

# Noise Power Ratio (NPR) Testing of HF Receivers

## - Using notched noise to evaluate dynamic receiver performance

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### A. Introduction.

Noise-power ratio (NPR) testing is a performance test technique in which a notched noise-band is applied to the input of the DUT, and the output of the DUT is connected to a selective level meter whose bandwidth is less than that of the notch in the noise spectrum. The ICN (idle-channel noise) is measured with the noise-band (1) not notched and (2) notched

The theory behind the NPR test is that the incident noise outside the notch will cause reciprocal mixing noise and multiple IMD products, which will appear in the idle channel (the passband of the selective level meter) and raise the ICN (idle-channel noise). This test method is used in characterising multi-channel FDM/FM systems (terrestrial microwave and satcom), where a notched noise-band of equal bandwidth to the baseband is applied at the transmit end, and a receiver with a channel filter as wide as (or narrower than) the notch is used to measure ICN with and without the notch inserted in the noise-band.

When testing an HF receiver, the receiver itself serves as the selective level meter. The test requires the IF bandwidth to be no wider than the bottom of the notch; the IF filter must not be wide enough to allow noise outside the notch to spill over into the IF. A bandpass (band-limiting) filter following the noise generator determines the total noise-band width. **Fig.1** illustrates a typical noise-band as defined by the band-limiting filter, with inserted notches as defined by the bandstop filters.

### B. Derivation of NPR; noise-bandwidth considerations.

NPR for a given noise bandwidth (or equivalent number of channels) is the reciprocal of the ratio of the noise power in the notched band to the power in an equal bandwidth adjacent to the notch.

I2VGO has shown (**Ref. 4**) that for a given noise bandwidth, and at the optimum noise-loading point (see **D** below),

$$\text{NPR} = P_{\text{TOT}} - \text{BWR} - \text{MDS} \quad (1)$$

where  $P_{\text{TOT}}$  = total noise power in dBm in the noise bandwidth  $B_{\text{RF}}$   
 $\text{BWR} = 10 \log_{10} (B_{\text{RF}}/B_{\text{IF}})$   
 $B_{\text{RF}}$  = RF bandwidth or noise bandwidth in Hz (RS-50 band-limiting filter)  
 $B_{\text{IF}}$  = receiver IF filter bandwidth in Hz  
MDS = minimum discernible signal (specified at  $B_{\text{IF}}$ )

This relationship can also be expressed as follows:

$$\text{NPR} = D_{\text{N}} + 10 \log_{10} B_{\text{IF}} - \text{MDS} \quad (1a)$$

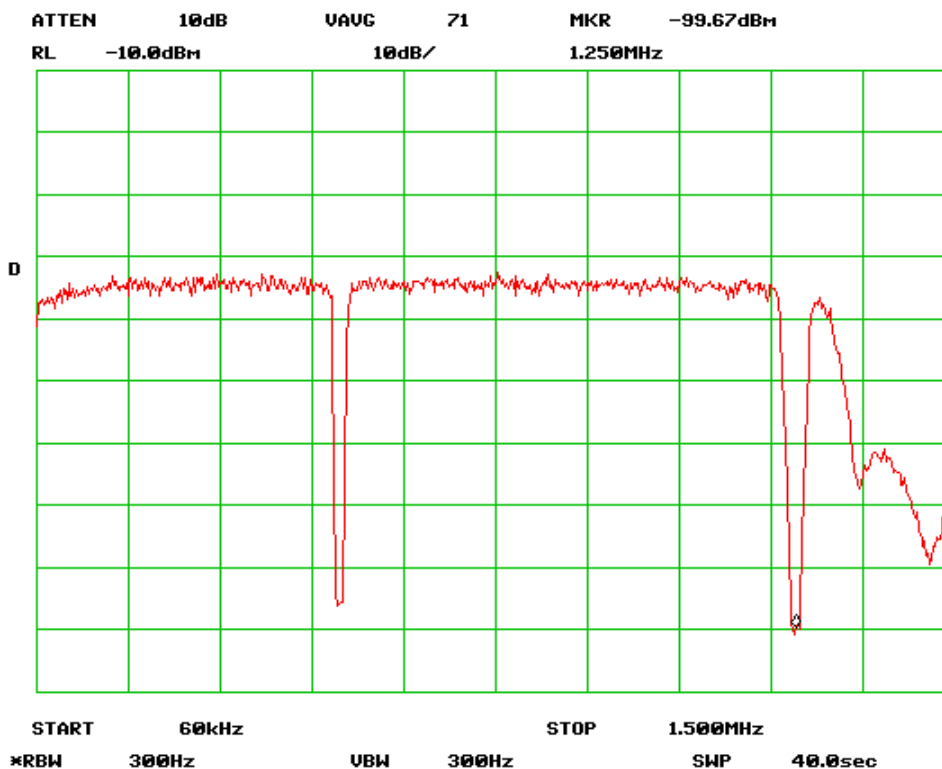
where  $D_{\text{N}}$  = noise density in dBm/Hz =  $P_{\text{TOT}} - 10 \log_{10} B_{\text{RF}}$

Note that noise density  $D_{\text{N}}$  is independent of RF bandwidth. The band-limiting filter selected for each test case should be wider than the DUT's front end, to ensure that the NPR test subjects all stages of the receiver to noise loading including any front-end filter or preselector. Thus, any effects which the incident noise generates in the front-end filter will be taken into account in the NPR measurement. To put the impact of the NPR test into perspective, a -9 dBm  $P_{\text{TOT}}$  level at 5.6 MHz  $B_{\text{RF}}$  is equivalent to **1200 simultaneous SSB signals at -43 dBm each, i.e. S9 + 30 dB!**

**Fig.1: Band-limiting filter response, including notches.**

**Note:** Spectrum analyser NPR can be read directly from displayed notch depth.

M&G RS-25 noise generator, 60-1296 kHz BPF, 534 & 1248 kHz notch filters. 09112012.



**C. Notch (bandstop) filter design considerations (see Fig. 5):**

1. The stopband width (notch width) at maximum attenuation must be greater than the IF bandwidth at which the receiver will be tested. It should also be wide enough to allow for any possible frequency drift in the filter.
2. The attenuation required in the stopband must be sufficient to prevent any direct transfer of noise to the receiver under test at its tuned frequency. Thus, if  $D_{TOT}$  is power spectral density (PSD) of the applied noise-band in dBm/Hz,  $B_n$  is stopband width in Hz and  $A_n$  is stopband attenuation in dB, and MDS is the receiver's minimum discernible signal in dBm, the measuring system must satisfy Equation 2.

$$(D_{TOT} + 10 \log_{10} B_n) - A_n \leq MDS \quad (2)$$

**Ref. 7** gives a correction factor which should be applied if the measured NPR is close to the notch depth of the bandstop filter.

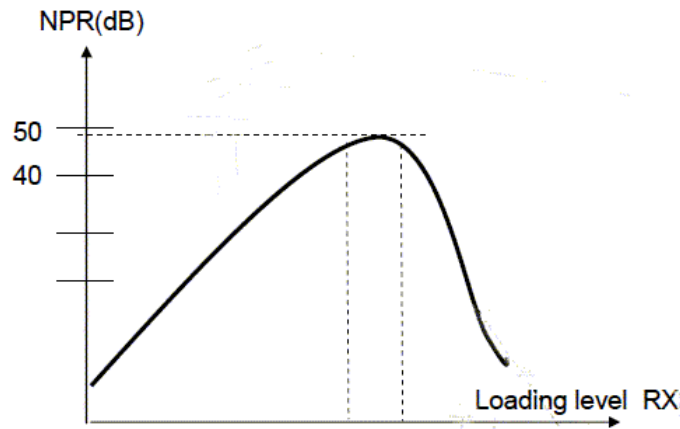
$$NPR = 10 \log_{10} \{ 10^{-(NPR_m / 10)} - 10^{-(A_n / 10)} \} \quad (3)$$

where  $NPR_m$  is the measured NPR and  $A_n$  is the stopband attenuation of the bandstop filter.

**D. Determination of optimum noise loading:**

**Ref. 3**, Section 7.1, describes the NPR curve of a typical multi-channel transmission system as a function of noise loading. At low incident noise power levels, thermal noise is dominant, and NPR is roughly proportional to noise loading, where an increase of 1 dB increases NPR by  $\approx 1$  dB. This curve is also presented in **Fig.2**, and in **Ref. 4**, Slide 28.

**Fig.2: Optimum NPR as a function of noise loading.**



As the noise loading level is further increased, the NPR increase is less than that in input power due to the effect of intermodulation (IMD) products. At a certain noise-loading level, IMD products begin to predominate over thermal noise and NPR starts to decrease. The turnover point is the “optimum noise loading level”, at which the receiver’s NPR will be measured. Per **Ref. 4**, the optimum noise loading level is determined for each test case by increasing noise loading until ICN (idle-channel noise) is **3 dB** above the level when the noise generator is switched off (ICN at MDS). This greatly simplifies the measurement of NPR on receivers.

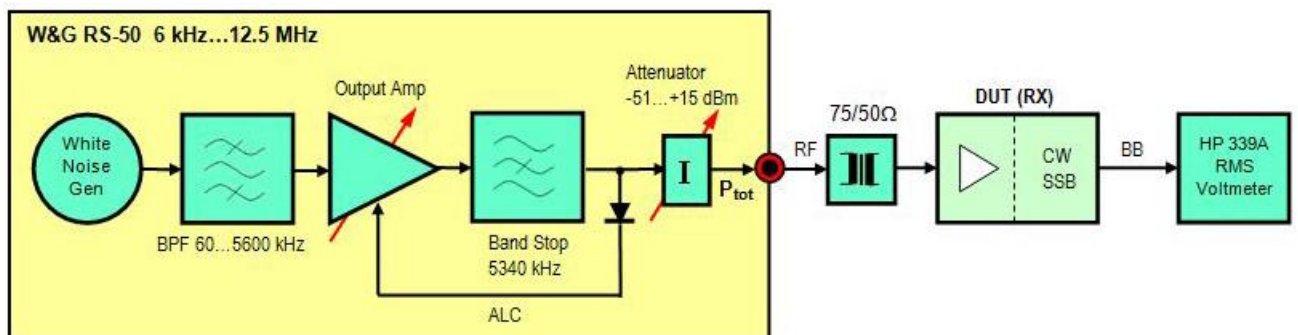
The NPR falls off rapidly at very high noise-loading levels. The slope on the right-hand side of the curve (noise loading > optimum value) is steeper since the IMD products are dominant in this case.

Any direct transfer of noise due to the limited stopband attenuation of the notch filter will add to the IMD noise, thus reducing the optimum noise loading value. This effect will be negligible if the notch depth satisfies Equation (2) above (as is the case for the W&G RS-50).

**E. NPR test instrumentation.**

The author was fortunate enough to locate a Wandel & Goltermann RS-50 White Noise Generator on the surplus test-equipment market. This generator, together with its companion RE-50 noise receiver forms the RK-50 NPR test system used for many years in the telecommunications industry. The RS-50 is illustrated in **Fig. 6**.

The RS-50 generates a 6 kHz...12.5 MHz noise-band. Its output level is adjustable from -51 to +15 dBm. The instrument is fitted with 3 band-limiting filters and 6 bandstop filters covering CCITT (ITU-T) standard FDM baseband widths and test channel frequencies. In **Fig. 3**, the 5340 kHz filter is shown; its stopband width and attenuation are 3.3 kHz and  $\approx 97$  dB respectively. The RS-50 incorporates a precision attenuator (1 and 0.1 dB steps) and an ALC loop which holds the output constant at any level setting, irrespective of which filters are selected. **Fig. 3** illustrates the test setup for NPR testing of an HF receiver.



**Fig.3: Noise Power Ratio (NPR) Measuring Setup**

#### F. NPR test procedure (conventional receivers):

1. Set RX IF bandwidth/mode to 2.4 kHz SSB. Select SHARP shape factor (if applicable) *The IF bandwidth should be narrower than the stopband width of the notch filter.* Noise Blanker (NB), Noise Reduction (NR), Attenuator (ATT) and Preamp are all OFF. RF GAIN is at maximum. Select 6 kHz roofing filter (if applicable), and set AGC to MID. Tune DUT such that the IF passband is centred in the notch. If the DUT has a switchable preselector, this should be ON initially.
2. On RS-50, set RF attenuator to minimum (-50 dBm). Press and hold GENERATOR BLOCKING key and adjust receiver AF GAIN for 0 dBr reading on the RMS voltmeter connected to the baseband (audio) output.
3. On RS-50, release GENERATOR BLOCKING key. Adjust attenuator for a +3 dBr reading on RMS voltmeter. Record attenuator setting: this is  $P_{TOT}$  (total noise power).
4. Calculate NPR using Equation 1 (refer to **B.** above):

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

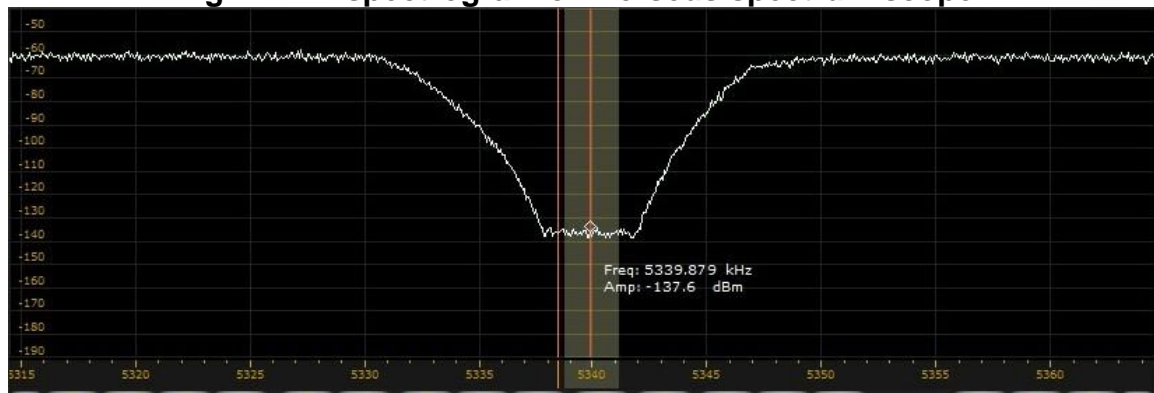
5. Repeat test with different combinations of preselector, roofing filter and preamp, and record results. Take each reading 2 – 3 times and average for highest accuracy.

#### G. NPR test procedure (direct-sampling SDR receivers):

When testing NPR on a direct-sampling SDR receiver, the noise loading level required to raise ICN by 3 dB may exceed the clipping (0 dBFS) point of the receiver's ADC. Thus, it is more convenient to increase the noise loading until the onset of clipping is reached, then back off the noise level until no clipping indication occurs for at least 10 seconds (**Ref.4**, Slide 36.) NPR can then be read directly off the spectrum scope display or the signal-strength meter.

1. Set RX detection bandwidth/mode to 2.4 kHz SSB. Select SHARP shape factor (if applicable) *The detection bandwidth should be narrower than the stopband width of the notch filter.* Noise Blanker (NB), Noise Reduction (NR), Attenuator (ATT), Dither and Preamp are all OFF. RF GAIN is at maximum. Set AGC to SLOW. Tune DUT such that the detection channel passband is centred in the notch. If the DUT has a switchable preselector, this should be ON initially. Spectrum scope averaging should be ON, at mid-range.
2. On RS-50, set RF attenuator to minimum (-50 dBm). Press and hold GENERATOR BLOCKING key to turn off noise output, and read MDS from DUT's signal-strength indicator or bottom of notch on spectrum display. Record MDS reading (in dBm).
3. On RS-50, release GENERATOR BLOCKING key. Adjust attenuator until ADC just clips, then back off until no clipping is observed over  $\approx 10$  sec. Record attenuator setting: this is  $P_{TOT}$  (total noise power). Read noise power from DUT's signal-strength indicator or bottom of notch on spectrum display. Record signal-strength reading (in dBm).
4. Now tune DUT to a frequency well outside the notch and read noise power on signal-strength indicator. Record signal-strength reading (in dBm).
5. NPR equals the difference between the signal-strength readings taken in steps 4 and 3.
6. Repeat test with different combinations of preselector, dither and preamp, and record results. Take each reading 2 – 3 times and average for highest accuracy.
7. NPR can also be read off the spectrum display by positioning the marker well outside the notch and in the center of the stopband. NPR is the difference between these two readings. (Refer to **Fig. 4.**)

**Fig.4. NPR spectrogram on Perseus spectrum scope.**



#### **H. Measurement results (with 60...5600 kHz band-limiting & 5340 kHz bandstop filters)**

**Tables 1, 1a** and **2** present the NPR test results for the radios tested with the W&G RS-50 fitted with 60...5600 kHz band-limiting and 5340 kHz bandstop filters.

$B_{RF} = 5.537$  MHz, BWR = 33.6 dB (except where noted), 1200 equivalent voice channels.

The Kenwood TS-590S was tested with the 60...5600 kHz band-limiting and 5340 kHz bandstop filters to select the **High 1<sup>st</sup>** IF (73.095 MHz), and also with the 60...4100 kHz band-limiting and 3886 kHz bandstop filters to select the **Inband 1st** IF (11.374 MHz). For the latter filters,  $B_{RF} = 4.037$  MHz, BWR = 32.3 dB, 960 equivalent voice channels.

MDS is specified at 2.4 kHz IF bandwidth, except where noted (SSB mode).

Since first publication of this article, the author has acquired the following additional W&G filter sets:

1. 12...552 kHz band-limiting with 70, 240 & 534 kHz bandstop
2. 60...1296 kHz band-limiting with 1248 kHz bandstop
3. 60...2044 kHz band-limiting & 1940 kHz bandstop
4. 60...2600 kHz band-limiting & 2438 kHz bandstop
5. 60...4100 kHz band-limiting & 3886 kHz bandstop
6. 316...8160 kHz band-limiting & 7600 kHz bandstop
7. 316...12360 kHz band-limiting & 11700 kHz bandstop

These filters permit testing on additional bands. As receivers and transceivers are tested on multiple bands, test data sheets will be posted on the website and linked from the Test & Measurement page:

<http://www.ab4oj.com/test/main.html#NPR>

**Table 1: NPR Test Results, Analogue/DSP Radios**

| DUT                  | Config   | MDS dBm           | P <sub>TOT</sub> dBm | BWR dB | NPR dB |
|----------------------|--|-------------------|----------------------|--------|--------|
| IC-7851              | Preamp off R15   | -123 <sup>3</sup> | -3.9                 | 33.6   | 85     |
|                      | R6   |                   | -2.9                 |        | 85     |
|                      | R3   |                   | -2.3                 |        | 85     |
|                      | R1.2   | -121              | +1.8                 | 40.4   | 82     |
|                      | Preamp 1 R15   | -135 <sup>3</sup> | -13.4                | 33.6   | 88     |
|                      | R6   |                   | -12.4                |        | 88     |
|                      | R3   |                   | -11.7                |        | 87     |
|                      | R1.2   | -133              | -10.3                | 40.4   | 82     |
|                      | Preamp 2 R15   | -137 <sup>4</sup> | -19.9                | 33.6   | 83     |
|                      | R6   |                   | -19.6                |        | 84     |
|                      | R3   |                   | -19.2                |        | 84     |
|                      | R1.2   | -139              | -16.7                | 40.4   | 82     |
|                      | Digisel R15  | -122 <sup>1</sup> | -4.2                 | 33.6   | 84     |
|                      | R6   |                   | -4.0                 |        | 82     |
|                      | R3   |                   | -3.4                 |        | 83     |
|                      | R1.2   | -122              | +1.6                 | 40.4   | 82     |
| IC-7700 <sup>1</sup> | Preamp off R15   | -124              | -11.6                | 33.6   | 78.5   |
|                      | R6   |                   | -4.8                 |        | 83.3   |
|                      | R3   |                   | -4.9                 |        | 83.1   |
|                      | Preamp 1 R15   | -138              | -24.6                |        | 79.5   |
|                      | R6   |                   | -14.8                |        | 87.3   |
|                      | R3   |                   | -14.8                |        | 87.3   |
|                      | Preamp 2 R15   | -142              | -29.7                |        | 78.4   |
|                      | R6   |                   | -22.4                |        | 83.7   |
|                      | R3   |                   | -22.5                |        | 83.6   |
|                      | Digisel R15  | -123              | -11.8                |        | 77.4   |
|                      | R6   |                   | -4.0                 |        | 83.0   |
|                      | R3   |                   | -4.2                 |        | 82.9   |
| IC-7800 <sup>2</sup> | Preamp off R15   | -122              | -8.7                 | 33.6   | 79.4   |
|                      | R6   |                   | -4.2                 |        | 81.9   |
|                      | R3   |                   | -1.2                 |        | 82.0   |
|                      | Preamp 1 R15   | -133              | -23.3                |        | 75.5   |
|                      | R6   |                   | -14.7                |        | 82.4   |
|                      | R3   |                   | -12.1                |        | 82.0   |
|                      | Preamp 2 R15   | -137              | -28.1                |        | 75.0   |
|                      | R6   |                   | -23.5                |        | 77.6   |
|                      | R3   |                   | -22.1                |        | 76.0   |
|                      | Digisel R15  | -122              | -8.8                 |        | 79.3   |
|                      | R6   |                   | -1.5                 |        | 84.6   |
|                      | R3   |                   | -0.1                 |        | 83.0   |
| TS-590S Inband       | Preamp Off   | -125              | -10.8                | 32.3   | 81.6   |
|                      | Preamp On  | -133              | -19.5                |        | 81.0   |
| TS-590S High         | Preamp Off   | -126              | -16                  | 33.6   | 76     |
|                      | Preamp On  | -134              | -25.5                |        | 74.1   |
| K3 #1                | <b>K3 #1: 2.7 kHz 5-pole roofing filter &amp; KSYN3A</b> |                   |                      |        |        |
|                      | Preamp off   | -125              | -9.5                 | 33.6   | 82     |
|                      | Preamp on  | -127              | -13.3                |        | 80     |
|                      | <b>K3 #1: 2.7 kHz 5-pole roofing filter, pre-KSYN3A</b>  |                   |                      |        |        |
|                      | Preamp off   | -124              | -9.7                 | 33.6   | 80.4   |
|                      | Preamp on  | -128              | -14.0                |        | 80     |

- Notes:**
1. MDS shown for R15. Correction factors: R6: 2 dB. R3: 2 dB.
  2. MDS shown for R15. Correction factors: R6: 2 dB. R3: 5 dB.
  3. MDS shown for R15. Correction factors: R6: 1 dB. R3: 2 dB.
  4. MDS shown for R15. Correction factors: R6: 0 dB. R3: 0 dB.

**Table 1a: NPR Test Results, Analogue/DSP Radios (cont.)**

| DUT                    | Config  | MDS dBm | P <sub>TOT</sub> dBm | BWR dB | NPR dB |
|------------------------|---|---------|----------------------|--------|--------|
| K3 #2                  | <b>K3 #2: 2.8 kHz 8-pole roofing filter, pre-KSYN3A</b> |         |                      |        |        |
|                        | Preamp off  | -124    | -11.7                | 33.6   | 78.4   |
|                        | Preamp on   | -129    | -15.7                |        | 79.4   |
| IC-7600                | Preamp off R15  | -127    | -14                  | 33.6   | 79     |
|                        | R6  |         | -12                  |        | 81     |
|                        | R3  |         | -12                  |        | 81     |
|                        | Preamp 1 R15  | -135    | -25                  |        | 77     |
|                        | R6  |         | -22                  |        | 79     |
|                        | R3  |         | -22                  |        | 79     |
|                        | Preamp 2 R15  | -137    | -27                  |        | 76     |
|                        | R6  |         | -25                  |        | 78     |
|                        | R3  |         | -26                  |        | 77     |
| IC-7410                | Preamp off R15  | -129    | -18                  | 33.6   | 77.4   |
|                        | R6  |         | -18.3                |        | 77.1   |
|                        | R3  |         | -17                  |        | 78.4   |
|                        | Preamp 1 R15  | -136    | -26.1                |        | 76.3   |
|                        | R6  |         | -26                  |        | 76.4   |
|                        | R3  |         | -22.4                |        | 80     |
|                        | Preamp 2 R15  | -139    | -28.1                |        | 77.3   |
|                        | R6  |         | -29.6                |        | 75.8   |
|                        | R3  |         | -27.5                |        | 77.9   |
| IC-9100                | Preamp off R15  | -129    | -17.8                | 33.6   | 77.6   |
|                        | R6  |         | -17.8                |        | 77.6   |
|                        | R3  |         | -17.7                |        | 77.7   |
|                        | Preamp 1 R15  | -137    | -26.3                |        | 77.1   |
|                        | R6  |         | -25.9                |        | 77.5   |
|                        | R3  |         | -25.4                |        | 78     |
|                        | Preamp 2 R15  | -137    | -27.8                |        | 75.6   |
|                        | R6  |         | -26.6                |        | 76.8   |
|                        | R3  |         | -25.9                |        | 77.5   |
| FT-950                 | IPO R15   | -119    | -11                  | 33.6   | 74     |
|                        | R6  |         | -11                  |        | 74     |
|                        | R3  |         | -9.2                 |        | 76     |
|                        | AMP1 R15  | -130    | -21.4                |        | 74.7   |
|                        | R6  |         | -19                  |        | 77     |
|                        | R3  |         | -18.4                |        | 77.7   |
|                        | AMP2 R15  | -138    | -28.4                |        | 75.7   |
|                        | R6  |         | -27.4                |        | 76.7   |
|                        | R3  |         | -26.8                |        | 77.3   |
| FTDX-1200 <sup>3</sup> | IPO R15   | -116.5  | -7.7                 | 33.6   | 74.9   |
|                        | R6  |         | -8.2                 |        | 76.4   |
|                        | R3  |         | -8.7                 |        | 77.9   |
|                        | AMP1 R15  | -129    | -22.7                |        | 72.4   |
|                        | R6  |         | -22.9                |        | 74.2   |
|                        | R3  |         | -23.5                |        | 75.6   |
|                        | AMP2 R15  | -134    | -31.2                |        | 68.9   |
|                        | R6  |         | -31.6                |        | 71.5   |
|                        | R3  |         | -31.8                |        | 72.3   |
| FT-991                 | R3  | IPO     | -120                 | -11.2  | 75     |
|                        |   | AMP1    | -132                 | -26.8  | 71     |
|                        |   | AMP2    | -139                 | -35.8  | 69     |

**Notes: 3.** MDS shown for R15. Correction factors: R6: 1 dB, R3: 2 dB.

**Table 1a (cont.): NPR Test Results, Analogue/DSP Radios (cont.)**

| DUT                                | Config             | MDS dBm | P <sub>TOT</sub> dBm | BWR dB            | NPR dB |
|------------------------------------|--------------------|---------|----------------------|-------------------|--------|
| IC-7200                            | Preamp off         | -124    | -18                  | 33.6              | 72.1   |
|                                    | Preamp on          | -135    | -28                  |                   | 73.1   |
| FTDX-3000                          | Preamp off         | -119    | -12.7                | 33.6 <sup>1</sup> | 72.4   |
|                                    | Preamp 1           | -131    | -27.3                |                   | 69.8   |
|                                    | Preamp 2           | -134    | -30.5                |                   | 66.6   |
| FT-897D                            | Preamp off         | -124    | -18.7                | 34.0              | 71     |
|                                    | Preamp on          | -131    | -31.7                |                   | 65     |
| IC-703                             | Preamp off         | -125    | -21.8                | 33.6              | 69.6   |
|                                    | Preamp on          | -134    | -30.4                |                   | 70     |
|                                    | Preamp off ATU in  | -125    | -21.8                |                   | 69.6   |
| FT-1000                            | Preamp off         | -124    | -22                  | 33.6              | 68     |
|                                    | Preamp on          | -132    | -32                  |                   | 68     |
| FTDX-5000D<br>Sub RX <sup>2</sup>  | IPO                | -118    | -18                  | 33.6              | 66     |
|                                    | VRF                | -123    | -15                  |                   | 73     |
|                                    | AMP1               | -130    | -30                  |                   | 66     |
|                                    | AMP2               | -135    | -35                  |                   | 67     |
| IC-718 (#22)                       | Preamp off         | -124    | -21.6                | 33.6              | 68.5   |
|                                    | Preamp on          | -132    | -32.1                |                   | 66     |
| IC-706                             | Preamp off 2.4 kHz | -132    | -31.1                | 33.6              | 67.4   |
|                                    | Preamp on 2.4 kHz  | -138    | -37.3                |                   | 67.1   |
|                                    | Preamp off 1.8 kHz | -132    | -30.9                | 34.9              | 66.2   |
|                                    | Preamp on 1.8 kHz  | -138    | -37.3                |                   | 65.8   |
| IC-R8500                           | ATT off 2.2 kHz    | -132    | -36.4                | 34.0              | 64     |
| IC-7000                            | Preamp off         | -125    | -24                  | 33.6              | 67.0   |
|                                    | Preamp on          | -135    | -37                  |                   | 64.3   |
| IC-7100                            | Preamp off         | -124    | -23.5                | 33.6              | 66     |
|                                    | Preamp 1           | -133    | -35                  |                   | 64     |
|                                    | Preamp 2           | -135    | -38                  |                   | 63     |
| FTDX-5000D<br>Main RX <sup>2</sup> | IPO                | -117    | -18                  | 33.6              | 65     |
|                                    | AMP1               | -129    | -33                  |                   | 62     |
|                                    | AMP2               | -135    | -41                  |                   | 59     |
| FT-817                             | Preamp off         | -125    | -26.6                | 33.6              | 64.5   |
|                                    | Preamp on          | -130    | -33.5                |                   | 62.6   |

**Notes:** 1. 3 kHz 1<sup>st</sup>-IF roofing filter selected.  
 2. 6 kHz 1<sup>st</sup>-IF roofing filter selected.



**Table 2: NPR Test Results, Software Defined Radios (SDR)<sup>8</sup>**

| DUT          | SW Ver.          | Presel         | Preamp  | Dither         | MDS dBm | Clip dBm | P <sub>TOT</sub> dBm | NPR dB <sup>1</sup> |       |                |           |       |       |       |      |
|--------------|------------------|----------------|---------|----------------|---------|----------|----------------------|---------------------|-------|----------------|-----------|-------|-------|-------|------|
| IC-R8600     | 1.20             | 1              | 0       | 0              | -126    | -8       | -15                  | 79                  |       |                |           |       |       |       |      |
| IC-7300      | 1.12             | 1              | 0       | 0              | -126    | -10      | -14                  | 78                  |       |                |           |       |       |       |      |
| ANAN100D     | 3.2.17           | 1              |         | 0              | -123    | -13      | -22                  | 72                  |       |                |           |       |       |       |      |
|              |                  |                |         | 1              | -123    | -13      | -22                  | 69                  |       |                |           |       |       |       |      |
| ANAN200D     | 3.2.17           | 1              |         | 0/1            | -128    | -16      | -22                  | 73                  |       |                |           |       |       |       |      |
| Flex-6700    | 1.3.8            | 0 <sup>3</sup> | 0dB     |                | -111    | 0        | -1                   | 75                  |       |                |           |       |       |       |      |
|              |                  |                | +10dB   |                | -118    | -12      | -13                  | 71                  |       |                |           |       |       |       |      |
|              |                  |                | +20dB   |                | -130    | -22      | -23                  | 71                  |       |                |           |       |       |       |      |
|              |                  |                | +30dB   |                | -134    | -32      | -33                  | 68                  |       |                |           |       |       |       |      |
| Perseus      | 4.0b             | 0              | 0       | 0              | -122    | -3.6     | -16.5                | 72                  |       |                |           |       |       |       |      |
|              |                  | 0              | 0       | 1              | -120    | -3.6     | -19.4                | 70                  |       |                |           |       |       |       |      |
|              |                  | 0              | 1       | 0              | -124    | -7.1     | -19.9                | 69                  |       |                |           |       |       |       |      |
|              |                  | 0              | 1       | 1              | -120    | -7.1     | -19.5                | 68                  |       |                |           |       |       |       |      |
|              |                  | 1              | 0       | 0              | -121    | -1.5     | -8.5                 | 75                  |       |                |           |       |       |       |      |
|              |                  | 1              | 0       | 1              | -120    | -1.5     | -8.8                 | 73                  |       |                |           |       |       |       |      |
|              |                  | 1              | 1       | 0              | -123    | -5.0     | -12.2                | 73                  |       |                |           |       |       |       |      |
|              |                  | 1              | 1       | 1              | -121    | -5.0     | -12.9                | 72                  |       |                |           |       |       |       |      |
| QS1R Rev. D  | 5.0.1.1          |                | 0       | 0 <sup>4</sup> | -113    | +11      | -1                   | 71                  |       |                |           |       |       |       |      |
|              |                  |                | 1       |                | -118    | +7       | -5                   | 72                  |       |                |           |       |       |       |      |
| KX3          | FW Ver.          | BB Flt         | Preamp  |                | MDS dBm | BWR dB   | P <sub>TOT</sub> dBm | NPR dB <sup>2</sup> |       |                |           |       |       |       |      |
|              |                  |                |         |                |         |          |                      |                     | 1.10  | 0              | 0         | -117  | 32.8  | -11.5 | 72.4 |
|              |                  |                |         |                |         |          |                      |                     | 1     | 0              | -116      | 33.7  | -8.5  | 73.5  |      |
|              |                  |                |         |                |         |          |                      |                     | 0     | 1              | -131      | 32.8  | -25   | 72.9  |      |
|              |                  |                |         |                |         |          |                      |                     | 1     | 1              | -130      | 33.7  | -21.3 | 74.7  |      |
| ANAN 8000DLE | SW Ver.          | Presel         | ATT dB  | Dither         | BWR     | Clip dBm | P <sub>TOT</sub> dBm | NPR dB              |       |                |           |       |       |       |      |
|              |                  |                |         |                |         |          |                      |                     | 3.4.2 | 0              | On or Off | 33.6  | -6    | -17   | 70   |
|              |                  |                |         |                |         |          |                      |                     |       |                |           |       | +20   | +14   | -1   |
|              |                  |                |         |                |         |          |                      |                     | 1     | 0              | On or Off | 33.6  | -5    | -15   | 71   |
|              |                  |                |         |                |         |          |                      |                     |       |                |           |       | +20   | +15   | -4   |
| ELAD FDM-S2  | SW Ver.          | FDM-SW2        | ATT     |                | MDS dBm | BWR dB   | P <sub>TOT</sub> dBm | NPR dB <sup>1</sup> |       |                |           |       |       |       |      |
|              |                  |                |         |                |         |          |                      |                     | 0     | -130           | 33.4      | -19.5 | 71    |       |      |
| SDR-IQ       | SW Ver.          |                | IF Gain |                |         |          |                      |                     |       |                |           |       |       |       |      |
|              |                  |                |         |                |         |          |                      |                     | 3.32  | +12dB          | -103      | 33.6  | -4.5  | 70    |      |
|              |                  |                |         |                |         |          |                      |                     |       | +0dB           | -100      |       | -4.5  | 64    |      |
| Cloud-IQ     | 2.3 <sup>6</sup> |                |         |                | -131    | 33.6     | -24                  | 70                  |       |                |           |       |       |       |      |
| SunSDR2 Pro  | 1.1.0RC          | 1              | 0       | 1 <sup>7</sup> | -115    | 33.5     | -8                   | 57                  |       |                |           |       |       |       |      |
|              |                  | 1              | 1       |                | -124    |          | -12                  | 65                  |       |                |           |       |       |       |      |
| Hermes Lite  | 3.2.27           |                | S-ATT   |                |         |          |                      |                     |       |                |           |       |       |       |      |
|              |                  |                |         |                |         |          |                      |                     | 0dB   | 1 <sup>5</sup> | 33.6      | -30   | 57    |       |      |
| Flex-1500    | SW Ver.          |                | Preamp  |                |         |          |                      |                     |       |                |           |       |       |       |      |
|              |                  |                |         |                |         |          |                      |                     | 2.7.2 | 0              | -100      | 33.6  | -16   | 55    |      |
|              |                  |                | 1       |                | -111    |          | -25                  | 60                  |       |                |           |       |       |       |      |

- Notes to Table 2:**
1. NPR value measured by observation (see G. above.)
  2. NPR calculated from  $P_{TOT}$  and BWR (see F. above.)
  3. No preselector fitted for 5 MHz range.
  4. Enabling Dither and/or Random does not affect NPR.
  5. "Dither ON" reduces LNA gain by 32 dB (default).
  6. SDR Console V2.3.
  7. Dither and Random ON.
  8. If not stated, BWR = 33.6 dB.
  9. NPR degraded due to PIM in preselector.

#### J. Notes on the theoretical maximum NPR of an ADC:

**Ref. 8**, Figure 2, p.3 gives the theoretical maximum NPR value of **74.01 dB** for a 14-bit ADC. This value can be derived at the optimum noise loading point where  $B_{RF} = f_S/2$ , where  $f_S$  is the sampling frequency of the ADC, and assuming a perfect, noiseless ADC whose noise floor  $N_0$  is:

$$N_0 = (6 * \text{no. of bits}) + 1.76 = (6 * 14) + 1.76 = \mathbf{85.8 \text{ dBFS}} \quad (4)$$

The noise floor of the LTC2206-14 ADC in the Perseus is 77 dBFS, which is 8.8 dB worse than the theoretical maximum value.  $f_S = 80$  MHz for the Perseus. An NPR test with  $B_{RF} = f_S/2 = 40$  MHz,  $B_{IF} = 2.4$  kHz (SSB mode) and the 5340 kHz bandstop filter yielded NPR = **64.75 dB**. This is 9.26 dB worse than the theoretical value, and is attributable to the ADC's finite noise floor. This difference is comparable to the 8.8 dB difference in noise floor between the theoretical and "real-world" values. **Ref. 9** addresses a 16-bit ADC.

Let us now derive the **process gain  $G_P$**  due to the presence of the band-limiting filter during the original NPR test:

$$G_P = 10 \log_{10}(f_S / 2 * B_{RF}) = 10 \log_{10}(80 / 2 * 5.537) = \mathbf{8.6 \text{ dB}} \quad (5)$$

We can now predict NPR for the first test case in Table 2 above:

$$\text{NPR} = (\text{NPR for } B_{RF} = f_S/2) + G_P = 64.75 + 8.6 = \mathbf{73.35 \text{ dB}} \quad (6)$$

The measured NPR was **72 dB**, well within the margin of error.

#### K. General discussion of results:

In a conventional receiver, the effect of the high noise power outside the notch is twofold and most likely impacts the first and second mixers more than any of the downstream sections of the receiver. Firstly, the incident noise mixes with the noise pedestal of the LO to cause reciprocal mixing, which shows up as increased noise in the IF passband (ICN). Secondly, the noise components mix with each other, the LO, any LO spurs and the LO phase noise to produce a very large number of IMD products - much closer to the effect of a heavily-occupied band than a 2-signal test. Some of these IMD products will fall into the IF passband, further degrading ICN.

Secondary effects due to passive IMD in RF filter components, semiconductor filter switches, roofing filters etc. under the high noise loading will cause a further slight degradation in NPR. (It should be noted here that classical narrow-band 2-tone testing has also revealed passive IMD in narrow crystal roofing filters in some receivers.)

In the IC-7700, the NPR improvement of several dB with the 6 or 3 kHz roofing filters suggests that the second mixer is a significant contributor of IMD and/or reciprocal mixing noise when subjected to the higher noise loading with the 15 kHz roofing filter selected.

In K3 #2, NPR is 2 dB worse with Preamp off than the corresponding value for K3 #1. This may be due to slightly higher passive IMD in the 8-pole filter as compared to the 5-pole filter in K3 #1.

In the Perseus SDR, the best-case NPR was measured with preselector on, preamp off and dithering off. This suggests that the preselector is preventing the noise loading from driving the ADC input circuit into its non-linear region at levels approaching 0 dBFS.

If we apply the notched noise load to a perfect (ideal) DUT, the notch depth at the DUT output will be the same as that shown in **Fig.5** below. Any noise generated in the DUT will fill the notch with added noise, reducing its measured depth. Thus, the actual measured NPR is a measure of the amount of degradation due to reciprocal mixing and IMD noise generated by the notched noise load.

From **Fig.5** below, the notch depth at a bandwidth of 3.3 kHz is  $\approx 97$  dB. Thus, the NPR of an ideal receiver with  $<3.3$  kHz Hz IF bandwidth would also be  $\approx 97$  dB. By this yardstick, a 70 - 80 dB measured NPR appears quite respectable. It will be interesting to correlate the results of the NPR test with those of the more familiar 2-signal IMD3 dynamic range measurement.

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**Fig.5: W&G 5340 kHz bandstop filter amplitude/frequency response.**

W&G RSS-5340 bandstop filter, BN 728/60, S/N 0006 (RS-50), 18.10.2011.

ATTEN 10dB      UAVC 67      MKR -107.3dBm  
 RL -10.0dBm      10dB/      5.34000MHz



CENTER 5.34000MHz      SPAN 20.00kHz  
 \*RBW 300Hz      UBW 300Hz      SWP 670ms

Fig.6: The Wandel & Goltermann RS-50 White Noise Generator.



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- 14 October 2012 (NPR test results for Yaesu FT-817 added to Table 1a.)
- 3 November 2012 (NPR test results for Elecraft KX3 added to Table 2.)
- 22 November 2012 (Refs. 10, 11 & 12 added.)
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- 4 May 2016 (IC-7300 data added.)
- 10 June 2016 (IC-7851 1.2 kHz roofing filter data added.)
- 31 December 2016 (Yaesu FTDX-5000D data added.)
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