

## AN121 Measuring Group Delay with the Bravo Analyzer

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### Abstract:

This paper outlines how to measure group delay of an active or passive circuit with the AEA Technology two port Bravo network analyzers.

### Introduction:

Group delay measures how evenly a spectrum travels through a system or subcircuit. If all frequencies of interest have the same transit time through the system or subcircuit, then we say that it has a “flat” group delay or a linear phase response. Engineers strive for flat group delay to prevent phase distortion of the signal. Below is the formula for group delay:

$$\tau_g = \frac{d\theta}{d\omega}$$

$\omega$  in the above formula = frequency \* 2 \*  $\pi$ , phase is in radians

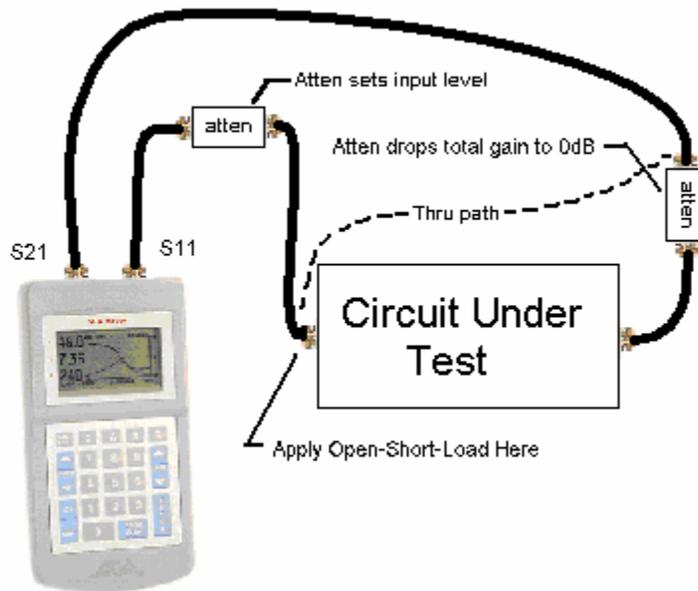
The AEA Technology two port network analyzers display the phase delay (called gain phase in some units) of the circuit under test. Each point of the plot represents the phase delay at a frequency. Changing from one point to the next always involves a constant step in frequency, called the step frequency. The group delay may be calculated by dividing the change in phase delay from one point to the next by the step frequency (in radians per second). A macro may be developed in Excel to calculate this for the entire sweep. To convert analyzer data (note: phase in degrees, frequency in Hz):

$$\tau_{gN} = (\text{gain phase}_N - \text{gain phase}_{N-1}) / (360 * \text{step frequency})$$

Circuit group delay may be measured using any 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 may need to be split to provide the proper 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 pigtailed 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 Group Delay ( $\tau_g$ ):

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. 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.
4. Connect the cables to the test fixture input and outputs.
5. Apply power, if required, to the test fixture.
6. Take readings, save plots as desired. See how circuit alterations affect the circuit characteristics. The group delay is equal to the gain phase reading divided by the frequency as explained above. This operation may be performed in Excel by exporting the data to an excel file and creating a group delay macro for the data.
7. Use saved data to document your design.

## 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. Enter formula into cell D1: = (B3-B2)\*360.

### Excel Group Delay Example

	A	B	C	D
		Gain		
1	Freq	Phase	$\tau_g$	57.6
2	63.600	-18.067		
3	63.760	-18.739	-0.01167	
4	63.920	-19.387	-0.01125	
5	64.080	-19.969	-0.01010	
6	64.240	-20.522	-0.00960	
7	64.400	-21.035	-0.00891	
...	...	...	...	

4. Enter the start frequency (63.6) into cell A2. Select cells in column A (one for each data point). From Menu: Edit|Fill|Series, enter the freq step (.160) into the step size, and then click OK.
5. Select Gain Phase data from saved data on first sheet. Select Edit|Copy, then select the second sheet, click once on cell B2. Select Edit|Paste. The Gain Phase data is now in column B.
6. Enter formula into cell C3: = (B3-B2)/\$D\$1. Fill the rest of column C (similar to step 4.)

Note that there is one less data point in column C because it takes two phase readings to make one group delay. You could optionally extrapolate an extra point in column B to add one more point to column C. A second effect of using two points to make the group delay: the group delay data shifts in frequency by  $\frac{1}{2}$  frequency step. For example: the group delay in cell C3 was from data points at frequencies of 63.6 and 63.76. The most accurate plot would associate the group delay data in cell C3 with a frequency of  $(63.6+63.76)/2=63.68$ . Alternately, you could shift the group delay data to align with the original frequency points, but this uses three points per group delay point and you end up with 2 less points. The formula in cell C3 would be: = 360\*(B4-B2)/(2 \* \$D\$1). This formula applies a small low pass “video filter” effect, but this will not affect readings from well behaved circuits.

**Conclusion:**

AEA Technology two port network analyzers may be used to measure your circuit's group delay, and will provide useful displays to guide you in the design of the circuit.

**References:**

- AN101 When to Use Cable Null, AEA Technology
- AN120 Measuring Amplifier Gain, AEA Technology
- AN122 Measuring Gain Compression, AEA Technology
- AN124 Measuring Differential Circuits, AEA Technology
- AN125 Measuring AM to PM Distortion, AEA Technology

**Keywords:** How to measure group delay tutorial, introduction to understanding group delay fundamentals, using excel to calculate group delay explained, about group delay basics