Agilent AN 1308-1
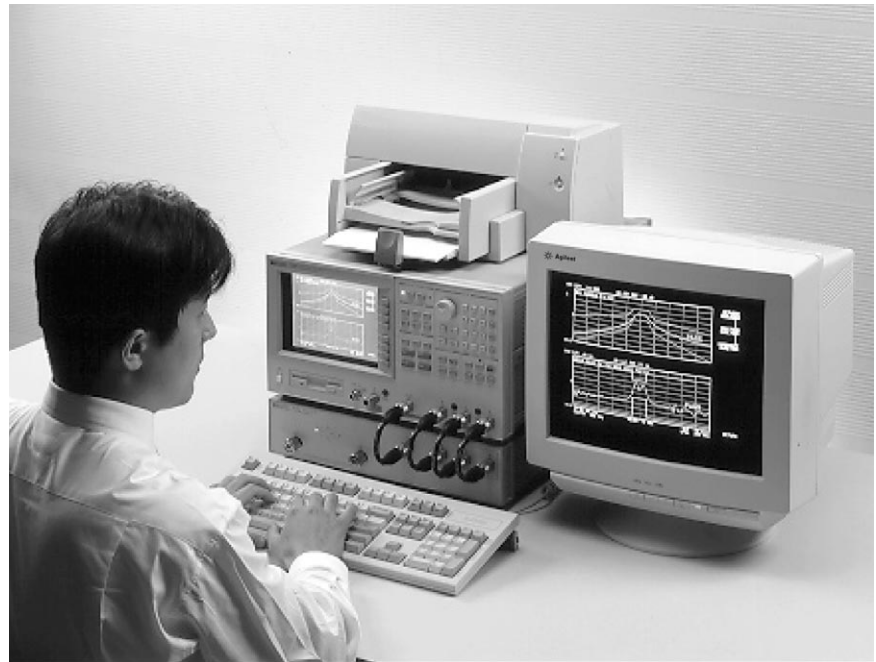
Network, Spectrum, and Impedance Evaluation of Electronic Circuits and Components

Application Note

Agilent 4395A/Agilent 4396B
Network/Spectrum/Impedance
Analyzer

Agilent Technologies
Innovating the HP Way

Introduction

With the current trends requiring higher performance, smaller physical size, lower cost, and higher reliability, fast cycle time is an increasingly important part of the product design. This is true not only in the consumer industry, but also in the communication and data processing industries.

As shown in Figure 1, the development procedure involves designing the overall architecture, evaluating electronic components, building prototypes, and evaluating circuit performance. From the design point of view, it is essential to measure the impedance characteristics of electronic components such as capacitors, inductors, or other devices at the actual working condition. An impedance analyzer makes this task easy.

After making a prototype, a review of the circuit operation requires measurement of the following parameters: harmonics, noise, transmission characteristics, and reflection characteristics. The vector network analyzer, and the spectrum analyzer must be used for making these measurements. The Agilent Technologies 4395A/4396B Network/Spectrum/Impedance Analyzer Family combines three analyzer functions in one instrument. This application note describes how the 4395A/96B can be used to contribute fast cycle time for product development.
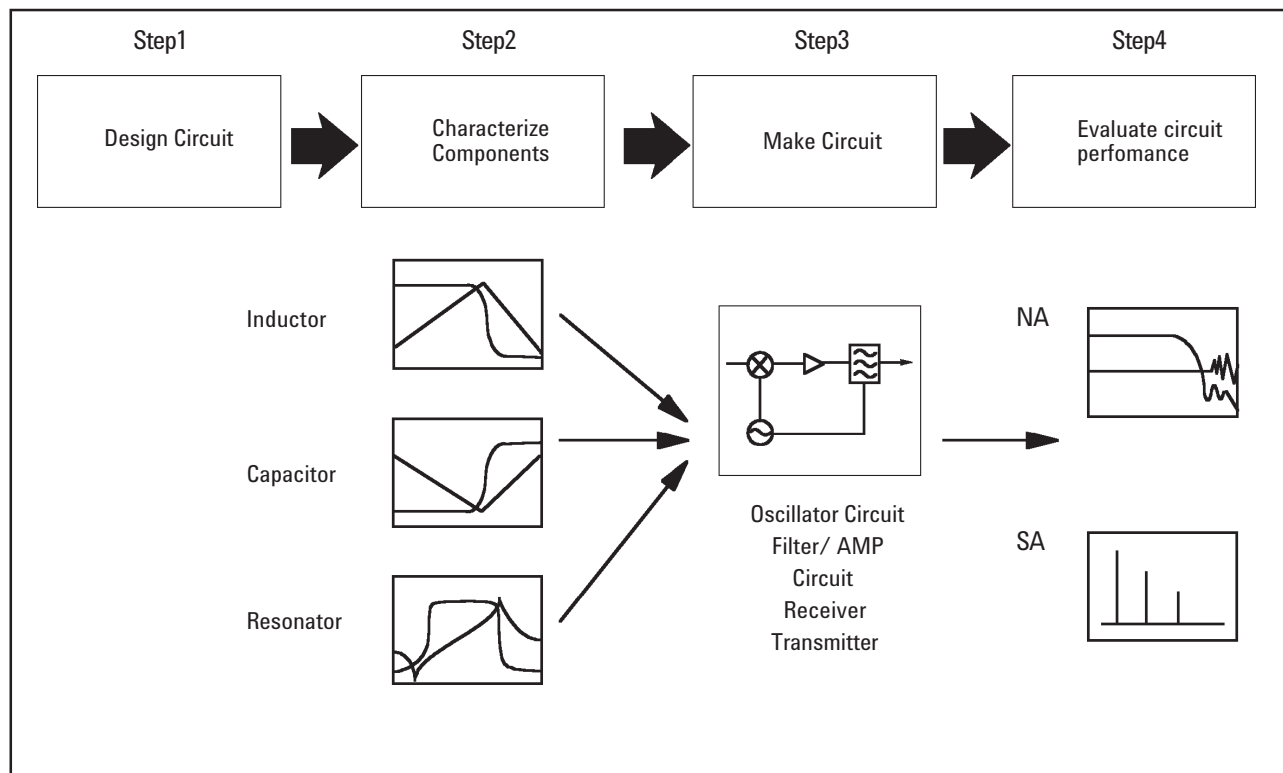

Figure 1. Circuit Development Process

The Agilent Combination Analyzers have the following features

Three analyzers in One box

As the name implies, the Agilent 4395A/4396B Network/Spectrum/Impedance Analyzer Family can perform vector network, spectrum, and (optional) impedance measurements. The combination analyzer family does not compromise vector network, spectrum, or impedance performance. It is a breakthrough in test instruments, giving you outstanding performance as a full-capability combination analyzer. Precision measurements and improved efficiency are possible with minimal training. Compared with using separate instruments, the 4395A/96B will save equipment cost and bench space.

Vector Network Analyzer Performance

The Agilent Combination Analyzer Family offers you fast measurement with wide dynamic range. Transmission and reflection data can be provided with an optional Reflection/Transmission Test Set or optional S-Parameter Test Set. As a vector network analyzer, the 4395A operates from 10 Hz to 500 MHz. The 4396B operates from 100 kHz to 1.8 GHz.

Spectrum Analyzer Performance

The Agilent Combination Analyzers, designed with new digital techniques, outperform the traditional analog spectrum analyzer. Agilent's Combination Analyzers feature a Fast Fourier Transform (FFT) digital-signal processing (DSP) technique for 20 to 100 times faster narrow-band spectrum measurement, when compared with swept-tuned spectrum analysis. The Agilent analyzer's stepped FFT tech-nique (4395A: all RBWs, 4396B: 1Hz to 3kHz RBW) breaks the speed barrier to give you lower noise floors without sacrificing speed. In addition, low phase noise provides improved signal resolution. Option 1D6 (The Time-Gated Spectrum Analysis Function) performs accurate burst signal analysis for burst-modulated signal evaluation. As a spectrum analyzer, the 4395A operates from 10 Hz to 500 MHz. The 4396B operates from 2 Hz to 1.8 GHz.

Impedance Analyzer Performance

When equipped with Option 010 and the Agilent 43961A, Combination Analyzers can perform direct impedance measurements. Measurement parameters such as |Z|, θ, C, L, Q, D, and more can be displayed directly on the color display. A built-in lumped equivalent circuit function aids circuit modeling and simulation. As an Impedance Analyzer, the 4395A operates from 100 kHz to 500 MHz. The 4396B operates from 100 kHz to 1.8 GHz.

Other Useful Functions

IBASIC, a subset of the HT BASIC programming language, is included with the standard 4395A/96B. IBASIC is extremely powerful and easy to use. It can be used for automated testing, analysis of measurement results, or control of external equipment via GPIB. Files such as instrument state files, TIFF files, and data files can be transferred via GPIB to the controller/PC (host), which can easily manipulate the files. Usability and productivity are improved through features such as the DOS supported Floppy Disk Drive, the list sweep function, the marker function, and the limit line function.

Table 1. Agilent 4395A Major Specification

Network Analyzer Specification		Spectrum Analyzer Specification		Impedance Analyzer Specification[2]	
Frequency Range	10 Hz to 500 MHz[1]	Frequency Range	10 Hz to 500 MHz	Frequency Range	100 kHz to 500 MHz
Frequency Resolution	1 mHz	Noise Sidebands	<-104 dBc/Hz typical at 10 kHz offset	Meas. Parameter	$\|Z\|$, θz, R, X, $\|Y\|$, θy, G, B, Cs, Cp, Ls, Lp, Rp, Rs, X, D, Q, $\|\Gamma\|$, Γx, Γy
Output Power Range	-50 to 15 dBm	Resolution Bandwidth	1 Hz to 1 MHz in 1-3-10 steps	Z Accuracy	3 % (typical, basic accuracy)
Dynamic Range	115 dB@10 Hz IFBW	Dynamic Range	> 100 dB third-order free dynamic range	Source Level	-56 dBm to +9 dBm(at DUT)
				DC Bias	40 V (20 mA(max))
Dynamic Accuracy	0.05 dB/0.3 deg.	Level Accuracy	0.8 dB@50 MHz		(Opt-001 DC source or
Calibration	full two-port	Sensitivity	-145 dBm/Hz @freq. = 10 MHz		External DC source is required.)
				Compensation	open/short/load Port Extension
Standard Features	: Instrument BASIC, GPIB port, 3.5" floppy disk drive, direct print, RAM disk, VGA Monitor Output				
Optional Features	: Impedance measurement (Opt. 010), Time-Gated spectrum Analysis (Opt. 1D6), High-Stability Frequency Reference (Opt. 1D5), 50 Ω to 75 Ω Spectrum Input Impedance Conversion (Opt. 1D7), DC Source(> 40V, 100 mA (ALC)) (Opt. 001)				

1. 100 kHz to 500 MHz if using the 87511A/B S-parameter test set.
2. With Option 010 and the 43961A RF impedance test kit.

Table 2. Agilent 4396B Major Specification

Network Analyzer Specification		Spectrum Analyzer Specification		Impedance Analyzer Specification[2]	
Frequency Range	100 kHz to 1.8 GHz[1]	Frequency Range	2 Hz to 1.8 GHz	Frequency Range	100 kHz to 1.8 GHz
Frequency Resolution	1 mHz	Noise Sidebands	<-113 dBc/Hz typical at 10 kHz offset	Meas. Parameter	$\|Z\|$, θz, R, X, $\|Y\|$, θy, G, B, Cs, Cp, Ls, Lp, Rp, Rs, X, D, Q, $\|\Gamma\|$, ΓX, Γy
Output Power Range	-60 to 20 dBm	Resolution Bandwidth	1 Hz to 3 MHz in 1-3-10 steps	Meas. range	2 Ω to 5 kΩ
Dynamic Range	>120 dB@10 Hz IFBW	Dynamic Range	> 100 dB third-order dynamic range	Z Accuracy	3% (typical, basic accuracy)
				Source Level	-66 dBm to + 14 dBm (at DUT)
Dynamic Accuracy	0.05 dB/0.3 deg.	Overall Level Accuracy	< 1.0 dB	DC Bias	40 V (20 mA(max))
Calibration	full two-port	Sensitivity	< -147 dBm/Hz @freq. = 1 GHz		(External DC bias source is required.)
				Compensation	open/short/load Port Extension
Standard Features	: Instrument BASIC, GPIB port, 3.5" floppy disk drive, direct print, RAM disk, VGA Monitor Output				
Optional Features	: Impedance measurement (Opt. 010), Time-Gated spectrum Analysis (Opt. 1D6), High-Stability Frequency Reference (Opt. 1D5), 50 Ω to 75 Ω Spectrum Input Impedance Conversion (Opt. 1D7)				

1. 300 kHz to 1.8 GHz if using the 85046A/B S-parameter test set.
2. With Option 010 and the 43961A RF impedance test kit.

Agilent Combination Analyzer Family Measurement Examples

The Combination Analyzer Family is a powerful tool for effective evaluation of electronic circuit and device performance. The following shows you some examples of measurements made by the combination analyzers.

Amplifier Evaluation

Amplifier characterization requires the evaluation of a variety of measurement parameters via vector network analysis and spectrum analysis. Figure 2 shows the major measurement parameters for amplifier evaluation.
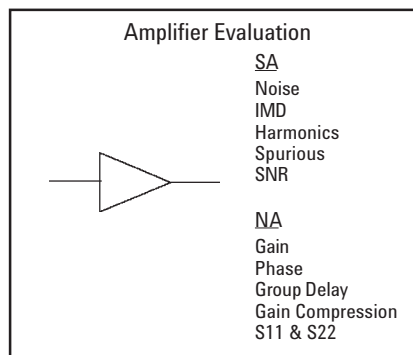

Amplifier Evaluation

SA
Noise
IMD
Harmonics
Spurious
SNR

NA
Gain
Phase
Group Delay
Gain Compression
S11 & S22

Figure 2. Major Measurement Parameters of Amplifier

Network Evaluation for Amplifier

The measurement configuration for network analysis of an amplifier is shown in Figure 3. Either an optional Reflection/Transmission test set or an optional S-parameter test set is required to perform this analysis.

Agilent 4395A/96B

Agilent 87512A R/T Test Set

Amplifier under test

(1) R/T Test Set is used

Agilent 4395A/96B

S-parameter Test Set

Amplifier under test

(2) S-Parameter Test is used
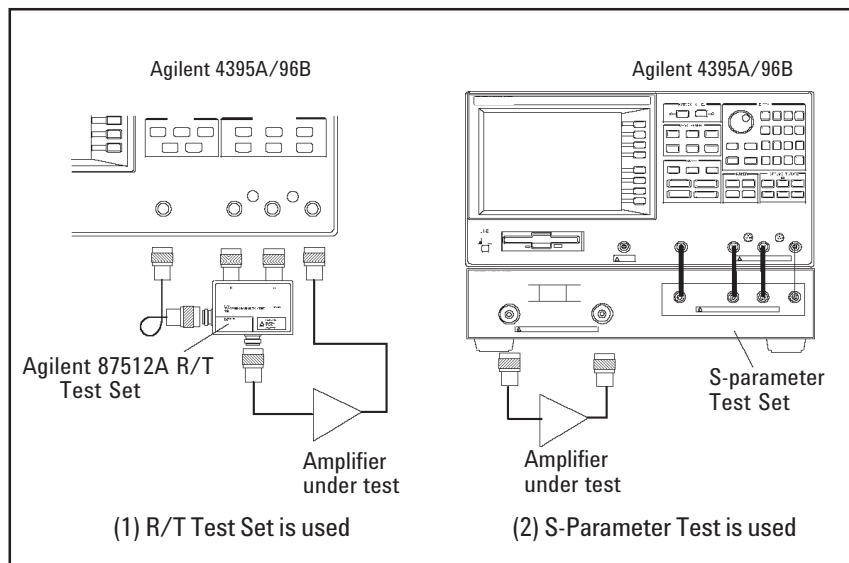
Figure 3. Measurement Configuration for Amplifier Network Analysis.

CH1 B/R log MAG   10 dB/ REF −40 dB

GAIN OF THE AMPLIFIER

Hld
IF BW 30 kHz   POWER 0 dBm   SWP 248.1 msec
CH1 START   300 kHz   STOP   500 MHz

CH2 B/R phase   200 °/ REF −400 °

PHASE OF THE AMPLIFIER

Hld
IF BW 30 kHz   POWER 0 dBm   SWP 248.1 msec
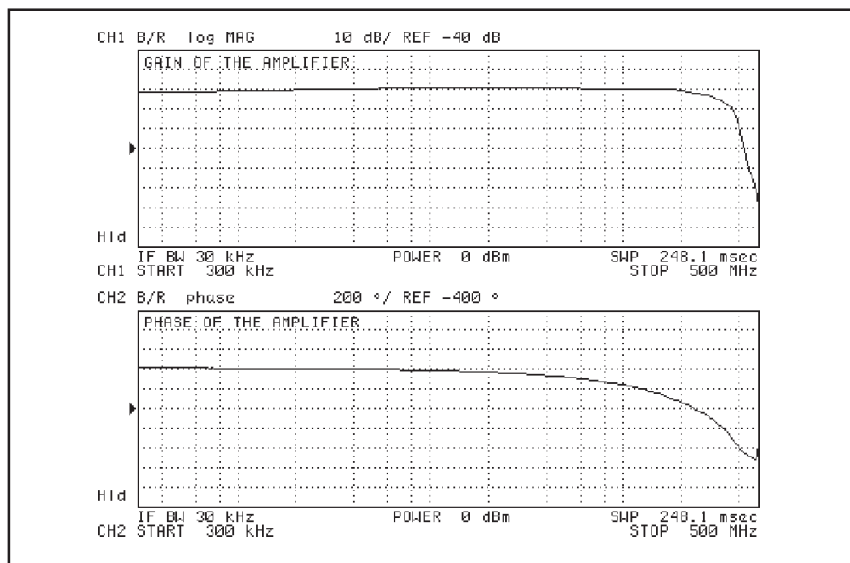CH2 START   300 kHz   STOP   500 MHz

Figure 4. Gain/Phase of the Amplifier

Gain and Phase Measurement

The amplifier gain is defined as the ratio of the amplifier output power (delivered to a Z_0 load) to the input power (delivered from a Z_0 source), where (Z_0) is the characteristic impedance of the system. The Amplifier gain is most commonly specified as a typical or minimum value over a specified frequency range, while assuming that input and output signals are in the amplifier's linear operating range. Figure 4 shows the gain and phase measurement result of an amplifier.

Gain Compression Measurement

The amplifier gain at a single frequency is based on ideally linear performance between the input power and the output power. The real amplifier gain is nonlinear. The output power becomes saturated even if the input power is increased. The most common measurement of amplifier compression is the 1-dB compression point. This is defined as the input power which results in a 1-dB decrease in amplifier gain. The easiest way to measure the 1-dB compression point is to directly display normalized gain (ratio between the reference channel and the test channel).

Figure 5 shows the gain compression measurement result (normalized gain). The flat part of the trace is linear, and the curved part (of the right side) corresponds to compression caused by higher input power. The Agilent Combination Analyzers have the ability to do power sweeps where the maximum range is 20 dB. The marker function can easily indicate the 1-dB decrease point. These functions help you to easily evaluate the gain compression of the amplifier.

Return Loss (S$_{11}$, S$_{22}$) Measurement

When S$_{11}$, S$_{22}$, or Return loss are measured, either the Reflection/Transmission Test Set or the S-Parameter test set is required (as shown in Figure 3).
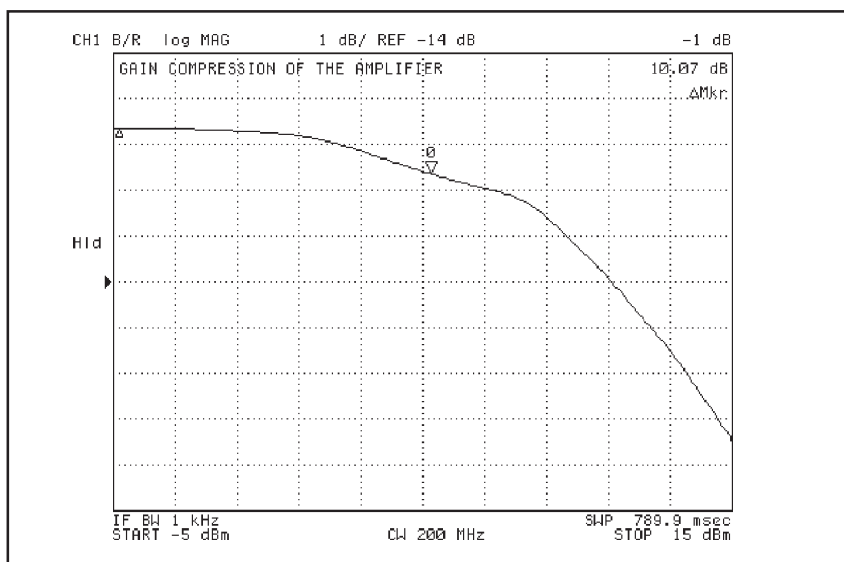
Figure 5. Gain Compression of Amplifier

The input and output in a high frequency circuit are matched with a characteristic impedance, which may drift from the ideal characteristic impedance depending on frequency. This change in characteristic impedance will cause reflections. The indicated reflection parameters are the reflection coefficient (Gamma (S$_{11}$ or S$_{22}$)) and return loss(Rl). The return loss is calculated by using the following formula.

$$Rl = -20 \times \log(S_{11}) \text{ or } -20 \times \log(S_{22})$$

When the input and the output are perfectly matched, there is no reflection, which means R1 is minus infinity. Figure 6 shows the return loss measurement result example for an amplifier.

In case of using the S-parameter test set with the instrument, you can perform the full two-port calibration to obtain the best accuracy for the input or output impedance and the other evaluations.
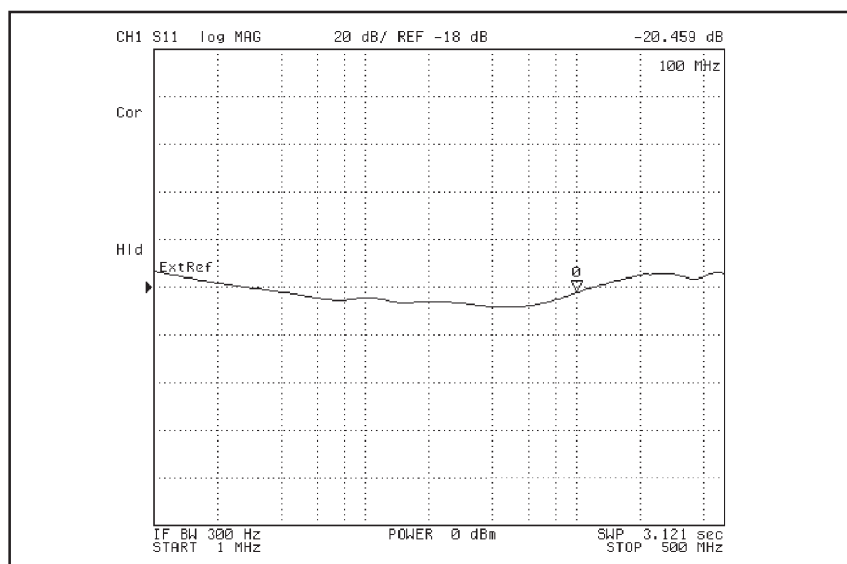
Figure 6. Return Loss Measurement Example

Spectrum Evaluation for Amplifier

Harmonic Distortion Measurement

Nonlinear behaviors in the amplifier will cause harmonics of the input signal to appear at the output along with the fundamental. These harmonics are integer multiples of the input (fundamental) frequency, and are usually specified in terms of dB below the fundamental signal for a given input level (commonly expressed as dBc). The measurement configuration for the harmonic distortion is shown in Figure 7.

The 4395A/96B has a multiple marker function. This function can easily indicate all of the harmonic distortion points. Figure 8 shows the measurement example for harmonic distortion of an amplifier.
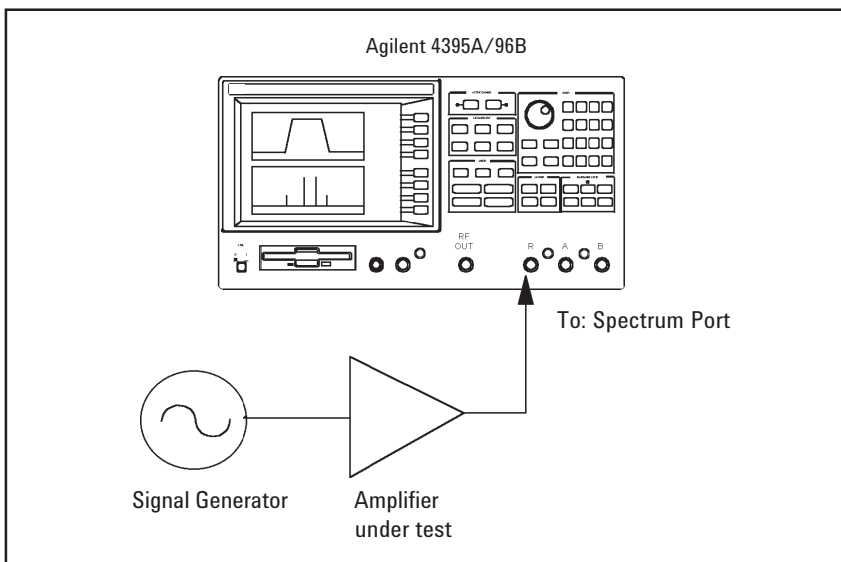
Figure 7. Measurement Configuration for Harmonic Distortion
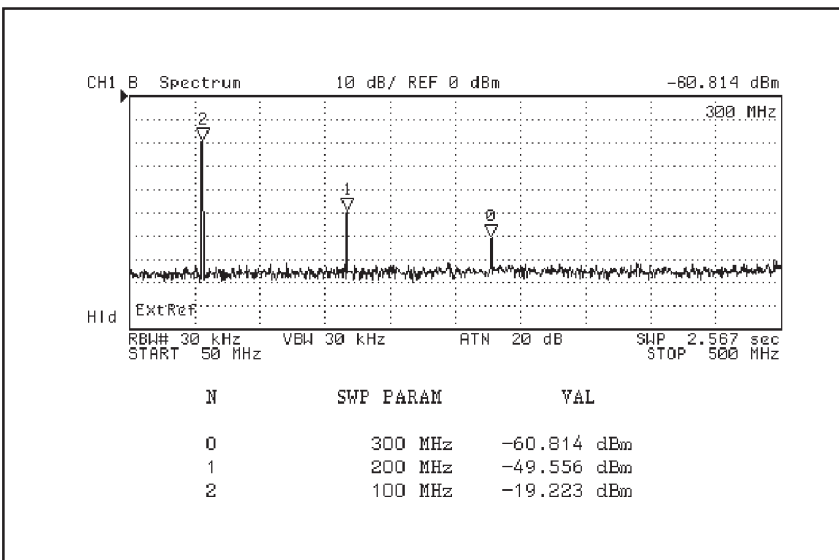
Figure 8. Harmonic Distortion Measurement

Intermodulation Distortion Measurement
Another nonlinear behavior in amplifiers is intermodulation distortion. When two input signals are applied to a nonlinear amplifier, the output contains additional frequency components. These additional components are the intermodulation distortion products. As products of a two-tone example, the output signal will contain frequency components at the two fundamental input frequencies [f_1 and f_2]; harmonics will be seen at [$2 \times f_1$, $2 \times f_2$, $3 \times f_1$, and $3 \times f_2$]; second-order products at [f_1+f_2 and f_1-f_2]; and third order products at [$2 \times f_1-f_2$ and $2 \times f_2-f_1$]. The third order products are very close to the fundamentals and typically fall within the bandwidth of the amplifier. To measure intermodulation distortion, two signal generators are required. The signal generators outputs are connected together through a coupler or combiner. This device must ensure sufficient isolation between the two RF sources so that no intermodulation occurs in their output stages. The measurement configuration is shown in Figure 9.

The Agilent 4395A/96B, using the list sweep function, allows you to break the span into segments with variable numbers of points and RBW's. This optimizes the sweep speed for proper dynamic range, and enables you to look at both the two tone signals and the intermodulation distortions. Figure 10 shows the measurement results by using the list sweep function.
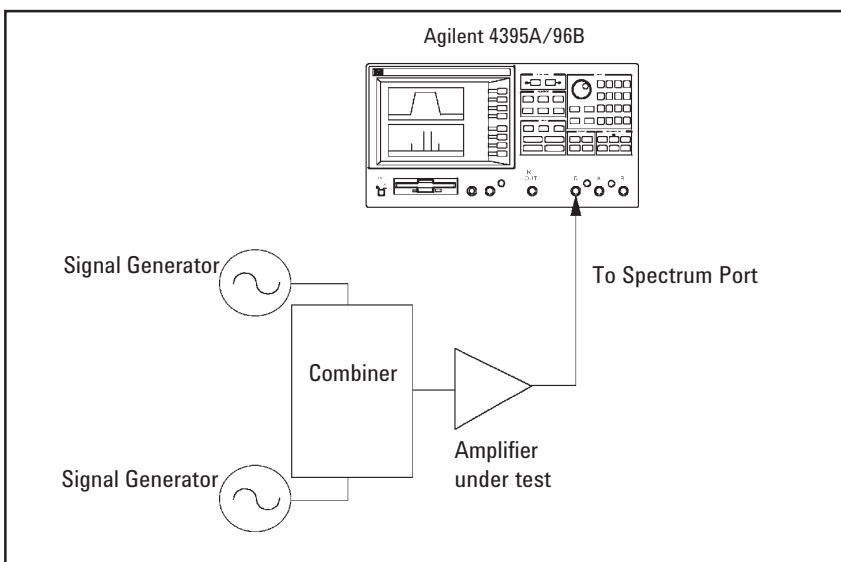

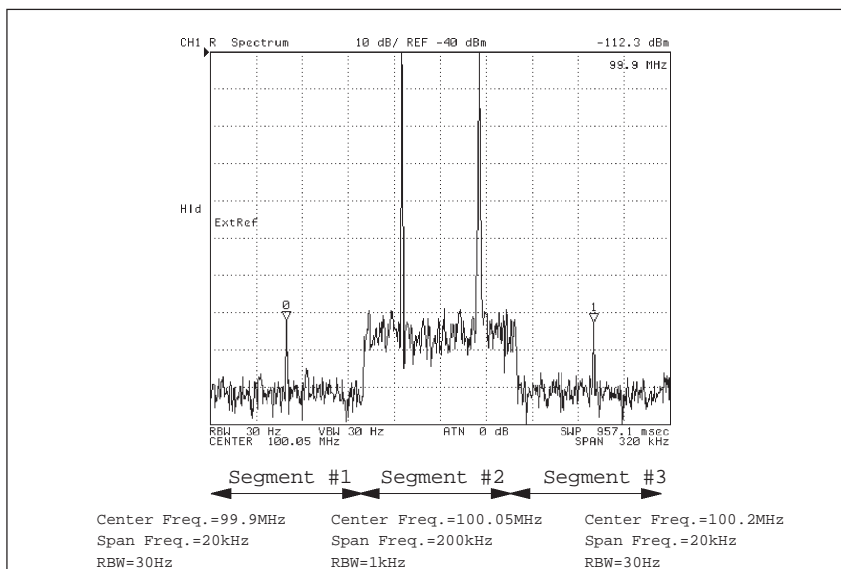**Figure 9. Measurement Configuration of the Intermodulation Distortion**

Figure 10. Measurement Results of Intermodulation Distortion by Using List Sweep Function

Noise Figure (NF) Measurement

Noise Figure (NF) expresses the degree of noise generated in an amplifier. The NF value for an ideal amplifier, with zero internal noise, is 1 (=0dB). The NF value for an amplifier is determined with the following formula.

$$NF = \frac{Cin/Nin}{Cout/Nout} = \frac{Cin/kTB}{CinG/Nout} = \frac{Nout}{GKTB}$$

Where,
Cin = Input Signal Power [W]
Nin = Noise Signal Power [W]
Cout = Output Signal Power [W]
Nout = Output Noise Power [W]
K = Bolzmann's constant =
1.281×10^{-13} (J/°K)
T = Absolute Temperature (°K)
B = Noise Bandwidth (Hz)
G = Amplifier Gain

The NF value can be displayed on the log scale by using the following formula.

$$NF \, [dB] = 10 \log \frac{Nout}{GKTB}$$

$$= 10 \log \frac{Nout}{B} - 10 \log G - 10 \log (KT)$$

The third item is a constant which becomes 10 log (KT) = -174 dBm/Hz when the temperature is 23°C. Thus, only the first item (i.e. noise power) and the second item (i.e. an amplifier's gain) have to be measured. The formula for determining NF can be expressed as follows.

NF [dB] = Nout [dBm/Hz] - G [dB] + 174 [dBm/Hz]

N and G are the noise level and amplifier gain as measured by the combination analyzers. For example, when Nout = -140 dBm/Hz and G = 10 dB, NF is 24 dB. These calculations can be easily customized using the built-in IBASIC function.

Filter Evaluation

Filters are generally passive, linear, two-port devices that, most often, can be completely characterized using swept frequency transmission/reflection techniques, and sometimes spectrum technique.

Figure 11 shows the major measurement parameters for filter (especially IF SAW filter) evaluation.
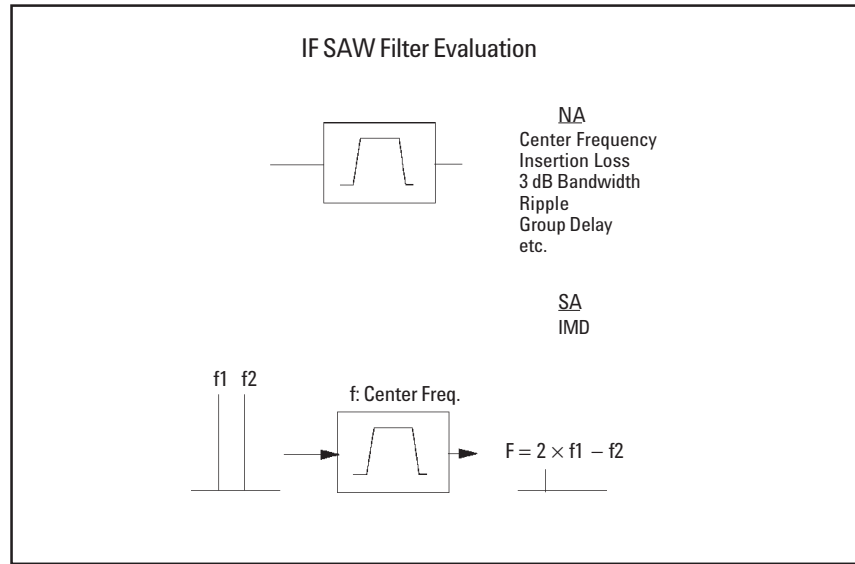

Figure 11. Major Measurement Parameters of IF SAW Filter

Network Evaluation for Filter

The measurement configuration for network analysis of a filter is shown in Figure 12. Either an optional Reflection/Transmission test set or an optional S-parameter test set is required to perform this analysis.
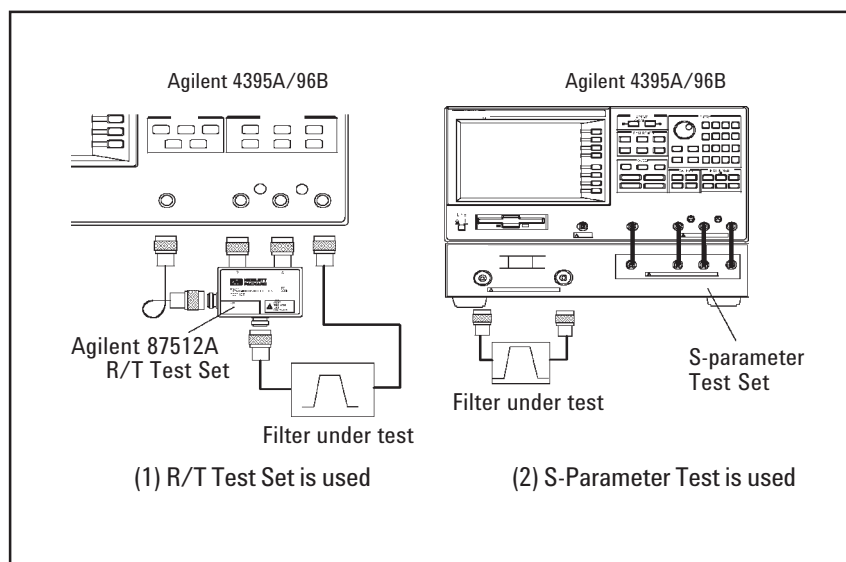

Figure 12. Measurement Configuration for Filter Evaluation

Insertion Loss/Bandwidth Measurement
Filters are required to pass signals falling within a specified bandwidth with minimum loss and distortion, while rejecting signals outside of that bandwidth. Insertion Loss is defined in dB as twenty times the log of the transmitted voltage divided by the incident voltages. (All signals within the bandwidth will be attenuated identically.) Out-of-band rejection is a measure of how well a filter passes signals within its bandwidth while simultaneously rejecting all other signals outside of that same bandwidth. The Agilent 4395A/96B is suitable for this measurement due to its wide dynamic range (≥ 115 dB). The bandwidth search feature automatically calculates the center sweep parameter value, bandwidth, Q, insertion loss, and cut-off point deviation (from the center of a bandpass or band reject trace). This feature also displays the calculation for all of these parameters. Figure 13 shows the measurement example using the bandwidth search feature.
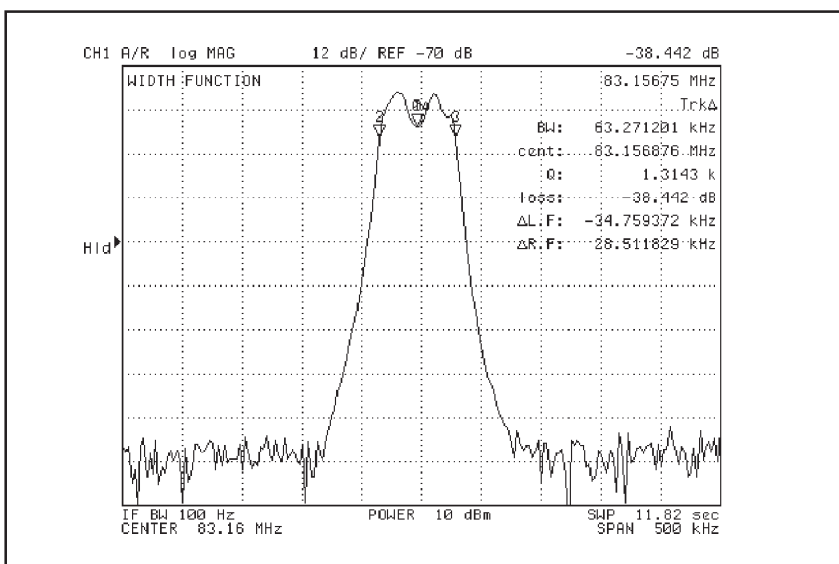

Figure 13. Measurement Example by Using the Bandwidth Search Feature

Group Delay Measurement

Recently, linear phase performance of a filter's bandwidth has become quite important in digital communication. The linear phase performance (linearity of the device's phase vs. frequency) is evaluated using group delay as the measurement parameter. Group delay is a measure of the slope of the transmission phase response. The formula for the group delay is as follows:

Group Delay =
 - delta phase/(360°×delta freq.)

Where,
delta phase: phase difference
 between frequency apertures
delta freq.: frequency aperture

The frequency aperture (%) must be set for the proper group delay evaluation result.

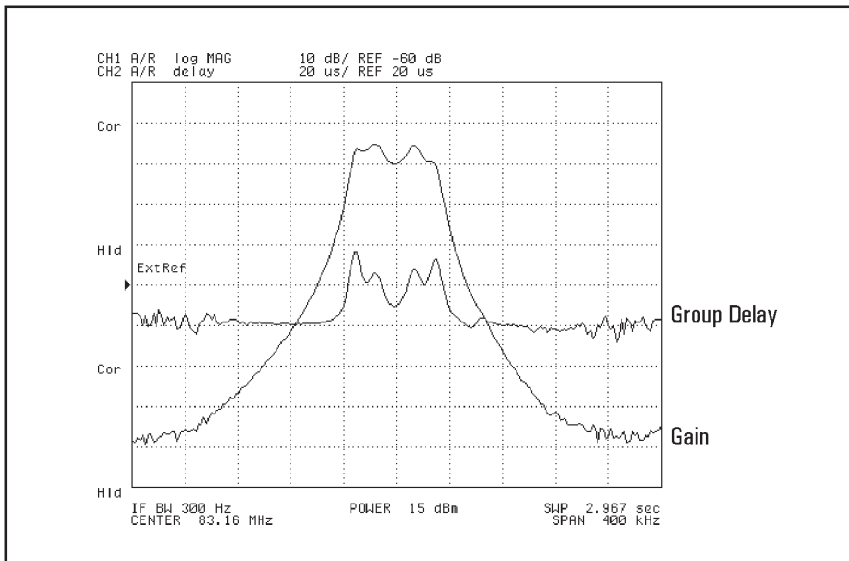Figure 15 shows the measurement results of group delay.

$$\text{Group Delay} \;=\; t_g \;=\; -\;\frac{1}{360°}\;\times\;\frac{\triangle\varnothing}{\triangle f}$$

Phase Samples 180° Apart

$\triangle$ = is the group delay aperture
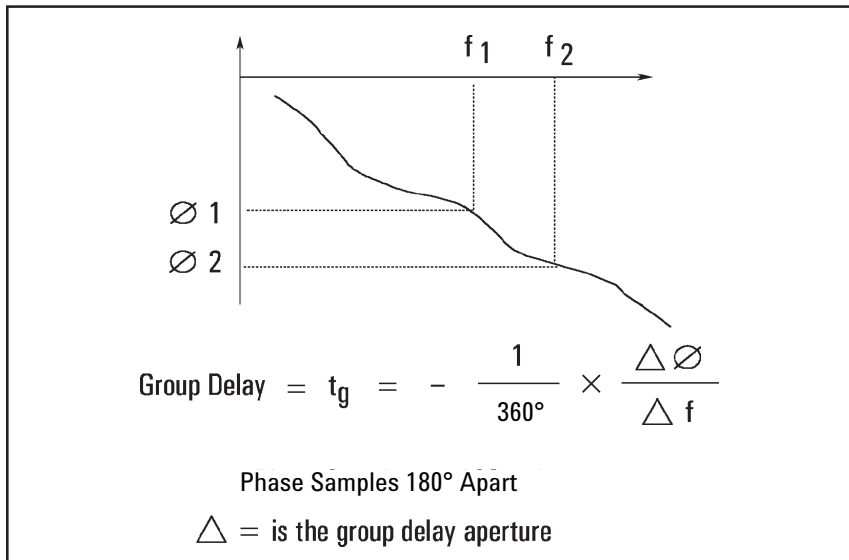
Figure 14. Group Delay

Figure 15. Group Delay Measurement Result

Spectrum Evaluation for Filter

Intermodulation Distortion Measurement

Intermediate Frequency (IF) SAW filter evaluations require not only the general network filter parameter evaluation, but also intermodulation distortion evaluation. This measurement is performed by applying two input signals to a filter. A third order signal can then be seen within the filter bandwidth. For example, when the center frequency of the filter is f_0, and the two input signals are $f_1 = f_0 + 100$ kHz, $f_2 = f_0 + 200$ kHz, the third order signal $((2 \times f_1 - f_2) = f_0)$ inputs to the filter. The size of this third order signal can be evaluated after going through the filter using the spectrum analyzer. The measurement configuration for the SAW filter intermodulation distortion is shown in Figure 16.

Figure 17 shows the 83.16 MHz SAW filter intermodulation distortion measurement, with two input signals (83.16 MHz + 100 kHz, 83.16 MHz + 200 kHz).

As described before, the 4395A/96B are capable of both the vector network analysis and the spectrum analysis. These abilities contribute to savings in equipment cost, bench space, and work when performing filter evaluations.
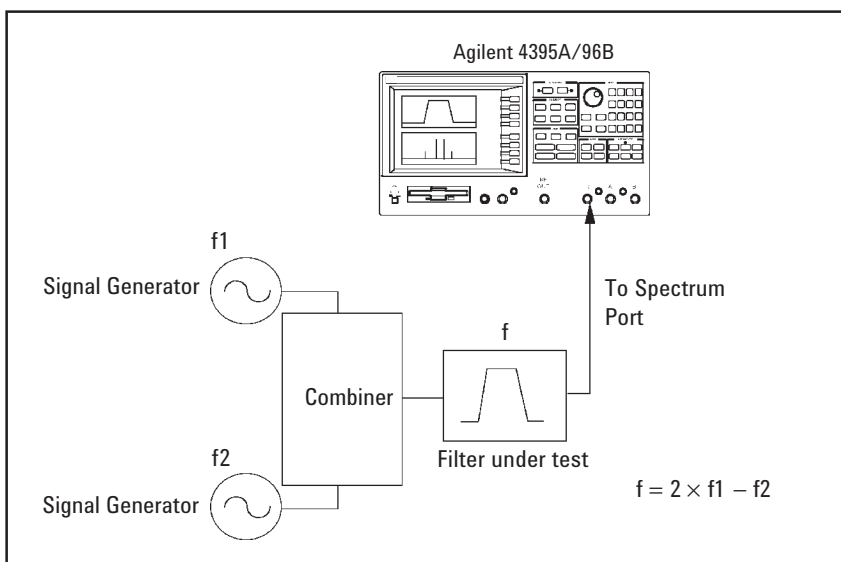

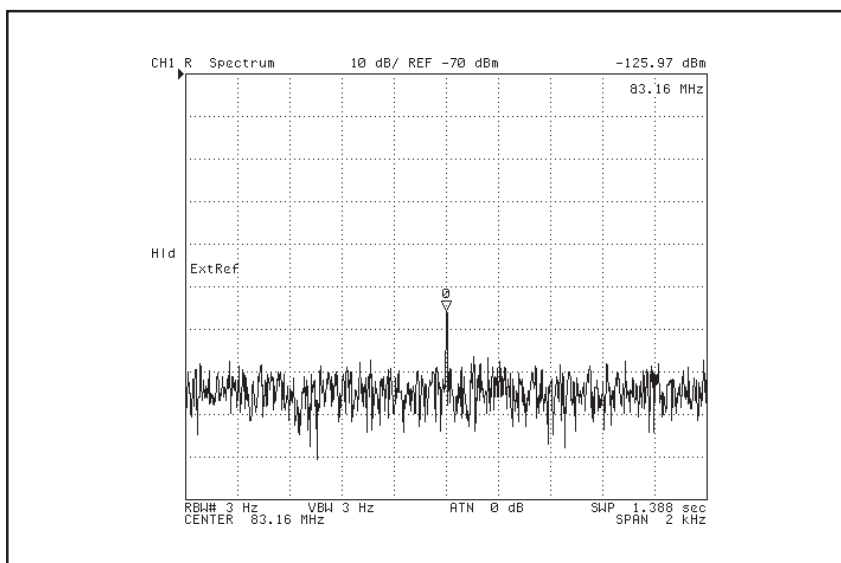**Figure 16. Measurement Configuration of the SAW Filter Intermodulation Distortion**

Figure 17. IMD measurement of SAW filter

Capacitor Evaluation

It is important to evaluate electronic devices at the actual operating condition before performing circuit design. A full-featured impedance measurement function can be added to the 4395A/96B by adding Option 010 and the 43961A RF Impedance Test Kit. The 4395A impedance measurement system covers from 100 kHz to 500 MHz, while the 4396B impedance measurement system covers from 100 kHz to 1.8 GHz. The impedance measurement system configuration is shown in Figure 18. A variety of 7 mm type Agilent test fixtures can be used.
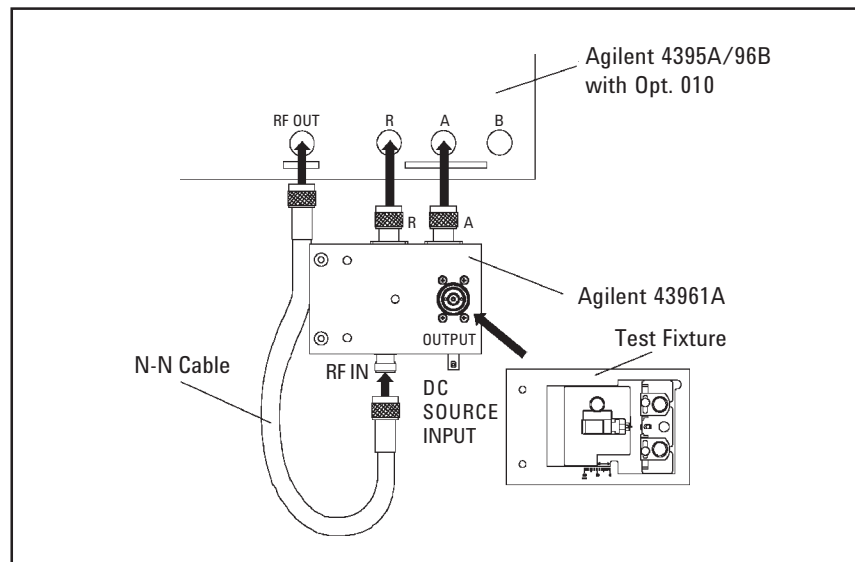

Figure 18. Impedance Measurement Configuration

Direct Impedance Measurement

The impedance measurement system provides accurate impedance measurement with direct impedance parameter read-out. To achieve accurate impedance measurement, these systems offer open/short/load and electrical delay compensation functions, which eliminate errors introduced by a test fixture. Figure 19 shows the impedance measurement results for a capacitor using the impedance measurement system.
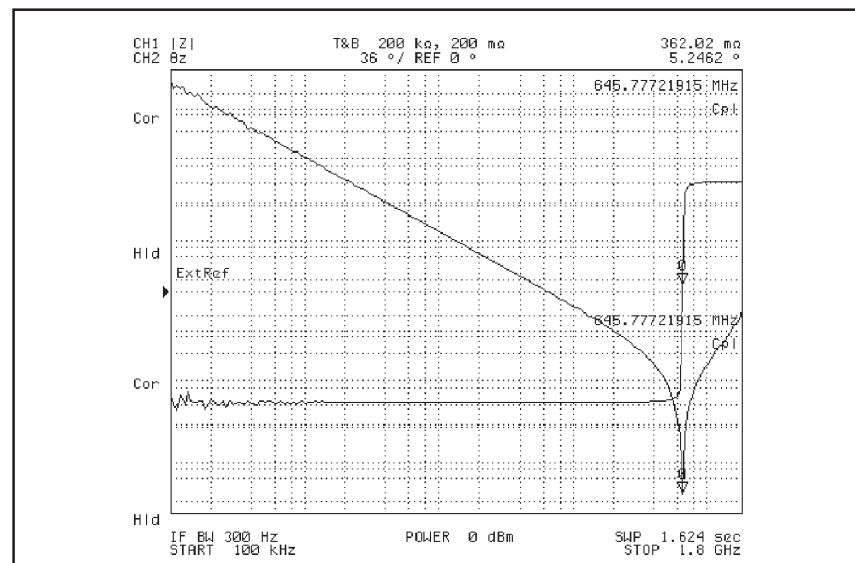

Figure 19. Impedance Measurement Result of Capacitor

Equivalent Circuit Analysis

The impedance measurement function of the Agilent Combination Analyzer Family provides equivalent circuit analysis capability based on a three- or four-element circuit (Figure 20). This feature allows Calculation of the impedance parameters for each equivalent circuit element, and will also simulate the frequency characteristics based on the calculated parameters.
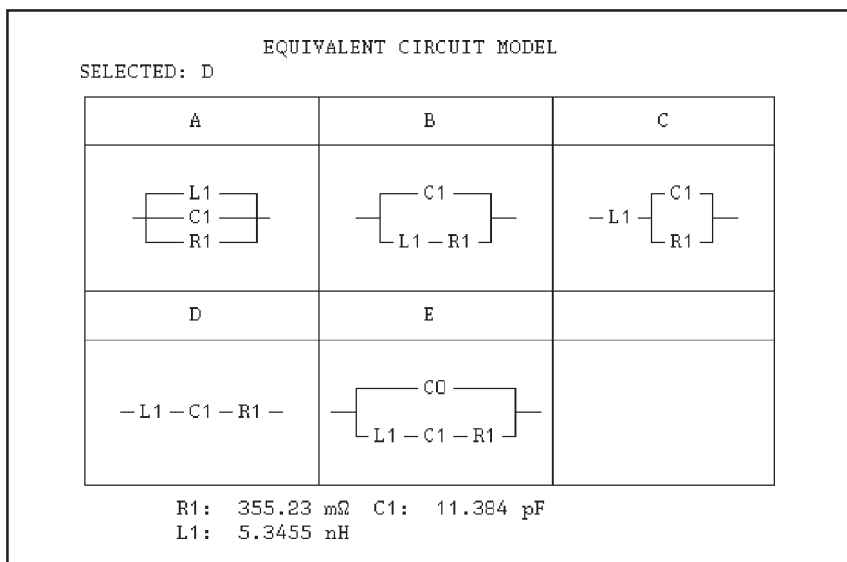

Figure 20. Five Equivalent Circuit Models

Figure 21 shows a comparison between an actual measurement result and the simulated result. You can see that the simulated characteristics are almost the same as the actual characteristics.

Conclusion

The Agilent Combination Analyzers keep up with your demands by offering the capabilities you need for your product's development.
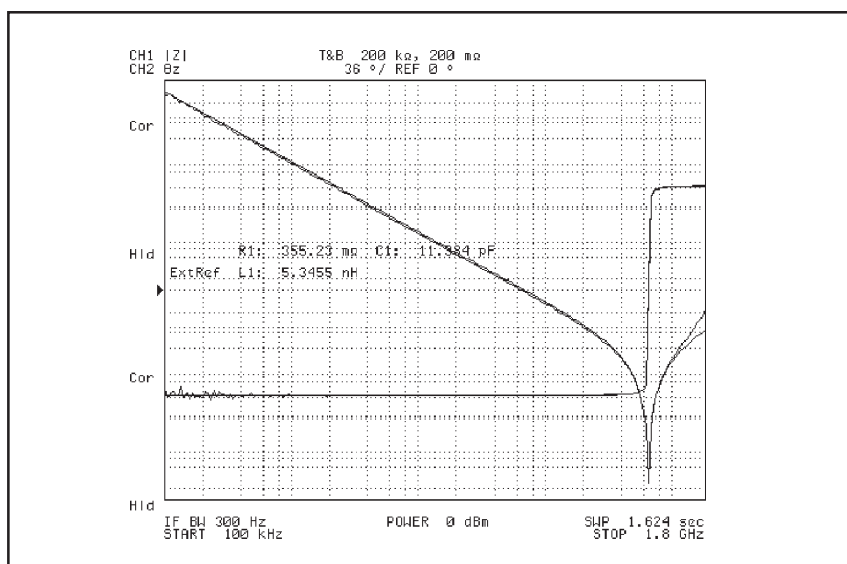

Figure 21. Simulation of Frequency Characteristics

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