

# Hand Wound Transformers

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Often the DIY builder will require a special power transformer for a project that's just not available off the shelf from a local supplier. The only solution is to custom order an expensive prototype from some commercial winder or make a severe compromise by using several transformers together to obtain the required voltages. This article will describe a method of taking a new or used transformer with the required primary and VA rating and rewind the secondaries to obtain the proper voltages required for your project.

1. Obtain a sacrificial transformer with known specs. In my case it was a 120 vac primary and a 24 vac secondary @ 2 amps. Power the transformer up and measure and write down the unloaded secondary voltage. Start loading the secondary with some big power resistors until the open circuit voltage drops by 30% or as close as you can get to 30%. Use ohms law to determine how much current the load has flowing through it. Multiply the current by the loaded voltage to obtain the CORE VA. This will verify the VA rating. Make sure this VA is equal to or a little larger than VA required in your new design.
2. If all is well with your new requirements, start disassembling your sacrificial victim. Remove the mounting brackets and any other hardware. Using a xacto or carpet knife, separate the laminations that are probably coated with shellac or wax so they can be removed from the core. (try not to bend them up too much) Put the laminations aside for now. We'll clean them up and re-use them later.
3. You should now have in you hands just the coil with the primary and secondary leads still attached. Carry it with you to the refrigerator, get a beer and show your wife or girlfriend what you've been doing for the last hour. Now, return to your bench and open the beer and sip slowly.
4. Secure the primary leads out of the way by stuffing them in center core to protect them. Now, remove the outer wrappings of the core down to where the secondary leads are attached. You need to make a little sketch of what you now see before the beer kicks in. Specifically make note of where the start and finish of the coils are and how they are routed in and out of the bobbin. Also note how the leads are attached and secured to the coil. They should be soldered and covered with several layers of tape and or paper.
5. Now here's the part you need to be careful with. Locate the **'END'** of the secondary winding. This is the wire that disappears into the OUTER most part of the coil. Follow and remove any tape or paper to expose the first layer of secondary windings.
6. Start unwinding very carefully counting each full turn of wire removed. When you've unwound the first layer WRITE DOWN the total turns on THAT layer. You will need to know this later. Now, remove the next layer of paper to expose the next layer of wire. Continue unwinding that layer counting the number of turns. If you run into a center tap, write down how many turns down into the secondary it was located. Also note how it was attached and insulated from the rest of the windings. Continue unwinding until you reach the **'START'** of the secondary. Go get another beer and say Hi to the wife unless she's watching American Idol. If she is, don't bother her. She hasn't missed you anyway.

7. Now, with NIN playing in the background, let's look at our notes. Add up all the turns you've unwound. The total number of turns divided by the RATED LOADED voltage will be the "TURNS PER VOLT" (TPV) on this particular core. If there was a center tap it should have been at pretty close to one half of the number of turns into the secondary. For example, if the transformer was a 120 volt primary with a 24 volt secondary, we know the turn's ratio is:

$$\text{"Ratio} = E_p \text{ divided by } E_s\text{"}$$

This turned out to be 5:1. on my project. If the secondary current was rated at 2 amps continuous, then the current that flows through the primary with a 2 amp load is about ***Is divided by 5 or .250 amps***. There are some losses that occur due to winding resistance and the quality of the laminations that we won't go into here. This will be discussed in another paper. Back to my design I had 192 turns or 8 TPV for my core in the secondary. This means there are X 5 or approximately 960 turns in the still intact primary.

8. In my design, I needed one secondary at 160 volts at .050 amps and another one of 15 volts at 1 amp. Using the data I've collected, I know that the 15 volt winding will require:

$$8 \text{ TPV} \times 15\text{V} = 120 \text{ turns to make } 15 \text{ volts.}$$

and

$$8 \text{ TPV} \times 160\text{V} = 1280 \text{ turns to make } 160 \text{ volts. Whew!!}$$

From the RDH 4<sup>th</sup> edition wire chart and the required current for each winding, I can determine the required wire gauge required for each winding. For the 15 volt @ 1 amp winding, I can use 20 ga. wire which is rated at 1.46 amps, or I could almost use 22 ga. which is rated at .996 amps. but always use the larger and be on the safe side. For the 160 volt @ .050 amps I need the 34 ga. that's rated at .057 amps. I've included a wire chart on the next page that you can reference for your project. I decided to wind the 15 volt winding first because it's the larger gauge and will use less wire being the turn's length is shorter. Also it will provide a more even surface for the 34 ga. winding that's to follow.

### **Winding**

9. I use a small drill press clamped horizontally in a vice and the foot pedal from the wife's sewing machine to control the speed (don't tell her this). I also have attached to the pulley on the drill press, a reflective tape dot and a Banner™ photo optical sensor to count the turns of the drill press. The open collector Banner™ sensor output is connected 10K pull-up resistor with a 9 volt battery and then to an old HP frequency counter set to the "accumulate" mode. This make a great turns counter that's good up to 3000 RPM.

## Wire Chart

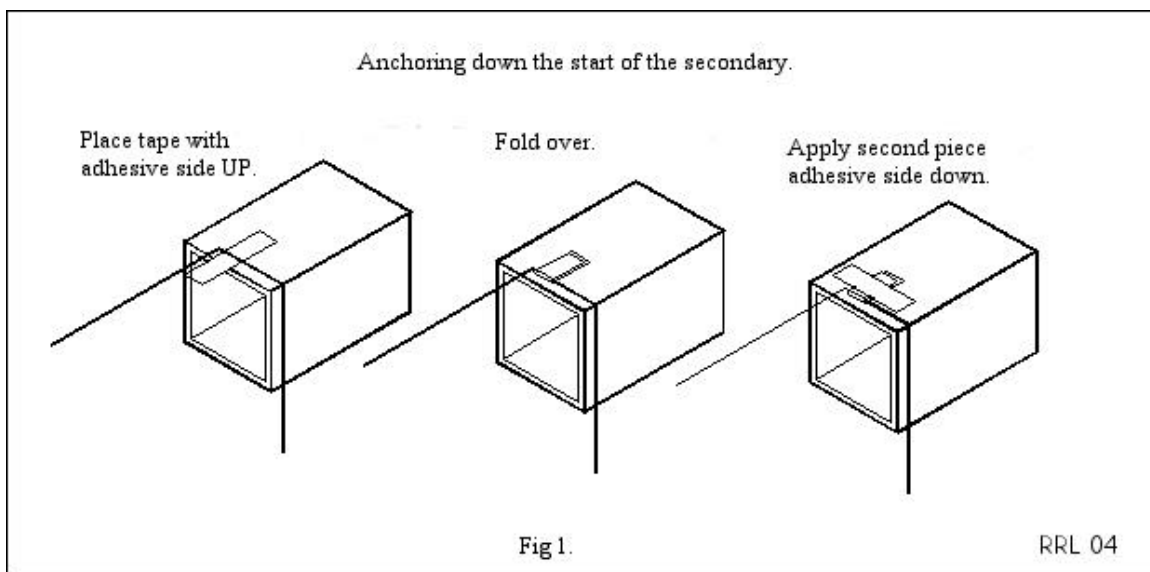
AWG	Diameter in millimeters	Turns Per Linear Inch	Current Capacity in Amps	Feet Per Spool Pound	Ohms Per 1,000 Feet
14	1.628	15	5.87	80.44	2.575
16	1.291	18.9	3.69	127.9	4.094
18	1.024	23.6	2.32	203.4	6.51
20	.812	29.4	1.46	323.4	10.35
22	.644	37	.918	514.2	16.46
24	.511	46.3	.577	817.7	26.17
26	.405	58	.363	1,300	41.62
28	.321	72.7	.228	2,067	66.17
30	.255	90.5	.144	3,287	105.2
32	.202	113	.090	5,227	167.3
34	.16	143	.057	8,310	266
36	.127	175	.036	13,210	423
38	.101	224	.022	21,010	673
40	.080	282	.014	33,410	1,070

10. I decided at this point to add an electrostatic shield between the primary and secondary on my project. This will help filter out all the RF noise and transients that are running around in the primary. I used .005 copper foil cut 1/8" smaller than the primary coil height. You must neatly solder a 12" length of 20 ga. stranded wire to the part of the foil that will be on the same side as the secondary wires exit on. Make sure the solder flows smoothly with no sharp points and wrap around the existing primary core. Trim the foil leaving about a 3/16" gap on the side the primary wires exit from. We must leave this gap to prevent creating a shorted turn in our transformer. If this gap in the electrostatic shield becomes shorted, it will become extremely hot and eventually cause a failure or worse, fire! Add several turns of Kraft paper or *Kapton*® tape (available from any motor re-winder) around the copper shield to secure it tightly. Wrap the shield with a single layer of craft paper and neatly tape in place. Route this lead out of the way for now. You should now have a smooth even surface around your core to start winding your secondary on.

11. Attached one end of the first winding to the bobbin on the opposite side of the primary leaving about 3" tucked over the edge and out of the way. See figure 1.

Starting 1/8" from the edge of the coil I wound the first few turns by hand to get every thing started off correctly.

Your turns should lay touching each other side by side as you wind. When your reach 1/8" from the end of the first layer, wrap that layer with a layer Kraft paper cut to the width of the existing coil form. Start under the last turn, and tape firmly in place as shown in figure 2a. below. Continue winding back in the opposite direction keeping your windings neat and as tight as possible. Continue winding adding Kraft paper between each layer. When all the prescribed turns have been wound for this secondary, terminate on the opposite side from the primary leads with the appropriate gauge lead wire and tape securely as in figure 2c and 2d. Wrap this completed secondary with Kraft paper as shown in figure 2e, Now, you can start the next secondary if you require one. With my next secondary being wound with small 34 ga. wire and so many turns, it won't matter so much if a few turns overlap. As long as the layer remains a smooth as possible. With this secondary now completed, terminate as you did before as shown in figure 1.



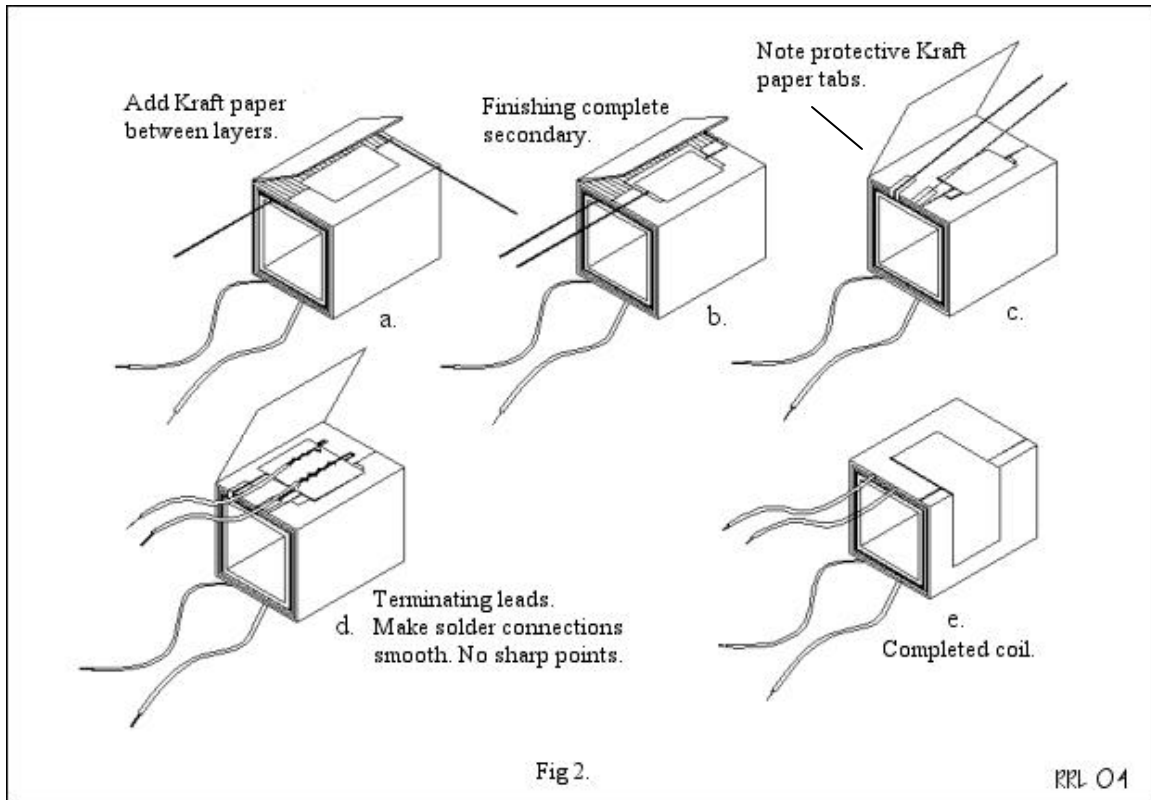
12. Again, carry the completed assembly with you to the refrigerator and get another beer. Check on the wife if she's still awake and show her what you've made. If she's asleep don't wake her just yet. She won't get it. She'll brag on you tomorrow. Now put on that new Dan Penn "Blue Light Lounge" album and lets complete this project.

13. Now comes the nasty part. The laminations need to be insulated from each other as they are assembled in the core. This is normally done using shellac and a vacuum impregnation chamber in the manufacturing process. We're going to use an alternate process. Get the laminations that were removed in your disassembly process.

Lightly buff the edges of the E and I laminations with a rotary wire brush on a bench grinder or, you can also use a rotary hand tool or sand paper.

Remove any flakes and build up of old shellac. Now, fill a "clean" small coffee can or other container with Marine shellac deep enough to completely submerge the laminations in. Using needle nose pliers, retrieve the laminations one by one and re-install them in the core from the notes you made when removing them. You did make notes didn't you? When you get to the last few laminations, you may have trouble getting them inserted.

This is because of the shellac build up in between them. You can use some small “C” clamps or vice to tighten the laminations and make the shellac ooze out wipe the edges and try to insert the rest. Don’t worry if you have a few that just won’t go back in. It won’t effect the operation at all.



14. Using a block of wood and a small hammer, Tap on the each side of the stack to get the lamination stack even and square in the core. Now for some quality control. The laminations must be very tight inside the core. If not, force some shims of wood or craft paper in the core to hold it tight. Anything loose will cause an annoying buzz and can cause IM distortion in the secondary output. Use an ohm meter to check continuity and check for shorts to the laminations and shorts from the primary to secondary. Congratulations if you’ve made it this far! You’re done! Pat yourself on the back from me. Allow the shellac to set up and dry for a few minutes while you throw away all the wire form the old transformer.(you didn’t reuse it I hope!) Also clean up all the shellac flakes from the floor. They are poisonous to animals and children if ingested.

15. Now you can do a dynamic test. Attach a line cord and plug it into a variac. Slowly bring it up while you monitor one of the secondaries with a meter. The unloaded voltage will be about 20% to 30% higher than the required specification. Check the other secondary in the same manner. Now you can wake the wife and show her what you’ve done.

### **Some things you need to remember.**

1. Rewinding your own transformer is a great way to save a lot of money and avoid buying custom transformers for special projects. This particular project was for a pre-amp that required 150 VDC for the plate and a 12 VDC regulated filament. It would be just as easy to add an additional 48 volt phantom supply winding. Also the same process can be used for high powered amps as well. Just start with the proper size core and insulation rating and determine the TPV and the required turns to get the voltages you need.
2. Make sure the sacrificial transformers VA is as large as the VA required in the new design. If it not, the laminations wont fit and it just won't work.
3. Make sure the bobbins insulation properties and the wire you're using meet your new requirements. Most transformer bobbins with 120 volt primaries are good up to 300 VAC. Make sure your wire is rated at least 150 C. What you buy from Radio Scrap is not suitable for transformers. It's ok for buzzers and RF, but find a motor rewinding shop that will work with you on supplies.
4. Don't reuse any wire removed from the old secondary. It may have minute cracks and has been stressed in the previous winding process and is just not suitable for reuse.
5. And by all means, don't use a rewound transformer in any life support or safety equipment or in an explosive environment.

#### Recommended reading:

*The Radiotron Designers Handbook, Forth Edition. Published in 1953.*

*The Audiocyclopedia Second Edition, By Howard M. Tremaine Published in 1973.*

*The Radio Handbook. Nineteenth edition, By William I Orr Published in 1972*

#### *About the author*

Ron Laury owns and operates Nash Audio, Nash Audio is a small company that specializes in custom vacuum tube pre-amps and other gear for the recording industry. Ron is also a busy engineer and producer around Nashville. You can visit his web site at <http://www.nashaudio.com> or email him at [rlaury@nashaudio.com](mailto:rlaury@nashaudio.com)