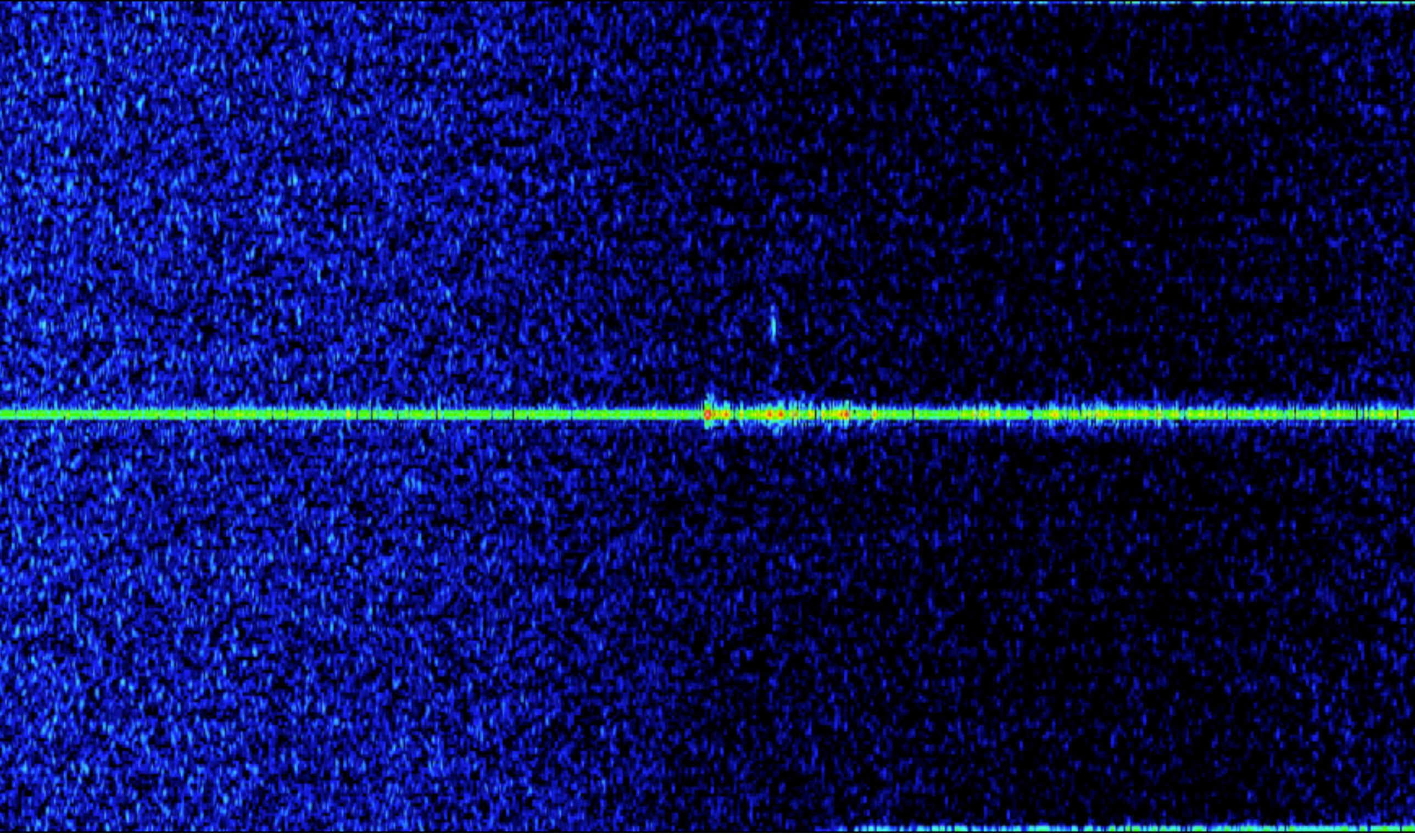


Hacking the Wireless World: Software Defined Radio Exploits

Balint Seeber
Director of Vulnerability Research
Bastille

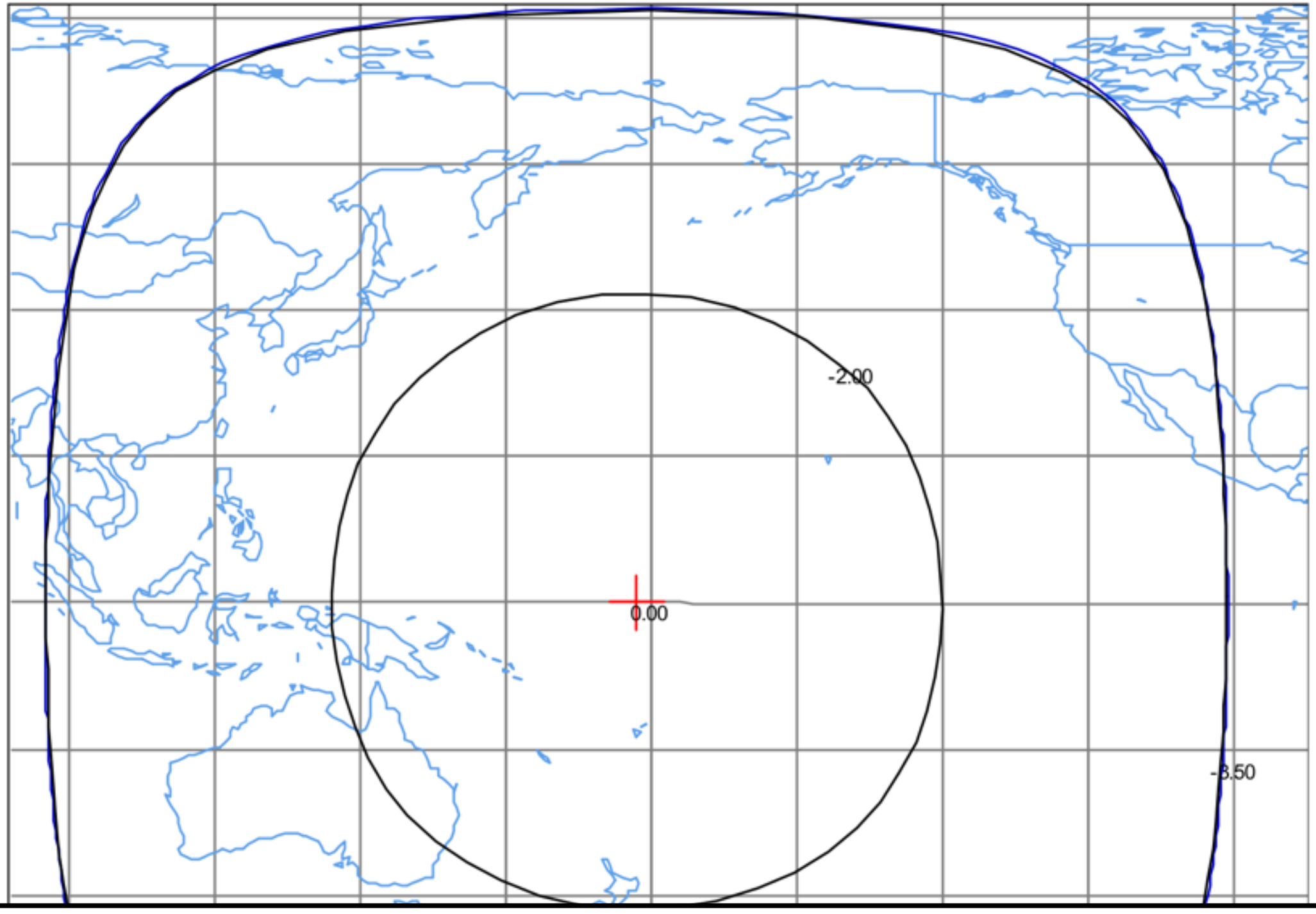
Overview

- INMARSAT
- Un-selective AM
- FMCW RADAR

INMARSAT

Hacking the Wireless World with #sdr

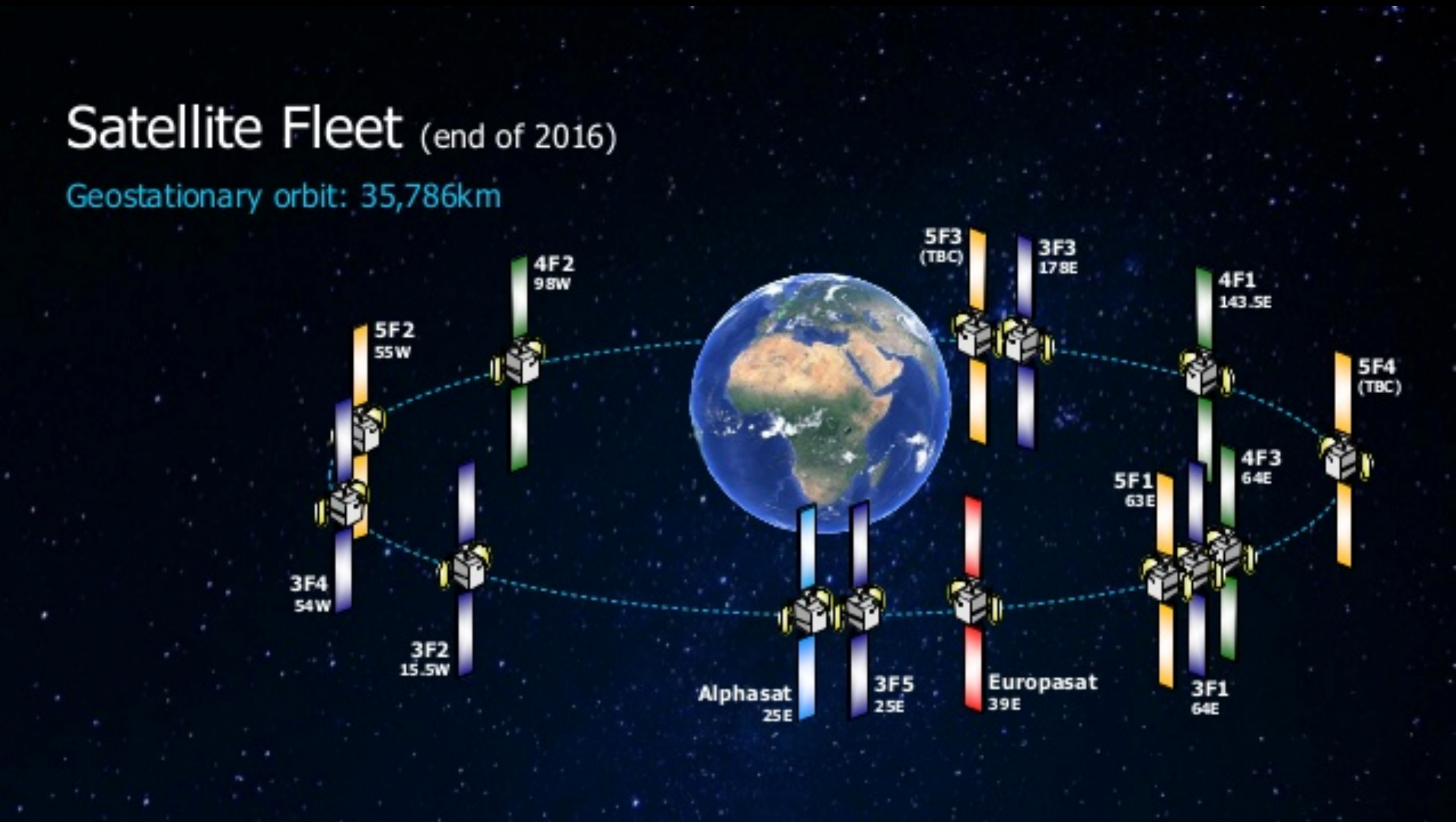
@spenchdotnet

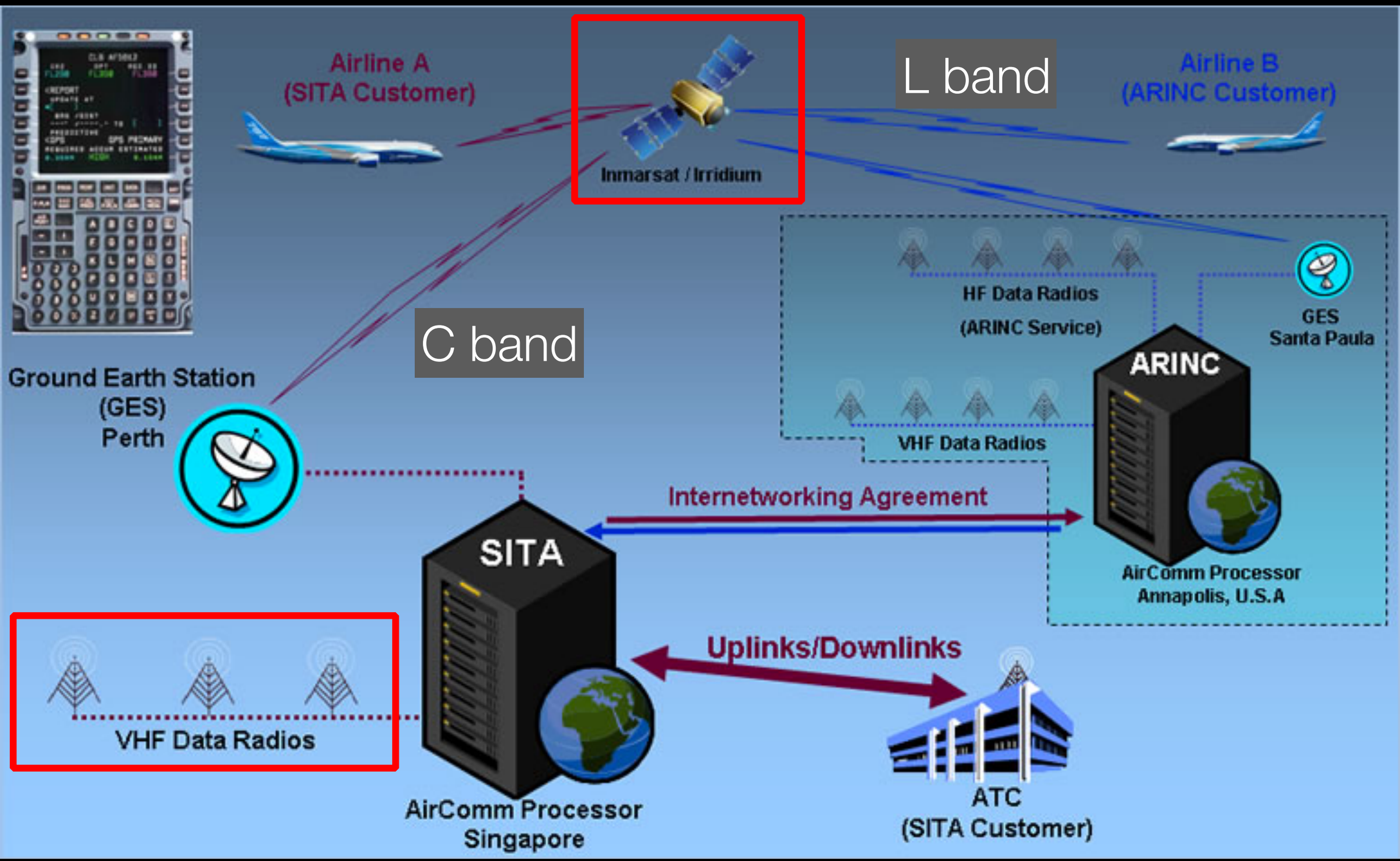


http://licensing.fcc.gov/cgi-bin/ws.exe/prod/ib/forms/attachment_menu.hts?id_app_num=68368&acct=263899&id_form_num=13&filing_key=-127644

INMARSAT-3

INMARSAT Geostationary Birds





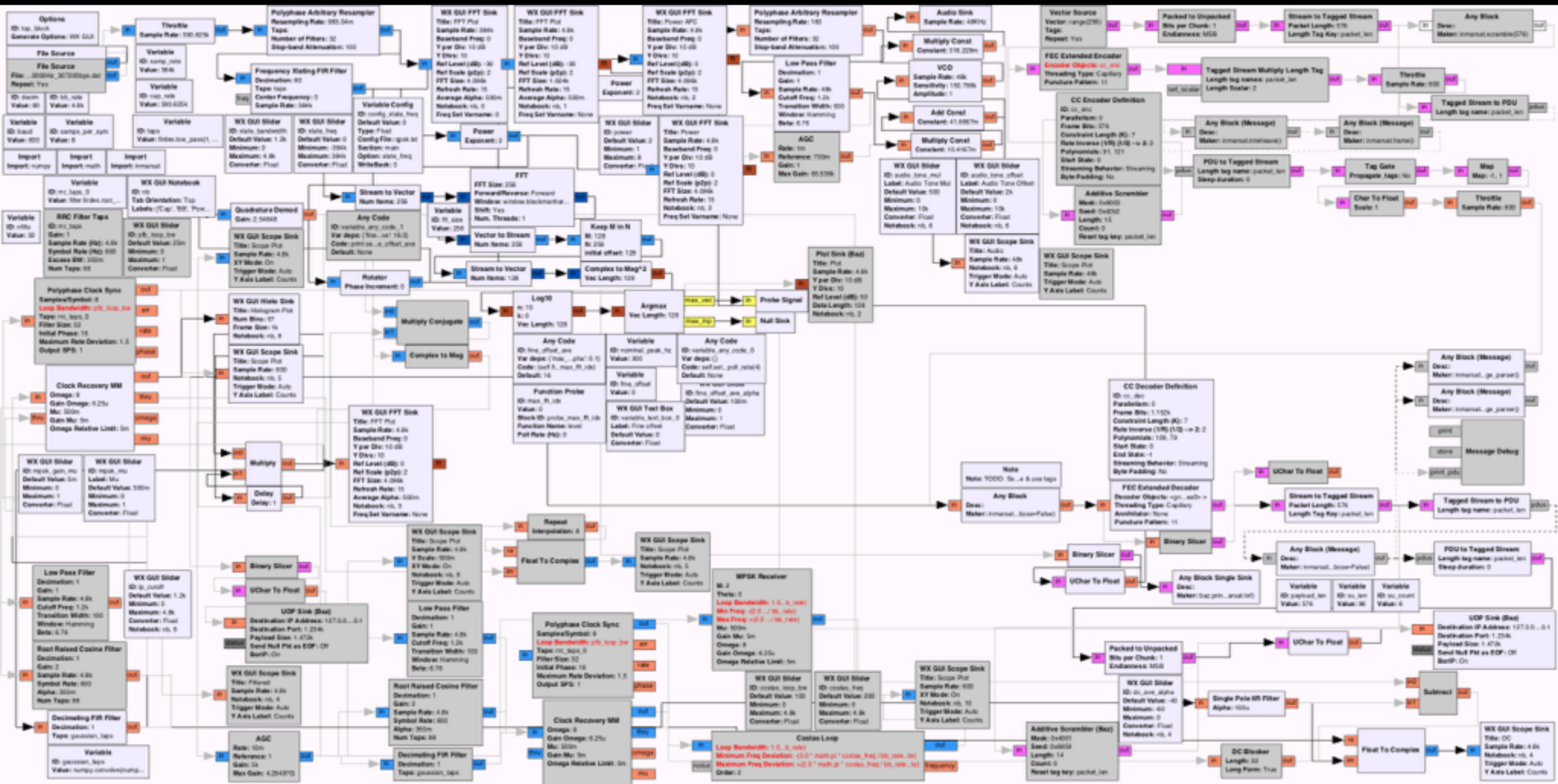
http://members.optusnet.com.au/~cjr/introduction.htm


Bandpass Filter 1560MHz, 120MHz BW
LNA - Gain 14.8dB, NF 0.46dB
LHCP Helical Feed

INMARSAT Aero

- **P Channel** - *coordination and timing begins here!*
  - Packet mode Time Division Multiplex (TDM)
  - Sent *to* aircraft, carries signalling & user data
- R Channel: random access signalling & user data, *from* aircraft
- T Channel: Reservation TDMA, *from* aircraft, for data transmission
- C Channel: Circuit-mode, *to & from* aircraft, carries voice and user data

The P Channel Flowgraph so far…

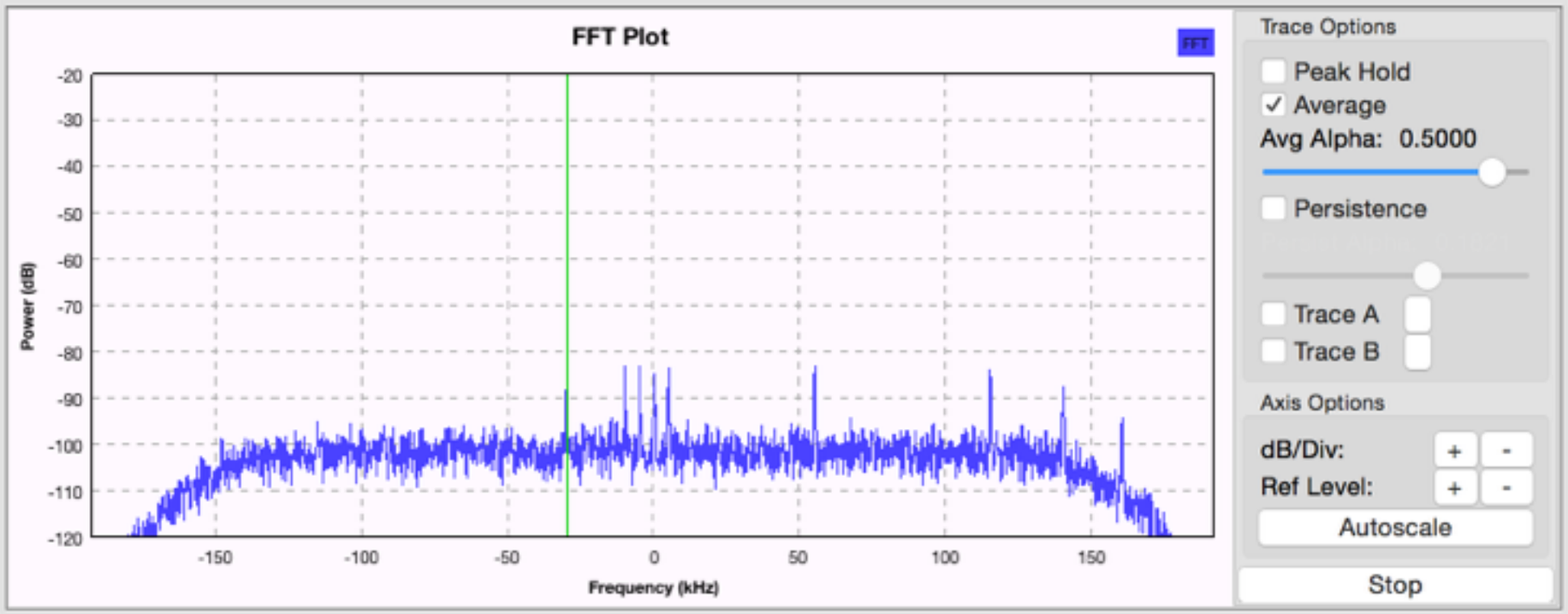


Top Block

xlate_freq: -29.6k

power: 2

Cap | BB | Power | Baud | Quad | Clock | Audio | FEC | Histo



Trace Options

Peak Hold

Average

Avg Alpha: 0.5000

Persistence

Trace A

Trace B

Axis Options

dB/Div: + -

Ref Level: + -

Autoscale

Stop

Mu: 500m

mpsk_gain_mu: 5m

lp_cutoff: 1.2k

Audio Tone Offset: 2k

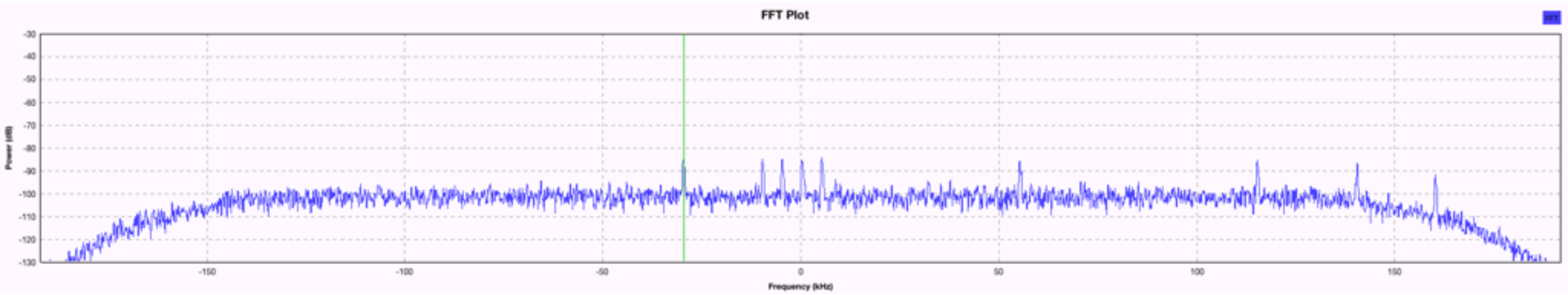
Audio Tone Mul: 500

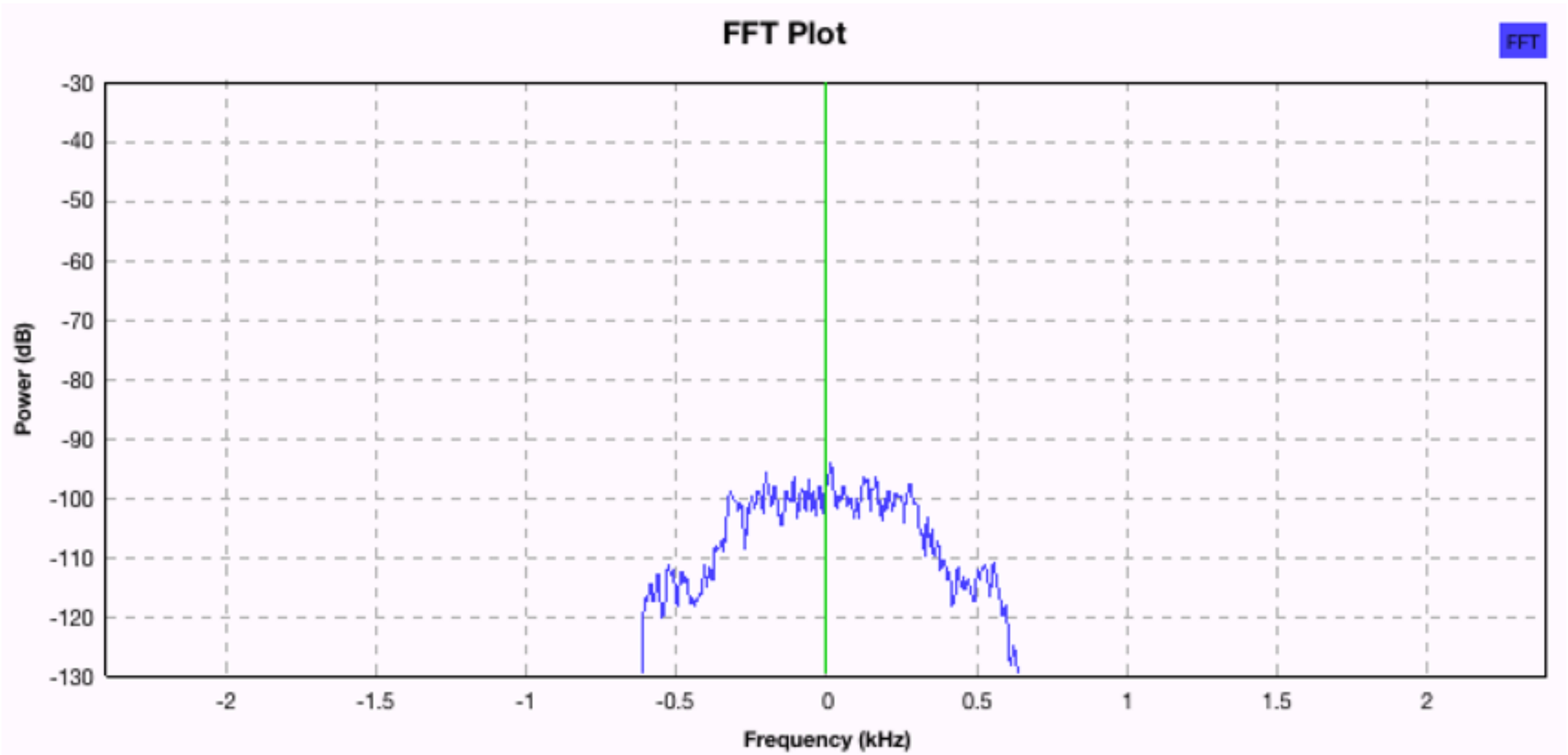
amp: -10

xlate_bandwidth: 1.2k

pfb_loop_bw: 25m

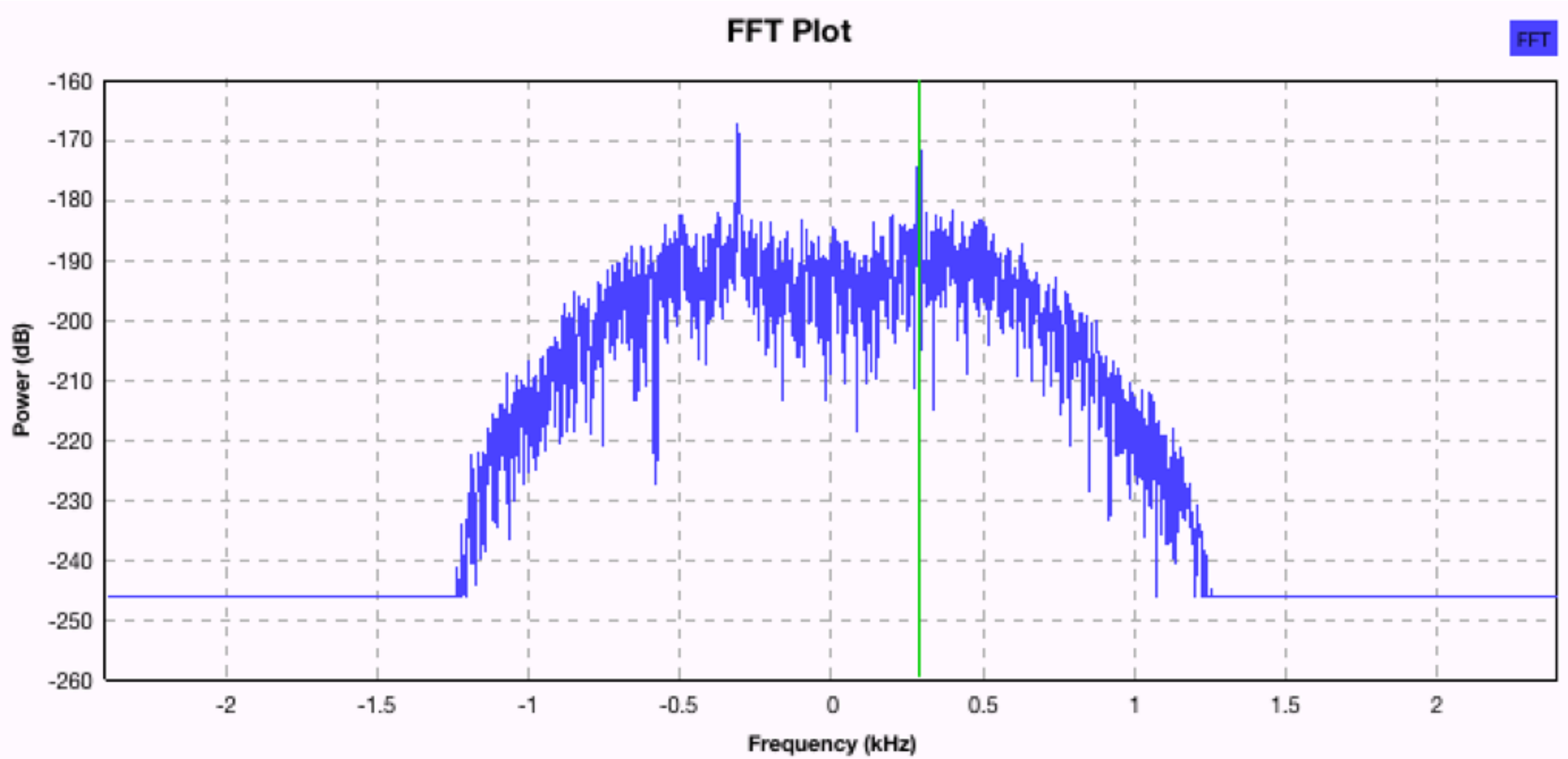
Channel Selection





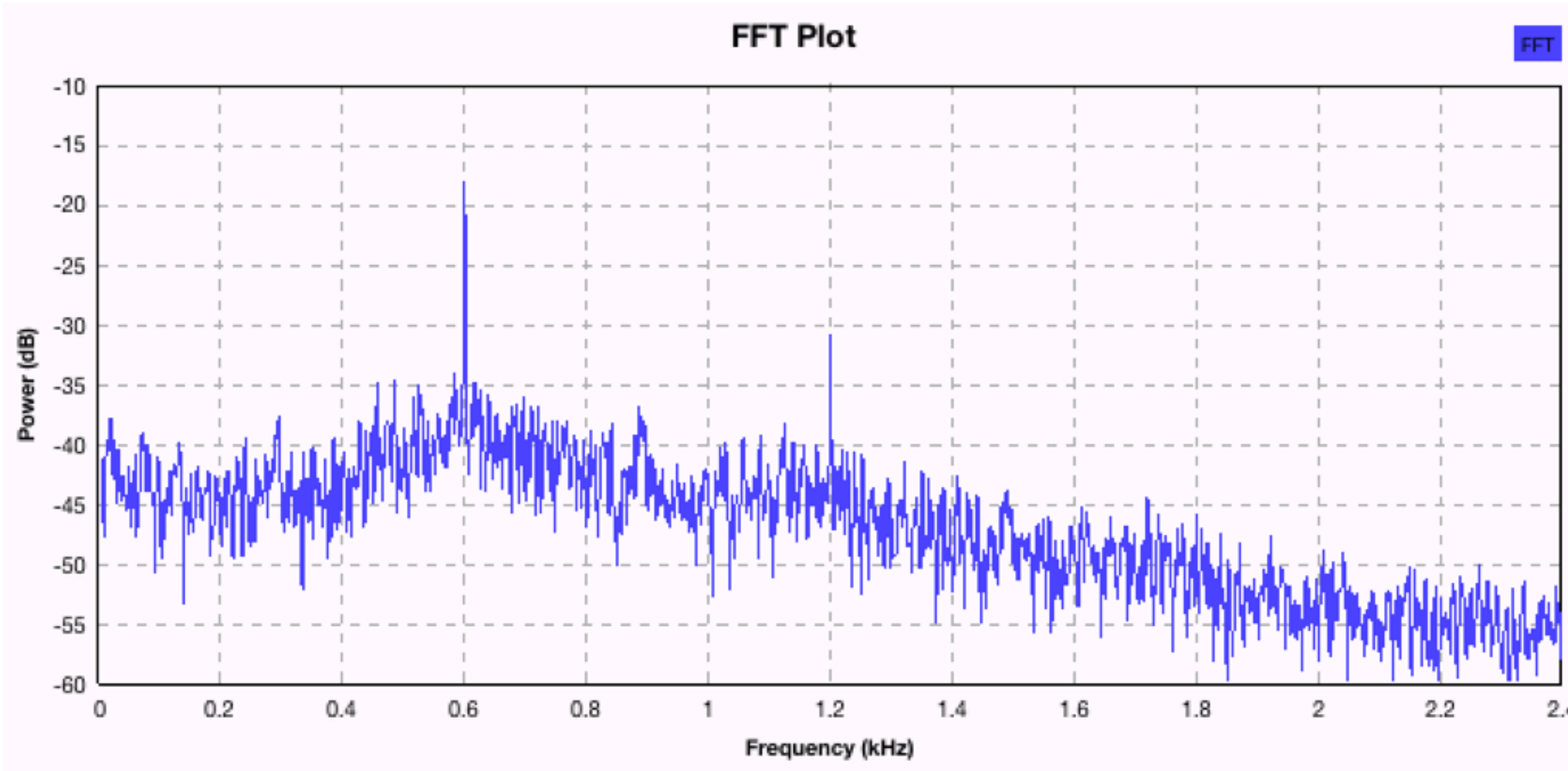
Modulation Type

- **G**aussian **M**inimum **S**hift **K**eying (GMSK): FFT of squared complex samples results in two peaks equidistant from 0



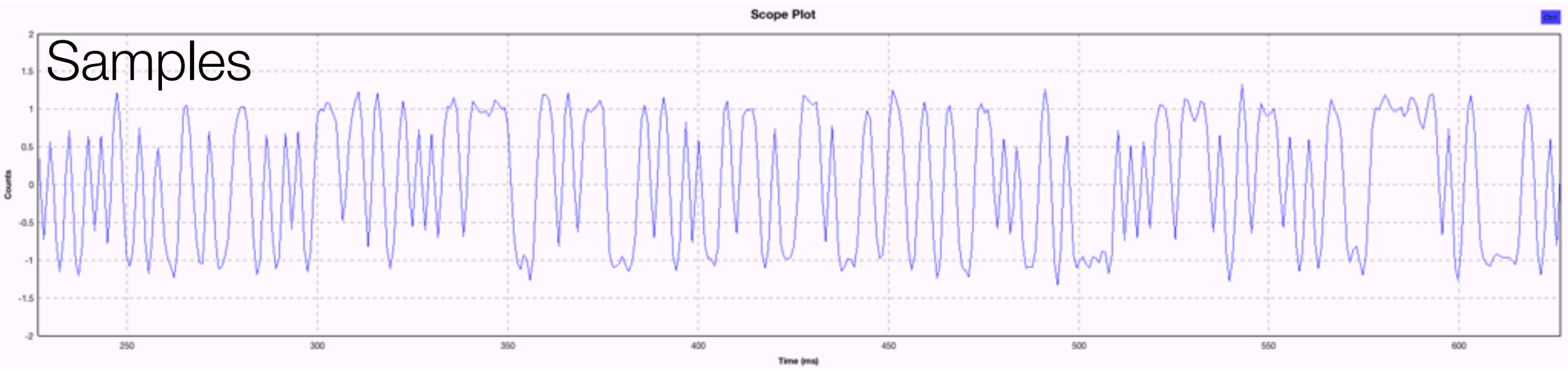
Symbol (Baud) Rate

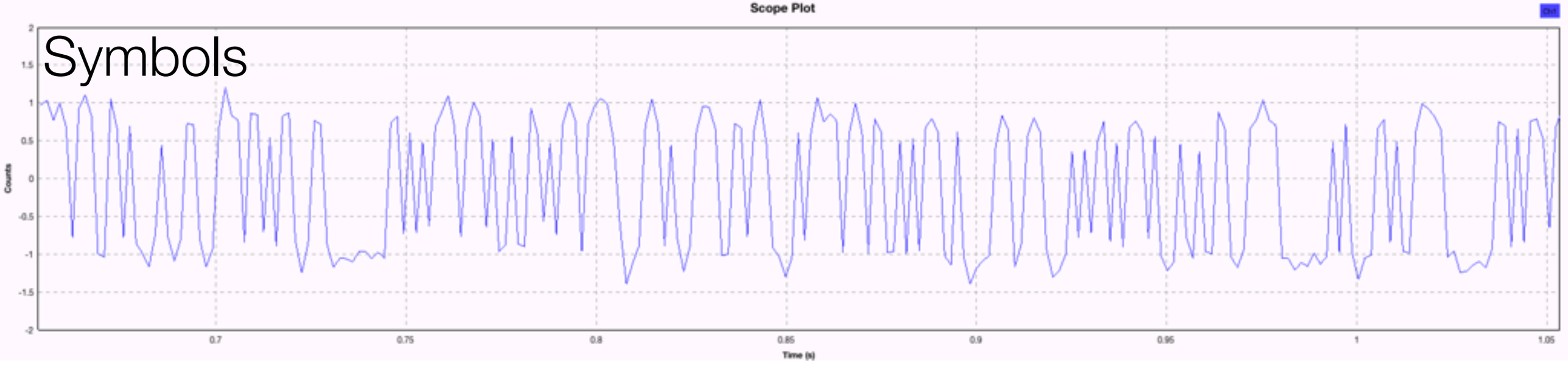
- Cyclostationary Analysis: rate is first peak in plot (600 bps, also distance between cyclo peaks)



Clock Recovery

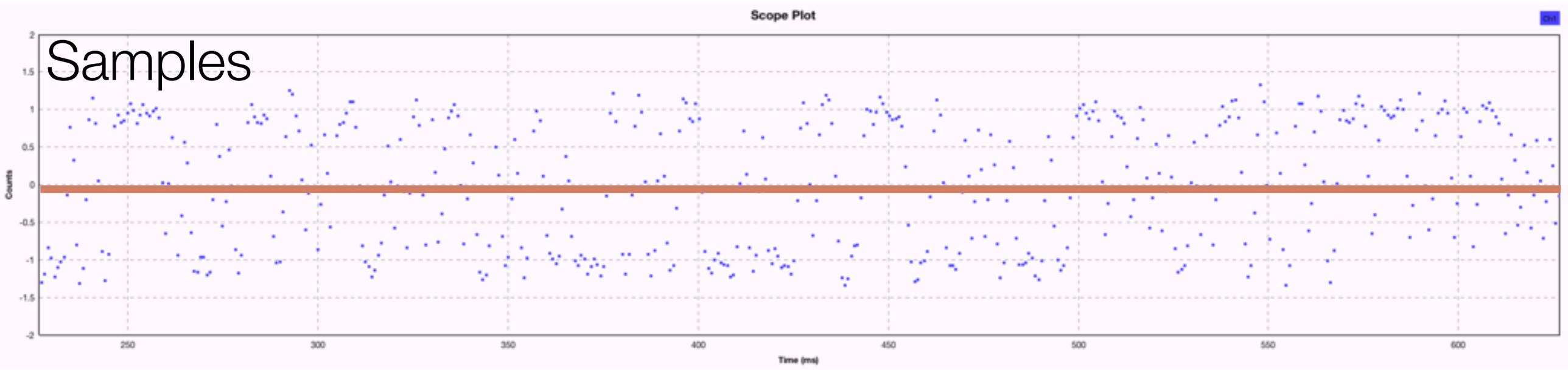
- Enough information to begin tracking symbols in channel (and output them to enable operation on bits)

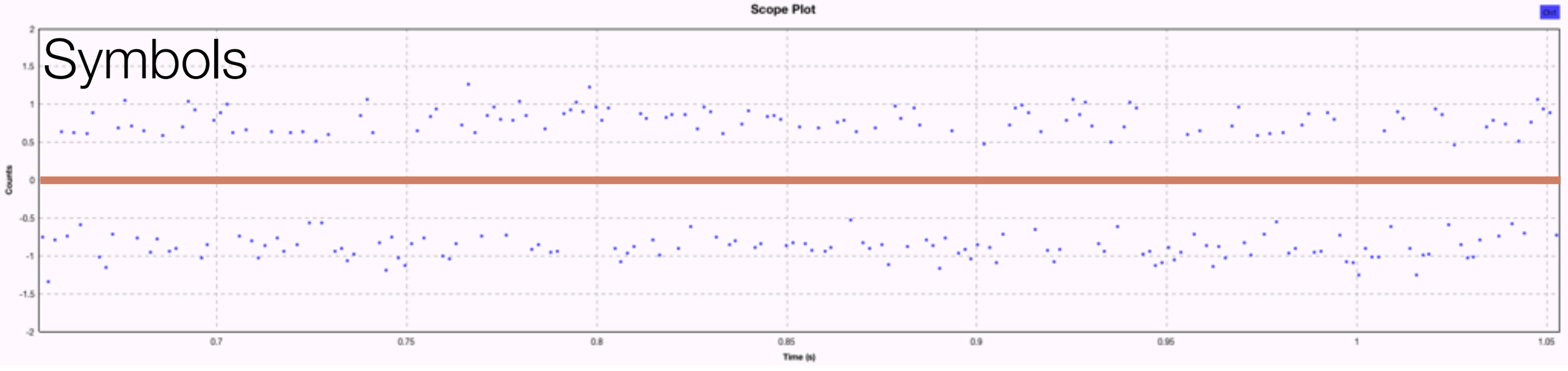




Clock Recovery Quality

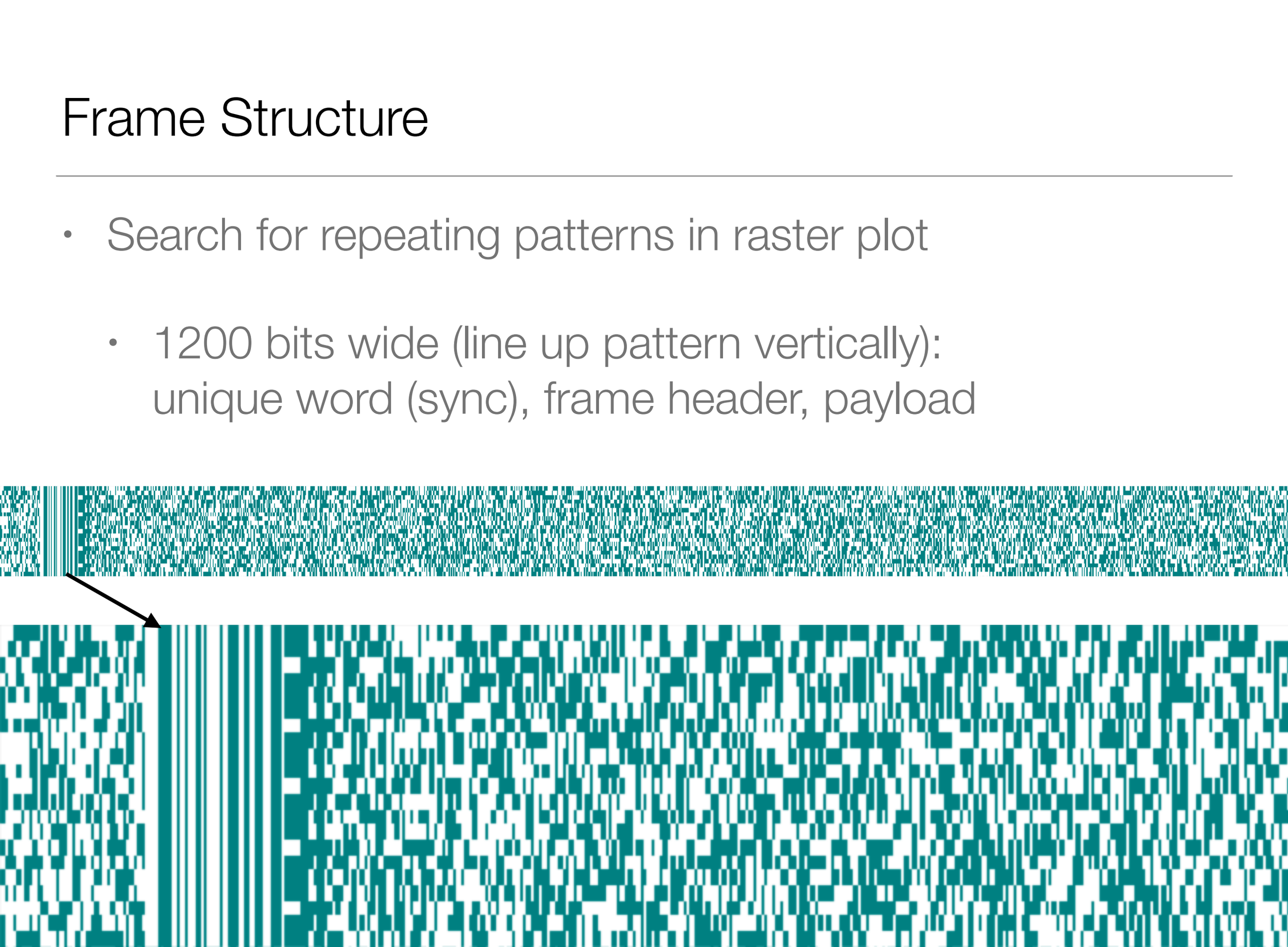
- Increased separation between symbols about 0





Frame Structure

- Search for repeating patterns in raster plot
  - 1200 bits wide (line up pattern vertically): unique word (sync), frame header, payload



Payload Encoding

- Appears ‘random’
- Generally data has gone through:
    1. Interleaving (protects against burst errors)
    2. **F**orward **E**rror **C**orrection (data redundancy)
    3. Scrambling (energy dispersal & clock recovery)
- Complex process - difficult to test each step individually

Payload Details

- RTFM

- Frame payload consists of multiple fixed-length Signal Units (number of SUs depends on data rate of channel, here 6 of 96 bits each)

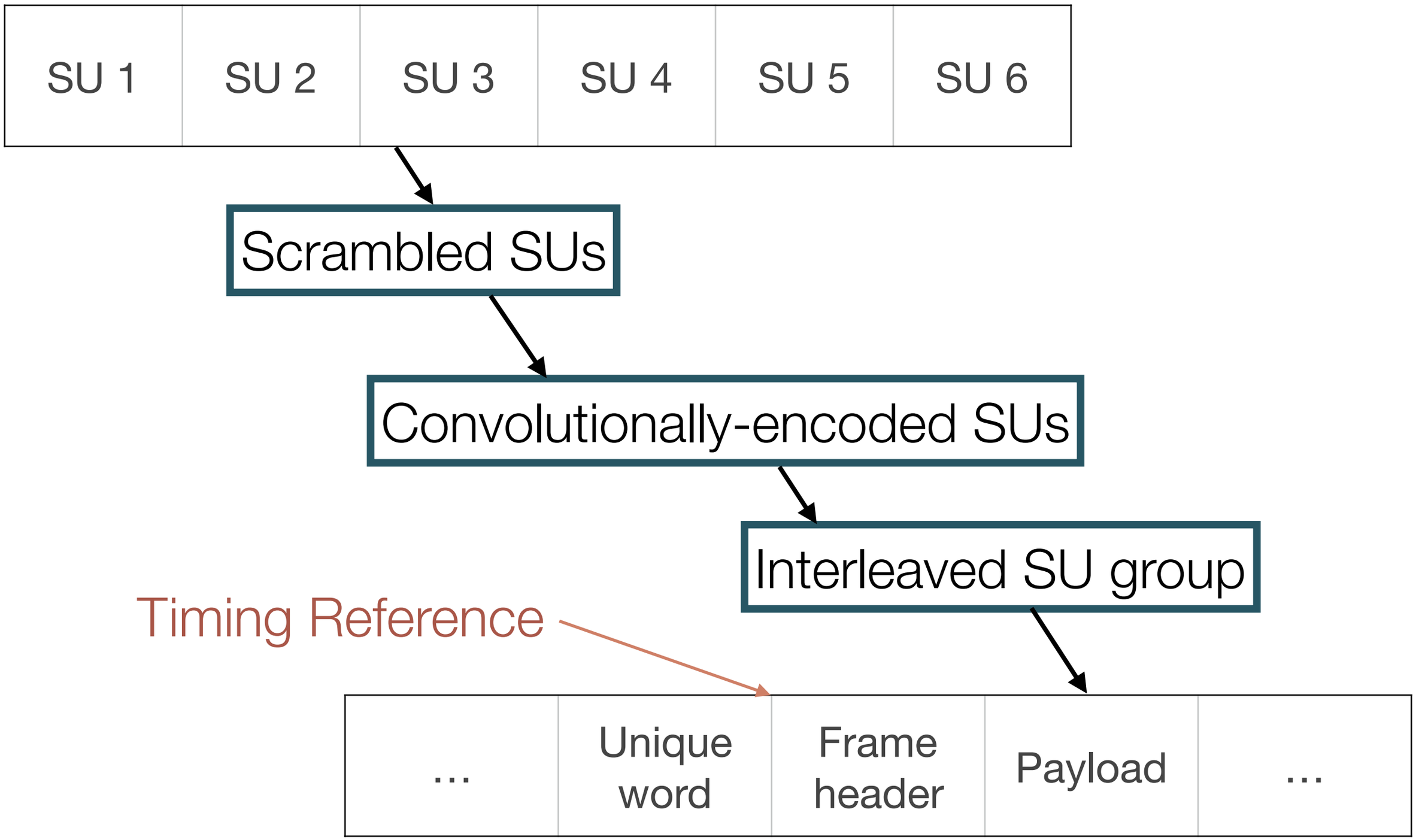
- For transmission, the entire SU group is:

    1. scrambled

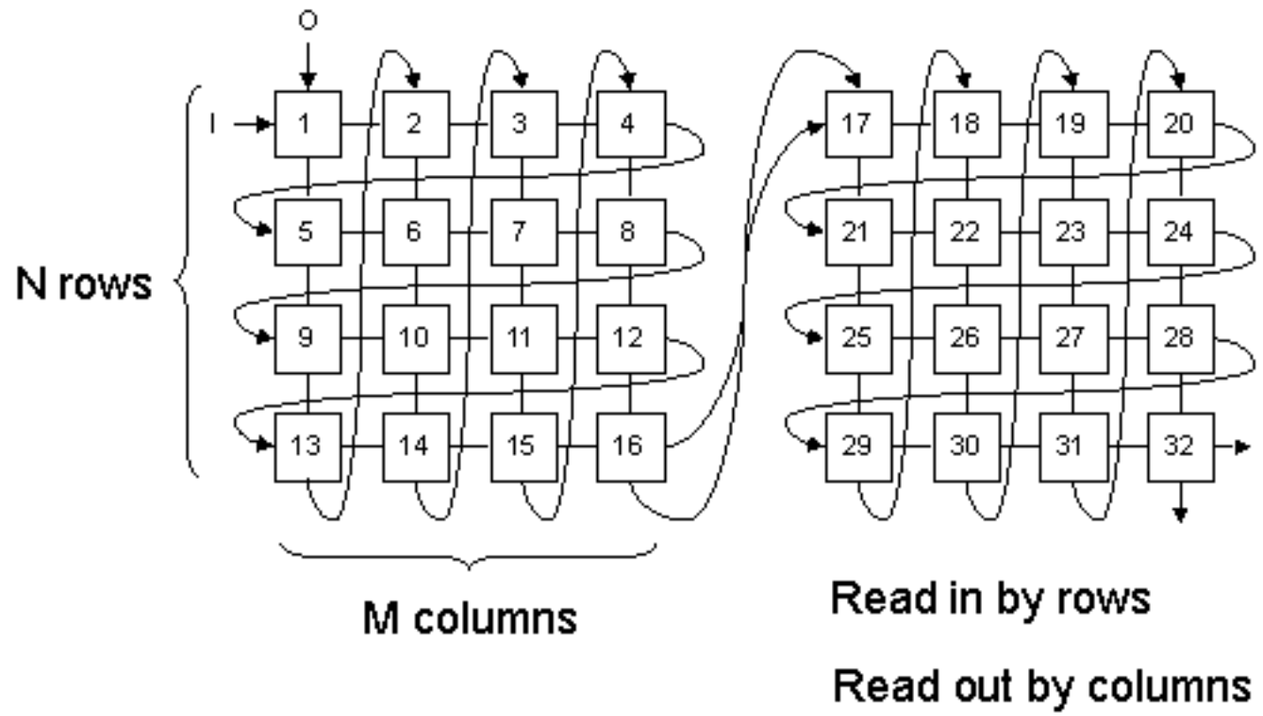
    2. 1/2-rate convolutionally encoded

    3. fed through an interleaver

Frame Details



#1: De-interleaving

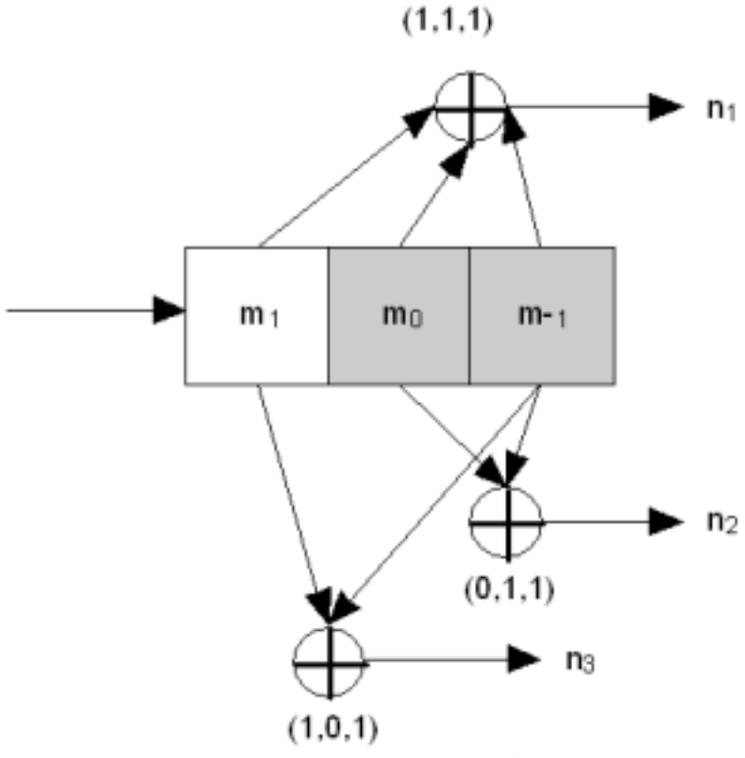


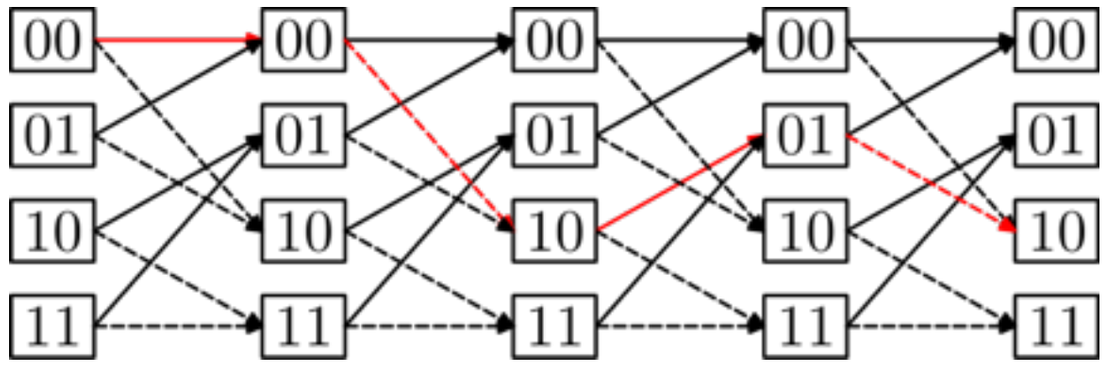
https://www.cl.cam.ac.uk/~jac22/otalks/rtpi/sld004.htm

#2: Convolutional (Viterbi) Decoding

- A convolutional code adds additional bits to a stream so that a receiver can correct errors

- Given received error-prone symbols, a Viterbi decoder will output the bits that represent the most likely path through a trellis matching the convolutional code

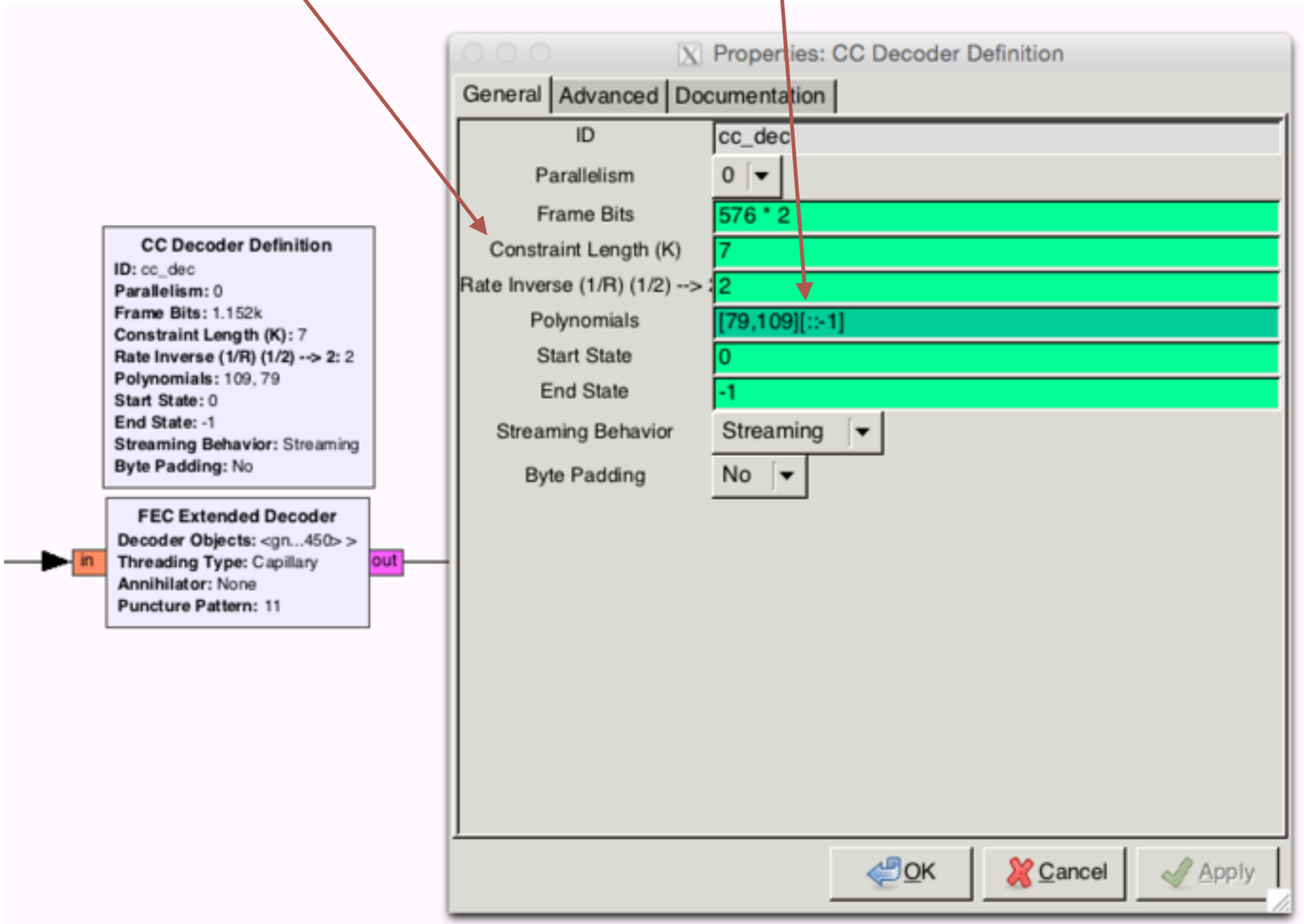




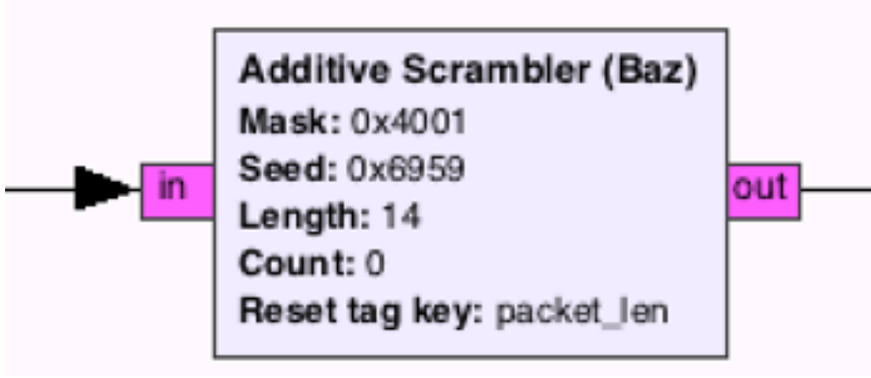
https://en.wikipedia.org/wiki/Convolutional_code

#2: Viterbi Decoder

- The NASA Voyager K=7 convolutional code is popular, and used here (gr-fec)

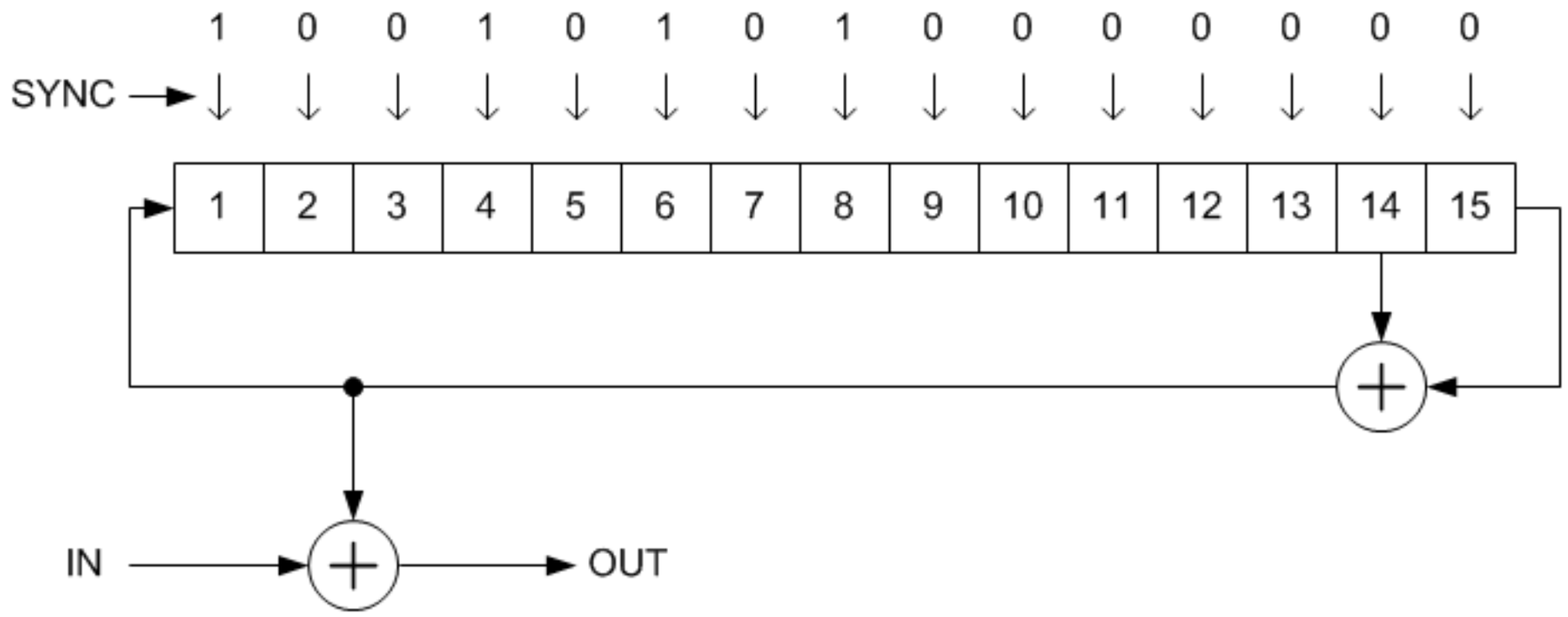


#3: De-scrambling



- Implemented as a Linear Feedback Shift Register
- Reset (sync'd) at the beginning of a new frame

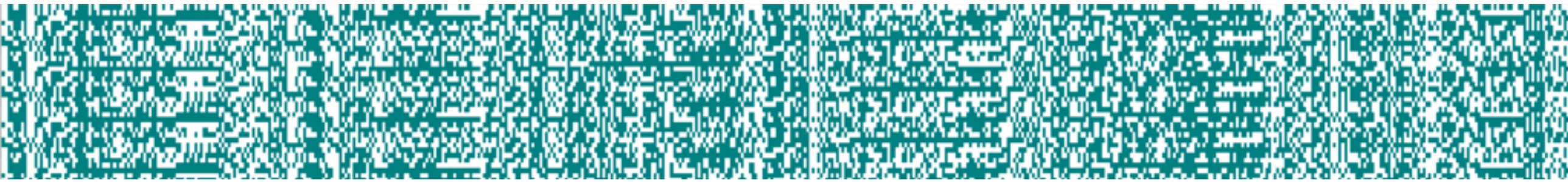
Example:



https://en.wikipedia.org/wiki/Scrambler

Validation

- Inspect raster plot of output to check if there is more structure:



- Compute CRC checksum to confirm correct decode: CRC-16-CCITT should yield **`f0b8`**

Decoding

71780a5b82751e60*ffff*1c75 f0b8 **ISU (User Data)**

62ae146182748e0000000eee f0b8 ACK

d676*d3542070616 7e520*01a8 f0b8 **User Data begins**

d576*2fae0d8a2fd33231*cbfb f0b8

d476*2f4ab0b031b52fc2*5cab f0b8

d376*b0322f46b0342f4f*8c67 f0b8

d276*31b5b0b00d8a2f43*7024 f0b8

d176*c1c4c44954494fce*4775 f0b8

d076*c14c2049ce464f526*db5 f0b8

11a9322582df000a84526d98 f0b8 Log on

40a9322582d831663856f222 f0b8 Channel control

c0d83781384a000000005331 f0b8

41a9322582d941063787551e f0b8 Channel control

c0d936c336b836c51101af14 f0b8

6271c274827d8e000000d259 f0b8 ACK

Decoding

cf76cdc154494fce2fae332f f0b8
ce760d8a2fc4b0324c2f7f34 f0b8
cd76ae2f542fae0d8a2f3719 f0b8
cc76c8b032b3b32fae2f10bd f0b8
cb764f31b6b0b02faec1be14 f0b8
ca76f2f2e97661ec20678197 f0b8
c97661f4e5206e756d624cd8 f0b8
c876e5f2ba0d8a2f4f31f556 f0b8
c776b6b0b02f5831b92f7d65 f0b8
c676450d8a2fd332b62f0091 f0b8
c5764f31b6b0b02fae0d2599 f0b8
c4768ac26167676167e576ea f0b8
c37620e3ec61e96d20e68b9d f0b8
c276eff220c8cbc720610933 f0b8
c176f2f2e97661ecba0db0a2 f0b8
c0768a2f9762917f0000f199 f0b8 **User Data ends**

User Data: ACARS Message

`2..B-KQKH1F- #T1O1600/X26/E

/S22/B02/O1600

/.Please arrive at the boarding gate at least/.

/O1500/X02/E/O1500

/S23/B02/X05/F04/O1500

minutes

/O1600/X12/ **before departure./.**

Late passengers may not be accepted for/.

travel.

Other Types of Messages: Notices

`2.N610FEA9YG,

AND H CLSD. TWY K CLSD,

BTWN RWY 33, AND TWY J.

TWY J CLSD, BTWN RWY

28R, AND TWY C. RWY 28L

ARRIVALS, EXPECT BACK

TAXI RWY 28R. CTN, PSNL

AND EQPT WORKING, EDGE

OF CLSD RWY 28R.

CAUTION, BIRDS NEAR

AIRPORT.

Other Types of Messages: Weather

```
METAR PACD 192153Z 36012KT 10SM SCT012
OVC060 08/08 A2931 RMK AO2

      RAE29 SLP924 P0001 T00830083
```

Other Types of Messages: AFN / CPDLC / ADS-C

```
@2.JA838JA0Y/ANCATYA.AFN/FMHJAL3,.JA838J,
86DA1E,212225/FAK0,PAZN/FARADS,0/FARATC,
004F0

P2.N620FEH1X- #MD/A6
OAKODYA.ADS.N620FE07030B000C010D010E0110010F
01799A

02.B-6535A6W/
UPGCAYA.ADS.B-6535080F13264825E41

2B-16705RAZQUTPEOCBR~1RA101192156
SA 19/21:54
```

Other Types of Messages: Scheduling

```
`2B-16708H1V- #T1:)DM01171719

/M99

/Q01

BR395/,/3SGN/,07:20/,T2/,C4/,On Time/./.

BR211/,/3BKK/,08:15/,T2/,C7/,On Time/./.

BR255/,/3DPS/,10:15/,T2/,C8/,On Time/./.

BR271/,/3MNL/,09:30/,T2/,C3/,On Time/./.

BR265/,/3PNH/,09:10/,
```

Other Types of Messages

```
//ATTN CREW MEMBER //

MOLIT(MINISTRY OF LAND,INFRASTRUCTURE AND
TRANSPORT)

RECOMMENDED ALL PAX SHALL TURN OFF

THE POWER OF SAMSUNG GALAXY NOTE 7

AND FORBIDDEN CHARGING DEVICES

AND NOT ACCEPTED CHKD BAGGAGE.

JNA
```

Other Types of Messages

```
START OF PART  1 OF   1- HDA  623  ZSHC  VHHH 10SEP16   9A200602

FLIGHT    FROM  TO    DATE    ACFT       REG     CAPTAIN

HDA  623  ZSHC  VHHH  10SEP16 A330-300   BHLK    COLMAN GC

CRUISE SCHEDULE - CI65

MET OBS 091800

AIRPATH ROUTE 001

FMS ROUTE   HGHHKG1

SPECIAL NAVIGATION NOTES

- ZGGG AND ZGSZ ARE NOT A COMMERCIALLY PREFERRED ALTERNATE

                    ~~~~CFP DUE ALTN ZGSZ~~~~
```

Other Types of Messages

```
FDX73 YOUR ROUTE GOES

THROUGH THE SIGMET AREA

FROM ABOUT 110 MILES

NORTHEAST OF GITON TO

ABOUT 200 MILES

SOUTHWEST OF GITON. IT

LOOKS LIKE THE WORST WX

WILL BE
```

Other Types of Messages

1 PUSH LWR SW ON THE DSP

2 PUSH MENU ON THE FMC CDU

3 PUSH MAINTENANCE INFO LSK

4 SELECT ATA 31 MAINTENACE PAGE ON THE LWR DISPLAY UNIT

5 PUSH ERASE

6 CONFIRM WXR MSG DISAPPEARD

IF NO HELP,

WE WILL BE FIXED A

Other Types of Messages

ZFW 147122

REV ZFW _____

MACTOW 25.3% CG SEL _____

****

FLIGHT PREPARATION RELEASE

I HEREBY CERTIFY THAT THE CONDITIONS OF FLIGHT, AS STATED IN

THE AUSTRALIAN CIVIL AVIATION REGULATION (CAR 1988) 233 HAVE

BEEN COMPLIED WITH.

_____

PILOT-IN-COMMAND

END

Other Types of Messages

```
FWD AND AFT INDEX LIMITS

TO: I------*----I

ZF: I----*------I

GALLEY CODE       Full Cater

PAX WEIGHT SET

  MEL-DPS-J:Business Std

  MEL-DPS-Y:Economy Std

POB (INCL CREW)  348

       TTL

Zone1   21

Zone2   28

Zone3  179

Zone4  108

TOTAL  336
```

```
UNDERFLOOR

-11L/N                          -11R/N

-12L/N                          -12R/N

-13L/N                          -13R/N

-14L/N                          -14R/N

-21L/N                          -21R/N

-22L/N                          -22R/N

-23L/AKE91536QF/40PC/B    -23R/
AKE92663QF/40PC/B

-24L/AKE91580QF/40PC/B    -24R/
AKE92356QF/40PC/B

-31L/AKE25736QF/40PC/B    -31R/
AKE92498QF/40PC/
```

Other Types of Messages

REMARKS

ALERT - GTOW EXCEEDS

PTOW BY 400 LB

MEL 28-24-1-2

--------- RWY 33 ---------

ENSURE T/O FOB <= 121.4

Other Types of Messages

QUDOHEOQR~1DIS01010101

Freetext Test

HI CAPTAIN,

REQ BEST ETA PLEASE TO REDUCE DELAY ON NEXT SECTOR

RGDS, PHIL, IOC

AK000607

Other Types of Messages

UPS 77/10

T/O FUEL 215401

ADD MEL 36-12-2-1

0.3% INCREASE T/OFF FUEL

I UPDATED AERODATA WITH THE MEL.

I ALSO CALLED GATEWAY AND HAD THEM BRING FUEL UP TO 219.4 TO TAKE INTO CONSIDERATION THE 0.3% FUEL BURN INCREASE

BALANCE RLSE SAME

ACK REQUIRED

KELLE DELANEY, 102209

Other Types of Messages

```
RKSI:ICN 33R    EDNO 4UU                VREF20+5 172

LDA : 12303FT /  3749M                  DVREF      0

 -1C    1022HPA    0HEAD                SPD INCR   0

MAN LAND        FLAP F20                VAPP     172

1 REVERSER           DRY                SETTINGS    (FT/M)  BTMS

                                        MAX MAN    4794/1461>6.3

NNC : EO2                               MAX AUTO   6497/1980>6.3

ENG SHUTDOWN F20                        AUTOBRK 4         NO DATA

-- 777-300ER GE90-115 --                AUTOBRK 3         NO DATA

ADVISORY LANDING DATA:                  AUTOBRK 2 11154/3399  >4

ALW 245.0                               AUTOBRK 1         NO DATA

LANDING FLAPS: F20                      INCL 1500FT AIR DIST AND

                                        15 PCT SAFETY MARGIN
```

Other Types of Messages

DEAR CAPT,

LAST OFF **CHOCKS** WITHOUT **DISCRETION** WAS 19:20 UTC. NOW YOU ARE UNDER DISCRETION

AND THE LAST OFF CHOCKS WILL BE 22:10 UTC. PLS CONFIRM IF BOTH OF YOU ARE AGREE.

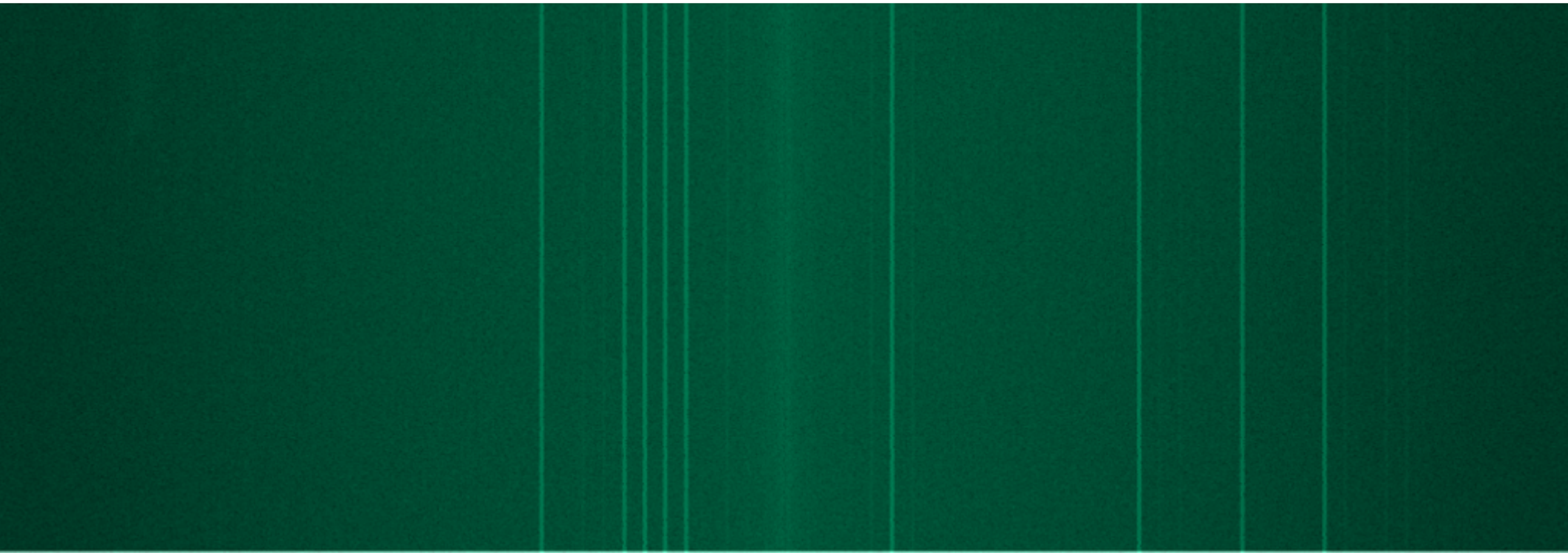
THANKS AND BRGDS/IO

THANKS FOR AGREEING TO **DISCRETION** CAPTIAN. PLEASE KEEP US UP TO DATE WITH ANY INFO

RGDS, PHIL, IOC

What about the other eight channels?

- Multi-channel Decoder
  - *Flow graph composition with hierarchical blocks*
  - *Running live*



Flight Plans

- *Waypoint parsing*

Un-selective AM

A Wideband Un-selective AM Receiver

- Originally conceived by Kevin Reid
- Demonstrated in ShinySDR at Cyberspectrum #15
- ‘Spatial audio’
- @switchborg
- kpreid.livejournal.com

A further refinement is to display in the graph not just the most recent data but average or overlay many. In the above image, the blue fill color in the upper section is an overlay (both color and height correspond to amplitude), the green line is the average, and the red line is the peak amplitude over the same time interval.

We can see signals across an immensely wide spectrum (subject to hardware limitations), but is there a way to *hear* them meaningfully? Yes, there is, with caveats.

What's pictured above is a small portion of the band assigned to aviation use — they are used primarily for communication between aircraft in flight and air traffic control ground stations. The most significant thing about these communications is that there are a lot of different frequencies for different purposes, so if you're trying to hear "what's in the area", you have to monitor all of them.

The conventional solution to this problem is a *scanner*, which is a radio receiver programmed to rapidly step through a range of frequencies and stop if a signal is detected. Scanners have disadvantages: they will miss the beginning of a signal, and they require a threshold set to trade off between missing weak signals and false-triggering on noise.

An alternative, specific to AM modulation (which is used by aircraft), is to make a receiver with very poor selectivity: the ability to receive only a specific channel and ignore other signals. (Historically, when RF electronic design was less well understood and components had worse characteristics, selectivity was a specification one would care about, but only if one lived in an area with closely-spaced radio stations — today, every receiver has good selectivity!)

I'm going to explain how to build an unselective receiver in software, and then refine this to create *spatial audio* — that is, the frequency of the signal shall correspond to the stereo panning of the output audio. This is the analogue of the spectrum display in audio.

Of course, this is an AM receiver and so it will only make intelligible sound for amplitude-modulated signals. However, many signals will produce *some* sound in an AM receiver. The exception is that a clean frequency-modulated (FM) or phase-modulated signal will produce silence, because its amplitude is theoretically constant, but this silence is still audibly distinct from background noise (if the signal is intermittent), and transmitted signals often do not have perfect constant amplitude.

Implementation

A normal software AM demodulator has a structure like the following block diagram (some irrelevant details omitted): The RF signal is low-pass filtered to select the desired signal, then demodulated by taking the magnitude (which produces an audio signal with a DC offset corresponding to the carrier).

In order to produce an unselective receiver, we omit the RF filter step, and therefore also the downsampling — therefore demodulating at the RF sample rate. The resulting real signal must be low-pass filtered and downsampled to produce a usable audio-sample rate (and because the high-frequency content is not interesting, see below), so we have now "just" swapped the two main components of the receiver.

This simple change works quite well. Two or more simultaneous AM signals can be received with clear stereo separation.

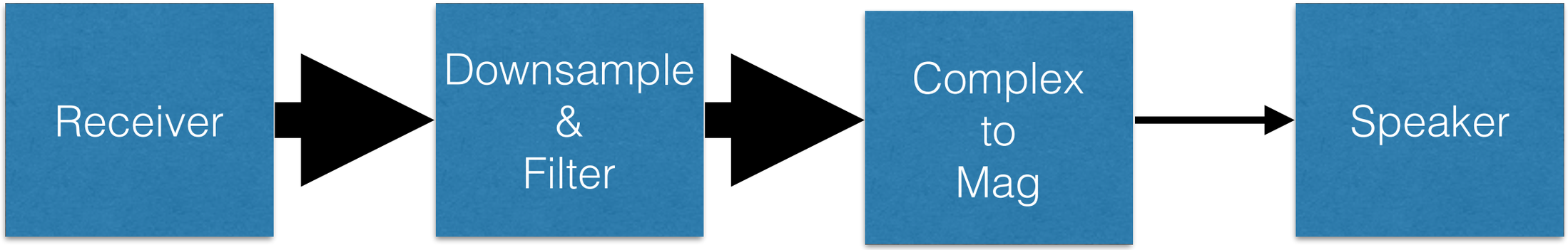
One interesting outcome is that, unlike the normal AM receiver, *the audio noise when there is no signal is quieter* (assuming AGC is present before the demodulator block in both cases) — this conveniently means that no squelch function is needed.

The reason for this is obvious in hindsight: loosely speaking, most of the noise power will be at RF frequencies and outside of the audio passband. In order to have a strong output signal, the input signal must contain a significant amount of power *in a narrow band* to serve as the AM carrier and sideband. (I haven't put any math to this theory, so it could be nonsense.)

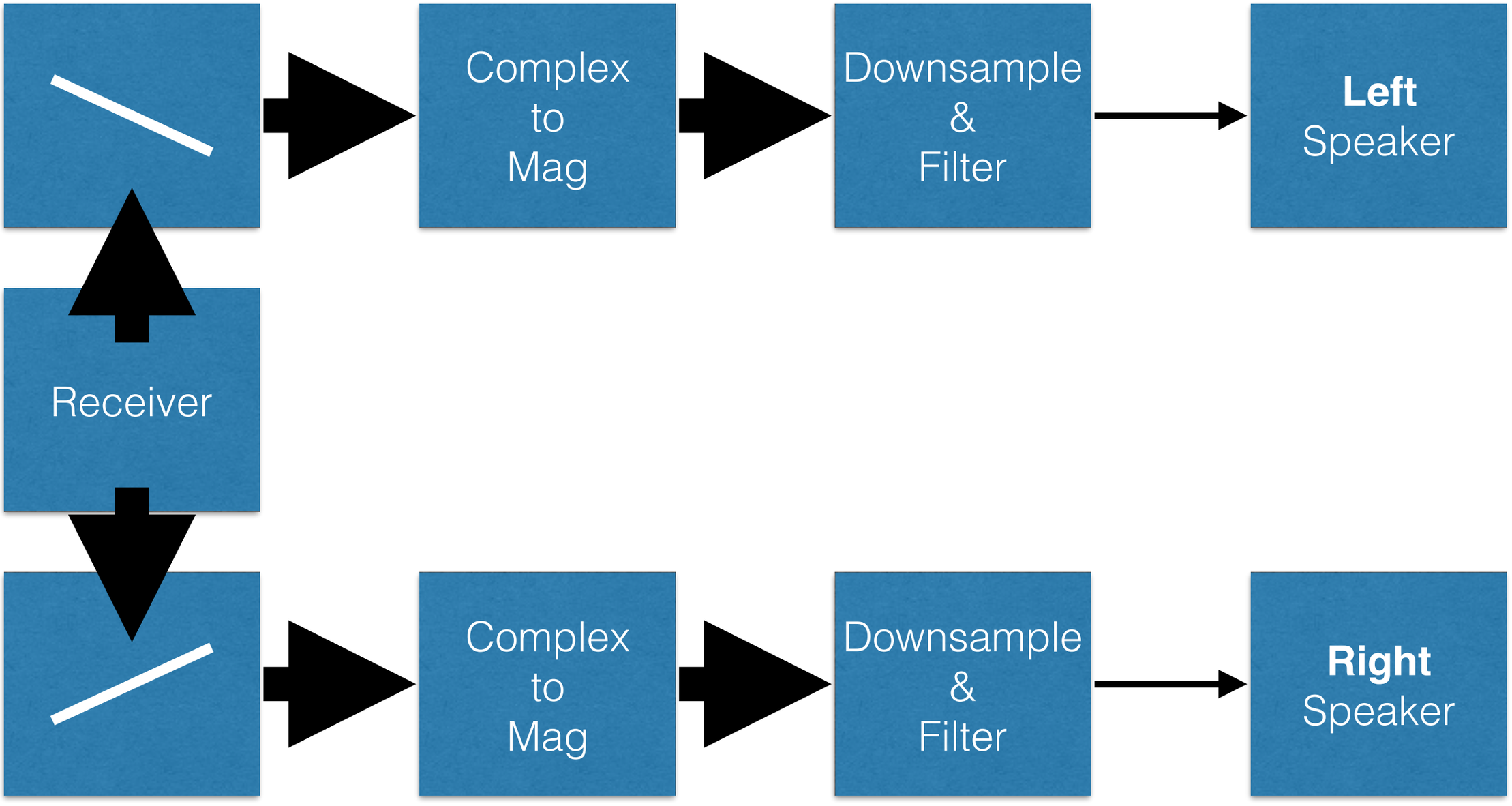
Adding stereo

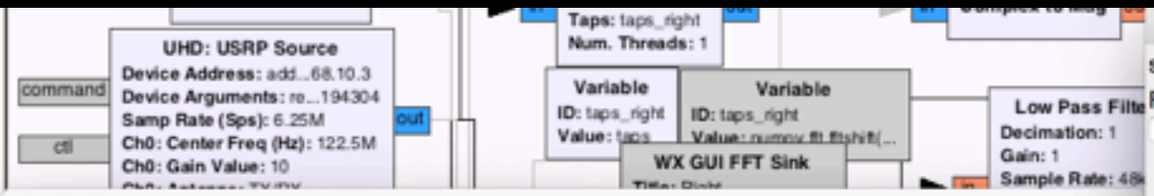
In order to produce the spatial audio, we want the audio signal amplitude, in a single stereo channel, to vary with frequency. And that is simply a filter with a sawtooth frequency response. The signal path is split for the two stereo channels, with opposite-slope filters. (AGC must be applied before the split.)

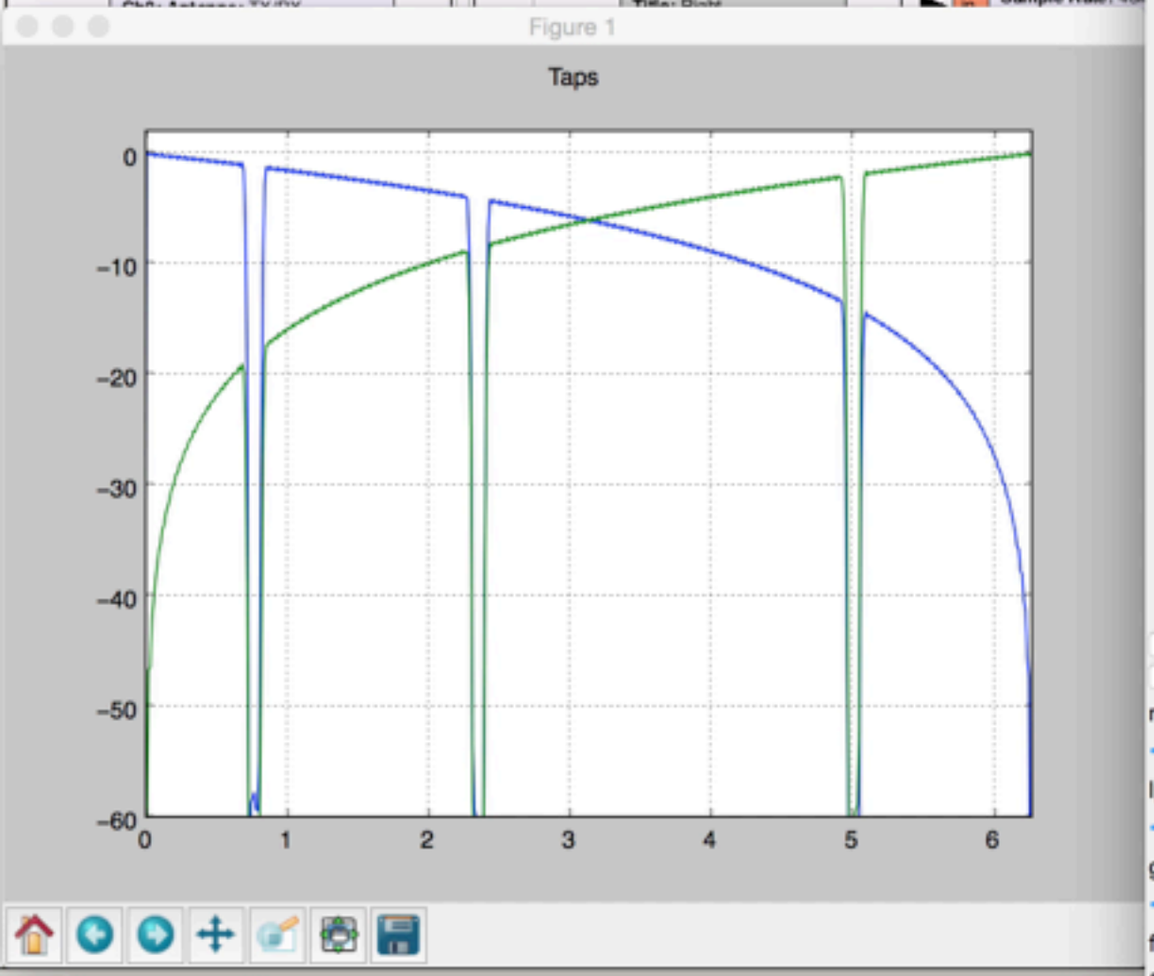
Mono ‘Un-selective’ Flow



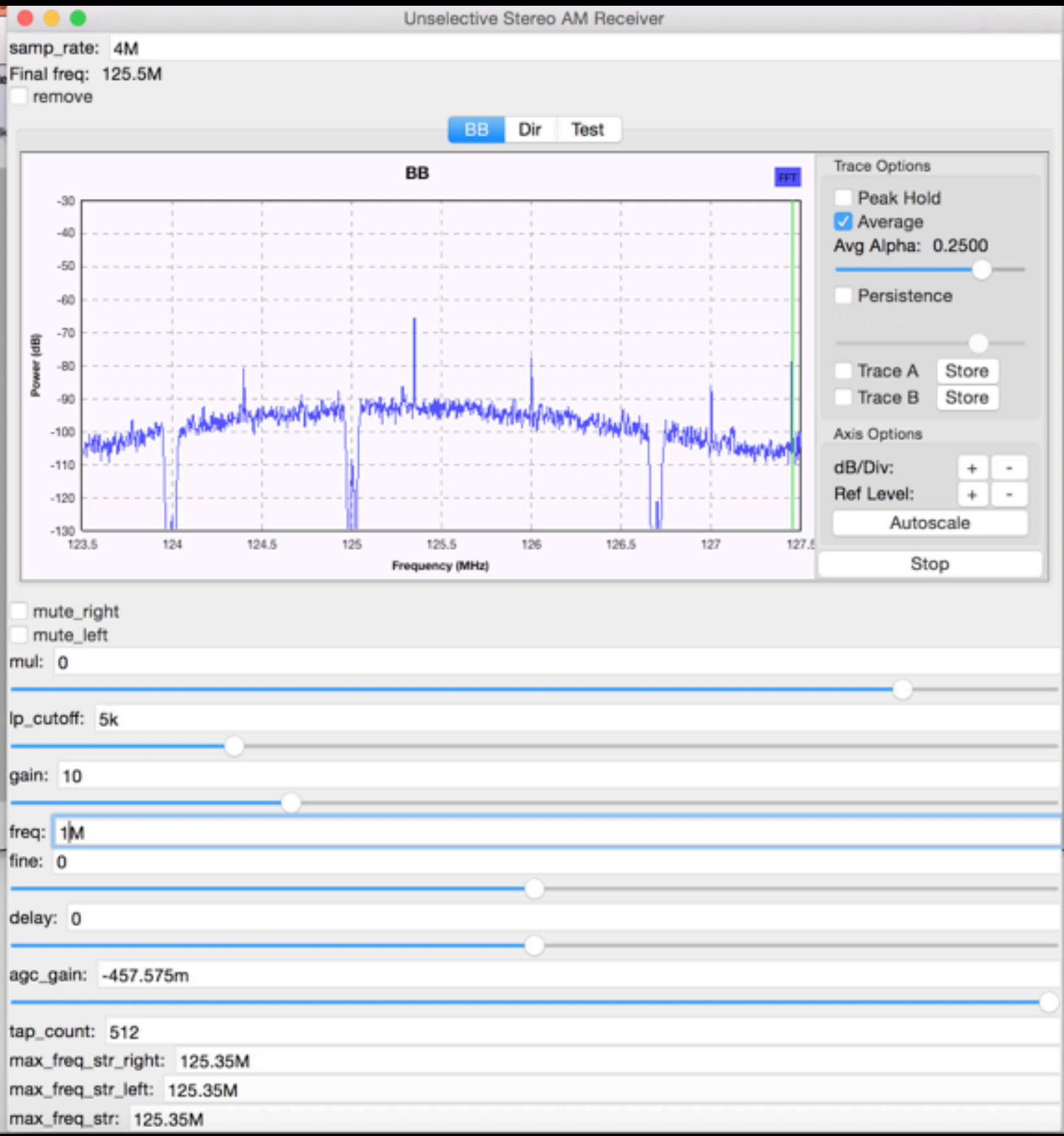
Stereo ‘Spatial’ Flow








```
Baseband freq: 1493577.98165
New stop band filter - taps: 397
Updating...
Saving to notches.json
Base freq: 123500000.0
Updating for 2 active notches: 125002752.294,123993577.982
Base freq: 124500000.0
Updating for 2 active notches: 125002752.294,123993577.982
Base freq: 125500000.0
Updating for 2 active notches: 125002752.294,123993577.982
Adding notch at: 126692660.55
Baseband freq: 1192660.55046
New stop band filter - taps: 397
Updating...
Saving to notches.json
```



How about those taps?

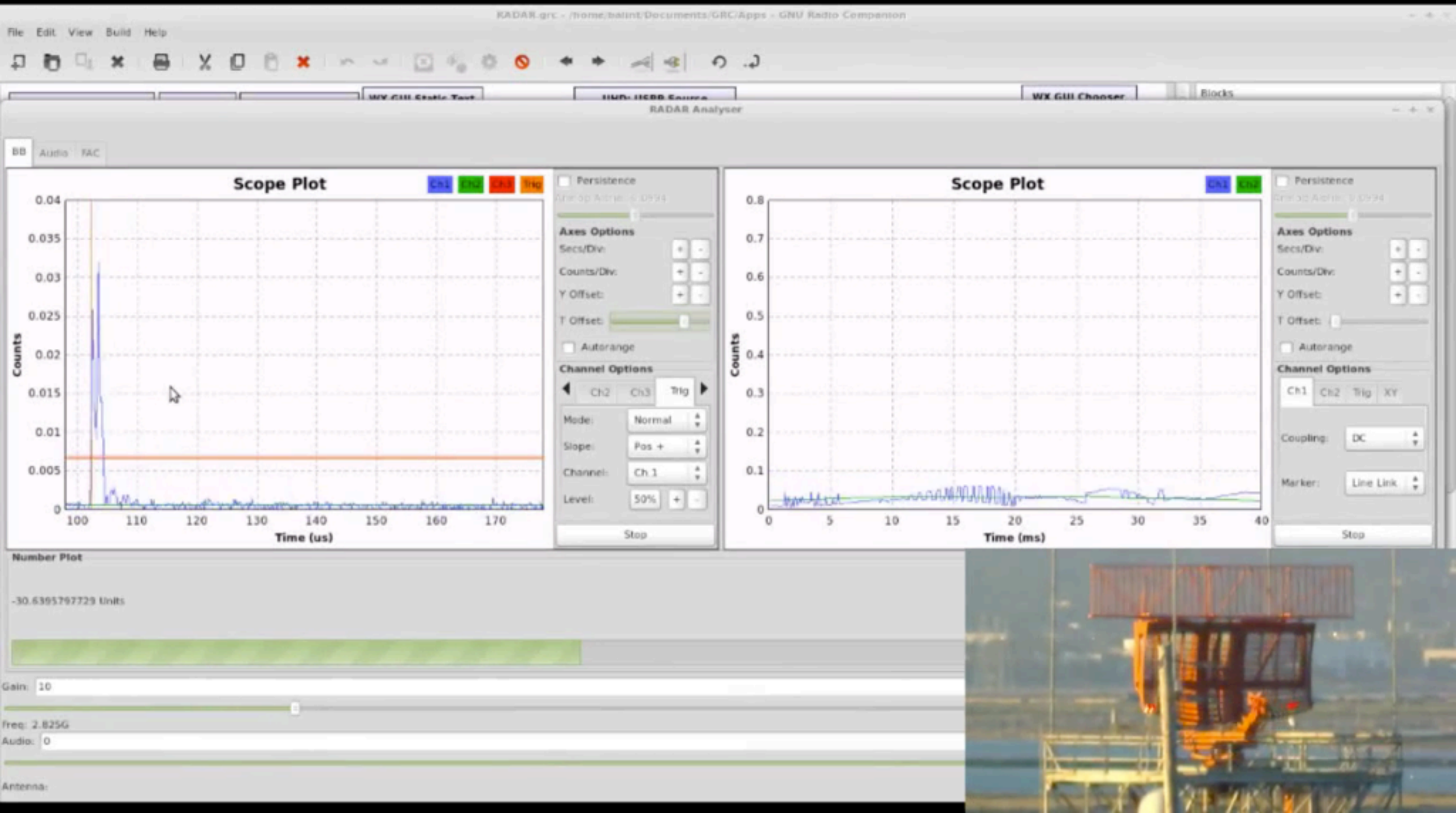
```
numpy.fft.fftshift(
 numpy.fft.ifft(
  numpy.fft.fftshift(
   numpy.linspace(0, 1, tap_count)
  )
 )
)
```

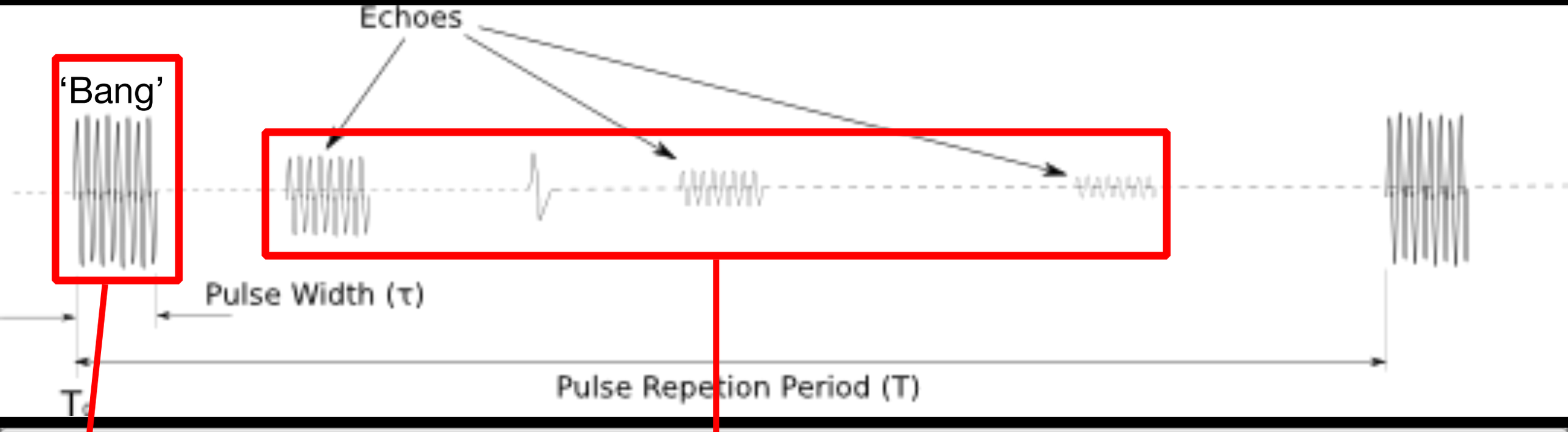
FMCW RADAR

Hacking the Wireless World with #sdr

@spenchdotnet

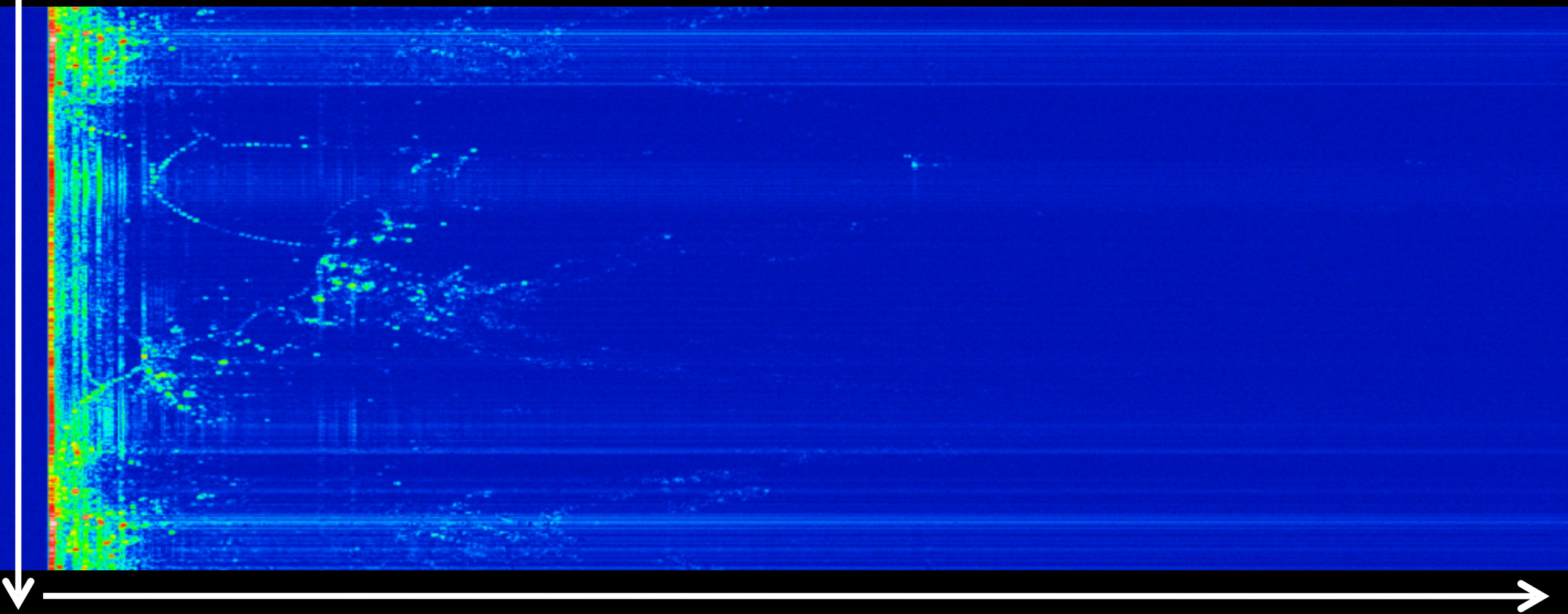
Primary **S**urveillance **R**ADAR (PSR)




Echoes
‘Bang’
Pulse Width (τ)
Pulse Repetion Period (T)
waveform LOCK amplitude=24X timebase=3X
0xFF96 -40.59 dBm 1312 ns

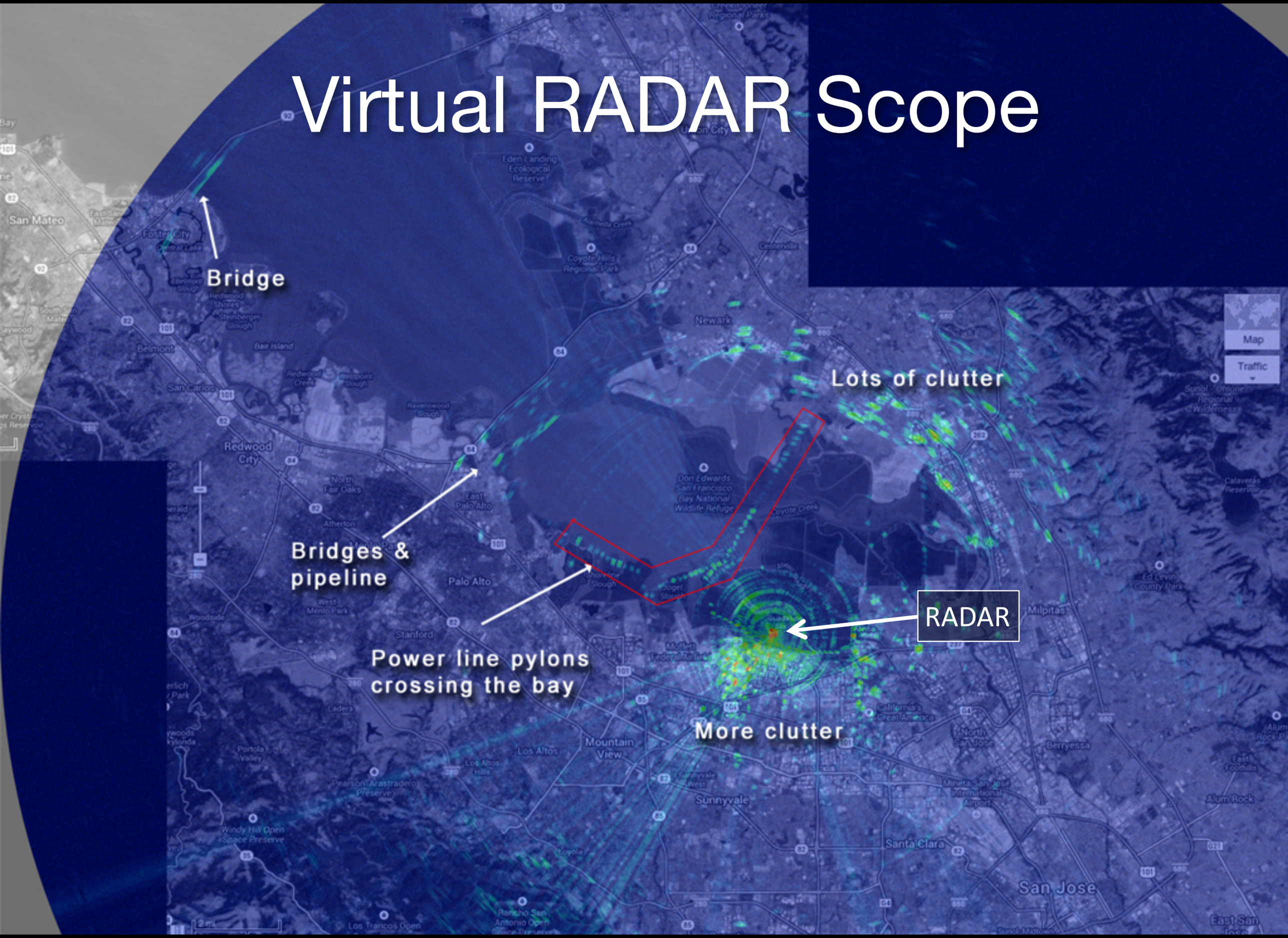
Raw RADAR Return Plot

Each scanline is synchronised to an emitted pulse



Scanline is amplitude of samples over time (also range of the return)

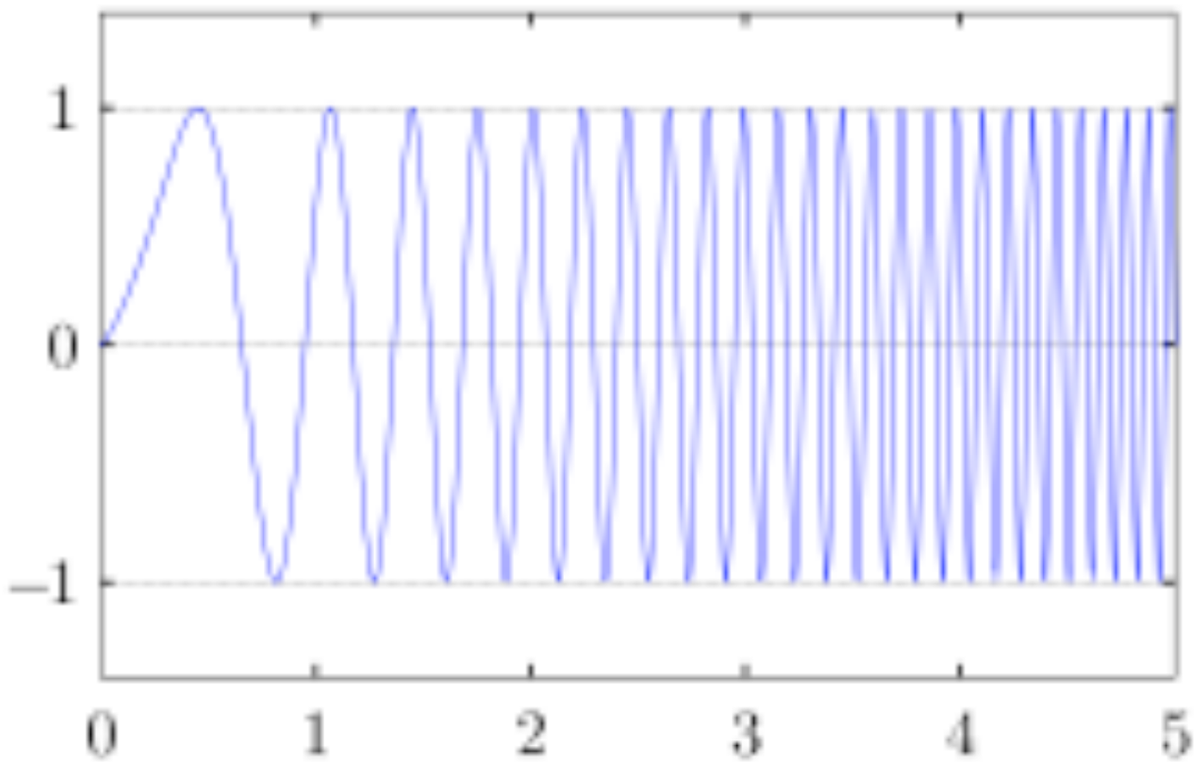
Virtual RADAR Scope



FMCW

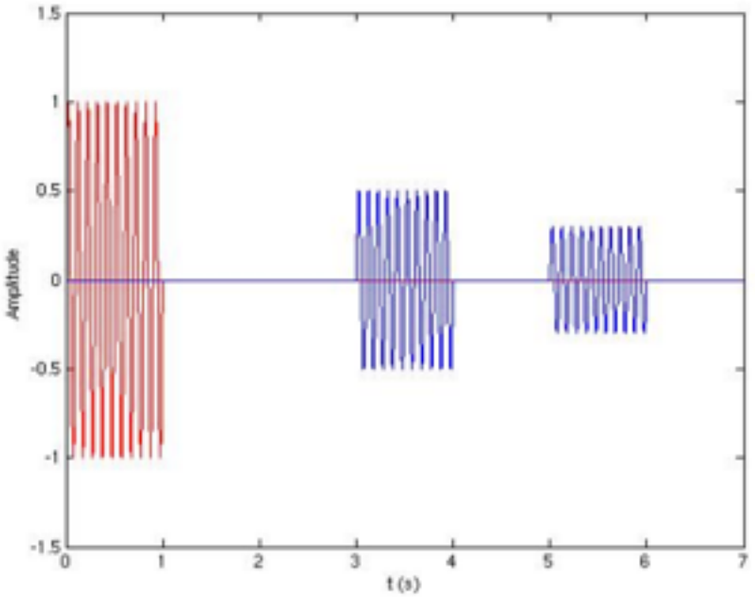
- Transmit a ‘chirp’ (strong self-correlation)
- Can be full TX duty cycle
- Think about chirp as a matched filter (not a VCO)

Filtered result is range information
like normal CW pulsed echos



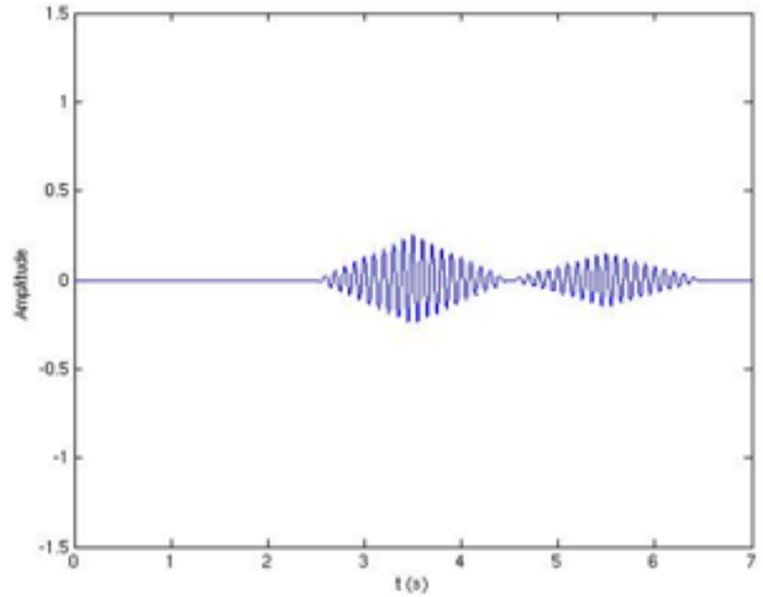
Example (simple impulsion): transmitted signal in red (carrier 10 hertz, amplitude 1, duration 1 second) and two echoes (in blue).

Before matched filtering

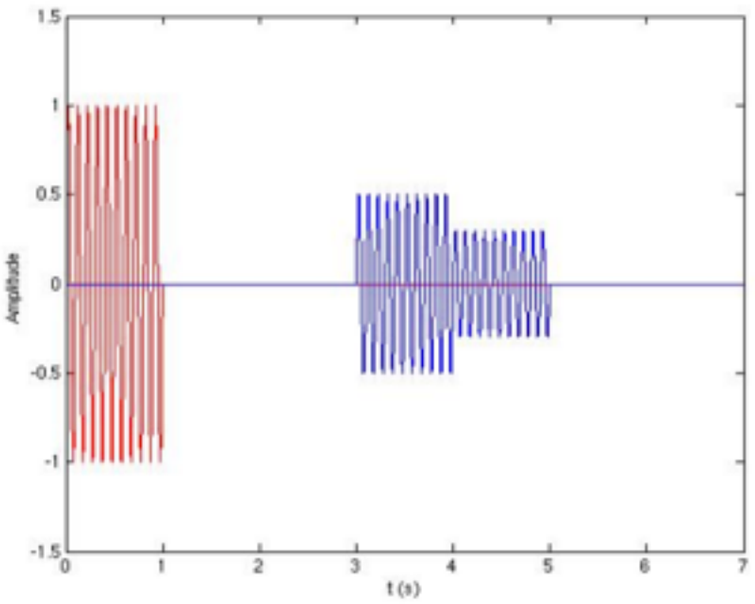


If the targets are separated enough...

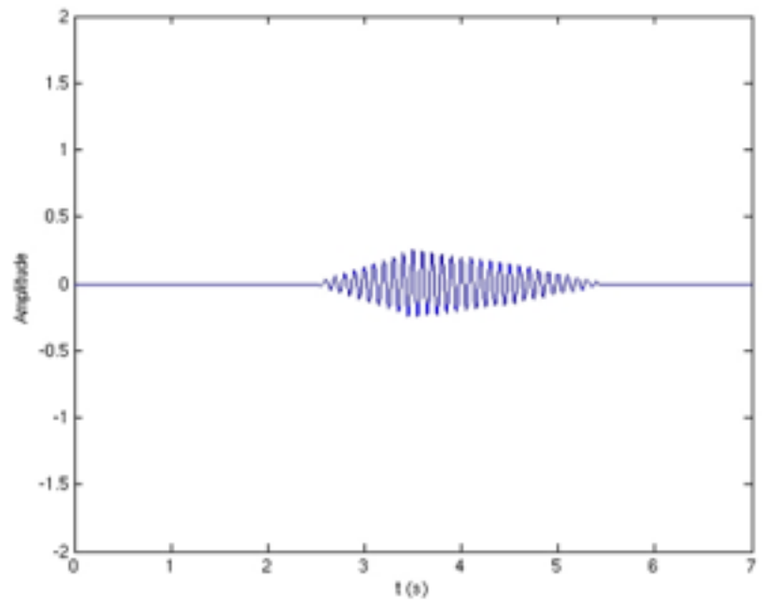
After matched filtering



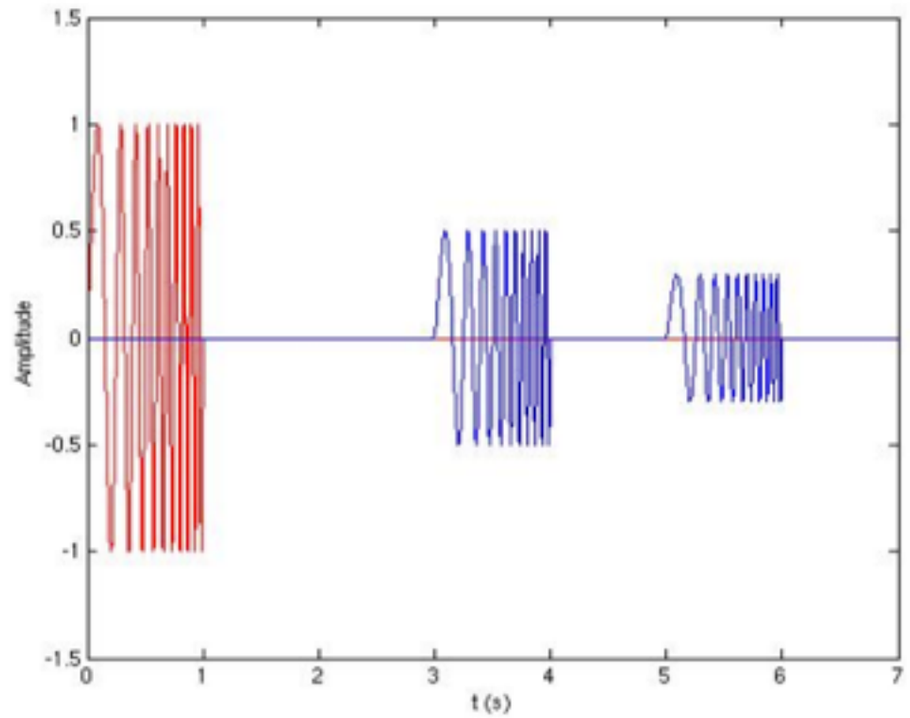
...echoes can be distinguished.



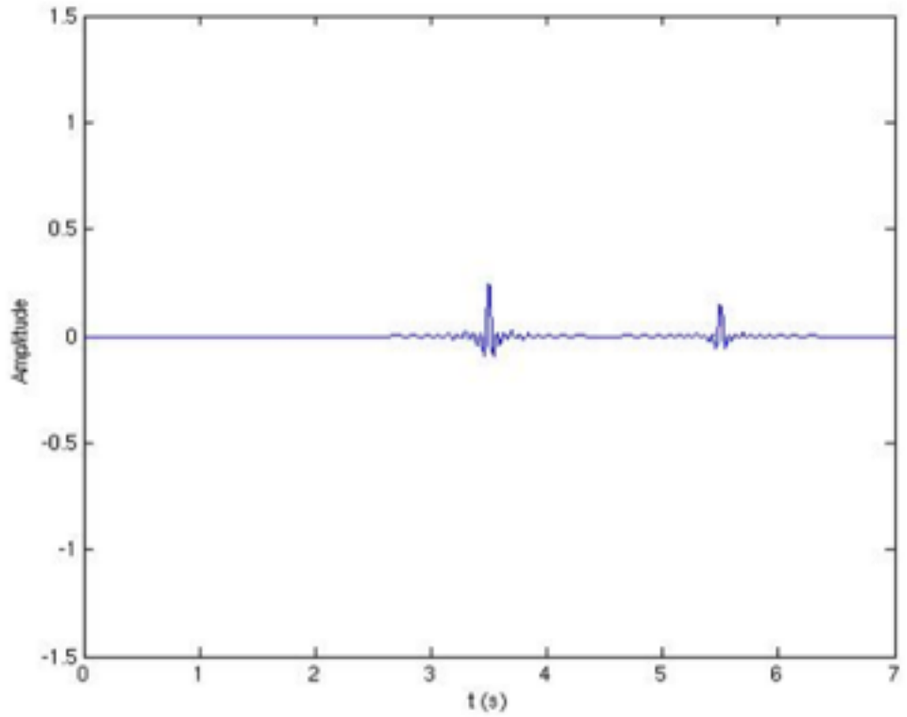
If the targets are too close...



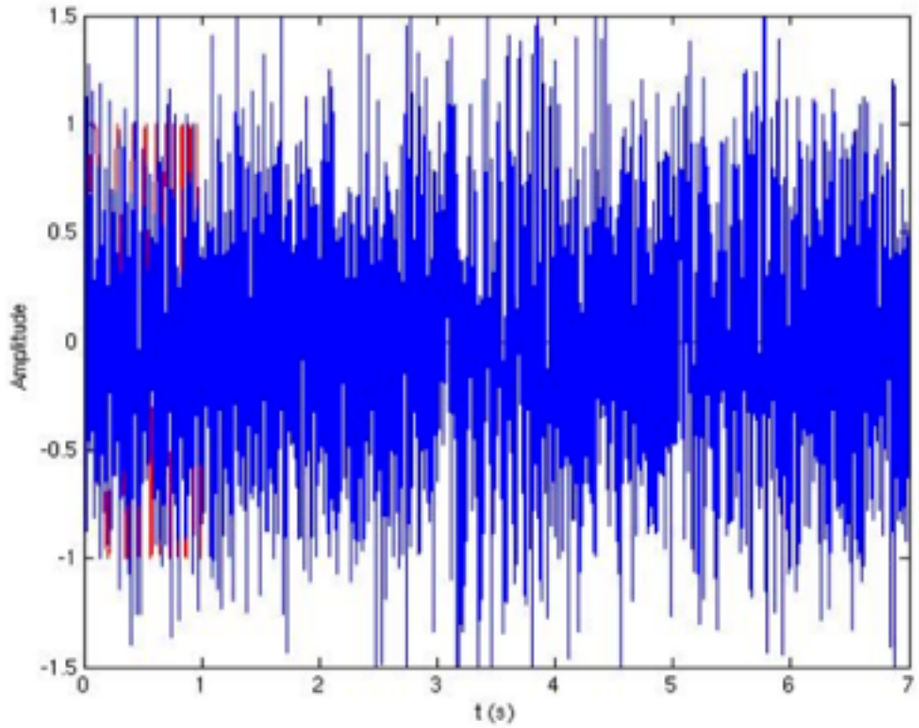
...the echoes are mixed together.



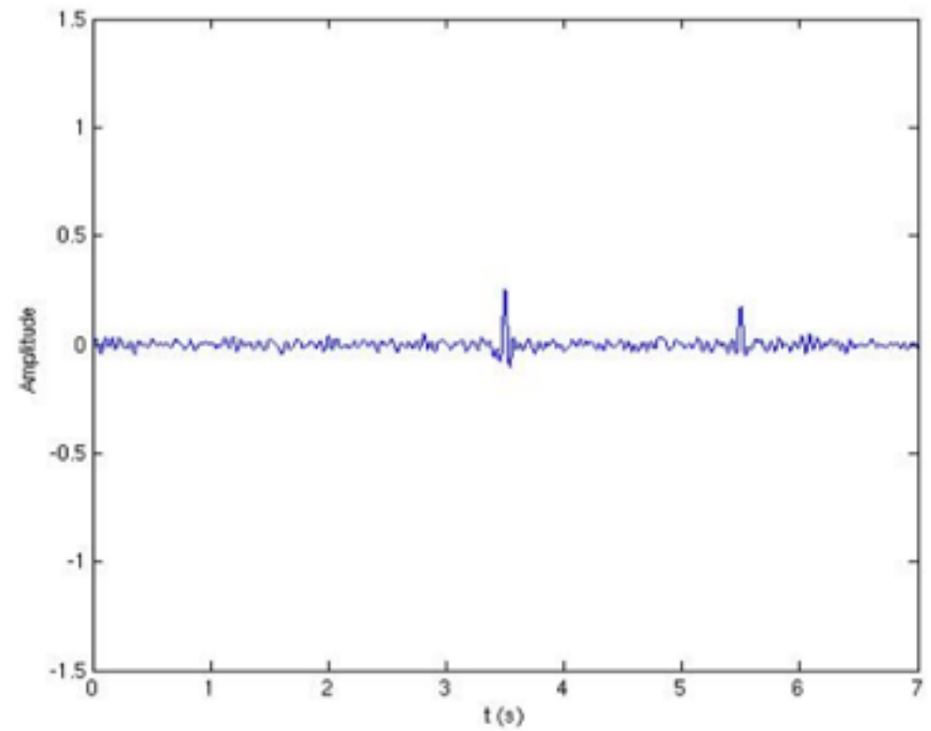
Before matched filtering



After matched filtering: the echoes are shorter in time.



Before matched filtering: the signal is hidden in noise

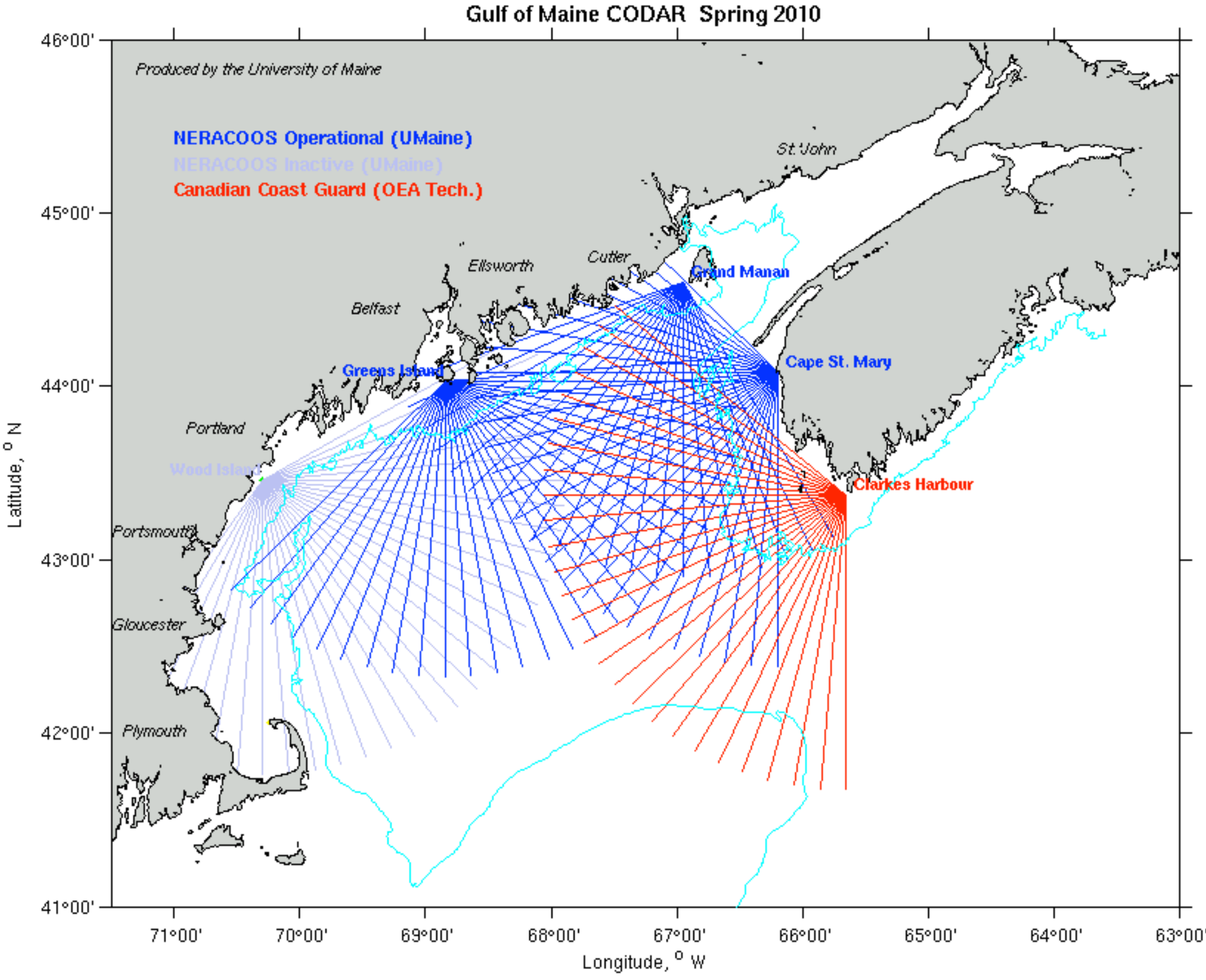


After matched filtering: echoes become visible.

CODAR

- Mapping ocean currents with HF RADAR

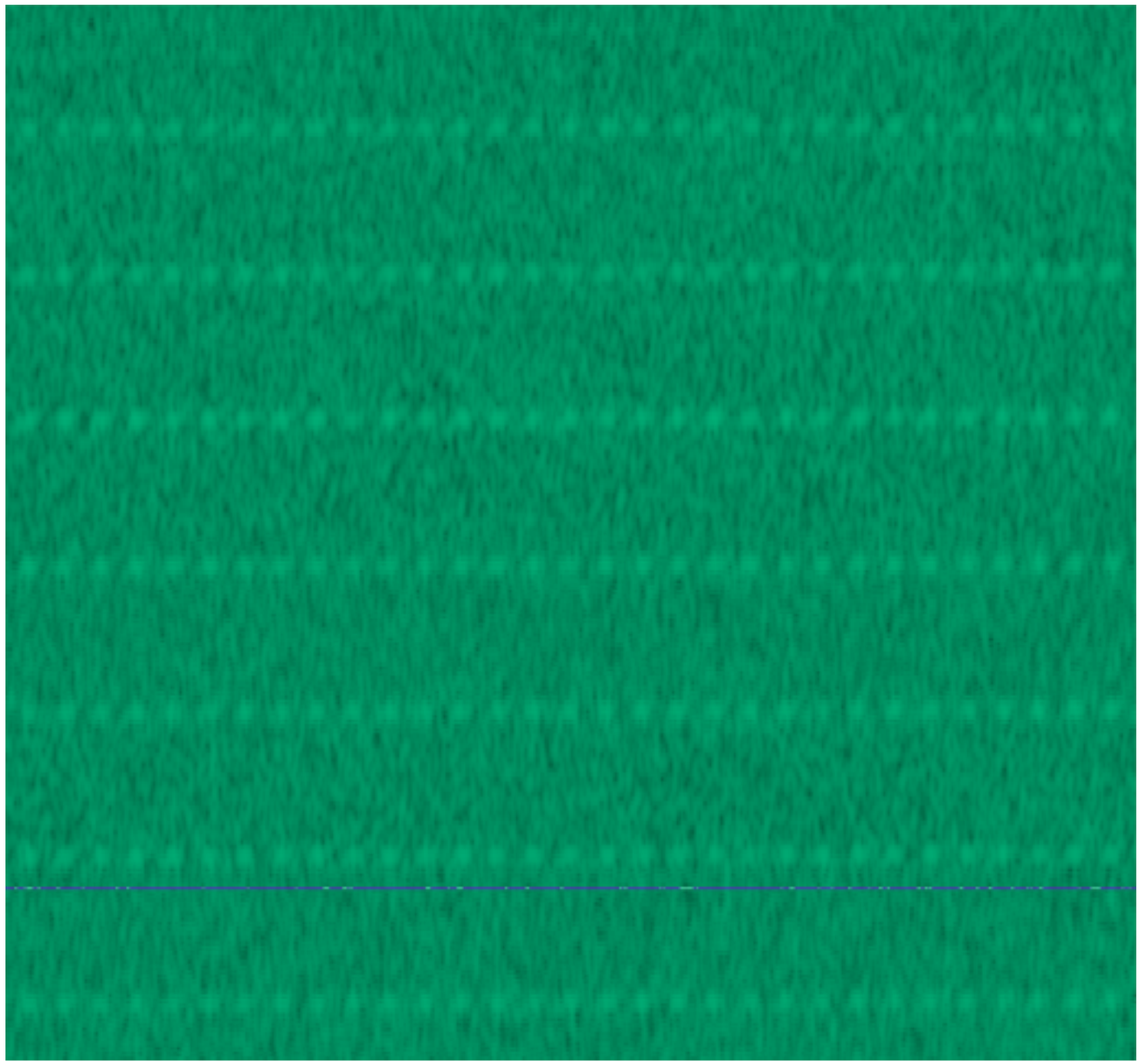
http://www.codar.com/

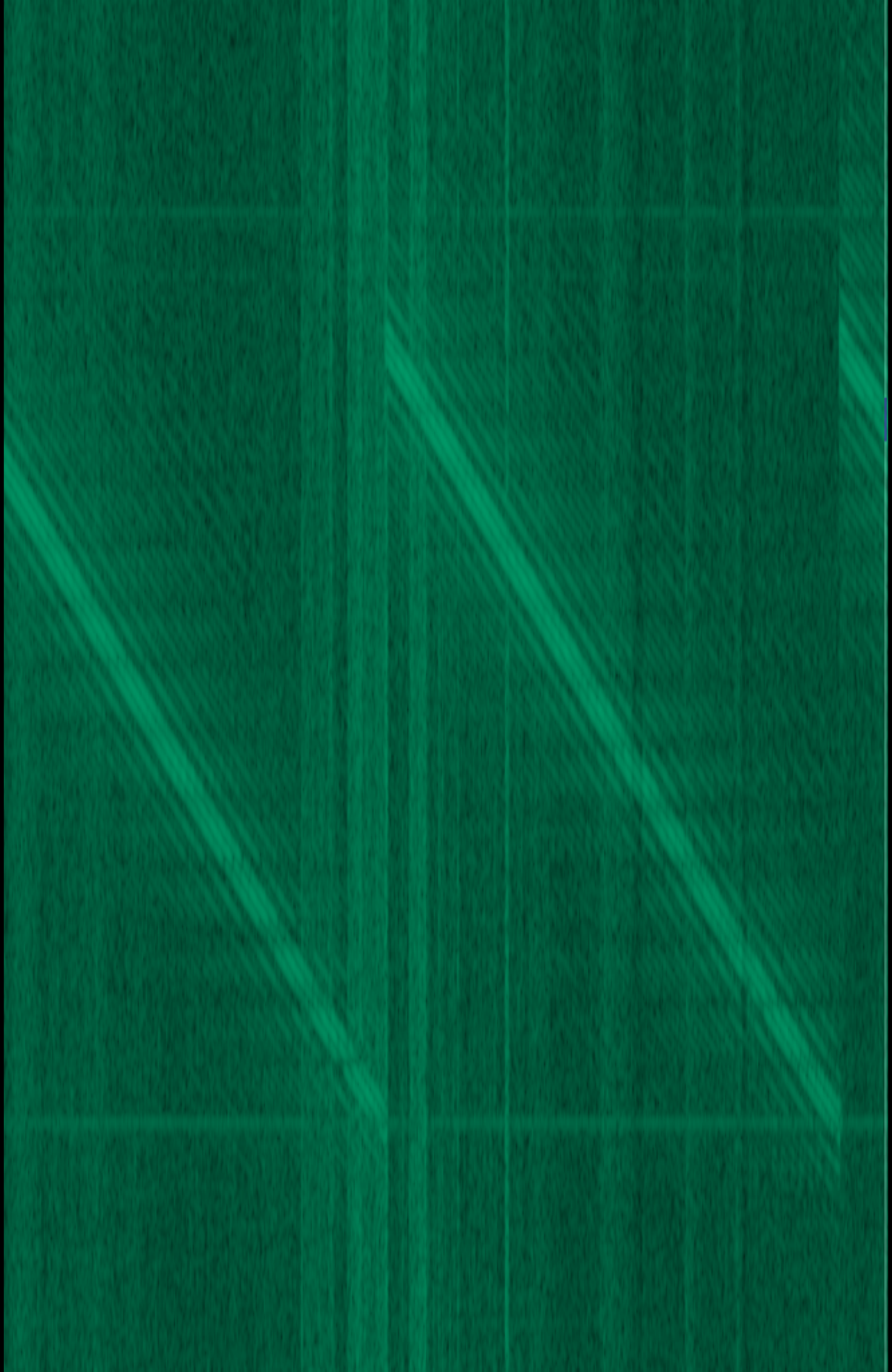


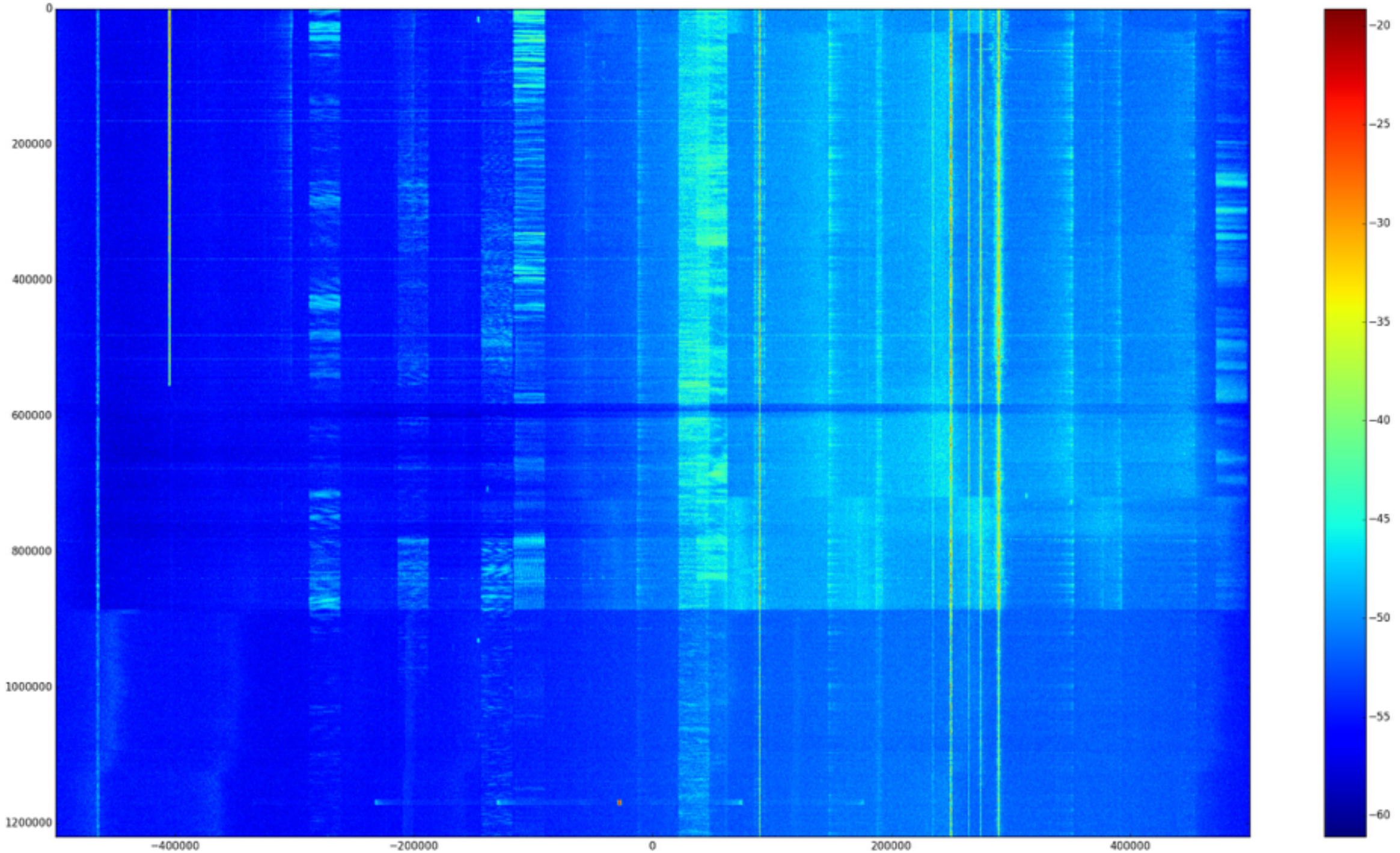
http://gyre.umeoce.maine.edu/gomoos/codar/

Mixing (Nulling) or Gating (Switching)

- TX & RX same site (monostatic)
- Remove TX signal at receiver before digitising (avoid saturation)
- Discontinuous TX (gating TX signal)
- Gating produces AM sidebands in frequency domain



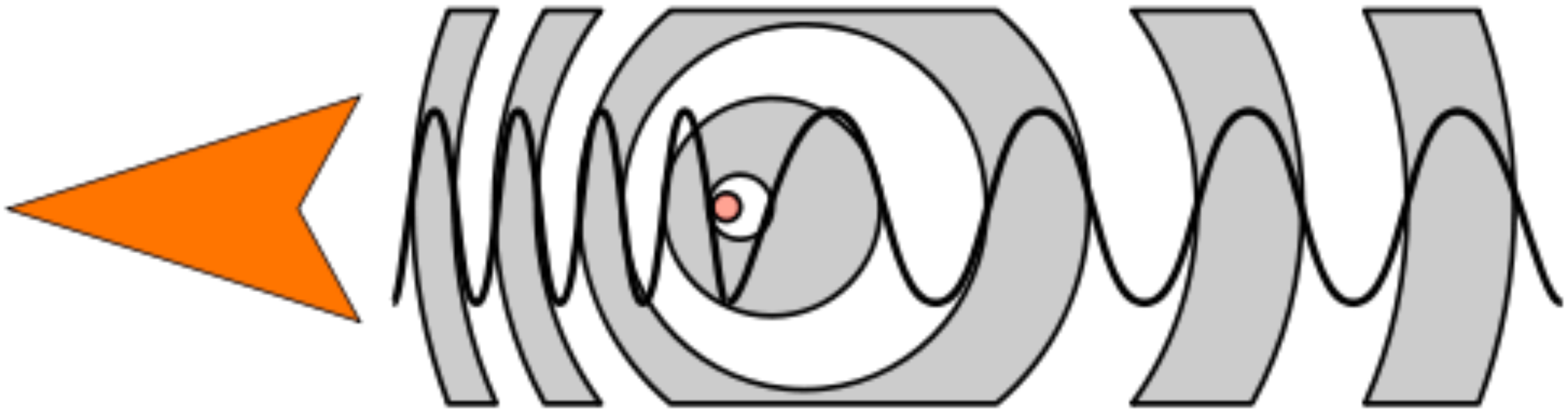



0
200000
400000
600000
800000
1000000
1200000
−400000
−200000
0
200000
400000
−20
−25
−30
−35
−40
−45
−50
−55
−60

What does it sound like?

Doppler Effect

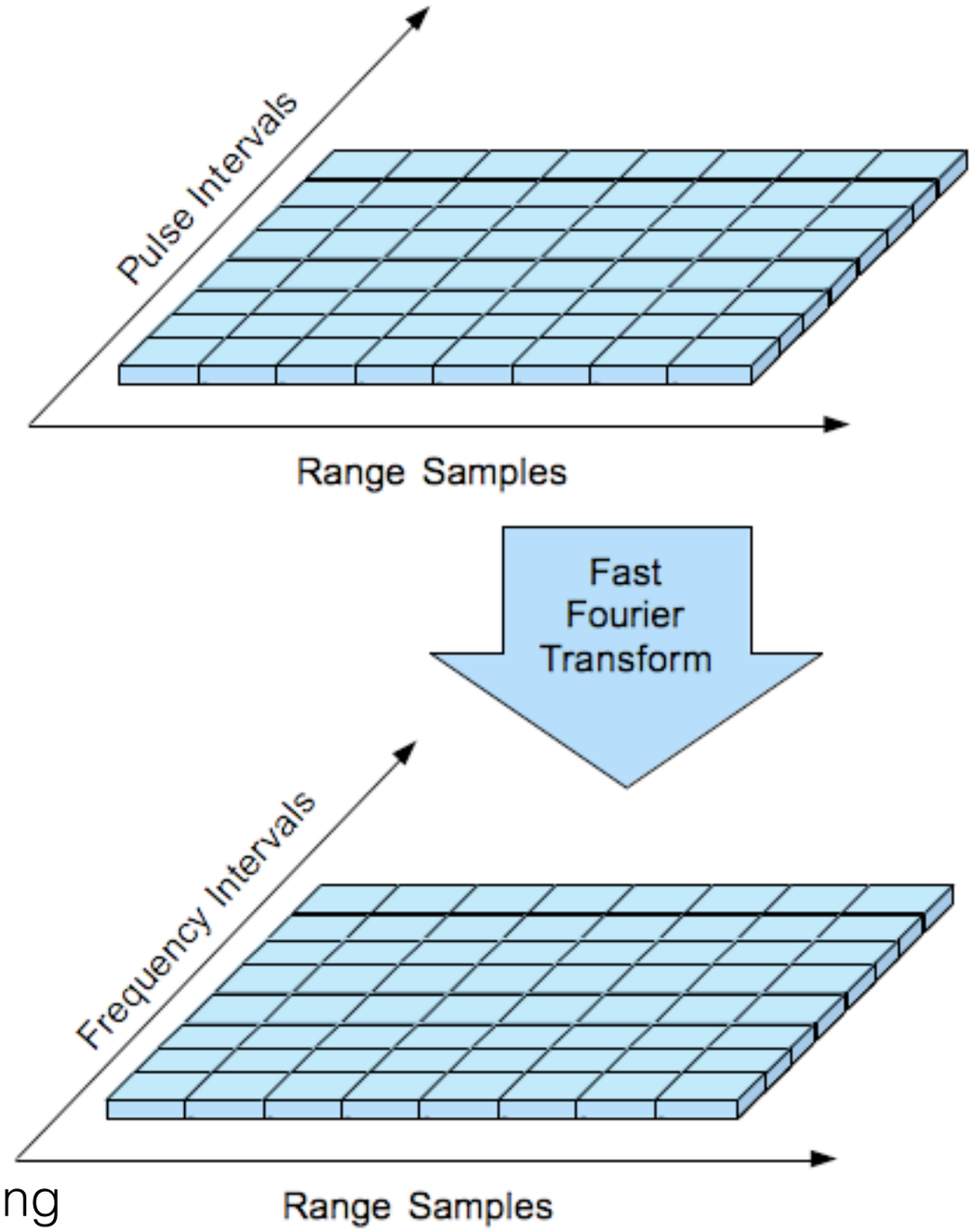
- Moving target will cause slight shift in received frequency
- Think about wavefront being received after reflection off target: phase change due to motion



https://en.wikipedia.org/wiki/Doppler_effect

Range-Doppler Processing

- Calculate range to target (discretised)
- How fast target is moving within that range bin
- Assuming phase coherent TX, Doppler effect causes phase change within same range bin over integration time
- FFT across each range bin!

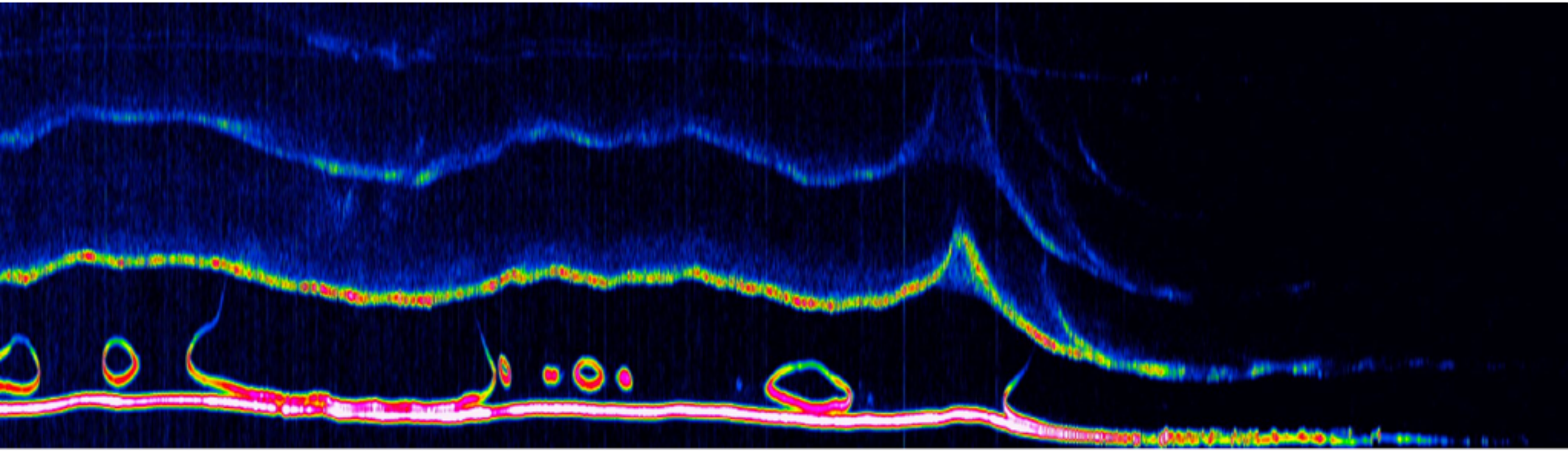


https://en.wikipedia.org/wiki/Pulse-Doppler_signal_processing

Let’s make one!

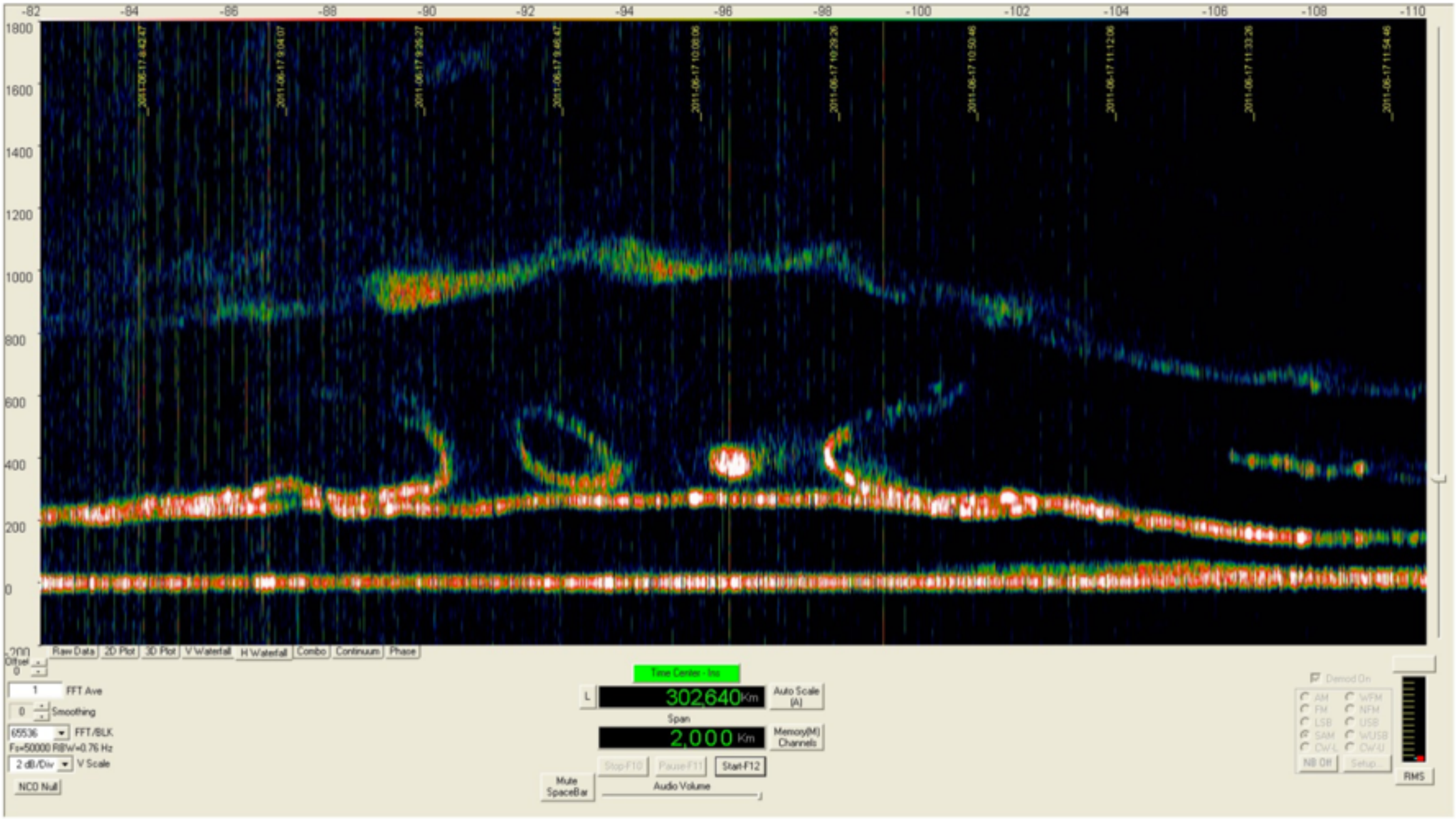
Inspiration

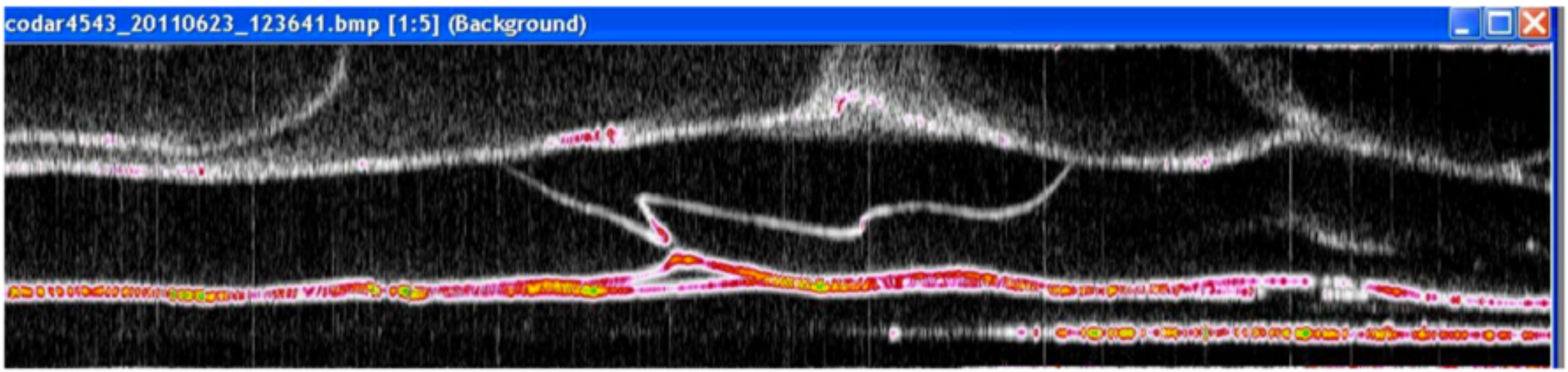
- Pieter Ibelings & Moe Wheatley
- RFSpace & Spectravue (moetronix.com)
- Beautiful pictures of ionosphere range plots



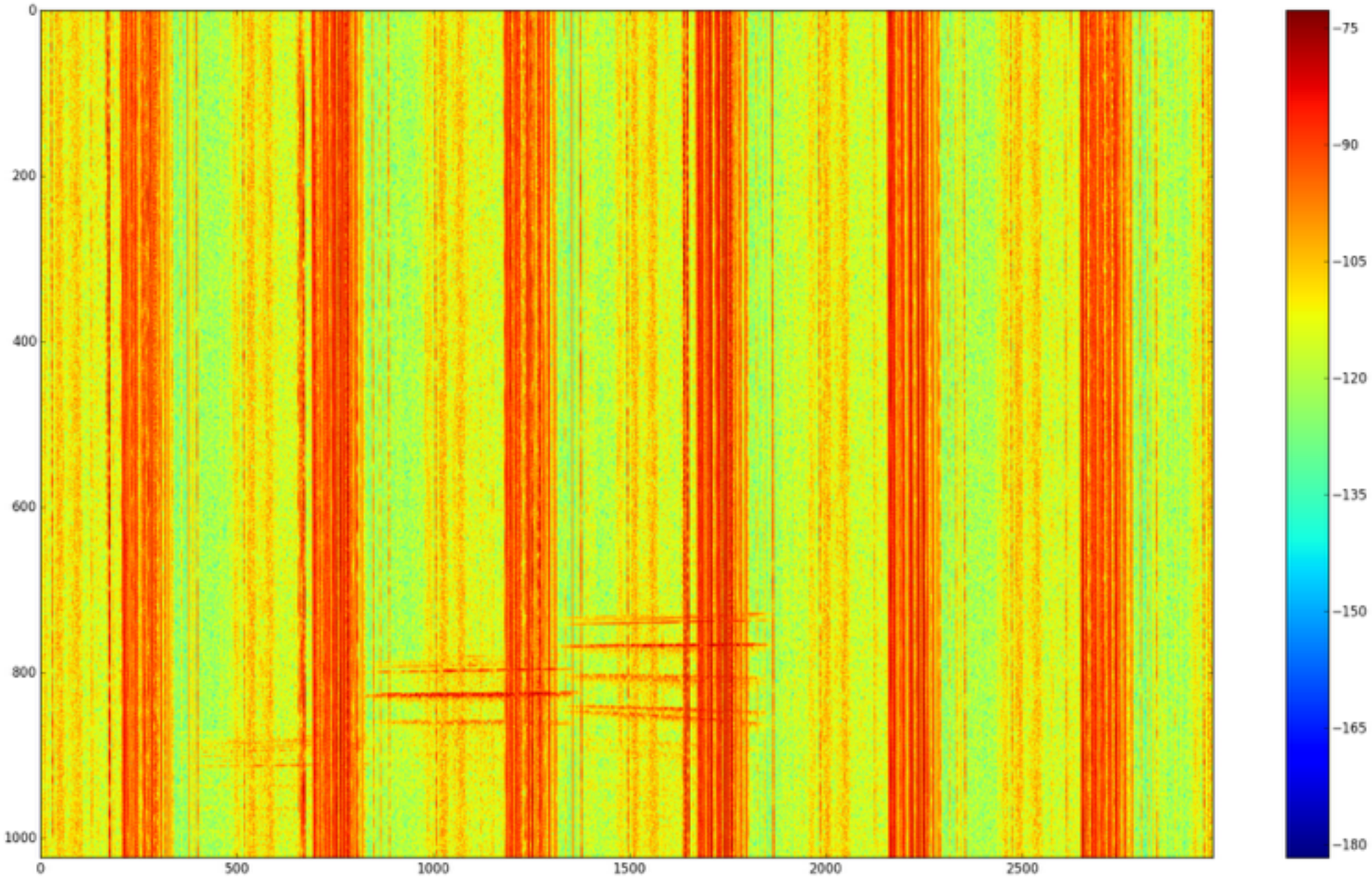
RFSPACE @rfspace · Sep 4
This is the time of the year when loops appear on ionosphere range plots. CloudSDR - 4543 kHz passive radar RX CODAR

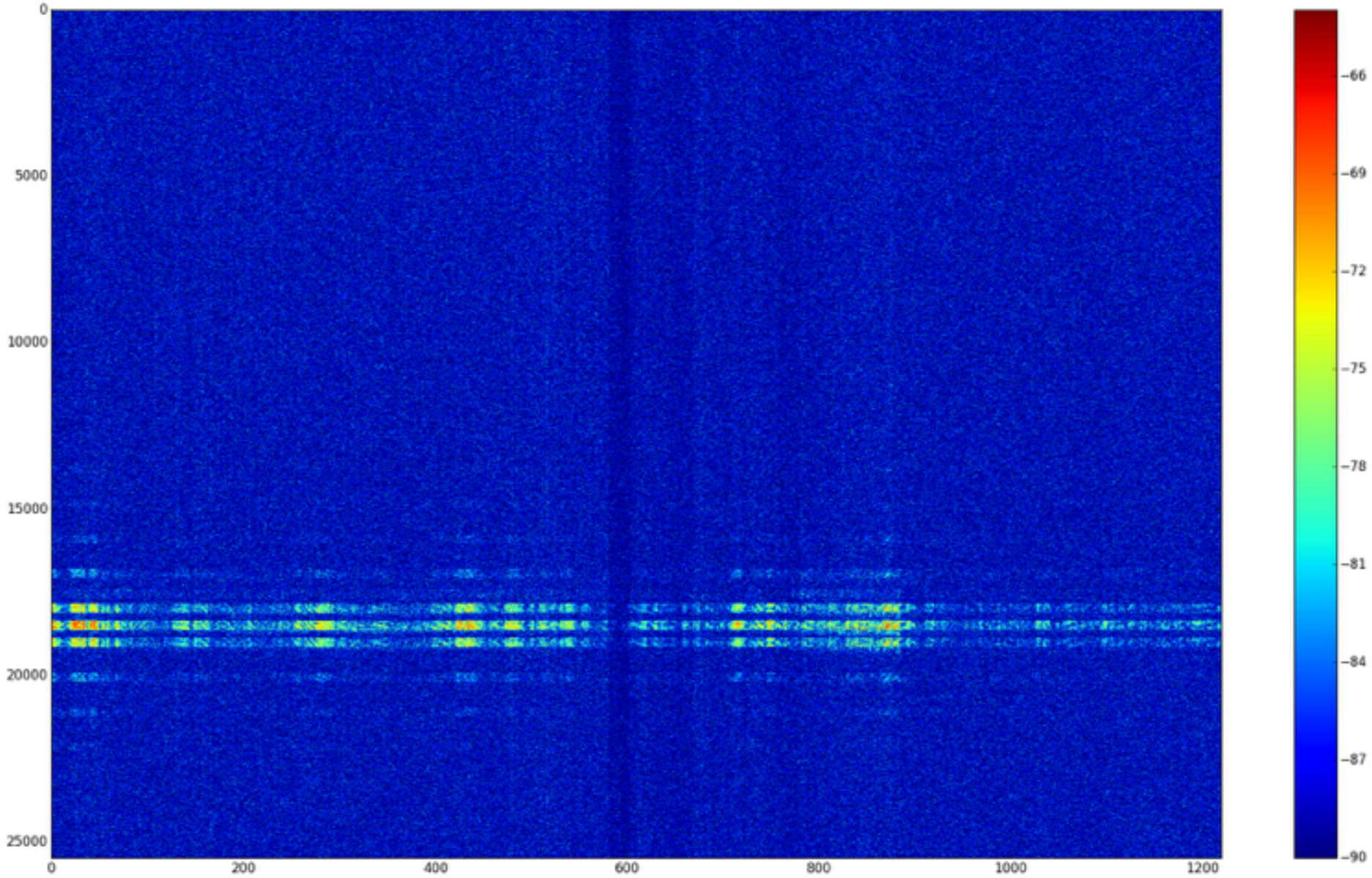
21 28

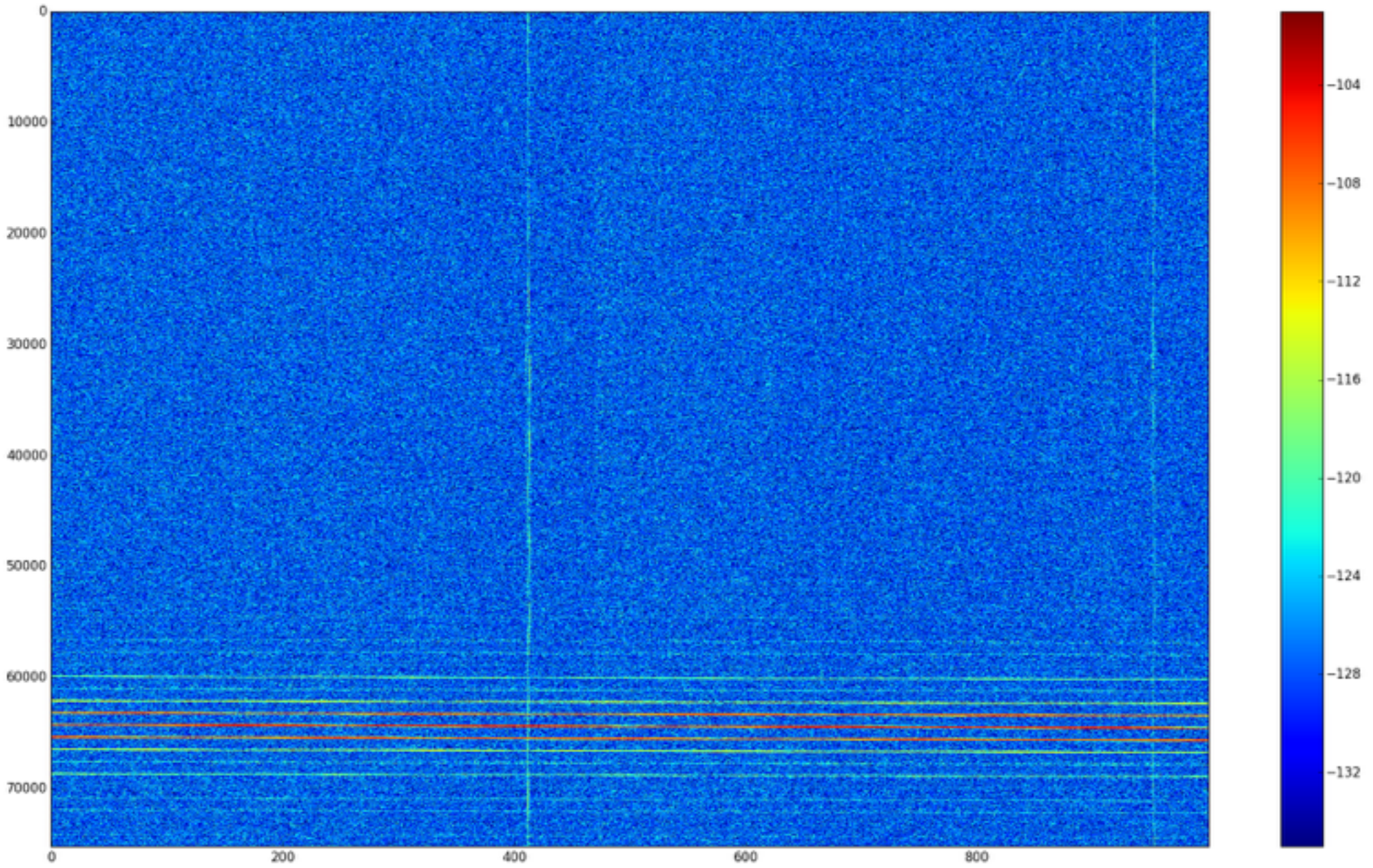


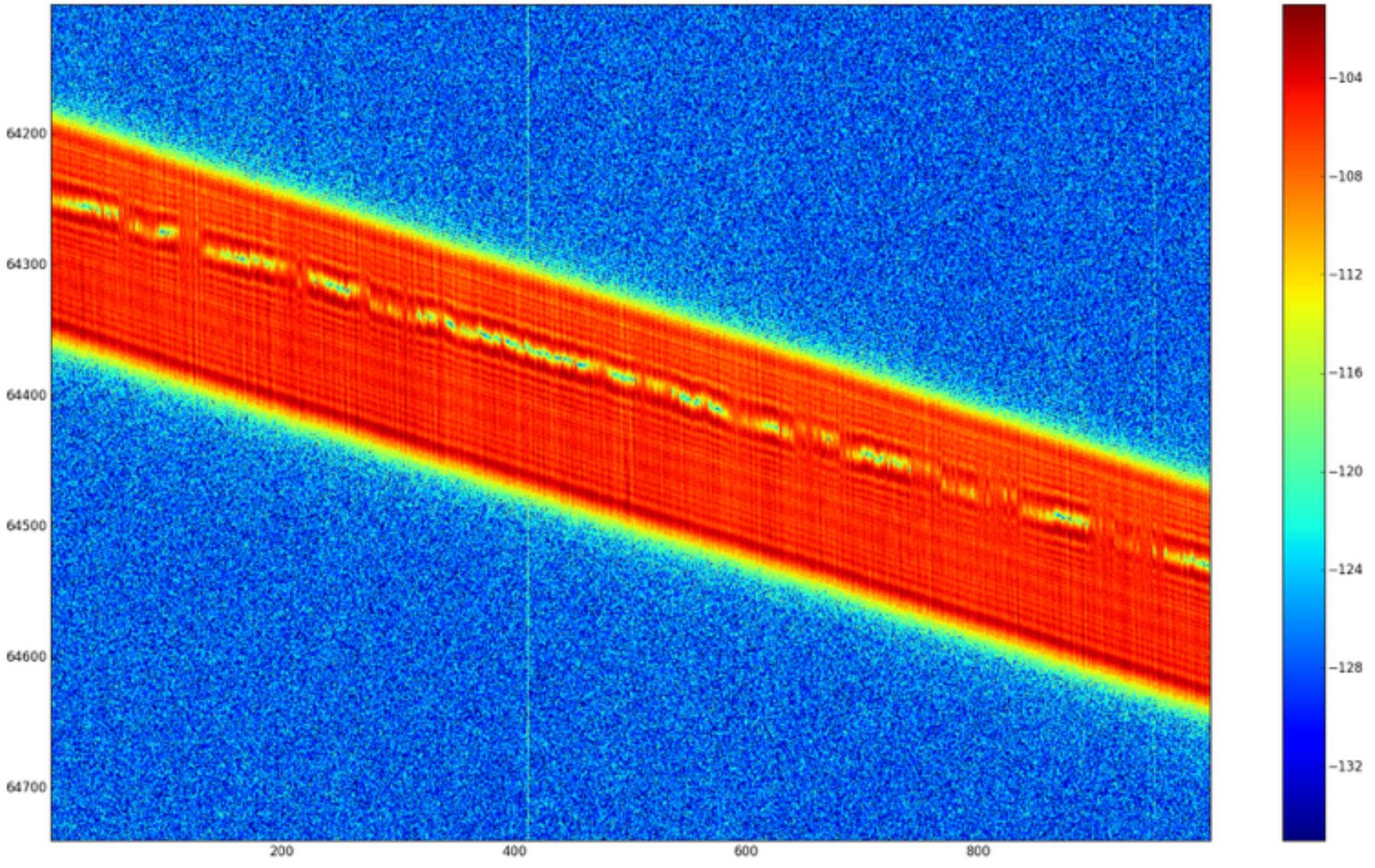


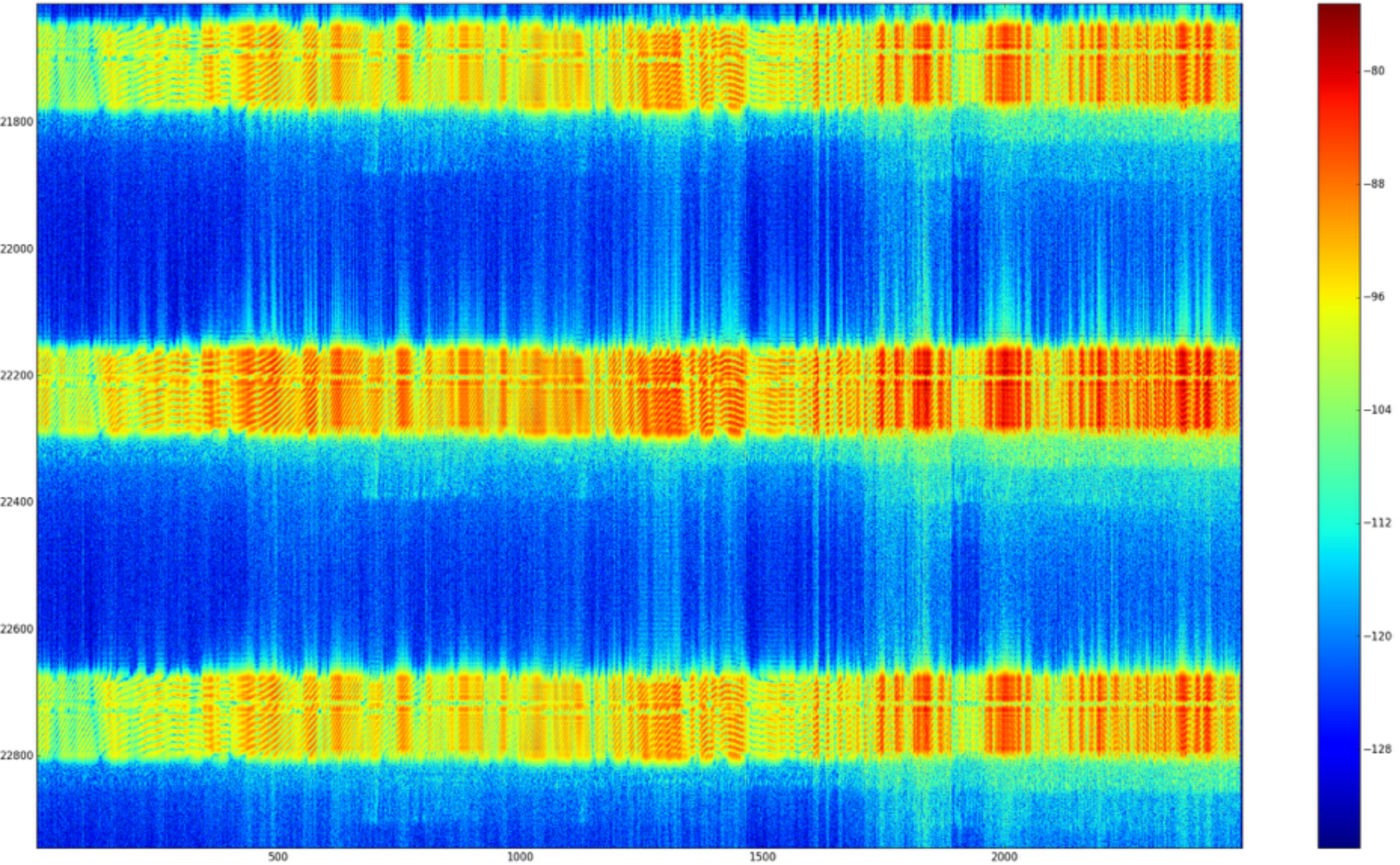
Ionosonde (inspiration from Juha Vierinen)



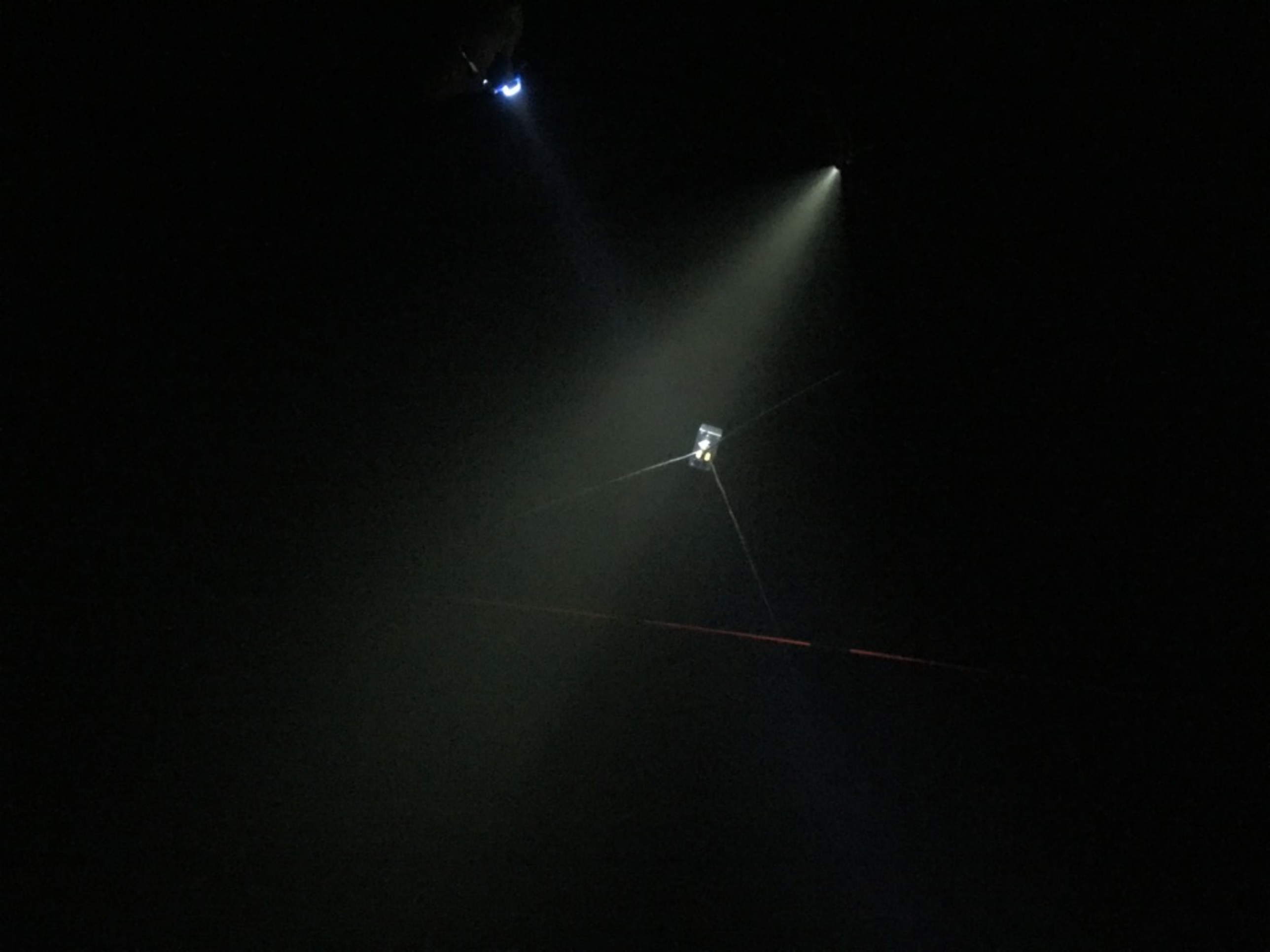

0
5000
10000
15000
20000
25000
0
200
400
600
800
1000
1200
−66
−69
−72
−75
−78
−81
−84
−87
−90


0
10000
20000
30000
40000
50000
60000
70000
0
200
400
600
800
−104
−108
−112
−116
−120
−124
−128
−132


64200
64300
64400
64500
64600
64700
200
400
600
800
−104
−108
−112
−116
−120
−124
−128
−132

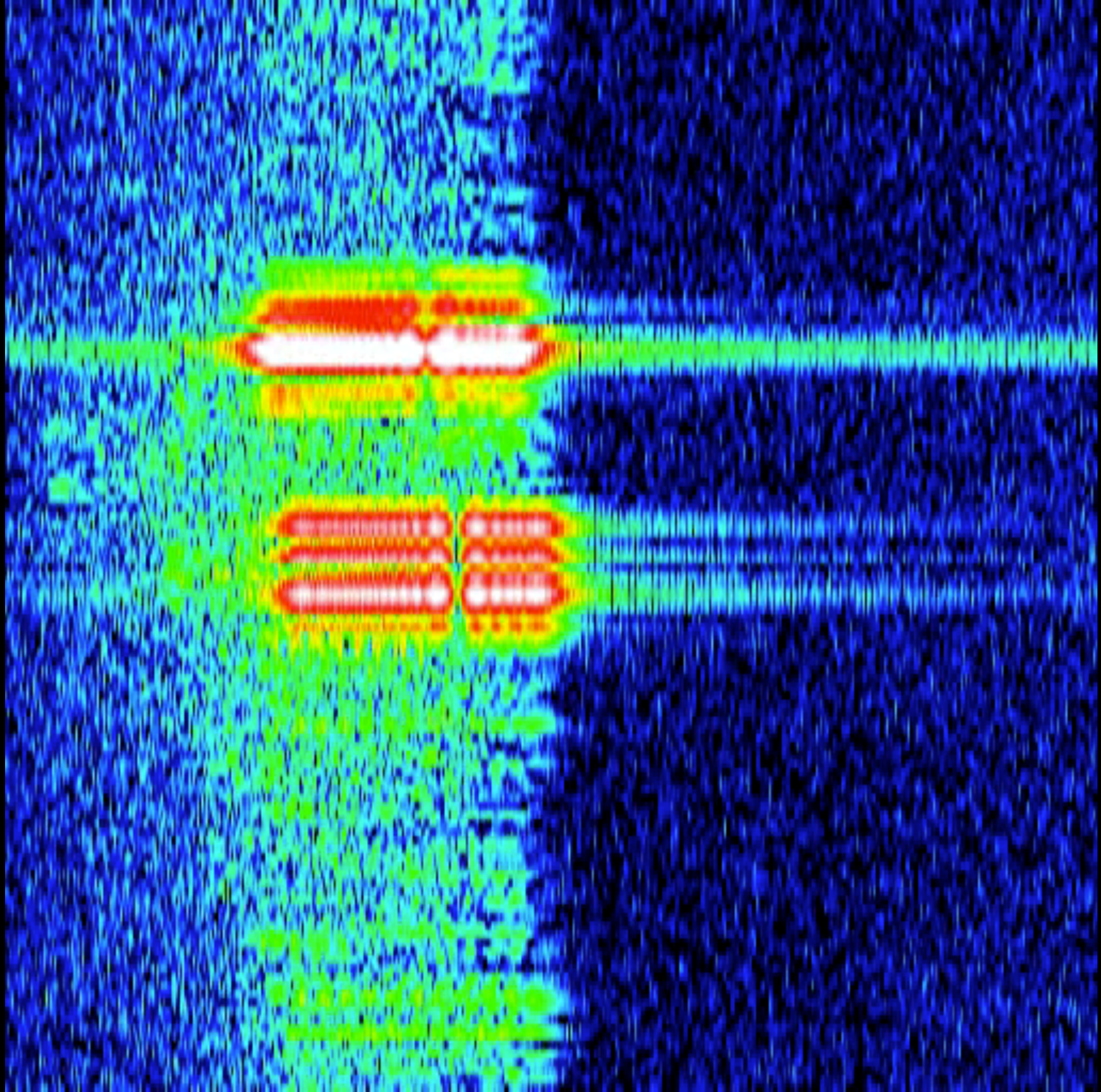

21800
22000
22200
22400
22600
22800
500
1000
1500
2000
−80
−88
−96
−104
−112
−120
−128


TRAVEL MAT



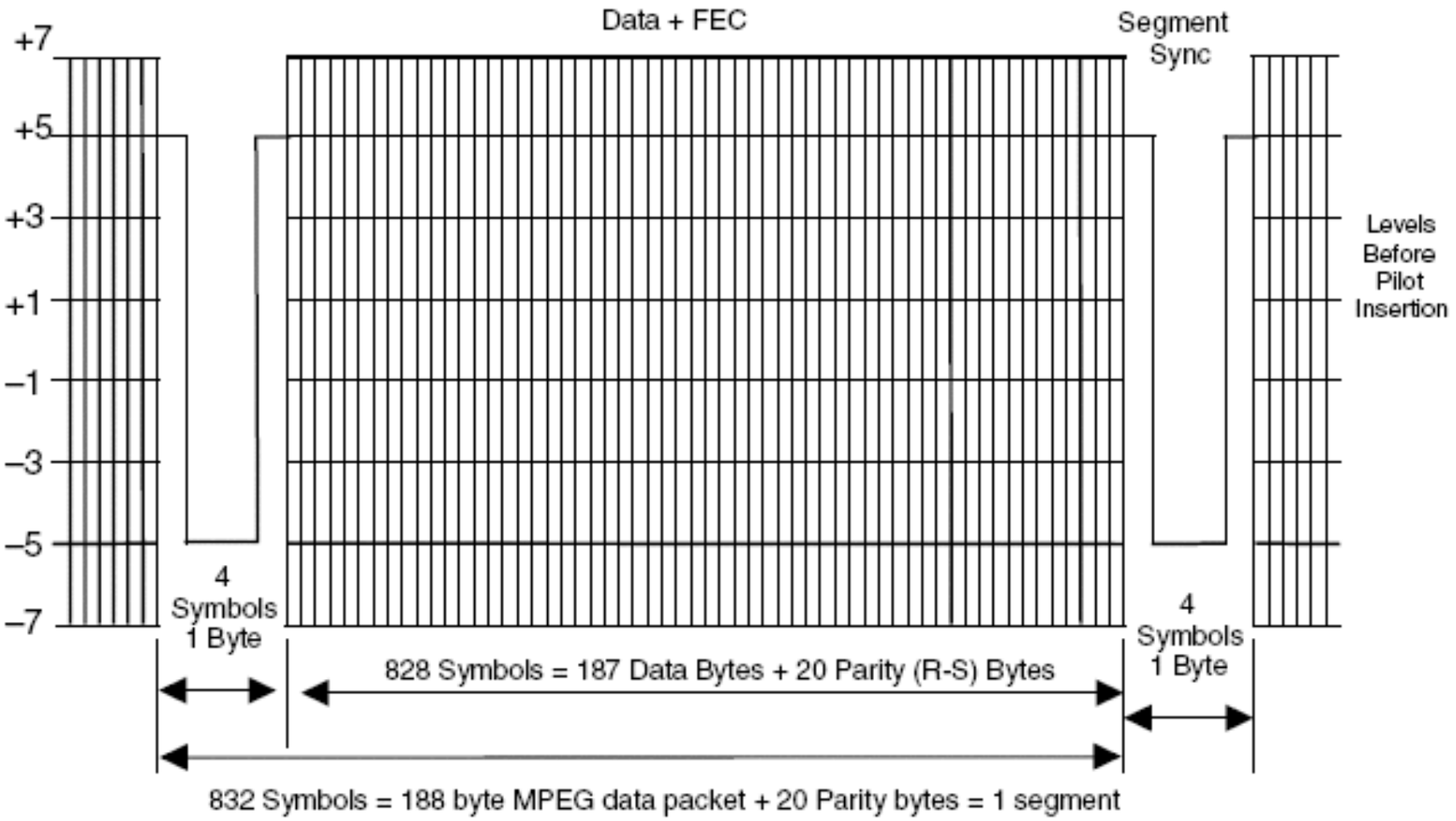
Range

Doppler



ATSC Live Passive RADAR

- Use known 511 PN synchronisation sequence

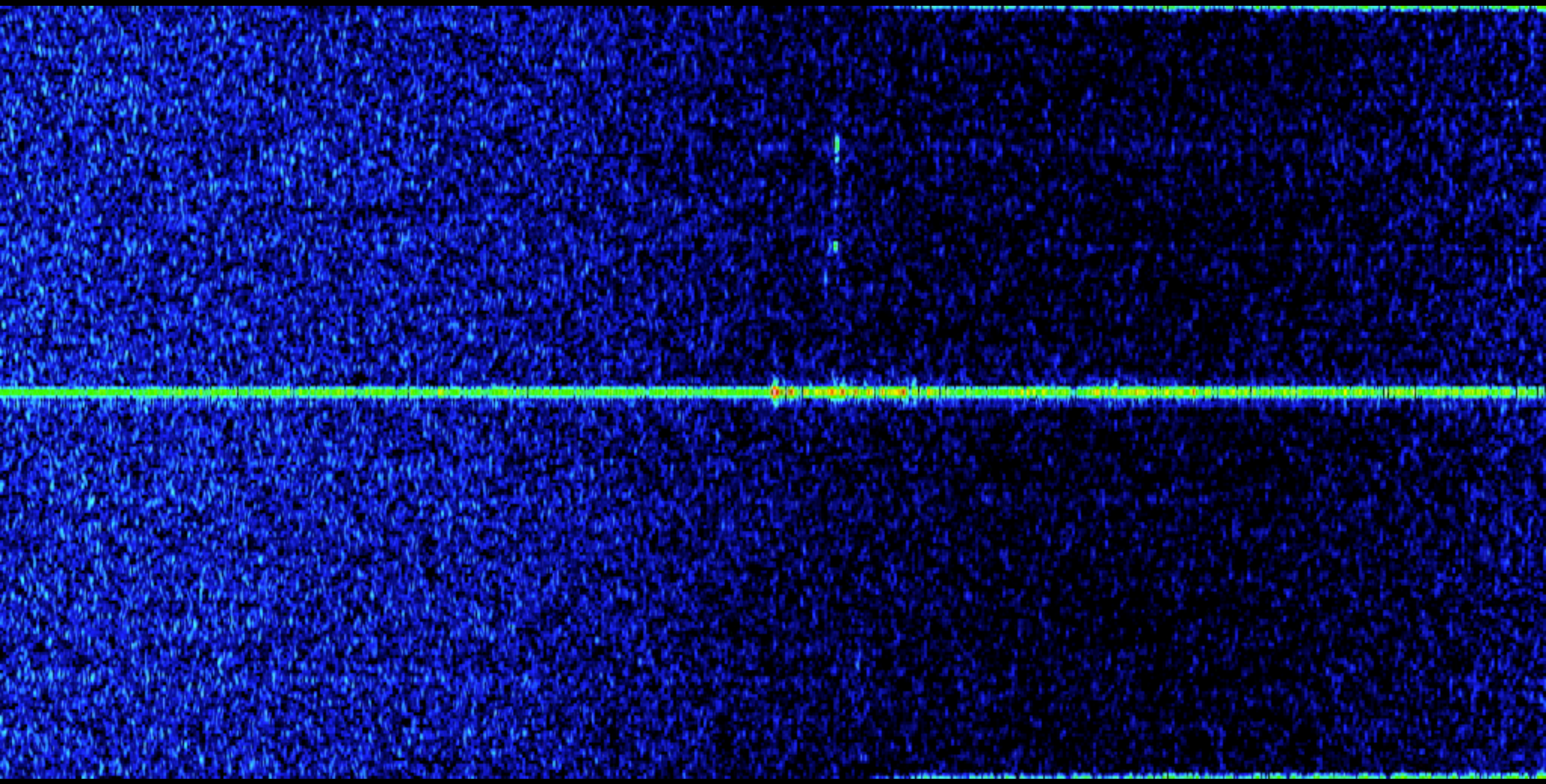


http://www.tek.com/document/primer/fundamentals-8vsb


14'

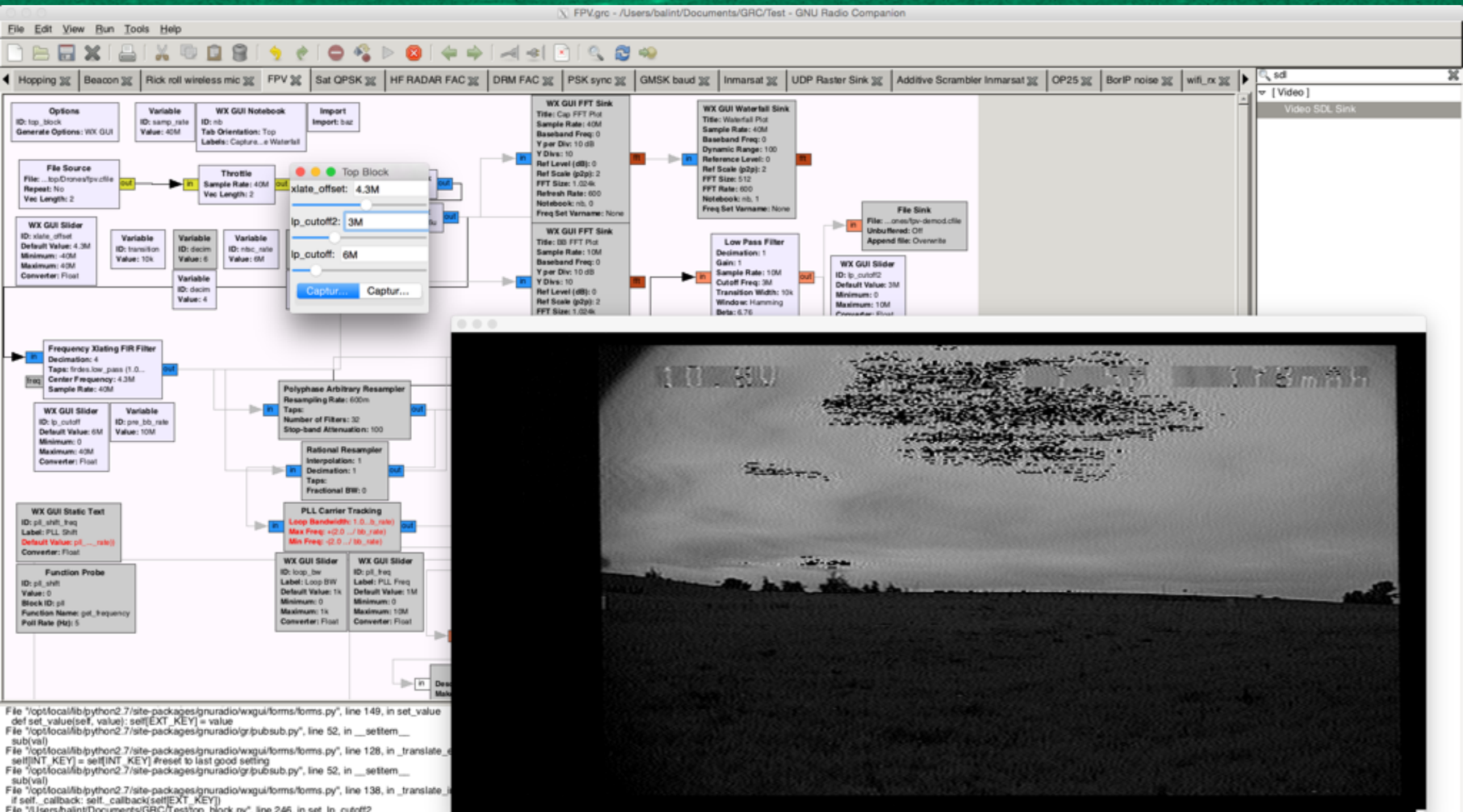

STOP
26TH ST
WEDNESDAY

Range



Doppler

Next time…


FPV.grc - /Users/balint/Documents/GRC/Test - GNU Radio Companion
File Edit View Run Tools Help
Hopping
Beacon
Rick roll wireless mic
FPV
Sat QPSK
HF RADAR FAC
DRM FAC
PSK sync
GMSK baud
Inmarsat
UDP Raster Sink
Additive Scrambler Inmarsat
OP25
BorIP noise
wifi_rx
Top Block
xlate_offset: 4.3M
lp_cutoff2: 3M
lp_cutoff: 6M
Captur...
Captur...
WX GUI FFT Sink
WX GUI Waterfall Sink
File Source
Throttle
WX GUI Slider
Low Pass Filter
File Sink
Frequency Xlating FIR Filter
Polyphase Arbitrary Resampler
Rational Resampler
PLL Carrier Tracking
WX GUI Static Text
Function Probe
sdl
[Video]
Video SDL Sink
File "/opt/local/lib/python2.7/site-packages/gnuradio/wxgui/forms/forms.py", line 149, in set_value
def set_value(self, value): self[EXT_KEY] = value
File "/opt/local/lib/python2.7/site-packages/gnuradio/gr/pubsub.py", line 52, in __setitem__
sub(val)
File "/opt/local/lib/python2.7/site-packages/gnuradio/wxgui/forms/forms.py", line 128, in _translate_e
self[INT_KEY] = self[INT_KEY] #reset to last good setting
File "/opt/local/lib/python2.7/site-packages/gnuradio/gr/pubsub.py", line 52, in __setitem__
sub(val)
File "/opt/local/lib/python2.7/site-packages/gnuradio/wxgui/forms/forms.py", line 138, in _translate_i
if self._callback: self._callback(self[EXT_KEY])
File "/Users/balint/Documents/GRC/Test/top_block.py", line 246, in set_lp_cutoff2
self.low_pass_filter_0.set_taps(firdes.low_pass(1, self.pre_bb_rate, self.lp_cutoff2, self.transition,

Thank you!

You can't protect what you can't see.

@spenchdotnet

balint@bastille.net

GitHub: balint256

GitHub: BastilleResearch

Bastille