# NPR – WHAT IS IT, HOW CAN I SIMULATE IT AND HOW DO I MEASURE IT?

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## Abstract

Noise Power Ratio (NPR) is a figure of merit for the linearity performance of RF and microwave amplifiers. It can be a useful metric for multi-carrier systems and provides an indication of the in-band distortion caused by multiple carriers on other channels. NPR has been used for many years and can be measured using noise generators, filters, and a spectrum analyser. More recently the availability of vector signal generators has allowed a higher degree of flexibility for NPR measurement set-ups. There are many approaches to predicting NPR but simulation at the circuit level requires the availability of accurate large-signal transistor models. Two techniques can then be considered, one using a simulated broadband noise source as the input and the other using many individual carriers.

This paper provides an overview of NPR and describes how it can be simulated using Keysight's ADS. Options for measuring NPR are described and practical NPR measurements of several PRFI-designed mmWave MMIC amplifiers are presented. The measurement set-up makes use of a Rohde & Schwarz (R&S) SMW200A vector signal generator to produce the input signal and an FSW spectrum analyser to measure the output signal and determine the NPR.

## 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 metric when multi-carrier wideband signals are used. A noise input simulates the wideband waveform with multiple carriers and is more representative than the two-tones used in IMD measurements. NPR has been around for some time, with origins in early FDM communication systems, though it is now most frequently used in satellite communications and defence applications.

To measure NPR, a PA is typically driven by a band-limited white noise signal 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 in the channel to the noise power density in the notch (as shown in Figure 1).

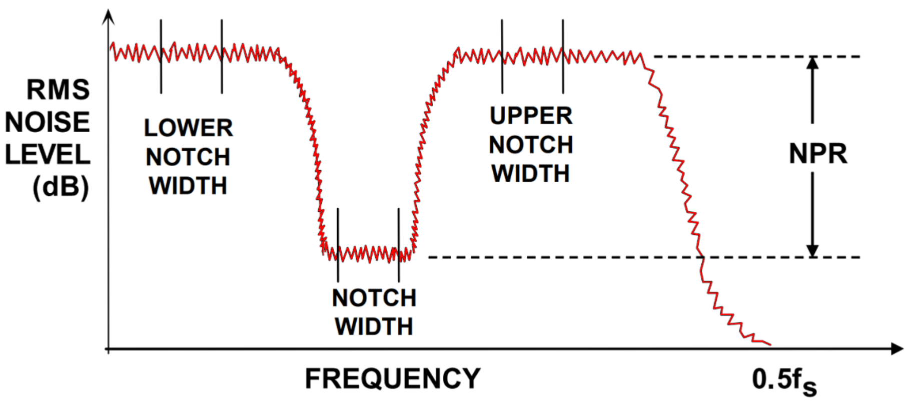


*Figure 1: NPR measurement trace [1].*

## Simulating NPR

There are various approaches for simulating NPR measurements. 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 as the input signal. The second approach (Figure 2b) replicates an alternative way of measuring NPR, where the noise source is replaced by multiple closely spaced CW tones.

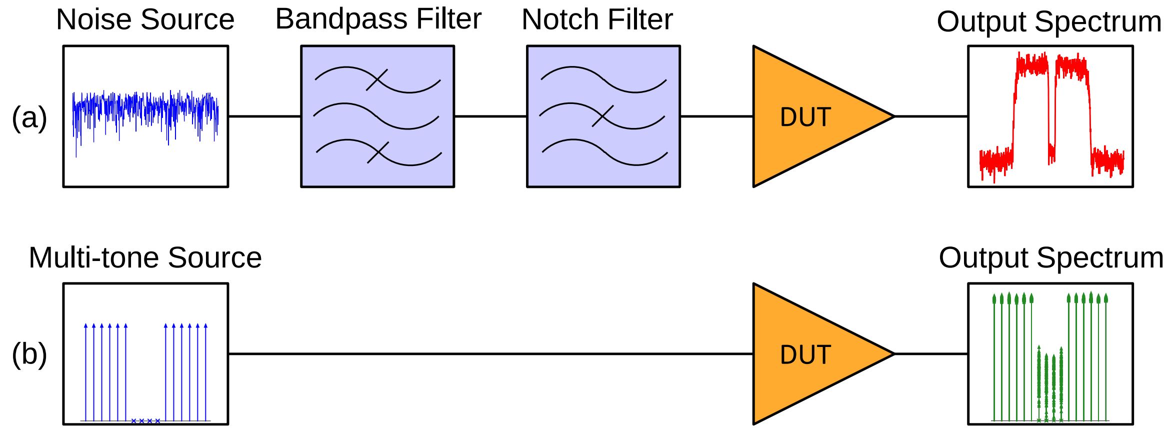


*Figure 2: Block diagram of NPR simulation setups.*

### *Noise Approach*

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. A typical output signal is shown in Figure 3. An example workspace [2] 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 could be run instead but they take considerably longer, so are not practical. Even with the envelope controller, simulations of PAs can take multiple hours. Frequency indices must be chosen carefully when calculating the notch power. Most of the notch width can be included when calculating the NPR if the band-stop filter has a high Q, but this does not apply for more lossy filters.

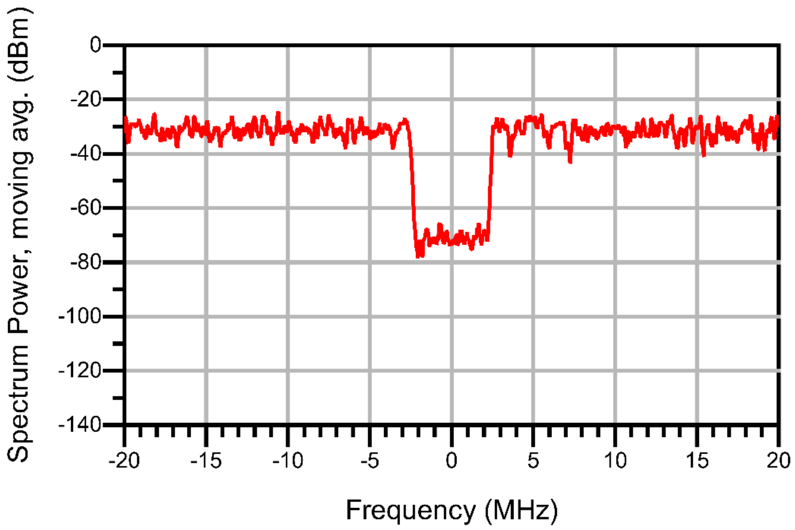


*Figure 3: Simulated output spectra using noise source.*

## Multi-tone Approach

In this approach, the noise source and both filters are replaced by a single multi-tone source comprised of multiple uniformly spaced tones, and the notch is created by leaving out tones in the desired band. A typical output signal is shown in Figure 4. The multi-tone simulations presented in this paper are based on another Keysight example workspace [3]. The harmonic balance simulation controller is used for this approach in 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 used to run multiple trials, so that the powers of the tones can be averaged.

Unlike with the noise source, the notch width is clearly defined for the multi-tone approach. 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 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. The multi-tone simulations in this paper use 1001 CW tones.

## Approach Comparison

Multi-tone simulations run faster than the noise source simulations, by a factor of 8-10 in most cases. Increasing the channel bandwidth of the NPR signal further increases simulation times for both approaches. Ultimately, if physical NPR measurements of a PA have been made or are planned it is likely to be best to adopt the simulation approach that is closest to the measurement setup.


*Figure 4: Simulated output spectra using multi-tone source.*

# Measuring NPR

Traditionally, multiple pieces of equipment are required to measure NPR (Figure 5a). A noise source generates the white noise input signal, a bandpass filter sets the noise bandwidth, which is normally the full bandwidth of the channel under test, and a separate band-stop filter creates the notch, typically much smaller than the signal bandwidth. The notch filter Q needs to be sufficiently high to avoid errors when the NPR approaches the notch depth [4]. 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 and complexity for the user.

Recent developments in digital signal processing allow for more flexible approaches to be adopted. These typically require an advanced signal generator to create the waveforms but require less test equipment. The traditional setup can be replicated by vector signal generators (Figure 5b) or, alternatively, multiple individual tones can be generated, and certain frequencies left "off" to create one or multiple notches (Figure 5c). Some signal generators may produce the exact waveform that the amplifier will operate with; it can be preferable to use this waveform to obtain more applicable results.

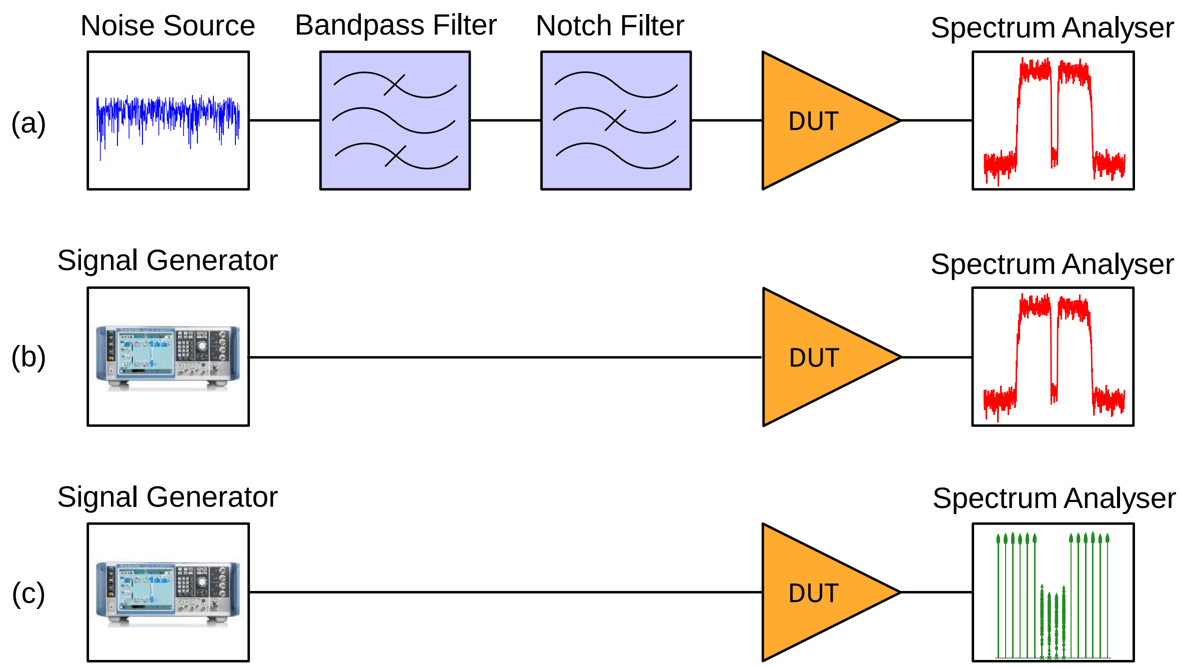


*Figure 5: Block diagram of NPR measurement setups.*

### *Measurement Limitations*

The NPR measurement range can be limited by several factors [5], primarily the thermal noise floor of the spectrum analyser, which dominates the NPR at low signal powers. Figure 6 shows the measured NPR increasing linearly as the power of the DUT input signal is increased, due to the fixed noise floor.

Eventually the power of the intermodulation distortion (IMD) products generated by the PA will equal the power of the noise floor; the first real NPR measurement is obtained here (peak NPR). The IMD generated by the PA begins to fill up the notch as the signal power increases further, decreasing the NPR.

At the top end, the measurement range could be limited by several factors, depending on the analyser setup: distortion in the analyser mixer, IF/analogue-to-digital converter overload, or attenuation due to the reference level.

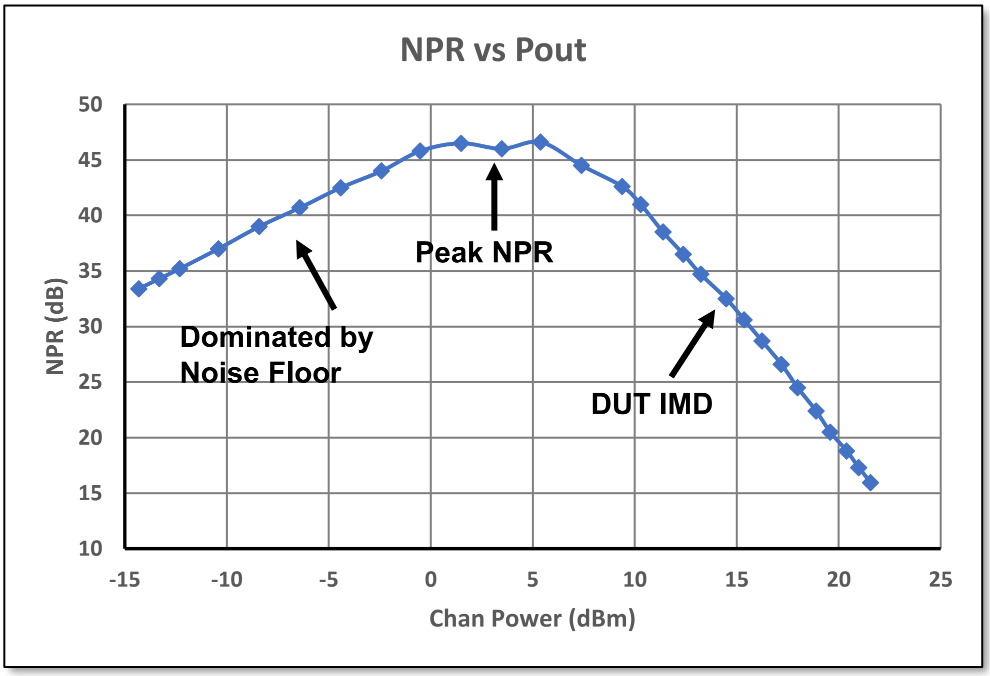


*Figure 6: NPR Measurement of a 28 GHz 0.4 W GaAs PA.*

## *Measurement Setup*

The NPR measurements presented in this paper were measured using the setup shown in Figure 7. An SMW200A vector signal generator and FSW50 spectrum analyser from R&S were used to generate and measure the NPR respectively. The SMW can generate both white noise and multi-tone NPR signals, which can be measured on the FSW. This paper presents measured results using the traditional NPR signal only. The FSW calculates the NPR automatically (Figure 8), though the power density of the notch (green vertical lines) and the signal channel (blue vertical lines) are displayed.

The two devices were measured: a 28 GHz 0.4 W GaAs PA (CMX90A702) and an 18.5 GHz LNA (CMX90B701), both designed by PRFI. The measurements were automated in a Python test environment, to improve consistency across runs and to save time.

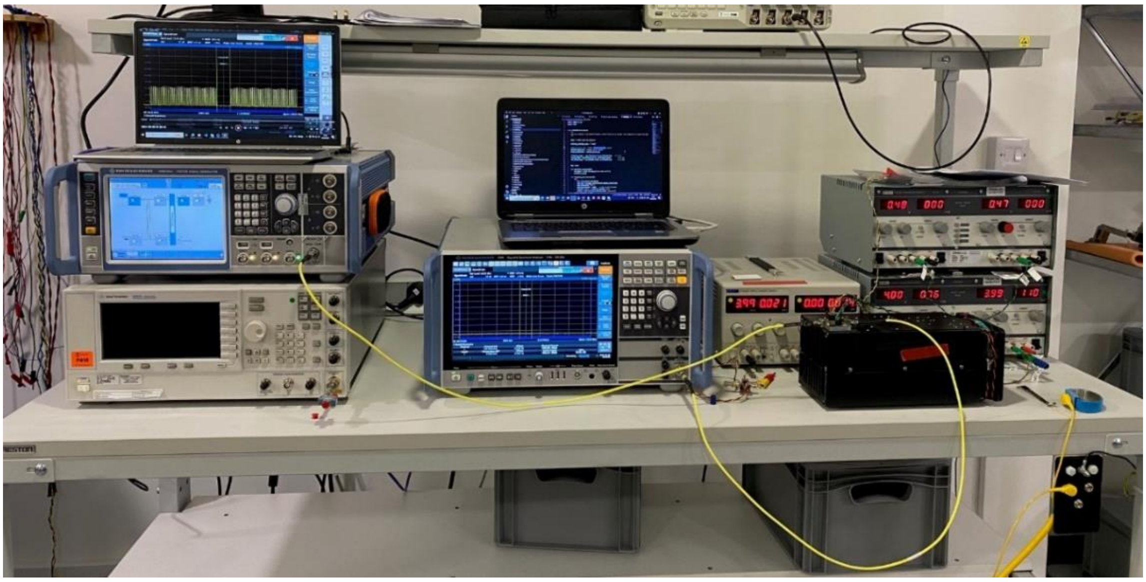

*Figure 7: NPR measurement setup in the PRFI lab.*


*Figure 8: NPR Measurement Screen on FSW.*

## *Measurement Results*

The two amplifiers were measured at several different channel and notch widths: 50 MHz to 1 GHz and 1% to 10% respectively. NPR is plotted against output back-off from P1dB in Figure 9 to Figure 12.

The CMX90A702 NPR varied moderately across the different channel bandwidths. The results in Figure 9 differ by 0.71 dB at P1dB (5% notch width). The variation across notch width is even lower: 0.13 dB at P1dB for a 500 MHz input signal (Figure 10). The greatest spread of 2.3 dB is seen across all measurement traces.

The CMX90B701 NPR measurements were less consistent across both channel and notch widths: 1.09 dB across channel width, 0.49 dB across notch width and 3.36 dB across all measurements at P1dB (Figure 11 and Figure 12).

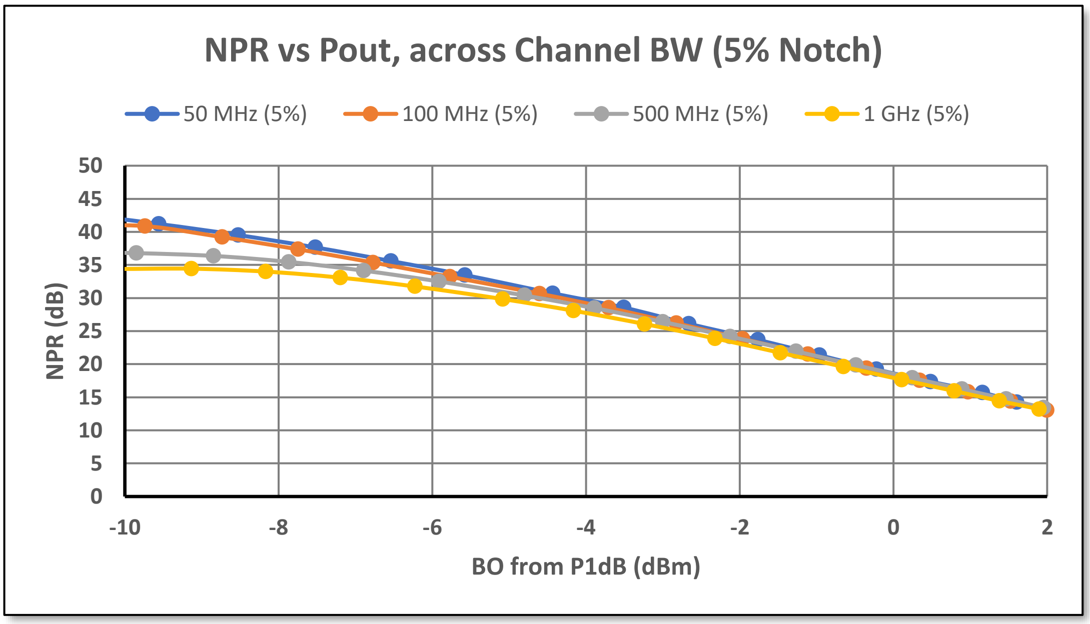


*Figure 9: Plot of NPR against Back-off from P1dB across different channel widths – CMX90A702 (notch width = 5%).*

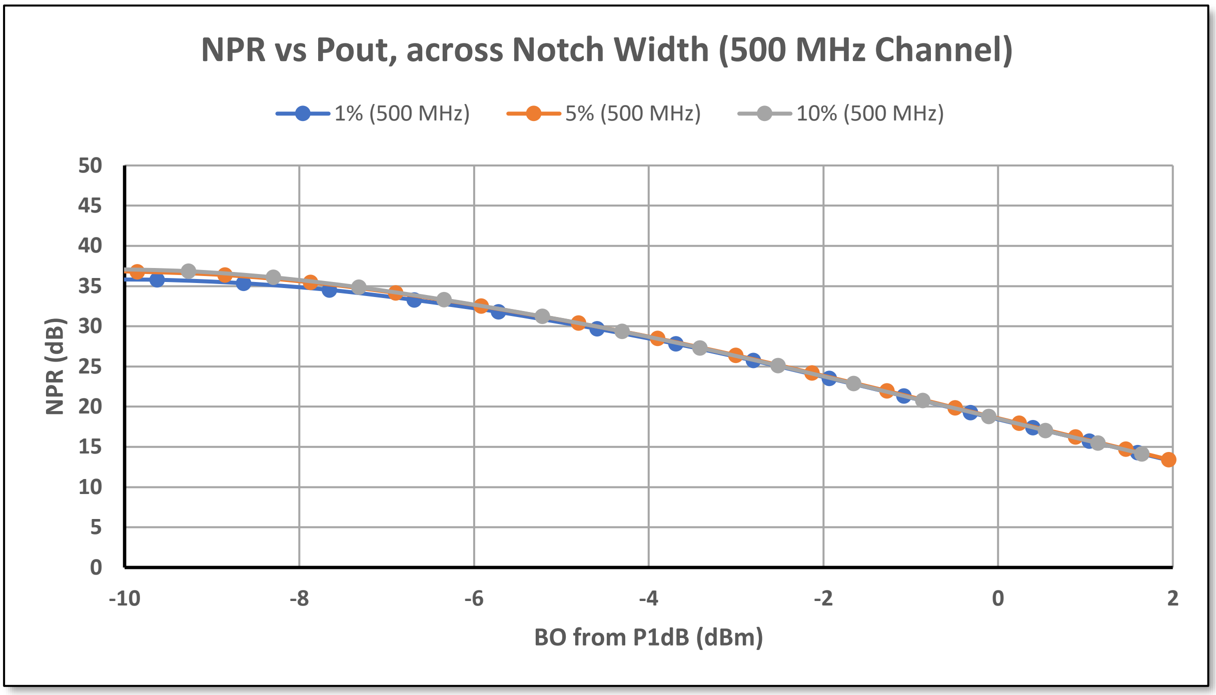


*Figure 10: Plot of NPR against Back-off from P1dB across different notch widths – CMX90A702 (channel width = 500 MHz).*

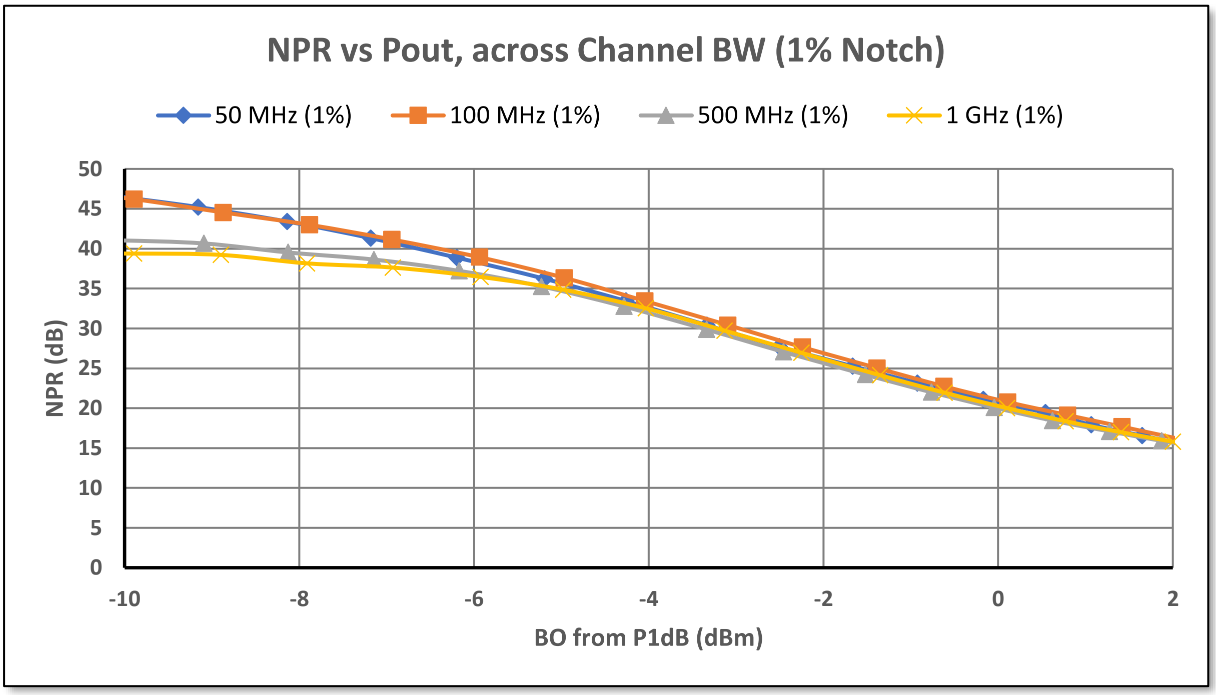


*Figure 11: Plot of NPR against Back-off from P1dB across different channel widths – CMX90B701 (notch width = 1%).*

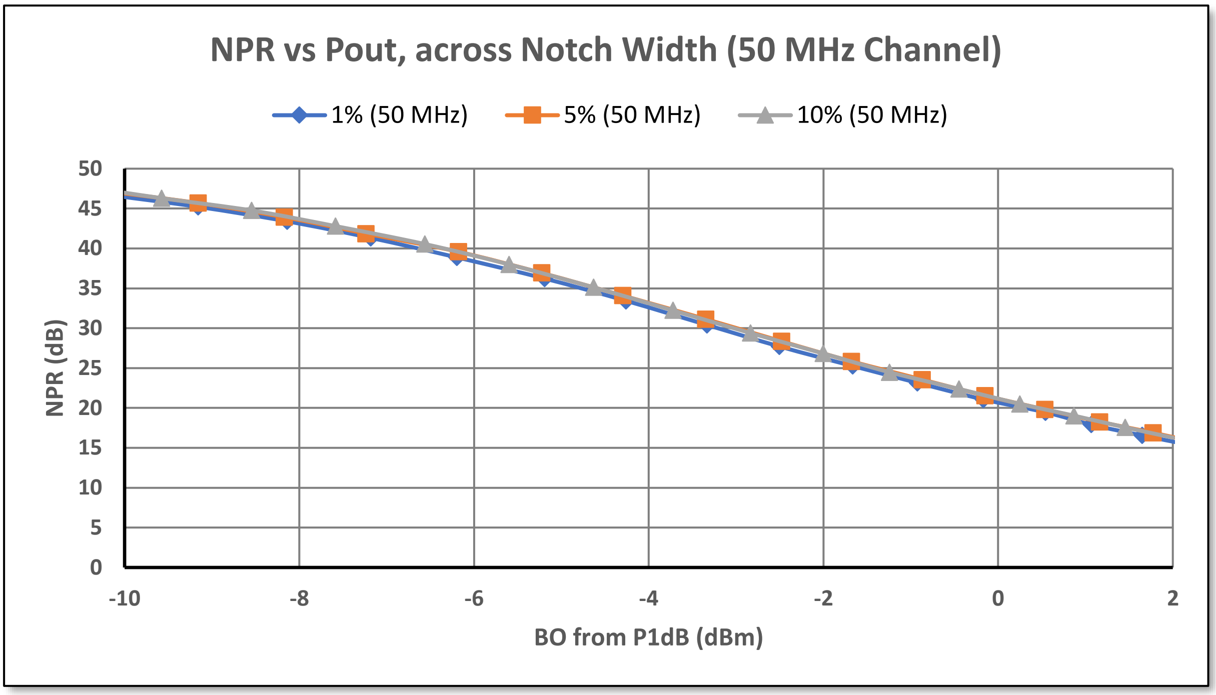


*Figure 12: Plot of NPR against Back-off from P1dB across different notch widths – CMX90B701 (channel width = 50 MHz).*

## Measurement and Simulation Comparison

The measured and simulated results for both amplifiers are compared to view the respective curve fits. Results are presented for two conditions (Figure 13 and Figure 14), but similar trends are seen in comparisons across the remaining states.

The multi-tone simulations show good agreement with between simulation and measurement, particularly for the B701. The multi-tone NPR simulations at P1dB differ from measurements by 0.29 dB and 0.54 dB for the A702 and B701 respectively.

The noise simulations follow the general trend of the measured data and, while the point-to-point agreement is not as good as the multi-tone simulations, the fit is reasonable, particularly at higher signal powers. The NPR simulations at P1dB differ from measurements by 1.36 dB and 1.03 dB for the A702 and B701 respectively.

Overall, the fit between the simulated and measured NPR is close enough that the simulations can be used with confidence during the design process.

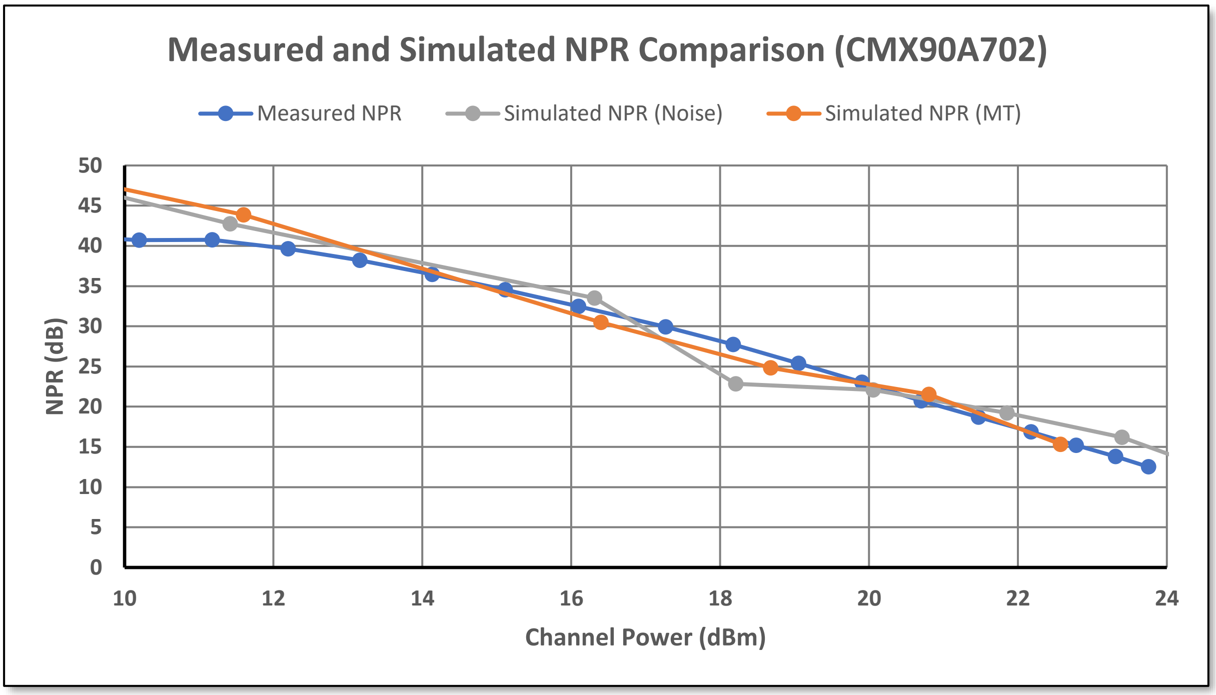


*Figure 13: Measured and simulated NPR plotted against channel output power – CMX90A702 (channel width = 100 MHz, notch width = 1%).*

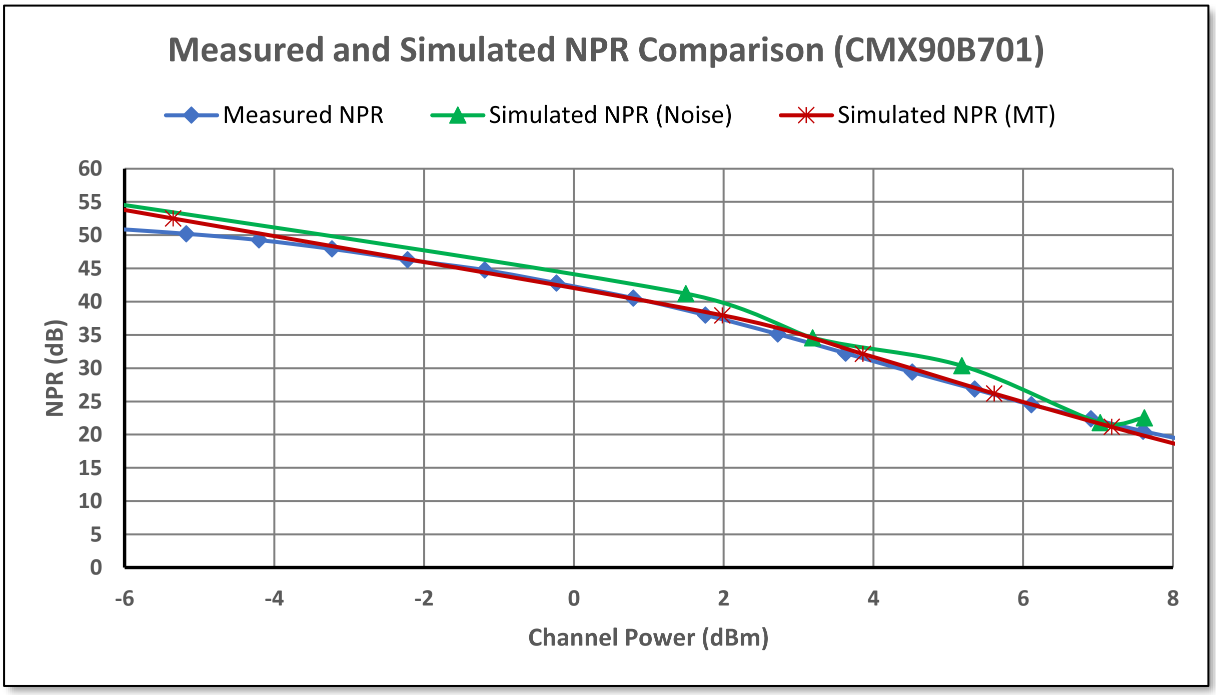


*Figure 14: Measured and simulated NPR plotted against channel output power – CMX90B701 (channel width = 50 MHz, notch width = 10%).*

## 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.), and can be designed to replicate the physical measurement setup if desired.

Multi-tone simulations can be a convenient alternative when designing PAs due to the reduction in simulation speed compared to circuit envelope simulations. Good agreement is observed between multi-tone simulations and NPR measurements using a noise source.


## Acknowledgements


The authors would like to thank Rohde & Schwarz for their support with the NPR measurements and Keysight for the example workspaces (details below).


## References


[1] W. Kester, “Noise Power Ratio (NPR)—A 65-Year Old Telephone System Specification Finds New Life in Modern Wireless Applications,” Analog Devices.

*The example workspaces available from Keysight’s Knowledge Centre require a support subscription:*

[2] Example Workspace: “Noise Power Ratio Simulation Using Envelope,” Keysight. Available: https://docs.keysight.com/eesofkcads/noise-power-ratio-simulation-using-envelope-17312776.html.

[3] Example Workspace: “How to Simulate Noise Power Ratio Using Harmonic Balance,” Keysight. Available: https://docs.keysight.com/eesofkcads/how-to-simulate-noise-power-ratio-using-harmonic-balance-591730684.html.

[4] A. Katz and R. Gray, “Noise Power Ratio Measurement Tutorial,” Linearizer Technology Inc.

[5] K.-U. Sander and S. Kehl-Waas, “NPR Measurements on Satellite Signals,” Rohde & Schwarz, 2022.