AN122
Measuring Gain Compression

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Abstract:

This paper outlines how to measure gain compression of a circuit with the AEA Technology two port network analyzers.

Introduction:

Gain compression measures gain linearity of a system or subcircuit. When the input signal level increases by 1dB, a linear amplifier will increase the output by 1dB. If the gain is less that 1dB, the amplifier has compressed the gain. Engineers minimize gain compression to prevent amplitude distortion of the signal. Below is the formula for gain compression:

$$\sigma = A_{ref} + Atten - A_m$$

$\sigma =$ gain compression
A_{ref} = output level (in dB) caused a low level reference input
Atten = dB of input signal above reference level (change in attenuator setting)
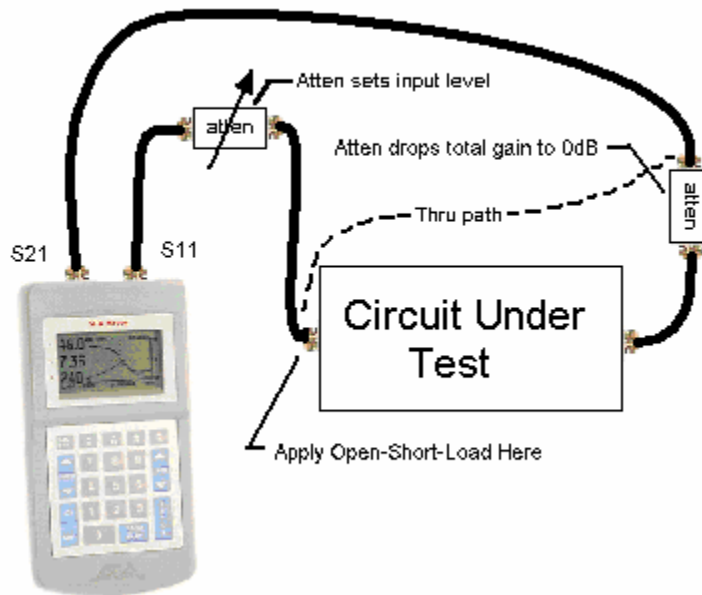A_m = output level (in dB) measured with higher input level

As the attenuator setting decreases (input increases), the output level increases. Eventually the output level gain compresses to a point where σ calculates to 1dB. We define this output level as the "1 dB compression point". Other compression levels may be determined as required by the system design.

The AEA Technology two port network analyzers display the log gain of the circuit under test. Each point of the plot represents the gain at a frequency. The network analyzer allows you to measure the gain compression (σ) across an entire band of interest for the about same effort it takes to measure σ at a single frequency using a power meter.

Circuit gain compression may be measured using any AEA 2 port network analyzer. When measuring active circuits, protect the front end of the analyzer with an attenuator between the circuit output and the analyzer S21 input. The AEA technology network analyzers are designed for isolation measurements (i.e. gain < 0 dB), so the attenuator should be slightly greater than the expected circuit gain. Quality connections to the analyzer, attenuator, and circuit are required to get accurate readings. Use coaxial connectors for all signal path connections. Connectors at the circuit end of the cables allow a convenient way to perform cable nulling.

Test setup:

Amplifier circuits require one or two attenuators, where the total attenuation offsets the expected amplifier gain to 0 dB (or a few dB of loss). The attenuator will need to be split to provide a variable input level to the amplifier. If you use an output attenuator, consider it as part of the test fixture when cable nulling. If you use an input attenuator, include it when performing the cable null (apply Open-Short-Load to fixture side of the attenuator. Passive circuits require no attenuators.

Test fixture quality is a key factor in measuring the circuit under test. Use good PCB mount coaxial connectors for the input and output ports. A ground plane usually improves performance by reducing stray inductance in the power distribution. Beware that many RF circuits, especially active ones, operate differently if the I/O ports use coaxial pigtails instead of good connectors. Using coaxial connectors for the I/O ports allows you to replace the test fixture with a barrel connector when cable nulling the "thru" path. Any power supply or control inputs should be well bypassed with capacitors to the fixture ground plane. Once you have created your fixture, measurements can begin.

Steps to Measure Gain Compression (σ):

1. Set the network analyzer center frequency and sweep range to cover the frequencies of interest. If you have a multiple band situation, you should prestore multiple sweeps to cover the various bands.
2. Set at least one of the plots to an S21 reading (linear gain, log gain, or gain phase). You may view two plots at once on the analyzer. If you also want to measure and save the S11 data, then the second plot *must* be one of the S11 plots. The S11 plots are only valid for the attenuator setting that the cable null was done for. You will have to mathematically or graphically remove the effect of the attenuator at other settings. You may view more than two plots simultaneously by operating the network analyzer via the PC Vision software. PC Vision Hint: read one plot, take the effort to save all the plot settings the way you like it (axes formats, colors, labels, etc) then select Chart Window|Save Settings. Future readings will be presented in a similar manner.
3. Cable null the network analyzer, including cables, input attenuator, and adaptors. Consider the output attenuator as part of the test fixture, so it does not appear in the thru path nulling. Set the input attenuator to minimum (maximum input level).
4. Connect the cables to the test fixture input and outputs.
5. Apply power, if required, to the test fixture.
6. Set the attenuator to provide an input level that is 10 to 20 dB lower than the expected gain compression point. Save this S21 data, it is the reference output level (where the amplifier is not distorting or has negligible compression).
7. Take readings, save plots as desired. See how circuit alterations affect the circuit characteristics. The gain compression is equal to the dBs (attenuator) above reference + reference gain level - gain reading. This operation may be performed in Excel by exporting the data to an excel file and creating a gain compression macro for the data.
8. Once gain compression has been achieved, use a spectrum analyzer to measure the amplifier output level. Alternately, set the analyzer to CW and use a power meter. Since the network analyzer log gain scale reads in dBs, measuring only one point for absolute power level allows you to translate all readings to absolute levels.
9. Use saved data to document your design.

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Use Excel to Process the Data:

1. Read the data from the unit into PC Vision (get new data or read memory). Save the data: File|Export Data|Excel (or as Text if you prefer).
2. Use Excel to open the file with the saved data (*yourfile*.xls). It is possible to also use archived files (*yourfile*.aea) or text files (*yourfile*.txt). Create a new sheet. Select the new sheet; be sure to erase all columns of data on the new sheet.
3. Optionally add labels to top row.

Excel Gain Compression Example

	A	B	C	D	E	F	G	H
1	Freq	attn ref	attn +1	attn+2	attn+3	attn+4	attn+5	attn+6
2	63.600	-8.592	-7.652	-6.806	-6.007	-5.302	-4.550	-3.892
3	63.760	-8.598	-7.657	-6.811	-6.011	-5.306	-4.553	-3.894
4	63.920	-8.596	-7.655	-6.807	-6.007	-5.301	-4.548	-3.889
5	64.080	-8.588	-7.646	-6.798	-5.997	-5.291	-4.537	-3.877
6	64.240	-8.581	-7.638	-6.790	-5.988	-5.281	-4.526	-3.866
7	…	…	…	…	…	…	…	…

4. Select frequency data from saved data on first sheet. Select Edit|Copy, then select the second sheet, click once on cell A2. Select Edit|Paste. The frequency data is now in column A.
5. Select reference level Log Gain data from saved data on first sheet. Select Edit|Copy, then select the second sheet, click once on cell B2. Select Edit|Paste. The frequency data is now in column B.
6. Select Log Gain data for other attenuator settings (in different file), paste into the next available column. Repeat until all data is pasted onto sheet.

Example Continued

	J	K	L	M	N	O
1	1	2	3	4	5	6
2	0.020	0.138	0.305	0.570	0.786	1.100
3	0.020	0.138	0.304	0.569	0.785	1.099
4	0.020	0.137	0.304	0.568	0.784	1.098
5	0.019	0.137	0.303	0.567	0.783	1.096
6	0.019	0.136	0.302	0.567	0.782	1.095
7	0.019	0.136	0.302	0.566	0.781	1.094

7. Enter attenuator step from 1 to max (1 to 6 here) across row a, starting in an empty part of the sheet (entered in J1 through O1 above).
8. Enter formula into cell J2: = $B2+J$1-C2.
9. Now select a block of cells (J2 to O82 in this example). Fill the rest of the block: using Edit|Fill|Right to end: then Exit|Fill|Down
10. We see the 1 dB gain compression occurring in column O.

Conclusion:

AEA Technology two port network analyzers may be used to measure your circuit's gain compression, and will provide useful displays to guide you in the design of the circuit. To obtain the exact power level of the compression, a power meter or spectrum analyzer would be required; however, you only need to measure one point to establish the absolute reference for all the plots.

References:

AN101   When to Use Cable Null, AEA Technology
AN120   Measuring Amplifier Gain, AEA Technology
AN121   Measuring Group Delay, AEA Technology
AN124   Measuring Differential Circuits, AEA Technology
AN125   Measuring AM to PM Distortion, AEA Technology