Calibrating a Low Frequency Field Strength Meter

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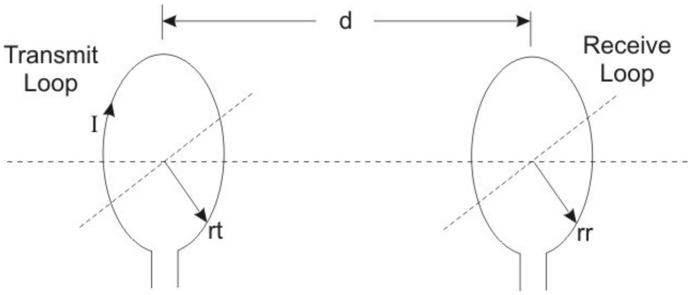
The first paper in this series dealt with selecting a receiver and constructing an antenna for field strength measurements in the 135.7 - 137.8 kHz (2200 meter) amateur/experimental band. While this paper will provide information specific to the Rycom 6041 SLM and 20-turn loop described in that article, the methods and computations should be of general interest.

The author was fortunate to have been hired by the late Elliot "Andy" Browning, WA1HAB, at WTAG, Worcester, MA, about five years before Andy's retirement. He had an infectious curiosity about measurement and calibration, and did regular calibration checks on the station's commercially-made field strength meter. The methods he used were developed by Dr. Hobart Newell at Worcester Polytechnic Institute many years ago. Prof. Newell constructed a series of field strength meters, and used them in his consulting work. I am indebted to both of them for stimulating my interest in this subject.

Over the years, I have concluded that the calibration methods described by Harold Taggert of the National Bureau of Standards (now NIST) in the 1960's were superior to Newell's approach. The NBS setup produces fewer variables, and is better suited to amateur/experimental purposes. What follows is drawn from Taggert's articles in "NBS Report 9229", dated in 1966.

Consider two co-axial loops as shown in the diagram below:



A known current, *I* (amperes), is sent through a small, circular, single-turn transmitting loop. The receiving loop, in this case the one on our field strength meter, is placed a distance *d* (meters) away. Note that the two loops are not in the same plane, as they would be for far-field measurements; they are facing each other side-to-side, along the same axis. The radius of the transmit loop is *rt* (meters), and the radius of the receive loop is *rr* (meters). If the receive loop is not circular, then just use the radius of a circle of the same area.

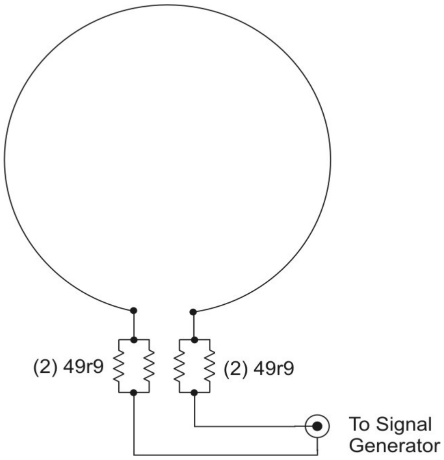
A number of magnetic fields are generated by the transmitting loop. But if the distance, *d*, is short (say, 1-2 meters), the predominant field will decrease as $1/d^3$. We can consider the magnetic field at *d* to have an equivalent free-space electric field of *E*, which is given by:

$$E = \frac{60 \cdot \pi \cdot rt^2 \cdot I}{\left(d^2 + rt^2 + rr^2\right)^{\frac{3}{2}}}$$

There is an additional term which is negligible below 5 MHz, and can be neglected for LF work. All units are metric as noted above, with *E* being in Volts/meter.

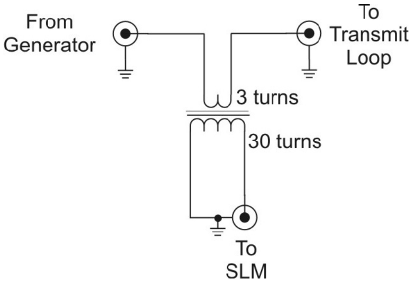
For our purposes, the job is now to build the transmitting loop, devise a way to measure the current through it, and create a setup where the two loops will be a known distance apart, and centered exactly.

The transmit loop should be small, exactly circular, made of copper tubing, and held rigidly in place. My setup uses a 12" (0.305 meter) diameter loop made of 1/4" soft copper tubing, such as that used in refrigeration work. The ends of the tubing are flattened and drilled for the 6-32 screws that mount it to the top of a small PVC electrical box. Here is a picture and the schematic:



Simple! The idea was to present a 50 ohm load to the generator, and essentially balance the loop by placing 25 ohm resistors in each side. Since the inductance of the loop is quite low at 137 kHz, an impedance bridge measured 50.1 +j0.7 ohms. You could insert a 1 uF film capacitor in series with the circuit and eliminate the inductive reactance if you desire.

The next project is to devise a way to measure the current in the loop. Since we will be using a signal generator output in the range of 0 to +10 dBm, the current will be in the range of 4 - 15 mA. The classic approach is to use a small thermocouple which can be calibrated against DC or 50-60 Hz AC, using a digital voltmeter. My approach was to use a current transformer, and send the output to either the Rycom SLM, an HP3586 SLM, or an RMS voltmeter. The HP3586 approach is particularly appealing, as that box can also supply a 0 dBm signal from its tracking generator. If you don't have the HP SLM, then I would suggest using the Rycom and a separate signal generator. The only requirement for the generator is that it hold its frequency and amplitude long enough for you to measure the current, and then to take the field reading. Here's the schematic of the current transformer:



My current transformer has a 1:10 ratio, consisting of 3 turns of #18 wire on the primary, and 30 turns of #22 wire on the secondary, using an FT-82-77 toroid core. I built it in a small die-cast box so that it could be used with other projects. However, you might consider putting it right in the PVC electrical box shown above, just providing another BNC jack to connect to the SLM. That would eliminate two BNC connectors and a die-cast box.

The SLM or RMS voltmeter should be connected with RG-58 cable, and a 50 ohm termination must be provided at the meter. The current transformer will then provide a current through that 50 ohm termination equal to 1/10 of the current in the loop. The meter will read that voltage, and you can use the following relation to calculate the current in Amperes:

$I = 44.72 \times 10^{-3} \left(10^{\frac{dBm}{20}} \right)$, and don't forget the minus sign before the dBm!

So a reading of -20.2 dBm on the SLM indicates a current of 4.37 mA in the transmit loop. If you use an

RMS voltmeter in place of the SLM, just multiply the reading in Volts by 0.2 to get the current in Amperes.

With the electronic goodies in hand, we can begin thinking about the physical setup. You will need a non-conducting flat surface about 2 meters long. There should be a minimum of large metallic objects or wiring within a couple of meters of the loops. I have gotten away with doing these tests in my cellar, which is a great advantage. My results with the same setup in an open back yard have been almost identical, once I figured out that my RMS voltmeter was temperature-sensitive! If you don't have a cellar or suitable indoor location, consider that a garage would at least offer protection from the weather. The professionals in this trade use outbuildings with minimal metallic conductors, but we appear to have great freedom at LF.

I suggest a separation of 1.2 to 1.5 meters between the two loops. The choice is not critical, but you must measure it. I have been using a door across two sawhorses as a working surface. With pencil, I marked a line the width of the door for the transmit loop, and then added parallel lines at 1.25 and 1.5 meters from that. Next, I marked a center-line down the middle of the table, and checked that the parallel lines were perpendicular to that. Now consider that the two loops must be exactly parallel, along the same axis, and that their centers must be an equal distance above the table. This will require some work with a tape measure and a pencil or felt-tip marker. If the receive loop was centered on the top of the Rycom meter, you can make center-line marks on the lower part of the Rycom case to allow you to line it up with the lines on the table. The transmit loop should be supported by a non-metallic box or similar device to bring its center to the same height above the table as the field meter loop. It will help to mark the center PVC support in the FSM loop with a felt-tip marker, and make whatever center-line marks you can on the transmit loop. The picture below shows my setup when I was checking it outside:

The transmit loop is supported by an old speaker cabinet (speakers, etc. removed), and an additional piece of plywood to bring the loop's center to the same height as the PVC loop. Use your imagination, and whatever is lying around your shack.

The cable(s) from the transmit loop box should be routed down at right angles to the table to the ground or floor. If you use a separate current transformer, it can be located at any point in the line from the signal generator to the loop as the 50 ohm system is properly terminated, and the current will be the same at all locations. The signal generator and/or SLM can be placed a meter or more away without any effect. Note that I have the Rycom meter turned so that my body is away from the field of measurement. I have seen no effects from touching the meter or moving around the area, though.

Having completed the equipment and the physical setup, it's time to establish a calibration for your field meter. Before you start, take a listen with the receiver and verify that there are no strong signals present that could throw you off. As a reality check, you will be reading the calibrate signal in the range of -30 to -50 dBm. If you've got something local that competes with that, then pick your test frequency accordingly. Otherwise, some round number like 137.0 kHz should be fine. If your signal generator or

RMS voltmeter requires some warmup time, allow for it.

I will present the measurement procedure in checklist format. You'll probably spend more time calculating than you will measuring. Be sure that you have a calculator or program that can handle exponents.

☐ Set the signal generator to the desired frequency, say, 137.0 kHz. Set the output level somewhere between 0 and +10 dBm. Greater levels are not necessary at this short distance.

☐ Feed the generator through the current transformer to the transmit loop. Connect the measuring port of the current transformer to your choice of SLM or RMS voltmeter. If not using the Rycom meter, be sure that your meter has a 50 ohm termination in place, and proceed to take a reading.

☐ If you are using the Rycom meter to measure the current, turn it on, and let it warm up for a minute or so. Then do the calibration at 250 kHz, setting the Cal Level control for a reading of -30 dBm. All of these measurements can normally be done in a 3.1 kHz bandwidth. If you feel it's necessary to use the 50 Hz BW, then have the meter in that mode when you do the 250 kHz calibration. There is a little more loss through that narrow filter, and it needs to be included in the process. Then set the Impedance switch to 50 ohms terminating, the Input switch to Unbal, and start with the Range switch at -20. Tune in the signal from your transmitting loop, and take the level reading. In this example, I got -20.2 dBm. Important: Disconnect the coax feed from the Rycom after you have taken the current reading.

☐ If you have used another meter to measure the current, you can leave it running during the calibration process. If the Rycom has not been used to this point, do the warmup and 250 kHz calibration as described above. Set the Rycom's Input switch back to Balanced, and the Impedance switch to 50 ohms, Bridging. Adjust the Range switch as needed to get a measurable signal. Record that signal. In my case, I read -45.7 dBm.

☐ Current calculation: $I = 44.72 \times 10^{-3}\left(10^{\frac{-20.2}{20}}\right)$ = 4.37 mA.

☐ Given that the radius of my transmit loop is 0.153 meters, the distance between the two loops is 1.25 meters, and the radius of the field meter loop is 0.254 meters, the following is the equivalent E field: $E = \dfrac{60 \cdot \pi \cdot (0.153)^2 \cdot 4.37 \times 10^{-3}}{\left[(1.25)^2 + (0.153)^2 + (0.254)^2\right]^{\frac{3}{2}}}$ = 9.09 mV/m

☐ The Rycom meter read -45.7 dBm in that field. Converting to Volts, you get

$$0.2236\left[10^{\frac{-45.7}{20}}\right] = 1.16 \text{ mV}$$

☐ This results in a calibration factor of $\dfrac{9.09 \times 10^{-3}}{1.16 \times 10^{-3}}$ = 7.84 for my loop and meter.

This calibration factor is then used to multiply the voltage reading that I get from any field strength measurement after converting dBm to Volts. The resulting units are Volts/meter. This is your "official" calibration of the field strength meter.

As a sanity check, let's use the expression for *E* field vs. loop terminal voltage from the first article, and see how it compares with the work we just did:

$$E = \frac{c \cdot Vloop}{2 \cdot \pi \cdot f \cdot n \cdot A}$$

where the measured terminal voltage must be divided by the loaded Q of the loop circuit. Plugging in the 1.16 mv measured above, and the parameters for the receiving loop, we get:

$$E = \frac{2.998 \times 10^{8} \cdot \dfrac{1.16 \times 10^{-3}}{10.5}}{2 \cdot \pi \cdot (137 \times 10^{3}) \cdot 20 \cdot (0.2026)} = 9.50\ \text{mV/m}$$

This is an error of 4.4% between the two-loop calibration process, and a simple calculation based on the loop constants and the terminal voltage. Frankly, anything less than 5% should be considered a success in such a venture, so I'm fairly confident that this field strength meter can take accurate readings.

This article has described the calibration process for a home-made loop antenna and a portable selective level meter. The results have been found to agree with predictions. A subsequent paper will discuss the choice of measuring locations, and analysis of the resulting data.