Noise Power Ratio (NPR)

Noise power ratio (NPR) is used to assess the linearity of power amplifiers, particularly those operating with wideband multi-carrier signals. There are many ways to measure and simulate NPR; this paper gives an overview of NPR and presents two potential simulation approaches (using white noise and multiple tones) and explores key considerations for the simulation setup.

Introduction

The linearity of power amplifiers (PAs) can be measured in various ways, such as intermodulation distortion (IMD) or P-1dB. NPR is a useful measurement when multi-carrier wideband signals are used. A noise input is used to simulate the wideband waveform with multiple carriers, and is a more realistic input than the two-tones used in IMD measurements. NPR has been around for some time, with origins in early FDM communication systems. It is now most commonly used in satellite communications and defence applications.

To measure NPR, a PA is typically driven by white noise containing a narrow notch in the band of interest. The non-linearity of the amplifier generates intermodulation products, which fill up the notch. NPR is the ratio between the noise power density outside the notch to inside it (as shown in Figure 1).

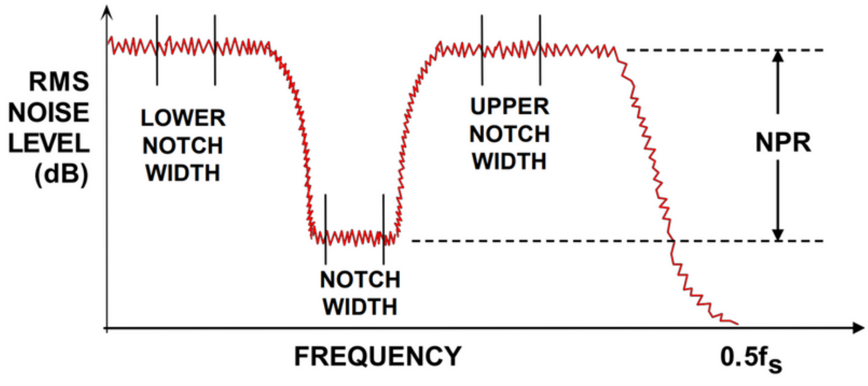

Figure 1: NPR Measurement Trace [1]

Measurement Considerations

Traditionally, the input signal for measuring NPR is white noise, which is generated by a noise source. A bandpass filter is used to set the noise bandwidth, which is normally the full bandwidth of the channel under test. A separate band-stop filter creates the notch, typically much smaller than the signal bandwidth. The filter Q needs to be sufficiently high to avoid errors when the NPR approaches the notch depth [2]. The NPR signal can either be generated at baseband and upconverted, or the noise could be upconverted first and then filtered at the carrier frequencies. There are trade-offs with both approaches; filtering the signal at the carrier frequencies can create a deeper notch, but different filters are required for each signal bandwidth and carrier frequency, increasing cost for the user.

Recent developments in digital signal processing allow a more flexible approach to be adopted: multiple individual tones are generated, and certain frequencies are left "off" to create one or multiple notches. This typically requires a more expensive source (an advanced signal generator) to create the waveform but achieves deeper notches and requires less test equipment. The phase of the tones can be randomised to better approximate noise and to prevent excessive voltages that can result from tones summing together.

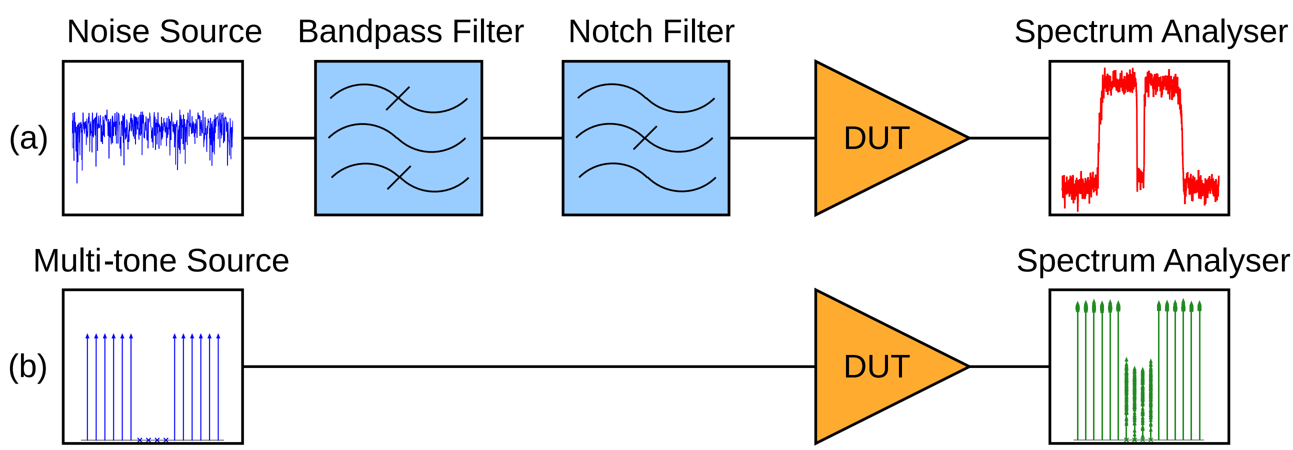

Figure 2: NPR Measurement and Simulation Setup

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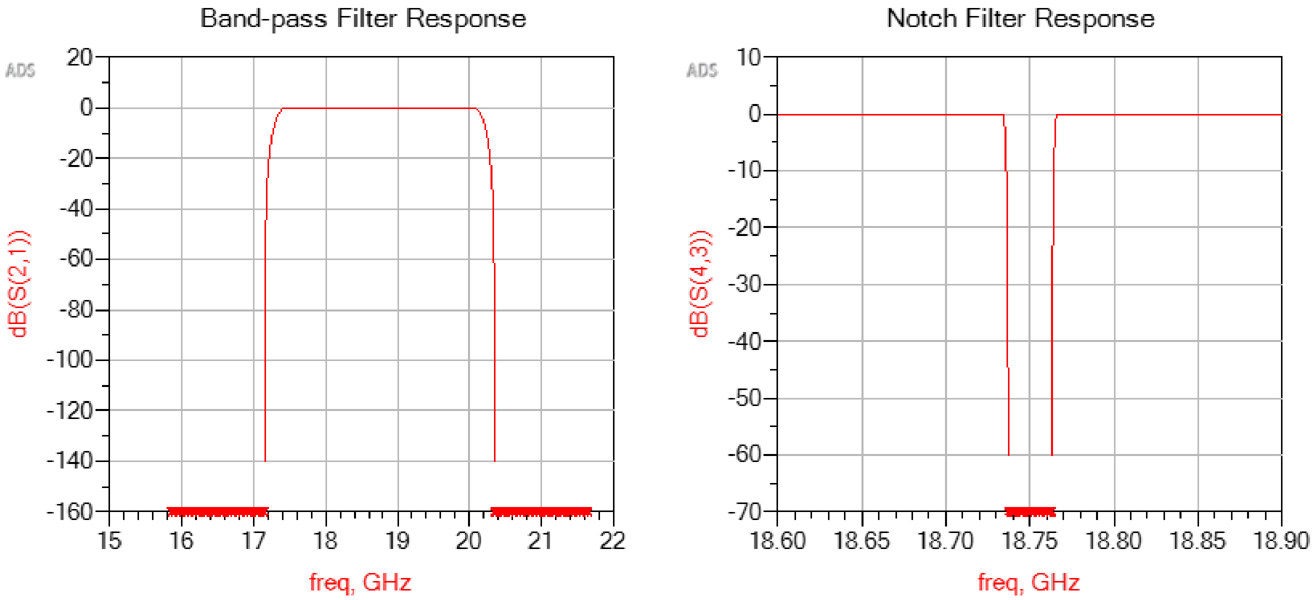

Figure 3: Responses of bandpass and band-stop filters for creation of NPR signal

Some signal generators may produce the exact waveform that the amplifier will operate with. If possible, it is preferable to use this waveform for more realistic NPR results.

Simulating NPR

There are various approaches for simulating NPR. Two approaches are discussed here, both simulated in Keysight ADS.

The first approach replicates the traditional NPR measurement setup (Figure 2a), using a noise source rather than multiple tones as the input signal. An example workspace [3] can be downloaded from Keysight's Knowledge Centre, which contains test benches that can be adapted for custom requirements (notch width, frequency range, custom DUT etc.). The envelope controller is the best choice for this simulation; transient simulations can be run instead but they take considerably longer, so are not normally practical.

A single-tone voltage source and an IQ modulator create a broadband noise signal, which is fed through a bandpass filter and then a notch filter to create the input signal to the DUT. Figure 3 shows the frequency response of the filters used; the notch width is 1% of the channel bandwidth, which is 2900 MHz.

Frequency indices need to be chosen carefully when calculating the notch power. Most of the notch width can be included if the band-stop filter has a high Q, but this does not apply for more lossy filters. When the simulated default value of half the notch width is used to calculate the noise power, the initial notch depth at the input to the DUT is 81.2 dB and the NPR after the DUT is 40.2 dB (simulation traces shown in Figure 4). In this case the DUT is a behavioural model within Keysight ADS.

The second approach replicates the more modern way of measuring NPR, where the noise source is replaced by multiple individual tones (Figure 2b). The simulations presented are based on another Keysight example [4]. The harmonic balance simulation controller is used for this approach in

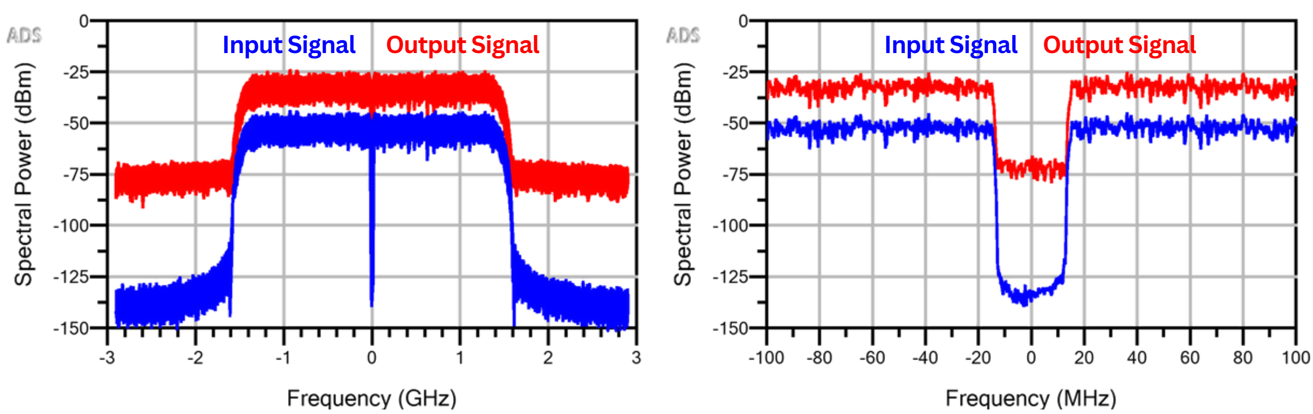

Figure 4: Simulated input and output spectra using noise source

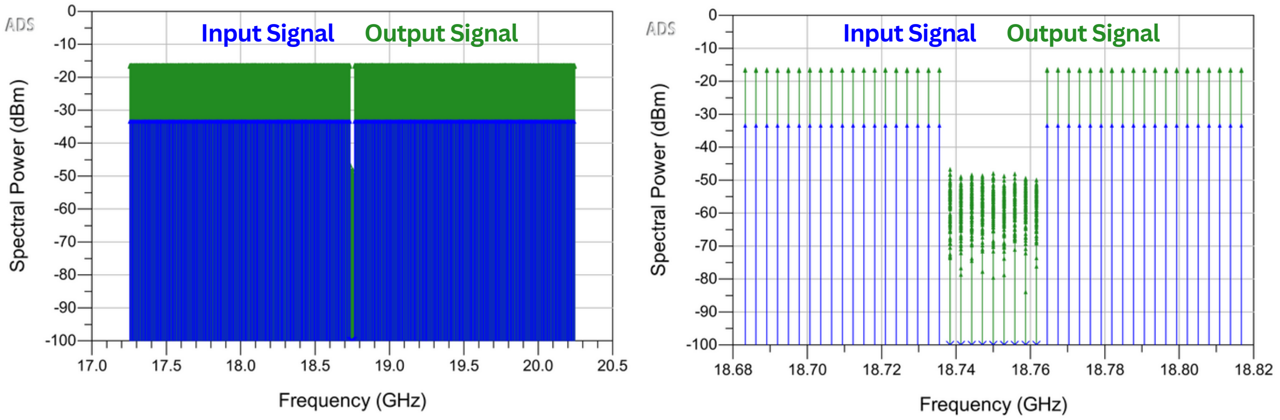

Figure 5: Simulated input and output spectra using multi-tone source

conjunction with the Monte Carlo simulation controller, which randomises the phase of the generated tones, preventing them summing in-phase and causing excessive peak-to-average-power ratios. The Monte Carlo block is also used to run multiple trials so that the tones could be averaged. The results shown in Figure 5 are from 100 iterations, but this can be increased further without significantly increasing simulation time.

The notch width is clearly defined for the multi-tone source. The main decision to make when calculating the NPR is how many tones to average outside the notch, rather than inside it, but this has little impact on the NPR result.

The power of each input tone was chosen so that the total DUT input power is the same for both simulation approaches. The initial notch depth for the multi-tone signal is effectively infinite and the NPR is 39.2 dB, 1 dB lower than the result with the noise signal. NPR is often plotted as a function of back-off from saturated output power (see Figure 6). The NPR difference between the two approaches is mostly within 1 dB as back-off increases.

The number of tones can be increased so that the multi-tone signal is a better approximation of white noise but this increases simulation time, making it less practical to average many iterations (1024 source tones are simulated in Figure 5). The envelope simulation required over 8x more time than the multi-tone simulation, though this is not always the case. Ultimately, if physical NPR measurements of a PA have been or will be taken, the best approach is generally closest to the measurement setup used.

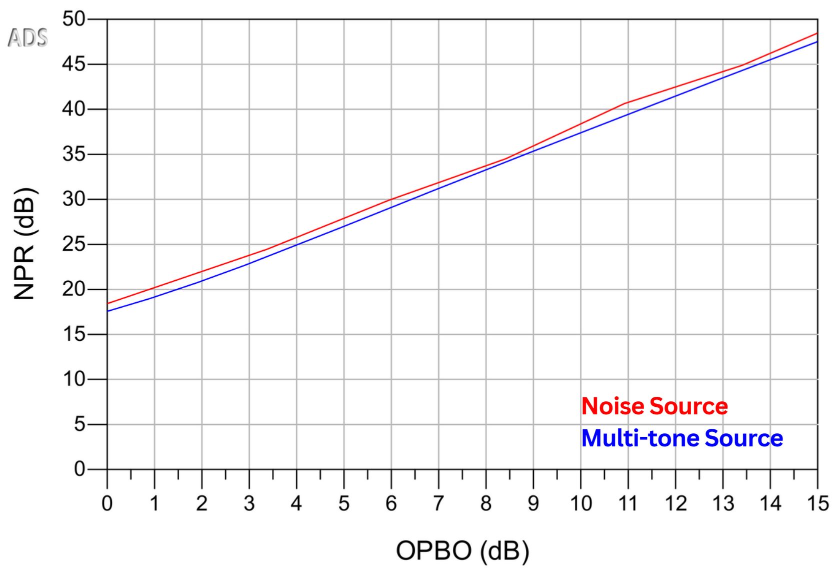

Figure 6: NPR vs OPBO for both simulation approaches

Summary

NPR is a metric to assess the linearity of PAs that operate with wideband muti-carrier signals. NPR can be simulated in several ways, including with a noise source or using multiple CW tones with randomised phases to approximate noise. The simulation setup has a lot of flexibility (number of source tones, fraction of the notch used for power averaging, etc.), but should generally be designed to replicate the physical measurement setup where possible.

References

[1] Analog Devices, *MT-005 TUTORIAL, Noise Power Ratio (NPR) by Walt Kester*

[2] Linearizer Technology Inc., *Noise Power Ratio Measurement Tutorial By Allen Katz and Robert Gray*

Example workspaces are available from Keysight's Knowledge Centre (support subscription required):

[3] Noise Power Ratio Simulation using Envelope (link)

[4] How to Simulate Noise Power Ratio Using Harmonic Balance (link)