Receivers and Receiver Specifications

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Goals for the Session

- What do receiver specifications mean?
- What do they mean to me?
- What receiver tradeoffs should I make when selecting radio?
- Does more expensive mean better?
- Help make a better decision on how to spend your hard earned dollar or the money your spouse gives you as an allowance.
What are we going to cover?

- Not features – Features are things like dual receivers, 100 watts versus 10 watts, LCD display, number of knobs, RTTY or FT8 capability, number of bands, etc.

- Not transmitters – Transmitters are relatively simple. Power output and the modulation type, in some cases spurious emission but for the most part transmitters are the same.

- Receivers are the complicated area due to the number of factors affecting performance.
Receiver specifications

- Tradeoffs
  - Broad versus narrow frequency coverage
  - Noise floor
  - Receiver IF bandwidth (or equivalent thereof)
  - Audio distortion
  - Ability to operate in a high RF level environment
  - Spurious responses
  - Artifacts
  - Size
  - Cost
Typical Receiver Block Diagram

- Receivers may have more IF stages and the IF frequencies can vary.
- They may use “real” filters or they may use Digital Signal Processing (DSP) filters or both.
- There may or may not be an RF amplifier.
Receiver Noise Floor

- The bandwidth determines the minimum noise floor, both theoretical and actual
- Bandwidth and noise floor are proportional
  - 2X bandwidth increases noise 3 dB
  - 10x bandwidth increases noise 10 dB

<table>
<thead>
<tr>
<th>Bandwidth</th>
<th>Thermal noise power</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Hz</td>
<td>-174 dBm</td>
</tr>
<tr>
<td>10 Hz</td>
<td>-164 dBm</td>
</tr>
<tr>
<td>100 Hz</td>
<td>-154 dBm</td>
</tr>
<tr>
<td>1 kHz</td>
<td>-144 dBm</td>
</tr>
<tr>
<td>10 kHz</td>
<td>-134 dBm</td>
</tr>
<tr>
<td>15 kHz</td>
<td>-132.24 dBm</td>
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<tr>
<td>100 kHz</td>
<td>-124 dBm</td>
</tr>
<tr>
<td>200 kHz</td>
<td>-121 dBm</td>
</tr>
<tr>
<td>1 MHz</td>
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<tr>
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<tr>
<td>3.84 MHz</td>
<td>-108 dBm</td>
</tr>
<tr>
<td>6 MHz</td>
<td>-106 dBm</td>
</tr>
<tr>
<td>20 MHz</td>
<td>-101 dBm</td>
</tr>
<tr>
<td>40 MHz</td>
<td>-98 dBm</td>
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<tr>
<td>80 MHz</td>
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</tr>
<tr>
<td>160 MHz</td>
<td>-92 dBm</td>
</tr>
<tr>
<td>1 GHz</td>
<td>-84 dBm</td>
</tr>
</tbody>
</table>

Notes:
- FM channel of 2-way radio
- One LTE subcarrier
- One LTE resource block
- GSM channel
- Bluetooth channel
- Commercial GPS channel
- UMTS channel
- Analog television channel
- WLAN 802.11 channel
- WLAN 802.11n 40 MHz channel
- WLAN 802.11ac 80 MHz channel
- WLAN 802.11ac 160 MHz channel
- UWB channel
Minimum Detectable Signal

- Indirect measurement of the receiver noise floor
- Must be measured at a reference bandwidth. ARRL uses 500 Hz for HF receivers and 3 dB above the noise with an unmodulated carrier
- Different modulations may have different results
Noise Figure

- Often not specified for receivers but may be specified for amplifiers
- Amount of noise the receiver adds above the thermal noise
- Receiver noise figure is basically determined by the noise figure of the first amplifier so noise figure will change with a pre-amp in or out.
Noise Figure

- ARRL uses the minimum detectable signal to determine the noise figure

- Examples
  - Thermal Noise @ 500 Hz = -147 dBm
  - HF Receivers @ 14 MHz
    - #1 = Preamp off 28 dB, Preamp on 19 dB
    - #2 = Preamp off 16 dB, Preamp on 8 dB
  - Which one has the lowest noise floor?
Things to Remember

- The best a receiver can be is the thermal noise plus the noise figure at the desired bandwidth.
- Why is there a preamp on and off switch? Low noise amplifiers generally do not handle high level signals resulting in receiver intermodulation.
- Higher cost may not mean a lower noise figure.
- Unless you have a very quiet location, lower noise figure may not be required.
Sensitivity

- Sensitivity is relative to noise floor but is measured for some modulation type at a reference distortion and bandwidth
  - CW usually considered at the MDS
  - AM @ 10 dB (S+N)/N (30% modulation)
  - FM @ 12 dB S+N+AD (Signal+Noise+Audio Distortion)(SINAD)
  - Digital @ specified BER typically 5% maximum 3% typical

- HF Receivers AM sensitivity @ 29 MHz
  - #1 Preamp off 9 uV Preamp on 1 uV
  - #2 Preamp off 1.3 uV Preamp on 0.4 uV

- VHF Receiver @ 12 dB SINAD
  - #1 0.16 uV
  - #2 0.21 uV
Selectivity

- Selectivity generally refers to close in signals. However, overall receiver front end selectivity does affect receiver performance.
- Selectivity affects the MDS, narrower = less noise
- Filter bandwidth is usually measured at the 3 dB down point. However, ARRL uses 6 dB
- FM receiver specifications are often in “adjacent” channel bandwidth. What is adjacent channel?
  - It depends, one has to read the fine print. Possibilities are: 12.5 kHz, 15 kHz, 20 kHz, 25 kHz, and 30 kHz
Selectivity

- IF filters do make a difference

AFM ±2.5 ACP with TIA Butterworth Filter

- 48.1 dB ACPR
- 10.000 kHz ENBW
- 0.500 kHz Offset

AFM ±2.5 ACP with TIA Butterworth Filter

- 70.8 dB ACPR
- 6.000 kHz ENBW
- -12.500 kHz Offset
Selectivity

- **IF Rejection** - Signals on the IF frequencies
  - First IF frequency is most likely to be a problem

- **Image Rejection** - Signals on the “other” output of the mixer
  - Can be a problem in a high signal environment

- **Out of Band (OOB) selectivity** not measured but can have an effect. Use Intermod test results to get an indication of OOB performance
Selectivity

- Selectivity must match the modulation type for best performance. Too little selectivity allows more noise and interference, too much blocks some of the signal
  - CW selectivity can be narrow around 500 Hz but too narrow and filters may exhibit some artifacts (ringing)
  - SSB should match the communications quality voice frequency energy around 2.2 kHz
  - AM needs both side bands so around 5 kHz
  - FM depends on modulation 5 kHz modulation needs around 10 kHz
Selectivity

- IF Rejection is the ability to reject signals coming in at the IF frequencies. Normally, 1st IF is the most likely to have a problem.
- Not normally a problem for VHF and higher receivers due to front end filters.
- HF IF frequencies can be 11.374 MHz, 73.095 MHz, 69.0115 MHz, or others.
- Newer DSP receivers can directly sample the RF spectrum, IF stages are all in software.
Selectivity

- Image rejection can be a problem in some receivers

What is the image frequency?
- Example: VHF Receiver, IF = 10.7 MHz
  - Desired frequency is 146.52 MHz
  - Local Oscillator is 146.52 + 10.7 = 157.22
  - Image frequency is 157.22 + 10.7 = 167.92
  - 167.92 MHz is in the Federal Government LMR band
Things to Remember

- More selectivity is generally good but must match the modulation type. Too narrow a filter will result in distorted modulation.
- Cost does not define selectivity as with many specifications.
- IF signal interference is not usually a problem but can be.
- Intermodulation response can make a receiver seem less selective.
Intermodulation and Blocking

- Amplifiers are not 100% linear and have an upper signal limit
Intermodulation and Blocking

- Non-linear operation in amplifiers causes additional signals to be created.
Intermodulation and Blocking

- Non-linear operation also defines the maximum signal that can be amplified. The amplifiers will eventually go into compression. The standard is the 1 dB compression point.
- Strong signal other than desired signal may cause amplifier to go into compression resulting in loss of linearity and gain.
- This also causes distortion and intermodulation
Intermodulation

- IP3 (3rd Order Intermodulation Point) is a measure of the ability to handle strong signals without generating intermodulation.
- Higher is generally better but higher IP3 amplifiers are generally noisier.
- HF is usually measured with two signals 20 kHz apart.
- VHF/UHF are measured with two signals 20 kHz and 10 MHz.
Intermodulation and Blocking

- Test results typically are:
  - HF
    - Rcvr #1: Blocking 128 dB, IMD 100 dB, IP3 +36 dBm
    - Rcvr #2: Blocking 111 dB, IMD 94 dB, IP3 +17.3 dBm
  - VHF
    - Rcvr #1: IMD 20 kHz 68 dB, 10 MHz 86 dB, Adj 74 dB
    - Rcvr #2: IMD 20 kHz 69 dB, 10 MHz 103 dB, Adj 78 dB

- In both of these cases the more expensive receiver performed better
Almost Final Thoughts

- Receiver specifications are a balance of needs. A more sensitive receiver may not handle large signals very well.
- Determine what you really want or need for receiver performance. If you live in an urban area with a high noise floor and strong signals, having the most sensitive receiver may be counter productive. IMD performance may be more important.
- 10 MHz intermodulation performance is critical in VHF/UHF radios operating in urban areas. In general, low cost radios do not have adequate IMD performance. Since the IMD response is non-linear even a few dB better performance will make a difference.
Next to Final Thoughts

- In reality, a more balanced system may be less frustrating.
- For example, an Elecraft KX3 portable HF radio has a receiver sensitivity of 0.9 uV without the pre-amp. There are other receivers with better sensitivity but if you have a very sensitive QRP rig receiver, you can hear things you most likely cannot work.
- Sometimes the most expensive rigs may have lots of features but lower performance specifications in some areas.
- DSP based receivers often respond differently than do more traditional receivers when experiencing high signal levels. Not a bad thing but may be different than one is expecting.
Final Thoughts

- Be realistic in what you want. Better noise blanking performance may be a good tradeoff for sensitivity.
- Don’t buy a rig because someone else says it works great for them without comparing specifications for yourself. They may be in a different operating environment.
- Don’t spend more money than your spouse has allocated to get marginal performance improvements. The local QRN probably isn’t worth it!
Questions

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