NPR and noise bandwidth

To determine the large signal strength of a receiver, a HF two-tone generator is usually used. In analog receivers, the IM3 products grow three times faster than the useful products when the signal is magnified and theoretically meet at an intersection point known as IP3 (Intercept Point 3rd Order). If an IP3 of e.g. +30dBm is reached, this is a good value and the user knows that he has a receiver that is quite resistant to large signals.
With digital, direct sampling receivers, the IMD3 distortion does not follow any particular rule or law when the signal is magnified. The first distortion products can be measured relatively early and should always be below the residual noise of the receiving antenna in good SDRs and thus not be detectable. Only when the ADC is at its maximum, the receiver reaches its largest IM-free dynamic range, of perhaps 100dB. This point is also called the "sweet spot". If the signal is further increased, the ADC then very quickly comes into limiting (clipping, saturation). Figure 1 shows the principle signal characteristics of the resulting IMD3 products of analog and direct-scan digital receivers. Here it can be clearly seen that "IP3" no longer exists in digital receivers and the large signal strength of an SDR can no longer be specified above this.

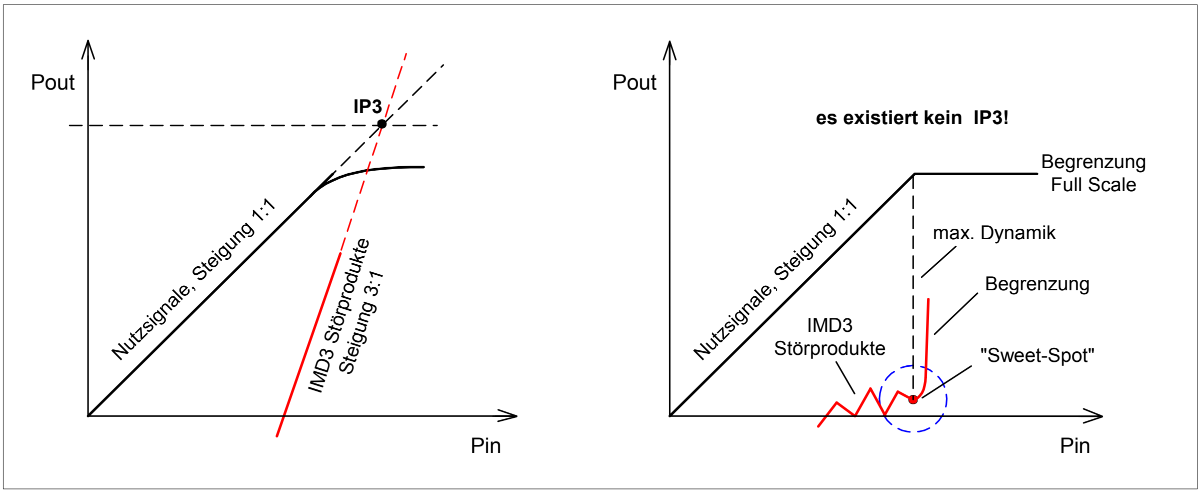


Figure 1: Principle IMD3 curve of an analogue receiver (left) and digital receiver (right)

A more suitable method is the noise power ratio (NPR) measurement, in which the receiver is driven by a white noise signal of defined bandwidth instead of a two-tone signal. The noise signal is amplified until the ADC is close to its limit and generates intermodulation products in the form of additive noise. In order to detect the low noise rise in the spectrum, a narrow-band notch filter (at 2.4 MHz in the example) is inserted between the noise generator and the receiver. This filter suppresses the noise at its cut-off frequency to such an extent that only the background noise (MDS) of the receiver can be measured at this point. If the receiver (ADC) exceeds its maximum output level, it generates intermodulation products which are noticeable as additional noise of 1...3dB in the socket of the notch filter. The maximum output level of the receiver is then reached and the difference between the noise power fed in (PTOT) and the sensitivity of the receiver (MDS) corresponds to the NPR. The NPR is therefore calculated as

$NPR = P_{TOT} - BWR - MDS$

with
P_{TOT} = noise power (related to a defined noise bandwidth)
BWR (Bandwidth Ratio) = 10log BRF/BIF
BRF = noise bandwidth of the generator (e.g. from 0-30MHz)
BIF = Filter bandwidth (noise bandwidth) of the receiver (e.g. 500Hz)
MDS = sensitivity of the receiver (e.g. -122dBm/500Hz)

NPR measuring station

An NPR measuring station basically consists of an adjustable HF noise generator and a notch filter. As noise source I use an arbitrary waveform generator (SDG6022X), which can generate signals of all shapes, as well as white noise of 0...200MHz, with a power of -47...+8dBm (Figures 2 and 3). The advantage of the function generator is that the desired noise bandwidth and noise power can be set arbitrarily and therefore additional, external filters are not required in the design (3). In my example, the noise generator is followed by a 2.4MHz notch filter (Siemens, eBay), consisting of eight LC circuits of high quality, with a bandwidth of about 10 kHz and a blocking depth of 100dB (Fig. 4). The practical construction of such filters is described by OE3HKL on its homepage (2).

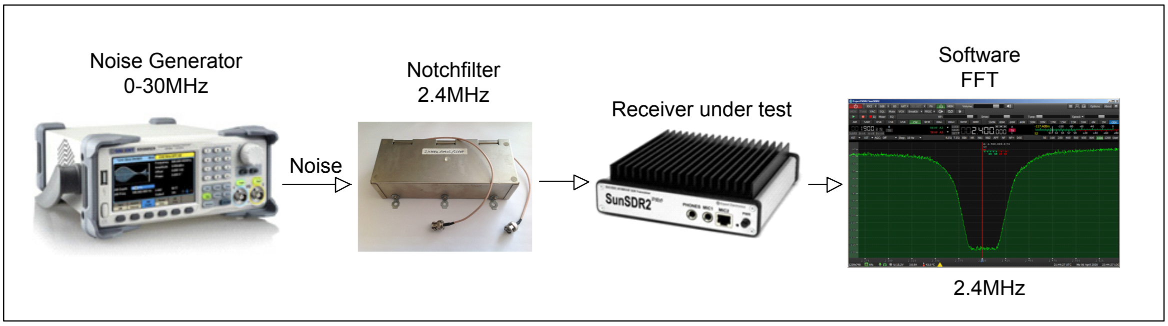
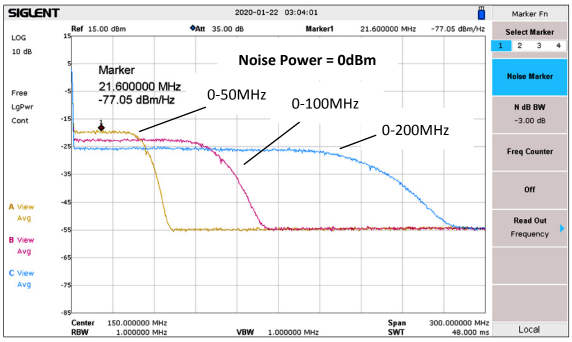


Figure 2: NPR measuring station



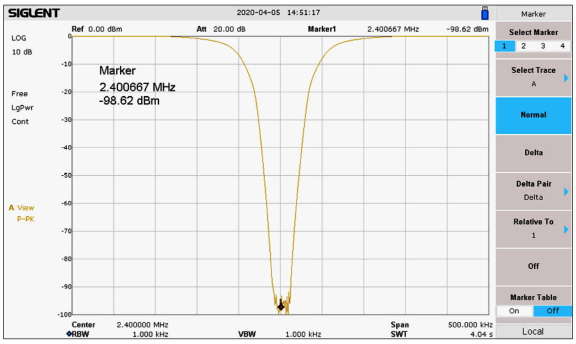


Figure 3: Noise signals of the SDG6022X

Figure 4: 2.4MHz notch filter, transmission curve

Basically, you should note that noise signals behave completely differently than CW signals. Figure 3 shows three noise curves, with bandwidths of 0-50MHz, 0-100MHz and 0-200MHz, measured with a spectrum analyzer. Although the power of all signals is 0dBm (224mVrms into 50Ohm), doubling their bandwidth (50->100MHz, 100->200MHz) reduces their average power by 3dB each. The power of the yellow noise curve measured via the marker is -77dBm/Hz. Related to a generated noise bandwidth of 0-50MHz, the noise power is P_N = -77dBm + 10lg50MHz/1Hz = 0dBm. This is exactly how the noise powers of the other two curves are calculated, with an equal result of P_N = 0dBm. For this reason, unlike CW signals, noise must never be named without the corresponding bandwidth (dBm/Hz).

NPR measurement on broadband receivers

Broadband, direct-sampling SDRs, such as the ColibriNANO or KiwiSDR, do not have preselectors (front-end filters) in their RF input, but only a high-frequency antialiasing LP filter whose cut-off frequency fg is <= half the ADC sampling frequency. The ColibriNANO has an ADC sampling frequency of fs=122.88MHz and an anti-aliasing TP filter of fg=55MHz, so that all signals from 0-55MHz reach the ADC from the RF input unfiltered. To determine its NPR, a noise bandwidth of at least 0-55MHz must therefore be used (Fig. 4). The result of the NPR measurement is shown in the spectrum of the ColibriNANO. At a noise figure of P_{TOT} = -23dBm/55MHz or -73dBm/500Hz, the ColibriNANO achieves a maximum NPR of 49dB (Fig. 5).

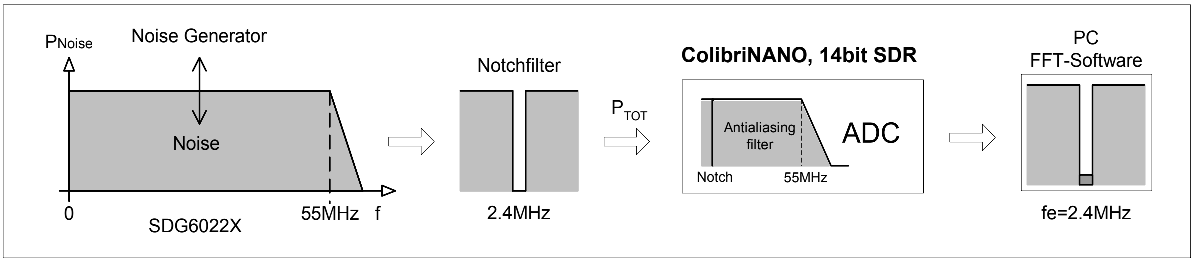


Figure 4: NPR measurement at ColibriNANO

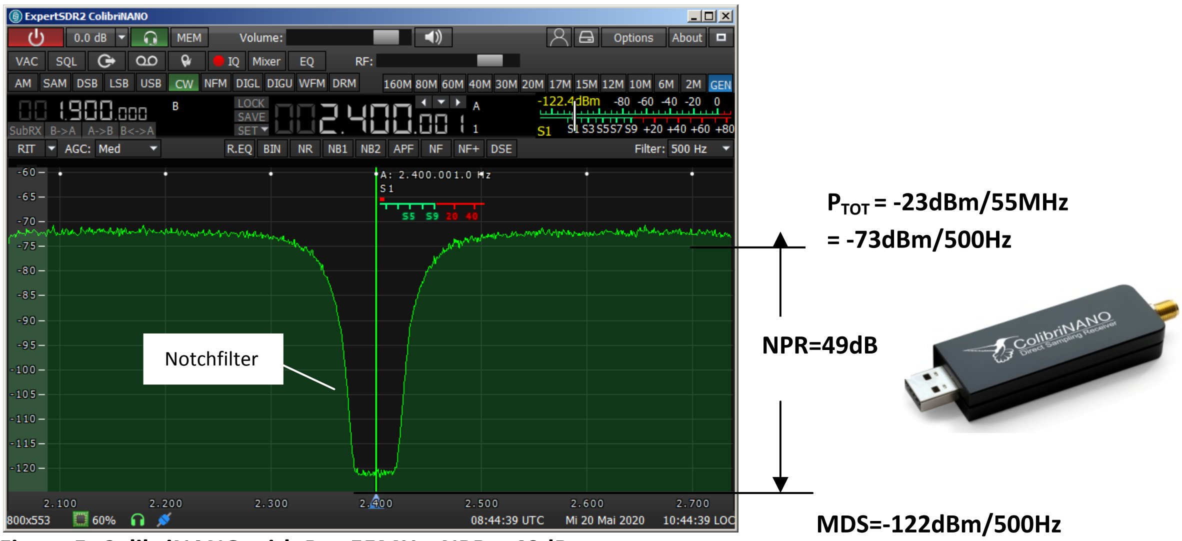


Figure 5: ColibriNANO with B_{RF}=55MHz, NPR = 49dB

Settings ColibriNANO: Filter 500Hz (CW), MDS -122dBm/500Hz, Attenuation 0dB, Preamplifier off, fs=122.88MHz, Antialiasingfilter fg=55MHz

Calculation: NPR = P_{TOT} - BWR - MDS = -23dBm -10lg55MHz/500Hz - (-122dBm) = 49dB

What happens if I reduce the noise bandwidth?

With noise reduction by a factor of 10, i.e. from 0-55MHz to 0-5.5MHz, the NPR should theoretically increase by the amount 10log55/5.5 = 10dB, although the noise power in both cases P_{TOT} = -23dBm.

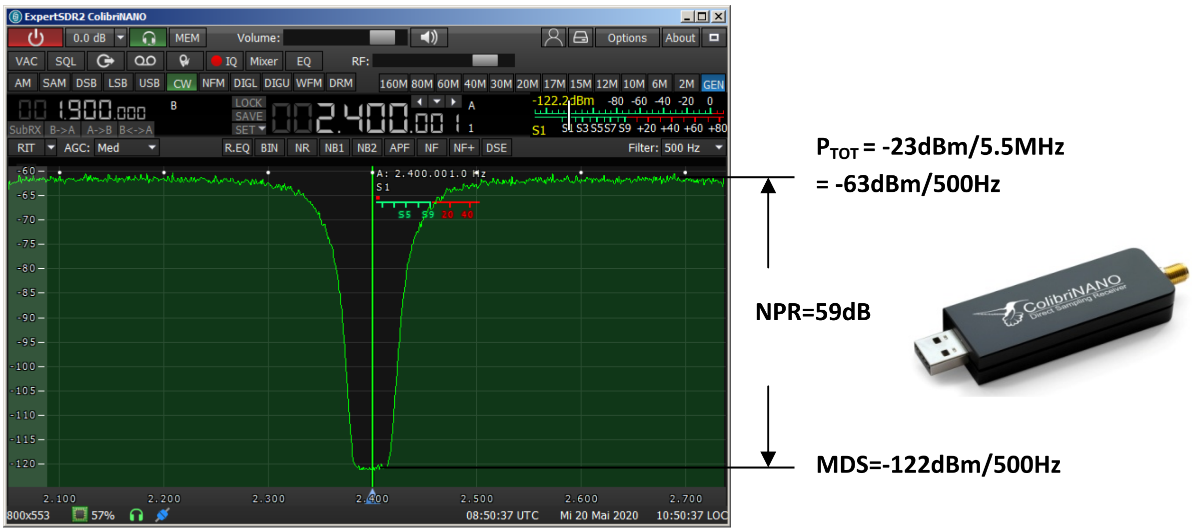


Figure 6: ColibriNANO with B_{RF}=5.5MHz, NPR = 59dB

Calculation: NPR = PTOT - BWR - MDS = -23dBm -10lg5.5MHz/500Hz - (-122dBm) = 59dB

The measurement result in Fig. 6 shows that the NPR actually increases from 49dB to 59dB, so theory and practice agree.

Which NPR of the ColibriNANO is correct, 49dB or 59dB?
In principle both values are correct. But an NPR of 59dB is unrealistic, because the receiver has an unfiltered bandwidth of 0-55MHz and does not stop receiving at 5.5MHz! The correct NPR of the ColibriNANO is therefore NPR=49dB, measured over a noise bandwidth of 0-55MHz.

The relationship between noise bandwidth and NPR is shown in Figure 7 and Table 1. When the noise bandwidth is doubled, the NPR drops by 3dB (10log2) each time, and vice versa. The noise power in all measurement points (P_{TOT}) = -23dBm.

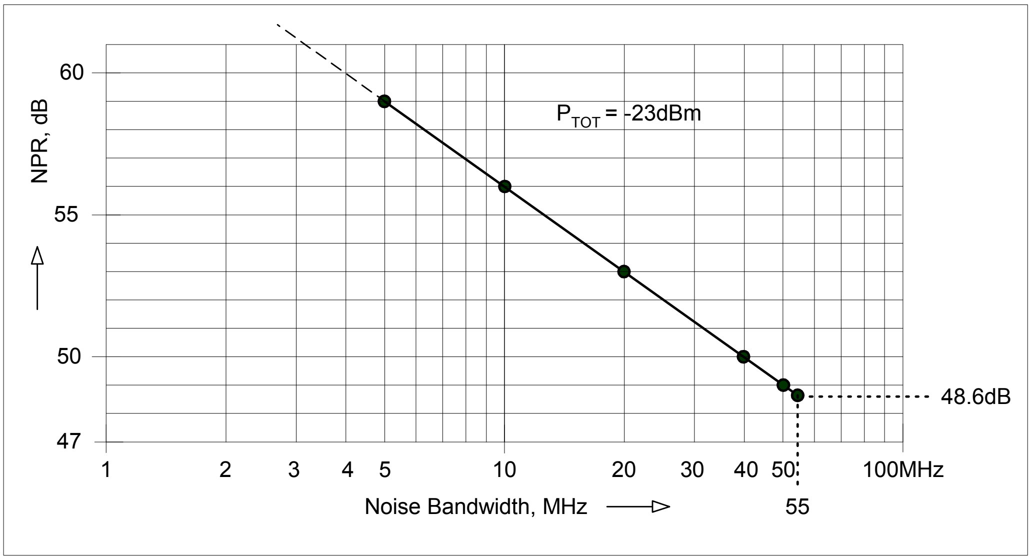


Figure 7: NPR of the ColibriNANO as a function of the injected noise bandwidth

Rauschbandbreite	NPR
0-5MHz	59dB
0-10MHz	56dB
0-20MHz	53dB
0-40MHz	50dB
0-50MHz	49dB
0-55MHz	48,6dB

Table 1: NPR of ColibriNANO with different noise bandwidths

NPR measurement on receivers with preselector (front-end filter)
High-quality direct sampling SDR receivers, such as the Perseus or IC-7300, have front-end filters in the RF input to protect the receiver from strong signals outside the set receiving frequency. In the measurement example I use the **IC-7300**, with a complete sum of preselector in his frontend. If the receiver is tuned to fe=2.4MHz, it automatically switches a bandpass filter (BPF) of 2-3 MHz in front of its input, so that only a noise signal with 1MHz bandwidth reaches the ADC. The noise generator is set to 0-30MHz bandwidth for this measurement (Figure 8). A noise bandwidth of 0-5MHz would be sufficient for the NPR measurement, but it would not be practical because the receiver or the HF antenna does not stop receiving at 5MHz, but at 30MHz. Therefore the applied noise bandwidth should be 0-30MHz (Fig.8).

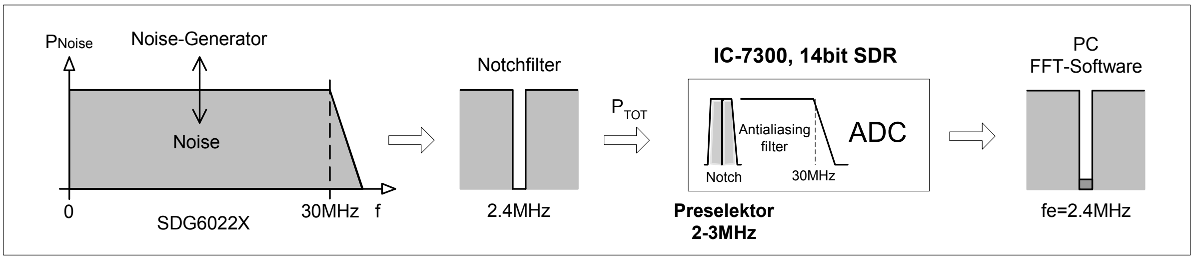


Figure 8: NPR measurement on the IC-7300

With a noise power of P_{TOT} = -8dBm/30MHz = -56dBm/500Hz, a maximum NPR of 76dBm results (Figure 9).

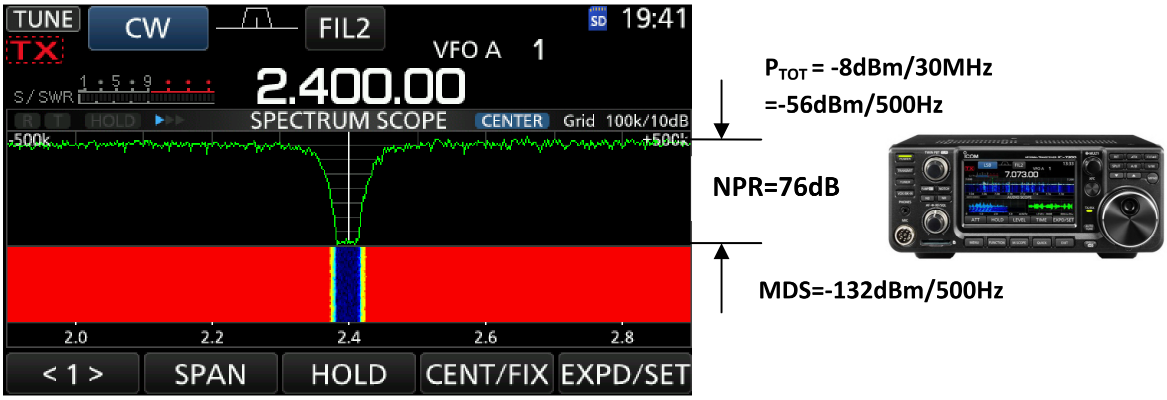


Figure 9: IC-7300, NPR = 76dB

Settings IC-7300: Filter 500Hz (CW), MDS -128dBm/500Hz, Attenuation 0dB, Preamplifier off

Calculation:
NPR = P_{TOT} - BWR - MDS = -8dBm -10lg30MHz/500Hz - (-132dBm) = 76dB

For NPR measurements on receivers with preselectors in the RF input, the front-end filters alone determine which noise bandwidth the receiver (ADC or 1st mixer) must process. In the IC-7300 example, it is only a narrow noise bandwidth of 2 to 3MHz, which results in a relatively good NPR of about 76dB. If the same measurement is performed with a notch filter at 14MHz (20m), the IC-7300 automatically switches a preselector of 10-15MHz in front of its input and the resulting NPR will be reduced by the amount 10lg5MHz/2MHz=4dB to 72dB.

Summary
For NPR measurements on receivers, the noise bandwidth used should be adapted to the bandwidth of the receiver. At a broadband HF-Receiver from 0-30MHz without any front end filter the injected noise bandwidth should be at least 0-30MHz. The injected noise is only limited by its anti-aliasing filter at e.g. 30MHz. If the NPR is measured with too narrow noise bandwidth, the result may be too "good" NPR, which is no longer relevant.
If the receiver has bandpass filters in its frond end, these alone determine the noise bandwidth with which the receiver is loaded. The set bandwidth of the noise generator has only to cover the bandwidth of the preselector (bandpass filters) which the receiver is using.
The following applies here: The smaller the bandwidth of the preselector, the better the NPR of the receiver, and vice versa.

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10.07.2020

(1) Noise Power Ratio, Walt Kester
https://www.analog.com/media/en/training-seminars/tutorials/MT-005.pdf

(2) OE2HKL, NPR Measuring station (noise generator)
http://www.oe3hkl.com/hf-measurements/npr-messplatz-rauschgenerator.html

(3) SDG6022X-Test, DC4KU, Werner Schnorrenberg
https://dc4ku.darc.de/SDG6022X-Test_DC4KU.pdf