re-discover radio

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TAPR DCC
Noise in a Digital World

September 15, 2017

Stephen Hicks, N5AC
VP Engineering, FlexRadio Systems

About me


N5AC


N5AC

TAPR DCC Noise in a Digital World

Agenda

- Knowing Noise
- dB, dBm, mW, W, Oh my…
- Noise Figure, Sensitivity and Gain
- FLEX-6000 Family Line-Up
- Q&A

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Knowing Noise

Do you know…?

- Why does the noise floor in my panadapter drop when I change panadapter bandwidth?
- Is my radio out of calibration if my receiver noise measurement doesn't match my panadapter noise floor?
- I can see a signal in my panadapter, but I can't hear it… my radio must be broken, right?

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Knowing Noise
Do you know…?

- You're selecting a radio … do you care about sensitivity, noise figure, preamp gain, something else?
- Is there a relationship between any of these numbers?
- Your buddy is boasting about his rig's sensitivity (which is 3dB better than yours). Is this important? Should you be ashamed and trade rigs?

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Knowing Noise

Do you know…?

- I looked up the ADC in my direct sampling receiver, it says 16-bits with an ENOB of 12.3 bits and 74dB SNR. I know there are 6dB per bit of dynamic range. 12.3 x 6 = 74. Heck, even if I could use all 16-bits, 16 x 6 = 96dB. My radio manufacturer says it has 105dB of 3rd order dynamic range.

He's lying, right?

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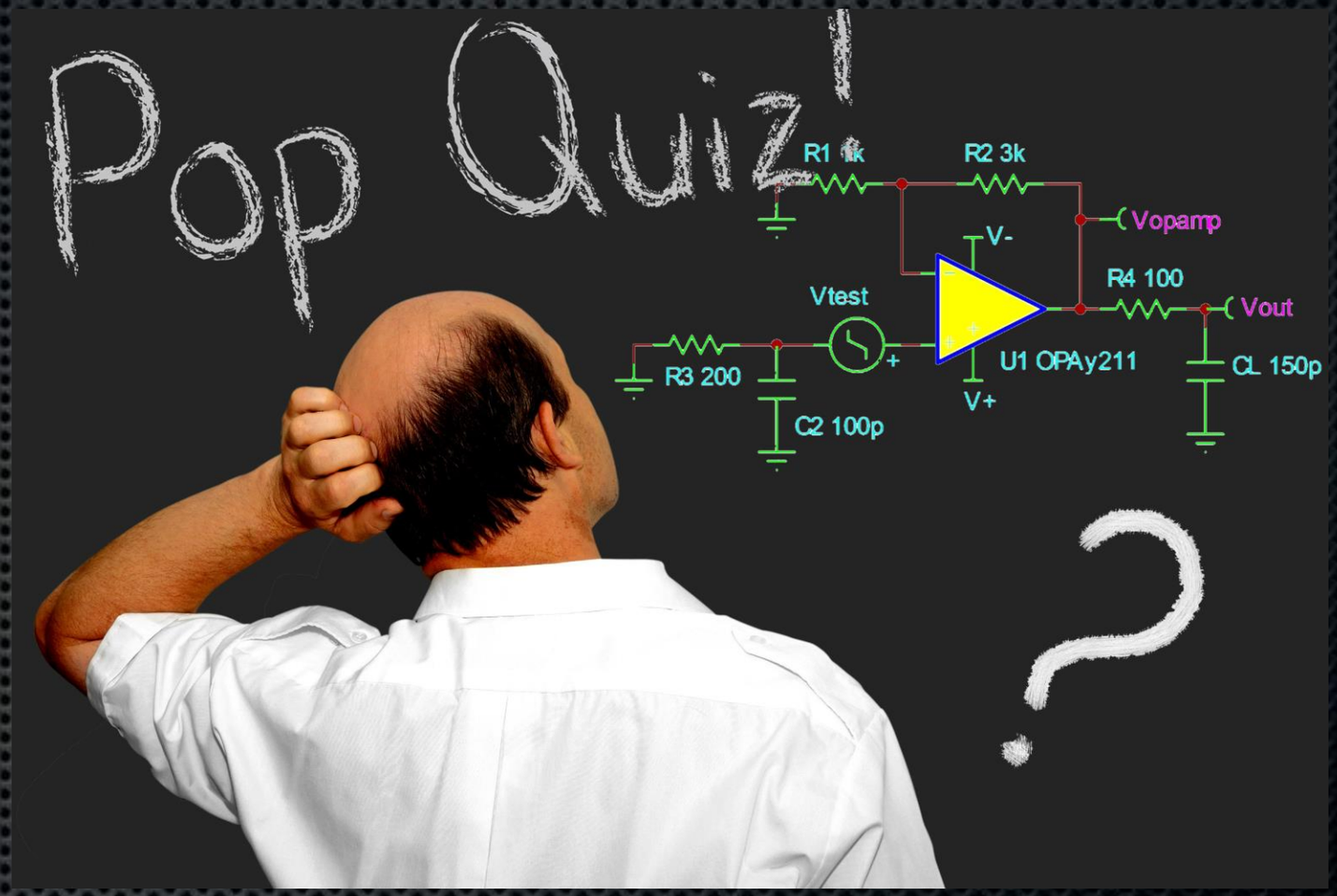
dBm, dB, et. al.

Quick review

- dB is a measurement of difference in two things (relative)
- dBm is a measurement of power (dB wrt 1mW)
- 2x power = 3dB, 10x power = 10dB
- Multiplication in power (W) = Addition in dB
- 1W = 1,000mW … 1000 = 10x10x10 = 30dB so 0dBm + 30dB = +30dBm

dBm, dB, et. al.

POP QUIZ!



- What is 20x power?
- 10x = 10dB
  2x = 3dB
  so 10 x 2 = 20, and
  therefore
  10dB + 3dB = 13dB
- What is 200mW in dBm?
- well 1mW = 0dBm
  200 = 10 x 10 x 2 …so
  10dB + 10dB + 3dB + 0dBm = 23dBm

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dBm, dB, et. al.

POP QUIZ!

- What is 5W in dBm?
- well 1W = 30dBm
  5W = 1W x 10 / 2
  = 30dBm + 10dB - 3db = +37dBm
- What is 4W in dBm?
- well 1W = 30dBm
  4W = 1W x 2 x 2
  = 30dBm + 3dB + 3dB = +36dBm

TRICKY!

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Knowing Noise Sources

They're everywhere

- Thermal noise
- Gaussian noise
- Flicker Noise
- Quantization Noise
- Phase Noise
- Additive Noise
- Powerline Noise
- Splatter
- Power Supply Noise
- Atmospheric Noise
- Spark Noise
- EMI

Noise can be complicated and even those that know it well will have to think and figure on some questions

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Noise and Bandwidth

What is the *Noise Floor*?

- We often hear “Noise Floor,” we know how to point at it, but what is it?

Noise Behavior

Better get a bucket…

What your ADC sees:

Think of noise as trough of water

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Noise Behavior

Better get a bucket…

What Happens if I split the trough into two troughs?

Water level drops by a factor of two (3dB)

(note: *all computations in the water domain*)

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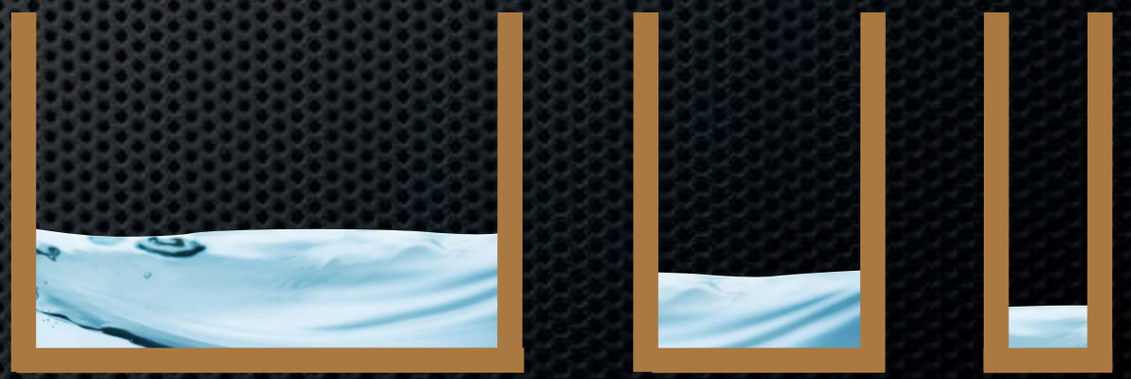
Noise Behavior

Find the diamond…

There's a diamond at the bottom of the trough

I'll give you as many bins as you want,
in many sizes (all factors of 2)

How can you find the diamond?



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Noise Behavior

Find the diamond…

What if you split the water into 1024 buckets, each 1/1024 the size of the original trough?

Congratulations, you've just created the first water trough FFT!

a.k.a. the WTFFT

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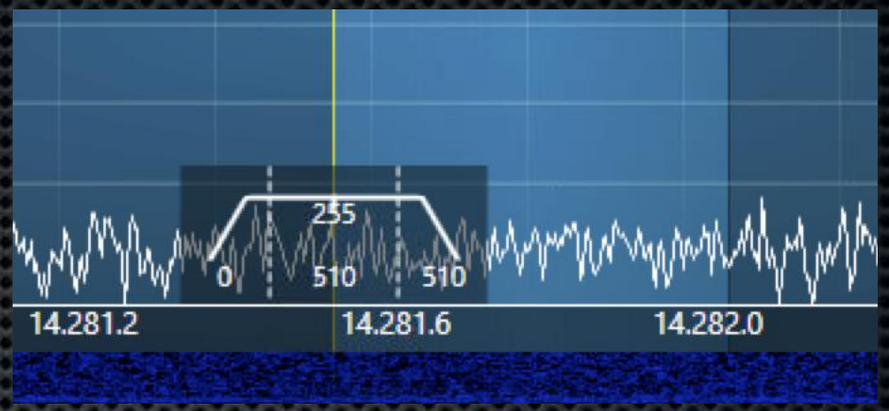
Noise Behavior

OK, what about a RADIO?



- In a receiver (on an FFT bin), we filter
- Bandwidth limited to receiver bandwidth
- Noise is reduced in dB by:

$$10\log_{10}\left(\frac{BW_{initial}}{BW_{final}}\right)$$

Think of an FFT as a series of receiver S-Meters stacked next to each other

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Noise Behavior

OK fine, but how does this work in a RADIO?

- So for our 1024-bin WTFFT, we reduced the water in each bin by:

$$10\log_{10}\left(\frac{1024}{1}\right)=30.1dB$$

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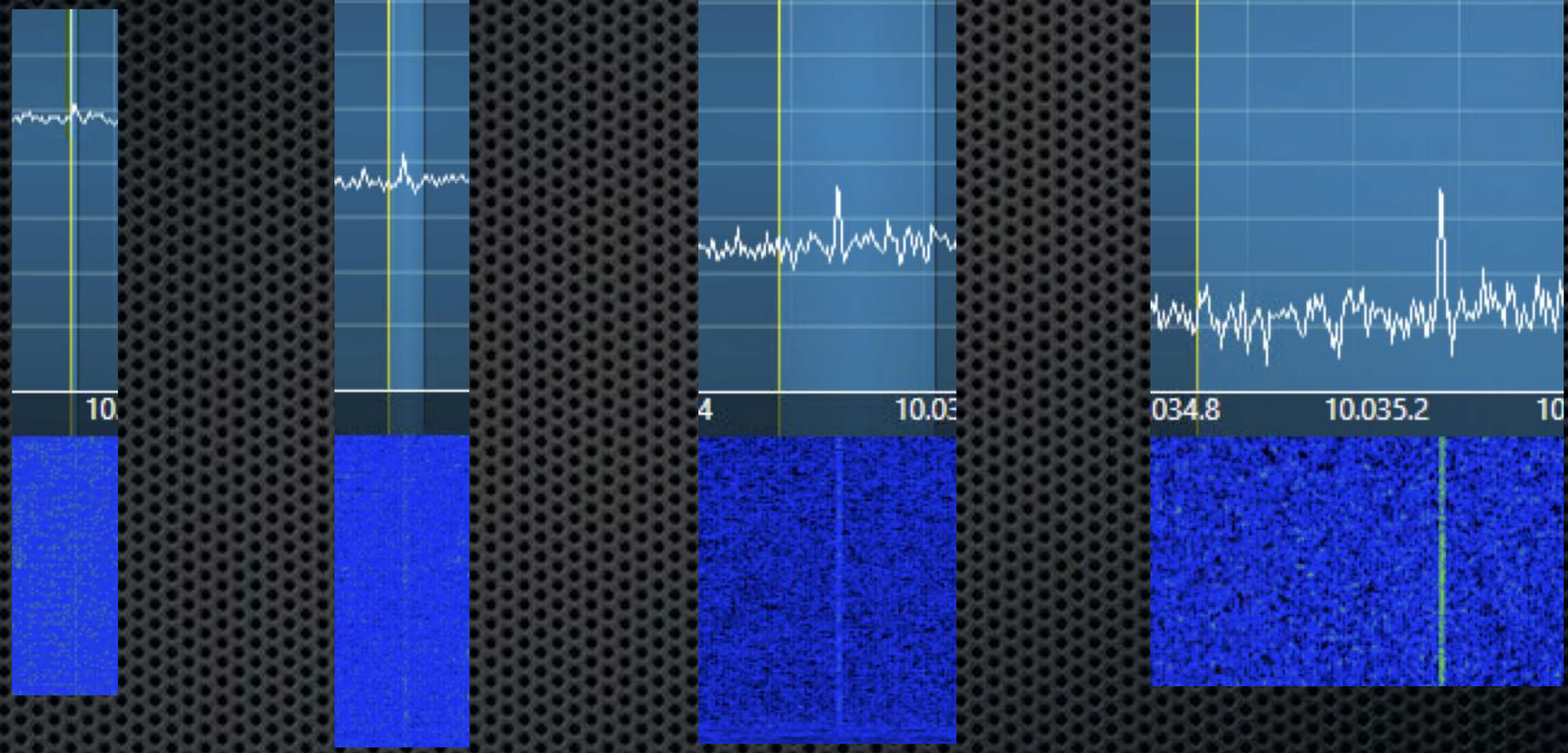
Noise Behavior

Why doesn't my signal go down too?

- If your signal is contained entirely in a single bin, you lose none of it by filtering
- If your noise is evenly distributed, you reduce it as shown in the previous slide
- If you split the signal (evenly) across two bins, it will reduce by 3dB in any one bin
- For the pedantic: yes we're ignoring window leakage, scalloping, etc.

Noise Behavior

WSJT



Noise drops as we narrow bandwidth, exposing the signal

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Noise Behavior

Does this ever NOT work?

- YES, when not evenly distributed (not AWGN)
- For example: Frequency dependent noise source
- Special tools…

Noise Behavior

Review

- QUESTION: Why does the noise floor in my panadapter drop when I change panadapter bandwidth?
- ANSWER: We reduce the noise by 3dB each time we reduce the bandwidth by half

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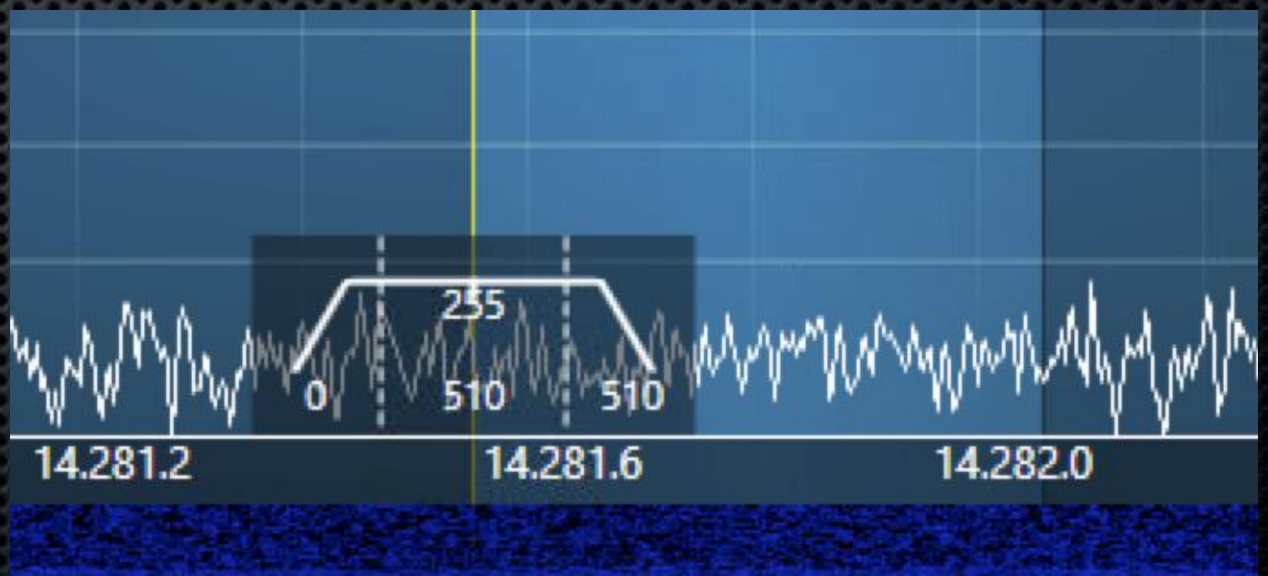
Noise Behavior

Review

- QUESTION: Is my radio out of calibration if my receiver noise measurement doesn't match my panadapter noise floor?

- ANSWER: NO, look at the difference in receiver bandwidth and panadapter FFT bin size



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Noise Behavior

Review

- QUESTION: I can see a signal in my panadapter, but I can't hear it… my radio must be broken, right??
- ANSWER: NO, a good FFT is generally a better instrument than your ear/brain when the bin size is small (<~50Hz).

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Noise Behavior

Review

- QUESTION: Assuming your signal strength in your 500Hz receiver (noise only) says -100dBm and your panadapter shows -120dBm, what is your FFT bin size?
- ANSWER: 5Hz

$$10\log_{10}\left(\frac{500}{x}\right)=20dB$$

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Noise Floor

Terminology

- “Noise Floor” is used haphazardly
- Vendors, ARRL, etc. use 500Hz bandwidth
- Noise Floor down as bandwidth is decreased
- WSJT, CW, etc take advantage of this
- “12dB below the noise floor,” they mean the 500Hz noise floor. If their detector (filtered receiver) is only 10Hz wide, they are hearing 5dB ***above*** the actual noise floor for the receiver.

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Noise and Bandwidth

What is the *Noise Floor*?

- “That’s pretty — what’s the noise floor of that receiver, there?”

Knowing Noise

Do you know…?

- I looked up the ADC in my direct sampling receiver, it says 16-bits with an ENOB of 12.3 bits and 74dB SNR. I know there are 6dB per bit of dynamic range. 12.3 x 6 = 74. Heck, even if I could use all 16-bits, 16 x 6 = 96dB. My radio manufacturer says it has 105dB of 3rd order dynamic range.

He's lying, right?

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Knowing Noise

Do you know…?

- 12.4 bits ENOB is spec'd at the *full bandwidth of the converter*
- We know how to convert — lets say we're going from 100MHz to 48kHz

$$10\log_{10}\left(\frac{100{,}000{,}000}{48{,}000}\right)=33dB$$

33dB+74dB = 107dB = 17.8-bits

Actual bits toggling = 16 * 6 + 33 / 6 = 21.5-bits

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Knowing Noise

Do you know…?

NO, He's not lying

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Noise Figure, Sensitivity & Gain

Oh My!

- You bought a 6m radio with a stated noise figure of 5dB

Where is the noise floor?

A. -128dBm B. -135dBm C. -142dBm
D. Insufficient Information

Noise Figure, Sensitivity & Gain

Oh My!

TRICK QUESTION!

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Noise Figure, Sensitivity & Gain

Oh My!

- You bought a 6m radio with a stated noise figure of 5dB

Where is the noise floor?

A. -128dBm B. -135dBm C. -142dBm

D. Insufficient Information

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Noise Figure, Sensitivity & Gain

What you need to know

- Golden Rule: **0dB NF = -174dBm in 1Hz**
- To calculate the noise floor in ANY bandwidth given the NF and bandwidth:

-174dBm + NF + (dB bandwidth difference from 1Hz)

For example, a receiver with a 5dB NF and a bandwidth of 500Hz has a noise floor of:

-174dBm + 5dB + (10 + 10 +10 - 3) = -142dBm

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Noise Figure, Sensitivity & Gain

What you need to know

What's the golden rule?

0dB NF = -174dBm in 1Hz

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Noise Figure, Sensitivity & Gain

Cascaded Noise Figure

- Cascaded NF tells us the final NF and Gain given a series of preamplifiers / attenuators heading into a receiver

$$NF_C = 10\log\left(nf_N + \frac{nf_{N-1}}{G_{N-1}} + \ldots \right)$$

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Noise Figure, Sensitivity & Gain

Cascaded Noise Figure

- Example: 10dB NF receiver with a 5dB NF preamp with 10dB gain:

Select number of cascaded amplifiers:

2

Noise(dB)	Gain(dB)
5	10
10	0

Calculate

6.1dB

Result:

Total Noise Figure: 6.088 dB
Total Gain: 10.00 dB

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Noise Figure & Sensitivity

What's Important?

	Sensitivity Noise Floor in 500Hz	NF	Preamp NF / Gain
Radio 1	-136dBm	13dB	5dB / 10dB
Radio 2	-123dBm	24dB	2dB / 30dB
Radio 3	-139dBm	8dB	7dB / 20dB

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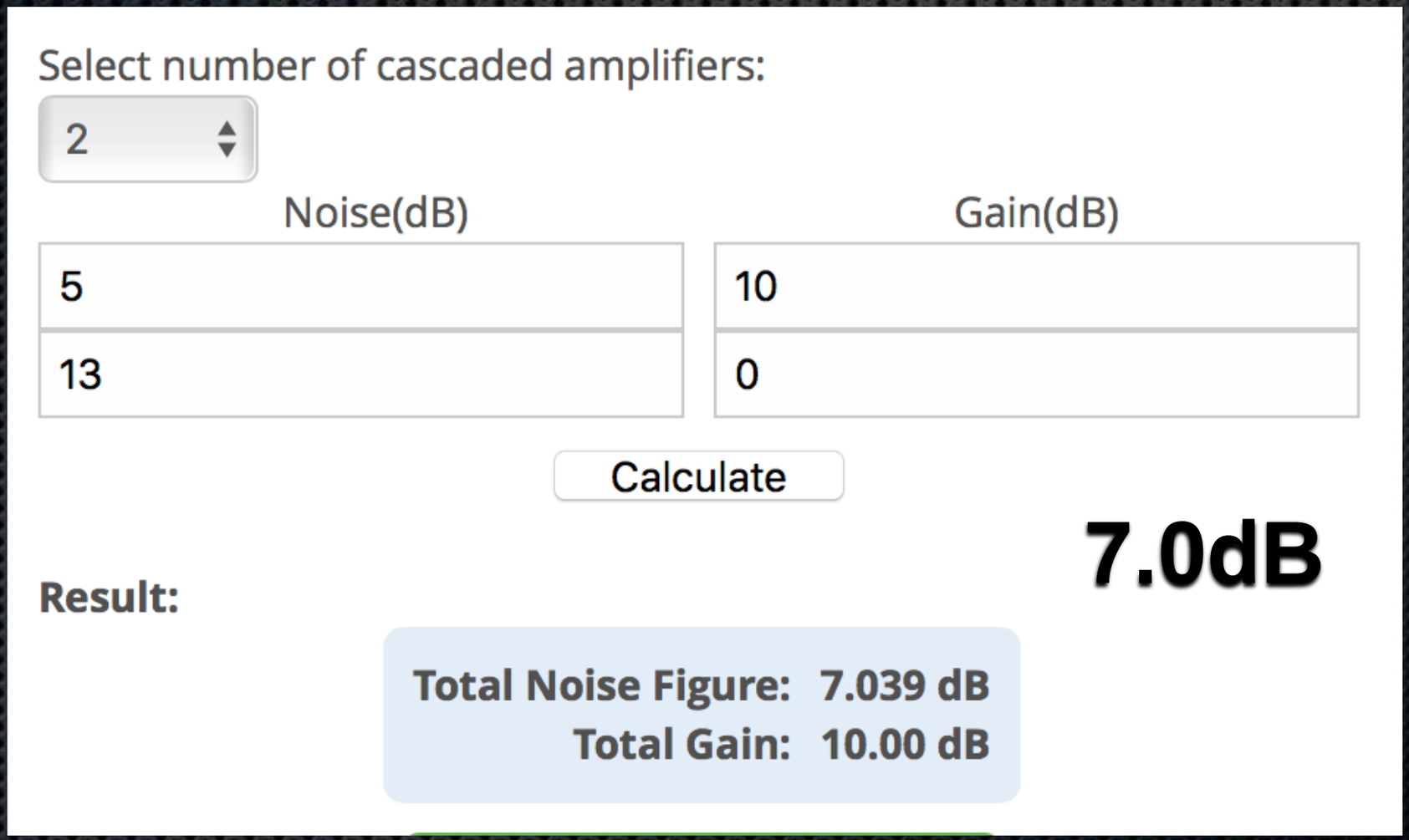
Noise Figure & Sensitivity

What's Important?



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Noise Figure & Sensitivity

What's Important?

Select number of cascaded amplifiers:

2

Noise(dB)	Gain(dB)
2	30
24	0

Calculate

Result:

2.6dB

Total Noise Figure: 2.637 dB
Total Gain: 30.00 dB

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Noise Figure & Sensitivity

What's Important?

Select number of cascaded amplifiers:

2

Noise(dB)	Gain(dB)
7	20
8	0

Calculate

Result:

7.0dB

Total Noise Figure: 7.046 dB
Total Gain: 20.00 dB

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Noise Figure & Sensitivity

What's Important?

	Sensitivity Noise Floor in 500Hz	NF	Preamp Gain	NF /	System NF
Radio 1	-136dBm	13dB	5dB / 10dB		7dB
Radio 2	-123dBm	24dB	2dB / 30dB		2.6dB
io 3	-139dBm	8dB	7dB / 20dB		7dB

The radio with the "worst sensitivity" has the best NF

Go Figure!

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Noise Figure, Sensitivity & Gain

What you need to know

What's the golden rule?

0dB NF = -174dBm in 1Hz

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Noise Figure, Sensitivity & Gain

QUIZ TIME!

You have figured out your radio with the preamp has a 6dB NF. You run coax from your radio to the tower and up the tower to your 6m antenna. You're using 180' of LMR-200 from the rig to the antenna.

What is your system Noise Figure?

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Noise Figure, Sensitivity & Gain

Coaxial Cable Data

Product:	LMR-200
Frequency (MHz):	50
Run Length (Feet):	180

« Reset | Calculate »

PRODUCT PERFORMANCE PARAMETERS

Attenuation:	2.3 db/100ft	7.5 db/100mtr
Average Power:	0.79 KW	
Cable Vg:	83 %	
Nominal Td:	1.22 nSec/ft	4.02 nSec/mtr
Capacitance:	24.5 pF/ft	80.3 pF/mtr
Typical Connector Loss:	0.01 dB/pair	

CABLE ASSEMBLY PERFORMANCE

Cable Run Attenuation:	4.1 dB
Total Cable Assembly Loss:	4.5 dB
Cable Run Efficiency:	38.8 %
Cable Run Time Delay:	220.34 nSec

180’ LMR-200 @ 50MHz

4.5dB LOSS

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Noise Figure, Sensitivity & Gain

What you need to know

Select number of cascaded amplifiers:

2

Noise(dB)	Gain(dB)
4.5	-4.5
6	0

Calculate

10.5dB

Result:

Total Noise Figure: 10.50 dB
Total Gain: -4.500 dB

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Noise Figure, Sensitivity & Gain

QUIZ TIME!

You have figured out your radio with the preamp has a 6dB NF. …

What is your system Noise Figure?

10.5dB!!!

What now?

MAST MOUNTED PREAMP

or BETTER COAX

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Noise Figure, Sensitivity & Gain

QUIZ TIME!

You realize your coax is killing you. You add a mast mounted preamp with 0.8dB NF and 10-20dB of gain (adjustable). What's your NF now?

Select number of cascaded amplifiers:

3

Noise(dB)	Gain(dB)
0.8	10
4.5	-4.5
6	0

Calculate

3.5dB

Result:

Total Noise Figure: 3.472 dB
Total Gain: 5.500 dB

Select number of cascaded amplifiers:

3

Noise(dB)	Gain(dB)
0.8	20
4.5	-4.5
6	0

Calculate

1.2dB

Result:

Total Noise Figure: 1.154 dB
Total Gain: 15.50 dB

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Noise Figure, Sensitivity & Gain

I've got it!!

I totally understand: You should add preamps to lower your NF so you can hear weak signals!

NO… only lower the noise floor to ~6-10dB below your atmospheric noise. Lower just reduces your dynamic range

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Noise Figure, Sensitivity & Gain

QUIZ TIME!

How do you decide where to set the gain??

As you move from 10-20dB, you lower your noise floor by **3.5-1.2 = 2.3dB**, but at the same time, your overload is lowered by **10dB.** The overall affect on DR is 2.3-10=**-7.7dB**

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Noise Figure, Sensitivity & Gain

QUIZ TIME!

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Noise Figure, Sensitivity & Gain

HF Atmospheric Noise

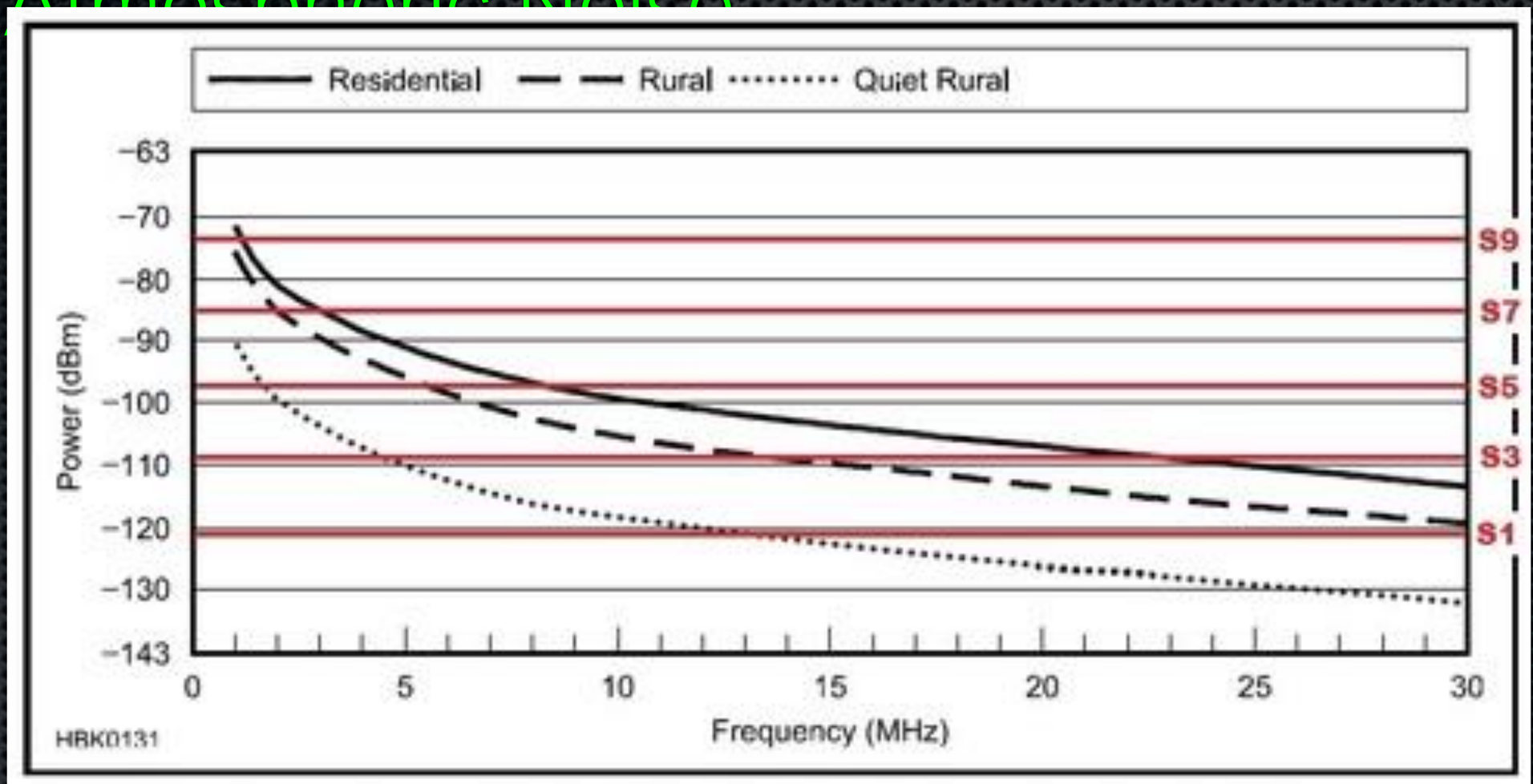

Fig 19.37 — Typical noise levels versus frequency for various environments. (Man-made noise in a 500-Hz bandwidth, from Rec. ITU-R P.372.7, *Radio Noise*)

Noise Figure, Sensitivity & Gain

Review

- QUESTION: Your buddy is boasting about his rig's sensitivity (which is 3dB better than yours). Is this important? Should you be ashamed and trade rigs?
- ANSWER: No, there are many other factors to consider including preamps, ergonomics, RMDR, DR, etc.

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TAPR DCC Noise in a Digital World

Agenda

The Blank Look — We can teach it!

Knowing Noise

dB, dBm, mW, W, Oh my…

Noise Figure, Sensitivity and Gain

FLEX-6000 Family Line-Up

Q&A

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FlexRadio Product Overview

FlexRadio Systems
Software Defined Radios

Maestro

A XVTR ANT1
TX
Po 2.5 5.0 7.5 10.0
S 1 3 5 7 9+20+40
USB 4.7 NB NR ANF QSK RIT DIV
14.303.600

MENU

B XVTR ANT1
TX
Po 2.5 5.0 7.5 10.0
S 1 3 5 7 9+20+40
USB 4.7 NB NR ANF QSK RIT DIV
14.262.500

-100 -105 -110 -115 -120 -125 -130
14.235 14.250 14.265 14.280 14.295 14.310 14.325 14.340 14.355 LIVE
-5s -10s -15s -20s
DISPLAY

A
AF AGCT SQL
LOW SHIFT HIGH WIDTH
SOLO
BW SELECT

B
AF AGCT SQL
LOW SHIFT HIGH WIDTH
SOLO
BW SELECT

MOX TUNE ATU
BYPASS
F1 F2 F3
F4 F5 F6

MIC SPEED PWR
TX MENU

RX RIT TX XIT
A>>B
RX RIT TX XIT

A STEP B

A LOCK B

A MENU/CLR
B MENU/CLR

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Maestro

Take your radio anywhere…

- Local or remote
- In front of the rig or across the world
- Production stalled for months due to supplier problem
- Problem now resolved and production resuming

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PowerGenius XL™

FlexRadio Systems®

Software Defined Radios

Power Genius XL

- 1500W, 33lbs
- 220V *or* 110V (reduced power)
- TRUE SO2R
- Works with any transceiver (CAT, CI-V, BCD, Ethernet)

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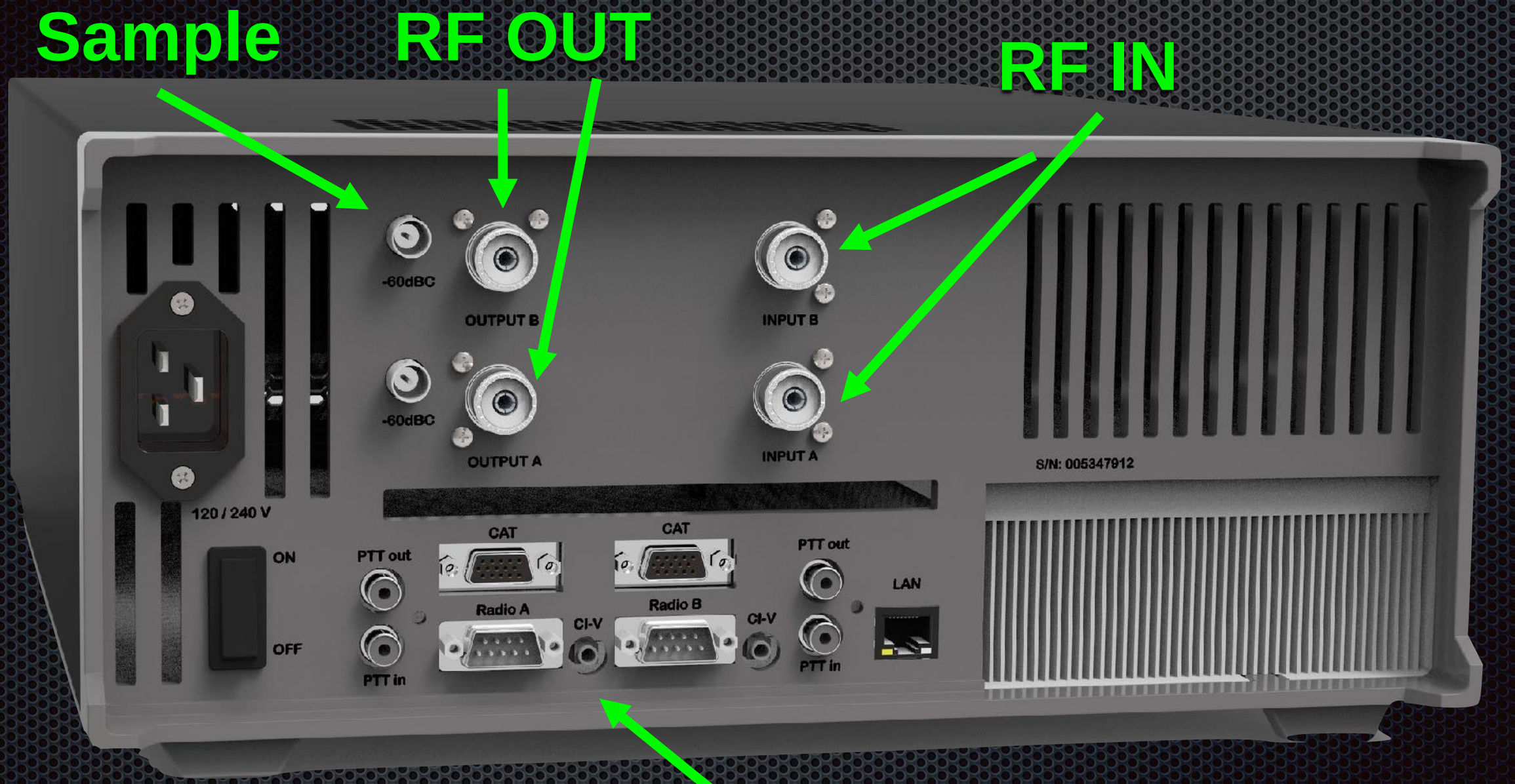
PowerGenius XL



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Introducing… FLEX-6600

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FLEX-6400 / FLEX-6600

Reimagined

- Both models:
  - Run SmartSDR just like all FLEX-6000s
  - Improved receiver
  - TWO VFO Controls
  - MARS/SHARES/CAP Option
  - 116db RMDR
  - Full Duplex
- FLEX-6600
  - Enhanced preselector
  - Two XVTR Ports / SO2R

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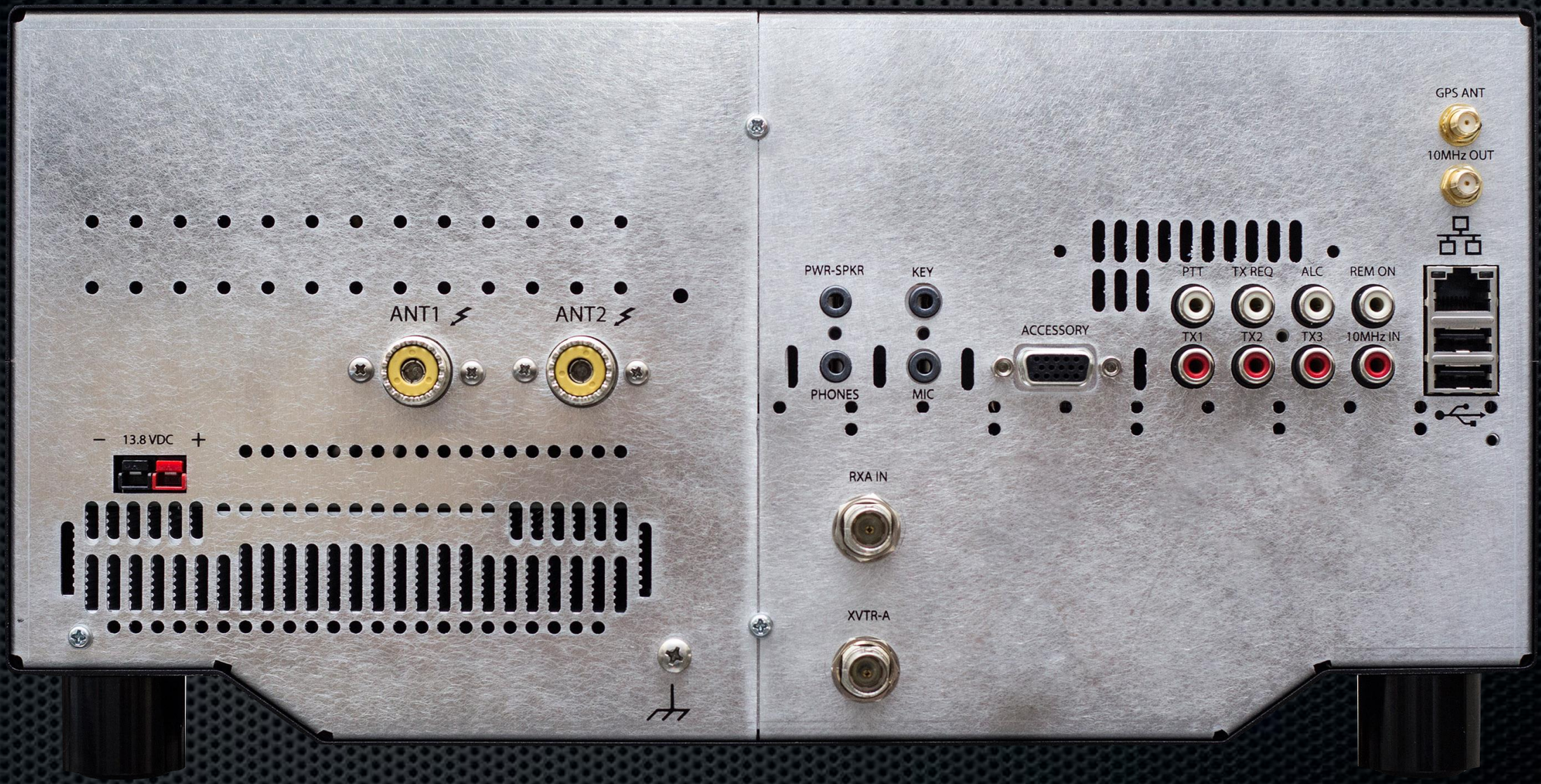
FLEX-6400

Rear View



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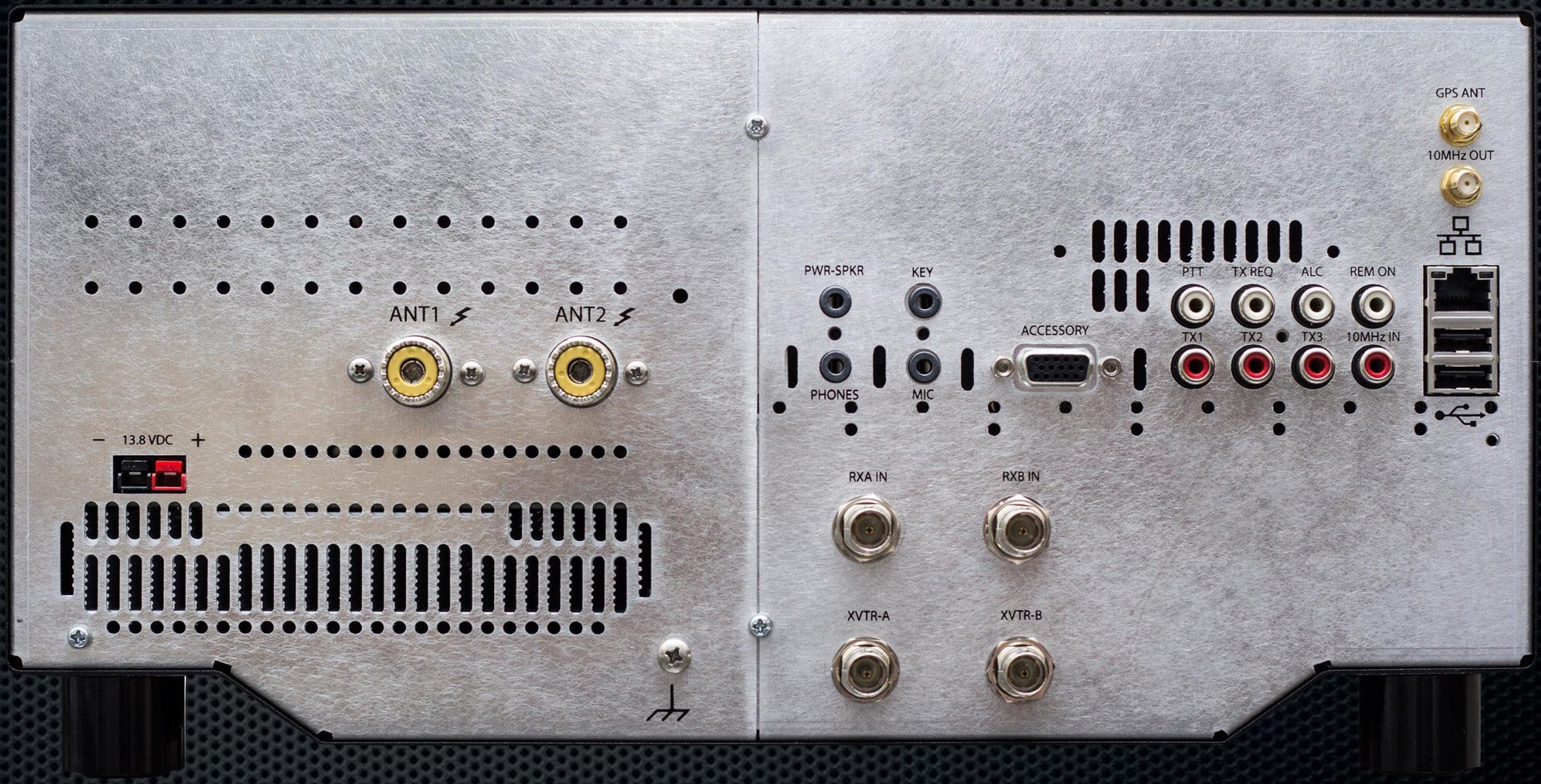
FLEX-6600

Rear View



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FLEX-6400M & FLEX-6600M

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FLEX-6400M & FLEX-6600M

Features

- All the capabilities of a FLEX-6400/6600
- Best screen available: 1920x1200 IPS CAP Touch
- Support for external HDMI display
- PLUS front panel with touch screen and controls
- Builds on excellent Maestro design
- Includes SmartLink for remote operation
- Can be used with Maestro, iPad, DogparkSDR, etc.

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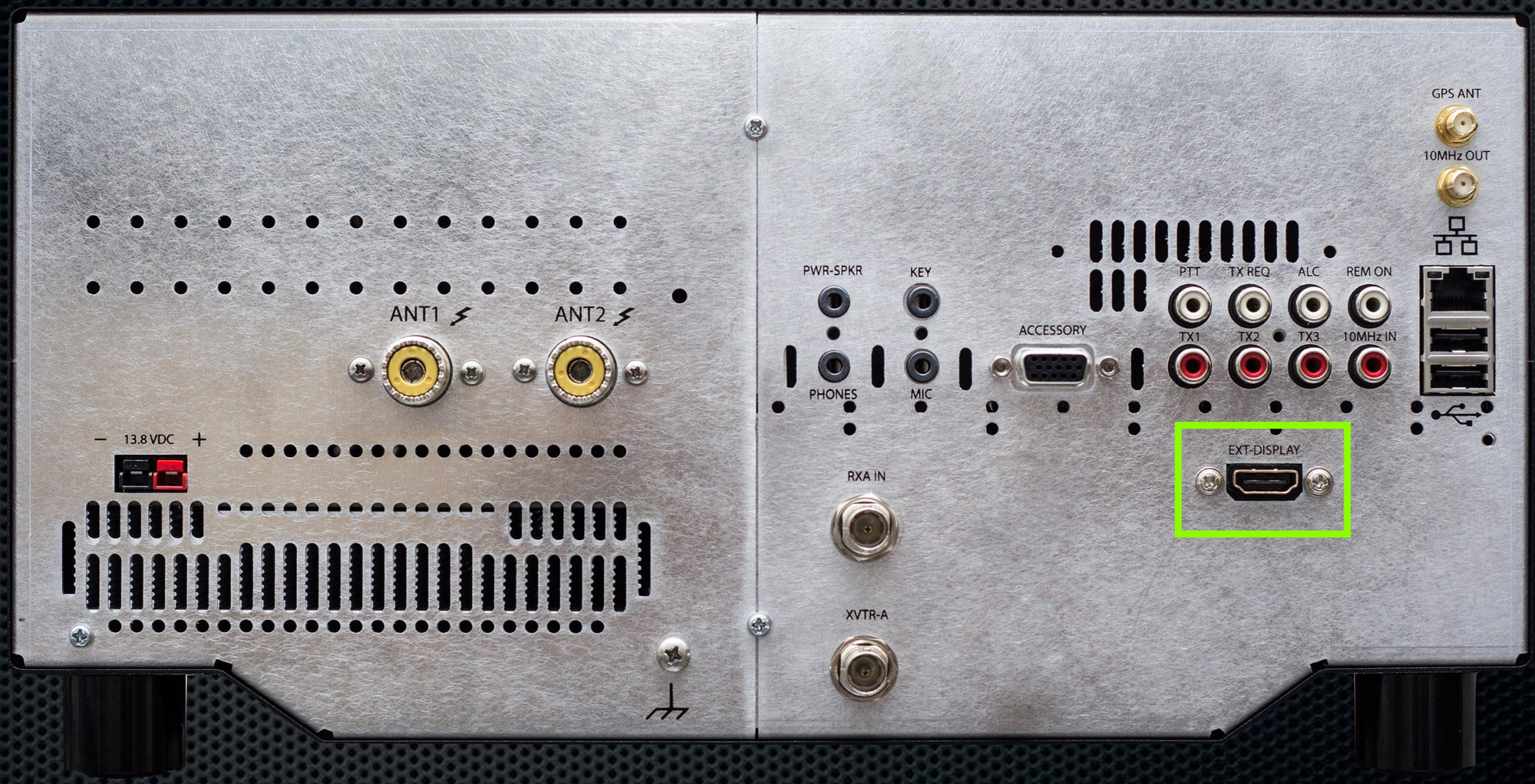
FLEX-6400M

Rear View



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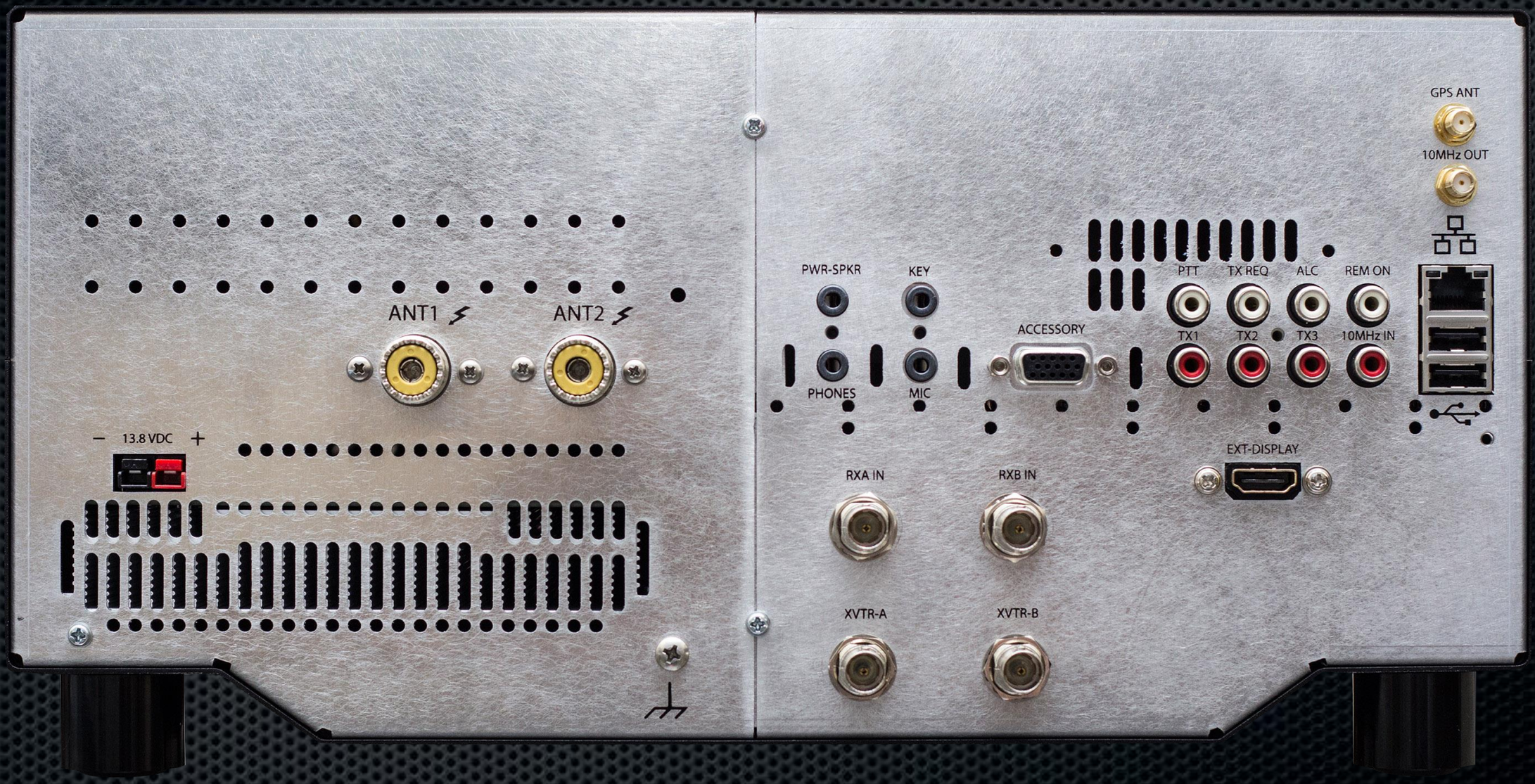
FLEX-6600M

Rear View



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FLEX-6000 Lineup

	6400	6400M	6600	6600M	6700
RX/Pan	2/2	2/2	4/4	4/4	8/8
Pan Width	7MHz	7MHz	14MHz	14MHz	14MHz
SCU	1	1	2	2	2
SO2R			✓	✓	✓
RX Presel	✓	✓	✓✓	✓✓	✓
XVTR	1/2	1/2	2/4	2/4	1
ATU	OPT	OPT	✓	✓	✓
GPSDO	OPT	OPT	OPT	OPT	OPT
MARS	OPT	OPT	OPT	OPT	✓
Displ/Knob		✓		✓	
	$1,999	$2,999	$3,999	$4,999	$6,999

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QUESTIONS?