The Two Faces of Q

Wes Hayward, w7zoi, November, 2010.
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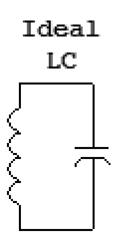
April 14, 2015. See addendum at document end.

Abstract

Most home-lab measurements of Q only evaluate an LC resonator. We then tend to associate the resulting Q with inductor loss while capacitor Q is assumed to be quite high. This assumption is now in greater doubt, especially with SMT components. In an effort to isolate capacitor Q from inductor Q, some well specified high Q mica capacitors were purchased and used in measurements. These allowed evaluation of some inductors that then become "standards" that can be used to evaluate capacitors. Several available capacitor types were investigated and some inductor Q measurements were extended.

Introduction

I've always been interested in the design of frequency selective filters and impedance transforming networks. Intimately connected to this has been a long standing interest in the measurement of Q with some of this work having appeared on this web site. This report is an update (and summary) of parts of that work.



This figure shows an ideal LC tuned circuit, or resonator. A separate document shows some of the mathematical formality.

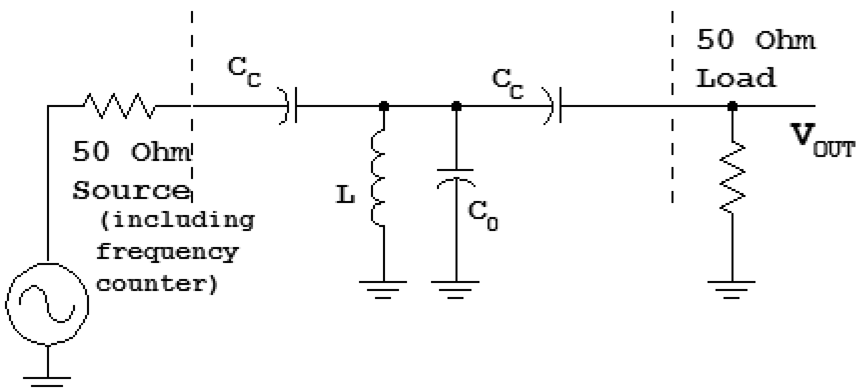
Measuring Resonator Q

Three methods for Q measurement are briefly discussed here. The details can all be derived from a simple **model** for resonator Q where all losses are represented by a single **resistor**. The resistor value is

$$R_R = \frac{\omega \cdot L}{Q_R} \quad \text{where f is frequency in Hz and} \quad \omega = 2 \cdot \pi \cdot f$$

A subscript "R" appears on both the resistor and the Q term, indicating that these are ***resonator*** related terms. For details, see **Introduction to RF Design**, ARRL, 1994, p58, or many other classic engineering text books. The three measurement methods presented are all resonator measurements and are not necessarily determinations of component Q. All analysis done in this discussion uses series resistors to model loss, but parallel resistors can also be used with no change in results.

1. The Q of a tuned circuit is equal to the center frequency divided by the 3 dB bandwidth of that resonator. This is not a definition or a rule of thumb, but is a **derived result**. This resonator characteristic can be used to measure the Q of a LC tuned circuit embedded in the following circuit:



The basic circuit to be measured is the tuned circuit built from L and C0. These components form a parallel tuned circuit and are then coupled to a 50 Ohm source and a 50 Ohm load with coupling capacitors Cc. The two capacitors should be nearly identical in value, should themselves have high Q, and should be much smaller in capacitance than C0. Typically, Cc=C0/100. The following experimental procedure is used:

a) The source is tuned to produce a maximum output response. The center frequency, **F0**, and the insertion loss is noted. The loss is just the power ***available*** from the generator to the load divided by the power delivered to the load. The ***available power*** from the generator is measured by removing the filter (the part of the circuit between the dotted lines) and replacing it with a

"through" connection, attaching the generator directly to the load.
b) The insertion loss should be 30 dB or more. If the loss is less than 30 dB, the values of Cc should be decreased and the procedure should be repeated. Remember to keep the Cc values approximately equal to each other.
c) Assuming IL> 30 dB, the exact value of IL is carefully measured and recorded. The generator is then tuned on either side of the peak to find the places where the loss is (IL+3 dB.) This requires careful experimental procedure.
d) The difference between the two 3 dB frequencies is **B,** the **bandwidth.** Once this number is determined, the bandwidth is known and the Q can be calculated as

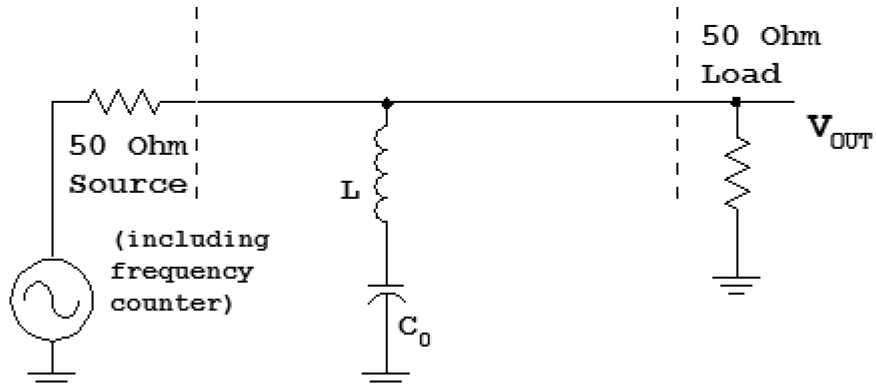
$$\mathbf{Q=F0/B}$$

The reason for picking an insertion loss of 30 dB or more is that this produces a Q number that represents the intrinsic loss in the resonator. This is called the unloaded Q, or Qu, and is the value we seek. An IL well under 30 dB would generate a lower Q value that is partially determined by tuned circuit loading by the external source and load. The loaded BW would be wider than the unloaded value. The center frequency for the composite filter will be slightly lower than the raw resonator formed by L and C0 owing to the two extra capacitors Cc.

A variation of this method uses larger values of Cc, which yield lower loss through the measurement filter. A mathematical correction is then applied to extract the unloaded Q information. It is now important to obtain a better measurement of the actual insertion loss. The information in IRFD, ARRL 1994, p58, can be used for this variation.

Some workers do a similar measurement where a source is weakly coupled to the resonator and the output is sampled with an oscilloscope and 10X probe. This method can provide reasonable results if done with great care, but can also be compromised by the loss in the scope probe. I prefer to avoid this uncertainty by using a measurement scheme where all loads are well defined.

2. A second scheme for measuring the Q of a resonator is to configure the L and C as a series tuned circuit. This series tuned circuit is then attached as a parallel connected trap as shown here.



The source generator is tuned to produce the lowest output in the load, which occurs as a narrow notch. The following procedure is used:

a) The generator is tuned to produce the notch response. The frequency is carefully noted.

b) The attenuation of this notch filter is carefully determined. This can be read directly if a network analyzer is used as the source and load. If a signal generator is used with a spectrum analyzer, power meter, or 50 Ohm terminated oscilloscope as the load, the attenuation can be obtained by removing the trap filter and inserting a step attenuator in its place. The variable attenuator, which should have 1 dB or finer steps, is adjusted to produce the same response that the filter produced. It may be necessary to interpolate to obtain resolution of about 0.1 dB for attenuation.

c) The trap is disassembled and the capacitance of C0 is measured. I usually do this with an LC meter from AADE. (See "Almost All Digital Electronics" on the web.)

d) The measured data is then used to calculate the Q. Additional detail is given on page 7.36 of EMRFD. (**Experimental Methods in RF Design**, ARRL, 2003.) The equation is

$$Q = \frac{(4 \cdot \pi \cdot F \cdot L_u)}{Z_0} \cdot \left(10^{\frac{A}{20}} - 1 \right)$$

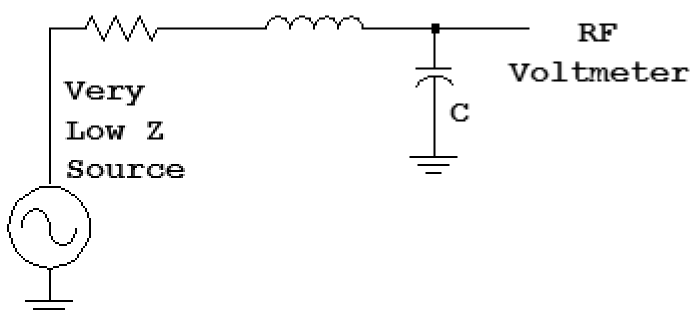
where F is in MHz, Lu is in microhenry and A is in dB.
Lu is calculated from the capacitance measurement.

It is important that the source impedance used for this measurement be well known at Z0, usually 50 Ohms. If there is uncertainty, it is best to place a pad right at the coax connector where the trap is applied. I usually use a 14 dB pad, even when using a network analyzer for the measurements. Source impedance is much more important than load impedance for this measurement.

This method has the advantage over the direct bandwidth method that only one careful level measurement is needed. This is the determination of the attenuation value. I tend to use method 2 for routine measurements, and use the bandwidth scheme (method 1) to confirm the experimental results.

A variation of this method uses a parallel tuned circuit connected as a series trap. This is not as handy, for neither component is attached to ground. It is usually handy to have C0 attached to ground.

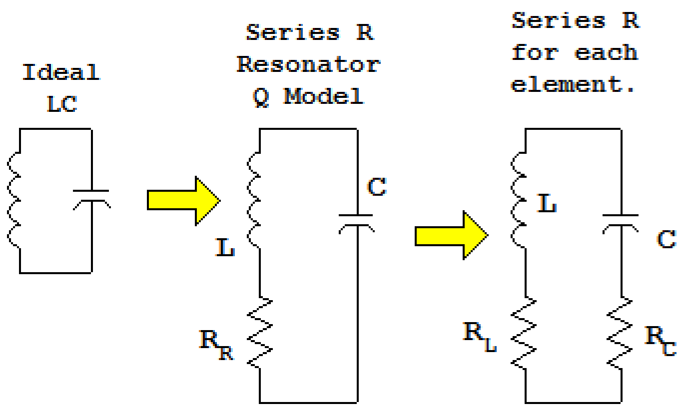
3. The fundamental circuit used in commercial Q-Meters is shown below and this is a third method.



There are two critical features to this circuit. The first is a very low source impedance. This is realized with a carefully built transformer in the instruments found on the surplus market. It may be possible to get good low Z results with modern wide bandwidth operational amplifiers. (That's an experiment on my list.) The other difficult, but important element in building a Q meter is the capacitor, C, usually a variable. The cap should have the highest possible Q. Some workers have reported good results with Jennings Vacuum Variable capacitors. If the capacitor is good enough, the measured results will faithfully describe the Q of the inductor. The manual for the HP-4342A Q Meter is often sold on the web and offers interesting reading. I believe this is the last commercially built Q meter and know of nothing on the market at the present time. Commercial Q meters have largely been replaced by network analyzers.

Modeling the Two Faces

Our home-lab measurements are all done on resonators, usually fabricated from discrete inductors and capacitors. Traditionally, we have assumed that the capacitor Q has been sufficiently high that it can be ignored, attributing all loss to the inductors. That is a reasonable viewpoint in some, but not all situations. In particular, many surface mount capacitors are sufficiently poor that they severely compromise resonator Q. We really must be able to measure both inductors and capacitors.



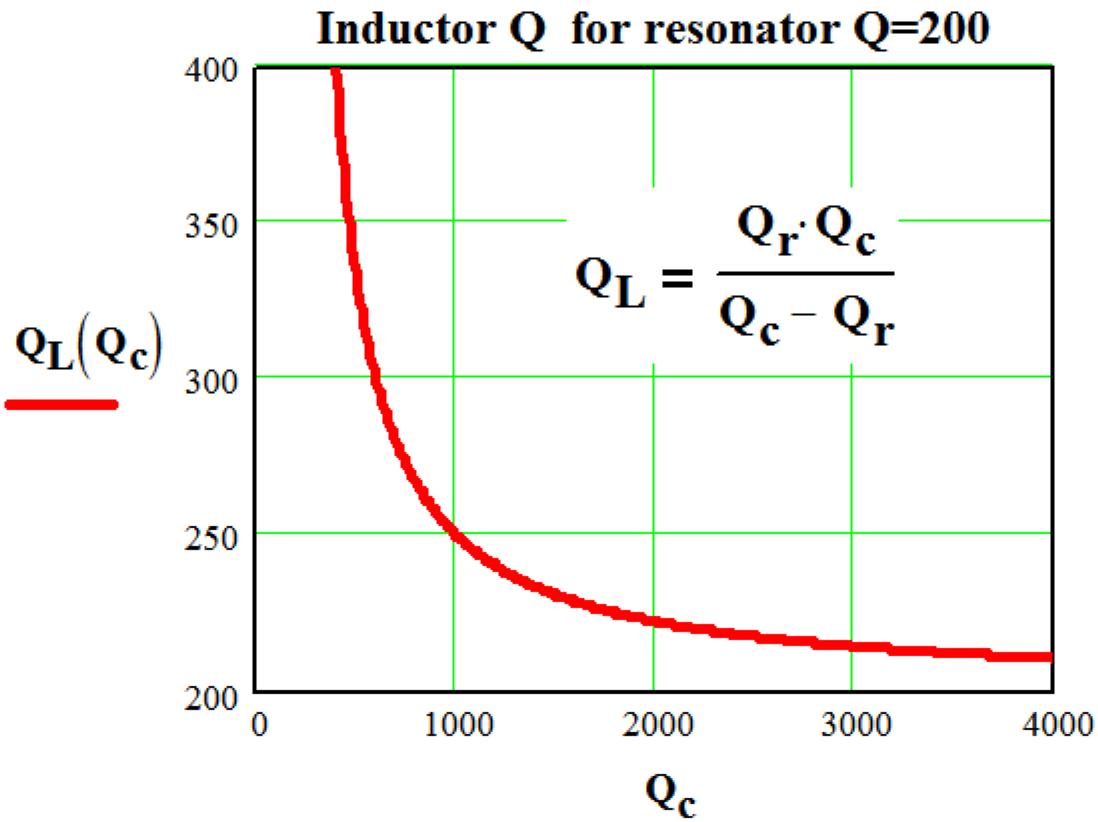
The ideal LC is modeled, as a resonator, with a single resistor, Rr. This resistance is the value that would generate the observed Q if the L and C were otherwise ideal. The resistor value is just the ratio of the inductive reactance to resonator Q, as presented in an earlier equation. The resonator resistor is drawn in series with the inductor in the above figure, but it is clearly in series with both the L and C.

The Q for the inductor and the capacitors alone is modeled with individual resistors. Again, these resistors are just the reactance of the elements divided by the Q of that element. We should emphasize that the these resistors are just models, usually frequency dependent.

The ***resonator*** R is a sum of the two component related resistors. (A mesh equation is written for the analysis.) This leads to a formula for resonator Q in terms of inductor and capacitor Q values,

$$\frac{1}{Q_R} = \frac{1}{Q_L} + \frac{1}{Q_C}$$

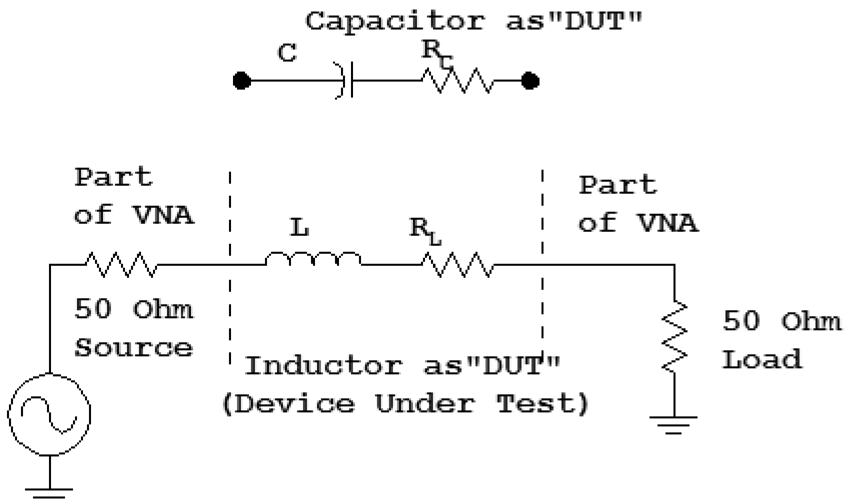
Although not immediately obvious, this equation is the familiar hyperbolic form.   The equation can be solved for inductor Q as a function of capacitor Q, treating resonator Q as a parameter.   The result is the following curve:



In this example, the resonator Q was set to 200.   Even when the capacitor Q is 10 times the resonator Q, there is still a 10% difference between inductor and resonator Q.

Direct Measurement of Inductors and Capacitors

It is, in concept, possible to measure a capacitor or inductor directly with a Vector Network Analyzer, VNA.   This is shown below



Vector Network Analyzer set for
Transmission Measurement

In this measurement, the "DUT" to be measured is placed in the signal path between the source and the load. The loss resistance of the L will alter the response at the output. In concept, measuring the magnitude and the angle of the voltage at the output will allow both L and R-L to be calculated for any applied frequency. But it is an extremely difficult measurement requiring exacting calibration of the VNA. The reactance is so large that it almost completely dominates the overall impedance. After all, this is what we desire -- we are predominantly interested in high Q inductors and/or capacitors that have low R components.

The above figure uses a transmission measurement. It is also possible to measure an L or a C attached as a load on a bridge attached to the VNA. This is termed a "reflection" measurement. The results are similar and remain equally difficult. The severe errors of this direct method are discussed in Agilent Applications note 1369-6. Much better measurements are obtained when one uses a scheme called RF I-V where a radio frequency source is applied to an unknown impedance. Then the current through the impedance and the voltage across it are both measured. The vector ratio of the values is calculated to obtain a better complex impedance value. This method is discussed in Agilent Applications Note 1369-2. (Thanks to N2PK for both references.)

An excellent reference I've found for this subject is the collected information presented on the web by Paul Kiciak, N2PK. Google "N2PK VNA" and you will immediately get to Paul's site where he describes his homebrew vector network analyzer. There is a Yahoo Group devoted to this design. The information on the Yahoo site provides links to numerous pertinent HP/Agilent documents and application notes having to do with network analysis.

Another interesting treatment of the VNA problem is the discussion by Thomas Baier, DG8SAQ. His first article appeared in QEX for March/April 2007, p46. A later, more refined instrument was described in January/February 2009 and in May/June 2009.

I've done experiments with a version of the N2PK VNA and get reasonable results for low and modest Q elements. However, the results are far from the "warm and fuzzy" ones that we would like to have, especially when measuring higher Q parts. N2PK has built his own version of the Agilent RF I-V scheme and has obtained much better data.

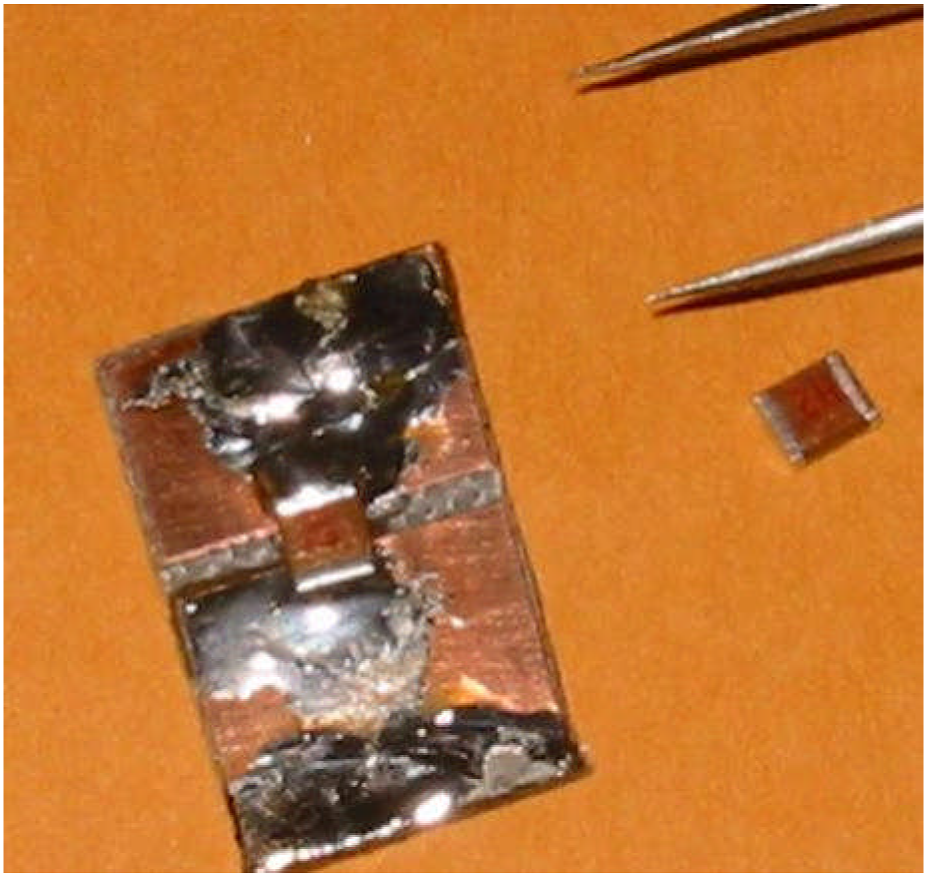
Using Capacitors with Known Q

There is an alternative to a direct measurement and that is the method we have used in this study. **Rather than trying to do the complete measurement, we merely looked for capacitors that were of moderately high Q and had well defined and published Q specifications. These capacitors would then become the basis for resonator measurements that could be extended to provide inductor results.**

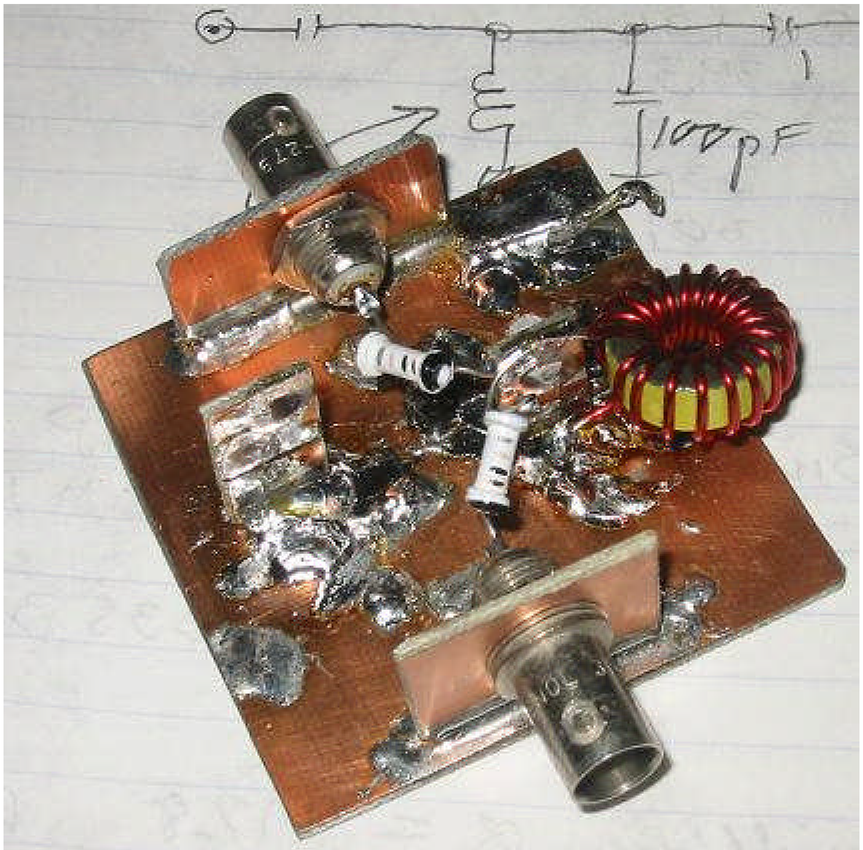
We searched the specifications in the data sheets for some readily available capacitors and found some good ones at Mouser. The parts we selected are mica capacitors manufactured by Cornell-Dubilier (CDE). These parts are in the CDE **MC** line. The data sheets can be downloaded from the Mouser web site. The MC capacitors are SMT parts, but they are physically large enough to be quite easy to handle, even for those folks uncomfortable with chip parts. The data is sparse with little more than typical curves for a few representative capacitors. However, the Q values are high enough at almost 4000 at lower frequencies. Q data is only given for a few samples, but they all seem to converge to a constant value at low frequency. Our procedure was to measure resonator Q with a selection of several of the MC mica caps, which would then give us a sampling over frequency. We used the highest Q toroid inductor we could build when doing these measurements, forcing a measurement that would emphasize capacitor Q. More data will be presented regarding the inductor. The Q data from the CDE MC data sheets, or estimates of it, were then used to characterize the inductors.

Very high quality Porcelain capacitors are also available from American

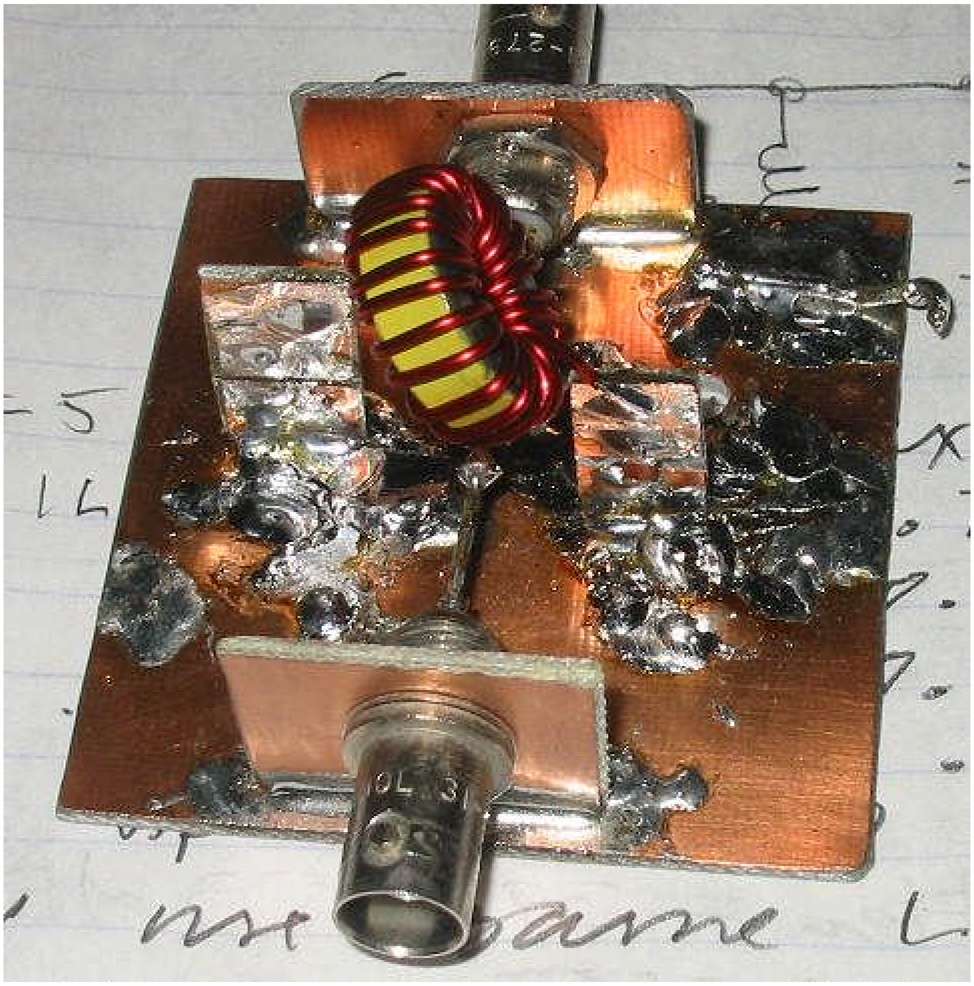
Technical Ceramics and from Johanson, both well established component vendors. See www.atceramics.com and www.johansontechnology.com on the web.



This is a close-up view of a loose CDE mica type MC capacitor and another mounted on a piece of **single sided** PC board. I used single sided board to hold these capacitors. (Later, we will present some data on the Q of circuit board.) The parts shown are 100 volt, 200 pF MC12FA201J-F. This part is kept on the small board, so it is only soldered once. When additional measurements are to be done, the original board is used.



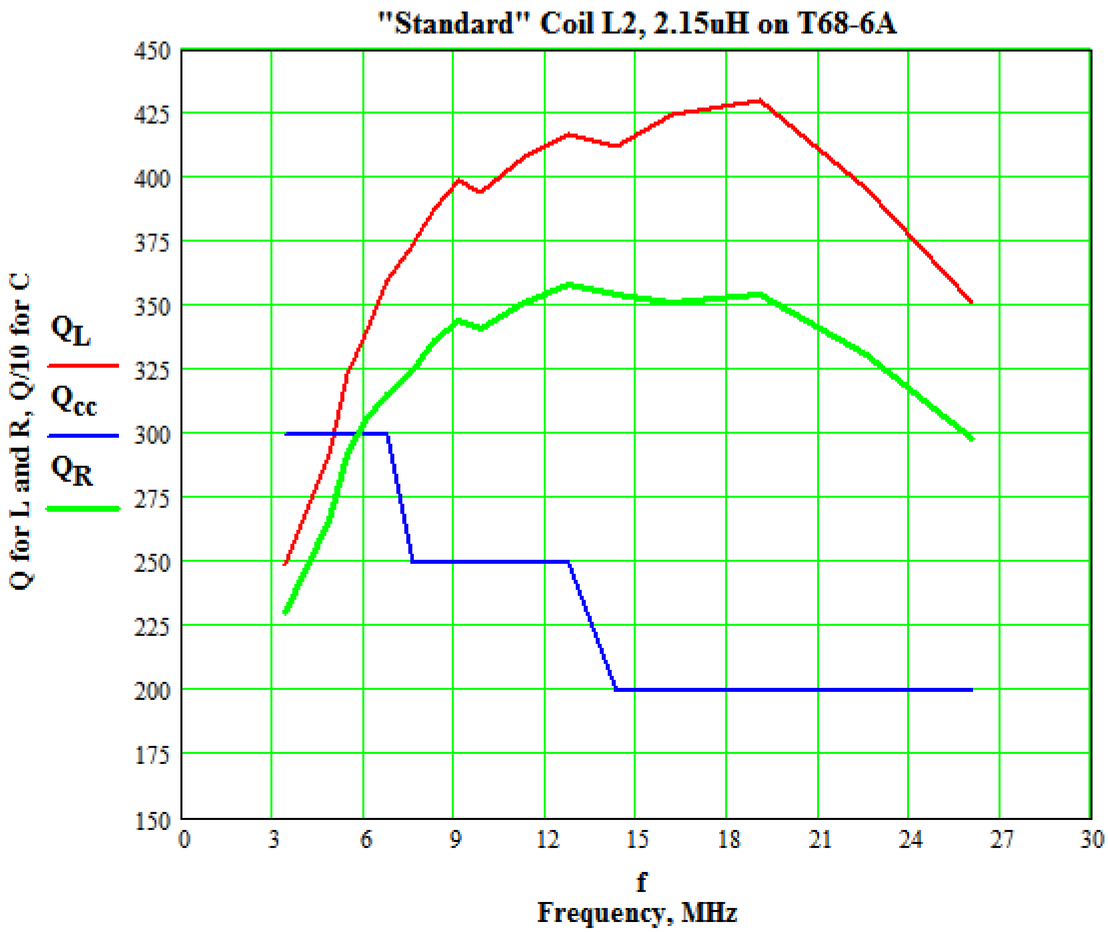
This photo shows a ***bandwidth*** test fixture using method #1 from above where the toroid is measured with a 100 pF 100 volt Mica MC capacitor. 1 pF ceramic "dog bone" capacitors couple the resonator to the outside world. The inductor is 20 turns of #18 wire on a T68-6A core. Although the T68-6 core is readily available, this "A" part is not. The "A" designator indicates a shape with a greater cross section of powdered iron material than is available from the usual T68 sized cores. This measurement yielded a Q value of 399 at 10.7 MHz, assuming a capacitor Qc of 2500. The resonator Q was 344 for this measurements.



This photo shows the same board with the same inductor and the same MC capacitor, but now configured for measurement with the trap method, scheme #2 from above. This resulted in an inductor Q of 420 at 10.8 MHz, again assuming Qc=2500. Resonator Q was 360. The two measurement methods produce nearly identical results.

Some Measurement Results

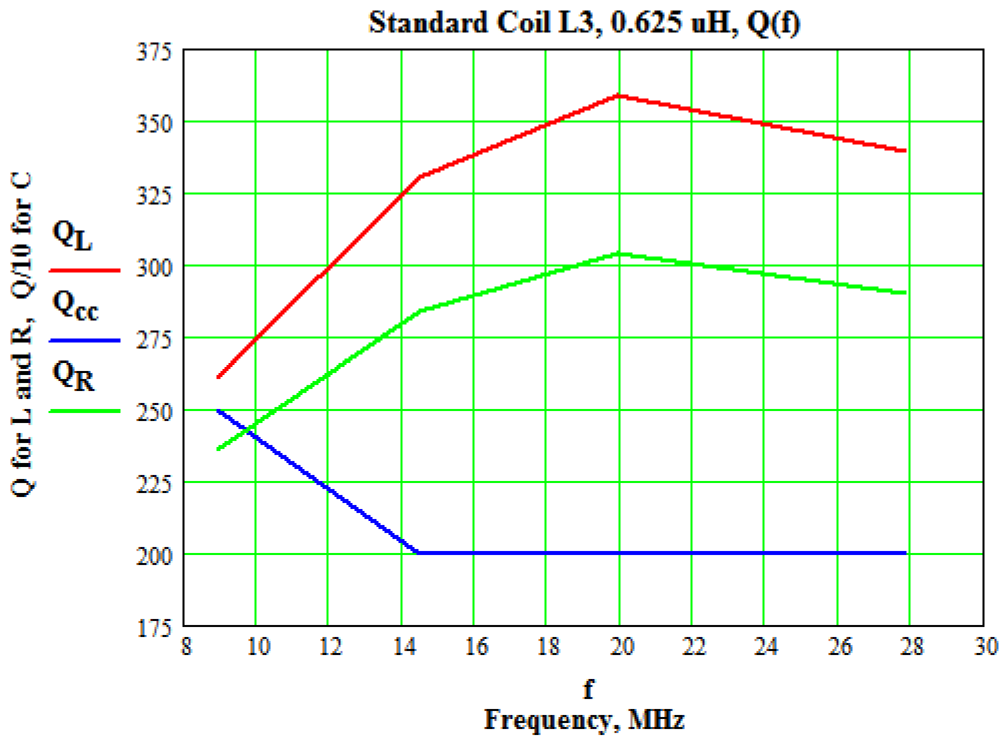
1. "Standard" inductor "L2", which is 20 turns of #18 on a T68-6A, tightly wound on the core. This was measured with the variable capacitor mentioned in item 3 below this entry. The Q of the inductor, the Q of the resonator during measurement, and the value of Qc assumed for the measurement are all plotted on the curve.



The blue trace shows the Q of the capacitor that we assumed for calculations. The Qc plot is actually of Q/10, so the actual low-frequency Q is 3000. Capacitor Q drops with increasing frequency.

This inductor was initially measured with three or four values of CDE MC fixed capacitor, providing the first points that set the inductor Q. More detail is given in item 3 below. Note that the resonator Q data above is a firm measurement that does not depend upon any assumptions. Inductor Q is then extracted from an assumed capacitor Q and the previously discussed tradeoff equation.

2. "Standard Inductor L3." This inductor also uses a T68-6A core, but has only 10 turns of #18, evenly spaced along the core. The Q is not as high as with "L2," but the smaller inductance allows operation to higher frequency.



The blue trace shows the Q of the capacitor that we assumed for calculations. The Qc plot is actually of Q/10, so the low frequency Q is 2000.

3. Variable Capacitor.

The initial experiments with the CDE MC capacitors used values of 100, 200, and 470 pF with two different inductors. The inductor Q for our L2 "standard" (20 t #18 on T68-6A) was 353 at 5 MHz as determined with a 470 pF MC capacitor with an assumed Qc value of 3600. Having a few measurements with this and the other MC capacitors provided a base for the inductors over a modest frequency range. This was used to measure the Q of the variable capacitor that was the base element in our Q measurement test fixture. This capacitor, which I think was manufactured in the UK by Jackson Brothers, is a dual section variable with almost 500 pF capacitance per section. We had determined it to be about the best variable in our junk box in early Q experiments a few years ago. The present results indicated the following capacitor Q values:

6 MHz Qc=2855
8 MHz Qc=2423
11 MHz Qc=2801

Based upon this data, the default capacitor Q in the program shown above has been set at 2500. The capacitor Q can be edited by the program user.

4. Porcelain Capacitors.
My junk box included a capacitor kit with a large variety of capacitors made by Tansitor. These were very expensive capacitors, even in their day and are no longer available. A 200 pF unit was tested with the previously mentioned standard inductor (20t #18, T68-6A). Assuming a 7 MHz inductor Q of 400 with a measured resonator Q of 363 yielded a capacitor Q of 3900. Several other measurements were done with capacitors from this kit, all producing values of several thousand. When the capacitor Q values become this high, the measurements become more difficult. Some of the other capacitors from this kit were used to fill in gaps and to extend the measurements.

5. Leaded Silver Mica
A 190 pF SM capacitor from the junk box was determined to have Qc=1600 pF at 7.85 MHz. This is not as good as the variable or the MC capacitor, but is good enough for many communications applications.

6. Leaded 100 pF Ceramic Capacitors.
I was able to put my hands on quite a variety of ceramic capacitors. They were all measured at about 10 MHz. QL of 400 was assumed, again for the T68-6A core. Three capacitors tested had Q of 2900, 4400, and 5900. All of these parts were pretty good and would be fine for homebrew LC filters, even though some were low priced parts.

7. SMT Capacitors
Several SMT caps were evaluated. All were elements from the junk box and all used my "standard L2" inductor.
1206 220 pF 7.3 MHz Qc=472. (unknown origin from junk box)
0805 330 pF 6.0 MHz Qc=1800 (Panasonic-ECG PCC 331 CGCT-NT from Digi-Key)
1206 120 pF 9.9 Qc= 1070 (PCC 121 CCT-ND from DigiKey).
1206 100 pF 10.6 Qc=660. (junk box unknown)

8. Double Sided Circuit Board Capacitors.
Two different pieces of PCB material were evaluated. The first was some standard FR-4, 3.5 x 3.7 inches, 234 pF. Qc=47 at 7.1 MHz. The second piece was 429 pF with a piece that measured 4.7 x 6 inches, with Qc=1368 at 5.2 MHz. This second piece was a material called Duroid and is used for microwave applications.

9. Polystyrene Film Cap.

This was a junk box cap with C=220 pF. At 7 MHz, we measured Qc=1180. More measurements with Polystyrene caps are in order.

10. Common Toroid Inductor ("L1", 17 turns #24, evenly spaced, on T50-6.)
This is a toroid that many of us have used in filters. The measured inductor Q values obtained for this core are:
14 MHz QL=273
10 MHz QL=291
6.7 MHz QL=281
This part would be satisfactory for the main inductor in these experiments, if I didn't have the higher Q parts available.

11. Solenoid at MF with 660/46 Litz wire. This high inductance "crystal set special" 44 turn coil was wound on a 4.5 inch diameter styrene from with a coil length of 3.2 inches. The coil was resonated with a 200 pF MC capacitor at 786 kHz. Measured resonator Q was QR=1164. Assuming Qc=3700, the inductor QL was almost 1700. A higher capacitor Qc would produce a more realistic, but nonetheless stellar value of QL around 1500. The same inductor was measured with a 200 pF Tansitor porcelain capacitor. The resonator Q was higher at 1286, indicating that the porcelain capacitor is measurably higher in Q than the MC mica capacitor. Our main interest in measuring this inductor was to extend the measurements down to the 1 MHz area where the MC mica capacitors have their highest Q. Incidentally, this is by far the highest inductor Q we have even seen. Some UHF helical resonators were getting close though.

12. Film Trimmer. A capacitor that I've used in many filter designs is a 4.5 to 65 pF film trimmer manufactured by Sprague-Goodman. One was measured as 75 pF fully meshed. It produced a Q of 2500 at 12 MHz, a very respectable number.

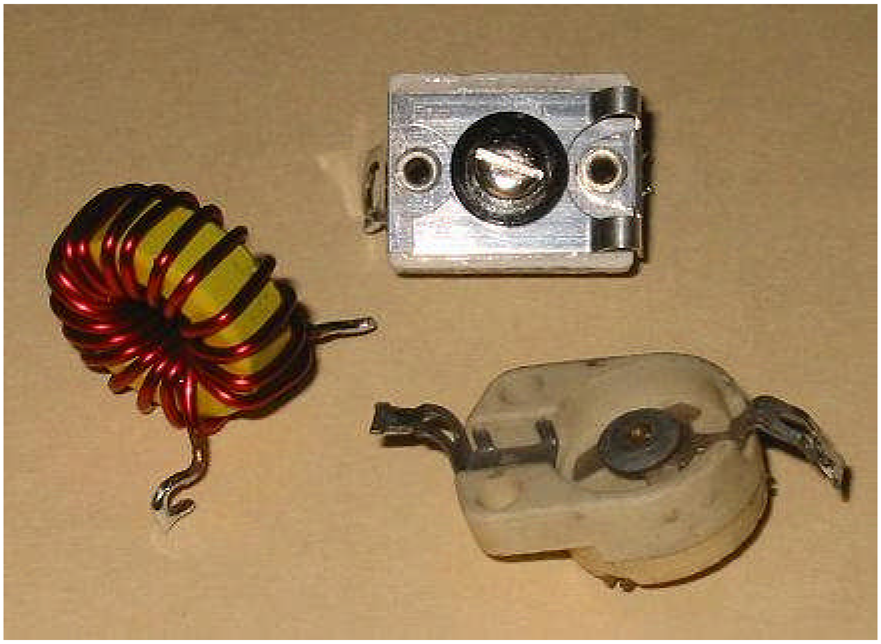
13. More SMT Ceramic Capacitors. (8Dec10 update) Item #7 in this list presents some preliminary results with SMT capacitors that were available in my stock. After these had been measured, I remembered that I had purchased a selection of SMT capacitors just for such a comparison. A little digging produced the parts. They were either 56 or 120 pF in value and were in either 0805 or 1206 sizes. These parts were measured with my "standard" inductor, "L2." Here are the results, presented in order of increasing capacitor Q. Only one part from each strip of 10 was measured.
a) 120 pF 0805 C0G 50V, manufactured by AVX, part # 08055A121JAT2A,

Qc=635 at 10 MHz.
b) 120 pF 1206 C0G 50V, Panasonic-ECG, part#ECU-V1H121JCH, Qc=880 at 10 MHz.
c) 56 pF, 0805, NP0, 50V, AVX, part # 08055A560JAT2A, Qc=955 at 14 MHz.
d) 56 pF, 0805, C0G, 50V, Kemet, part # C0805C560J5GACTU, Qc=1100 at 14 MHz.
e) 56 pF, 1206, C0G, 50V, Panasonic-ECG, part # ECU-V1H560JCM, Qc=1240 at 14 MHz.
f) 56 pF, 1206, C0G, 50V, AVX, Part # 12065A560JAT2A, Qc=1500 at 14 MHz.
g) 56 pF, 0805, C0G, 100V, Murata, Part # GRM2195C2A560JZ01D, Qc=1840 at 14 MHz.
------------- The next two measurements were done merely to further validate the measurement scheme. -----------------
h) 130 pF, Porcelain chip, TC?, V?, Tansitor Corp. Qc=4600 at 9.7 MHz.
i) 56 pF, Porcelain chip, TC?, V?, Tansitor Corp. Qc=3900 at 14 MHz.

We should avoid generalizations about these parts, for the sampling is very small. The last two in the list were parts pulled from my stash of "golden" parts and were done merely for "calibration." The one valid conclusion we can draw is that none of the routine SMT parts (in our junk box) are spectacular and some are pretty poor.

Another observation was that this is a tedious measurement and some sort of a test fixture is needed where a SMT part can be inserted, measured, and returned to the appropriate envelope to be used at a later time.

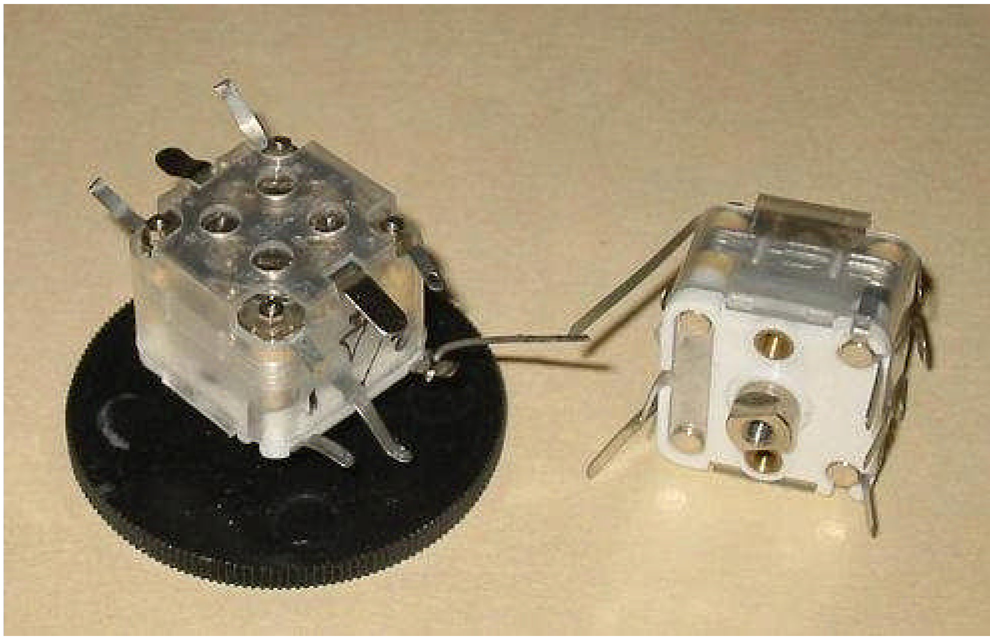
14. Mica Compression Trimmer (Tektronix surplus, marked GMA40300)
I have often used this part, or similar ones, for tuned RF power amplifiers at HF and 50 MHz. Set C to 104.8 pF with AADE L/C meter and resonated with the "L2" standard. Capacitor Q was 2187 at 10.5 MHz, assuming Q-L=400. See the tradeoff curve and the photo below.


The inductor is our "standard, L2" used for many of these measurements. The upper trimmer is the mica compression measured in case 14 while the lower capacitor is the rotary ceramic part measured in case 15.

15. Ceramic Trimmer. Nominal 50 pF max C. This is a classic rotary ceramic design, set for maximum capacitance and measured with L2. The Q was only 1000 at 14.7 MHz.

16. Dog Bone Ceramic, nominal 47 pF. This is a part that remains a mainstay of my junk box, even though it is perhaps 40 years old. It is a very stable NP0 part that I've used in perhaps too many variable frequency oscillators. This sample measured 47.3 pF and had a Q over 3000 at 15.5 MHz.

17. *Polyvaricon* variable capacitor. A popular, inexpensive variable capacitor is one with plastic sheets between the plates. It otherwise tunes like a familiar air variable with a rotary motion. The shaft holds an edge driven knob. Owing to the close plate spacing filled with dielectric material, we expect higher loss than a similar structured air dielectric capacitor. But I had no idea how bad or good it might be. The Sprague-Goodman film trimmer (data in item 12 above) produced quite good Q in a rotary structure with a plastic dielectric.


The part with the black knob is the one measured here.

The variable that I measured has two sections, each with a capacitance that ranged from 6 to 270 pF. The measurement used inductor "standard" L2 and the variable capacitor set at 100 pF. The result was a very poor Qc of **540** at 10 MHz. This was a major surprise. The measurement was then extended down to 6.5 MHz where Qc was even worse at **340**. Capacitance was then maximum. Just to be sure that the equipment was behaving properly, an air variable was then measured; the result there was a Q of 3100 at 6.5 MHz, which is great. This particular *polyvaricon* capacitor has **now become the lowest Q capacitor that I have measured**. It may still be useful in some applications.

The term *polyvaricon* is one I have seen used a great deal, especially within the QRP community (low power enthusiasts) where such parts are often used for antenna tuners. The name is actually a trade name coined by **Mitsumi.** (Tnx to VK2TIL) This measurement of one sample would suggest that the parts are best used with care in any new design. Indeed, I now want to replace the ones that I'm using in a portable antenna tuner with air variable capacitors. Antenna tuners, or transmatchs are especially critical circuits because we often ask that they match a wide variety of circuits. If the impedance is extreme, loss in the matching unit could dominate. This is an application where Q really does matter. But it will all depend upon the antenna. Other applications may not be as critical.

The particular parts I have were purchased from one of the major suppliers many years ago. But their catalogs no longer list these variable capacitors. (29Dec10)(2Jan11)

Conclusions

The measurements with the CDE type MC capacitors, although less than profound, was certainly a worthwhile exercise. Extracting Q values from the curve offered in the CDE data sheet has allowed some internal "standard" inductors to be characterized. Those inductance standards are then used to evaluate a variety of other capacitors. The mica capacitors have moderately high Q and are readily available with affordable, although not cheap prices.

The results obtained in this study are not offered as being highly accurate. We are still estimating capacitor Q values when an inductor is being measured. The results are, however, consistent and are a step in the right direction. The Q-L versus Q-C curve presented in the text illustrates the nature of the tradeoff.

It is probably not necessary for the casual experimenter to refine his or her measurements to isolate capacitor Q values. The most common application is the fabrication of LC bandpass filters. For that, it is perfectly acceptable to measure resonator Q. Even there, it is rarely necessary to have highly accurate knowledge of resonator unloaded Q. Rather, all that is required is to be sure that the Qu values are high enough that a desired filter can be realized. This detail always emerges from a simulation so long as Q is included in the models. There are, on the other hand, some applications where Q is much more important. The methods outlined here offer a first glimpse at those Q values.

Several capacitors were measured, yielding both expected and some surprising results. Some SMT capacitors are indeed poor Q while other are OK. Some variable capacitors were found wanting. Some positive surprises were found, such as the mica compression trimmer.

Addendum, April 14, 2015

In early 2014 I purchased an old HP-4342A Q-Meter. This is a classic instrument that resulted when Boonton Corporation was purchased by HP. Much of the technology in the HP Q-meter was engineered by the folks at Boonton. The HP Q meter was a solid-state instrument, but included the extremely high Q variable capacitor that seems to have originated at Boonton. (See Kito & Hasegawa, “Measuring Q—Easier and Faster,” Hewlett-Packard Journal, Vol 22, Nr 1, September, 1970.) This new Q meter has proved to be a handy way to evaluate tuned circuits and inductors, and has been especially useful in the evaluation of capacitors.   But there have been no major surprises. We have NOT updated any of the previous data, but have learned a few things from the Q-meter. Here are a few of thing details that emerged:

1. The scheme presented in EMRFD Section 7.9, Fig 7.66, Eq. 7.4, is sound. The results are in complete agreement with those of the Q-meter. The EMRFD scheme is that used for other measurements presented in this report.

2. The classic assumption that we have all made from time to time, myself included, that capacitors have high Q and that all problems can be attributed to inductors is not valid.   Some capacitor are really poor.

3. Many variable capacitors have a Q that varies a lot with frequency.   A 365 pF air variable with a Q of several thousand at 1 MHz may have a Q of only 1000 or even less at 10 MHz.

4. The silver mica capacitors that we always assumed to be good are sometimes not the highest Q parts.

5. Careful fixtures are important.   Wire interconnects often have too much inductance. Brass straps are better.   Circuit boards are problematic.   Even banana plug connections can compromise Q measurements.

As always, rules-of-thumb should be avoided.   Measurements should be done instead.