APPLICATION NOTE 171-1

APRIL 74

Measurements with SIGNAL GENERATORS

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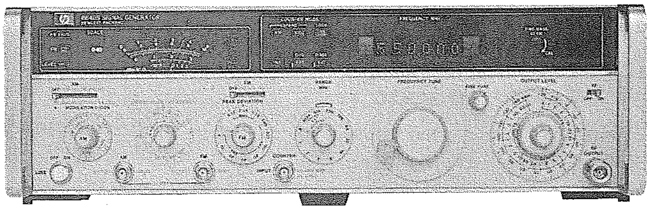
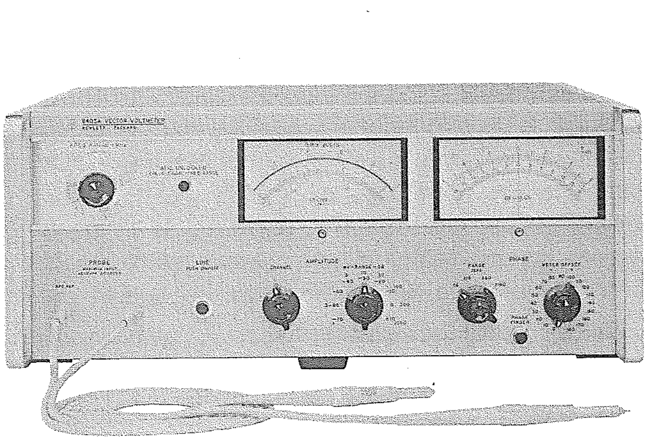
Crystal Testing

WITH THE HP 8640A/B AND HP 8405A



8640B Signal Generator



8405A Vector Voltmeter

The HP 8640A and 8640B are signal generators which cover the frequency range of 450 kHz to 550 MHz and can be extended to 1100 MHz with a frequency doubler. These generators provide AM, FM and pulse modulation. The 8640A has a mechanical dial, the 8640B has a built-in counter and phase lock synchronizer. The synchronizer phase locks the RF output frequency to the crystal time base used in the counter. Output level range of the 8640B is +19 dBm to −145 dBm (2 volts to 0.013 μ volts). The high stability and low residual FM make the 8640A/B ideal for this measurement.

The 8405A Vector Voltmeter is a two-channel (A and B), tuned voltmeter/phasemeter with a 1 kHz bandwidth. Its frequency range extends from 1 MHz to 1000 MHz. The 8405A has >90 dB dynamic range. Voltages from less than 100 μ volts to 1 volt can be measured with the 8405A. Phase (the phase difference between channels A and B) can be measured over 360° with 0.1° resolution. Four phase scales are available: ±180°, ±60°, ±18°, and ±6°. A meter offset selectable in precise 10° increments makes it possible to get 0.1° resolution throughout the 360° phase measurement range.

The 8405A uses phase-locked coherent sampling to translate the incoming RF signals in channels A and B to 20 kHz IF signals that retain the same amplitude and phase relationship as the original RF input signals. Phase lock is automatic at any frequency, only coarse tuning covering octave or greater spans is needed to phase lock.

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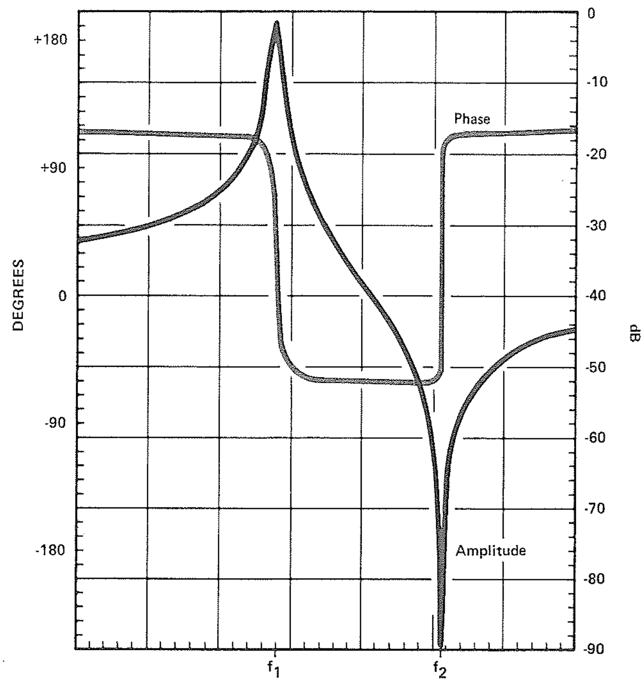

Figure 1. Amplitude and Phase Characteristics of a Typical Crystal.

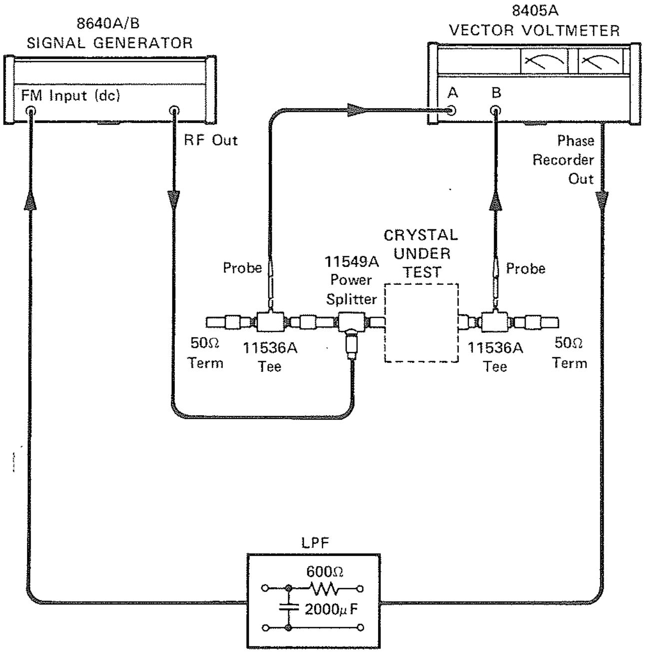

Figure 2. Crystal Series Resonance Testing with the 8640A/B and 8405.

This application note describes a procedure to measure the crystal resonant frequency. Resonant frequency is defined as the frequency at which the crystal phase goes through zero degrees. A typical crystal has two such frequencies as shown in Figure 1. One frequency corresponds to series resonance (i.e., crystal impedance is minimum and therefore loss in the crystal is minimum) and the other frequency corresponds to parallel resonance (i.e., crystal impedance is infinite and loss due to reflection is maximum). After measuring the resonant frequencies, a procedure is outlined to measure the rest of the amplitude and phase characteristics.

Objectives:

1. Measure zero-phase crossing corresponding to series resonance.
2. Measure zero-phase crossing corresponding to parallel resonance.
3. Make a complete amplitude and phase characterization versus frequency.

Equipment Needed: The 8640A and counter or 8640B signal generator, 8405A vector voltmeter, 11507A accessory kit for the 8405A, an inverter amplifier and a low pass filter.

Test Description

The block diagram shown in Figure 2 can be considered as a frequency lock loop where the 8640A/B is locked to the zero-phase frequency of the crystal under test. Initially, channels A and B are equal in phase, that is, the phase meter reads zero degrees, and the 8405A is tuned to the input frequency in channel A. After the crystal to be tested is inserted in the setup, it introduces some phase shift depending on its phase versus frequency response. However, at the crystal resonant frequency, phase shift through the crystal is zero and channels A and B are equal in phase again.

The phase recorder output is a dc voltage proportional to the phase meter reading (phase difference between channels A and B). It is an error signal that shifts the 8640A/B frequency up or down depending on polarity. The low pass filter shown in the block diagram acts as a lag network (RC time constant typically is 0.1 - 0.5 second) which eliminates loop oscillation and reduces loop bandwidth.

Once the lock condition is achieved, the feedback loop reduces frequency disturbances in the system by a factor related to open loop gain*. For example, the 8640A/B Fine Tuning control tuning range is reduced; we can see this by turning it from one end to the other. Large frequency disturbances, however, can not be re-

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*The loop action reduces frequency disturbances at series resonance by $\frac{1}{1 + 1/2\, K_1 K_2 K_3}$

where K_1 = the slope of phase vs frequency response of the crystal (degree/Hz).

K_2 = 8405A phase meter range sensitivity, (volts/degree: 0.25/6°, 0.25/18°, 0.25/60°, 0.25/180°).

K_3 = 8640A/B FM sensitivity (Hz/volt).

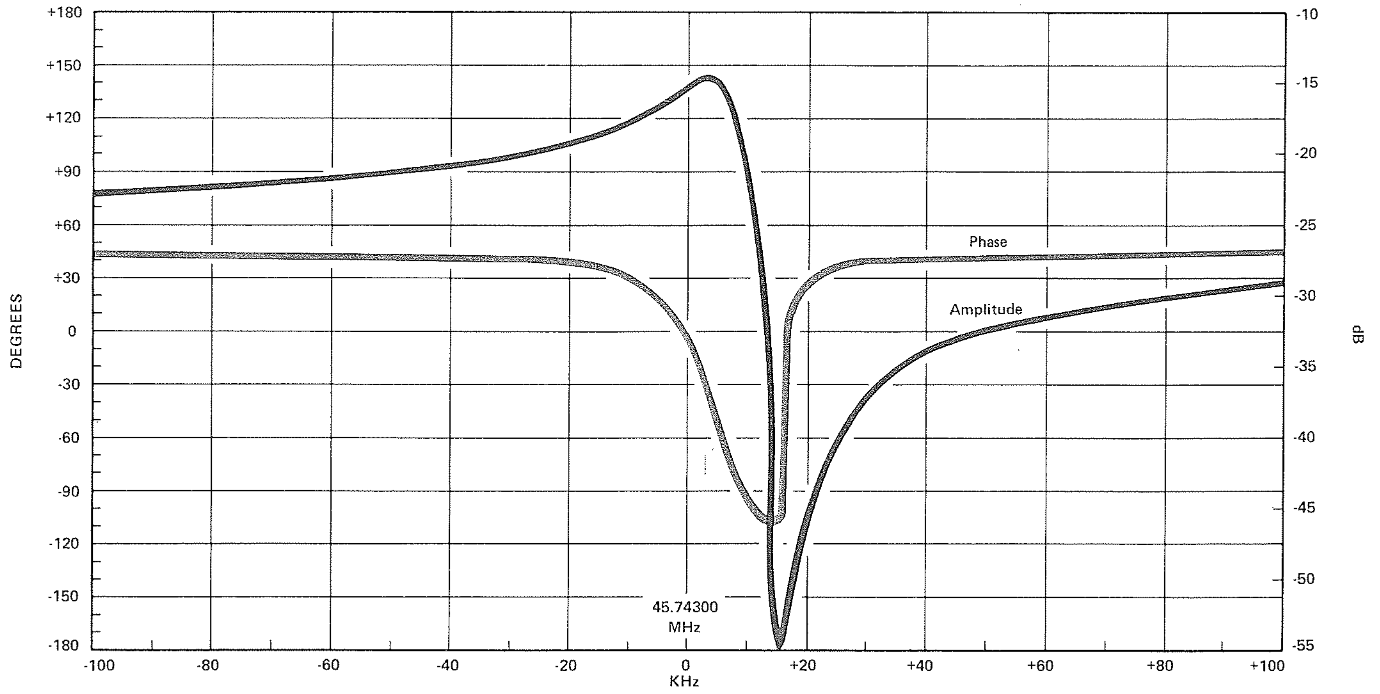

Figure 3. Complete Amplitude and Phase Characteristics of 47.5 MHz Crystal. Note the two zero-phase crossings.

duced sufficiently so lock breaks.

Measuring the zero-phase crossing at series and parallel resonances is easy and straightforward. The response shown in Figure 3 is for a 47.5 MHz crystal. Note the steep amplitude and phase characteristics. For series resonance, we simply tune the 8640A/B for maximum or near maximum indication on the 8405A amplitude meter. For parallel resonance, an inverter amplifier must be inserted in the feedback loop. However, since the crystal amplitude response at parallel resonance is at or near minimum, it might be difficult to pinpoint the parallel resonance point of a crystal whose parallel resonance response is 70 dB or greater because the zero-phase point will be obscured by the noise in the 8405A test channel.

Procedure

We will establish the series resonant frequency first and then proceed to characterize the crystal (amplitude and phase) around series resonance. We will repeat the same procedure at parallel resonance.

Set the 8640A/B and 8405A as shown in Figure 2. Select the 8640A/B frequency range which covers the crystal frequency and set the signal generator as follows:

Peak Deviation: Maximum allowable
FM slide switch: Ext. dc
FM Vernier: Maximum CCW
Lock (8640B): Off

1. With the crystal under test removed, establish the phase meter null, that is, zero the 8405A phase with the range switch in ±6° range. Return the range switch to the ±180° position after nulling the meter.
2. Insert the crystal and tune the 8640A/B to see an indication on the amplitude meter. Peak the amplitude meter using the 8640A/B fine tune control.
3. Slowly turn the FM vernier maximum clockwise and observe the 8405A meter—it should be at or near zero degrees. Since the loop has a slow response time (governed by the low pass filter's time constant), the FM vernier should be turned at a slow rate. This precaution is recommended to avoid transients which the loop may not track and would result in breaking lock.
4. To get the best phase resolution, reduce the phase range to the ±6° position. Fine tune the 8640A/B to center the phase meter at zero.
5. Read the frequency displayed by the 8640B, or the external counter if the 8640A is used. This is the series resonant frequency of the crystal. Return to the ±180° position.

Starting from the zero-phase crossing just established, we can tune the 8640A/B down (to the left of resonance) to characterize the crystal in amplitude and phase. Simply tune the 8640A/B downward and observe the amplitude and phase meters. Do not tune so far

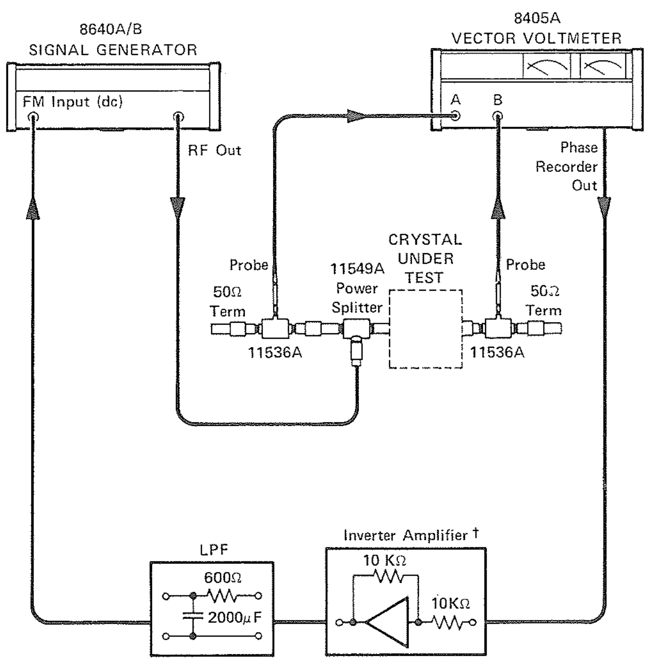

Figure 4. Crystal Parallel Resonance (Feedback loop uses inverter stage).

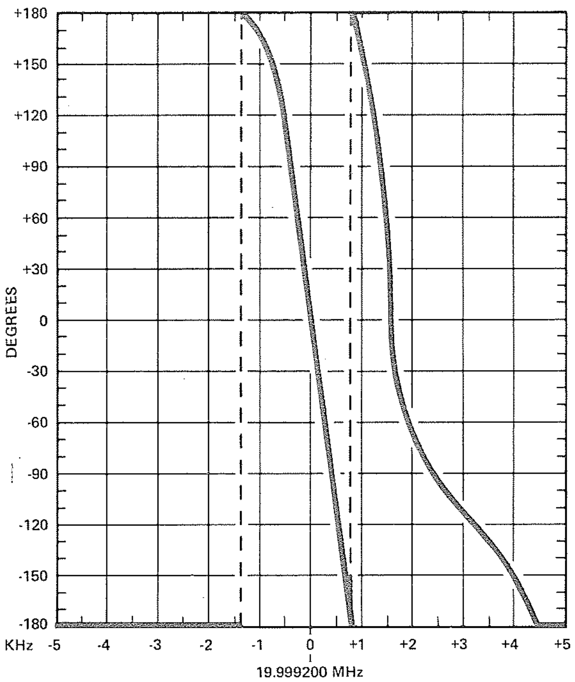

Figure 5. Phase Response of a 20 MHz Bandpass Filter.

that you lose lock. If lock breaks, re-establish zero crossing.

Again, come back to the zero-crossing frequency and tune the 8640A/B up (to the right of zero-crossing). Observe the amplitude and phase meters. As you approach the parallel resonance frequency, the amplitude response decreases rapidly and, at some point, the phase response changes slope and the meter swings from the negative end to the positive end of its range.

At this point, turn the FM vernier fully counter clockwise and insert an inverter stage in the feedback loop as shown in Figure 4. This stage is needed to provide the correct dc polarity for the FM input of the 8640A/B. Reduce peak deviation two or three ranges. Tune the 8640A/B and observe the frequency which gives minimum amplitude response. Turn the FM vernier fully clockwise, the phase meter should be at or near zero degrees. Fine tune to bring the 8405A phase meter to zero degrees. The frequency displayed by the counter is the parallel resonance frequency. Tune the 8640A/B up to characterize the amplitude and phase of the crystal in this region. Again, care should be taken when measuring the zero-phase crossing at parallel resonance because of a low signal-to-noise ratio in the test channel and a sharp phase versus frequency slope.

Measurement Considerations

This measurement system has three sources of error which affect frequency accuracy:

1. Counter accuracy.
2. The 8405A zero-phase adjust.
3. The physical length of the device under test*.

Assuming the physical length of the device under test is negligible at resonance, the frequency accuracy is equal to:

$$\text{Counter accuracy} + \text{zero phase adjust x } \frac{\Delta F^{**}}{\Delta\phi}$$

If physical length of the device under test is not negligible, a phase shift could occur due to the electrical length of the device (we assume the device resonates at the center plane of its physical configuration). To estimate this error, we can measure the device physical length, convert it to electrical length at resonance and convert the electrical length to phase shift. Then multiply by $\frac{\Delta F}{\Delta\phi}$ to find the error in Hz.

In summary, this measurement system represents an economical way of testing crystals, crystal filters, crystal oscillators and other frequency selective circuits. Figure 5 shows phase characteristics of a two-crystal 20 MHz filter. Note the two zero crossings and the phase reversals at ±180°.

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*The effects of physical length are discussed in HP AN 91, "How vector measurements expand design capabilities".

**$\frac{\Delta F}{\Delta\phi}$ is equal to the inverse of phase versus frequency slope.

†LM301AH, National Semiconductor.