RadFXSat-2 (Fox-1E)

BPSK Modulator and Demodulator

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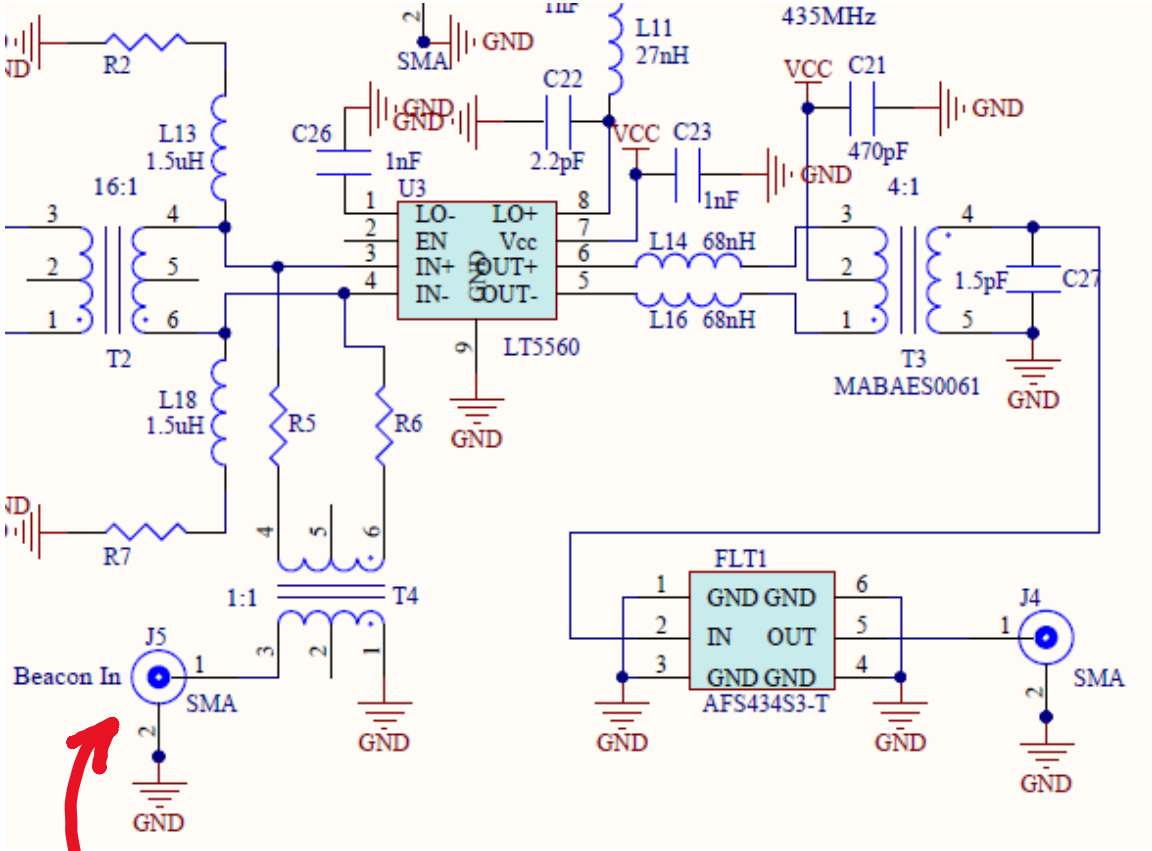
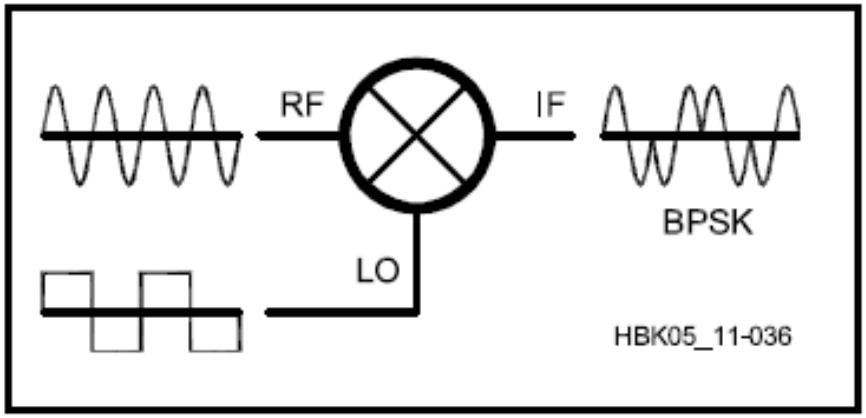
Requirements

- Fox-1E RF Design required a 45MHz carrier with PSK modulation, to mix with TX signal
- Had to work seamlessly with the existing IHU which had one analog output available



Theory

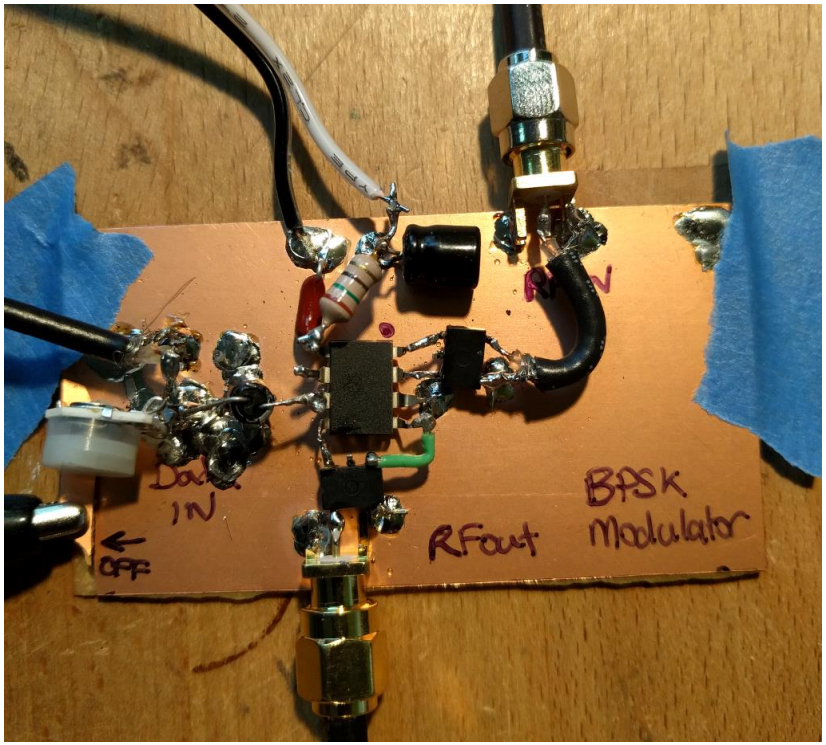


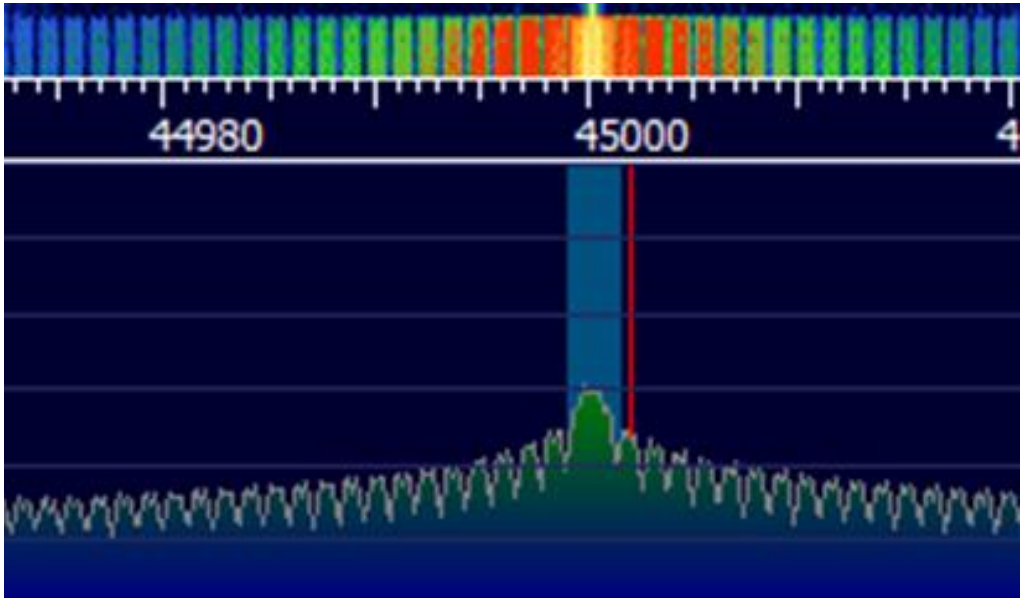
From Ch 10: ARRL Handbook

- Conceptually simple
- Long history at AMSAT in hardware
- BPSK is a double sideband suppressed carrier modulation and we can produce it from a balanced modulator (Miller, 1991)*.

* James Miller G3RUH (1991), The Shape of Bits to Come. *Amsat-UK's Oscar News, 1991 Apr No.88 p.29-37*

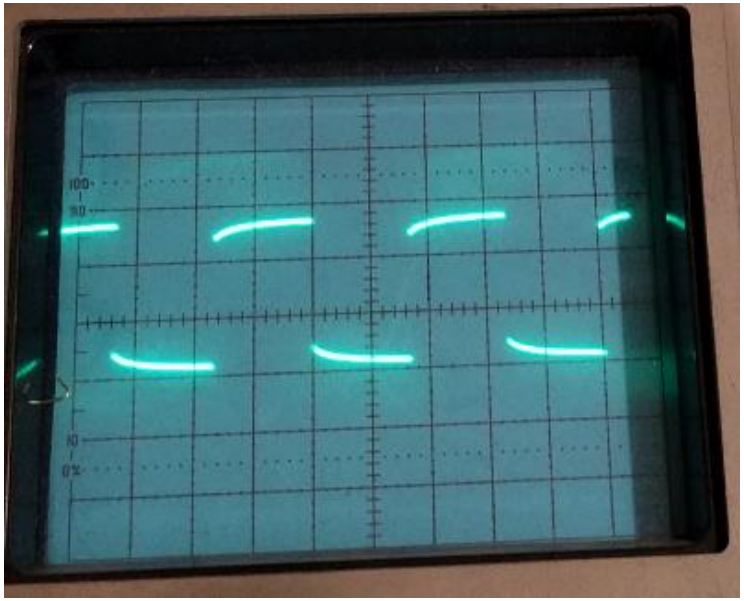
The need for filtering

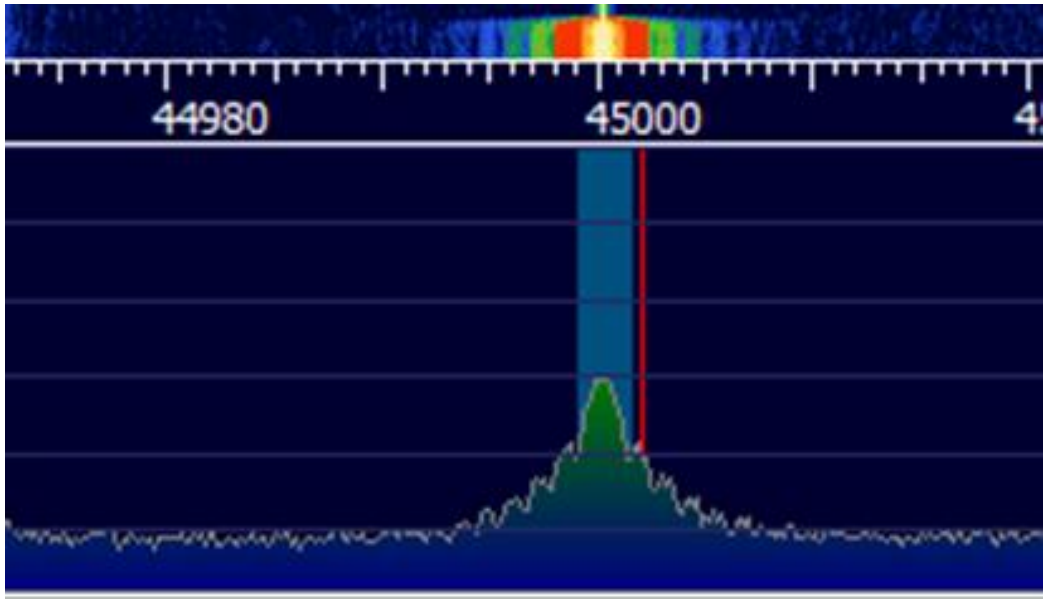




- Spectrum with square bits is very wide and shows the characteristic sinc shape in the frequency domain

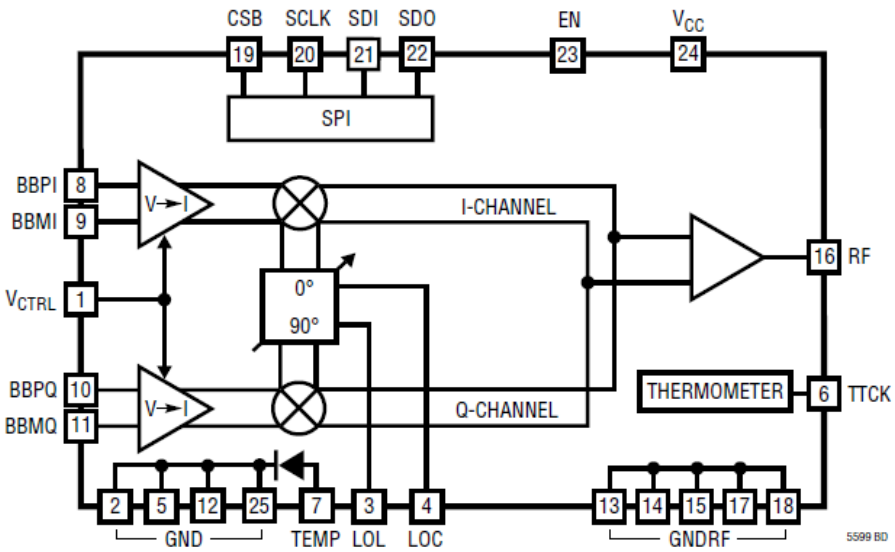
Simple Filter



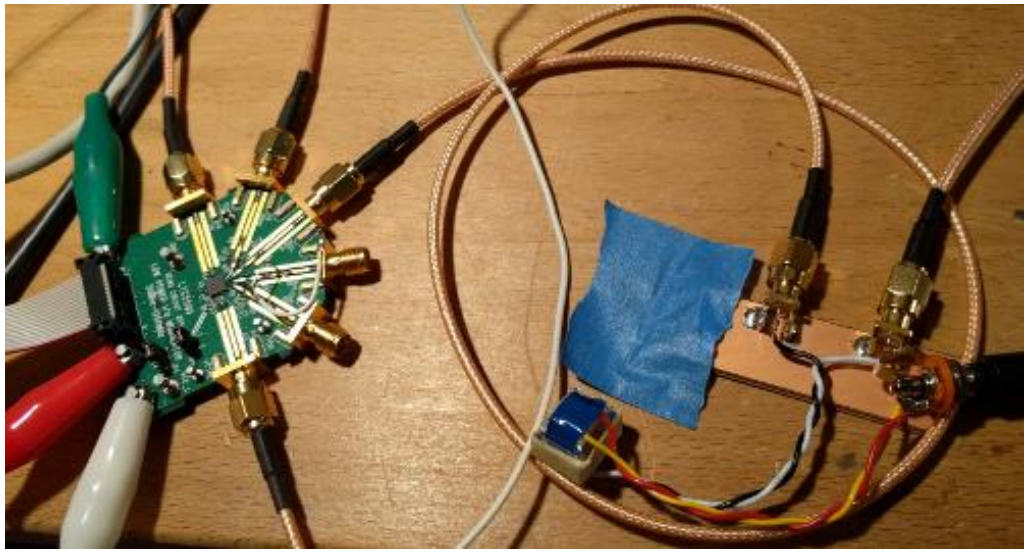


- Even gentle filtering has a dramatic impact on bandwidth
- Above shows 270ohm resistor and a 1uF capacitor is 6dB per octave
- All other settings the same including compensation for filter loss
- We use root raised cosine filter on the spacecraft

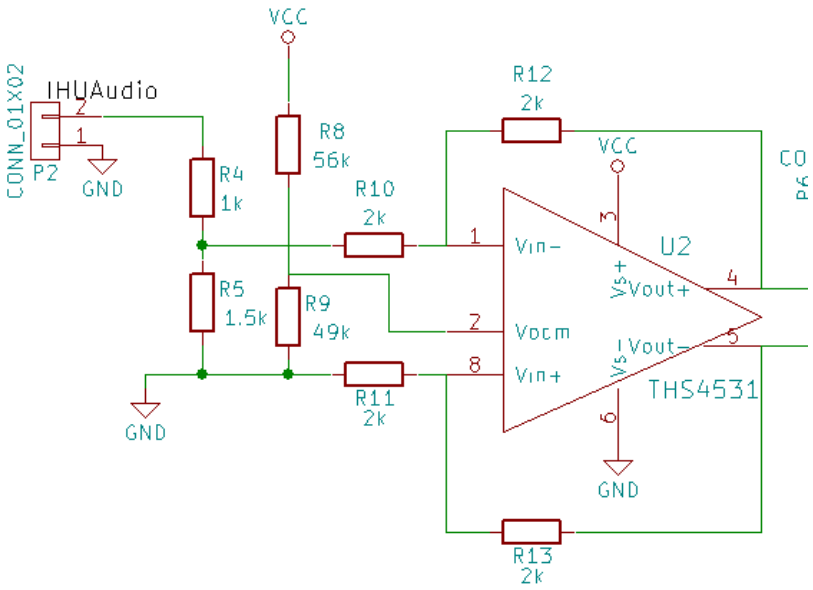
Prototype 2 – IQ Modulator



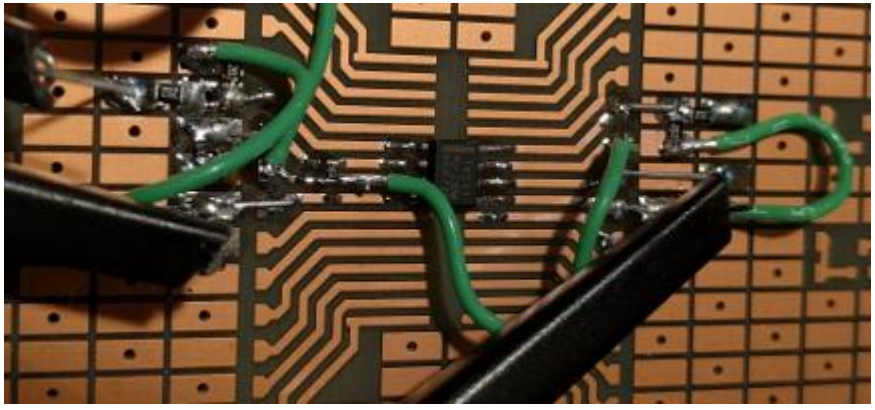
- LT5599
- SPI programming interface
- Ability to balance out carrier exactly
- Digital Adjustable gain
- Low current
- Differential inputs

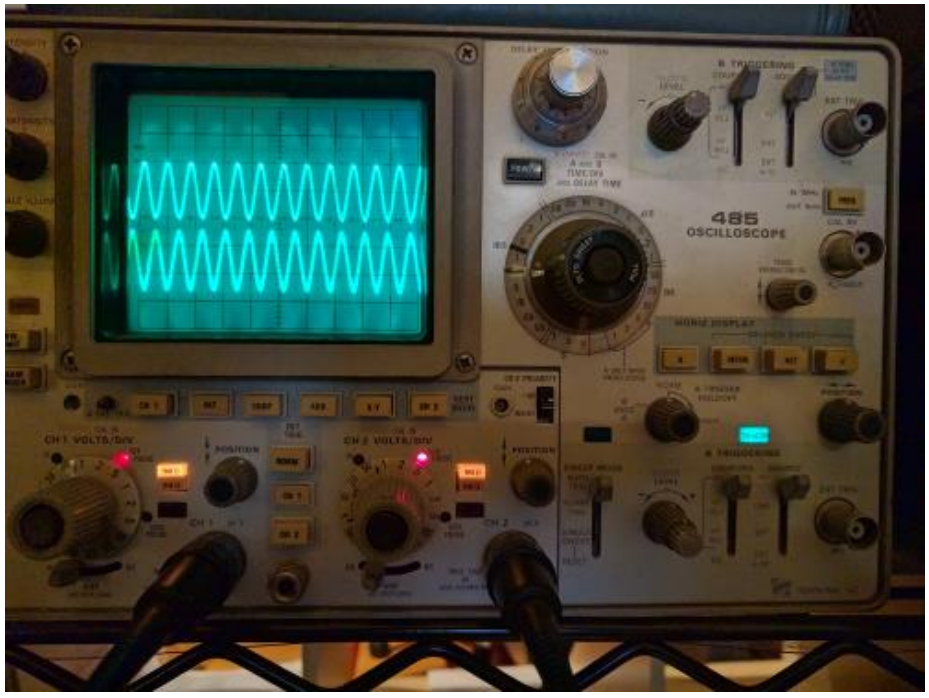


Differential Signal

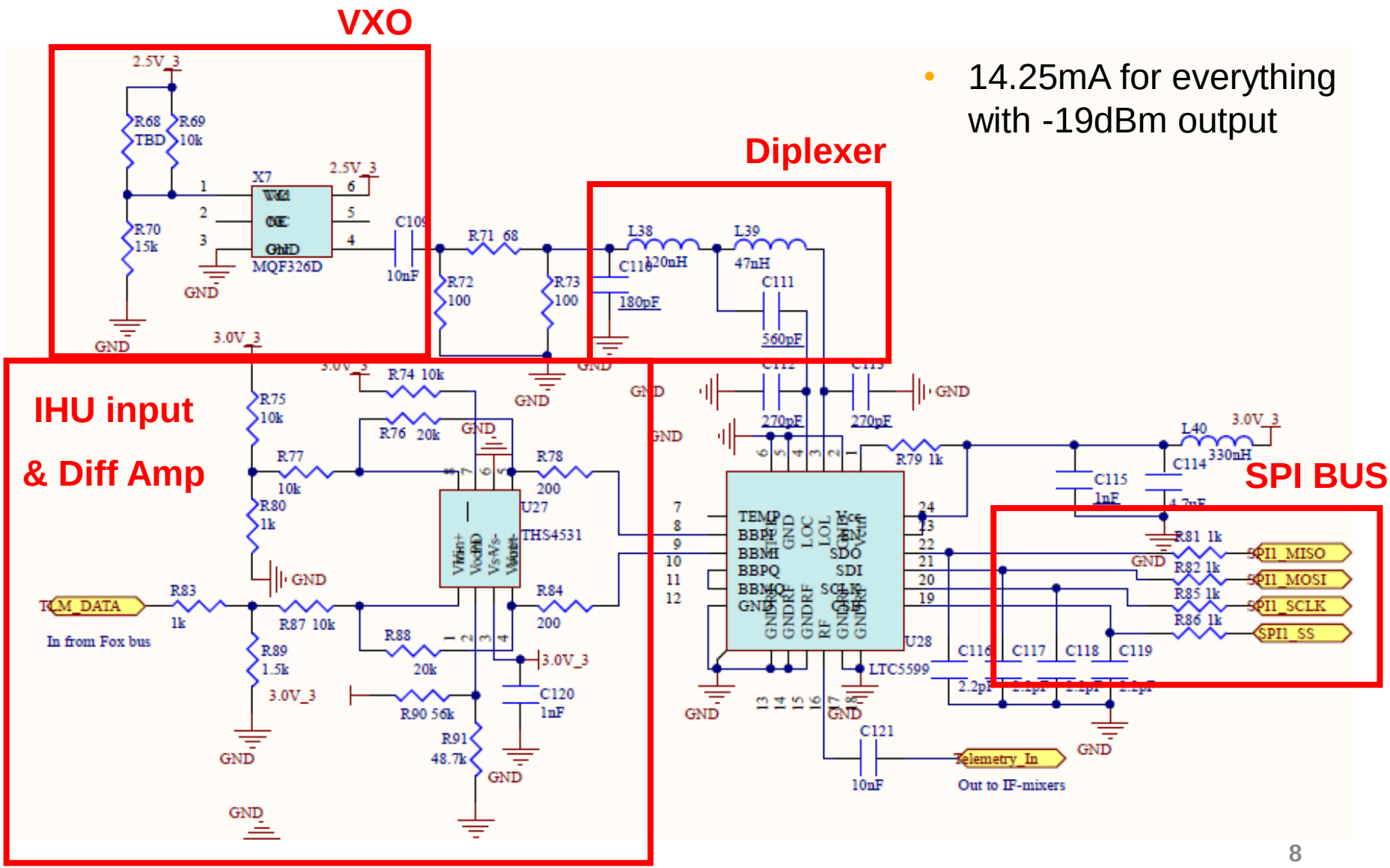


- Gain is -3dB, which surprised me
- 2k resistors can be 10k or 100k
- Need to know IHU audio level to get R4, R5 right





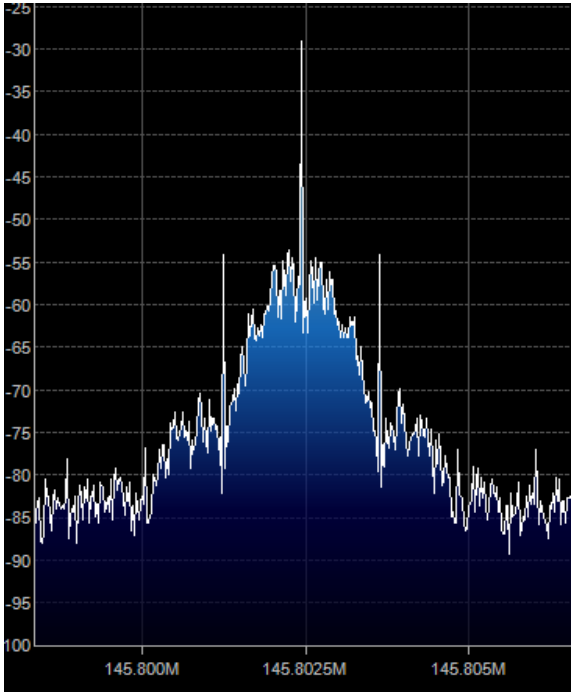
BPSK Modulator on Fox-1E

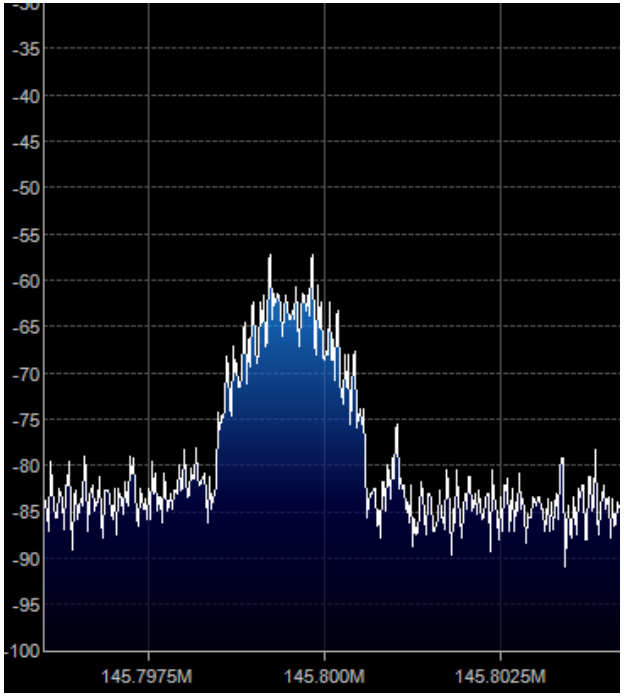


- 14.25mA for everything with -19dBm output

Carrier suppression

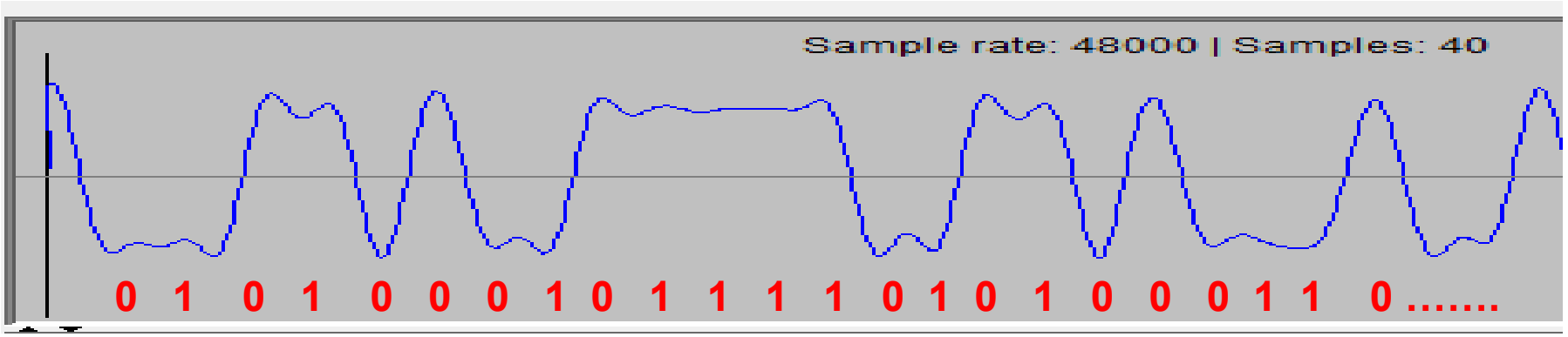
- Important to get differential input levels right
- Can then adjust I and Q in software
- Can adjust gain from the ground after launch if needed





Demodulation

- Demodulation of DSB is achieved by mixing with the original carrier
- Our data is Differential BPSK
  - If the phase changes we have a 0 otherwise it's a 1



Demodulation

Incoherent Demodulation

- We can demodulate without matching the phase exactly by just checking if the phase changes from bit to bit – integrated over a bit period
- This was the initial design
- If carrier mistuned, demodulation is impaired

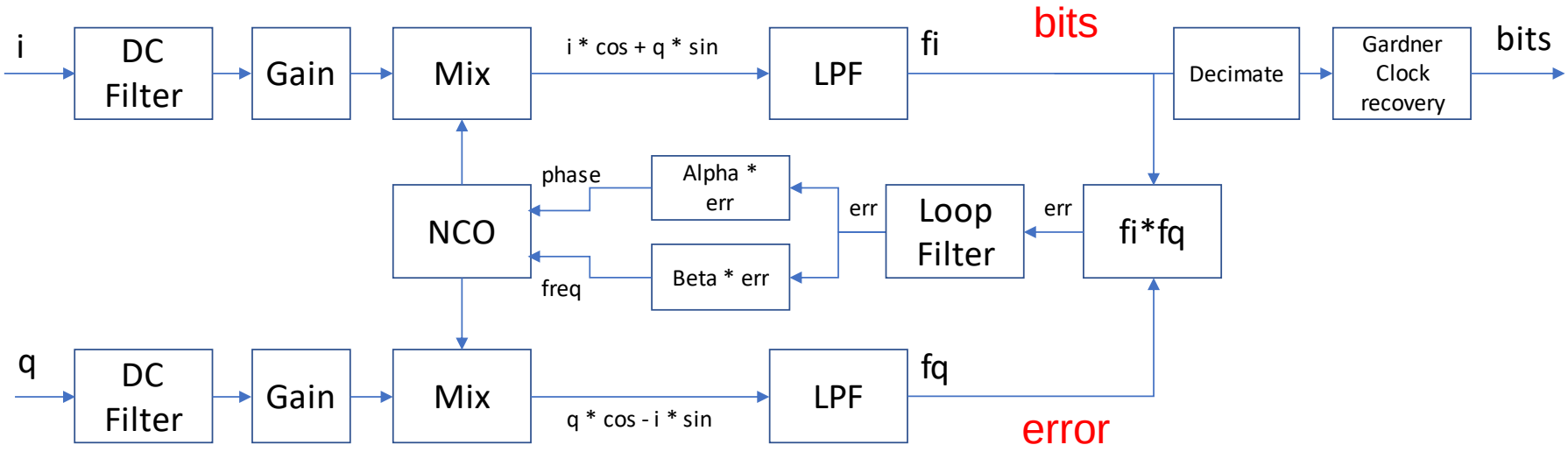
Coherent Demodulation

- Coherent demodulation requires not only recovery of the carrier but exact recovery of the phase of the carrier
- Coherent demodulation is more efficient than a non coherent decoder, especially with noisy signals (Best, 2007)*.
- Best achieved with a PLL
- A Costas Loop PLL works with the 180 degree phase changes
- Need to decide if this should work at Radio (RF) or Audio Frequency (AF)
  - And if there is a difference?

* Roland E. Best (2007), Phase-Locked Loops: Design, Simulation and Applications, 6e

FoxTelem Costas loop

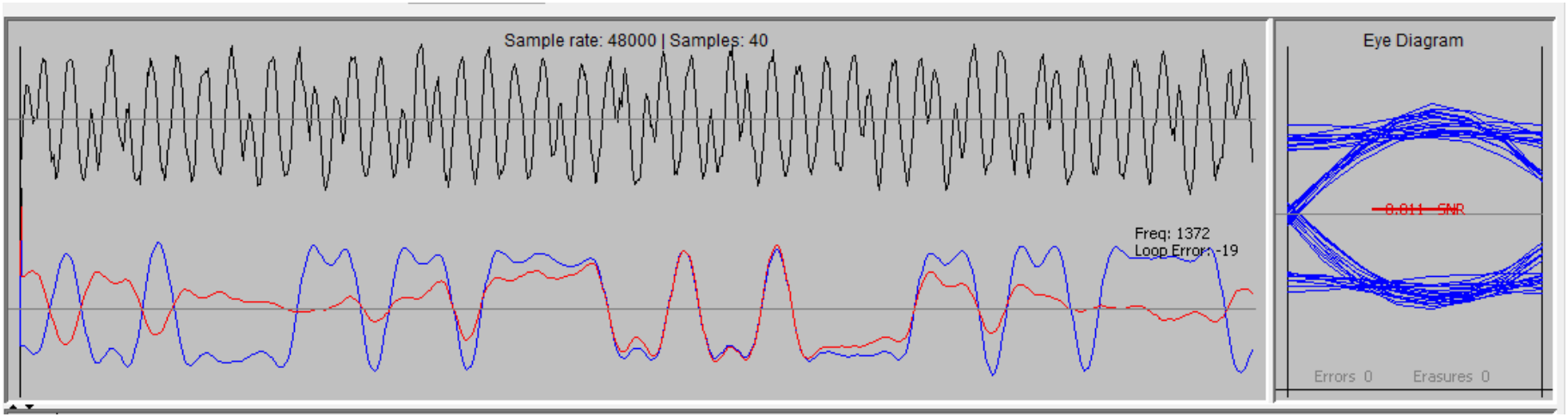
- **Coherent Demodulation**



- i and q inputs are the same for the AF decoder, in quadrature for RF

FoxTelem Costas Loop

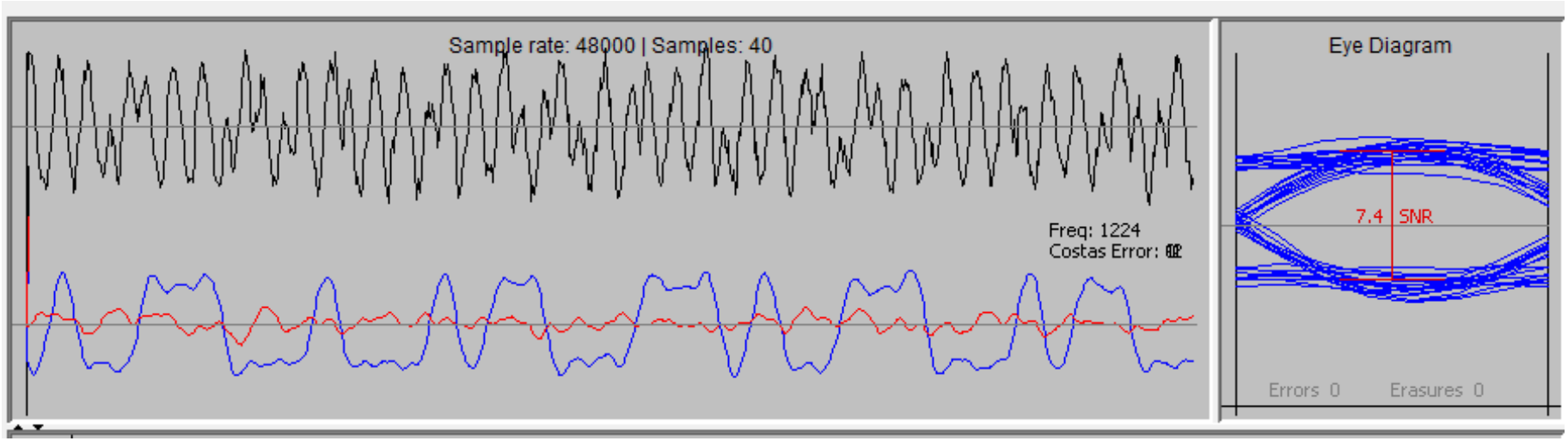
- **<u>This is NOT what we want!</u>**
- Too much delay in the loop from filters, won't lock
- Eye diagram oscillates open/closed



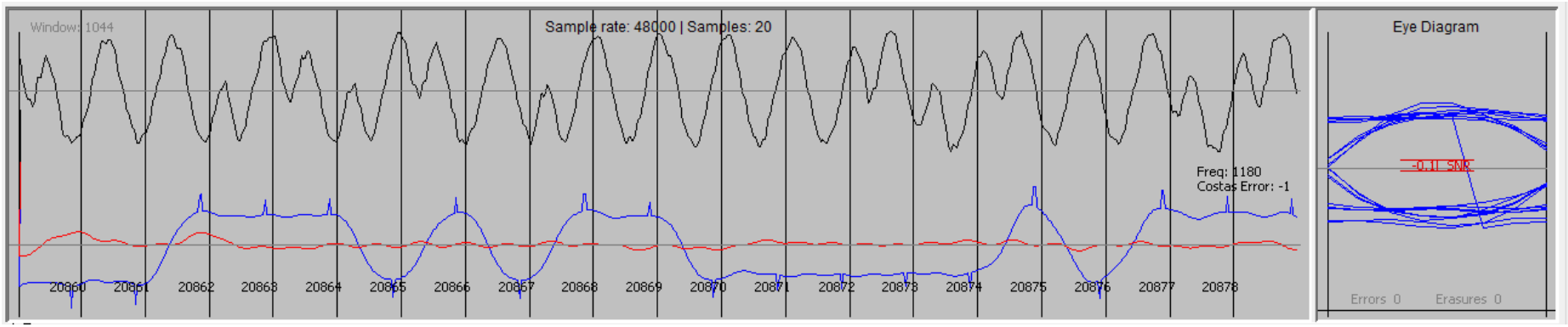
- <u>Fast Filters:</u> very important that **all filters are very fast** IIR filters. Loop filter is very simple single pole filter. LPFs are 4 pole Chebyshev filters at 1200Hz

FoxTelem Costas Loop

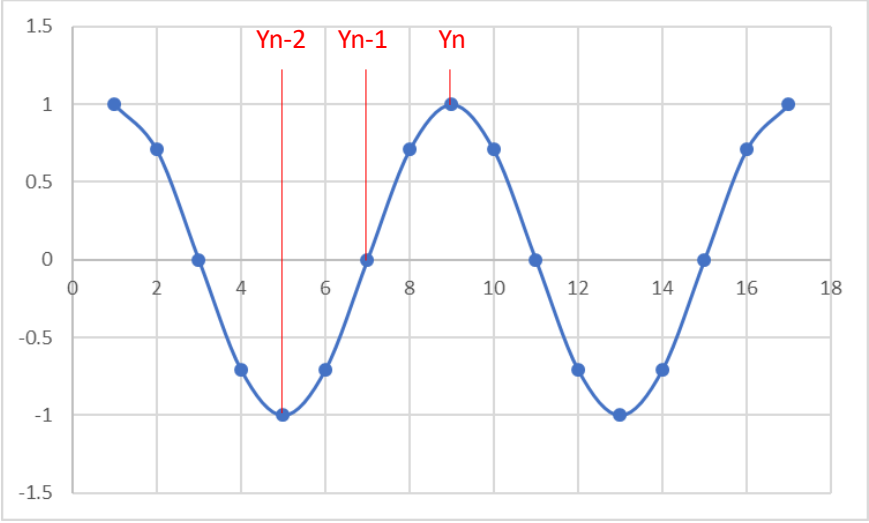
- **This is what we want!**

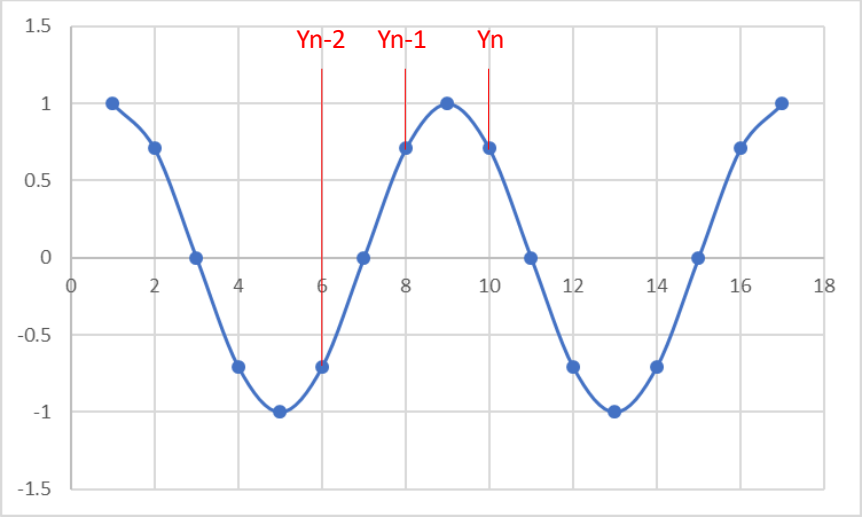


Clock Recovery



Gardner Clock Recovery Clock_error = (Yn – Yn-2) * Yn-1





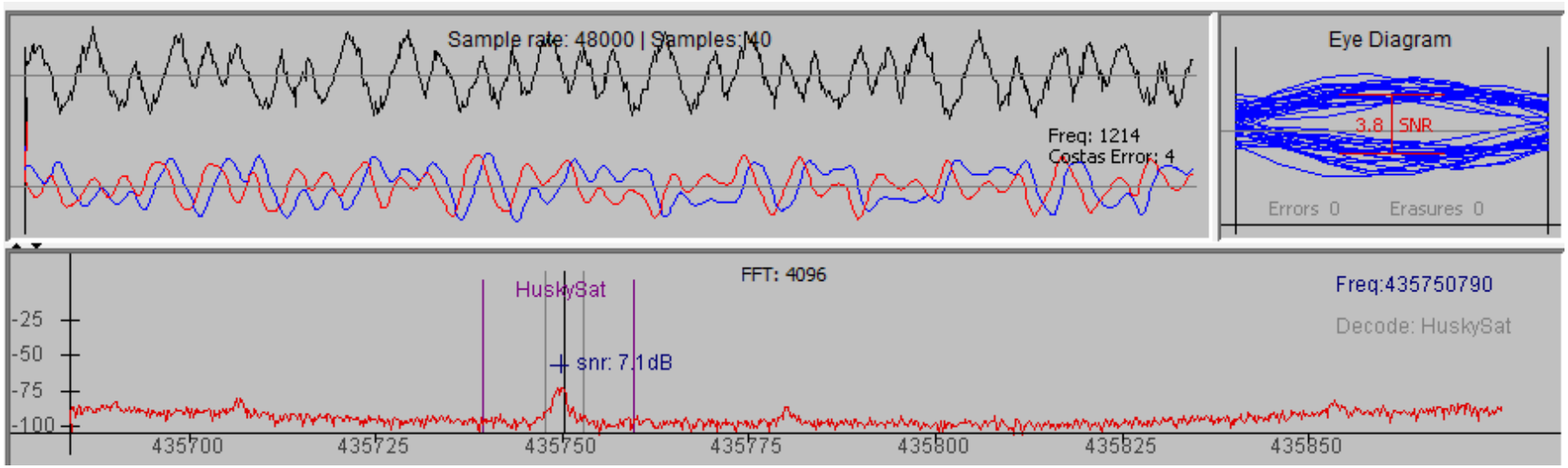
On time, err = (1 - -1) * 0 = 0

Late, err = (0.75 - -0.75) * 0.75 = 1.125

Early would be e.g., err = (0.75 - -0.75) * - 0.75 = -1.125

False Lock

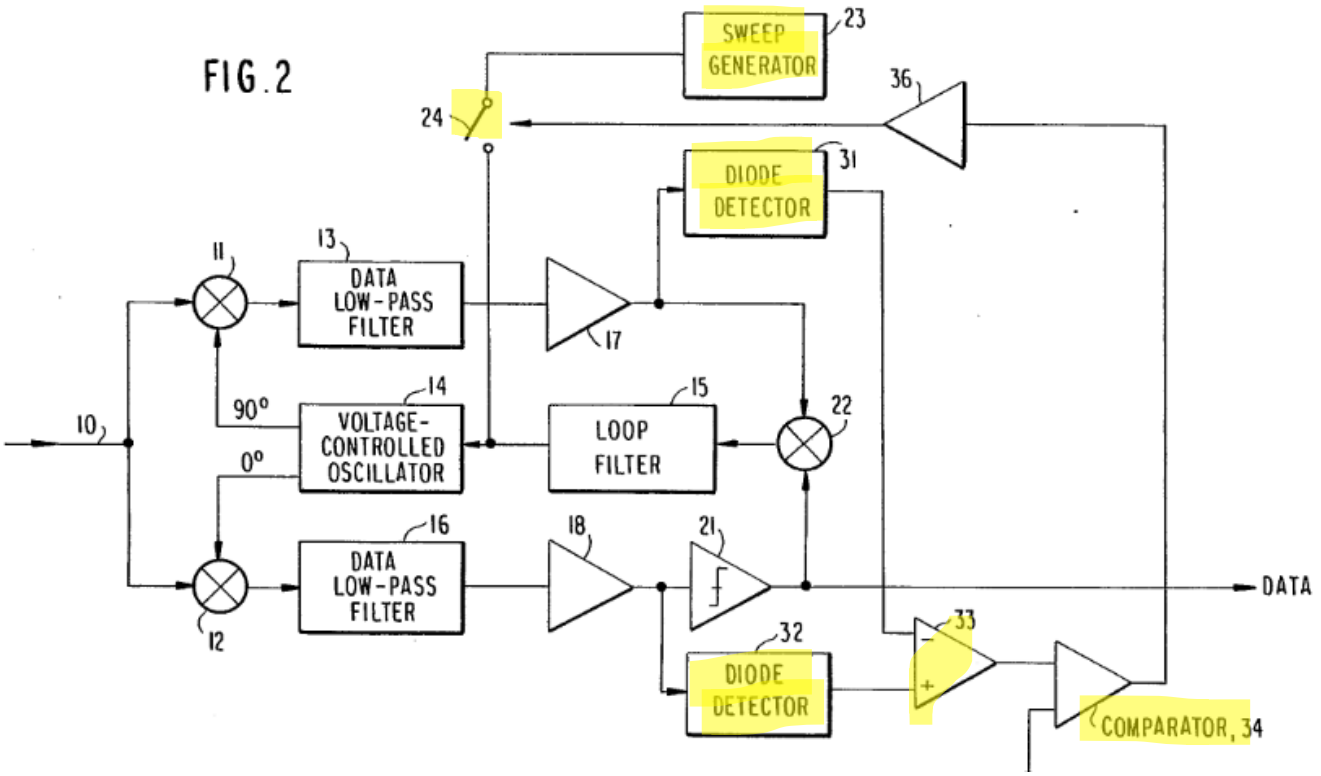
- Locked 600Hz to the right of the signal!



"False lock, typically at half the symbol rate, is a classic problem in suppressed-carrier BPSK tracking loops operating at low symbol rates relative to the frequency uncertainty (i.e., virtually every amateur satellite ever flown)" – Phil Karn KA9Q

Tom McDermott, N5EG, recommended a review of the patent literature and in particular US Patent US4713630A (Matthews, 1986)

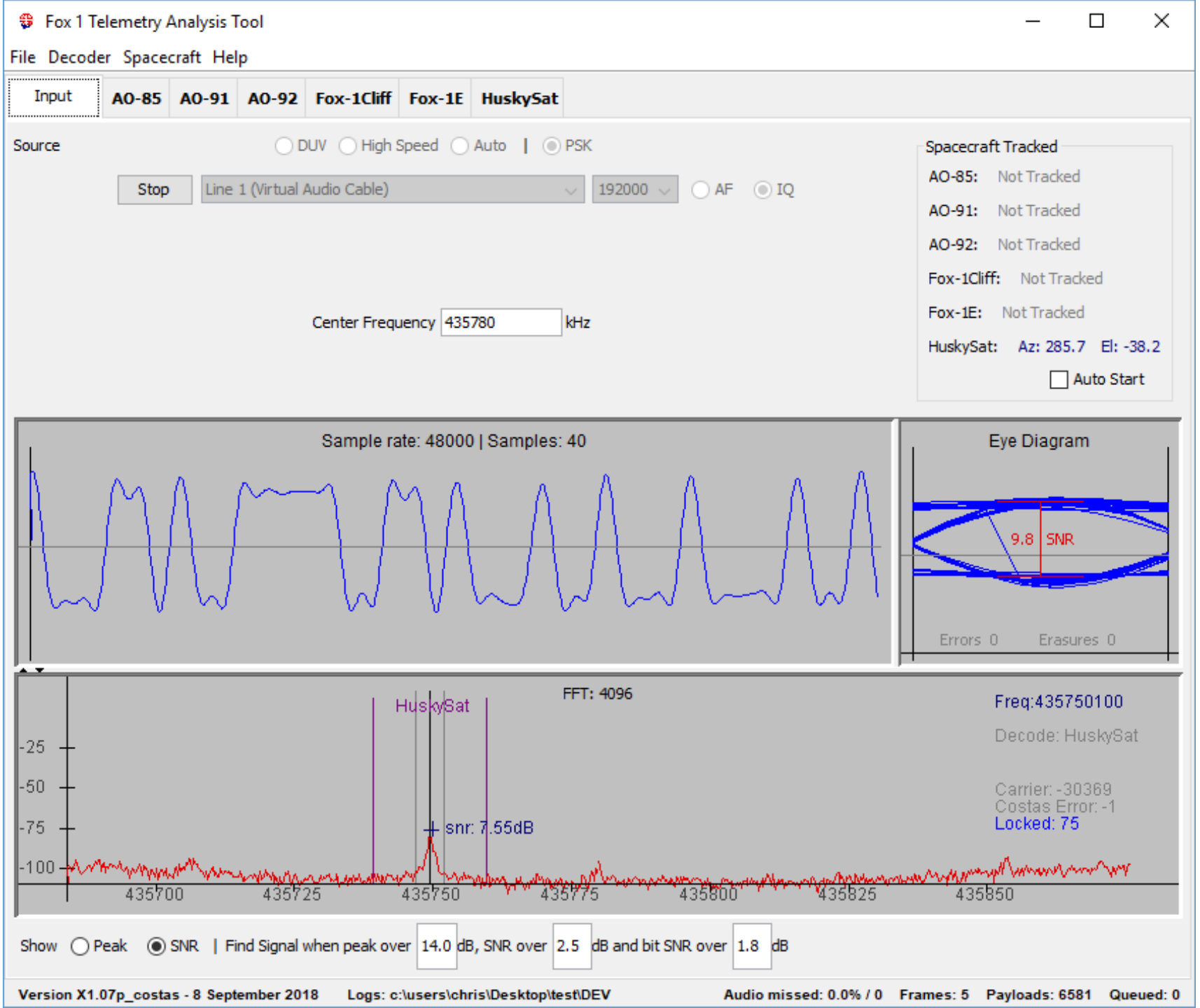
Defeating False Lock



U.S. Patent Dec. 15, 1987 Sheet 2 of 2

US Patent US4713630A (Matthews, 1986)

When the loop is not locked we increment the frequency of the NCO by a fixed amount - determine experimentally - so that the Costas loop will still lock when it is at the right frequency


Fox 1 Telemetry Analysis Tool
File Decoder Spacecraft Help
Input
AO-85
AO-91
AO-92
Fox-1Cliff
Fox-1E
HuskySat
Source
DUV
High Speed
Auto
PSK
Stop
Line 1 (Virtual Audio Cable)
192000
AF
IQ
Spacecraft Tracked
AO-85: Not Tracked
AO-91: Not Tracked
AO-92: Not Tracked
Fox-1Cliff: Not Tracked
Fox-1E: Not Tracked
HuskySat: Az: 285.7 El: -38.2
Auto Start
Center Frequency 435780 kHz
Sample rate: 48000 | Samples: 40
Eye Diagram
9.8 SNR
Errors 0
Erasures 0
FFT: 4096
HuskySat
Freq:435750100
Decode: HuskySat
Carrier: -30369
Costas Error: -1
Locked: 75
snr: 7.55dB
-25
-50
-75
-100
435700
435725
435750
435775
435800
435825
435850
Show Peak SNR | Find Signal when peak over 14.0 dB, SNR over 2.5 dB and bit SNR over 1.8 dB
Version X1.07p_costas - 8 September 2018
Logs: c:\users\chris\Desktop\test\DEV
Audio missed: 0.0% / 0
Frames: 5
Payloads: 6581
Queued: 0

Much More work to do …

- **Loop acquisition time can be improved**. Currently we don't always decode the first 1-3 frames as it locks in. Theoretically we have 60ms to lock (31 bit SYNC + ~40 FEC correctable bits) which the RS Decoder can compensate for

- **SAFE mode beacons are a challenge** – 10 seconds of PSK with 31 bits of known preamble. But 2 mins of post processing time if we need to use brute force