Practical Guidelines for building a Magnetometer by Hobbyists

Part 2:Practical Building Guidelines

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<u>Version 1.2</u>

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1. Introduction

Now that you have had the opportunity to read an analytical view over the 'mysteries' of magnetism and proton behavior applied to Magnetometers, we can gather all that accumulated knowledge to start building a real one.
The first decision you will have to take depends both on your electronic skills and the purpose of such a project.

Case 1. Not much manual skills
In this case, you probably do not fit in this scenario. If you absolutely require a mag to be used in any particular application, you should go to the ready-to-run (but rather expensive) commercial product lines.

Case 2. Good manual skills but no or few electronic design skills
This is the least you need to envision a simple mag project.
Here, you need to decide whether you will be happy to build a simple but rather crude operational system and use it ASAP or if you just want first to experiment with the PPM technology itself with or without any end result as operational instrument.

Case 2.1. Build-and-Use
In that case, you could choose to build a 'differential' magnetometer (or rather, an analogue gradiometer). This system is very easy to build, to test and to operate and it will give you its results in real-time. Your ears will be the main instruments to detect potential ferromagnetic targets of a certain volume.
This system can be made based on one of two possible sensor types: Fluxgate and Proton Precession. However, as such, this system will not have a fantastic sensitivity; the best you should expect is to detect gradients of at least 15 to 25 nT.

- There is a **Fluxgate Gradiometer** Project description in the Carl's MAG site. It is based on ready-made sensors and accessory electronic chips that you can buy from a producer in UK or a representative in US for around 150 bucks. Carl has also provided a ready-made PCB layout. I know that he has built it a few years ago and it was working according to its (limited) specs. The mechanical mounting and adjusting of the Fluxgate sensors are a bit critical for the good functioning of the system but there is nothing a DIY can not do. I have heard from Carl that this project could still be improved in sensitivity but I still do not know how.

- A simple **differential PPM** is fully described in a CD sold by Phil Barnes. The necessary material to build this one can be found everywhere and would cost a few tens of bucks. It is mounted on a prototype board, so no PCB making is involved in the building. If the building is strictly made according to the instructions and schema's, there should also not any problem in the testing. However, applying the step-by-step testing procedures described further on in this paper will help to know better your system and to discover any possible flaws. This system can also be used as a test platform for those who still want to experiment with different sensor specs.

Case 2.2. Experiment and Learn (possibly use it later on the field)
There are a multitude of experiments that can be made with PPM's. As soon as a few functional modules have been built and tested, a lot of possible options can be tried (sensors, polarization control, low noise pre-amp, signal processing, mechanical arrangements,...)
The very first (and most critical) modules are:

1. **Sensor**: In our step-by-step procedures, we shall start with the simplest-to-build sensor type: a double coil solenoid sensor closely wound around a single bottle full of distilled water, one of the easiest proton-rich fluids to deal with. It is non-aggressive and has a long relaxation time. However, other fluids should be attempted later on because water freezes and requires a rather long polarization time (thus, consume much battery energy) to acquire its full activity.
2. **Polarization Control module:** This module could be implemented very simply but it needs to respect a minimum set of conditions. The triggering of the polarization and its end could be entirely controlled by hand or it could be put under control of a micro-controller for the timing adjustment. We shall start with a rather simple relay-based switching and will continue with a sophisticated solid-state switching system giving all guarantees of a perfect switching ON and OFF of the polarization current.
3. **Low Noise Pre-Amplifier**: The tiny captured sine wave signal(at μV level) will be amplified keeping as much as possible its original shape without adding spurious noise.

With only these modules and a few simple tools, we shall already be able to experiment and learn many important facts about this technology. The following tools are invaluable to this task:

1. DMM

with RMS Voltage (beware if the AC mode gives you an Effective V_p or an RMS = $V_p/1.4142$ value), Frequency, Capacitance and, possibly, but not mandatory, Inductance measurements

2. AF or Function Generator

This need not be sophisticated, it has just to cover the lower audio frequencies (0.5 KHz to 5 KHz) and generate sine wave signal with an adjustable RMS magnitude. If you do not have one, it is also possible to use the Spectrum Analyzer Program described here after.

3. Audio Spectrum Analyzer

The audio Spectrum Analyzer is the most important instrument for the testing and experimentation of a mag.
If you have access to a true digital scope; it's obviously OK since they always have this function included.
But, it can also be a PC-based scope with or without an external electronic box.
If you, poor man, have no access to any of those specialized instruments, don't worry, you can also use a pure software PC package available free on the net there. It has been written and improved over several years by a bunch of smart radio-amateurs.
It will give great satisfactions provided you run it alone on any modern desktop or laptop of reasonable CPU power.

Before using it for good, you should better exercise yourself with its main operations since, although free, it is a smart and sophisticated piece of software.

CALIBRATING THE SPECTRUM ANALYZER

- Make a 1000/1 attenuator (resistance bridge e.g. 1 Mohm/1 Kohm)
- Connect a **Spectrum Analyzer** adjusted to the audio band to the low side of the bridge.
- Connect an **AF/FUNCTION Generator** to the high side of the bridge.
- Adjust the generator to a sine wave signal of around 1V RMS @ 2 kHz
- Set the vertical scale of the spectrum analyzer to mV.
- Calibrate the vertical scale to measure an FFT peak of exactly 1 mV

4. WAVE File Editor

There are many, many programs like that available free on the net but this is the multi-platform one I am personally using with satisfaction (still a few bugs left but nothing catastrophic)

5. **An Analog or Digital Time-Domain Scope** can be of help as well but not absolutely necessary in my opinion for this particular project.

1.1. Building a simple Solenoid Sensor

The specs of a sensor depend on its required practical application:

- Large Underwater Target Search from a boat which can provide all the required energy
  - Big coil (more turns of thicker wire), lots of fluid, to get a better signal
  - With a higher signal, no need of resonant coil circuit.
- Underground Target or Structure Search with limited weight battery backpacking
  - Smaller, less energy-eating coil→ Less signal→ Resonant coil circuit recommended.

A standard sensor for starting your first experimentations and tests, although not the best in the world, is described hereunder:

1. Look for a 100ml polythene or glass bottle with a cylindrical length of around 100mm and a diameter of around 60mm.
2. You can choose between winding the coil directly on the bottle (if in plastic, fill it completely first) or on a cylindrical form fitting the diameter of the bottle .
3. Make two pairs of two round sides with thick board or any equivalent material and glue them on the form or on the bottle spaced of around 45mm. The two middle sides are separated by 10mm.
4. Use the Excel program provided by Jim Koehler HERE to calculate the expected signal magnitude and its S/N ratio playing with the number of turns, current… for a default fluid of **WATER** and a polarization voltage of **12V**. Select a wire gauge that you can easily buy. You should try to get at least a **signal of 1µV and an S/N ration of 100**.
   For example, a solenoid sensor built around this type of bottle and wound with **1130 turns of 20 AWG** wire would give the following results:
   - Inductance = 57mH
   - DC resistance = 8.3 Ohms
   - Polarization Current = 1.46 Amps
   - Signal = 1.6 µV RMS
   - S/N ration = 172 for a relatively wide bandwidth of 500Hz

   It would need a resonant cap of around 108nF for a nominal frequency of 2030Hz.
   There is also an interesting Excel program here. From the definition of the Voltage appiled on each coil of the sensor and its dimension, it plots the variations of the expected signal magnitude, Current, SNR, Weight and inductance giving the optimized number of wire layers to be wound.
   This is the procedure in details:

   1. In the common parameters sheet, select a Voltage which will be applied to each of the two coils. (= half the total voltage)
   2. In the common parameters sheet, define the diameter and length of the bottle in mm
   3. Define a maximum weight
   4. Look at each AWG sheet (starting with the thicker wire) and locate the line of your maximum weight. If the corresponding current is reasonable enough, select this wire and wind that number of layers of that wire. Otherwise, take the next AWG sheet.

   Example for a bottle of 90mm long of diameter 50mm and voltage = 6Volts (this is the specs of my bottles)

   A coil of pre-defined weight of **1 Kg** gives a signal of around **0.7µV**.
   With a wire AWG 14, we need more than 15Amps--> Too high
   With a wire AWG 16, we need 6.5Amps--> Too high
   With a wire AWG 18, we need 2.3Amps--> OK
   Thus, we get an SNR of 136 with 9 layers of AWG18.

   If we accept a pre-defined weight of **2 Kg** for the same dimensions, each coil will give a signal of around **1.1µV**.
   With a wire AWG 14, we need more than 7Amps--> Too high
   With a wire AWG 16, we need 3.2 Amps--> OK
   Thus, we get an SNR of 241 with 11 layers of AWG16.

We could as well define a **maximum current** as constraint and search for the best SNR with a reasonable weight.

For example, given a constraint of maximum current of 1 Amp,
AWG 14 and AWG 16 are not applicable because the coils would be too heavy.
AWG 18 is good since it needs a weight of 2Kg with a maximized SNR of 143. With this solution as base, we can still decide to slightly decrease the current (at the expense of the weight) or slightly increase the current to make the coils a bit lighter. These changes would not vary the SNR too much since its peak is so wide there.
If we want to reduce the battery energy, AWG 20 is also good with a lower weight of 0.8Kg but with a lower SNR of 81.

5. Wind the two coils in opposite directions with half the turns each.
6. Fix them in epoxy or any special electrical varnish to protect them against humidity which would be detrimental to the quality of the signal.
7. Connect them in series.
8. **IMPORTANT NOTE:** Do not use ANY ferromagnetic material to fix or to contain the sensor, use nylon nuts and bolts only.

1.1.1. Coil made resonant?

+	-
• Free Supplementary Gain	• Region-dependent Adjusting
• Free Pass-Band Filtering	• Signal grows exponentially during 100 msec instead of immediately at its max. magnitude, thus loosing some useful signal duration for measurement

When to use it?
- Sensor is small (for backpacking)
- Used in same region for long time periods
- Polarization Fluid is Water or Benzene (long relaxation time)

When to avoid it?
- Sensor is big (underwater usage)
- Kit or international product
- Polarization Fluid is kerosene or alcohol or diesel fuel.

1.1.2. Adjusting a resonant coil

- Use any of the numerous WEB calculators to know the nominal earth magnetic field value in your region.
- Multiply this B value in nT by **0.04256** to get the corresponding precession frequency.
- If you have an instrument to measure the inductance of the coil, measure its inductance in mH and apply the following formula to evaluate the required capacitance in **nF** to make the LC circuit resonant at center frequency **F** for a coil of inductance **L in mH:**

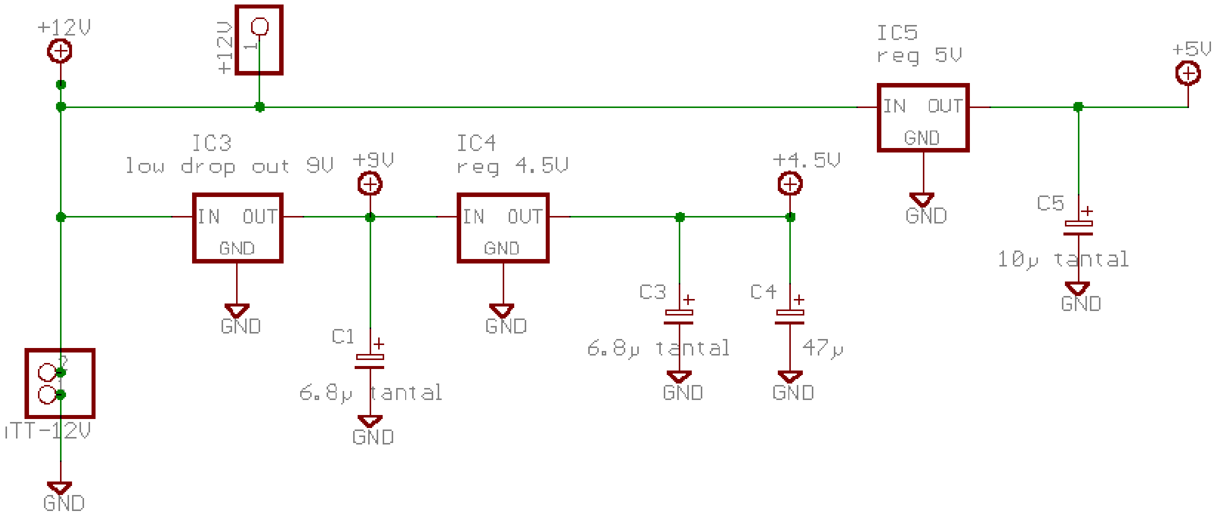
$$C = 10^9/(0{,}03948 * F^2 * L)$$

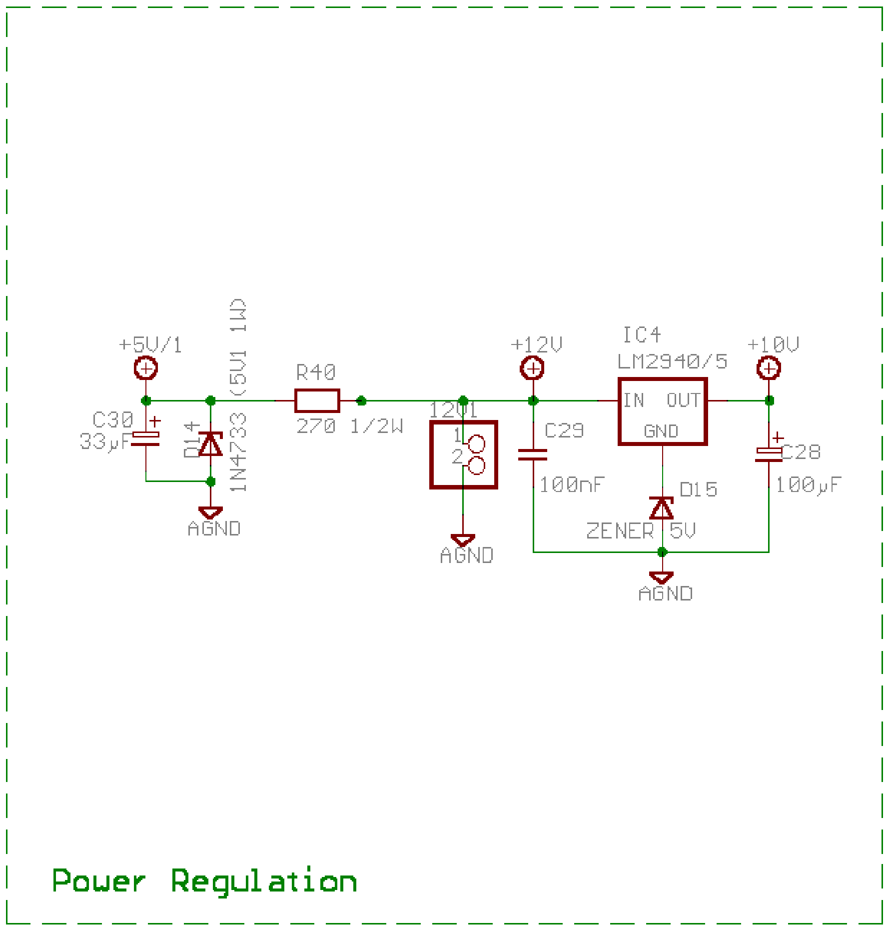
and connect a sufficient number of standard value capacitors in parallel to build the required value else you will have to start from scratch and start with a 50 nF Capacitor or so.

- Slowly sweep the AF Frequency of the generator from 1 kHz to 5 kHz.
- Evaluate the peak height during this sweeping process.
- The natural LC resonance frequency is the one for which the peak is maximum.
- If you had calculated a C value, the peak frequency should not be very far from the required result, otherwise it is probably higher than the required one since its C component is only made of the internal capacitance of the coil and its connecting wires added to the first 50 nF cap.
- If the peak frequency is too high, you must increase the cap value by putting more caps in parallel, otherwise, you must decrease the current value by removing an existing cap and choose its next lower standard value.

2. *Power Supply module*

It is important that the power supply for the analog part of the circuit be regulated separately from the supply of the digital circuit.
This is two separate and simple examples of power supply circuits enough to feed a PPM. Do not hesitate to replace them by your favorite circuit, if you wish. Except for the polarization which requires a lot of current under the unregulated 12V, the rest of the circuit should only consume less than 100mA.





3. Polarization Control sub-system

3.1. Building

Let's now start with the polarization control circuit.

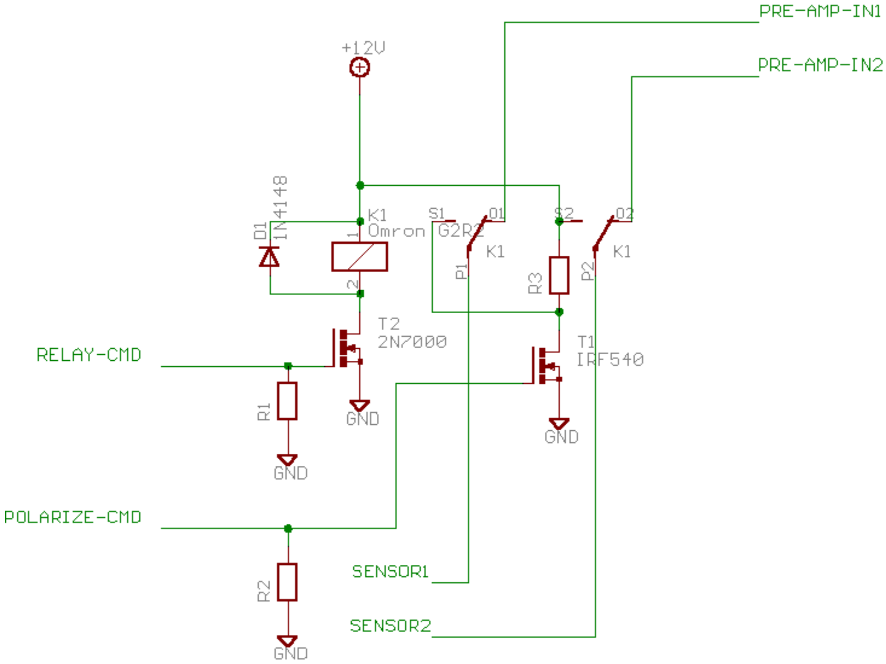
Here follows the list of Mandatory Specs for this module:

1. ON/OFF Current Switching without any contact bouncing
2. Polarization Current switch OFF (down to null) **in less than <u>50 to 100µsec</u>**
3. Very low Switch ON DC resistance (for main current, to avoid generating heat - for µV level signal, to avoid loosing any amplitude)
4. Pre-Amp Input protected from spikes; disconnected during polarization period
5. Pre-Amp Input re-connected to sensor a few msec after the end of polarization.
6. No spurious current (not even 1 nA) through coil during measurement period.
7. If Coil is made resonant, Caps should NOT be connected during polarization.

For the first experiments, you should select a **manually-triggered** polarization and relaxation cycle to easily control the durations of the two phases.
The simplest system using a **multi-circuit two-direction manual switch** as in the Phil Barnes circuit depends too much on the quality of switching of the manual device and could possibly not respect all the above mandatory specs. I do not recommend building it except if you already have in your drawers a very good switch like that.
A better variant is to use a relay with cold contacts (i.e. no current flowing during its switching transitions). In this case, the main HOT switch is a power HEXFET whose gate can be triggered by a simple DC level change or a simple push-button. This is the case of the easily found **N-Channel HEXFET** T1 in the following figure but it can be replaced by an other N-channel device of equivalent parameters.
This device is also taking care of the snubbing (or anti-ringing) of the spikes due to the switching OFF of the polarization current.
The HEXFET T1 takes care of the points 1,2,3 and 6 of the specs.
The relay takes care of the points 4,5 and 7 of the specs.
Thus, a complete cycle should start with a switch ON of the RELAY-CMD (disconnect pre-amp from coil, connect the coil to T1 but still no current through the relay contacts) followed immediately with the switch ON of the POLARIZE-CMD (starts DC current flowing in the coil), wait in that state for the duration of the polarization, then switch OFF the POLARIZE-CMD, and, 20msec later, switch OFF of the RELAY-CMD.
At that moment, the signal measurement period can start.

For the preliminary tests and experimentations, the delay of 20msec between the two commands can easily be implemented with **a simple 555 Timer connected in one-shot** or even a simple RC circuit with appropriate values.
However, if you master any type of micro-controller technology, it would be a piece of cake to make the complete switching control cycle with a **small controller** (it need not be fast) having a few digital I/O ports.
For such an application, I am personally using a PIC 12F675 or 12F629 from Microchip but I am sure that there are a number of other choices.

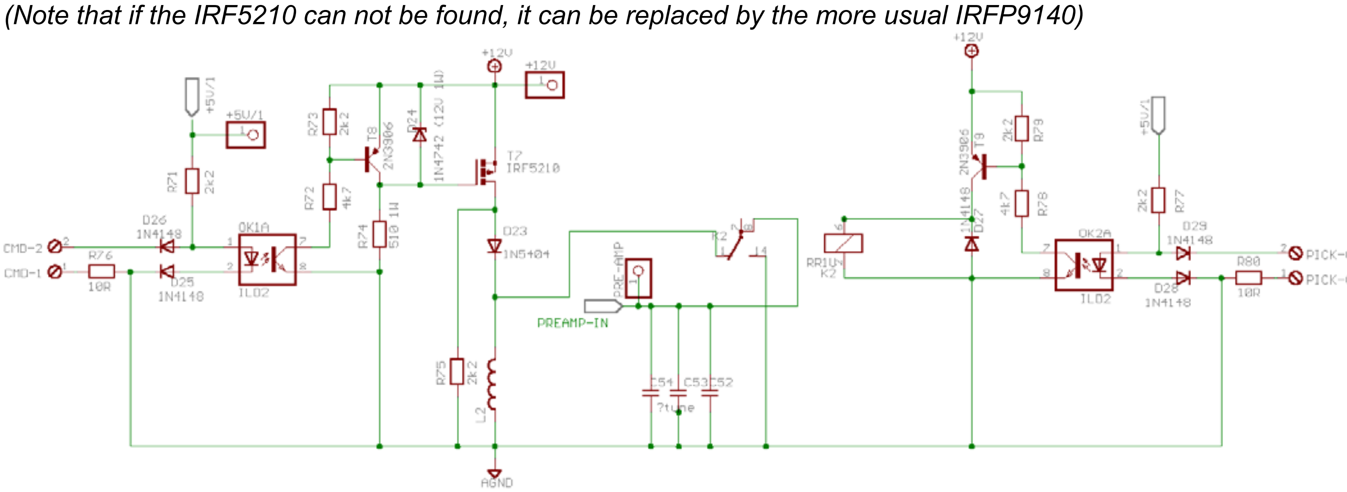
For the real system, a micro-controller will take care of that with its digital control lines together with the signal post-processing. We shall see this later on the paper.



This second variant uses a main **P-Channel HEXFET** with a particularly low RDS(ON) and has a few more interesting characteristics:

1. The two command lines could be controlled by any system with different power and ground circuits and completely protects, through optocouplers, against any kind of digital noise circulating between the two systems.
2. The auxiliary switching is made by a small two-direction REED relay which could even be easily replaced by two small HEXFET to make a complete solid-state switching system.

(Note that if the IRF5210 can not be found, it can be replaced by the more usual IRFP9140)



A third, more sophisticated variant could be implemented according to the description of Jim Koehler at page 46 of his paper. This variant will require a controller to execute the rather complex state changes.

3.2. Testing

Test first the switching cycles of your circuit **without coil connected** and check the voltage changes with a DMM.
Then, put the coil in circuit and redo the test with measuring the DC current going through. It should normally be at least 1 Amp. If you have a digital scope, it's now the right time to check the quality of the

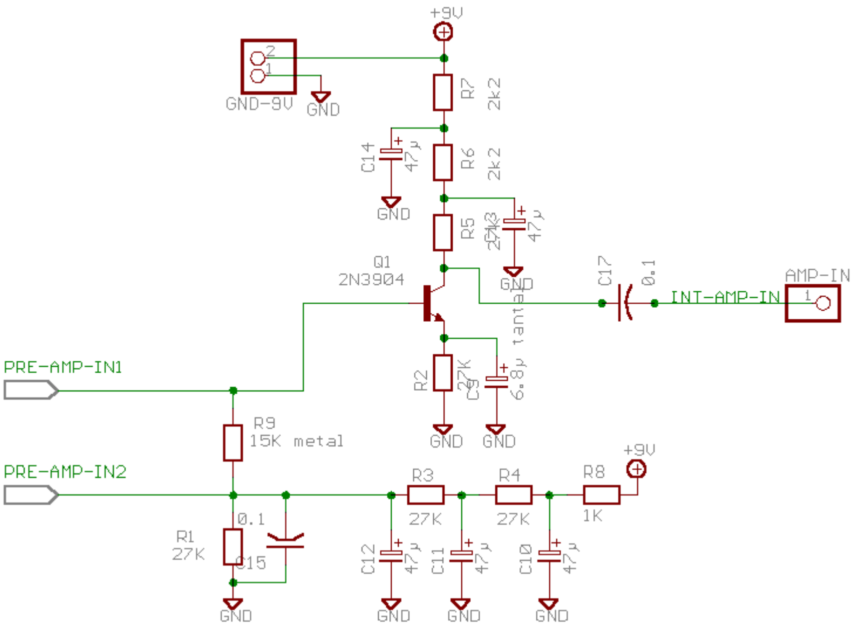
switch ON and switch OFF voltage and current transitions. They should be as clean as possible to get the best results on the quality of the signal.

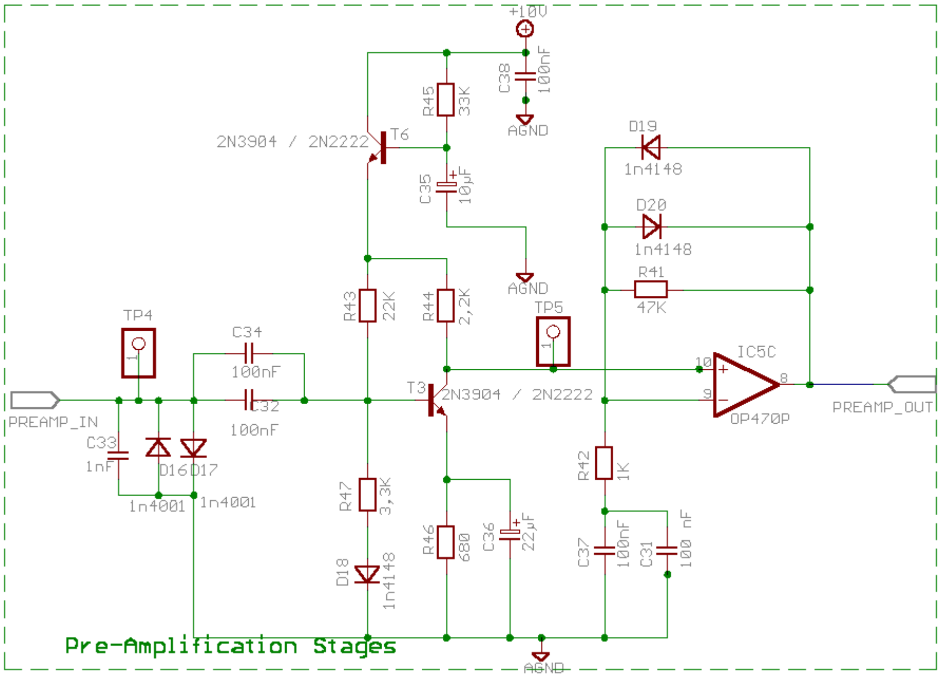
4. *Audio Amplification Chain*

4.1. PRE-AMPLIFIER STAGE

- Simple Transistor with low noise collector currents of about 0.1 mA
- Use metallic film resistances (lower noise)
- Gain should be kept rather low for the first stage (µV -->mV range = 1000 to 2000)
- Possible second stage with low noise OpAmp.
- Good Power Supplies decoupling and filtering
- Ground Plane on PCB
- PCB dimensions preferably long and narrow to keep output far away from input.

These are two different examples of proven low noise pre-amplifier stages using easy-to-find components and a single voltage power supply.
The first circuit could be followed by the OpAmp stage of the second circuit (but based on an LM324) to increase the total gain before the filtering stages.





+10V
C38
100nF
AGND
R45
33K
2N3904 / 2N2222
T6
C35
10µF
D19
1n4148
D20
1n4148
R41
47K
R43
22K
R44
2,2K
TP4
TP5
C34
100nF
C32
100nF
IC5C
T3
2N3904 / 2N2222
OP470P
PREAMP_IN
PREAMP_OUT
C33
1nF
D16
D17
1n4001
1n4001
R47
3,3K
R42
1K
D18
1n4148
R46
680
C36
22µF
C37
100nF
C31
100 nF
Pre-Amplification Stages
AGND

4.1.1. PRE-AMPLIFIER TESTING

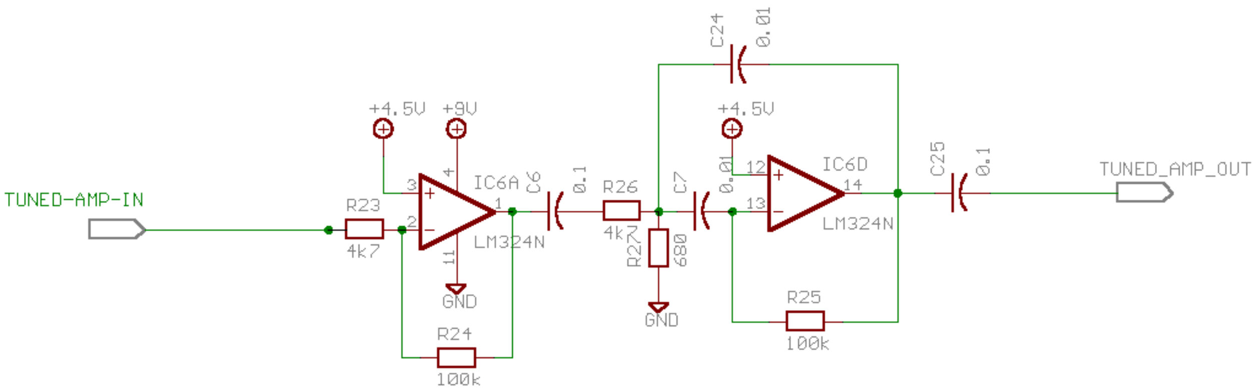
- Check first the voltage of the power supply before inserting the OpAmp.
- Make a 100000/1 voltage attenuator (resistance bridge e.g. 1 Mohm/10 ohm)
- Connect the pre-amp to the low side of the bridge.
- Connect a **Spectrum Analyzer** adjusted to the audio band to the output of the pre-amp.
- Check level of noise with nominal input impedance only, it should be very low : **-90 dB**.
- Connect an **AF/FUNCTION Generator** to the high side of the bridge.
- Adjust the generator to a sine wave signal of around 100 mV RMS @ 2 kHz
- The output signal magnitude will give you the gain of the pre-amp. You should observe a **single, clean, narrow FFT peak @ 2 kHz with an height of x mV on the vertical scale**. The total gain would then be 1000 * x.
- The noise level should still be very low: max. **-80 dB**.

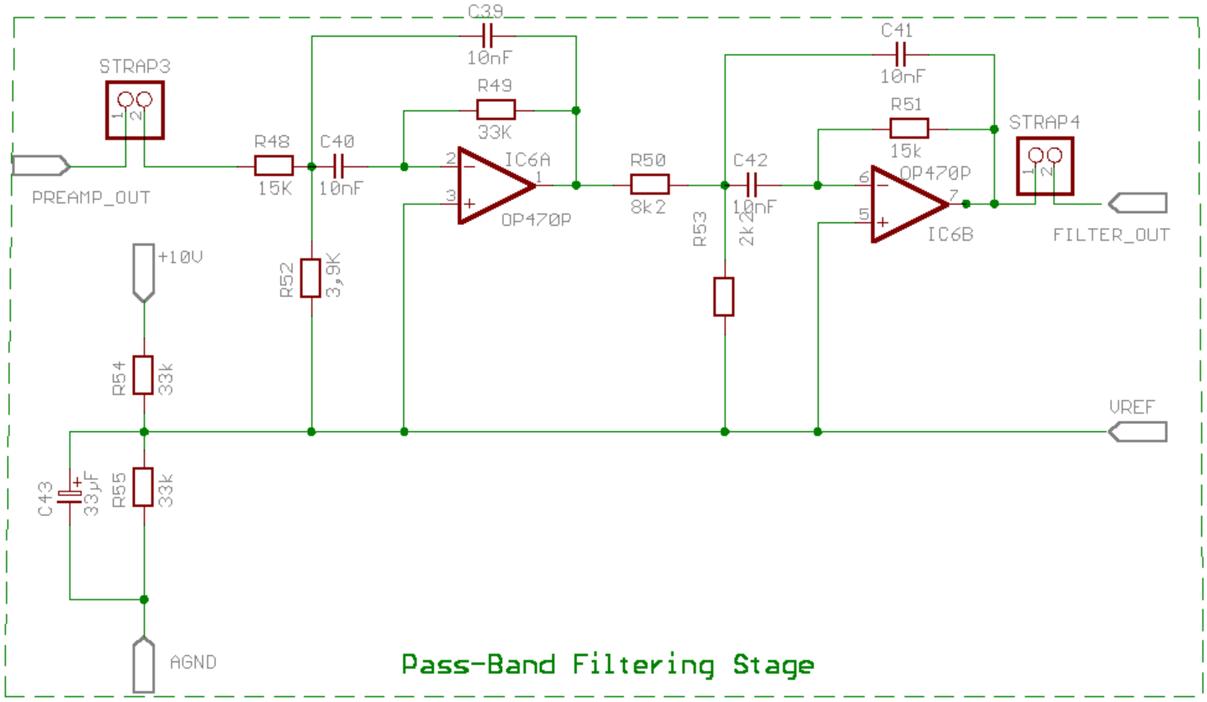
4.1.2. TESTING PRE-AMP WITH SENSOR

- Remove the attenuator.
- Connect the sensor (**W/O any resonant circuit**).
- Wind a small auxiliary coil made of a few turns of thin wire with a 1K resistance in series to match the output impedance of the generator.
- Connect it to the AF/FUNCTION generator adjusted as a sine wave of 2 KHz
- Set the vertical scale of the spectrum analyzer to mV instead of dB
- Observe the amplitude of the FFT peak at the pre-amp output, adjust the amplitude of the generator and/or modify the position of the auxiliary coil to get a peak of 1 to 2 mV.
- The signal-to-noise ratio (SNR) should probably now be higher because the coil is now picking up external electromagnetic disturbances and low frequency radio electric waves. (At this stage, it could even be possible to hear some strange music from local radio emitters). The noise level could now be around **-40 dB.**

4.2. TUNED AMPLIFIER STAGE

A pass-band filtering stage is highly recommended to remove the too low and too high frequencies after the first wideband pre-amp stages.
Usually, a bandwidth of **500 to 700Hz** is enough to get rid of the spurious frequencies while still wide enough to fit most of the occidental regions without re-adjustment. Its center frequency could be around **2KHz**.
There are a large number of active filter calculators on the web. I am personally using this one from the site of Analog Devices: **Active Filter Calculator**
This is also a very convenient **Excel Calculator** for designing Multiple Feedback Bandpass Filters like the one shown on the following figures.

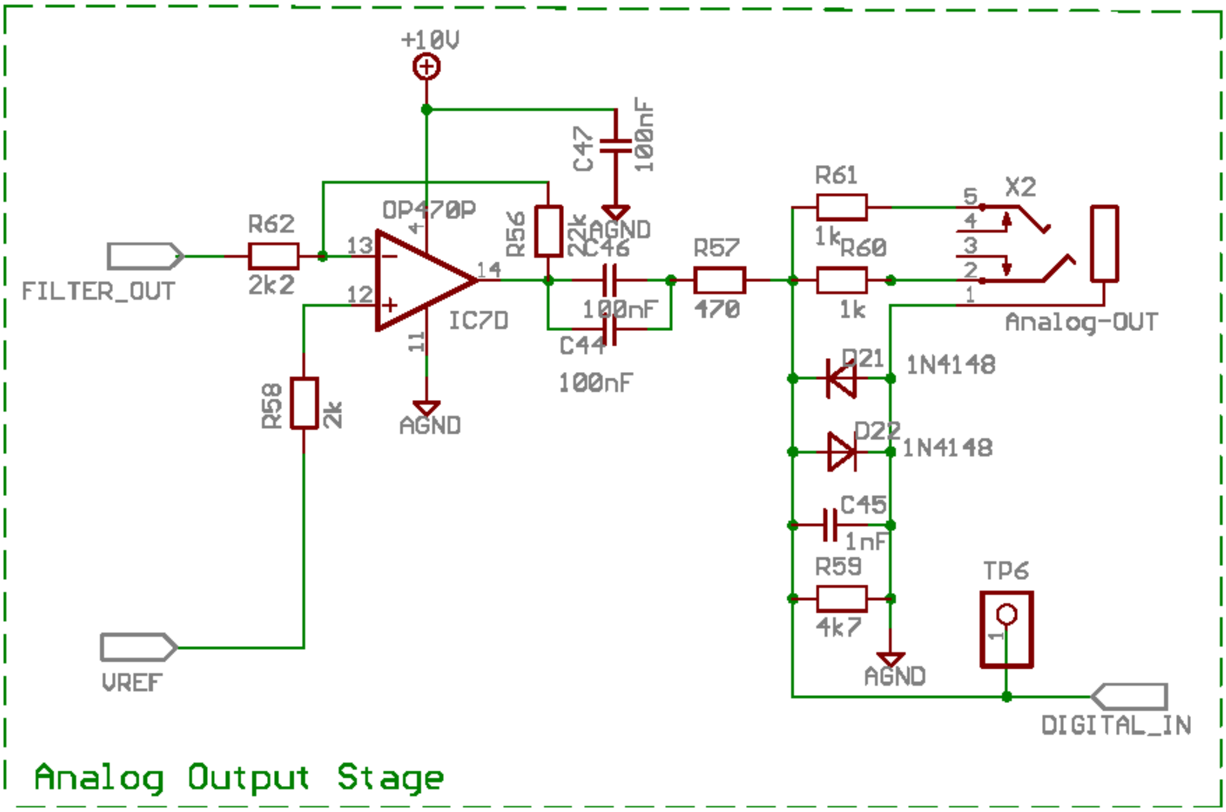




Note that the bandwidth of the filter of this last example is rather wide: 1500Hz.

4.3. ANALOGUE OUTPUT STAGE

This amplification stage is setting the final gain of the whole amplifier chain. It all depends on the requirements of the signal post-processing.
If you want to feed an earphone for a differential mag, the gain should be enough to get to the 0.5 Volt level.
If you want to feed a PC audio card to look at the final signal spectrum, a level of 10 to 100mV is more than sufficient.
If you want to feed a digital output stage, a level of 1 to 10 mV is enough for a comparator to shape square waves from the zero-crossings of the sine wave signal.



4.3.1. TESTING FULL AMPLIFIER CHAIN WITH SENSOR

Redo the procedure 4.1.2. on the whole chain.

5. Polarization/Relaxation cycle testing

This is THE most critical turning point of this project. I should modestly acknowledge that it took me more than one month of hard work and hit-and-misses before listening to the first true 'proton singing' out of my system.
Why did I take so much time? Because I did not know and meet ALL the conditions to get such a result.
I am now going to try to avoid the same trip for you.
As soon as the previous steps have been carefully executed, you are sure that your amplification chain and your polarization circuit are working well.

IMPERIOUS CONDITION 1:

You ABSOLUTELY need to move the sensor coil away from any building and any electrical power line. It means that you should put the sensor somewhere in your backyard or garden away from the street and from the electrical supply of your house..

IMPERIOUS CONDITION 2:

The sensor **SHOULD be put at least, at 50 to 100cm above the ground.**

Since you probably want to make the following tests from the table of your lab, you could connect the sensor to the electronics through a long, thick shielded cable. You can use 50 ohm LAN Coax or thick (low noise) microphone cable.

IMPERIOUS CONDITION 3:

There should **not be any switched-on AC-powered device closer than 5 meters** to the electronic circuit until it will be safely put in a shielded box**. No PC, no neon light, no lab power supply.**
It means that the results of the following tests should be captured by **a laptop powered from its battery**.
If you do not meet this condition, you will observe numerous permanent 50/60Hz harmonic peaks much bigger than the temporary one of the signal.

5.1. Test procedure

When all conditions have been met, you could now **start a 3 to 5 seconds polarization cycle**. At the end of this cycle, you should observe a **growing and quickly decreasing FFT peak at around your nominal precession frequency**. The water fall display option of the spectrum analyzer will show this very clearly.
If you see it now, you have successfully executed most of the critical steps of the project. Use the spectrum Analyzer to record the signal into a WAV file and analyze it in more details using a WAV file editor.

Now, if you do not see anything but noise on all frequency bands, you should first carefully double-check all the connecting circuits (and possibly redo the previous modular test steps) and verify that you have met ALL the imperious conditions.
If you still do not see anything, there can be several possible reasons:

- Check your battery, it could be that you do not get enough current out of it.
- If you did not make a resonant coil, it could be that your total amplification gain is not enough. You could try to increase the gain or to make your coil resonant.
- It could be that the location of your sensor happens to be disturbed by an hidden strong source of magnetic or electromagnetic noise. Move your sensor away to an other place which you feel safe and retry.

If you see a continuous FFT peak without any decay, it means that your amplifier chain is oscillating. This is an annoying case which often happen with high gain amplifiers. It really means that there az positive feed-back between the last stages of the chain back to the first stage or to the sensor input. It could be that reducing the total gain of the chain cure the problem but this is not sure. Otherwise, you must review your component placement and ground plane.

5.2. What's next?

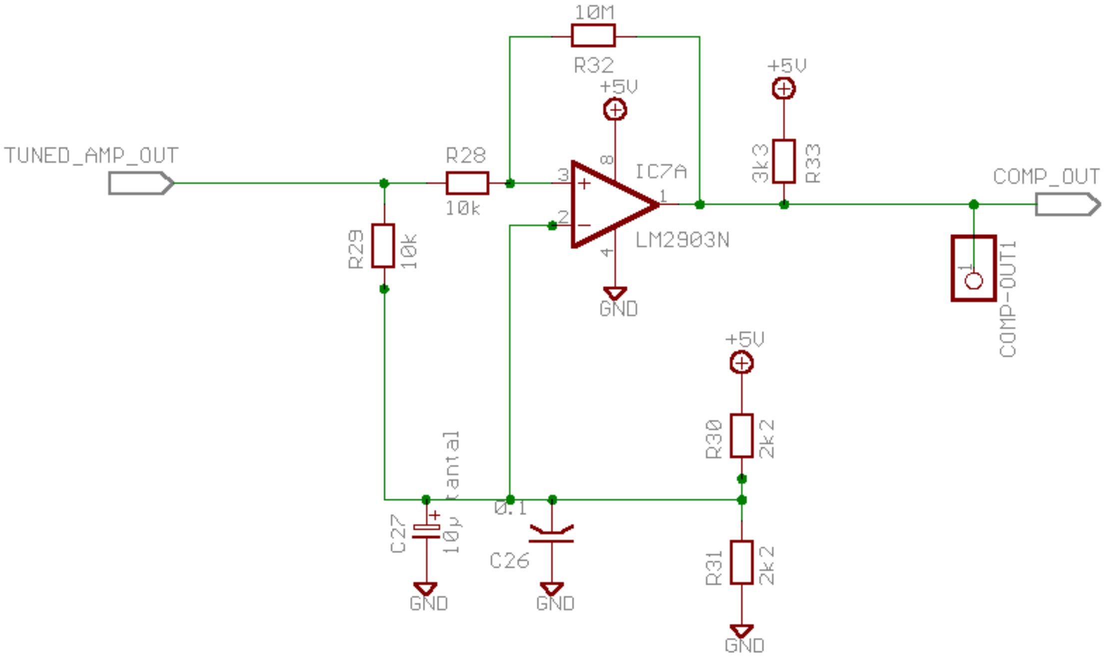
If you are at this point, you still not have a working PPM instrument but its main engine is there.
Now, what can you do?

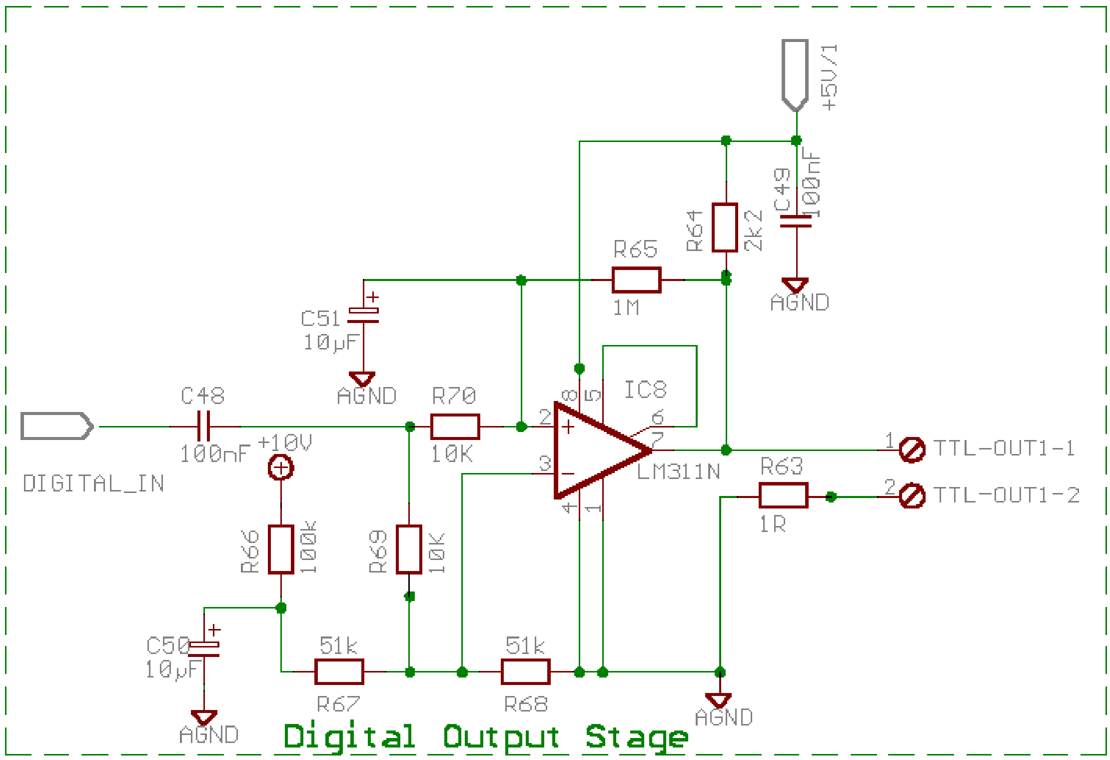
- You could build a second sensor identical to the first, connect them in series and in opposition, re-tune the two together and mount them 1 or 2 meters apart. You package the electronic circuit in a proper shielded box and you connect a quartz earphone to the analog output. Thus, you get a rather good **Differential Magnetometer**. If you now put an iron or steel mass around the sensors (closer to one and farther to the other), you will hear the characteristic amplitude beat generated by the adding of two slightly different frequencies.
- If you went this far, it would be a pity to stop here. There are now plenty of very interesting experiments you can do with the already built modules. Since you now have a basic reference in terms of **Signal/Noise Ratio** with your first simple sensor, you will try to optimize it. It is now time to **experiment with different types of sensors and different proton-rich fluids**. You can compare the captured WAV files and select the combination which is giving the best results. Note that it is not yet time to worry about the frequency value of the signal but rather about its quality. You still do not have the tools to precisely measure its frequency as the spectrum analyzer has not enough resolution.
- I consider that you should at least have an **SNR of 40 to 50dB** to have any chance to accurately measure the frequency in the next steps of the procedure. If you get too much noise in the signal, there will be spurious and missing period transitions giving more or less random results.
- When you are happy with the quality (SNR) of the signal, so that its frequency can be measured, then read the next chapter.

6. *Signal Post-processing and Display sub-systems*

6.1. DIGITAL OUTPUT STAGE

The low level sine wave signal at the analog output needs now to be converted into a TTL-level square wave digital stream to be fed into a micro-controller for its further processing and display.
This is two examples of comparator stage doing this task.





6.2. MODULE TESTING

Redo the procedure 4.1.2. on the whole chain. You should now get a continuous PCM stream at the same magnitude (5 Volts). If you capture from this stream the part during which there was a sufficient signal, you should see a main FFT peak at the same frequency as before but now, surrounded with a large number of powerful harmonics due to the square wave shape of the digital signal.

6.3. DIGITAL ANALYSIS

To accurately measure such a low frequency within such a small interval of time (max. 500 or 1000msec) , it is not enough to just count the number of periods during this time. The best result would be a precision of +- one period per second, which translates to only +- 23nT in magnetic field value.

The minimum required algorithm is to count an exact number of periods (as many as possible) starting a few msec after the polarization phase and precisely time their total duration using a high speed timer. The accuracy of the frequency measurement will only be depending on the timer. With a timer counting by steps of 0.2µsec, we could then get a precision of 0.01nT for the measurement of a single period. However, since we measure the time of at least 512 consecutive signal periods, we could expect to get even a much better precision.
I must repeat again that this accuracy is only correct for the calculation itself provided the counted periods are right. If there were missing or supplementary zero-crossings due to a noise level being too high, the end result would be much more degraded.

If you do not have a high speed timer, it may be wise to count and time 512 periods together and divide the total time by 512 to get the average time of one period giving the frequency.

If you have a fast timer (> 1MHz), it would give a better result in terms of noise suppression if you capture the cumulated timer value of each period and add it to a first large accumulator for the first 256 periods, then do the same for the next 256 periods to a second large accumulator. Subtract the first from the second accumulator and divide the result by 65536. This gives you the average time of one single period with a much better accuracy.

If you are ready to go even further in the precision of the frequency measure, analyze this document and implement its algorithm.

I shall not teach you in this paper how to design a micro-controller circuit as it is not its purpose. I suppose that you either already master this technique or you could use any evaluation card delivered by all manufacturers.
It is the same for the programming of those small beasts. The polarization switching logic and the counter/timer handling are elementary programming tasks, even in Assembler. If you are a beginner in that technology, you have a lot more to experiment there and, subsequently, a lot of fun.

The nT result of each measurement cycle should be stored in any kind of permanent memory like, for example, a serial RAM or EEPROM waiting to be picked-up by a higher level display and storage system.

6.4. STORAGE AND DISPLAY

A magnetometer measuring the total earth field like the one you have built up to now is probably not useable alone in the field.
The most usual and practical system configuration is a **Gradiometer**. As it was explained before, it is made of **TWO complete parallel single mag systems** whose simultaneous measurements are digitally subtracted to give a **field gradient value** which is the practical unit needed for 3D mapping surveys.

If you built you first system on some kind of breadboard for your first experiments, it is now time to design and build a real PCB whose dimensions are calibrated to fit two of them in a proper shielded (copper or aluminum) box. These will be the two slave cards controlled by a higher level control card.

This control system is a classical micro-controller card with its usual I/O devices like an **LCD** to display gradient results in real-time, a few **push-buttons** to trigger the measurements, a large **serial EEPROM** to store the results of the survey of the day and an **RS232 link** to upload these results to a PC for further storage and 3D graphical color display.

End of Document