THE TRAP Q MEASUREMENT METHOD REVISITED

By Phil Anderson, WØXI

For some dedicated crystal set enthusiasts, measuring the Q of created coils is the JAVA of the hobby, right up there with that late night cup of coffee. But like the coffee, the ritual can often bite back, with results that confound the winder or "can't be right!" Comparison of Q measurement methods abound as do comparison of Q values obtained with "similar" methods and coils. Several frustrations for me have been measurement repeatability and loading of the coil under test by the signal source, scope probes, and/or bench environment. For the last year, I've settled on using the 3-dB Bandwidth Method and carefully watching for launch coil and scope probe loading. The B&K 4017B DDS Signal Generator with digital readout, while moderately priced, has done a good job, and I love my dual-trace 150 MHz Tektronix 2445 scope, with frequency and voltage cursors. However, the 3-dB method is tedious.

Recently I evaluated several other Q measurement methods: Ring-down and trap (ref 1, 2). The ring-down method, used in many commercial and scientific applications requires a high generator output, is tedious, but works. IMHO, the trap method is by far the easiest to use, is accurate and inexpensive – within the reach of most of us budget-wise. *While not as well known as the 3-dB Bandwidth Method, it should become popular as crystal radio enthusiasts find out how easy and convenient it is to use.* A brief description of the equipment required, the method, procedure used, and my recent measurements are outlined below.

You'll need a stable generator with known frequency or frequency readout, a do-it-yourself jig – to hold the coil and tuning cap, a step attenuator - see the 8-step kit offered by the Society - and a scope or sensitive voltmeter. Measurements can be made at one frequency – no need to measure 3 dB above and below resonance. An inexpensive generator or crystal oscillator with a 10 volt output and 50 ohms of impedance can be used; here you may need a pad and low-pass filter to eliminate any harmonic content.

The Trap Q Measurement System

With RF circuits, the term trap implies the use of a resonant circuit. The system description that follows, outlined in Figure 1, assumes that the unit under test includes L1 – with its internal resistance – and C1 in series, attached at one end to ground, and placed in a jig with input and output BNCs. The generator drives the jig which in turn is attached to a step attenuator. While the schematic shows only one pi-network resistive pad, the usual system uses a set of 8, within one attenuator package. The output of the pad, in turn, is terminated with a 50 ohm resistor and hi-impedance meter or scope input.

The measurement idea is simple: use the circuit to measure the coil series resistance at resonance and calculate coil Q knowing the resonant frequency, coil inductance, and coil resistance. Several assumptions are made: the capacitor loss is low or disregarded, the generator and load resistances are the same - with 50 ohms the usual choice, and the generator produces a clean signal, without harmonics. If L1,C1 is tuned to resonance, i.e. is resistive, the ratio of output voltage with L1,C1 connected to the output voltage with L1,C1 disconnected is easily calculated or measured. I used LTspice, a circuit simulation program by Linear Technology to check out the full system. Let's refer to the reduced system in Figure 1 to demonstration making a measurement. Pictures and results follow, showing the system I actually built, including the society 8-step attenuator. A derivation of the Q formula is included in the appendix.

Figure 1: Trap Q Measurement System

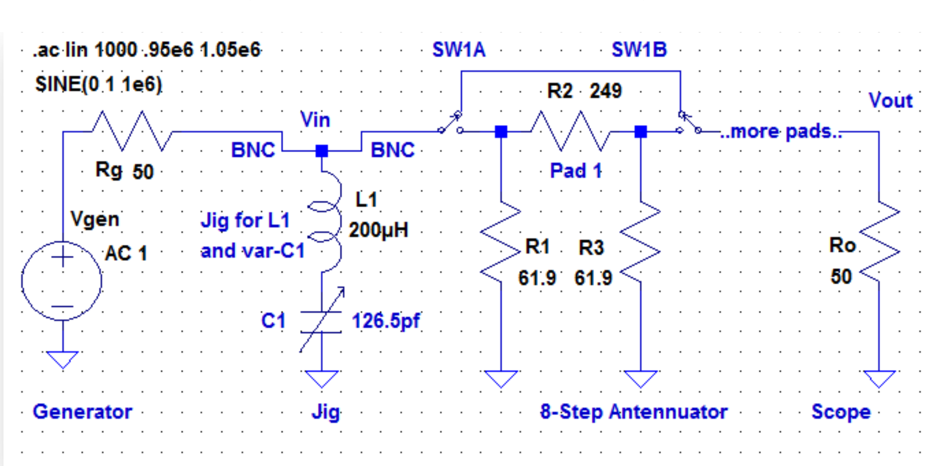
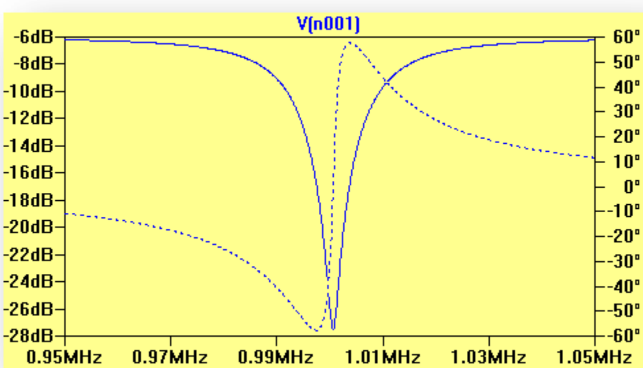


Figure 2: Simulation of Trap Q System



1. The generator is set for 1 volt at 1 MHz. The pad switches are pushed up to bypass the pads. With L1,C1 tuned much higher or lower than 1 MHz or with the them switched out of the circuit, the voltage at Vout will be ½, or -6 dB, as noted in the simulation output, Figure 2.
2. C1 is then tuned to trap the signal, i.e. resonate at the generator frequency. Note in Figure 2 that the output drops to -28 dB, or -22 dB below that in step 1. At this point, you should note the frequency and the dB or voltage level.

3. The coil and cap are then removed from the circuit and the voltage goes back up to -6 dB or ½ the generator open circuit voltage.
4. A combination of pads are then toggled in (assuming an 8-step attenuator) until the output level matches that achieved with the trap in line, i.e., -28 dB. The total reduction in voltage the attenuator should provide is -22 dB.
5. Coil Q is then calculated using the Q formula knowing the step attenuation (α), frequency, and inductance. If the inductance is not known, the cap is measured with a meter in order to calculate the inductance.

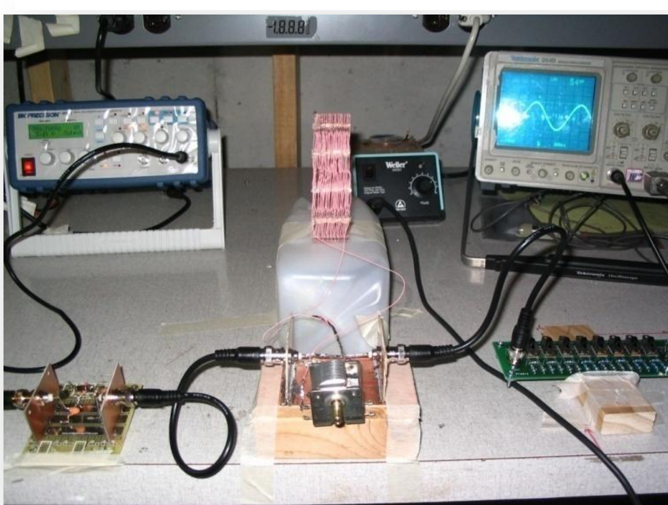
$$Q_u = \frac{4\pi fL}{50}(10^{-xdB/20dB} - 1). \tag{1.1}$$

Let’s say the pads totaled -22 dB, L1 = 2 00 uH, C1 = 126.5 pf, and f is 1 MHz. Qu would then be 545.

My Bench Arrangement

My Trap Q Measurement System in shown in Figure 3. The B&K Generator is at upper left and is cabled to a second jig, consisting of a low-pass filter and -6 dB pad. That, in turn, is cabled to the system jig, with a basket-weave coil and capacitor in series, mounted on an HDPE milk carton. The jig is connected to the XS-SA8 8-step attenuator, which in turn is tied to the Tekronix scope (with 50 ohm load at input).

Figure 3: Implementation of Q Measurement System



Why the low-pass filter following the generator? I noticed that the scope signal after step 2, when L1,C1 was resonated, was closer in shape to a triangle wave than a sine wave, indicating my inexpensive generator was contributing some 3rd-harmonic energy. The filter added and depicted in Figure 4A, with its frequency plot in Figure 4B, restored the 1 MHz signal to a sine wave. I added the pad to, hopefully, make sure the trap was seeing 50 ohms. The physical circuit is shown at bottom left of Figure 3, cobbled up with junk box parts and a couple of new shinny BNC connectors. L1 & L2 are molded chokes from Mouser.

Figure 4A: Low-Pass Filter and 6 dB Pad

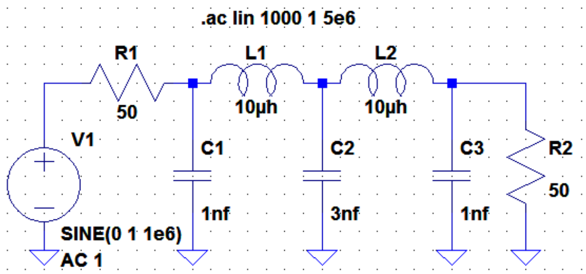


Figure 4B: Frequency Sweep of the Filter

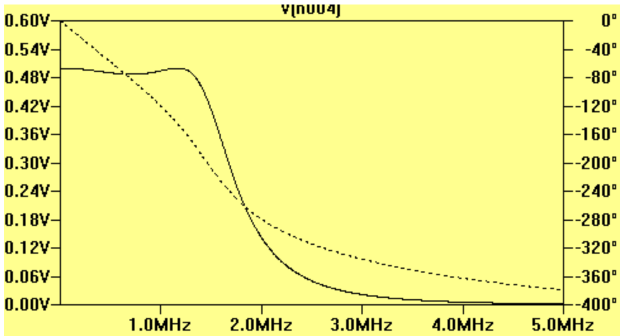
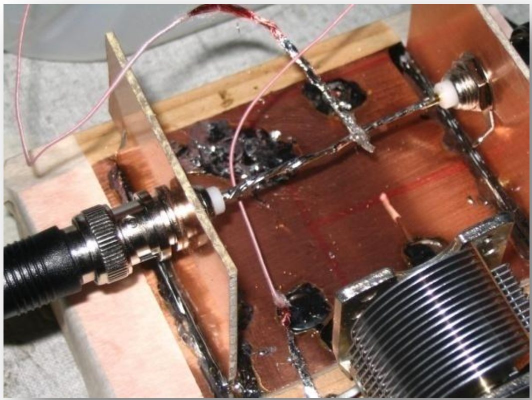


Figure 5: Close-up of System Jig



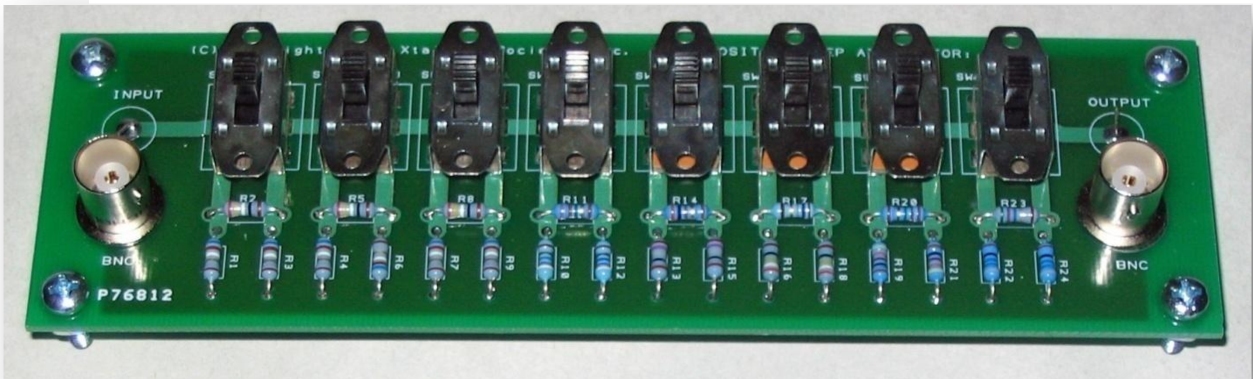
System Jig

The system jig is shown in Figure 5. I modeled this after Wes's (ref 3). The Litz wire, shown soldered to the feed-through between the two BNCs, goes to the top of the coil. The bottom lead of the coil goes to whatever cap is used to resonate the coil. The rotor or fixed lead of the cap goes to ground.

The XSS-SA8 8-Step Attenuator Kit

The step attenuator kit is shown in Figure 6. It provides 20, 20, 20, 10, 5, 3, 2, and 1 dB pads. All resistors are ¼-W, 1%, metal film. See the society website for details.

Figure 6: XSS-SA8, An 8-Step Attenuator Kit



As mentioned in the introduction, I found the Trap Q Measurement Method easy to use and pretty much insensitive to hand-waving and grounding. While resonating the coil and observing the scope signal change, I could see the signal change as I waved my hand within a few inches of the coil. There was no observable effect at 6 inches. I measured the 4.2 inch diameter, 1.0 inch length, 39 turn coil, wound with 150/46 Litz wire, and shown in Figure 3, obtaining a Q of 545. This compared closely with Wes's basket-weave coil (ref 3) and other coils I measured of similar size/makeup with my 3-dB system.

Perhaps my next experiment shall be to place a parallel resonant circuit in the jig, capacitive-coupled at input and output, to see if this equipment arrangement might be used for ring-down measurements too, since the generator signal will provide a high voltage in and out.

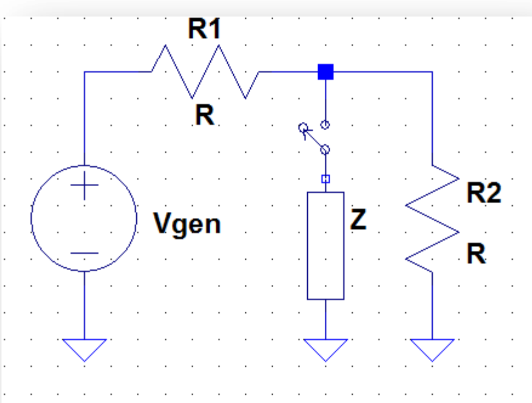
Appendix

Derivation of an Inductor Q Formula Using the Trap Measurement Method

Call me crazy if you like; but, I enjoy – and are maybe driven to - deriving the equations I use. A plus is that the process often produces additional insights into how a system or circuit works.

The circuit in Figure 7 can be used to assist us in deriving the Q formula. Several Assumptions are made: Z is an RLC series circuit, the tuning capacitor is lossless, and the generator is free of any harmonics. Tuning Z to resonance reduces it to a resistor, representing the loss of the coil. The unloaded Q can then be calculated knowing its coil resistance, inductance, and the resonant frequency of the test arrangement.

Figure 7: Insertion Loss due to Z



When Z is a resistance, the ratio of output voltage with Z connected to Z disconnected is easily calculated.

With the switch open, the circuit is a simple voltage divider and

(1.2) $$V_{out} = \frac{1}{2} V_{gen.}$$

With the switch closed, Z connected, we have another voltage divider; and Vout (labeled V^*_{out}) is

(1.3) $$V^*_{out} = V_{gen} \frac{R \| Z}{R + R \| Z} = V_{gen} \frac{Z}{R + 2Z}.$$

Solving for the ratio of output voltage with Z connected to that with Z disconnected, call it α,

(1.4) $$\alpha = \frac{V_{out}^{*}}{V_{out}} = \frac{V_{out}^{*}}{V_{gen}}\frac{V_{gen}}{V_{out}} = \frac{Z}{R+2Z}(2).$$

Knowing the ratio and system resistance, we can find Z,

(1.5) $$Z = \frac{\alpha R}{2(1-\alpha)}.$$

For example, suppose α = 0.14 (-12 dB), R=50; hence, Z is then 4 ohms.

Finally, to find the Q of the coil, substitute the resistance found in (1.5) into the standard Q formula:

(1.6) $$Q_u = \frac{2\pi fL}{Z} = 2\pi fL\frac{2(1-\alpha)}{\alpha R} = \frac{4\pi fL}{R}(\frac{1}{\alpha}-1).$$

If a step attenuator is being used, (1.6) can be expressed as:

(1.7) $$Q_u = \frac{4\pi fL}{R}(10^{-A/20}-1),$$

where A = 20log(α), f is the frequency in MHz, and L is the inductance in uH.

We use –A in the exponent of equation 1.6 because α in a step attenuator is less than 1. The result is an exponent with positive fraction in the formula. For example, suppose the attenuator reads 12 dB (use – 12dB), f is 1 MHz, L is 200 uH, and R=50. Coil Q is then equal to 150. Or suppose the attenuator reads -22 dB; coil Q is then 582! Some authors have written formula 1.6 with A rather than –A in the exponent, and simply plug is the dB amount of the attenuator as a positive number. Results are the same.

References:

1. Richley, Ed, "The Design of Unpowered AM Receivers Using Detectors Made From Rocks," XSS Newsletter, Vol. 5, No. 1, January 1, 1995. This 3-part landmark paper is a contributing source for many of today's crystal sets. Ed introduced capacitor coupling on both sides of a single-tank set; presented a simple DIY antenna measurement bridge for the AM band; and designed a simple resonant circuit to measure coil resistance (and thereby calculate Q).
2. Hayward, Wes, et al, "Experimental Methods in RF Design," page 7.36-37, ARRL, 2003.
3. Hayward, Wes, "Experiment with Coils and Q," http://w7zoi.net/coilq.pdf
4. Anderson, Phil, "A Basket Weave Coil Construction Project," The Xtal Set Society Newsletter, September, 2008.

See these articles posted on the society website at http://www.midnightscience.com/articles-index.html

1. "Derivation of Pi-Network Pad Resistor Formulas."