Design of a 1296 MHz SDR Radio System for EME

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Summary Outline

EME or Earth Moon Earth communications requires sensitive receivers, relatively high power transmitters and signal processing to be able to communicate by reflecting a signal off the moon.

- System Design
    - Definitions
    - Noise
    - Intermodulation
    - A2D and D2A Converters
- EME System Performance
- Hardware
- Software
- References

Voltage, Power, dBm and all that...

- In the analog world, signals are actually power.
  - Receiver: the power is small, enough to displace a charge on a gate of a FET
  - Transmitter: the power is large, even cook your lunch!
- It can be represented in several ways

$$Power = P = Voltage \cdot Current = V \cdot I$$

$$Voltage\ across\ a\ resistor : P = \frac{V^2}{R} \Rightarrow V = \sqrt{PR}$$

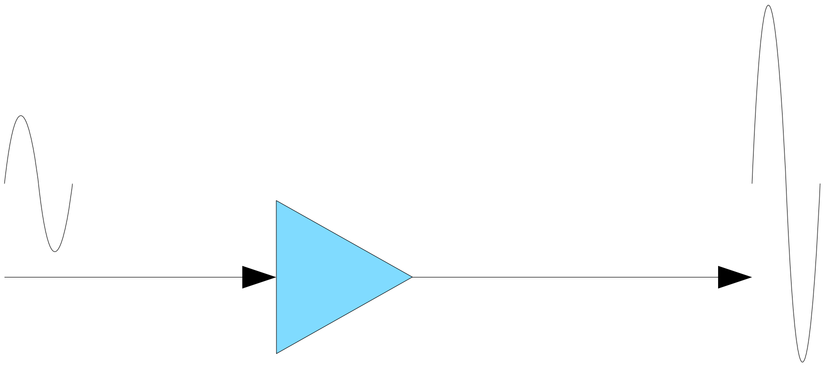
Decibels or dB is a logarithmic measure of power ratio

$$dB = 10\log_{10}\left(\frac{P_{out}}{P_{\mathrm{in}}}\right) \qquad dB = 10\log_{10}\left(\frac{V^2_{out}}{V^2_{\mathrm{in}}}\right) \Rightarrow 20\log_{10}\left(\frac{V_{out}}{V_{\mathrm{in}}}\right)$$

dBm is a measure of power referenced to 1 milliwatt

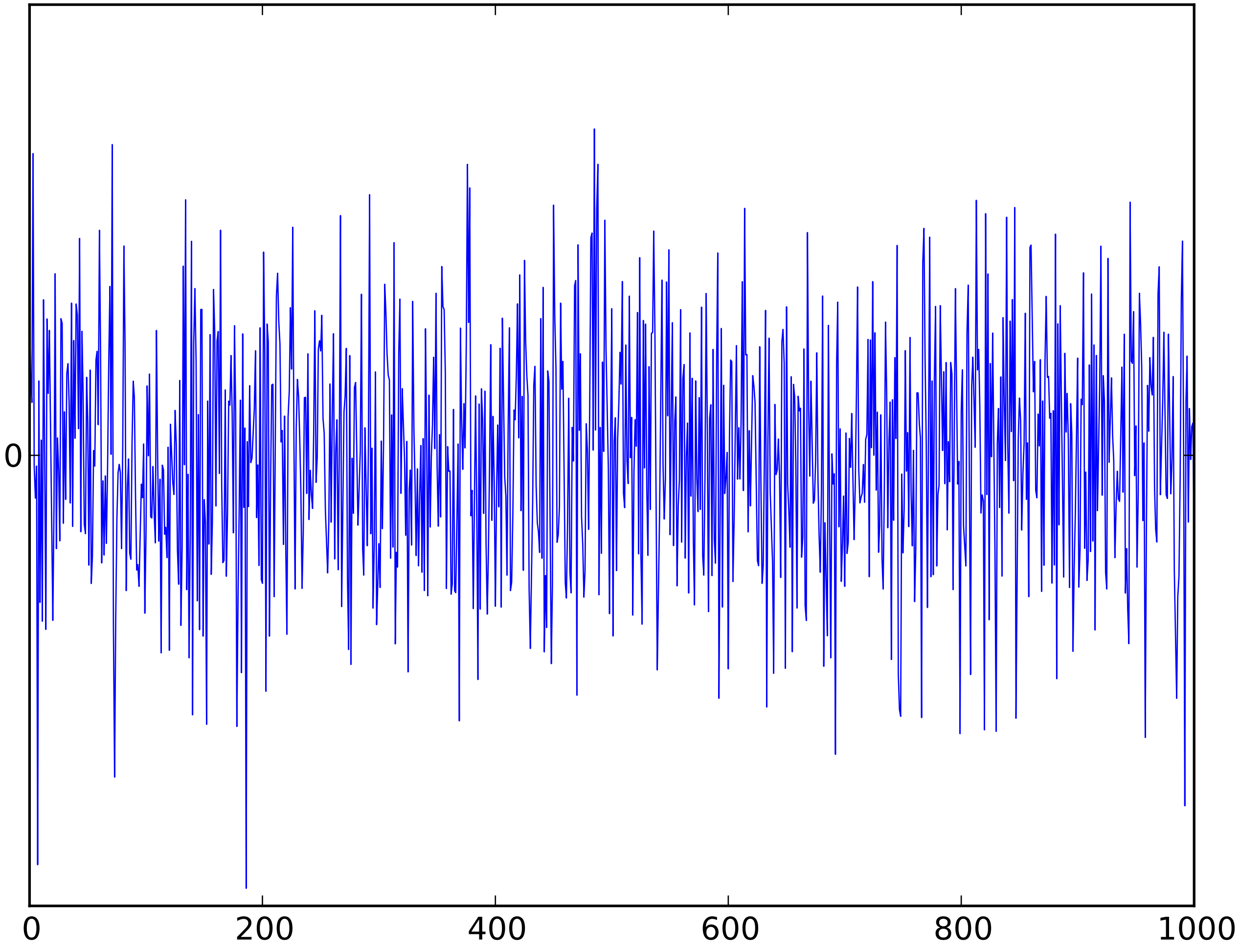
$$dBm = 10\log_{10}\left(\frac{P}{0.001}\right) \qquad 0\,dBm = 1\,milliwatt \qquad +30\,dBm = 1\,watt$$

Amplifier Properties



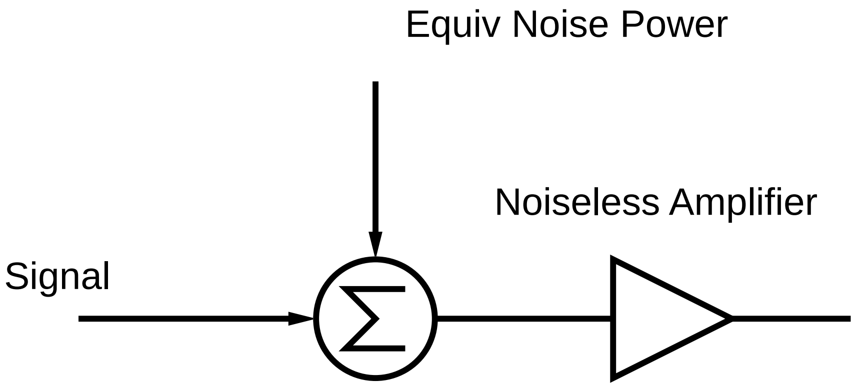
- It makes a small signal “bigger”
- It introduces no distortion or noise
- **This is not true!**
  - An amplifier introduces noise!
  - An amplifier introduces distortion!

Noise



Noise

- Various components generate noise that limits the smallest signal that can be used.
- Noise is generated by the resistive or lossy components of an electronic circuit.
- The noise can be represented by a noiseless device (amplifier) with an equivalent noise source injecting noise power into the input



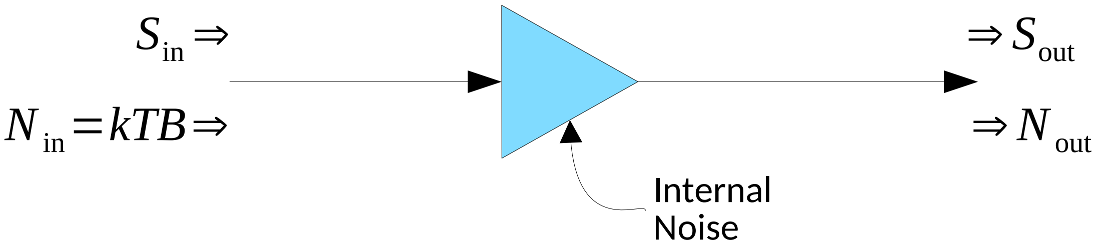
$$P_N = KTB$$

$$\begin{aligned} &where: \\ &K = Boltzmans\ constant\ (1.38\ x\ 10^{-23}\ J/K) \\ &T = Temperature\ (K) \\ &B = Bandwidth\ (Hz) \end{aligned}$$

Signal to Noise Ratio (SNR)

- We can describe the internal noise generated by a circuit as the ratio of the output SNR with respect to the input SNR
- For “real” devices the Noise Factor is always greater than 1

$$SNR_{\text{in}} = \frac{S_{\text{in}}}{N_{\text{in}}} \qquad SNR_{\text{out}} = \frac{S_{\text{out}}}{N_{\text{out}}}$$



$$Noise\ Factor\left(F\right) = \frac{\dfrac{S_{\text{in}}}{N_{\text{in}}}}{\dfrac{S_{\text{out}}}{N_{\text{out}}}} = \frac{SNR_{\text{in}}}{SNR_{\text{out}}}$$

$$Noise\ Figure\left(NF\right) = 10\log_{10}\left(F\right)$$

Noise Figure of Devices

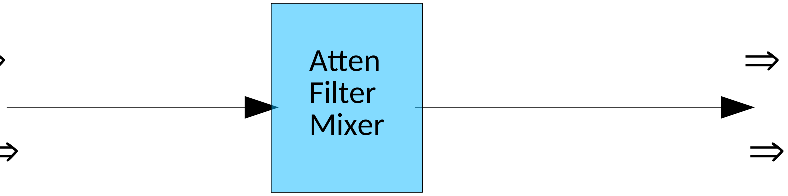
- What is the Noise Figure and Noise Factor of a lossy device (attenuator, filter, passive mixer etc.)

$$SNR_{in} = \frac{S_{in}}{N_{in}}$$

$$SNR_{out} = \frac{S_{out}}{N_{out}}$$

$$S_{in} \Rightarrow$$

$$N_{in} = KTB \Rightarrow$$



$$\Rightarrow S_{out} - Atten_{dB}$$

$$\Rightarrow N_{out} = KTB$$

$$Atten\,Ratio = 10^{\left(\frac{-Atten}{10}\right)} = \frac{1}{a}$$

$$S_{out} = \frac{S_{in}}{a}$$

$$Noise\ Factor\,(F) = \frac{\dfrac{S_{in}}{N_{in}}}{\dfrac{S_{out}}{N_{out}}} = \frac{\dfrac{S_{in}}{KTB}}{\dfrac{S_{in}}{aKTB}} = a$$

$$Noise\ Figure\,(NF) = 10\log_{10}(a) = Atten_{dB}$$

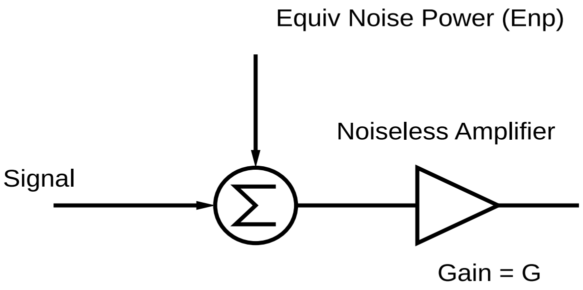
Noise Figure = Attenuation!

Noise Figure of Devices

- Noise of active devices is often represented by Noise Figure (NF) is related to Noise Factor (F)

$$\mathit{Noise\ Figure}\left(NF\right)=10\log_{10}\left(F\right) \qquad G=\mathit{Amplifier\ Gain}$$

$$SNR_{\mathrm{in}}=\frac{S_{\mathrm{in}}}{N_{\mathrm{in}}} \qquad SNR_{\mathrm{out}}=F\left(\frac{S_{\mathrm{in}}}{N_{\mathrm{in}}}\right)$$



$$S_{\mathrm{in}}\Rightarrow$$

$$N_{\mathrm{in}}=KTB\Rightarrow$$

$$\Rightarrow G\left(S_{\mathrm{in}}\right)$$

$$\Rightarrow N_{\mathrm{out}}=GFKTB_{\mathit{Noisy\ Amplifier}}$$

$$\Rightarrow N_{\mathrm{out}}=GKTB_{\mathit{Noiseless\ Amplifier}\left(F=1\right)}$$

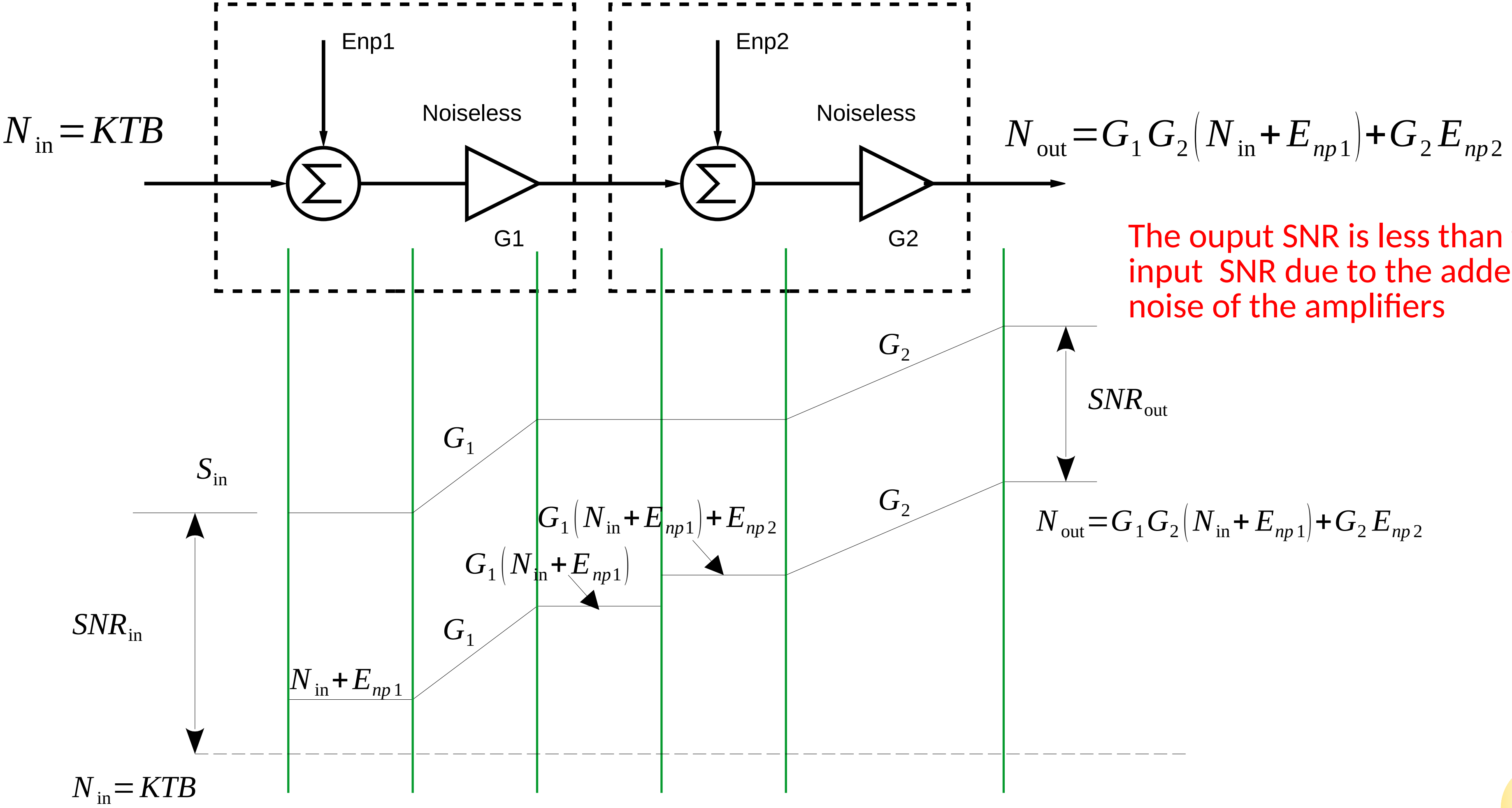
$$N_{\mathrm{out}}=GFKTB=G\left(N_{\mathrm{in}}+E_{\mathrm{np}}\right)$$

$$FKTB=KTB+E_{\mathrm{np}}\Rightarrow E_{\mathrm{np}}=KTB\left(F-1\right)$$

$$E_{np}=KTB\left(F-1\right)=\mathit{Equivalent\ Noise\ Power\ input\ to\ a\ noiseless\ amplifier}$$

Cascaded Noise Figure

- Often, we need to work out the noise figure of a chain or cascade of blocks that all contribute noise



The ouput SNR is less than the input SNR due to the added noise of the amplifiers

Cascaded Noise Figure

- Doing a little math we get:

$$F_{total} = \frac{SNR_{in}}{SNR_{out}} = \frac{\dfrac{S_{in}}{N_{in}}}{\dfrac{S_{in} G_1 G_2}{G_1 G_2 (N_{in} + E_{np1}) + G_2 E_{np2}}} = \frac{G_1 G_2 (N_{in} + E_{np1}) + G_2 E_{np2}}{G_1 G_2 N_{in}}$$

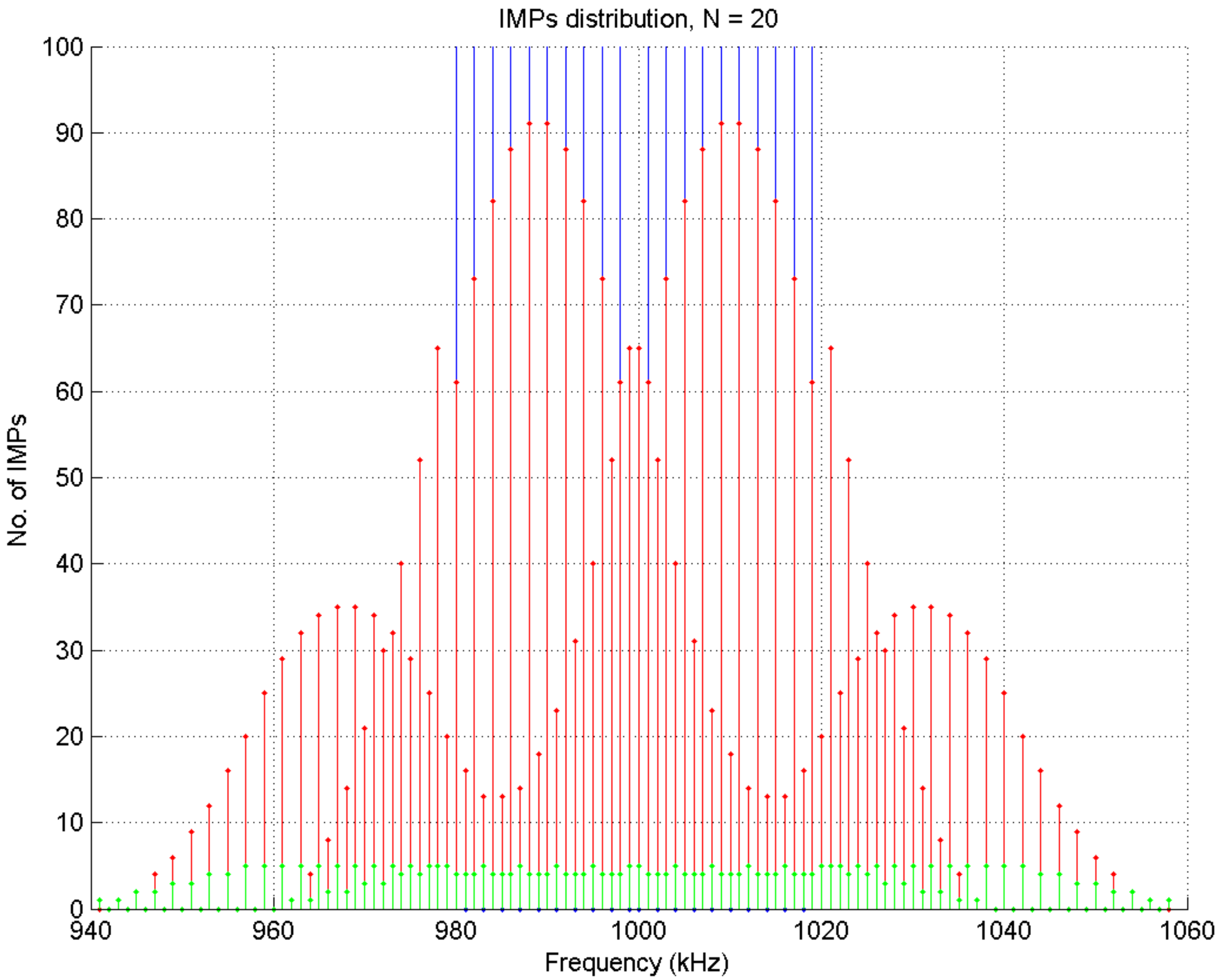
$Substituting:$

$$E_{np} = KTB(F-1) \qquad N_{in} = KTB$$

$$We\ get: \qquad F_{total} = F_1 + \frac{F_2 - 1}{G_1} = Cascade\ Noise\ Equation\ (Fris\ Equation)$$

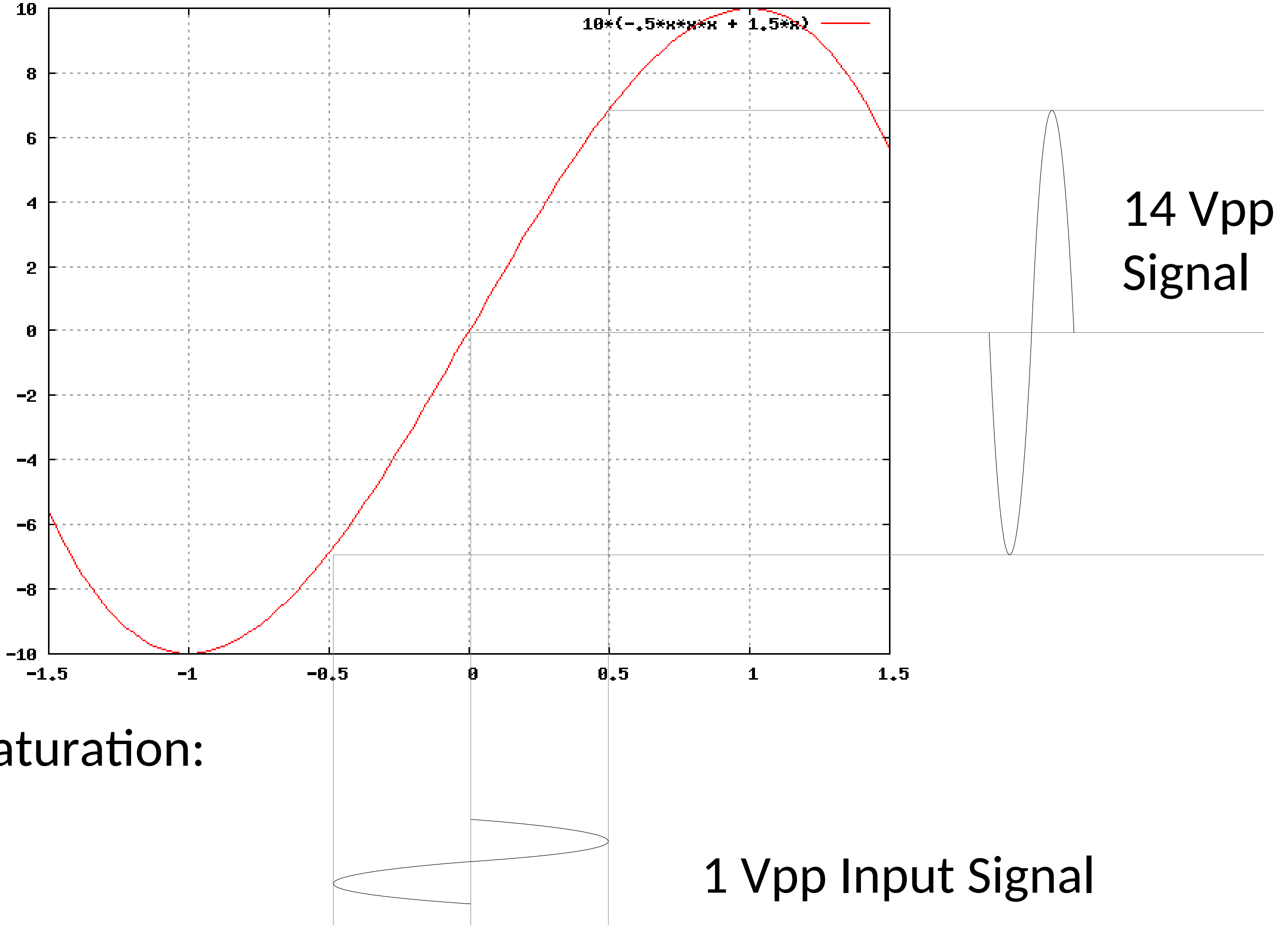
The total noise is dominated by the noise of the first stage, the next stage noise contribution is reduced by the gain of the preceding stage

Intermodulation



Small Signal vs Large Signal Amplifier Gain

Small Signal Gain:
= Vout / Vin
= 14 Vpp / 1Vpp = 14
= 20 Log10 (14)
= 23 dB



14 Vpp Output Signal

1 Vpp Input Signal

Large Signal Gain at Saturation:
= Vout / Vin
= 20 Vpp / 2 Vpp = 10
= 20 Log10 (10)
= 20 dB

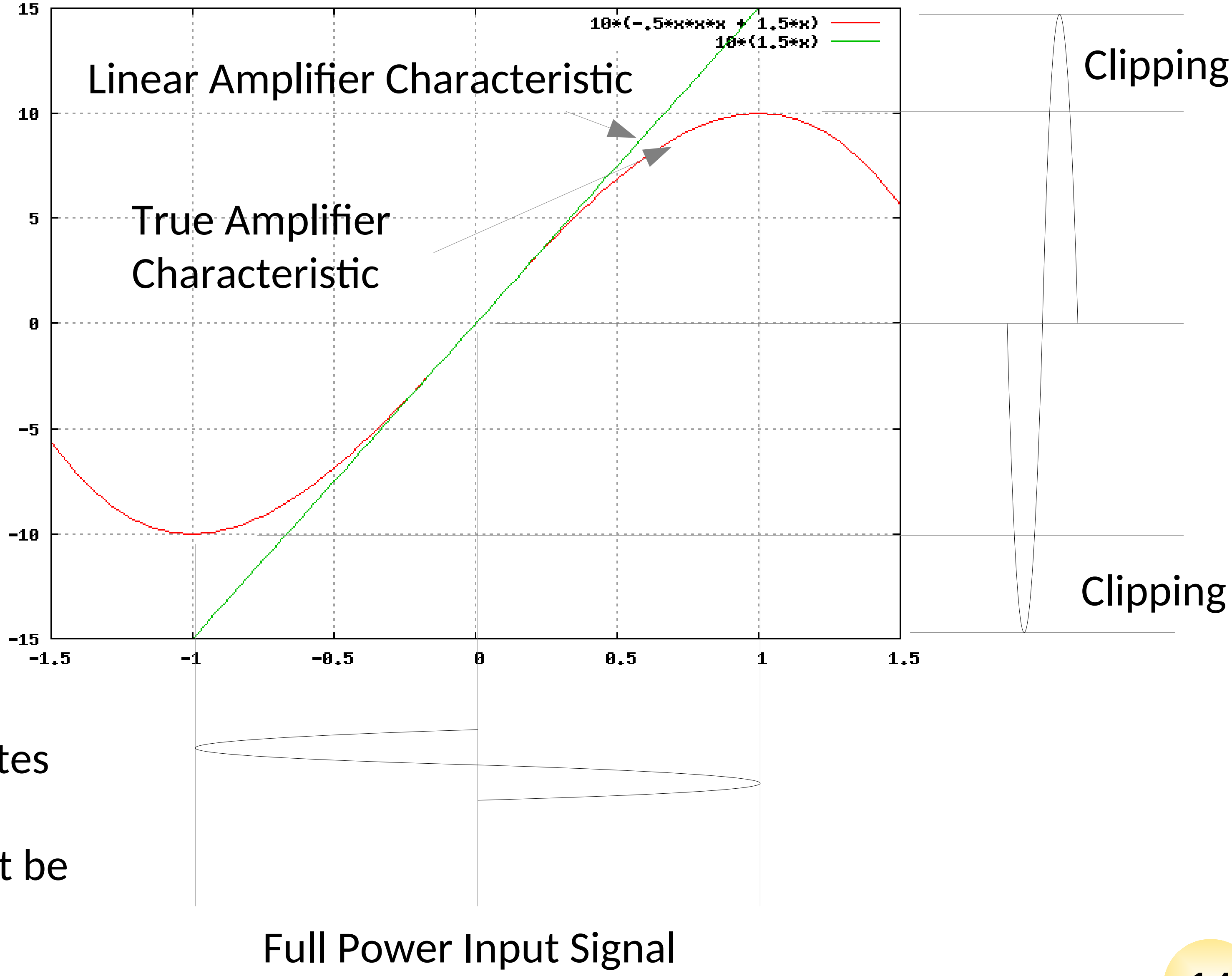
At Saturation we lost 3dB, What's Going On?

Large Signal Amplifier Gain

As you drive the amplifier toward full power, it saturates, and can no longer deliver power.

The output becomes distorted as the top and bottom of the output signal is “clipped” off.

This “clipping” generates “in-band” distortion products which cannot be filtered.



Linear Amplifier Characteristic

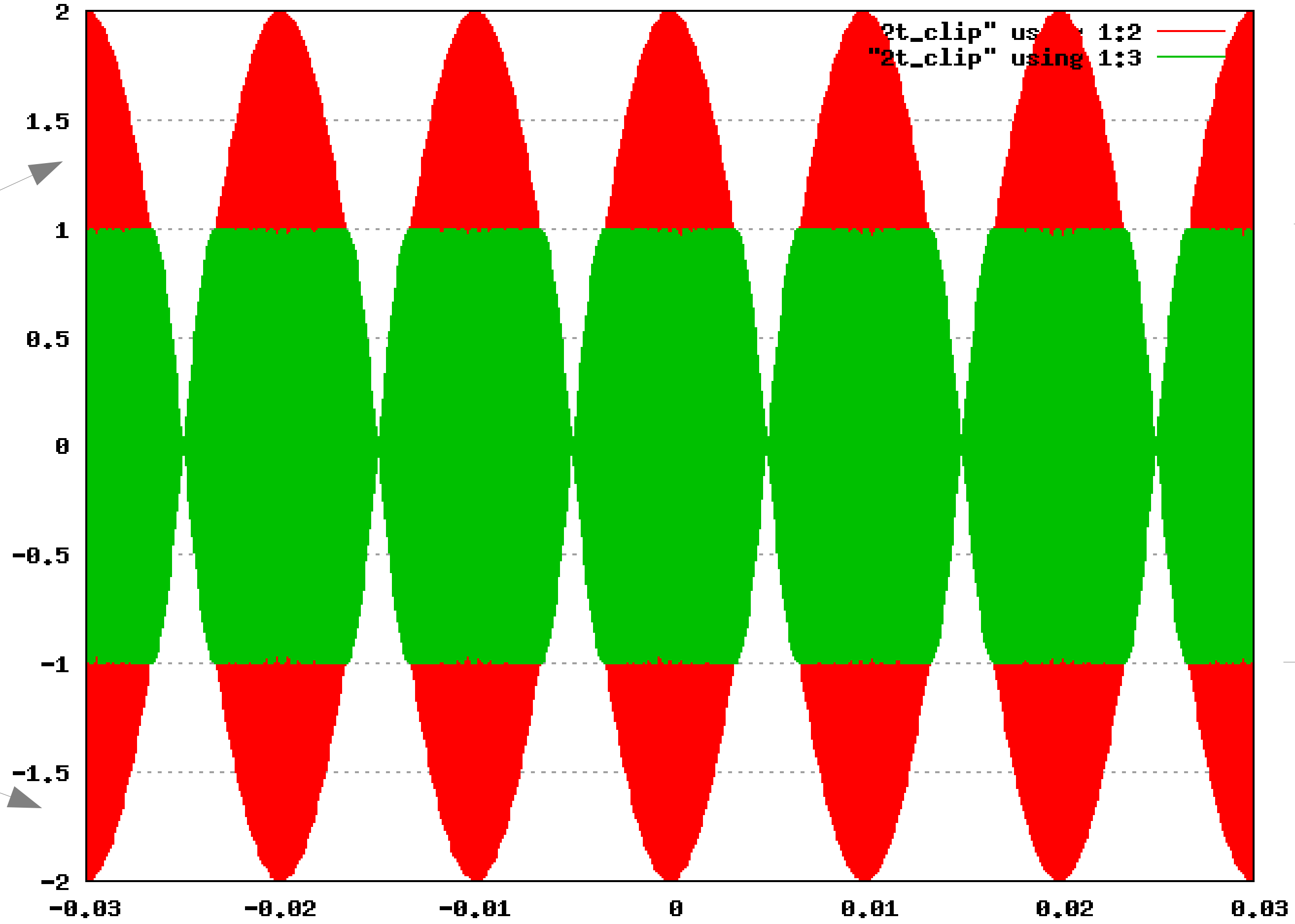
True Amplifier Characteristic

Clipping

Clipping

Full Power Input Signal

Large Signal Amplifier Amplitude Clipping



This portion of the output cannot be generated by the amplifier and causes distortion!

Maximum Output of Amplifier

Intermodulation

- We can describe the transfer characteristic of an amplifier or any device as a polynomial

$$v_{out} = a_1 v_{\text{in}} + a_2 v_{\text{in}}^2 + a_3 v_{\text{in}}^3 + \cdots$$

$$Replacing\, v_{\text{in}}\, with\, v_{\text{in}} \cos(\omega_1 t)\, \text{and}\, doing\ some\ math$$

$$Gain = \frac{v_{out}}{v_{\text{in}}} = a_1 \left(1 + \frac{3 a_3}{4 a_1} v_{\text{in}}^2\right) \qquad If\ \frac{a_3}{a_1} < 0,\ the\ gain\ compresses\ with\ increasing\ amplitude$$

If we replace the input signal with two sinusoidal signals we can look at the interaction between the signals and determine a great deal about the linearity properties of the amplifier

$$v_{\text{in}} = A(\cos \omega_1 t + \cos \omega_2 t)$$

Theory of Two Tone Intermodulation

$$K_1(a+b)=K_1A\left[\sin(\omega_1 t)+\sin(\omega_2 t)\right]$$

Linear Term

Second Order Terms

$$K_2(a+b)^2=K_2A^2\left[\frac{1}{2}\left[1-\cos(2\omega_1 t)\right]+\left[\cos((\omega_1-\omega_2)t)-\cos((\omega_1+\omega_2)t)\right]+\frac{1}{2}\left[1-\cos(2\omega_2 t)\right]\right]$$

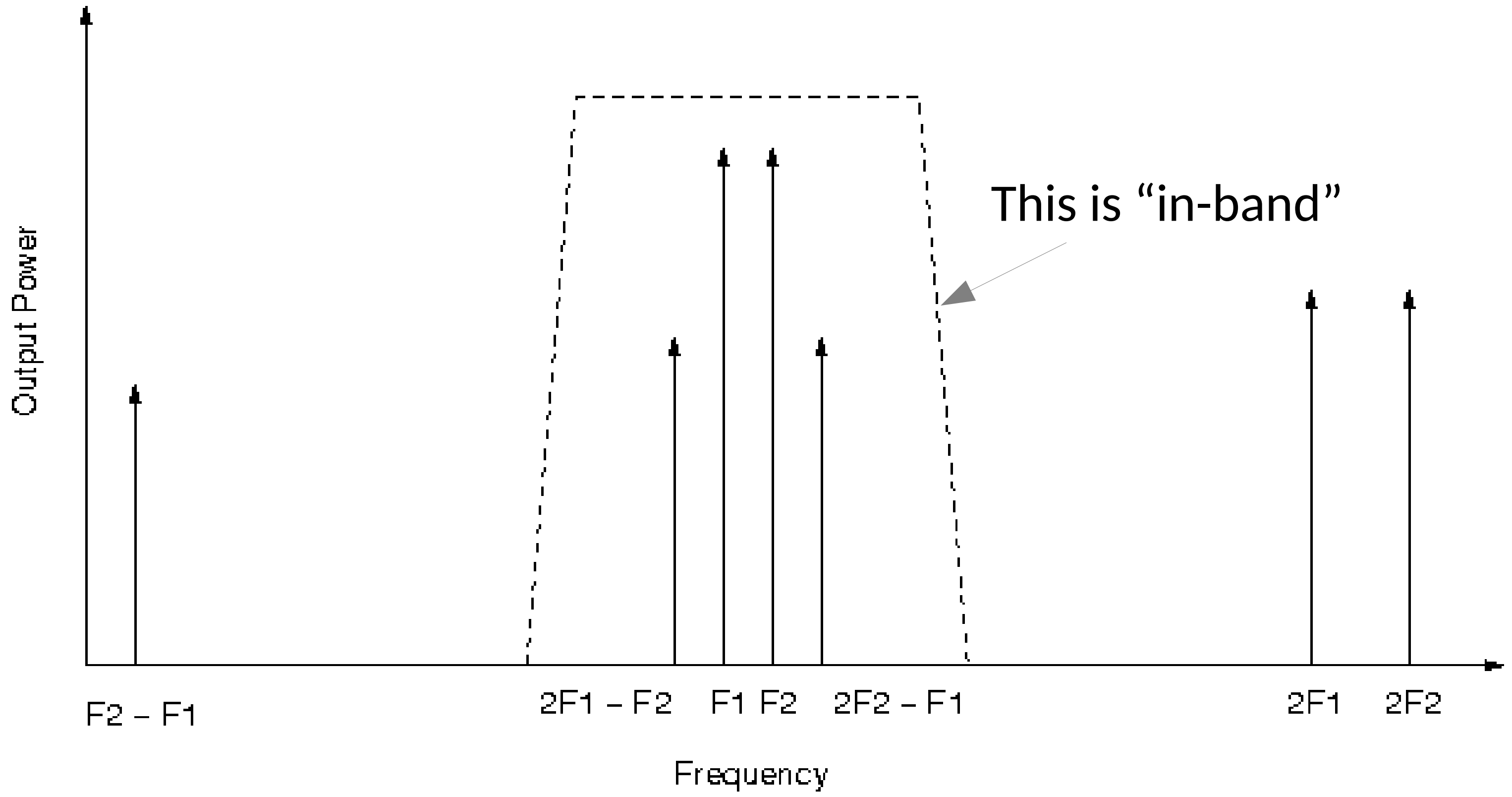
$$K_3(a+b)^3=\frac{K_3A^3}{4}\left[9\left[\sin(\omega_1 t)+\sin(\omega_2 t)\right]\right.$$
$$-3\left[\sin(2\omega_1+\omega_2)t+\sin(\omega_1+2\omega_2)t+\sin(\omega_2-2\omega_1)t+\sin(\omega_1-2\omega_2)t\right]$$
$$\left.-\left[\sin(3\omega_1 t)+\sin(3\omega_2 t)\right]\right]$$

These are “ in band “

Third Order Terms

If we filter our output signal, then the linear terms and some of the third order terms fall “ in band “
It's the “ in band “ third order terms that give us noticeable distortion!

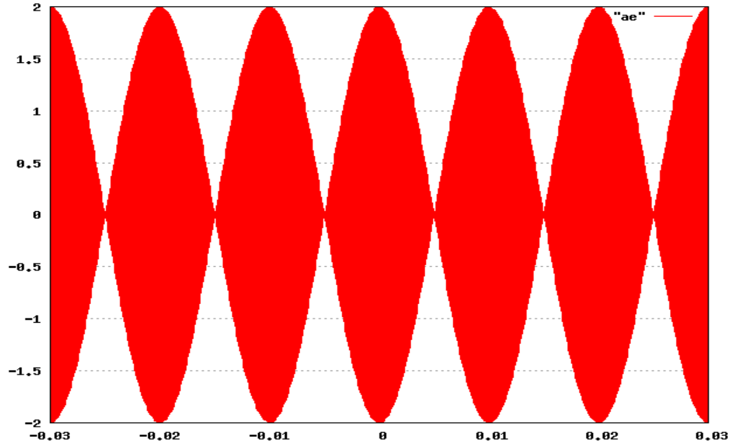
Theory of Two Tone Intermodulation

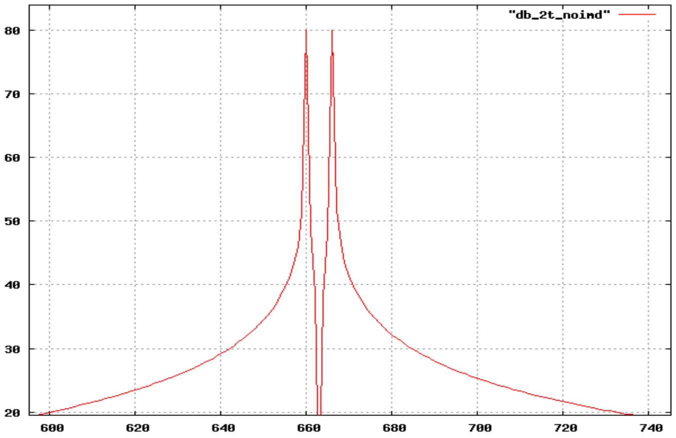


Example:
F1 = 835.000 MHz
F2 = 836.000 MHz

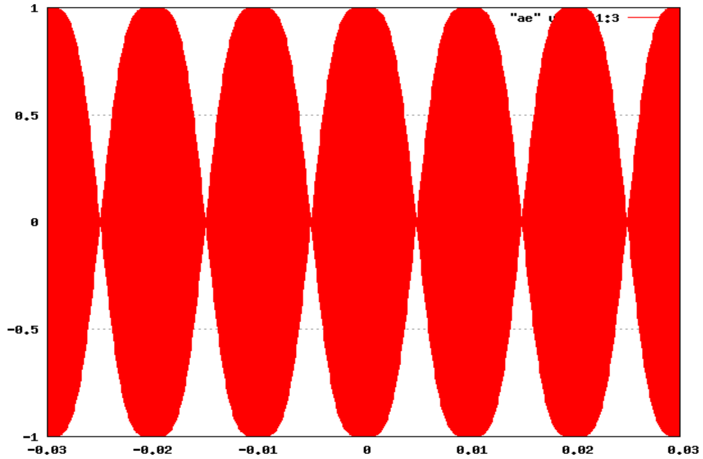
2F1 – F2 = 834.000 MHz
2F2 – F1 = 837.000 MHz
2F1 = 1670.000 MHz
2F2 = 1672.000 MHz
F2 – F1 = 1.0 MHz

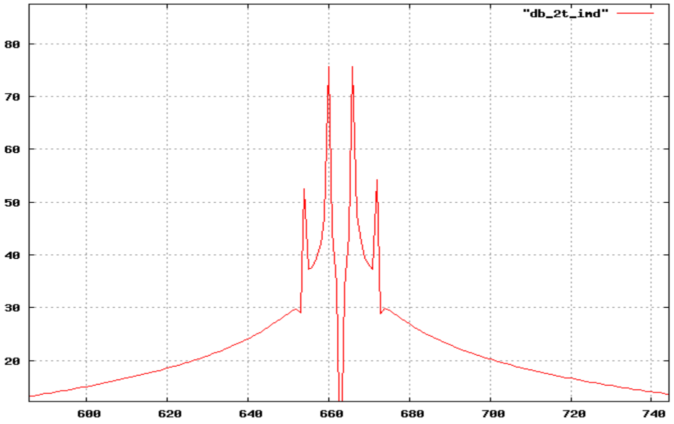
Two Tone Signal Intermodulation Distortion





No Distortion





Distortion

Time Domain
What you see on a scope

Frequency Domain
What you see on a spectrum analyzer

Intermodulation Intercept

Looking at the log amplitude coefficients by converting to dB we get:

$$dB_{\text{First Order}} = 20\log_{10} K_1 A$$

Slope = 2

$$dB_{\text{Second Order}} = 20\log_{10} K_2 A^2 = 2\cdot 20\log_{10}(A) + 20\log_{10} K_2$$

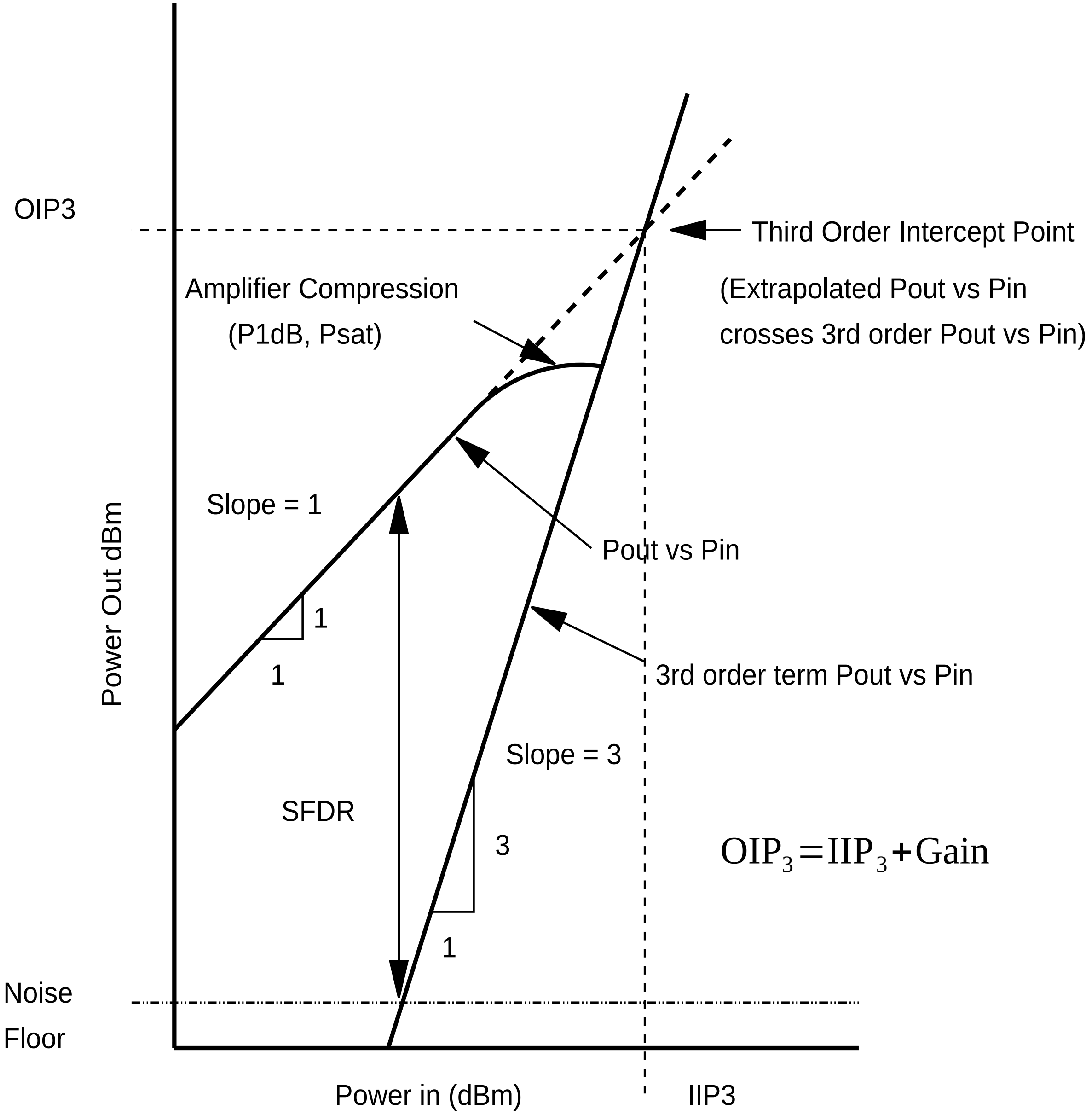
Slope = 3

$$dB_{\text{Third Order}} = 20\log_{10}\left(\frac{K_3 A^3}{4}\right) = 3\cdot 20\log_{10}(A) + 20\log_{10}\left(\frac{K_3}{4}\right)$$

We can now plot the equations of these lines

$P_{out} = P_i + Gain$	Linear Output Power
$P_{\text{out}}^{\text{2nd}} = 2P_{\text{i}} - \text{OIP}_2 + 2\,\text{Gain}$	2nd Order Output Power
$P_{\text{out}}^{\text{3rd}} = 3P_{\text{i}} - 2\,\text{OIP}_3 + 3\,\text{Gain}$	3rd Order Output Power

Third Order Intercept



$$OIP_3 = IIP_3 + Gain$$

Given that we know the third order intercept point and small signal gain, we can easily calculate how big our third order intermodulation products will be for any given input power!

OIP3 = Output Third Order Intercept Point

IIP3 = Input Third Order Intercept Point

SFDR = Spur Free Dynamic Range

The Pout [dB] vs Pin [dB] plot is a line with the slope of 1

The third order Pout [dB] vs Pin [dB] plot is a line with the slope of 3

Cascaded Third Order Intercept

- Using a similar analysis using a power series to describe the non-linear behavior of multiple amplifiers, we can work out an equation for cascaded IP3
- It turns out there are two solutions depending upon whether the intermodulation products are in phase or not.

In Phase (Coherent)

$$\frac{1}{IIP_3} = \frac{1}{IIP_{31}} + \frac{G_1}{IIP_{32}} + \cdots + \left(\frac{G_1 G_2 \cdots G_{n-1}}{IIP_n}\right)$$

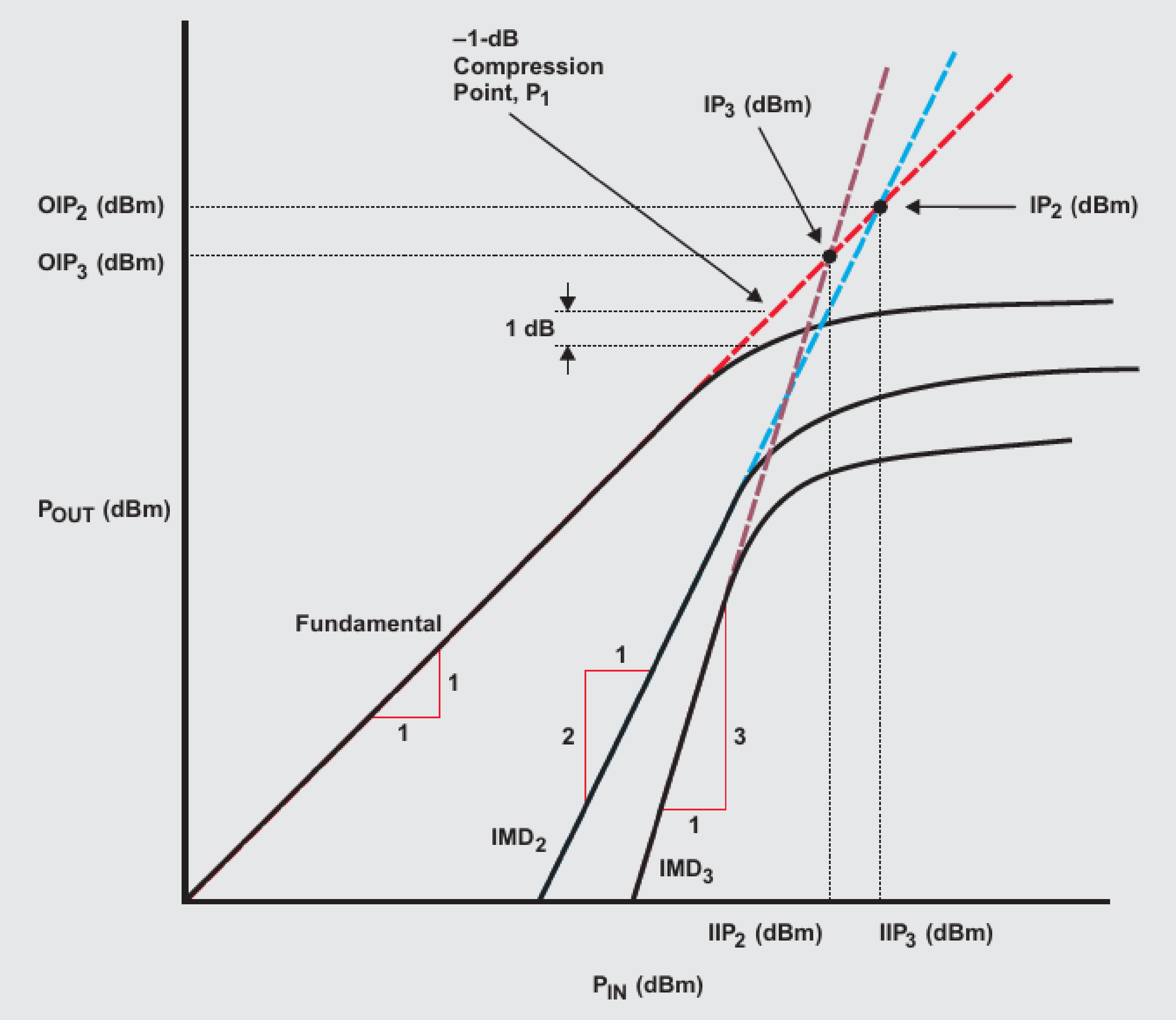
Out of Phase (Non-Coherent)

$$\frac{1}{(IIP_3)^2} = \frac{1}{(IIP_{31})^2} + \frac{G_1}{(IIP_{32})^2} + \cdots + \left(\frac{G_1 G_2 \cdots G_{n-1}}{(IIP_n)^2}\right)$$

There are limitations with this method

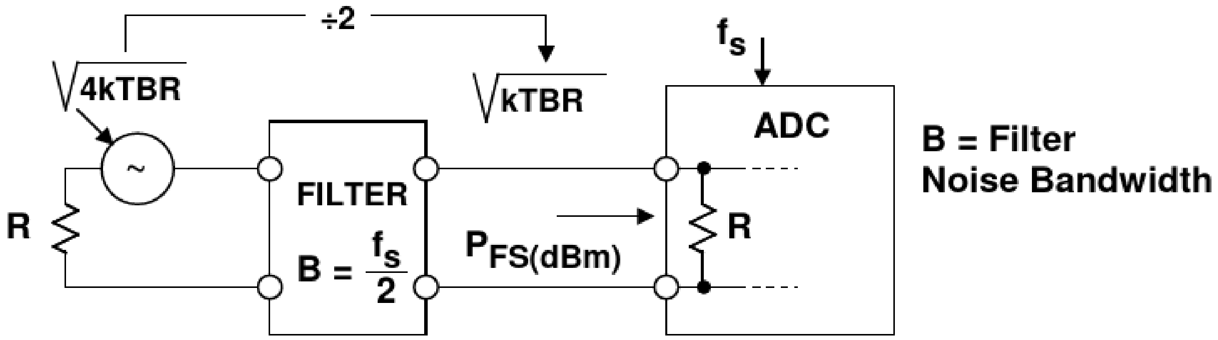
- The worst case is Coherent (it is used most often)
- No concept of frequency response
- Gain is constant with regard to power
- Multiple signal paths are ignored

Intermodulation Summary



A2D Converters

- The analog to digital (A2D) converter is where the analog world meets the digital
- It is nothing more than a high speed voltmeter
- The signal power is represented as a voltage across a terminating resistance, either internal or external to the A2D converter



$$F = \frac{(\text{Total input noise})^2}{(\text{Total input noise due to R})^2}$$

·Assume the noise comes from a source having resistance R

·Noise bandwidth is Fs/2

A2D Converter Noise Figure

From the datasheet we can get the SNR of the A2D converter and compute the equivalent noise

$$V_{\text{noise RMS}} = V_{\text{full scale}} \cdot 10^{\frac{-\text{SNR}}{20}}$$

$$F = \frac{V^2_{\text{noise RMS}}}{\text{KTRB}} = \left(\frac{V^2_{\text{full scale}}}{R}\right)\left(\frac{1}{KT}\right)\left(10^{\frac{-\text{SNR}}{10}}\right)\left(\frac{1}{B}\right)$$

$$F = \left(\frac{1.13^2}{50}\right)\left(\frac{1}{1.38 \text{ x } 10^{-23} \cdot 300}\right)\left(10^{\frac{-82}{10}}\right)\left(\frac{1}{40 \text{ x } 10^{06}}\right)$$

$$F = 2.433 \text{ x } 10^3 \qquad \text{NF} = 10 \log_{10}\left(2.433 \text{ x } 10^3\right) = 33.9\,\text{dB}$$

$$\text{where}: V_{\text{full scale}} = \frac{V_{\text{full scale P-P}}}{2\sqrt{2}}$$

$for: AD9446$

$V_{full\,scale} = 3.2\,V_{pp} = 1.13\,V_{RMS}$

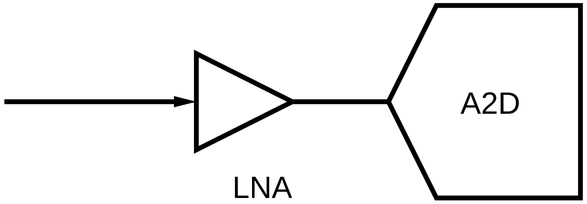
$SNR = -82\,dB$

$BW = 40\,MHz = \left(\frac{80_{MSPS}}{2}\right)$

We can improve the NF by an impedance transformation or adding a low noise amplifier

A2D Converter Noise Figure

Adding a low noise gain stage can improve the A2D converter noise figure



Gain = 20 dB

NF = 1 dB

$$\text{Gain} = 10^{\left(\frac{20}{10}\right)} = 100$$

$$F = 10^{\left(\frac{1}{10}\right)} = 1.259$$

$$F_{A2D} = 2.433 \text{ x } 10^3$$

$$F_{total} = F_1 + \frac{F_2 - 1}{G_1}$$

$$F_{total} = 1.259 + \frac{2433 - 1}{100} = 30.62$$

$$\text{NF}_{\text{Total}} = 10 \log_{10}(30.62) = 14.9 \text{ dB}$$

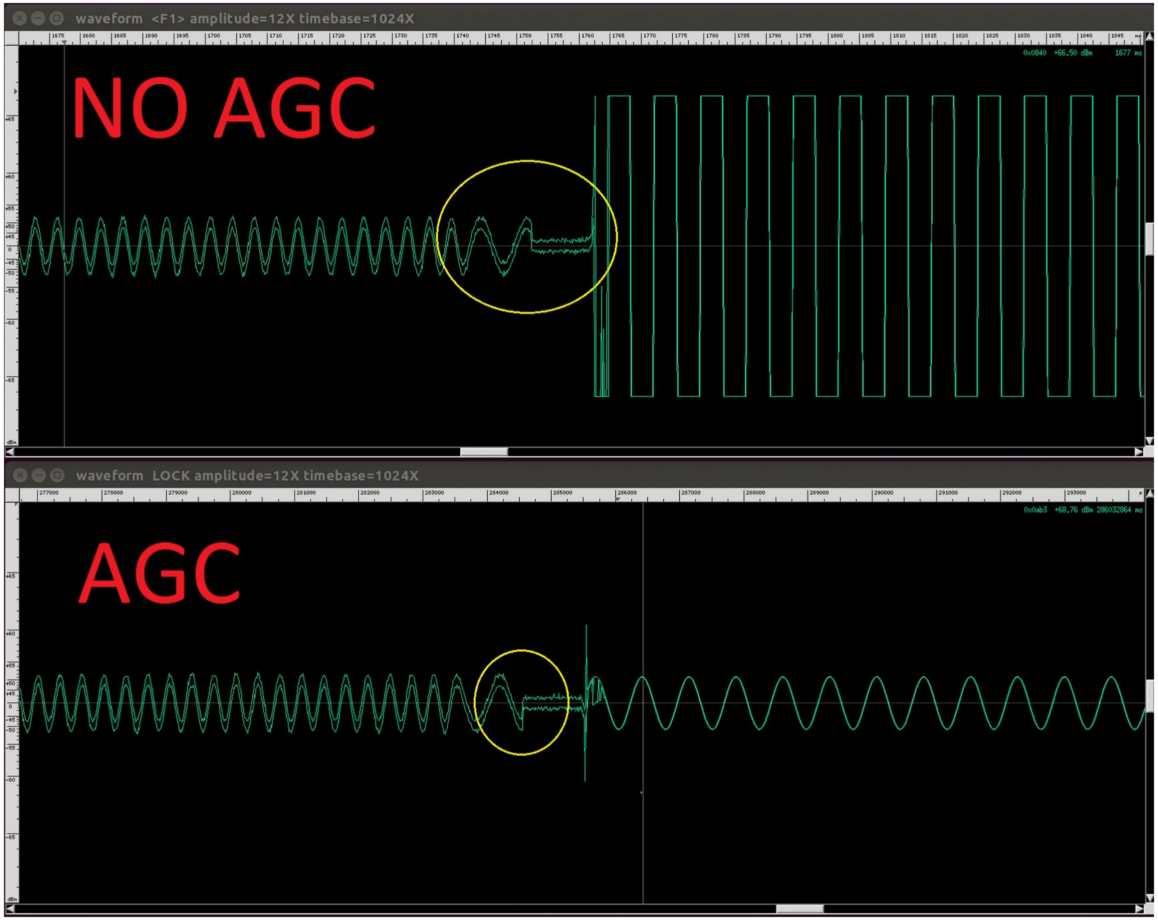
But now our maximum signal level dropped by the voltage gain of the amplifier

$$\text{Vgain} = 10^{\left(\frac{20}{20}\right)} = 10$$

$$V_{\text{in max}} = \frac{V_{\text{out}}}{\text{Gain}} = \frac{3.2\, V_{PP}}{10} = 0.32\, V_{PP}$$

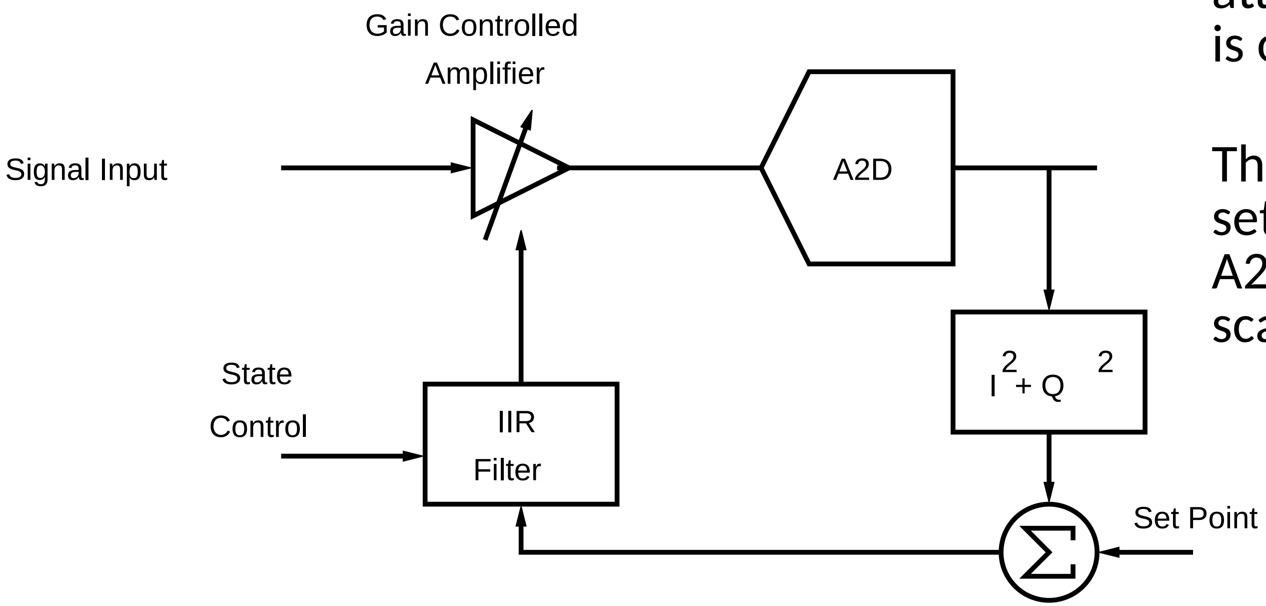
Automatic Gain Control (AGC)

- To solve the problem of having to deal with both strong and weak signals we add a gain control loop to keep the signal to noise ratio as high as possible into the A2D converter without overloading it.



Automatic Gain Control (AGC)

- We sample the signal level and adjust the gain of one of more stages in the receiver to keep the level into the A2D within its dynamic range
- The feedback IIR filter state may be dynamically changed depending upon demodulator state



Gain Controlled Amplifier

Signal Input

A2D

$I^2 + Q^2$

State Control

IIR Filter

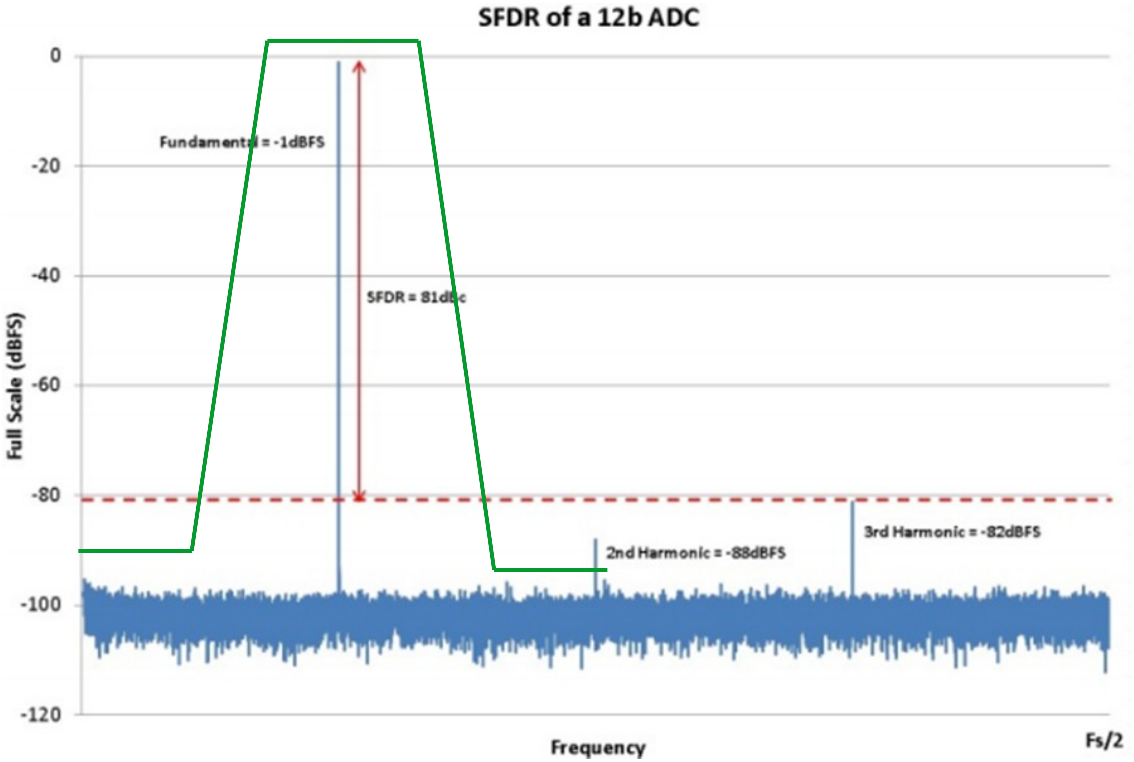
Set Point

Some form of “fast” attack and “slow” decay is often used

The set point is usually set to hold the incoming A2D level below full scale

Digital to Analog Converters

- Digital to Analog (D2A) converters also have a finite SNR.
- It is most often specified as Spur Free Dynamic Range (SFDR)



In narrowband situations an analog filter can be used to exclude the unwanted spurious signals

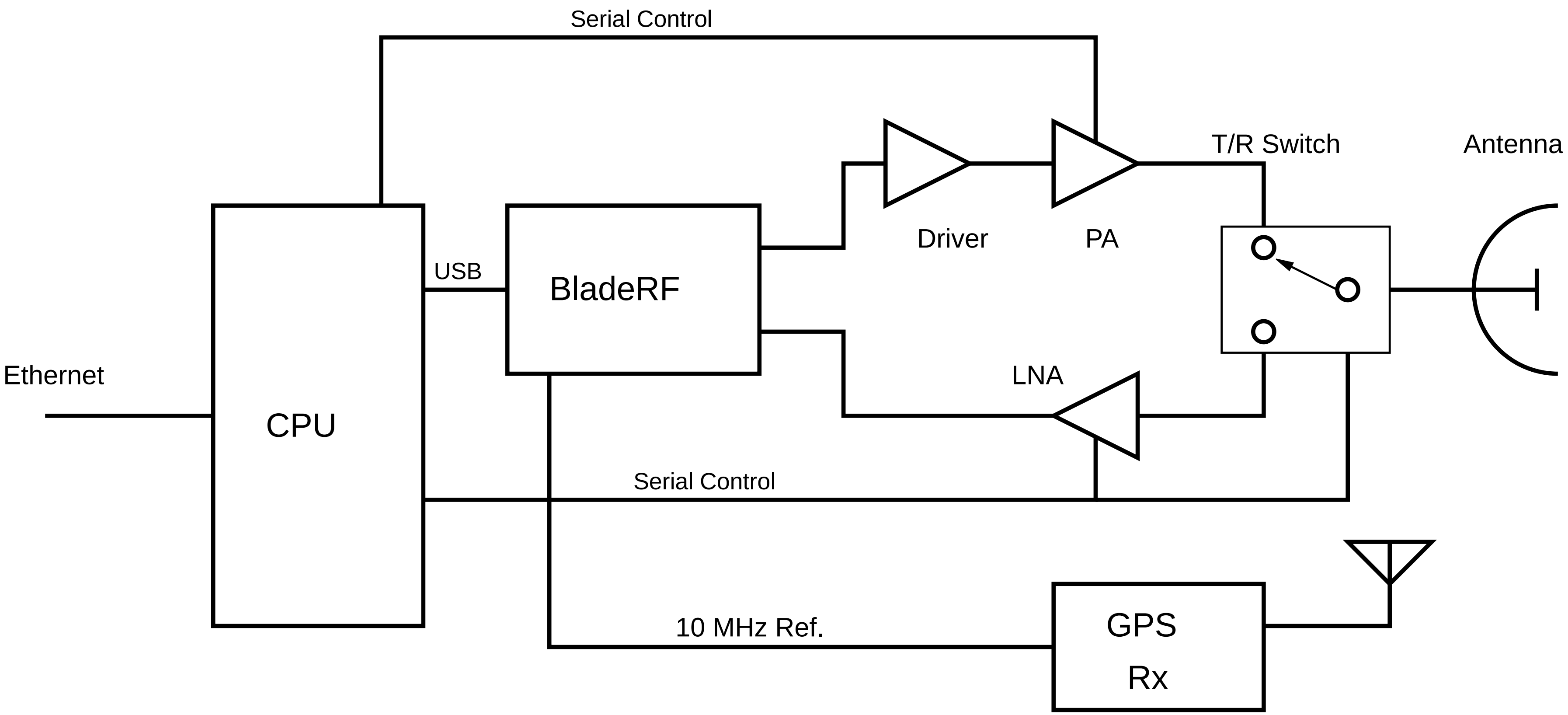
To get the largest SNR you want to desired signal to be at the highest level possible

Earth Moon Earth (EME)

“Shoot for the moon; you might get there”

– Buzz Aldrin

Outside Equipment Block Diagram



- The BladeRF directly receives and transmits on 1296 MHz.
- Sample rate is 960K I/Q samples/sec.
- Frequency reference and sample clocks are locked to GPS derived 10 MHz.

EME System Analysis

- We can use the Radar equation to compute the path loss from a transmitted signal reflected from the moon.
- At 1296 MHz we get:

$$loss = \frac{\sigma r^2 \lambda^2}{64 \pi^2 d^4}$$

$where:$

$\sigma = lunar\ reflection\ coefficient\ (0.065)$

$r = radius\ of\ the\ moon\ (1.738\ x\ 10^6\ m)$

$\lambda = wavelength\ (c / 1296\ MHz = 0.2313\ m)$

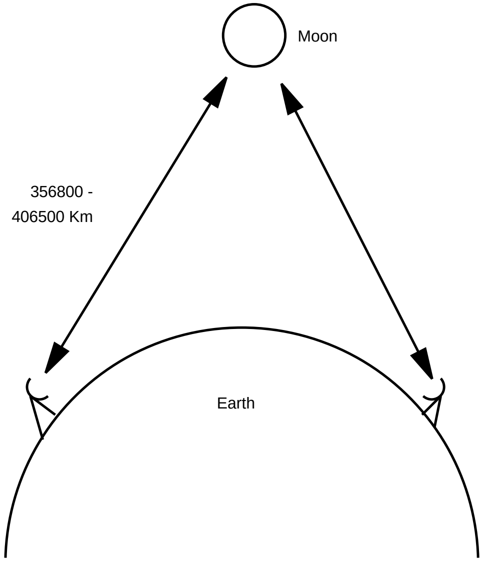
$d = distance\ to\ the\ moon\ (3.844\ x\ 10^8\ m)$

$$loss(dB) = 10 \log_{10}\left(\frac{\sigma r^2 \lambda^2}{64 \pi^2 d^4}\right)$$

$$loss = 7.618\ x\ 10^{-28}$$

$$loss(dB) \boxed{= -271.1817\ dB}$$

- The lunar coefficients are nominal values
- The moon orbit is elliptical, apogee is 406500 Km, perigee is 356800 Km



EME System Analysis

- Transmit Station:
    - Tx Power 900W
    - Antenna Gain 26 dB (1.8 m parabolic dish)
- Receive Station:
    - Antenna Gain 28 dB (2.4 m parabolic dish)

		Total (dBm)	Total (Watts)
Tx Power	59.542 dBm	59.542 dBm	900 W
Tx Antenna Gain	26 dB	85.542 dBm	358000 W EIRP
Path Loss	-271.18 dB	-185.64 dBm	
Rx Antenna Gain	28 dB	-157.64 dBm	172.2 e -21 W

EME System Analysis

- The received noise can also be estimated
- WSJT-x uses a 2500 Hz bandwidth to report its SNR
- KTB noise power received:

$$Pnoise = KTB$$

where:

$K = Boltzmans\ constant\ (1.38\ x\ 10^{-23}\ J/K)$

$T = Reference\ Temperature\ (290\ K)$

$B = Bandwidth\ \mathrm{in}\ Hz\ (2500)$

$$Pnoise\,(dBm) = 10\log_{10}\left(\frac{KTB}{0.001}\right)$$

$$Pnoise = 1.001\ x\ 10^{-17}\ W,\ (-140\ dBm)$$

$$SNR = \frac{Signal\ Power}{Noise\ Power} \qquad SNR\,(dB) = Rx\ Power\,(dB) - Noise\ Power\,(dB)$$

For an ideal receiver:

$$SNR\,(dB) = Rx\ Power - Noise\ Power = -157.6 - (-140) \boxed{= -17.6\ dB}$$

WSJT-x SNR detection threshold = -27.6 dB

EME System Analysis

- There are other sources of noise in the system
- They can all be summed as noise power at the input to the receiver
    - Receiver Noise Figure
    - Sky Noise (noise temperature at 1296 MHz)
    - Antenna noise (sidelobes picking up a warm ground)

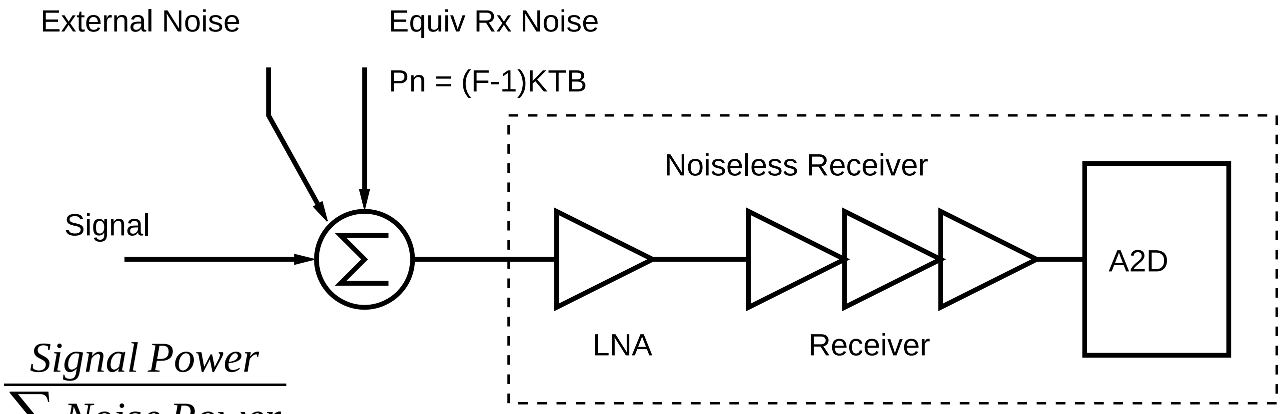
$$\text{Equiv } Rx\ Noise\ Power = (F-1)\,KTB$$

$$\text{Sky Noise Power} = KTB\,,\ (T = Sky\ noise\ temperature)$$

$$\text{Antenna Noise Power} = KTB\,,\ (T = Antenna\ temperature)$$

$$\text{F} = \text{Noise Factor, not Noise Figure}$$

$$\text{F} = 10^{\left(\frac{NF_{dB}}{10}\right)}$$



$$SNR = \frac{Signal\ Power}{\sum Noise\ Power}$$

EME System Analysis

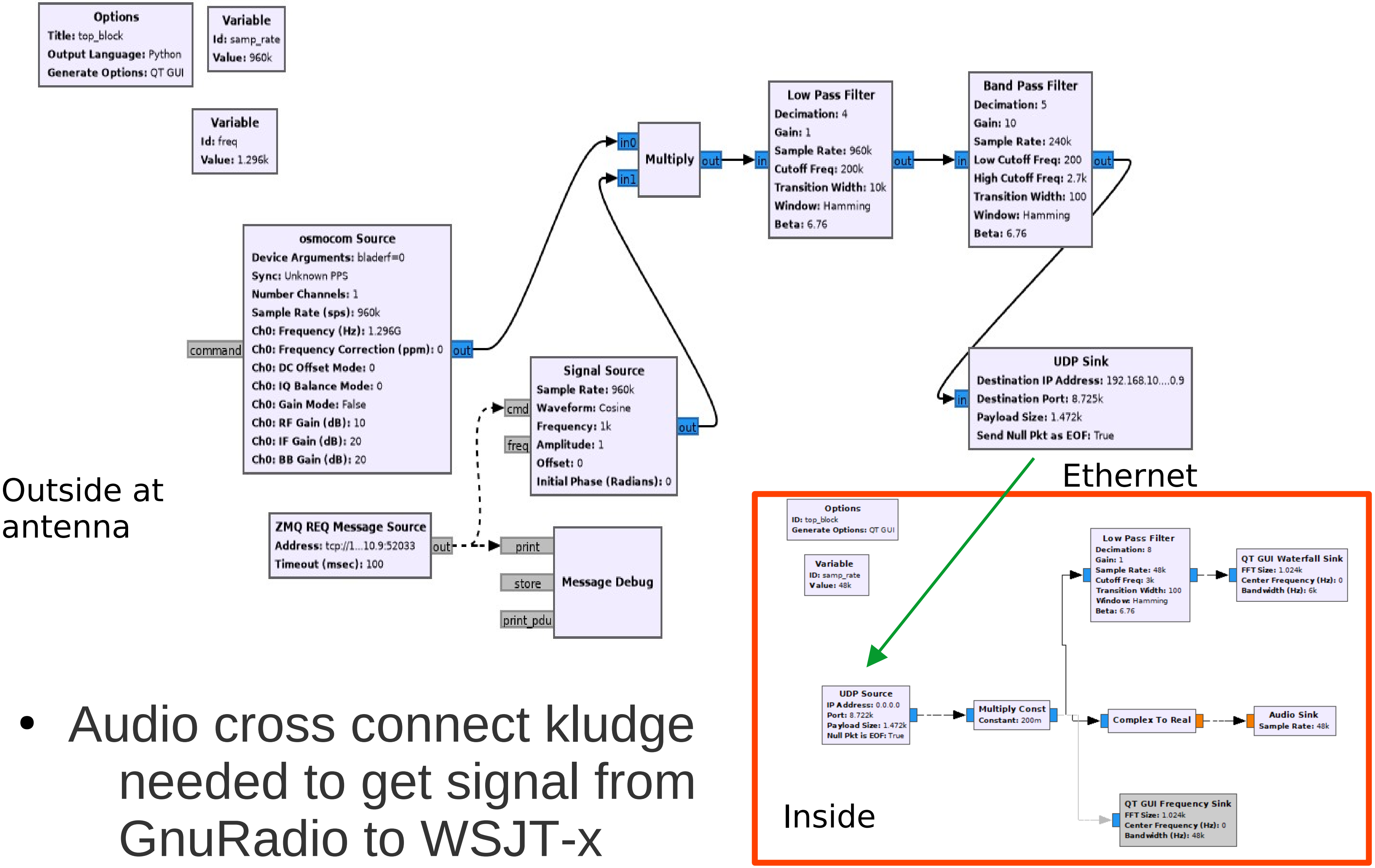
- Estimated Received Signal to Noise Ratio (SNR)

Receiver	Noise Figure	Gain
LNA NF	0.33 dB	35 dB
Receiver NF	2.5 dB	
Total Cascade Rx NF	0.331 dB	
Equivalent Noise Power	7.92 e -19 W	

Noise Contributions	Power (dBm)	Power (Watts)
KTB Noise	-140.0 dBm	1.001 e -17
Receiver Noise	-181.0 dBm	7.92 e –19
Sky Noise (Sky Temp, 10 K)		3.45 e –19
System Noise Temp (200 K)		6.9 e -18
Total Noise Power at Rx Input	-137.4 dBm	1.8 e -17

Final SNR = -157.6 - (-137.4) = -20.2 dB

First Receive using GnuRadio



Outside at antenna

Options
Title: top_block
Output Language: Python
Generate Options: QT GUI

Variable
Id: samp_rate
Value: 960k

Variable
Id: freq
Value: 1.296k

osmocom Source
Device Arguments: bladerf=0
Sync: Unknown PPS
Number Channels: 1
Sample Rate (sps): 960k
Ch0: Frequency (Hz): 1.296G
Ch0: Frequency Correction (ppm): 0
Ch0: DC Offset Mode: 0
Ch0: IQ Balance Mode: 0
Ch0: Gain Mode: False
Ch0: RF Gain (dB): 10
Ch0: IF Gain (dB): 20
Ch0: BB Gain (dB): 20

Multiply

Low Pass Filter
Decimation: 4
Gain: 1
Sample Rate: 960k
Cutoff Freq: 200k
Transition Width: 10k
Window: Hamming
Beta: 6.76

Band Pass Filter
Decimation: 5
Gain: 10
Sample Rate: 240k
Low Cutoff Freq: 200
High Cutoff Freq: 2.7k
Transition Width: 100
Window: Hamming
Beta: 6.76

Signal Source
Sample Rate: 960k
Waveform: Cosine
Frequency: 1k
Amplitude: 1
Offset: 0
Initial Phase (Radians): 0

UDP Sink
Destination IP Address: 192.168.10....0.9
Destination Port: 8.725k
Payload Size: 1.472k
Send Null Pkt as EOF: True

ZMQ REQ Message Source
Address: tcp://1...10.9:52033
Timeout (msec): 100

Message Debug

Ethernet

Options
ID: top_block
Generate Options: QT GUI

Variable
ID: samp_rate
Value: 48k

Low Pass Filter
Decimation: 8
Gain: 1
Sample Rate: 48k
Cutoff Freq: 3k
Transition Width: 100
Window: Hamming
Beta: 6.76

QT GUI Waterfall Sink
FFT Size: 1.024k
Center Frequency (Hz): 0
Bandwidth (Hz): 6k

UDP Source
IP Address: 0.0.0.0
Port: 8.722k
Payload Size: 1.472k
Null Pkt is EOF: True

Multiply Const
Constant: 200m

Complex To Real

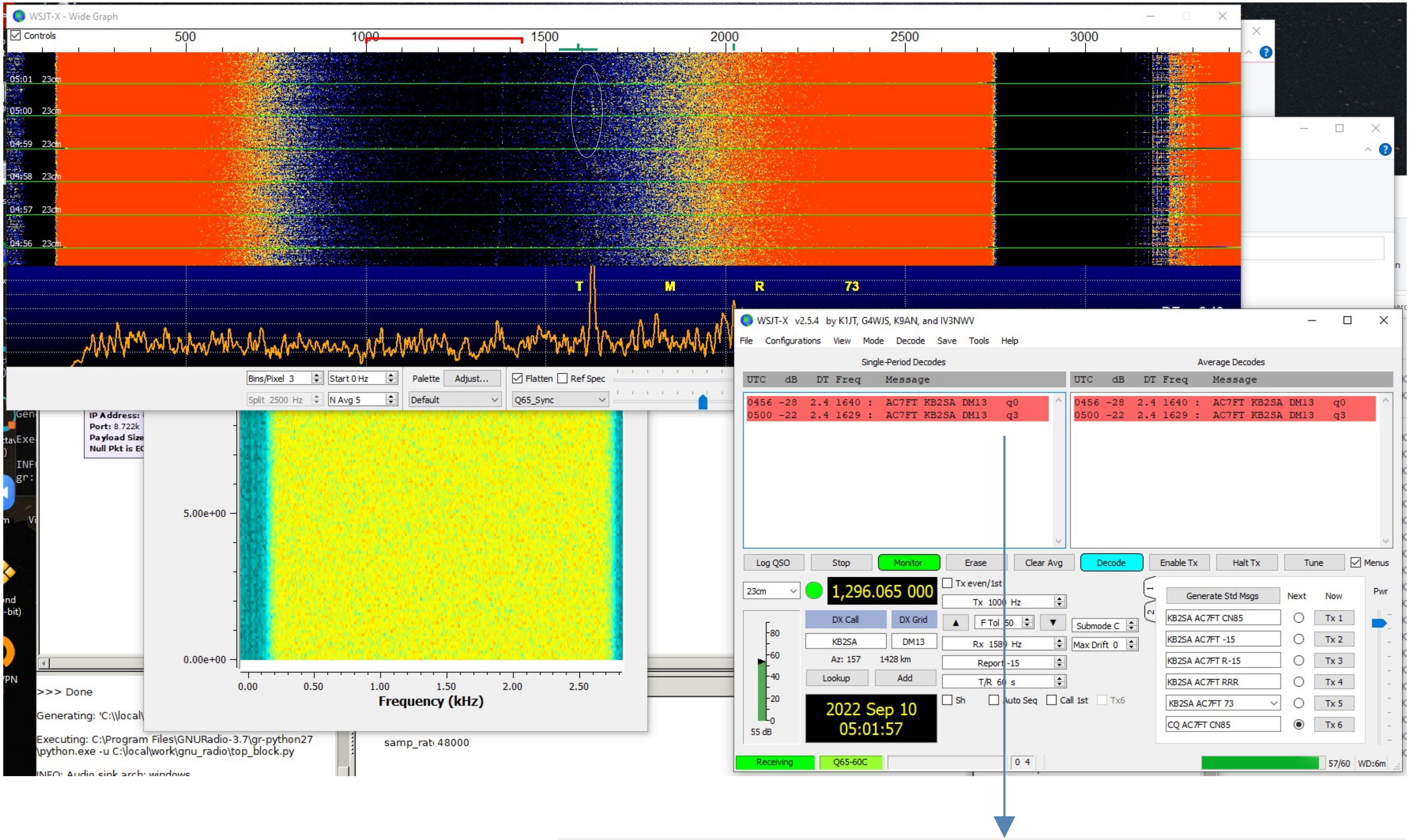
Audio Sink
Sample Rate: 48k

QT GUI Frequency Sink
FFT Size: 1.024k
Center Frequency (Hz): 0
Bandwidth (Hz): 48k

Inside

- Audio cross connect kludge needed to get signal from GnuRadio to WSJT-x

First Decode via EME at 1296 MHz



Single-Period Decodes:

```
UTC   dB   DT Freq    Message
0456 -28  2.4 1640 :  AC7FT KB2SA DM13    q0
0500 -22  2.4 1629 :  AC7FT KB2SA DM13    q3
```

Average Decodes:

```
UTC   dB   DT Freq    Message
0456 -28  2.4 1640 :  AC7FT KB2SA DM13    q0
0500 -22  2.4 1629 :  AC7FT KB2SA DM13    q3
```

1,296.065 000

DX Call: KB2SA DX Grid: DM13

Az: 157 1428 km

Tx 1000 Hz F Tol 50 Rx 1589 Hz Report -15 T/R 60 s

Submode C Max Drift 0

2022 Sep 10
05:01:57

KB2SA AC7FT CN85
KB2SA AC7FT -15
KB2SA AC7FT R-15
KB2SA AC7FT RRR
KB2SA AC7FT 73
CQ AC7FT CN85

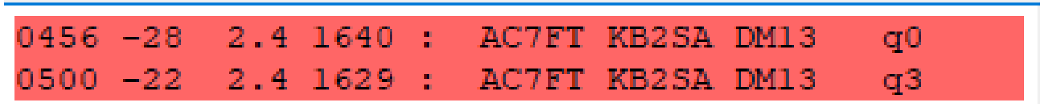
Receiving Q65-60C 57/60 WD:6m

>>> Done

Generating: 'C:\\local\

Executing: C:\Program Files\GNURadio-3.7\gr-python27\python.exe -u C:\local\work\gnu_radio\top_block.py

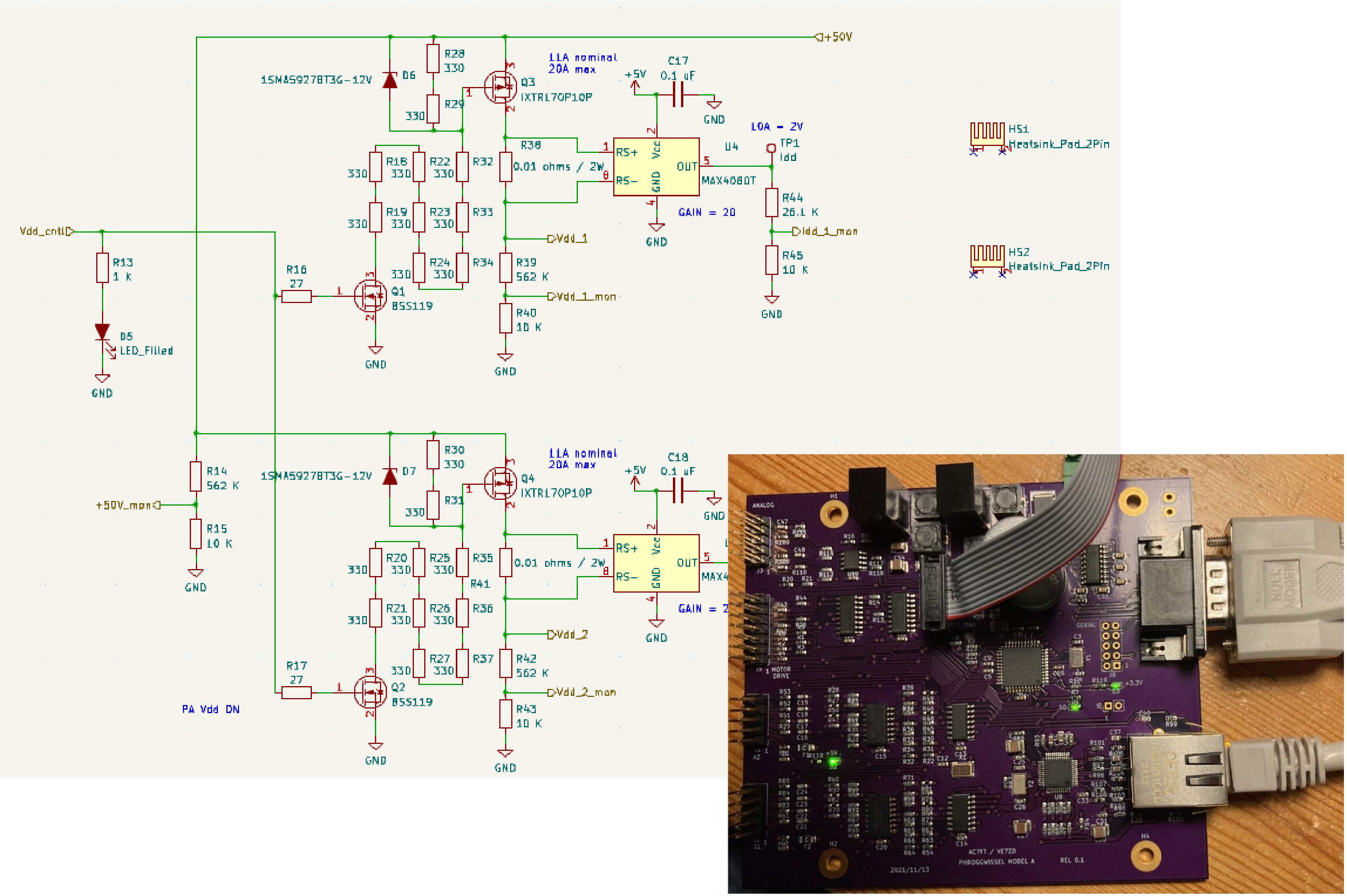
samp_rate 48000



```
0456 -28   2.4 1640 :  AC7FT KB2SA DM13    q0
0500 -22   2.4 1629 :  AC7FT KB2SA DM13    q3
```

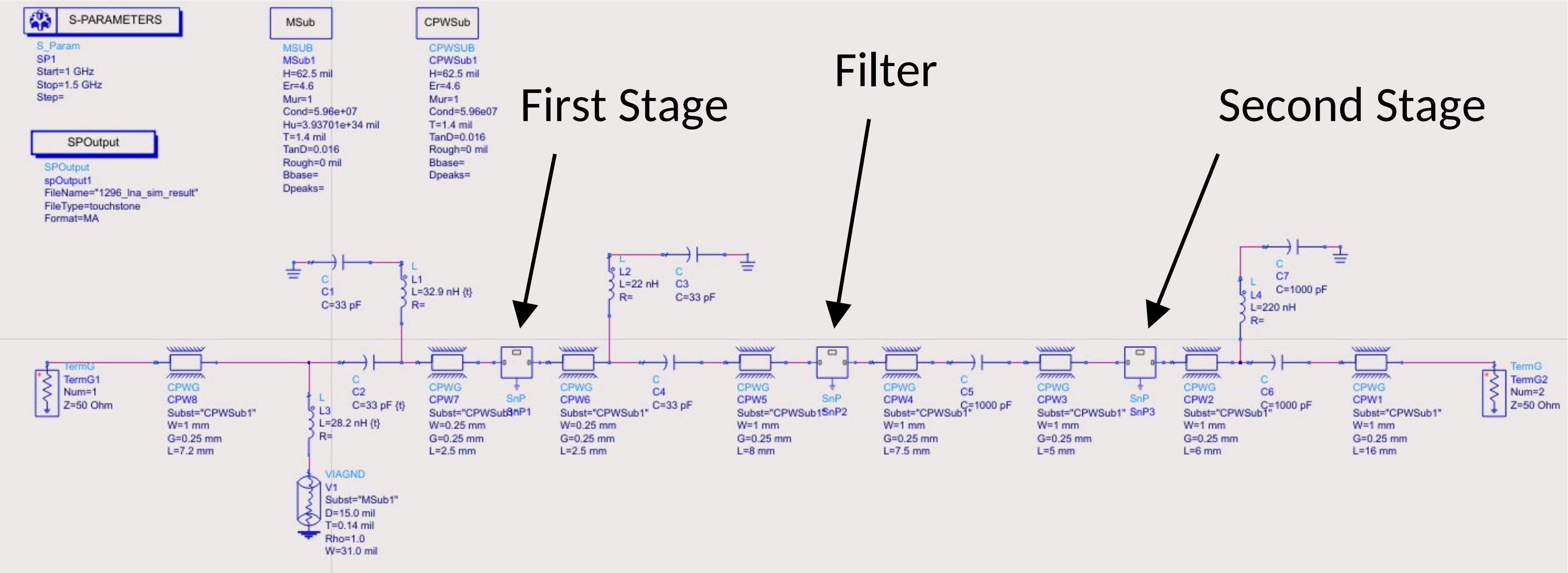
- Copied KB2SA!!
- SNR -22 dB

Hardware



+50V
R28
330
R29
330
D6
1SMA5927BT3G-12V
Q3
IXTR170P10P
11A nominal
20A max
+5V
C17
0.1 uF
GND
10A = 2V
TP1
Idd
U4
RS+
RS-
Vcc
GND
OUT
MAX4080T
GAIN = 20
R38
0.01 ohms / 2W
R18
330
R22
330
R32
R19
330
R23
330
R33
R24
330
R34
R39
562 K
R40
10 K
R44
26.1 K
R45
10 K
Idd_1_mon
Vdd_1
Vdd_1_mon
Vdd_cntl
R13
1 K
D5
LED_Filled
R16
27
Q1
BSS119
HS1
Heatsink_Pad_2Pin
HS2
Heatsink_Pad_2Pin
R30
330
R31
330
D7
1SMA5927BT3G-12V
Q4
IXTR170P10P
11A nominal
20A max
C18
0.1 uF
R14
562 K
+50V_mon
R15
10 K
R20
330
R25
330
R35
0.01 ohms / 2W
R41
R21
330
R26
330
R36
R27
330
R37
R42
562 K
Vdd_2
Vdd_2_mon
R43
10 K
R17
27
Q2
BSS119
PA Vdd DN
ANALOG
MOTOR DRIVE
SERIAL
JTAG
+3.3V
AC7FT / VE7ZD
PHROGGWISSEL MODEL A
REL 0.1
2021/11/13

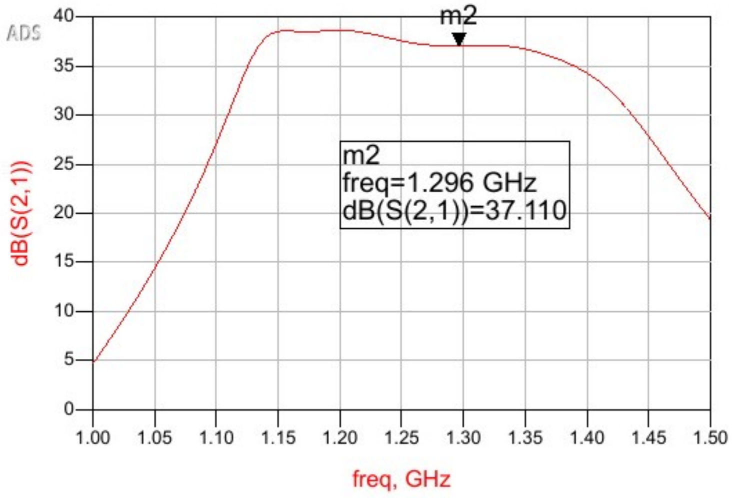
LNA Simulations

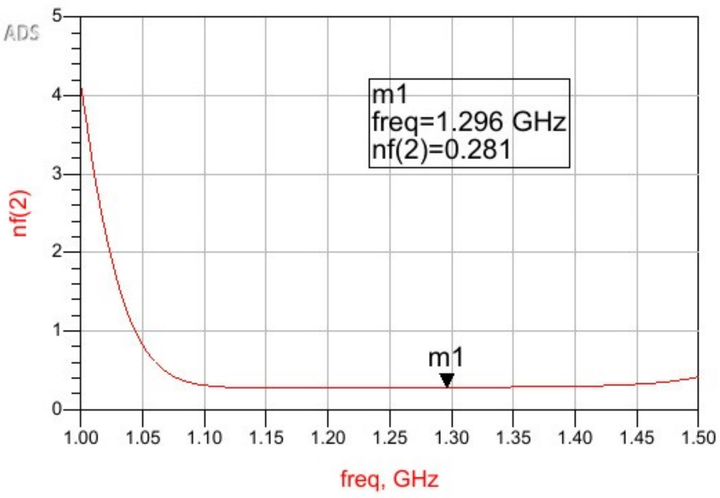


First Stage

Filter

Second Stage





LNA HW Measurements

Simulated Gain: 37.11 dB
Measured Gain: 36.96 dB

Simulated NF: 0.281 dB
Measured NF: 0.329 dB

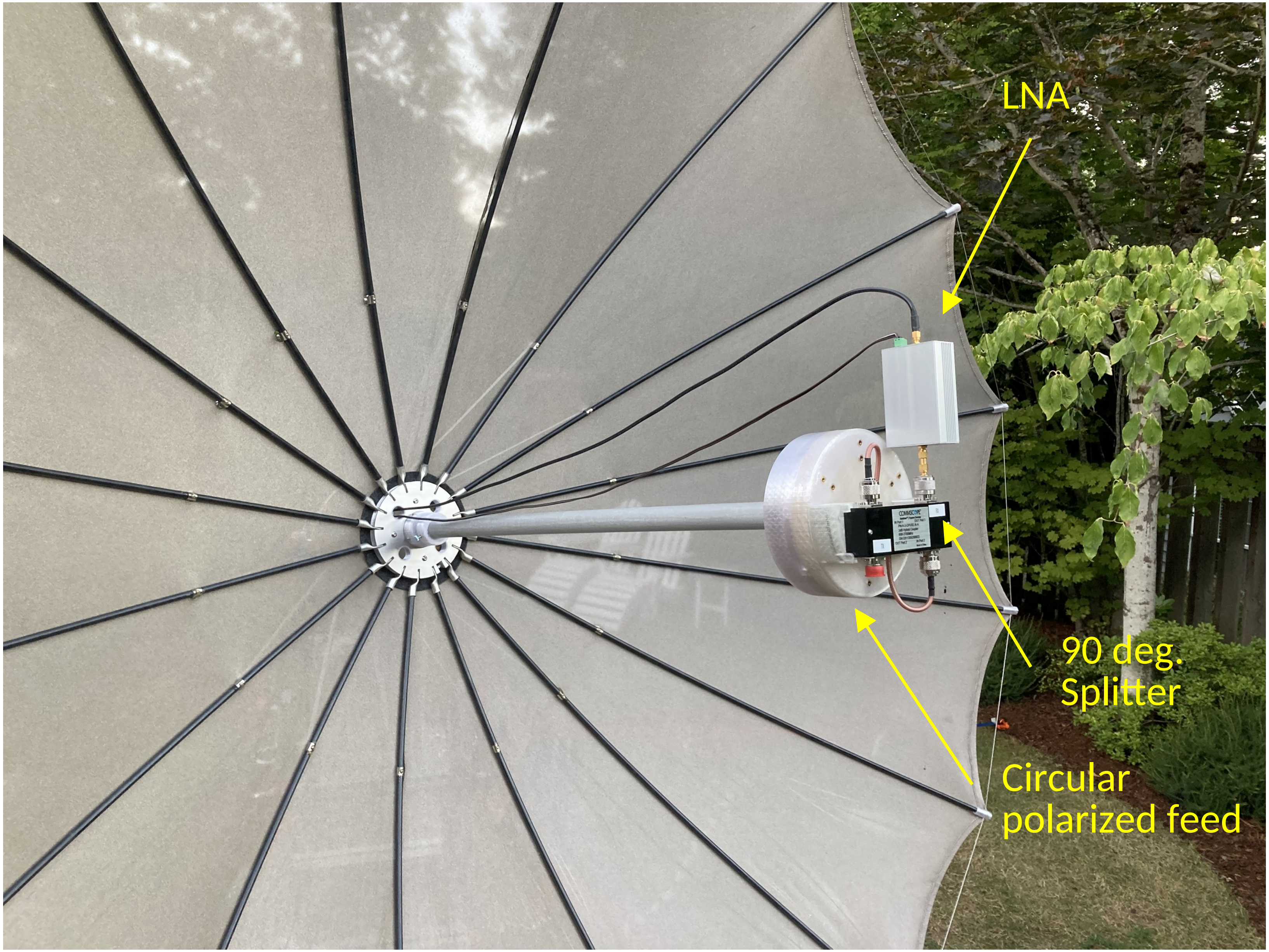
Input: RF
Coupling: DC
Align: Auto
Input Z: 50 Ω
Freq Ref: Int (S)
Atten: 0 dB
Preamp: On
DUT: Amplifier
Averaging: >10/10
Sys Downconv: Off
FREQ = RF
Cal State: CAL
ENR State: ENR

Noise Figure
Scale/Div 0.100 dB
Ref Value 0.4 dB
Mkr1 1.296 GHz
0.329 dB

Gain
Scale/Div 0.200 dB
Ref Value 37.6 dB
Mkr1 1.296 GHz
36.961 dB

Start 1.200 GHz
BW 4.0 MHz
Freq Mode: Swept
T cold 296.50 K (Default)
Noise Source: Normal
Stop 1.300 GHz
Points 51
Apr 01, 2022
5:54:18 AM

Antenna Feed



Initial SDR Receiver

Az/El Antenna Rotor Control

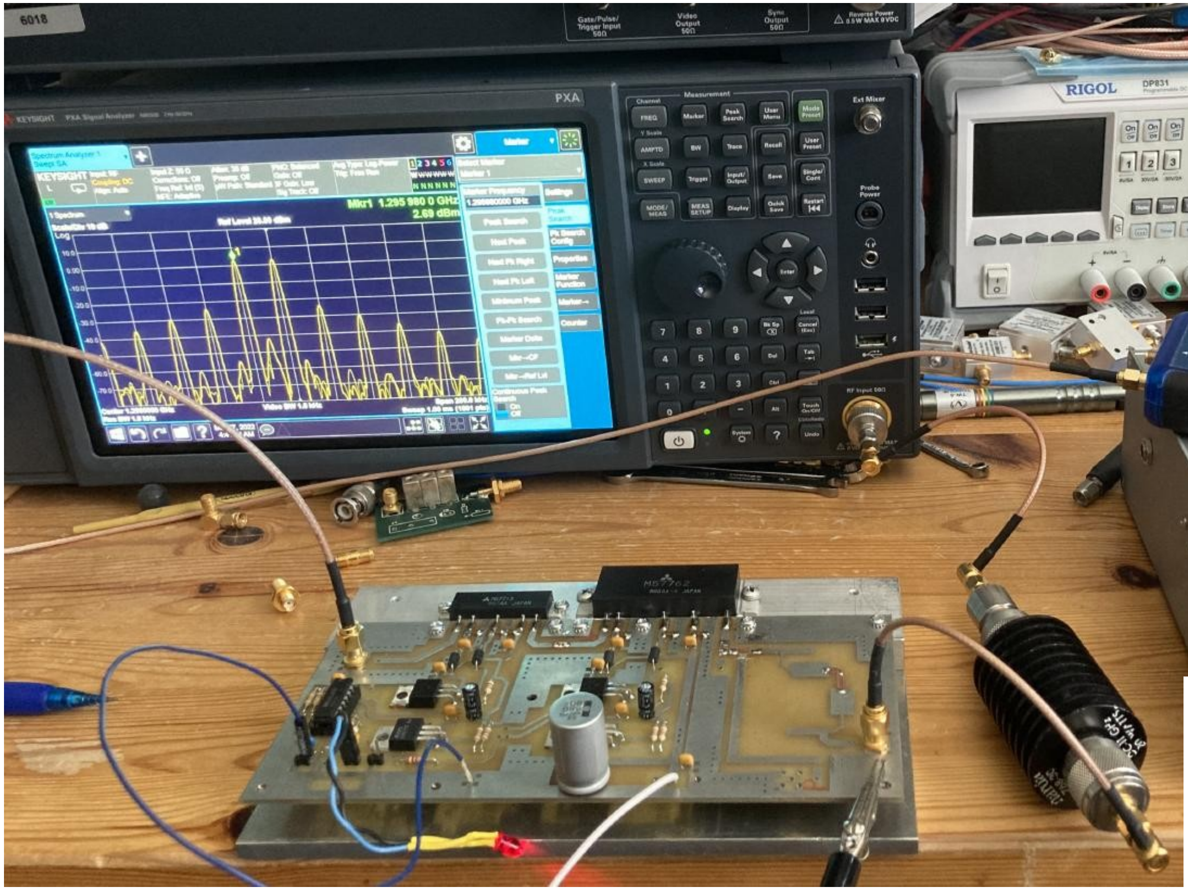
Computer

RF in from LNA

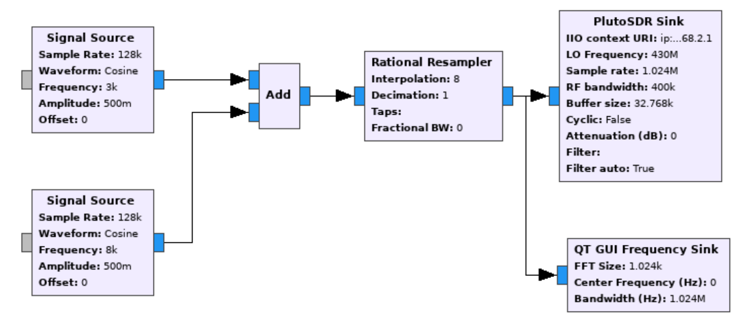
BladeRF SDR

GPS Locked 10 MHz
Reference Receiver

Transmit Driver



Pluto with GnuRadio is used as a 2 tone intermodulation source



Signal Source
Sample Rate: 128k
Waveform: Cosine
Frequency: 3k
Amplitude: 500m
Offset: 0

Signal Source
Sample Rate: 128k
Waveform: Cosine
Frequency: 8k
Amplitude: 500m
Offset: 0

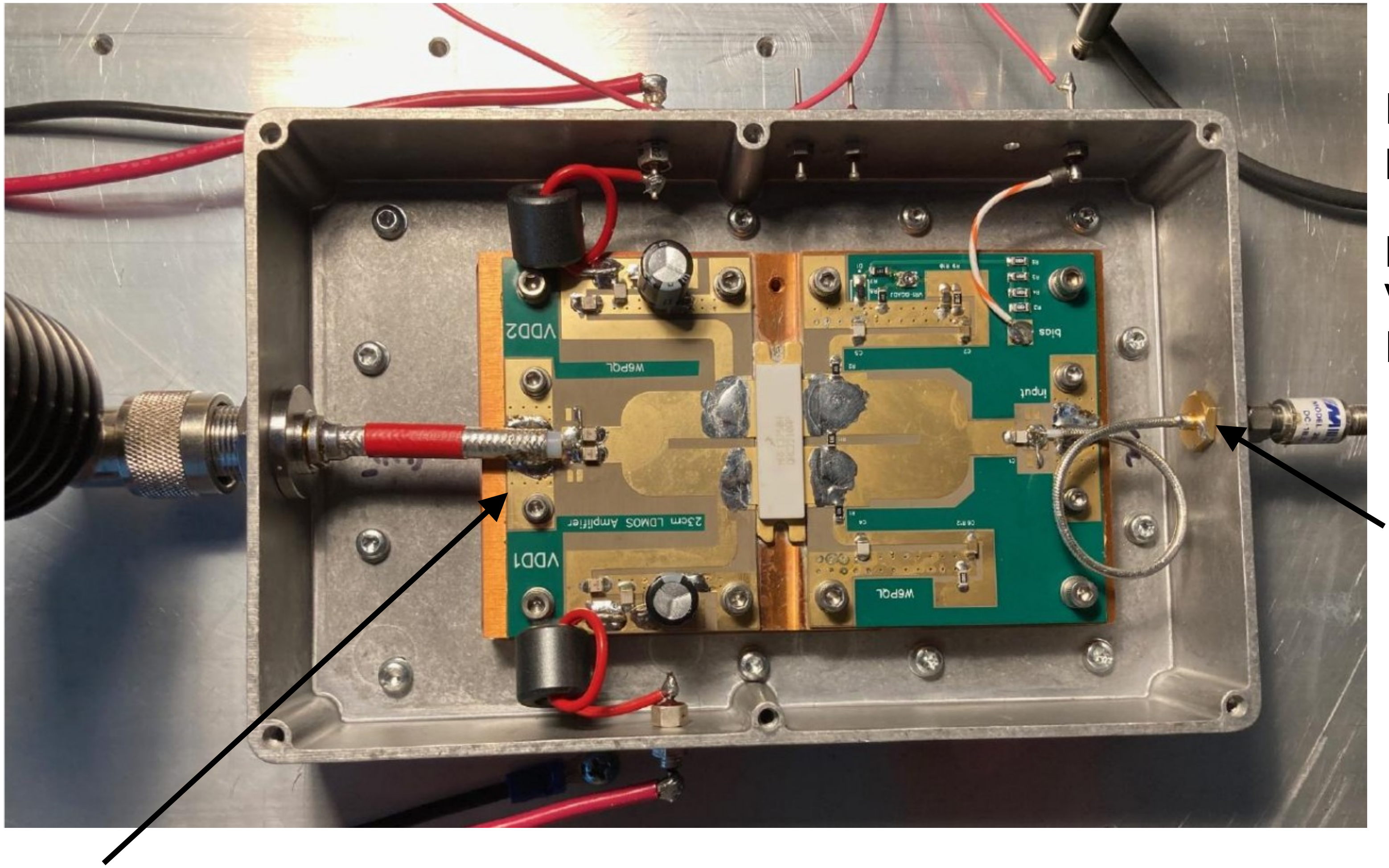
Add

Rational Resampler
Interpolation: 8
Decimation: 1
Taps:
Fractional BW: 0

PlutoSDR Sink
IIO context URI: ip:...68.2.1
LO Frequency: 430M
Sample rate: 1.024M
RF bandwidth: 400k
Buffer size: 32.768k
Cyclic: False
Attenuation (dB): 0
Filter:
Filter auto: True

QT GUI Frequency Sink
FFT Size: 1.024k
Center Frequency (Hz): 0
Bandwidth (Hz): 1.024M

500 Watt 1296 MHz PA



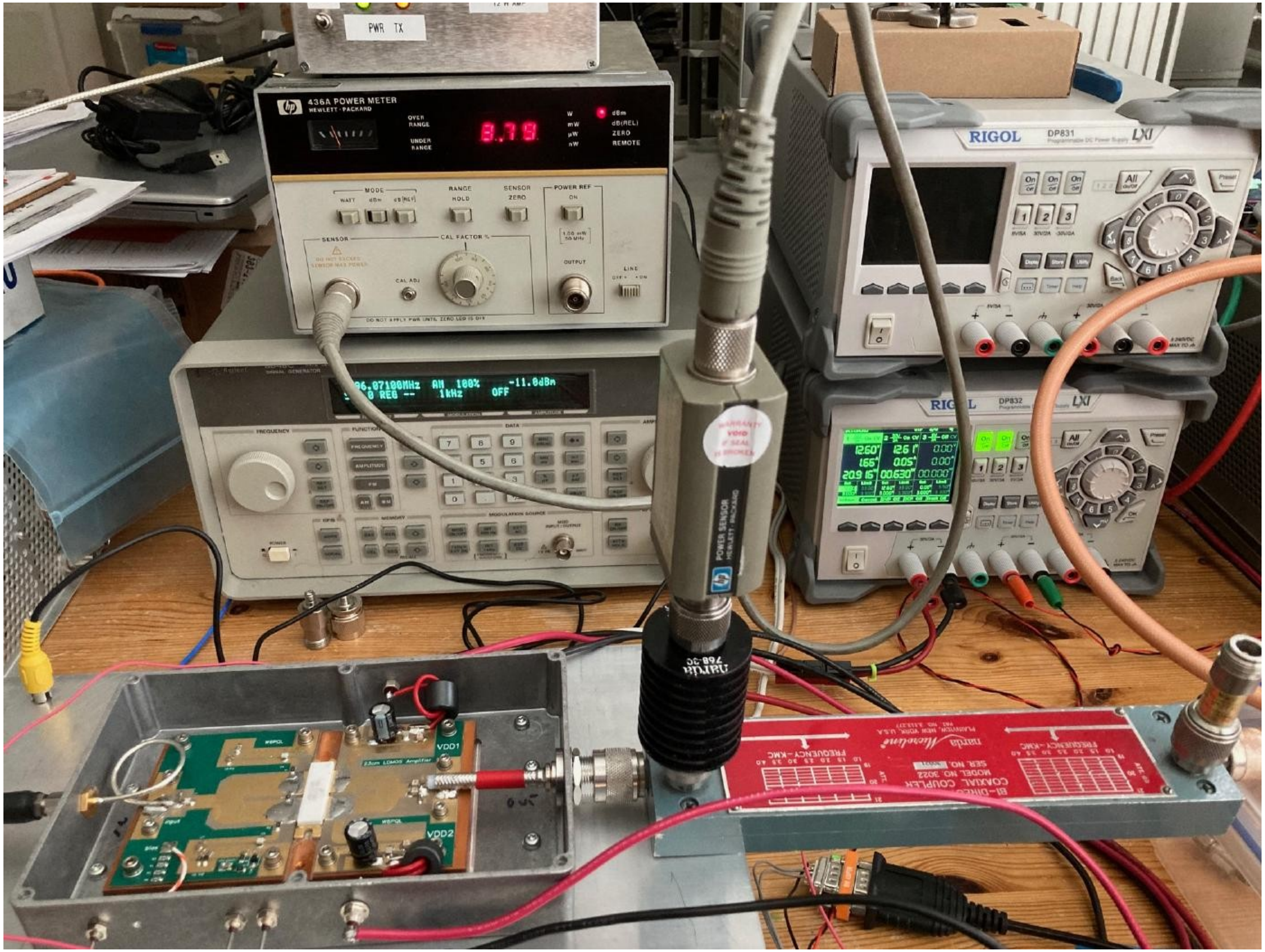
MRF13750 LDMOS
power amplifier

P1dB 530 W
Vdd 50V
Idd 20A

Input

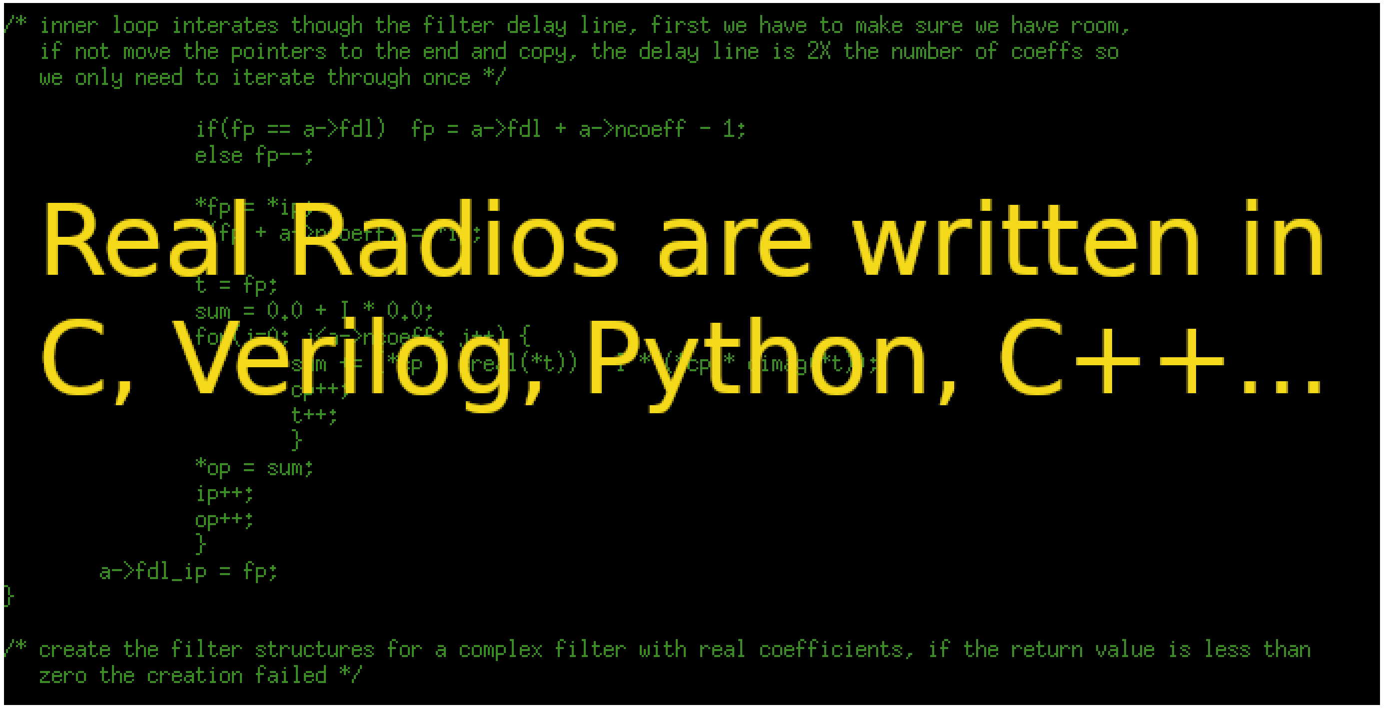
Output

500 Watt 1296 MHz PA Under Test



MRF13750 LDMOS
power amplifier

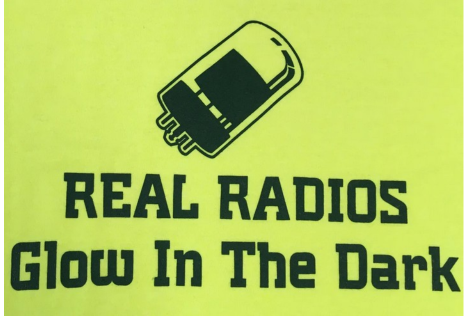
Software



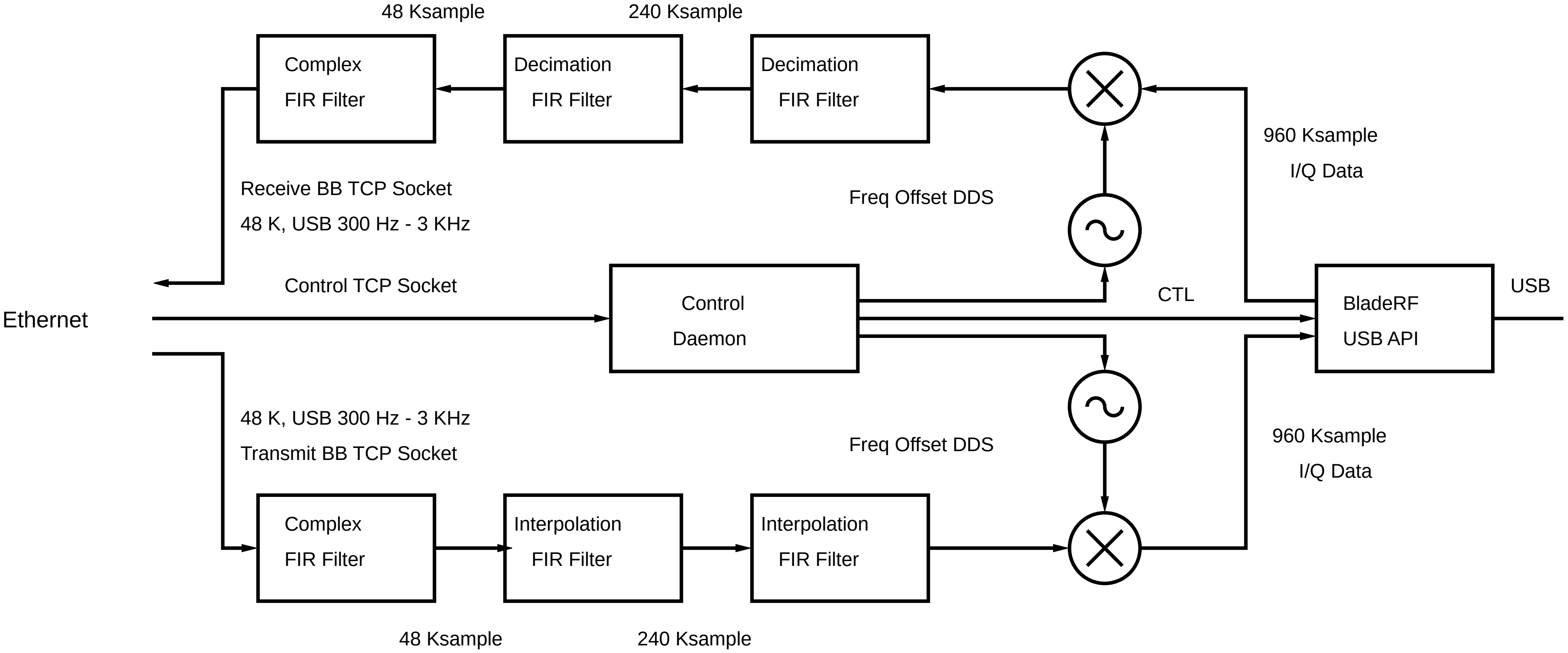
```
/* inner loop interates though the filter delay line, first we have to make sure we have room,
   if not move the pointers to the end and copy, the delay line is 2X the number of coeffs so
   we only need to iterate through once */

                if(fp == a->fdl)  fp = a->fdl + a->ncoeff - 1;
                else fp--;

                *fp = *ip;
                *(fp + a->ncoeff) = *ip;

                t = fp;
                sum = 0.0 + I * 0.0;
                for(i=0; i<a->ncoeff; i++) {
                        sum += (*cp * creal(*t)) + I * (*cp * cimag(*t));
                        cp++;
                        t++;
                        }
                *op = sum;
                ip++;
                op++;
                }
        a->fdl_ip = fp;
}

/* create the filter structures for a complex filter with real coefficients, if the return value is less than
   zero the creation failed */
```

Real Radios are written in C, Verilog, Python, C++…

Outdated?

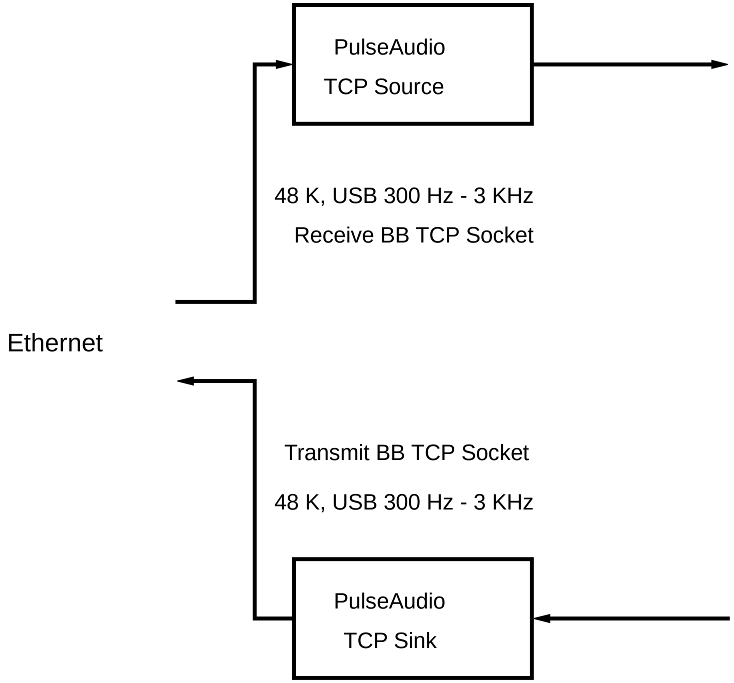


Software (Outside)



- The DSP software was re-written in C to facilitate a clean data and control method over TCP sockets
- LiquidDSP libraries were used

Software (Inside)



PulseAudio TCP Source

48 K, USB 300 Hz - 3 KHz

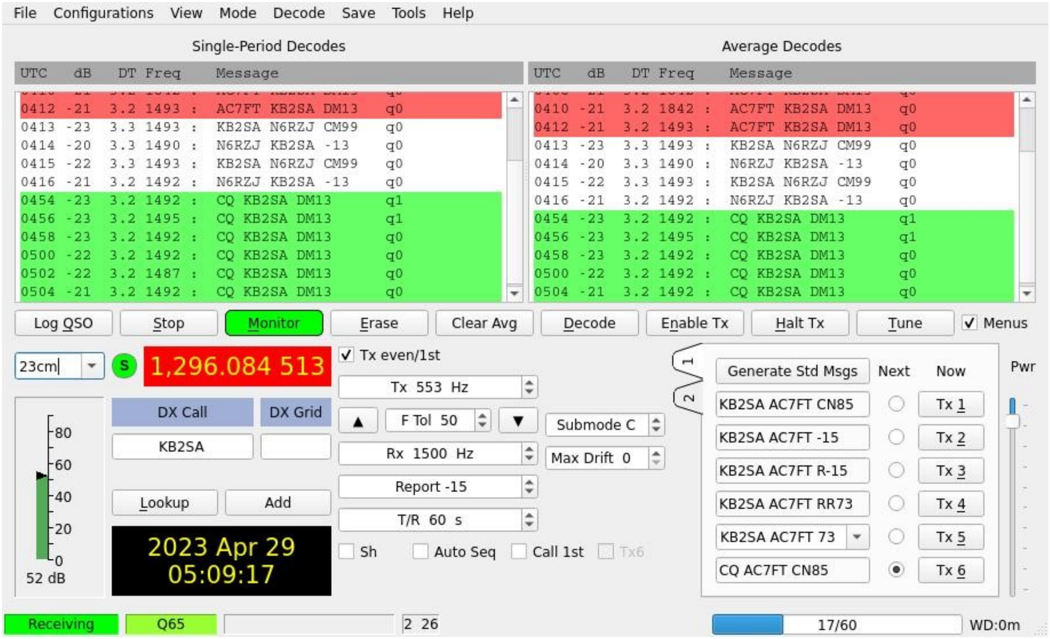
Receive BB TCP Socket

Ethernet

Transmit BB TCP Socket

48 K, USB 300 Hz - 3 KHz

PulseAudio TCP Sink



Single-Period Decodes

```
UTC   dB   DT Freq    Message
0412 -21  3.2 1493 :  AC7FT KB2SA DM13    q0
0413 -23  3.3 1493 :  KB2SA N6RZJ CM99    q0
0414 -20  3.3 1490 :  N6RZJ KB2SA -13     q0
0415 -22  3.3 1493 :  KB2SA N6RZJ CM99    q0
0416 -21  3.2 1492 :  N6RZJ KB2SA -13     q0
0454 -23  3.2 1492 :  CQ KB2SA DM13       q1
0456 -23  3.2 1495 :  CQ KB2SA DM13       q1
0458 -23  3.2 1492 :  CQ KB2SA DM13       q0
0500 -22  3.2 1492 :  CQ KB2SA DM13       q0
0502 -22  3.2 1487 :  CQ KB2SA DM13       q0
0504 -21  3.2 1492 :  CQ KB2SA DM13       q0
```

Average Decodes

```
UTC   dB   DT Freq    Message
0410 -21  3.2 1842 :  AC7FT KB2SA DM13    q0
0412 -21  3.2 1493 :  AC7FT KB2SA DM13    q0
0413 -23  3.3 1493 :  KB2SA N6RZJ CM99    q0
0414 -20  3.3 1490 :  N6RZJ KB2SA -13     q0
0415 -22  3.3 1493 :  KB2SA N6RZJ CM99    q0
0416 -21  3.2 1492 :  N6RZJ KB2SA -13     q0
0454 -23  3.2 1492 :  CQ KB2SA DM13       q1
0456 -23  3.2 1495 :  CQ KB2SA DM13       q1
0458 -23  3.2 1492 :  CQ KB2SA DM13       q0
0500 -22  3.2 1492 :  CQ KB2SA DM13       q0
0504 -21  3.2 1492 :  CQ KB2SA DM13       q0
```

23cm

S 1,296.084 513

☑ Tx even/1st

Tx 553 Hz

F Tol 50

Submode C

Rx 1500 Hz

Max Drift 0

Report -15

T/R 60 s

☐ Sh ☐ Auto Seq ☐ Call 1st ☐ Tx6

DX Call: KB2SA

DX Grid:

52 dB

2023 Apr 29
05:09:17

KB2SA AC7FT CN85 ○

KB2SA AC7FT -15 ○

KB2SA AC7FT R-15 ○

KB2SA AC7FT RR73 ○

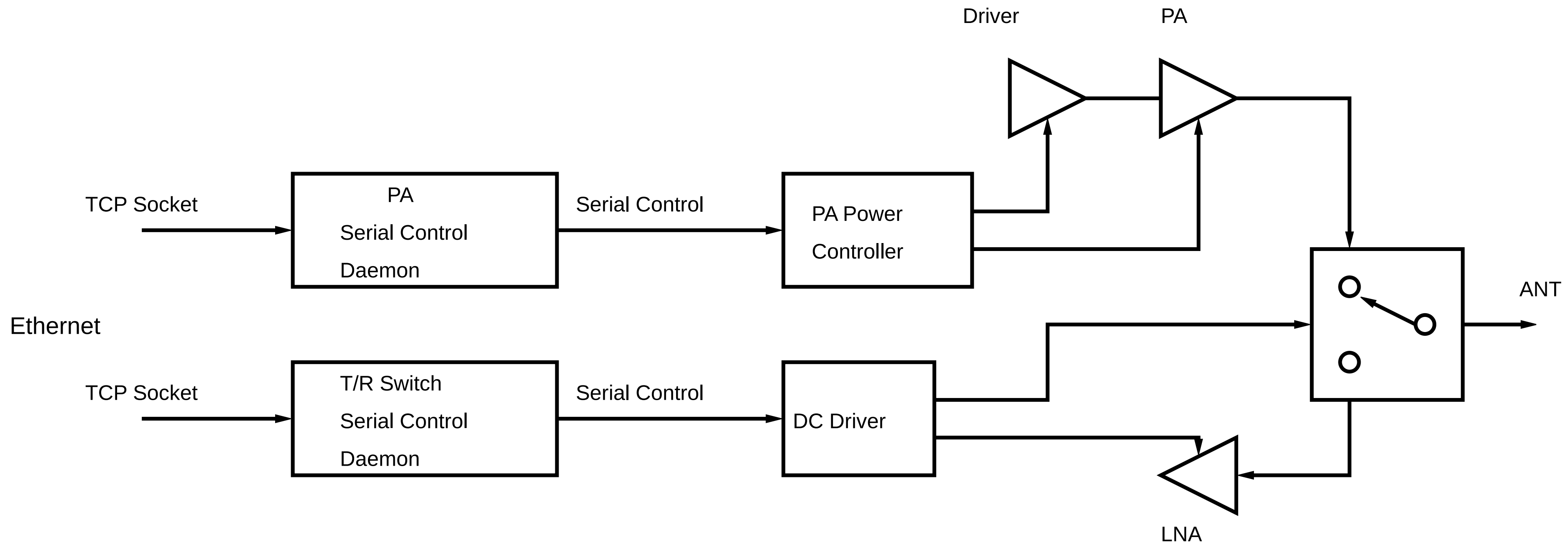
KB2SA AC7FT 73 ○

CQ AC7FT CN85 ●

Receiving | Q65 | 2 26 | 17/60 | WD:0m

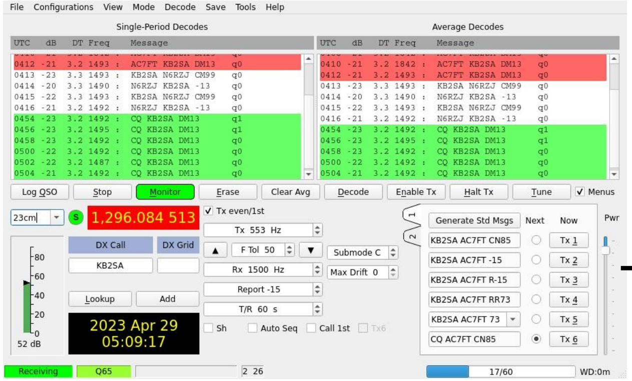
- The PulseAudio “module-simple-protocol-tcp” was used to create a 48 Ksample/sec audio device that would be visible to WSJT-x
- WSJT-x has no audio or baseband socket interface!
- WSJT-x is the “de-facto” EME SDR modem

T/R Control



- There are two control daemons on the “outside computer” that select beetween receive and transmit operation
- They also monitor the electrical parameters (voltage, current etc.) of the hardware

T/R and Frequency Control



Single-Period Decodes

```
UTC   dB   DT Freq    Message
0412 -21  3.2 1493 :  AC7FT KB2SA DM13    q0
0413 -23  3.3 1493 :  KB2SA N6RZJ CM99    q0
0414 -20  3.3 1490 :  N6RZJ KB2SA -13     q0
0415 -22  3.3 1493 :  KB2SA N6RZJ CM99    q0
0416 -21  3.2 1492 :  N6RZJ KB2SA -13     q0
0454 -23  3.2 1492 :  CQ KB2SA DM13       q1
0456 -23  3.2 1495 :  CQ KB2SA DM13       q1
0458 -23  3.2 1492 :  CQ KB2SA DM13       q0
0500 -22  3.2 1492 :  CQ KB2SA DM13       q0
0502 -22  3.2 1487 :  CQ KB2SA DM13       q0
0504 -21  3.2 1492 :  CQ KB2SA DM13       q0
```

Average Decodes

```
UTC   dB   DT Freq    Message
0410 -21  3.2 1842 :  AC7FT KB2SA DM13    q0
0412 -21  3.2 1493 :  AC7FT KB2SA DM13    q0
0413 -23  3.3 1493 :  KB2SA N6RZJ CM99    q0
0414 -20  3.3 1490 :  N6RZJ KB2SA -13     q0
0415 -22  3.3 1493 :  KB2SA N6RZJ CM99    q0
0416 -21  3.2 1492 :  N6RZJ KB2SA -13     q0
0454 -23  3.2 1492 :  CQ KB2SA DM13       q1
0456 -23  3.2 1495 :  CQ KB2SA DM13       q1
0458 -23  3.2 1492 :  CQ KB2SA DM13       q0
0500 -22  3.2 1492 :  CQ KB2SA DM13       q0
0504 -21  3.2 1492 :  CQ KB2SA DM13       q0
```

23cm

1,296.084 513

☑ Tx even/1st

Tx 553 Hz

F Tol 50

Submode C

Rx 1500 Hz

Max Drift 0

Report -15

T/R 60 s

☐ Sh ☐ Auto Seq ☐ Call 1st ☐ Tx6

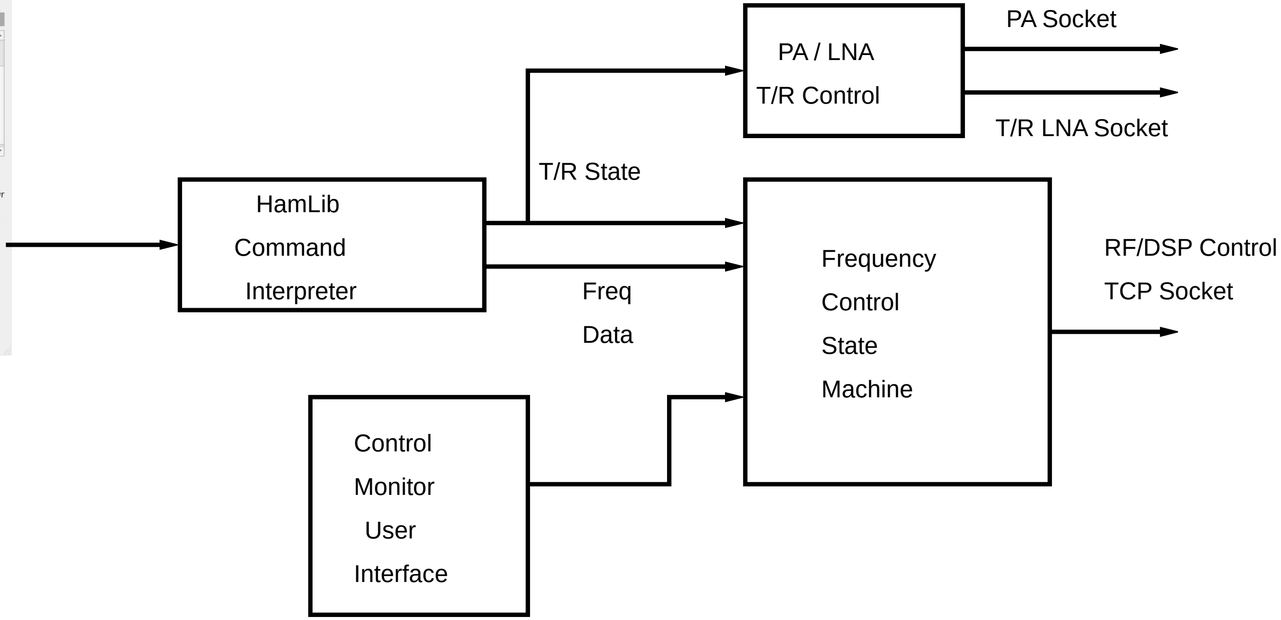
DX Call: KB2SA

52 dB

2023 Apr 29
05:09:17

KB2SA AC7FT CN85 ○ Tx 1
KB2SA AC7FT -15 ○ Tx 2
KB2SA AC7FT R-15 ○ Tx 3
KB2SA AC7FT RR73 ○ Tx 4
KB2SA AC7FT 73 ○ Tx 5
CQ AC7FT CN85 ● Tx 6

Receiving | Q65 | 2 26 | 17/60 | WD:0m



- WSJT-x can send the current Doppler compensated transmit and receive frequency as well as the Tx/Rx state via a HamLib socket
- The frequency and state information is separated and frequency data is forwarded to the RF/DSP control socket running on the outdoor computer
- The state information is sent to the T/R control and PA control processes
- A listening socket is available for control and monitoring functions

Questions

References

References:

Joe Taylor, K1JT; Bill Somerville, G4WJS; Steve Franke, K9AN; and Nico Palermo, IV3NWV April 3, 2021, “Quick-Start Guide to Q65”, https://wsjt.sourceforge.io/Q65_Quick_Start.pdf

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