HEWLETT PACKARD

Application Note 339-9

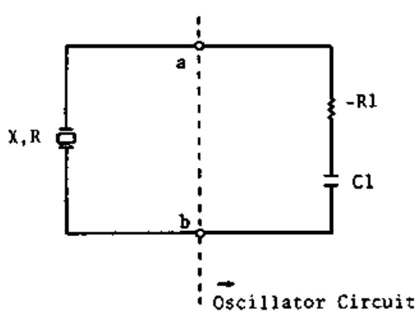
Negative Impedance Measurements of Crystal Oscillators

- HP 4194A Impedance/Gain-Phase Analyzer -

Introduction

Negative impedance, one of the most important parameters to be considered when characterizing crystal oscillators and resonators, can be measured easily by using the HP 4194A Impedance/Gain-Phase Analyzer and the HP 41941A/B Impedance Probe Kit. This ability to perform negative impedance measurements provides a powerful tool for oscillator development and evaluation.

The relative ease with which negative impedance measurements can be performed with the HP 4194A and the HP41941A/B also means you can significantly reduce oscillator and clock generator cost and development time in crystal/ceramic oscillator and resonator manufacturing labs, and in the labs of electronic instrument manufacturers.



X: Reactance of crystal

R: Resistance of crystal

C1: Load capacitance of oscillator

-R1: Negative resistance of oscillator

Figure 1. Equivalent Circuit of a Crystal a Crystal Oscillator

Measurement Requirements and HP 4194A Solutions

Figure 1 shows an equivalent circuit for a crystal oscillator. Because an oscillator must have enough negative resistance to compensate for the resistance of a crystal for oscillation to start, negative resistance measurements are important when determining oscillator characteristics.

Figure 2 shows an example of a crystal oscillator chip. The negative input impedance of an oscillator circuit should be measured under actual operating conditions to verify that the circuit is performing as designed. As a rule, all oscillator circuits are low-grounded. The HP 4191A, 4192A, and 4193A Impedance Analyzers have the capability to perform low-grounded measurements, but these instruments limit the ability to fully characterize oscillators for the following reasons.

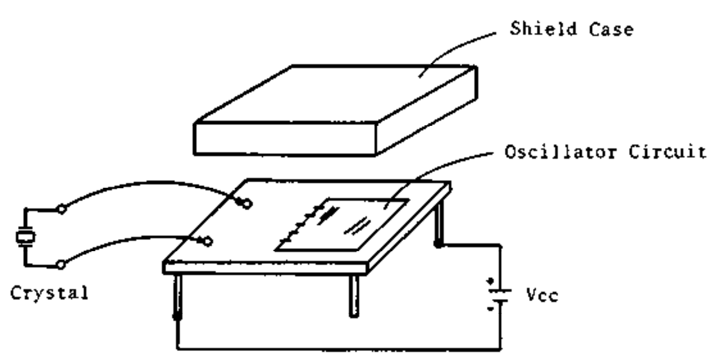


Figure 2. Example of Crystal Oscillator

- The HP 4191A only covers the higher frequency range of 1MHz to 1GHz.
- The HP 4192A only covers the lower frequency range of 5Hz to 13MHz.
- The HP 4193A only measures Z-θ, and has a spot oscillator level.

The HP 4194A with the HP 41941A/B, however, can measure grounded circuits and can evaluate the negative input impedance of oscillator circuits with the following features.

- Wide frequency coverage of 10kHz to 100MHz with an accuracy of 1.5% to 3% for Z-θ, plus R-X measurements.
- Variable OSC level and OSC level sweep.
- The 4194A's Auto Sequence Program (ASP) function enables automatic evaluation without the need for an external computer.

Measurement Specifics

To determine whether an oscillator operates at its specified frequency, voltage (Vcc), and output level, the items discussed in the following paragraphs are required when evaluating oscillators.

Connect an external DC power supply (Vcc) to the oscillator circuit (without a crystal installed), as shown in Figure 2, and connect the HP 41941A/B probe to the location where the crystal is to be installed.

- Vcc Effects on Input Impedance

Confirm that the oscillator works at the Vcc value as designed. Vcc margins can be evaluated by varying the Vcc and observing the value of R vs. Vcc on the display.

- Oscillator Input Impedance as a Function of Frequency (Figure 6)

This measurement is for evaluating negative impedance characteristics in detail at frequencies around the designed oscillation frequency. The frequency range of oscillation can be found by determining the frequency range over which the input impedance is negative.

- Oscillator Input Impedance as a Function of Input Level (Figure 7)

You can substitute the input level characteristics for the output level characteristics of an oscillator. Use the HP 4194A's oscillator level sweep function to determine the dependency of negative input impedance on input signal level.

The HP 4194A is also cost effective for evaluating the resonators used in oscillator circuits. Figure 3 shows an ASP program for automatically measuring the frequency and OSC level (input signal level) characteristics of an 11.904 MHz crystal oscillator. This ASP program performs sequential measurements as follows:

```
10 ! ***** OSCILLATOR EVALUATION *****
20 RST
30 CMT"IMP CHARACTERISTICS OF CRYSTAL"
40 ASC2;SWM2;R0=.5                  ! R0=DEFAULT OSC LEVEL
50 CENTER=16.667 MHZ;SPAN=50 KHZ
60 DISP"CONNECT CRYSTAL RESONATOR"
70 PAUSE
80 SWTRG
90 AUTO;DISP"OSC=",R0
100 BEEP
110 PAUSE
120 CMT"R/POWER-OSC CHARACTERISTICS"
130 IMP2;SWP3;ASC1
140 R1=16.65E+6                     !R1=OSC FREQ(HZ)
150 FREQ=R1;UNIT0;DISP "FREQ=",R1
160 START=0.05 V;STOP=0.2 V
170 R2=0.001                        !R2=POWER LIMIT(W)
180 SWTRG
190 B=X*X/A;AUTO                    !B=POWER(W)
200 MCF3;CUR2;LCURS=R2;R3=LCURSL    !R3=MIN OSC LEVEL
220 MKR=R3;R4=MKRA                  !R4=RESISTANCE AT R3
230 DISP"SETUP 41941A/B & OSCILLATOR"
240 BEEP
250 PAUSE
260 FNC3;IMP2;SWP1;PWS2
270 ITM2;DPA1;DPB0
280 DISP "OSC=",R3;OSC=R3
290 CENTER=R1;SPAN=50 KHZ;UNIT1
300 CMT"R-FREQ CHARACTERISTICS OF OSCILLATOR"
310 SWTRG
320 AUTO;MCF3;CUR1;LCURS=-R4
330 DISP"PRESS<CONT> TO R-OSC"
340 BEEP
350 PAUSE
360 SWP3;FREQ=R1;CENTER=R3 V;SPAN=.1V
370 CMT"R-OSC CHARACTERISTICS OF OSCILLATOR "
380 SWTRG
390 AUTO;MCF3;CUR1;LCURS=-R4;DISP "FREQ=",R1
400 END
```

Figure 3. ASP Program List

1) Measure the impedance characteristics of a crystal. Refer to Figure 4. The marker indicates the design oscillation frequency (11.904 MHz).

2) The OSC level required to drive a crystal at 1mW can be determined from the OSC level characteristics of the crystal. Measure the resistance R-OSC level characteristics at 11.904 MHz and calculate power P from OSC level and R. The marker in Figure 5 shows the OSC level that produces 1mW.

3) Measure the frequency characteristics of the oscillator input impedance. The marker in Figure 6 shows the oscillation frequency. This indicates that the -R of the oscillator is enough to cancel the crystal's R, allowing oscillation at and around 11.904 MHz.

4) Measure the input level characteristics of the oscillator input impedance. The marker in Figure 7 shows the oscillation level (135mV). This indicates that the -R of the oscillator is enough to cancel the R of crystal at approximately 135mV.

Figure 4. Impedance Characteristics of a Crystal Resonator

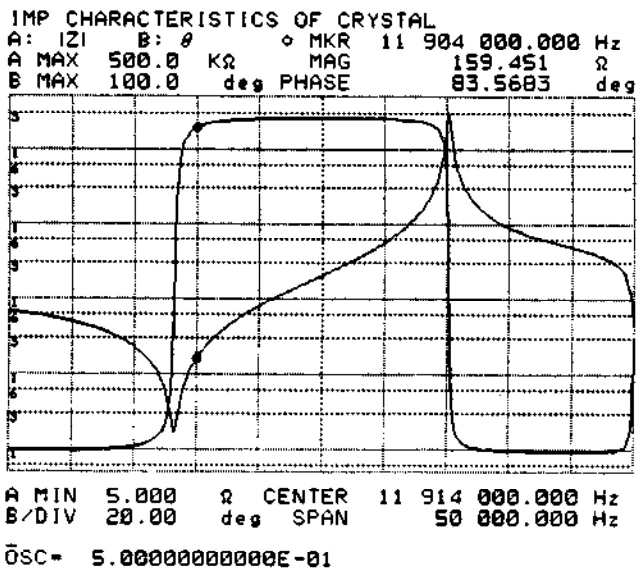


Figure 5. R/Power vs. OSC Level Characteristics of Crystal Oscillator

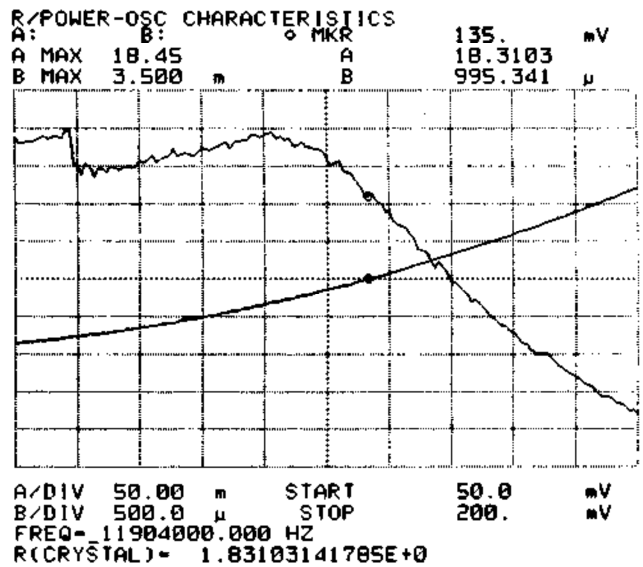


Figure 6. R vs. Frequency Characteristics of Crystal Oscillator

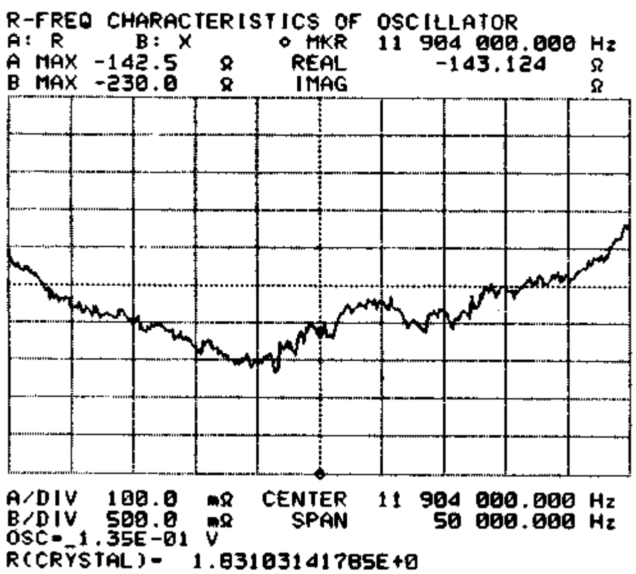
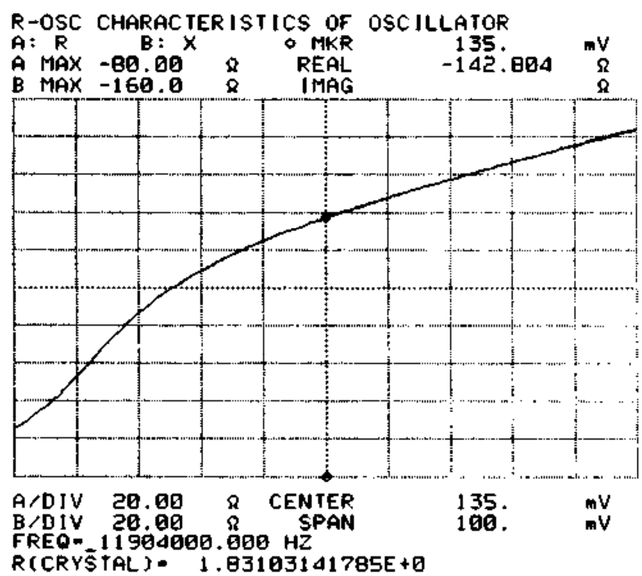


Figure 7. R vs. OSC Level Characteristics of Crystal Oscillator



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Printed in Japan December , 1986 5950-2924