APPLICATION NOTE

Network Analyzer Measurements: Filter and Amplifier Examples

KEYSIGHT

Introduction

Both the magnitude and phase behavior of a component are critical to the performance of a communications system. A vector network analyzer can provide electrical response information on a wide range of your devices — from active devices such as amplifiers and transistors to passive devices such as capacitors and filters. And, with the addition of time-domain capability, a network analyzer can also gate out unwanted responses during measurements, leaving only the desired measurement trace. This application note illustrates swept-frequency measurements on an RF filter and swept-power measurements on a communications-band amplifier.

Measuring a filter

You can achieve complete characterization of filters with swept-frequency measurements. Figure 1 shows the frequency responses of a filter. On the lower left, you can see the transmission response in log magnitude format, and on the right is the reflection response (return loss). The most commonly measured filter characteristics are insertion loss and bandwidth. Figure 1 shows bandwidth on the lower plot with an expanded vertical scale. Another standard measurement parameter is out-of-band rejection. This measurement shows how well a filter passes signals within its bandwidth while simultaneously rejecting signals outside that same bandwidth. A test system's dynamic range determines how accurately it evaluates this characteristic.

The return loss plot is typical of passive reflective filters. This measurement shows high reflection near 0 dB in the stopbands and good impedance matching in the passband, indicated by the low power level of the trace in the passband.

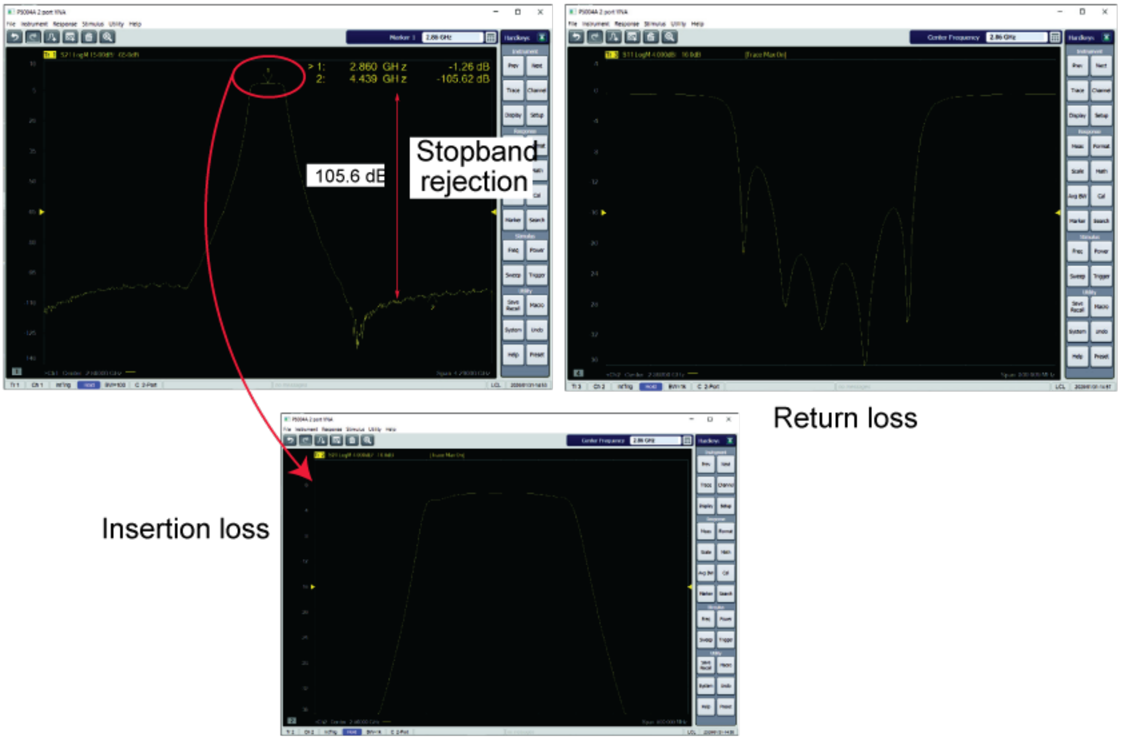

Figure 1. Testing filters with frequency sweeps

Error Correction for Accurate Passband Measurement

Variation from a constant amplitude response within the filter's bandwidth results in signal distortion. Error correction is often essential for accurate measurements of the filter passbands. The response may vary depending on the network analyzer and test cables used when measuring a filter's passband with a network analyzer without calibration (Figure 2).

Following vector-error correction (two-port calibration), it is apparent that the filter's passband amplitude response varies by less than ±0.1 dB around the center frequency. The trace measured previously with the uncorrected test system is not representative of the filter's actual passband response. By performing error correction with a vector network analyzer, the true nature of the filter reveals better passband performance around the center frequency, meeting a tight amplitude performance window for low distortion applications.

Measuring filter insertion loss

Figure 2. Systematic measurement errors

Swept-Power Amplifier Measurements

In addition to performing the swept-frequency measurements used to evaluate a filter, many network analyzers can also execute swept-power measurements. These measurements are useful in characterizing the nonlinear behavior of a device. The example in Figure 3 shows an amplifier's output power versus input power measured at a single frequency. The amplifier has a linear region of operation at which gain is constant regardless of power level. The gain in this region is the small-signal gain and is proportional to the slope of the power response.

As the input power continues to increase, the point on the curve at which amplifier gain begins to decrease defines where the compression region begins. The amplifier's output is no longer sinusoidal in this region, and some of the output appears in harmonics rather than only in the fundamental frequency of the signal. As input power increases, the amplifier becomes saturated, and output power remains constant. At this point, the amplifier's gain drops to zero, and increases in input power will not produce increased output power. While this is true for most types of amplifiers, the output power of traveling-wave tube amplifiers and a few other types decrease beyond the saturation point.

A network analyzer must have enough output power to drive the amplifier into saturation to measure an amplifier's saturated output power over a power sweep. A booster amplifier is often needed at the input of high-power amplifiers to achieve saturated conditions because of the relatively low levels of test port power available from a network analyzer at higher frequencies.

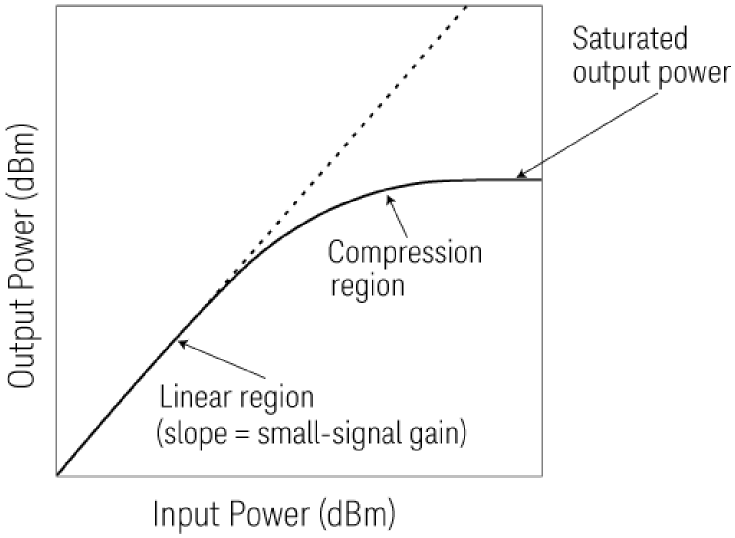

Figure 3. Power sweeps characterize the compression region

The most common measurement of amplifier compression is the 1 dB compression point (Figure 4). At the 1 dB compression point, the amplifier's output lags 1 dB below the linear output. You can measure the 1 dB compression point by displaying normalized gain from the power sweep.

Tr 1 S21 LogM 2.000dB/ 19.0dB

Tr 2 S21 LogM 2.000dB/ 0.00dB

>Ch1: Start -20.00 dBm CW 1.00000 GHz Stop 5.00 dBm

Ch2: Start -20.00 dBm CW 1.00000 GHz Stop 5.00 dBm

Move Trace command undone.

Figure 4. Example of 1-dB compression

- 1-dB compression: input power resulting in 1-dB drop in gain
- Ratioed measurement
- Output power available (non-ratioed measurement)

In this display, the flat part of the trace is the linear, small-signal region of operation, while the part of the trace with a negative slope corresponds to compression at higher input power levels.

It is useful to know the output power corresponding to the 1 dB compression point. The dual-channel capability of most network analyzers simultaneously displays the normalized gain and absolute power. Display markers read the input power and output power where 1 dB compression occurs. Alternatively, the gain of the amplifier at the 1 dB compression point is added to the 1 dB compression input power to compute the corresponding output power.

In these types of compression tests, the power-sweep range must be large enough to drive the amplifier under test from its linear region of operation to its region of compression. Modern network analyzers typically provide power sweeps with more than 30 dB of range, which is enough to drive most amplifiers into compression. It is also especially important to sufficiently attenuate the output of high-power amplifiers not only to prevent damage to the network analyzer's receiver but also to keep power levels low enough to avoid receiver compression.

Evaluating AM-to-PM Conversion

Measurements of amplitude-modulation-to-phase-modulation (AM-PM) conversion are also useful in characterizing the nonlinear behavior of high-frequency amplifiers. These measurements require a vector network analyzer. AM-to-PM conversion is a measure of the undesired phase shifts that occur as a result of any amplitude variations in a system.

In communications systems, unwanted phase modulation occurs when unintentional amplitude variations such as power supply ripple, thermal drift, or multipath fading. Variations can also result from the type of modulation used in the system, as is the case with quadrature amplitude modulation (QAM) or burst modulation.

- Use transmission setup with a power sweep
- Display phase of S_{21}
- S21AM - PM = 1.52 deg/dB at 1.5 dBm input power

Figure 5. AM-to-PM conversion

AM-to-PM conversion is critical in systems based on phase modulation, such as quadrature phase shift keying (QPSK), since phase distortion can cause signal degradation in analog systems and increased bit-error-rate (BER) in digital systems. AM-to-PM conversion is related to BER, and measurements of AM-to-PM conversion can help provide insight into the cause of increased BER in each system. The measurement complements BER measurements, which do not give you any real insight into the phenomenon causing the bit errors.

The definition of AM-to-PM conversion is the change in the output phase for a 1 dB increment in the input power to an amplifier, expressed in degrees / dB. An ideal amplifier would not have an interaction between its phase response and the level of the input signal. AM-to-PM conversion is measurable with a power sweep on a vector network analyzer (Figure 5). The test data displays the phase of forward transmission (S21) versus power. You can compute the AM-to-PM conversion for a DUT by measuring the change in phase of a small increment of the amplitude (such as 1 dB) centered at a specific power level. The changes in amplitude and phase are measurable with trace markers. Dividing the phase change by the amplitude change yields the AM-to-PM conversion. In Figure 5, AM-to-PM conversion is 1.52 degrees / dB, centered at an input power of 1.5 dBm and output power of 15.55 dBm.

Conclusion

As demonstrated, the vector network analyzer is a highly accurate instrument that can evaluate both active and passive components, such as amplifiers and filters. Keysight Technologies offers a wide range of RF and microwave network analyzers for measurements from 5 Hz to 120 GHz. These instruments are available with a wide range of options and test sets to simplify measurements in stand-alone and automatic-test-equipment (ATE) setups.

To learn more about vector network analyzers, read the following:

Title	Publication number
Understanding the Fundamental Principles of Vector Network Analysis	5965-7707E
Exploring the Architectures of Network Analyzers	5965-7708E
Applying Error Correction to Network Analyzer Measurements	5965-7709E

Keysight enables innovators to push the boundaries of engineering by quickly solving design, emulation, and test challenges to create the best product experiences. Start your innovation journey at www.keysight.com.

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