Noise Power Ratio (NPR) Testing of HF Receivers

- Using notched noise to evaluate dynamic receiver performance

by Adam Farson, VA7OJ/AB4OJ

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),

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

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

This relationship can also be expressed as follows:

$$NPR = D_N + 10 \log_{10} B_{IF} - MDS \qquad (1a)$$
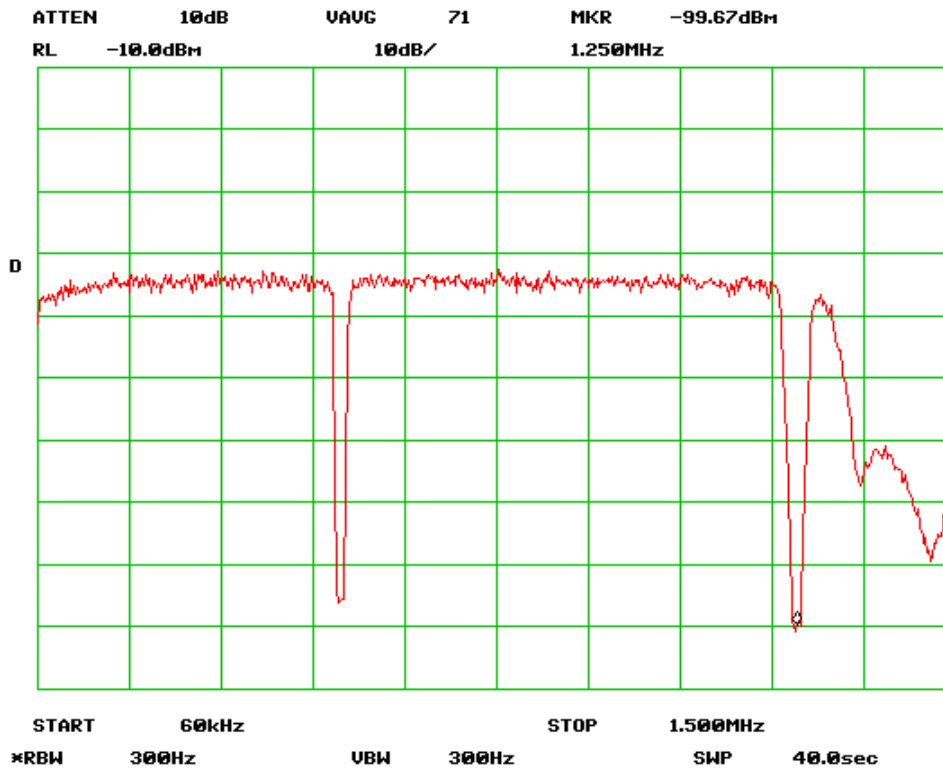
where D_N = noise density in dBm/Hz = $P_{TOT} - 10 \log_{10} B_{RF}$

Note that noise density D_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_{TOT} level at 5.6 MHz B_{RF} is equivalent to **1200 simultaneous SSB signals at -40 dBm each, i.e. S9 + 33 dB!**

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

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

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


```
ATTEN      10dB          VAVG     71         MKR      -99.67dBm
RL    -10.0dBm                10dB/           1.250MHz
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```
START      60kHz                   STOP      1.500MHz
*RBW      300Hz          VBW    300Hz          SWP      40.0sec
```

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.

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

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

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

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 ≈ 1 dB. This curve is also presented in **Fig.2**, and in **Ref. 4,** Slide 28.

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Fig.2: Optimum NPR as a function of noise loading.
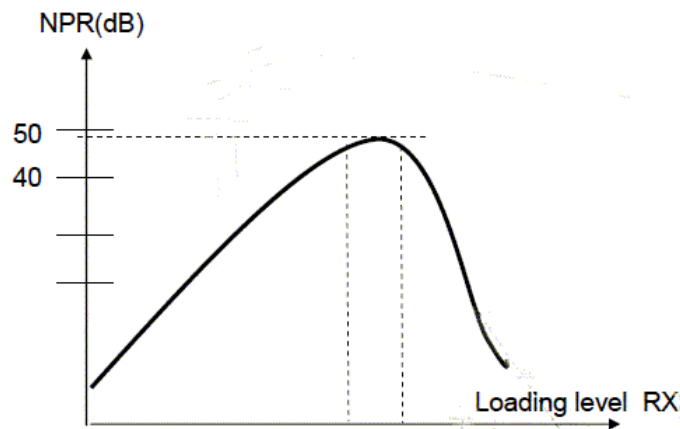
As the noise loading level is further increased, the NPR increase is less than that in input power due to the effect of intermodulation (IMD) products. At a certain noise-loading level, IMD products begin to predominate over thermal noise and NPR starts to decrease. The turnover point is the "optimum 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 ≈ 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.
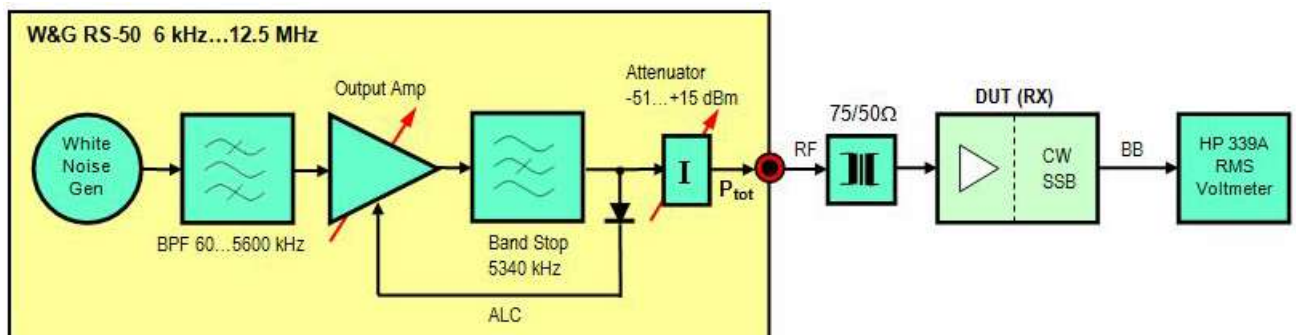

Fig.3: Noise Power Ratio (NPR) Measuring Setup

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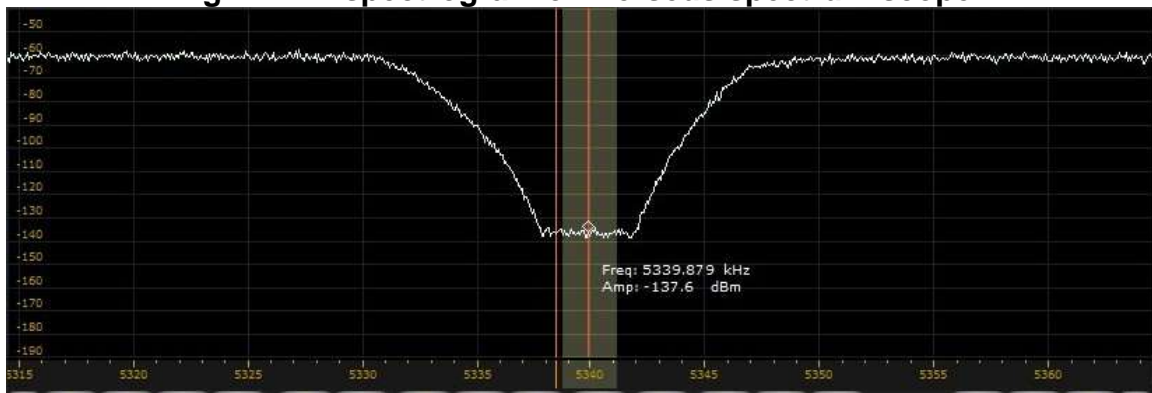
H. Measurement results *(with 60…5600 kHz band-limiting & 5340 kHz bandstop filters)*

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** 1st 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: (All filters are LC except those marked *, which are crystal filters.)

1. 12…552 kHz band-limiting with 240 & 534 kHz bandstop
2. 6…108 kHz band-limiting with 16, 34 & 70 MHz bandstop
3. 60…1296 kHz band-limiting with 1248 kHz bandstop
4. 60…2044 kHz band-limiting & 1940 kHz bandstop
5. 60…2600 kHz band-limiting & 2438 kHz bandstop
6. 12…3284 kHz band-limiting with 3150 kHz bandstop
7. 60…4100 kHz band-limiting & 3886 kHz* bandstop
8. 4650 kHz* bandstop (used with 60-5600 kHz band-limiting)
9. 12…8160 kHz band-limiting & 7600 kHz* bandstop
10. 316...12360 kHz band-limiting & 11700 kHz* bandstop
11. 316…17300 kHz band-limiting & 16400 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$_{TOT}$ dBm	BWR dB	NPR dB
IC-7851	Preamp off R15	-123[3]	-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[3]	-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[4]	-19.9	33.6	83
	R6		-19.6		84
	R3		-19.2		84
	R1.2	-139	-16.7	40.4	82
	Digisel R15	-122[1]	-4.2	33.6	84
	R6		-4.0		82
	R3		-3.4		83
	R1.2	-122	+1.6	40.4	82
IC-7700[1]	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[2]	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	**K3 #1:** 2.7 kHz 5-pole roofing filter & KSYN3A				
	Preamp off	-125	-9.5	33.6	82
	Preamp on	-127	-13.3		80
	K3 #1: 2.7 kHz 5-pole roofing filter, pre-KSYN3A				
	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$_{TOT}$ dBm	BWR dB	NPR dB
K3 #2	**K3 #2:** 2.8 kHz 8-pole roofing filter, pre-KSYN3A					
	Preamp off		-124	-11.7	33.6	78.4
	Preamp on		-129	-15.7		79.4
IC-7600	Preamp off R15			-14		79
	R6		-127	-12		81
	R3			-12		81
	Preamp 1 R15			-25		77
	R6		-135	-22	33.6	79
	R3			-22		79
	Preamp 2 R15			-27		76
	R6		-137	-25		78
	R3			-26		77
IC-7410	Preamp off R15			-18		77.4
	R6		-129	-18.3		77.1
	R3			-17		78.4
	Preamp 1 R15			-26.1		76.3
	R6		-136	-26	33.6	76.4
	R3			-22.4		80
	Preamp 2 R15			-28.1		77.3
	R6		-139	-29.6		75.8
	R3			-27.5		77.9
IC-9100	Preamp off R15			-17.8		77.6
	R6		-129	-17.8		77.6
	R3			-17.7		77.7
	Preamp 1 R15			-26.3		77.1
	R6		-137	-25.9	33.6	77.5
	R3			-25.4		78
	Preamp 2 R15			-27.8		75.6
	R6		-137	-26.6		76.8
	R3			-25.9		77.5
FT-950	IPO R15			-11		74
	R6		-119	-11		74
	R3			-9.2		76
	AMP1 R15			-21.4		74.7
	R6		-130	-19	33.6	77
	R3			-18.4		77.7
	AMP2 R15			--28.4		75.7
	R6		-138	-27.4		76.7
	R3			-26.8		77.3
FTDX-1200[3]	IPO R15			-7.7		74.9
	R6		-116.5	-8.2		76.4
	R3			-8.7		77.9
	AMP1 R15			-22.7		72.4
	R6		-129	-22.9	33.6	74.2
	R3			-23.5		75.6
	AMP2 R15			-31.2		68.9
	R6		-134	-31.6		71.5
	R3			-31.8		72.3
FT-991	R3	IPO	-120	-11.2		75
		AMP1	-132	-26.8	33.6	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_{TOT} 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[1]	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 Sub RX[2]	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 Main RX[2]	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 1st-IF roofing filter selected.
2. 6 kHz 1st-IF roofing filter selected.

Table 2: NPR Test Results, Software Defined Radios (SDR)[8]

DUT	SW Ver.	Presel	Preamp	Dither	MDS dBm	Clip dBm	P_{TOT} dBm	NPR dB[1]
IC-7610	1.04	1	0	0	-125	-6	-4	87
		0	0	0	-128	-9	-18.5	76
IC-R8600	1.20	1	0	0	-126	-8	-15	79
IC-7300	1.12	1	0	0	-126	-10	-14	78
FT-710	202212		IPO	1	-121		-12	75
			AMP1	1	-130		-22	75
			AMP2	1	-137		-37	76
IC-705	1.12	0	0	0	-122	-6.5	-14	74
ANAN200D	3.2.17	1		0/1	-128	-16	-22	73
ANAN100D	3.2.17	1		0	-123	-13	-22	72
				1	-123	-13	-22	69
Flex-6700	1.3.8	0[3]	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[4]	-113	+11	-1	71
			1		-118	+7	-5	72

DUT	FW Ver.	BB Flt	Preamp		MDS dBm	BWR dB	P_{TOT} dBm	NPR dB[2]
KX3	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

DUT	SW Ver.	Presel	Gain dB	MDS	BWR	Clip dBm	P_{TOT} dBm	NPR dB
FLEX 6600M	2.3.9.43	0	0	-109	33.6	-2	-3	72

DUT	SW Ver.	Presel	ATT dB	Dither	BWR	Clip dBm	P_{TOT} dBm	NPR dB
ANAN 8000DLE	3.4.2	0	0		33.6	-6	-17	70
			20			+14	-1	68
		1	0			-5	-15	71
			20			+15	-4	60[9]

DUT	SW Ver.		ATT		MDS dBm	BWR dB	P_{TOT} dBm	NPR dB[1]
ELAD FDM-S2	FDM-SW2		0		-130	33.4	-19.5	71

DUT	SW Ver.		IF Gain					
SDR-IQ	3.32		+12dB		-103	33.6	-4.5	70
			+0dB		-100		-4.5	64
Cloud-IQ	2.3[6]				-131	33.6	-24	70
SunSDR2 Pro	1.1.0RC	1	0	1[7]	-115	33.5	-8	57
		1	1		-124		-12	65

DUT	SW Ver.		S-ATT					
Hermes Lite	3.2.27		0dB	1[5]		33.6	-30	57

Table 2a: NPR Test Results, Software Defined Radios (SDR)

	SW Ver.	Presel	ATT dB	Dither	BWR	P_{TOT} dBm	NPR dB
ANAN 7000DLE	3.4.2	0	0	0/1	33.6	-17	69
		0	20			+2	68
		1	0			-14	71
		1	20			+5	69
FLEX-1500	2.7.2	Preamp	MDS		33.6		
		0	-100			-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.

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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:

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

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:

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

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

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

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 thereceiver. 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.

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 ≈ 97 dB. Thus, the NPR of an ideal receiver with <3.3 kHz Hz IF bandwidth would also be ≈ 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.

Adam M. Farson VA7OJ/AB4OJ
North Vancouver, BC, Canada
http://www.ab4oj.com/

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.

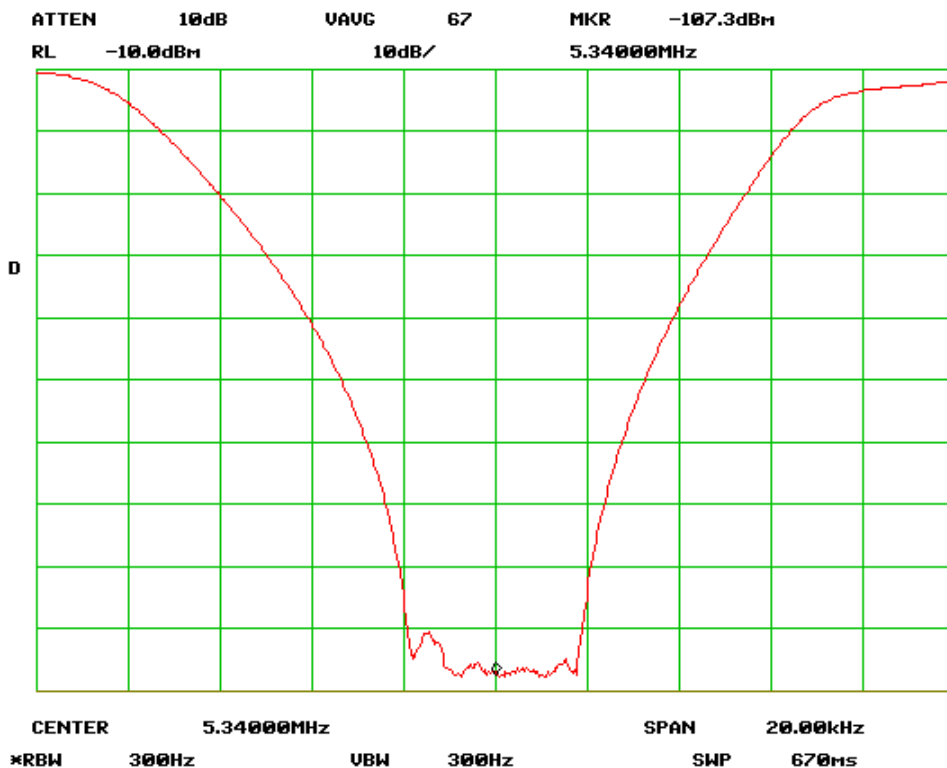| ATTEN | 10dB | VAVG | 67 | MKR | -107.3dBm |
| RL | -10.0dBm | | 10dB/ | | 5.34000MHz |

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

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

L. References:

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- 8 June 2012 (Notes on theoretical max NPR of ADC added.)
- 2 September 2012 (TS-590S and FT-950 data added to Table 1.)
- 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.)
- 11 January 2013 (NPR test results for Icom IC-7200 added to Table 1a.)
- 4 March 2013 (NPR test results for Yaesu FTDX-3000 added to Table 1a.)
- 30 March 2013 (Section B & Fig.1 updated.)
- 6 June 2013 (NPR test results for Yaesu FT-1000 added to Table 1a.)
- 26 June 2013 (NPR test results for Icom IC-7800 added.)
- 25 July 2013 (NPR test results for Yaesu FTDX-1200 added.)
- 24 August 2013 (NPR test results for IC-7100 and ANAN100D added.)
- 3 September 2013 (new Ref. 9 added.)
- 11 March 2014 (IC-718 data added to Table 1a.)
- 17 June 2014 (Section J, Equation 4 corrected.)
- 22 June 2014 (NPR test results for Flex-1500 added.)
- 19 August 2014 (NPR results for ELAD FDM-S2 added.)
- 27 September 2014 (ANAN200D data added; procedural error in Section G corrected.)
- 28 October 2014 (Flex-6700 data added.)
- 30 October 2014 (SDR-IQ data added.)
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- 12 February 2015 (Rounding error in Eq. 4 and FTDX-3000 MDS error in Table 1a corrected.)
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- 10 June 2015 (Ref. 14 & Hermes Lite data added.)
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- 14 January 2016 (RFSpace Cloud-IQ data added.)
- 3 February 2016 (SunSDR2 PRO data added.)
- 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.)
- 16 October 2017 (ANAN-8000DLE data added.)
- 3 November 2017 (Icom IC-R8600 data added.)
- 5 February 2018 (Icom IC-7610 data added.)
- 22 July 2018 (ANAN-7000DLE and Flex-6600M data added.)
- 13 June 2019 (additional W&G filters listed.)
- 17 December 2020 (IC-705 data added.)
- 17 April 2023 (FT-710 data added, Tables 2 & 2a tidied up.)