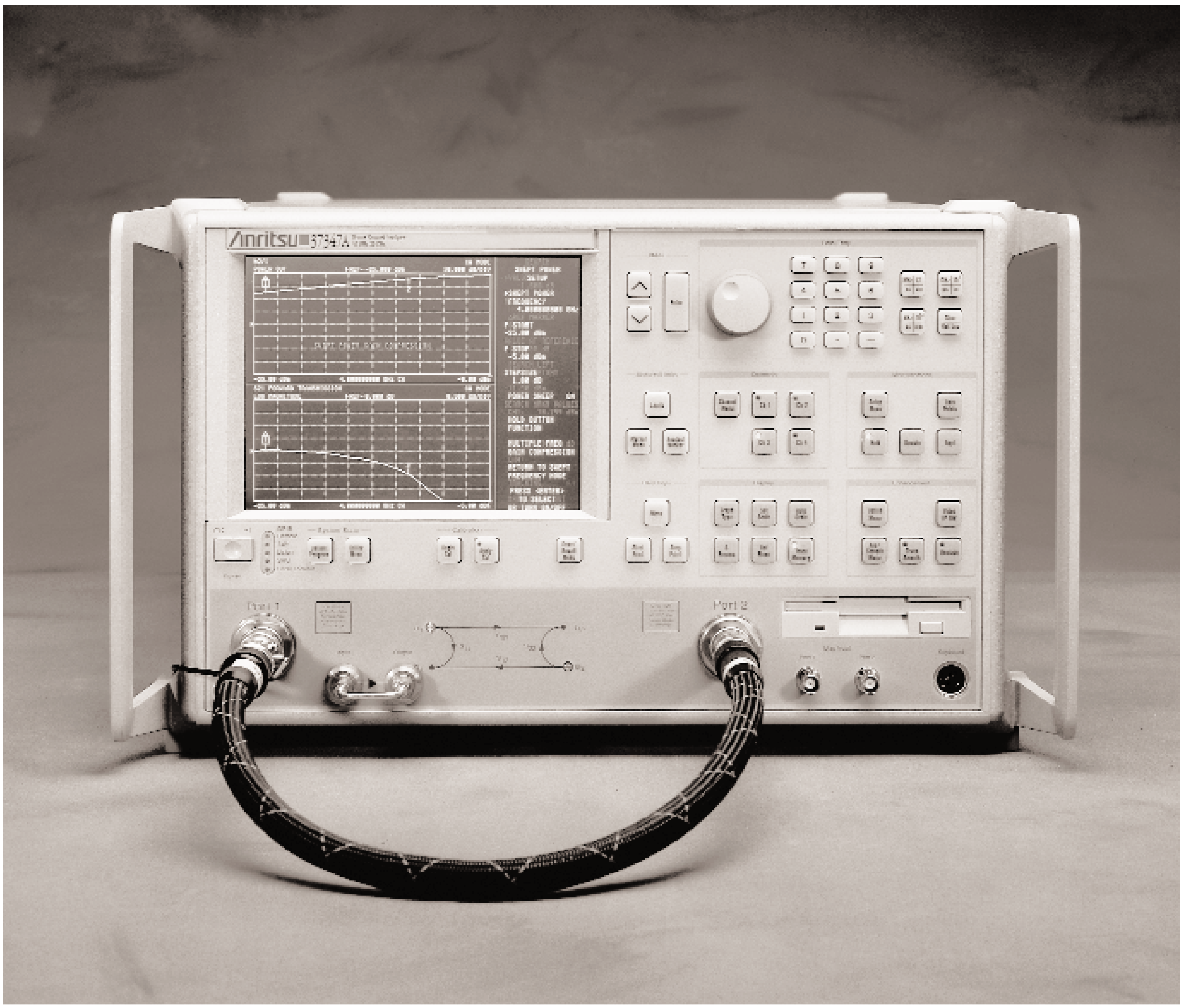
Amplifier Testing

With The 37300A VNA

Application Note



Linking the World

Introduction

Vector Network Analyzers (VNA) are designed to measure S-Parameters of RF and Microwave devices and circuits. S-Parameters are by definition ratios and as such the actual test power utilized is not critical. When amplifier S-Parameters are measured it becomes important to know approximate input and output power levels so that the user can insure that the amplifier is operating in its proper range and that the instrument's power handling capability is not exceeded. If the user wants to measure non-linear effects such as the 1 dB compression point or AM to PM conversion, it is necessary to know power levels more accurately and it becomes desirable to sweep the power over a desired range. The Anritsu 37300A has a number of features: nominal port power specified in dBm, power sweep, power meter calibration and a user interface that simplifies and increases productivity for testing amplifiers.

Linear Tests

Linear tests are standard S Parameter measurements. They provide information on the following amplifier parameters:

S21	Gain- magnitude as a function of frequency as well as drift performance.
	Phase and Group Delay.
S11, S22	Input and output impedance and match.
S12	Isolation.

The important factor is that the above S Parameters are made with the amplifier operating in its linear range. This range is usually known from amplifier specifications which typically specify operating gain, frequency range and power supply requirements (figure1).

Typical Amplifier Specifications	
Frequency:	8-12 GHz
Minimum Gain:	22 dB
Gain Flatness:	±1 dB
Maximum SWR	
Input:	2:1
Output:	2:1
Output Power @ 1dB Gain Compression:	+8dBm

Figure 1.

Linear operation can be confirmed by increasing the input power by 3db and observing that S21 remains the same. The requirement to operate in the linear range often dictates and input level far below the default power of a VNA, particularly for high gain amplifiers. The Anritsu 37300 VNAs include a test port power specified in dBm as well as a built-in step attenuator that simplifies setting the appropriate input signal level. On the output side it is important that the power level input to the VNA does not exceed its capability either for power handling or measurement linearity. The standard 37300 systems can handle a maximum input of 1 watt (+30 dBm).

There is a built in step attenuator associated with the S21 measurement receiver that can reduce the receiver input power to less than -10 dBm which insures linear instrument performance (see figure 2).

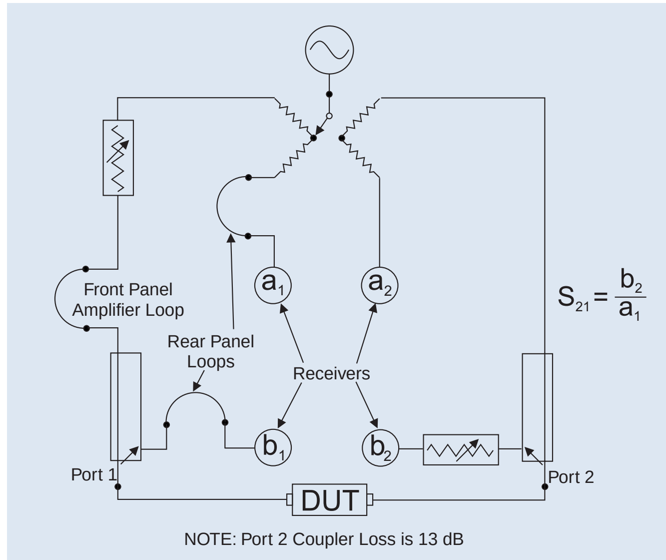


Figure 2.

Figure 3 shows a four S Parameter display of amplifier parameters.

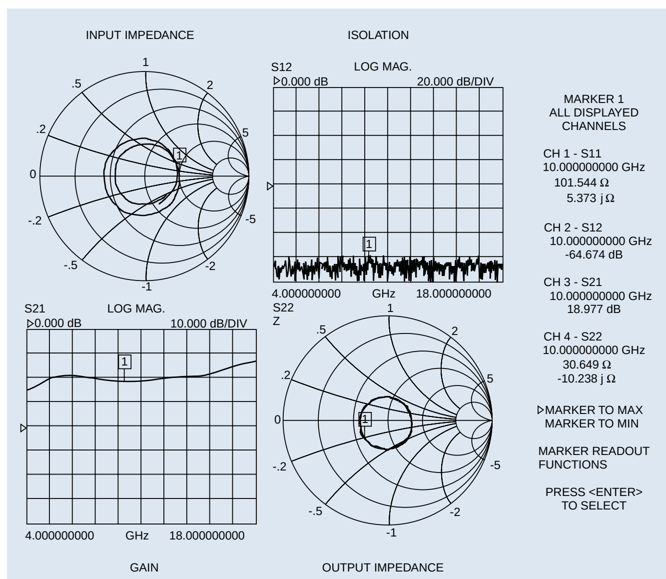


Figure 3.

Group Delay

Group delay is an important parameter for amplifiers used in communications systems. It is a measure of the time it takes for energy at a given frequency to travel through a device. Unless all important frequency components have essentially the same delay, distortion occurs in the output signal. Group delay is derived from the transmission phase response by the expression:

$$\text{Delay} = -\frac{\Delta\varnothing}{\Delta\omega}$$

The actual appearance of the group delay display is very dependent upon the aperture ($\Delta\omega$) selected. Aperture and smoothing are terms that are used in describing delay measurements and they are essentially the same from a functional point of view. The 37300A gives the user control of this parameter. It's very important that apertures be close to identical if group delay measurements are to be compared. Figure 4 shows the group delay of an amplifier. The aperture for this display was set to 3% of the sweep width: 420 Mhz.

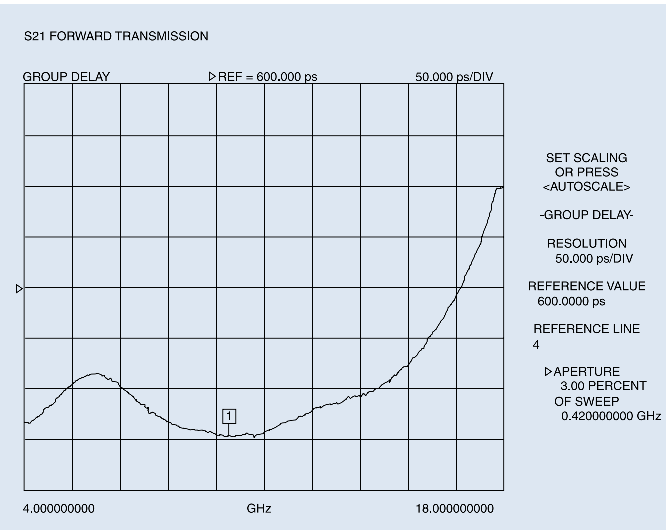


Figure 4.

Non Linear Testing

Active devices are usually designed to provide linear, distortion free operation for a specific level or power range of input signals. If the input level is increased there will a transition from linear to non-linear operation - the output will start to compress when the device can no longer provide its nominal linear gain. A common specification is the 1 dB compression point, which indicates the level at which the gain has decreased by 1 dB. As the input power is further increased the gain will continue to drop and depending upon the device and application, the user may want to observe performance at these higher compression levels. As more and more power is driven into the input the gain will continue to drop until the point of saturated output power has been reached (Psat).
At Psat no further increase is output power can be obtained.

Non linear testing can be done with a number of instruments including Vector Network Analzers. Parameters that must be considered for this type of test include: Test Port Power, DUT input power, power sweep range, and the output power of the amplifier. The block diagram below is representative of this type of test environment.

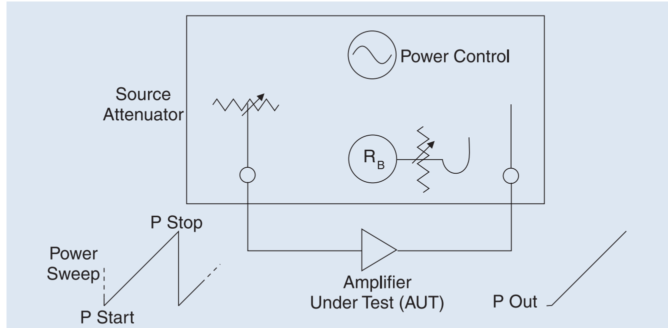


Figure A.

In most applications the user is interested in measuring both S Parameters and non linear performance. As described above, S Parameters are typically measured in the amplifiers linear region. Input power is then increased so that the amplifier's non linear performance can be measured. It is recommended that the frequency and linear operation power parameters be established before performing the S Parameter calibration. This will minimize the possibility of inadvertently overpowering either the device or the receiver during testing.

Power and VNA's

It is necessary to measure absolute power to determine Gain Compression. VNA receiver channels are typically downconverters and do not measure power directly. They are; however, linear so that an accurate power calibration at one level will result in a receiver channel that will accurately indicate power in dBm. This is accomplished by calibrating the VNA using an external power meter which in effect transfers the power meter/sensor accuracy to the VNA. The 373XXA firmware will support calibration with the following power meters: Anritsu ML2430A,-hp-437B, -hp-438A and Gigatronics 8540.

These meters differ in the way they handle sensor efficiency (consult the power meter manual). The 37300A does expect to receive corrected data from the power meter.

Errors can result if the proper correction factor isn't applied by the power meter - see Table A.

Correction Factor	Error (dB)
1%	.043
3%	.128
5%	.212
10%	.414

Table A.

The vector error correction available in VNA's is dependent upon ratioed S Parameter measurements. Power is measured using a single unratioed channel; therefore, when power is being measured error correction must be turned off.

Gain Compression

As mentioned above there are a number of ways to measure Gain Compression. Power meters can be used, although this is often a tedious procedure, scalar analyzers can also be used and VNA's can do the job as well. . Each method has some limitations in either convenience or accuracy. The VNA does have the advantage that it can also provide S-parameter data. The phase information associated with S21 can provide group delay and AM/PM data, which is not available using the other instruments. It should also be noted that VNA's are tuned receivers and do not respond to harmonics that may be present in the device output. When using a VNA two approaches can be used: Swept Frequency Gain Compression (SFGC) and Swept Power Gain Compression (SPGC). The 373XXA offers a very straightforward approach to each of these measurements.

It is normally desirable to make S Parameter measurements in the linear operating region of an amplifier and then observe Compression or AM/PM characteristics by increasing the input power sufficient to drive the amplifier into its nonlinear region. The characteristics of the amplifier to be tested (AUT) dictate the operating power levels required for the tests. Prior to making measurements on a specific amplifier the user must determine the desired operating levels. A recommended level for linear region operation is:

P = PGC - Gain - 15dB (PGC = Nominal 1 db compression of the AUT)

The actual level is constrained by the power available from the VNA in conjunction with the built in 10 dB step attenuator. In the case of the 373XXA this is easily supplemented by the addition of an external amplifier/attenuator combination. The power input to Port 2 must also be considered as the test should not drive the VNA into nonlinear operation. Typical specifications show .1 dB compression at a VNA receiver input level of -10 dBm. The receiver signal (this is the signal at b2 in Figure 2) is derived through a 13 dB coupler from the Port 2 signal.

The 373XXA includes a 10 dB step attenuator in this path which enables linear operation with input signals as high as 30 dBm (1 watt), the maximum signal level that should be input to Port 2. Higher power levels can be measured by attenuating the signal prior to Port 2.

The following sections will show results obtained from tests on a specific amplifier performed on an Anritsu 37347A. Appendix A includes a complete description of the set up used for the tests.

Swept Frequency Gain Compression

This is a manual procedure in which the user obtains a normalized amplifier response as a function of frequency at Pstart and manually increases the input power while observing the decrease in gain as the amplifier goes into compression. This permits the user to easily observe the most critical compression frequency of a broadband amplifier. The SFGC process is implemented in the 37300A by following the procedure outlined after accessing the Applications (APPL) menu and selecting Swept Frequency Gain Compression. This brings up the menu shown in Figure 5a and the user follows the menu instructions which would normally include a power meter calibration detailed in 5b at the power level defined by Power Target (Power Target is usually set to Pstart). The menu guides the user through the steps required to obtain a result such as that shown in Figure 6. This clearly indicates that for this specific amplifier, the 1 dB compression point is reached first at the high end where the gain is maximum.

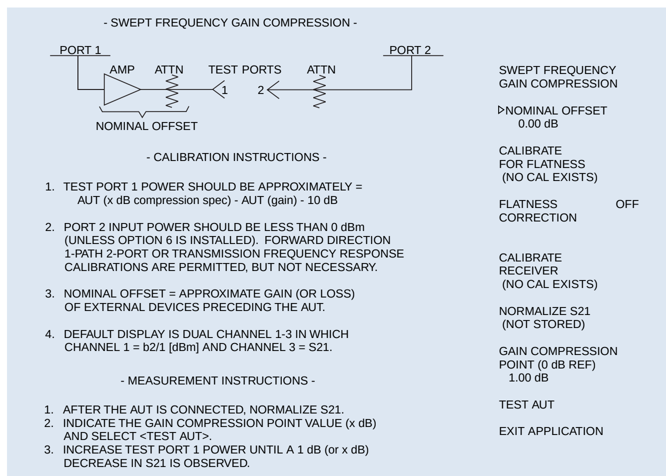


Figure 5a.

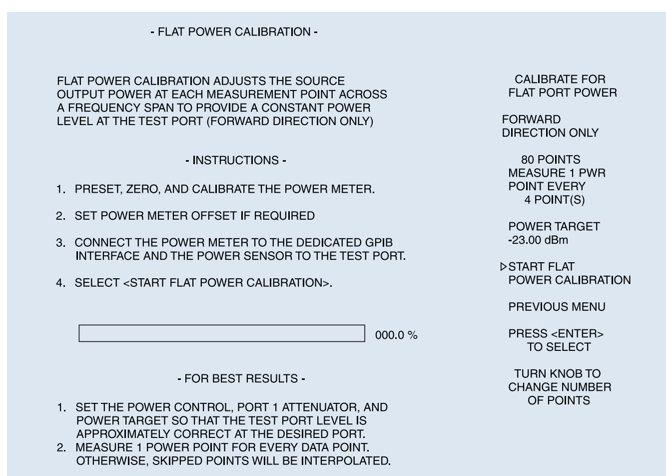


Figure 5b.

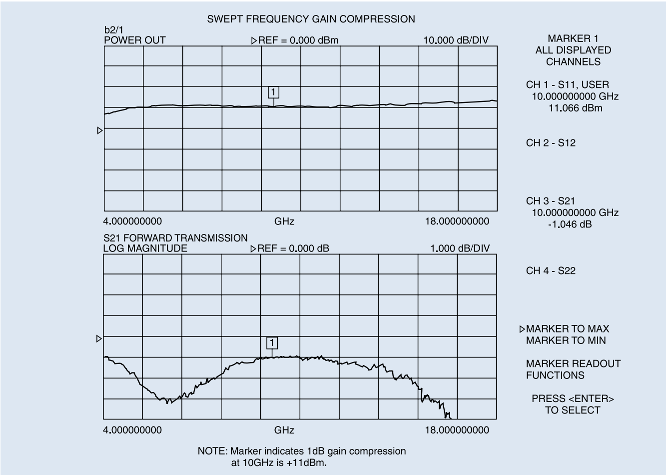


Figure 6.

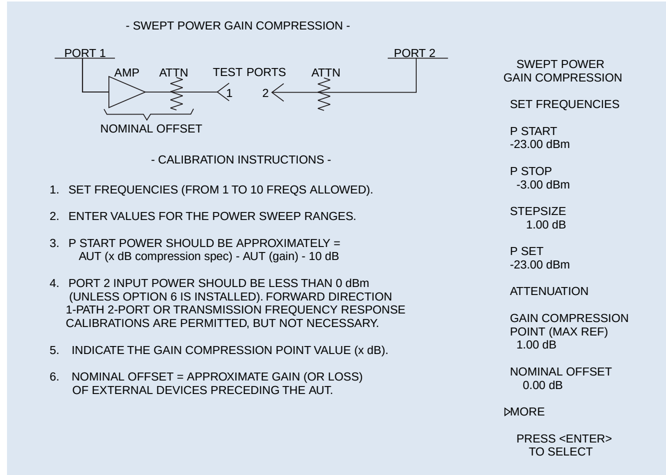


Figure 7b.

Swept Power Gain Compression

A swept power test is done at a CW frequency. The input power will be increased with a step sweep starting at Pstart and ending at Pstop. The step increment is also user defined. This enables the user to observe the conventional Pout vs. Pin presentation or a display of phase vs. Pin. The 37300A actually permits the user to select up to ten frequencies for swept power gain compression tests. The SPGC process is implemented in the 37300A by following the procedure outlined after accessing the Applications (APPL) menu and selecting Swept Power Gain Compression which results in the menus shown in Figures 7a and 7b. This permits the user to enter test frequencies, power parameters and follow a straightforward calibration procedure. At this time the user can test the AUT and obtain a Multiple Frequency Output such as is shown in Figure 8 or a single frequency display, shown in Figure 9.

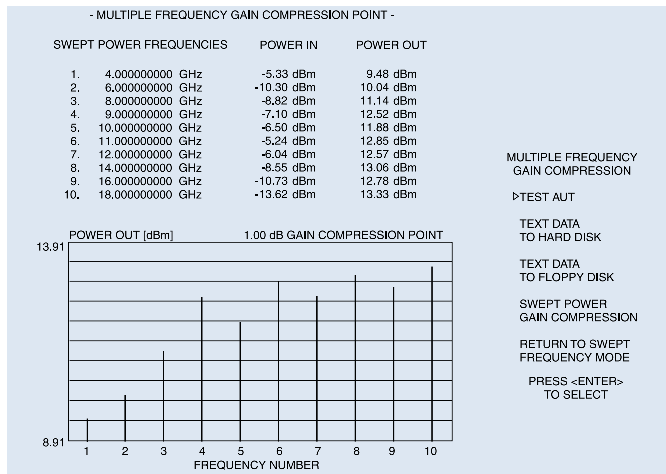


Figure 8.

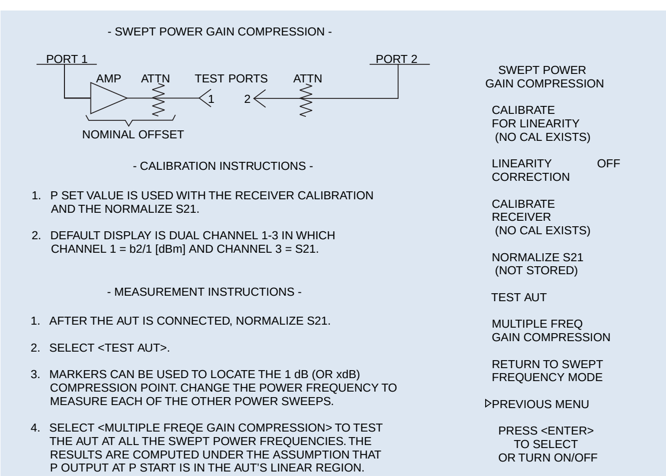


Figure 7a.

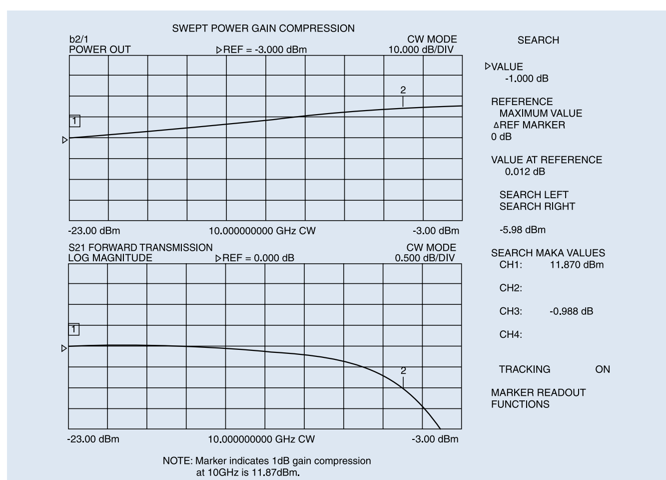


Figure 9.

AM/PM Conversion

When the power is swept, as in SPGC, the output phase of the amplifier may change which introduces distortion. AM/PM conversion provides relative and quantitative information about this distortion. It is readily observed on the 37300A by selecting a phase display. The 37300A display flexibility permits an overlay display of Pout and Phase vs. Pin shown in Figure 10 which is preferred by many users.

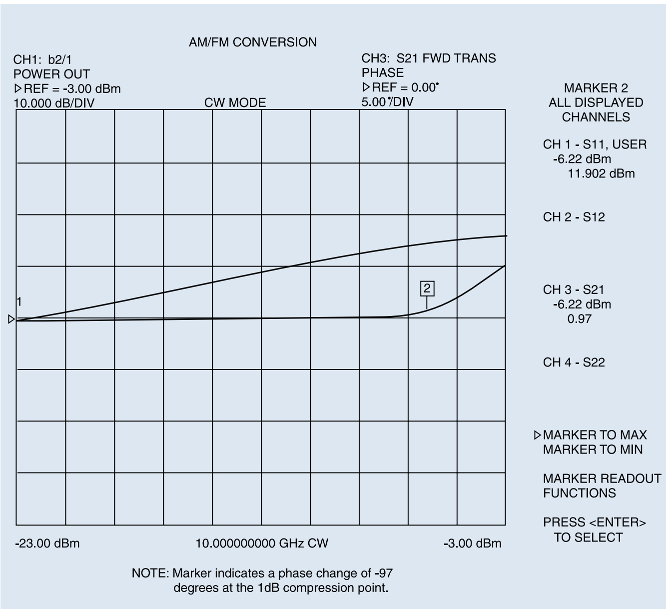


Figure 10.

Harmonics and Intermodulation

Many applications require information regarding harmonic performance and Intermodulation performance. Actual measurement of these parameters usually requires additional procedures and equipment such as spectrum analyzers and synthesizers. For many applications it has been shown that these parameters are mathematically (Reference 1) related to the 1 dB compression point. For example: the third order intercept point is nominally 10.7 dB higher than the 1 dB compression point. The actual 3rd harmonic level is 28.8 dB below the fundamental at the 1 dB compression point.
In some applications these relationships may result in savings in test time.

Accuracy Considerations

There are quite a few factors that affect the actual measured 1dB compression result, which in the example presented was at an output power level of 11.88 dBm at 10 Ghz (see Figure 8). These factors include:

- ❑ Accuracy of the power meter used in the power calibration process.
- ❑ Transfer of that accuracy to the receiver which permits the receiver to read in absolute power (dBm). This becomes more of a factor when attenuation is required at the input, output or in many applications - in both places.
- ❑ Method used - SFGC or SPGC.
- ❑ Determination of the exact 1dB down level.
- ❑ DUT performance - harmonics, sensitivity to heating, and sensitivity to power supply or bias voltages.
- ❑ Mismatch errors - during both calibration and measurement.

The first two and the last are likely the most significant and will be discussed below.

Power meter accuracy is a complex subject that is covered in detail in power meter manuals. The time required for a power meter to settle at the low end can be significant - this requires averaging which lengthens the power meter calibration process. Sensor calibration is important and the technique used by commercial power meters varies. The 37300 expects to receive corrected data from the power meter. In general accuracy's on the order of low tenths of a dB are achievable; but, when used at the low end of a meter's operating range these can easily exceed 10%.

Transferring the accuracy to the receiver is a straightforward step; but, the actual accuracy realized will be related to the Signal to noise ratio at the receiver input. A level of about -20 dBm is ideal, this would result if about -7 dBm was input to port 2 and no attenuation was required in the port 2 test attenuator. However if high gain, high power amplifiers are being tested the normal receiver input power during calibration can be low and the actual signal to noise ratio should be calculated. High averaging (200) and/or narrow IF Bandwidths should be used in this step to reduce system noise enhancing signal to noise ratio. The error associated with this step can be quantified by using Anritsu's RF Measurement Chart.

Whenever power measurements are made the mismatch uncertainty associated with the "source" and "sensor" lead to uncertainty. The magnitude can be expressed mathematically as:

$$unc(maximum\ dB) = 20*\log(1+\rho 1*\rho 2)$$

In the gain compression measurement setup there are two mismatch situations: VNA source-DUT input and DUT output-VNA load. For broadband VNA's which usually have a coupler at their test ports, source and load match are in the 10-15 dB ($\rho \sim .2$ to .3) range. A typical amplifier has input and output SWR specifications of 1.5 to 2.0($\rho \sim .2$ to .3). Therefore each mismatch can contribute: unc = 20*log(1.09) = +or - .8 dB! This is a substantial error. It can be reduced by including good quality attenuator pads at each port (6 dB is a good value). This improves source and load match to about 25 dB (r = .06) and the resultant uncertainty is reduced to + or - .2 dB which is usually an acceptable level. For some applications well matched isolators can be used to obtain similar results. Isolators have the advantage of lower forward loss; but, usually limit the frequency range of operation.

If SFGC is used the power is increased manually to establish the compression point. This assumes linear performance of the ALC circuitry - a questionable assumption as the nonlinearity can exceed 1 dB. Therefore SFGC should be used primarily to obtain an overall look at the frequency compression characteristic of the amplifier. In the SPGC measurement the calibration process in effect calibrates the ALC system at specific frequencies.

The results obtained at Anritsu based upon extensive tests of several different types of amplifiers suggest the following: For a given power meter calibration and receiver calibration, measurement repeatability is excellent - typically <.1 dB. The repeatability realized when using different receiver and power meters/sensors calibrations is typically <.4 dB. Correlation with other techniques, scalar analyzer or direct power meter measurements is typically <.5 dB.

Absolute Accuracy

It's important to realize that there are no "standards" available to measure and confirm absolute accuracy. Of the various techniques used to measure gain compression all have Limitations. For example: is harmonic power is being measured? The simplest power meter method uses a 10 dB change in level- is that adequate to take the DUT from truly linear operation to the 1 dB point?

Therefore, it is inappropriate to place too much emphasis on a couple tenths of a dB. It seems more important to come up with and approach that provides consistent repeatable data quickly and economically and the Anritsu 37XXXA series of VNA's offers that capability.

Appendix B provides a convenient worksheet that will help in setting up the system for the specific amplifier you wish to test.

Appendix A

Pertinent Amplifier Specifications:

Frequency Range:	4 - 18 GHz
Gain:	20 dB
Nominal 1dB Compression:	14 dBm

Using the recommended level for linear operation:

P linear test = 14-20-15 = -21 dBm.

The standard power sweep range of the Anritsu 373XXA VNA's is 20 dB; therefore, the optimum power sweep range for the test would be -21 to -1 dBm. This would insure linear operation at the low end and provide ample power to drive the amplifier into compression to observe non linear effects.

Now, the specific VNA's capabilities have to be considered. The 37347A default power setting is +5 dBm. This is achieved with a power control setting of 0 (the range is from +5 to -15). It is therefore necessary to attenuate the signal to obtain the -21 starting level. An external 10 dB attenuator will be used. The internal source attenuator could be used to attenuate the signal; but, an external attenuator accomplishes the same purpose and improves match, which improves accuracy.

This will of course impact the high power end of the sweep so -1 dBm is a question. Actually the +5 dBm default is established for operation over the full range of the instrument: 40 Mhz to 20 Ghz. For the specific amplifier being tested the frequency range is under 20 Ghz. For the lower frequency range the unit may put out more than +5 dBm. The actual capability of a specific instrument can be observed by setting up the frequency range to be used and increasing the power control above 0 until an unleveled message appears on the screen. For the instrument used for these tests the 37347A showed unleveled at +4 (This corresponds to an output power of +9 dBm). It is recommended that the user set test limits 2 dB below this value; therefore a high end for the power sweep was selected to be -3 dBm (A power control setting of +2 results in a test port power of +7 dBm attenuated by 10 dB provides the -3 dB- result) which is not quite the "optimum" -1 dBm, but it's close enough to expect the system to work. The actual range used was:

Pstart=-23 dBm

Pstop= -3 dBm

If the high end power of the VNA was inadequate to drive the amplifier into its nonlinear region an amplifier to boost the port power would be necessary. When required the preamps are easily installed on the 37300A.

The final factor that must be considered is the power input to port 2 of the VNA. The test amplifier will put out powers up to about +15 dBm. If this is input to port 2, no damage will occur but the input to the receiver will be about +2 dBm (The port 2 power is reduced by the 13 dB coupling factor) which is well in excess of its linear operating capability of -10 dBm. To improve the accuracy, a 6 dB attenuator was used at the Port 2 input. The 40 dB step attenuator associated with the receiver should be set to 10 dB. This leads to a receiver input of -14 dBm which will insure that the instrument does not contribute to the nonlinear measurements made on the amplifier to be tested.

Appendix B

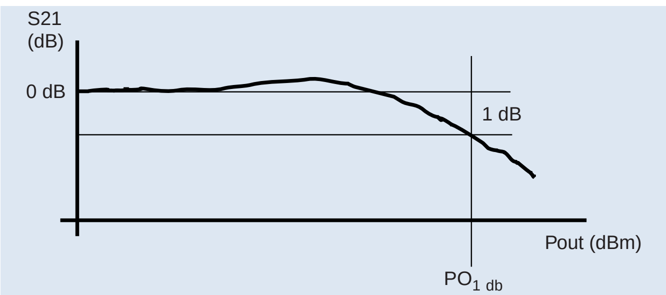
Worksheet for Gain Compression Setup

The proper implementation of a SPGC measurement requires the frequency, gain, and output power compression specifications of the amplifier. The 37300 family supports measurements up to 10 frequencies; however, this discussion is limited to a single frequency. Space is allocated for User-Defined calculations.

Case	Frequency	Gain	PO_{1db}
User-Defined			
Example #1	6 GHz	20 dB	15 dBm
Example #2	10 GHz	45 dB	25 dBm

Determine Amplifier Power Output Range

The SPGC measurement process begins by analyzing the desired output and working backwards to the instrument settings. Consider the following typical gain compression curve.



This gain compression curve has been labeled to show the output 1 dB compression point.

Case	PO_{1db}
User-Defined	
Example #1	15 dBm
Example #2	25 dBm

The 37300 family supports up to 20 dB of power range for gain The 37300 family supports up to 30 dB of power range for gain compression measurements. With this specification, simply choose the approximate position within the 30 dB (or less) range for the 1 dB compression point. For this discussion, the 15 dB position of the 20 dB range is arbitrarily selected. In this way, the Amplifier Output Range is determined by partitioning the 20 dB range into two parts: 15 dB of range before compression and 5 dB of range after compression. This approximation establishes the desired output range of the amplifier, which also corresponds to the input range to Port 2 of the VNA.

Case	PO_{1db}	$PO_{start} = PO_{1db}$ -15 dB	$PO_{stop} = PO_{1db}$ +5 dB
User-Defined			
Example #1	15 dBm	0 dBm	20 dBm
Example #2	25 dBm	10 dBm	30 dBm

Determine Amplifier Power Input Range

Clearly, subtraction of the gain from the output amplifier range determines the input range.

Case	Gain	$PO_{start} = PO_{1db}$ -Gain	$PO_{stop} = PO_{stop}$ -Gain
User-Defined			
Example #1	20 dB	-20 dBm	0 dBm
Example #2	45 dB	-35 dBm	-15 dBm

This input amplifier range (PIstart and PIstop) corresponds to the source power required to view the output 1 dB compression point for the SPGC measurement.

VNA Block Diagram

The next important step is to configure the VNA to provide the desired input amplifier range and to handle accurately the desired output amplifier range for the measurement. This configuration process requires an understanding of how the VNA architecture contributes to the measurement. Accordingly, refer to the block diagram of the VNA in Figure 2 for consideration during the configuration process.

VNA Configuration

In order to perform a SPGC measurement, the VNA requires the following information (reference application menu on VNA for SPGC measurements): SET FREQUENCIES, P START, P STOP, STEP SIZE, ATTENUATION (PORT 1 ATTN & PORT 2 ATTN), GAIN COMPRESSION POINT, and NOMINAL OFFSET.

SET FREQUENCIES refers to the desired frequencies for the measurements. The setting of frequencies is straightforward using the front panel menu. Similarly, the GAIN COMPRESSION POINT is typically choosen as 1 dB since the output 1 dB compression point is a common specification.

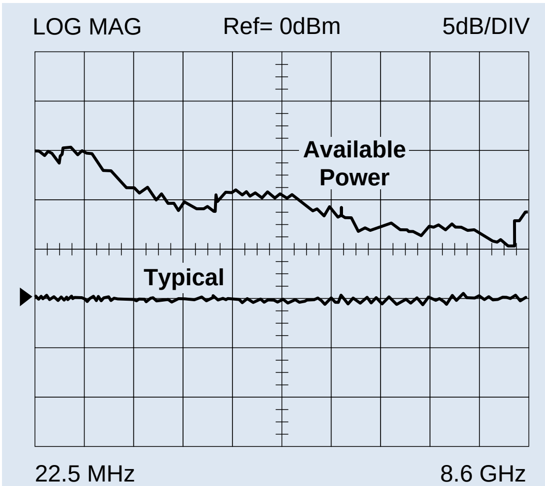
VNA Source Power Settings

P START, P STOP, and STEP SIZE refers to the VNA source power for the measurement. The VNA will perform a power meter calibration between P START and P STOP in STEP SIZE increments for each specified frequency. The desired VNA source power range is PI_{start} and PI_{stop}, which corresponds to P START and P STOP.

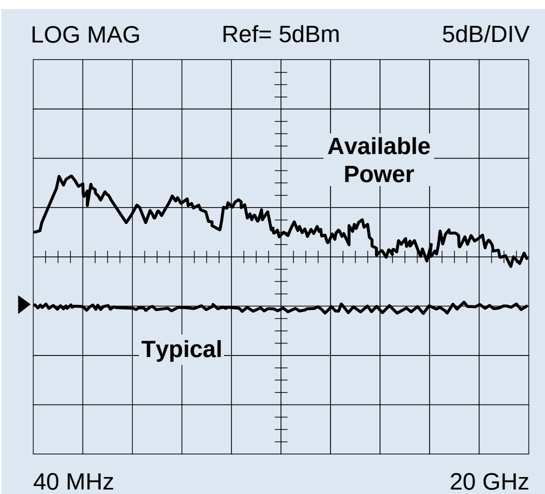
Case	P START = $P1_{start}$	P STOP = $P1_{stop}$	STEP SIZE
User-Defined			
Example #1	-20 dBm	-0 dBm	1 dB
Example #2	-35 dBm	-15 dBm	1 dB

VNA Available Power Considerations

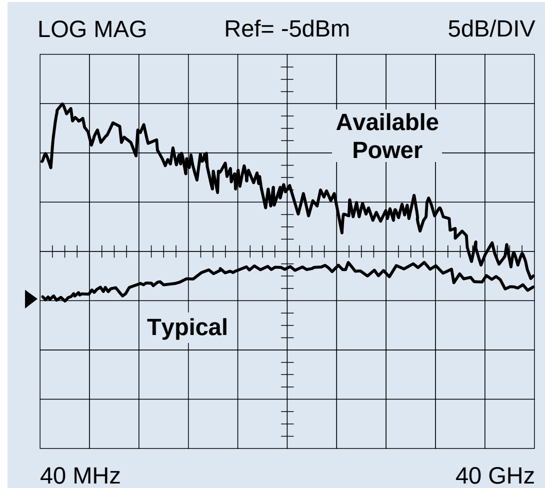
Before continuing, the VNA Available Power curves should be consulted to ensure enough available power for the measurement. For convenience, the following available power curves are reprinted from the Technical Data Sheet for the 37300 family.



Model 37311A and 37317A Port 1 Power



Model 37347A Port 1 Power



Model 37369A Port 1 Power

In application, find the Available Power for the instrument being used in the measurement. A comparison between P STOP and the Available Power indicates whether enough power is available for the measurement.

It is important to note that these Available Power curves represent typical performance and exceed Power Range Specifications for the 37300 family; consequently, actual performance varies from instrument to instrument. It is always a good idea to verify Available Power on the instrument before proceeding with the measurement.

External Amplifier or Attenuator Implementation

An external amplifier boosts the VNA source power when P STOP exceeds the Available Power of the instrument. Referencing the previous VNA block diagram, an amplifier inserted in the front panel Amplifier Loop increases the Available Power capability of the VNA. The limitation for this implementation is the input to Port 1 of the VNA cannot exceed 1 Watt (+30 dBm)!

Also, an external attenuator increases the source match of the VNA when placed between the VNA and the input of the amplifier.

When using an external amplifier or an external attenuator, NOMINAL OFFSET is the approximate gain of the external amplifier or loss of the external attenuator, respectively. Without an external amplifier or an external attenuator, NOMINAL OFFSET is 0 dB.

VNA Attenuation Considerations

The proper selection of VNA Attenuation ensures accurate measurements and protects the VNA from damage. Attenuation settings within the VNA are available for both the input and output of the amplifier (PORT 1 ATTN & PORT 2 ATTN, respectively). Both of these attenuators are set in 10 dB increments. Refer to the previous VNA block diagram for their position within the measurement path.

It is important to note that input to Ports 1 and 2 of the VNA cannot exceed 1 Watt (+30 dBm)!

Port 1 Attenuation

Port 1 Attenuation value depends on the amplifier power input requirements for compression, available power, and the 30 dB power range available from the VNA for the measurement.

It might not be intuitive, but setting the Port 1 Attenuation primarily depends on the PI_{start} value. The following table shows PI_{start} values versus Port 1 Attenuation.

PORT 1 ATTN (dB)	37347 PI_{start} (dBm)	37369 PI_{start} (dBm)
0 (0 dB)	≥ -15	≥ -29
1 (10 dB)	≥ -25	≥ -39
2 (20 dB)	≥ -35	≥ -49
3 (30 dB)	≥ -45	≥ -59
4 (40 dB)	≥ -55	≥ -69
5 (50 dB)	≥ -65	≥ -79
6 (60 dB)	≥ -75	≥ -89
7 (70 dB)	≥ -85	≥ -99

Based on the previously determined PI_{start} value, find the corresponding PORT 1 ATTN setting. Start at the top and continue down the table until PI_{start} satisfies the greater-than relationship. The following table is updated using this procedure.

Case	$P1_{start}$	PORT 1 ATTN	P START	P STOP
User-Defined				
Example #1	-20 dBm	0 dB	-20 dBm	0 dBm
Example #2	-35 dBm	2 dB	-35 dBm	-15 dBm

With this PORT 1 ATTN setting, set P STOP to the PI_{stop} value. Verify both P STOP and P START on the VNA. Continue with the setup when there are no errors on the display for these values of PORT 1 ATTN, P START, and P STOP.

Attenuation

The Port 2 Attenuation value provides protection to the VNA's receiver and allows it to operate in the linear region. Refer to the previous VNA block diagram for the following discussion.

Two factors that influence the Port 2 Attenuation value of the VNA are the receiver compression point and the loss between Port 2 and the receiver. The 0.1 dB compression point of the receiver is approximately -10 dBm. The coupler loss between Port 2 and the receiver is approximately 13 dB.

Subtracting 13 dB from PO_{stop} determines the power at the receiver. The difference (rounded up to the next value of 10) between the power at the receiver and the receiver compression point is the Port 2 Attenuation. The following table should clarify these calculations.

Case	$P0_{stop}$	Loss	At Receiver	Difference	PORT 2 ATTN
User-Defined		-13 dB			
Example #1	+20 dBm	-13 dB	7 dBm	7-(-10)= 17 dB	2 (20 dB)
Example #1	+30 dBm	-13 dB	17 dBm	17-(-10)= 27 dB	3 (30 dB)

Conclusion

This concludes the setup of a generic swept power gain compression (SPGC) measurement. It began with amplifier frequency, gain, and compression specifications and ended with VNA setup parameters for the measurement.

The following table summarizes the VNA configuration for SPGC measurements given various amplifier gain and compression specifications.

Case	Gain	PO_{1dB}	P START	P STOP	PORT 2 ATTN	PORT 2 ATTN
User-Defined						
Example #1	20 dB	15 dBm	-20 dBm	0 dBm	0 (0 dB)	2 (20 dB)
Example #2	45 dB	25 dBm	-35 dBm	-15 dBm	2 (20 dB)	3 (30 dB)

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