7.10 CRYSTAL MEASUREMENTS

A quartz crystal is modeled as a series RLC paralleled by a capacitance, **Fig 7.68**. Crystals are of special interest, for they are often used in construction of narrow filters. For this purpose, we need to know all of their parameters. Great precision is needed in knowing resonant frequency, for that strongly controls filter tuning. The knowledge of the other parameters is needed at an accuracy similar to that encountered in an LC filter.

There are numerous measurement schemes that will produce the four values. A 50-Ω measurement setup was presented in Chapter 3. Results from it are informative, especially if a batch of "junk box" crystals is encountered. However, more refined measurements are desired for filter design. An extremely useful, yet simple oscillator was also presented in Chapter 3 and is repeated here as **Fig 7.69**. A Colpitts oscillator with an emitter follower drives a frequency counter. A capacitor in series with the crystal, C_s, may be short circuited with a toggle switch. This produces a change in frequency that, when combined with the frequency and capacitor value, yield the motional capacitance, C_m. The motional inductance, L_m, is then calculated from series resonance, which is well approximated by the oscillator frequency when the switch is closed. The design equations are included in the figure. F is the frequency while DF is the frequency shift, both in Hz, when the switch is toggled; C_S and C_P , in Farads, are from the circuit. And as usual, $\omega=2\pi F$.

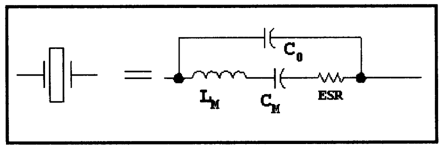

Fig 7.68—Model for a quartz crystal.

If this test oscillator is built with Colpitts capacitors of C_p=470 pF and a series capacitor of C_s=33 pF, the circuit will function (fundamental mode) with crystals from 2 to 25 MHz. Simple equations are valid when C_p is more than $10 \times C_s$. It is also important that the C_s value be determined by measurements that include the switch. The 33 pF capacitor in our test set plus switch capacitance produced a net C_s=41 pF.

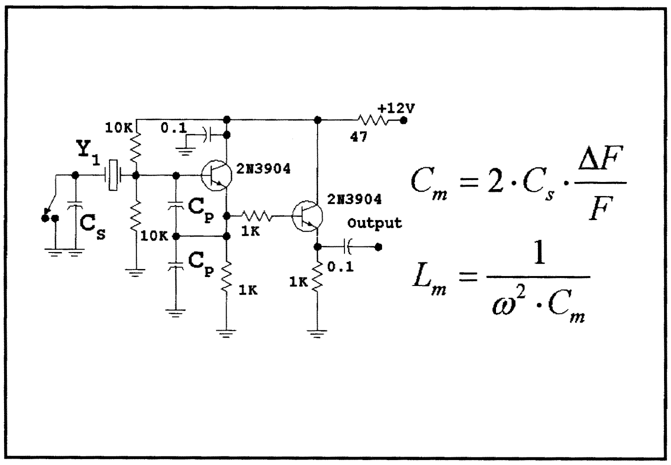

Fig 7.69—Colpitts oscillator for crystal testing, based on an insightful suggestion by G3UUR.

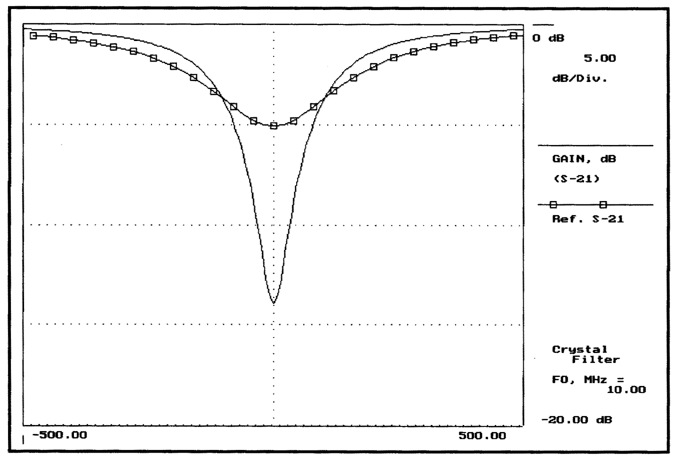

Fig 7.71—Sweeping two crystals while investigating their properties as traps. One has a Q of 40,000 while the one producing the deeper notch has a Q of 200,000. Notch depth is measured to determine Q.

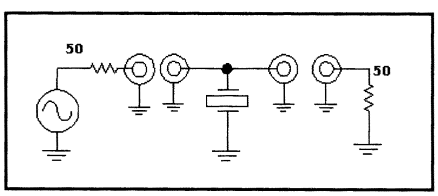

Fig 7.70—Using the trap nature of the crystal for a Q measurement.

The crystal is essentially a series tuned circuit when operating near series resonance, so the series trap scheme described earlier for LC tuned circuits will also provide Q_U, as shown in **Fig 7.70**. Computer generated plots are shown for two different 10 MHz crystals in **Fig 7.71**. The shallow notch represents a low Q crystal with Q_u=40,000. The deeper and narrower notch corresponds to Q_u=200,000. The crystal Q relates to attenuation A in dB, motional L in Henry, frequency in Hz, and terminating resistance Z in Ω with...

$$Q = 4 \cdot \pi \cdot f \cdot L \cdot \frac{\left[10^{\left(\frac{1}{20} \cdot A\right)} - 1\right]}{Z} \qquad \textbf{Eq 7.6}$$

We performed an experiment with a crystal that had also been measured with earlier methods. The notch method for Q measurement yielded QU=202,000 with ESR=17.5 Ω. This was within a few percent of the earlier measurements. The ESR values for crystals are higher than we usually see with an LC resonator, so the notches are not as deep. This allows measurement with a power meter such as the AD8307 based design described earlier; a spectrum analyzer is not necessary. ESR can be 100 to 1000 Ω for very low frequency crystals, so the series connected parallel tuned circuit method might offer better measurements here.

Parallel capacitance, C_0, is easily measured with other tools such as the AADE or W7AAZ circuits. They are effective because those instruments operate at low frequency, around 1 MHz, well away from typical crystal resonance. With all four crystal parameters available, the designer/builder can proceed with the filter designs presented in Chapter 3.

The equipment described has also been used to evaluate HF ceramic resonators. In one measurement on an ECS type ZTA358MG (from Mouser) we saw L_M=761 µH, C_M=2.74 pF, C_0=31 pF, and Q_U=636. Series resonant frequency was well below the marked 3.58 MHz frequency at 3.38 MHz. The part is normally used in oscillators with a series capacitance.