APPENDIX 3
MEASURING TECHNIQUES

INTRODUCTION

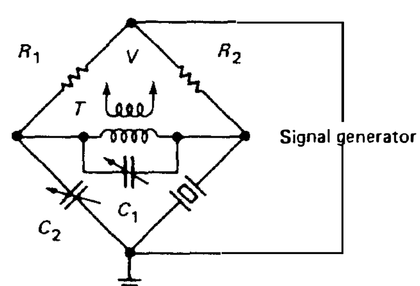
The CI-meter provides the most convenient method for determining the resonant frequency and the equivalent resistance of the main mode of the quartz resonator, but it is not suitable for determining the frequency or equivalent resistance of the inharmonic and other weakly excited modes of vibration.

Information concerning these modes, which is often required of units designed to operate as elements in filter circuits, may be obtained by one of the following methods.

BRIDGE METHODS

A circuit which is especially useful in detecting and measuring the resistance of weak modes is shown in Fig. *a*.

T is a ferrite core transformer balanced with respect to ground and broadly tuned to the crystal frequency by C_1. The signal generator supplying the input to the bridge must be capable of being adjusted within a few hertz of the frequency



(a)

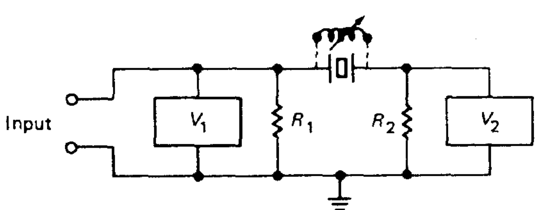
of the unit under test. It must have excellent frequency stability and it is helpful if the output voltage is variable over a wide range. The Hewlett-Packard Signal Generator Model 606A is easily modified to meet all these requirements by adding a vernier to the fine-frequency control. A still better source is one of the excellent frequency synthesizers which are now available.

R_1 and R_2 are each 100 Ω, roughly matching the generator impedance. The bridge is balanced at a nonresonant frequency of the crystal unit by making C_2 equal to C_0, the static capacitance of the crystal unit. The change in impedance at the resonant frequency disturbs the balance of the bridge, as indicated by the vacuum-tube voltmeter V.

The bridge circuit is especially useful in searching for weakly excited modes, since the admittance of the static capacitance C_0 is balanced out by means of C_2. The resistance in parallel with C_2, which restores the balance of the bridge at the resonant frequency, is equal to the series-resonant frequency resistance R of the crystal unit.

PI-NETWORK METHODS

The Pi-network of Fig. *b* has certain advantages for determining the frequency and equivalent resistance of easily excited modes. V_1 and V_2 are vacuum-tube voltmeters of suitable range. The Hewlett-Packard Signal Generator Model 606A provides the input voltage. R_1 and R_2 are each 50 Ω. It is essential to use a voltmeter at the input terminals, since the voltmeter in the 606A reads correctly only when the terminal impedance is 50 Ω.



(b)

The current through the crystal unit is a maximum at the resonant frequency. Hence, a maximum reading on V_2 indicates that the crystal unit is operating at its series-resonant frequency. The current through the crystal unit is then given by

$$i = \frac{V_1}{R + R_2}$$

provided that the equivalent resistance $R \ll 1/\omega C_0$. In this case,

$$V_2 = iR_2 = V_1 \frac{R_2}{R + R_2}$$

from which

$$R = R_2 \left(\frac{V_1}{V_2} - 1 \right)$$

The Pi-network has the advantage that the equivalent resistance is easily obtained provided $R \ll 1/\omega C_0$. For weak modes, R is likely to be of the order of $1/\omega C_0$ or even greater, in which case the method is not applicable. The modes may not even be observable, because the current through the series arm of the equivalent circuit is small compared with the current through the static capacitance C_0.

It is possible to identify weak modes using the Pi-network by placing a variable inductance across the crystal unit and using it to tune C_0 to resonance. It is simpler, however, to use the bridge circuit of Fig. *a*.

VECTOR VOLTMETER METHODS

The vector voltmeter provides a very straightforward (but expensive) method of determining all the parameters of the crystal unit and it can be used on weak and strong modes. The circuit used is shown in Fig. 7.4. The series-resonant frequency is the frequency at which the vector voltmeter indicates zero-phase angle. The voltmeter may be used to measure V_1 and V_2 and R can be calculated using the equations above.

The antiresonant frequency of the crystal unit with a load capacitance C_x may be determined by placing C_x in series with the crystal unit and using the vector voltmeter to determine the frequency of zero phase. This frequency is the same as the parallel-resonant frequency. See page 108 ff.

An important improvement is the addition of a phase-locked loop to control the generator frequency, thus eliminating the tedious task of adjusting the frequency of the generator to the resonant frequency of the crystal unit. In this way the vector voltmeter (or transmission line) method may be used for making temperature runs as well as for routine measurements of frequency.

ZERO-PHASE RESISTORS

Adjustment and calibration of vector voltmeters is done by substituting a resistor for the crystal unit and tuning the circuit to zero phase. It is assumed that the phase angle of the resistor is zero. At frequencies above a few megahertz, carbon resistors are usually inductive. For example, a 0.1 W carbon resistor, at a frequency of 10 MHz, may have a positive phase angle of 10°.

Noninductive resistors may be prepared by putting small, high-quality capacitors in parallel with the resistors. The parallel combination should be mounted in a crystal holder identical to that used with the crystal unit which is to be tested. The impedance of the parallel combination can be measured with a suitable bridge or RX meter at the frequency of the crystal unit. The socket used in the measurement should be identical to that used in the vector voltmeter. By selection and adjustment, a combination of carbon resistor and capacitor can be found which yields the desired resistance at zero phase at the nominal frequency of the crystal unit. Measurements should be made with the can in place, and after the correct values are found, the can should be sealed and marked with the resistance and frequency.

It was shown on page 116 [Eq. (79)] that the frequency of a typical 10 MHz unit changes about 1 Hz/degree. Hence, the measurement of frequency made against a 10° resistor may be in error by 10 Hz, or about 1 ppm.