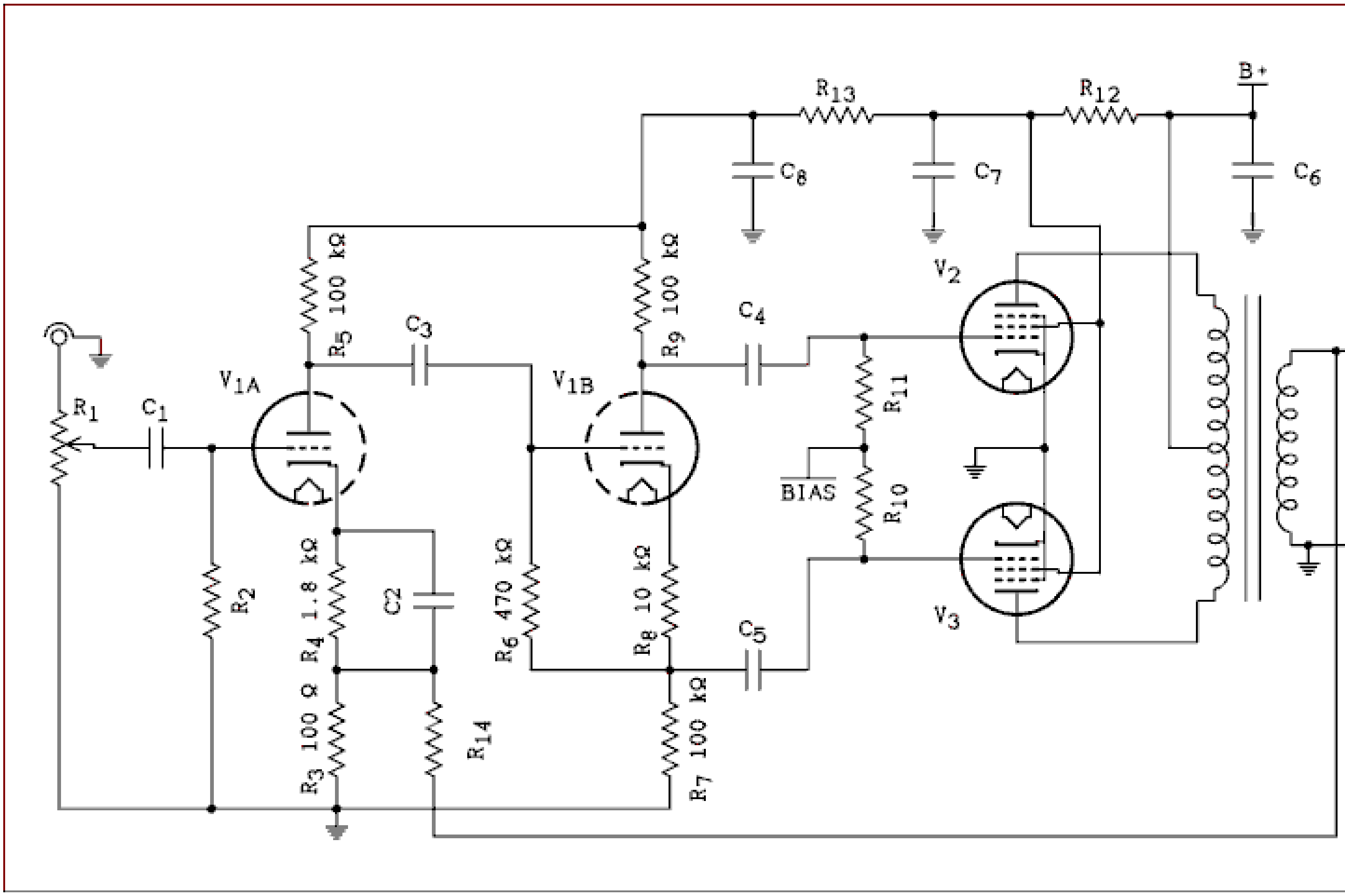

Figure 8.3 Complete Push-Pull Amplifier.

For a verbal description click here.

The figure above shows variation 3 of Figure 8.2(a). It also shows how NFB is applied to the circuit. The output transformer must be phased, correctly connected, to obtain negative feedback instead of positive. This amplifier suffers all the same failure modes as the single ended amplifier except there is more to go wrong. Push-pull amplifiers are found more often in audiophile equipment whereas single ended amplifiers are more likely to be found in musical instrument amplifiers. This rule is broken when the musician wants more power. Many instrument amplifiers such as those made by Fender do use negative feedback and push-pull outputs.

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8.2 Radio Receivers.

The All American Five.

The All American Five represents a triumph of the bottom line over quality and safety. It was the radio that the Atwater-Kent company went out of business rather then make. Every feature had one purpose, to reduce the cost of manufacture. After World War II there were millions sold under hundreds of brand names from Admiral to Zenith.

It is called the All American Five because all brands were made in America. This was long before the mass exodus of the electronics industry. The five comes from the fact that it used 5 tubes. There were variations using 4 tubes which didn't perform very well and 6 tubes which costs more. The average person who didn't stay up late to see how many distant stations they could hear (known as D X ing) didn't care about the improvements provided by 6 tubes. Consequently the All American Five became a post war standard which did not fade away until replaced by the All Japanese Six, the six transistor radio made in Japan.

The most prominent feature of the AA5 was that it had no power transformer. The result was that the circuit common was connected to one side of the power line. Because there was no polarized plug there was a 50 - 50 chance that the radio's chassis would be connected to the hot side of the power line. Very late models from the sixties were carefully designed not to have any metal parts on the outside even going so far as to recess screws in deep holes. In the 40s and 50s there was no such concern on the part of manufacturers. It was common to see chassis mounting screws exposed on the bottom of the plastic case. These radios could be, and sometimes were, lethal. All it would take was for an unwary person to complete the circuit between a metal part on the radio to a kitchen sink. I once owned one that was in a metal case. My friends and I called these radios "suicide boxes".

Because these radios were made literally by the millions there are still many of them around and in working order. The odds are better than even that one which has been in regular use by a nostalgic owner will be brought to your service shop.

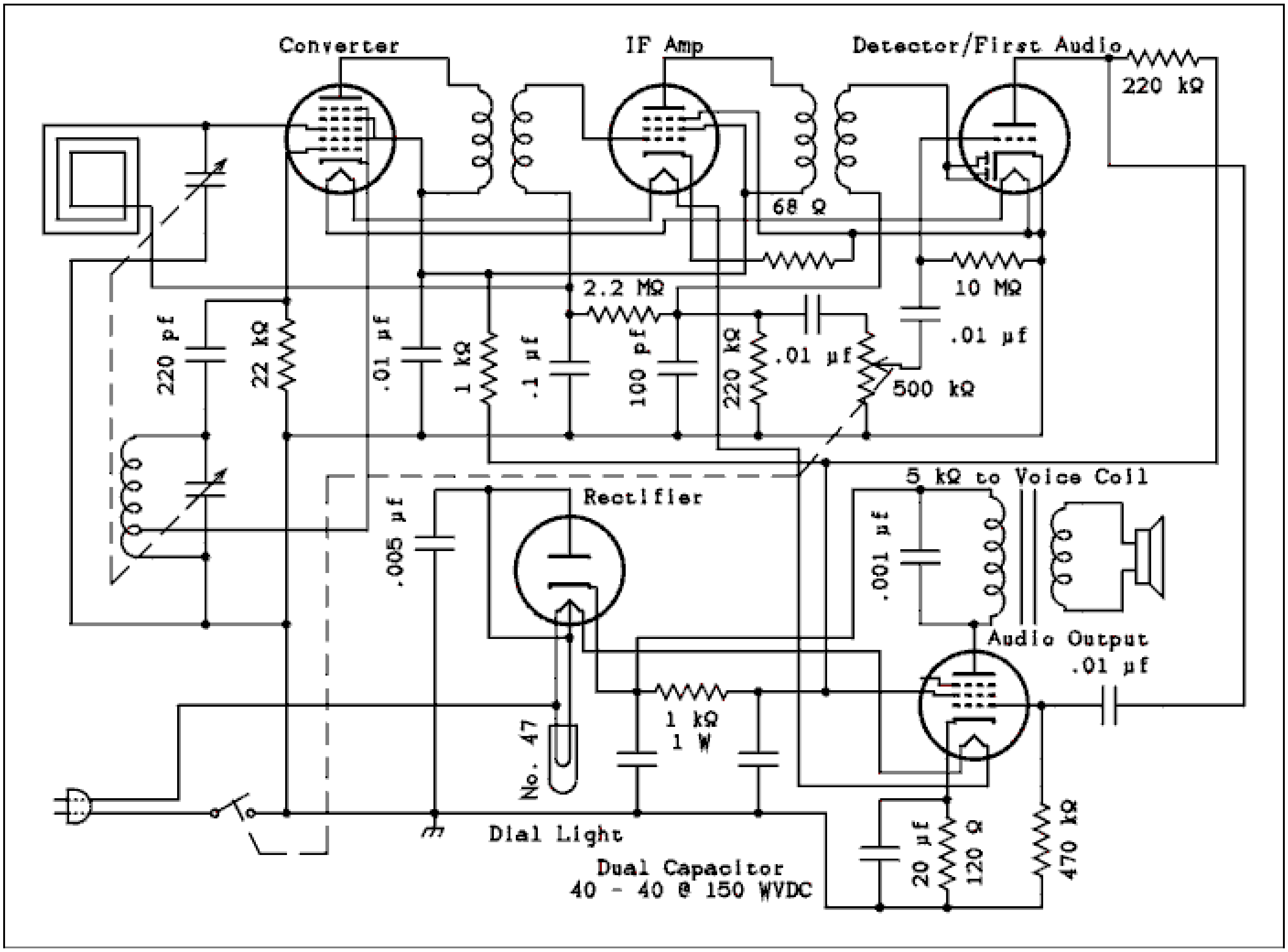

Figure 8.4 A Typical All American Five Radio.

For a verbal description click here.

These radios came in two main varieties, the octal tube versions built mostly between 1946 and 1950, and the 7 pin miniature tube type built between 1950 and fading out in the late 1960s. I have seen a few hybrid radios that must have been made in the transition period and the designers used whatever tubes were priced the lowest by the tube manufacturer.

The tube line up was as follows.

Function	**Octal**	**7 pin mini**

	tube.	tube.
Converter	12SA7	12BE6
IF Amplifier	12SK7	12BA6
Detector and First Audio	12SQ7	12AV6
Audio Power Output	50L6	50C5
Rectifier	35Z5	35W4

Radios of this type constitute a real danger to you and your test equipment. You don't want to join the "great balls of fire" club by burning off the ground lead of your oscilloscope probe or worse.

The safest way to work on a radio of this type is to use an isolation transformer. You need at least 36 watts to be on the safe side. You could gin up an isolation transformer out of two 6.3 volt 6 amp filament transformers connected back to back, that is the two filament windings connected together and the two 120 volt windings used as the primary and secondary of the isolation transformer. You could also use a pair of 12.6 volt 3 amp transformers or a couple of 25.2 volt 1.5 amp transformers. Larger current rating wouldn't hurt, smaller is not recommended.

If you just can't arrange an isolation transformer Plug the radio into an outlet strip that has a switch. Temporarily solder a jumper wire across the radio's on/off switch so it can't be accidently turned off. Measure the AC voltage between the cathode of the 12SQ7 or 12AV6 and AC power ground. If it is 120 volts reverse the plug. Use the switch on the power strip to turn the radio on and off while making tests.

Troubleshooting.

The most likely symptom is a loud hum which comes up as the tubes warm up. The loudness is not or very slightly effected by the volume control. Sometimes you can actually tune in a station and hear it through the hum. This is caused by the electrolytic capacitor in the power supply being dried out. It can't be reformed or recovered in any way. It must be replaced. The circuit above shows a duo 40 microfarad 150 volt capacitor. In most radios these will be a bit smaller. I have seen ones as small as 20 - 20. They may be 20 - 30, 20 - 40, 30 - 40, or 30 - 30. If you can't find the exact replacement use something that is close. You can go up in value but you should never go down. Same goes for voltage.

None of the tubes light up and there is no sound. All of the tube heaters are in series. One opens up and they all go out. Pull the tubes and perform resistance measurements on the heaters. They should range from roughly 20 to 85 ohms. Replace the burned out tube.

Tubes light up but there is no sound. It's time to do a little disturbance testing and half splitting. Turn the volume control to about 2/3 rotation. Touch a screwdriver tip to the center terminal of the three on the side of the volume control. Touch a finger to the metal shaft of the screwdriver. You may or may not hear a loud hum. You have just half split the radio. A hum means the audio section is fine and the trouble is in the Converter, IF, or detector. No hum means trouble in the audio section.

If you've got hum touch the screwdriver blade to the grid pin of the IF amplifier. No need to touch the screwdriver shaft. If you hear static the IF amplifier is good and the problem is most likely that the oscillator is not running. Use a high resistance DC voltmeter to measure the voltage at grid 1 of the converter tube. You should get a voltage ranging from -2 to -20. It will vary slightly as you tune across the band. In an AA5 sitting on my bench I read approximately -10. If you have an authentic VTVM it will measure this voltage without any major errors. A DMM may or may not work. One way to ensure that it will is to wrap one lead of a 1 meg ohm resistor around the probe or clamp it in the alligator clip. Use the other lead as the probe to touch the terminal. The reading will be about 10% low but you aren't worried about accuracy, you just want to know if the voltage is present.

If there is no static when touching or scratching on the IF amplifier grid terminal, or the oscillator is not running, check DC voltages on the IF and converter tubes. A zero plate voltage might well be caused by an open IF coil. Zero plate and screen voltages will likely point to a shorted bypass capacitor.

If you have the equipment you may find signal injection or signal tracing to be more fun. To do signal injection make absolutely sure the signal generator has a DC blocking capacitor in its output. If it does not, modify the equipment or use one externally held in an alligator clip test lead.

Set the generator for audio output and touch the lead to the plate of the output tube. Turn the amplitude up to full. You should hear a weak tone in the speaker. Move the probe to the grid of the output tube. If the output tube is functioning properly you'll get a blast of sound. Reduce the amplitude to a normal level and move the probe to the grid of the first audio tube. You'll get another blast. Turn it down again and move to the top of the volume control.

Now change the generator to modulated RF and tune it to the frequency of the IF in the receiver you are working on. 455 kHz in the case of an AA5. Touch the probe to the plate connection of the two diodes in the detector. Some AA5s use only one of the diodes for audio detection. You should hear the modulated tone on the RF generator. Touch the probe to the plate of the IF amplifier. You should still hear the tone at about the same strength. Now move to the grid of the IF amplifier. The tone should grow much louder and require you to reduce the output. Rock the frequency of the generator a little to be sure you are tuned in exactly on the IF. An older set may have drifted a little off frequency or been mis-aligned by a previous owner or technician. Move the probe to the plate of the converter tube. There should be no significant change in the amplitude of the tone. Now move the probe to grid 3 of the converter tube. Although the tuned circuit is off from the frequency you are injecting you should still hear something just by brute force injection. You would hear this tone even if the oscillator is not running.

Now tune the generator to the band that the receiver is tuned to. Tune the generator around to see if you can find it. If not, the oscillator is likely not running.

There can be a number of reasons for a non running oscillator. The oscillator coil could be open. The 22 k ohm resistor, or its equivalent in your receiver, could be open. The 220 pf capacitor, or its equivalent in your receiver, could be either open or shorted. The tuning capacitor could be damaged and the plates may be touching shorting it out.

Other Types of Radio Receivers.

Not all tube radios that still work are AA5s. There are console radios that use a conventional transformer power supply. All the tube numbers begin with a 6 and all are in parallel across the 6.3 volt transformer winding. The rectifier is sure to be a tube maybe a 5Y3 or if the audio section produces some power a 5U4. If the radio has shortwave bands, and most tube consoles did, clean the contacts on the band switch. Switches that don't make reliable contact are a major cause of malfunctions in such radios. The main feature that distinguishes these radios from an AA5, other than the power supply, is an RF stage before the converter.

There are also many receivers that were intended for use by hams and serious SWLs (Shortwave Listeners). These receivers were made by National, Hallicrafters, Hammerland and others. The more deluxe ones of these had a first If somewhere above the AM broadcast band and a second IF below it. These are called double conversion receivers. The very top of the line receivers made in the 1950s were triple conversion.

No matter how complex they may be the basic principles are the same as those of the AA5. Conversion to an Intermediate Frequency (IF), amplification, and detection.

Alignment.

Aligning the IF amplifier in an AA5 is about as straight forward as it gets. Set a signal generator to 455 kHz and turn on modulation. Connect the generator's output to grid 3 of the converter tube. Connect a VTVM set to AC to the plate of the output tube.

WARNING!!! There is a high DC potential at this point. The classic VTVM included a DC blocking capacitor to allow this measurement to be made safely. A DMM or Transistorized analog meter might have a low voltage capacitor or might not have one at all. If this is the case connect the meter across the speaker terminals.

Some top of the line radios from the 30s made by Zenith and others used stagger tuned IF transformers. If you try the procedure below you will really mess them up. Get hold of a service manual for such radios. It will have alignment instructions.

If you have an AA5 on your bench go ahead with this procedure. Set the volume to a comfortable listening level and adjust the range of the meter to get a good reading. Gently turn the trimmers or slugs in the IF cans. Adjust all for maximum reading.

For Antenna and oscillator tracking alignment the loop antenna can easily be thrown out of resonance by direct connection of a signal generator to the antenna circuit. You may be tempted to use the external antenna connection, usually just a wire sticking out of the back of the radio, as a connection point for your signal generator. DON'T DO IT!

Make a transmitting loop antenna by driving a few small nails into a piece of plywood. Make the shape circular or oval which ever strikes your fancy. Wind several turns, say 4 or 5, around the nails. Place the board so the transmitting loop is parallel to the loop in the radio and at least a foot away from it. Connect the output of your signal generator to the transmitting loop and turn up the amplitude until you can find the signal on the dial of the radio. Note: If you have a good ear you can use a local station for this part of the alignment.

Tune to the high end of the band and adjust the oscillator trimmer so the dial is in calibration. Adjust the antenna trimmer for strongest signal.

If the oscillator coil has no adjustment slug the alignment is complete. If it does, continue.

Now tune to the low end. It is difficult although not completely impossible to do this part of the alignment with a station instead of a signal generator. Set the generator's frequency to about 600 kHz or a nearby spot which is clear of a local station. Turn the radio's tuning knob to bring in the signal generator. There is no way to adjust the inductance of the loop antenna. Read the voltmeter and turn the slug in the oscillator coil until the signal is off tuned. Turn the tuning knob on the radio to bring the signal back in. Read the meter again. If it is less you turned the slug the wrong way. Turn it the other way and tune the signal again Keep doing this until you get the highest signal possible. This is known as rocking the oscillator. If it is something you do frequently you will develop a rhythm in which you are almost turning the slug and tuning knob in unison.

Go back to the high end and if necessary touch up the oscillator trimmer for dial calibration and antenna trimmer for strongest signal. A small table radio such as an AA5 usually does not need repeated iterations of this procedure. Put it back in the case and send it home.

Shortwave and Communications Receivers.

The short wave bands on an AM radio may require more attention. You should not attempt alignment of these bands without an accurately calibrated signal generator. A service manual is always a good idea but if you don't have one you can likely figure out which adjustment goes with which band if no other way than by trial and error. If the latter is necessary be sure to mark the adjustments so you won't get confused and turn an adjustment on a band which has previously been aligned.

Start at the high end. Choose a frequency that is near but not at the high end of the band. Something that is about 20 degrees of rotation of the variable capacitor from the top. Adjust the oscillator trimmer for proper calibration and the antenna trimmer and if the radio has an RF stage the RF amplifier plate trimmer for maximum signal.

Now go to the low end but not the bottom. Once again about 20 degrees off the low end. Adjust the slug in the oscillator coil for proper calibration and the antenna and RF coil slugs for strongest signal.

Now go back to the same frequency you used at the high end and repeat the dial calibration and strongest signal adjustments. Back to the low end and repeat. Go back and forth until the adjustments stop needing to be changed.

Never, never, never, never, attempt alignment of a communications grade receiver without a service manual or a lot of experience. Of course, if you have a lot of experience you will be writing your own book instead of reading mine.

Car Radios.

Car radios are only slightly different from other AM radios. Four major differences are; Car radios are with few exceptions tuned by variable inductors rather than variable capacitors, the intermediate frequency is 262.5 kHz, the B+ is derived from a vibrator power supply, and the radio will always have an RF amplifier stage.

The hardest part of repairing car radios is getting them out of the car and then back in after repair is complete. A typical transistor bench power supply may not have enough current capability to power a tube car radio. If all else fails you may have to take the battery out of the car and bring it into your shop. If you do, **BE WARE OF SHORT CIRCUITS!** A car battery can deliver enough current to heat a test lead instantly red hot and set the insulation ablaze. In-line fuse holders are available from electronics suppliers and you should by all means get one and fuse the battery. You could use a smaller battery such as one for a motorcycle or riding lawnmower. Even these should be fused.

If you frequently work on car radios I would recommend the construction of a battery eliminator as they were called in the day. Use one or more filament transformers, a bridge rectifier, a **BIG** filter capacitor, and a variac.

In some cases the speaker is mounted in another part of the car, such as in the dash above the radio and was not removed with it. But any small speaker can be substituted for troubleshooting purposes.

One complaint may be that there is excessive ignition noise and generator hash in the radio. This problem is very difficult to troubleshoot because it can't be tested outside of the car. Power is fed into the radio through feed-through capacitors which in car radio parlance are known as spark plates. A spark plate is a square of metal which is connected to the hot power lead and insulated from the radio chassis with a sheet of mica. There is little to go wrong with such a device except corrosion at the point where the power lead connects to the plate. Here we have a wide open opportunity for finger pointing. The radio repair man will say the fault is in the car while the mechanic will insist that the radio is at fault.

I have no direct experience with functioning car radios either in or out of the car, except for listening. If there are any experienced troubleshooters out there who would like to write a section on this subject be sure to get in touch with me. There's no pay, just credit.

The Vibrator and Buffer Capacitor.

The problem you are most likely to encounter is trouble in the vibrator power supply. The problem may be the vibrator itself or the buffer capacitor which is connected across the secondary of the transformer.

There are two main types of vibrator circuits used, Figure 8.5(a) is an external rectifier type and figure 8.5(b) is a synchronous rectifier type.

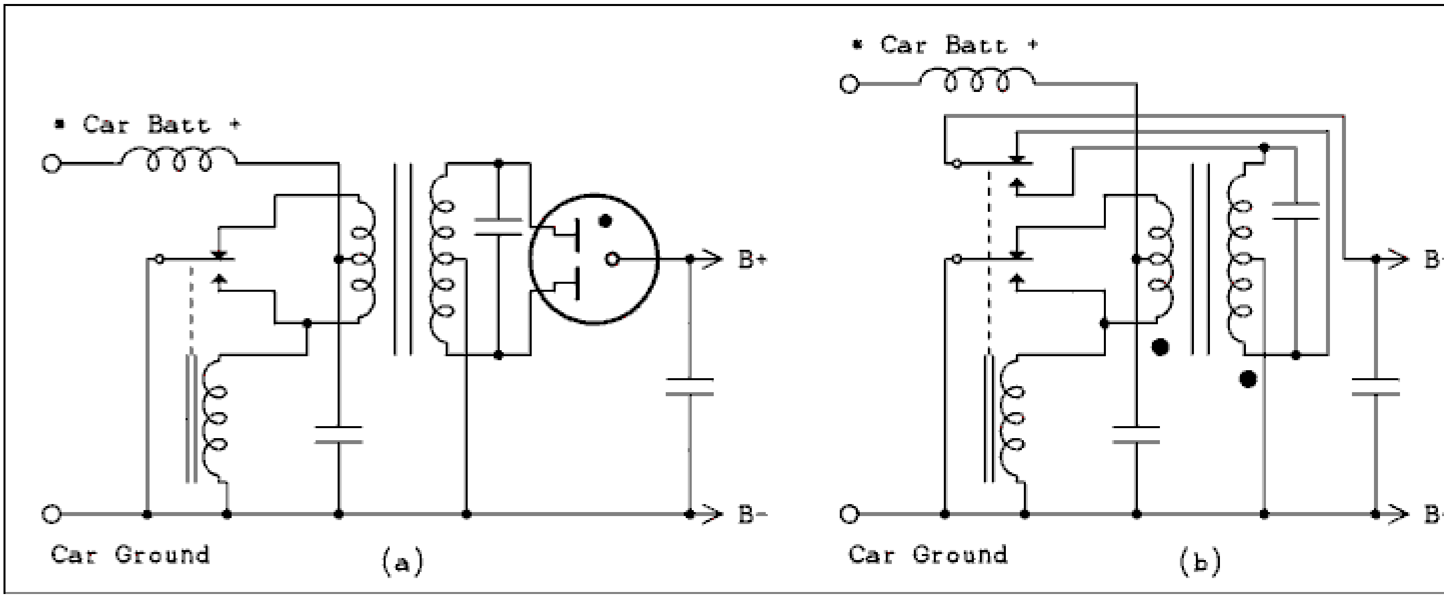

Figure 8.5 (a) Uses a Rectifier Tube, (b) Extra Contacts Accomplish Rectification.

For a verbal description click here.

Note: * Some cars in the tube era used positive ground instead of negative ground. OEM radios were properly designed for the make and model of car they were intended to fit. Some after market radios were universal while others were not. This would be a problem for the troubleshooter only if someone has tried to fit an after market or wrong model into a vintage car. Such an event is unlikely for a vintage car restorer. More on battery polarity later. End of note.

A vibrator is nothing more than a fast relay. You can wire any small DC relay so it's coil is energized through a normally closed contact. As soon as you apply the power the relay armature will change states opening the normally closed contact and interrupting the current to the coil. The contact will close reenergizing the coil and causing the contact to open again. This is an electromechanical oscillator. With most relays it will only operate at about 10 cycles per second. A car radio vibrator has been designed so the armature has a mechanical resonance at approximately 100 Hz where it operates.

The vibrator could be arranged to just turn the 6 or 12 volts of the car's electrical system on and off to form a square wave but it would have a DC component of ½ the supply voltage. This DC component would saturate the core of the transformer making it necessary to design the transformer with a larger core cross section. Rather than do that the transformer primary has a center tap which prevents a DC magnetic field from appearing in the core. The positive, or negative, of the car battery is applied through a filter consisting of an inductor and capacitor to the center-tap of the primary. The purpose of this filter is to keep vibrator hash out of the heaters of the tubes and causing interference. The vibrator contacts alternately connect the top and bottom ends of the primary to ground.

You will note that the vibrator coil is connected to the bottom of the primary which does not allow the current through the bottom half to drop completely to zero. Perhaps the primary has been wound to allow for this or maybe it just doesn't make any real difference.

Note: The circuit above shows the vibrator coil being energized from one of the contacts that also serves to switch the transformer. Some vibrators have been designed to use a separate contact for the coil which keeps coil current from flowing in the transformer. This connection is made inside the vibrator can and is invisible to the repair technician. Research has shown that a majority of radios were designed as shown above.

This continuous switching causes an alternating magnetic field to be induced in the core of the transformer which causes an alternating voltage across the secondary. The secondary has more turns than the primary so the voltage is stepped up. The capacitor which is shown connected across the secondary combines with its inductance to form a resonant circuit at the frequency of the vibrator. This attenuates the higher harmonics of the square-wave and makes it closer to a sine-wave. This gives higher peaks and hence more B+ and makes the vibrator work more smoothly.

Back in the day this was called a buffer capacitor and was a frequent cause of trouble. In fact it failed more often than the vibrator. This capacitor carries a considerable alternating current which common radio capacitors are not normally called upon to do. Replacement with an X or Y rated capacitor might be a good idea if space permits.

If the vibrator is bad you are not up the creek although vibrators have not been made for several decades. A Google search will turn up many DIY vibrator circuits as well as companies making silicon replacements. I have not included any links here because like bananas they have a way of going bad over time.

As shown in Figure 8.5(a) the rectifier tube is a 0Z4. This is a gas filled cold cathode type which is no longer available. I am told there are occasionally some on eBay but one can never tell if tubes from that source are good or not. I recommend removing the tube and soldering silicon diodes to the socket terminals. In a number of other places I have strongly recommended against this practice but the 0Z4 is an exception. Unlike a vacuum diode it's forward voltage drop is a nearly constant 14 volts. The slight increase in B+ voltage resulting from silicon replacements is not significant enough to cause trouble.

If the radio is from a 6 volt car you might be tempted to replace the 0Z4 with a 6AX5 and extend the heater wiring to the tube. The two plates and cathode use the same pins in both tubes. The heater current for the 6AX5 is 1.2 amps which will add this much current to the total radio current draw. Also the voltage drop across a vacuum diode is much greater than that across the gas filled diode it replaced. The B+ will be much lower which may adversely effect the performance of the radio. There is doubt in some circles that the 6AX5 would stand up to the vibration experienced by tubes in a car radio. Silicon diodes are the best replacement. If you don't want to solder them in you can destroy a bad octal tube and mount the diodes in the empty socket.

This circuit will deliver a positive B+ regardless of the polarity of the DC input voltage. As long as the designer didn't use the car battery voltage for bias somewhere such a radio should be universal with respect to positive or negative ground.

Synchronous Rectifier.

The circuit of Figure 8.5(b) is of a synchronous rectifier vibrator. Another set of contacts on the vibrator switches the secondary to the reservoir capacitor eliminating the need for any sort of electronic rectifier. The timing of the second set of contacts has been adjusted in the design so switching takes place when the current is zero. The advantage of this circuit is that there is one less component to fail and the disadvantage is that there are 3 more contacts in the vibrator to fail. The synchronous vibrator was also more costly to manufacture offsetting the cost of the rectifier tube.

The most important difference between this circuit and the external rectifier circuit is that the "B+" will have the same polarity as the car battery. If this circuit were to be used in a positive ground car either the primary or secondary leads of the transformer would have to be reversed. But not both. As this would not be considered by the manufacturer as a field adjustment the radio would be made for either positive ground or negative ground and substitution would not be possible. It is conceivable that a service switch could be added to the design which would reverse the leads of the transformer primary. But there is another set of contacts to shake loose and cause trouble.

The construction techniques used in a car radio are meant to withstand the heavy vibration that a radio in a car is likely to encounter. You will find things like hold down straps and springs, loops in wires that may seem unnecessary, and devices meant to hold the tubes in their sockets. The loops in wires are to prevent tension in wires that cause them to break under vibration and temperature extremes. **DO NOT REMOVE ANY OF THESE SPECIAL FEATURES.**

Other than that a car radio is pretty much standard radio. The same troubleshooting techniques and failures as an AA5 apply.

One thing that might be overlooked is the antenna trimmer. It is a screwdriver adjustment which is accessible from the outside and is usually located next to the antenna jack. To properly adjust it extend the antenna to full height and tune in a weak station near the center of the band. If no suitable station can be found power line noise can be used. Adjust the trimmer for maximum volume. Remember to use a plastic alignment tool rather than a metal screwdriver. The AGC in car radios is designed to work very well making it impossible to hear any change on a strong station when adjusting the trimmer.

Hybrid Car Radios.

My web research resulted in radios for hybrid cars rather than hybrid radios for cars. Why can't Google give you exactly what you want instead of exactly what you ask for.

A hybrid car radio is one that uses both tubes and transistors. In most examples found the pleural use of tubes was correct but the pleural for transistors was not. Hybrid car radios used 4 tubes and one transistor.

Hybrid radios for cars were produced in a very narrow time window. Research on the web resulted in spotty information at best but it appears that the first radios that used space charge tubes were produced in 1958 and the last model year to use tubes in car radios was 1962.

Space charge tubes have a very special design that permits them to operate with plate voltages as low as 12 volts. Such tubes were designed to function in a radio as the RF amplifier, Converter, IF amplifier, Detector, and First audio amplifier. In the early days of the transistor age these are the functions which transistors did rather poorly as evidenced by the performance of table and portable transistor radios from those years. Customer's expectations for the performance of car radios were, and still are, much higher than for home radios. A car radio which would not easily bring in out of town stations during the day and distant stations at night would not be excepted.

The only thing that these 12 volt tubes could not do was deliver audio power measured in watts, as opposed to milliwatts. On the other hand audio power in the single digit watts range was about the only thing that transistors of the day could do well. So the logical answer was to combine 12 volt tubes with an audio power transistor and that was exactly what was done.

The high impedance of the post detection triode was stepped down by a transformer to the low impedance of the power transistor's base. Another larger transformer matched the collector of the transistor to the speaker and they had a working radio that didn't need a vibrator to operate.

In my web research I saw someone in a forum suggest that switching transistors took the place of the mechanical vibrator in tube car radios. I have doubts that this was ever done outside of the R and D lab.

If one of these vibrator-less hybrid radios lands on your bench the output transistor is most likely to be at fault. These were PNP germanium transistors which did not stand up well to high temperatures. The only radio of this type I have had my hands on was missing it's speaker and output transformer so I junked it out. The transistor did not have a very effective heatsink. Germanium transistors are still available but they cost an arm and a leg. Substitution of a silicon transistor is possible but some reengineering will be necessary. Since both input and output are transformer coupled a change from PNP to NPN would be feasible.

FM did not appear in car radios until FM stations started playing pop and country music which was sometime in the mid 60s. By then transistors had completely supplanted tubes in most all radios including those for cars.

FM Receivers and Tuners.

Alignment of an FM receiver will be discussed after some circuit information. There are only two differences between an FM receiver and an AM receiver. The frequency range and the type of detector. The receiver tunes a range of 88 to 108 MHz and the IF is 10.7 MHz. The IF bandwidth is about 200 kHz as opposed to 15 kHz for an AM broadcast band radio. The higher frequencies make the coils much smaller but the basic principles are the same. The FM detector is another story.

FM Detectors.

There are three main types of FM detectors. The Foster-Seeley Discriminator, the Ratio detector, and the Quadruture detector. Of these the first is almost never used because it has poor AM rejection and must be preceded by very hard limiters.

The ratio detector has very good AM rejection and low distortion. It was used in most high fidelity tuners and receivers in the tube era.

The quadruture detector was developed by RCA in an attempt to get around the patents of Edwin Armstrong. The detector was used in almost all TV sets both color and monochrome. Because of the very poor sound reproduction of tube based TV sets I had never thought of this detector as high fidelity. When I had the pleasure of working on a Citation tuner I found to my surprise that it used a quadruture detector. If the Citation used it, it must have been a pretty good detector.

The Ratio Detector.

Below is the circuit of the Ratio detector used in the Stromberg-Carlson model SR-402 AM FM tuner. For a detailed discussion of the operation of the ratio detector click here. Use your back button to return here.

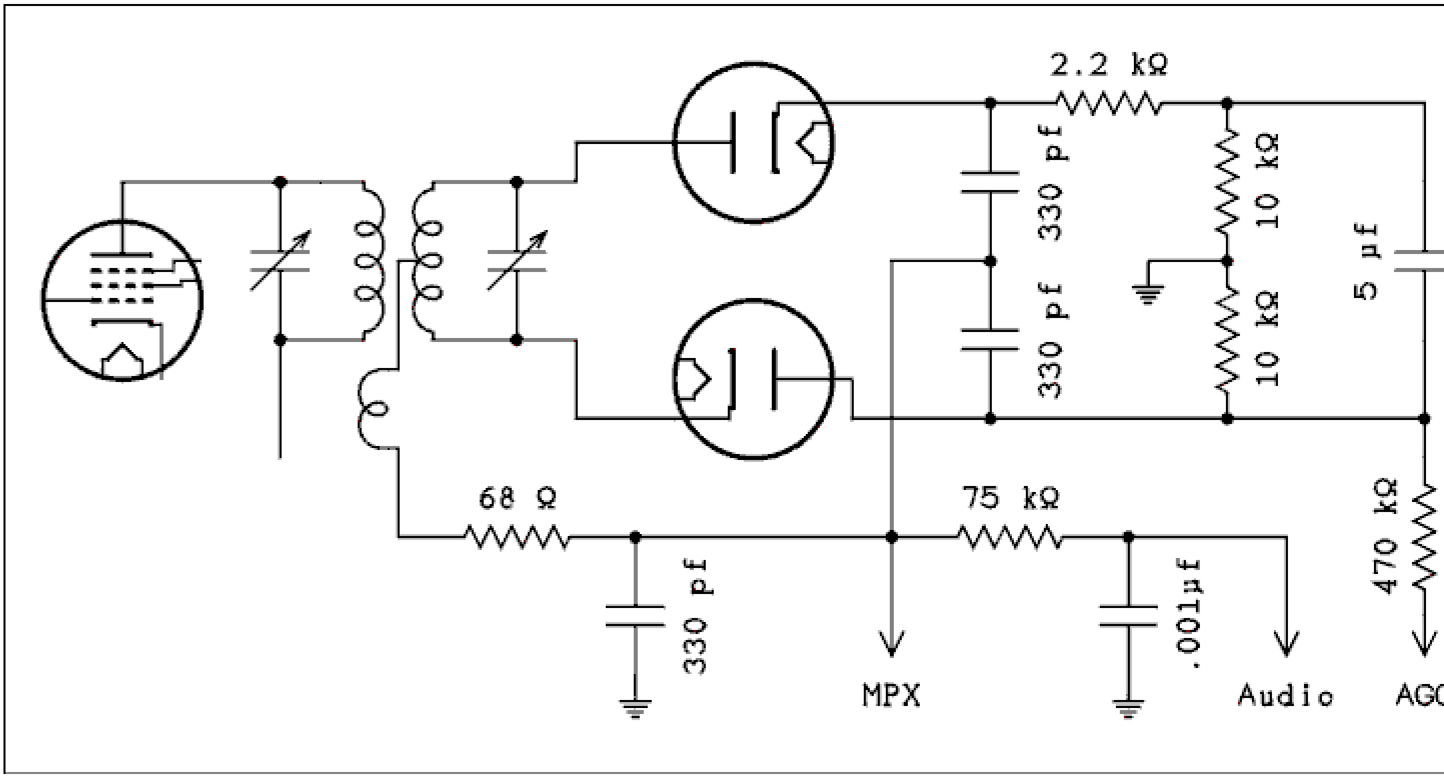

Figure 8.6 A Typical Ratio Detector.

For a verbal description click here.

This was a pre multiplex stereo model however it was on the horizon. There was an extra jack on the back which was labeled detector that mirrored the main audio output. Modifying it to bring pre de-emphasis signal to this jack was very simple.

There are no large currents or voltages in this circuit which reduces the probability of component failure. Resistors and capacitors can simply fail from old age. The most likely one to fail from this cause is the 5 µf capacitor which is a low voltage electrolytic. This capacitor in conjunction with the 2.2 k ohm resistor set the AM rejection. If the electrolytic should dry out and its value be reduced the AM rejection of the receiver will be considerably poorer than when the set was new. Do not assume that if 5 µf is good that 10 µf is better. The impedance and time constant of the circuit consisting of the 2.2 k ohm resistor and 5 µf capacitor in conjunction with the Q of the transformer secondary set the best value of AM rejection. Changing the value of the capacitor will reduce the AM rejection of the detector. In this particular case the substitution of a 4.7 µf capacitor would probably be acceptable especially since 5 µf capacitors are no longer made.

Note: In diagrams of the Ratio Detector you are likely to find in other textbooks the 2.2 k ohm resistor will be split between the top and bottom of the circuit. S-B designers are taking the AGC voltage from the bottom end of the 5 µf cap. My best guess is that if there were a resistor between the diode and this cap there would be an additional RC time constant in the AGC which might render it unstable.

The two 10 k ohm resistors are listed as 5% on the diagram. If one of them were to increase in value, a common result of old age, this would cause you to alter the tuning of the secondary of the discriminator transformer in an attempt to balance the circuit at center tuning. The effect of this would be to decrease the dynamic range of the detector possibly introducing a considerable amount of distortion.

The Quadruture Detector.

The circuit for this detector is somewhat simpler because a special discriminator transformer is not required.

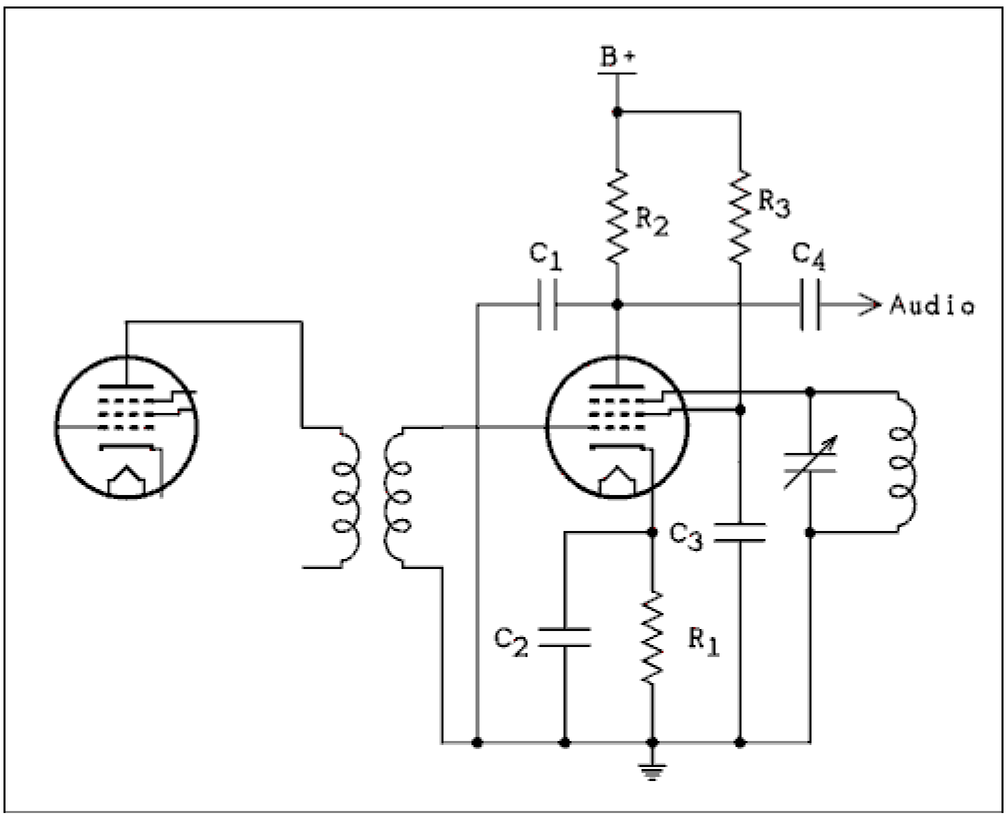

Figure 8.7 A Quadruture Detector.

For a verbal description [click here.]

As mentioned earlier this circuit is found as the detector in the Citation tuner. This detector has no output for AFC or AGC. I had no diagram of the Citation. All I did was to restring the dial cord and touch up the detector coil a bit. I don't recall if it had an AFC switch. Perhaps its designers had temperature compensated the oscillator well enough that none was required.

The internal structure of the tube used in the detector such as a 6BN6 is such that grid 3 has a negative resistance characteristic. This makes the combination of grid 3 and the tuned circuit oscillate at the resonate frequency of the LC tank circuit. When a signal is present at grid 1 of the tube the oscillator is locked to the incoming frequency. If the tank circuit is tuned to the incoming frequency the relative phase of the signal and the oscillator will be 90 degrees, hence the name of the detector.

As the frequency of the incoming signal changes the relative phase of the signal and the oscillator varies. Alterations of the phase will cause the average plate current of the tube to vary. C1 filters out the RF variations at the plate and in conjunction with the parallel combination of R2 and the plate resistance of the tube adds de-emphasis.

Both C2 and C3 must be large enough to present a low reactance to audio frequencies as well as RF. When this circuit fails, round up the usual suspects, shorted capacitors and open resistors.

FM Receiver Alignment.

Before attempting alignment of the IF strip be sure it needs it. If you remove the tubes for testing be sure to mark them so you can get them back in the same sockets. Small differences in tube capacitances can significantly throw off the alignment of the IF section.

Repeat after me.

NEVER ATTEMPT TO ALIGN THE IF SECTION OF AN FM RECEIVER OR TUNER!

"Never attempt to align the if section of an fm receiver or tuner."

I CAN'T HEAR YOU!

"Never Attempt To Align The If Section Of An Fm Receiver Or Tuner."

I STILL CAN'T HEAR YOU!

"NEVER ATTEMPT TO ALIGN THE IF SECTION OF AN FM RECEIVER OR TUNER!"

YOU ARE GETTING CLOSE, TRY IT AGAIN!

NEVER ATTEMPT TO ALIGN THE IF SECTION OF AN FM RECEIVER OR TUNER!

OK. Now remember that.

Although the drill sergeant would never put up with you asking why, I will. The why is that the IF tuned circuits are stagger tuned. That means that each one is tuned to a slightly different frequency. The purpose is to obtain a wide band response with a flat top. The Citation tuner went one step further and designed an IF amplifier that was phase linear. That is, the phase shift across the bandwidth of the IF was a straight line. They used a very high priced swept frequency instrument to align the IF tuned circuits at the factory. The high priced instrument is still available, but apparently there is no one left who remembers how to perform the alignment. My advice is "don't try it." That said, if you have a sweep frequency generator and a scope and know how to use them and the IF is so badly out of alignment that the receiver does not function then you have nothing to lose.

Other brands of FM tuners weren't so sophisticated so if you have experience in aligning stagger tuned IF strips and it is clear that the IF needs alignment then go ahead. But if you make it worse, don't blame me.

Front End Alignment.

Adjust the oscillator trimmer for best calibration at the center of the band. Adjust the RF and antenna trimmers for strongest signal as indicated on the signal strength meter, maximum AGC voltage, or maximum reading at one end or the other of the equivalent of the 5 µf cap in the ratio detector.

If the frequency calibration is way off at the ends of the band you may have to get into coil adjustment. Some tuners do have slug tuned coils. If so follow the alignment instructions for the short wave bands above.

If you aren't so lucky you will find the coils to be air wound coils. Turn spacing may look a little irregular as the factory alignment consisted of altering the turn spacing of the coil. This is how inductance is changed. Follow the alignment instructions for the short wave bands above but squeeze or stretch the coils to alter their inductance.

Detector Alignment.

Unless the tuner on your bench has been in the hands of someone who tightened up all the loose screws the IF and detector really won't need much if any alignment. In every old tuner I have seen the detector was slightly miss-aligned. You shouldn't need to turn the alignment slug more than 1/2 turn and more likely it will require less than a quarter turn.

The evidence for a misaligned detector is found by tuning across a strong local station which has only very weak signals nearby. When the detector is properly aligned you will observe three distinct listening peaks, not peaks on any meter. As you approach the signal you will begin to hear audio and it may not be distorted but it may be mixed with a little noise. The tuning meter will read quite low. As the tuning meter rises the sound will grow quite distorted. As you continue tuning the distortion will clear and the tuning meter will be at its peak. The stereo light will most likely come on. As you continue to tune the sound will once again grow distorted, the tuning meter will drop, and the stereo light will go out. The distortion will clear but the audio will be a bit noisy, and the tuning meter will read quite low.

A misaligned detector will give you two peaks and it may be ambiguous as to which one is the right one. Make small changes in the discriminator transformer or quadruture coil and tune across the station until you observe the signature of a properly aligned detector described above. If a symmetrical triple peak can't be obtained it may indicate trouble in the detector, or an IF that is seriously out of alignment.

Never adjust the detector for maximum noise when tuned off a station. You will adjust the detector so it won't detect FM at all but might detect AM if the limiters aren't to hard.

Stereo Demultiplexing.

The tube version of the stereo demultiplexer could be much more complex than the IC version. The stereo decoder in the Heathkit AR-15 outdid the tube version because it was pre IC. It worked well but had a temperature drift problem.

For a discussion of the theory of operation of FM stereo click here. Use your back button to return here.

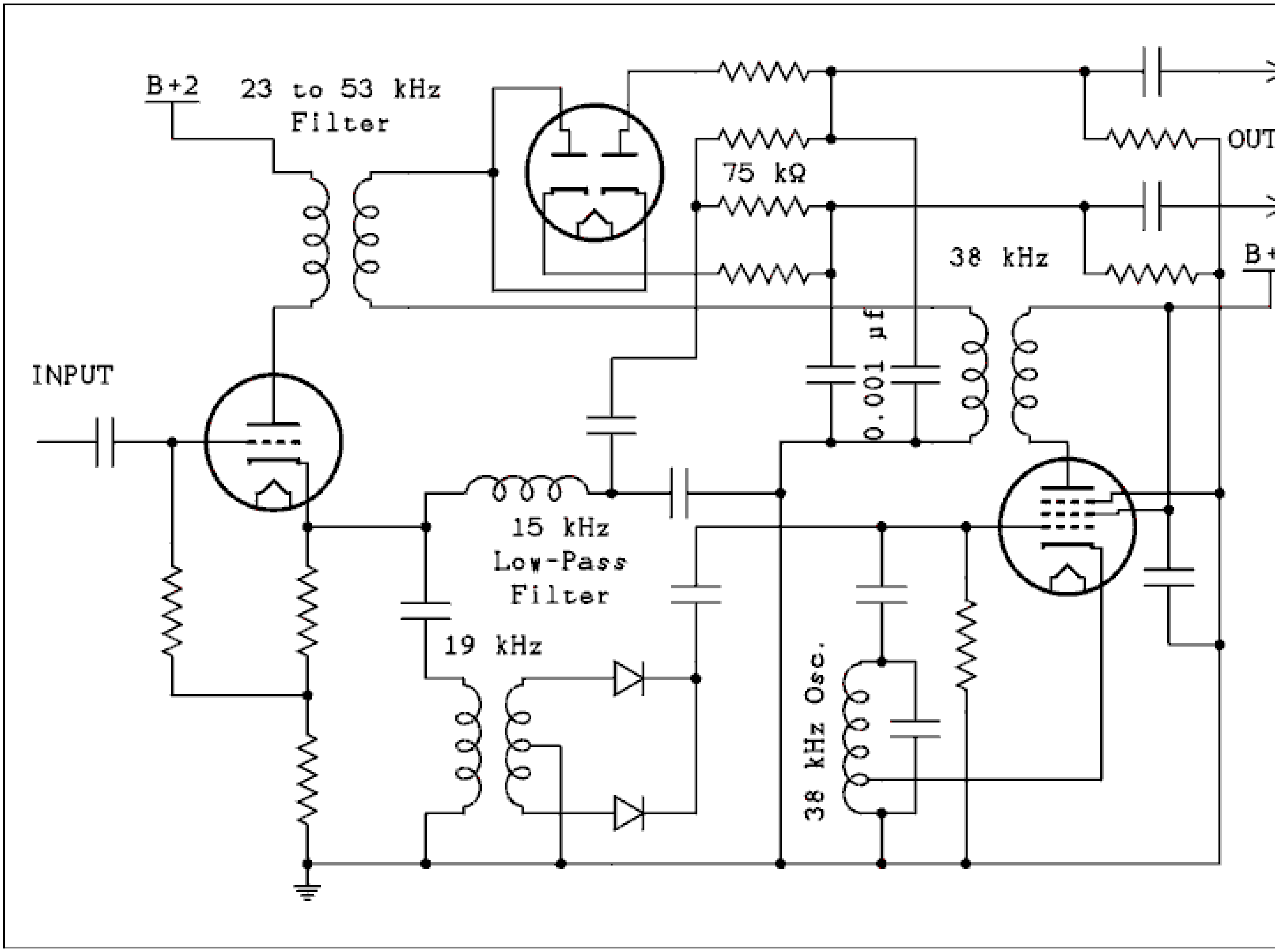

Figure 8.8 Tube Stereo Demultiplexer.

For a verbal description click here.

A typical tube type stereo demultiplexer is shown in figure 8.7 above. The input stage is a hybrid cathode follower and common cathode which provides signal to all three parts of the circuit. You will note the absents of component values. When you are working on a tuner its schematic diagram will give you the values.

Unlike the IC version the stages of the tube version are incapable of selecting the proper signal and ignoring the rest. The sum signal is separated from the others by being passed through a low pass filter which has a bandwidth of 15 kHz. This filter consists of the inductor and capacitor to ground. There is DC from the cathode follower present at the output of the filter which would upset the operation of the two detector diodes. The signal is coupled by a capacitor to the de-emphasis network where the difference signal is added and subtracted.

The 19 kHz pilot tone is taken off the cathode of the cathode follower by a capacitor which forms a series resonant circuit with the primary inductance of the 19 kHz transformer. The secondary circuit appears to be a full-wave center-tapped rectifier. That is exactly what it is however there is no filter capacitor. The circuit doubles the 19 kHz pilot to a frequency of 38 kHz. The output of the frequency doubler is fed into the grid of the 38 kHz oscillator which is a Hartley circuit. The oscillator is synchronized with the doubled pilot by a phenomenon known as injection locking. When the free-running frequency of the oscillator is close to the injected frequency the oscillator will fall into step with the injected signal. Adjusting the slug in the oscillator coil will set the phase of the oscillator with respect to the 19 kHz pilot. Proper phase is important to proper stereo signal decoding.

The wide band filter transformer in the plate of the cathode follower pulls off the difference signal. It is applied to the anode of one diode and the cathode of the other to give L - R and -L + R signals. The 38 kHz transformer in the plate circuit of the oscillator couples carrier to the suppressed carrier double sideband difference signal for proper detection by the diode detectors. The L - R signal should be the one taken off the cathode of the diode but there is an inversion from the input triode which switches the signals around reversing left and right channels.

The two capacitors block the DC from the two detectors from upsetting the bias on the next stages and the two resistors provide DC return to ground for the detectors.

As with the IC demultiplexer you can use an oscilloscope in X-Y mode to tell if the signal at the output jacks is really stereo or just two identical monaural signals. If there is no stereo or the separation is very poor a slight adjustment of the oscillator slug will bring it back. This adjustment is particularly sensitive to temperature and should only be done after a thorough warm-up. The 19 kHz transformer and the 38 kHz transformer in the plate of the oscillator will also effect the phase of the injected carrier. These transformers should be adjusted for maximum signal and the oscillator used for phase adjustment. The 23 to 53 kHz filter requires a very special sweep and marker generator for alignment. I don't think any ever existed outside of the J W Miller factory. There were very few of these coil sets made because designers came up with a less complex circuit that didn't require so many coils. If one of these goes bad your chances of ever finding a replacement are slim and none. If you are absolutely positively certain that the filter can needs alignment you might as well give it a try.

About that simpler circuit. I have it in one of my old notebooks. They are in storage until I finish building book cases to hold them. When the cases are finished and the books come out of storage I will post that simpler circuit.

Well, my books are back and I found the circuit. There are two unidentified coils and an unidentified transformer. Not only that there are several resistors and capacitors which have no value specified. That's nobody's fault but mine. I drew the diagram from a verbal description and I guess I just forgot to write them down. I hope you weren't waiting for the circuit. I'll have to see what I can brew up with some tubes and RF chokes. Oh no! Another addition to my to do list.

Chapter 9 Antique Equipment.

Chapter 9.

Antique Equipment.

Many items of tube equipment are more than 50 years old which qualifies them as antiques. If one of these items turns up on your service bench how it is treated depends on whether it has not been turned on for several decades or if it was in daily use and suddenly failed to operate. The former case is covered in This chapter.

When such an item is brought to your shop by a tearful owner who states that he or she used to listen to it at age six and asks you if you can make it work again even though it may have been stored in a damp basement or hot attic for the last 50 years you are definitely on the hot seat. Such an item requires special care.

There are many special procedures which must be followed if the item is ever to function again. Failure to observe even one of these procedures may result in serious damage to the equipment that may be difficult or even impossible to repair.

One of the many things that is unique about servicing antique equipment is that except for common parts such as tubes, resistors, and capacitors, many of the parts are simply no longer available at any price. Great care must be taken to avoid either physical or electrical damage to these parts.

Authentic Parts Verses Modern Parts.

Some restorers are nuts, that's right I said nuts, over keeping the inside of their radios authentic looking. How many people are going to be interested in looking inside a radio. OK, other restorers. If you are fixing up a radio for competition you will need to be nuts. But most of us just want the radio we found on eBay that is the same make and model on which we used to listen to The Loan Ranger to work and we don't care if it has dog bone resistors and capacitors that look like they are wax paper even if they are plastic on the inside.

In the final analysis you have to decide just how authentic you want your treasured radio to be.

If you are doing the restoration for someone else you must be sure that you and the owner are in agreement about the degree of authenticity. Be sure that the owner understands that as the radio becomes more authentic that the bill will rise. Failure to communicate may result in you having a very authentic radio on your hands with hundreds of dollars of your own money wrapped up in it with no way to recoup your losses.

Authenticity Verses Safety.

In this area I am absolutely adamant. Safety always trumps authenticity when ever and where ever they come into conflict. The example that is most often sighted is the All American Five radio. There were millions of these produced in the years roughly between 1945 and 1965 and there are still hundreds of thousands still in existence and in more or less working order.

Their danger comes from the fact that the chassis is connected to one side of the power line through the off/on switch. You may find that the chassis of the radio has 120 volts between it and an earth ground such as the kitchen sink. I hope you didn't find this out the hard way. So you do the logical thing and reverse the plug in the socket. All is fine until you turn the radio off. Then you find that there are 120 volts between the radio chassis and ground. That's right, you can't win. The chassis is "hot" no matter which way the plug is inserted in the socket. Detailed rewiring instructions with diagrams will be given in the section on post WW II radios. This is one area in which authenticity MUST be sacrificed for safety's sake.

For additional information on tube amplifier and radio circuits see The Fun with Tubes website. Also see Electronics for Physicists particularly chapter 4A.

Back to Fun with Transistors.
Back to Fun with Tubes."

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Back to top.

9.1 Before Turning on the Power.

There are certain dos and don'ts that should be observed when working on any piece of antique equipment. They are as follows.

1. Don't plug it in and turn it on.

2. Do replace paper and electrolytic capacitors and selenium rectifiers.

3. Do check all resistors for value and replace if more than 20% high or low.

4. Do check the power transformer by applying power with all tubes removed from sockets.

Replace Capacitors and Selenium Rectifiers.

The photographs below show examples of the capacitors that should be replaced.

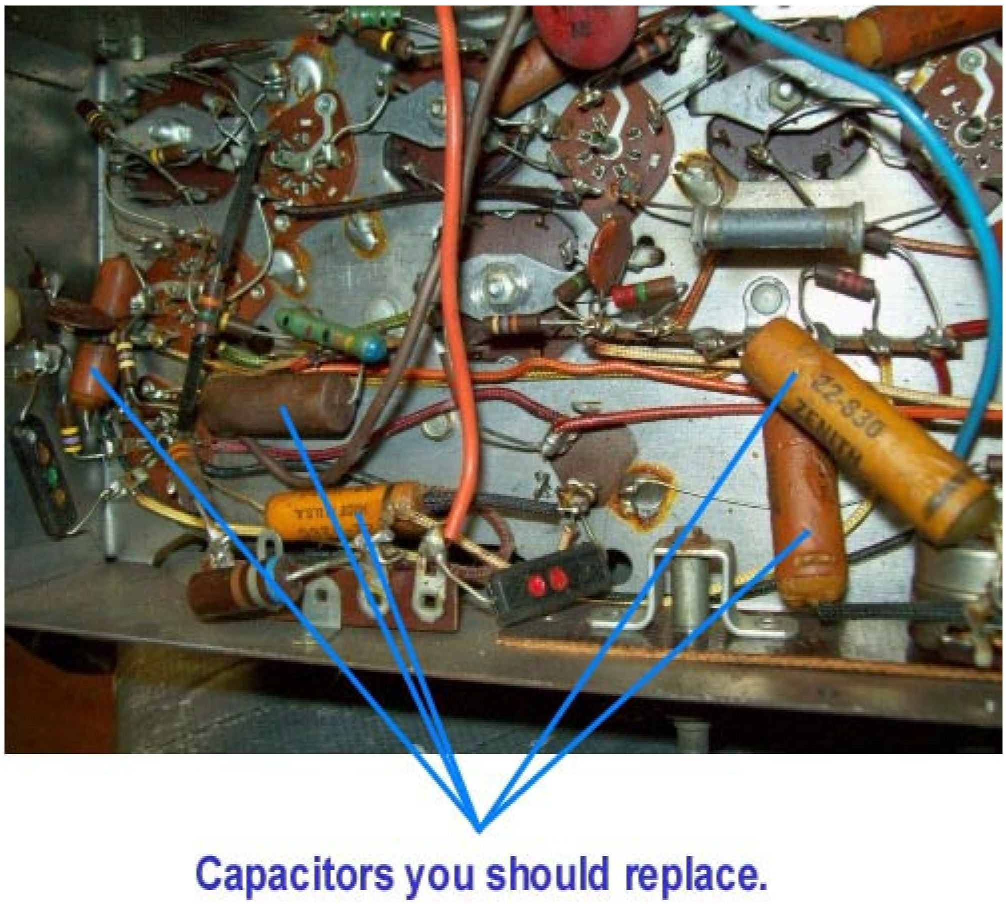

Figure 9.1 Paper capacitors in a radio chassis.

These are wax paper capacitors. They are not just wax paper on the outside, they are wax paper on the inside as well. Refer to the construction of a capacitor in chapter 3. Instead of plastic film these capacitors use wax paper which is not unlike the stuff your mother used to wrap your school lunch sandwiches in. Paper is a hydroscopic material which means that it likes water. The wax is supposed to prevent the absorption of water but it won't work forever. Over time moisture in the air seeps into the capacitor and gets absorbed by the paper and its insulation property is compromised.

Capacitors are supposed to be a totally open circuit for DC but a paper capacitor conducts some DC current. This is referred to as leakage current and a capacitor that conducts is said to be leaky.

When you find these capacitors in radios or other old equipment replace them with modern plastic film capacitors. Don't bother testing, don't turn it on to see if it will work, don't hesitate, don't ask, don't tell, just replace them.

The photo below shows some capacitors that look nice but they are wolves in sheep's clothing. Or paper capacitors in plastic clothing.

Figure 9.2a Black Beauty and Paper Capacitors.

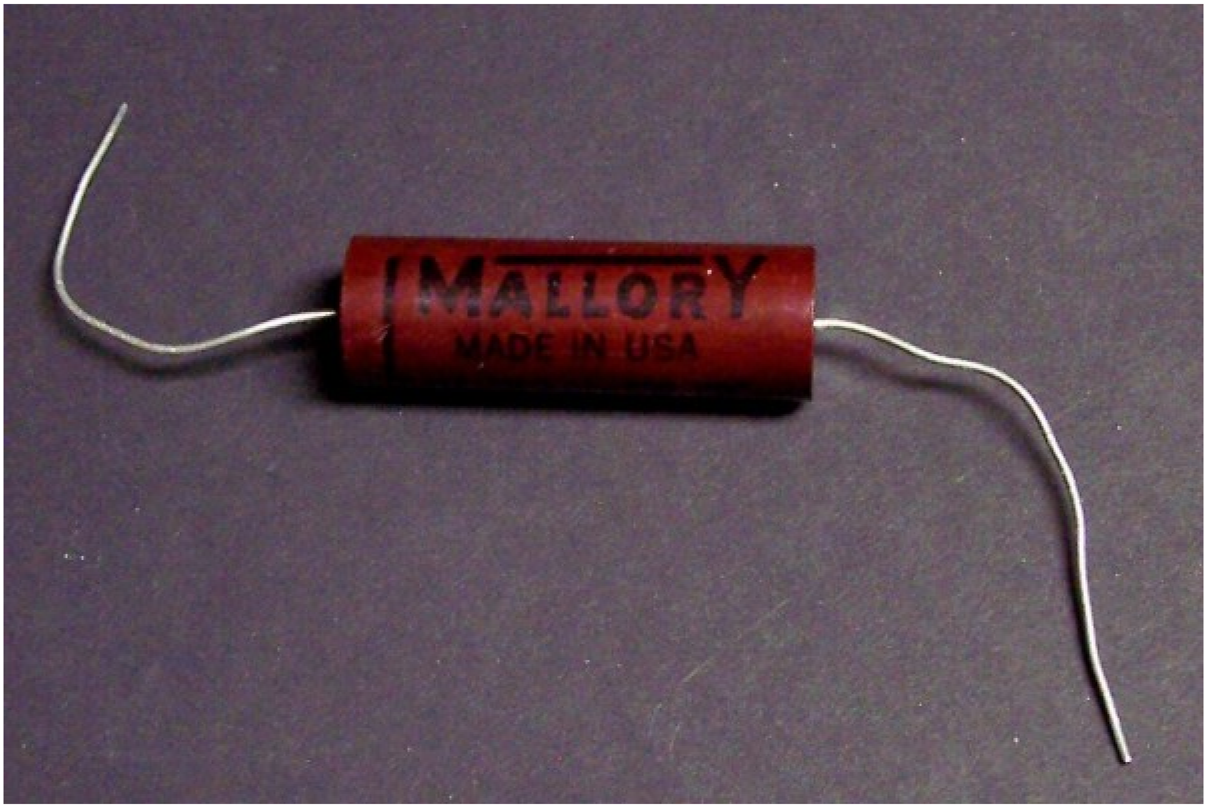

Figure 9.2b Dark Red Mallory Paper Capacitor.

The one on the left in Figure 9.2a is a 47,000 pico farad, center is a 6800 pf and the one on the right is unknown. The 6800 pf is really blue, gray, red, but the blue and gray didn't translate well to the internet.

The oddball on the right is disguised as a mica capacitor but it is nothing more than alternate stacks of foil and wax paper. True mica capacitors rarely have to be replaced but the paper ones are usually thicker than mica. True mica capacitors are not very thick.

The type of capacitor shown in Figure 9.2b are especially troublesome. In the mid 1960s, 50 years ago, I stocked up on these thinking they were good capacitors. They were at the time but time has been their enemy. They look really good. The ends of the plastic tube are filled with epoxy and they even test good on a digital RLC meter. The only clue that something is wrong is that the value reads out of tolerance high. I just finished going through them and they are 100% too leaky to be used in any circuit. Every last one out of more than 200 capacitors was bad and had to be thrown away.

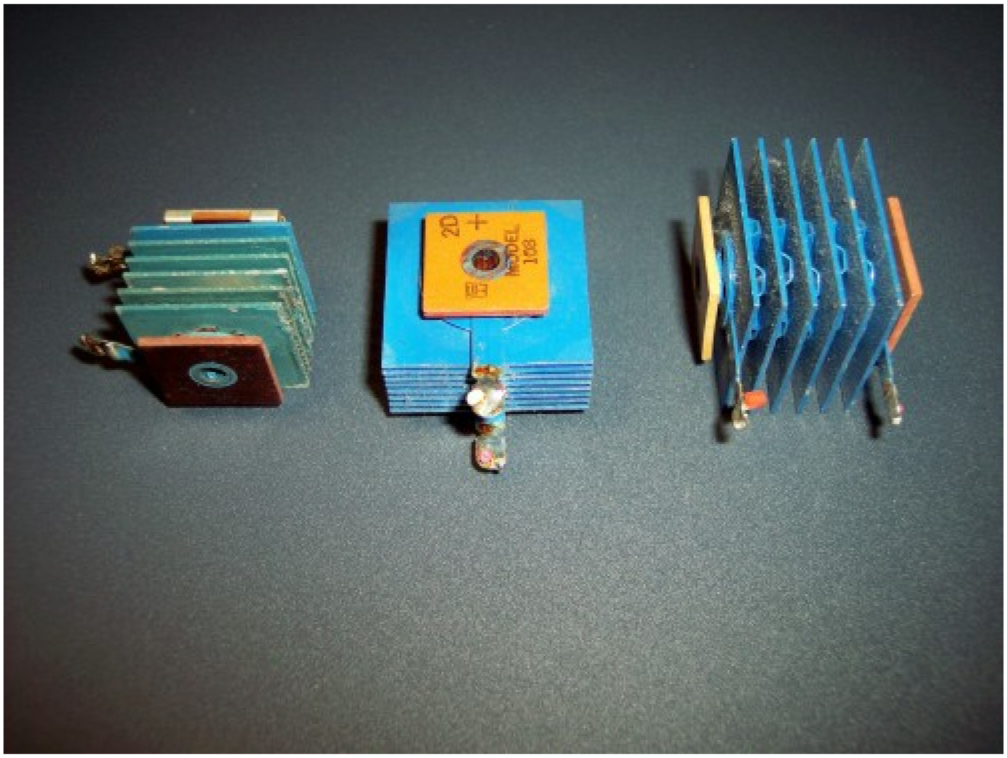

Figure 9.3 Selenium Rectifiers.

Something else that should be replaced before turning on the power are selenium rectifiers. Selenium dioxide is not just a bad smell it is a rather deadly poison in high concentrations. Replace them with silicon diodes and a series resistor. More about this when 3 way portables are covered. Use the rectifier's mounting screw to mount a terminal strip and solder the wires, the resistor and silicon diode to the terminals.

Never, never, never, solder the diode across the terminals of the rectifier. It is going to short out some day and the results will certainly be catastrophic.

The section below was written by Mike (Mac) McCarty. Mac is a regular contributor to the Fun with Tubes email forum and Is highly knowledgeable in the areas of electricity, electronics, and mathematics. He has so many cogent thoughts on questions that are asked on the forum that I have prevailed on him to become a contributor to this book. I was going to write this section myself but when I remembered that Mac had written something along the same lines I read it over. I can't improve on what he said so why should I try to reinvent the wheel? I now place you in Mac's capable hands.

Max Robinson.

Steps To First Power On.

by Mike (Mac) McCarty.

***** C A U T I O N *****

The high voltages associated with the older tube type equipment CAN KILL YOU!

Before I get into trying to power up a piece of equipment (especially an old tube type) that hasn't been powered up in quite some time, let me say that I presume that the person performing these steps is aware of the dangers presented by high voltages, and is capable of using high voltage power supplies safely. If you have any doubts about your ability to take measurements of high voltages including AC line voltages, then do not perform these tests. Get someone else who is comfortable and experienced with high voltages to do them for you.

Disclaimer.

This little missive surely contains a mistake, or omission, or requires some other polishing. It is assumed that the reader has some electronic theory background. So use this guideline at your own risk. No one associated with the development of this document assumes any responsibility if you electrocute yourself, wife, cat, or dog.

Introduction.

You've acquired a "new" piece of vintage equipment and want to restore it to service. What steps should you follow?

There are several ways to power up a piece of equipment that hasn't been used in a long time.

1. The quickest and most likely destructive way, is just to plug it in and turn it on. This can result in anything from a working unit, to blown fuses, or smoked parts. NOT a good method.
2. Another method is to use a light bulb limiter. This does not allow high current, even if there is a short in the piece of equipment being powered up. The light bulb is in series with the piece of equipment under test. So if the equipment has a short, the only current that flows is that

required to light the light bulb. For a 60 W 120 V bulb, that is 1/2 A.

A good rule of thumb is that a light bulb limiter allows a maximum of about 40 % of the lamp's rated power to be dissipated in the load.

For information on building a light bulb current limiter see:
Light Bulb Current Limiter.
Or Current Limiting with a Dim Bulb Tester.

Though this method has much to recommend it over just plugging in the equipment, by itself it is not enough to ensure that the equipment does not get damaged.

3. Another popular method is to use a variac to slowly bring the voltage up to "reform" the filter capacitors. Electrolytic capacitors have a tendency to loose their ability to store a charge if they have been lying around, not used, for a long time. I DO NOT RECOMMEND "bringing up voltage on a variac to reform capacitors". That is not a proper way to reform electrolytic capacitors.

Especially when the rectifiers are tubes, attempting to use that method can seriously shorten the lifetime of the rectifiers. Pulling current from the cathode of a rectifier running with reduced heater voltage can damage or destroy it.

Properly reforming electrolytic capacitors requires a current limited power supply, which a variac run through a transformer and rectifier is not. For more information on reforming electrolytic capacitors refer to Restoring Dead Capacitors.

This technique is superior to just plugging in the equipment, but it is also not enough by itself to prevent damage to the equipment.

4. The recommended method takes a lot longer than the previous methods, but definitely reduces or limits the chances of doing any damage to the equipment. This requires disconnecting many parts of the equipment. Because of this, remember - the high voltages used in the old tube type equipment CAN KILL YOU. So proceed at your own risk.

Preparing to power vintage tube equipment for the first time.

Before beginning work on vintage equipment which has not been powered in some time, first remove all tubes, and mark them as to where they go. Sometimes "identical" tubes don't perform identically. If you remove an IF amplifier tube from an FM set, you may need to tweak alignment if you replace it with an "identical" but not the same tube.

The heart of any piece of equipment is the power supply, and until the power supply is working properly and supplying proper voltages at adequate currents, one cannot hope to try to troubleshoot any of the other stages. Power supplies are like Mama. If Mama ain't happy, ain't nobody happy! So, I recommend you start with the power supply stage(s).

Preparing the Power Supply.

Power supplies often supply several different voltages at different currents. Usually, there are one or more heater or filament supplies which may be AC, and one or more high voltage DC supplies, usually called something like B+1, B+2, etc. Since a variety of voltages is supplied, and also to provide isolation from the AC line, such power supplies usually contain a transformer with separate windings for each heater or filament supply, and one or more high voltage windings, usually center tapped, with a rectifier followed by filtering stages, and sometimes voltage dividers, to supply the various B+ voltages.

Many low end vintage radios have a so-called AC/DC power supply, that is a power supply without a transformer. If this is the case, then one may skip the steps necessary to test the transformer, and check the integrity of the insulation. Look down below to the section Testing the Input Side of the Power Supply. However, spend the time to read and understand the intervening sections, even if you are dealing with an AC/DC power supply, since the principles apply, and some of the techniques are used, in AC/DC supplies as well.

Otherwise, the first step in preparing the power supply is to test the transformer and ensure the power supply is safe to plug in.

Testing the Transformer.

This describes how to check a "characterized" transformer, one whose characteristics are known. It's behavior is characterized, it's a known item, or one which is installed into a piece of equipment which is characterized, and from which we can derive approximate characteristics for the transformer.

If the transformer is "bare", we have no information about it other than perhaps some meaningless (to us) OEM part number, and it is "bare" in the sense of just the transformer, no equipment it is installed in, so we can't guess, except very vaguely like by its weight, what its characteristics might be, then some other checks must be performed.

However, since the transformer is in a piece of equipment which we want to power up, we omit some steps necessary for uncharacterized transformers in this procedure.

1. Disconnect all windings from their sources or loads, or ensure that they were effectively disconnected when the tubes were removed, then test each winding for continuity using a multimeter. If any winding is open, then obviously there is a problem.

The resistance of the primary of a transformer intended for 120 VAC is usually of the order of tens to perhaps low hundreds of ohms. The higher the power, the lower the resistance, and high power transformers may have primary resistances of just a few ohms. Transformers for 240 VAC have primary resistances about double that of transformers for 120 VAC.

Heater and filament windings are usually much less than one ohm, and just a continuity check is all that gets done here.

The high voltage windings are usually center tapped, and may have resistances on the order of hundreds to a few thousand ohms.

Check for the center tap to be roughly centered for resistance. It will not be exactly balanced for resistance, because the winding is wound in layers, and is balanced for turns. The length of wire required for the outer turns is greater than that for the inner turns, so the tap is not precisely balanced for resistance.

2. Check the integrity of the insulation between the various windings, and the core. To do this, apply a high DC voltage, of the order of 400 VDC, using in series a neon test lamp with integral resistor. Do not exceed the capability of the neon lamp tester with the DC voltage used for insulation tests. These lamps are available at many

auto supply houses, or in the automotive section of Wal-Mart. This type of tester or equivalent is what you need:

Figure 9.4 Photo of Electrical Test Lamp.

Similar devices are available from [Glow Circuit Tester.]() or [Circuit Tester.]()

Check the test lamp, to make sure it lights up, by attaching one terminal of the power supply to a winding, the other terminal to the test lamp, and probing another end of the winding with the free probe of the test lamp. The test lamp should light indicating that there is a good connection. We don't want to think the insulation is good, when in reality it was not good, but the lamp didn't light because there was a bad connection to the winding. This check to ensure that the lamp lights up must be repeated for each winding connection.

Now, again using the free probe of the test lamp, probe all other winding ends not part of this winding, and the core. Expect to see a single flash, as the inter-winding capacitance (or to core) charges, and then little or no glow after that. If the lamp glows continuously, then there is an inter-winding short, or short to core. Such a transformer is not safe, and must not be used until the short is corrected, or the transformer must be replaced.

Note that some transformers use a single lead connecting to an internal shield, which may also be connected to the core. This lead is often uninsulated. I mention this so you won't think that there is a short from a winding to the frame, when you are actually just probing the shield, which may be intentionally connected to the core.

Repeat this test on every winding on the primary and the secondary side of the transformer.

Before applying 120VAC power, if there are line filter capacitors present on the primary side winding, then they must be replaced before doing any full power tests. This means that, if the capacitor is only across the line power, it must be X2 rated. If one or more connects from either side of the line to ground, or to the chassis, it must be Y2 rated. Below are some examples of X and Y rated capacitors.

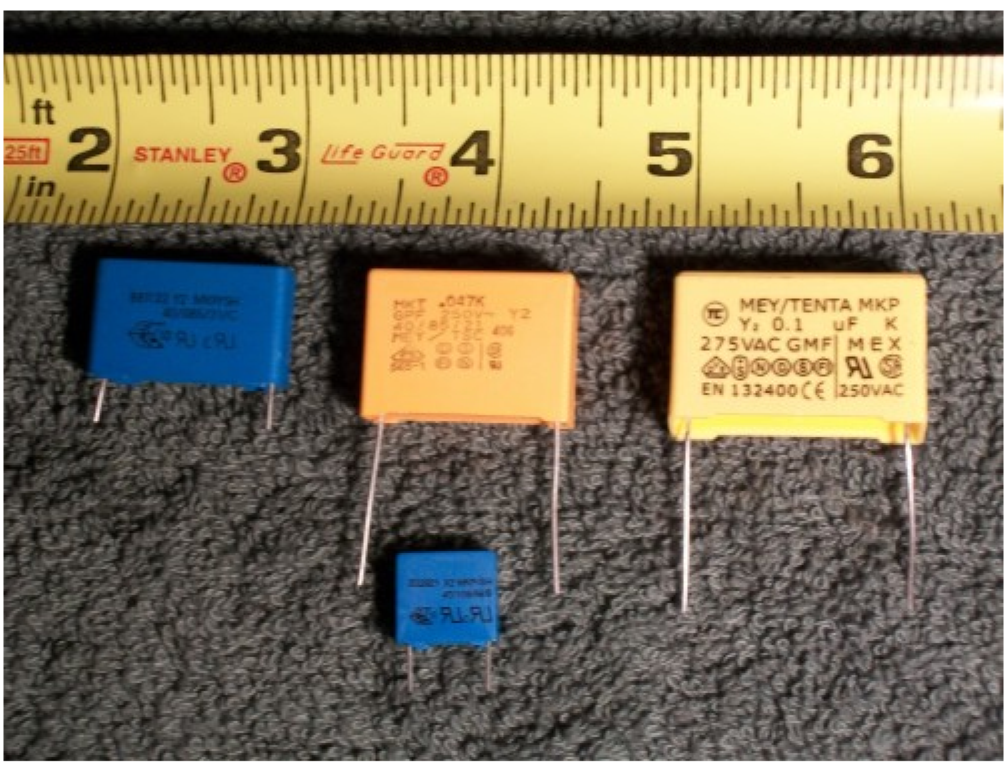

Figure 9.5 Photo of X and Y Rated Capacitors.

The capacitors are, top left to right 0.047 uf Y2 250 VAC, 0.047 uf Y2 250 VAC, 0.1 uf Y2 275 VAC and the smaller one below is 0.047 uf X2 305 VAC.

This needs to be done between reattaching the primary winding to the switch, fuse, etc. present in the primary side and any further testing on the primary side.

Also, rarely but occasionally, there are paper capacitors in the power supply on the secondary side. These must be replaced with modern films before powering up the entire supply.

- After verifying insulation integrity, try verifying voltages, and balance for tapped windings.

Instead of using 120V AC, try applying 12 VAC to the primary. This makes it easy to compute voltages at 120 VAC, and yet not deal with high voltage unnecessarily. Apply the voltage through a 12 VDC automobile tail lamp. If the lamp lights, there is a problem. If not, then check the windings to see that they produce approximately 1/10 normal voltage, and that center tapped windings are balanced for voltage. If all looks well, then you are ready to apply full voltage.

The full voltage is applied to the primary through a lamp current limiter. I use a 120 V lamp, and check for shorted windings this way. A variac is optional, but the lamp is not. I usually start with a 7 W lamp for small transformers, and a 40 W lamp for larger ones. Apply 120 VAC through the lamp, and expect to see little or no glow. With a 40 W lamp, you should expect to see no glow. If I use a variac (not usually, but sometimes) I ramp it up fairly quickly to 120 VAC.

If the lamp lights, then there is a shorted winding somewhere, or the transformer is not truly isolated from the circuit, or the voltage is applied to the wrong winding.

If all looks well, then another voltage check is done, and voltages should be somewhat high. For example, a 6.3 VAC winding may read 7.5 VAC with no load. To avoid unnecessarily checking high voltages, check tapped windings only from the tap to each end, and not end to end.

At this point, we have a working transformer. Reattach it, and then start to check integrity of insulation to chassis.

Testing the Input Side of the Power Supply.

Using the same neon lamp technique as above, check the insulation from each side of the power line to the chassis. If all looks good, then we are getting close.

Check the fuse, and the power switch with a ohmmeter. Measure from prong to prong on the power line cord, and ensure that the switch can make it open, and also go down to the previously measured resistance of the primary, plus an ohm or two for the fuse. If this is an AC/DC power supply, then replace any line filter capacitors, or one across the rectifier(s) connected directly to the line with X2 rated capacitors as described in section 3 just above.

Testing the Output Side of the Power Supply.

The next step is to investigate the secondary side of the power supply, that is the rectifier(s) and filter. Check all resistors and filter chokes for in tolerance resistance. Disconnect any filter capacitors, and disconnect all B+ outputs, and any resistive dividers, and check integrity of insulation to B- and chassis (if different), using the same neon lamp technique described above. Don't exceed the rating of the components of the rectifier, however.

1. Attempt to reform the filter capacitors.

Any electrolytic capacitor which has been out of service for two years or more needs significant reforming before having full voltage applied to it. Some restorers don't like to reform capacitors if they've been out of service for several years, and simply replace them. In that case, the replacements must be reformed. One doesn't know how long an electrolytic capacitor may have been sitting in a vendor's shelf. If it's two years or more, then it needs reforming. That information comes from several manufacturers, like Sprague, Hitachi, and Nichicon. All agree with that assessment, and I believe them.

Reforming of electrolytic capacitors is worthy of a missive on its own, and is not covered in detail here. See Restoring Dead Electrolytic Capacitors, which describes some acceptable ways to reform electrolytic capacitors.

You may expect the reforming process to take a period of at least five minutes plus one minute per month of storage. So, if the equipment has not been powered for 20 years, expect to spend about four hours or more reforming.

After the filter capacitors are reformed (and possibly replaced) they can be reattached to the circuit. Then measure the actual resistance between B+ and B-. The positive probe from the multimeter goes to B+, the other to B-, observing polarity. That's not necessarily across the filter caps, since some sets use B- filtering or other unusual circuitry. The idea is to protect the rectifier. I've measured from the rectifier cathode to the return connection on the transformer (likely center tap of the HT winding). That's probably the best way. You want to see how much current the supply is going to demand from the rectifier. It'll take a while for the capacitors to charge up, so the reading will start out low and increase. Some meters reverse the polarity on ohms to that on volts, so that the black lead is positive. Check your meter.

The ultimate purpose, since we've already checked the capacitors themselves by reforming them, and also checked the insulation using the neon bulb, is to ensure that we haven't inadvertently introduced a short or near short into the supply when reattaching the caps.

The ohmmeter likely will read a low resistance, which gradually increases as the filter capacitors charge. Wait for the reading to stabilize. It should be such that not more than 2 mA of current would flow at full B+.

2. If that's met, then I attach any resistive dividers, and it's time for First Power On of the power supply only.

If the rectifier is a tube, I install it after checking it for shorts. See below for how to do that. No other tubes get installed.

Ensure that the Device Under Test is not between you and the door.

With the possible assistance of a variac but definitely with a light bulb current limiter of appropriate rating, I apply power to the power supply. A bulb limiter permits a maximum dissipation of approximately 40 % of its rating. So, a 100 W bulb would permit a maximum of 40 W or so. That's too high for a First Power On. I normally start with a 20 W to 40 W bulb. If I use a variac, I ramp it up over a space of perhaps five or ten seconds to full voltage. Normally, I just use the switch on my bulb limiter.

The light bulb current limiter may light to perhaps yellow brilliance for a couple of seconds, then dim down to no more than a dull red glow. If that passes, then I check output voltages. They should all be "ballpark", but somewhat high. If that passes, then the power supply is probably in pretty good shape. If the output voltage has not risen to the point where it's not good for the filter caps, then I'll leave it that way, on a bulb limiter, for a few hours, to weed out any sudden changes which may occur.

So far, all that works is the power supply. It's time to move on to Part II, powering the equipment with the power supply connected to a load.

Good, we now have a working power supply. However, it still isn't time to plug the equipment in and turn it on. It may be that it was simply superseded, but the chances are that it was retired for a reason. Even if the equipment was in reasonable working condition when it was retired, there are components which deteriorate although they are not in use.

Many who have not dealt with vintage tube equipment much are inclined to believe that the tubes need extensive testing, or are likely to be bad. This is usually not the case. Tubes are essentially low power and low temperature light bulbs. Even the very early ones, like the 201, though they are not low temperature, are still essentially light bulbs. Light bulbs do not go bad sitting on a shelf.

There are three kinds of vintage components which are likely to be bad in vintage equipment. These are electrolytic capacitors, paper capacitors, and resistors. So, let's handle these likely problem spots first.

The case for electrolytic capacitors has already been covered in the description of preparing the power supply. They must be reformed or replaced. If they are to be replaced, then the replacements must be reformed before putting them into the equipment.

Paper capacitors are commonly subject to two kinds of deterioration. There are others, but these are the most common.

Power line filter capacitors are subject to other stresses, but we covered replacement of them above.

One is electrolysis which takes place in the oils and waxes of the capacitor when it has a DC voltage impressed upon it. The other is corrosion which is a result of residual water which remains in the paper. Paper is extremely hygroscopic, and even when the paper has been dried by heating in a vacuum, as was done when papers were the common capacitor, some still remains. This corrosion takes place even when there is no voltage impressed upon the capacitor.

For this reason, all paper capacitors must be replaced. Some try to replace only those needing it, or to "save" them. I did that when I first started restoring vintage equipment to service, but found that, when the capacitors were properly tested at their rated voltage, 97 % of them were leaky. Even if they are not leaky enough to require replacement at the time the equipment is received, they will become so with use. They are like time bombs waiting for the moment when they explode. When a paper capacitor becomes leaky, the consequences may be disastrous for the equipment. They were commonly used for coupling capacitors from plate to grid. If one of them becomes leaky, it may cause a power amplifier to pull sufficient current through an output transformer that it damages the transformer. Transformers are expensive, when obtainable.

If you want to retain original look, then re stuff with Modern film capacitors. They are smaller than the originals, and can be put inside the old outer wrap. This procedure is not covered here, but it is not difficult, though it is time consuming. The same is true of electrolytics. Modern electrolytic capacitors may be fitted inside the cases of vintage electrolytics.

The third commonly bad component type is the carbon composition resistor. All resistors, carbon or not, should be measured to verify that they are within tolerance. It is very common for carbon composition resistors to change values, almost always increasing in resistance, sometimes by orders of magnitude.

I realize that some equipment may have hundreds of resistors. However, it is much easier to troubleshoot equipment when the easy to find problems have already been repaired. A screen resistor being two orders of magnitude higher than it should be can make a tetrode act like a triode, introducing weird "birdies" into a receiver, because it now requires neutralization, and there are no neutralizing components present. It's much easier just to measure a resistor, find it out of tolerance, and replace it, than it is to track down a birdie. A cathode resistor which is five times as large as it should be can reduce gain to unacceptably low levels, causing the equipment to work, but not work well. Partially functional equipment is hard to troubleshoot.

If you absolutely just can't wait, then perhaps you should be doing something besides restoring vintage equipment. There are many aspects to restoring vintage equipment to service which require patience. Knobs, for example, often require special care and time to remove without damage. Often switches or other controls have frozen shafts which require time and deliberation to free up.

Flexible wire resistors, looking like a piece of insulated wire, often with a terminal on each end, are subject to being open. I recommend checking all resistors for being in tolerance. Note that vintage parts often do not have the same appearance as their modern counterparts. If you are going to work on pre WWII equipment, then I suggest you familiarize yourself with the appearance of vintage components, like dog bone resistors, wire wound resistors which look like half of a mica capacitor having dots on them, and so on.

Something especially to watch for are paper capacitors having the appearance of a vintage mica capacitor. These usually have the trade name "Mica Mold" stamped upon them. While paper capacitors are frequently bad, and need replacement in any case, mica capacitors are very stable, and rarely need replacement. Ceramic capacitors, which often look similar to dog bone resistors, are also very stable, and normally do not need replacement.

The way to discern these is that vintage mica capacitors have reddish brown cases, but the paper capacitors mimicking them have black cases. Also, the dot in the upper left corner is a different color. So, familiarize yourself with the appearance of vintage components.

There is one other thing which requires checking before powering the equipment up as a whole. That is, the tubes need to be checked for shorts. This does not mean you have to have a tube tester. The reason tube testers exist has always been to sell tubes, that is to encourage customers to purchase replacements for otherwise perfectly functional tubes. If you were a repairman working for pay on someone else's set and wanted to maximize your profits, this would make sense. You are working on your own equipment and not for pay, and any tube replacements are going to come out of your own pocket.

What I suggest is to use test equipment similar to that used for checking the insulation resistance of transformers. Use approximately 100 VDC to 200 VDC and a neon test lamp with integral current limit resistor. Check each pair of tube pins which are not supposed to be connected internally. The lamp should not light.

Now, any reasonable tube tester can do this, perhaps a little faster, perhaps not. If you want a tube tester, then certainly feel free to use one to do at least the "shorts" test. If you want to do more extensive tests, then I can recommend one to use the Sencore "Mighty Mite" line of emissions testers for shorts, for rectifiers and other power tubes' emission, and for the grid leakage test for non rectifier tubes, at which it is superb. For testing gain, the Hickok circuit, used in certain Stark testers from Canada, is also excellent, and the Stark line, while internally a Hickok, will not cost nearly as much. However, bear in mind that the best test of the functionality of a tube is the equipment into which it is going to be placed. Unless a tester complains about shorted elements, or the tube has an open heater/filament, do not discard it just because a tester says to do so. Also, do not expect that a tube will perform adequately simply because a tube tester indicates "GOOD".

At this point, reconnect all the power supply connections, and re insert the tubes into their respective sockets. We are now ready for a true First Power On. Ensure that the equipment is not between you and the door. You should have a Master Power Off switch which is accessible from the door, and certainly not requiring you to reach over the equipment to reach it. Many like to use a variac, and if you wish to do so, then it comes first in the power chain. Next, and not optional, is a lamp limiter. Select the lamp to have a power rating approximately twice the expected power consumption of the equipment, or perhaps a little more. If the equipment to be tested has an AC/DC supply, then an isolation transformer comes between the variac and the bulb limiter.

Set the variac, if used, to minimum voltage. Turn the lamp limiter off, and set it to limit. Plug in the test equipment. Plug in the equipment under test to the test equipment, and turn it on. Turn the lamp limiter on, but leave it set to limit. If a variac is used, then ramp the voltage up to full voltage over a period not to exceed about thirty seconds.

Expect to see the limit lamp to light to perhaps half brilliance for up to several seconds, perhaps ten or so, and then dim down to yellow, and then to dull red glow. If the lamp lights brightly, or if the glow does not dim fairly rapidly, then there is a problem, which must be investigated. However, if the First Power On succeeds, it's time to start to do initial checkout, and troubleshoot any remaining problems in the equipment.

The equipment will probably function somewhat even with a limit lamp, and I normally will use a receiver and check each function, band, tone control, etc. If it appears that the equipment is mostly working, then I'll use it for a period of a few hours with the limit lamp to weed out early failures. If all looks good after that, then I'll set the limit lamp to full power, and after a few moments, begin real checkout.

Checkout and troubleshooting are outside the purview of this document, but a reasonable first step is to measure all socket voltages and ensure that they are all within 10 % or so of nominal. One thing to watch for is that often vintage equipment literature specifies a 1000 ohms/volt or 5000 ohms/volt sensitivity meter when making measurements. Use of a modern 10 Meg ohm meter would show all voltages as being too high. Parallel your meter with an appropriate value and rating resistor to avoid this problem.

Congratulations on successfully powering your equipment without damaging it!

Thank you Mac.

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9.2 Pre 1930 Radios.

Radio receivers were in a pretty primitive state in the 1920s. Many were home made crystal sets. Some manufacturers provided kits for constructing 1 or 2 tube radios. The TRF (tuned radio frequency) set was more or less the standard for commercially produced radios in the 20s.

In a TRF all amplifiers up to the detector were tuned to the frequency of the received station. Early designers had not figured out how to make the circuits track. That is if the tuning capacitor were set to the same angle all tuned circuits would be tuned to the same frequency. When tracking was achieved all tuning capacitors could be on the same shaft and tuned by a single knob. The resonance phenomenon was not well understood in 1920 and what seems obvious to us now was not to them then.

In 1920 the top of the line for those who could afford the price was Atwater-Kent. Here are a couple of photographs of one that I had the pleasure of restoring and have the pleasure of owning.

A Case Study.

Figure 9.6 Restored Atwater-Kent Model 20.

Figure 9.7 Chassis of Atwater-Kent Model 20.

In figure 9.7 from right to left the tubes' functions are; first RF amplifier, second RF amplifier, grid leak detector, first audio amplifier, and audio output amplifier. The round can which appears to be behind the detector tube is an audio coupling transformer between the detector and first audio stage. There was another one which was between the first and second audio stages which had an open primary. When this picture was taken the second audio interstage transformer had been replaced by a modern one. It can't be seen in the picture. I melted the tar in the defective transformer and pulled the guts out of the can. I installed the now empty can over the new transformer to give the radio an authentic look. In case you have a similar problem the new transformer came from Antique Radios inc. The original transformer is wound with many turns of very fine wire and is lacking in the complete magnetic circuit we know from modern transformer designs.

Troubleshooting.

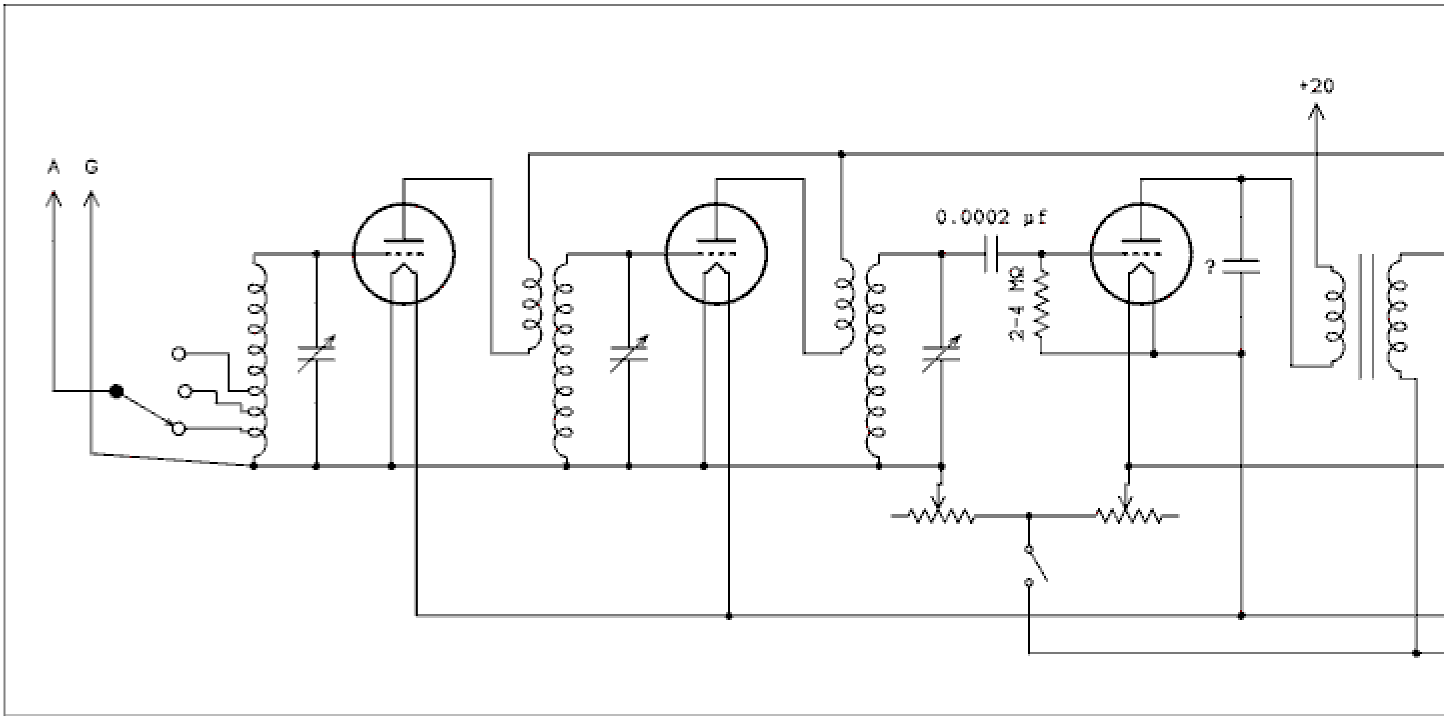

Figure 9.8 Schematic of Atwater-Kent Model 20.

This radio is so simple there isn't really much to go wrong. The one I restored probably presents a typical set of problems. There was no plate voltage on the first audio stage because the interstage transformer was open. When I connected a 100 k ohm resistor from B+ to the plate the radio began to work, sort-of. I found the grid leak resistor which is specified as having the range of 2 to 4 meg ohms read approximately 15 megs. I soldered a 3.3 meg ohm resistor under the chassis where it is out of sight. I left the snap-in grid leak in place for appearance.

Why did the radio work with an open audio transformer? Evidently there was enough capacitance from the primary to the secondary and enough secondary inductance to couple signal from the plate of the first audio to the grid of the audio output. After installing the replacement transformer the audio quality was not improved very much. As you can see from the first picture above I am using the radio with the wrong speaker. This is in fact an RCA horn speaker. The Atwater-Kent speaker may have better quality. I am on the lookout for one.

The operating instructions I found on line state that the B+ should be 90 volts. In fact the radio performs much better at 40 volts. This must have extended the useful life of the B battery. The instructions are also written for use with a 6 volt storage battery as the A source. I used a 5 volt logic power supply which matches the 5 volt filaments in the tubes. This means I don't have to be as cautious with the filament rheostats as the instructions state. These rheostats are the only means of volume control.

To say the radio is difficult to tune is an understatement of gigantic proportions. With patient tuning I have managed to find some distant high power stations at night. It actually helps to have a noisy fluorescent lamp on the table next to the radio. Turn it on to peak the tuned circuits and off to see what's on that frequency.

The model 20 dates from about 1920. TRF radios were improved through the 20 as manufacturers figured out how to make the circuits track. At first the three knobs were reduced to two with each one controlling two tuned circuits giving a total of three amplifier stages and finally with higher gain tubes one knob controlling three tuned circuits while returning to two amplifier tubes.

Although the super heterodyne circuit was invented in 1916 I'm not sure when it came into the radio market but I am sure it was phased in gradually. It seems to have been well established by 1930.

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9.3 Pre World War Two Radios.

By 1930 the superhet was well established so any radio of this vintage you encounter is more than likely to be of this design. Now we will study the principles behind the superhet.

The Super Heterodyne Radio.

It's hard to say why the heterodyne radio was considered super. I suspect it was marketing ad verbiage. In any case we are stuck with the term and most of the time it is shortened to superhet.

The TRF radio receivers have brought us up to about 1925. The principle of heterodyning had been developed by Edwin Armstrong in the 19 teens and patented by him in 1916. An early version was offered to the public as early as 1919 but it really didn't catch on in the consumer market until the late 1920s.

The Principle of Heterodyning

Heterodyning is more commonly known as "mixing", "conversion" or "modulation". OK; but what is it? If you combine two frequencies in a device known as a "mixer", "converter" or "modulator" you get two new frequencies. These new frequencies are the sum and difference of the two original frequencies. For example if you combine 5 MHz and 6 MHz in a mixer you get the two original frequencies and in addition you get 1 MHz and 11 MHz. If you combine 650 kHz and 1105 kHz you get 455 kHz, 650 kHz, 1105 kHz and 1755 kHz. There are some types of mixers in which the original signals are canceled out and ONLY the sum and difference frequencies appear in the output. These devices are called "doubly balanced mixers" or DBMs for short. We will likely get to them in time. But for now we will be talking about mixers in which the original two signals appear in the output along with the sum and difference frequencies.

So What is a Mixer?

Well, it's any nonlinear device. A nonlinear device is anything that has a graph that isn't a straight line. A diode, either vacuum or semiconductor makes an excellent mixer. A tube or transistor which is being driven into overload is another excellent mixer. The balanced variety consists of combinations of diodes and transformers, or transistors (usually in an integrated circuit). There was even a special tube developed in the 1960s that was a balanced mixer.

The Superhet Receiver.

In connection with the TRF receiver I mentioned that tracking of the tuned circuits was a problem. But the major problem with TRF receivers is changing selectivity as you tune across the band. The stations at the high end (near 1600 kHz) tune more broadly than the stations at the low end (near 540 kHz). If there are two stations close together in frequency at the high end you would have trouble separating them. This is not a problem at the low end.

The reason for this is that selectivity (or bandwidth) is a constant percentage of the center frequency. Suppose the Q of a tuned circuit is 40. At a frequency of 600 kHz the bandwidth is 15 kHz. That's about right for AM reception. On the other hand the bandwidth at 1500 kHz is 37.5 kHz. There is no way around this. We would have to repeal some of the laws of electricity and magnetism to keep this bandwidth change from happening.

If we could find a way to change the frequency of any given station to some predetermined frequency we could build a set of tuned circuits and amplifier stages that would always have the proper bandwidth and we wouldn't have to worry about tracking because the frequency of the circuits will never be changed. Calling up the station and asking them to change frequency doesn't seem to be a practical solution. We need some way to change the frequency after the station's signal enters our radio.

Are you ahead of me? Yes. The mixer is it. The frequency we generate to combine with the incoming station is produced within our own circuitry so it is local. It is called the "local oscillator". Let's say we have constructed a fixed tuned amplifier at a frequency of 455 kHz. (That's the almost universally used frequency for this amplifier. Car radios usually use 262 kHz. I don't know why.) So if we want to listen to a station on 780 kHz we must tune our local oscillator to 780 kHz + 455 kHz = 1235 kHz. The 1235 kHz local oscillator combines with the incoming station at 780 to produce two new frequencies at 455 kHz and 2015 kHz. The tuned circuits select the frequency at 455 kHz and reject all others. The frequency of 455 kHz is in-between the station's frequency and the audio frequencies so it is called the "Intermediate Frequency" or just IF for short.

Image Frequencies

Suppose you live in Cincinnati so you have a strong local station on 1530 kHz. (It used to be WCKY; I don't know if it has changed. I haven't heard it in a long time because it skips over me here in BG KY.) Well, suppose you would like to listen to an out of town station which is operating on 620 kHz. You tune your local oscillator to 620 + 455 = 1075 kHz. What do you hear? Well, WCKY on 1530 is also there and combines with your local oscillator on 1075 to produce a difference frequency of 1530 - 1075 = 455 kHz. OOPS! That's the main drawback to a Superhet receiver. It receives two frequencies simultaneously at the same time. It's up to the antenna coil which is tuned to 620 kHz to reject the strong signal on 1530 so you can listen to the station you want to hear. A really good AM radio will have an amplifier stage before the mixer, called the "RF Amplifier" or "RF Stage" with two tuned circuits to make sure you are only listening to one station at a time.

The 1930s are often referred to as the golden age of radio. Most of the people who use this phrase are thinking of radio programming content. However it was also technically the golden age of radio. The difference between a 1930 model and a 1940 model is striking. Probably the most striking improvement to a nontechnical person would be sound quality. But there were also large improvements in reliability, stability, and ease of tuning.

Many consoles incorporated record players and a few even had the newest thing, FM radio. Many had push-pull output stages some boasting output power of 25 watts.

At the other extreme there were still many battery radios which were not intended as portables. These days they are called farm radios because they were intended to be used on farms where there was no electricity at all or if there was electricity it was 6 or 32 volts DC from a gasoline powered generator and a system of storage batteries.

Types of farm radios are as follows.

1. **Dry battery only.** The source of power was a large cardboard box containing A and B batteries that sat in a compartment in the bottom of the radio. When the batteries ran down the user had to buy a new one. I suspect that when the battery pack went dead that many farms did without radio during the depression.
2. **Dry B battery and storage battery for A battery.** If a means existed to charge batteries this was a good solution. A single B battery was less expensive than an A-B pack. In some radios the A battery was a 2 volt single cell lead acid battery. In others it was a 6 volt battery of the same type.
3. **Vibrator derived B+ from a 6 volt storage battery.** Many farms had wind powered 6 volt generators that kept one or more 6 volt lead acid batteries charged. A 6 volt radio could operate well from such a system without the ongoing expense of buying replacement B batteries.
4. **32 volt vibrator radios.** Other farms, such as the one I grew up on, had a Delco gas powered 32 volt DC generator system. A bank of five 6 volt batteries were charged daily by the generator. The trick was to manage the power usage so there would be enough juice left in the batteries the next morning to start the generator. In addition to making electricity the generator made enough RFI to make radio

listening impossible for all but the strongest station which was WHO in Des Moines.

Troubleshooting.

What all these radios have in common are tubes, resistors, capacitors, and inductors. The same kinds of component failures afflict all 4 types. Remember to half split at the volume control and then signal trace or signal inject to find the defective stage.

One component found in two of the types is the vibrator. Because it is an electro-mechanical device it is the least reliable part in the radio. If you are asked to repair one of these sets you may find that the vibrator can't be made to function. There are companies you can find with a Google search that will provide vibrator replacements that use transistors as the switching elements. You really don't have any choice in replacing this part. Nobody is making mechanical vibrators anymore. In addition the owner will likely want you to build a suitable DC power supply to run the radio. This should not be difficult in this age of power transistors and IC voltage regulators. Remember that the original battery gave a wide range of voltages from fully charged to near run down. Any power supply does not have to be regulated within 1 millivolt or even 1 percent.

AC Powered Radios.

Refer to "Steps to First Power on" Above. Near the end of the decade early versions of the All American Five were beginning to be seen but most of the line powered radios you will encounter will have power transformers. This is both a blessing and a curse. The blessing part is that the circuitry is isolated from the power line making the set safe to work on. The curse is that the transformer may be burned out and you will have to find a replacement for it. Hammond makes a wide range of power transformers so you won't have any trouble finding a good electrical match for the original but physical mounting will be the major problem. If you are lucky the replacement will mount in the same way and it will fit in the allotted space. You may have to drill 3 new holes in the chassis to mount the new transformer. If you are unlucky there a whole host of problems that can rear their ugly heads to make your life difficult. You won't know for sure what you need to do until you have the replacement transformer in hand.

Some Common Problems.

At this point it is assumed that you have troubleshot the power supply section and replaced all capacitors except micas. One common problem you may have already found is for the field coil of the speaker to be open. Now the issue of authenticity versus cost of repair comes into play. In most radios the speaker field coil was used as a filter choke in the power supply. There are companies out there that will rebuild old speakers including field coil and cone and voice coil replacement. I'm not going to quote a dollar figure but it is likely to cost you more than two limbs. The easiest solution is to buy a modern permanent magnet speaker of the correct size and install it. The diagram is likely to state the resistance of the field coil and a resistor close to this value should be installed in its place.

If after the radio is working you hear hum in the speaker you may need to add a filter choke in series with the resistor. 5 henrys will usually be enough. The filter choke may not be required if the filter capacitors which were quite small in the original were replaced with larger values. For example it was not uncommon to find filter capacitors of 2 or 4 microfarads particularly in radios of the early 30s. If you replace these with 22 or 47 uf caps the resistor will usually provide sufficient filtering. Leave the can capacitors standing on top of the chassis and install the modern ones under the chassis out of site. Don't forget to disconnect the old capacitors.

The oscillator and antenna coils in these radios may be quite fragile and a touch or unfortunate bump from a tool may cause it to disintegrate. If this happens don't despair. Antique Electronic Supply has an assortment of oscillator coils and a few antenna and RF coils. The ones made by Hammond are the best.

The if transformers are a different story. The fragile coils are encased in square cans and are not likely to suffer any accidental physical damage. If one is found to be open you may be out of luck. Your best chance is to substitute an IF transformer from a 1950s or 1960s radio. The only alternatives are winding a new one or make one out of RF chokes. Either way it's going to be a lot of work.

In some 1930s Philco radios I have seen there are capacitors that are disguised as terminal strips. They have 3 terminals mounted on a black Bakelite block. Inside the block is a capacitor and it has a 99% chance of being too leaky to allow the radio to work properly. These will be found in the audio section used as coupling capacitors. Some people melt the tar out of the block and install a modern capacitor in it. I simply mounted a modern terminal strip on the mounting screw and connected a new capacitor to it. I jumpered from the input side of the capacitor to one side of the new capacitor and unsoldered the wire to the grid and the grid resistor from the block and soldered it to the other side of the new capacitor. The capacitor blocks were left in place so as not to preclude a more authentic restoration in the future.

One more thing you are likely to encounter is a noisy volume control. Most pots have a small slit opening behind the terminals. Turn the radio so the terminals are up and use a medicine dropper to drop control cleaner at the slit. Rotate the control vigorously to work the cleaner into all of the rotating contacts. If the radio has short wave bands the band switch will also need cleaning. I have seen many radios in which the switch was so dirty that the radio would not work. If the audio section is functioning but the radio is silent clean the band switch first.

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9.4 The All American Five.

During World War II the American electronics industry turned its efforts to supplying military electronics and there were very few if any civilian radios built in the years 1942 through the first half of 1945. At the end of the war the industry started cranking out a simple and inexpensive, some might even say cheap, table radio that became known as the All American Five.

This radio circuit represents a triumph of the bottom line over quality and safety. It was the radio that the Atwater-Kent company went out of business rather then make. Every feature had one purpose, to reduce the cost of manufacture. After World War II there were millions sold under hundreds of brand names from Admiral to Zenith.

Much scorn has been heaped on the little AA5 by myself and others but the truth is it's a wonder of design and simplicity. The word is starting to get around and local antique dealers are bringing me their AA5s to put into operating condition. I have had the opportunity to see a great many different radios. The marvel is how well they work considering their construction. There's no such thing as a wiring harness. Wires go every which way, crossing over, twisted around, power next to audio, audio next to RF, power next to RF. Terminal strips are seldom used or used in great moderation. That sometimes means that wires are just brought together in the middle of the air and soldered together. Yet still they keep on ticken'. The design has been so well refined that it seems impossible to build one that won't work.

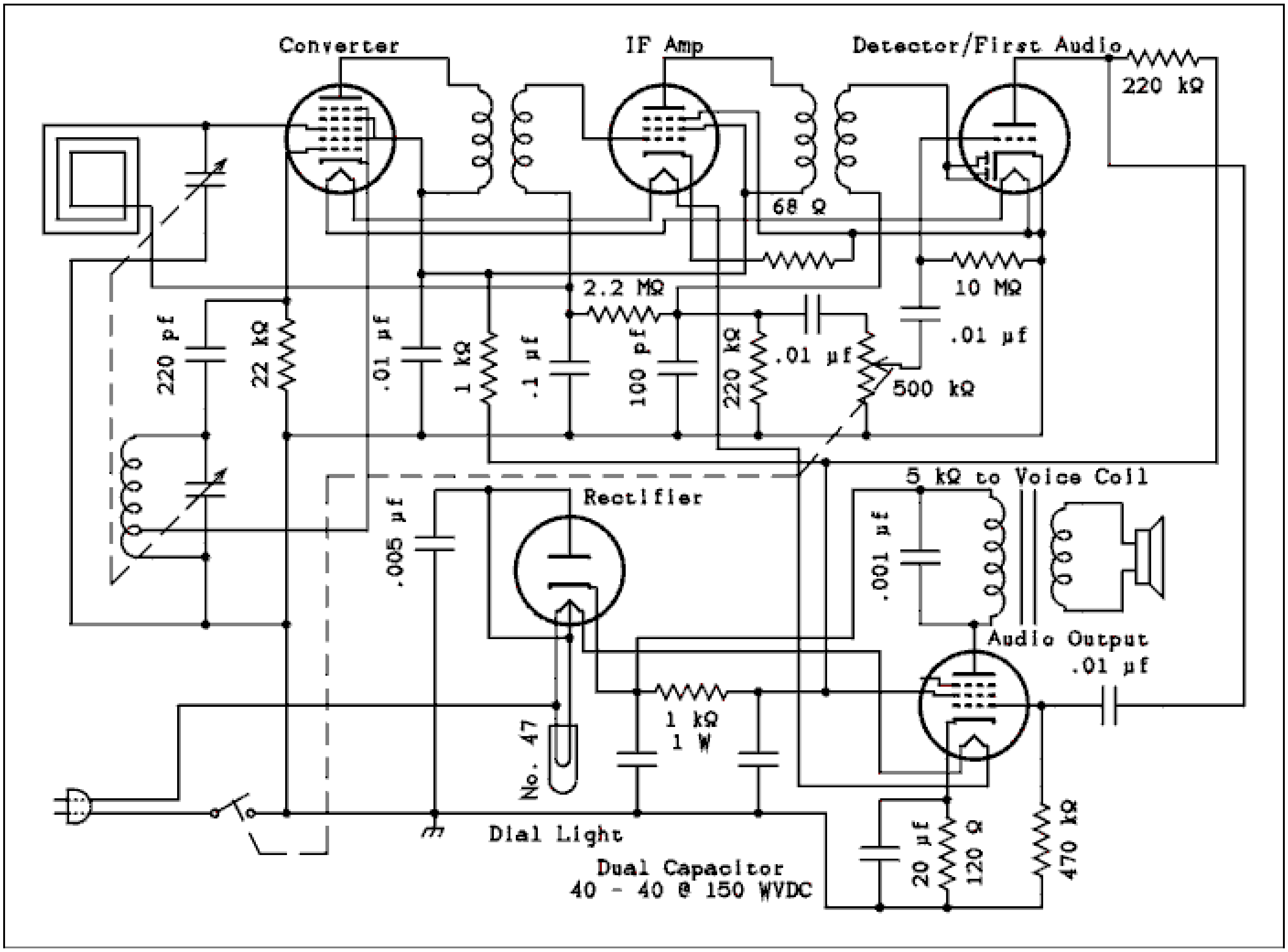
It is called the All American Five because all brands were made in America. This was long before the mass exodus of the electronics industry. The five comes from the fact that it used 5 tubes. There were variations using 4 tubes which didn't perform very well and 6 tubes which cost more. The average person who didn't stay up late to see how many distant stations they could hear (known as D X ing) didn't care about the improvements provided by 6 tubes. Consequently the All American Five became a post war standard which did not fade away until replaced by the All Japanese Six, the six transistor radio made in Japan.

The most prominent feature of the AA5 was that it had no power transformer. The result was that the circuit common was connected to one side of the power line. Because there was no polarized plug there was a 50 - 50 chance that the radio's chassis would be connected to the hot side of the power line. Very late models from the sixties were carefully designed not to have any metal parts on the outside even going so far as to recess screws in deep holes. In the 40s and 50s there was no such concern on the part of manufacturers. It was common to see chassis mounting screws exposed on the bottom of the plastic case. These radios could be, and sometimes were, lethal. All it would take was for an unwary person to complete the circuit between a metal part on the radio to a kitchen sink. I once owned one that was in a metal case. My friends and I called these radios "suicide boxes".

Most people who owned and used them were blithely unaware of the danger. I'm sure it must have cost some of them their lives. One side of the power line connects to the chassis. Depending on how it happens to be plugged in the chassis could be "hot" 120 volts above power line ground. Most of them have the switch in the chassis side of the line which means that even if you have it plugged in correctly, when you turn the switch off the chassis will be electrically hot. With these units there is no right way to plug them in.

A Change For Safety.

First of all you should have replaced all paper capacitors with modern or with X or Y rated capacitors as described in section 9.1 above. Following that there is another change which must be made to make an AA5 safe to work on and use. Here is how most AA5s have the power switch wired.



For a verbal description click here.

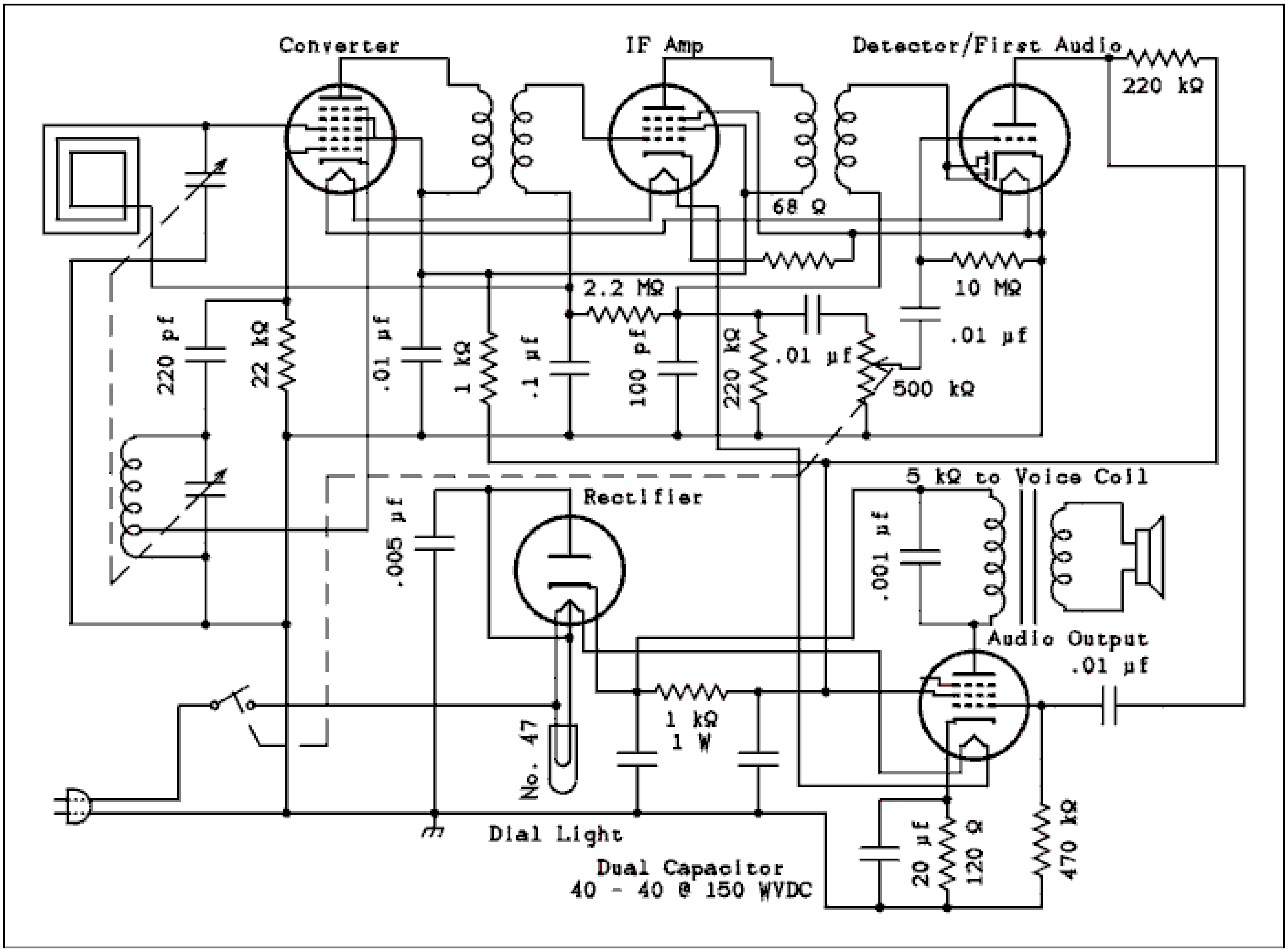
Figure 9.9 Unmodified AA5.

The common wiring method had one side of the line cord going to a pin on the rectifier tube and the other side going to one terminal of the on/off switch. The other terminal of the on/off switch went to chassis.

It should be noted that not all radios used the metal chassis as the circuit common. In some radios all connections that went to common connected together with wire usually at a terminal lug. From this point there was a resistor and capacitor in parallel to the chassis. Commonly used values for these were 220 k ohms and 0.001 uf. When modifying such a radio the 0.001 uf capacitor should be replaced with one that is X rated. When the instructions below refer to the chassis the common point is meant.

Suppose you plugged it in so the chassis was "cold" when the radio was turned on. That would mean that the bottom prong of the plug was connected to the power line neutral. Everything would be fine until you turned the radio off. Now the top prong of the plug is connected to the hot side of the power line. The tube heaters are cold and have a very low resistance (very approximately 100 ohms). This resistance is connected from the hot side of the power line to the chassis of the radio. You could connect a clip lead from the radio chassis to a water pipe and the radio would come on and play. If part of your body should complete the circuit instead of a clip lead you might never play again.

I strongly urge modification of the radio circuit to make it somewhat safer. Here's the diagram.



For a verbal description click here.

Figure 9.10 AA5 Modified for Safety.

Before starting to modify the radio go to a discount store and buy a polarized 2 prong plug extension cord. They are usually a dollar or less. Cut away the old power cord but leave short pieces of it on the rectifier tube and switch. If the insulation is in good shape (not always the case in these old sets) leave enough wire to reach to the switch. If the insulation on the old cord is rotten replace it with a piece of wire cut from the extension cord. Decide how long you want the new cord on the radio to be and cut the cord that length from the plug end. You will most likely never find a use for the socket end so cut off the extra cord, save it, and throw the socket end away. Thread the new cord in through the chassis hole, and secure it in the same manner that the old one was, for example tying a knot in it.

Separate the two wires for a couple of inches, and strip about 1/4 inch of insulation off the ends of the wires. Twist the fine strands of wire tightly together and melt a small amount of solder over them to hold the strands together. This is known as tinning the wire.

Now remove the wire connected from one side of the switch to the chassis. Strip and tin the piece of wire connected to the rectifier tube socket. Connect this wire to the terminal of the switch you just removed the chassis grounding wire from. Solder the wire in place.

Remove the piece of old line cord from the other terminal of the switch. Solder the wire coming from the **NARROW** prong of the new line cord to that terminal of the switch.

Solder the wire from the **WIDE** prong of the new line cord to the chassis connection where the switch used to be grounded.

You may find after making this modification that the hum level has increased. The phrase "lead dress" was probably never spoken in an AA5 factory so the wires go every which way. The reason for putting the switch in the neutral lead was to minimize hum transfer from the off on switch to the volume control pot. Now that the switch is in the "hot" side of the line there may be more hum than desirable in the speaker. When installing the polarized cord make sure the hot leads run along the chassis and as far away as possible from the three terminals on the side of the control. It may be best to route the wires straight down to the chassis perpendicular to the shaft. Route the leads that carry audio along the chassis and away from the power line leads. You may have to solder new pieces of hookup wire in these leads to make this possible. Experience has shown that careful routing of the leads will reduce the hum to acceptable levels.

The switch modification will make the radio much safer to use and work on but the safest way to work on these sets is to obtain and use an isolation transformer. The minimum you need is a 30 watt transformer. A higher wattage unit would give you more flexibility. It may cost you some money but how much is your life worth. If you think you are immortal or just want to live dangerously there isn't much I can say to you. If you decide to work without an isolation transformer get one of those test lights or a small night light and permanently connect one side of it to the power ground and terminate the other in a test wire. Touch the wire to the radio chassis. If the light lights up reverse the plug. Test it with the switch off. If there is no right way, plug the radio into a plug strip with a switch and use that to turn the radio on and off. Temporarily solder a jumper across the radio's off on switch to prevent yourself from absent mindedly turning it off.

Jim sent me an email in which he makes the following recommendations.

"These are excellent suggestions. However, I would suggest taking these steps further, by equipping the radio with a ground fault interrupter (GFI) .

In my research, I find that many hair dryers are equipped with cords that have plugs containing the GFCI protective device. These look like wall warts on the end of the cord. I found used hair dryers in second hand stores selling for under $5 each. So, the plan is to purchase a used hair dryer with a good cord and GFCI plug, remove the cord and use it to power an AA5 radio, in one of two ways:

The simplest way to power the radio is to make the hair dryer cord into a GFCI extension cord. Purchase, from a hardware store, an outlet that installs on the end of a cord. Then, properly wire and attach the outlet to the hair dryer cord and you have a GFCI extension cord. Plug the radio into your GFCI extension cord and plug the GFCI extension cord into AC power. Secure the radio cord into the extension cord outlet, since you want the extension cord permanently connected.

The other way is to use the hair dryer cord to replace the cord that came with the radio. If you choose this method, note that the hair dryer cord is thicker than most AA5 radio cords. The entry hole into the chassis may need enlargement and the strain relief may require replacement to fit the larger cord.

Look for hair dryers with plugs that have two buttons labeled TEST and RESET. If an outlet is available in the second hand store, test for proper operation of the GFCI before buying the hair dryer.

Hair dryers have been manufactured with GFCI plugs for over 10 years now, but not all models have GFCI plugs. Therefore, check very carefully to be sure you purchase a hair dryer with a GFCI plug. GFCI plugs may also be found on hair curlers and other bathroom and kitchen electrics, so check those as well if you can't find a suitable hair dryer.

Jim also sent along this anecdote.

In my own case I repaired an AA5 radio which used a capacitor between the metal chassis and one side of the line cord. I found about 120 volts DC between the radio internal ground and chassis. I traced the problem to continuity between the audio output transformer's primary winding and its frame. The radio played well despite this problem. I remounted the transformer with insulated fasteners and spacers. GFI would have protected humans from electrical shock if I hadn't fixed the problem, or if the problem developed later.

Jim"

Testing tubes.

You don't necessarily need a tube tester. All you need is a functioning radio that has the same tube lineup as the one you're working on. In the process of testing tubes whether it's with a tube tester or another radio, NEVER PUT A HOT TUBE INTO A COLD RADIO OR A COLD TUBE INTO A HOT RADIO. What the heck do I mean by that? Here is the hot tube into a cold radio scenario. The radio you are working on lights up but doesn't work. You turn it off and take out one of the tubes to test it. You find the tube to be good, yank it out of the tester or other radio, plug it into the radio being repaired and turn it on. The heater of the tube you just switched is hot but the heaters of all the other tubes in the radio are cold. The resistance of the cold heaters is quite low while the resistance of the hot heater is close to its operating value. In the series heater circuit the highest resistance gets most of the voltage. For a few seconds the hot heater will get almost all of the line voltage. It may burn out before the other heaters warm up and start taking their fair share.

The cold tube into a hot radio goes like this. You have a complete set of AA5 tubes you know to be good and decide to substitute them in to a defective radio one at a time. You turn off the radio, remove one tube, replace it with one of the same type number and turn the radio back on. The cold heater won't take its share of the voltage for a few seconds. The other tubes will proportionally divide up the over voltage until the cold one warms up. If the one you plugged in cold is one of the 12 volt tubes the chances of doing serious damage are small but still exist. If the cold one is the 35 or 50, the other tubes are going to get quite a large over voltage shot and at least one of them may not survive.

The Dial Light.

As you learned the dial light carries the B+ current. When you first turn the radio on the light glows at normal brightness for a fraction of a second and then dims down. As the tubes warm up and the radio begins to play the light comes back to normal brightness. If you turn the radio off and right back on the light will light up very bright for a fraction of a second and then dim back to normal. You don't have to do this many times before the light burns out. SO DON'T DO IT.

If the light burns out the voltage across that part of the heater of the rectifier tube will go up to about 12 volts. That portion of the heater will over heat and will burn out within a few hours of operation. Since dial light bulbs are much cheaper than rectifier tubes, don't operate a radio with a burned out dial light. If you have a large collection of AA5s you should keep some spares on hand.

Troubleshooting Hints.

The most common defect of these radios is a bad filter capacitor. This is the one I have designated in the diagrams as a dual 40 microfarad at 150 volts. In real radios it could be as low as a dual 20 microfarad. The symptom is a loud hum that may be changed slightly, if at all, by the volume control. Sometimes you can tune in a station and hear it through the hum. The only thing for this is to replace the capacitor. One with this failure mode can't be reformed. You can go up in capacitance or voltage but not down. For example if the radio has a 20 - 20 microfarad at 150 volts you could replace it with a 20 - 30 at 150 volts or 40 - 40 at 250 volts.

If you have a radio which lights up but has no sound try this. Touch the tip of a screwdriver to the center terminal on the volume control while touching the metal part of the screwdriver with one finger. There are two terminals on the back of the control, these are the on-off switch. You don't want to touch them! The terminals of the potentiometer are in a group of 3 and are on the side of the control. Turn the volume to middle or higher. Touch the screwdriver to the terminal and touch the metal shaft of the screwdriver with a finger. You may or may not hear a loud hum or buzz. If you do the audio section is working and the trouble is in the converter, IF or detector. If you don't hear anything the trouble is in one of the two audio tubes. Not necessarily the tubes themselves. As you learned earlier this is a form of half splitting.

Use a DC voltmeter to measure the voltages on plates and screen grids. A leaky capacitor can put a positive voltage on the control grid of the 50L6/50C5, but you already replaced that one didn't you?

If the audio section is working, try scratching on the grid terminal of the IF tube with the screwdriver. If you hear static the IF amplifier is OK and the trouble is most likely in the converter.

Check to see if the oscillator is running. The oscillator grid of the converter tube should have a negative voltage on it. A VOM won't work here. Use one of those cheap DMMs. Wind one lead of a 1 meg ohm resistor around the measurement probe. Touch the other lead to the oscillator grid terminal and read the voltage. The purpose of the resistor is to keep the input capacitance of the DMM from stopping the oscillator. You should read anything from about -2 volts to -50 volts. The reading will be about 10 % low but you're not going after precision, you just want to know if there is a negative voltage indicating that the oscillator is running.

If you are using an authentic VTVM you don't need to use the resistor. The DC probe on most VTVMs has a 1 meg ohm resistor built in and the meter calibration takes this into account.

Some AA5s might fool you because of a peculiar money saving modification. Look ahead to figure 9.11. Note the connections to grid 1 of the 1R5. You will note that there is no capacitor in the grid line and a coil that someone forgot to connect. There is virtually no inductive coupling between the tuned winding of the oscillator coil and the grid winding. The coupling is capacitive and replaces the typical 220 pf capacitor which is usually found here. I have worked on such an AA5 and I can say that it does work. It strikes me as going to great lengths to save a few cents on one capacitor per unit. It must have been economically feasible or it wouldn't have been done.

One more thing you are likely to encounter is a noisy volume control. Most pots have a small slit opening behind the terminals. Turn the radio so the terminals are up and use a medicine dropper to drop control cleaner at the slit. Rotate the control vigorously to work the cleaner into all of the rotating contacts.

Variations on a Familiar Theme.

As I noted earlier there was an All American 4 which didn't work very well and an All American 6 which worked very well but cost more.

In some radios, particularly AM/FM there wasn't enough heater voltage for the rectifier so the 35Z5/35W4 would be replaced by a selenium rectifier. If you get one of these go ahead and replace it with a silicon. The extra voltage won't hurt anything in this case.

In the AA4, 35 + 50, + 2 X 12 doesn't add up to the line voltage. A tube manual I have from 1946 lists 45Z3 and 45Z5 which could have been substituted for the 35Z5 in an AA4. I once owned one of these radios and it didn't use one of these 45 volt tubes. I assume that most other AA4s used a fixed resistor to drop the extra voltage as mine did.

AA6s on the other hand needed a lower voltage tube in one of the sockets. The 35L6 and 35C5 were made for this purpose. I have seen AA6s which had a 50L6 in the output tube socket while the schematic listed a 35L6. Either someone didn't know or didn't have a 35L6 in stock and decided to send the radio home with a 50L6 to get the radio working rather than wait to order the correct tube.

Millions of AA5s were made and thousands have been restored. There are still tens of thousands out there waiting to be restored. Have fun.

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9.5 Three Way Portable Radios.

The 3 way portable radio was call that because it could operate from AC line, DC line, or an internal battery pack. They ranged in size from small enough to fit into a large coat pocket to luggables that were about 12 inches wide and 10 high. I owned one of the latter which wasn't very heavy without the battery but when batteried up was quite a load. It was a Motorola model

6L1. I don't have it anymore but I spotted it on a museum site and found the schematic on Nostalgia Air. I suppose it was for sentimental reasons that I have chosen this circuit to represent 3 way portables.

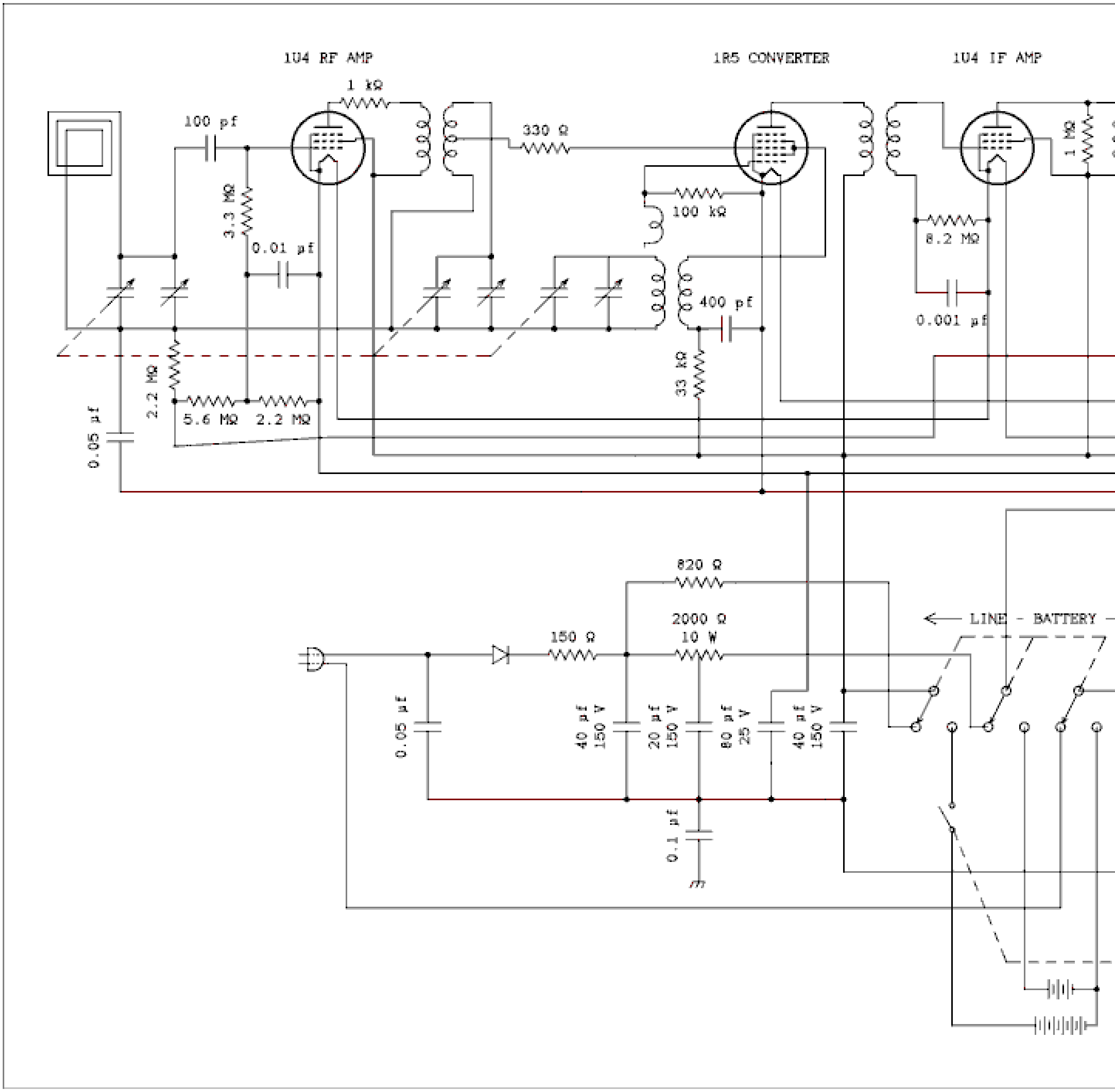

Figure 9.11 Schematic of 3 Way Portable.

Upon examining this schematic the first thing that struck me was that AGC is applied only to the RF tube and no other. After a few minutes of puzzlement I got it. The 1U4 is a sharp cutoff pentode. A remote cutoff pentode can provide gain control over a wide range even for voltages measured in volts or even 10s of volts. if this is attempted with a sharp cutoff tube serious distortion of an amplitude modulated signal will result. A sharp cutoff *can* be used as a gain control element if the signal level is kept small, in the single digit millivolts or below. That is exactly what is being done in the RF stage of this radio.

I remember that the AGC action was about the same as an AA5 but not as good as an AA6 wherein the AGC is applied to RF, converter, and IF stages. In keeping with small voltages approximately 25% of the derived AGC voltage is applied to the control grid of the RF stage. I assume that the tapped secondary of the RF plate coil and the resistor in series with grid 3 of the 1R5 is to improve performance under extremely strong signal conditions. I don't remember it ever being blocked even when riding in a car with it and driving past a radio station's tower.

The oscillator needs a special note as this method of coupling to grid 1 of the converter tube is used in many AA5s as well. What appears to be a link winding which has one end not connected is just that although there is probably very little in the way of magnetic coupling going on. Capacitance from the tuned section of the oscillator coil to the link replaces the mica capacitor which is usually found here. This strikes me as going to great lengths to eliminate one capacitor but the economics must have worked or it wouldn't have been done this way.

Note that local audio ground is established from the negative side, pin 1, of the filament of the 1U5. You may find the filament string a bit tough to tease out so here is a simplified diagram of the chain.

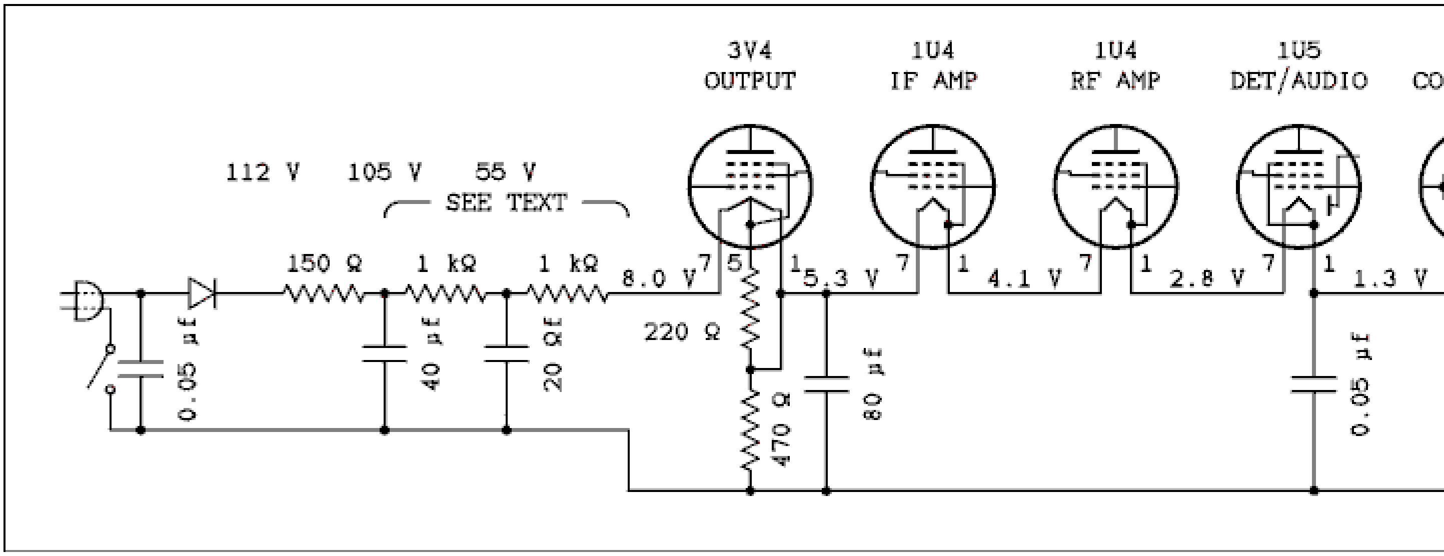

Figure 9.12 Filament circuit of 3 Way Portable.

The two resistors associated with the 3V4 are to conduct the plate and screen current to ground. Without them this current would flow through the filaments of the other tubes. You will note that the filaments are a little starved for voltage and they are not all equal. When the applied voltage is 9 volts as when operated from batteries the voltages will be a bit higher. There should be more resistors for cathode current along the line. The Zenith Transoceanic has several resistors to ground along the filament chain. I don't see that adding these resistors would significantly effect the battery life. I'm sure they were left out to reduce the manufacturing cost.

The two 1 k ohm resistors shown in this diagram are actually the 2 k ohm tapped resistor shown in the complete diagram above. This resistor became open while I owned the radio and before I had acquired sufficient skill to replace it myself. I suppose that just one of the sections opened up. The service shop where I took it made no attempt to obtain the original Motorola part. Instead they hung a 10 watt resistor by stiff wires coming through a hole drilled in the chassis. If I still had the radio I would do something about this.

Troubleshooting.

I have already pointed out the most likely failure in the radio. The 2 k ohm resistor is dissipating 5 watts and is the most likely component to fail.

Remember that the selenium rectifier should be replaced with a silicon diode. Do not give in to temptation to leave it in place. When a selenium rectifier fails it gets hot and some of the selenium is oxidized. Selenium is in the same column of the periodic table as sulfur and shares some of its characteristics. Of interest here is it's oxide. Sulfur dioxide and selenium dioxide are both rather poisonous. Also they both smell like rotten eggs. If you are working on a radio that still has a selenium rectifier in place and you smell rotten eggs, unplug the radio and open the windows. A selenium rectifier is a poison bomb waiting to go off. Physically remove the rectifier from the radio because some future owner might try to restore it to authenticity by reconnecting it. Use a shorter machine screw than was used to mount the rectifier and mount a terminal strip. Connect the wires that originally went to the rectifier and solder a silicon diode in place of the rectifier. The plus marked side of the selenium corresponds to the banded, cathode, end of the diode.

The value of the 150 ohm resistor will most likely have to be increased to keep the voltage at pin 7 of the 3V4 from exceeding 9 volts. Actually 9 or even 9.5 volts at this point wouldn't hurt any. If you are uneasy with the differing voltages along the filament string you can always do a little re-engineering by adding equalizing resistors.

If the 20 uf capacitor shorts it would most likely take out the top half of the 2 k resistor especially if the owner unwisely left the radio turned on even though it was silent.

If the 80 uf capacitor shorts out it will also silence the radio but it is unlikely that any additional damage will be done even to the 3V4. The 2 k resistor from the 105 volt supply is almost a constant current source and the 3V4 will not sustain any damage.

Elsewhere the circuitry is not unlike an AA6 so if the filaments have proper voltage but the radio remains silent all you need to do is round up the usual suspects.

If you or the owner wants battery capability you will have to construct a battery. If you are extremely lucky you will be able to find an AB pack that fits the radio. You might even find one still in it. It will be run down long ago but you can use the box and the connector socket. If not you will have to devise a method of connecting the battery that is easy to connect and disconnect.

The 90 volt B battery is easy. Just ten 9 volt transistor batteries will do perfectly. I have heard of people making up the B battery from AA cells but I view this as overkill. The current drawn from the B battery is less than that drawn by a 6 transistor radio so the 9 volt batteries should last a long time. In the original AB pack the A battery was made up of F cells which was probably overkill. After the B battery was run down I could get several months of experimentation out of the A battery. Modern D cells or even C cells should do the job nicely. It may be that the B battery was intended to run down so the user would stop using it before the A battery lost sufficient voltage to damage the filament's coating from being operated below design temperature.

One more thing you are likely to encounter is a noisy volume control. Most pots have a small slit opening behind the terminals. Turn the radio so the terminals are up and use a medicine dropper to drop control cleaner at the slit. Rotate the control vigorously to work the cleaner into all of the rotating contacts. If the radio has short wave bands the band switch will also need cleaning. I have seen many radios in which the switch was so dirty that the radio would not work. If the audio section is functioning but the radio is silent clean the band switch first.

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9.6 Phonographs and Record Changers.

As far as I can tell the first electric phonographs intended for home use appeared about 1930. At one time I actually had ownership of a variable reluctance pickup cartridge intended to adapt a spring driven acoustic phonograph to electrical reproduction. I couldn't make it work and not realizing the antique value even of a nonfunctional unit I either threw it away or gave it to a friend. Oh, the indiscretions of youth.

Beginning after world war II the crystal phonograph became very popular. I owned one myself. These players used a Rochelle salt crystal cartridge which delivered about 6 volts into a 500 k ohm load. This high output meant that only one amplifier tube was required. The diagram is shown below.

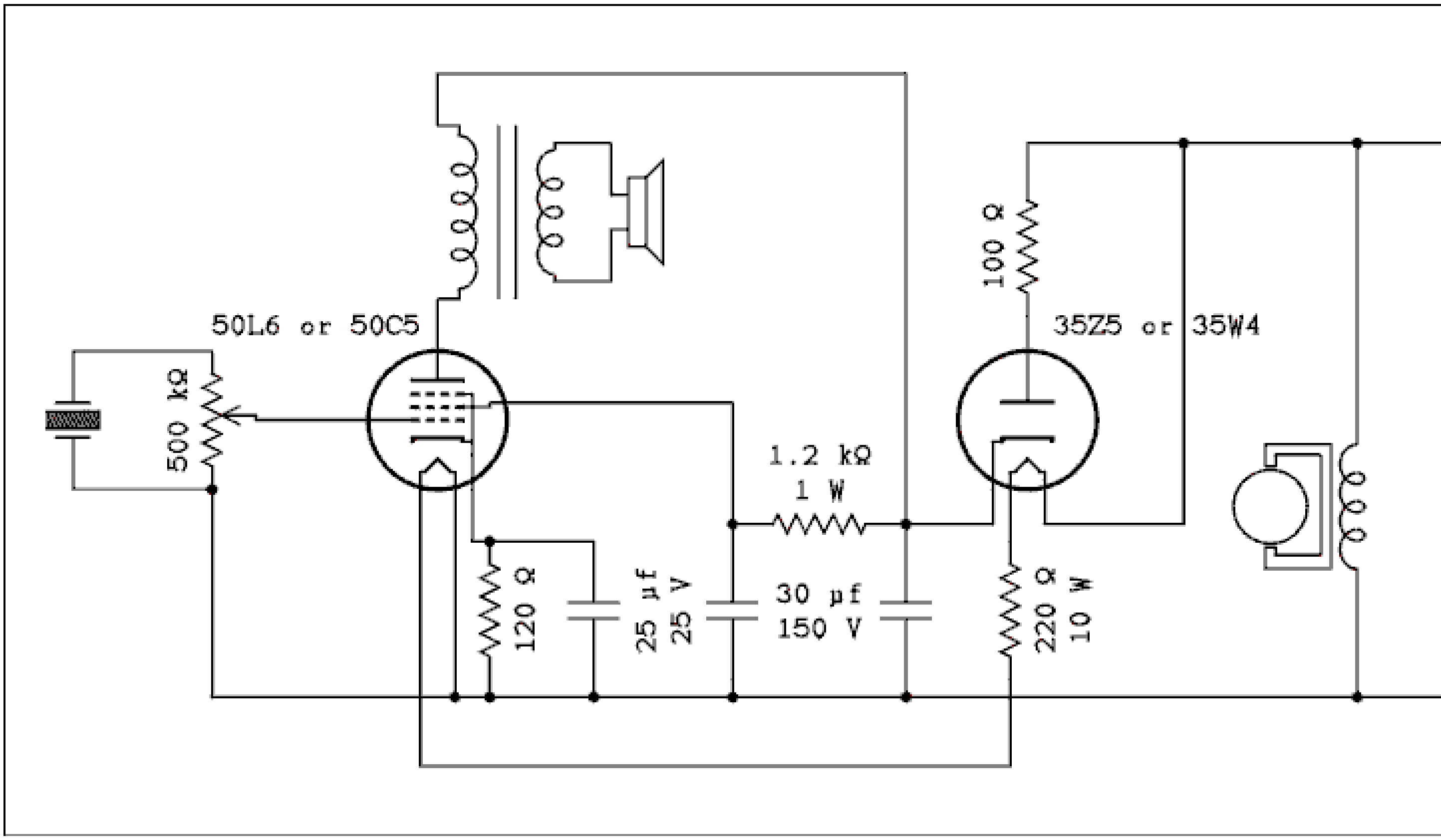

Figure 9.13 Crystal Phonograph.

There were other variations than those indicated in the schematic. The first electric phonograph I owned used a 117L7/M7 which incorporated the rectifier and the power amplifier into the same envelope with a 117 volt heater. Another variation I saw used a selenium rectifier and a 25L6 amplifier. The motor had been designed to operate from 92 volts at a current of 300 mA. The motor was in series with the heater.

If you find one of these phonographs your chances of ever getting it to operate in its original state are absolutely zero. The reason is the crystal pickup. Rochelle salt is a very hydroscopic material. That means it loves water and will grab onto any stray water molecules that come by. My original phonograph was bought and used for about 2 years in Iowa. Then we moved to Florida. In that humid climate it only lasted about 6 months. After having the cartridge replaced for a cost of 8 dollars it went out after another 6 months. 8 dollars was a considerable sum of money in 1952 and my mother said I would just have to do without rather than spend another 8 bucks on another crystal. The symptom is the sound grows progressively weaker and weaker until the volume control is up all the way and from that point it fades out to inaudibility. No doubt one of these cartridges would last for several years in Arizona but humid climates are death to them.

If you must get one of these phonographs restored to operation the only way I can see to do it is to install a ceramic or even a magnetic cartridge and install a transistor preamp to bring up the level to that required. It could easily be powered from the DC level at the cathode of the power tube and hidden in an electrolytic capacitor can.

A much better phonograph was the one with two stages of amplification. If you take away the 12SA7/12BE6 and the 12SK7/12BA6 from an AA5 and replace the heaters of the missing tubes with a 150 ohm 5 watt resistor you have the circuit of a ceramic phonograph. These were a little more expensive but if you lived in a humid climate the difference would be made up in a year. The reason that more gain was needed was that the ceramic cartridge output was less than 1 volt.

Other than the cartridge the filter capacitor was the part most likely to fail. In an old player this is one of the parts that should be replaced as a matter of routine.

The test for either a one stage or two stage phonograph amplifier is to lift up the arm with the unit turned on and the volume up all the way. Touch the cartridge pins one at a time while not touching anything else. If you hear a loud hum when touching one the amplifier is alright and the cartridge is dead. Even ceramic cartridges can go dead after 50 years. Although I do have a Silvertone wire recorder and phonograph that has a working ceramic cartridge in it. The sound is a little weak but it is still usable enough to record from a record to wire.

Record Changers.

I don't know when the record changer was invented but I once owned one that dated from about 1940. It made an incredible amount of mechanical noise. The change cycle began with a metallic bang that was a projection on the rim of the turntable hitting a lever which the eject button or the arm tracking the eccentric groove at the end of the record had pushed into the path of the projection. This raised a roller that engaged a spiral groove in the bottom of the turntable. This pulled the roller toward the center of the turntable which moved the rack in one direction. When the roller reached the end of the groove an inclined plain pushed it down which caused another one to pop up that was positioned at the beginning of the groove. This was the halfway point of the cycle. The second roller was pulled toward the center which moved the rack back in the other direction. The incline pushed the roller down completing the cycle. The rollers in the groove were metal on metal. The cycle sounded like this. Music ends, record scratch, click bang, grind grind grind, flop as the record dropped, grind grind grind record scratch, music starts.

The odds of either one of us encountering this exact model are small although I must say the movement was quite robust and as long as I kept things oiled it worked fine.

The three types you are most likely to encounter are the ones made by BIC, yes, that's the same as the pen company, VM (Voice of Music), and the RCA 45. The BIC name is not on every changer built by BIC. They made drop in changers for console units made by many different manufacturers. Most manufacturers put their own name on the changer. VM also made changers for consoles but you are apt to see the VM name plate on these changers. I suspect that VM wrote a clause in their contracts that required that the VM name remain on the changer.

The BIC and VM changers worked much the same. There are gear teeth cut into the bottom end of the turntable bushing. The change drive is a gear about 5 inches in diameter with a gap at one point. During play the gap is positioned around the gear on the turntable. When the cycle is triggered a small projection is moved forward which catches the teeth and turns the change drive gear just enough to engage its teeth in the turntable's gear. There are various grooves and projections on the change gear that move the arm, activate record size detectors and initiate record drop. The change cycle takes place over about 4 revolutions of the turntable.

The RCA 45 was another of those innovations that comes along about once in a generation. It and the records it played had been designed for each other. The entire change cycle took place in a single revolution of the turntable.

Troubleshooting.

If the turntable runs the most likely problem is that it stalls when going through the change cycle. One cause of this is a slippery idler wheel. If you do a Google search you may be able to find a replacement idler wheel or the rubber tire that goes around it. One thing you may be able to do is to remove the rubber tire, turn it inside out, and reinstall it. This exposes rubber which has been protected from the ravages of time. Be warned, the tire may be too fragile to withstand this treatment. If the previous option is out of the question but the tire has not totally disintegrated you may be able to resurrect it by roughing the surface with sandpaper or a file. Be careful not to create flat spots. A change in diameter of the idler will not alter the speed of the turntable. Sometimes it is necessary to shorten up the idler spring a little but don't carry this too far.

Another cause of stalling is a frozen up bearing in the changer mechanism. The lighter hydrocarbons in the oil have evaporated leaving behind a substance that is more like tar than anything else. The bearings most likely turn with great difficulty if at all. The right way to treat this condition is to completely disassemble the mechanism and soak all parts in a degreaser, then relubricate with sewing machine oil and reassemble. I must admit that I have never felt up to such a time consuming procedure with its high risk of losing parts or forgetting how they go back together.

One way is to simply flood the bearings with new oil and wipe up the excess. The idea is to flush out the heavy hydrocarbons and replace what's in the bearings with good oil. In particularly stubborn cases WD-40 can be used to flush out the tar and then oil the moving parts. **DO NOT LEAVE WD-40 IN THE BEARINGS.** It is **NOT** a lubricant. You **MUST** replace the WD-40 residue with real oil or they will freeze up tighter than they were before.

You should use a very light oil on the parts of a record changer. The old hardware store standby 3 in 1 will do but it will tar up again in a few years. Sewing machine oil is a much better choice and you don't have to look very hard to find it.

Troubleshooting a record changer can be difficult because it is hard to see what's going on under there. Here is a way to get the inner workings into the open and still allow it to be operated.

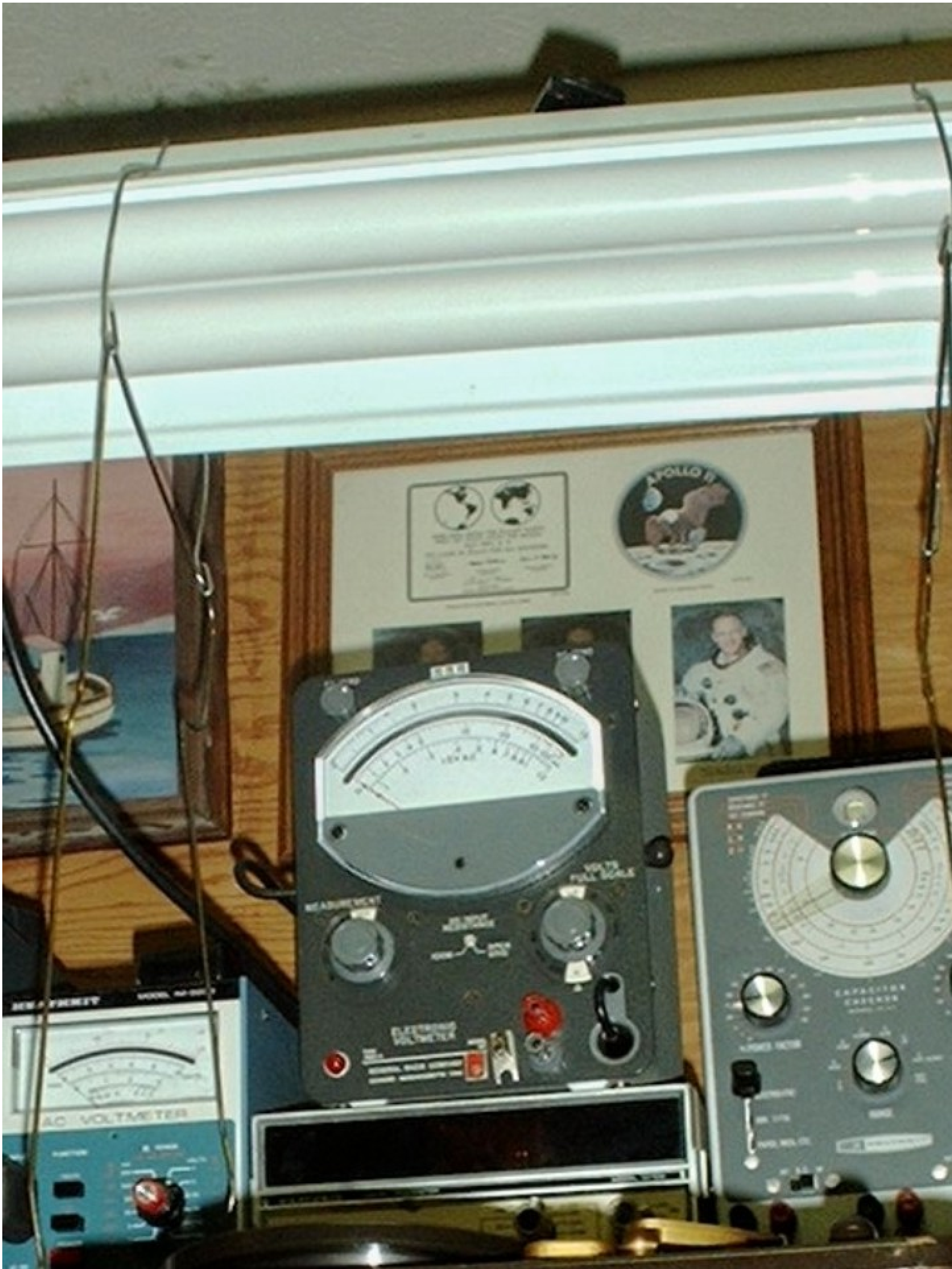
APOLLO 11
AC VOLTMETER

Figure 9.14 Hang the Changer by Wires.

This picture shows the transport mechanism from a Silvertone wire recorder hung by coat hanger wire from my workbench light. The florescent fixture is hung from the ceiling by chains attached to screw hooks that go into ceiling joist. Any record changer can be hung in the same way. The wires pass through hooks in wires that go over the top of the fixture. This is so the wires can be folded up against the fixture out of the way when not in use.

Once the bearings are properly lubricated and running freely the changer will work most of the time. If it doesn't there may be a missing spring, misadjusted or misaligned part, or a warn part.

Ace hardware does stock a few helical springs and if you need one of those you may be able to find it. If a flat spring is called for it may be harder to find. Flat springs are found in old windup clocks. Here is a case where you may need to sacrifice one antique to restore another one.

Misalignment is sometimes the result of a missing screw. They do tend to vibrate out and get lost. Finding a new screw shouldn't be hard even if it is metric. Changer parts often pivot on nylon inserts. Do not oil these. If a previous owner did the insert has likely disintegrated and needs to be replaced. Such parts may be very hard or impossible to find. If you have some skills with files and other small hand tools you may be able to fabricate one out of aluminum or hardwood. If made of wood the friction surface should be heavily waxed, not oiled.

A previous owner may have bent a part for some reason known only to that person. Bending it back is probably the only solution but be cautious. Metal fatigue can set in very quickly particularly if the part is made of aluminum. If it breaks you are probably back to fabricating a new part.

If a part is just warn out the only option is to make a new one as indicated above.

Sometimes a changer will be just so warn out that it can't be restored. One option is to disable the change mechanism by removing the change cycle initiation part or parts and using it as a single play turntable. Another option is to say "it can't be fixed". If you are working on it for someone else and they insist that they want it to work you may have to say "take it to someone else".

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9.7 Consoles and High Fi Components.

High fidelity seems to have come into existence sometime after World War II. I'm going to put it at about 1950. By 1955 the word if not the sound had become rather prevalent if not ubiquitous. Many older console designs were given a facelift, labeled as high fidelity usually in script, and remarketed with few or no internal changes.

These renamed consoles usually featured a 12 inch electro magnetic speaker, push-pull outputs and no negative feedback. The power tubes were most likely to be 6V6s although some had 6F6s or 6K6s. A few did have 6L6s. These were monophonic. The output transformer was usually mounted on the speaker. Although stereo was introduced in late 1957 it did not really catch on with the general public until after 1960.

Phase Inverters.

Because most of these consoles had push-pull outputs the phase inverter circuit is important to the performance of the set. The earliest consoles used a circuit known as the open loop phase inverter. An example circuit may be seen at this location. Look at the first diagram on the page. Use your back button to return here. The duo triode would likely be a 6SN7 rather than the 12AU7 shown, and the single triode would likely be a 6J5. Resistor values would be different.

A variation on the open loop is the closed loop phase inverter. Negative feedback is used to make the circuit self balancing as shown below. This circuit was found in a Westinghouse console.

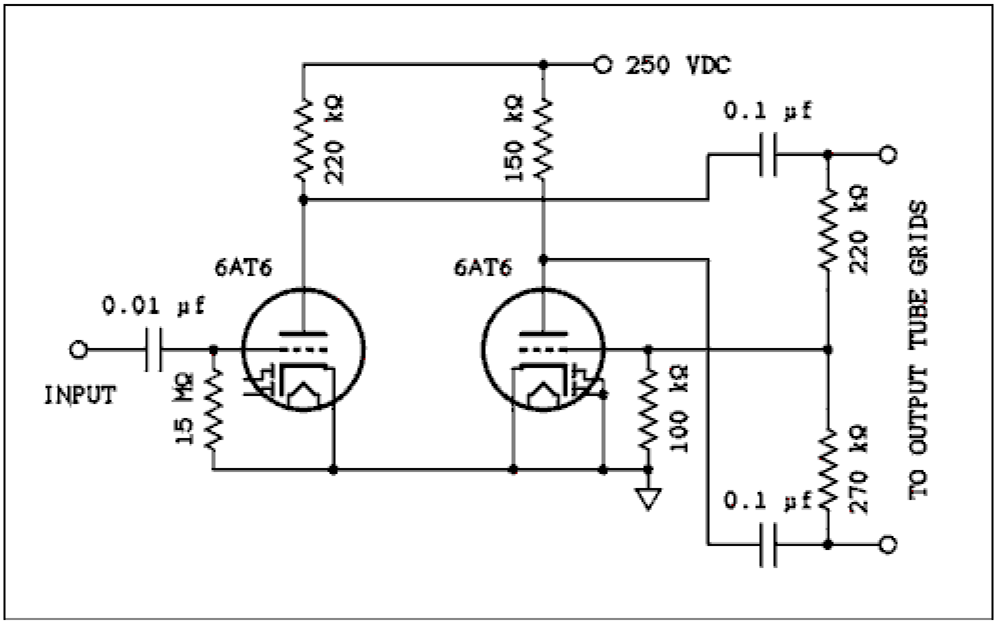

Figure 9.15 Closed Loop Phase Inverter.

The 220 k and 270 k ohm resistors form a voltage divider across the two output tube (6V6) grids. When the voltages at the two grids are equal in amplitude and opposite in phase the voltage at the junction of the two resistors is just what is needed to make the AC voltage at the plate of the second 6AT6 exactly what it should be. If aging tubes imbalances the drive to the two 6V6s, say to reduce the drive to the bottom tube, the voltage at the junction of the two resistors will increase driving the grid of the lower 6AT6 harder partially restoring the voltage to its proper value.

The diodes in the first 6AT6 are used as the AM detector as in the all American 5.

Troubleshooting.

First of all it is assumed that all capacitors have been replaced or reformed as appropriate. All resistors should have been checked and replaced if out of tolerance.

If the set still doesn't work the band switch probably needs attention. Older consoles are very likely to be either AM/FM or AM/SW or even AM/SW/FM. There may also be a phono position for a record player included in the console. Silver plating of switch contacts was common in this era as it is today. Silver can be oxidized to the point of making poor or no contact. The rubbing of contacts together which keeps them clean when in daily use is not sufficient when a radio has sat unused for several decades. Contact cleaner applied to the switch contacts will very likely restore the set to operation.

Other causes of non operation could be an open speaker field coil. Even if the set plays, check the plate voltage on the plates of both output tubes. If one side of the output transformer is open there may be no noticeable effect on the sound at low listening volume. The tube on the open side which has screen voltage but no plate voltage will not last very long under these conditions.

The record player, usually a changer, likely employs a ceramic pickup cartridge. Unless the set has been stored in a very damp basement, chances are good that the cartridge is still good. In units made in the late 40s and early 50s the changer was most likely a single speed 78 RPM player. I have seen many consoles from this era in which the original changer had been pulled and a 3 speed or 4 speed changer dropped in its place. At some time the size and mounting of record changers was standardized which made a drop-in retrofit possible.

Another thing you are likely to encounter are noisy volume and tone controls. Most pots have a small slit opening behind the terminals. Turn the chassis so the terminals are up and use a medicine dropper to drop control cleaner at the slit. Rotate the control vigorously to work the cleaner into all of the rotating contacts.

High Fi Components.

High fi components basically took the parts of a console radio phonograph and packaged each separately. Because customers were willing to pay more for quality components they were all more elaborate than would be found in a typical console.

The radio section was marketed as a tuner. Invariably FM and usually including an AM section as well. The FM section was as good as the state of the art at that time permitted. Sometimes the AM section was skimped although it was often of a high quality.

The amplifier would always have negative feedback, lower distortion, and more power than a console. In the bottom of the line amplifier the output tubes would be 6V6s but higher priced amplifiers would have 6L6GCs or EL34s. For details on the circuitry of amplifiers I suggest study of all the articles under the heading of "Audio Amplifiers How they Work" on this website. You might also find useful information under the heading "Building Amplifiers". I've already written those pages so why should I reinvent the wheel. Although there was movement towards high quality capacitors some amplifiers and tuners still used wax paper capacitors. Many manufacturers thought of the black beauty as being a quality part but it was a wolf in sheep's clothing. If any of these are found they should be replaced just as in an AA5.

Speaker systems were built in large boxes and there was little in them to go wrong. One common problem with vintage systems is that the rim support of the woofer was made from a kind of plastic that disintegrates after about 20 years. Even the much touted Acoustic Research speakers suffer this fait. You could have the speaker reconed but it is a lot cheaper to just buy a new speaker and figure on replacing in another 20 years. The crossovers have capacitors, inductors, and occasionally resistors. Unless the speaker system has been over driven it is unlikely that any of these components will be defective.

Speaking of over driven I remember an anecdote from the late 50s. It seems that a local TV shop sold and installed a component system for a well to do family. The shop unwisely installed a standard AC outlet on the back of the cabinet containing the electronics and AC plugs on the ends of the wires from the speakers. Shortly after the installation was completed the family decided that the listening room needed to be carpeted. After the departure of the carpet installers the sound system no longer worked. You guessed it. The carpet installers in an attempt to be nice plugged everything back in as they had found it, almost. I can't imagine what sound must have come from those speakers with 120 volts AC applied.

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9.8 Wire and Tape Recorders.

In the late 40s and early 50s there were a few home disk recorders sold but they never really caught on. The main reason was probably that the media could not be reused if the performer made a mistake or if it was recorded with too low or too high a recording level. Also they needed the constant attention of an operator to sweep away the fine thread of plastic that the stylus cut out of the surface of the disk.

Sears introduced the first wire recorder in 1948 under its Silvertone brand. The selling point was that the recording media could be used over and over until performers and engineers got everything right. There were other makes of wire recorders most notably Webcor which made machines intended for office dictation. The recording wire was very fine and there was more than a mile of it on a spool. The wire speed was 22.5 inches per second which meant if something went wrong the wire would be in a hopeless tangle before the user could get to the stop control. Such a tangle could not be recovered and the tangled section had to be cut out and thrown away with the loss of anything recorded on it.

The wire recorder had a fairly short run and was replaced by the tape recorder in the early 50s. Tape had the advantage of running more slowly, 3 and 3/4 or 7 and 1/2 inches per second so a real did not need to contain nearly as much of it. The tape was 1/4 inch wide which made tangling caused by a malfunction of the machine much less likely. It would take a kid or a cat playing with a real to get the tape in a hopeless tangle.

Magnetic recording.

In theory the principle seems simple enough. To record just apply the signal to be recorded to the coil of an electro magnet and pull the media across it at a constant speed. To playback just connect the coil of the electro magnet to the input of a high gain amplifier and pull the media across the iron core at the same speed and in the same direction.

What you will get will be the biggest mess of distortion you have ever heard. Language will be incomprehensible, Musical instruments unrecognizable, and you won't want to listen to it for very long. The problem is the magnetization curve of almost any metal. Below is the graph showing amount of magnetization versus the magnetizing force.

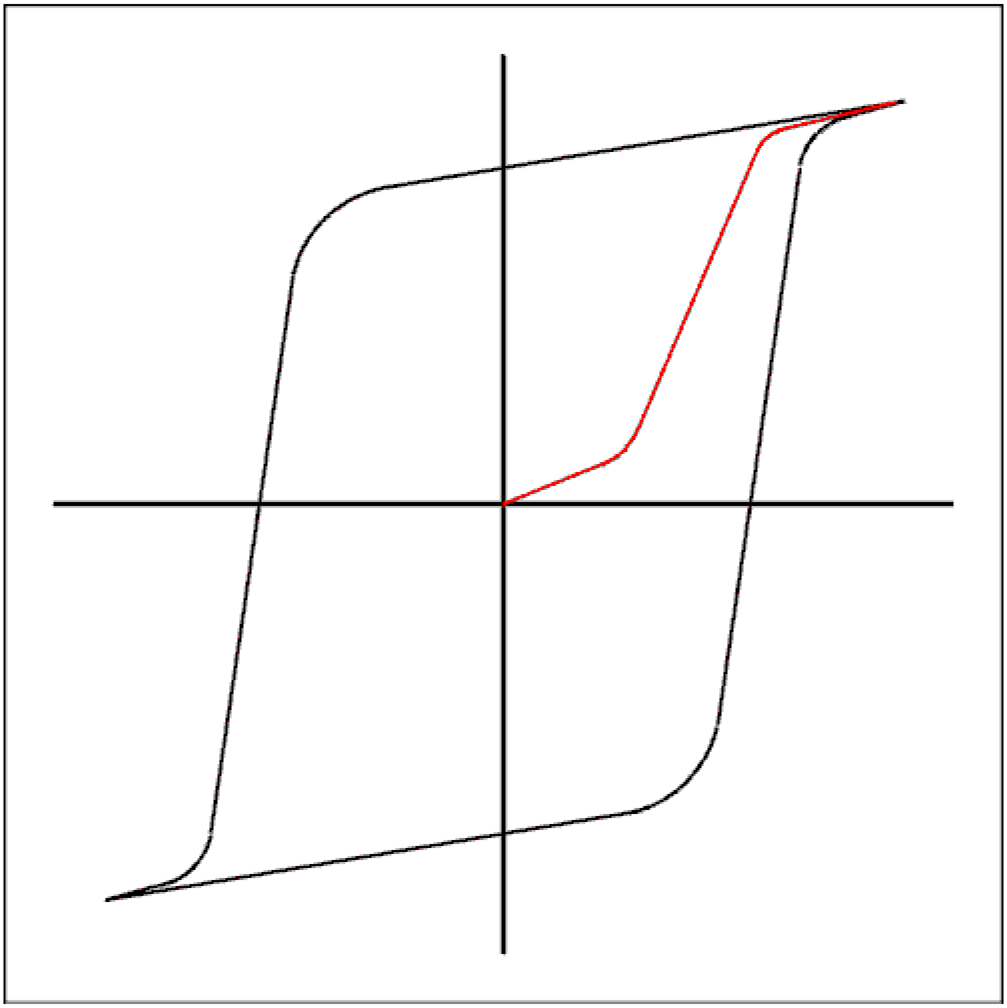

Figure 9.16 Hysteresis Curve of Magnetizable Material.

If the material starts out with zero magnetism and magnetizing force is applied the amount of magnetism will follow the red line up to the hysteresis loop and then it will be stuck on the loop. The only way to get back to zero will be to apply a slowly decreasing AC magnetizing force which will loop back to zero as shown in figure 9.19.

If magnetizing force is altered from zero and then brought back to zero the remaining magnetism will depend on whether the magnetizing force was positive or negative. If the force goes up the red line to the tip of the curve in the first quadrant and then is reduced to zero the remaining magnetism will follow the right hand side of the curve back down to zero force but there will be some magnetism left. This is desirable but the problem is the nonlinearity of the curve.

If in each case we start with a piece of fully demagnetized material and take the magnetizing force up from zero to a specific value and then back to zero the remaining magnetism can be plotted on a graph. What results is the graph below.

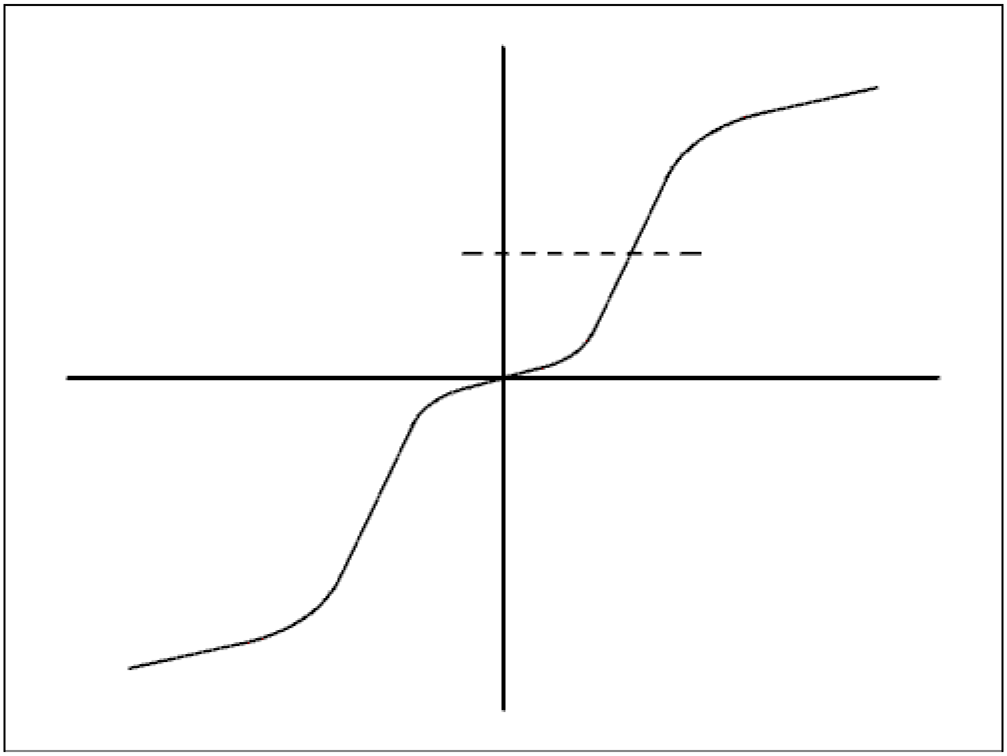

Figure 9.17 Transfer Function of a Magnetic Recorder.

This is the transfer function of our intuitive tape recorder described at the beginning of this section. Some method of linearizing the function is needed. The very first thing tried when magnetic recording was being invented was the use of DC bias.

If a direct current was superimposed on the audio signal to be recorded and the value of the DC places the magnetizing force at the center of the linear region as indicated by the dashed line recording can take place with a tolerable amount of distortion. I once owned a recorder that used a permanent magnet to erase the tape and DC bias for recording. It wasn't suitable for music but I used it for several years to exchange voice letters with members of my family.

What got magnetic recording off the ground was the use of AC bias. A frequency of approximately 10 times the highest frequency to be reproduced is added to the audio. Note, the audio does not alter the amplitude of the bias signal as in amplitude modulation. It is simple addition. That electro magnet I mentioned earlier is called the Record/Playback Head. A much oversimplified diagram of it is shown schematically in Figure 9.18.

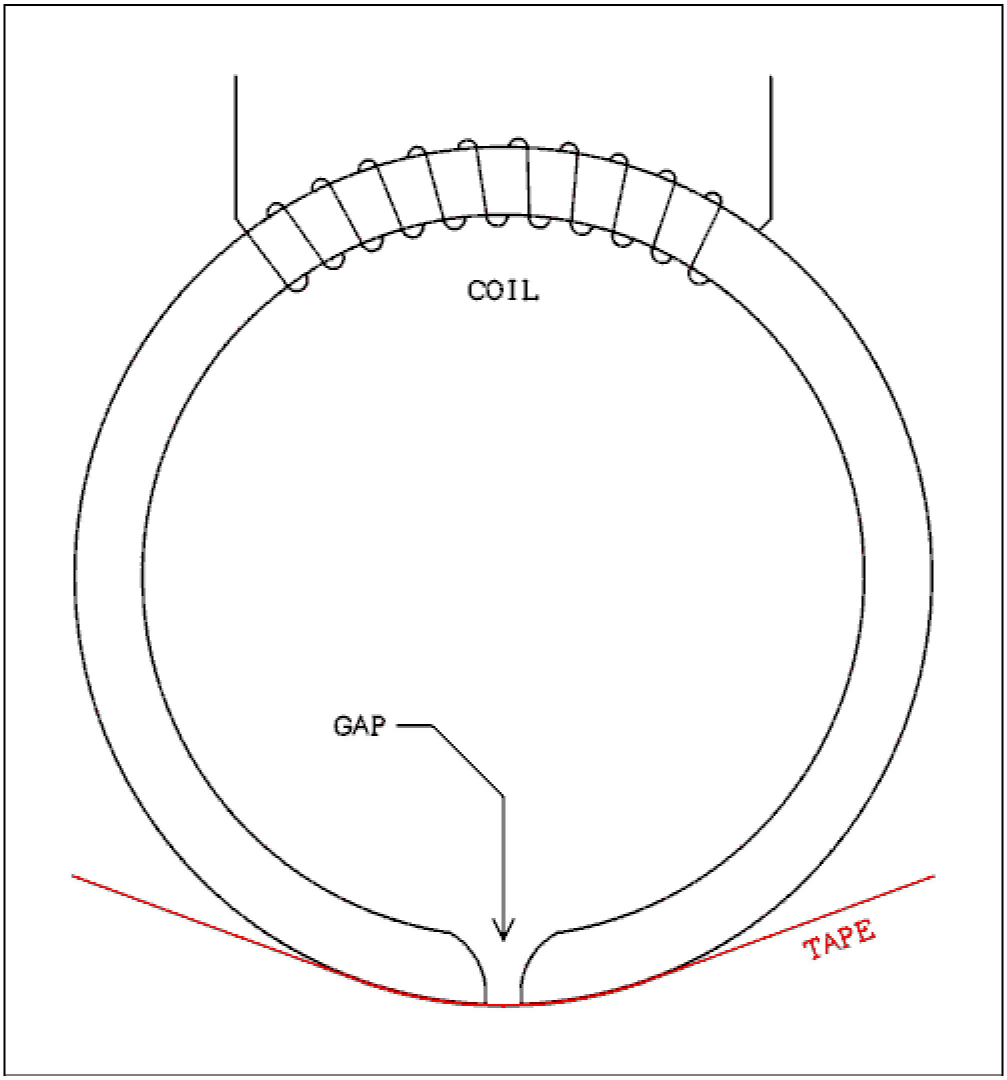

Figure 9.18 Magnetic Recorder Erase, Record, or Playback, Head.

The same AC bias signal is used to energize the erase head to clean the tape before recording. As the tape passes the gap in the head a given magnetic domain will "feel" many cycles of the bias signal. For the first half of the trip across the gap the strength of the field is increasing but for the second half it is decreasing. The figure below shows what happens to a single domain as it passes from the center of the gap to its edge. Figure 9.19 below shows what happens to the magnetization of each domain as the bias field decreases.

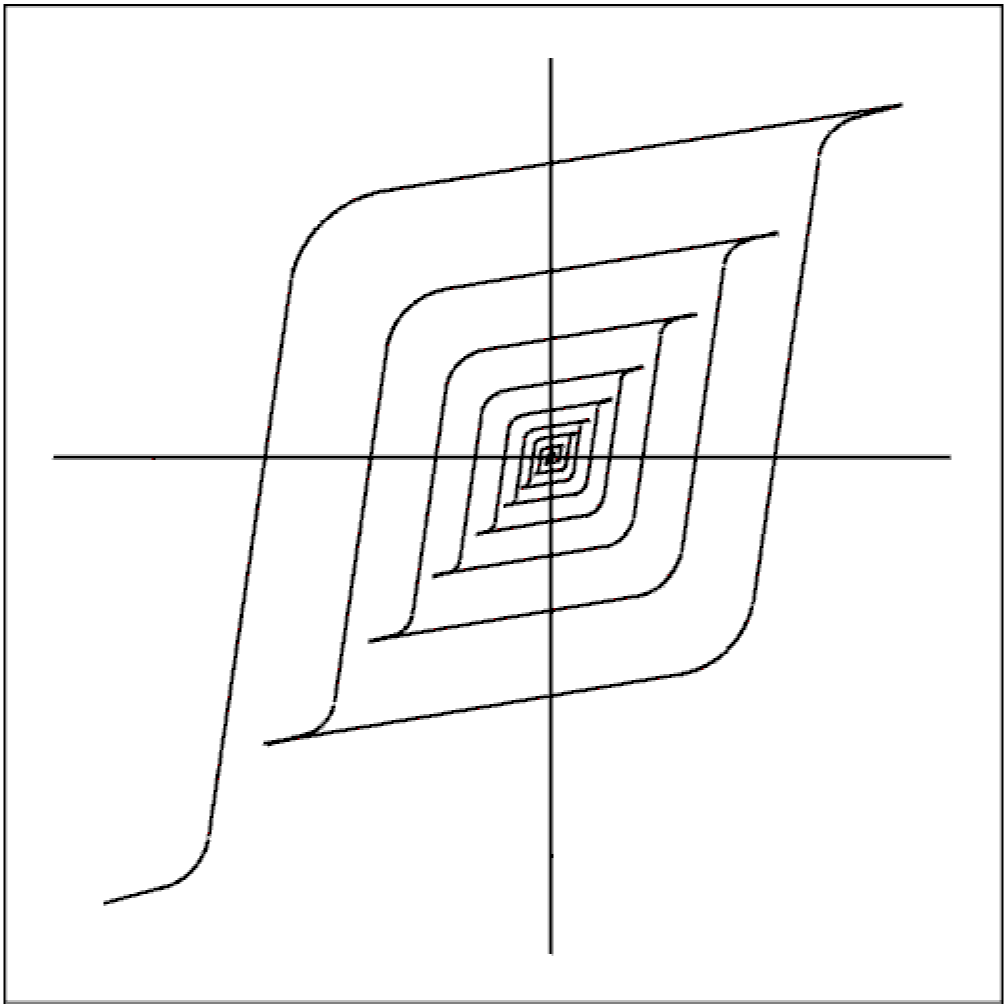

Figure 9.19 Bias Loops for a Magnetic Recorder.

The remaining magnetization is brought to zero by the bias field leaving the tape free of any magnetized domains. "Blank" for all practical purposes. Next the tape passes over the record head. The Bias field is not as strong as from the erase head. A given magnetic domain will pass the gap in less time than the period of the highest frequency to be recorded. So as far as any one domain is concerned the signal to be recorded is just a DC level.

If you are no stranger to tape recorders you have probably read that recording takes place at the trailing edge of the gap. I have, but it was never explained. Here is that long overdue explanation. As a single domain passes from the center to the edge of the gap the bias field is decreasing as for the erase head. But the field does not reduce to zero. The value it loops to is the value of the recorded signal at that moment. After the domain passes the gap it is left magnetized to the exact value of magnetism to correctly represent the recorded wave. When the tape is passed over the playback head the wave comes out accurately reproduced instead of being distorted.

What keeps the recorded signal from going to zero at the trailing edge of the gap is the frequency relative to the width of the gap. The bias frequency is much too high to be recorded because the head gap would have to be much narrower to make that possible. The bias signal makes recording linear without being recorded itself.

Troubleshooting.

I don't know how many times people have asked me why their tape recorder doesn't sound as good as when it was new. When I ask them when was the last time they cleaned the heads they reply, "cleaned the heads?" Head cleaning fluid is pretty much a thing of the past. Some people used to recommend carbon tetrachloride but it is too toxic to mess with. Common drugstore alcohol will do but it is half water so be sure to avoid getting it into the works or electronics of the recorder and dry the heads thoroughly after cleaning. When you instruct the owner on how to clean the heads using a Q-tip be sure to emphasize that they are not to run tape through the machine until all liquid has either been wiped up with a dry Q-tip, or has evaporated.

Other than dirty heads the most common problem with a tape recorder is that it will not erase a recorded tape and when a new or bulk erased tape is tried the recorded sound is weak and badly distorted. Are you ahead of me on this one? The AC bias signal is generated by an oscillator and it is not running.

Many people record infrequently so the record/playback switch contacts have become corroded. Most times cleaning the contacts of the switch will restore the recorder to operation. This is also true for a recorder that has not been used in any way for several years or decades.

Because a tape recorder is a mechanical device it can have similar troubles to a record changer. Many have idler wheels that no longer grip. Cleaning of rubber surfaces and tightening springs will usually set things right.

Old recorders with rubber belts are another story. Some compounds of rubber turn to gue after 20 years. Those that don't, stretch and become too loose to transfer power. In many cases such belts can be replaced with O rings. They are available from auto and industrial supply houses.

The Silvertone Wire Recorder.

The Silvertone wire recorder is an especially tough nut to crack. In all that I have seen the idler wheels are made of hard plastic which even if you can get them to drive make so much mechanical noise you can't hear the content of the wire. I presume there was some kind of soft rubber coating them but it must have been very thin because there is little clearance between the wheels and what they drive. It was probably the latest material in the post war 40s and there had not been enough time to life test it before it was used.

I have no solution for this in spite of giving it considerable thought. If anyone out there has found a successful fix I hope you will share it with me so I can share it with others.

I will tell you how I fixed mine for all the good it will do you. I knew that Pentron made tape recorders for sears and when I was buying Silvertone wire recorders I saw a Pentron and bought it on the off chance that that might have been true for wire recorders as well. The electronics were quite different but the transport turned out to be identical. Pentron had had the good sense to use time tested and proven rubber rimmed steel idler wheels. The paint job on the Pentron was different from the Silvertone I wanted to restore so I transferred the idler and drive wheels from the Pentron to the Silvertone. So I have a working wire recorder.

You might be fortunate enough to find phonograph idler wheels that will fit. If that fails I can't give you much hope. I have another rare portable Silvertone I would like to restore but so far I have not found any wheels to replace the plastic ones that were original equipment.

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9.9 Why TV Sets Are Not Covered.

I have little experience with TV sets. The few times in the 60s that I tried to repair a set belonging to my family I failed miserably. It's true I did successfully assemble a Heathkit color TV and get it aligned but building a kit with the quality instructions provided by Heath and repairing a set in which something has gone wrong are two very different kettles of fish. I'm sure there are lots of other resources available on the web. If anyone would like to volunteer to write a chapter on TV repair please submit it to my email address which can be found on the website that linked you to this book.

Chapter 10 Things That Have Never Worked.

Chapter 10

Things That Have Never Worked.

As a trouble shooter you will occasionally encounter something that has never worked. This may be a prototype constructed in an industrial or university research and development laboratory. It might be a DIY (do it yourself) project that was brought to your shop. It night be a kit that was constructed by someone else or yourself. What ever it is the fact that it has never worked can make the job of troubleshooting much harder than with something that used to work and stopped. The malfunction might be caused by a defective component but it is more likely to be cause by a wiring error or wrong component value.

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10.1 Power Supplies.

Power supplies can range in complexity from simple transformer-rectifier-filter circuits to multi output with electronic voltage and current regulation. If the power supply is one of the latter the regulator circuits should be separated from the basic rectifier filter and the basic circuit tested separately.

Although a simple power supply has little to go wrong, as pointed out earlier in this book failures can cascade turning a simple problem into a more complex one. An electrolytic capacitor may have been taken from NOS (new old stock) and may not be formed up to its rated voltage. Such a capacitor may show good using an ohmmeter but will blow fuses and diodes when the power is turned on. Since the capacitors have never been put into use they should be tested at their rated voltage.

For a brief discussion on the construction of an electrolytic capacitor, how to test it, and its behavior in a circuit, refer back to 3.2 Electrolytic Capacitors.

For a discussion on testing a power supply which may have unformed electrolytic capacitors and how to reform them refer back to 4.3 The Power Supply Section.

If the basic rectifier filter section is working properly The problem is in the electronic regulator circuit. If the unit uses IC regulators there is little to do but replace the one that seems to be causing the trouble. If the unit is blowing fuses it will be necessary to isolate the individual regulator circuits probably by removing the ICs. If the circuit is built with discrete components refer to section 5.2.

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10.2 Audio Amplifiers.

10.2.1 Transistor amplifiers.

Beware of treating the symptom. Many amplifiers I have opened up have revealed a burned or scorched resistor. Replacing this resistor will not fix the amplifier. The replacement will just burn out as the old one did. However, this will point you to the area of trouble.

Transistor audio amplifiers usually just blow fuses. This requires testing with power off. Most DMMs only apply 200 mV or less to the test leads. This may not reveal the problem. A VOM is a much better instrument for this kind of testing. Test from power supply positive to ground, from power supply negative, if the amplifier has one, to ground, and from power supply positive to negative. Be sure the polarity of the leads is such that the proper polarity is applied to the test point, positive to the positive rail and negative to the negative rail. This is likely to reveal that there is a short, which you already knew.

If the amplifier has multiple PC boards you can unsolder the power supply leads to each one in turn and determine which board the trouble is on. If there is only one board isolating the trouble is more difficult. Removing the power transistors from their sockets one channel at a time may, at least, show which channel the problem is in.

Testing Transistors.

Now that you have the power transistors out you might as well test them. A transistor tester is handy but not essential. The most basic test is the junction test. A DMM cannot be used for this test because it does not apply enough voltage to cause the junctions to break down. Set the VOM to measure ohms on the RX1 range and connect it to the collector and base. It should show a diode with the anode to the base in an NPN and the anode to the collector in a PNP transistor. The polarity reversing switch on the Simpson 260 is a real time saver when making this test. The transistor should also show a diode between base and emitter. Anode to base in NPN and anode to emitter in PNP. It should show open in both directions from emitter to collector.

WARNING: APPLYING POWER TO THE AMPLIFIER WHILE THE OUTPUT TRANSISTORS ARE REMOVED MAY DAMAGE THE DRIVER AND PREDRIVER CIRCUITS. THIS IS NOT RECOMMENDED.

A voltage breakdown test might also be a good idea. The schematic will tell you how much voltage is applied to the transistors. If for example the power supply is plus and minus 40 volts then in the static condition 40 volts is applied across each output transistor. Connect an external power supply with a series connected current limiting resistor of 10 k ohms to the collector and base of each transistor one at a time in tern. Positive to the collector of NPN transistors and negative to the collector of PNP transistors. Connect a voltmeter of any type across the 10 k ohm resistor. The meter should not indicate a voltage any grater than a few millivolts. If the reading is more than 1 volt the transistor should be replaced. Note: a reading of 1 or 2 volts might be observed if the transistor is a good germanium.

If the outputs test good.

If the transistors test good the problem may be caused by a transistor or other defective component earlier in the circuit causing the output stage to draw too much current. The high power transistors in the output are usually in sockets which require the removal of two screws to take out each transistor for testing. On the driver and predriver level the transistors will have to be unsoldered from the board. To junction test low power transistors set the VOM to the RX 10 or RX 100 range. When doing the breakdown test use a 100 k ohm resistor instead of a 10 k ohm.

If all transistors test good you need to start looking at the passive components. Shorted capacitors are the most likely suspects. Test electrolytic capacitors at their rated voltage not with the low voltage applied by an ohmmeter. Open resistors are also a possibility. For example an open resistor connected from the positive power supply rail to the collector of a predriver transistor could allow the transistor to go into saturation pulling the amplifier's output to the negative rail resulting in an apparent short.

If the defective component can't be located it may come down to shotgunning.

10.2.2 Vacuum Tube Amplifiers.

The first assumption when a non working vacuum tube amplifier is encountered is to assume a tube is defective. Although failure statistics tell us to check the tubes first in my personal experience with tube radios, TV sets, and instrument amplifiers is that the problem was caused by a passive component as often as it was by a tube. That said, the tubes should be checked first because they are so easy to replace. Even if the tubes are brand new they still should be checked. If they were taken from NOS (new old stock) there is a higher probability one is bad.

Unless you have a high quality vintage tube tester which is in good operating condition the best way to test the tubes is by substitution of tubes that are known to be good. There are two conditions in which this should not be done. One is if the amplifier is blowing fuses and the other is if one or more tubes has a red hot glowing plate. In these two cases the known good tubes may not be good after the test.

If the unit is blowing fuses and it has a rectifier tube, unplug the tube and see if the fuse blowing continues. If it does the most likely defect is a shorted power transformer. There is one thing you should check before condemning the transformer. Check to see if there are any shorts in the heater wiring or bypass capacitors in the heater circuit. Check the capacitors for shorts. If there are no capacitors unplug all the other tubes making sure you know which tubes go where. If there are no numbers imprinted on the chassis and you don't have a layout drawing, make one so you don't get the tubes mixed up. Heater shorts in a tube are rare but possible. If the amplifier still blows fuses the power transformer is the culprit.

If unplugging the rectifier tube prevented fuse blowing then the filter capacitors become the prime suspect. If the amplifier has silicon diodes check the power supply capacitors and diodes. Remember that a shorted diode is likely to be part of the symptom rather than the cause. Check the capacitors at their operating voltage before assuming the diodes are at fault.

Another way of testing the power supply is to unplug all of the tubes and use the dim bulb test. Remember you can't possibly burn out a 120 volt bulb by applying 120 volt line voltage to it. Start with a low wattage bulb and move to higher wattages. For full details on the dim bulb test refer to 9.1 Steps to First Power on.

If the fuse doesn't blow immediately after the power switch is turned on but the plate of one or both of the output tubes begins to glow red hot and then the fuse blows the outputs are drawing far too much current. In the case of a new design or kit oscillation is a good possibility. This may be taking place at a frequency above human hearing and will only be detectable with an oscilloscope. The primary leads of the output transformer may have been reversed turning negative feedback into positive feedback. Be certain there are no oscillations going on before proceeding.

Capacitors are the next suspect. If the amplifier uses cathode bias a shorted or reversed cathode bypass capacitor may be at fault. If fixed bias is used there may be a shorted or reversed capacitor in the bias rectifier/filter circuit which is preventing any negative bias from being applied. Shorted or even leaky coupling capacitors from the plates of the driver tubes to the control grids of the outputs could be applying a positive voltage to the grids causing too much current to flow. If the screen grid voltage is electronically regulated the regulator may be defective allowing too much voltage on the screen grids. This can cause too much plate current to flow.

If fuses are not being blown but the sound is week and distorted coupling capacitors earlier in the circuit are suspect. Plate load resistors which may be defective or the wrong value can also cause this symptom.

If static testing does not reveal the problem it may be necessary to disconnect the negative feedback and use signal injection or signal tracing in conjunction with signal substitution techniques to localize the defect. Be cautious when negative feedback is disconnected. The overall gain of the amplifier will be 10 times or more greater than it was with the feedback connected. Oscillation is a possibility under these conditions. Keep input and output leads separated as much as possible and by all means use shielded cables between the oscillator and input of the amplifier. Set the volume control on the amplifier very low so the oscillator can be operated at a higher level.

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10.3 Radio Receivers.

A communications or even a simple AM broadcast radio that has never worked can be a difficult problem. There are all those tuned circuits that have never been adjusted because the receiver doesn't work.

The first step is to half split at the detector. In most receivers the volume control is just after the detector. This is usually true even in short wave or ham receivers. Inject an audio signal at the top of the volume control and if you hear it the trouble is in the RF or IF circuits. If you don't hear the signal then the problem has been reduced to a simple audio amplifier problem and should be easy to solve. Once you have the audio working chances are you can align the IF and RF stages.

To troubleshoot and align the pre detector section an RF signal generator is an absolute must. It might be possible to trouble shoot without one but we are talking about a receiver that has never worked and has not been aligned.

Some service shop RF signal generators such as those made by Heath and Eico included DC blocking capacitors in the output. Higher end generators do not have a blocking capacitor and one should be added on the outside when making the following tests. Use a coaxial cable with the appropriate connector on one end and clip leads on the other. If you don't have one, make one. Clip the ground lead to the chassis* and clip one lead of a 0.001 microfarad capacitor in the hot lead clip. Use the other capacitor lead as a probe to make the tests.

* If the receiver being worked on is line operated and has no power transformer, the chassis is connected to one side of the power line. These radios, commonly known as All American Fives, should only be worked on while powered from an isolation transformer. Question. How did you get hold of an AA5 that has never worked?

Tune the generator to the frequency of the IF and turn on the modulation. Turn the generator's output up full or to 1 volt if it goes higher than that. Touch the test lead to the collector or plate of the last IF amplifier stage. You should hear a tone in the speaker. If not, find out why because you should.

If you heard a tone move the probe to the base or grid of the same amplifier stage. The tone should get much louder. Reduce the output of the generator and tune the adjustment or adjustments in the last IF transformer for maximum signal.

If the receiver is a simple tube type AM broadcast radio it most likely has only one IF amplifier stage. If a transistor AM radio it will have two IF stages. If it is a sophisticated communications receiver it will have several IF amplifiers and will likely be a double or triple conversion receiver. Work your way back through the amplifiers following the same procedure. Only align the transformer in the output of the amplifying device while the generator is connected to the input of the device. When you come to a mixer connect the probe to the plate or collector to see if you are getting a signal through all stages between there and the speaker.

Next check to see if the oscillator signal is present. If not, find the problem and fix it. If so tune the signal generator to the frequency of the preceding IF or if the receiver is single conversion to the received band. Tune the generator around until you hear it in the speaker. If this is a multi conversion receiver and the IF is off frequency adjust the oscillator frequency until it is correct. A transistor receiver may have amplifying stages between the two mixers. A tube receiver most likely will not.

As you work your way back through the receiver stages you will be aligning the tuned circuits and upon arriving at the antenna you may find the receiver is working properly. The alignment may need a little touching up.

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10.4 Simple Test Equipment.

There is a problem with test equipment. To test and repair a VOM, you need a working VOM. To test and repair an oscilloscope, you need a working oscilloscope etc etc. Since the heading is simple test equipment we will not try to repair oscilloscopes and let's not even think about digital multimeters.

If the problem is a VOM the first question is, "Is it completely dead or works on some ranges but not on others?" If the answer is completely dead the chances are the meter movement is defective. Unless you have the skills of a jeweler or watch maker repairing the meter movement is beyond consideration.

If it works on all voltage and current ranges but not the resistance ranges, check to see that batteries have been installed.

If it works on some ranges but not on others the probabilities point toward a wiring error or miss placed resistor. Since this device has never worked the chances that you will see a cooked resistor are small.

If the device is a VTVM or SSVM and it is completely dead check to be sure the amplifier is getting voltage from its power supply. Such meters have a rather complicated switching circuit between the amplifier and meter movement to allow for measuring negative voltages. Make sure this switch is wired correctly. If the meter will not come into calibration on any of its ranges check the amplifier for proper wiring and component values. If it works on DC but not on AC check the AC to DC converter (rectifier) for proper wiring and component values.

For simple things such as an RF probe the RF probe for the Signal Tracer described in section 2.7 if one of the diodes were to be installed backward there would be no output. For a wave meter, not described in this text, if the meter moves backward either reverse the diode or the connections to the meter movement.