Receiver

Performance – What's Possible?
+
Performance – What's Needed?

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How to optimize what you currently own

What is important in a DX pile-up environment?

- We need Good Dynamic Range to hear weak signals in the presence of near-by strong signals.
- For the DXpedition, it's like a contest crammed within a few kHz !
  - CW signals "Up 2" or SSB signals "Up 5"
- You need a better receiver for CW than for SSB.
- **How does published test data relate to reception of weak signals?**

State-of-the-Art in Dynamic Range today

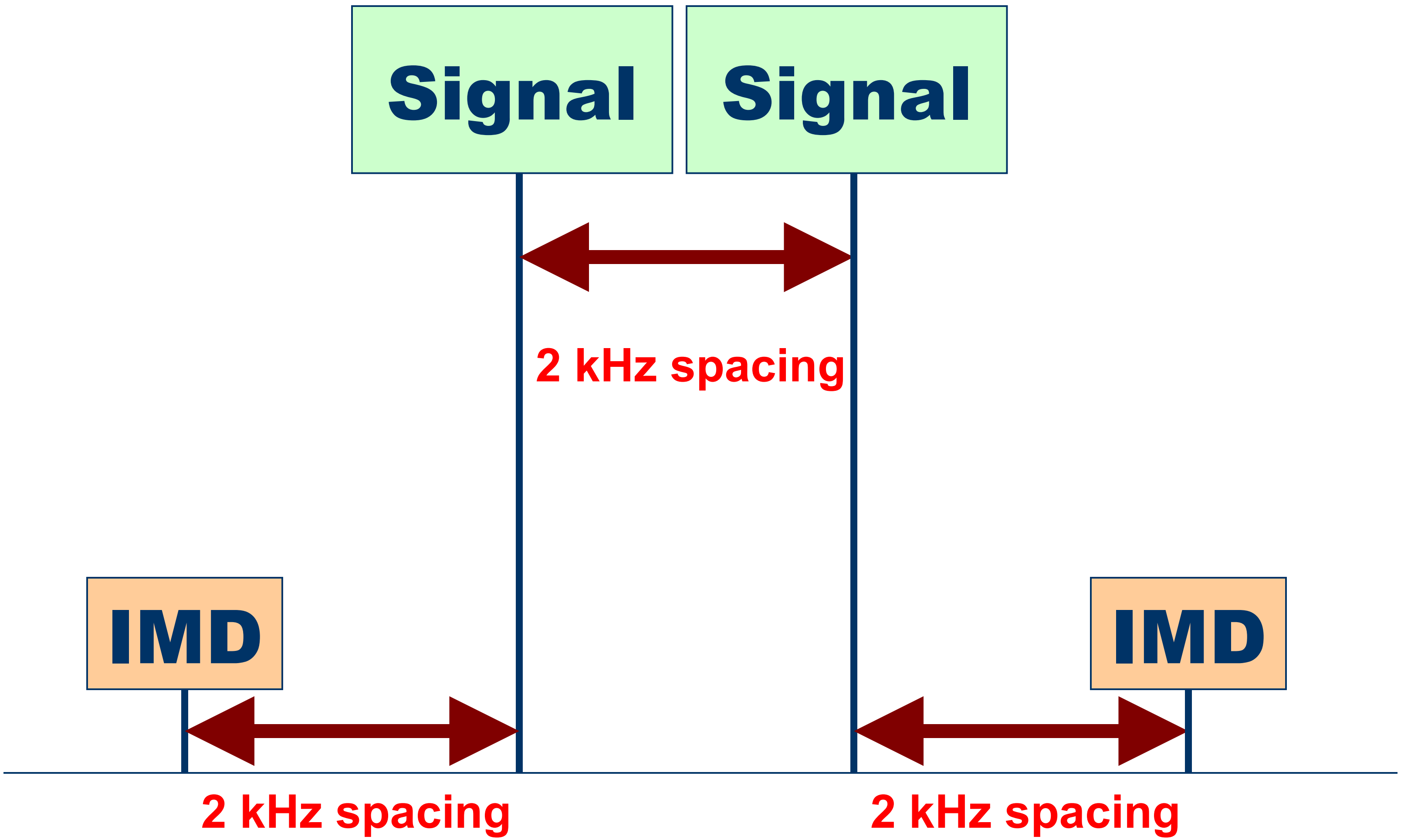
- Close-in dynamic range (DR3) > 100 dB
- Phase noise @ 10 kHz ≤ -145 dBc / Hz
- Reciprocal Mixing (RMDR) > 115 dB

- Rigs with this kind of performance:
- Icom IC-7851, Flex 6700 & Elecraft K3S
- Apache ANAN-8000DLE

What does dynamic range mean?

- Two equal signals are fed into the receiver.
- Measure third-order IMD product.
- Level adjusted until distortion = noise floor
- This level vs. the noise floor = dynamic range
- Defined in QST & *hr magazine* 1975
- Example: level = -35 dBm, NF = -135 dBm
- Dynamic Range (DR3) = 100 dB
- Note: -35 dBm = S9 +38 dB
- Note: K3S noise floor = -135 dBm preamp OFF

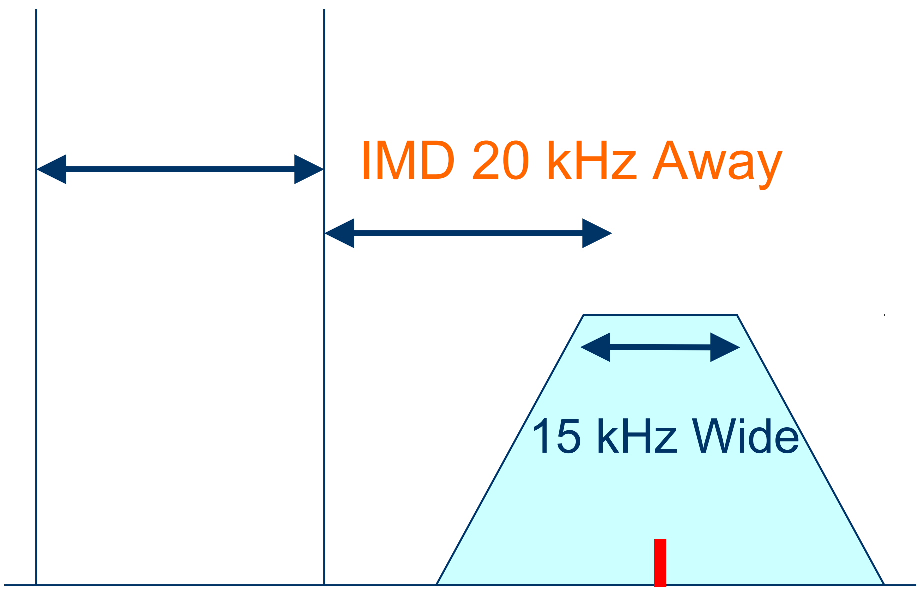
Third Order IMD to Measure Dynamic Range



Up-conversion radio, single wide roofing filter only

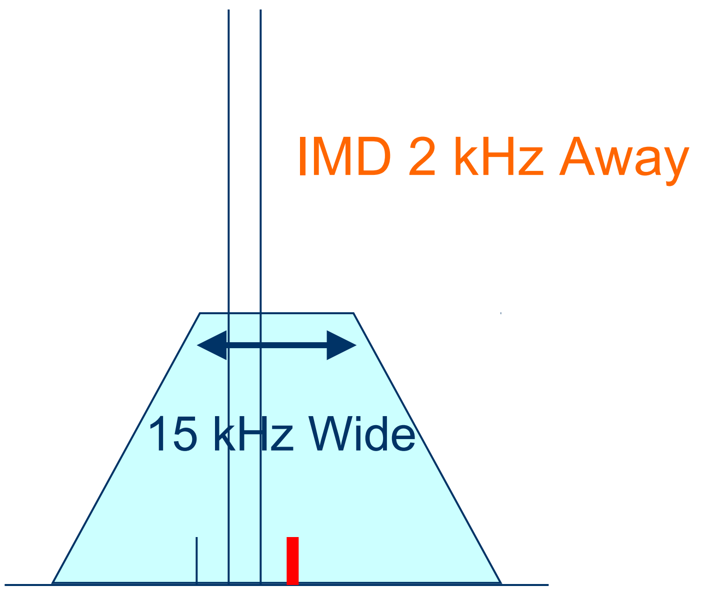
Wide & Close Dynamic Range

20 kHz Spacing



First IF Filter at 70.455 MHz

2 kHz Spacing

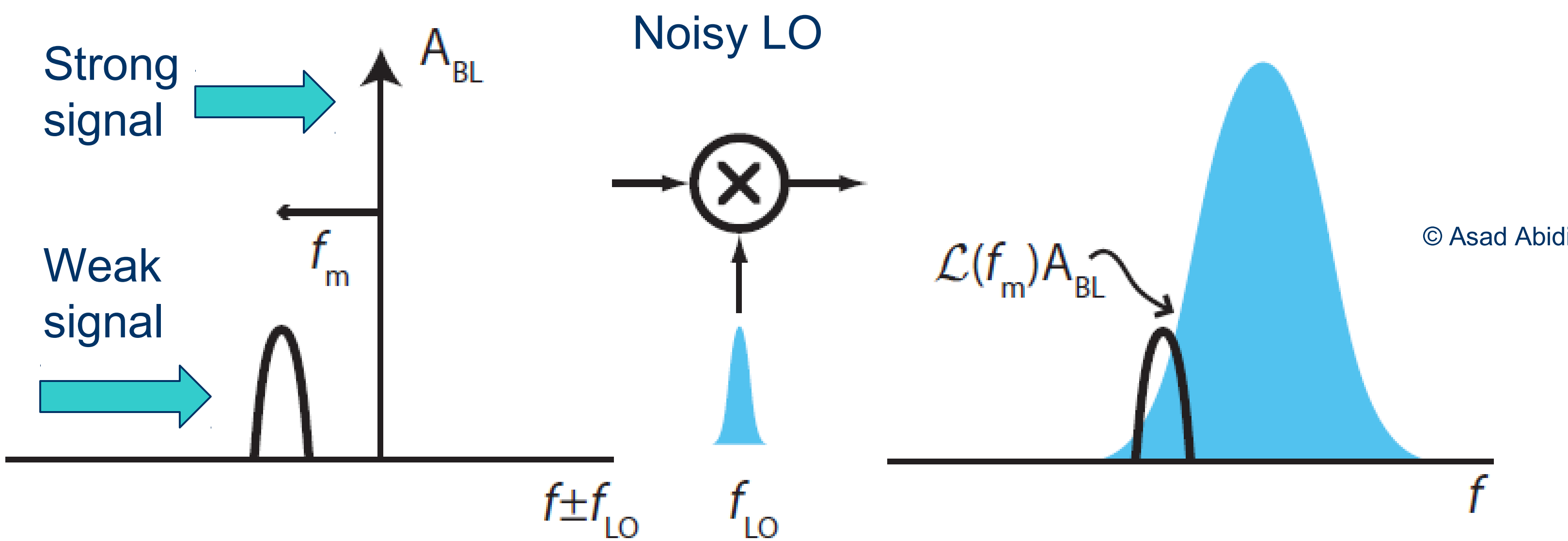


First IF Filter at 70.455 MHz

A note on phase noise / RMDR

- Reciprocal Mixing Dynamic Range (RMDR)
- Only since late in 2013 has the ARRL consistently emphasized the importance of good phase noise performance (RMDR).
- Read Bob Allison's sidebar April 2012 QST & his latest update May 2016 QST for details.

Reciprocal mixing puts LO noise on top of weak signal



Noisy local oscillator (LO) transfers its noise to the strong out-of-passband signal and on top of the weak signal we are trying to copy.

RMDR often dominates over DR3

- Only a few “legacy” superheterodyne transceivers, plus direct-sampling SDR radios have RMDR > DR3.

- Elecraft K3 w/ new synthesizer, K3S or KX3
- Hilberling PT-8000A
- Icom IC-7851 & IC-7300
- Flex 6700, 6500 & 6300
- Apache ANAN-200D & 8000DLE

What do these numbers mean?

- Typical receiver, preamp OFF
- Noise floor = -128 dBm
- “Holy grail” 100 dB DR3 radio (@ 2kHz)
- Can handle signals -28 dBm = S9 +45 dB
- Note: That is above the receiver’s noise floor
- How does that relate to band noise?
- Will get to that in a moment.

Luckily we can live with 85 dB radios

- What performance is usually good enough?
- From the advent of “up-conversion” radios around 1979 (TR-7) until 2003 with the Orion I, all we had were 70 dB DR3 radios at 2 kHz.
- These were barely adequate on SSB and not acceptable on CW in DX pile-ups or contests.
- If we operate our 85 to 90 dB radios properly, they perform well in most environments.
- Most of the time our radios are not stressed to their limits.

Close-in 2-kHz Test @ 500 Hz BW

Dynamic Range of Top 14 Transceivers on Sherwood website

Elecraft K3S	106 dB	
Icom 7851	105 dB	
Hilberling	105 dB	
Elecraft KX3	104 dB	(Opposite sideband limited)
FTdx-5000D	101 dB	
Flex 6700	99 dB	(preamp OFF)
Apache 200D	99 dB	(New clock update)
Flex 5000	96 dB	
Elecraft K3	95 dB	(original synthesizer)
Orion II	95 dB	
Icom 7300	94 dB	(81 dB with IP+ OFF)
Orion I	93 dB	
TS-590SG	92 dB	
TT Eagle	90 dB	

Why is higher DR3 needed on CW?

- Transmitted bandwidth of an adjacent strong signal may be the limit, not receiver overload.

- A CW signal is about 1 kHz wide at -60 dB.
- An SSB signal is about 10 kHz wide at -60 dB.

- A CW pile-up may overload your receiver.
- On SSB, splatter will likely dominate before the receiver dynamic range is exceeded.

What is the Bandwidth of a CW Signal?

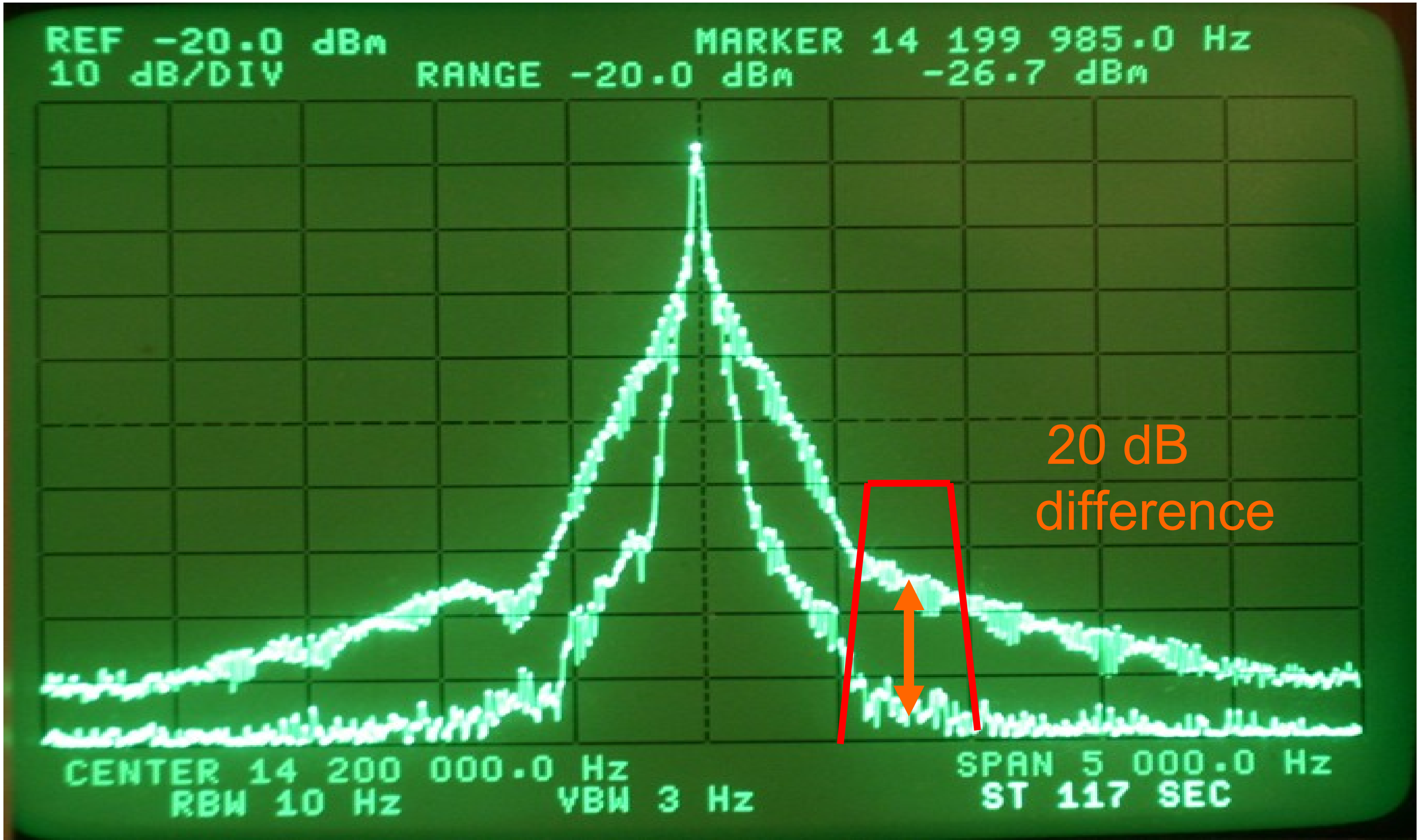
On-channel signal = S9 + 40 dB (-33 dBm)
Receiver = K3, 400 Hz 8-pole roofing + 400 Hz DSP Filter
Transmitter = Omni-VII with adjustable rise time
Undesired signal 700 Hz away, continuous "dits" at 30 wpm

Rise time of Omni-VII	Strength of CW sidebands		
Signal	S9 + 40	-33 dBm	Ref
3 msec	S7	-83 dBm	-50 dB
4 msec	S6	-88 dBm	
5 msec	S6	-88 dBm	
6 msec	S5	-93 dBm	22 dB !
7 msec	S4	-99 dBm	
8 msec	S4	-99 dBm	
9 msec	S4	-99 dBm	
10 msec	S3	-105 dBm	-72 dB

Many rigs are much faster than 3 msec

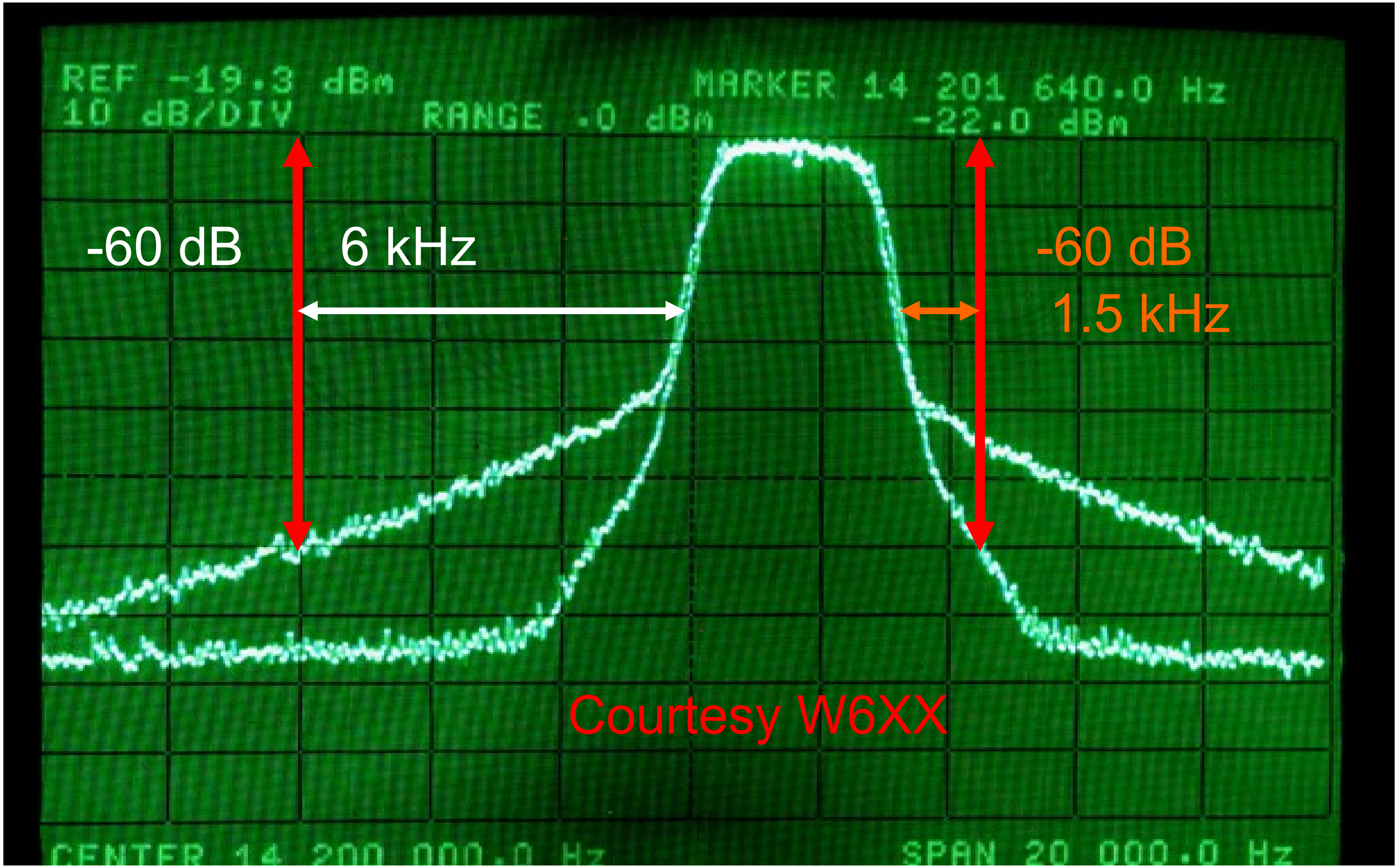
Spectrum of CW Signal on HP 3585A Analyzer

Comparison of 3 msec vs 10 msec rise time



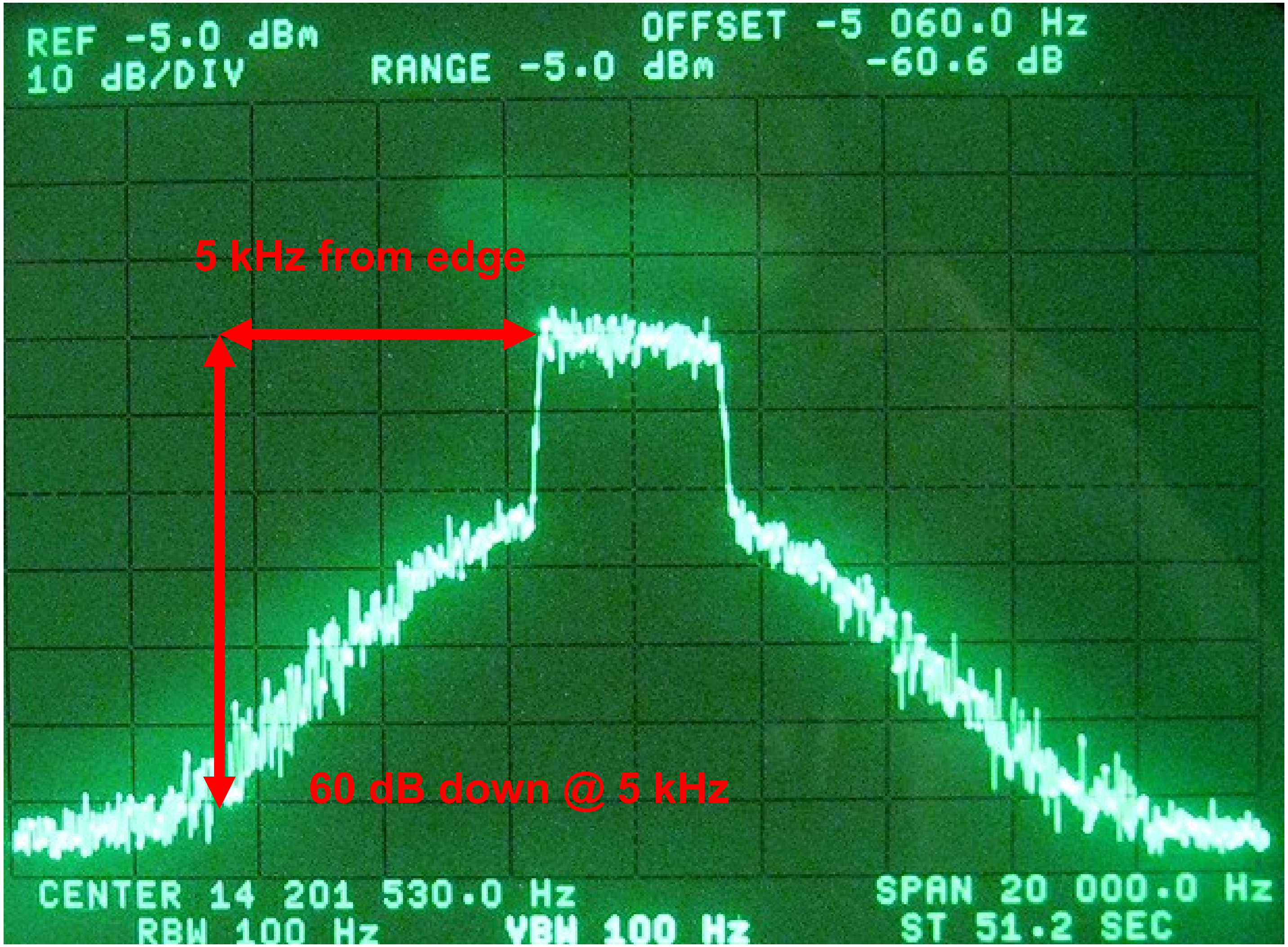
Apache PureSignal better than class A

White Noise Mk V Class A vs. K3 Class B @ 75 Watts



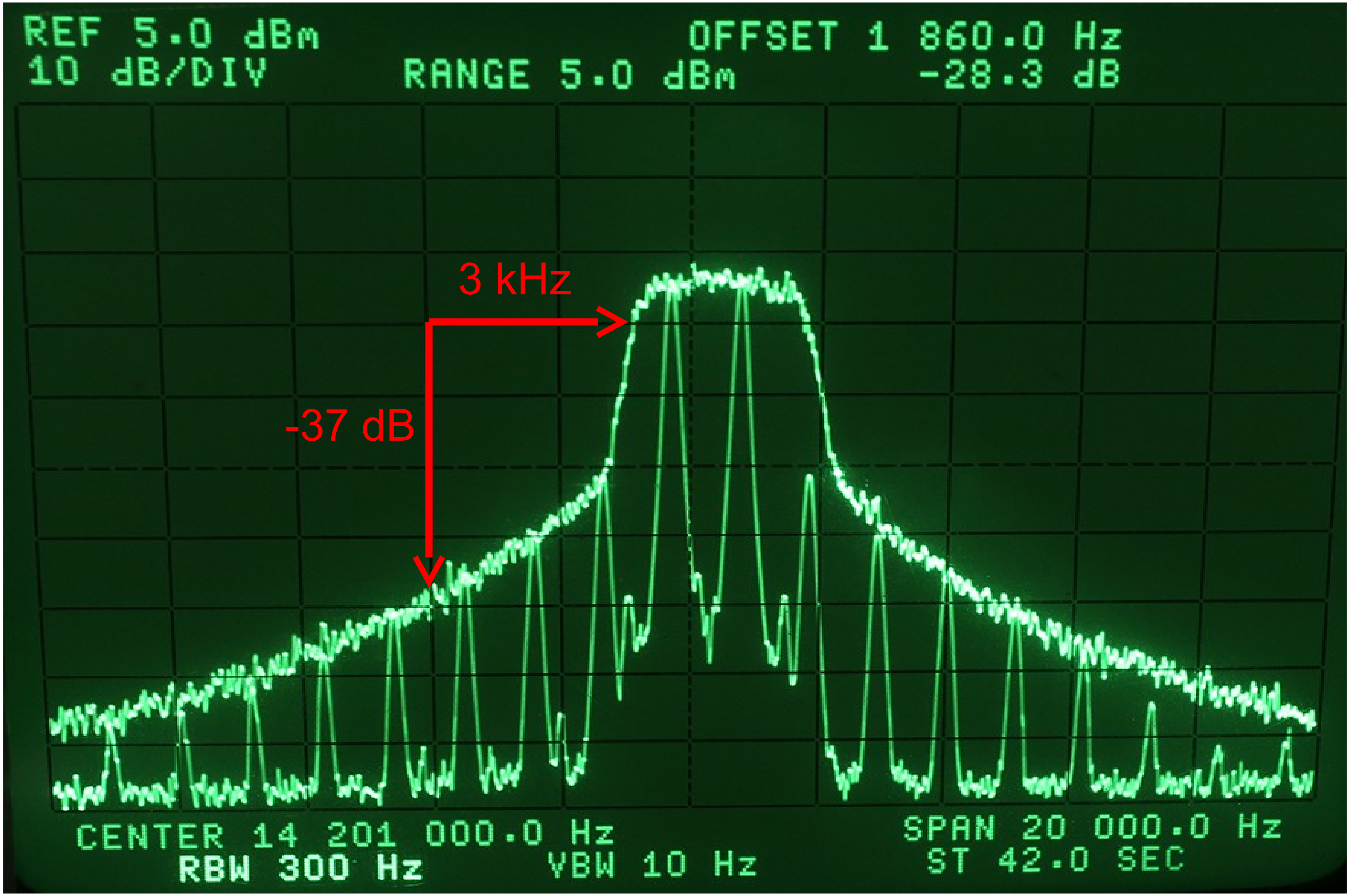
Noise source = GR 1381, 5-kHz -3 dB BW

Icom IC-7410 Class AB, White Noise



How Wide Is Your Signal ?

Comparison 2-Tone vs. Noise Intermodulation Bandwidth



How do we optimize what we have?

- While we might own a 100 dB DR3 radio, many of us have somewhat less performance.
- A TS-990S is around a 90 dB radio @ 2 kHz.
- Consider dynamic range a “window” of performance that can be moved around in absolute level by properly using your attenuator or preamp.

Receiver Noise Floor vs. Band Noise

When is the spec for noise floor significant?

Why does it rarely matter on most bands?

Noise Floor is usually significantly lower than Band Noise.

An ITU graph published in the ARRL Handbook gives us a starting point to relate band noise to noise floor.

This ITU data is in a 500-Hz bandwidth, just like typical noise floor data.

Band Noise vs. Frequency from ARRL Handbook

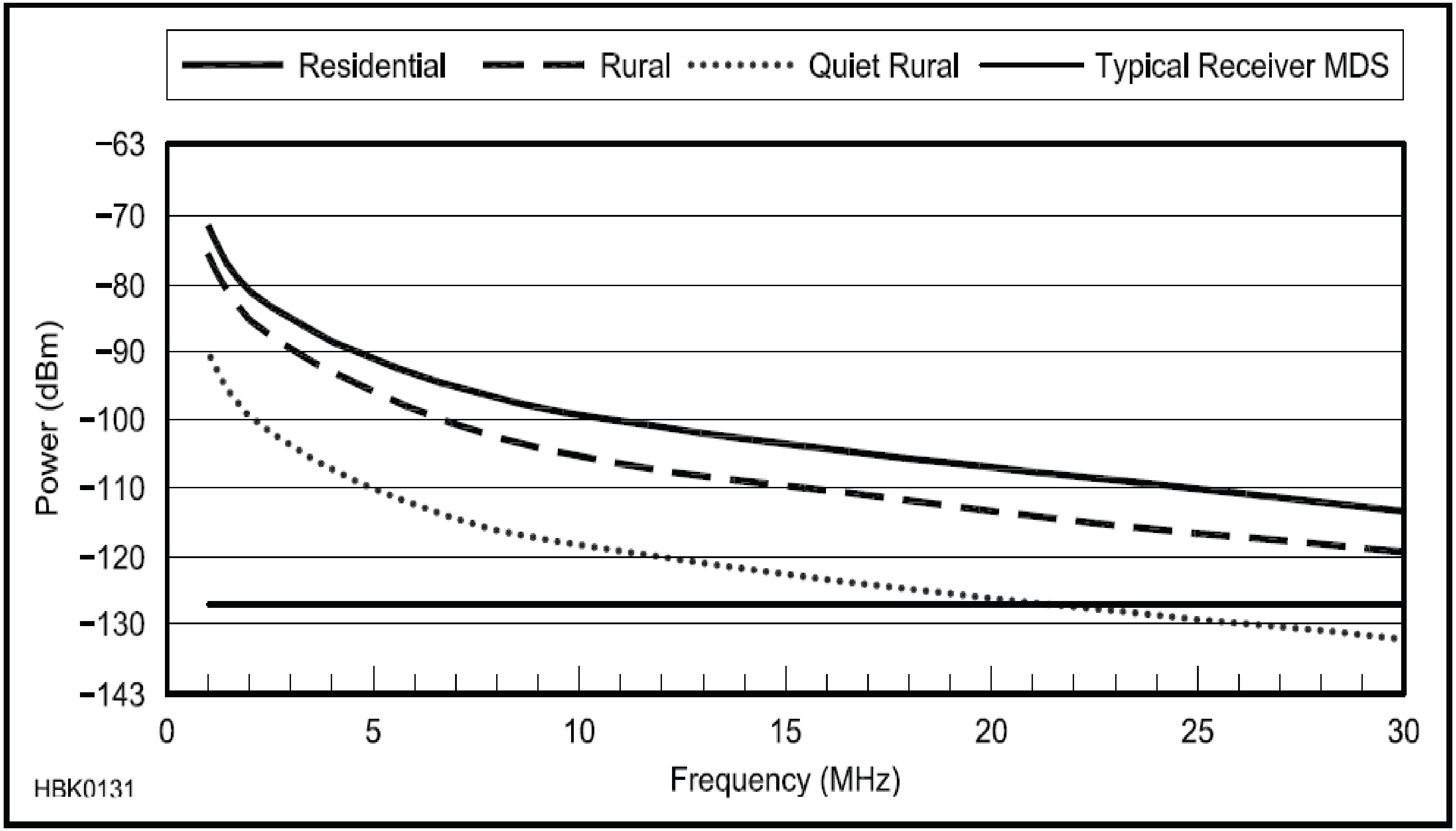


Fig 1 —Typical noise levels versus frequency for various environments. (Man-made noise in a 500-Hz bandwidth, from Rec. ITU-R P.372.7, *Radio Noise*)

A note about the ITU data

- The ITU data assumes an omni-directional antenna.
- Your Yagi or directional low-band antenna* can significantly improve on your band noise in some directions.
- * 4-square, Beverage, RX only antennas

Most Radios are designed for 10 meters

Typical rural band noise on 10 meters is -120 dBm

Typical rural band noise on 20 meters is -110 dBm

On 20 meters, band noise is almost 20 dB higher than typical receiver noise with the preamp OFF !

Optimally receiver noise should be 8 to 10 dB lower than band noise to have minimal effect on receiving weak signals.

Even on 10, 12 & 15 meters, a preamp isn't needed all the time in a rural environment.

A simple test with only an analog meter

- Most hams don't own a calibrated signal generator.
- How do you evaluate your receiver?
- This also evaluates your antenna !

- Measure the noise gain when you connect your antenna.

- All you need is an analog meter with a dB scale, hooked up to your speaker.

Measure the noise gain

- Switch to a dummy load and set the volume so your dB meter reads -10 dB.
- Switch to the antenna and see how many dB the noise goes up on the meter when tuned to a dead spot on the band.
- Do this with Preamp OFF and ON.
- Also rotate your Yagi 360 degrees.
- Noise can easily change 10 dB with azimuth!

15, 10 & 6 meter antenna noise gain

Rig = Icom IC-756 Pro III

6 meter antenna = Ariane C5-50 @ 50 feet

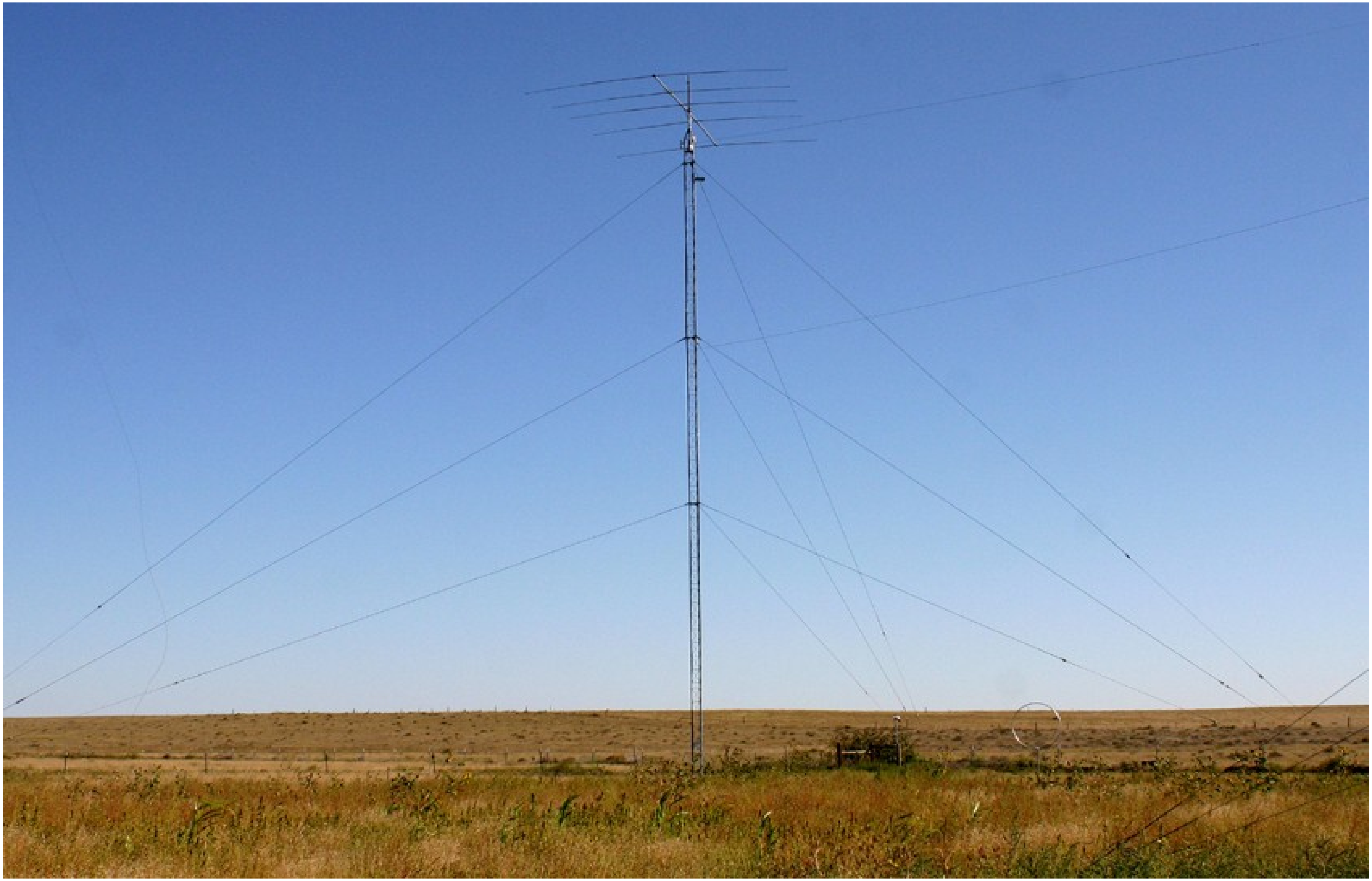
10 meter antenna = Hy-gain 105CA @ 65 feet

15 meter antenna = Hy-gain 155CA @ 70 feet

Preamp	15m	10m	6m
None	4 dB	3 dB*	1 dB
Preamp 1	11.5 dB	9.5 dB	4.5 dB
Preamp 2	13.0 dB	11.0 dB	9.5 dB

* @ 3 dB, receiver noise = band noise = not OK

LJ-155CA Yagi in band noise example



LJ-105CA Yagi in band noise example

5-element 6-meter Yagi in band noise example

How does band noise vary by band?

If we take the ITU rural data as a starting point, what is typical?

160 meters:	-87 dBm *
80 meters:	-93 dBm *
40 meters:	-101 dBm *
20 meters:	-109 dBm #
15 meters:	-114 dBm #
10 meters:	-119 dBm #

That's a 30+ dB difference in band noise

* = nighttime   # = daytime

Measured band noise at NC0B 160 meters

Omni-directional top-loaded Marconi T antenna
60 foot vertical radiator with flattop length = 150 feet

160 meters 8:00 AM MST: -105 dBm
160 meters 4:00 PM MST: -101 dBm
160 meters 6:30 PM MST: -91 dBm

ITU rural typical value: -87 dBm

(January 2014 160 meter CQWW CW Contest)

Beam headings October 20, 2013 9 to 11 AM

Measured band noise at NC0B

Band	20 meters	15 meters	10 meters
0 degrees:	-114 dBm	-124 dBm	-129 dBm
30 degrees:	-113 dBm	-124 dBm	-123 dBm
60 degrees:	-110 dBm	-118 dBm	-120 dBm
90 degrees:	-108 dBm	-114 dBm	-120 dBm
120 degrees:	-107 dBm	-113 dBm	-122 dBm
150 degrees:	-107 dBm	-114 dBm	-122 dBm
180 degrees:	-108 dBm	-114 dBm	-121 dBm
225 degrees:	-109 dBm	-120 dBm	-130 dBm
270 degrees:	-109 dBm	-120 dBm	-130 dBm
315 degrees:	-111 dBm	-122 dBm	-130 dBm
ITU rural value:	-109 dBm	-114 dBm	-119 dBm
Antenna	204BA	155CA	105CA
Height	70 feet	70 feet	65 feet

Typical receiver noise floor values

- Rig Preamp OFF Preamp ON
- TS-990 -127 dBm -138 dBm
- ITU nighttime band noise on 40 meters is around -100 dBm!
- On the low bands receivers are way too sensitive at night.
- No preamp needed, 12 dB attenuator OK

Numbers with Preamp-1 ON

Sensitivity a non-issue for dacades

- Elecraft K3s -138 dBm
- Elecraft KX3 -138 dBm
- Flex 6700 -135 dBm
- FTdx-5000D -135 dBm
- Flex 5000 -135 dBm
- Orion II -133 dBm
- IC-7300 -141 dBm
- T-T Eagle -132 dBm
- 756 Pro III -140 dBm
- TS-590SG -135 dBm
- Drake R-4C -138 dBm (For comparison)

What does all this imply?

- For most radios: superhet or direct sampling -
- On the lower bands at night, attenuation is often appropriate.
- There is no point in band noise reading upscale on your S meter.
- A preamp is usually NOT needed on 20 meters.
- A preamp would ***never*** be needed at night on 40 meters and below, assuming the transmit antenna is used on receive.

Optimize your AGC threshold

Set the AGC threshold about 6 dB above band noise.

Use attenuator, RF gain control or AGC threshold adjustment, if available. (AGC-T 50 to 60 for Flex)

You don’t want the AGC to bring up band noise to equal a weak signal.

Preamp on 160 or 80 meters OK?

- Many rigs today have an RX input for a receive only antenna.
- A Beverage or a small loop would usually have a head amp, at least for impedance matching. (Maybe just a transformer)

- A preamp for a receive-only antenna may well be appropriate on the low bands.
- Use common sense for special cases.

Times of day can break the general rules

- In a rural environment, daytime band noise on 80 and 40 meters can be quite low.
- Noon at my QTH 40 meters -115 dBm
- 8:30 AM my QTH 80 meters -120 dBm
- Flex 6300 at that time had no preamp on 80.

How do we optimize a reception?

- 160 – 40m receivers are too sensitive at night.
- Make the most of the radio’s dynamic range.
- Use the attenuator and preamp appropriately.

How do we evaluate a transceiver?

- Published dynamic range can be misleading.
- It depends on how it is measured.
- Look at RMDR, as this typically dominates.
- (RMDR* = Reciprocal Mixing Dynamic Range)
- *QST April 2012 & May 2016 for sidebars by Bob Allison, ARRL test engineer

What environments are the worst?

- Field Day is very challenging with multiple transmitters.
- Having another ham a few miles away is a problem, particularly on 160 and 80 meters, due to good ground wave propagation.
- Contests: Multi-2 or Multi-Multi

What to do?

- Learn what the review numbers really mean.
- It is a numbers game to some extent.
- Once a radio is good enough, there are lots of other factors when selecting a transceiver.
- Which radios are really performing in the field?
- Start with lab numbers, but in no way do they approximate a CQ Worldwide contest!

Sherwood Engineering

Videos Contest University presentations: 2013 - 2016

https://www.contestuniversity.com/videos/

CTU 2011, NC0B only, download wmv file

http://www.pvrc.org/webinar/radioperformance.wmv