Gain Compression Measurements with the SNA Network Analyzer

APPLICATION NOTES
AN2408-P0013EN01

SIGLENT TECHNOLOGIES CO.,LTD

Trademark Information

SIGLENT is a registered trademark of SIGLENT TECHNOLOGY CO., LTD.

Statement

· Our products are protected by approved and pending patents of the People's Republic of China

· Our company reserves the right to change specifications and prices

· The information provided in this manual supersedes all previously published materials

· The contents of this manual may not be copied, excerpted, or translated in any form or by any means without the consent of our company

Product Certification

SIGLENT certifies that this product complies with China's national product standards and industry product standards, and further certifies that this product complies with the relevant standards of other members of international standards organizations.

Contact Us

Service Hotline: 400-878-0807

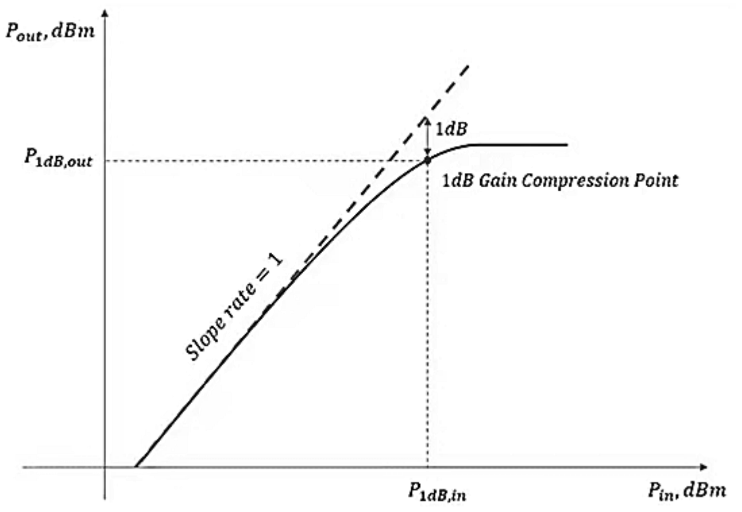
E-mail: support@siglent.com

Website: https://www.siglent.com

1 Introduction

As the core components of a system, amplifiers are widely used in various RF and microwave systems. Amplifiers have a linear gain region where the input power and output power are linearly related. The gain in this region is referred to as linear gain (also known as small-signal gain). As the input power is increased to a level that causes the amplifier to approach saturation, the gain will decrease. The slope of the curve at a specific point represents the gain of the amplifier at that input power level.

The 1 dB gain compression is defined as the input power level that causes amplifier gain to drop 1 dB relative to the linear gain. The gain compression function is to determine the compression power of the amplifier at various frequency points within a specified frequency range and to measure the parameters at that point.

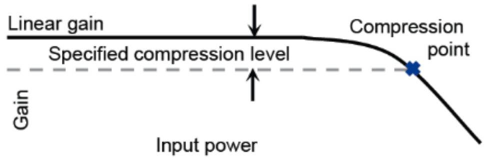
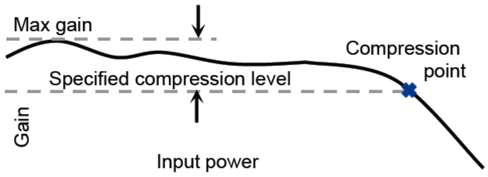
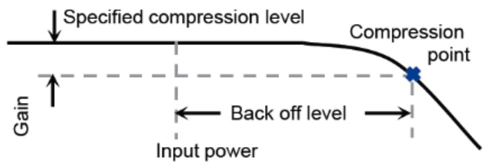
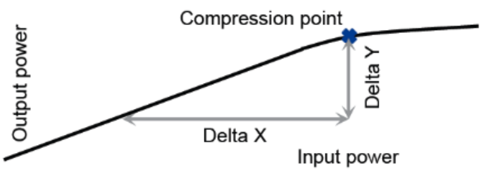
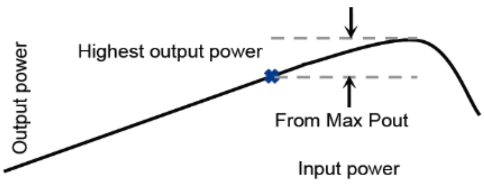


Amplifier Gain Compression Characteristics

2 Compression Definitions

When introducing the compression point in the previous section, it was mentioned that the point where the gain decreases by 1 dB relative to the reference gain is identified as the compression point. The reference gain here refers to the linear gain. However, the selection of the reference gain can vary in different situations. Based on the selection of the reference point, compression can be classified as Compression from Linear Gain, Compression from Max Gain, Compression from Back Off, X/Y Compression, and Compression from Saturation.

Available Compression Methods

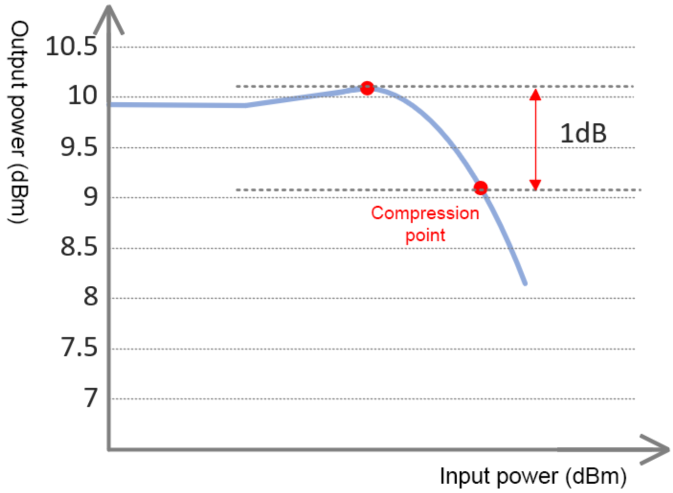
<table>
<tr><td>Compression from linear gain</td><td>The linear gain is measured using the specified linear (input) power level. The compression point is calculated as the linear gain minus the specified compression level.</td><td>
</td></tr>
<tr><td>Compression from max gain</td><td>The highest gain value that is found at each frequency is used as the max gain. The compression point is calculated as the max gain minus the specified compression level.</td><td>
</td></tr>
<tr><td>Compression from back off</td><td>The gains at two input powers that are different with the specified back off level are compared. The compression point is found as the highest input power with the gain difference of the specified compression level.</td><td>
</td></tr>
<tr><td>X/Y compression</td><td>The output powers at two input powers that are different with the specified delta X are compared. The compression point is found as the highest input power with output power difference of the specified delta Y.</td><td>
</td></tr>
<tr><td>Compression from saturation</td><td>The compression point is found at the highest output power minus the value specified as From Max Pout.</td><td>
</td></tr>
</table>

2.1 Compression from Linear Gain

Compression from linear gain is the most widely used method for defining compression. The reference gain is measured using the specified linear (input) power level. The target gain is calculated as the linear gain minus the specified compression level.

2.2 Compression from Max Gain

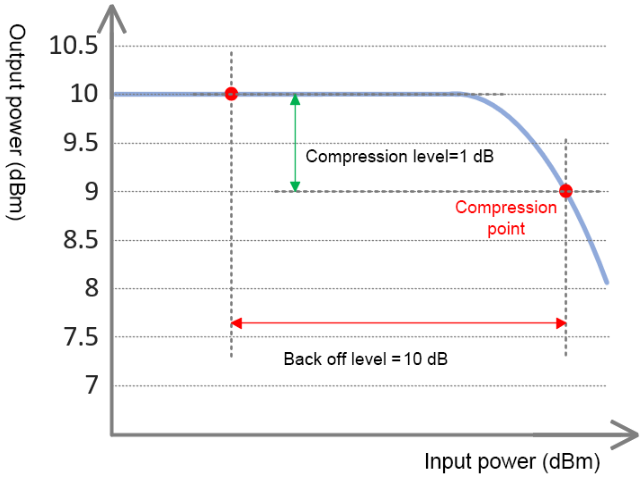
Some amplifiers experience an expansion or increase in gain just before the onset of compression, often due to a subtle re-biasing of the amplifier that slightly increases the gain. In fact, some amplifiers are designed particularly for this effect as a means to extend the linear operating range. In these amplifiers, the gain versus drive power peaks and then compression quickly ensues. For these types of devices, the gain compression is sometimes specified as compression from maximum gain, rather than compression from linear (or low power) gain. This definition is somewhat more conservative than the prior one, in that it will report a lower output power for 1 dB compression than will compression from linear gain. Note that for an amplifier following a normal compression curve, where maximum gain is at the linear power, the definitions are identical.



Compression from Max Gain

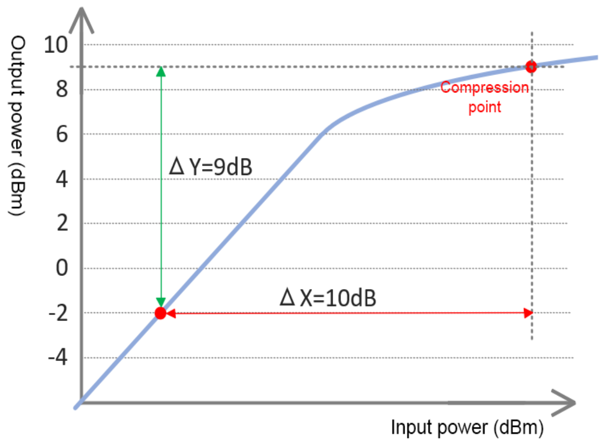
2.3 Compression from Back-off or X-Y Compression

Back-off compression and X-Y compression work on the same principle, but they are called differently because of the different implementation methods. Both methods specify the input power (X-axis) difference between the linear region and the compression point. The basic principle of the back-off method is to specify two points on the input signal with a certain difference, and the gain difference between the two points is the compression level. The measurement task is to find a point on the S21 curve where the compression level is the specified level (1 dB) and the excitation level at this point is the specified difference (usually 10 dB) from the reference point excitation level.



Compression from Back Off

The X-Y method, which is functionally equivalent, looks for a specified change in output power (usually 9 dB) over a specified change in input power (usually 10 dB).



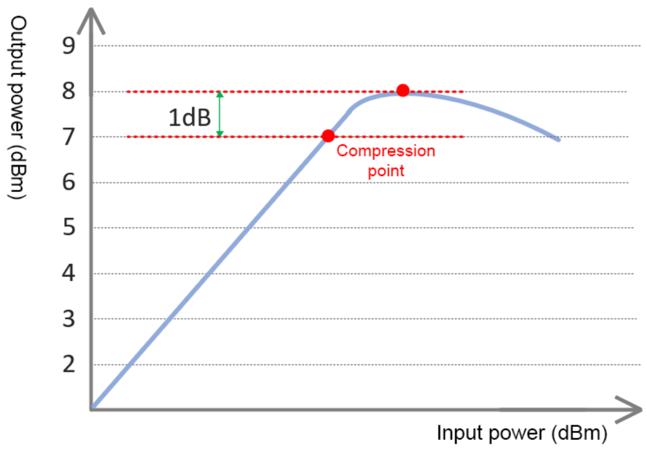
X/Y Compression

It is insensitive to noise at the linear power range and it incorporates a concept of looking for a change in gain over a nominal change in input power. Compare this with the max gain or compression from linear methods: Max gain requires the maximum gain be determined, which might require a very dense point spacing in the power sweep to ensure that the maximum power is correctly measured; compression from linear means that trace noise at the very low power of the linear measurements will directly affect the compression computation at high power.

Further, for some amplifiers, the gain drops very slowly with increasing power, so that the power sweep range must be very large to ensure that the linear power is achieved. However, the X-Y or back-off compression is always found within the X dB (e.g., 10 dB) range of the compression point. For many modulated signals, which maintain some average power level and have some specified peak-to-average ratio, the compression from back-off provides a more real-world use case for a compression measurement. If the modulated signal provides an average power, it is probably more reasonable to use that power as reference for the measurement of compression at the peak than it does to use a very low linear power, which some modulation formats will never impart.

2.4 Compression from Saturation

While somewhat of a misnomer, compression from saturation is a method that is applied to amplifiers that are normally used at or near their saturation point. For some amplifiers, such as traveling wave tube (TWT) amplifiers, a very clear saturation point occurs in the input power/output-power curves. The amplifier is operated backed-off, just below this saturation point, with a specified back-off level. Sometimes this offset level is quite low, such as 0.03 dB below saturation (or max power) typically found in TWT amplifiers. This level is very close to the maximum output power level, but one key operating point metric is the input power for maximum output power, sometimes called the normal operating point (NOP). When the saturation curve is very flat, even the slightest noise in the trace can cause large swings in the input power measurement at saturation, so backing off just a slight amount, such as 0.03 dB, provides a much more stable number for the NOP.



Compression from Saturation

3 Acquisition Modes

In the previous section, we discussed five methods for defining the compression point, but the compression measurements discussed were all performed at a single frequency point, that is, the compression point was found by scanning the power. However, in many cases, the compression point varies with frequency, especially for narrowband tunable amplifiers, where the compression point changes with the bandwidth. Therefore, it is necessary to measure gain compression across the entire frequency range. Based on this need, the Siglent SNA series provides three data acquisition modes: two 2D sweep modes, including sweep power per frequency and sweep frequency per power, and smart sweep. The smart sweep mode also includes the safe mode, and users can choose whether to turn it on.

3.1 2D Sweep

2D Sweep is the easiest method to understand and the least efficient for finding the compression point.

- Sweep Power Per Frequency: Input power is stepped from start to stop at each specified frequency. From the following example you can see that the device is exposed to the highest power level (p3) at the first frequency (f1). This could heat the device early in the measurement and affect compression results. The following examples show (frequency, power) values for three frequency points and three power points, resulting in a total of 9 measurements:

1	2	3	4	5	6	7	8	9
f1,p1	f1,p2	f1,p3	f2,p1	f2,p2	f2,p3	f3,p1	f3,p2	f3,p3

- Sweep Frequency Per Power: Frequency is swept from start to stop at each specified power level as follows. This could avoid problems caused by overloading the device.

1	2	3	4	5	6	7	8	9
f1,p1	f2,p1	f3,p1	f1,p2	f2,p2	f3,p2	f1,p3	f2,p3	f3,p3

Both 2D sweep modes work as follows:

[1] All GC measurements begin by measuring S-parameters at the specified Linear Power level. Reverse parameters are measured only if full 2-port calibration is applied or if a reverse parameter is displayed.

[2] Gain measurements are then made at all of the specified frequency and power values. Although these are conceptually 2-Dimensional sweeps, a single sweep is constructed in firmware.

[3] After data has been measured, a search is performed to find the compression point. You can choose to interpolate between the two measured points closest to the target gain.

It is not possible to plot all of the 2D measurement data on the VNA display. However, it can be saved to a *.csv file and then read into an Excel spreadsheet. The initial S-parameter measurement data is not saved to this file. You can also view on the VNA all power sweep information at a selected frequency using the Compression Analysis feature.

3.2 Smart Sweep

Smart sweep is usually the fastest and most accurate method to measure gain compression. Unlike the 2D acquisition modes which measure all of the specified frequency / power points, Smart sweep performs a series of power search iterations. At each frequency, an intelligent guess of input power is made to find the compression level that is within tolerance. This guess is further refined with each successive power search iteration sweep.

Smart sweep continues to iterate until one of the following conditions occur:

[1] All data points are within tolerance. When the compression level for a data point achieves the specified tolerance, it continues to be measured and input power changed to improve the measurement within

tolerance.

[2] The specified compression level cannot be achieved for the remaining frequencies that are not in tolerance. Either the start power is too high or the stop power is too low.

[3] Maximum iterations have been achieved. If a measured gain is not within the specified tolerance before the specified Max number of Iterations has been reached, then the last power reading is used as the compression point.

The intelligent guess process works differently depending on the compression method. Backoff and X/Y compression methods subject the DUT to significant changes in input power during an iteration sweep. This can affect the DUT and the measurement results.

- Backoff and XY: Because both compression methods specify the separation between the linear region and the compressed region, each iteration requires a single sweep at two different power levels over the same frequency range. The first half of the sweep measures the DUT at the Backoff or X power level. The second half of the sweep measures the DUT at the compressed power level, specified by the start and stop power range. At the beginning of the second half, the power level rises by the Backoff or X value. The specified settling time is applied at this point to allow the DUT time to react to this significant change in power level. Safe sweep does not minimize this change in input power. However, safe sweep with Backoff and XY methods does prevent the DUT from being exposed to too much input power.

- Compression From Linear Gain: After the reference gain is measured at the linear input power, the next iteration measures the DUT at a higher power level which attempts to push the DUT well into compression. Subsequent sweeps, depending upon the compression level of the DUT, either increases or decreases the power in order to reach the desired compression level. Usually, by the third iteration sweep, a curve-fit algorithm is utilized to precisely find the compression point.

⚠	**Note:** The DUT can be subject to significant changes in power from one iteration sweep to the next. This can be minimized by the use of safe sweep and careful selection of the corresponding settings.

- Compression from Max Gain: The maximum gain that is found at each frequency is stored and used to calculate the compression point. Smart sweep does not perform extra iterations to search for the maximum possible gain of the amplifier at each frequency.

- Compression from Saturation: The maximum power out that is found at each frequency is stored and used to calculate the compression point. Smart sweep does not perform extra iterations to search for the maximum possible power out of the amplifier at each frequency.

3.3 Safe Mode

While the iterative method of finding the 1 dB compression point can be very fast, it does have a drawback in that it can also overdrive a DUT if the DUT has a lot of gain variation, and the power settings for the initial gain readings are high enough to overdrive the amplifier. Also, if the amplifier does not follow a normal compression curve, it is possible that the predicted power for the next iteration will overdrive the amplifier. Particularly for very high power amplifiers, an overdrive condition must be avoided both to protect the DUT and to protect the test equipment connected to the DUT.

In such a case the iterative method may be modified to provide a safe mode of operation. Such a safe mode would need to have some defined limits to the power setting and the output power; in particular, there should be limits set so that the input power is not increased in the next iteration if the output power has exceeded a predetermined limit, even if the amplifier is not compressed. In addition, a compression threshold should be defined such that when an amplifier exceeds some safe compression threshold (perhaps 0.5 dB), the step size automatically switches from course step to fine step. Such a scheme ensures that the amplifier will never exceed a specified output power (thus protecting the external equipment) and never be overdriven by more than the fine step size (thus protecting the amplifier).

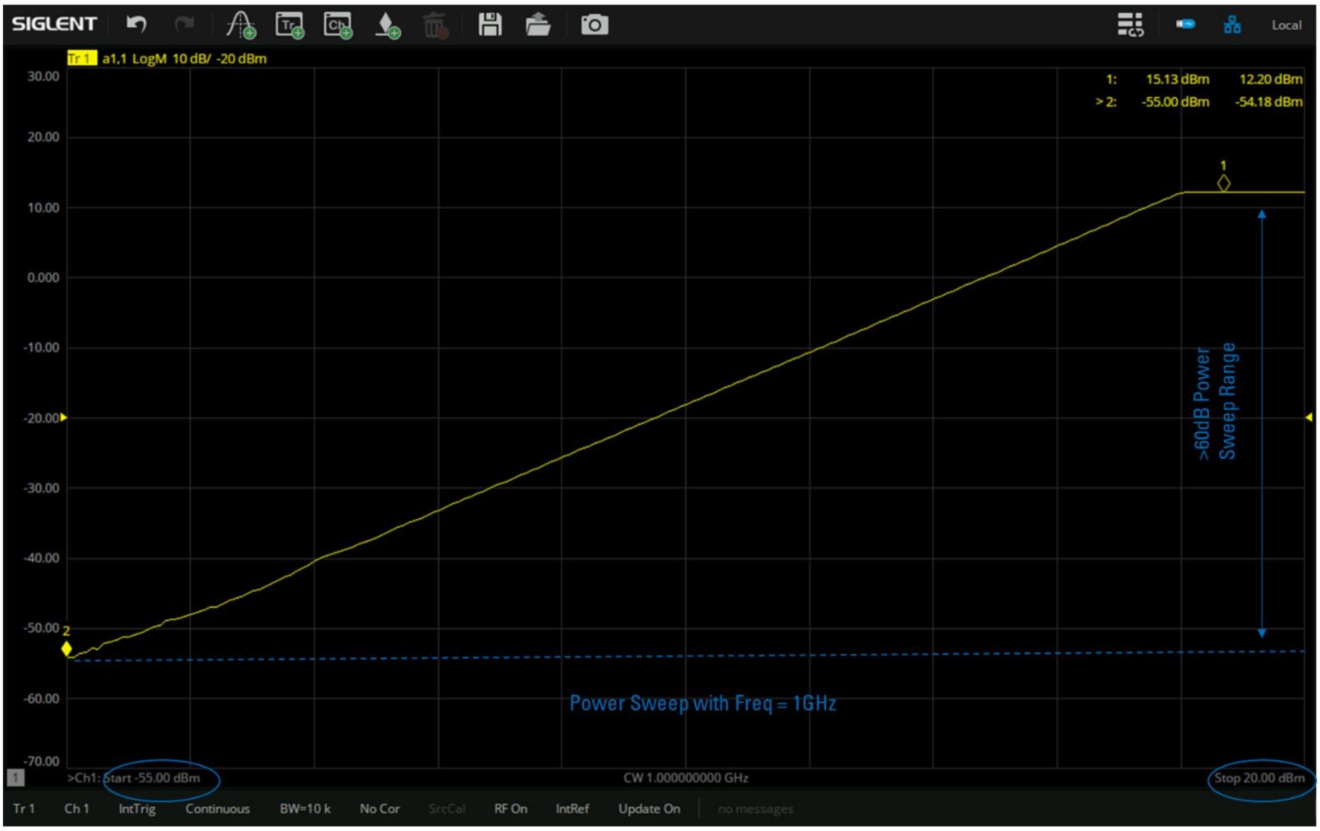
4 Using the Gain Compression Application

Before measuring the performance of an amplifier in earnest, it is a good practice to try to ascertain some of characteristics like its linear operating point first. These investigations can be done with wide bandwidths, no calibration and large number of points to quickly detect problems.

For this pretest, the VNA source power is set to a low level where it is expected that the amplifier must be linear, and the S21 trace is placed into memory and the data over memory traces are displayed. Continue raising the source power until a clear offset in the S21 trace occurs. The most common figure of merit is 1 dB compression. The compression trace is the high power gain divided by the memory trace, which was saved at a linear power.

Amplifier Pretest

The SNA5000A built-in signal source can provide a very large power sweep range (-55 dBm to 10 dBm) to drive the amplifier from the linear operating region to the compression region. The large power sweep range is achieved by electronic attenuators instead of traditional mechanical step attenuators. Mechanical attenuators have poor amplitude repeatability and a short service life. This makes the SNA5000A a perfect tool for testing active device nonlinearity and gain compression.



Large Power Sweep Range

SNA5000A offers multi-channel testing capabilities, allowing different channels to be configured with either identical or distinct sweep methods. This enables engineers to observe changes in the amplifier P_{1dB} while simultaneously measuring its S parameter. Users can add a new test channel by pressing *Window Setup* > *Add Window* > *New Trace + Channel + Window* from the Display menu. Configure this new channel to measure the output power of source port B1 through power sweep. Press *Sweep Type* > *Power Sweep* from the Sweep menu to perform a power sweep test.

Using the conventional S parameter measurement function of the vector network analyzer, the compression point is found by performing power sweep (also called one-dimensional sweep) at specific frequency points, and observing the change in gain with input power. The disadvantage is that a single measurement only obtains the compression point of a single specific frequency point. How can the compression point test of the entire frequency band be quickly achieved? The gain compression function of SNA5 series vector network analyzer completes accurate and automatic compression measurements. In this mode, only one setup, one calibration and one connection are required to automatically complete the full-frequency power sweep and obtain all the compression parameters and linear parameters of the amplifier.

One-dimensional Sweep

The amplifier on SNA-TB02 is used as an example to demonstrate test configuration and calibration method. The following is a general procedure for performing gain compression measurement. Press *Meas* > *Mode* > *GC* to select measurement mode. After selecting the GC measurement mode, users can choose whether to check "New Channel". Click OK to turn on the gain compression function on the current channel or the newly created channel. Set the frequency and power according to the DUT characteristics, and select the appropriate measurement and gain compression setting.

Set the measurement frequency range of the network analyzer according to the operating frequency of DUT. Set IFBW value to yield acceptable trace noise when measuring gain at the linear power level. This level of noise contributes directly to the accuracy of compression point. A lower value (narrower IFBW) allows for more accurate but slower measurements. The maximum number of measurement data points depends on acquisition method and compression method.

Data Points Limit

Compression Method	SMART Sweep	2D Sweep
Compression from Linear Gain	Data points = freq points Max = 20,001	Data points = freq. points * power points Max power points = 2,001 Max data points = 20,001
Compression from Max Gain	Data points = freq points Max = 20,001	
X/Y and Backoff	Data points = 2 * freq points Max = 10,001	
Compression from Saturation	Data points = freq points Max = 20,001	

Set the start and stop power. The start power value should be within the linear range of the DUT, while the stop power value should cover the power range where gain compression may occur. For example, if the P1dB point is expected to be around 5 dBm, the input power can be set from 0 dBm to +10 dBm, increasing step by step. Check the input power range of the DUT to avoid damage caused by applying an excessive signal during the test.

The power point setting is the number of power points to be measured in 2D acquisition mode. This setting is not available in smart sweep, which uses only enough power points to find the specified compression level. The power points may be limited due to the number of frequency data points. The power step value is calculated based on the start frequency, stop frequency and number of power points. This setting cannot be changed manually.

- 2D Sweep: In Backoff, X/Y and Compression from Max Gain methods, sets the range of power levels that are applied to the DUT to find both the reference gain and compression point. Make sure this range is wide enough to include both. For example, if the Backoff level is 10 dB, then the power range must be greater than 10dB. Otherwise, GC will report a compression value using the closest reference gain and compression point, which may be inaccurate. In Compression from Linear Gain, the reference gain is measured at linear power level, so the start and stop power levels are used to find the compression point.

- Smart Sweep: Sets the range of power over which GC will search for compression point. The reference gain is found using the linear power level, backoff and X values, depending on the Compression Method. To reduce the number of iterations that are required to find the compression point, limit the start / stop power range to the input levels that will achieve compression. Do not include the linear region.

Select the appropriate compression setting. The gain compression point is typically set at 1 dB, therefore 1 dB can be set as the target compression level in the VNA. Other values can also be set according to specific test requirements. Add compression parameter and linear parameters traces. Each trace can be individually set with a reasonable scale and reference level to facilitate reading of measurement values.

Compression Parameters

Parameter		Description
Linear S Parameters	S11	Input Match
	S21	Gain
	S12	Reverse Isolation
	S22	Output Match
Compression Parameters	CompIn21	Input power at the compression point
	CompOut21	Output power at the compression point
	CompGain21	Gain at the compression point
	CompS11	Input Match at the compression point
	RefS21	Linear gain value used to calculate the compression level. This is calculated differently depending on the compression method.
	DeltaGain21	CompGain21 MINUS Linear Gain

Gain compression calibration includes three items: power calibration, S-parameter calibration and receiver calibration. During the Source Power Cal, a receiver calibration is applied to the port 1 reference receiver, and indirectly to both test port receivers during S-parameter calibration, correcting for impedance mismatch between the power meter and the VNA source, and the DUT and the VNA source. Therefore, the gain compression calibration procedure is divided into two steps: source power calibration and full two-port calibration. Receiver calibration is automatically completed without configuration after power calibration and S-parameter calibration. In the example, a power meter and Ecal are used for calibration.

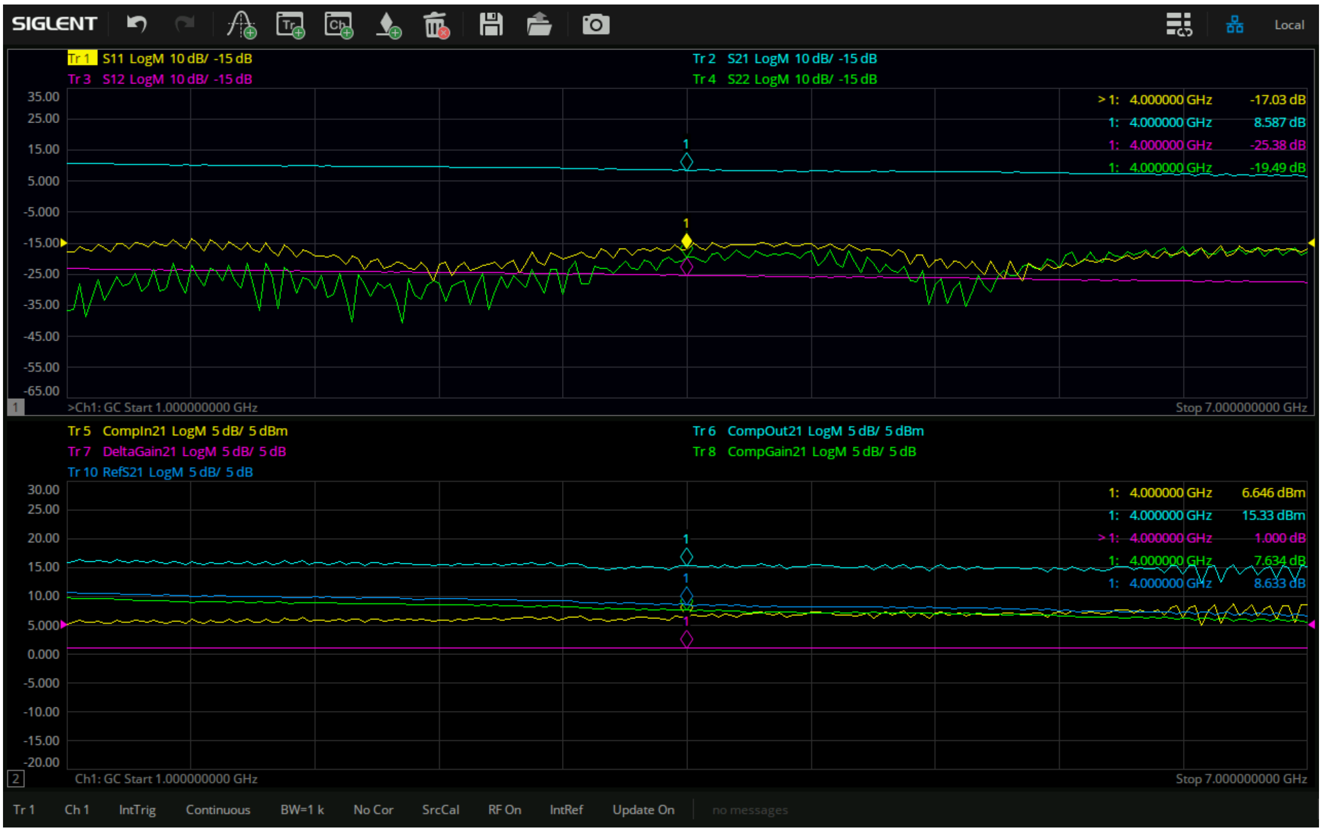
Press *Cal* > *Gain Compression Cal…* to enter the calibration wizard. Click next to enter the power calibration, connect the power meter to VNA as the input port, and click *About Power Measurement* to perform power calibration.

GC Power Calibration

After completing power calibration, click *Next* to enter the S-parameter calibration interface, select whether to enable electronic calibration as required, and connect the selected port to the corresponding calibration part to start calibration. After completing S-parameter calibration, receiver calibration will be automatically performed. Click *Finish* to complete GC calibration.

GC S-parameters Calibration

Connect DUT. The X-axis values are always frequency. Imagine behind each frequency data point, a traditional power sweep curve with corresponding measurements and calculations to find the specified compression point. The Y-axis values are always reported at the compression point. Add a marker to display all parameters at 4 GHz. Tr 5 CompIn21 value is 6.646 dBm which is the DUT power required to reach the compression point. Tr 8 CompGain21 value is 7.634 dB which is the gain measured at the compression point. Tr 10 RefS21 is the S parameter measured separately under Linear Input Power in GC mode. Tr 7 DeltaGain21 indicates that the difference between Tr 10 RefS21 and Tr 8 CompGain21 reaches 1 dB. If the difference is less than 1 dB, it indicates that the input power to DUT has not yet compressed the DUT gain by 1 dB. Continue increasing the power until P_{1dB} is achieved.



Gain Compression Measurement Result

A final step is saving the measured data for subsequent analysis or design optimization. Press *Save Recall* > *Save Data* to save the last complete scan data in a .csv file format. If calibration is turned on when the file is saved, then all data is calibrated. Otherwise, raw data is saved. All *.csv data saves include a reference power level sweep at the beginning of each frequency data. When saving or recalling 2D data, when linear input power equals start power, then the number of data points (rows)/ freq = num power points. When linear input power does not equal start power, the number of data points (rows)/ freq = num power points + 1. CSV data is convenient because it may be directly read into an Excel spreadsheet. CSV file output function can give several choices such as only outputting a single trace or all the displayed traces. The data format can be either the default format or another specified format such as LinMag/Angle, LogMag/Angle, Displayed data or Real/Imaginary.

Gain compression measurement is one of the key measurements to evaluate the performance of RF and microwave devices. It is necessary to evaluate the approximate specifications of the DUT, whether the analyzer can provide enough power to drive the amplifier into saturation, and whether the analyzer can withstand enough power. If the analyzer cannot provide sufficient output power, an amplifier can be added before the DUT. If the analyzer cannot handle the output power of the DUT, an attenuator can be used at the DUT output. And you can also calibrate the amplifier, attenuator and line loss in the link through *GC Calibration* > *Fixture*, import the S2P file of the fixture and move the calibration plane to the cable plane (i.e., the DUT connection plane).

5 Summary

Characterizing the characteristics of active devices and determining their compression points are crucial. Traditional S-parameter measurements using vector network analyzers can only obtain compression point at a single frequency, while the gain compression measurement function can complete the measurement of compression parameters and linear parameters such as linear gain, gain at the compression point, input/output power at the compression point, etc. within the operating frequency band through one connection and one calibration.

The gain compression measurement function ensures measurement accuracy through power calibration and calibration wizard, and supports three data acquisition mode: smart sweep, sweep power per frequency and sweep frequency per power to adapt to different test scenarios; it provides linear gain compression, max gain compression, back-off compression, X/Y compression, saturation compression methods to flexibly responding to complex test requirements and ensure comprehensive and accurate characterization of the nonlinear behavior of the device.

About SIGLENT

SIGLENT is an international high-tech company, concentrating on R&D, sales, production and services of electronic test & measurement instruments.

SIGLENT first began developing digital oscilloscopes independently in 2002. After more than a decade of continuous development, SIGLENT has extended its product line to include digital oscilloscopes, isolated handheld oscilloscopes, function/arbitrary waveform generators, RF/MW signal generators, spectrum analyzers, vector network analyzers, digital multimeters, DC power supplies, electronic loads and other general purpose test instrumentation. Since its first oscilloscope was launched in 2005, SIGLENT has become the fastest growing manufacturer of digital oscilloscopes. We firmly believe that today SIGLENT is the best value in electronic test & measurement.

Headquarters:

SIGLENT Technologies Co., Ltd

Add: Bldg No.4 & No.5, Antongda Industrial Zone, 3rd Liuxian Road, Bao'an District, Shenzhen, 518101, China

Tel: + 86 755 3688 7876

Fax: + 86 755 3359 1582

Email: sales@siglent.com

Website: int.siglent.com

North America:

SIGLENT Technologies America, Inc

6557 Cochran Rd Solon, Ohio 44139

Tel: 440-398-5800

Toll Free: 877-515-5551

Fax: 440-399-1211

Email: info@siglentna.com

Website: www.siglentna.com

Europe:

SIGLENT Technologies Germany GmbH

Add: Staetzlinger Str. 70

86165 Augsburg, Germany

Tel: +49(0)-821-666 0 111 0

Follow us on Facebook: SiglentTech