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Noise Power Ratio Testing

HF receiver performance evaluation using notched noise

(also presented at 2013 ARRL-TAPR DCC, Seattle)

Adam Farson VA7OJ

A Little History

NPR testing in the telecom industry

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- **1950's – 1980's: Telecom carriers used NPR testing to characterize multi-channel analogue FDM (frequency-division multiplex) transmission systems (coax, microwave, satellite).**
- **Notched noise-band injected at TX baseband input.**
  - **Notch filters at low-end, midband and high-end channel freqs.**
- **Receiver with corresp. channel filters at RX baseband output.**
  - **RX reads idle-channel noise (ICN) in channel filter with TX notch out & in.**
- **NPR = ratio of ICN with notch out to ICN with notch in.**
- **ITU-T specified max. NPR as end-to-end performance objective.**
- **Obsolescence when PCM replaced FDM (1970's-1980's).**
  - **NPR instrumentation now quite inexpensive on surplus market.**
- **We can now use these noise generators for HF receiver testing.**
  - **Many of the notch filters fall into LF, MF and HF broadcast & ham bands.**
  - **Typical generators: Wandel & Goltermann RS-50/RS-25, Marconi TF2091B.**

HF Receiver Impairments

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- **Intermodulation Distortion (IMD)**
  - **Odd-order IMD**
  - **Even-order IMD**
  - **IMD from multiple carriers approaches noise**
- **Reciprocal Mixing Noise**
  - **RF signal or noise mixes with LO phase noise**
- **Image Response, IF Leakage**
  - **RF signal or noise response at image freq. & IF**

IMD

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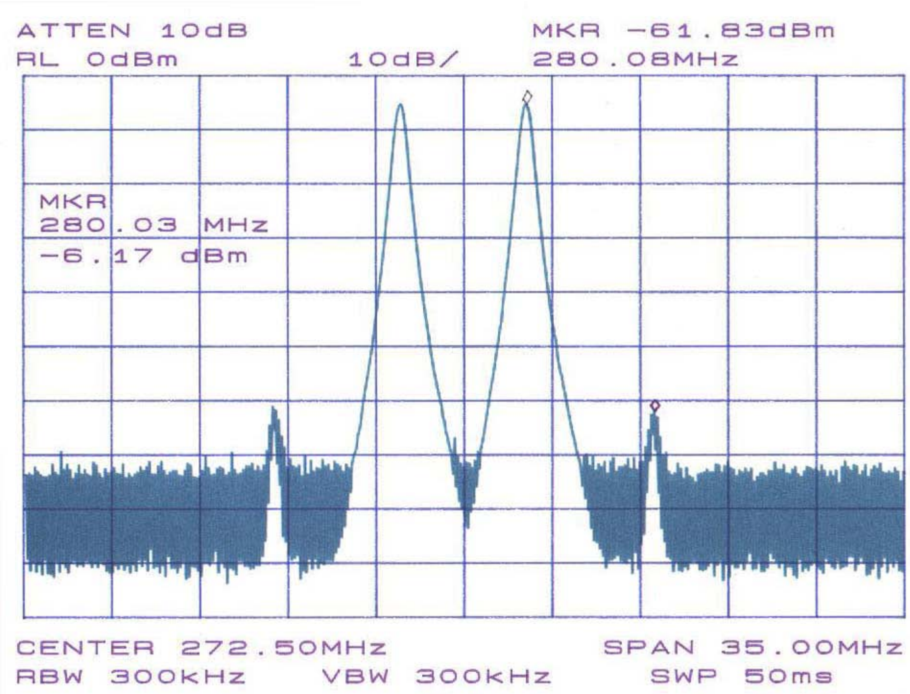
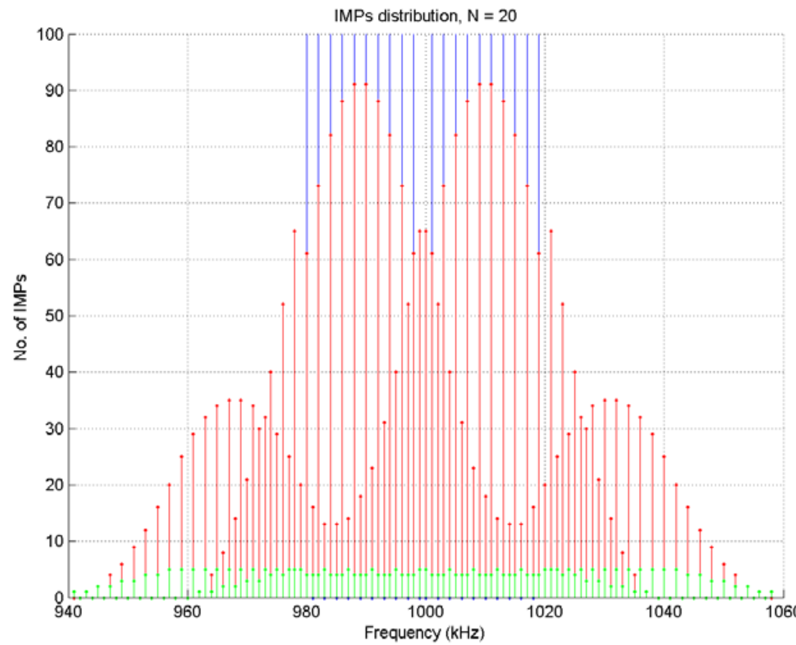
- **Odd-order IMD**
  - IMD products usually in same band as received signals f_1, f_2
  - 3^{rd}-order IMD products: $2f_1 - f_2$, $2 f_2 - f_1$
    - Example: $f_1 = 7010$ kHz, $f_2 = 7015$ kHz. Products: 7005, 7020 kHz
- **Even-order IMD**
  - IMD products not in same band as f_1, f_2.
  - 2^{nd}-order IMD product: $f_1 + f_2$
    - Example: $f_1 = 8025$ kHz, $f_2 = 6010$ kHz. Product: 14035 kHz
- **In a crowded band, multiple carriers generate a large number of IMD products**
  - Limiting case is where spectrum of IMD products approaches [Gaussian noise]

IMD Examples

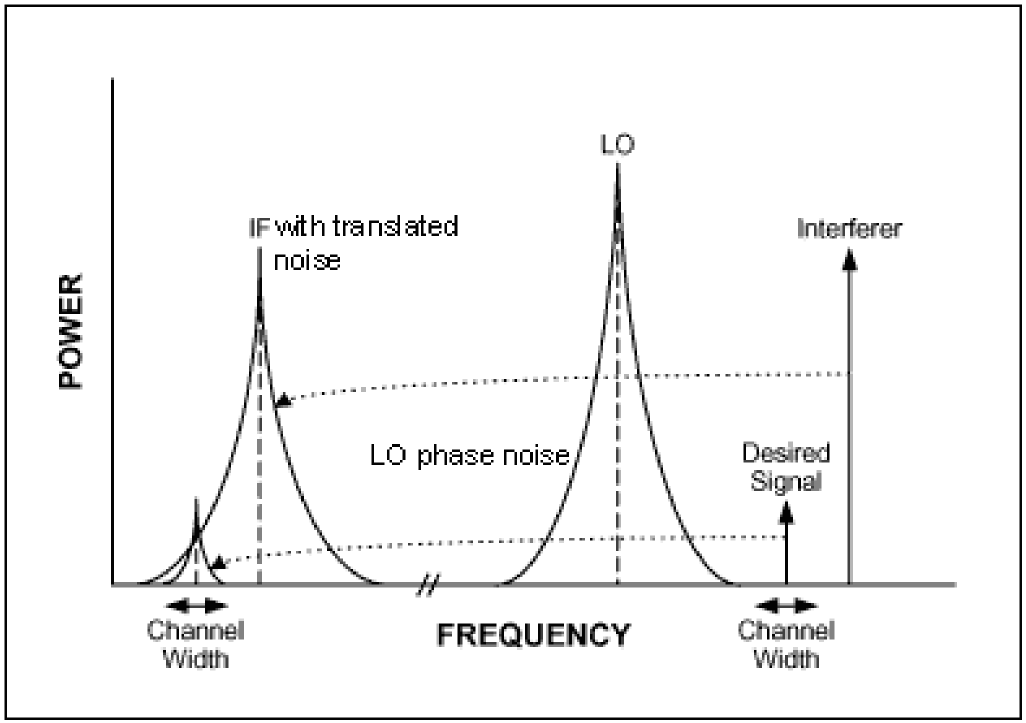


IMD Example: f_1 = 270 MHz, f_2 = 275 MHz.
IMD products at 265 and 280 MHz.



IMD from multiple carriers.
Blue: carriers. Red: Dominant IMD products.
Envelope of IMD products • Gaussian noise.

Reciprocal Mixing Noise



Strong interferer mixes with LO phase noise to “throw” noise into IF channel. If the interferer consists of wideband noise, the IF channel will be filled up with noise.

Image Response, IF Leakage

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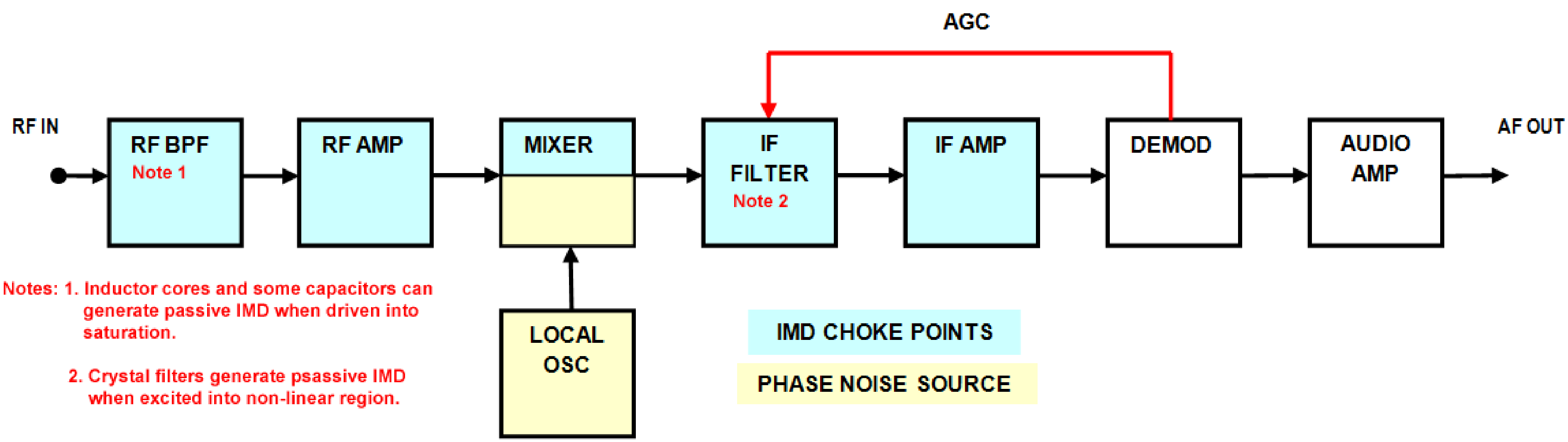
- **Image response:**
  - **Acceptance of signals at $f_0 \pm 2 * IF$ (f_0 = signal freq.)**
    - **Example: f_0 = 10455 kHz, IF = 455 kHz. Image: 10000 or 10910 kHz.**
  - **In modern receivers with high 1st IF, RF preselector suppresses image response almost completely.**
- **IF leakage:**
  - **Acceptance of signals at or close to 1st IF.**
    - **Example: 1st IF = 9 MHz. On 30m band, preselector may be sufficiently wide to pass some energy at 9 MHz. This will enter the IF chain and interfere with desired signals.**
  - **This is not a problem in receivers whose 1st IF is above the highest operating frequency.**

Typical Superhet Receiver
showing impairment areas

Simplified block diagram of superhet receiver



- Wideband noise applied to RF IN will provoke IMD products at IMD choke points, and mix with LO phase noise to cause reciprocal mixing noise.
    - Steering diodes in RF/IF signal paths can also generate IMD.
- Passive IMD can occur in RF BPF components and crystal or mechanical filters.
- In addition to IMD and phase noise, image responses and IF leakage can arise if RF BPF is too wide to attenuate undesired signals at image frequency and IF.
- All these products will appear in IF/AF chain as added noise.

Principle of NPR Test

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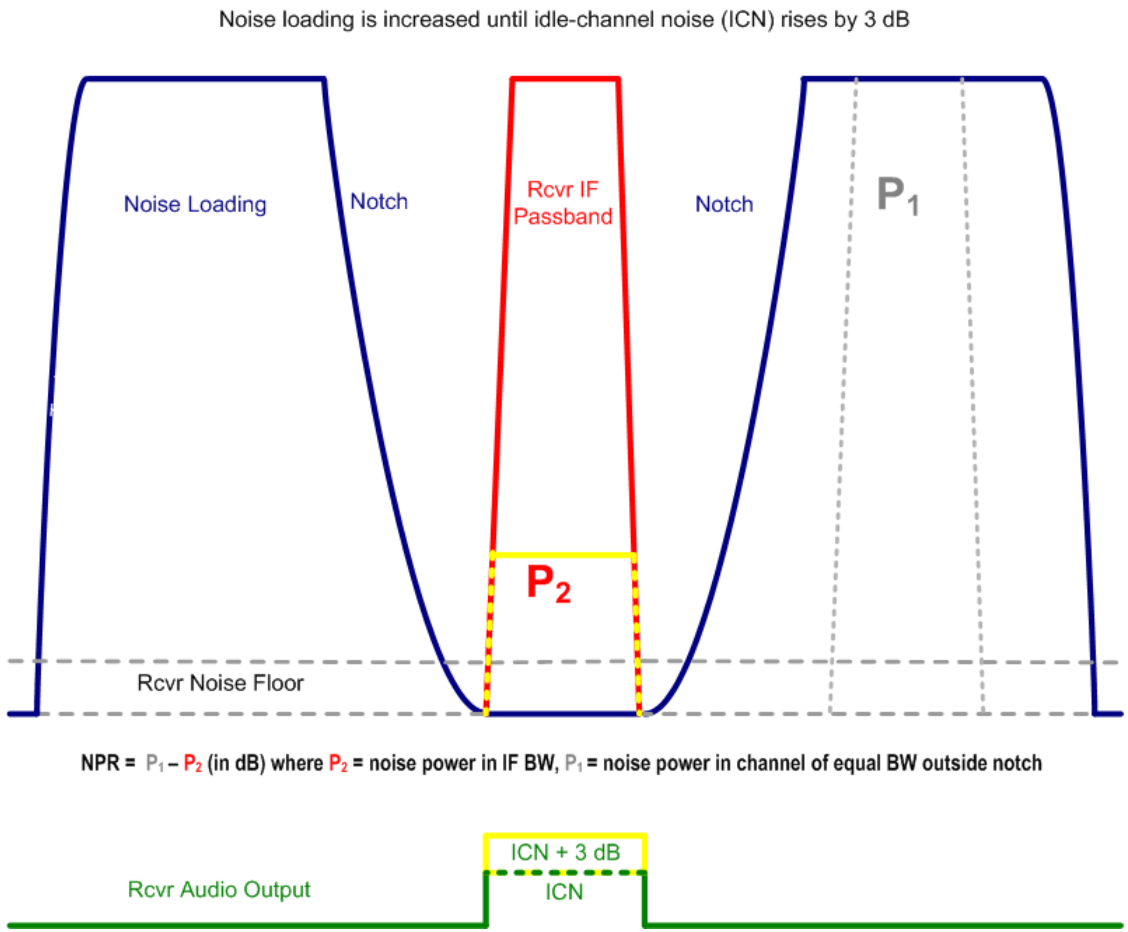
- Wideband Gaussian noise from a noise generator is applied to the receiver input. This *noise loading* provokes added noise in the receiver as described above.
- Added noise power is a measure of overall receiver performance.
  - Less added noise = better receiver. *A perfect receiver will add no noise at all.*
- We can measure added noise power by creating an *idle channel* (a channel as free of noise as possible) in our applied noise band.
  - This is done by placing a deep notch (bandstop) filter just wider than the receiver's IF filter at the noise generator output.
  - The receiver is tuned to place the IF passband in the centre of the notch.
  - A band-limiting (bandpass) filter ahead of the notch filter defines the applied noise bandwidth.
  - Ideally, only the added noise generated by the receiver's impairments will appear in the notch. This noise is termed *idle-channel noise (ICN).*
- NPR = noise power in a channel equal in bandwidth to the idle channel, but outside the notch ÷ noise power in the idle channel.

Graphical Example of NPR Test



Limitations of narrowband tests

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- 2-tone IMD test produces measurable 2nd- and 3rd-order IMD.
  - 2-tone test does not apply sufficient signal power to provoke passive IMD.
- Offset single-tone test generates reciprocal mixing noise.
- Such narrowband tests do not accurately reflect weak-signal performance degradation due to multiple strong signals and the numerous undesired products they generate.
- A given receiver may have excellent narrowband "numbers", yet may miss a weak signal on a crowded band.
  - The NPR test method emulates a band filled with many strong signals by loading the receiver with white noise. Thus, all possible combinations of carrier frequency spacing are taken into account – a true worst-case test.
- One can "zero in" on potential trouble spots by comparing NPR readings for various configurations such as RF amplifier in/out, different IF filters, different preselectors etc.
  - Narrowband tests alone do not give a true picture.

Optimum Noise Loading
and derivation of NPR value

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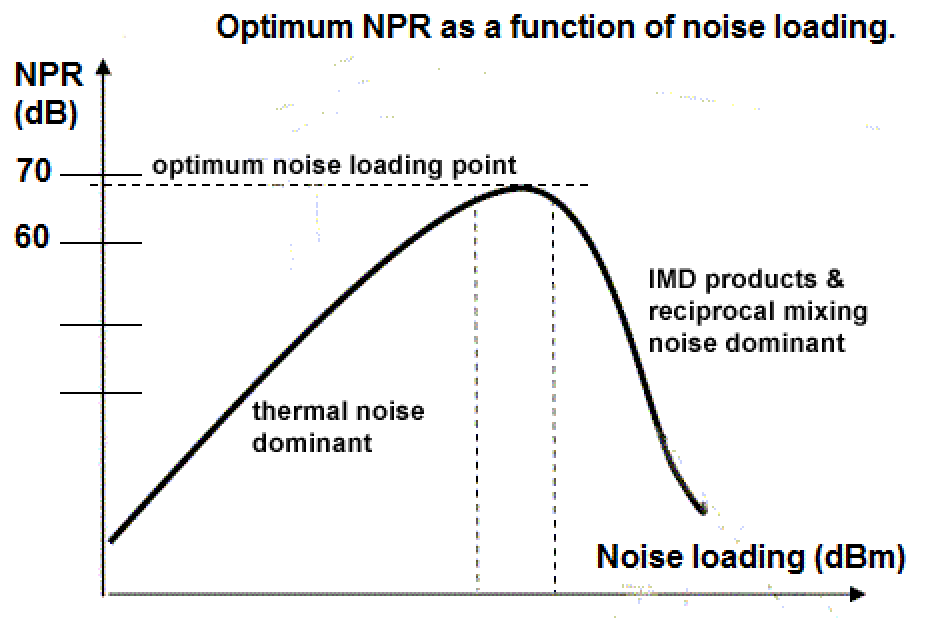
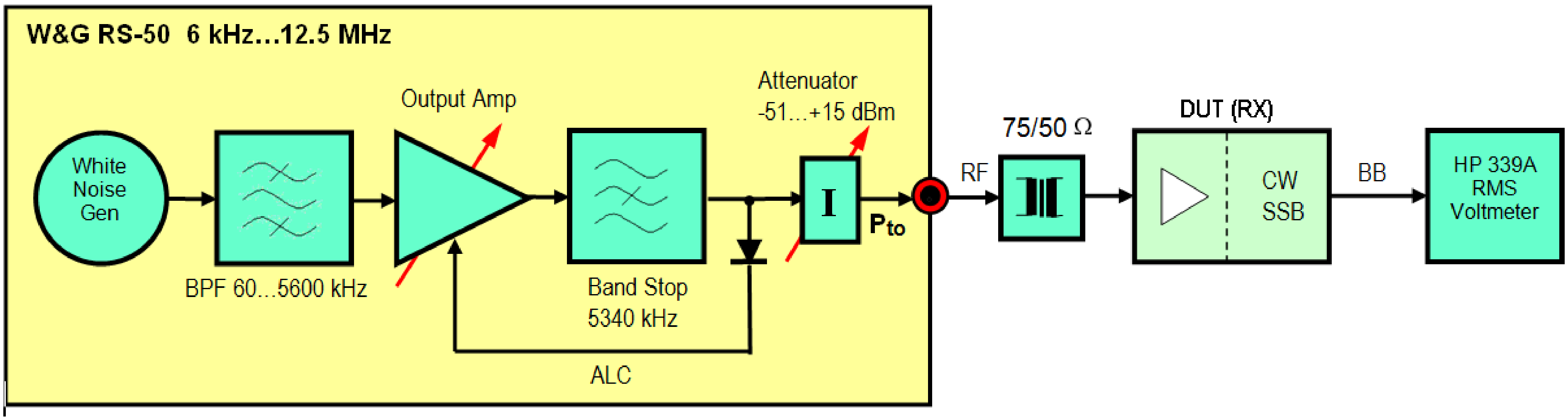


- **Peak of curve is *optimum noise loading level* , determined by increasing noise generator output until noise level at receiver AF OUT increases by 3 dB over level with noise generator switched off.**
- **Total noise power P_{TOT} at this point (in dBm) is read directly off attenuator on noise generator.**

NPR Measuring Setup



Noise Power Ratio (NPR) Measuring Setup

- The 75/50• transformer matches the 75• output of the Wandel & Goltermann noise generator (RS-50 or RS-25) to the 50• DUT input.
- The generators are fitted with bandpass/bandstop filter pairs for the LW/MW broadcast bands, and for the 160, 80, 60 and 40 metre amateur bands.
- Usually, the bandpass filter matching the bandstop filter is selected, e.g. 60-5600 kHz/5340 kHz.
- Typically the bandstop filters have 95 dB stopband attenuation, and 3.3 kHz stopband width at the bottom of the notch.

List of Standard Filters
suitable for LF/MF/HF receiver testing

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Band Limiting kHz[1,2]	Bandstop kHz[3]	Band	Usage
12-252	240	LF	LWBC
12-552	534	MF	MWBC, 600m
60-1296	1248	MF	MWBC
60-2048	1940	160m	Amateur
60-4100	3886	80m	“
60-5600	5340	60m	“
316-8160	7600	40m	“
316-12360	11700	~ 30m	“
316-17300	13677	~ 20m	“

Notes: 1. W&G uses BPF’s; Marconi uses separate LPF’s and HPF’s.

2. A wider band limiting filter may be selected than the one shown for a given bandstop filter.

3. All filters are on ITU-T standard FDM baseband and channel frequencies.

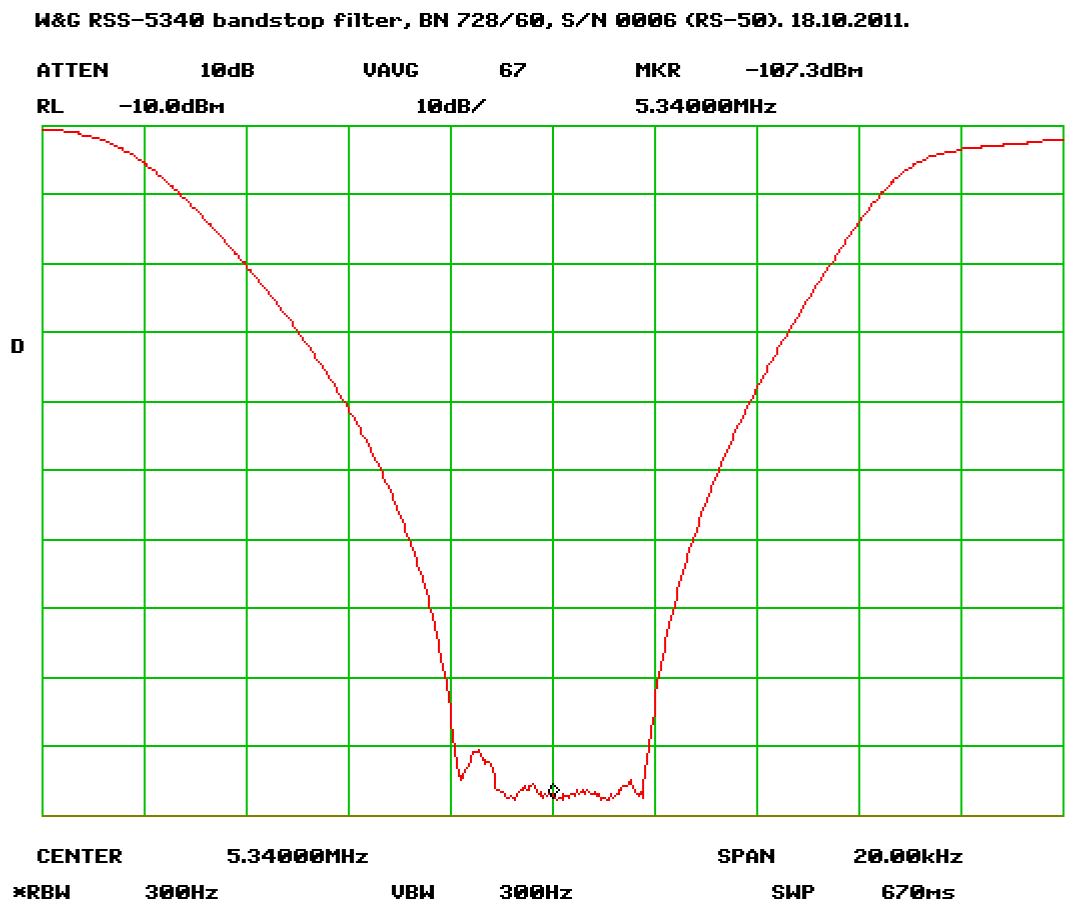
Noise Generator Output Spectrum

60-1296 kHz BPF, 534 & 1248 kHz notches

5340 kHz Bandstop Filter Response

- • - •   - - • -   - • •   •   • • • -   •   - - • • •   - •   • • •   • - •

The bottom of the notch must be below the DUT noise floor to ensure that the applied noise does not degrade measurement accuracy.



W&G RS-50 Noise Generator

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Attenuator and mode selector **Band limiting (bandpass) filters**

Bandstop (notch) filters

Derivation of NPR Value

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- **NPR for a given noise bandwidth is the defined as the ratio of the noise power in the notched band to the power in an equal bandwidth adjacent to the notch.**
    - **I2VGO has shown that for a given noise bandwidth, and at the optimum noise loading level,**

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

where P_{TOT} = total noise power in dBm in the noise bandwidth B_{RF} for a 3 dB increase in noise at the DUT audio output

$BWR = 10 \log_{10} (B_{RF}/B_{IF})$

B_{RF} = RF bandwidth or noise bandwidth in Hz (band-limiting filter BW – 3000*)

B_{IF} = receiver IF filter bandwidth in Hz

MDS = minimum discernible signal (in dBm, specified at B_{IF}).

MDS should be measured in 2.4 kHz SSB mode at each of the notch frequencies in use, and recorded.

**** BW at bottom of notch = 3 kHz***

- **Go to Slide 19**

NPR Measurement Procedure
(analogue & DSP receivers)

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1. **Initial receiver configuration:**
   - **2.4 kHz USB or LSB; Sharp filter shape factor (if applicable)**
   - **Roofing filter 6 kHz (if applicable)**
   - **RF Gain at maximum; AGC SLOW or MID**
   - **NR, NB, ATT, Preamp off; Preselector on**
2. **Tune receiver to place IF passband in centre of notch.**
3. **Noise source off. Adjust AF Gain for -3 dB on RMS voltmeter.**
4. **Noise source on. Adjust noise gen. attenuator for 0 dB on RMS voltmeter. Record attenuator setting = P_{TOT}.**
5. **Calculate NPR using Equation 1 (Slide 18).**
6. **Repeat test with different combinations of preselector, roofing filter and preamp; record results.**
   - **Take each reading 2 – 3 times and average for highest accuracy.**

NPR Measurement Procedure
(direct-sampling SDR receivers)

1. **Initial receiver configuration:**
   - **2.4 kHz USB or LSB; Sharp filter shape factor (if applicable).**
   - **RF Gain at maximum; AGC SLOW or MID.**
   - **NR, NB, ATT, Preamp, Dither off; Preselector on.**
2. **Tune receiver to place IF passband in centre of notch.**
3. **Noise source off.**
   - **Record signal power P_0 in dBm on S-meter or spectrum scope. *(P_0 = MDS)***
4. **Noise source on. Adjust attenuator until ADC just clips, then back off until no clipping is observed over • 10 sec.**
   - **Record attenuator setting = P_{TOT} and signal power P_1 in dBm on S-meter or spectrum scope.**
5. **Tune receiver well away from notch. Record signal power P_2 in dBm on S-meter or spectrum scope. NPR = $(P_1 – P_2)$ dB.**
6. **Repeat test with different combinations of preselector, dither and preamp; record results.**
   - **Take each reading 2 – 3 times and average for highest accuracy.**

Typical NPR Test Data:
analogue/DSP receiver (Kenwood TS-590)

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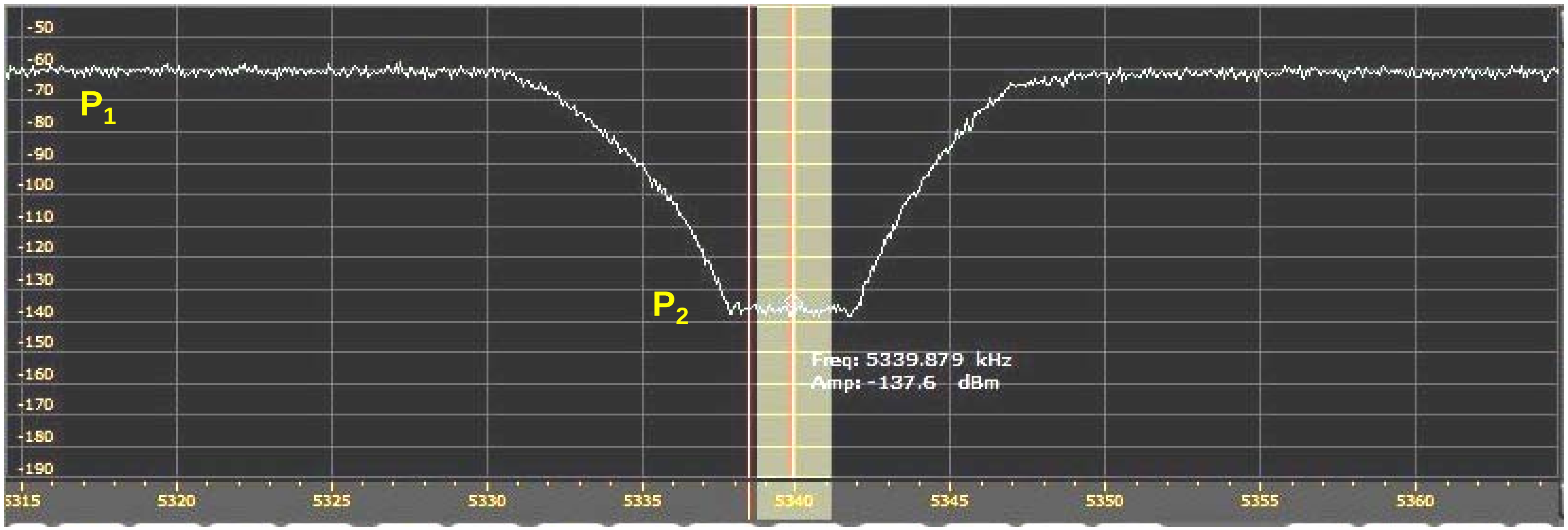
Notch Freq. f_0 kHz	NPR dB		1st IF
Preamp:	Off	On	
1940	82	83	Inband
3886	81.5	81	Inband
5340	76	74	High
7600	78.5	78	High

Kenwood TS-590 NPR Test Results

- **The difference in NPR between the inband (11.374 MHz) and high (73.045 MHz) 1st IF cases is in the range 3.5 – 9 dB.**
- **The difference in NPR readings can be accounted for by considering passive IMD in the 1st IF filter, and reciprocal mixing, as contributors to the idle-channel noise. Both these impairments will be more severe when the high 1st IF is active.**

Typical NPR Test Data:
direct-sampling SDR receiver (Perseus)



Perseus NPR Test Results

- **NPR = 73 dB, Preselector on, Dither on, Preamp on**
- **Measured NPR is very close to <u>theoretical value</u>***
- **60m filter pair: 5340 kHz Bandstop, 60-5600 kHz Bandpass**

Refer to Section J, p.8 of Web article

NPR Testing as Diagnostic Tool: *a case study*

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Poor NPR led us to check LO spectral purity

DUT	Notch kHz	BPF kHz	NPR dB	Figure
JRC NRD-525	534	12-552	73	
"	5340	12-10164	72	
JRC NRD-545	534	12-552	57	1
"	5340	12-10164	68	2
Preselector in, preamp out for all test cases.				

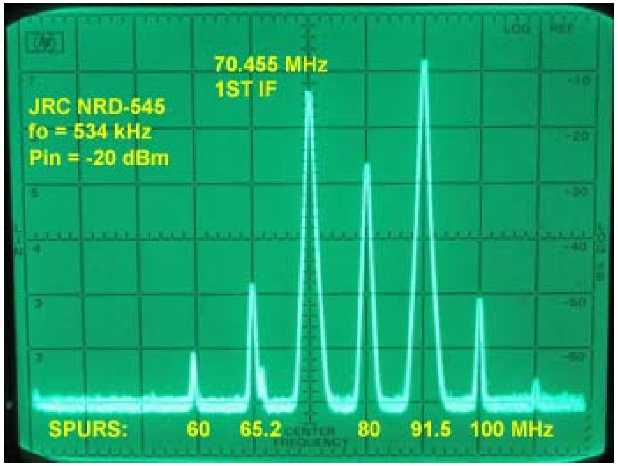

Fig.1: LO spurs degrade NPR.

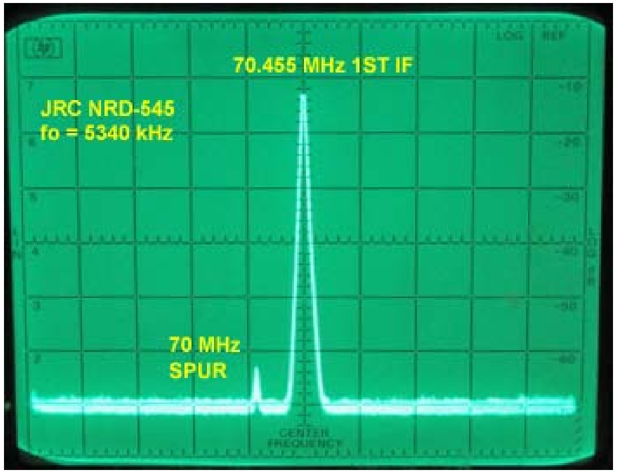

Fig.2: One minor LO spur. NPR is OK.

References for further study

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