Agilent
Crystal Resonator Measuring Functions of the Agilent E5100A Network Analyzer

Product Note E5100A-2

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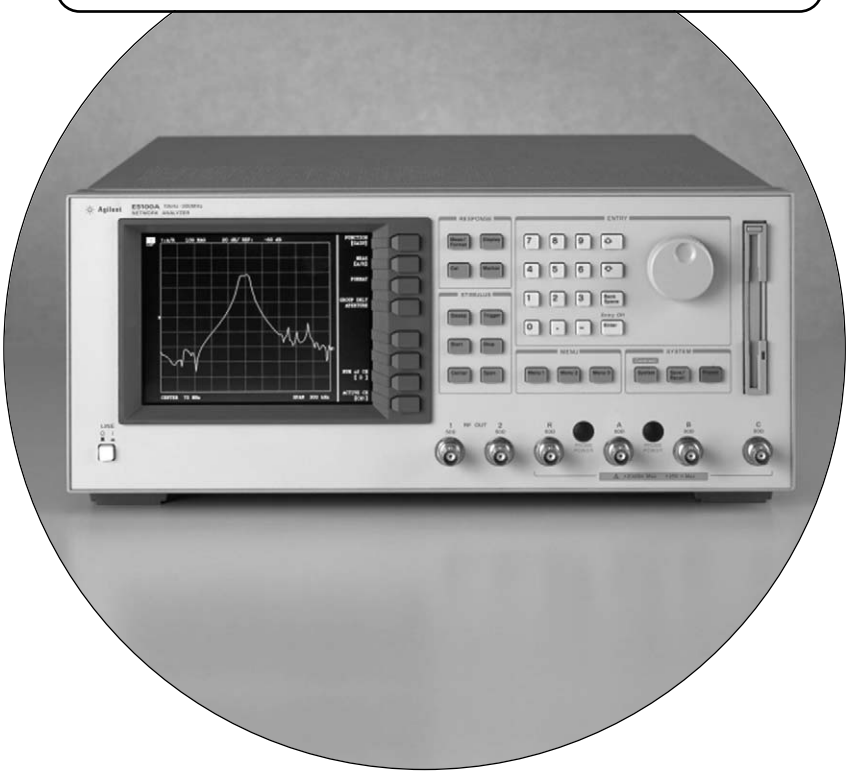
Introduction

Crystal resonators are employed in various types of equipment that are in great demands in recent years such as communications equipment, computers and auto mobile electronic controls. The increasing performance of equipment requires higher resonator performance. For example, communication equipment uses resonators at low drive levels, and so the basic operation of the equipment is seriously affected by resonance failure due to changes in the drive level and temperature characteristics. As a result, stricter requirements are being imposed on the measurement of resonant frequency, resistance and equivalent circuit constants, and the detection of spurious signals on each drive level. It has become essential to ensure effective and accurate measurements of these factors. This product note introduces an effective evaluation procedure for crystal resonators based on the E5100A network analyzer.



E5100A network analyzer

Overview of the crystal measuring functions for the E5100A network analyzer

- Measurement frequency ranges: 10 kHz to 180 MHz or 300 MHz
- Measurement drive level range: -52 dBm to +18 dBm (E5100A-600 and E5100A-618)
- Measurement parameters: amplitude, phase, group delay, impedance, admittance
- Built-in high speed waveform analysis functions
- Options dedicated for crystal measurement (DLD and evapolation)
- Built-in IBASIC functions, 3.5 -inch FDD, built-in RAM disk (DOS format)

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Resonator evaluation using the E5100A

Measurement of high speed drive level characteristics
(E5100A-023 or E5100A-823)

The crystal resonator drive level characteristics have recently gained in importance together with stricter requirements for quick and accurate evaluation of characteristics. The following introduces an effective evaluation method for the measurement of drive level characteristics, using the E5100A.

Current problems

- Use of the Pi-network test fixture is accompanied by excessive signal damping because the output power level in the measuring instruments is insufficient. This results in measurement difficulties on drive levels of as high as 100 μW.
- Frequency sweep of evaluation of characteristics requires the resonant frequency and impedance to be obtained by frequency sweep on each drive level, as illustrated in figure 1. This results in longer overall measurement time, and hence reduced throughput.
- The number of drive levels to be evaluated is restricted by the limited measurement time, making it difficult to ensure detailed drive level of the evaluation characteristics (multi-point evaluation).
- Use of normal power sweep to reduce measuring time results in the resonant frequency undergoing changes in conformity to changes in drive level. This makes it difficult to ensure accurate measurement of drive level characteristics.
- In the measurement of a device having a higher Q factor, the phase of the frequency sweep is likely to deviate significantly from 0° in comparison with the case where the drive level is changed. This causes device frequency sweep response to be delayed, adversely affecting the overall throughput.

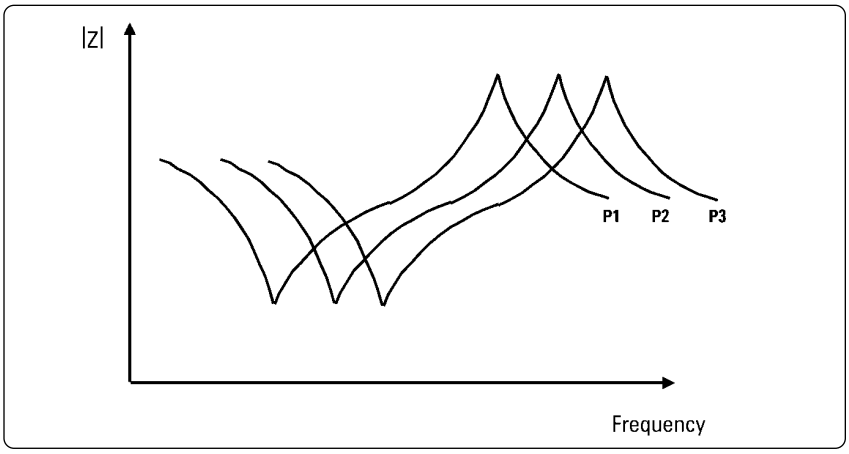

Figure 1. Drive level characteristics evaluation based on frequency sweep

Solutions with the E5100A

The E5100A has a built-in power splitter (E5100A-002 and E5100A-802). The level after passing through the power splitter ranges from -52 dBm through +18 dBm (E5100A-600 and E5100A-618). Even when using the pi-network test fixture featuring substantial signal damping, the CI value is 25 Ω, and power up to a maximum of 1 mW can be applied to the device. This permits evaluation over a wide range, from a very low to a very high level. Furthermore, use of the E5100A's phase tracking measuring function (E5100A-023 and E5100A-823) allows quick and detailed drive level of the evaluation characteristics.

Overview of the phase tracking measuring function

The phase tracking measuring function provides tracking to ensure that the measurement signal will reach the phase value (normally 0°) of the specified resonance, thereby obtaining the frequency and impedance at that phase. Based on the measurement result at the measuring point and the information from the 3 dB bandwidth of the device, the point of 0° phase (the resonant frequency) at that power and level is predicted, and measurement is repeated at the predicted frequency to ensure tracking of the 0° phase. Figure 2 illustrates the basic tracking procedure.

This method allows the fr and CI values to be tracked while the drive level is changed. This eliminates the need for frequency sweeping at each drive level. Thus, the tracking measuring function permits the measurement of the deviation of resonant frequency (Δf) and the drive level resonance impedance (|Z|) characteristics in one sweep, as shown in figure 3. The reference frequency of Δf is equal to the resonant frequency at the lowest drive level, which makes it possible to avoid the response delay resulting from changes in the device due to frequency sweep in the measurement of drive level characteristics of a device having a high Q factor, and cuts down your measurement time.

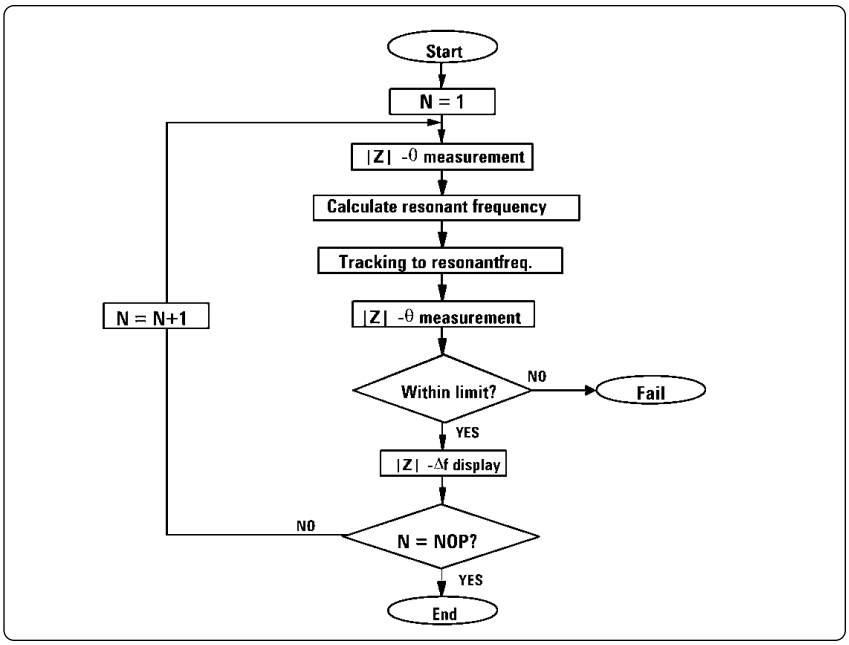

Figure 2. Flow of basic phase tracking functions

An example of measuring the actual drive level characteristics

In the measurement of actual drive level characteristics, the SRCHFR? command searches for resonant frequency at the drive level of the first of the drive level characteristics after execution of pi-calibration. The phase tracking measuring function obtains the drive level characteristics in the vicinity of the resonant frequency (see figure 4). Figure 5 illustrates the measurement of the characteristics in one sweep when the drive level is raised from 10 nW to 100 µW or lowered from 100 µW to 10 nW.

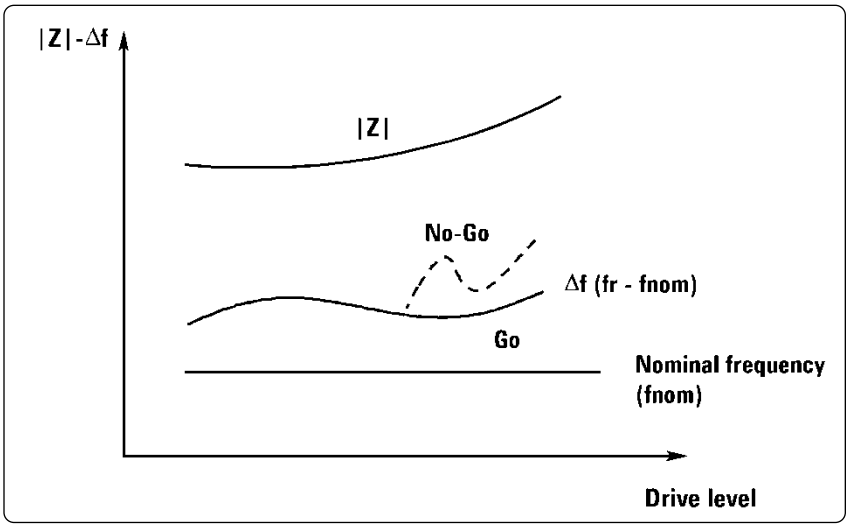

Figure 3. Drive level sweep by phase tracking function

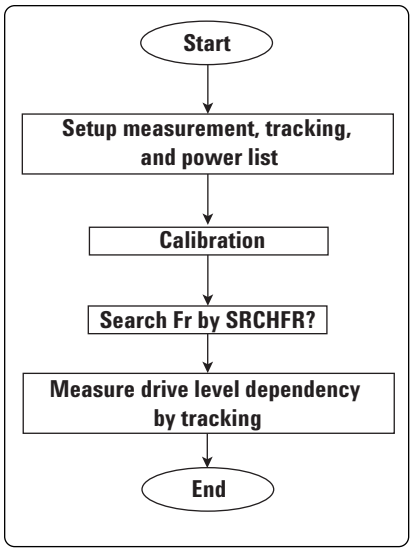

Figure 4. Flow of drive level characteristics measurement

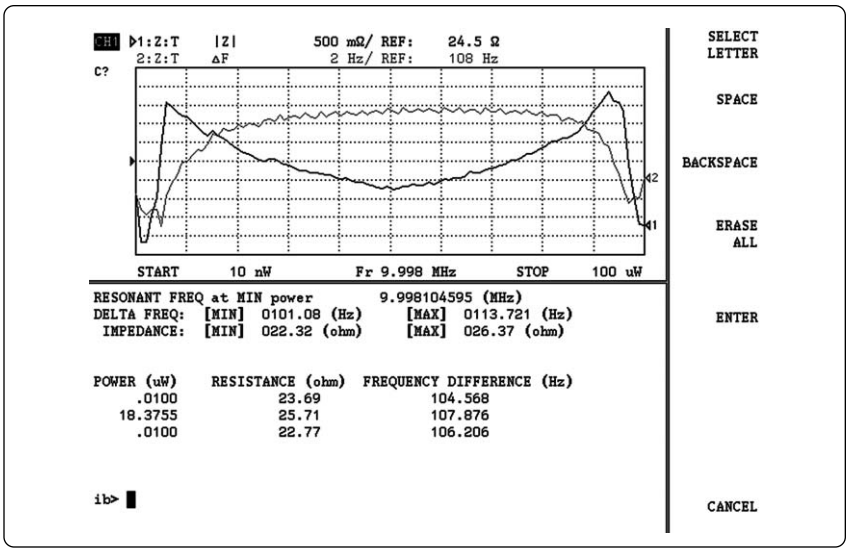

Figure 5. An example of measuring drive level characteristics

Tracking measurement in temporal changes

The phase tracking measuring function can be used to measure drive level characteristics as well as transient characteristics of the device responding to environmental changes. For example, when the device is subjected to abrupt changes in temperature from low to high in order to measure steep transient changes in resonant frequency and resistance of the device, measurement may not be completed in time if frequency must also be measured. This problem is solved by the phase tracking measuring function which ensures highly reliable measurement without missing abrupt changes in characteristics. Use of the phase tracking function provides quick GO/NO-GO selection and detailed evaluation of the drive level characteristics of the device.

Evaporation system control (E5100A-022)

In evaporation of a crystal resonator, resonant frequency is lowered and adjusted to the desired level during silver deposition. The evaporation system requires the amount of evaporated silver to be controlled while changes in resonant frequency are measured during evaporation. The frequency trap function of the E5100A (E5100A-022) ensures the quick monitoring of changes in the resonant point, without using the normal frequency sweep. This function allows real-time transmission of the changes in the resonant frequency of the device, using control signals and provides highly efficient control of the evaporation system.

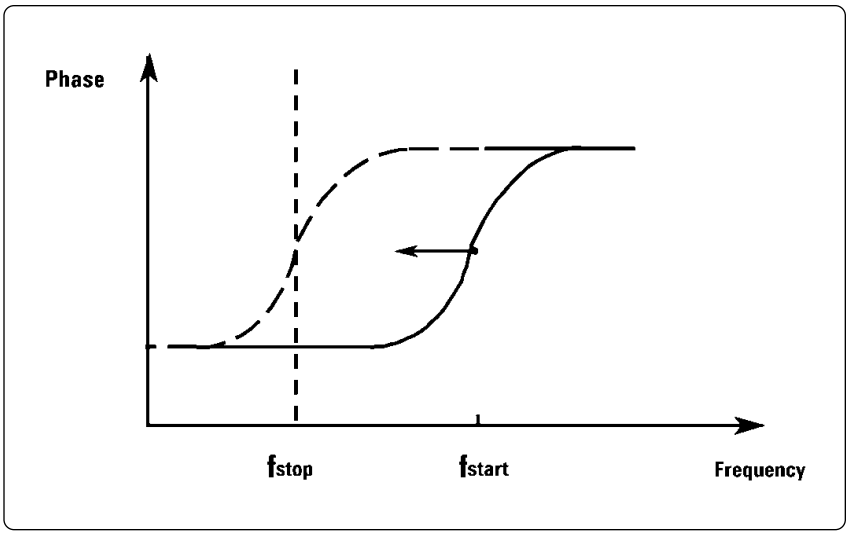

Figure 6. Behavior of the device resonant frequency during evaporation

Basic operation of the frequency trap function in the evaporation process

With the start of evaporation, the device resonant frequency (frequency at phase 0°) starts to decline from its resonant frequency (f-START) prior to evaporation and approaches the target frequency (f-STOP), as illustrated in figure 6. In this case, as shown in figure 7, the phase value begins to exhibit a gradual increase from around -90° at the target frequency (f-STOP), and the phase becomes 0° when the device resonant frequency has reached the target frequency during evaporation.

To adjust the device resonant frequency to the target frequency, the E5100A continues phase measurement at the target frequency from the start of adjustment. The system determines that the target frequency is reached when the phase has changed from a negative value to 0° at that frequency and sends the I/O control signal to the evaporation system to terminate evaporation.

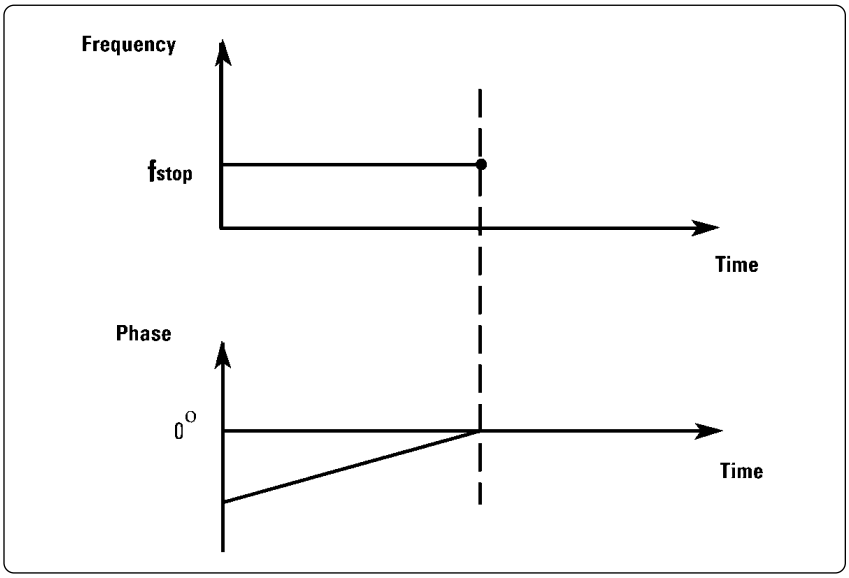

Figure 7. Changes of phase at the target frequency during evaporation

An example of use in an actual evaporation system

As in the basic operation shown above, where the evaporation control consists of only on/off control, evaporation should be terminated if the phase has reached 0° at the target frequency. In addition to such on/off control in actual evaporation, however, it is possible to control the frequency adjustment by the gradual reduction of the amount of deposited silver, as illustrated in figure 8. This is made possible by repeating the above procedure. A concrete example is given in figure 9. The E5100A measuring frequency is set at more than one point. It is set between the frequency prior to adjustment and the target frequency, as well as at the final target frequency. Phase measurement is carried out sequentially from the highest frequency. When the phase of 0° is measured, the I/O signal is sent and the next frequency is measured; this process is repeated.

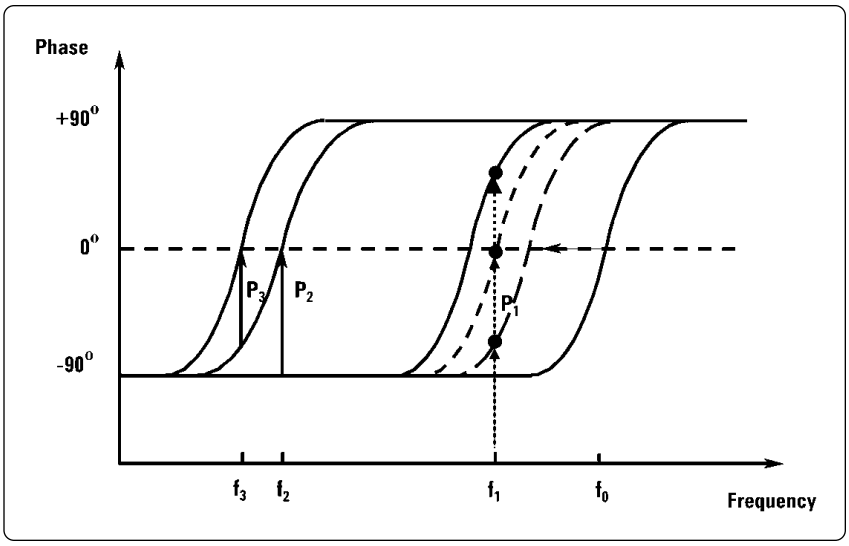

Figure 8. Changes of device phase in evaporation control at more than one point

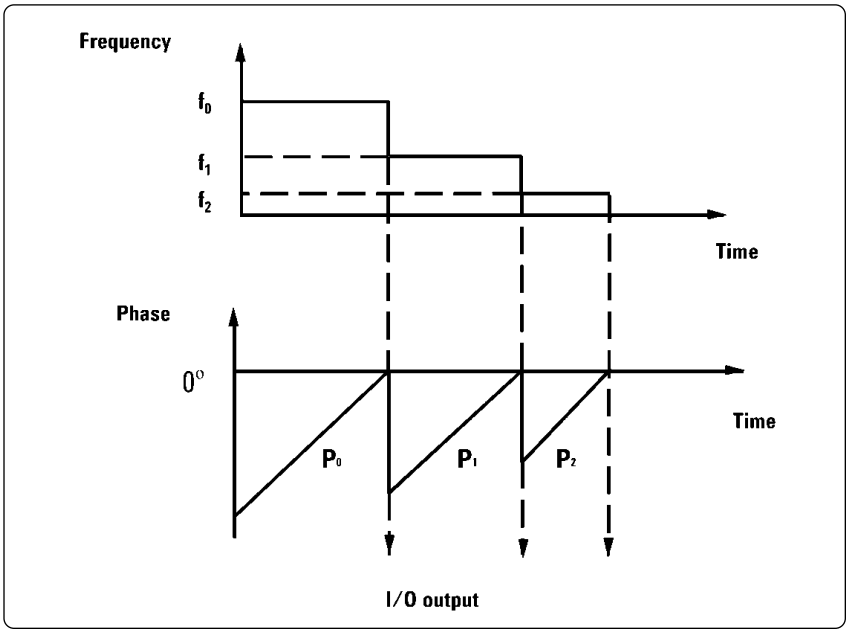

Figure 9. Changes of E5100A measurement frequency and measurement phase in evaporation control at more than one point

Additional E5100A functions and characteristics in crystal device measurement

High speed measurement and analysis

- **List sweep function**
  This function permits the high speed measurement of a maximum of 0.04 ms/points. In addition, the list sweep function provides high speed measurement by setting the measurement segment only at the frequency and level required for measurement. Even when the measurement frequencies are separated from each other, as, for example, in simultaneous evaluation of the basic resonance and harmonics, this function permits measurement of only frequencies close to the desired frequency and their effective measurement and analysis.

- **High speed analysis command/ resonance parameter analysis**
  Crystal parameter analysis: This function provides a high speed analysis of resonant frequency (Fr) and resonance resistance (CI value) at the phase of 0° as basic parameters of the crystal resonator, with a single command.

  Analysis of spurious levels (resistance): Spurious response may be present as a specific characteristic of the device. Generally, spurious occurs within a frequency range of ±10% of the resonant frequency. High-quality resonance circuits can be designed only when resistance of the circuit is sufficiently higher than the resonance resistance at the nominal resonant frequency. Thus, not only the CI value close to the nominal frequency but also spurious level are sometimes evaluated to see if there is any spurious effect. In this case, the measurement shown in figure 2 is performed to confirm differences in resistance between the two.
  The E5100A uses the maximum/ minimum peak values analysis function to provide high speed evaluation of spurious signal resistance and the CI value.

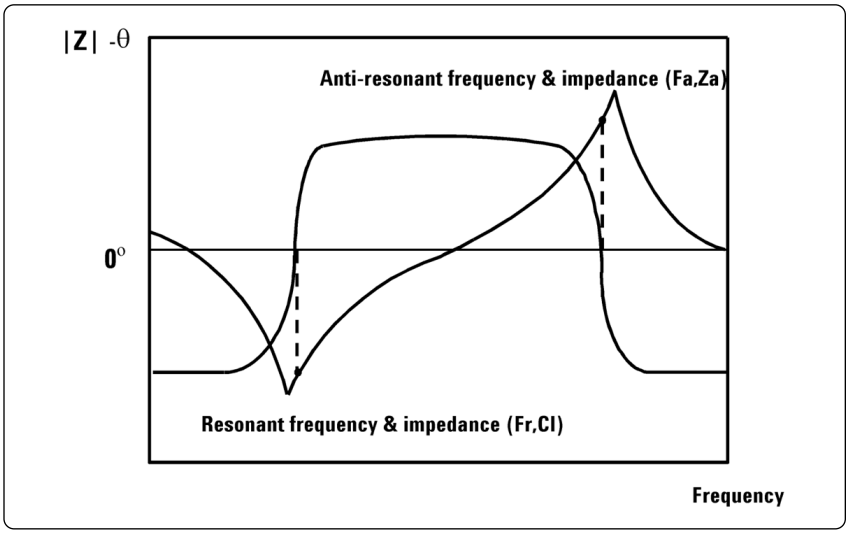

Figure 10. High speed analysis of resonant frequency and resistance at the phase of 0°

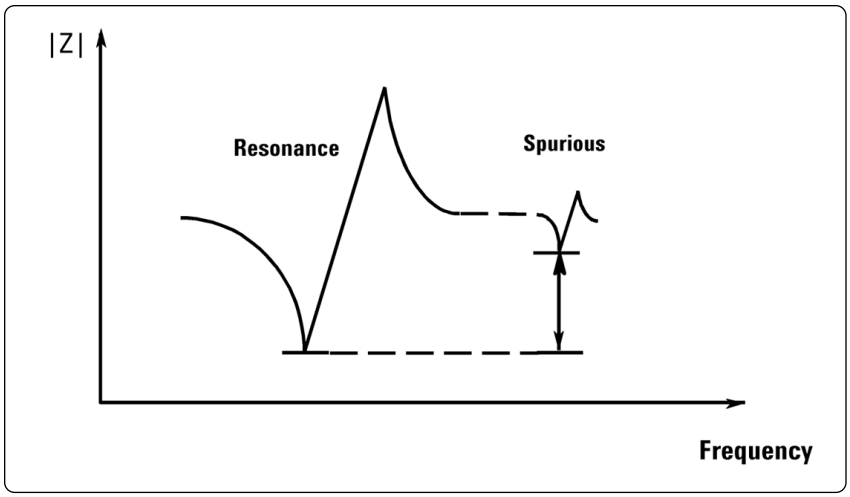

Figure 11. Comparison of the CI value and spurious signal resistance

- **Equivalent circuit analysis function**
  The equivalent circuit constant as well as the resonant frequency and resistance of the device are important parameters in evaluating the characteristics of the device. Generally, the 4-element equivalent circuit shown in figure 12 is used as a crystal resonator equivalent circuit. In practice, however, resistance is also present in the resonator lead and electrode. Therefore, more accurate analysis may be ensured by the 6-element equivalent circuit as given in figure 12. Furthermore, if the measurement data close to the resonant point is used to analyze the parallel capacitance C0 as an equivalent circuit parameter, a capacitance greater than the actual C0 value due to the influence of sub-resonance will result. In this case, measurements mode at a frequency sufficiently separated from the resonant frequency are effective an effective method for separating C0 from the data obtained in this way. In addition to the general 4-element equivalent circuit analysis command, the E5100A also has commands to analyzes the 6-element equivalent circuit and to analyze the C0 value with sub-resonance and its effect eliminated. This ensures stricter, high speed equivalent circuit constant analysis.

- **High speed resonant point search by SRCHFR? command (E5100A-023 and E5100A-823)**
  Without using the frequency sweep, the SRCHFR? command automatically moves the E5100A signal source to the 0° phase point, thereby finding the Fr and CI values. This function finds the Fr and CI values at a much higher speed than normal frequency sweep measurement. The SRCHFR? command is particularly effective for devices having high Q-values. Sweeping over an extensive range will be required if accurate resonant frequency is not clear. When the measurement range is the same, measurement with the SRCHFR? command is much more rapid than by frequency sweep. For example, measurement requiring about 350 msec. by frequency sweep method can be completed only in 31.2 msec. by the SRCHFR? command. Since measurement is made directly at the phase of 0°, this method provides higher frequency accuracy than interpolation with frequency sweep.

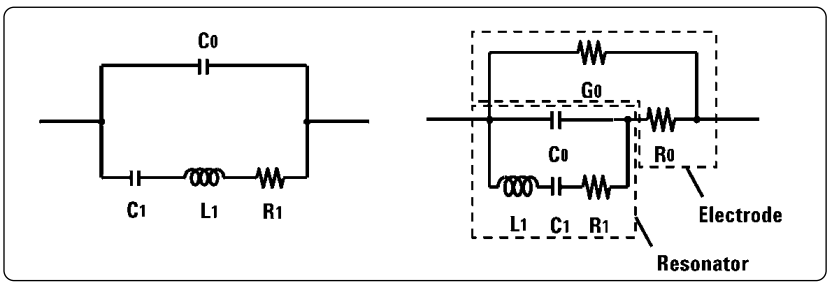

Figure 12. 4- and 6-element equivalent circuit models

High accuracy measurement when using pi-network test fixture

The pi-network test fixture shown in figure 13 is currently used as a measurement fixture for high frequency crystal resonators than 1 MHz. The E5100A provides many functions to facilitate the use of the pi-network test fixture.

- **Direct power setting when using pi-network test fixture**
  The network analyzer output power has been represented in terms of dBm. In addition to this, the E5100A permits setting in terms of watts and amperes, with consideration given to damping when using the pi-network test fixture. Accordingly, the drive level applied to the device can be set directly from the front panel.

- **3-term calibration function of pi-network test fixture**
  When using the pi-network test fixture for measurement, through-calibration alone will make it more difficult to remove the impact of residual impedance and stray admittance around the fixture with increasing frequency (mainly in the range of 10 MHz or more) and will result in increased measurement errors. This problem can be solved by the 3-term calibration function (pi-calibration function) of the E5100A.

  Basic pi-calibration principles

  As shown in figure 14, the pi-network test fixture in S21 measurement contains four error components. Assuming the device equivalent circuit as shown in figure 15. Then these error components can be replaced by three variables. To eliminate these three error components, three standards (open/short/load) are used to perform 3-term calibration (pi-calibration), as shown in figure 16. This pi-calibration allows all three error components to be removed and enables the pi-network test fixture to make highly accurate measurements at high frequencies that would be difficult if only conventional through-calibration were used.

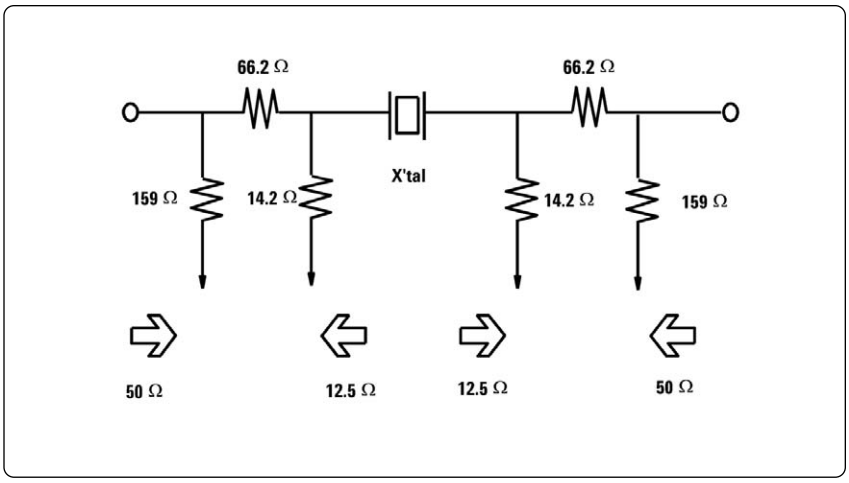

Figure 13. Pi-network test fixture

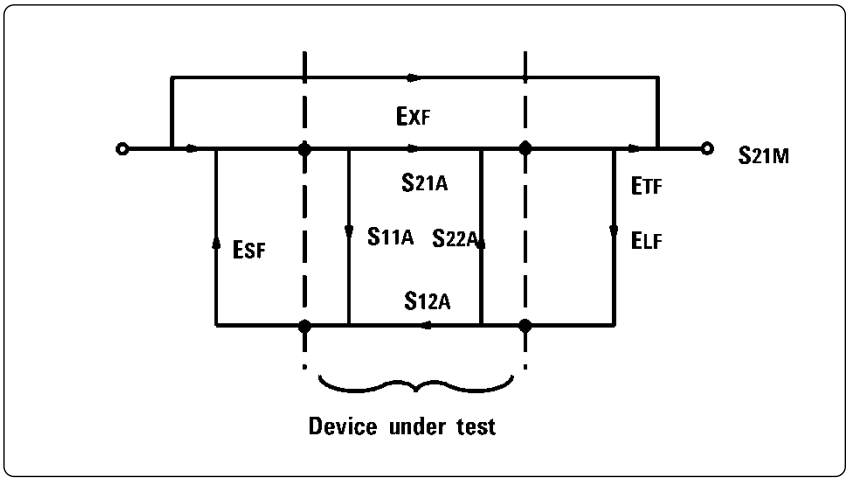

Figure 14. Pi-network

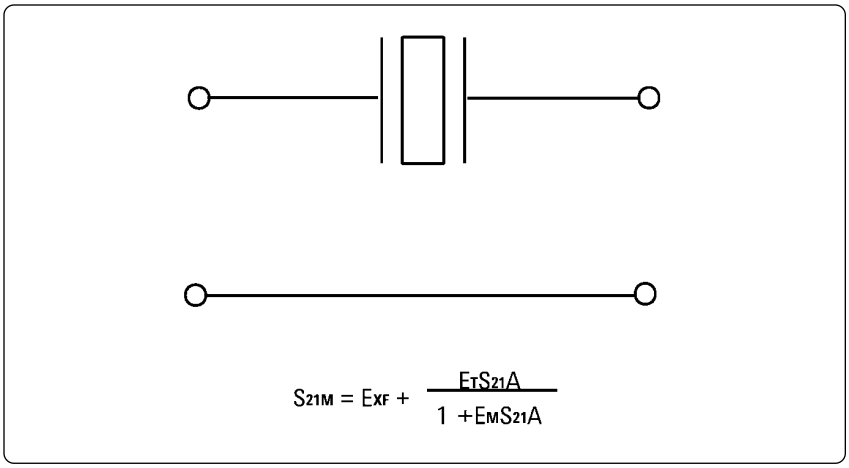

Figure 15. Basic formula for device equivalent circuit and 3-term calibration

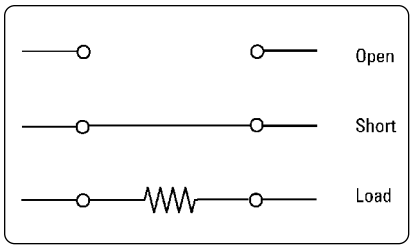

Figure 16. Three standards for pi-calibration

Automatic measurement and effective data processing

Instrument BASIC (IBASIC) programming function

The system has a built -in IBASIC programming function and provides automatic measurement and GO/NO-GO selection as a single the network analyzer. In addition to control of measuring functions from an external PC, the E5100A supports a program subsystem command that allows measurement and analysis data processing in the PC-controlled automatic measurement system and optimization of the measurement sequence. When this function is utilized, analysis data and calculation results obtained from the IBASIC program can be transmitted to the external PC. This function also allows changes in the IBASIC arrays from the external PC, and permits transfer of the IBASIC program itself between the external PC and E5100A. Figure 17 illustrates the use of the program subsystem command to the variables gained in the IBASIC program from an external PC. This function serves to ensure that measurement, analysis and data analysis processing are executed by the IBASIC program, and that only the final result is sent to the external PC. This allows the external PC processing load to be reduced, and enables all measurement-related files to be managed on the PC.

Furthermore, the EXECUTE command is dedicated to the IBASIC program, thus providing quicker handshaking than the GPIB command, and ensuring high speed data analysis.

3.5-inch FDD and built-in RAM disk

The DOS format 3.5-inch floppy disk drive incorporated in the system ensures easy program management and statistical processing of the measurement data by the PC.

24 bit/8 bit parallel I/O interface

Use of the parallel I/O interface allows high speed handshaking with the automatic equipment. This function ensures effective system design for automatic measurement accompanying the GO/NO-GO selection. This function can also be used for trigger input from an external switch, including a foot switch in the manual measurement mode.

Conclusion

The many functions of the E5100A support an effective crystal resonator production line and from pre-process to post-process, provide an effective means of evaluation throughout an automatic inspection line.

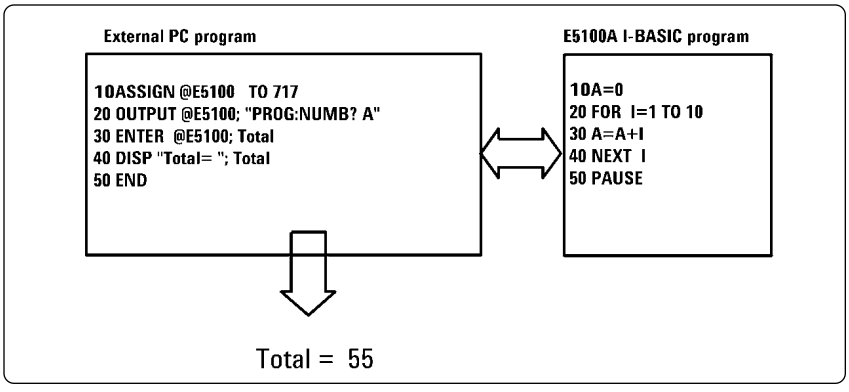

Figure 17. An example of data transmission using the program subsystem command

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Printed in USA, July 13, 2006
5965-4972E

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