

Using the LINC2 Visual System Architect to Determine the System Spurious-Free Dynamic Range (SFDR)

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The concept of Spurious-free Dynamic Range (SFDR) provides an indication of the range of signal amplitudes that a radio receiver can process. The ability of a receiver system to process the desired signal information is impaired if the signal is in the presence of spurious interfering signals (spurs) or buried in the noise. The useful signal level is limited at the low end by noise and at the high end by distortion products (spurs created by the non-linear characteristics of the receiver). The need for the desired signal to be above the noise by a certain amount for a practical detector to process the signal will be addressed later by employing a SFDR offset in dB equal to the required detector threshold. The offset value will be used to calculate the effective SFDR based on the receiver's minimum detectable signal (MDS). For simplicity in demonstrating the concepts, it will initially be assumed that the MDS for the system is equal to the noise level.

Therefore, the range of signals that can be processed most effectively is one in which the signal is at least as strong as the interference from noise but not so strong as to produce intermodulation (IM) spurs that are stronger than the noise level. (It is of no concern if the spurs are below the noise level since they would be masked by the noise anyway). The SFDR referred to here is the third order spurious-free dynamic range. This is the most common usage since the third order IM spurs are the ones that are of most concern (because it is usually impossible to remove them by filtering).

The concept of SFDR will be applied in this article to a receiver circuit. The concept and supporting measurements used here could apply to other circuits as well, but the application to receiver circuits is com-

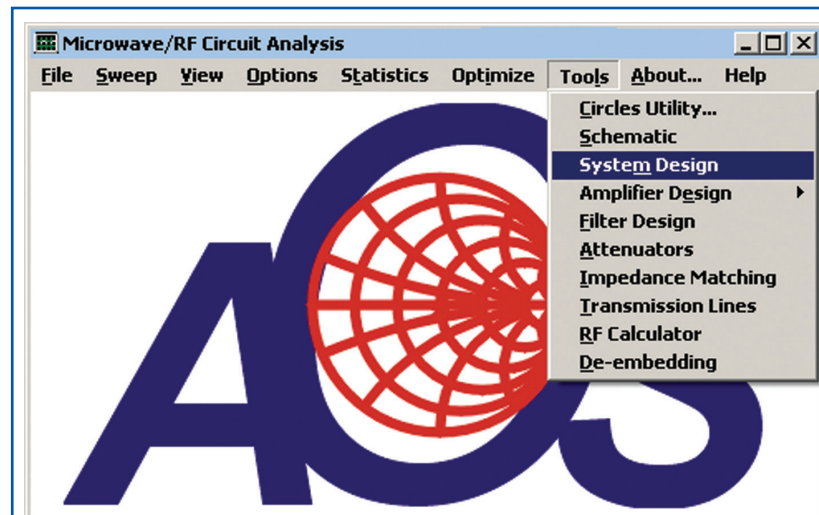


Figure 1: Selecting the Visual System Architect from the LINC2 Tools Menu

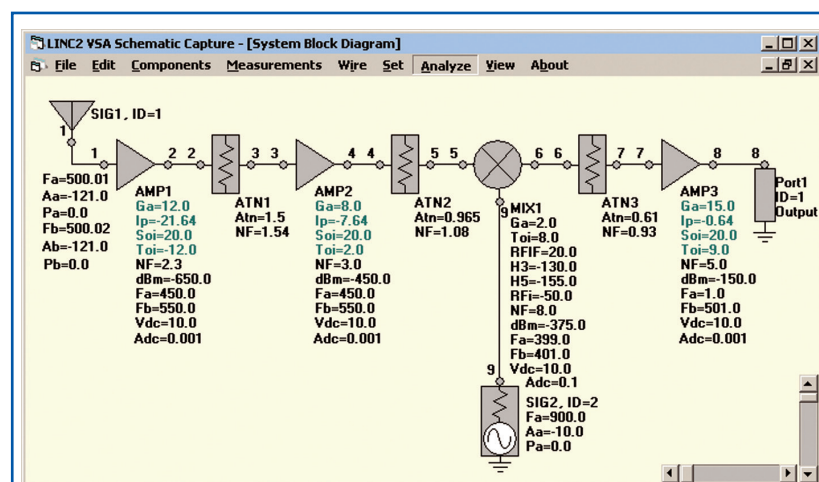


Figure 2: LINC2 VSA Receiver Schematic for SFDR Analysis

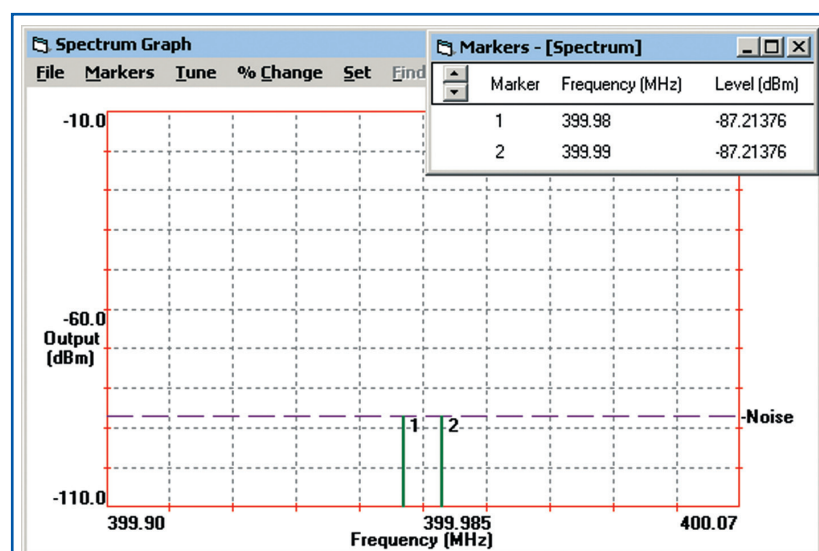


Figure 3: VSA IF Output Spectrum at the Noise Level (for Input Signal Levels of -121 dBm)

mon. The LINC2 Visual System Architect software (VSA) from ACS (Applied Computational Sciences, Escondido, CA) will be used to demonstrate the concept and measurement of

Spurious-free Dynamic Range for a typical radio receiver.

The LINC2 VSA program (Figure 1) offers at least two different ways to determine the SFDR, direct simulated SFDR

measurement and calculated SFDR via system cascade budget analysis. Both methods will be presented in the following paragraphs. First, the VSA's Spectral Analysis capability will be used to display all the signals, IM spurs and noise spectra necessary to directly measure the SFDR. Employing the VSA spectral analysis method has the advantage that it visually applies the concept of SFDR in an intuitive manner that is analogous to real world instruments (i.e. a spectrum analyzer) making the same measurement. Then, finally, the VSA's Cascade Budget Analysis method will be used to arrive at the same value for the system SFDR. While cascade budget analysis does not provide as much insight into the concept of SFDR (by simply reporting its value), it does provide additional valuable information on how the system design affects the SFDR. In particular, the SFDR budget analysis will show graphically how the inclusion of filter components contributes directly to improving the system SFDR.

Using the Visual System Architect's Spectral Domain Analysis to Measure SFDR

The LINC2 VSA Spectrum Analysis plots will be used to find the SFDR for the receiver circuit in Figure 2. The lowest signal level (at the input from the antenna terminal) will be found that generates an output signal at the detector (Port 1, Output) that is just at the noise level. The input signal level will then be increased until IM3 products appear at this same noise level at the output port. The difference between these two levels is the SFDR. The SFDR found by VSA spectrum analysis will then be compared to other methods [1].

With the receiver circuit schematic entered as in Figure 2, clicking Analyze and View >

Plot yields a view of the output spectrum as shown in **Figure 3**.

We note that an input signal level of -121 dBm (at the antenna input terminal in **Figure 2**) puts the two output (fundamental) tones just at the noise level of -87.2 dBm (as shown in **Figure 3**). We denote this input level as $SFDR_Sig_Pwr_In1 = -121$ dBm.

The antenna input signal level that caused the output in **Figure 3** to coincide with the noise level was predetermined by simultaneously adjusting the two fundamental tones (at 500.01 and 500.02 MHz) until the corresponding receiver signal outputs were equal to the noise output level (dashed line labeled Noise in **Figure 3**).

The horizontal dashed line representing the noise floor in **Figure 3** is a function of the system Noise Bandwidth which was set at 100 KHz via the **Set > Simulation Control** menu (Noise). Since there are no filters in the schematic (**Figure 2**) the noise bandwidth setting of 100 KHz represents the detector bandwidth. In this case the detector bandwidth is the limiting factor for determining system noise bandwidth. In the next section the same noise bandwidth will be explicitly enforced by the addition of an ideal 100 KHz IF filter.

The next step is to find the input level that produces two IM3 spurs with levels equal to the noise floor as shown in **Figure 4**. Note that this time it is the IM3 spurs (markers 3 and 4 in **Figure 4**) that are set equal to the noise floor (by appropriately adjusting the level of the antenna input signals). This results in the two fundamental output tones (markers 1 and 2) increasing to nearly 70 dB above the noise. As before, we check the level of the input signals and find that they are both at -51.06 dBm. We denote this input level as $SFDR_Sig_Pwr_In2 = -51.06$ dBm. The input SFDR is therefore:

$$Input\ SFDR = SFDR_Sig_Pwr_In2 - SFDR_Sig_Pwr_In1 = (-51.06) - (-121) = 69.94\ dB \leftarrow$$

We can also find the SFDR

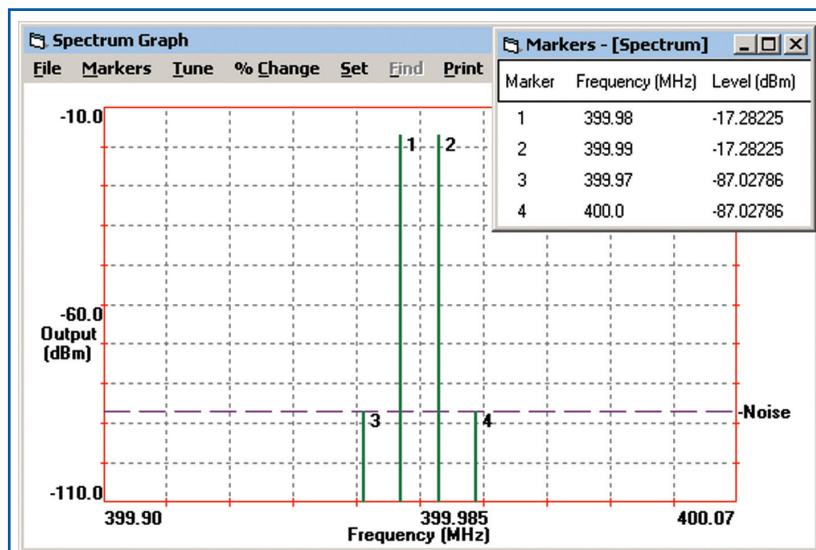


Figure 4: VSA IF Output Spectrum with Input Signal Levels set at -51.06 dBm

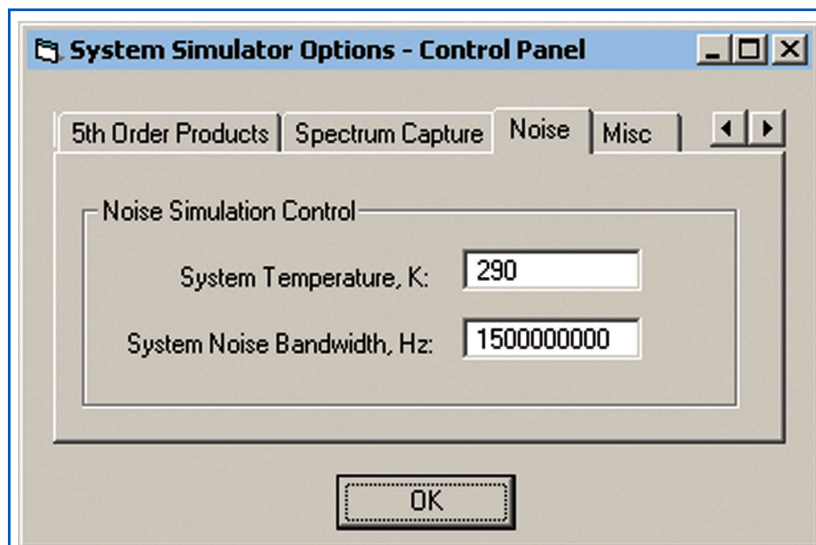


Figure 5: VSA Noise Simulation Control (Global System Temperature and Noise BW Setting)

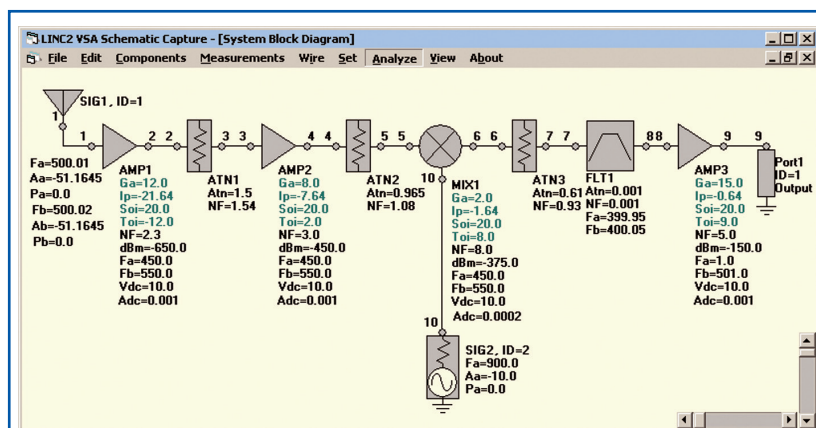


Figure 6: Using an IF Filter to Control Noise Bandwidth in the LINC2 VSA System Simulation

from the difference between the fundamental output levels from **Figures 3** and **4** as follows:

$$Output\ SFDR = (Marker\ 1,\ Figure\ 4) - (Marker\ 1,\ Figure\ 3) = (-17.28) - (-87.21) = 69.93\ dB \leftarrow$$

The input and output SFDR are virtually identical as would be expected from measurements made in the linear por-

tion of the system's gain curve where a difference in two input levels yields the same difference between the corresponding output levels. In this case we simply report the system $SFDR = 69.94$ dBm ← relative to the input.

Using the LINC2 VSA's Cascade Budget Analysis to Plot the Cumulative SFDR

through the System Cascade

The following is an alternative method of determining the SFDR based on the system IIP3 (input third order intercept point) and the relation $SFDR = (2/3) * (IIP3 - P_n)$, where P_n is the noise floor relative to the input ($P_n = 10 * \text{Log}(KTBF)$). Both IIP3 and P_n are expressed in dBm.

It was mentioned earlier that the noise floor (and thus the SFDR) is a function of the system Noise Bandwidth which was set at 100 KHz in the previous analysis via the **Set > Simulation Control** menu. The receiver system schematic in **Figure 2** has no explicit frequency selective devices and therefore all the simulations up to this point have used this global simulation noise bandwidth (BW) setting of 100 KHz.

From this point forward we will use an ideal 100 KHz IF filter in the schematic (FLT1 in **Figure 6**) to explicitly define the system noise bandwidth. To demonstrate the fact that we will now use the IF filter to define the noise bandwidth instead of the global simulation BW, we set the **System Noise Bandwidth** via the **Set > Simulation Control** menu (**Figure 5**) to 1.5 GHz. The simulator will then use the global noise BW (in all parts of the circuit where there is no defined BW) from the input port to the IF filter, and use the 100 KHz IF filter bandwidth from there on to the output port.

The arbitrarily large setting (1.5 GHz) for the global NBW specified in **Figure 5** will be in effect until the first circuit component is encountered that has a narrower noise bandwidth (at this point the narrower NBW applies).

The schematic in **Figure 6** has two things that are different than the schematic in **Figure 2**. In addition to the IF filter already mentioned, **Figure 6** uses a different mixer model. This is to demonstrate that the SFDR measurement is not sensitive to the type of mixer model used as long as we can

specify the mixer’s gain, IIP3, and NF in the model. All of the LINC2 VSA mixer models allow for the specification of these three parameters, so any one of the several VSA mixer models can be used to model the system SFDR.

We will not use VSA Spectrum Analysis to manually measure the system SFDR this time. Instead, we will use the SFDR measurement that is already a part of the built-in functions in the Set > Output menu as shown in Figure 7.

Before running the simulation on the schematic of Figure 6, we add Output Spurious-Free Dynamic Range (SFDR_{Out}) to the list of measurements. Next, clicking Analyze and View > Cascade Budget Analysis produces the plots shown in Figure 8. The bright blue plot at the top of the stack of curves in Figure 8 shows the SFDR at the output of each stage in the cascade of system components.

We can immediately see the effect of the IF filter in the jump in SFDR between the outputs of stages 6 (ATN3) and 7 (FLT1). This improvement in SFDR is a result of the narrowing of the system noise bandwidth through the IF filter (which reduces the total noise power). The filter’s reduction of the noise power is also seen in the simultaneous drop in total integrated noise power (Noise PWR curve near the bottom of the graph).

The VSA simulation can produce numerical tables of values for all of these plots by selecting Save Output... from the Chain Analysis graph’s File menu. The numerical values for SFDR from Figure 8 are in Table 1.

The final output SFDR value of 69.925 dB compares very favorably with the value (69.94 dB) obtain earlier by manual measurements taken from the VSA Spectrum Analysis graph. We can conclude that either method is an accurate way of determining the system SFDR.

If we are only interested in the final system SFDR or other total system parameters, we can simply select View >

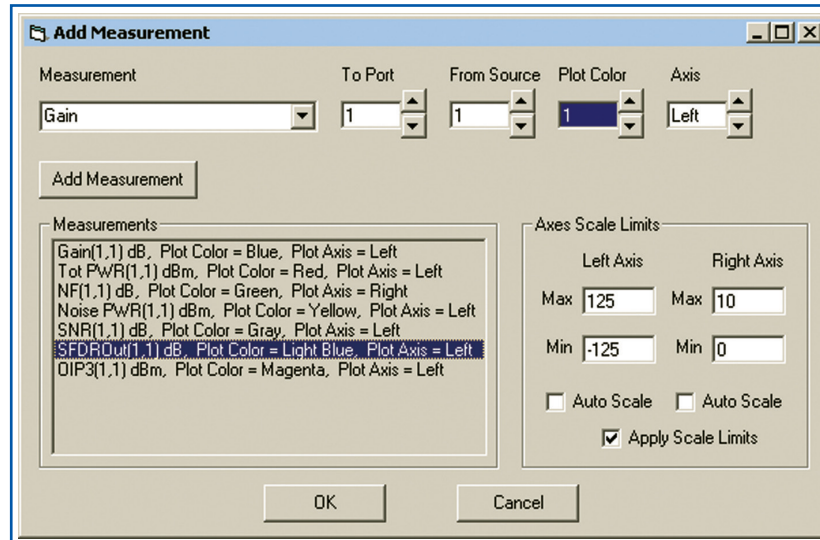


Figure 7: Adding Measurements to the LINC2 VSA Cascade Budget Analysis

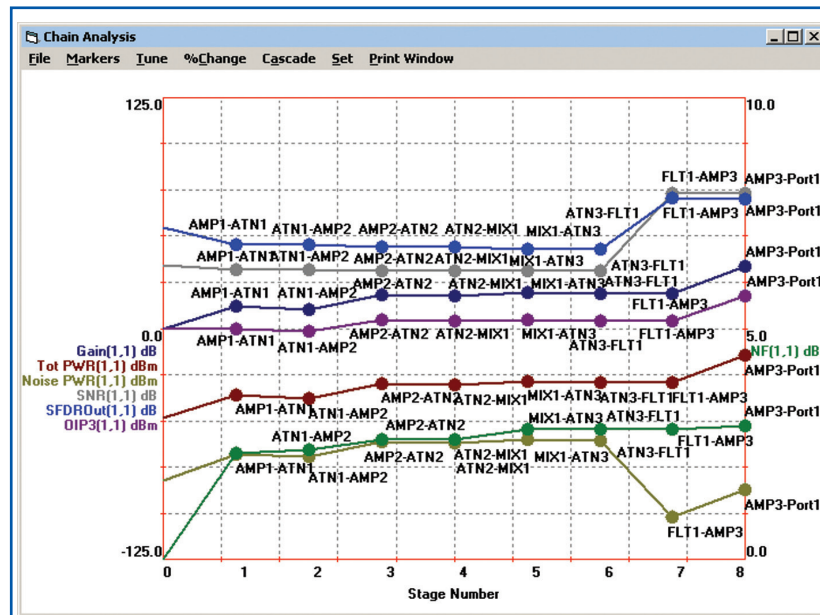


Figure 8: LINC2 VSA Cascade Budget Analysis

Table 1: Measurement Type: SFDR_{Out}

Stage	Parameter Value	Units
0	54.8097	dB
1	45.2764	dB
2	45.2309	dB
3	44.0166	dB
4	44.0102	dB
5	42.9075	dB
6	42.9035	dB
7	70.7441	dB
8	69.9253	dB ← Final output SFDR

Reports after running a simulation (Analyze) to get the total system values as shown in Figure 9.

The values reported for the SFDR in Figures 8 and 9 do not depend on the power levels of the signals at the input port

(SIG1, ID=1) for the schematic of Figure 6. However, the Signal-to-Noise Ratio (SNR) does depend on the power of the input signals. Figure 9 reports a SNR for the combined power of both fundamental signals. Since the simulation of the Figure 6 schematic was run for input levels very close to the high end of the input spurious-free dynamic range, the SNR for one tone should be very close to the total SFDR value. Taking the SNR value of 72.93 dB from the table in Figure 9 and subtracting 3 dB we get 69.93 dB which agrees very closely with the SFDR value of 69.925 dB from the same table.

It is implicit in the analyses previous presented that the system can detect a signal with a power level equal to the noise floor. In practical systems the detector will need to be presented with a signal somewhat greater than the noise floor for proper processing. We can specify a threshold or minimum power level above the noise that a signal must be at for adequate processing. This specification reduces the effective SFDR by each dB that the signal is required to be above the noise floor. The LINC2 VSA has provisions for entering this number as a SFDR offset when SFDR measurements are included in the VSA’s Cascade Budget Analysis plots (as shown in Figure 10).

Figure 11 shows the SFDR plotted with and without a 6 dB SFDR offset applied (dark blue and light blue plots respectively). The plotted data is shown numerically in Table 2.

Summary

Two methods of determining the SFDR for a receiver was demonstrated. First, LINC2 VSA Spectrum Analysis was used for calculating the SFDR. The Spectrum Analysis method yielded a great deal of insight into the process but required a few steps to complete. It was then shown how the LINC2 VSA can automate the SFDR measurement by using the SFDR measurement that is already a part of the built-in

System Parameters	Source Port	Termination Port	Parameter Value	Units
Gain	1	1	33.924	dB
Tot PWR	1	1	-14.23851	dBm
NF	1	1	2.88207	dB
Noise PWR	1	1	-87.16946	dBm
SNR	1	1	72.93094	dB
SFDR0ut	1	1	69.92532	dB
OIP3	1	1	17.71852	dBm

Figure 9: LINC2 VSA System Performance Analysis Reports

functions in the **Set > Output** menu.

LINC2 is a high performance RF and microwave design and simulation program from ACS. In addition to schematic based circuit simulation, optimization and statistical yield analysis, LINC2 Pro includes many value-added features for automating design tasks, including circuit synthesis.

The Visual System Architect from ACS adds many built-in measurement functions for producing the stage-by-stage cumulative system budget analyses that are essential to successful system design, analysis, system performance verification and report generation. Full spectral domain analysis provides a spectrum analyzer view of all signals and spurs at any point in the system. More information about the

ACS Visual System Architect and LINC2 Pro can be found on the ACS web site at www.appliedmicrowave.com.

References

[1] The schematic of Figure 2 along with the subsequent analysis results in Figure 9 closely follow Example 5.4 - Combined Parameters for a Standard Cascade in section 5.4 “Optimizing Cascades” in the book “Practical RF System Design” by William F. Egan, published 2003 by John Wiley & Sons, ISBN: 0-471-20023-9.

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The image shows a 'Set' menu with 'SFDR(1,1) Offset (dB)' selected. A red arrow points to a dialog box titled 'Spur-free Dynamic Range Offset' which contains a text input field with the value '6.0' and 'OK' and 'Cancel' buttons.

Figure 10: Specifying a Detector Threshold as an SFDR Offset Value

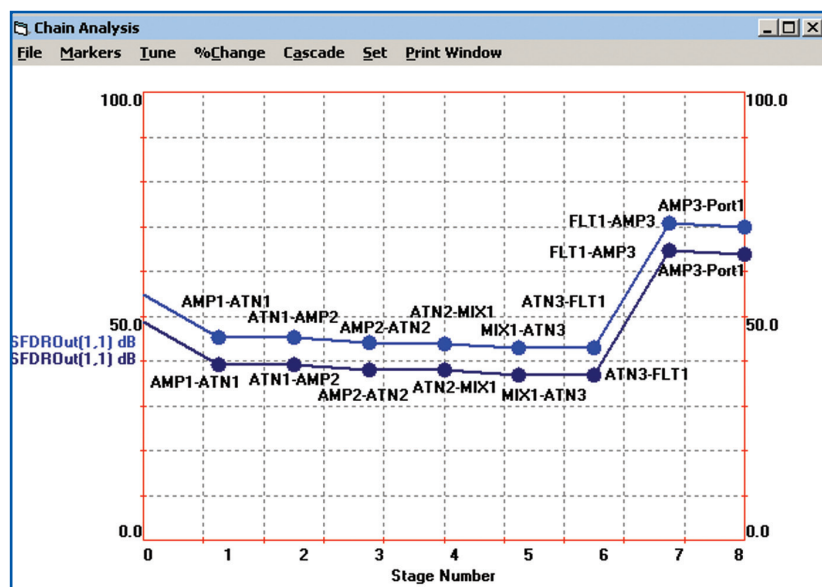


Figure 11: SFDR Plotted With and Without a 6 dB Offset (Dark Curve has Offset Applied)

Table 2: Measurement Type: SFDR0ut

Stage	Parameter Value	Units	6 dB Offset Value	Units
1	45.2764	dB	39.2764	dB
2	45.2309	dB	39.2309	dB
3	44.0166	dB	38.0166	dB
4	44.0102	dB	38.0102	dB
5	42.9075	dB	36.9075	dB
6	42.9035	dB	36.9035	dB
7	70.7441	dB	64.7441	dB
8	69.9253	dB	63.9253	dB ← Final output SFDR