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Ground Ohms Test Set

Measure installed grounding and bonding resistances, as well as earth resistivity.

When first conceived, this article was intended to describe the details of the test set that I designed and built. However, when the project was essentially complete, there was something I discovered that changed the emphasis of this article. I discovered that many Amateur Radio operators do not want to know the competency of their grounds. Therefore this article will be directed 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. 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 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 the mostly solid limestone just inches below the surface over most of the property. I wanted to know the condition of my grounding. There are a number of competent clamp-on instruments for measuring ground resistance of installations, 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 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, I wondered why not measure installed grounds. I will address this further below.

While this instrument is capable of the measurement of earth resistivity, the emphasis here will be on measuring installed grounding and bonding resistances.

The Problem

We spend a good bit of time and effort designing and installing grounds for our stations.[1,2] Every situation is different. The very nature of our hobby exposes us to lightning events[3] 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 very little discussion about 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 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 the inductance of a tower and the various transmission lines involved. While this is true; the ground system can be only as good as the dc resistance permits. That is the bottom line. 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 the dc ground 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

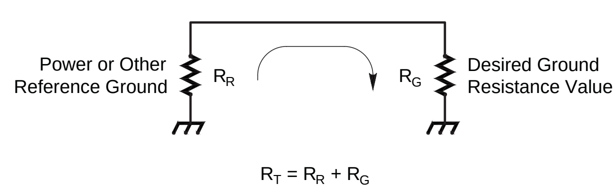

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Figure 1 — Measurable ground loop.

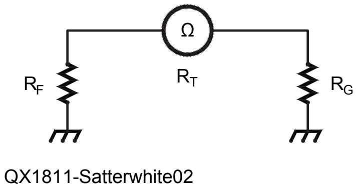

Figure 2 — Measurement using a simple ohm meter.

between the core halves is problematic and 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. I suspect that it can be non-linear. It can vary from day to day and from month to month.

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

The Measurement

When making this measurement, see Figure 1, 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: use the power utility system ground as a reference.

Measurement Methods

There are several methods available to measure the resistance of the installed ground. Each has it's advantages and disadvantages.

Ohm meter measurement

The installed ground resistance can be measured with an ordinary ohm meter as seen in Figure 2, 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 measured as much as 15 amperes flowing in a telephone cable sheath. However, in most cases it is much less than that depending on the ground location relative to power lines. Yet, it is still a concern for reliable measurement.

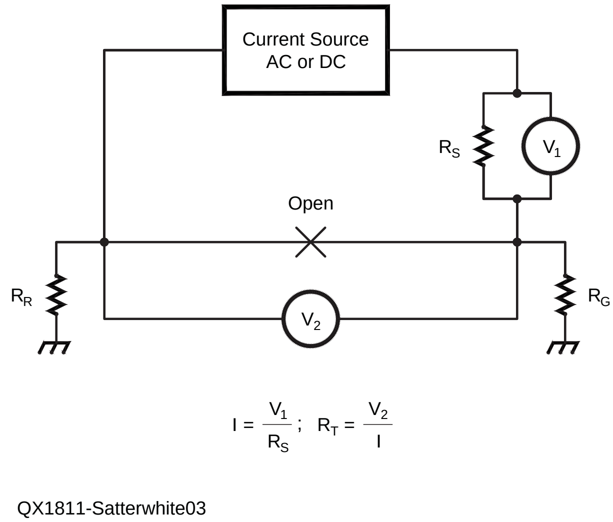

Figure 3 — Measurement using a four-terminal measurement system.

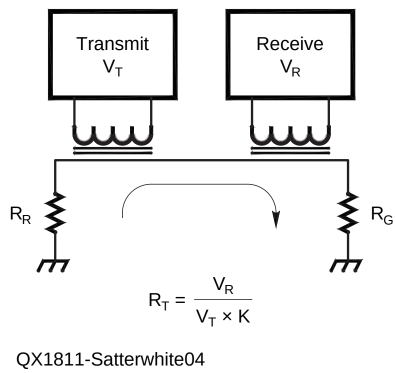

Figure 4 — Measurement using inductive coupling.

Four-terminal ac or dc measurement

In most cases the four terminal ac or dc resistance measurement, see Figure 3, 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.

Inductively coupled ac measurement

In a good many cases, an inductively coupled ac measurement does not require opening the ground circuit, see Figure 4. 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.

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 using 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 tools 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 its own. On this system the netbook or laptop computer is clumsy to use in the field, particularly in bright sunlight. However, it is needed 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.

The functional modules, Figure 5, are designed and laid out in Cadsoft Eagle. Insulation displacement wiring, Figure 6, 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, and 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.

Hardware

Figures 7 and 8 show top and bottom views respectively of the test set I designed and built. It consists of an instrumentation box, two clamp-on inductive transducers and a small computer such as a notebook or netbook 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.

Figures 9 and 10 show the front and rear panel views of my test set. Figure 11 shows the clamp-on inductive transducers. The

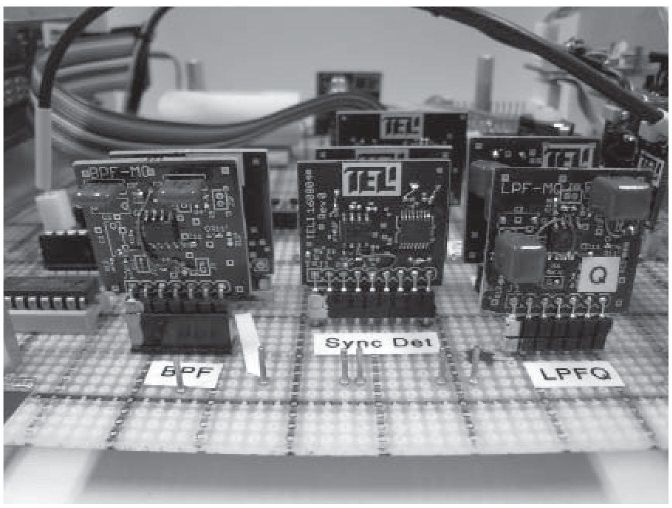

Figure 5 — SMD function modules.

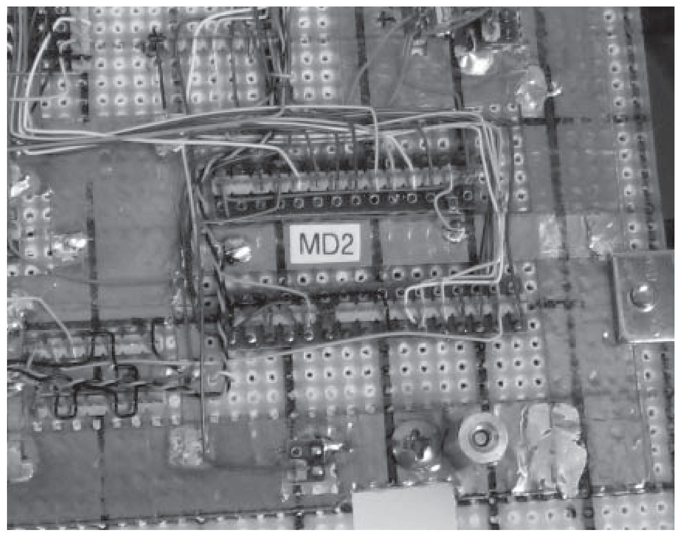

Figure 6 — Insulation displacement wiring.

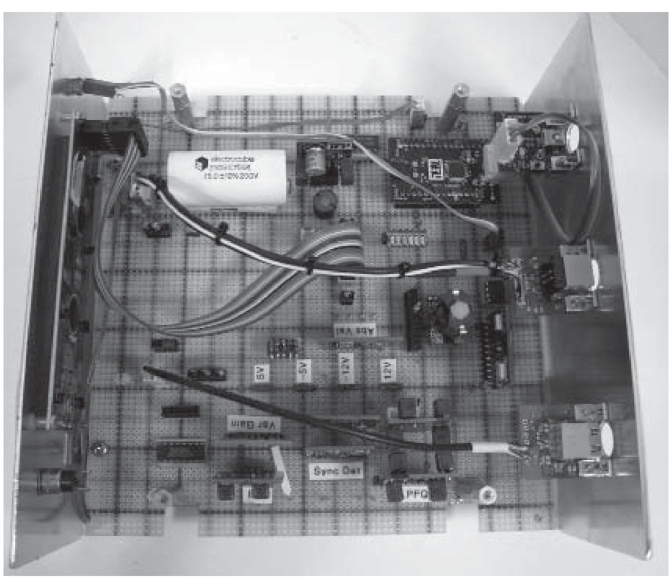

Figure 7 — View of top side.

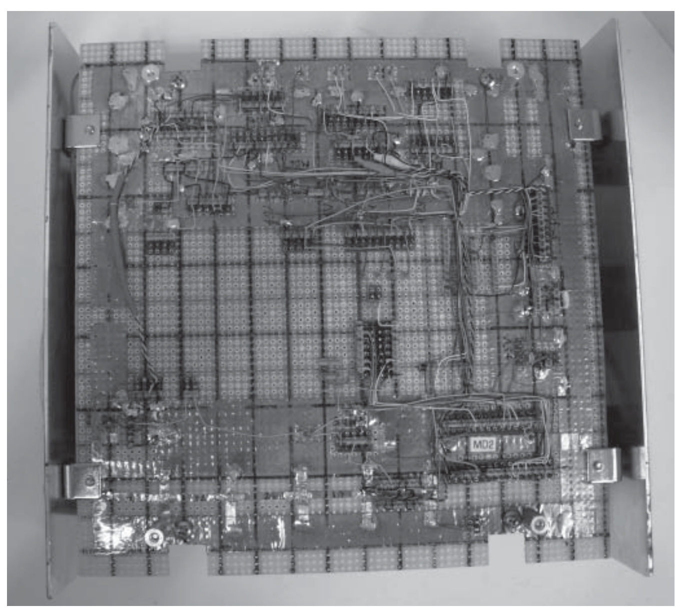

Figure 8 — View of bottom side.

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.

Functional Description

Figure 12 shows a simplified ground ohms system block diagram. A 2048 Hz sine wave is generated and drives a clamp-on inductor to induce a current in the ground conductor that is under evaluation. 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 on the front panel of the test set (Figure 9).

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 13 shows a 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 frequency 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 14 shows the simplified block diagram of 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

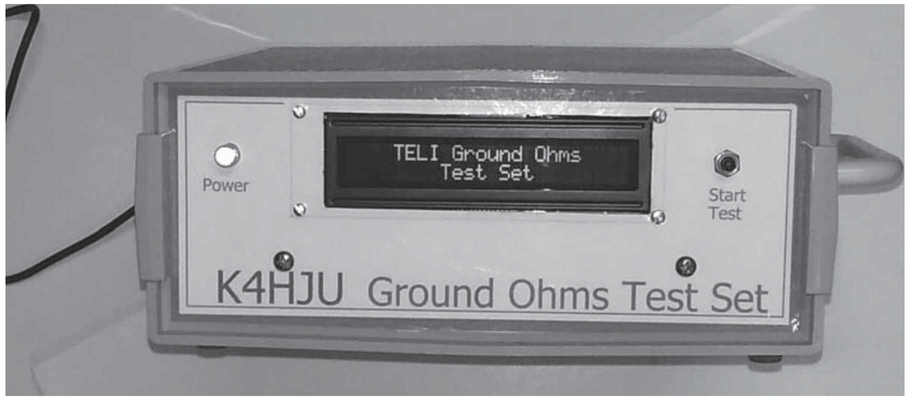

Figure 9 — Front panel view.

Figure 10 — Rear panel view.

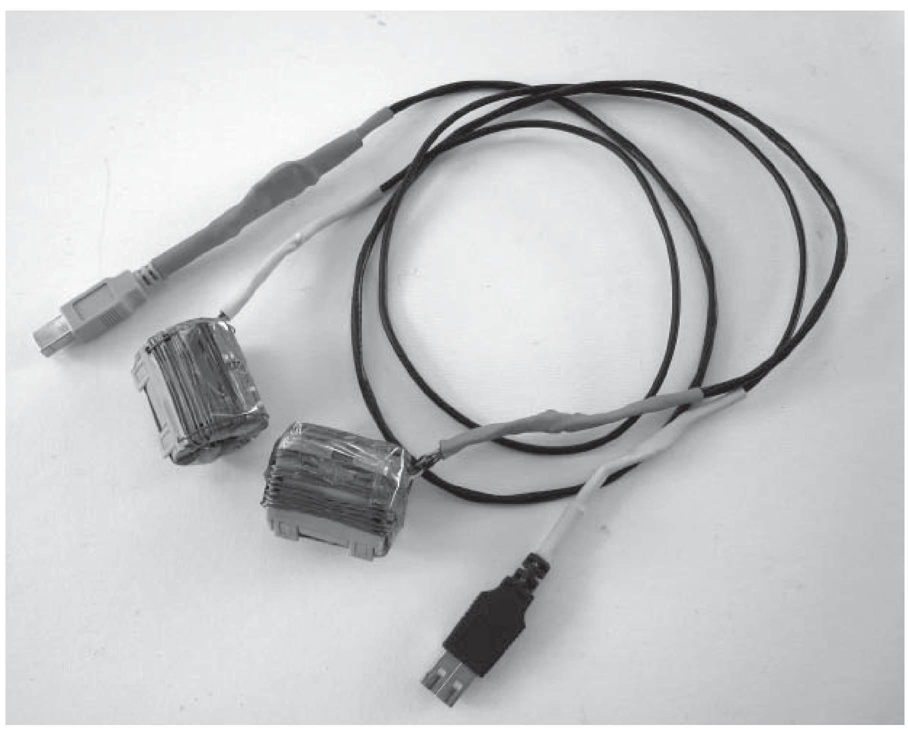

Figure 11 — Clamp-on inductive transducers.

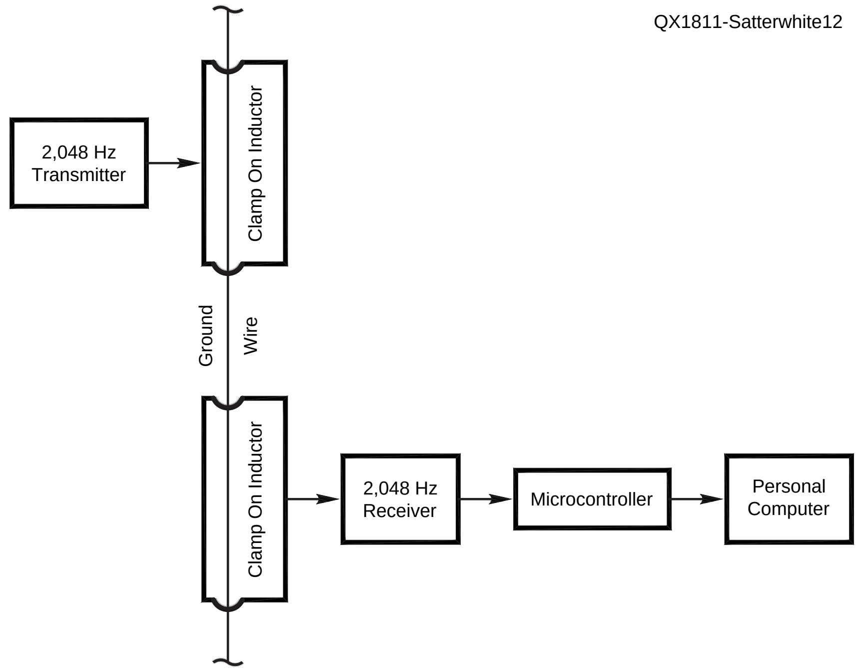

Figure 12 — Simplified ground resistance system block diagram.

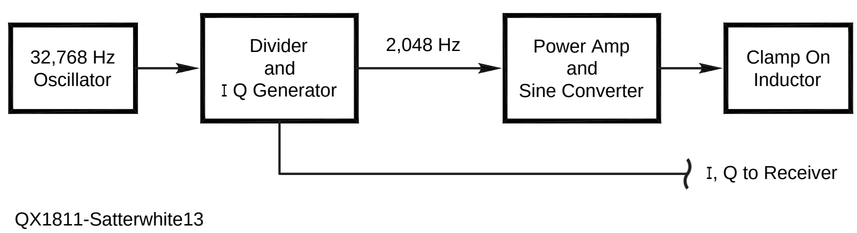

Figure 13 — Simplified ground resistance transmitter block diagram.

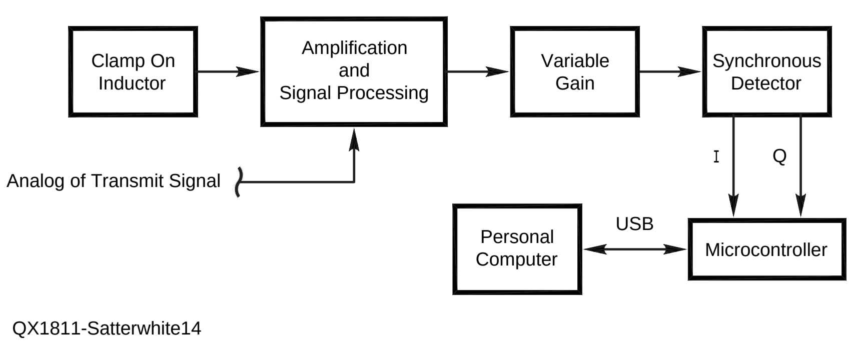

Figure 14 — Simplified ground resistance receiver block diagram.

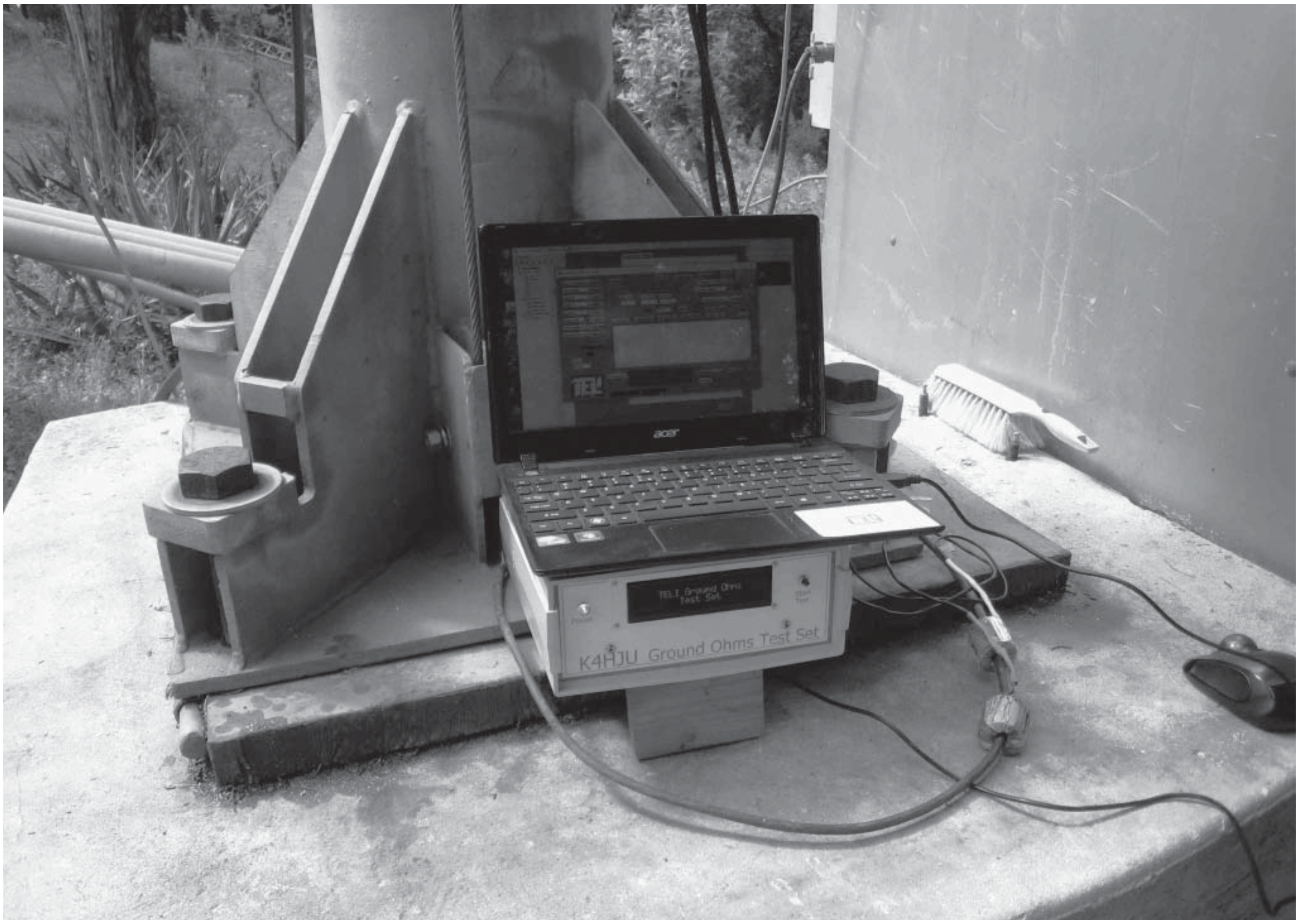

Figure 15 — Measuring the a ground at the base of a tower.

detected signal is fed to amplification and signal processing circuits to reject unwanted interference signals and select the signals to be processed.

The 2048 Hz signal frequency is chosen to minimize the effects of power line induced noise in the ground current. From studies for the effects of power line induction interference on outside plant telephone circuits, it has been observed that the harmonics of the power line frequency are mostly odd and 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 15 shows the ground resistance test set in action, measuring the competency of the grounding at the base of a tower.

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. While my design might never be in production, there may be some hams who will build this instrument or something similar. In any case, I recommend that clubs, organizations, those hams with antenna farms obtain or purchase a competent tester for use by their members. In these cases the cost is small compared to the investment in towers, antennas and electronic equipment.

ARRL member Jim Satterwhite, K4HJU, was first licensed in 1956 as KN4HJU, and later that year as K4HJU. He now holds an Amateur Extra class license and a General Radiotelephone Operator License. Jim is a registered Professional Engineer (Ret) in North Carolina. He is an iNarte Certified EMC Engineer (Ret) and a Life Senior Member of IEEE. He received a BEE degree from the University of Florida in 1965 and an MSEE degree from Purdue University in 1966. Jim has been involved in electronics research and development for more than 60 years, including 12 years as a member of the technical staff at Bell Labs and 34 years as a research and development engineer with Teltest Electronics, the company he founded in 1982. He holds a number of patents and patent applications. While in high school he built an AM transmitter from the ARRL Handbook. Jim enjoys developing electronic systems and is much more comfortable with MathCad or a soldering iron than a microphone. "There is no greater teacher than the lab." His Amateur Radio interests have included HF radio, slow scan TV, developing an antenna tuner using a unique power meter, and antenna analyzer design.

Notes

[1]Understanding Ground Resistance Testing AEMC Instruments publication, **www.aemc.com/techinfo/techworkbooks/Ground_Resistance_Testers/950-WKBK-GROUNDWEB.pdf**.

[2]H. Ward Silver, NØAX, *Grounding and Bonding for the Radio Amateur*,ARRL, 2017.

[3]Ken Rand, "Lightning Protection & Grounding Solutions for Communication Sites", PolyPhasor, Jan. 2000.