Receiver Performance
+
What is the limit today?

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Lots of good RX but transmitters lagging

- **What is important in a DX pile-up?**
- We need Good Dynamic Range to hear weak signals in the presence of near-by strong signals.
- In a DXpedition the pile-up is typically:
- CW signals “Up 2” or SSB signals “Up 5 to 10”
- DX pile-ups Contests, it is the same problem
- You need a better receiver for CW than for SSB.
- **What is the weak link today? Transmitters!**

State-of-the-Art in 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
- TS-890S & FTdx-101D top RMDR performers
- Apache 7000DLE
- None are RMDR (phase noise) limited

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 CQWW SSB

- Yaesu FTdx-101D shipped in late April 2019
- Hybrid architecture
- Dual receivers
- Arrives at Sherwood lab May 9, 2019.

Kenwood TS-890S

- The weak point of the TS-990S was phase noise in the LO (local oscillator).
- Likely only a problem in high RF environments
- This limitation is 100% corrected in the new TS-890S, plus the much better bandscope.
- To get accurate RMDR measurements I had to purchase several Wenzel low-noise crystal oscillators.
- However measuring dynamic range (DR3) was not an issue with HP 8642A synthesizers.

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)

Will there ever be a TS-990SG model that merges the 890S technology into the 990S?

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.

Hybrid Down-conversion Superhet with Direct Sampling Bandscope & Waterfall
RMDR measurements made on 7.0 MHz with Wenzel crystal oscillator.

A comment on the Elecraft K4

- The K4 was announced at Dayton 2019.
- The base unit will be much like an IC-7610.
- Add the superhet module, (K3s performance) the architecture will be similar to the Yaesu FTdx-101D.
- The K4 superhet mixer option will feed its output to the ADC chip, and then down stream.

How did these two rigs stack up?

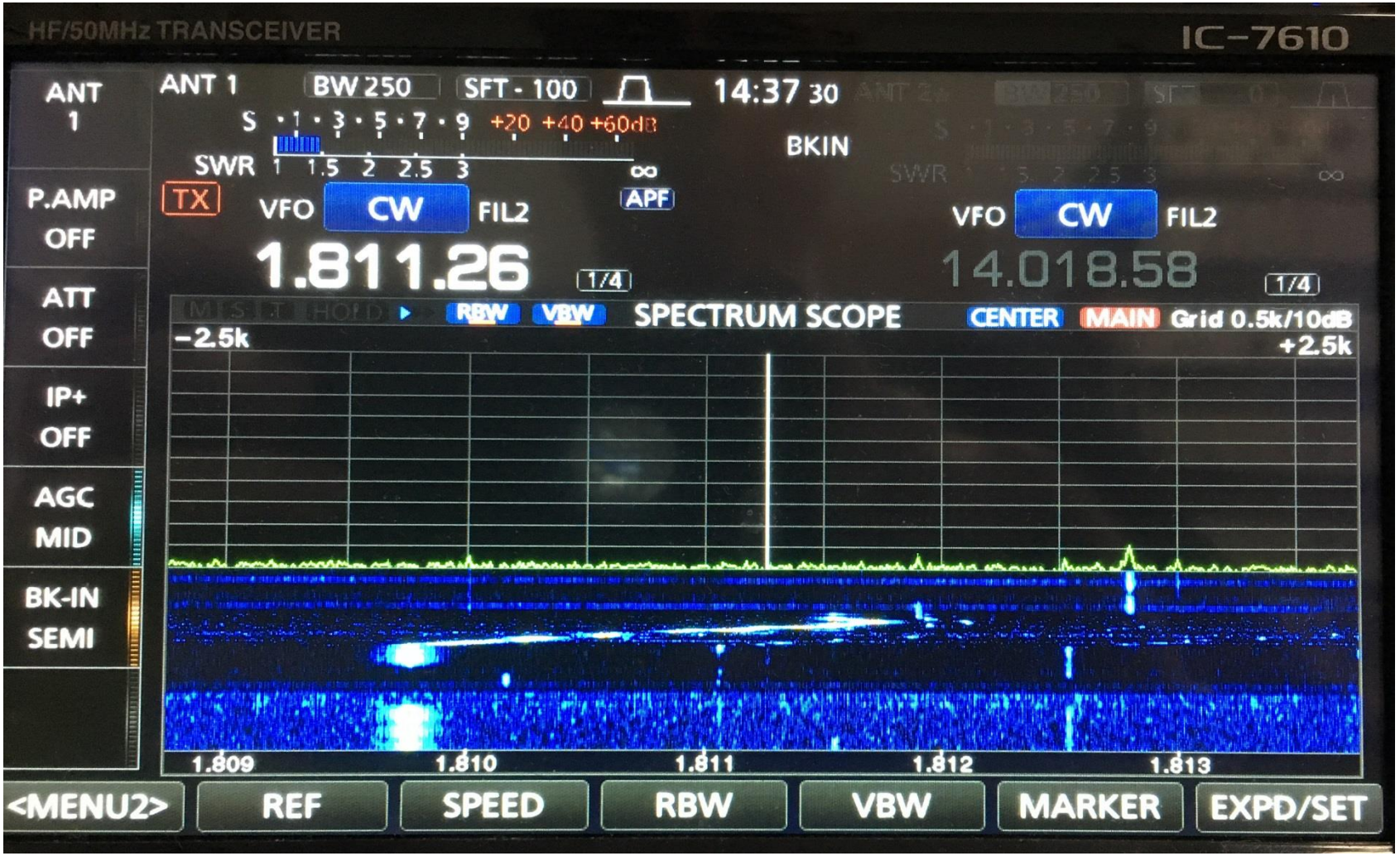
- While CQWW SSB is important, adjacent-channel splatter dominates over rig differences.
- More on transmit issues later.
- ARRL 160m CW a good test for lots of QRM.
- ARRL 10m: A good test for weak signals.
- DSP & APF selectivity excellent on both.
- NR & NB the Icom wins
- Waterfall the Kenwood wins hands down, at least the way I operate S&P CW.

For me the Kenwood waterfall makes the radio

- If you are “running”, I doubt the scope/waterfall make much difference.
- For the S&P operator, CW or SSB, Kenwood “thought out-of-the-box” from my perspective.
- The following show the differences in the waterfall as you tune the radio to the next station to work.

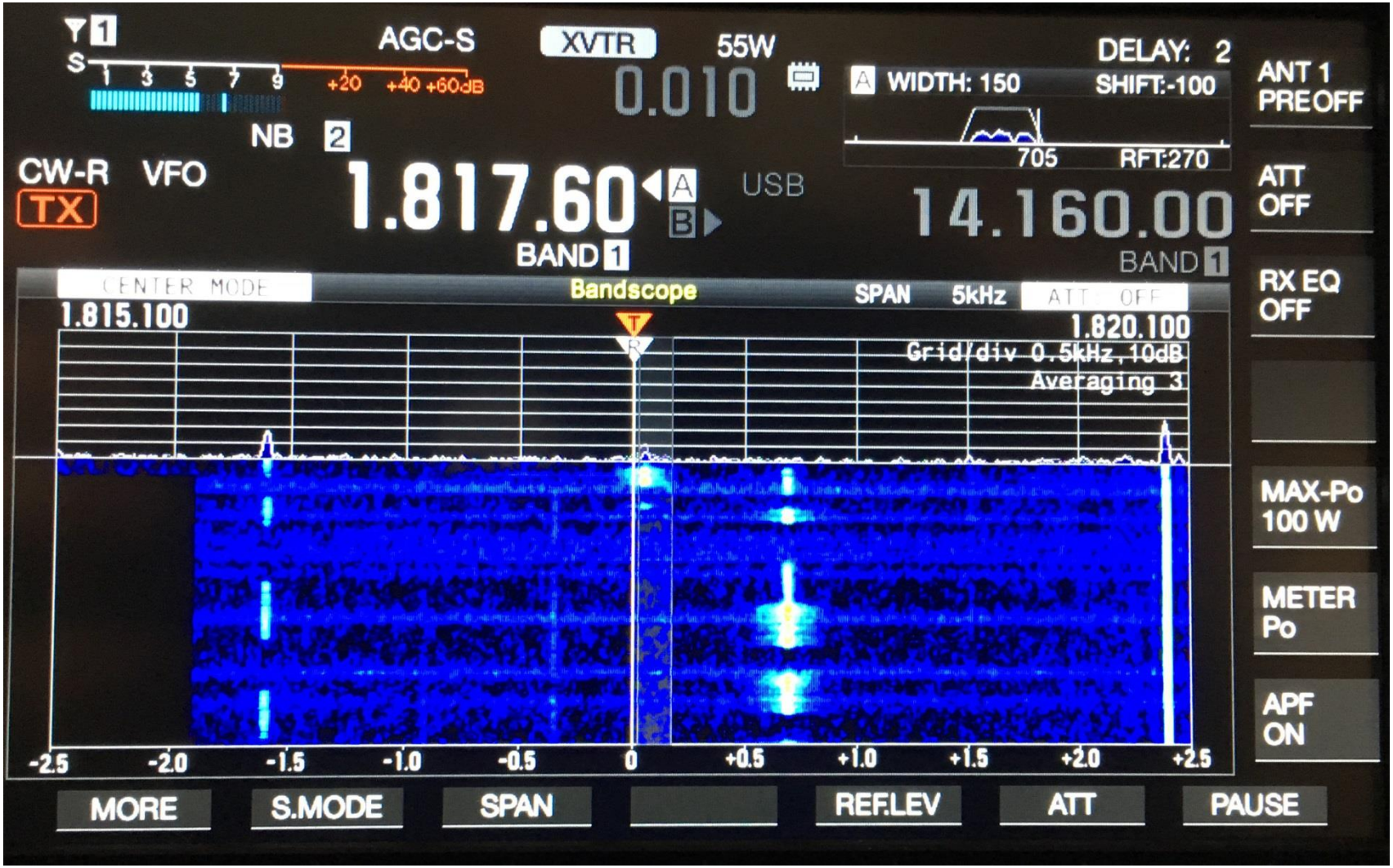
My workaround: use band scope with averaging OFF

Icom waterfall slewing issue while tuning



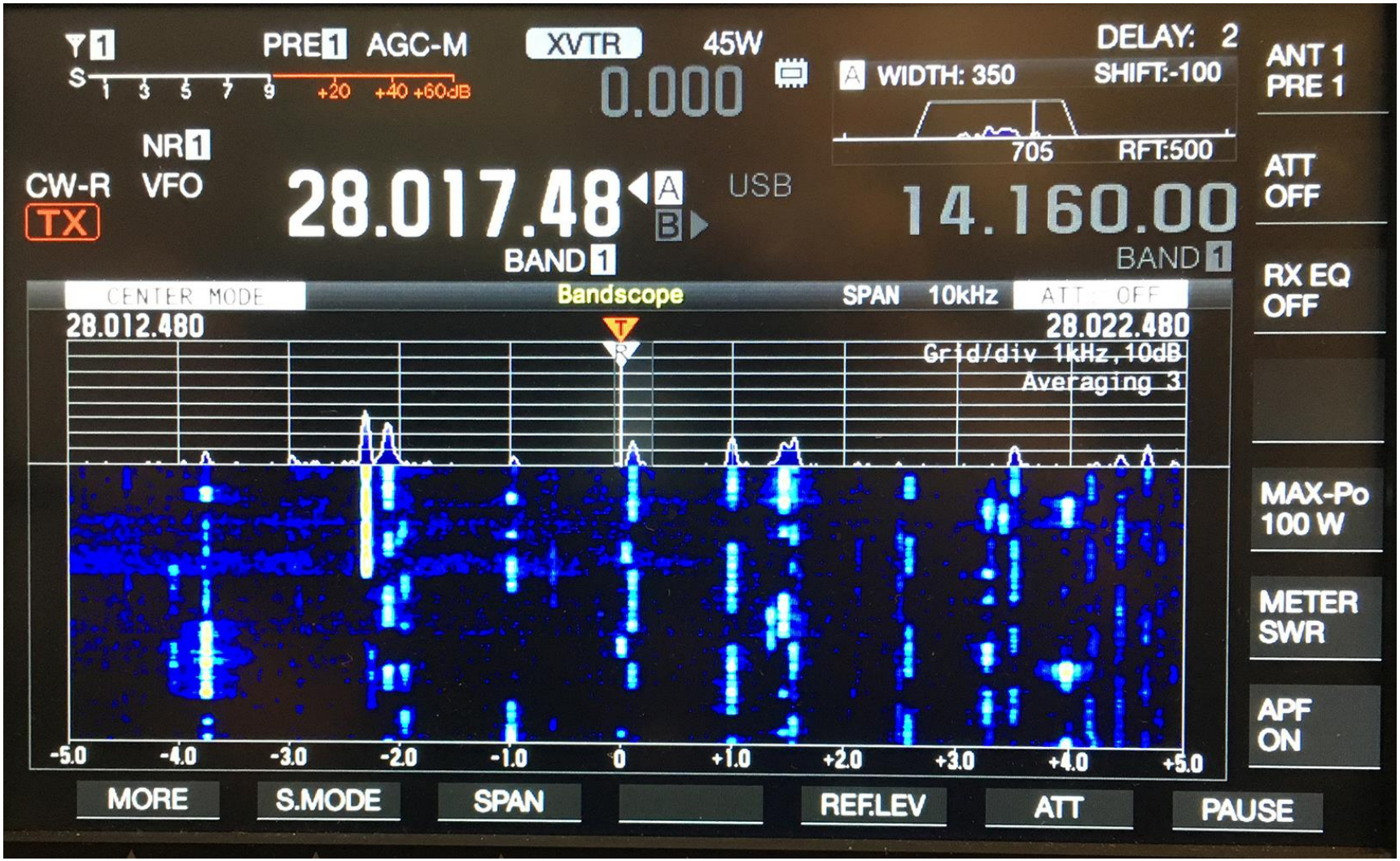
Whole waterfall shifts, but leaves a blank space

Kenwood waterfall while tuning



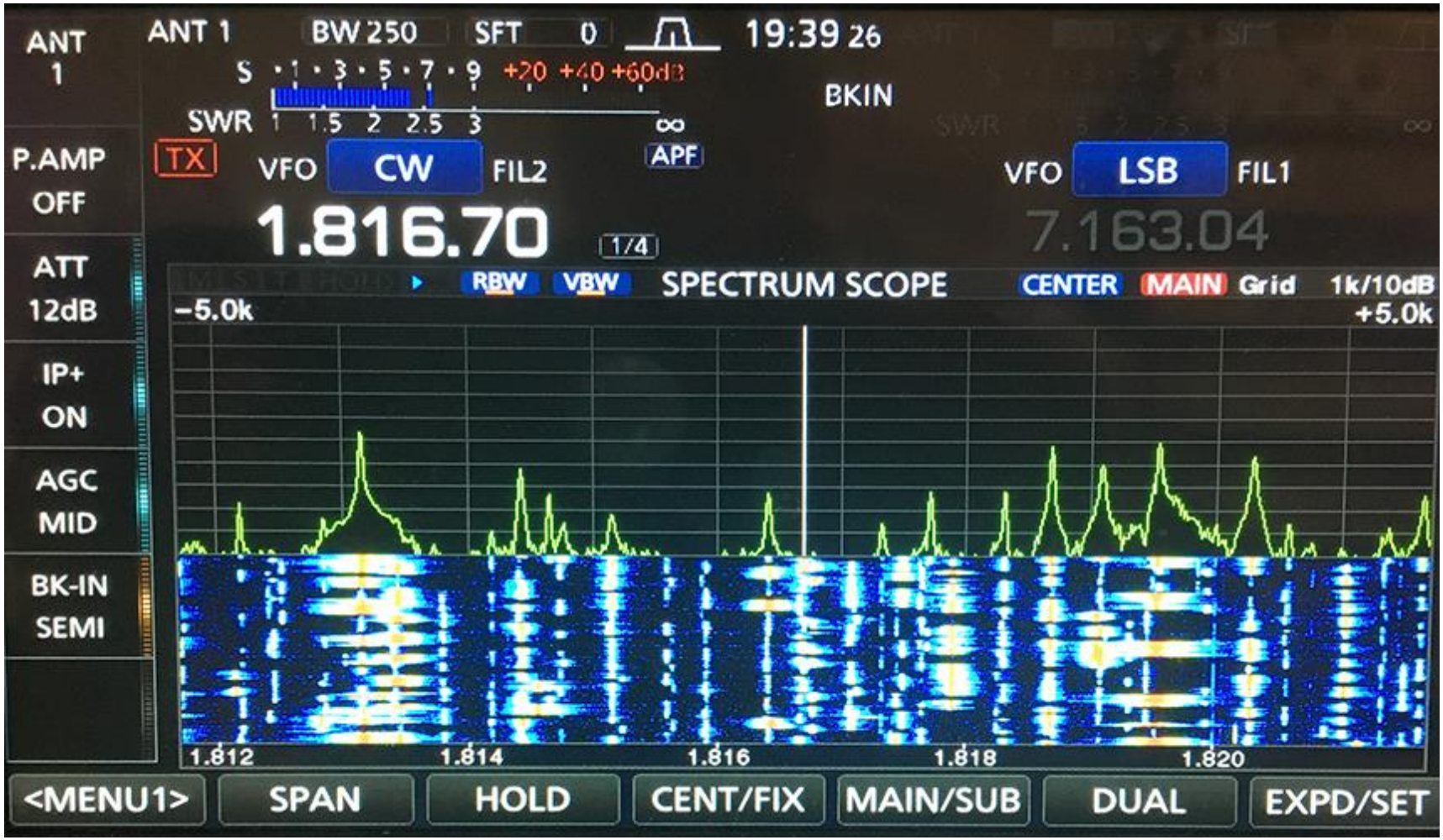
Over 20 stations in 10 kHz (ARRL)

The 10m band Saturday afternoon



Over 30 stations in 10 kHz IC-7610

CQWW 160m CW Friday 7:40 PM



The year of the hybrid legacy & DS SDR radios

- Examples Legacy: K3S & Ftdx-5000, down conversion
- Examples Direct Sampling: Apache, Flex & Icom
- Dayton 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!
- * Slightly different in 101D, but accomplishes same thing.

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
- Flex knob, or possibly Maestro for Flex

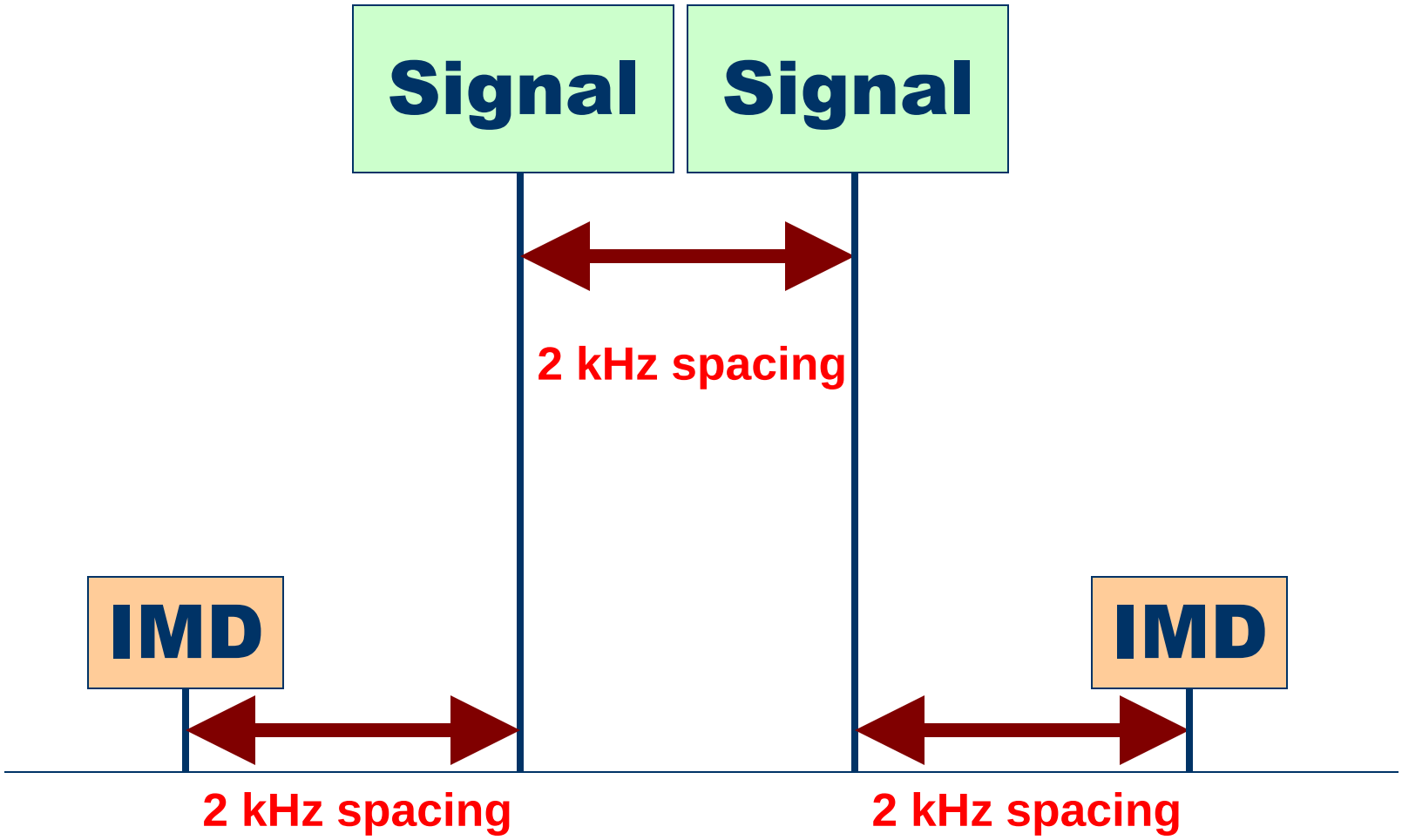
Time for the numbers

- 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.

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
- Defined in QST *& hr magazine* 1975
- Noise floor = -128 dBm, test signals = -28 dBm
- -128 dBm minus -28 dBm = 100 dB
- Dynamic Range (DR3) = 100 dB

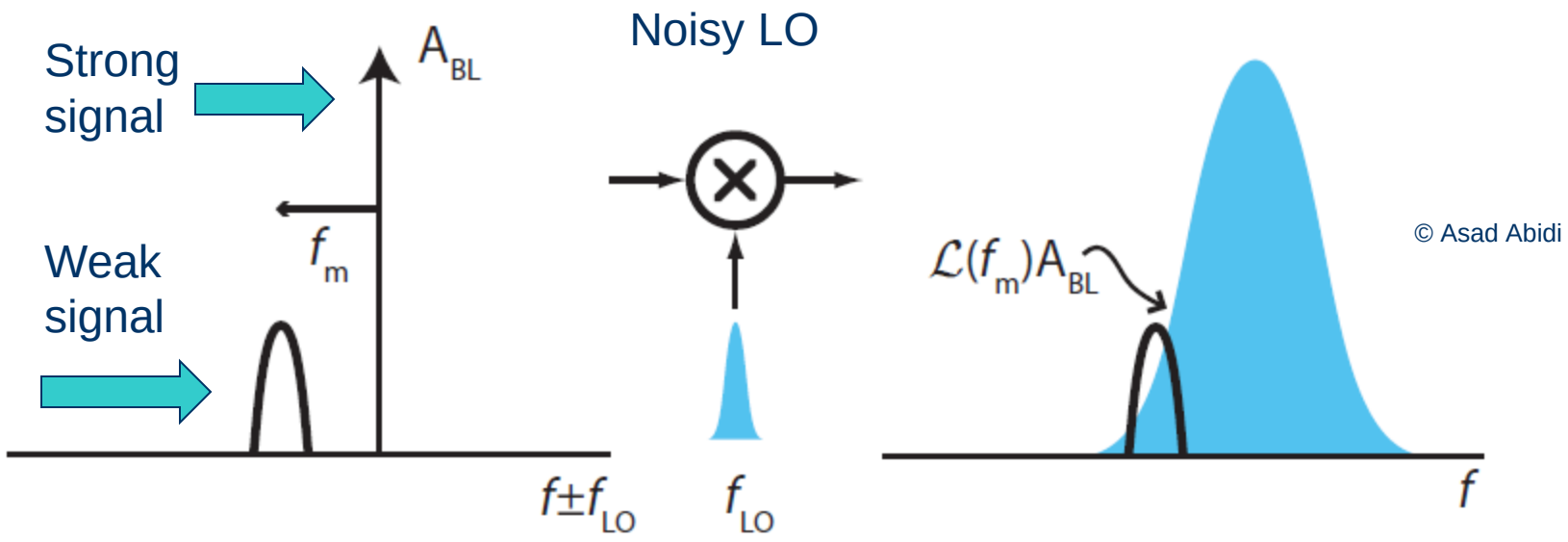
Third Order IMD to Measure Dynamic Range



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 even lower

Why is higher DR3 needed on CW?

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

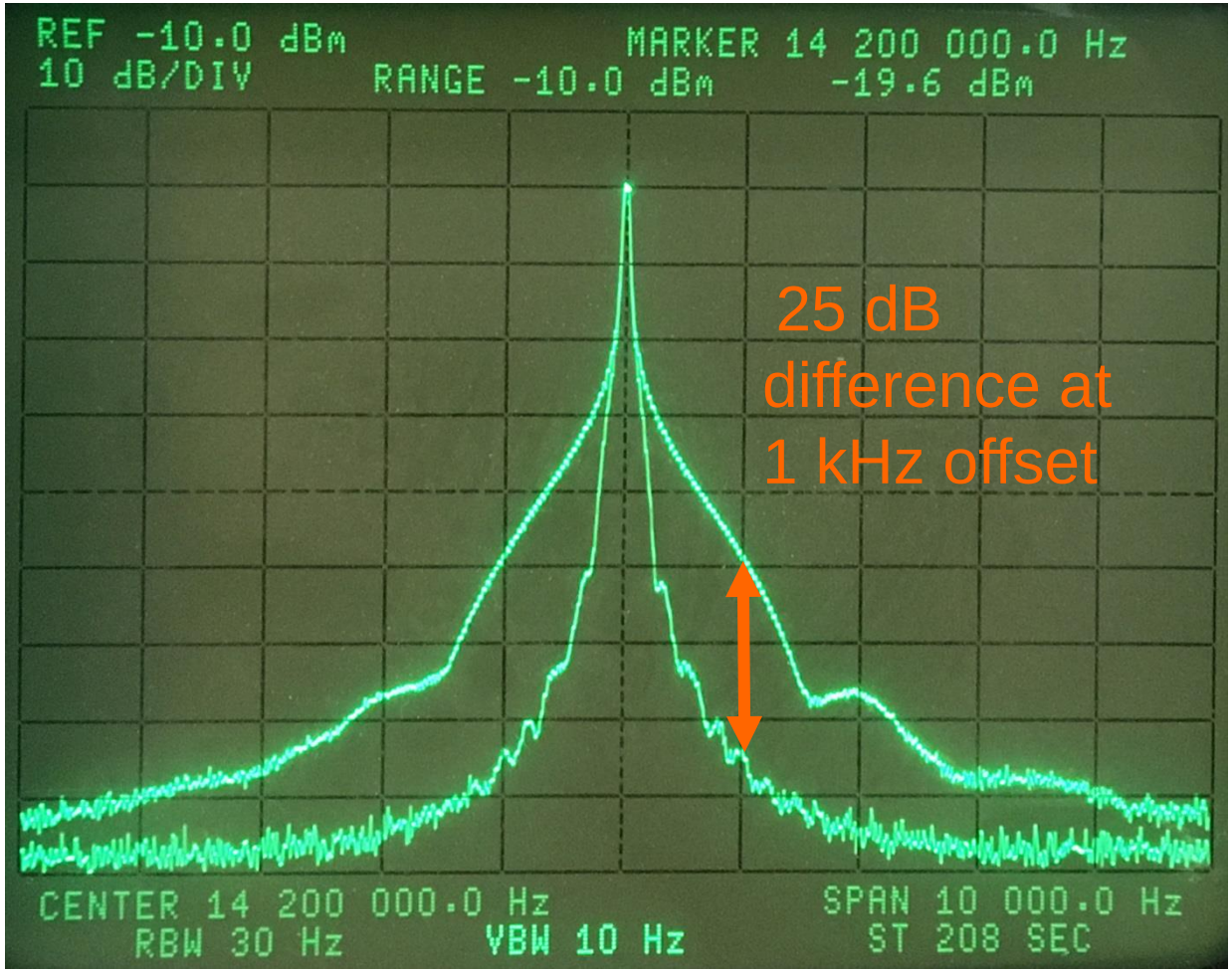
- A CW signal is about 1 kHz wide at -60 dB.
- An SSB signal is about 10 kHz wide at -60 dB.

- 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 !!!!

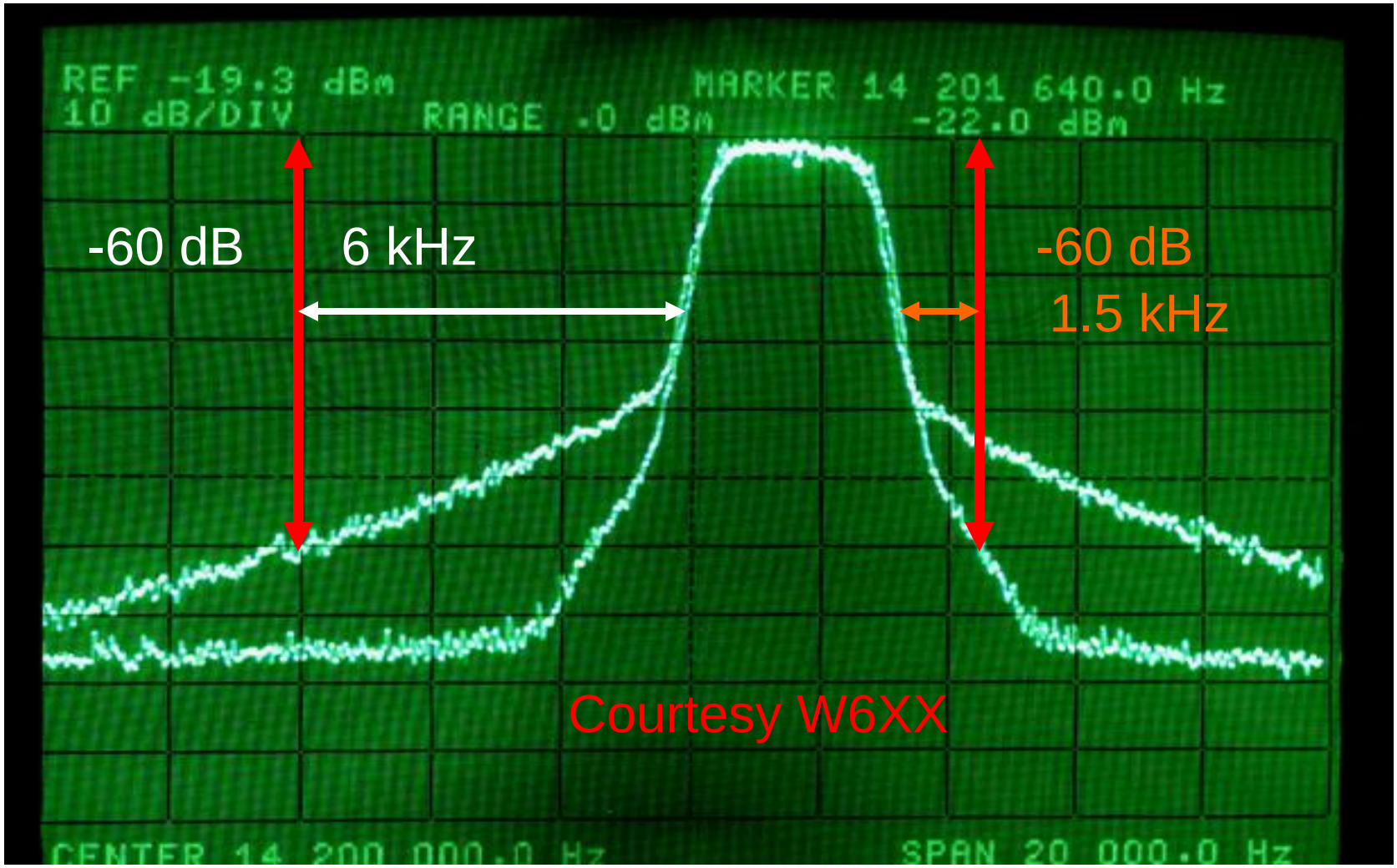
Spectrum of CW Signal on HP 3585A Analyzer

Comparison of 1msec vs 6msec rise time



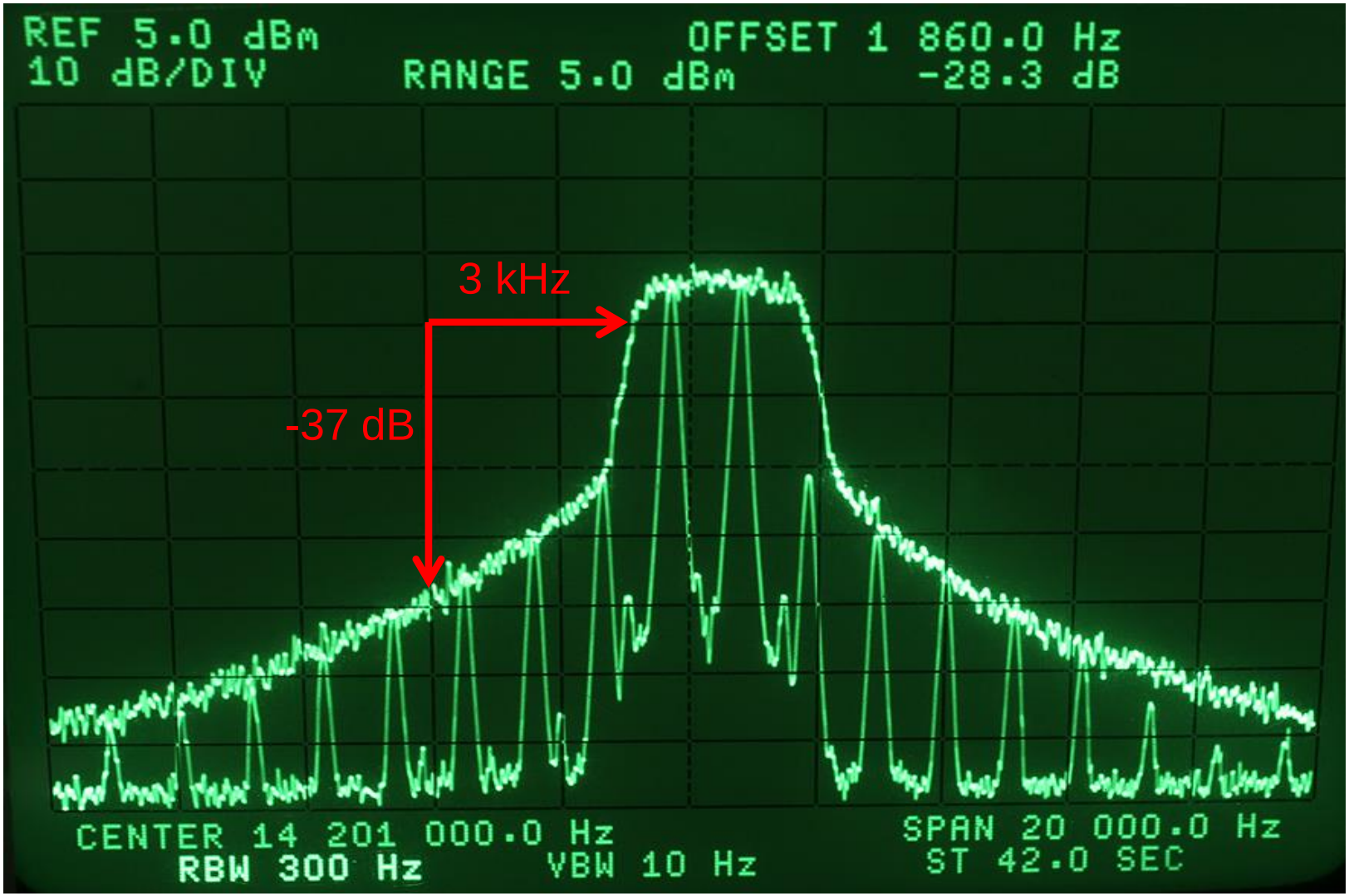
Apache PureSignal similar to class A

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



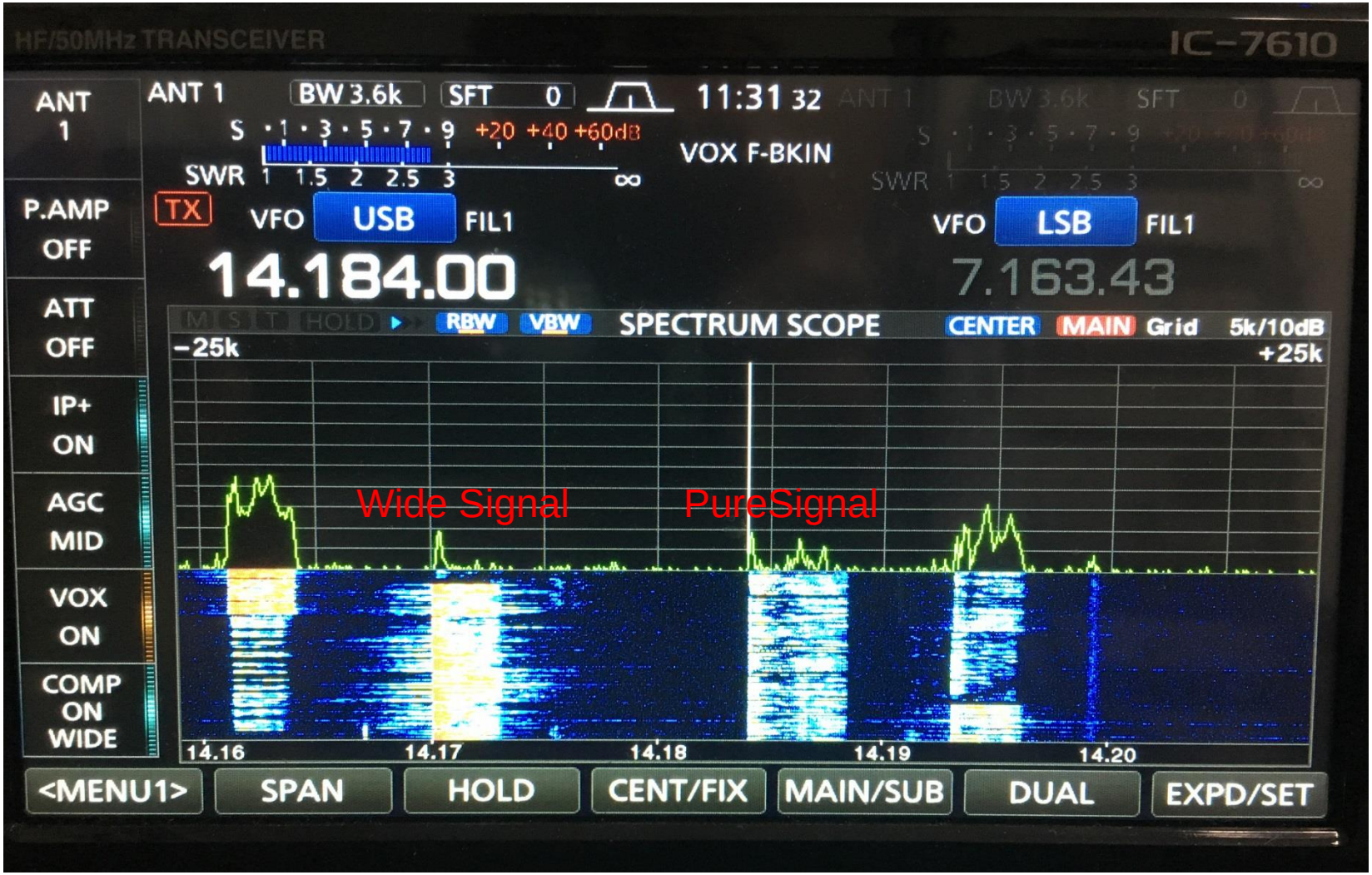
How Wide Is Your Signal ?

Comparison 2-Tone vs. Noise Intermodulation Bandwidth



Pre-distortion example on 20m June 2019

Will we ever see pre-distortion as a standard feature?



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-590SG is a 92 dB radio @ 2 kHz.
- N2IC wins contests with two TS-590 radios.
- Consider dynamic range a “window” of performance that can be moved around in absolute level by properly using your attenuator or preamp.

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 usually the limit today.
- During January 2019 CQWW 160m CW, one station had key clicks at least 2 kHz wide.

* Apache PureSignal the exception on SSB

3 kinds of Transmitted noise

- We have odd-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 100 watts

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.

Low drive amps are an issue

Noise gets worse at 30 watts output

Rig	10 kHz dBc/Hz	100 kHz dBc/Hz
K3S	-132	-140
IC-7851	-123	-133
IC-7610	-122	-127
Flex 6400	-120	-137
FTdx-3K	-117	-117
TS-890S	-115	-135
IC-7300	-110	-116

Do you have a multiplier station besides your run station?

Broadband noise matters.

There is a trade-off. The rig may be cleaner from an IMD splatter standpoint at 30 to 50 watts, but the composite noise is worse.

The League is looking at a solution

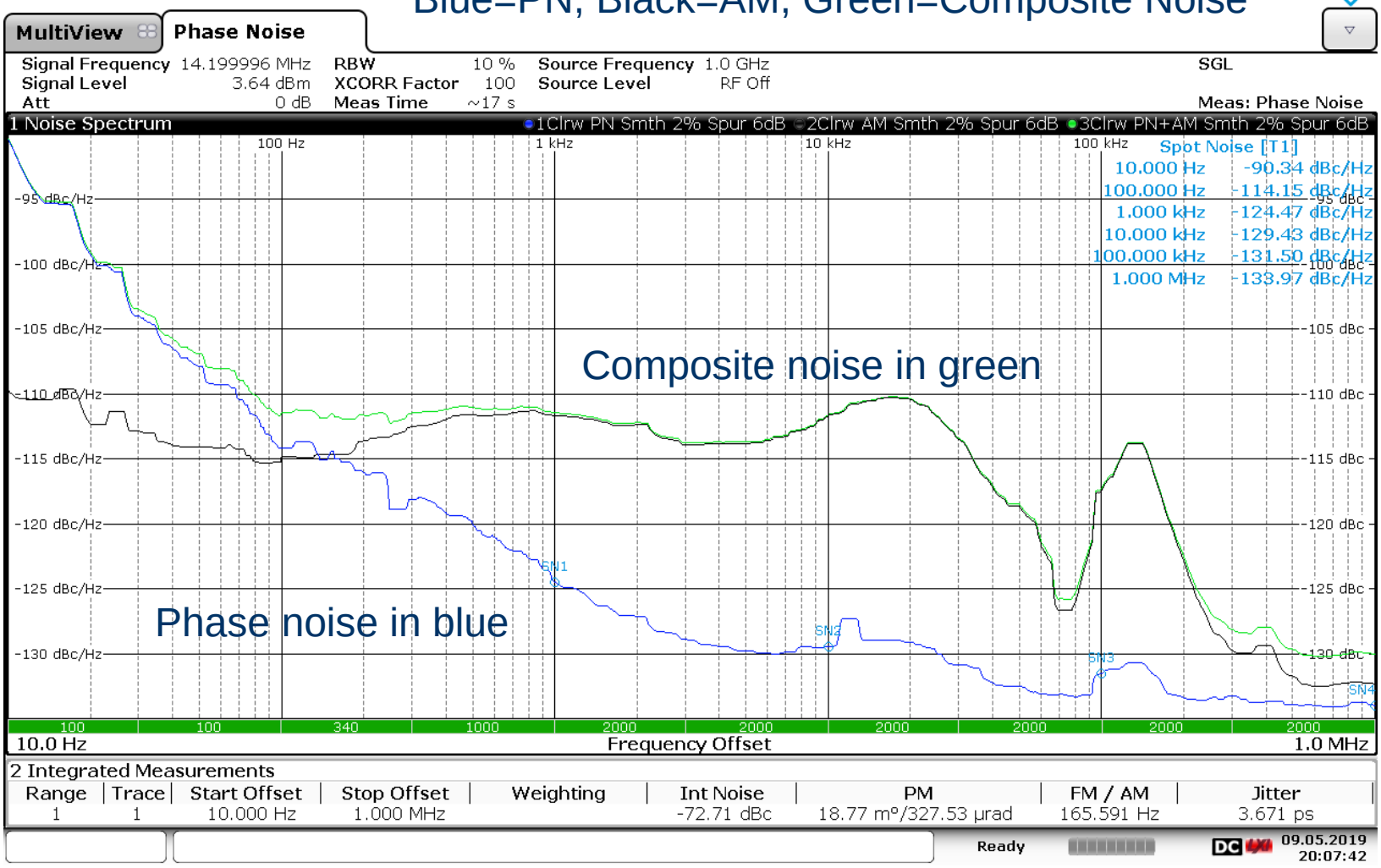
ARRL noise measurements are incomplete

- 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 of 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 a popular solid-state amp listed third-order IMD down only 30 dB, with no comment on this value.

Another new amp measured only 27 dB 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.

What is the bottom line?

- On the lower bands at night, use of your receiver attenuator is usually appropriate.
- There is no point in band noise reading upscale on your S meter.
- 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)

How do we evaluate & optimize a transceiver?

- 160 – 40m receivers are too sensitive at night.
- Make the most of the radio's dynamic range by properly using the attenuator, and using the preamp only when necessary on the high bands.
- Published dynamic range can be misleading, depending on how it is measured.
- This could be a presentation on its own.
- Get feedback from successful contesters & DXers.
- What works for them?

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 then look at the whole picture.
- Examples: good ergonomics, reliability, factory service, clean RX & TX audio, NR & NB, spectrum display, timely firmware upgrades.
- Total cost of ownership – Repairs over time.

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.
- Unless your main emphasis is Field Day in a multi-transmitter environment, or multi-multi contest operation, if you operate your radio properly, overload should not be an issue for most of us.
- Europe on 40m is a different environment.

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 “dud” radio! Hi Hi
- Your radio doesn’t have to cost a fortune.

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/