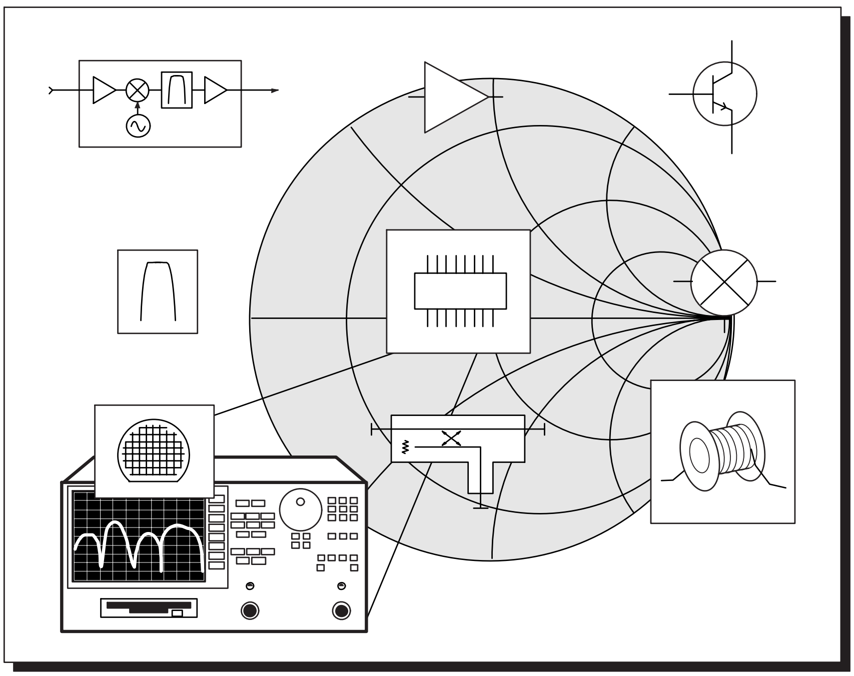
Agilent AN 1287-4

Network Analyzer Measurements: Filter and Amplifier Examples

Application Note



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Introduction

The network analyzer is used for a variety of device and component characterization tasks in both laboratory and production environments. This highly accurate instrument can evaluate both active and passive components for measurements of a filter and amplifier, as will be demonstrated in this application note. With the addition of time-domain capability, a network analyzer can also gate out unwanted responses during measurements, leaving only the desired information.

Agilent Technologies offers a wide range of RF and microwave network analyzers for measurements from DC to 110 GHz. These instruments are available with a wide range of options and test sets to simplify measurements in standalone and automatic-test-equipment (ATE) setups.

Often, both the magnitude and phase behavior of a component can be critical to the performance of a communications system. A vector network analyzer can provide information on a wide range of these devices, from active devices such as amplifiers and transistors, to passive devices such as capacitors and filters. This application note illustrates swept-frequency measurements on an RF filter, and swept-power measurements on a communications-band amplifier. The amplifier is typical of those used in Global System for Mobile Communications (GSM) service.

Measuring a Filter

Complete characterization of filters is typically achieved with swept-frequency measurements. Shown in Figure 1 are the frequency responses of a filter. On the left and bottom we see the transmission response in log magnitude format, and on the right we see the reflection response (return loss).

The most commonly measured filter characteristics are insertion loss and bandwidth, shown on the lower plot with an expanded vertical scale. Another common measured parameter is out-of-band rejection. This is a measure of how well a filter passes signals within its bandwidth while simultaneously rejecting signals well outside that same bandwidth. A test system's dynamic range generally determines how well it can evaluate this characteristic.

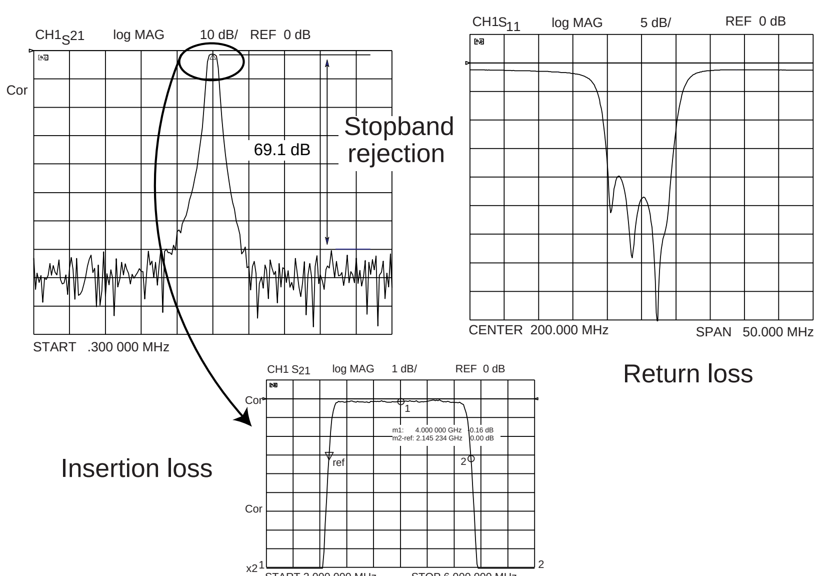


Figure 1. Testing Filters with Frequency Sweeps

The return loss plot is typical of passive reflective filters, showing high reflection (near 0 dB) in the stopbands, and good impedance matching in the passband. A different type of filter, known as an absorptive filter, tends to be well matched in both the stopband and passband, providing a good match over a broad frequency range.

Error Correction for Accurate Passband Measurements

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

When the same filter is evaluated after doing a response calibration (normalization), the test system's transmission-tracking frequency-response error is removed from the measured response, resulting in a much narrower amplitude-distortion window. After normalization, the filter's displayed frequency response still shows some amplitude ripple caused by interaction between the test system's source and load match. This ripple even goes above the 0 dB reference line, indicating gain (which is impossible since passive devices cannot amplify signals). This apparent anomaly is due to mismatch measurement error. By performing a two-port calibration prior to the filter measurement, these errors are removed.

Following vector-error correction (two-port calibration), it is apparent that the filter's passband amplitude response varies by only ±0.1 dB around the center frequency. The ±1 dB amplitude variations measured previously with the uncorrected test system are not representative of the filter's actual passband response. By performing error correction with a vector network analyzer, the true nature of the filter is revealed as having minimal amplitude variation around the center frequency, meeting a relatively tight amplitude performance window for low distortion applications (see *Applying Error Correction to Network Analyzers Measurements*, Agilent Application Note 1287-3).

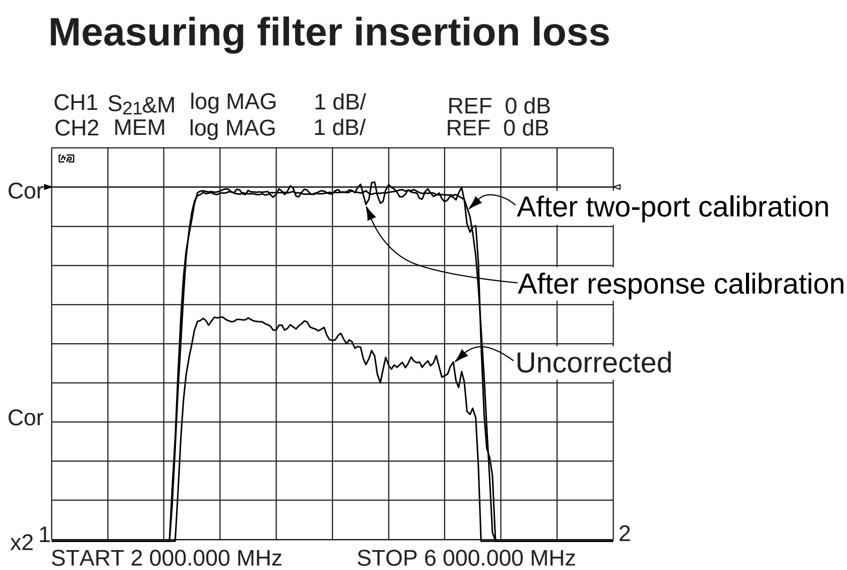


Figure 2. Response versus Two-Port Calibration

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, which 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 called 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 is increased even more, 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 actually decreases beyond the saturation point.

To measure an amplifier's saturated output power over a power sweep, a network analyzer must have sufficient output power to drive the amplifier into saturation. 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.

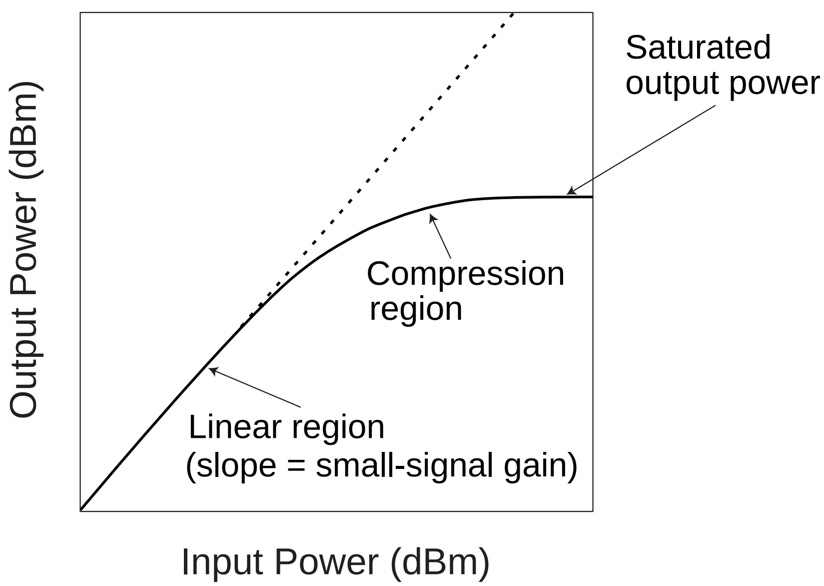
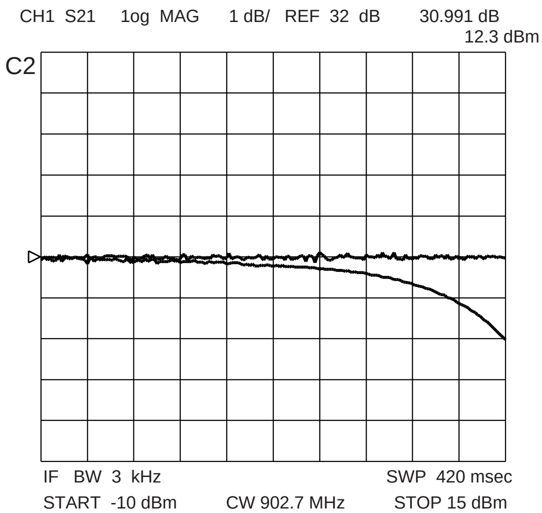


Figure 3. Power Sweeps Characterize the Compression Region

The most common measurement of amplifier compression is the 1-dB compression point (Figure 4). This is defined as the input power (or sometimes the corresponding output power) that results in a 1-dB decrease in amplifier gain referenced to the amplifier's small-signal or linear gain. An amplifier's 1-dB compression point can be measured by displaying normalized gain from the power sweep.



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

Figure 4. 1-dB Compression

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. For the example amplifier under test, 1-dB compression occurs at +12.3 dBm of input power, when measured at a fixed CW frequency of 902.7 MHz.

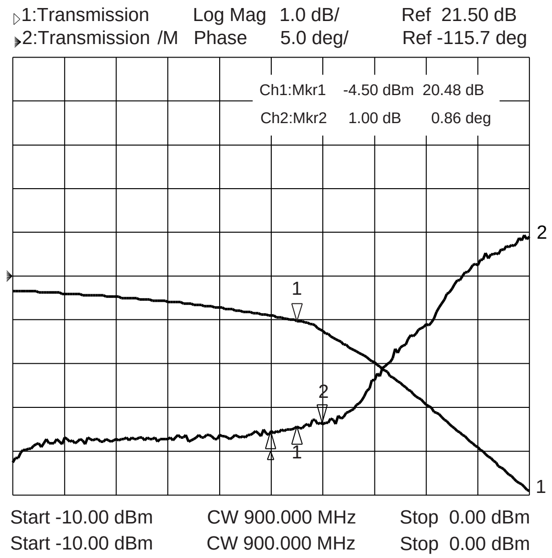
Since it is often useful to know the output power corresponding to the 1-dB compression point, the dual-channel capability of most network analyzers can be employed to simultaneously show normalized gain and absolute power. Display markers can read out both the input power and output power where 1-dB compression occurs. Alternatively, the gain of the amplifier at the 1-dB compression point can simply be added to the 1-dB compression input power to compute the corresponding output power. In Figure 4, the output power at the 1-dB compression point is 12.3 dBm + 31.0 dB = 43.3 dBm.

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 15 to 20 dB of range, which is great enough to drive most amplifiers into compression. It is also very 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 can be caused by 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}
- AM - PM = 0.86 deg/dB at –4.5 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 directly related to BER, and measurements of AM-to-PM conversion can help provide insight into the cause of increased BER in a given system. The measurement complements BER measurements, which in themselves do not provide any real insight into the phenomenon causing the bit errors.

AM-to-PM conversion is usually defined as the change in output phase for a 1-dB increment in the input power to an amplifier, expressed in degrees/dB. An ideal amplifier would have no interaction between its phase response and the level of the input signal. AM-to-PM conversion can be measured with a power sweep on a vector network analyzer (Figure 5). The test data is displayed as the phase of forward transmission (S_{21}) versus power. The AM-to-PM conversion for a DUT can be computed by using a small increment of the amplitude (such as 1 dB) centered at a particular power level, and noting the change in phase. The changes in amplitude and phase can be easily measured 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 0.86 degrees/dB, centered at an input power of –4.5 dBm and an output power of 16.0 dBm

Suggested Reading

Understanding the Fundamental Principles of Vector Network Analysis, Application Note 1287-1.

Exploring the Architectures of Network Analyzers, Application Note 1287-2.

Applying Error Correction to Network Analyzer Measurements, Application Note 1287-3.

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5965-7710E

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