Find A Transformer's Turns, Phasing And Coupling Factor With An RLC Bridge

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During my tenure in telecom rectifier and central office power design, we had the luxury of having the production floor about 50 paces from the engineering lab. It was a real benefit for an effective, efficient operation, however production collaboration had some opposition.

We had a superior, best described as a future case study in the wrong, who frowned upon production interaction. I chose to do it anyway, seeing clear, immediate benefits. From this interaction, I learned some very important lessons. One of the most useful was on measuring transformer turns ratio, coupling, and phasing with nearly nothing for equipment.

I was releasing a transformer that was to be built in-house. I used large EE cores and needed three sets in parallel with spacers between cores to get airflow over the cores and windings. The windings were copper foil secondaries and Litz primaries. Huge interleaving, complex winding, large aspect ratio on the bobbin, huge pins and a class F insulation system—it was a monster.

I knew production feedback was coming. I walked out to the transformer winding cell and asked politely. The foreman directed me to a couple of winders. I asked how the design looked.

Boy, did I get it! Pins, tape, insulation system. "You got it all wrong!" I asked if they had the instrumentation to measure phasing. The winder laughed and said something to the effect of, "You en-guh-neers think you know it all."

I repeated the inquiry on phasing. By now the winder was mad. "No, we don't have any of that [expletive] … and we don't need it!" Yet there was something to the invective—clearly, something I didn't know. I had an obligation to figure it out.

She might as well have grabbed my ear with a pair of long nose pliers and dragged me over to the resistance-capacitance-inductance (RLC) bridge. When we got there, she maneuvered at lightning speed and added a jumper. "This winding is 6.20 mH open circuit, this winding is 1.22 mH open circuit and when I jumper them together they add or subtract. That is how I determine phase."

It was easily the coolest lesson I'd learned that year. What an amazing trick. And it's very versatile. In this article, I'll repeat that trick and show what else you can learn about a transformer with just an RLC bridge and some wire.

A Transformer For Measuring

To demonstrate, let's say we have an unknown transformer, with primaries and a secondary and nothing more than an RLC bridge (Fig. 1).

Fig. 1. We'll measure key parameters of this example transformer using this simple bridge.

First, let's measure the direct current resistance (DCR) and open-circuit inductance of the windings. In the case of a larger structure, DCR is likely below what the RLC meter can read. But, if the structure has a lot of pins and the terminations can't be seen, that tells us where the windings and respective pins are located (Fig. 2).

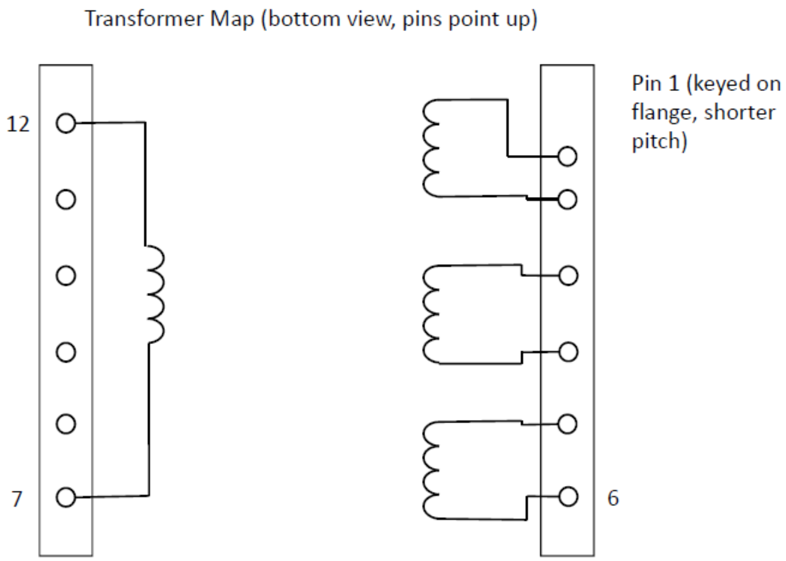

Fig. 2. Preliminary transformer schematic showing winding locations and pinout. This pinout is determined by measuring DCR across the terminals. At this point, we have not determined which windings are primary and which are secondary.

Next, we'll measure the open-circuit inductance of the windings. Assuming they are on the same core set and the structure doesn't have any magnetic shunts between the windings, this information tells the turns ratio.

Recall that inductance changes with the square of turns. If the coupling between the windings is good and they are on the same structure, we can compute turns ratio from this information. At this point we know where the windings are in terms of the pinout and what the turns ratio is, but know nothing of phase.

The inductance can also be measured into a shorted winding. The open-circuit inductance is the magnetizing inductance of the structure. The inductance that is measured with the other windings shorted is the leakage inductance of the structure.

Measurements taken on the example transformer are shown in Table 1.

Table 1. Open- and short-circuit inductances.

Winding DCR and inductances			
Pins	DCR (Ω)	L of windings, open (μH)	L of windings, open (μH)
1-2	0.3	433	17
3-4	0.4	85	2.6
5-6	0.3	433	17
7-12	0.1	42	1.2

Next, the coupling coefficient of the structure can be computed as:

$$K_{COUPLING} = \sqrt{1 - \left({}^{L_{SC}}/_{L_{OC}}\right)}$$

For phase, we add a jumper and tie the primary and secondary winding together. The inductance across the composite structure either increases (windings add in phase, they are "boosting" as a boost configured autotransformer would) or decreases (windings subtract; bucking as a buck autotransformer would). With this, phase can be assigned. Table 2 shows the results of these phase measurements for our transformer.

Table 2. Phase assignments.

Phasing (added jumper)				
RLC + lead attaches to this pin	Jumper across these pins	RLC – lead attaches to this pin	Inductance (μH)	Dot placement
1	2-6	5	1.2	First dot arbitrarily placed on pin 1
1	2-5	6	1804	Second dot placed on pin 5
1	2-7	12	671	Third dot placed on pin 7
1	2-12	7	245	
1	2-3	4	818	Fourth dot placed on pin 3
1	2-4	3	173	

For the last part, the exact numbers of turns on the structure can be computed. If we can add a few turns into the structure, again, located near the primary and secondary, perhaps threading in some thin lab wire as a temporary measurement tool, we can measure the inductance of this winding on the same structure and determine the A_L factor for the structure in μH/turns^2. With this A_L value and the open-circuit inductance of each winding, we can "back out" the turns on the winding

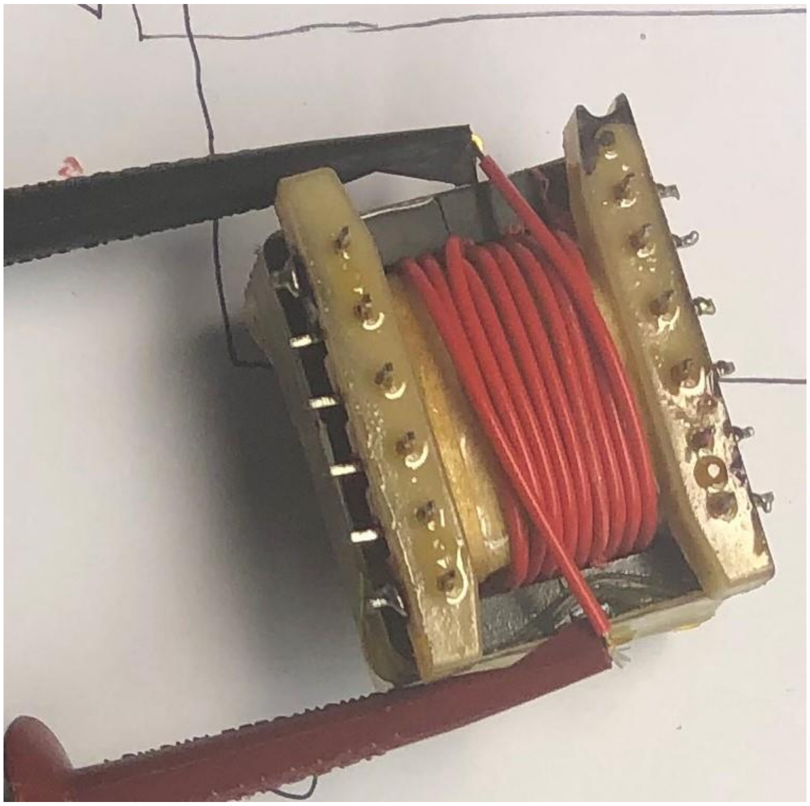

Fig. 3. Picture of the transformer with turns added.

For our example transformer, 9 turns were added and their inductance was measured at 54 µH. The turns calculations for the primary and secondary windings then proceeds as follows.

$$L\_added = A_L * N^2$$

$$54\ \mu H = 81*A_L \rightarrow A_L = 0.6667\ \mu H/turns^2$$

Knowing AL, we calculate the turns:

Primaries (pin 1-2 and pin 5-6) $A_L*N^2 = 433\ \mu H \rightarrow N = 25$ turns

Secondary (pin 7-12) $A_L*N^2 = 42\ \mu H \rightarrow N = 8$ turns

Bootstrap (pin 3-4) $A_L*N^2 = 85\ \mu H$; $N = 11$ turns

To check the work, look at the sum of the two primary windings. If the windings buck, we should have 0 turns, or a very low inductance value. If the windings boost, we should have 50 turns or roughly 4x the inductance of one primary winding on its own. Looking at the measurements in Table 2, this appears to be true.

As for the primary and secondary groupings, this was an educated guess on my part. The transformer came from an isolated dc-dc converter. Normally in a design like this, one flange is associated with the primary or hot side. The other flange is associated with the secondary or cold side. Galvanic isolation of course operates between them, usually with a hipot specification.

The converter ran from 120-Vac mains voltage with no PFC, the output was used to run a small machine and charge a small battery. The separation between primary and secondary is based on the required insulation system and temp rating, which we cannot measure in the context of this brief note. It is important to note that primary and secondary can't be arbitrarily assigned.

As we have seen, with a simple RLC bridge, a jumper wire and a few extra temporary turns, we can figure out the phasing, turns ratio, coupling coefficient and turns per each winding in an unknown transformer. A powerful lesson I completely credit to a candid coil winder.

The lesson was a fantastic one, delivered with enough grit to be nonvolatile in deep memory storage. Instead of fussing with a function generator and an oscilloscope to figure out phase, it can be done with a simple RLC bridge. I've used this technique in motors, transformers and polyphase systems. It works incredibly well and garden variety test equipment can offer insight on coupling coefficient, phasing, magnetizing and leakage inductance and turns count.

Perhaps you are working on a current-mode dc-dc converter, with our SG1846 or related PWM controller and our rad-hard MOSFETs? If so, these simple tricks might shave a little time off the transformer validation runs.

About The Author

Paul Schimel is a principal power electronics engineer in the Aerospace and Defense group at Microchip Technology. He has over 24 years of theoretical and hands-on experience in power electronics, spanning military, aerospace, automotive and industrial markets. Paul's work regularly includes module design, dc-dc converter design, device-level analysis, root cause analysis, failure analysis, EMI mitigation, PCB layout, control loop compensation, inverter design, transformer design, rotating machine design, bench-level measurement and validation techniques and system-level analysis/comprehension.

He has designed dc-dc converters from milliwatts to megavolt-amps, inverters to 5,000 HP. He is a licensed professional engineer (PE) and holds two FCC licenses (First Class Radiotelephone and extra class amateur). In addition, Paul holds three patents on power electronics matters. He can be reached at Paul.schimel@microchip.com.

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