Noise-Power-Ratio (NPR) measurements are a common procedure and a simple but useful tool to characterize the performance of power amplifiers for satellites or other multi-channel communication systems. The main advantage is the use of wideband signals like noise or multi-carrier CW tones which leads to a better simulation of the real environment. This application note provides information how to perform NPR measurements with spectrum analyzers. The R&S®FSW spectrum and signal analyzer offers an automated function for NPR measurements. The limiting factors of a spectrum analyzer are explained, and measurement examples show the practical results of NPR measurements.

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1 Introduction

Many different methods are available to test the linearity performance of power amplifiers for satellites or other multi-channel communication systems. While some engineers prefer to use very clean two-tone sinewave test signals and measure third-order intermodulation, the use of wideband signals like white noise or multi-carrier CW tones leads to a better simulation of the real environment. Measuring noise power ratio is popular in the satellite industry as a better way to assess the linearity of high power amplifiers operating close to maximum output power. The concept of the noise power ratio measurement has been around for a long time and presents a simple but useful tool to characterize the performance of such a system. The wideband noise that is used instead of the sinewave test signals simulates the presence of many single carriers and makes the test conditions more realistic. The intermodulation products generated in the non-linear amplifier will fill up the notch that is placed within the channel bandwidth of interest.

For the purpose of noise power ratio measurements of high quality power amplifiers it must be sure that the spectrum analyzer is capable of measuring the noise power without generating significant intermodulation distortion itself, or masking the distortion generated by the amplifier with its own amplitude noise floor. With the knowledge of the spectrum analyzer hardware architecture and its capabilities, the measurement can be performed with the correct amount of attenuation and level settings in the spectrum analyzer. There are multiple applications for NPR tests, this application note describes NPR measurement techniques for satellite transmissions.

The R&S®FSW offers an automated measurement function for NPR. The limiting factors of the R&S®FSW for this measurement are explained, and measurement examples show the practical results of NPR measurements. The next sections will give further details.

2 NPR Measurement details

2.1 Fundamentals of the NPR measurement

Noise power ratio measurements have been performed since the first release of FDMA systems as a characteristic for the quality of the system. The amount of noise power in a multi-channel system is measured in an unused channel, while all other channels are loaded with signals. Noise and intermodulation distortion will fill up the unused channel, and the measurement of this noise power gives an indication of the system performance.

Practical NPR measurements often use white noise as a test signal. The white noise has similar characteristics as many individual carriers with random distribution of amplitude and phase of each signal. The noise signal passes through a band pass filter to represent a signal with similar bandwidth as used in the real system. A band stop filter (reject filter) simulates the unused channel and creates a deep notch within the band-limited noise signal. Instead of a real white noise signal it is also practical to use multi-carrier CW signals with a high number of tones to simulate the signal.
The above figure gives an overview of the traditional way to generate the test signal for NPR measurements. This signal is used to test the power amplifier or transmission system components. The distortion of the amplifier will produce intermodulation products that will be located on both adjacent sides of the band limited signal, but will also fill up the notch. A spectrum analyzer is used to measure the ratio of the signal level (average pedestal level) and the level in the notch. The ratio of these two readings is the noise power ratio (NPR).

The NPR measurement range is limited by two important characteristics: the depth of the test set notch will be an absolute limit that cannot be overcome and must be seen as hard measurement range limit. The other parameter that limits the NPR range is the quality of the spectrum analyzer, as the input mixer and the IF amplifiers will also produce intermodulation that fills up any notch of the measured signal. Testing at these limits of the test setup will lead to systematic errors when the NPR of the DUT is too close to that of the test set.

The test system shall typically have at least 10 dB better performance than the test requirements. The typical requirement for power amplifier tests is 40 to 50 dB NPR, which leads to a requirement of 60 dB for the test system. The next chapters describes a test setup to verify the performance of the R&S®FSW for NPR tests.
3 Test setup for NPR measurements

The performance of the R&S®FSW noise power ratio measurement is verified with a test setup that is able to generate a very clean signal and reliable notch depth over a wide level range.

![Figure 2: Picture of the test setup for NPR performance verification of the R&S®FSW](image)

The vector signal generator R&S®SMW generates the test signal for the NPR verification of the spectrum analyzer. The generated test signal can be either a band limited noise signal or a user-defined arbitrary waveform file for a test signal. For practical NPR test on amplifiers the generator is used to create a NPR test signal with a selectable number of notches. Another possibility for NPR tests the signal generator can be used to provide a multi-carrier CW test signal, in this case the notches are a number of disabled tones in the multi-carrier spectrum.

NPR measurements have been difficult in the past as each notch configuration required a band reject filter in RF path. The band-reject filter is now implemented in the baseband to provide notches in all required channels, and the signal is converted to RF. The generator output amplifier and the modulators will also contribute to the overall available noise power ratio, and the notch depth is typically limited to about 50 dB, which is still adequate for NPR measurements on amplifiers.
For the purpose of this paper the generator provides a band limited noise signal and an external band reject filter is used between the signal generator and the spectrum analyzer. Figure 2 below shows the block diagram of the test setup:

![Test setup for NPR measurement](image)

**Figure 3: Test setup for NPR measurement performance verification of the R&S®FSW**

For the verification of the spectrum analyzer measurement range a very clean signal with a reliable notch is required. For the purpose of this test a band reject filter is used that will suppress all noise and distortion signals from the generator. In order to make accurate tests on the spectrum analyzer the notch depth shall be at least 10 dB more than the required performance for NPR measurements (60 dB).

![Test result screen display for mean and peak power of a pulsed signal](image)

**Figure 4: Test result screen display for mean and peak power of a pulsed signal**

The above screen shot shows the measurement result for the notch attenuation of the notch filter measured with a network analyzer. The notch depth is the ratio between the pedestal in the passband (marker R) and the attenuation in the notch (marker M1). The notch depth measurement shows about 80 dB of attenuation. This external filter provides a reliable notch (level suppression) which offers sufficient measurement range for the spectrum analyzer verification.
4 NPR Measurement with the R&S®FSW

For the NPR measurement the R&S®FSW spectrum analyzer provides an optional software routine R&S®FSW-K19 Noise Power Ratio (NPR) Measurement.

Fig. 5: Screen copy of NPR measurement with the R&S®FSW

The screen shot above shows the measurement screen of the NPR measurement. The active channel is marked with the vertical blue lines, the notch is marked with the green lines. The channel power density, the notch power density, and the noise power ratio are calculated and displayed in the table below the spectrum.

Fig. 6: NPR measurement configuration dialog in the R&S®FSW

The noise power ratio measurement allows defining the satellite channel bandwidth and up to 25 notches in the NPR setup. The integration bandwidth that is used to measure the transmit power density can be freely selected within the channel bandwidth.
4.1 NPR measurement range limitations

The inherent NPR measurement range of the R&S®FSW is determined by three factors:

- the thermal noise floor of the spectrum analyzer
- the spectral re-growth due to 3rd order intermodulation of the input mixers
- the spectral re-growth due to 3rd order intermodulation of the A/D converter

The phase noise of the R&S®FSW spectrum analyzer is extremely low and therefore phase noise limitations are omitted for the remainder of the analysis.

The noise floor of the spectrum analyzer places a limit on the lowest level in the notch that can be measured. The available NPR range is hence proportional to the input signal level that reaches the mixer of the analyzer. The dynamic range due to the noise floor increases by 10 dB with each 10 dB increase of the signal level, as the noise floor is constant.

As the input level of the signal increases the inherent distortion of the analyzer appears above the noise floor. Therefore an optimum mixer level can be found where the maximum dynamic range of the analyzer is achieved, which is the case when the internally generated distortion has the same level as the noise floor. Combining the noise floor and the mixer influence results in the theoretical “V” shape often shown for the achievable dynamic range for third-order intermodulation measurements or adjacent channel power measurements with spectrum analyzers. Similar results can be expected for the NPR measurement.

4.2 NPR measurement results in practice

The described test setup is used to measure the available NPR dynamic range of the R&S®FSW spectrum analyzer. The known high performance of the test signal (after the notch filter) allows the verification of very wide dynamic ranges. The build-in NPR measurement routine of the spectrum analyzer is used to derive the results.

For the following example a band limited noise signal with 26 MHz bandwidth was used. The band-reject filter has an effective notch bandwidth of 3.5 MHz positioned in the center of the signal, and the notch bandwidth in the NPR measurement is set to 2 MHz bandwidth centered in the middle of the notch (see figure 5).

The first measurement shows the dynamic range achievable dependent on the mixer level of the R&S®FSW (mixer level = mean power at the input mixer = mean power at the RF input - RF attenuation). For the purpose of the measurement the analyzer is set to 0 dB RF attenuation and the maximum possible reference level, which is -10 dBm. The input signal level (mean power) is varied between -40 and +10 dBm.
The attainable dynamic range is shown in figure 7. The curve shows the expected behavior across the input level over a wide level range. At low input levels the noise floor of the spectrum analyzer dominates the available NPR range.

The expected NPR value can be calculated from the input level and the R&S®FSW datasheet value for the noise floor. From 1 to 3 GHz input frequency the specification for the noise floor is -154 dBm/Hz. The minimum input level in the above plot is -40 dBm, this equals -114 dBm/Hz. The NPR is the difference between the noise density in the active part of the signal and the noise density in the notch, the calculated NPR value is 40 dB. The plot shows excellent agreement between the calculation and the measurement.

At high input levels the curve does not strictly follow the expected curve for intermodulation distortion. In the level range above -5 dBm the R&S®FSW is indicating an IF overload condition. The A/D converter in the IF can handle signals up to 2 dB above reference level without clipping. For greater signal levels it starts to clip the signal and generates very high distortion. Measurements in this region must strictly be avoided. From the above plot we can see that the best possible NPR range is at -10 to -8 dBm, slightly below the point when the IF overload starts to warn the user. The NPR value in this level region is about 65 dB, which is much higher than required by most satellite power amplifier measurements (typ. 40 dB). From this measurement we can see that it is important to drive the input mixer of the R&S®FSW with the correct level to obtain the best possible measurement range.

In practice the input signal from the DUT has a fixed level that is applied to the spectrum analyzer, and the analyzer hardware must be set in the right way in order to get the best possible accuracy. Two parameters have to be considered when setting up the optimum dynamic range:

- The RF attenuation, to avoid distortion in the mixer stages
- The reference level, to avoid overdrive of the IF path or A/D converter

In the standard setting of the R&S®FSW the RF attenuation is coupled to the reference level setting to obtain -10 dBm mixer level, which perfectly fits to the optimum level as...
we have seen in the previous measurement. In other cases the RF attenuation can also be set independently from the reference level. To obtain the best possible dynamic range the A/D-converter shall be driven to full scale. Dependent on the crest factor of the signal the mean power of the signal is well below the full scale on the screen in this case. The next measurement assumes a fixed level from the DUT with +10 dBm mean power. The reference level on the R&S®FSW is varied to determine the NPR results.

![NPR measurement range](image)

Figure 8: NPR value, RF attenuation and Overload indication versus reference level

The above diagram shows an example of this measurement result for a fixed input signal with +10 dBm mean power. In addition to the NPR reading and the overload indicator there is a curve for the mechanical RF attenuation setting.

The RF attenuator in front of the mixer of the R&S®FSW can be set in 5 dB steps. In addition the analyzer provides an electronic attenuator in the IF stage in 1 dB steps. In the above measurement the RF attenuation is coupled to the reference level, the attenuation is split between the 5 dB steps before the mixer and the 1 dB steps before the A/D-converter. For a better understanding of the effect only the attenuator in front of the mixer is shown, as this has a direct impact on the spectral regrowth in the mixer.

In the range below 0 dBm reference level the R&S®FSW is fully overloaded. The NPR result is driven by the intermodulation in the A/D converter which is overloaded. No viable measurement is possible in this range.

Above 0 dBm the NPR follows the expected rules for third order intermodulation. The 5 dB-step at 0 dBm reference level leads to a 10 dB improvement in the NPR. The next 5 dB step at +5 dBm does not give another 10 dB improvement as the noise floor prevents such a step. At this point the maximum possible NPR measurement range of 65 dB is reached.

Any further increase of the reference level above 10 dBm leads to a linear loss of NPR measurement range with respect to the RF attenuation setting. Any additional 5 dB step leads to about 5 dB dynamic range loss due to the increased noise floor. The 1 dB steps in the IF (in front of the A/D converter) have very little influence on the noise floor of the R&S®FSW.
5 Conclusion

The R&S FSW signal and spectrum analyzer equipped with the option R&S®FSW-K19 forms the basis of a solution for accurate noise power ratio measurements on wideband power amplifiers. The integrated automated measurement function together with the excellent RF performance of the R&S®FSW frontend is a powerful tool that performs NPR measurements with a very high dynamic range. The 5 dB step size of the mechanical RF-attenuator offers sufficient resolution of the level setting in order to reach a very high NPR measurement range.

6 Literature

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

7 Ordering Information

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<td>R&amp;S®FSW13</td>
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The herein described measurement function for NPR is available in the R&S®FSW equipped with option R&S®FSW-K19 (Noise power ratio measurements).
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