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Curing KWM-2/2a IF Feedthrough

The Collins KWM-2/2a transceiver is the precursor to all contemporary hf transceiver designs. Between 1959 and 1979, well over 30,000 of these units were produced by Collins Radio[1], and many are still in service today. Great care was taken to minimize spurious emissions from the transmitter. The receiver however, has poor immunity to signals within the range of the tunable IF. This note discusses the causes for the poor receiver performance, and provides a solution by way of an optimized passive LC filter. The filter can be constructed, adjusted, and tested without modifying the transceiver.

Overview

Some Background on the KWM-2/2a

The Collins advertisement in the 1961 ARRL Handbook refers to the KWM-2 as the "Collins KWM-2 *Mobile* SSB Transceiver". The picture of the KWM-2 is through an open door of an automobile and the ad copy states:

> "*Engineered* for the amateur who desires an 80 through 10 meter *mobile* transceiver, the KWM-2 incorporates time-proven and advanced communication concepts."

This leaves little doubt as to the role the Collins engineering and marketing departments felt this transceiver was intended to fill. On the following page, the famous S/Line (75S-1 312B-4 32S-1 and 30S-1) is shown on a desktop. The ad copy makes no reference to the KWM-2. Its simple, the S/Line is for fixed service, the KWM-2 is a mobile rig.

Several years pass and the 1965 Handbook advertisement would indicate that Collins has taken on a different perspective. The 'market has spoken', and the KWM-2 has moved out from the auto interior and is now integrated into a family portrait of the upgraded S/ line: 32S-3 75S-3B 30L-1 and 30S-1.

The ad copy making references to the KWM-2 driving the 30S-1 and 30L-1 are easy to spot. The transceiver is now referred to as the "KWM-2 SSB Transceiver" with the *mobile* term being dropped. The KWM-2 copy starts out:

> "This versatile transceiver serves both fixed station and mobile needs....".

Mobile operation would appear to have taken a back seat to fixed station use. Some amateurs no doubt preferred the 'single box' solution over the multi-box (75S-3 / 32S-3) configuration. Cost, space, and convienence were possible factors.

Why make speculations based on these advertisements? Two reasons. First, it may come as a surprise to many (it did to me!) that a piece of gear manufactured by Collins Radio, would have this IF feedthrough deficiency. However, most amateurs would agree that a rig optimized for mobile use unlikely to be ideal for fixed station use. Therefore, secondly, appreciating that the rig is *designed* for mobile use, makes the technical (and operational) tradeoffs far easier to comprehend and accept.

Synopsis of the IF Feedthrough Problem

The KWM-2 uses a double conversion architecture with a tunable first IF covering 2.955 to 3.155 MHz. The receiver rejection of signals in the range of the first IF with respect to desired signals (tuned by the 'exciter tuning' and band selector), has been measured to be in the 30-35 dB (@ 3.7 MHz) to 45-50 dB (@ 28.6 MHz) range. These measurements were made on three KWM-2/2a's with vastly different serial numbers (1218 and 16928, 38132)[2]. It is therefore reasonable to conclude that this characteristic is typical of all units.

This level of IF rejection is poor by most standards. The level of IF rejection is not specified in the KWM-2 manual[3], and possibly, for good reason! It should be stressed that these transceivers, in all likelihood, meet their published receiver specifications. The line item in the specifications listing the *image rejection* and *internal spurious signals* does not address IF feedthrough.

One would be hard pressed to notice the feedthrough while using a KWM-2 in its intended mobile environment. Mobile antennas are physically short, and typically narrow-band. This give them natural filtering properties that minimize the signals in the range of the tuneable IF therefore minimizing the feedthrough. It is safe to assume that more than 95% of the KWM-2s in use today are in fixed service, not mobile, so now we have a different story.

Antennas, Operating Habits, Propagation, and the Quest for Perfection

Antennas

The antenna used with the KWM-2 will have a large impact on the amount of IF feedthrough. A 80-10 meter multi-band antenna of virtually any kind (vertical, random wire, rhombic etc.) will be the worst offender. This style of antenna will do a great job picking up signals in the 3 MHz region. The best antenna to use with the KWM-2 is one that does not receive well in the 3 MHz range. Antennas that satisfy this condition include mono or tri-band beams designed for 30-10 meters. Antenna tuners may help, or actually hurt. It depends on the details of the design.

Operating Habits

If you only use your KWM-2 on 20-15-10 meters with a beam antenna, don't bother plowing through the rest of this note! Most beams look like very good high-pass filters.

However, being that this solar cycle seems to be erratic, many of us are using the lower bands more frequently. The 80 meter band is the most susceptible to the IF feedthrough since there is only a 600 kHz frequency difference between the IF and the middle of the band. Therefore, most antennas used for 80 will be hauling in plenty of 3 MHz signal energy.

Propagation

Sometimes it is there, sometimes it is not. While writing this note, the signal levels in the 2.955 to 3.155 MHz region were checked on a Collins R-390. Using a 40 meter inverted V, there were 4 signals present at or below the 100 uV level. This level (or less), is not objectionable since a 40 dB rejection brings us to 1 uV, which is typically in the background noise.

However, when propagation is good at these frequencies, the signal levels can be considerably higher. On the west coast, several marine communication stations emit very strong signals in 2.9-3.2 MHz band. These signals often became objectionable to me, hence the reason for this 'fix'.

The Quest for Perfection

We all have this disease to one degree or another. If one is not interested in fine radio equipment, why mess with this Collins stuff? A high quality receiver simply should not have significant responses to signals that it is not tuned to. This is a big issue to some of us.

Two Tests for Feedthrough

Actual Operating Conditions

This is where it really matters. Lets face it, if the problem does not occur or annoy you under normal operating conditions, why deal with it?

To eliminate confusion between other possible spurious receiver responses and the IF feedthrough, the best method found to date is as follows:

1. With a *trustworthy* communications reciever, tune the 2.955 to 3.155 MHz band when propagation is good at these frequencies or when you normally operate. Use an antenna that works well in the 3 MHz region (not the 10m beam!).
2. Log the the stronger (e.g. >200uV) signals heard with their frequency and type of emision.

The corresponding KWM-2 dial readout in KHz that tunes the IF to these frequencies will be:

$N_{readout} = 3155 - f_{station}$ (KHz)

For example, if a station was logged at 3010 KHz, setting the main dial to

3155-3010=145

would tune the first IF to 3010 KHz.

For each band that you operate your KWM-2 on, try the following:

1. select the band of interest
2. select the antenna normally used
3. peak the received signals (or noise) using the exciter tuning
4. set the main tuning dial to receive the frequencies logged with the known good receiver.
5. note the signal level for each signal heard (if any)

If all is in good order, none of the logged signals will be heard. If you hear one of the signals on one band, you will most likely hear them on others at exactly the same dial readouts, but at possibly different signal strengths.

If the existence of these signals annoys you as much as it did me, press on.

Using an External Signal Generator

To make accurate measurements, a stable, shielded, RF source is required. The source should have a leveled (constant amplitude vs. frequency) output and a calibrated attenuator with a 90 dB range and 1dB resolution. The absolute calibration units used to set the level do not matter, (dBV or dBm)

Note: the s-meter in the KWM-2 can only be used to set a reference level (e.g. S9). The absolute 'calibration' of the s-meter is virtually meaningless. A 10 dB change in input level can produce a wide variety of meter movements!

To insure that signals are not entering the KWM-2 from other paths (e.g. the power line), do the following: Connect the generator output to the KWM-2 antenna input with a good quality (RG-58 or better) coaxial cable. Set the generator to 3.9 MHz. Set the KWM-2 to the 3.8 MHz band and tune/peak this signal. Adjust the generator level so that an S9+40dB signal is present. Disconnect the coax from the signal generator. The signal should disappear entirely. Then, try touching just the shield of the coax to the generator ground. The signal level should be minimal (barely audible, and well below S1). If you have success with these tests, the generator shielding is sufficient to give accurate results.

Each band of the KWM-2 can be checked by using the following steps. To be explicit, the 3.8 MHz band will be checked first.

1. set KWM-2 band switch to 3.6 MHz.
2. set the main tuning dial to 100

3. set signal generator to 3.6+0.1 = 3.7 MHz
4. tune in signal by adjusting signal generator frequency and peaking the s-meter with exciter tuning.
5. set signal generator output level to give an S9 signal and note the attenuator setting. For this example, assume it turned out to be the -75 dB setting on the generators attenuator.
6. then set signal generator to 3.055 MHz
7. fine tune the signal generator's frequency till you hear its signal, it will not be very strong.
8. reduce the generators output attenuation till the KWM-2 s-meter again reads S9. ... For this example, say this is -40dB on the generators attenuator.
9. The difference between the two generator attenuator settings is the IF rejection at 3.7 MHz. For this example it is: -45-(-75)=30 dB

This procedure can be repeated for other bands by simply setting the generator up 100 kHz from the selected band edge. The following table shows the measurement results obtained on KWM-2a SN38132:

Test Frequency MHz	IF rejection in dB
3.7	30
7.1	40
14.1	49
21.1	46
28.6	50

Details of the IF Feedthrough

The KWM-2 Dual Conversion Scheme.

The KWM-2 design uses the dual conversion scheme shown in Figure 1. The RF amplifier (V7) serves as a tunable preselector with the objective of *eliminating* all signals except those at the frequency of interest. The first mixer with an appropriate frequency from the crystal oscillator, translates the preselected signal to the 2.955-3.155 MHz range. The remainder of the circuitry forms the tunable IF which is simply a receiver that covers the fixed frequency range of 2.955-3.155 MHz. Note, 0 on the main dial corresponds to 3.155 MHz, and 200 corresponds to 2.955. Therefore 100 on the dial corresponds to the IF being tuned to 3.055 MHz.

The Two Flaws in the Design.

The Collins engineers did a first class job in minimizing transmitter spurious emissions. One of the techniques they used was the 'single balanced mixer' (note V5 and V6). A mixer has two input ports and one output port. The key property of the single balanced mixer is its ability to attenuate signals present on the port that is balanced which minimizes them on the IF output port. Unfortunately, the Collins engineers chose not to make the RF-port of the first mixer (Figure 1) balanced. Consequently, signals on the RF-port appear at the IF-port along with the desired sum and difference frequency terms. This means that any signal on the RF-port within the IF passband of

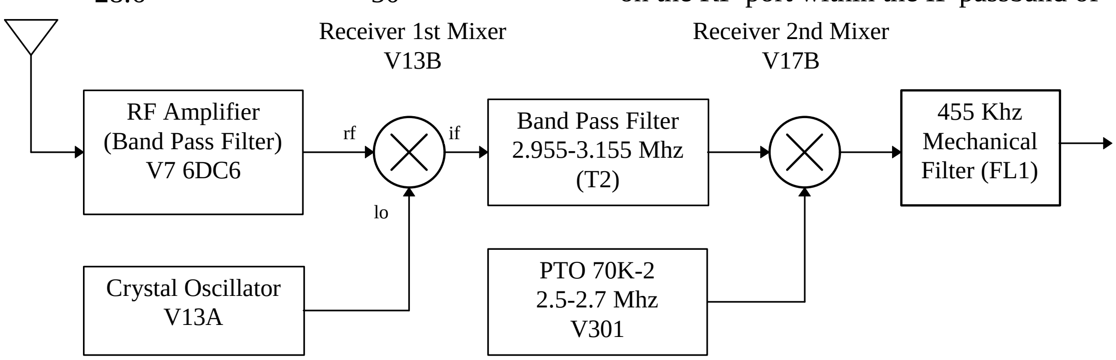

Figure 1 - Receiver Block Diagram

2.955-3.155 MHz will be passed to the tunable IF, with a possible amplification to boot!

Clearly the job of the pre-selector must then be to prevent signals in the range of the tunable IF from getting into the first mixer RF port. Flaw number two.

Close study of the schematic diagram will show that the low side of the RF amplifier's (V7) plate tuned circuit (L10 and capacitor selected by S5) is returned to ground by a 220 pF capacitor (C121). This capacitor value limits the ultimate effectiveness of the plate tuned circuit in rejecting frequencies in the tunable IF region. Normally one would use a far larger capacitor value so as to provide a very low RF impedance to ground.

This value of capacitor was chosen since this circuitry is utilized in both transmit and receive modes. When in transmit mode, the capacitor is part of the rather elaborate neutralization and RF feedback scheme. This scheme ostensibly improves the RF power amplifier linearity (linearity only to be rendered virtually useless by a speech processor!). Consequently, the ability of the RF amplifier's plate tuned circuit to attenuate signals at lower frequencies is hindered. It is interesting to note that the 75S series receivers use a 10,000 pF (0.01uF) capacitor to bypass the low side of the plate tuning inductor. Their IF rejection should be substantially better.

If either the mixer were single balanced at the RF port input, or the RF amplifier was not compromised by the transmitter design, the IF feedthrough would not be a problem.

Some Possible Cures

Single Balanced First Mixer

From a purely technical point of view, this would be the most satisfying solution. The problem is, the surgery required, would be pretty outrageous. One could possibly fashion a small sub-chassis containing a nine pin tube base. This could be plugged into the existing socket for V13. Circuitry could then be designed (2 tubes) to duplicate the functionality of V13 required for the crystal oscillator and provide a single balanced mixer. This will not be a physically 'pretty' solution and it has a high technical risk due to the sensitivity of the associated circuitry to small stray capacitances.

Passive Filter in the RF (Out) Transmission Line.

This solution is attractive since it requires no modification to the KWM-2 unless one wants a mechanically integrated package. The downside is the components used in the filter (inductors in particular) must be capable of handling the transmitter output power. This forces the physical size of the components to be relatively large making integration into the cabinet potentially difficult.

Passive Filter for the Receive Signal Path

This solution has several desirable features:

1. by definition, it will not effect the transmitter in any way
2. physically small components can be used
3. the size should allow an easy mechanical integration into the KWM-2 package
4. minimal wiring changes will be required

This was the approach chosen.

Details of the Passive Receiver Filter

The electrical design

The optimal design of the IF rejection filter cannot be found in a table. The design goals are somewhat unusual:

Frequency	Attenuation
f < 2.955 MHz	don't care
$2.955 \leq f \leq 3.155$ MHz	> 40 dB
f > 3.155 MHz	minimal

The filter topology is shown in Figure 2. The element values were determined with the aid of a computer simulation to provide the frequency response shown in Figure 3. A 50 ohm source and load impedance is assumed.

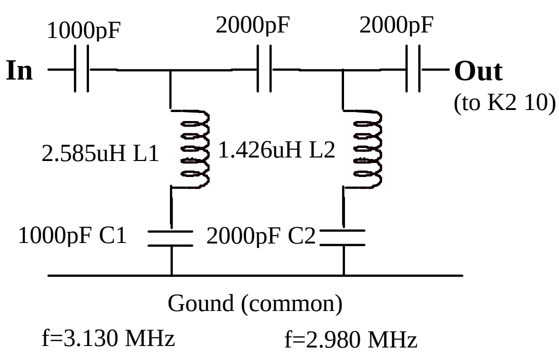

Figure 2 - IF Reject Filter Circuit

To attain the response shown in Figure 3, the inductor Q should be greater than 150. The optimal resonant frequencies for the series LC circuits were found to be 2955+25=2980 kHz and 3155-25=3130 kHz. This filter provides almost 50 dB of rejection across the 200 kHz IF tuning range.

The filter frequency response is plotted on a log frequency axis. The 80 and 40 meter bands are shown by the broken lines. It can be seen that signals in the 80 meter band will be attenuated by up to 5 dB while 40 meters and above, the attenuation of the filter is less than 1 dB. The attenuation on 80 meters is of little consequence since signals (and noise !) are typically very strong on this band.

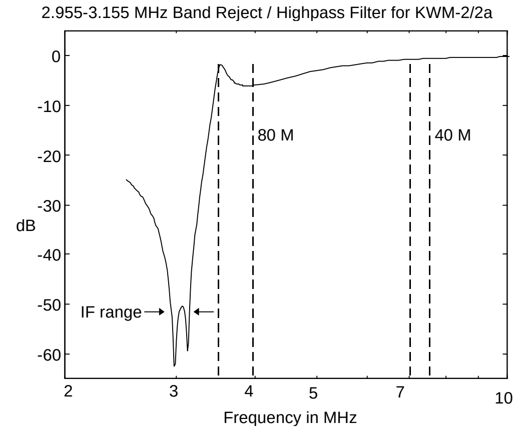

Figure 3 - Filter Frequency Response

Two items are critical to obtaining good filter performance:

1. inductor Q
2. resonant frequencies of series LC circuits

The capacitors should be silver mica for the best Q and stability. The tolerances of the capacitors should be 5% or better. The inductors should have adjustments so the resonant frequency of the series LC tuned circuits can be precisely set.

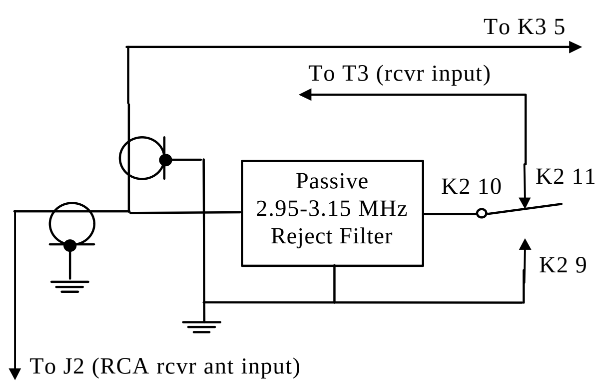

Figure 4 - Insertion of Filter in the KWM-2 Antenna Relay Circuitry (open relays)

Electrical and Mechanical Location

Figure 4 shows how the filter is electrically inserted into the KWM-2. Initially the center conductors of two coaxial cables were connected to pin 10 of K2. This connection is severed, and the filter circuit inserted between the two cables signal conductors and the relay pole. If the circuit is constructed with the recommended components, it will fit under the chassis in the area housing the transmit/receive relays. Since the filter is inserted between the antenna and the receiver input on T3, it *has no impact* on transmitter operation. This diagram is accurate for the earlier tranceivers that did not have the enclosed relays. However, the same nodes are present in the newer rigs.

Filter Construction

Component Details

Without question, the most difficult part of implementing this filter will be locating suitable materials for constructing the inductors. To get the maximum amount of IF rejection with minimal attenuation in the 80 meter band, the inductor Q should be 150 or greater. In order to fit the filter into the relay area, the inductors must be small. Pot core ferrite inductors fit the requirement nicely. The parts list in Table 1 is for one inductor.
Note: ptptt=polyterephthalate is an insulating substance similar to bakelite.

The two important core specifications are the material properties and the core size. It was found that the A40-4C4 material of core size 14x8 mm was ideal for this application. This, however, does not mean that other selections would not work as well or better. Again, the keys are Q and the ability to adjust the value. If the inductor value could not be adjusted, one could tweak the series capacitors (C1,C2) by 5 or 10% with no significant ill effects on the filter shape. Adding trimmers or padding capacitors must be balanced against the increase in size of the filter.

The 2.585 uH inductor is constructed by close winding exactly 8 turns of #24 enameled wire on the bobbin. It will require two layers and 'scramble wound' just won't do! The 1.426 uH inductor is made with 6 turns of #24. Both six and eight turns requires the wire enter and exit the bobbin through the same service slot. If the wires do not go through the same slot a half turn will be present.

Be careful when working with the cores. They are brittle and will surely break if excess force is applied. Do not attempt to fit the wound bobbin into the core by forcing it. Adjust the winding with needle nose pliers until the bobbin fits easily into the core. If you have not worked with small cores such as these, it would be prudent to have at least one spare on hand.

You might wonder about repeatedly specifying the inductance to 4 decimal places when we can only get a 1/2 turn out of 8 resolution on the winding. This is where the adjusters come in! They are essential for precise tuning of the series resonant frequency.

Filter Mechanics

A piece of copper clad circuit board material (single sided is preferable) is cut to 1.5 x 1.75 inches and the entire filter circuit

Part	Material	Size	Phillips PN
pot core	A40-4C4	14mmx8mm	B65541- +40-A1
adjusting device	K1 - A40	to fit core	B65549-E3-X101
threaded sleeve	polyamide	to fit adjuster	B65808-L3002
bobbin	ptptt	to fit core	B65542-B-T1
spring washer	makrofol	to fit core	B65542-A5000
connecting plate	ptptt	to fit core	C42035-A11-B4
yoke	stainless	to fit core	C61035-A12-C28

Table 1 - Inductor Components

easily fits in this real estate. The overall size of the filter is 1.5 x 1.75 x 0.6 inches including the silver mica capacitors. Two insulating standoffs were used as terminals for the input and output nodes. The copper is the common ground.

Filter Tuning

For this, all you really need is a stable, shielded signal generator with a decent attenuator, and your unmodified KWM-2. It is recommended that the transmitter of the KWM-2 be disabled by pulling the 5R4 from the power supply. Inadvertently pumping 100 watts into the signal generator could have unpleasant side effects. Once the filter is constructed, temporarily add the proper cables and connectors to insert it between the signal generator output and the KWM-2 antenna connection. Use good coax to try this, not audio grade RCA cables.

Set the KWM-2 bandswitch to 3.4 MHz and the exciter tuning to 1 on the log scale. Set the signal generator to 3.130 MHz, and the KWM-2 main dial to 25. Adjust the output amplitude of the generator and touch up the frequency till an S9 signal is present. Adjust the L1/C1 resonant circuit for a minimum reading on the s-meter.

Set the signal generator to 2.98 MHz and the KWM-2 main dial to 175. Adjust the output amplitude of the generator and touch up the frequency till an S9 signal is present. Adjust the L2/C2 resonant circuit for a minimum reading on the s-meter.

While adjusting the inductors, if you cannot get clearly defined minimums on the s-meter, the most obvious problems will be an incorrect value, or a low Q, for one or both inductors. High quality inductors will provide attenuations of 60 dB at the notch frequencies. This compares favorably with the notch depth in Figure 3 indicating the actual inductor Q obtained must be around 150. Using the signal generator and an RF voltmeter (or scope) one should be able to

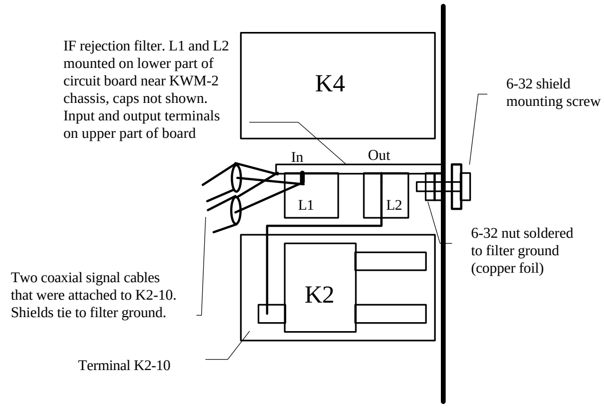

Figure 5 Filter mechanical mounting.

get an idea of where the problem is. A grid dip meter is useful for getting a rough idea of resonant frequency and Q.

Once the filter is believed to be working, the IF feedthrough measurements should be repeated. You should see at least a 30-40 dB improvement in the IF rejection across all the bands bringing the rejection up to a respectable 60-70 dB.

Installing the Filter in Older KWM-2s

The filter is compact enough to fit inside the relay shield under the chassis. Before working in this area, ***please disconnect the power cable*** from the power supply to the KWM-2 since line voltages are present on some relay contacts. A tool slip could create a painful mess, for both you and the transceiver.

There are 3 screws with associated washers that need to be extracted to remove the relay cover. *Be very careful* when removing this hardware. It is all too easy to drop a screw or washer down a ventilation hole and have it end up in the power amplifier shielded enclosure. You can have a very entertaining evening trying to get washers and/or screws out of this compartment! I know.

There is enough space to insert the filter between the relays. Figure 4 shows the electrical connections while Figure 5 shows a sketch of the relay compartment with the filter. One of the coaxial cables going to the input terminal will need to be extended a couple of inches in order to reach the filter input terminal. A piece of insulated (preferably Teflon) hook up wire is used to route the filter output to K2 terminal 10. A short ground wire should also be installed between the filter ground and a chassis ground lug.

As to mounting, one approach is to solder a brass 6-32 nut on the copper clad PC board. This is done once the filter is in place. A longer than stock screw is threaded though both the captive (PEM) nut on the shield wall and this new mounting nut. When the filter is in its desired place, the mounting nut is soldered to the filter board.

Material can be removed from the shield cover hole associated with this screw so as to make a slot. The screw can then be left mounted in the assembly and the shield slot will then slip over the screw shank. This, admittedly, is not a great mounting scheme, and suggestions are welcome.

Installing the Filter in Newer KWM-2s

There is actually more room for the filter in the later series of transceivers which us the relays enclosed in plastic housings. The dust shield is not present. Making a mounting hole in the RF PA shield enclosure is one way to mount the filter. A less intrusive way (certainly less fillings!) would be to attach the circuit board with a spring clip arrangement. The details remain to be worked out.

Conclusion

The IF feedthrough rejection of the KWM-2/2a receiver can be improved considerably by the addition of a passive LC filter. From my point of view, this filter removes a very irritating problem with the transceiver. The change can be neatly and almost invisibly incorporated into the mechanical package. The filter can be built, adjusted and tested outside the KWM-2 before performing any modifications whatsoever to the transceiver. If all goes well, the only test equipment required, besides the transceiver, is a good quality signal generator.

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[1] *The Pocket Guide to Collins Amateur Radio Equipment 1946 to 1980*, Jay Miller KK5IM, Butch Schartau K0BS, Trinity Graphics Systems, 5402.5 Morningside Ave., Dallas, Texas 75206.

[2] Many thanks to Foster Paulis, W4HCX, for providing the 2 late serial number KWM-2a's for testing, and, for his constructive comments on this note.

[3] *Instruction Book KWM-2 Transceiver* 6th edition, 15 November 1960, Collins Radio Company, Cedar Rapids, Iowa.