The 24:548 VLF Input Transformer

Evans Paschal, August 3, 2022

Modified by Ryan Dick, March 17, 2023. Adjustments to the original document were made in AVIDs experience winding the transformers, specifically what worked and some modifications to the construction. All measuring parameters and techniques, as well as diagrams are from [1]. Essentially, this document is a copy of [1], with the construction section being slightly modified. Initial transformer theory and design considerations are from [2].

This transformer is used to match a 1-ohm/1-millihenry loop antenna to a low-impedance preamplifier to receive signals from 300 Hz to 50 kHz. It has a 24-turn primary winding, an intermediate electrostatic shield, and a 548-turn secondary winding on a plastic bobbin inside a ferrite pot core.

Parts from Magnetics, Inc.

- 1 each 0W-43622-UG Ferrite pot core set, 2 halves
- 1 each B3622-01 Single-section bobbin
- 1 each C3622-17 Clamp

Additional Parts:

- Belden 8056 #32 AWG insulated magnet wire
- Belden 8049 #18 AWG insulated magnet wire
- 0.002 Gauge Brass Shimstock
- GC Electronics Red Insulating Varnish (10-9002-A) *Toxic

Note that all wires in the transformer must be insulated, not bare copper, otherwise the signal will short between wires.
In addition, neatness of the winding is necessary, otherwise not all the wire will fit in the bobbin. It is necessary to have a jig to wind the wire and count the wind at the same time.

Construction:

1. Put the bobbin on the turning rig such that the bobbin will not spin while turning. Getting the number of turns right is crucial. Our rig is shown on page (#), where the nuts are tightened down so that the bobbin and supporting rubber stops do not move on the turning rig.

2. Wind the secondary first. Starting at the bottom of the bobbin, hook the wire around the notch in the bobbin and tape the wire outside to hold it down so the wire doesn't slip during winding. Wind on 274 turns of #32 AWG wire, winding in layers from the bottom to the top, back to the bottom, up to the top until you reach 274 turns. With neat, tight turns, this should take a little less than 5 layers so that you end near the top of the bobbin. Pull out 2 to 3 inches of wire to form the secondary tap loop, and tape it through the slit at the top. Continue winding the other 274 turns in about 5 layers, ending at the bottom of the bobbin. This end will be the finish of the secondary.

Use tape or some marking to distinguish between the start and end of the secondary. It should also be clear that the start of the secondary, loop, and end of the secondary will all be on the same side of the bobbin (see page # if this is unclear).

3. Cover the secondary in a single layer of masking tape, making the ends slightly overlap. You may need to cut the tape so it is thin enough to fit in the bobbin without riding up on the sides to keep the bobbin from expanding.

4. We will use brass shimstock as an electrostatic shield. Cut the electrostatic shield so that it fits neatly into the bobbin. This should be done by cutting 0.45" wide strips from the short side of the brass shimstock using a foot shear or something equivalent. This ensures that the strip will be straight and fit into the bobbin. Depending on the length of the short side of the brass shimstock, each cut strip should be long enough for two transformers.

5. The length of the shield should be such that there should be a small gap between the ends of the shield when wound around the bobbin, so it does not form a shorted turn in the transformer. Solder the drain wire onto the shield. Install the electrostatic shield with the drain wire coming out the opposite side of the bottom of the bobbin from the start of the secondary winding. Mark places to cut clearance notches, cut them, and then re-install the shield. Cover the shield with a single layer of masking tape.

6. At this point an adjustment is made before winding the primary. Take the bobbin off the rig and install a large metal washer on each side of the bobbin, as seen on page (#). This ensures that the bobbin does not warp while winding the primary. A warped bobbin will push the pot core halves outward and result in unacceptable transformer measurements.

7. The primary is wound in bifilar, meaning two wires at once, using #18 AWG wire. Start this process by winding one #18 AWG wire around the bobbin 12 times, leaving about 5 inches on each end of the winding. Then, use this wire to measure another equally long wire from the spool, such that you have two equally long #18 AWG wires to wind around the transformer. Make the wire longer than necessary to ensure that the wires are not too short after winding. Mark both ends of one wire before winding, which will be relevant in step 10. When winding, start at the bottom of the bobbin on the same end as the drain wire from the shield. It helps to make a 90 turn and taping the ends down before winding. Wind 5 turns in one layer, 5 on the next, and 2 on the final, ending at the top of the bobbin and totaling 12 turns of each wire (24 total). Cover the outer winding with two or three layers of tape.

8. Assemble the pot core halves around the bobbin and hold in place with the clamp. Be sure there is no dirt on the mating surface of the cores as they must touch completely to complete the magnetic circuit. Use Kimtech wipes and isopropyl alcohol or some other means to ensure there

is no dirt. The core halves must be aligned correctly as well. If possible, construct a metal rod that is the same width as the center hole in the pot core to ensure the pot cores are aligned correctly.

9. Scrape or solder the insulation off the ends of the primary and secondary windings. Solder some insulation off the tip of the loop on the secondary. Solder the marked end of the primary on the top of the bobbin with the start of the unmarked end of the primary on the bottom. This will function as the primary center tap and will join both wires to give 24 turns of primary winding.

10. Measure the primary inductance and secondary inductance as detailed on page 4. If either are outside the accepted range, it means the pot core halves are not aligned properly, or there is dirt between them. Adjust the pot core halves until the primary and secondary inductances are in the accepted range.

11. Dab GC Electronics Red Insulating Varnish (10-9002-A) through the openings in the core to protect the windings and cement the bobbin in place. As noted above, this varnish releases toxic vapors and should not be touched, inhaled, or get into eyes. Use eye protection, a respirator rated 5500 or above, and allow to dry under a fume hood for at least 24 hours. A full safety data sheet is supplied from the distributor with the purchase of the varnish.

12. Measure the electrical parameters of the transformers as detailed on pages 4 and 5.

Measuring the transformer parameters:

1. Primary Inductance Lp: Measure the inductance Lp and Q of the primary winding from start to finish (the two bifilar windings in series) with the secondary open-circuited. This measurement should be made at 100 Hz, well below the resonant frequency of the secondary winding (around 5 kHz). I use an Agilent U1732A LCR meter for all the inductance measurements. The nominal inductance is 24.4 mH, but measurements may range from 19 to 27 mH. Q is typically 15 to over 30 at 100 Hz. The inductance will vary depending on the particular ferrite pot core used and also the ferrite temperature. However, values much less than 19 mH may indicate incomplete contact between the two pot core halves. It's important to ensure the two halves of the pot core are clean and mate smoothly during assembly.

2. Secondary Inductance Ls: Measure the inductance Ls and Q of the secondary winding from start to finish. Again, this measurement should be made at 100 Hz. Nominal Ls is 11.6 H, but typical values for inductance range from 8 to 13 H. Q is typically 33 to 45. A low Q may indicate a turn-to-turn short in the winding.

3. Ratio of Ls to Lp: Since the inductance of the windings is proportional to the square of the number of turns, the square root of (Ls/Lp) should equal the turns ratio, 548/23 or 22.8. In practice, the actual ratio is around 21.5 to 22.2, mostly due to errors measuring Ls because of distributed capacitance. A ratio outside this range may indicate a error in counting turns during winding.

4. Secondary Resistance: Using a multimeter capable of reading resistance down to tenths of an ohm, measure the resistance Rs of the secondary winding. It will be necessary to measure and subtract the meter lead resistance from your measurements. Typical values range from 18.3 to 19.0 ohms. The resistance will vary somewhat depending on the particular batch of wire used in the secondary. The primary resistance is too low to be reliably measured.

5. Leakage Inductance L2: Measure the leakage inductance as seen at the secondary, L2. To do this, short the primary winding by clamping the start and finish leads together and measure the inductance and Q at the secondary at 10 kHz. Typical values range from 3.6 to 4.2 mH, with Qs from 3.3 to 4.0. The leakage inductance represents that flux generated by the primary winding that does not get coupled into the secondary and is due to the unavoidable gap between the two windings. It affects high-frequency performance and should be kept as low as possible. The Q of this measurement depends a lot on how low the resistance of the short between the primary leads is.

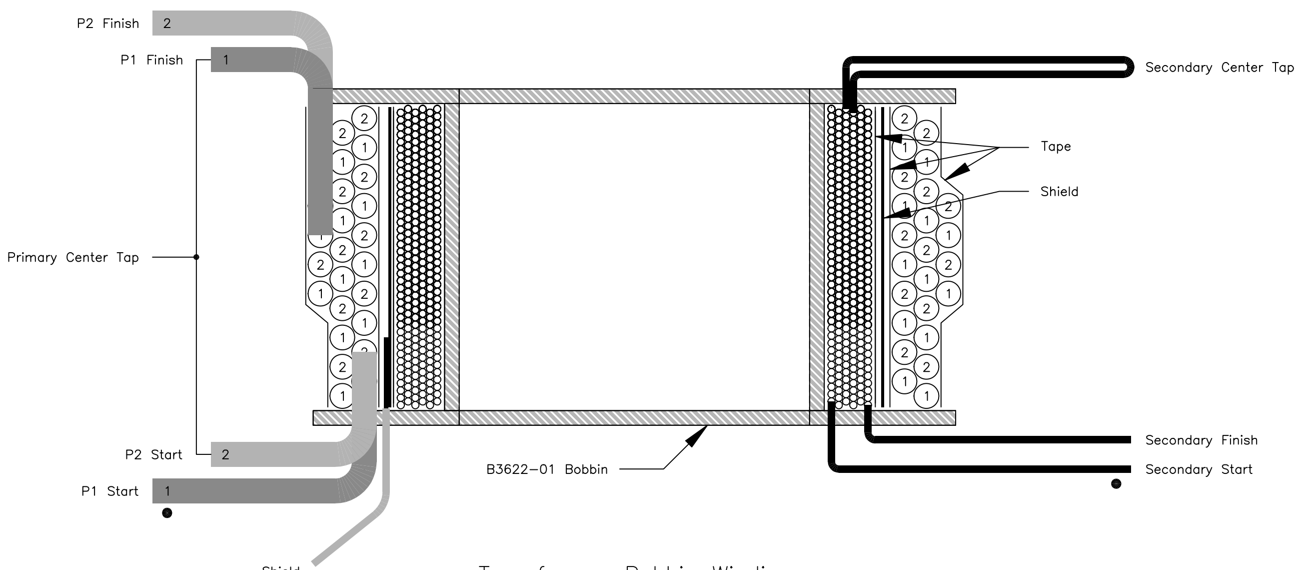
6. Secondary Resonant Frequency fs: This measurement is made in order to calculate the distributed capacitance of the secondary. For this test, connect an audio oscillator to the secondary winding (primary open-circuited) through a 1 Megohm resistor. Monitor the output of the oscillator and the voltage across the secondary winding with two low-capacitance probes (i.e., 10x probes) on a dual-channel oscilloscope, one probe from each side of the resistor to ground. Apply a signal of about 1 volt and sweep the oscillator to find the resonant frequency of the secondary. At resonance, the secondary will present a very high impedance and there will be little voltage drop across the 1 M resistor. The signals measured by the oscilloscope will be nearly equal and in phase. Typical resonant frequencies are from 4.8 to 5.6 kHz.

7. Secondary Shunt Capacitance C2: Calculate the secondary equivalent shunt capacitance from Ls and fs measured above, as C2 = 1/(Ls*(2 pi fs)^2). Typical values are from 80 to 110 pF.

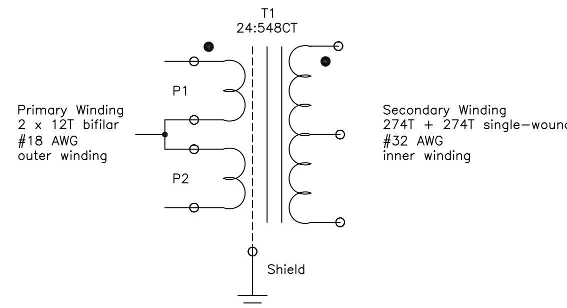
Citations:

[1]

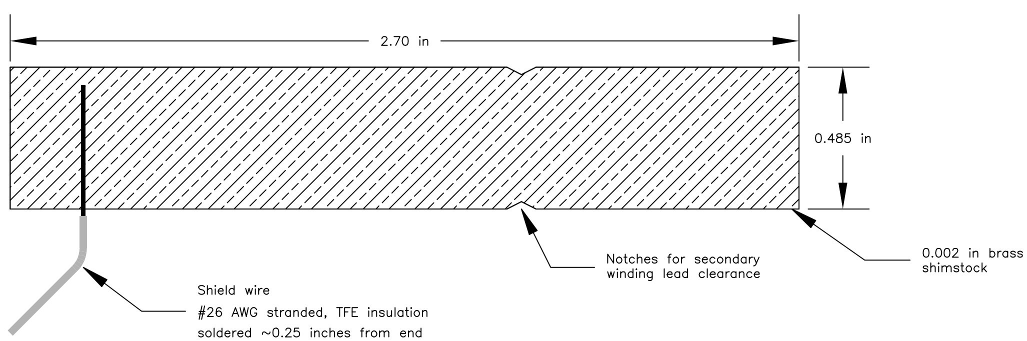
[2] E. W. Paschal, “The design of broad-band VLF receivers with air-core loop antennas,” STARLab, Stanford Univ., Stanford, CA, 1980. Tech. Rep.



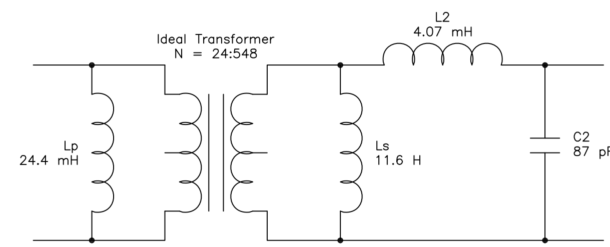
Transformer Bobbin Winding



Magnetics, Inc. components:
0W-43622-UG pot core set
B3622-01 single-section bobbin
C3622-17 clamp



Inter-winding Shield
(not to scale)



Equivalent Circuit

VLF Preamp 24:548CT Input Transformer	
E. Paschal	9/20/13
WHISTLER RADIO SERVICES	


NZ-1 HAND SHAKE ELECTRIC WIND THREAD MACHINE
MAXIMUM SPEED 2000 r/min
SPEED RATE 1:8
MAXIMUM NO. 99999
WARP 0.02–1.6
MADE IN CHINA
U.S. SOLID
USS-HWM01 2204032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