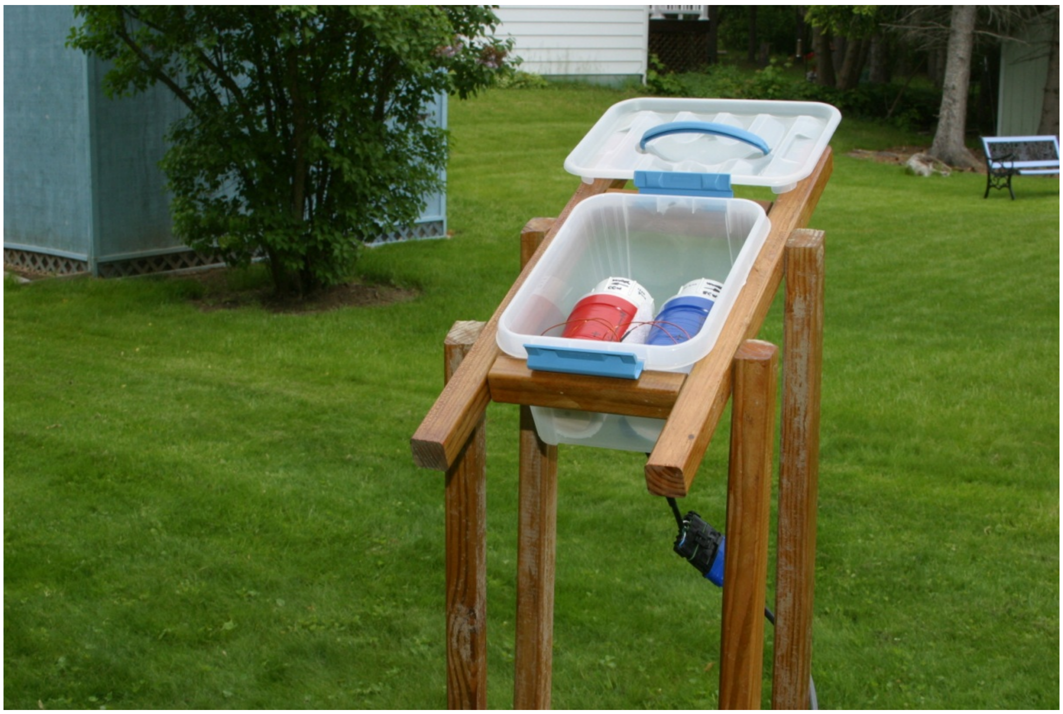
Build an Earth's Field Magnetic Observatory!

PART IV, The Counter-Wound Coil Pair

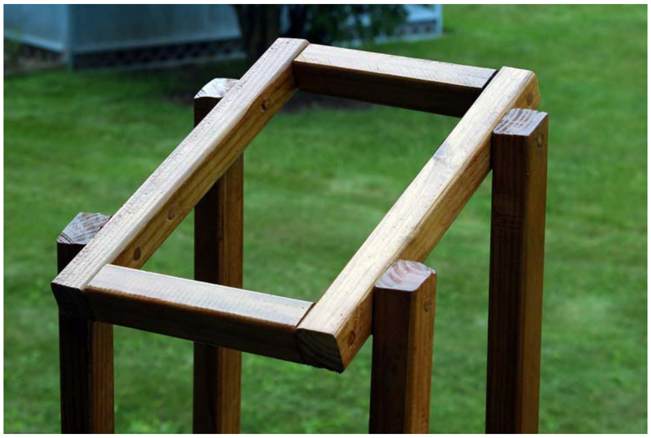


COIL STAND

The coil stand was made from standard 2" x 2" pressure treated wood stock and covered with a polyurethane combination stain and sealer. The parts are held together by 3/8" oak dowels. Initially, as seen in the photo above, we left longer lengths with extensions, to support for example, a flat surface for testing other coil and sensor systems. The plastic box used as the coil holder is not waterproof because of holes in top for the handle. To allow for a smaller heavy white plastic bag[1] as a rain cover, we later removed the extensions as seen in the photo below.

One way to build the stand in a backyard is to use a heavy iron pole to make pilot holes in the ground for the four upright vertical wood members. The stand should be oriented towards magnetic North (in the northern hemisphere, the back higher part towards North). Tap the four posts into the pilot holes. Next mark the desired heights, and cut off the excess, optionally at the elevated angle so as to match the plane of the rectangle that will hold the coil box. In general, probably three to five feet will provide sufficient ground clearance to avoid undesirable coupling to any local electrical ground currents.

With careful planning, there might be enough wood in the cutoff pieces to form the rectangular structure to support the coil box. As seen in the photos, holes for dowels can be drilled through two pieces to be affixed to one another, and a wood dowel can be tapped in to make the connection. You can make the dowel fit snug and/or use wood glue. We cut off the excess dowel ends with a flat saw blade. More tapping on the vertical posts (with a block of wood to prevent dents) can be done to place the plane of the coil box support structure normal to the local total field vector (i.e. normal to the local inclination or dip angle).[2] Here in upstate, NY our plane is elevated to an angle of about 20 degrees for the local 70 degree dip angle. Paint the stand with some appropriate weather sealing paint.[3]



Other stand systems can be used. In general, if metal fasteners are used, some types of non-magnetic brass hardware are thought to be most desirable. If metal parts are used for stand members, be very careful not to create coupled shorted one-turn coils or electrical conduction paths to earth ground. In most systems, it will probably work best to completely isolate the outdoor counter-wound coil pair (electrically floating) from earth ground at or near the sensor stand. As described below, we provide a single point earth ground at the analog power supply common, which also includes one single common connection between the analog common and the polarization power supply common.

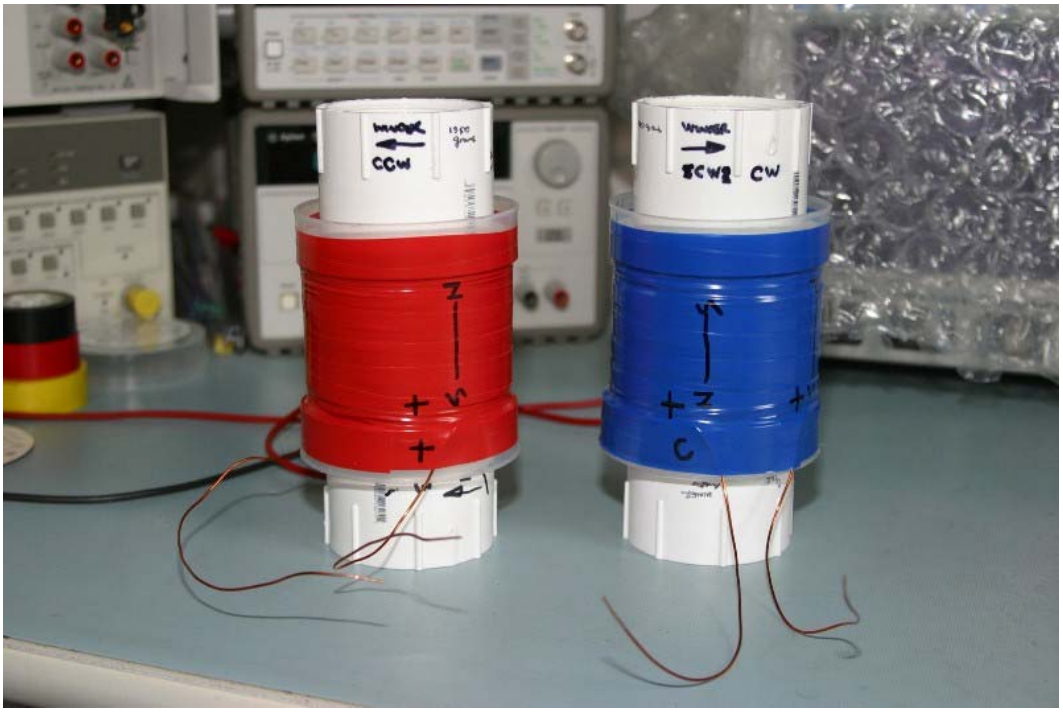
COILS

The coils are wound on 2” PVC pipe sections with threaded cap end pieces which support side walls for 600 turns of #18 wire and multiple layers to give about a 2” coil length. The two coils are counter-wound. That is, one of the coils is wound clockwise and the other coil of the counter-wound coil pair is wound counter-clockwise.[4] Two wires from each of the coils are fed back into a building from an outdoor coil stand via a shielded four conductor cable. Probably two pair shielded cable is best (#22 AWG or larger), however, other types of four conductor cable will also probably work okay. The threaded insert caps are only used in the lower sections of the coils and are installed backwards (i.e. the square bolt end goes into the threaded insert to provide a flat surface on the outside to rest against the tilted side of the coil box. Also, the square bolt end, in combination with a wood spacer, provides a raised internal platform for the fluid bottle, so that the fluid sample sits well within the solenoid on the powered coil side. We used a ¾” plywood plug made with a hole-saw, so a 125 mL Nalgene specimen bottle is supported about even with our powered solenoid coil. Only one of the coils is powered to align the spins of the protons of the liquid in the specimen bottle.

It is unimportant whether the clockwise wound or counter- clockwise wound coil is powered, only that the sample bottle be located in the powered coil! The coil pair should be substantially aligned to match the longitudinal solenoid fields of the coils (of each other) for best cancellation of ambient magnetic field noise. Also, for maximum precession signal strength, the longitudinal axis of the coils should generally be aligned in a horizontal North-South direction, with an elevation angle that places the coil longitudinal axis normal to the local inclination angle. For example, our local inclination or dip angle is about 70 degrees, and the longitudinal axes of our coils are therefore elevated to about 20 degrees above the horizontal plane.

A water resistant automotive connector[5] can be used to allow for an easy disconnect of the coil pair for lawn and coil package maintenance. In operation, a heavy plastic bag should cover the coil sensor package for protection from wind and rain. You might need to add tie strings to keep it from flapping in the wind.

What follows is a description of how we wound our present operational counter-wound coil pair. There are probably much better ways to create the end stops or side walls for the multi-layer coils.



From our May 19, 2010 journal entry: I wound the counter-wound coils with 600 turns of #18 AWG magnet wire. I used 5" long 2" PVC sections (about 2.3" diameter) with threaded cleanouts on either end. The threaded cleanout provides both an end stop for my 2" long solenoid coils, as well as a mount to affix the coil form to the coil winder. To make a crude coil bobbin, I cut a 2.5" diameter hole in one cover of a 3M electrical tape package with a hole saw in the drill press. The hole saw generally did not finish the cut, so I cleaned them up a bit with a razor blade. Next, I would vinyl foam insulation around one end of the threaded PVC cleanout to support the 3M electrical tape cover. Then I placed the tape cover over the insulation on the threaded cleanout. Here are a couple of more pics: pic1, pic2. Then I tapped (no PVC cement) the assembly together to make the 2" coil form bobbin. I used some rubber cement to better seat the covers (not shown). Then I screwed each bobbin onto the coil winder (winding could be done by hand without a coil winding machine). Note that I run the coil winder from the large hp supply. Also, I modified the winder motor by bringing out wires from the series connected motor to a reversing switch that I added to the winder (reversing polarity to a series connected DC motor does not reverse the direction because the polarity of both the stator and the rotor windings change). To reverse a series connected DC motor, you literally need to break the series connection and reverse either the stator or rotor winding with respect to the other. I only use the counter on the winder and stop it by reaching across and turning down the current limit knob on the hp supply.

I wound the counter-wound coils, marking the direction of each wind. It was remarkably easy this time to balance the coils (match the inductance) using my like new, but very old, hp 4562B Impedance Bridge (a super nice piece of equipment!). I did the balancing on a wood floor in the middle of a room. It only took one turn to match the inductance.

The counter-clockwise (CCW) red coil is 17.61 mH, Q 36, R 2.84 ohms, weight 1346 grams. The clockwise (CW) blue coil is 17.61 mH, Q 36, R 2.85 ohms, weight 1359 grams. I applied power and marked the leads for N-S field with a "+" label. The "C" marker designates what will be the center-tap back at the polarization PCB (both coils are brought back on their own twisted pair and later joined during switching at the polarization circuit (*see April 17, 2010*). The coils still fit in the storage bin on the coil test stand, pic1, pic2, pic3. (It is possible that better cancellation could be achieved with some more separation between the counter-wound coils, perhaps by as much as 1/2 to one radius, I hope to get back to this question.)

The counter-wound coils are wired into the short cable that goes to the water-proof connector, pic1, pic2. The new pair resonated with about 125 nF. The 125 ml sample plastic bottle sits on a wood plug on top of a backwards mounted PVC threaded cleanout plug, which places the center of the sample volume about in the middle of the powered (red) coil. Note that as described earlier, only one coil is powered, while the other (blue) is only switched in for ambient noise cancellation during a digitization interval.

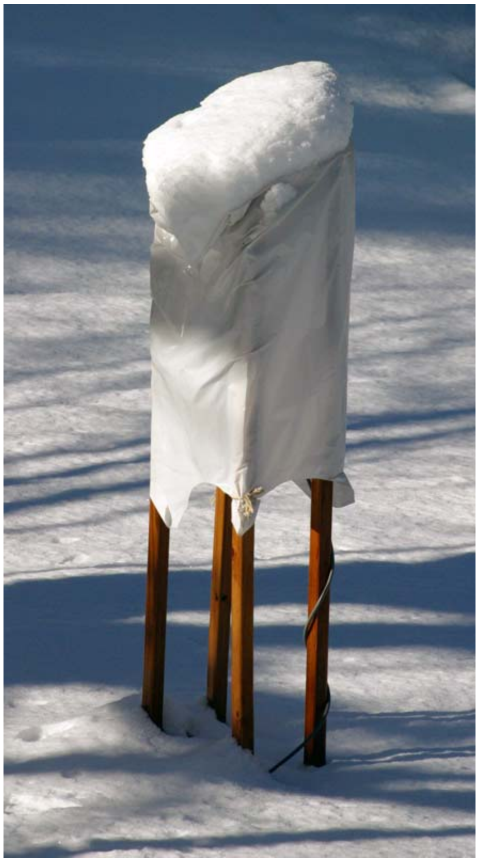
CABLE

We were fortunate to purchase one hundred foot length of Alpha 86702CY SupraShield (Premium Foil/Braid) XTRA GUARD two twisted pair shielded cable from Mouser Electronics before the price doubled earlier this year. We also believe that a good lower priced alternative is probably Belden's 5541P1WATERBLOCK direct burial cable. On the other hand we ran for months on a surplus four conductor shielded cable (an eBay buy, $9 for a new old stock reel). Also, we have had reports of other systems that run acceptably well with unshielded cable, although I would recommend using a cable with at least an outer shield were possible.

Both the clockwise and counter-clockwise windings are brought back to the FDM magnetometer electronics independently. When available, use one twisted pair for each coil. There are no connections between the coils at the counter-wound sensor coil pair. Also, when available, a cable shield remains open at the outdoor sensor coil side. If additional shielding braids or foils (generally not needed) are used to cover the connector or short wires into the sensor coil enclosure, those too should be electrically coupled to the main shield, but still generally left floating from local earth ground. The coils are *not* wired as a center-tapped pair at the sensor stand. As discussed in our switch control board article, each measurement cycle, the SWCTRL board automatically reconfigures the counter-wound sensor coil pair between isolated coils and the center-tapped configuration.

EARTH GROUND

We recommend a single point Earth ground for the FDM Magnetometer instrument at the common of the analog power source. Both of the SWCTRL and NBLNA boxes are connected to this common ground via a single pad at one of the PCB mounting holes. The USB 6008 is not connected to the single point common, but finds Earth ground via the computer ground. The common terminal of the polarization power supply (output voltage) is connected to the USB 6008 ground, and not to the analog common. The polarization power supply itself (but, not the DC output terminals) is grounded in the conventional way by its three terminal AC line cord. Generally, no Earth ground is used at the wood sensor stand.[6]



[1] Husky 18 gallon True Tie compactor bags from Home Depot (also useful for covering 19" rack mount instruments in storage. The plastic bag also helps to protect the cable connector.

[2] My understanding is that maximum precession signal from a solenoid can be had when the coil side (i.e. the polarization field) is normal to the local total field vector (the "F vector"). You can picture a plane perpendicular or normal to the vector. Any rotation of the coil within that plane should give a maximum precession signal (all other factors working properly). I prefer the coil's longitudinal (long) axis pointed N-S and tilted up by (90 degrees minus the local inclination angle) because it helps experimenters to visualize, as well as to explain to visitors, the direction of the Earth's total magnetic F vector, the direction of the total magnetic field (including the concept of inclination or "dip angle"). However, as you picture the plane, you can see that as the coil rotates in the plane to E-W for the long axis, it is now flat (picture the plane going through a table top). Also, since the coil is cylindrically symmetric, probably once it is E-W (longitudinal axis), you can now lay both coils down on a flat surface (e.g. a flat table top), for in that special case, any parallel plane probably also gives a maximum precession signal response.

[3] We used Miniwax® Polyshades stain and polyurethane, classic oak 470. It seems to last about one year in our relatively harsh upstate, NY winters. It might be best to allow some newly treated woods to dry for some time before painting them.

[4] Note that "Turning over" a same direction wound coil does NOT yield a counter-wound coil. It was some time before I realized this myself.

[5] We used the WEATHER PACK WEATHERTIGHT 6 PIN WEATHERPACK KIT connector kit from eBay seller perfplusconnection (e.g. http://cgi.ebay.com/ebaymotors/ws/eBayISAPI.dll?ViewItem&item=230380978017) and Pico dielectric grease to further waterproof the connection from Summit Racing (http://www.summitracing.com/parts/PCO-0099PT).

[6] Generally, no earth grounding is needed at a wood sensor stand. However, if there is any possibility for life threatening electrical potentials and/or currents at your individual sensor stand, than a local earth ground is required for safety reasons, at least when working at the stand. Also, wear safety glasses and observe good electrical grounding practice for any mains operated power tools while assembling the stand and coil pair. In other words, ***individual experimenters are solely responsible for their own safety*** and we (GELLER (Geller Labs) are not in any way responsible for or liable for any injuries incurred while performing this FDM magnetometer experiment. Please do not use our plans or kits if you do not agree to accept full responsibility for your own personal safety.