RX & TX Performance
+
Testing and Evaluation

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NCØB

Great RX improvements, TX degrading

What is sensitivity & Noise Floor?

- The term sensitivity goes back decades. For SSB it means a 10 dB S+N/N ratio in a 2400 Hz bandwidth (BW).
- I quote it in microvolts for historical reasons.
- Noise floor is similar, but it is a 3 dB S+N/N ratio.
- Usually quoted in dBm in a 500 Hz BW, but chosen bandwidth can be anything as long as it is defined.
- Audibly the test tones sound very similar due to the different bandwidths vs. the signal to noise ratio.

Defined in QST and *hr magazine* in 1975

What does dynamic range mean?

- Two equal signals are fed into the receiver.
- Third-order IMD is dominant.
- Level increased until distortion = noise floor
- This level vs. the noise floor = dynamic range
- Example:
- Noise floor = -128 dBm, test signals = -28 dBm
- -128 dBm minus -28 dBm = 100 dB
- Dynamic Range (DR3) = 100 dB

State-of-the-Art in RX Dynamic Range today

- Close-in dynamic range (DR3) > 100 dB
- Reciprocal Mixing (RMDR) > 115 dB

- Rigs with DR3 96 dB or greater:
- Icom IC-7851, Flex 6000 & Elecraft K3S
- Icom 7300 & 7610, Apache 7000DLE
- Kenwood TS-890S
- Yaesu FTdx-101D

What are the latest new rigs?

- Kenwood TS-890S
- Hybrid architecture
- Best RMDR I have ever measured
- Single receiver, unlike TS-990S
- Shipped in time for October 2018 CQWW SSB

- Yaesu FTdx-101D shipped in late April 2019
- Hybrid architecture
- Dual receivers
- Arrives at Sherwood lab May 9, 2019.
- Missed the entire 2018/2019 contest season.

TS-990S vs. TS-890S Comparisons

RIG	TS-990S #	TS-890S
20 kHz dynamic range:	111 dB	106 dB
2 kHz dynamic range:	87 dB*	105 dB
20 kHz RMDR:	116 dB	131 dB^
2 kHz RMDR:	89 dB	127 dB^

* (phase noise [RMDR] limited)

^ (measured on 40 meters, Wenzel oscillator)

Kenwood dropped the ball on RMDR during the time the League ignored phase noise.

FTdx-101D provided by Randy W2KRY

Yaesu FTdx-101D vs. TS-890S

RIG	FTdx-101D	TS-890S
20 kHz dynamic range:	110 dB	106 dB
2 kHz dynamic range:	110 dB	105 dB
20 kHz RMDR:	129 dB	131 dB
2 kHz RMDR:	125 dB	127 dB

- Yaesu arrived after 2018/2019 contest season.

Both are so good I wouldn't make a rig purchase choice just on the number differences. On the air you would never know the difference.

Icom IC-7610 & Kenwood TS-890S

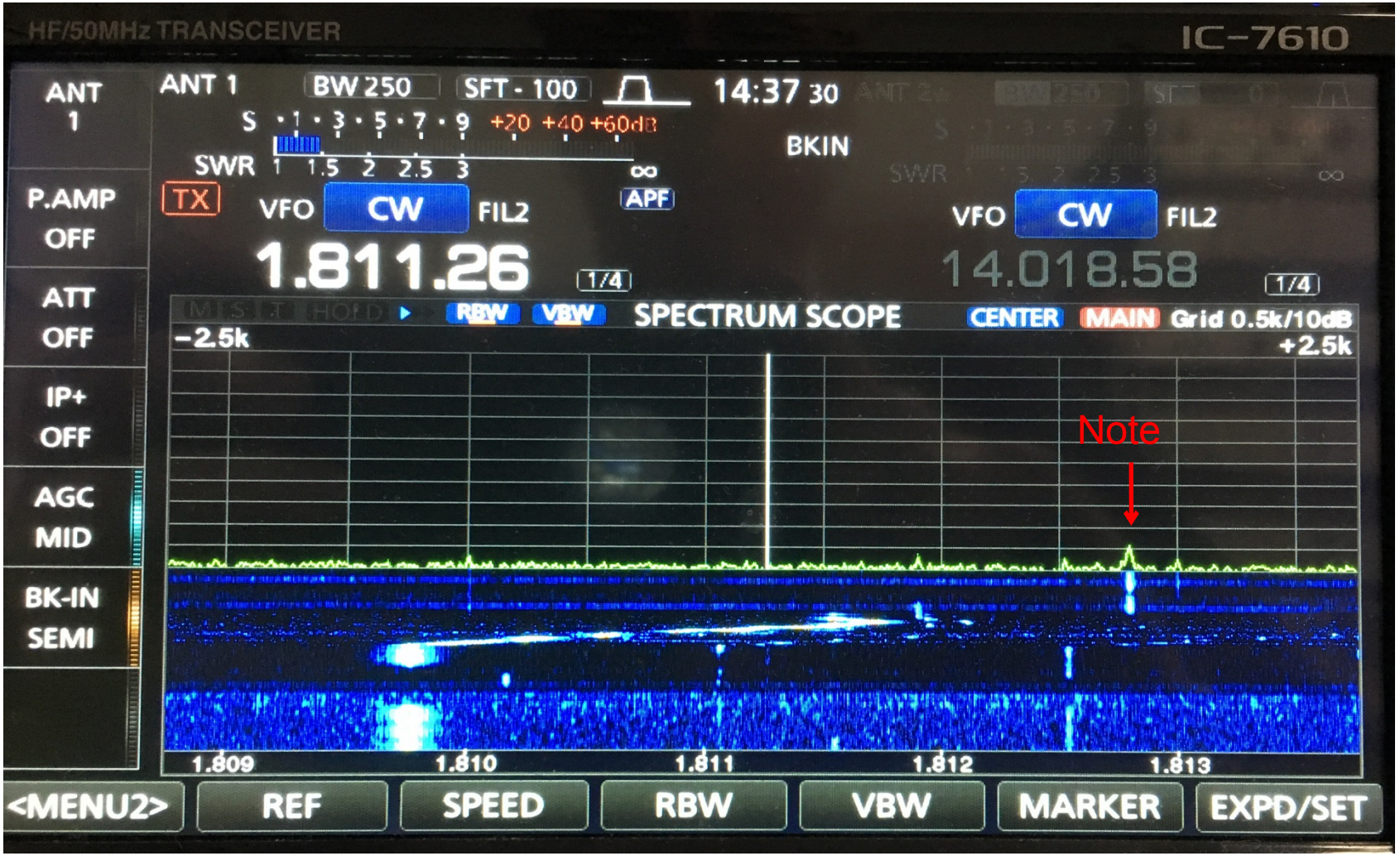
Compare direct sampling 7610 to hybrid 890S

- ARRL 160m CW a good test for lots of QRM.
- ARRL 10m: A good test for weak signals.
- DSP & APF selectivity excellent on both.
- Ergonomics excellent for both transceivers
- NR & NB the Icom wins, at least at my QTH
- Waterfall the Kenwood wins hands down, at least the way I operate S&P CW.

Less useful waterfall

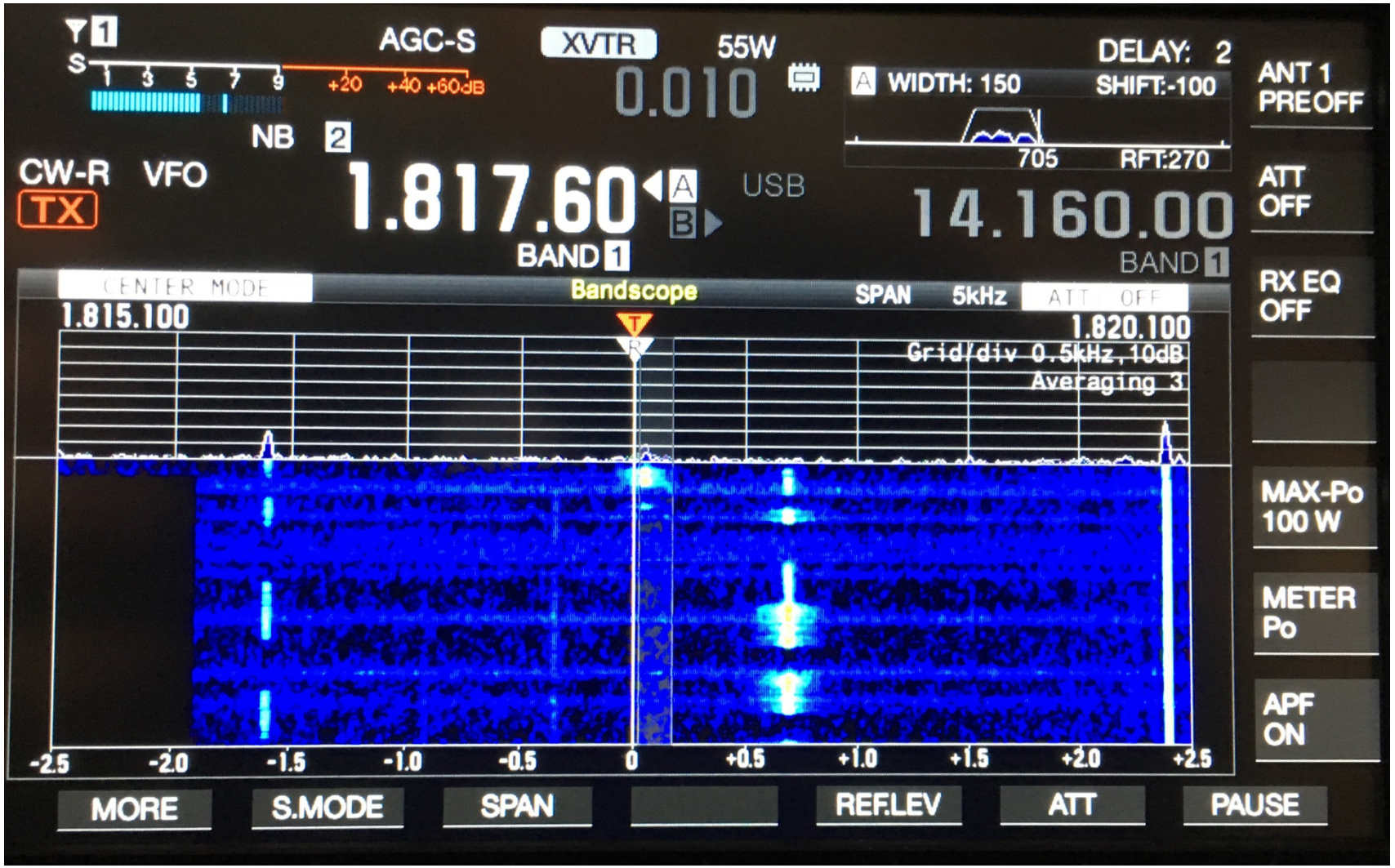
My workaround: use band scope with averaging OFF

Icom waterfall slewing issue while tuning



Whole waterfall shifts, but leaves a blank space

Kenwood waterfall while tuning doesn't slew

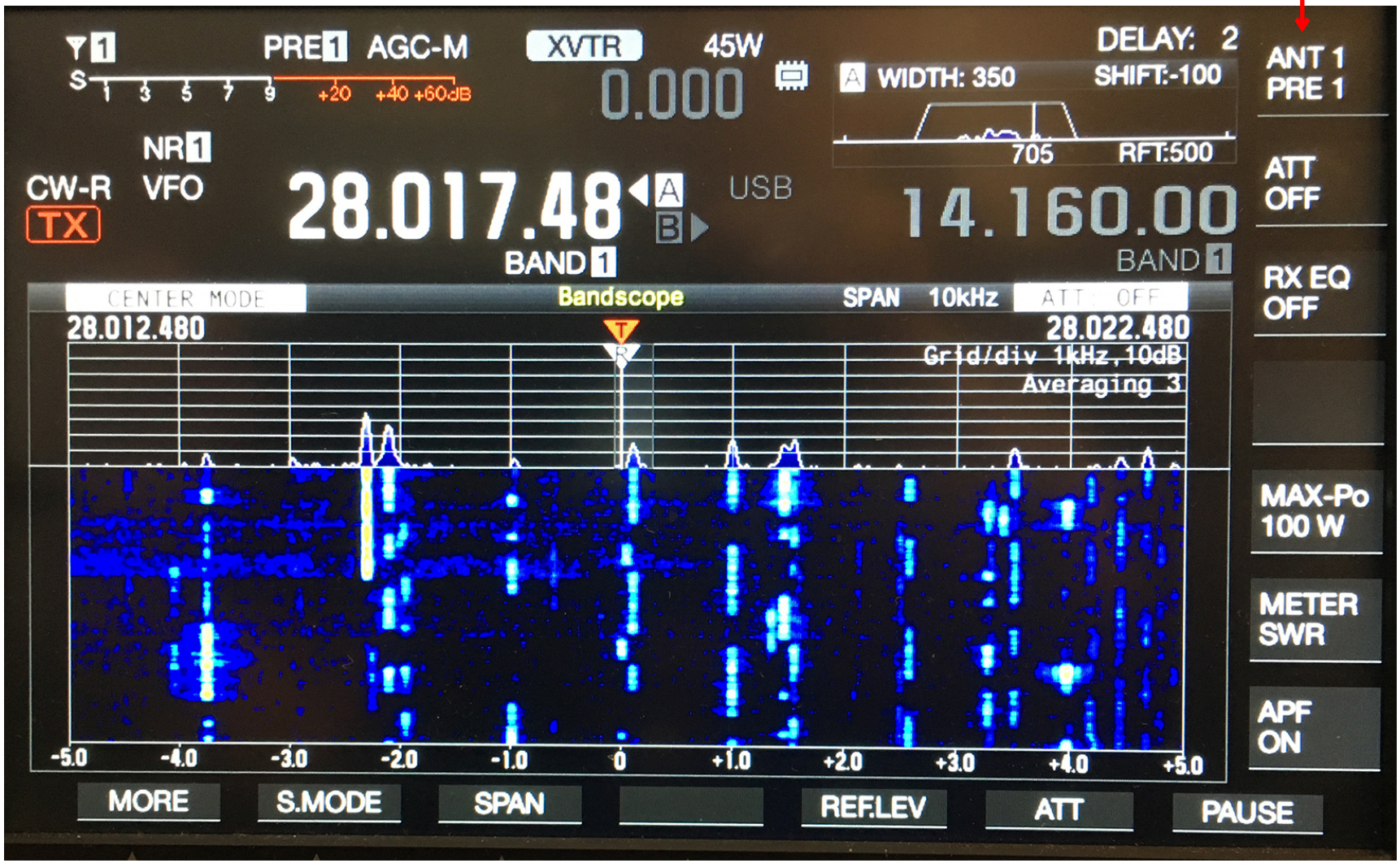


December 2018

Over 20 stations in 10 kHz TS-890S

ARRL 10m Saturday afternoon

Note preamp



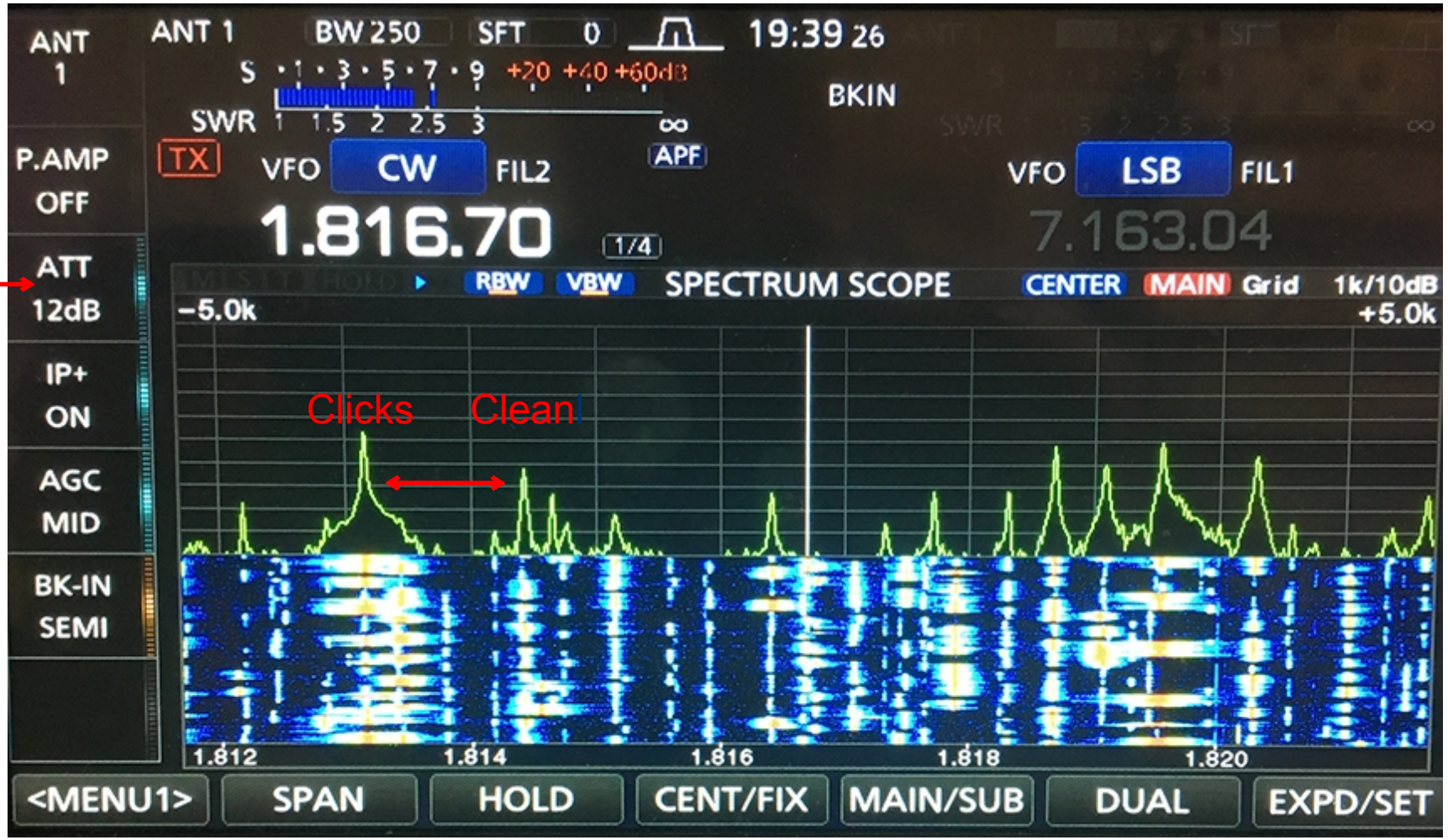
December 2018

Over 30 stations in 10 kHz IC-7610

ARRL 160m CW Friday 7:40 PM

Note

ATT



The year of the hybrid legacy & DS SDR radios

- Examples Legacy: K3S & TS-990S, down conversion
- Examples Direct Sampling: Apache, Flex & Icom
- 2018 & 2019 combined both architectures.
- Main RF/IF chain: mixer, roofing filter, mixer, DSP
- Display: Direct Sampling after the first mixer but before the roofing filter
- Best of both world? In high RF environment. Field Day
- Direct sampling SDR (DS SDR) requires the operator to manage net receiver gain more carefully.
- With a down-conversion radio with a roofing filter you can be careless!

Testing differences for legacy superhet vs. hybrid = None

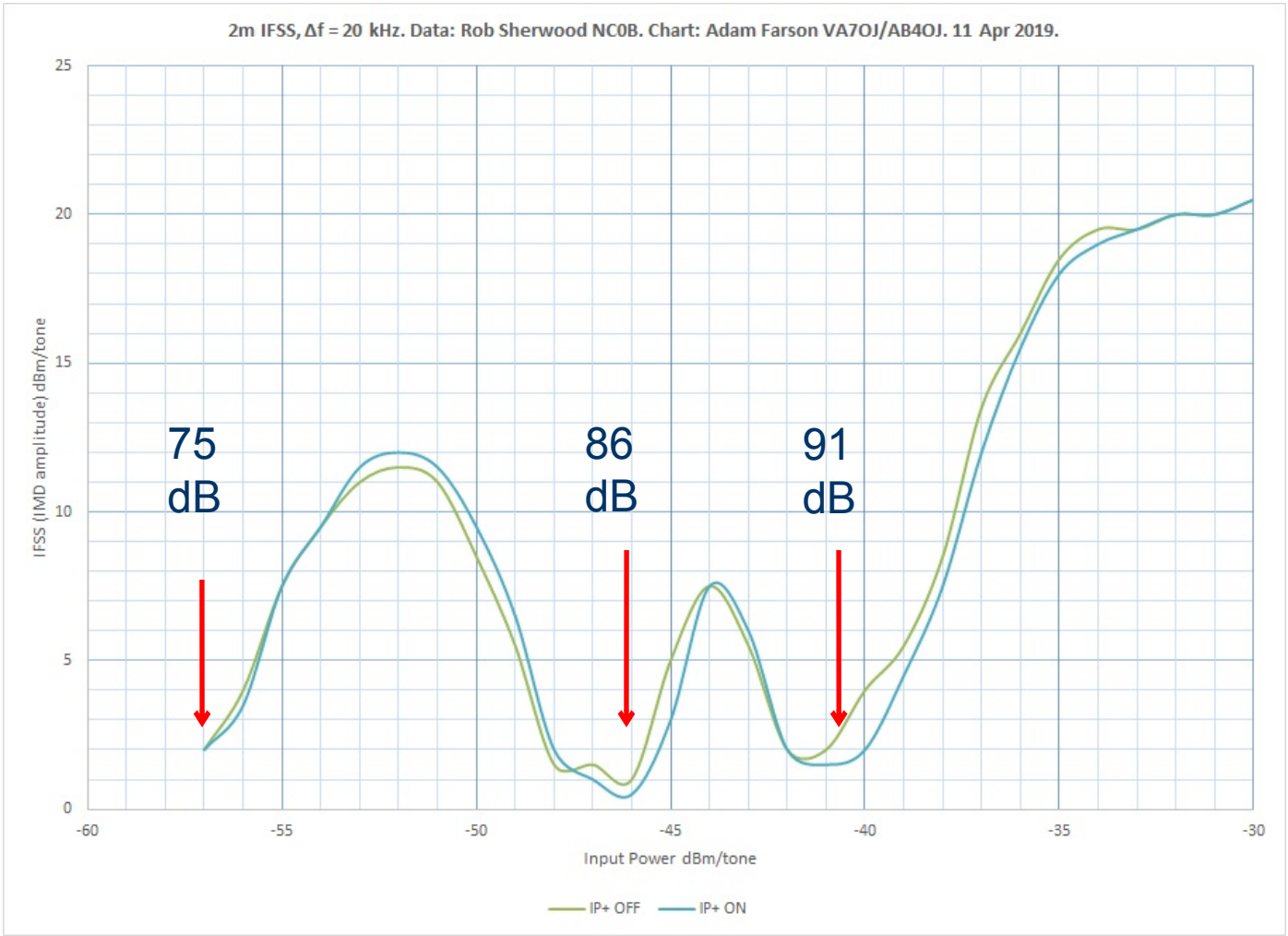
- The hybrid radio has a direct sampling display. Otherwise both the TS-890s and the FTdx-101D have roofing filters and multiple conversions of slightly different methods.
- The basic Elecraft K4 will be much like an Icom IC-7610.
- The K4HD, with the legacy superhet module, will be like the Yaesu architecture.
- Testing a direct sampling radio (Apache, Flex & Icom) is a different story, depending on its I/O distortion curve.
- If the distortion curve is monotonic (doesn't go up and down), then the legacy dynamic range value is similar to a superhet radio.

Superhet vs. Direct Sampling distortion curves

- A legacy superhet is almost guaranteed to have a monotonic distortion curve starting at the noise floor and going up in level.
- Two direct sampling transceivers I have tested have very wobbly distortion curves.
- The following slide is the distortion curve of the Icom IC-9700 VHF/UHF direct sampling transceiver.
- There are three points where the third-order distortion equals the noise floor, which is the definition of dynamic range.

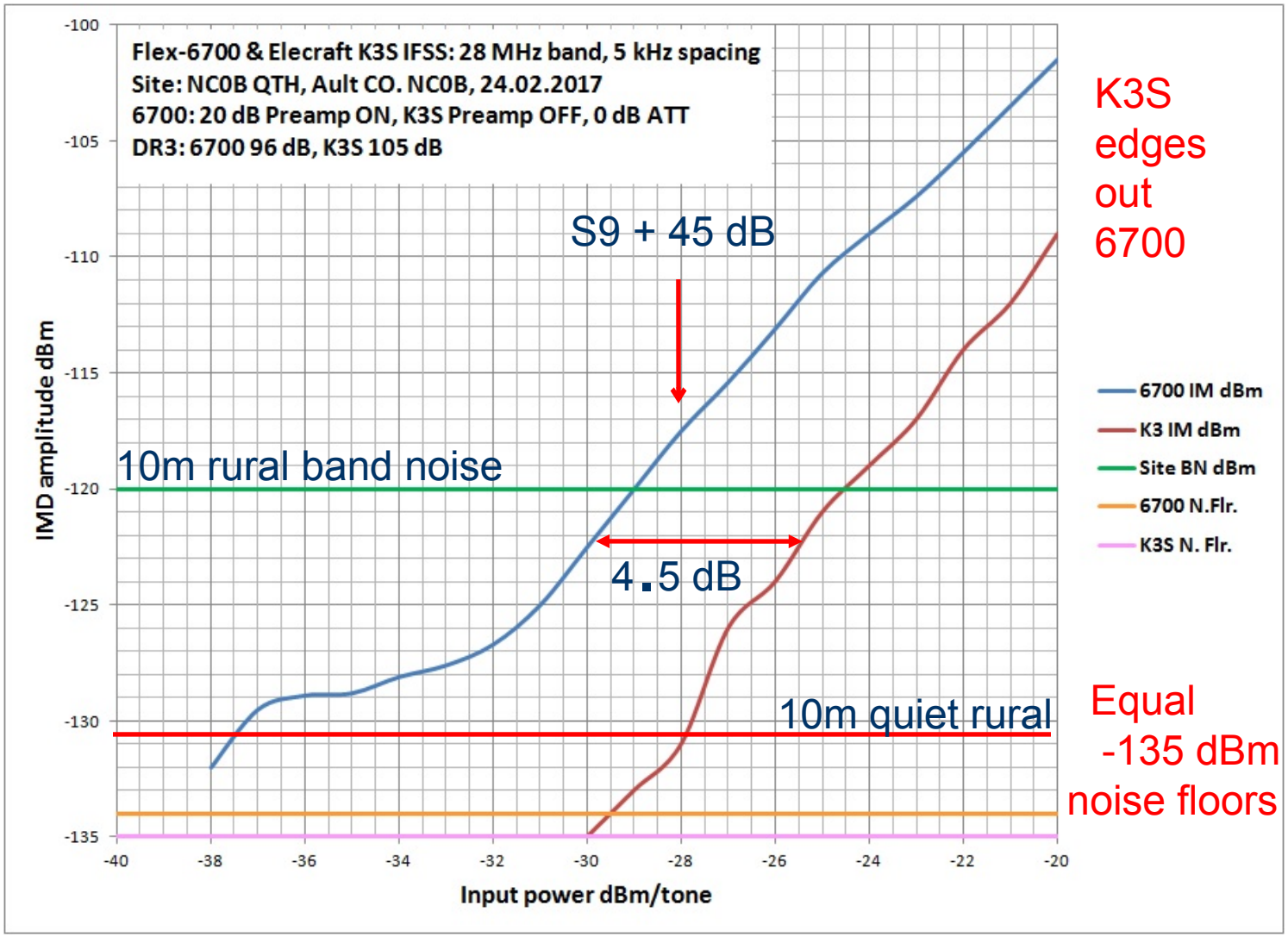
IC-9700 Non-monotonic distortion curve

Where do we pick the distortion = noise floor point?



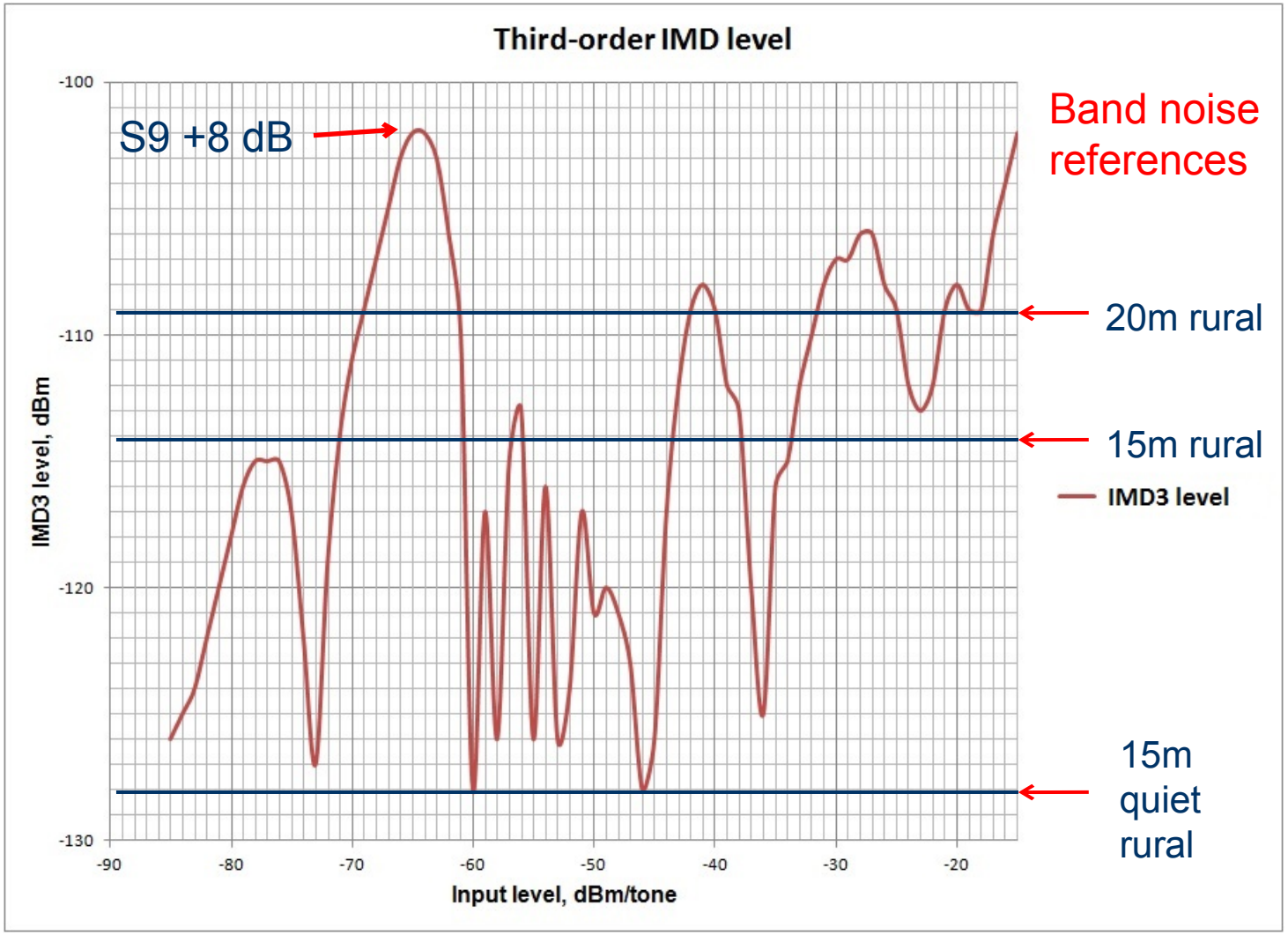
Data by NC0B Graph by VA7OJ
These two curves are well behaved

Distortion Curves: Elecraft K3S vs. Flex 6700 10 meters



Data by NC0B Graph by VA7OJ

Worst case distortion curve I have measured



Why is direct sampling gain important?

- Field Day, a ham 1 mile away, or a multi-multi contest station is a tough RF environment for a direct sampling radio.
- In effect the roofing filter bandwidth is the entire band, or more likely a half octave filter, for example 11 to 15 MHz ! (IC-7610)
- A tracking pre-selector helps to some extent.
- Keep the preamp OFF, and use input attenuation or RF gain to control overload.

When is Attenuation a Win – Win Scenario?

- Note: If band noise is reading upscale on your S meter, then add attenuation.
- You lose NOTHING in terms of sensitivity!
- I set AGC threshold about 6 dB or so above band noise for least “contest fatigue” and lowest chance of overload on ANY radio.
- Attenuation at night on 40, 80 and 160m is a given, assuming you are listening on your transmit antenna: 6 to 12 dB attenuation 40/80m, 12 to18 dB attenuation160m

Some are only CW oriented *

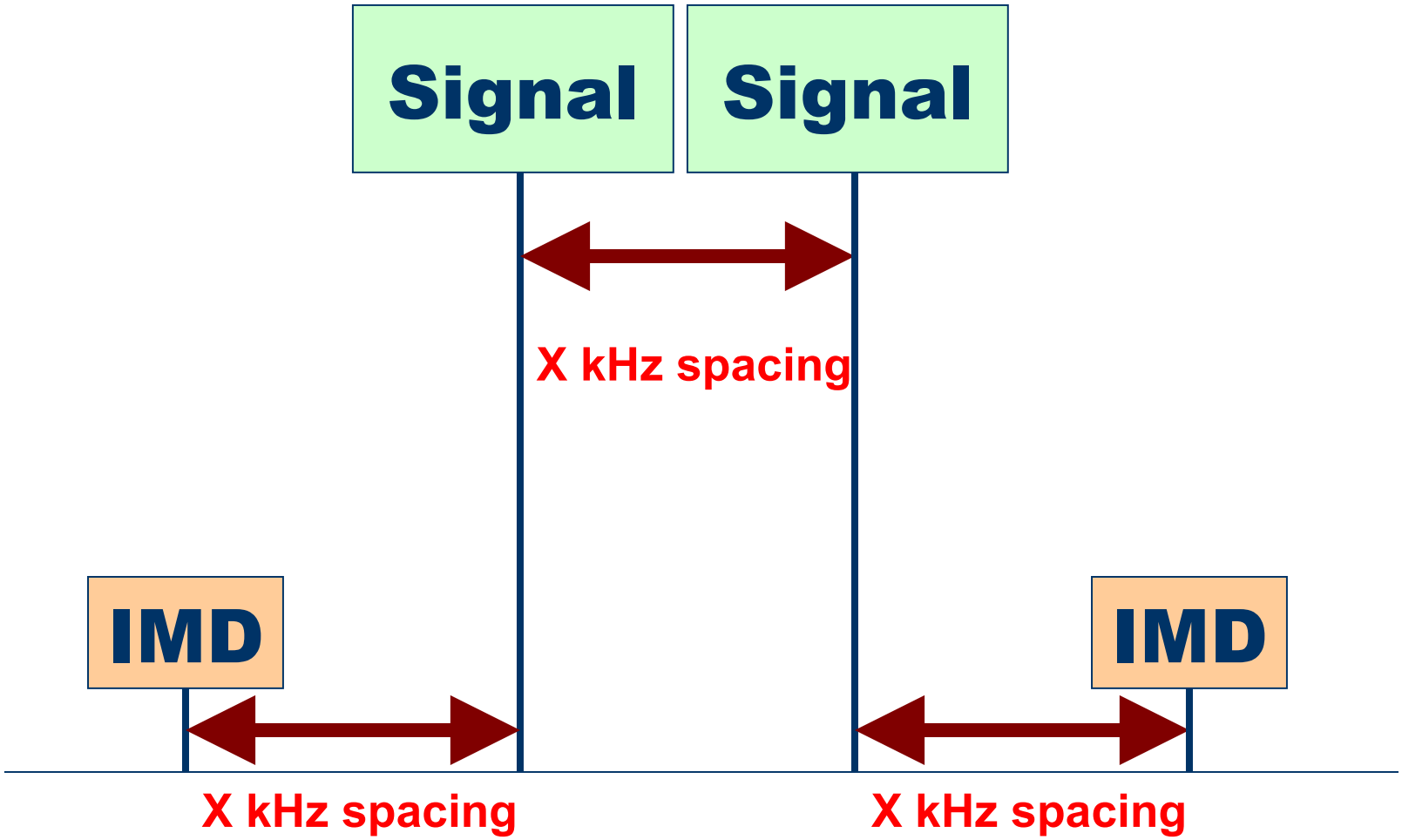
Features desirable today

- QSK, or at least click-free semi-break-in *
- APF to reduce band noise and fatigue *
- Bandscope & waterfall display for S&P contesting, for multipliers, & watch the pile-up
- Efficient User Interface
- Rock solid connection to logging program
- For most, at least some kind of external manual controls for computer-controlled rigs.
- DJ Console, as an example for Apache

Time for the numbers

- What do these state-of-the-art numbers mean?
- How do we cope with a more typical radio?
- We can optimize the performance of an 85 dB, let alone a 90 dB radio.
- Lots of transceivers can be perfectly adequate.

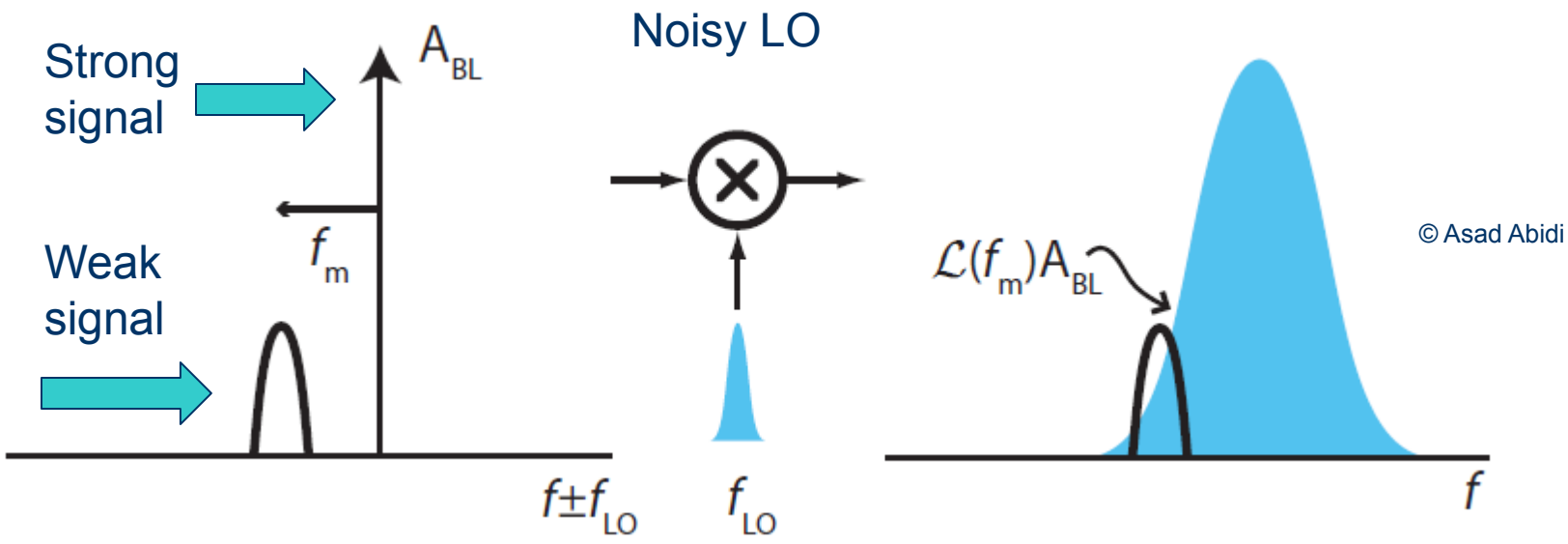
Third Order IMD to Measure Dynamic Range



A note on phase noise / RMDR

- Reciprocal Mixing Dynamic Range (RMDR)
- Since late in 2013 the ARRL has consistently emphasized the importance of good phase noise performance (RMDR).
- Read Bob Allison's sidebar April 2012 QST & 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” transceivers, plus direct sampling SDR radios have RMDR > DR3.
- Superhet examples:
- Kenwood TS-890S & Yaesu FTdx-101D
- Elecraft K3S or K3 w/ new synthesizer
- Hilberling PT-8000A, Icom IC-7851
- Direct sampling examples:
- IC-7610 & IC-7300
- Flex 6000 series, old and new
- Apache ANAN series

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 adequate on SSB and a big compromise 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 18 Transceivers

- Yaesu FTdx-101D 110 dB
- Elecraft K3S 106 dB
- Icom 7851 105 dB
- Kenwood TS-890S 105 dB
- Hilberling 105 dB
- Elecraft KX3 104 dB
- ANAN-7000DLE 103 dB
- Yaesu FTdx-5000D 101 dB
- Flex 6600 / 6600M 99 dB (16 dB preamp ON)
- Flex 6700 (2017) 99 dB (Preamp OFF)
- Icom 7610 98 dB
- Icom 7300 97 dB (IP+ ON, high serial number)
- Flex 5000 96 dB
- Elecraft K3 95 dB (Original Synthesizer)
- Orion II 95 dB
- Orion I 93 dB
- TS-590SG 92 dB
- Ten-Tec Eagle 90 dB

You can effectively work DX and Contests with any of these fine transceivers.

New price range $1000 to $12,000+

Used market price even lower

I have run contests with 12 of the 18

Why is higher DR3 needed on CW?

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

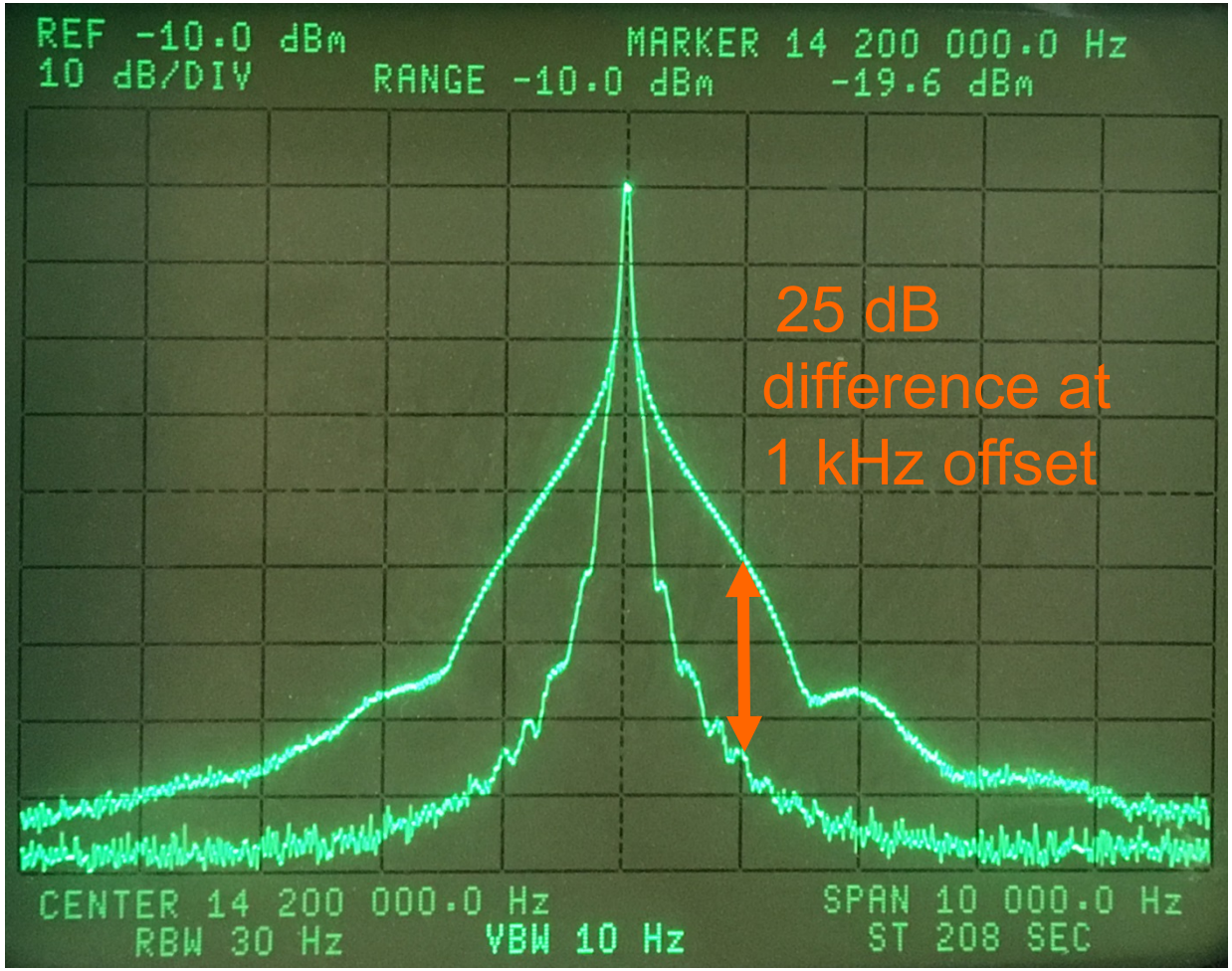
- A CW signal is about 1 kHz wide at -60 dB.
- An SSB signal is about 10 kHz wide at -60 dB.

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

You can select 1 msec on many rigs !!!!

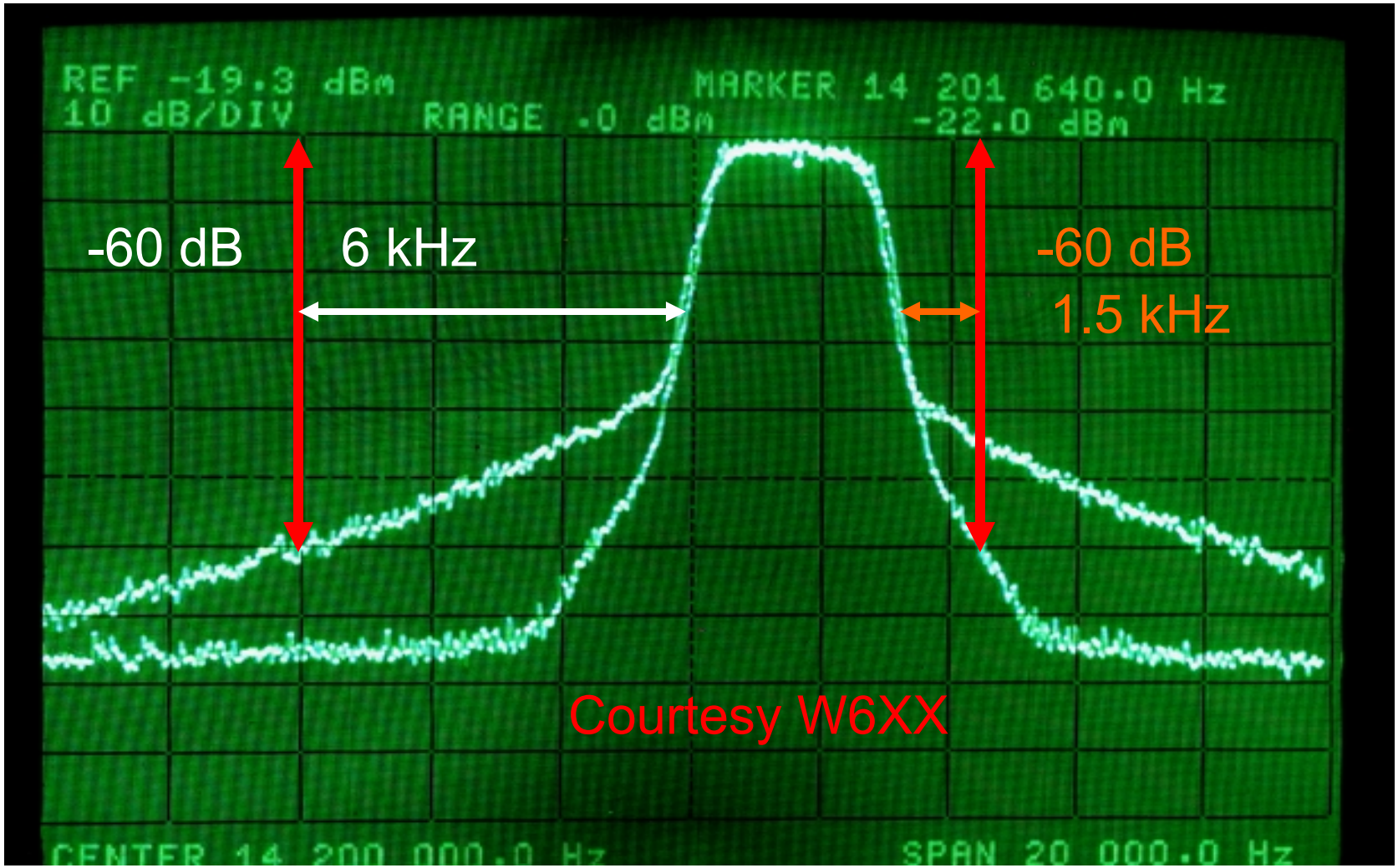
Spectrum of CW Signal on HP 3585A Analyzer

Comparison of 1 msec vs 6 msec rise time



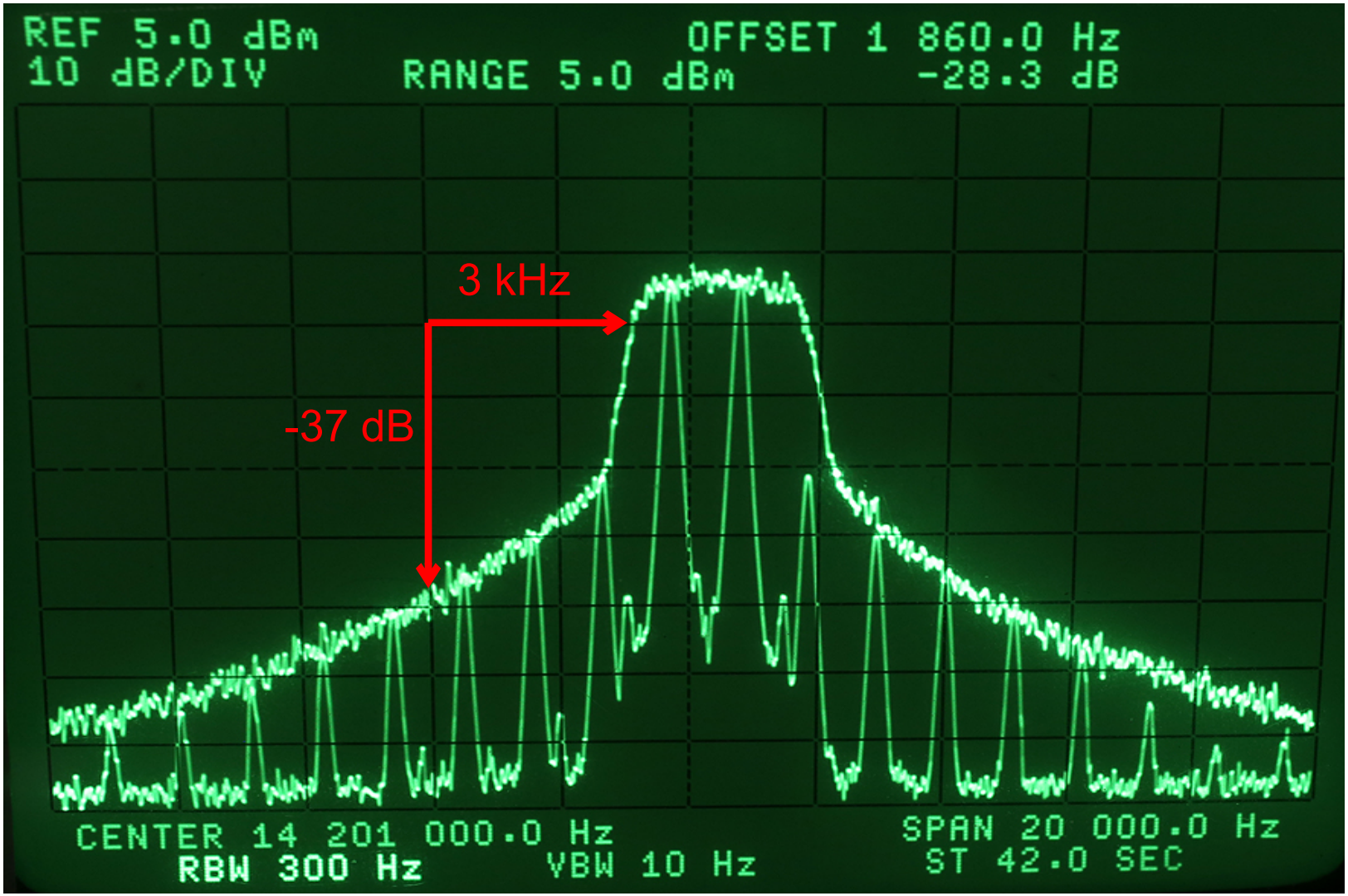
Apache PureSignal similar to class A

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



How Wide Is Your Signal ?

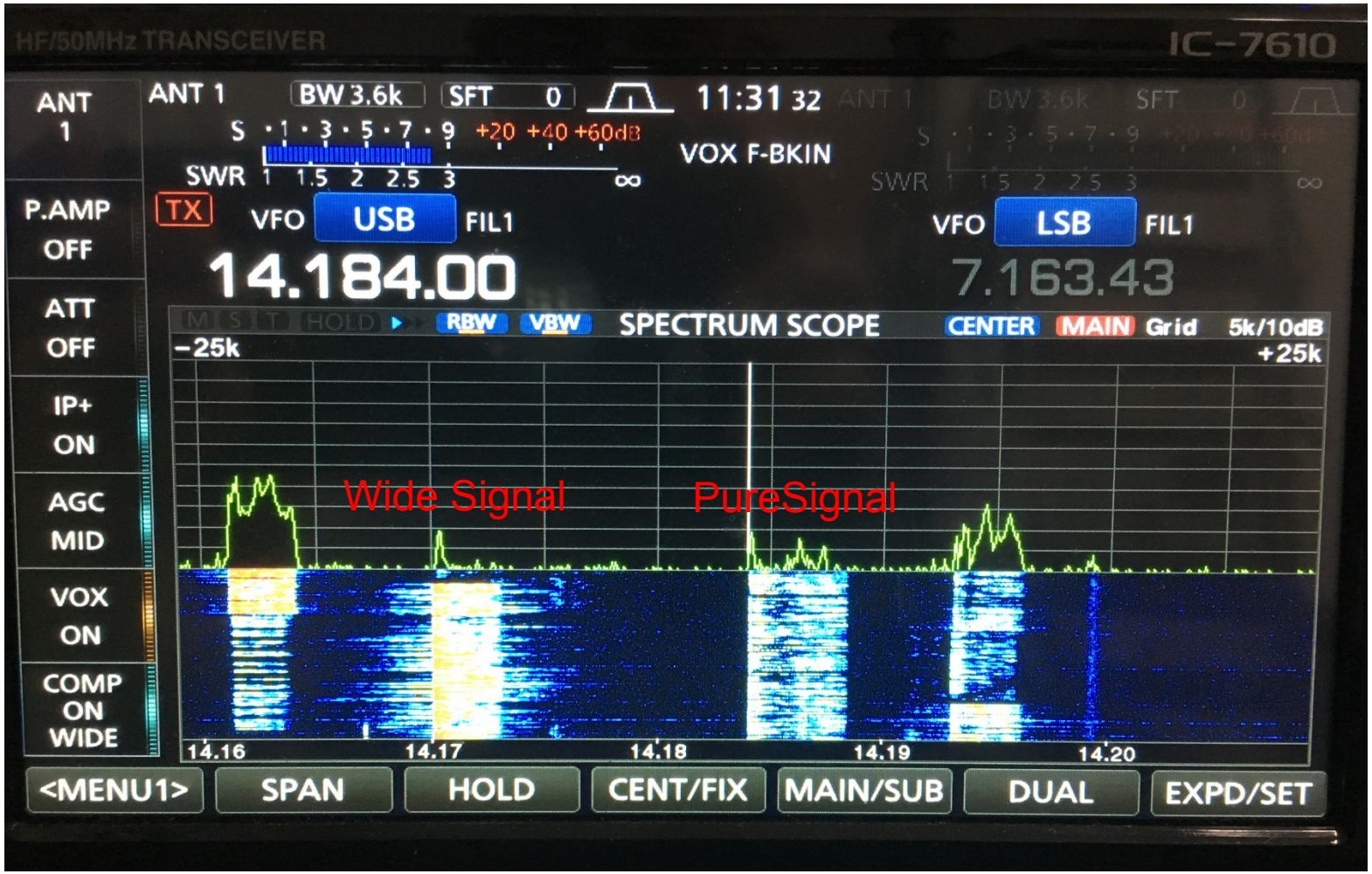
Comparison 2-Tone vs. Noise Intermodulation Bandwidth



KA0KA chose 4.6 kHz transmit bandwidth

Observe the waterfall differences

On air example of PureSignal



What is often the limit today?

- Receivers have drastically improved in the past 10+ years.
- Transmitter cleanliness: No Improvement !*
- Transmitted splatter, transmitted broadband noise, and CW key clicks are now often the limit today.

* Apache PureSignal the exception on SSB

3 kinds of Transmitted noise

- We have 3rd order IMD splatter “noise”.
- Rigs where you can “turn on” key click “noise”.
  (Rise time can be set to 1 or 2 milliseconds!)
- I recommend no faster than 6 milliseconds.
- Rarely mentioned “transmitted broadband noise”.
- I believe only Icom even mentions transmitted broadband noise in their ad copy.
- We need to be a good neighbor.

Noise hopefully falls off with spacing

Broadband noise comparisons

Rig	10 kHz dBc/Hz		100 kHz dBc/Hz	
K3S	-141		-143	
IC-7851	-129		-138	
IC-7610	-128		-142	
Flex 6400	-122		-139	
IC-7300	-121	*	-124	*
FTdx-3K	-120	*	-121	*
TS-890S	-119		-139	

- * Note: Noise hardly falls off at all. Likely a problem on Field Day with two stations on the same band.

The League is testing a solution

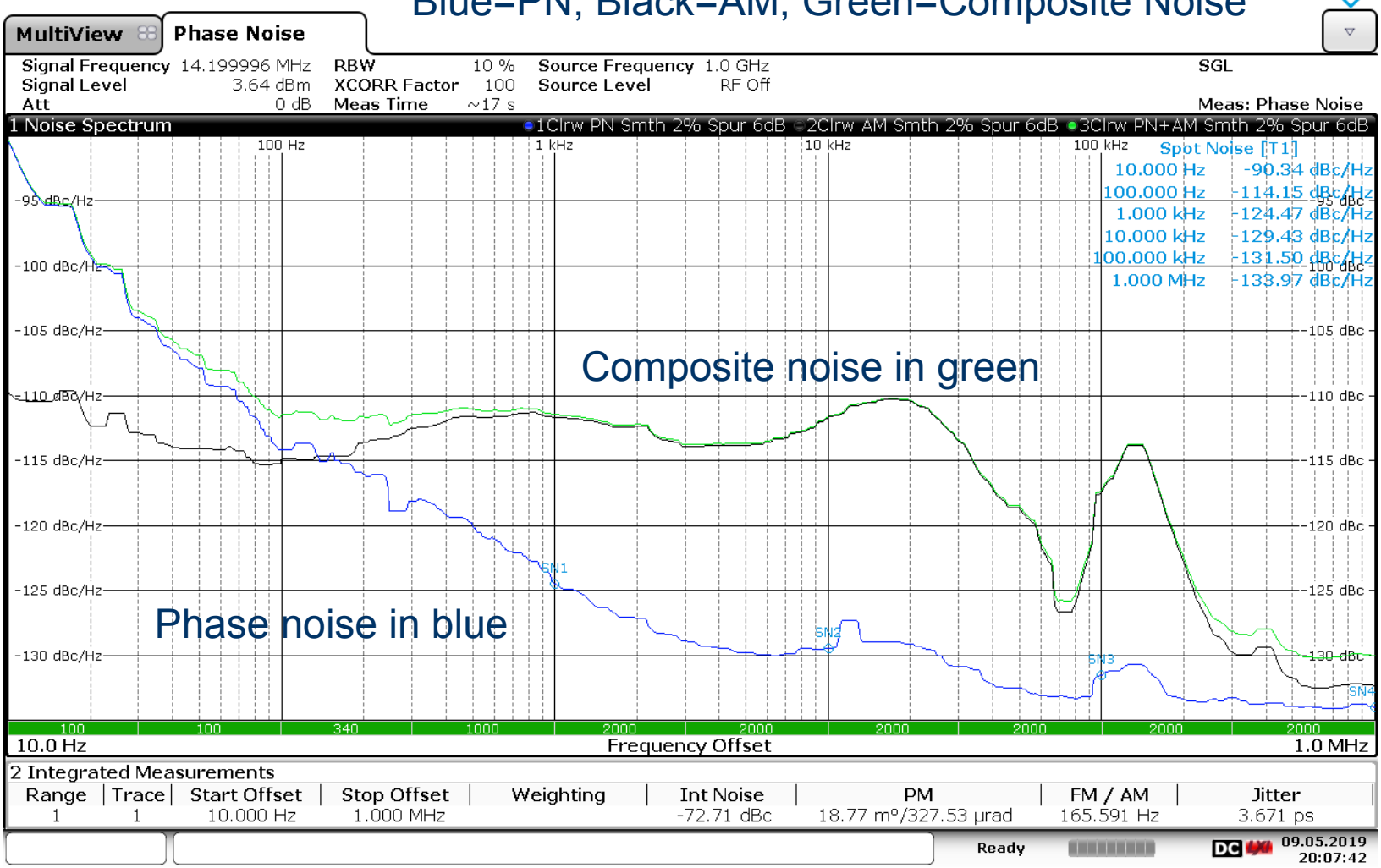
ARRL noise measurements are incomplete

- How transmit noise is measured is important.
- Two types of noise exist: Phase and Amplitude
- ARRL only measures Phase Noise.
- “On the air” Composite Noise is what matters.
- Composite noise measures both types !
- Some rigs have minimal AM noise.
- Other rigs have lots of AM noise.
- The following slide is the IC-7300 at 30 watts where AM noise dominates past 200 Hz offset.

Data courtesy Conrad PA5Y

Transmit noise IC-7300 on 20 meters

Blue=PN, Black=AM, Green=Composite Noise



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Solid-state Linear Amps not so Linear

The ARRL published a compendium of tube-type linear amplifier odd-order distortion performance copyright 1997.

All the amps had third-order IMD down between 40 and 50 dB below PEP.

A recent review in QST of the Elecraft KPA1500 amp listed third-order IMD down only 30 dB PEP, with no comment on this value.

Flex PowerGenius XL measured only 27 dB PEP on 10 and 6 meters !

30 dB is 6 to 10 dB worse than the cleaner transceivers in use today.

The cleanest transmitter I have ever owned was the Collins 32S-3.

Transmitters have gotten worse, and now solid-state amps are worse.

We have wonderful receiver performance today, not so much our transmitted signal. This problem adds to QRM.

Watch for my article in November 2019 QST

"It's Time to Clean Up our Transmitters" is the title of the article.

Initially the article was to be in QEX, but to my surprise it got bumped up to QST.

Good for the League to emphasize we now need to do better on the transmit side.

What is the bottom line?

- On the lower bands at night, use of your receiver attenuator is usually appropriate.
- For a superhet radio there is no point in band noise reading upscale on your S meter.
- Flex and Apache adjust AGC threshold differently.
- A preamp is generally 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.

My caution about preamp usage !

- With a superhet, like a K3S, TS-890S & FTdx-101D, you can often get away with improper usage of a preamp due to the narrow roofing filters. Most signals on the band will be rejected by the roofing filter.
- Overload is less likely.
- A direct sampling radio in effect has a roofing filter (BPF) of more than the whole band. (IC-7610)
- 3-4 MHz, 6-8 MHz, 11-15 MHz, 15-22 MHz, 22-30 MHz
- Running a preamp when there is zero reason to do so just asks for the ADC to be driven into overload.

  (OVF display for an Icom 7610/7300/9700)

Don’t be a slave to one number !

- Let me emphasize there are great products now from all five major OEMs.
- Note the 18 models listed earlier with a dynamic range of 90 dB or greater at 2 kHz.
- Pick your personal desired performance level and price, then look at the whole picture.
- Examples: good ergonomics, reliability, factory service, clean RX & TX audio, NR & NB, spectrum display, timely firmware upgrades.
- Long term cost of ownership!

What not to worry about today

- Sensitivity is not an issue 160 – 6 meters.
- Selectivity with today's DSP is excellent.
- Drift? Long gone !
- Alignment is no longer an issue.
- (No more slug-tuned pre-selectors.)
- Unless your main emphasis is Field Day in a multi-transmitter environment, have another ham very near by, or operate a multi-multi contest station, if you operate your radio properly, overload is unlikely.

Rankings by importance

- This may be “heresy” from someone who tests transceivers.
- Location, Antennas, Operator Skill, choice of your radio model.
- You may not have many options for #1 & #2.
- I moved to the country and put up 6 towers.*
- Operator skill can always improve.
- Don’t buy a really poor performing radio!
- Your radio doesn’t have to cost a fortune.

*See next slide

Here is where I moved 12 years ago!

http://www.NC0B.com

Sherwood Engineering

Videos from past CTU presentations

CTU 2013 through 2019 (Select desired year)

http://www.contestuniversity.com/videos

Sherwood Shootouts (Contest Comparisons) published by DJ0IP

http://www.dj0ip.de/sherwood-forest/sherwood-s-shootouts/

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