K4HJU

Amateur Radio
Woodcreek, Texas

Ground Ohms Test Set

Rev 0.04
Jim Satterwhite K4HJU

A Work in Progress

K4HJU
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1. Introduction

When this article was first conceived the article was to describe the details about the test set I have designed and built; however when the project was basically complete, there was something I discovered that changed the emphasis for this article. What I discovered is that many amateur radio operators do not want to know the competency of their grounds. Therefore this article will be largely about the need to measure the resistance of installed grounds.

I am not an expert in the area of grounding. I do know some parts and I have significant experience in the design of successful test and measurement equipment for telephone outside plant test and measurement. After many years of thinking about the methods of design for measuring the resistance of amateur radio station grounding, I decided to do something about it. From my experience working with telephone outside plant testing instrumentation, I knew that grounding measurements were not trivial. There are a number of complicating factors, not the least of which are AC and DC currents flowing in the earth.

My interest came to a head when I moved into my present home and had a really difficult time achieving what I would consider good grounding due to mostly solid limestone just inches below the surface of the earth over most of the property. I wanted to know what the condition of my grounding was. There are a number of competent clamp-on instruments for measuring installed ground resistance; however they were outside my budget and I wanted the experience of designing and building such an instrument.

I find it a bit frustrating and somewhat amusing that a number of references on grounding and bonding discuss in detail methods of choosing and installing such systems. I see few discussions of methods to verify that the installation is indeed competent. I suspect that this is due to the difficulty involved in achieving valid measurements. This test set is my attempt to measure such systems competently.

I had a surprise when I got the test set completed, and put the word out in the local ham community that I would be willing to come and measure their installed grounds. I wanted to do this to verify the test set for myself on a variety of situations. There were and still are NO takers. I began to suspect that there was something deeper going on. As much as hams want to measure and quantify things, why not installed grounds. I will address this further below.

While this instrument is capable of the measurement of earth resistivity, I have no interest in that at the moment. The emphasis here will be on measuring installed grounding and bonding resistances.

2. The Problem

We spend a good bit of time and effort designing and installing grounds for our stations. Every situation is different. The very nature of our hobby exposes us to lightning events that can cause considerable damage and potentially loss of life. Therefore, it is important that we apply due diligence to proper grounding and bonding. There is one subject related to this, and that is that there is very little discussion about and that is verifying the performance of the grounds that we install. There are some very good references and techniques for designing and installing good grounds. Some installations present some difficult challenges. For example, here in central Texas, the presence of solid limestone just inches below the soil surface makes installing ground rods and ground systems particularly difficult and potentially expensive. It seems to me that verification of the installed ground is essential to completing and maintaining the ground system.

As pointed out by some, there are factors of concern that a ground resistance measurement will not tell you. An example is inductance of a tower and the various transmission lines involved. This is true; however the ground system can only be as good as the DC resistance. That is the bottom line. I agree that there are a number of issues such as inductance that require due diligence in the design and installation. A low ground resistance is essential. The other factors will not matter if the DC ground is inadequate. Therefore it is very important to verify it's integrity.

In my estimation, the accuracy of the measurement is not as important as getting a good reading in the vicinity of the actual value. I bring this up because of the situation I ran into with the clamp-on induction coils. For high accuracy the ferrite core halves must consistently mate very tightly around the measured conductor. As I will discuss below, due to the way I wound the wires on the clamp-on ferrite core, getting a good mating between the core halves is problematic and somewhat affects the accuracy of the measurement.

Soil resistance behavior is anything but uniform and varies significantly with the type of soil, moisture and dissolved salt content. It can be non-linear. It can vary from day to day and month to month.

The competency of the ground system is subject to change over time and environmental conditions. In my opinion maintenance of the ground system requires periodic inspection and measurement.

3. The Measurement

When making this measurement you are always measuring a loop consisting of some sort of reference resistance and the desired unknown ground resistance. You must know something about the reference ground to infer the value of the desired ground resistance. There are established techniques for using other ground rods in specific locations relative to the primary ground, making resistance measurements and applying an algorithm to those measurements to yield the desired installed ground resistance value. Sometimes this is inconvenient if not impossible. I suggest that there is an alternative and that is to use the power utility system ground as a reference.

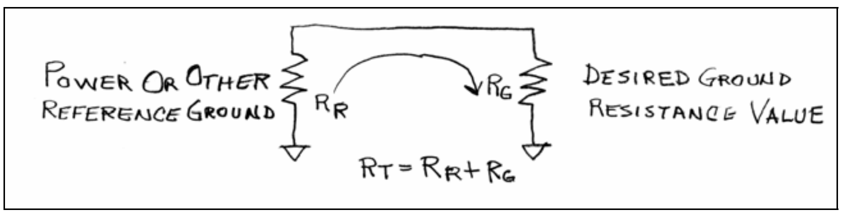

Figure 3-1 Measurable Ground Loop

4. Measurement Methods

There are several methods available to measure the resistance of the installed ground, each with it's advantages and disadvantages.

4.1. Ohm Meter Measurement

The installed ground resistance can be measured with an ordinary ohm meter; however there are some significant considerations. The first is that the ground must be taken loose to insert the meter to make the measurement. Many times this is quite inconvenient. The second is that there is a good possibility that there are DC and/or AC currents flowing in the ground system due to earth currents and power line induction. Even small DC currents will affect the resistance measurement. The power line induction currents can in some cases be dangerous. I have seen as much as 15 amps flowing in a telephone cable sheath; however in most cases it is much less than that depending the ground location relative to power lines, yet still a concern for reliable measurement.

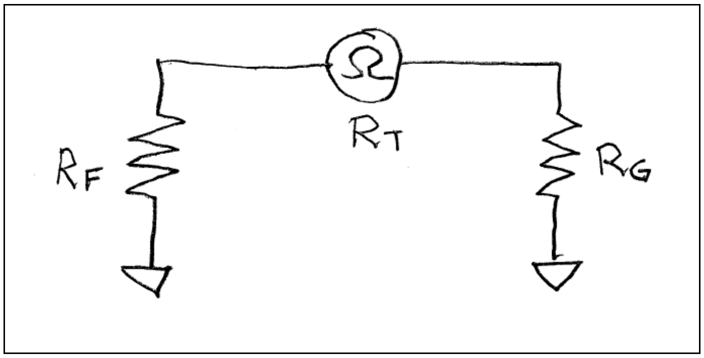

Figure 4-1 Measurement Using a Simple Ohm Meter

4.2. Four terminal AC or DC Measurement

In most cases the four terminal AC or DC resistance measurement can overcome the problems due to AC or DC earth currents if the measurement configuration is set up properly and the applied current is significantly higher than the potential earth currents. It still has the disadvantage that the ground connection must be opened to make the measurement and calculations must be made to know the measured resistance. I suppose that it would be easy enough to build a test set around this type of measurement that would make the calculations. That said, if accomplished properly, the four terminal measurement is probably the most accurate method, since the applied current can be sufficient to make the effects of the potential earth currents insignificant.

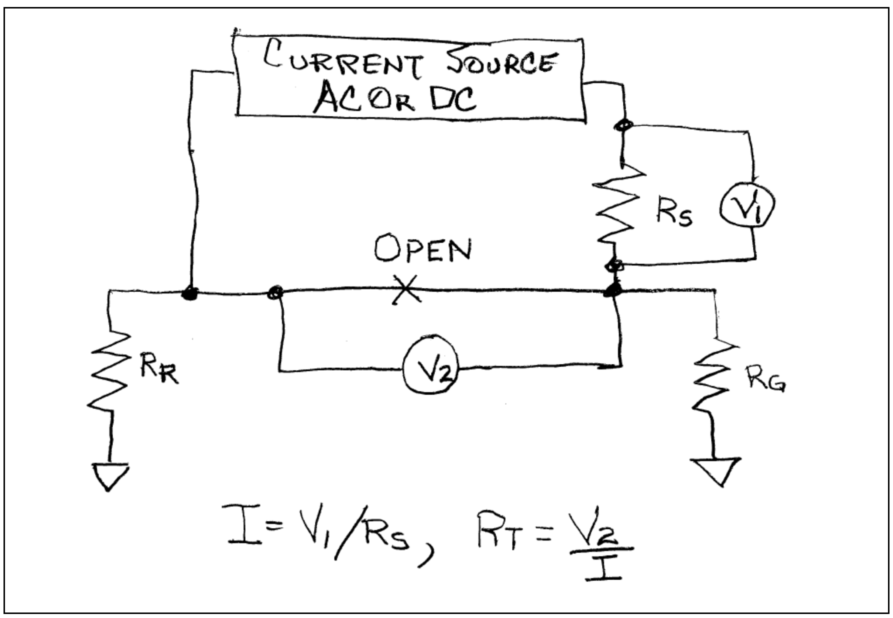

Figure 4-2 Measurement Using a Four Terminal Measurement System

4.3. Inductive coupled AC Measurement

In a good many cases, an inductive coupled AC measurement does not require opening the ground circuit. Also, the effects of DC and AC earth currents are significantly minimized. It is a simple and convenient method of making this measurement. In this case an AC current is induced into the loop formed by two independent grounds, the connecting conductor and the earth. The resulting current in the conductor is sampled by a second clamp-on inductor. The resulting sampled current along with the voltage across the transmit clamp-on inductor are then analyzed to display the measured resistance.

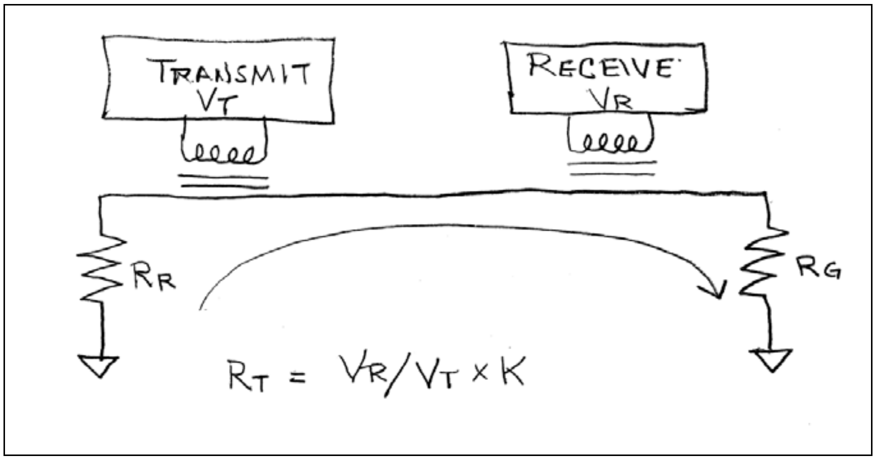

Figure 4-3 Measurement Using Inductive Coupling

5. Design Approach

I wanted the test set to measure the installed ground resistance under general field conditions that might include AC and DC earth currents. Also, I wanted to use inductive coupling employing easily available snap-on ferrite modules. My system development technique generally uses development of a Windows application to display data and manage the various calculations required in addition to communication to the test set via USB-RS232. In the test set communication, control and data measurement are managed by an Arduino like microcontroller module. The measurement hardware performs the desired function and presents data to the microcontroller for analog to digital conversion. A computer provides a display mechanism and applications for the development of the Windows application and the microcontroller firmware. The various electronic functions are implemented using functional surface mount modules and insulation displacement wiring. This way the development environment is totally fluid allowing the design process to evolve. On some systems, once the development is complete, the computer becomes superfluous and the developed system can operate on it's own. On this system the net book or laptop computer is clumsy to use in the field, particularly in bright sunlight; however it is necessary to analyze the data and calculate the results. It might be possible to perform these calculations in the microcontroller; however I have put no effort into that. Ideally, at some point I might replace the computer with an internal Raspberry Pi.

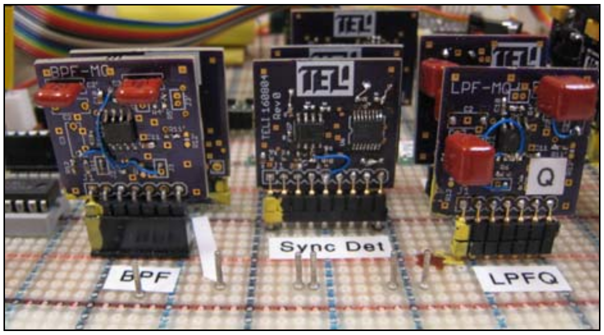

Figure 5-1 SMD Function Modules

The functional modules are designed and laid out in Cadsoft Eagle.

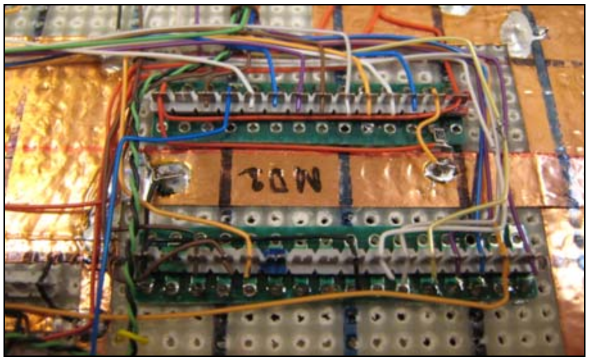

Figure 5-2 Insulation Displacement Wiring

Insulation displacement wiring allows flexibility and reliability in construction and maintenance and also the ease of keeping documentation current. Between the insulation displacement wiring and the method of creating a ground plane that I employ, with care circuits handling near 100 MHz can be implemented. I say this to give some idea of the viability of using this type of construction.

I wanted the system to make measurements with reasonable accuracy and repeatability over a wide range of resistance values. It turns out that this required a good bit of attention to detail.

6. Hardware

Shown below are photographs of the test set I have designed and built. It consists of an instrumentation box, two clamp-on inductive transducers and a PC such as a notebook or net book connected via USB. The USB supplies communication and power for the unit. I decided early on to use surface mount devices (SMD) functional modules and insulation displacement wiring to develop the test set. Also, I choose to develop a Windows application in National Instruments Lab Windows to manage the operation and analyze and present the data.

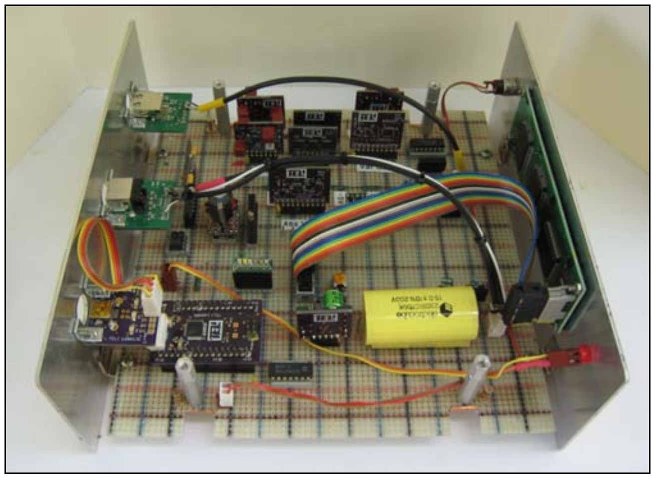

Figure 6-1 View 1 of Top Side

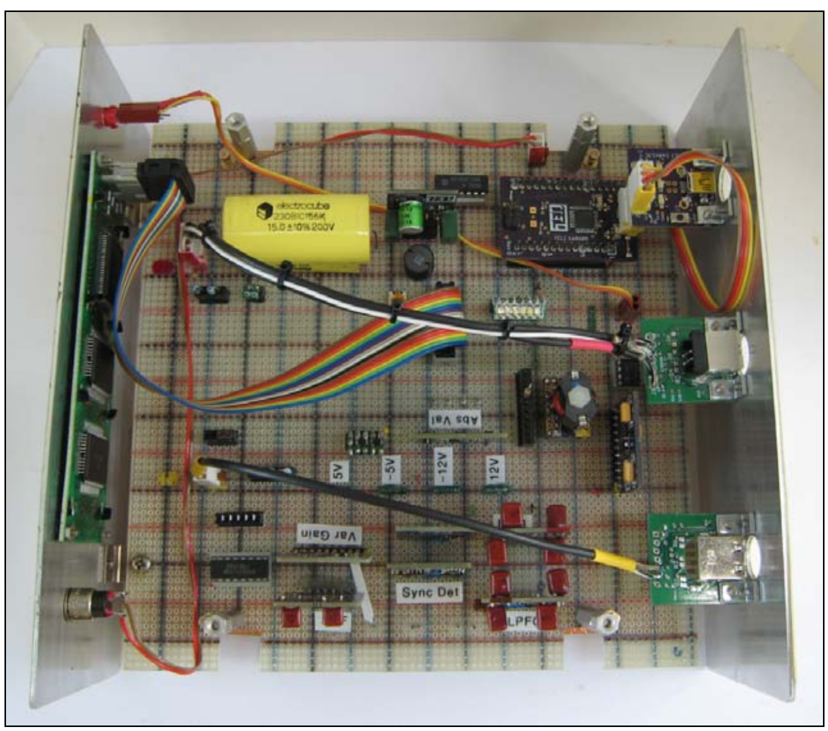

Figure 6-2 View 2 of Top Side

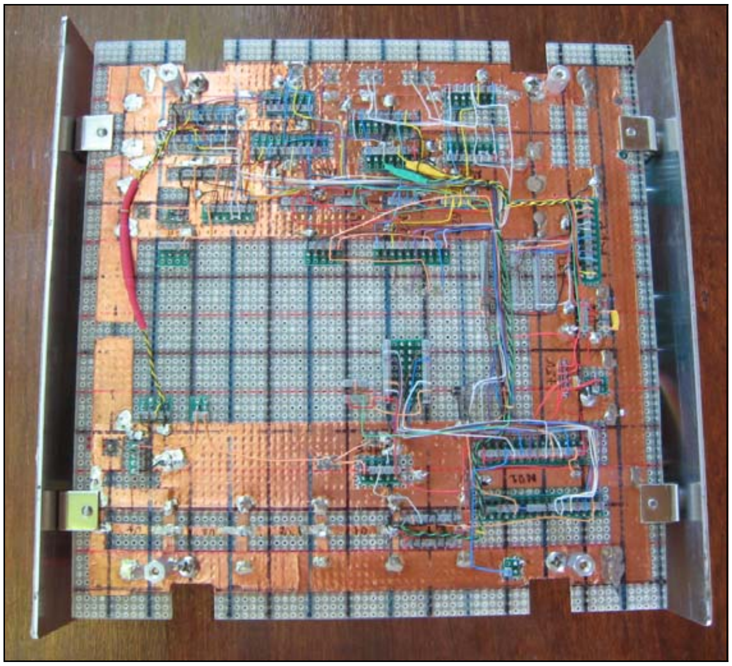

Figure 6-3 View of Bottom Side

Figure 6-4 Front Panel View

Figure 6-5 Front Panel View

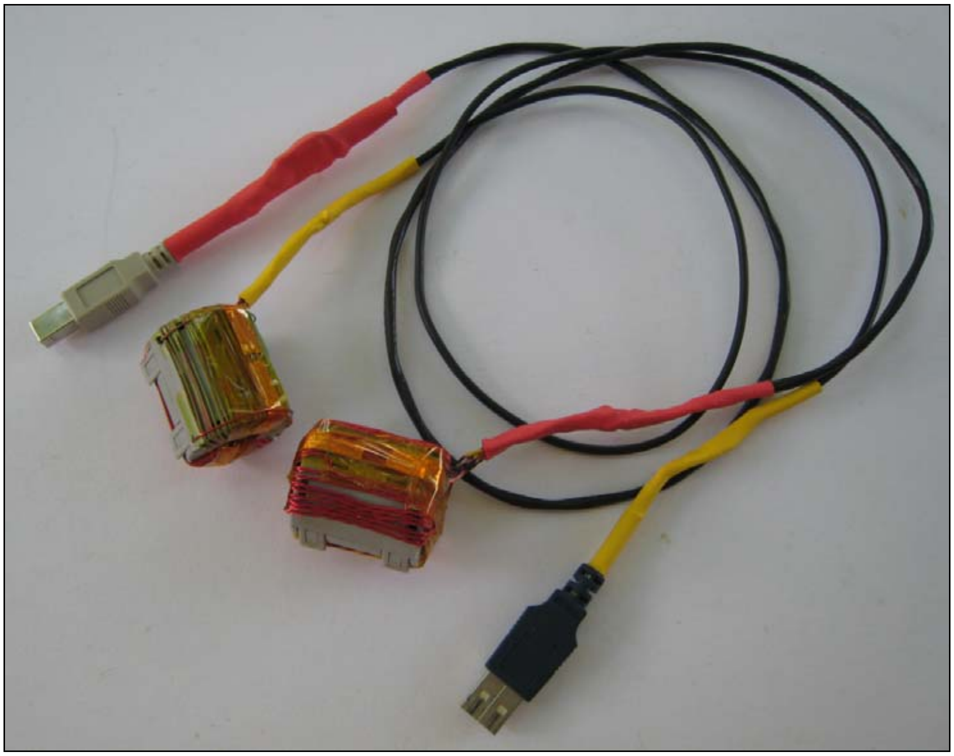

Figure 6-6 Clamp-On Inductive Transducers

The transmit and receive transducers are made by winding turns onto clamp-on ferrite cores. I found that the windings interfere somewhat with the molded in springs in the clamp-on case. This means that mating of the core halves is not consistent. This can be remedied by using an external clamp to mate the halves more precisely. Without the external clamp, this potentially introduces a variation in the resistance readings of up to +8% from the rather repeatable accuracy of +/- 2% over most of the test set's range. To address this I am considering using 3D printing to make my own core shells where the windings do not interfere with the clamping action.

7. Functional Description

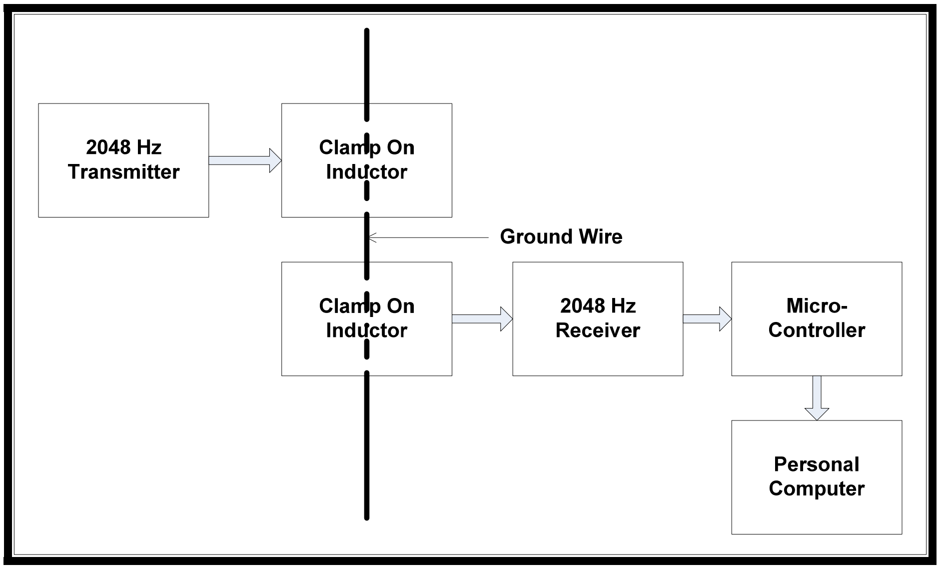

Figure 7-1 Simplified Ground Ohms System Block Diagram

Figure 7-1 shows the simplified block diagram of the Ground Ohms system. A 2048 Hz sine wave is generated and drives a clamp-on inductor to induce a current in the ground conductor being evaluated. The induced current is proportional to the resistance of the loop. The induced 2048 Hz current is detected by a second receive clamp-on inductor and the signal is fed to a 2048 Hz synchronous receiver. The output of the receiver is fed to the microcontroller that digitizes the received signal and sends it to the Personal Computer (PC). The PC via a Windows application analyzes the signals and displays the result on the PC screen and the front panel of the test set.

As mentioned above, the nature of this instrument is that it measures the resistance of a circuit; therefore in grounding and bonding measurements there are at least two grounding connections being measured. This means that if you don't know something about one of the resistances, all you know from the measurement is the sum of the circuit resistances. If one side of the circuit is the electrical power ground, you generally have a low ground resistance to compare the unknown side to and that is helpful.

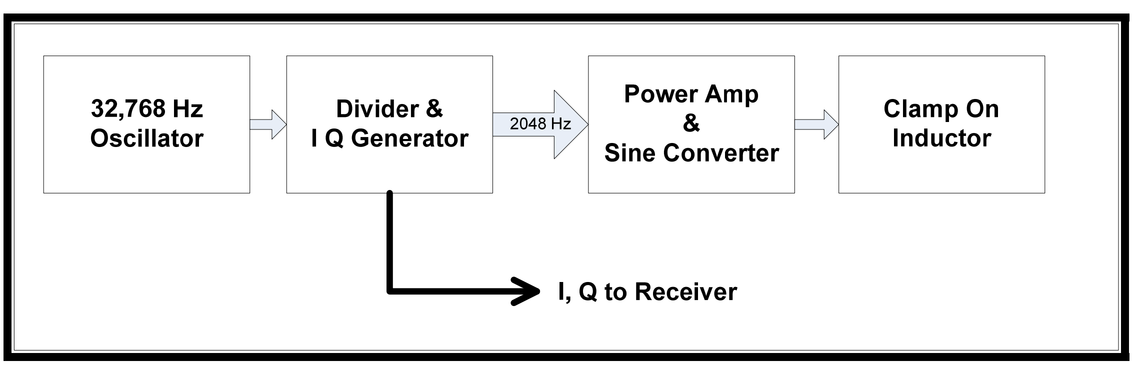

Figure 7-2 Simplified Ground Ohms Transmitter Block Diagram

Figure 7-2 shows the simplified block diagram of the transmitter portion of the system. The basic frequency reference for the system is a 32,768 Hz crystal oscillator. This signal is divided to yield the 2048 Hz transmit signal and logically manipulated to give the I and Q clocks at 2048 Hz to drive the receiver synchronous detector. The 2048 Hz transmit signal square wave is converted to a sine wave with a resonant convertor to drive the resonant transmit clamp on inductor. This induces the 2048 Hz transmit signal into the ground wire.

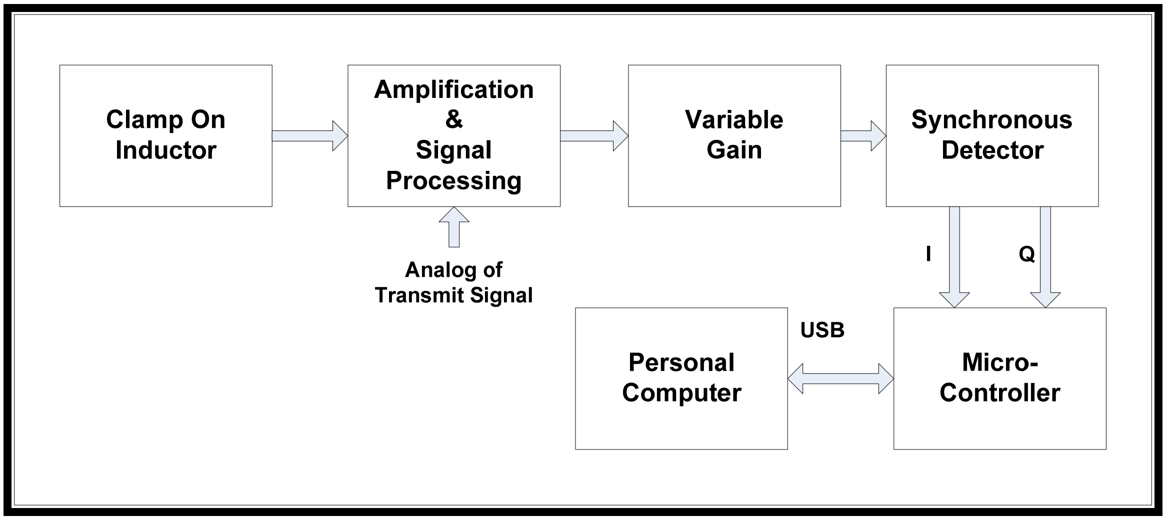

Figure 7-3 Simplified GroundOhms Receiver Block Diagram

Figure 7-3 shows the simplified block diagram the receiver portion of the system. The signal induced on the ground wire is detected by receive clamp on inductor, that is operated in a non-resonant mode. The detected signal is fed to amplification and signal processing circuits to rejected unwanted interference signals and select the signals to be processed.

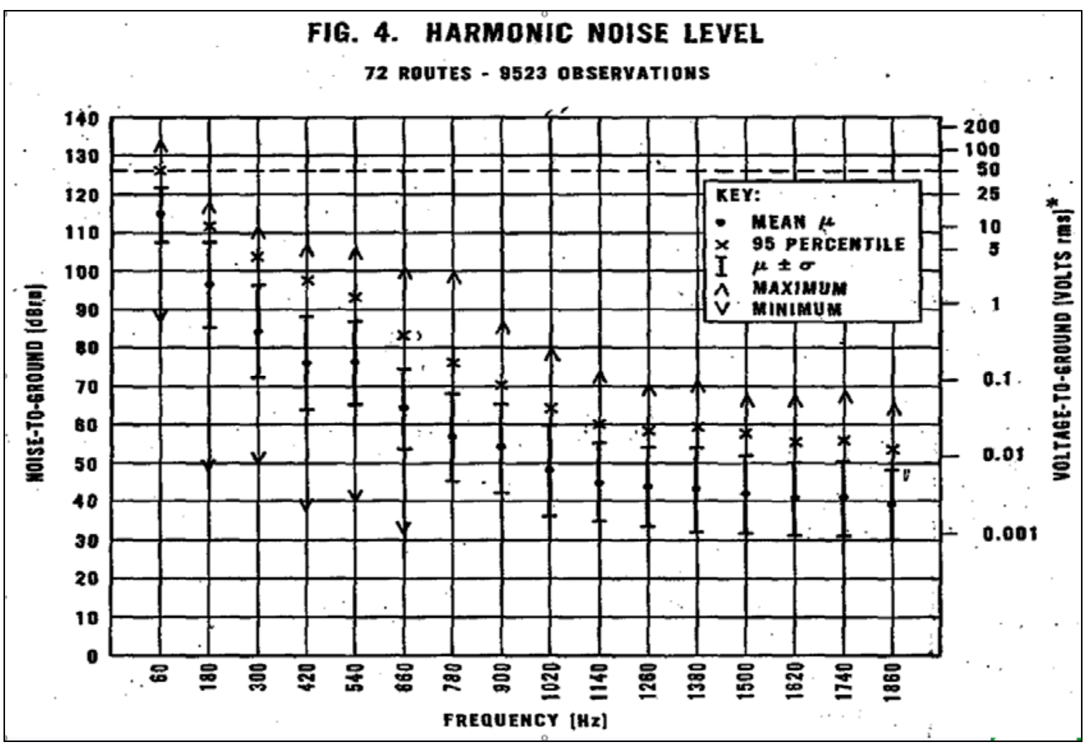

Figure 7-4 Typical Power Line Induced Noise On Telephone Cable

The 2048 Hz signal frequency is chosen to minimize the effects power line induced noise in the ground current. From studies for the effects power line induction interference on outside plant telephone circuits, it has been observed that the harmonics of the power line frequency are mostly odd can be quite large. Assumptions have been made that the even harmonics are sufficiently lower than the odd harmonics to the point they can be ignored. Figure 3-1 shows an example of one such study on Bell System cables many years ago. This chart only goes to 1680 Hz (31st harmonic of 60 Hz); however the trend is clear and the effects of power line induction fall off significantly with increasing frequency. 2048 Hz is slightly above the 34th harmonic of 60 Hz and significantly below the 35th harmonic.

8. Conclusions and Recommendations

What I have learned most from this exercise is that developing a culture of amateur radio operators measuring their installed ground resistance is important. Most likely my design will never be in production. There may be some who will build this instrument or something similar; however for the majority that will not be the case. I recommend that clubs and like organizations buy a competent tester for use by their members. For those with antenna farms, and there are many, I recommend the purchase of such a unit. In these cases the cost is small compared to the investment in towers, antennas and electronic. equipment.

9. References

- "Understanding Ground Resistance Testing" AEMC Instruments publication, http://www.aemc.com/techinfo/techworkbooks/Ground_Resistance_Testers/950-WKBK-GROUND-WEB.pdf
- H. Ward Silver(N0AX), "Grounding and Bonding for the Radio Amateur" ,ARRL, 2017
- "Lightning Protection & Grounding Solutions for Communication Sites", Ken Rand, PolyPhasor, January 2000

10. Overall Schematic

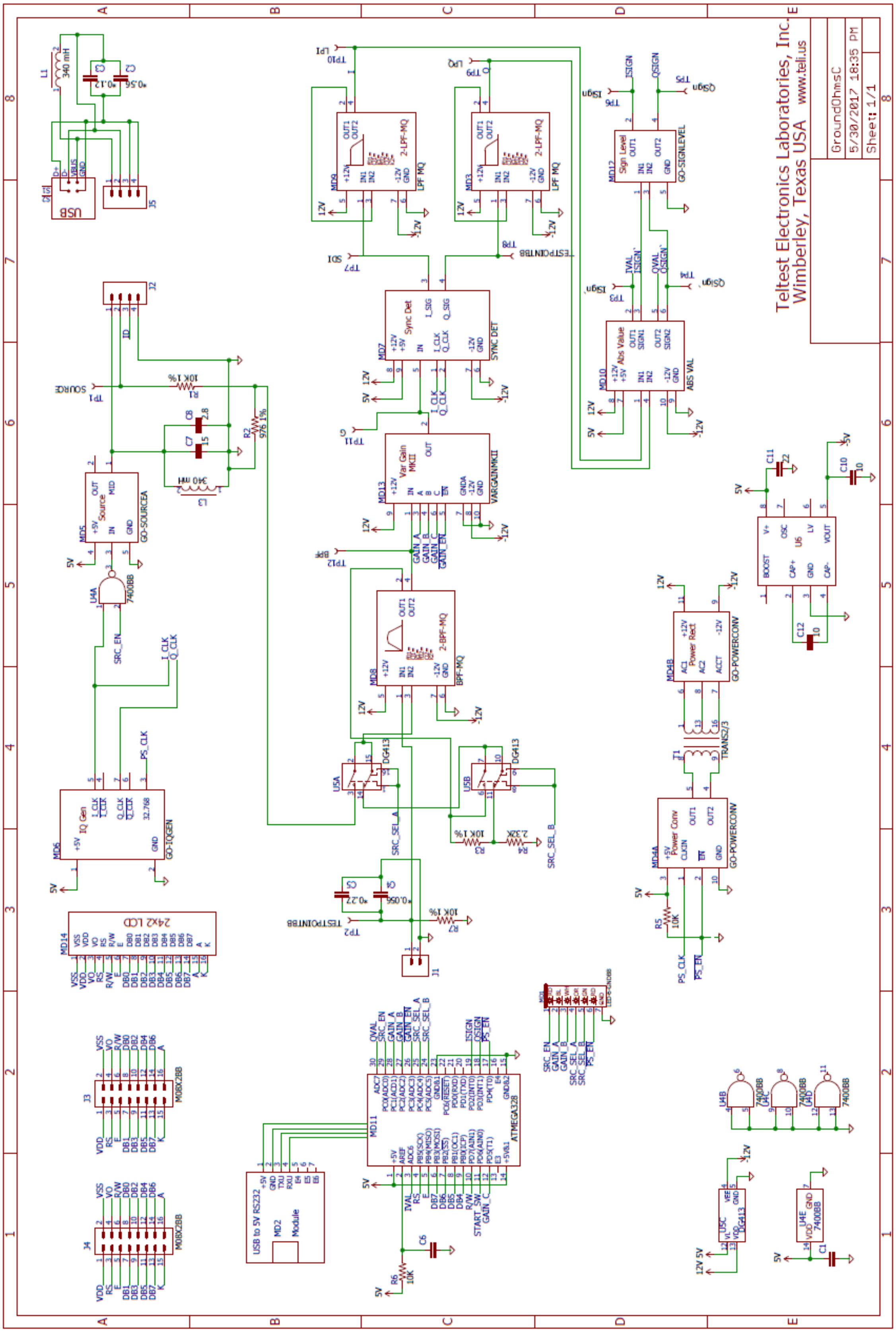

Figure 10-1 Schematic

11. Module Schematics

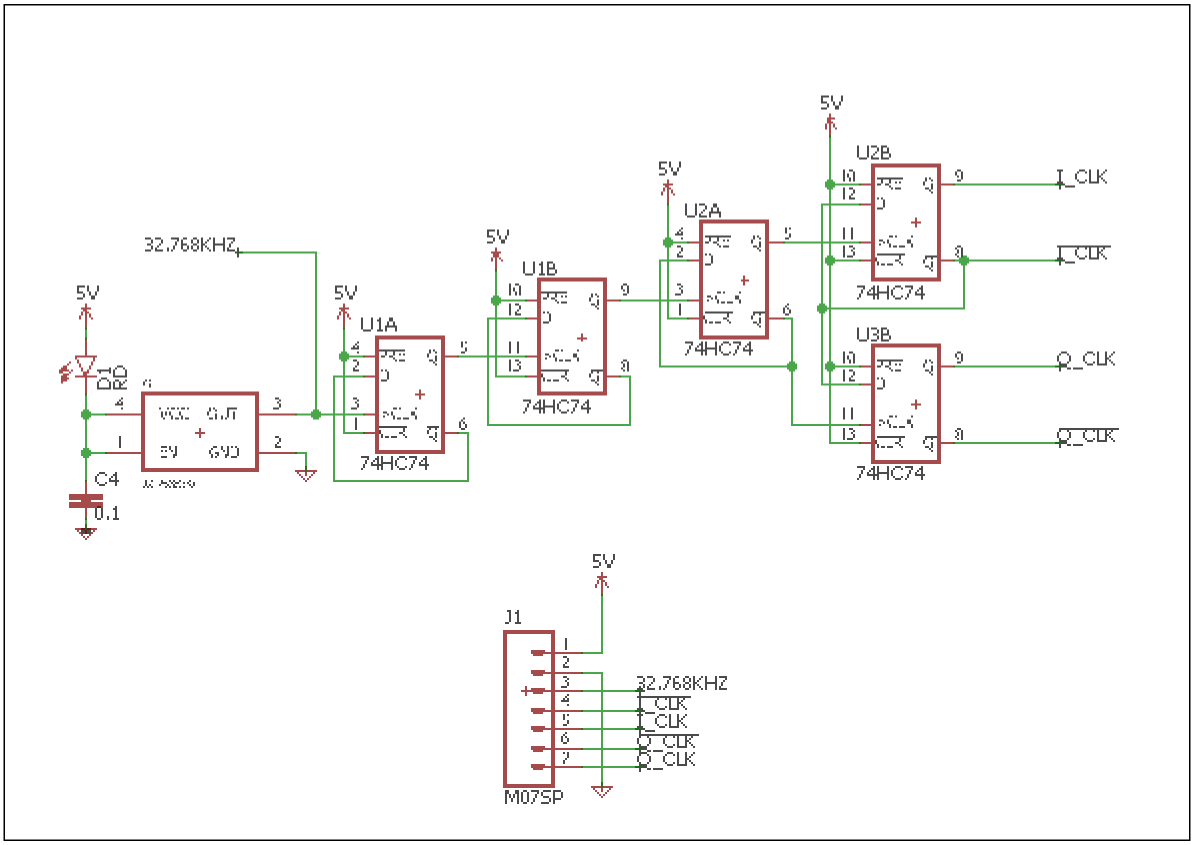

Figure 11-1 I Q Generator Module

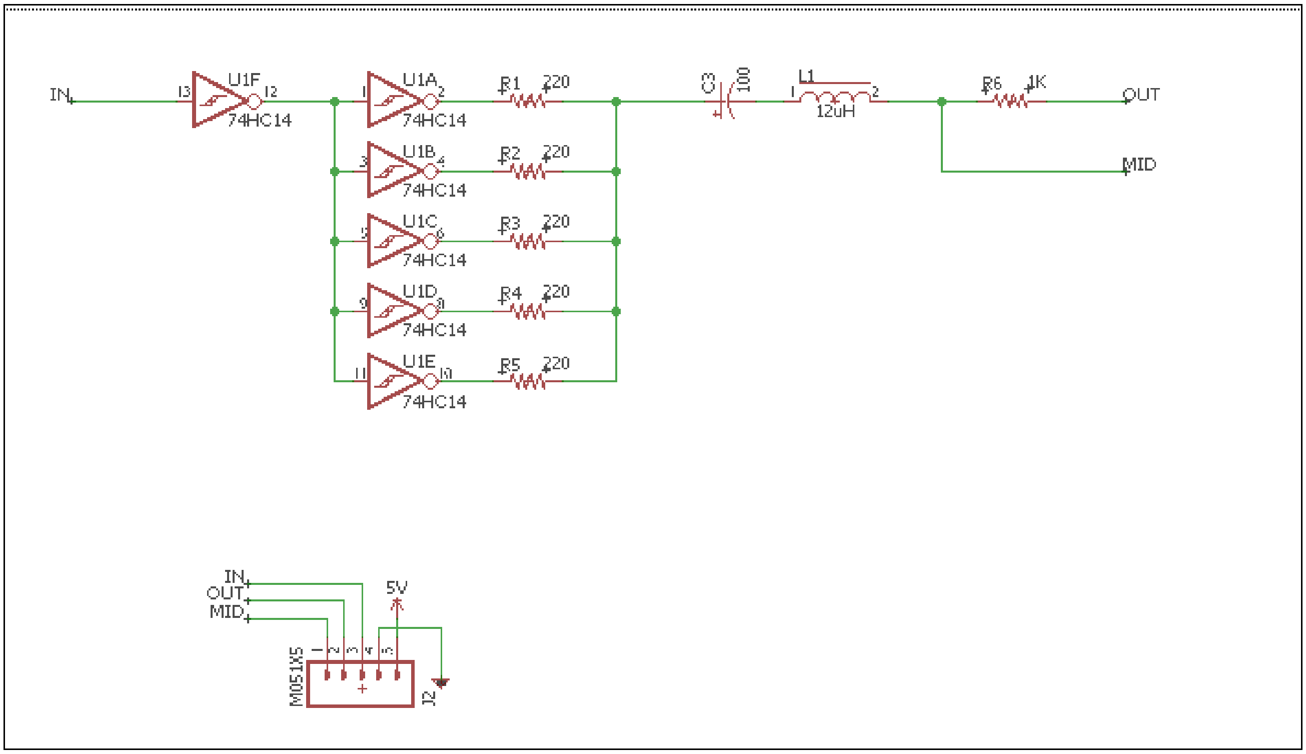

Figure 11-2 Signal Source Module

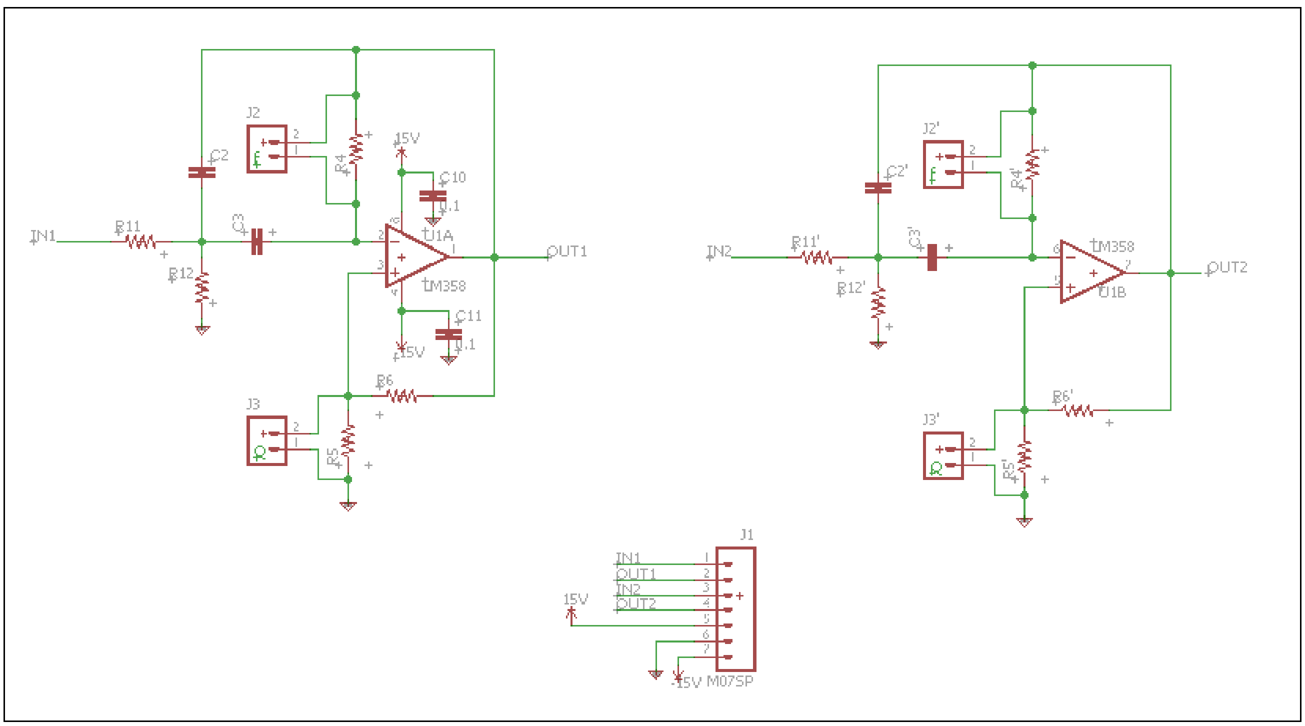

Figure 11-3 Band Pass Filter Module

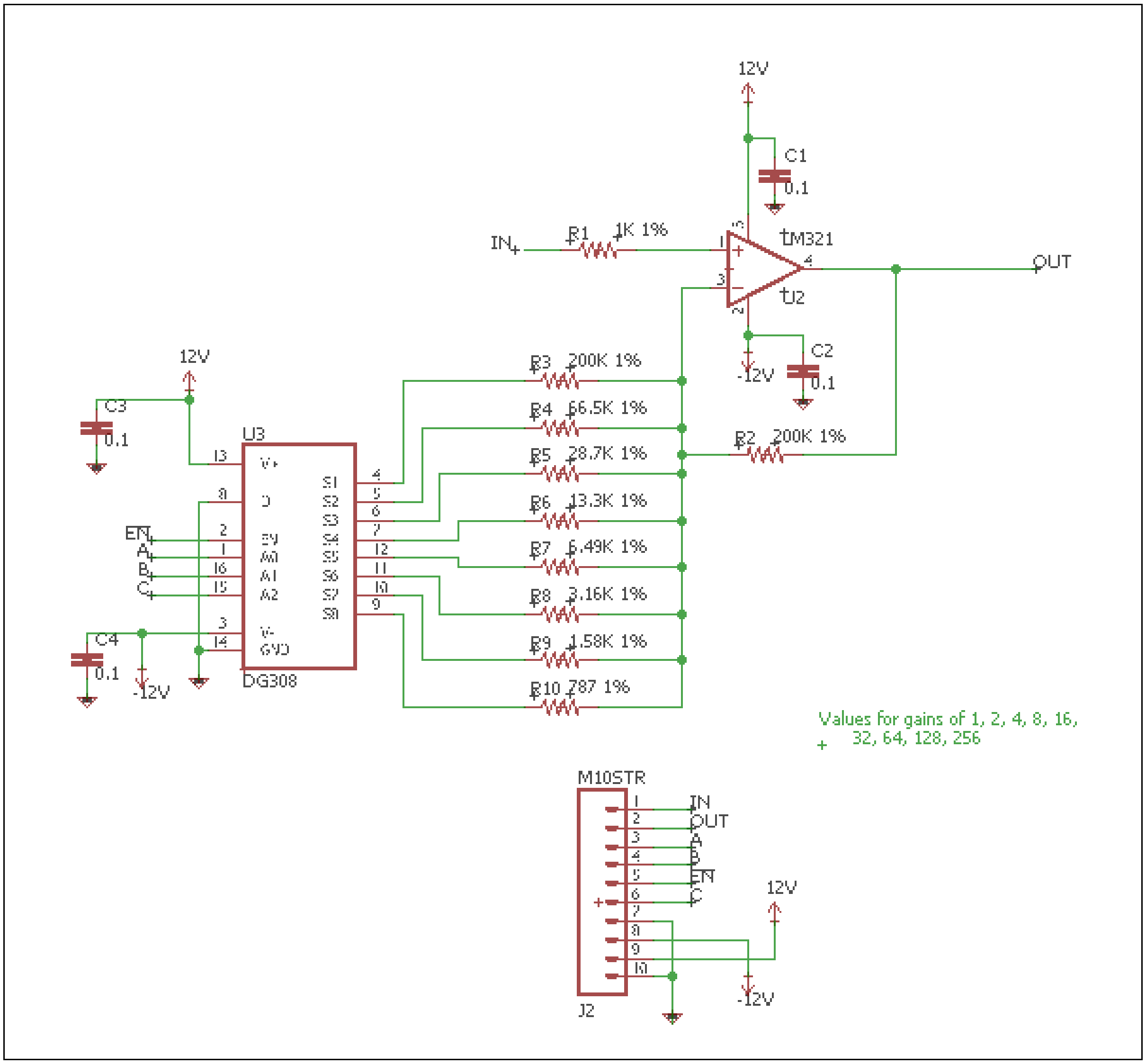

Figure 11-4 Variable Gain Module

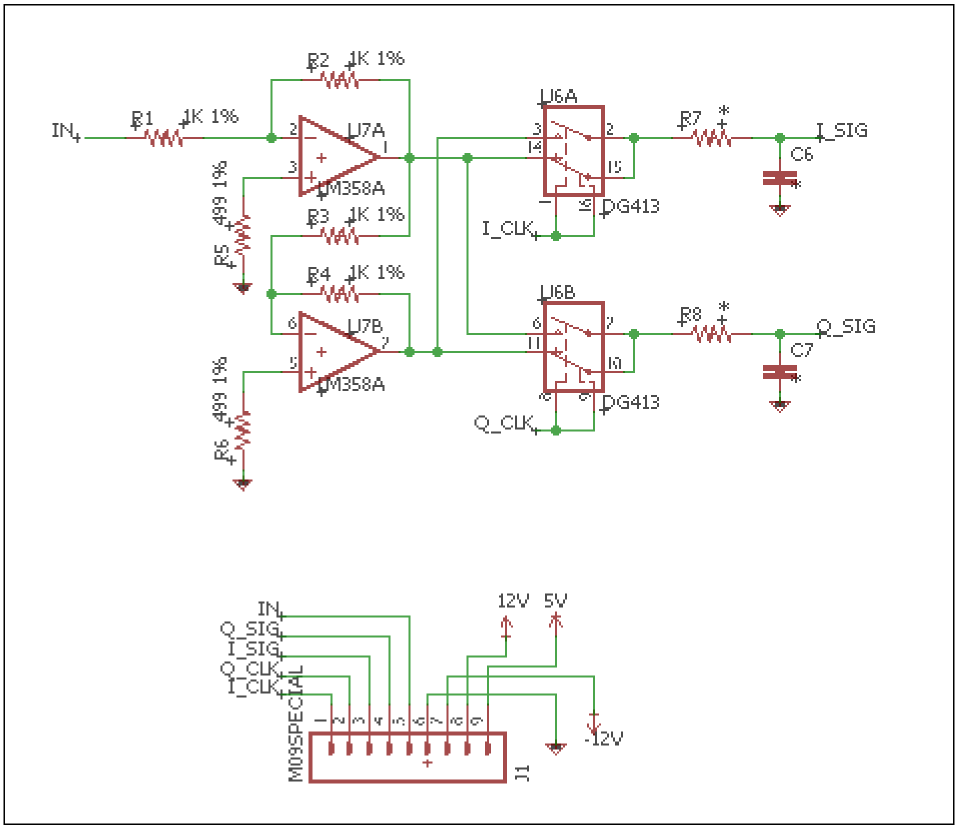

Figure 11-5 Synchronous Detector Module

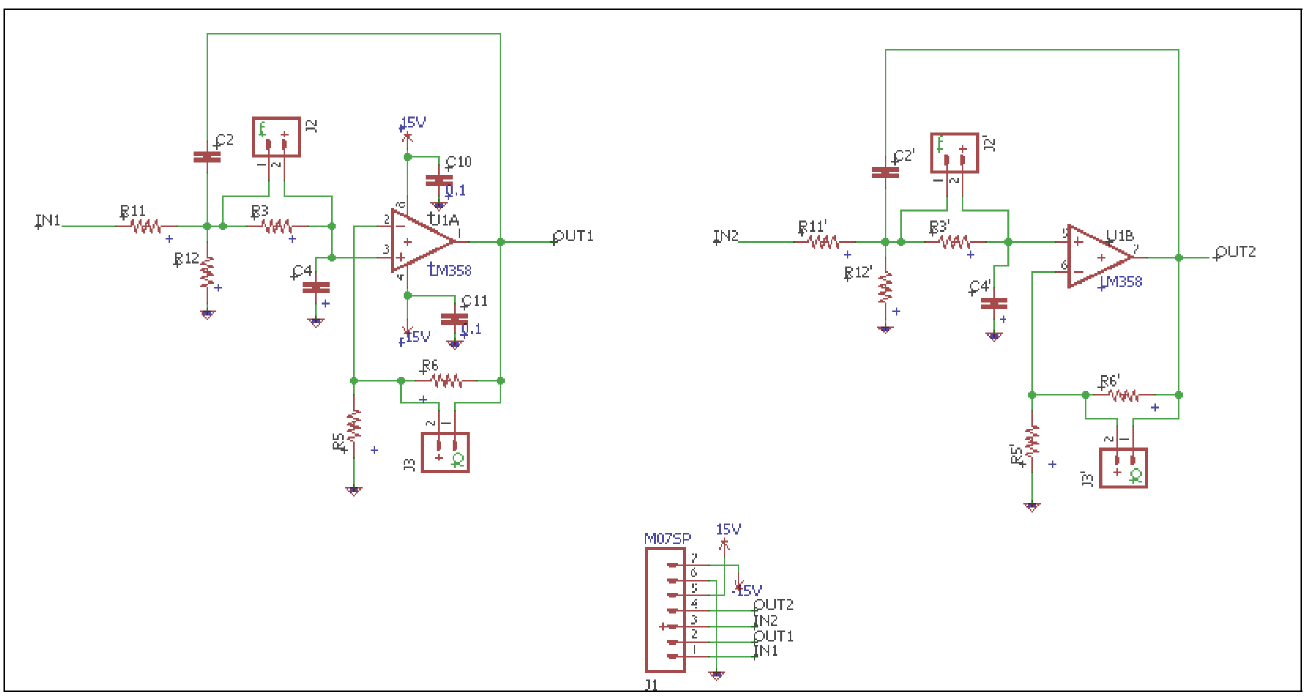

Figure 11-6 Low Pass Filter Module

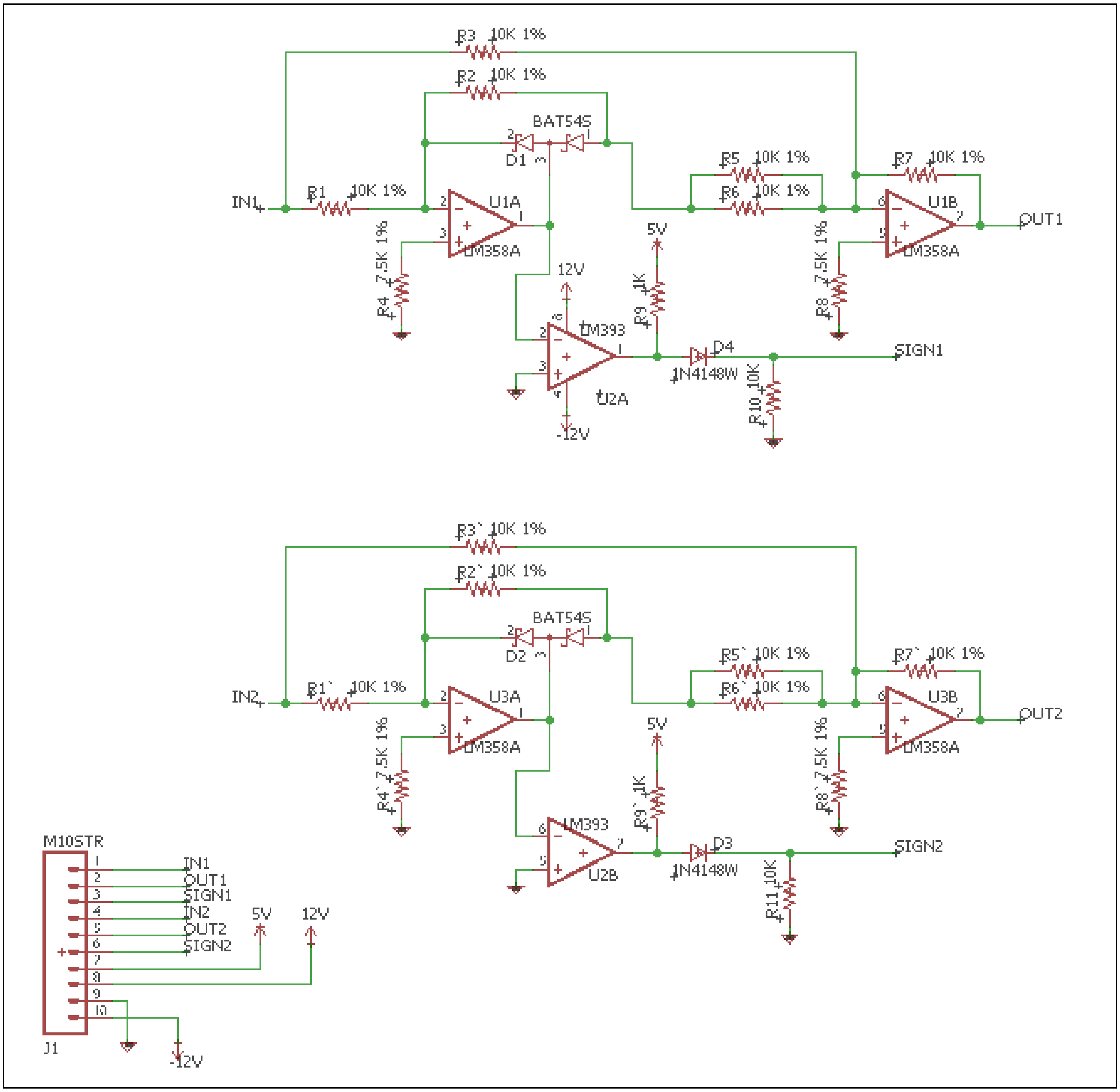

Figure 11-7 Absolute Value Module

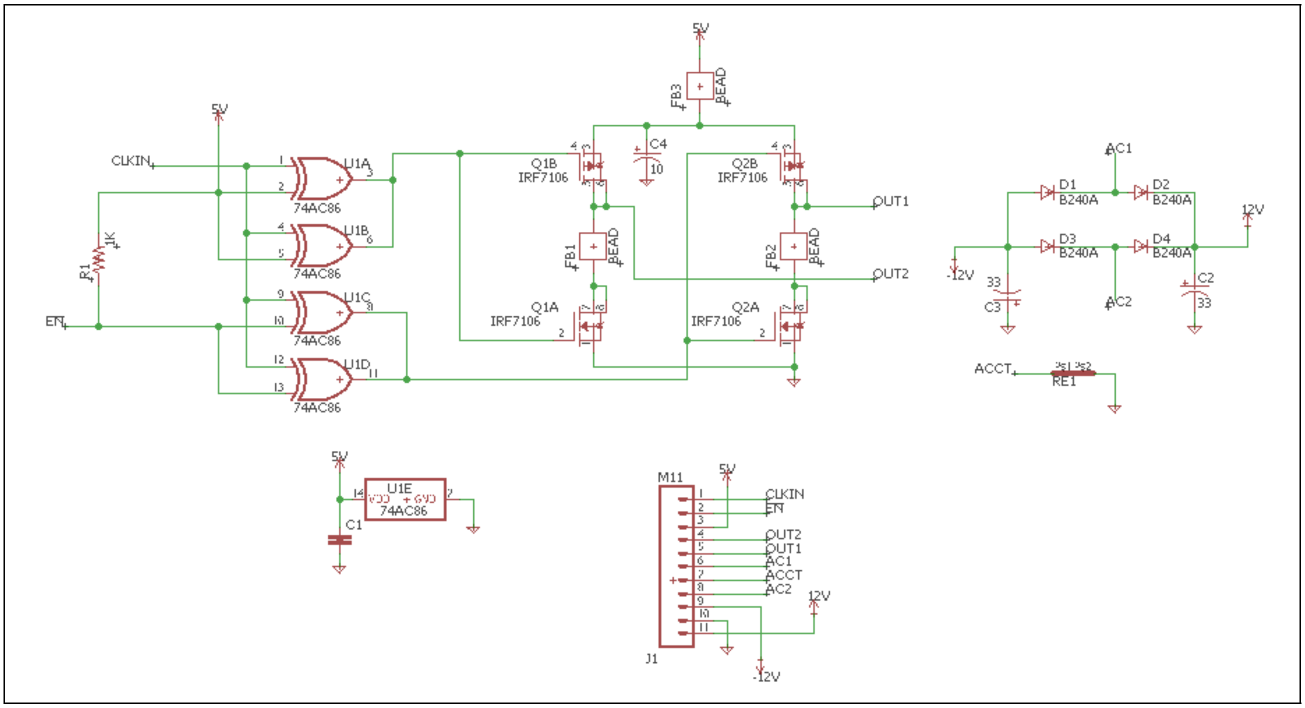

Figure 11-8 Power Supply Module

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