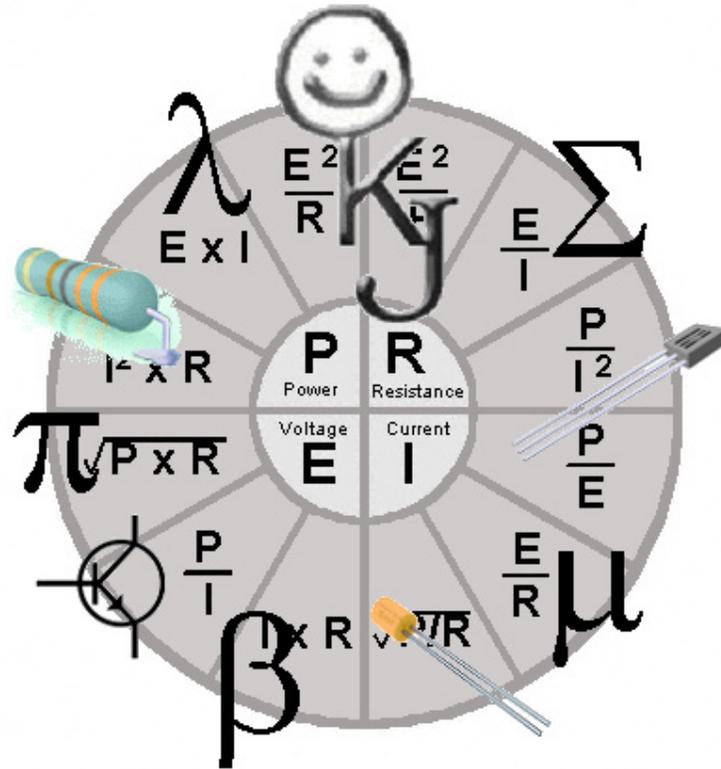


Metal Detector



Content of Report : PI & LC.Osc Metal Detector

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1 Introduction to Metal Detectors:

Metal detector is a device that can detect metal, the basics can make a sound when it is near some metal, and the more advanced can tell what kin of metal and how deep it is down, they are using different detecting principles.

We got the assignment to built a detector there could detect a 10kr coin at 5cm. The device had to be battery operated and transportable. We used these principles:

1.1 BFO Detector:

The basic way the Beat Frequency Oscillator (Later only BFO) works, when the detector coil is above some metal, it will change the frequency in the detector oscillator, which has the detector coil in the frequency depended circuit. The detected frequency is compared to a reference oscillator in a mixer, so there will be both the different and the sum of the 2 frequencies. The detector we has made isn't really a real BFO, while the reference is internal in a Micro Controller (Later only μC) and the signal from the detector oscillator is connected directly to the μC 's external timer pin. In the code for the μC there is implemented an average function, so if the ground has high magnetic fields it will compensate for it after some seconds. The output is indicated by Light Emitted Diodes (Later only LED) and by a sound in different locked frequencies.

1.2 PI Detector:

The Pulse Induction (Later only PI) uses a totally different way of sensing the metal, it sends out a very short magnetic pulse. Just after the pulse is finished the coil makes a spark (Later Reflected pulse). The reflected pulse is changing shape when metal comes near the coil. A part of the reflected pulse is amplified and put into some kind of a pulse detector.



2 Conclusion:

The Project elapsed great, the timetable was almost true, only approximate 1 day later with the finished design than we planned. The project was a little more difficult than I expected from the beginning, but already when we got the assignment I had an idea to solve the problem, but after some hour's work, and no positive result, I was almost quitting the idea. After a little time more we got the detector part to work so it was sensitive enough. The frequency detector was mounted and it worked great even the average part.

We tried to make another detector to see if it could be more sensitive, and if the first failed, we had another horse to carry on with. Actually it ended up with almost 2 different working detectors, the second wasn't finished when we need to stop and finish the report. But since it is an analogue project I decided to describe the second detector also.

Our team worked out the project without big conflicts. But if the knowledge of designing circuits and build circuit was almost at the same level in the group, the time used to make the product could be reduced. I mean one in the group maybe would have gained more if he had joined the basic level.

Place: EUC-SYD

Date: 1-Dec-03

Name: Kasper Jensen



3 How Metal Detectors Work:

3.1 Detection of Metal:

When some metal is moving close to a coil the magnetic field around the coil is changed and the coil induces some energy, called Eddie current. The same principle is true, if there is putted some energy in the coil it changes the magnetic field around the Coil. The way is also used in loudspeakers, when it is playing, the energy is conducted to the speaker, and if there is measured on the speaker and pushes a little to the membrane, the speaker generates some energy. If the terminals on the speaker are shorted, the membrane is hard to push, the coil can't make the energy, and the coil is locked. But the difference between the speakers and the earth is that the speakers have big magnetic part to help the membrane to move, otherwise in the metal detector it is normally not a magnetic object there has to be detected, so the coil has to produce it own magnetic field. When the detectors magnetic beams are reaching a metal, the metal start to induct the fields, and reply the magnetic field in another direction / time, this change can be seen in the frequency / pulse response of the coil.

There are big different

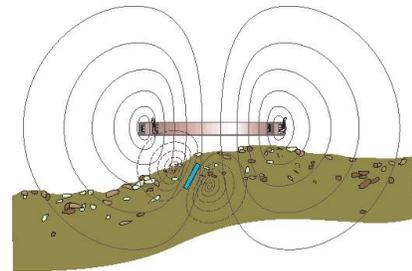


Figure 1 Magnetic Fields

3.2 Detection Method:

There are 2 major groups of detectors:

Passive detector uses the detector coil in a frequency depended part of a circuit, example a Oscillator where the inductance of the coil and the capacitive of a capacitor are making a oscillation, when these parts have positive feedback, and the amplifier a gain of 1, it will continue oscillating. When some metal is coming close to the alternating magnetic field, the metal changing the field, and the inductance in the coil changes a little, and then the frequency. Example: BFO

Positive:

- Easy to build
- Cheap
- Easy discrimination of Ferro / non Ferro metals
- Low Current / Voltage

Negative:

- Sensitive to electro magnetic noise
- Difficult to make working on "long" distance
- Difficult to get the frequency change big
- Sensitive to high magnetic fields in the earth / water

Active detectors uses the coil to transmit a pulse or a continually waveform, some uses the same coil to receive with, and others have 1 or 2 receiving coils. The PI loads the coil with some current in a narrow pulse, and when it releases the coil it make a reflective pulse the duration of

the reflected pulse is only a few μS , and the pulse can be several 100v high. When some metal are coming close to the coil the amplitude of the reflective pulse is getting little lower and the duration of the pulse a little longer, almost like

the metal behaves like a capacitor for magnetic energy, in the top of the reflective the metal collect magnetic energy, and when the pulse is falling in voltage it returns the energy slowly. Different metal, have different reaction time. Just after the normal duration time of a spike, the measurement has to be done, like in Figure 2 illustrates, the pulse will rise a little when some metal comes near. The sampled signal has to be amplified up to a signal that can be used.

Positive:

- Not sensitive to electro magnetic noise
- “Long” distance detect
- Detection near wires / high magnetic fields in the earth / water

Negative:

- High Current / Voltage
- Difficult to build
- Difficult discrimination of Ferro / non Ferro metals

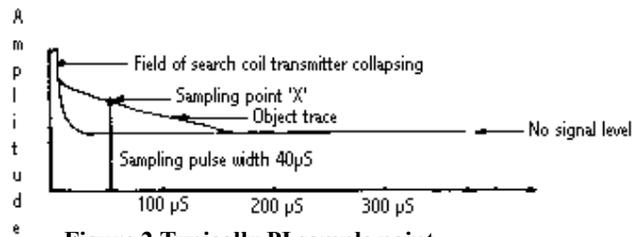


Figure 2 Typically PI sample point

3.3 Discrimination of different metal:

Expensive metal detectors can show which kind of metal there is registered, and even be setup to discriminate between them, so there wont be any kind of detection it comes near an old can, but if it is gold or other non-ferrous metal it shows some result. The way that can be done is to closely analyse the returned signal. VLF principle is the best type to discriminate metal, it sends out a constant magnetic field, and receive it in another coil. When the received field is changed in the phase there must be a metal close. The amplitude of the signal tells how deep / big the object is. Fig. 3 & 4 show how different metal response to the magnetic pulse.

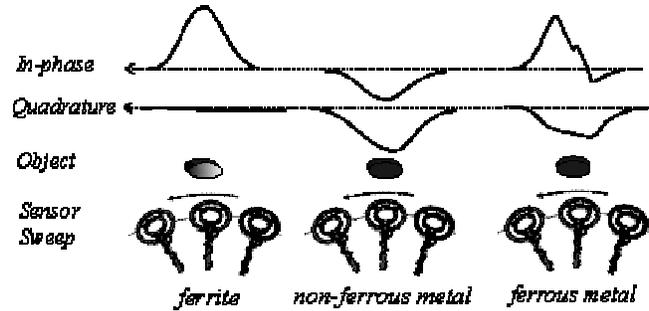


Figure 3 Different metals pulse feedback

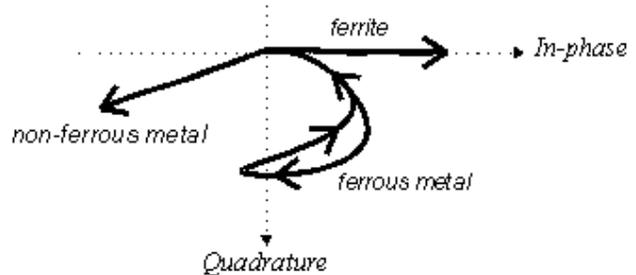


Figure 4 different metals phase feedback

4 “BFO” Detector Design:

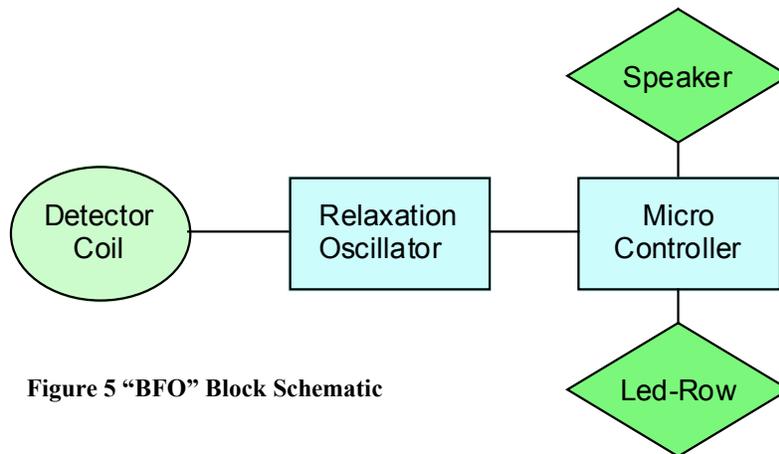


Figure 5 “BFO” Block Schematic

This relative simple metal detector isn't a real BFO, but it is the closest group of detectors. The Oscillator makes a frequency change when some metal is near the detector coil. The signal is send to a timer pin on the μC . Internal in the μC the calculation is made, and showed on the LED and some different sounds are made. The μC gives a big advantage of detecting the signal it makes detection of small changes down to a few hertz. Average is also a function the μC can manage, and then it can discriminate high level of magnetic fields in the earth, a kind of auto gain control.

4.1 Coil & Oscillator:

The coil is a flat spiral coil, with 13 turns around an old CD, which have the diameter of 12 cm. The used copper wire has a diameter of 1.5 mm. The coil is made in the spiral shape to get the magnetic field as wide as possible. Different types of coils where tested, but this seemed to be the best.

<Appendix A> shows the calculation for the coil.

The metal sensing part of our designed metal detector, is built around an inverter, where the frequency depended components is the detector coil and the 2 capacitors.

The inverter delivery enough power to the oscillation parts, so it continues to oscillate. The oscillator always starts when the power is turned on, while the dc level on the output is inverted and dc coupled to the input. The LC components limit the frequency to the oscillating frequency.

The oscillating frequency can approximately be calculated using this formula:

$$F_{osc} = \frac{1}{2\pi\sqrt{L*C}} = \frac{1}{2\pi\sqrt{42.2\mu H \frac{39nF*39nF}{39nF+39nF}}} = \underline{\underline{175.4kHz}}$$

The 2 capacitors are coupled in series, through the ground, and it makes a parallel oscillation circuit. The resistor in the top gives the coil a little lower Q, and the oscillation a higher bandwidth.

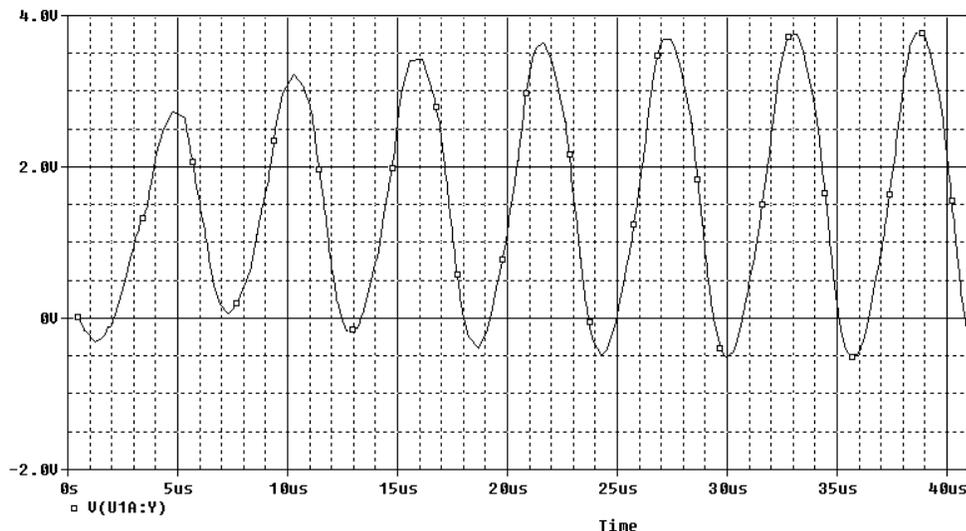


Figure 8 Simulated output of the first inverter

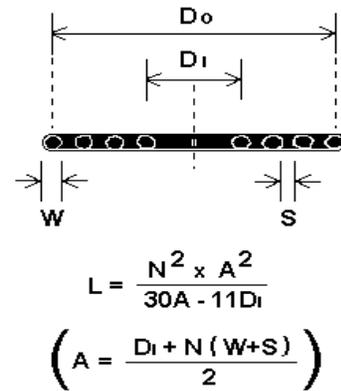


Figure 6 Flat Spiral Coil. [Inch]

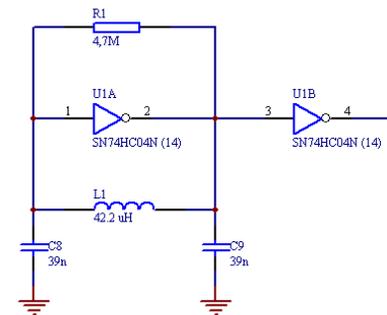


Figure 7 Relaxation Oscillator.

4.2 μC Circuit:

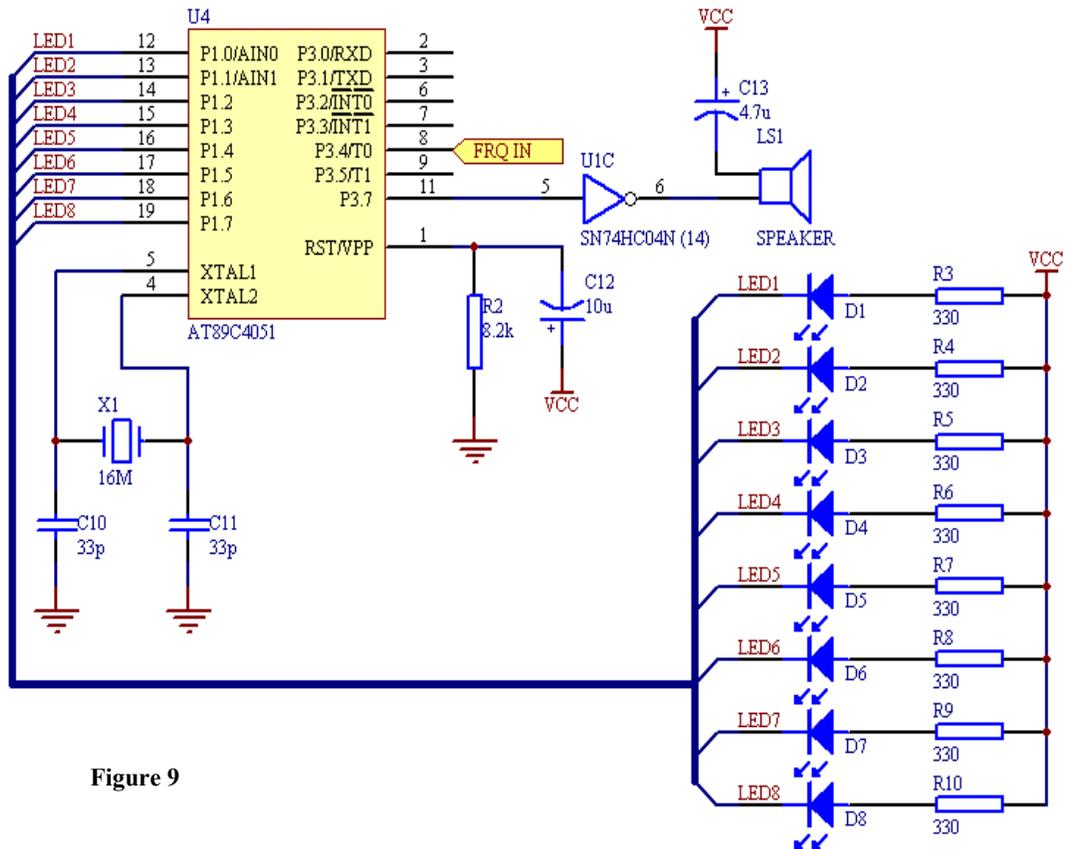


Figure 9

The Function of the μC is to compare the input frequency with a reference, in this case an internal timer in the μC , it counts for approximate $250\text{ms} = 4$ samples in a second. The frequency from the oscillator is connected to an internal 16bit counter, every time the timer generates an overflow the counter is read. The result of the counter $\times 4$ gives the incoming frequency, but there is no need to now the frequency, only the difference is important.

When the detector is turned on, the oscillator has to stabilize, the μC waits until the frequency is stable, in the meanwhile all LED's are flashing.

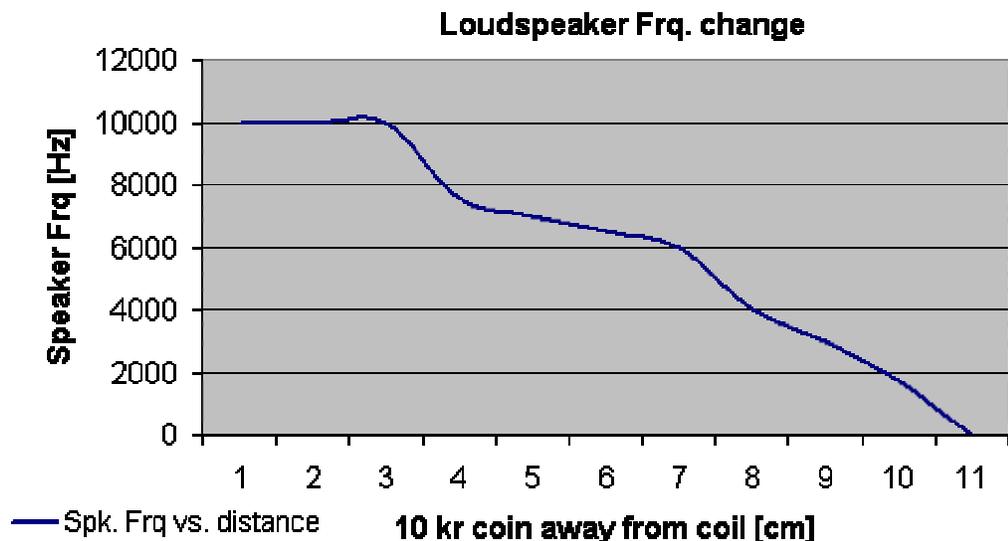
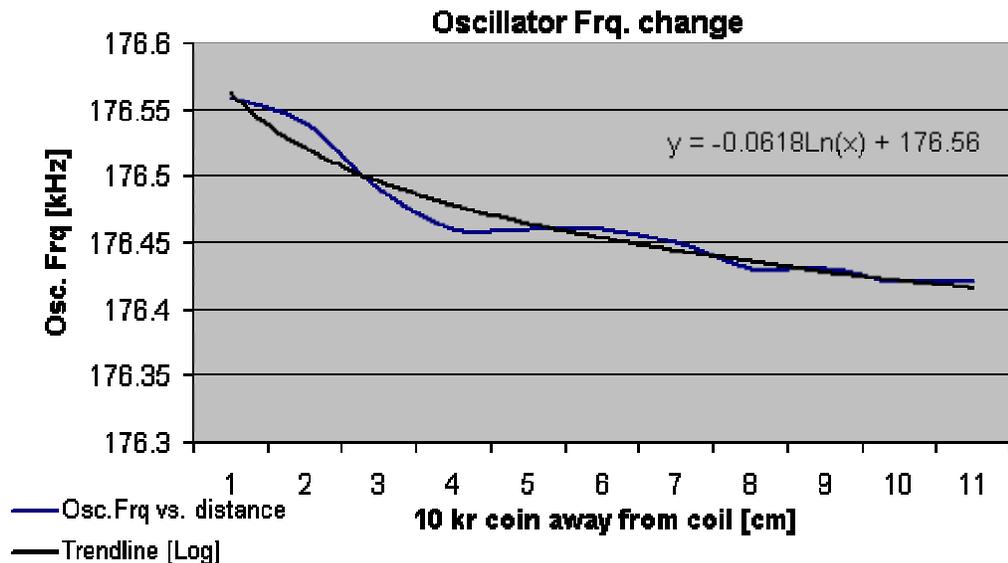
The detector is averaging the incoming signal all the time, if the same frequency has been present for 16 measurements the frequency will be the new zero point. It is necessary for using the detector in areas with high level of iron in the ground.

The speaker and LED indicates the level of detected material, in zero point it is around the middle of the area, so it can detect both ferrous and nonferrous metal, and make different output of it. The μC reset circuit is R2 & C12, which makes a time delay before the reset pin is on the high level, the μC doesn't start before the reset pin is high. The capacitor on the loudspeaker is the ensure there only flows a current in the changes of the signal. The software can be found in <Appendix B>.

4.3 Measuring Results of BFO:

The following measurements are made with a 10Kr coin in different positions from the coil:
The measurements are approximate.

Distance from the coil [cm]:	Oscillator frequency [kHz]:	Spk. Frequency [Hz]:
0	176.56	10000
1	176.54	10000
2	176.49	10000
3	176.46	7600
4	176.46	7000
5	176.46	6500
6	176.45	6000
7	176.43	4000
8	176.43	3000
9	176.42	1750
10	176.42	0



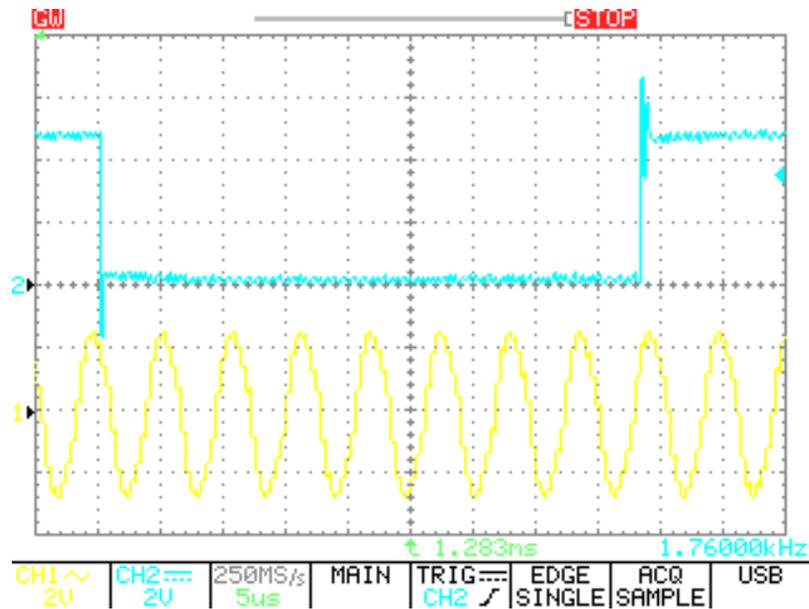


Figure 10 BFO Sound signal & Oscillator signal

Trace 1 in figure 10, shows the oscillator frequency, with a piece of metal near, the signal is between the 2 inverters U1A & U1B. The second trace is the output to the loudspeaker. The output frequency in this case is 11.3kHz, the signal have a duty cycle of 50/50(not showed).

- Settling time when cold = 42 sec approx.
- Settling time when warm = 13 sec approx.
- Min voltage = 6.1 v
- Supply Current = 38.9 mA
- Supply Current with speaker = 40.2 mA
- Ht min frequency = 20 Hz
- Ht max frequency = 10 kHz
- Frequency when warm = 178.029 kHz
- Power supply = 9V Battery

4.4 Improvements to be done:

Improvements to get better performance of the metal detector:

- Change the inverter to a cmos-ic, so it can run on 3V.
- Change the voltage regulator to a 3V low dropout regulator.
- Change the battery to 3*1.5 AA batteries (rechargeable 2200mAh).
- Change the crystal to 12MHz.
- Power supply monitor (with μ C analogue comparator)
- Make the oscillator more stable.
- Change the coil cable to a coax.
- Add a few more LED.

5 PI Detector Design:

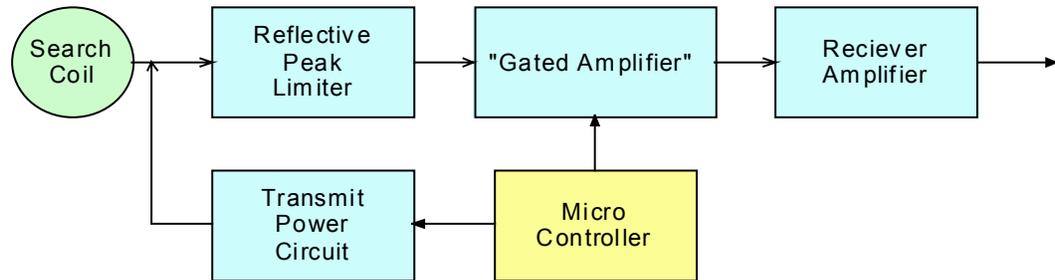


Figure 11 PI Detector's Block Schematic

5.1 Transmitter & Coil:

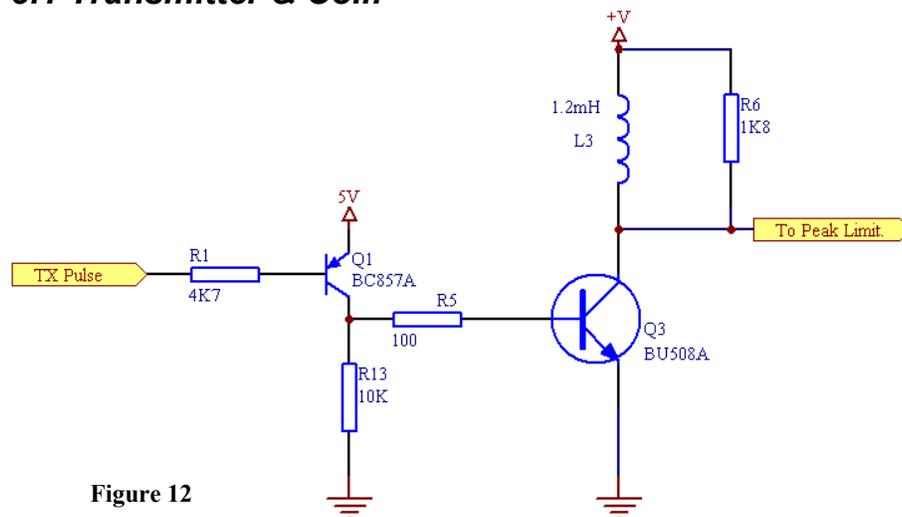


Figure 12

“TX pulse” comes from the μC , which control the time the dc current flows through the coil. Q1 amplifies the current from the weak μC pin, which can sink more current. When the “TX pulse” stops, the collector gets high impedance, and L3 returns a reflective pulse (counter electromotive force). R6 loads the coil, so the reflected pulse doesn't make “ringing” pulses after the big reflective. Q3 is a high voltage transistor, which can handle up to 1500V on the collector, and has not built in diode. The coil is turned around a CD with 0.5mm wire. The voltage across the coil has to be regulated, else the reflected pulse can move a little. If the voltage across the coil gets to high, there will come some pulses inside the “TX pulse” time. In figure 13 the reflective pulse (1) and charging (2) pulse is showed. The reflective pulse amplitude is about 500-700V when the supply to the coil is 9.6V. The interesting point is where the pulse starts to flatten off. If R6 weren't present, there would be some peaks in that area. The pulse comes 1000 times in a second, to reduce power the samples can be limited, but if the output of the amplifier has to be integrated a lot of sample is needed to get at god result.

The output of the amplifier is almost always shorted to Gnd after a resistor, only the period after the reflective pulse where the pulse is flattened out, is the signal not shorted to Gnd. The result is a gated amplifier, which only give output in the μC controlled period, just after it turned of the TX pulse. Q2 is a current amplifier so the μC pin isn't loaded too much. On the output there is a filter there only passes AC.

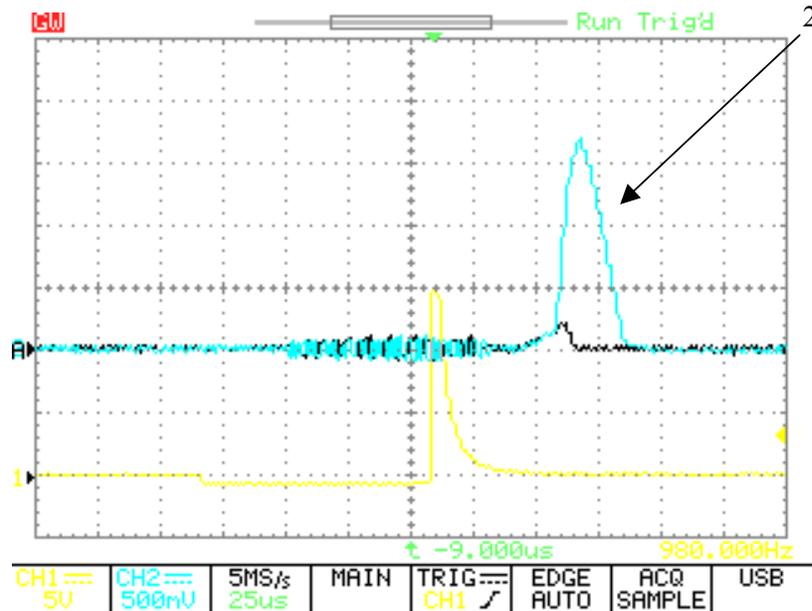


Figure 15 Before and after 1st. amplifier

Trace 1 shows the input of the amplifier after the limiter. Trace A (the one with the smallest amplitude) shows the output of the amplifier. The last trace (2) shows the output with a big metal object at the coil.

5.3 Receiver / Amplifier:

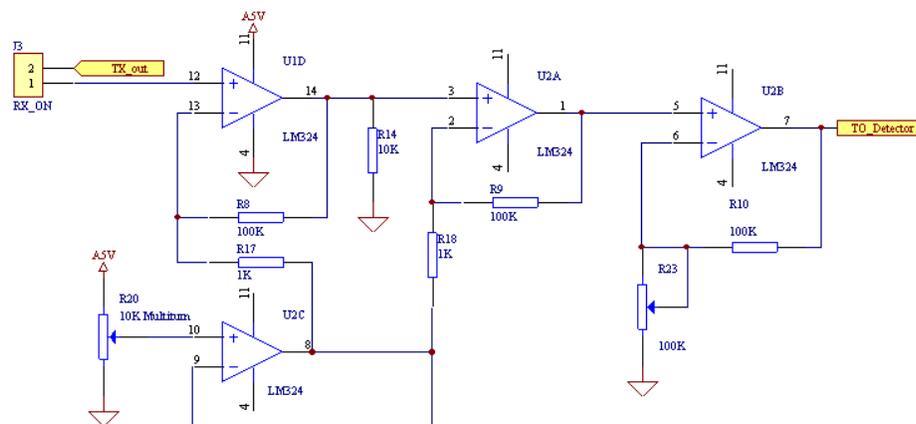


Figure 16 Amplifiers

The purpose of the amplifier is to amplify the signal coming from the gated amplifier so the signal can be detected either with an ADC triggered in the pulse or an integration circuit to get a DC. The 2 first amplifiers have the gain of 60db(1000times) and have lifted reference to run the opamp correct, and decide from which DC level the pulse will be amplified. The last amplifier has variable gain, from 2times to the open loop gain

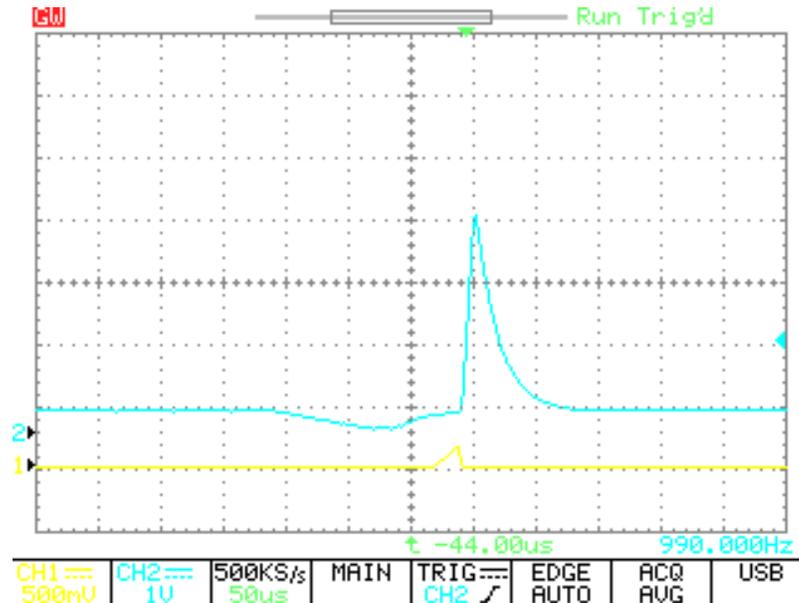
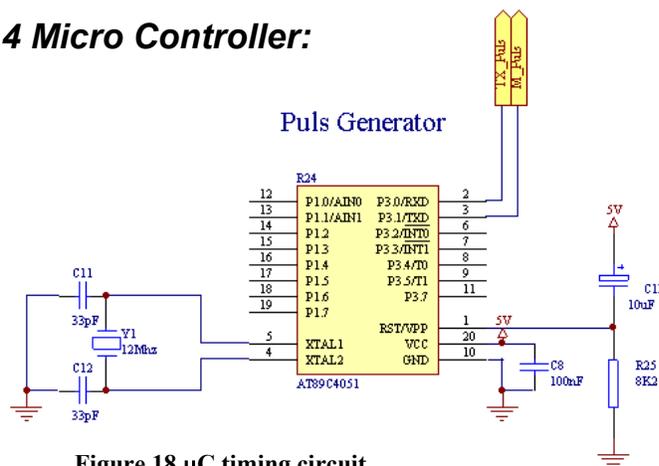


Figure 17 Input & output of the amplifier

Trace 1 shows the input to the amplifier with some metal on the coil. The 2nd trace shows the output adjusted to max gain.

5.4 Micro Controller:



The timing of the transmit pulse and the signal to open the gated amplifier is controlled of the μC , to make it simple to change and get the pulses at the right places. Can be used later to put an ADC to sample the signal and make some visual signals.

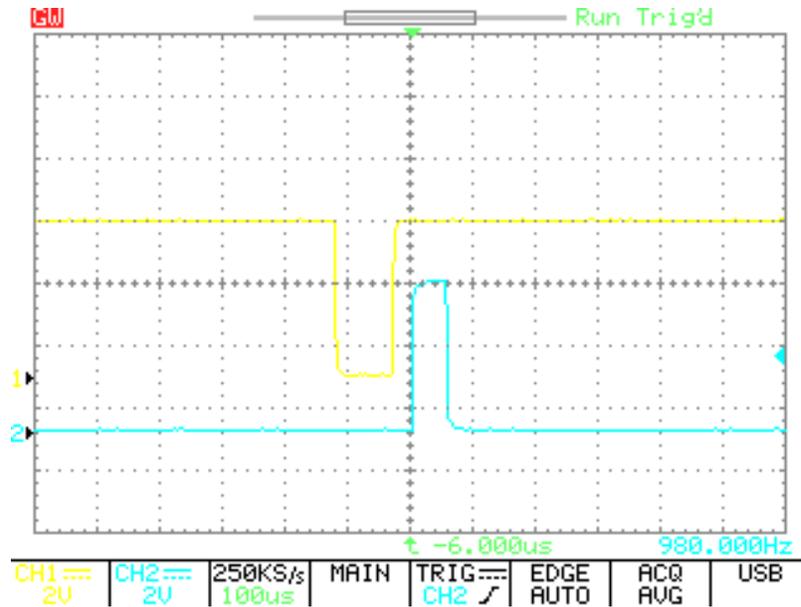


Figure 19 Outputs from the μC

Trace 1 shows the time the coil is loading with power. Trace 2 shows the time the gated amplifier is open.

5.5 Improvements to be done:

- To get longer detecting distance, there has to be more power to the coil.
- Receiver / Amplifier has to be better
- A detector has to be made
- More battery power
- Maybe a better coil

Calculation of coil in the Relaxation oscillator

Coil inner diameter :		=	12 cm
Coil wire diameter :		=	1.5 mm
Coil wire cross section area :	$3.1416 \cdot 0.75 \cdot 0.75$	=	1.76715 mm^2

Coil Wire Length :

Turns on Coil :	$\text{Pi} \cdot (\text{Diameter} + (\text{Coil Wire Diameter} \cdot \text{Turns on coil}))$		
0	$3.1416 \cdot 12 + (0 \cdot 1.5 \text{ mm})$	=	37.70 cm
1	$3.1416 \cdot 12 + (1 \cdot 1.5 \text{ mm})$	=	38.17 cm
2	$3.1416 \cdot 12 + (2 \cdot 1.5 \text{ mm})$	=	38.64 cm
3	$3.1416 \cdot 12 + (3 \cdot 1.5 \text{ mm})$	=	39.11 cm
4	$3.1416 \cdot 12 + (4 \cdot 1.5 \text{ mm})$	=	39.58 cm
5	$3.1416 \cdot 12 + (5 \cdot 1.5 \text{ mm})$	=	40.06 cm
6	$3.1416 \cdot 12 + (6 \cdot 1.5 \text{ mm})$	=	40.53 cm
7	$3.1416 \cdot 12 + (7 \cdot 1.5 \text{ mm})$	=	41.00 cm
8	$3.1416 \cdot 12 + (8 \cdot 1.5 \text{ mm})$	=	41.47 cm
9	$3.1416 \cdot 12 + (9 \cdot 1.5 \text{ mm})$	=	41.94 cm
10	$3.1416 \cdot 12 + (10 \cdot 1.5 \text{ mm})$	=	42.41 cm
11	$3.1416 \cdot 12 + (11 \cdot 1.5 \text{ mm})$	=	42.88 cm
12	$3.1416 \cdot 12 + (12 \cdot 1.5 \text{ mm})$	=	43.35 cm
13	$3.1416 \cdot 12 + (13 \cdot 1.5 \text{ mm})$	=	43.83 cm
Total length [cm] :		=	570.67 cm
Total length [m] :		=	<u><u>5.71 m</u></u>

DC Resistance in Coil :

	$R_{\text{wire}} = (R_{\text{material}} \cdot \text{length}) / \text{cross section area}$		
Conductivity for copper :		=	0.0175 Ω
R_{wire} :	$(0.0175 \cdot 5.71) / 1.767$	=	<u><u>0.056518 Ω</u></u>

AC characteristics for the coil :

Average Radius :	$A = \frac{\frac{Di}{25.4} + N \left(\frac{W}{25.4} + \frac{S}{25.4} \right)}{2} = \frac{\frac{120 \text{ mm}}{25.4} + 13 \left(\frac{1.5 \text{ mm}}{25.4} \right)}{2}$		= 2.746 Inch
------------------	--	--	--------------

Coil inductance :	$L = \frac{N^2 \cdot A^2}{30 \cdot A - 11 \cdot \left(\frac{Di}{25.4} \right)} = \frac{13^2 \cdot 2.746^2}{30 \cdot 2.746 - 11 \cdot \left(\frac{120}{25.4} \right)}$		= <u><u>41.91 μH</u></u>
-------------------	---	--	--

N=Turns on coil; A=Average Radius; Di=Inner Diameter; W=Wire width; S=Spacing between wires

Coil inductance :	Measured		= 42.2 μH
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Total Capacitance :	$C_{\text{tot}} = \frac{39 \text{ nF} \cdot 39 \text{ nF}}{39 \text{ nF} + 39 \text{ nF}}$		= 19.5 nF
---------------------	--	--	-----------

Q_{coil} :

$$Q = \frac{\sqrt{\frac{L}{C}}}{R_{\text{wire}}} = \frac{\sqrt{\frac{42.2 \mu\text{H}}{19.5 \text{nF}}}}{0.057 \Omega} = \underline{\underline{816 \text{ Q}}}$$

Z_{resonans} :

$$Z_{\text{res}} = R_{\text{wire}}(1 + Q^2) = 0.057(1 + 816^2) = \underline{\underline{38 \text{ K}\Omega}}$$

Loaded Oscillator :

R1 in parallel with Z_{res} :

$$Z_{\text{tot}} = \frac{38 \text{K} * 4.7 \text{M}}{38 \text{K} + 4.7 \text{M}} = \underline{\underline{37.7 \text{ K}\Omega}}$$

Q_{new} :

$$Q_{\text{new}} = \sqrt{\frac{Z_{\text{tot}}}{R_{\text{wire}}}} = \sqrt{\frac{37.7 \text{ K}\Omega}{0.057 \Omega}} = \underline{\underline{813 \text{ Q}}}$$


```
#include <AT89x051.H>
#include <stdio.h>

// External Subroutines prototype
extern initint();
extern inittimer0();
extern inittimer1();
// Internal Subroutines prototype
void timerlint(void);
void showlevel(unsigned int);

//declare global variables
unsigned char timerlofl=0, array1_count=0, change_count=3, change1_count=10;
unsigned int array_1[16];
int difference = 10;

/*-----
MAIN C Function
-----*/
void main(void)
{
    //declare variables
    unsigned int i=0, freq;

    //call all init subs
    initint();
    inittimer0(); //as counter
    inittimer1(); //as timer

    //start timer 0 and 1
    TR0 = 1;
    TR1 = 1;

    //Wait for frequency difference to be stable, it's stable when the
    //difference is between -1 and 1 5 times
    while(i < 5)
    {
        while(difference >= 1 || difference <= -1)
        {
            //Blink leds on port 1
            for (freq=0;freq<0x3fff;freq++)
            {
                P1 = 0x00;
            }
            for (freq=0;freq<0xffff;freq++)
            {
                P1 = 0xff;
            }
        }
        i++;
    }

    //runs till the power is taken of(for infinity)
    while(1)
    {
        //makes the sound when difference it less or equal to -2
        while(difference <= -2)
        {
            //port 3.7 toggles each time the for loop it ran through
            //the frequency this happens with it determined by a
            //fixed value multiplied with the absolute value
            // of the frequency difference from the coil
            freq = 0x005c * (0-difference);
            for (i = 0;i < freq;i++)
            {
                P3_7 ^= 1;
            }
        }
        //makes the sound when difference it more or equal to 2
        while(difference >= 2)
        {
            //port 3.7 toggles each time the for loop it ran through
            //the frequency this happens with it determined
            //by a fixed value divided by the
            //value of the frequency difference from the coil
            freq = 0x005c / difference;
        }
    }
}
```

```
        for (i = 0;i < freq;i++)
            {
            }
        P3_7 ^= 1;
    }

}

}

/*-----
TIMER 1 OVERFLOW Function
-----*/
void timerlint(void) interrupt 3
{
    //declare variables
    unsigned int presentval;

    //increments the timer overflow register
    timerlofl++;
    //checks if the overflow has happened 8 times(roughly 250 m[S])
    if (timerlofl==8)
    {
        TR0 = 0;
        TR1 = 0;
        //read counter
        presentval = (0xff * TH0) + TL0;
        //setup counter and timer for next load and start
        timerlofl = 0;
        TH0 = 0;
        TL0 = 0;
        TH1 = 0x5e;
        TL1 = 0xe0;
        TR0 = 1;
        TR1 = 1;
        //read out and get difference(in the global variable difference)
        showlevel(presentval);

        //If the frequency difference is small(less than 4
        //{Hz} either way) the difference is stored
        //it as a part of the average and the change count
        //registers is reset
        if (difference < 4 && difference > -4)
        {
            array1[array1_count] = presentval;
            array1_count++;
            change_count = 0;
            change1_count = 0;
            //makes sure that there only is written data
            //in the array
            if (array1_count == 16)
            {
                array1_count = 0;
            }
        }
        else
        {
            //If the frequency difference is medium
            //(between than 4 and 9 {Hz} either way) a register is
            //incremented(change_count), when it reaches 3
            //the difference is stored it as a part of the average
            if (difference < 10 && difference > -10)
            {
                {
                    if (change_count == 3)
                    {
                        array1[array1_count] = presentval;
                        array1_count++;
                        //makes sure that there only is
                        //written data in the array
                        if (array1_count == 16)
                        {
                            array1_count = 0;
                        }
                    }
                }
            }
        }
    }
}
```

```
        }
        else
        {
            change_count++;
        }
    }
    else
    {
        //If the frequency difference is high
        //(more than 9 [Hz] either way) a register is
        //incremented(change1_count), when it reaches
        //10 the difference is stored
        //it as a part of the average, and the change
        //count is set equal to 3
        if (change1_count == 10)
        {
            array_1[array1_count] = presentval;
            array1_count++;
            change_count = 3;
            //makes sure that there only
            //is written data in the array
            if (array1_count == 16)
            {
                array1_count = 0;
            }
        }
        else
        {
            change1_count++;
        }
    }
}

}

}

/*-----
SHOW THE FREQUENCY DIFFERENCE Function
-----*/
void showlevel(unsigned int presentval)
{
    //declare variables
    unsigned char i;
    unsigned long average=0;
    //gets the last saved frequencies
    for(i=0;i<16;i++)
    {
        average += array_1[i];
    }
    //calculates the average
    average = average/16;
    //calculate the difference between the average and the current frequency
    difference = presentval - average;

    // "prints" the difference on the LEDs
    if (difference < -11)
    {
        P1 = 0xfe;
    }
    if (difference <= -7 && difference > -11)
    {
        P1 = 0xfd;
    }
    if (difference <= -3 && difference > -7)
    {
        P1 = 0xfb;
    }
    if (difference > -3 && difference < 3)
    {
        P1 = 0xf7;
    }
    if (difference >= 3 && difference < 7)
    {
        P1 = 0xef;
    }
    if (difference >= 7 && difference < 11)
    {

```

```
        P1 = 0xdf;
    }
    if (difference >= 11 && difference < 15)
    {
        P1 = 0xbf;
    }
    if (difference >= 15)
    {
        P1 = 0x7f;
    }
}

//EXTERNAL SUBS//

#include <AT89x051.H>

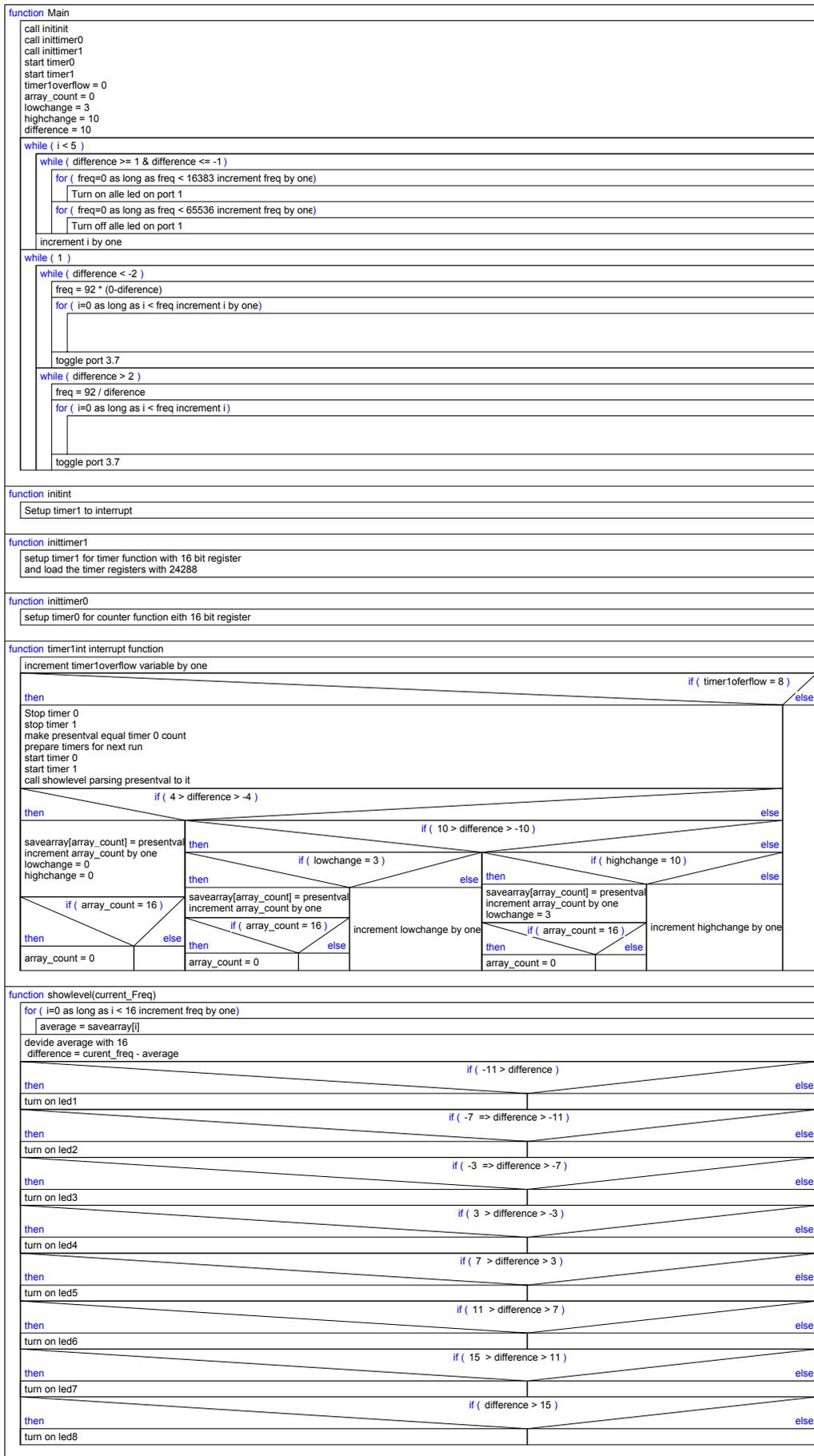
void initint(void)
{
    //interrupt for timer 1
    ET1 = 1;
    //activate all int
    EA=1;
}

#include <AT89x051.H>

void initTimer0()
{
    // Sets timer0 mode to 16bit counter
    TMOD &= 0xF5;
    TMOD |= 0x05;          // Sets timer0 mode to 16bit counter
    //loads timer register with 0
    TH0 = 0;
    TL0 = 0;
}

#include <AT89x051.H>

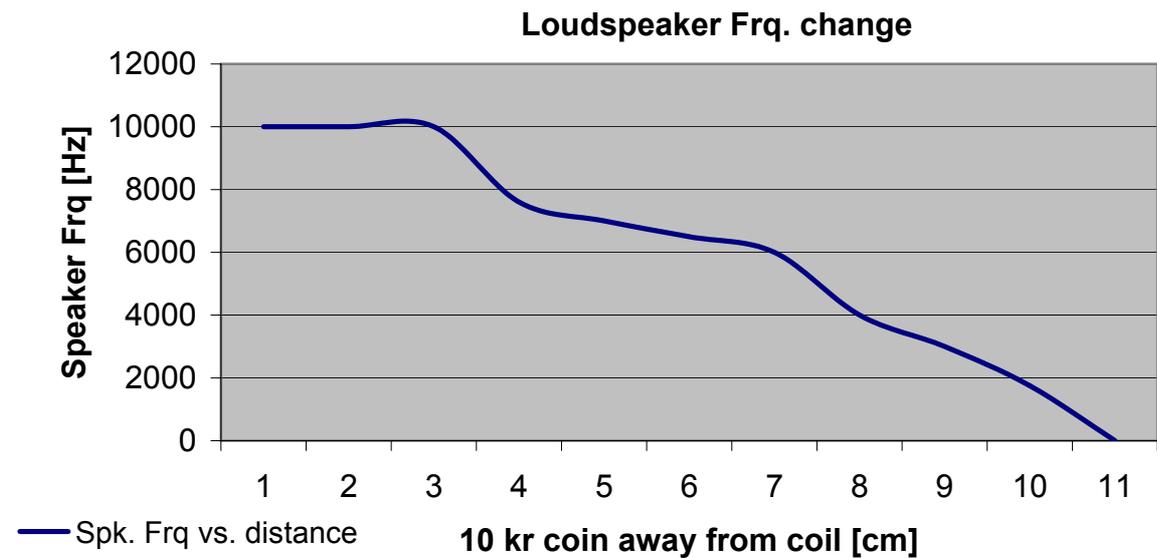
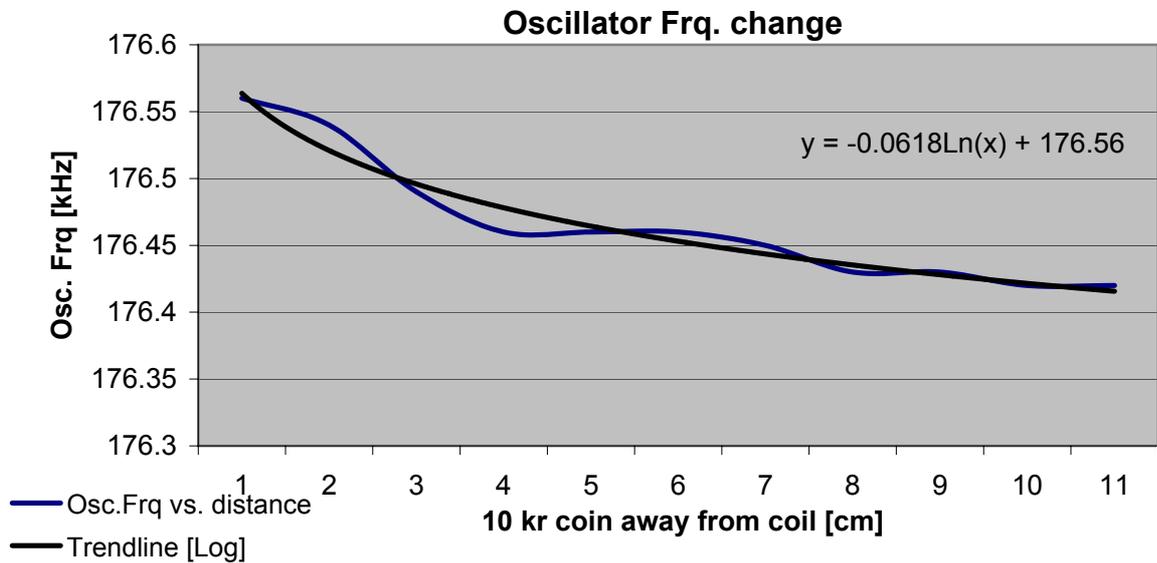
void inittimer1(void)
{
    //Sets timer1 16 bit timer
    TMOD &= 0x1f;
    TMOD |= 0x10;
    //loads timer register with 24288 which is roughly 250 m[S] when the
    //timer runs over 8 times
    TH1 = 0x5e;
    TL1 = 0xe0;
}
```



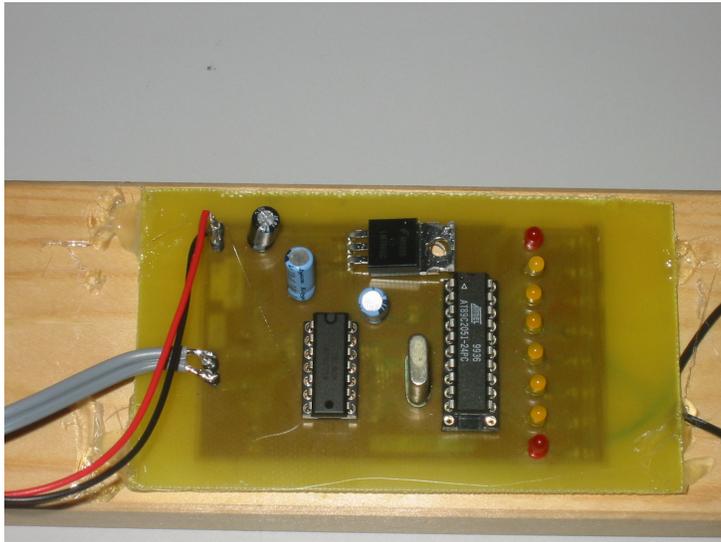
Measuring Results of BFO

The following measurements are made with a 10Kr coin in different positions from the coil :
The measurements are approximate.

Distance from the coil [cm] :	Oscillator frequency [kHz] :	Speaker Frequency [Hz] :
0	176.56	10000
1	176.54	10000
2	176.49	10000
3	176.46	7600
4	176.46	7000
5	176.46	6500
6	176.45	6000
7	176.43	4000
8	176.43	3000
9	176.42	1750
10	176.42	0



Pictures of project:



Picture of PCB to BFO Metal Detecor



Picture of BFO Metal Detector

Reference list :

Internet addresses :

<http://demining.jrc.it/aris/events/mine99/program/P155-160/MINE99PO.htm>

http://www.deepfriedneon.com/tesla_f_calcsipiral.html

<http://www.nuggetshooter.com/articles/UnderstandingPIDetector.html>

<http://home.clara.net/saxons/bfo.htm>

http://wildcat.phys.nwu.edu/classes/2002Fall/Phyx135-2/Projects/Metal_Detect/MetalDetector/PI.html

<http://www.gi.alaska.edu/~jesse/treasure/misc/howdetector.html>