Optimizing Radio Settings for Algorithms

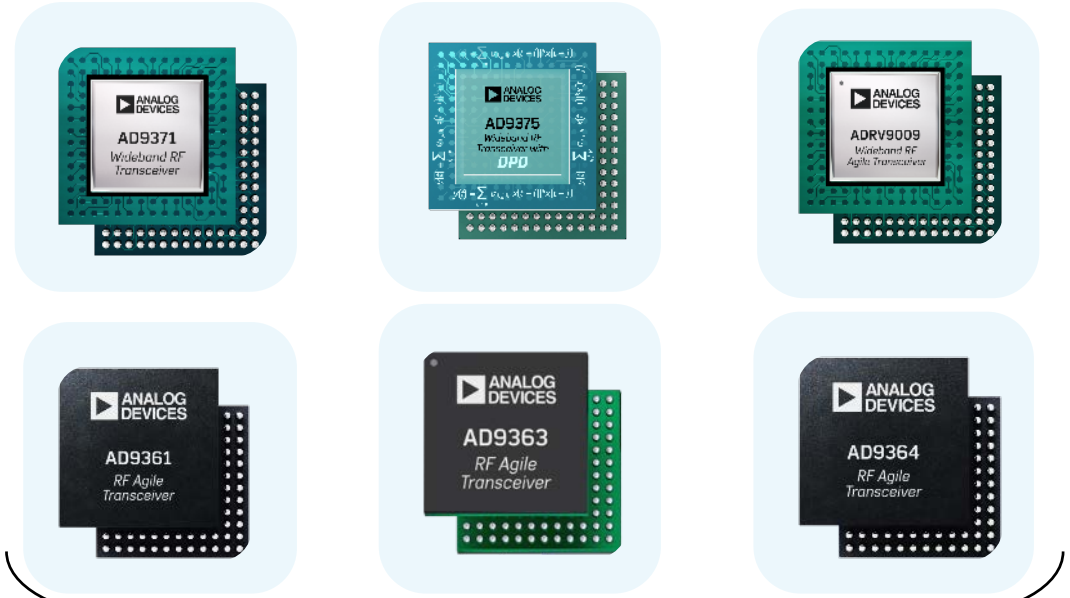
Robin Getz

Engineer, Analog Devices

AHEAD OF WHAT'S POSSIBLE™

Challenge

From devices/chips:



To Products:

Design Flow terminology

MathWorks

ANALOG DEVICES

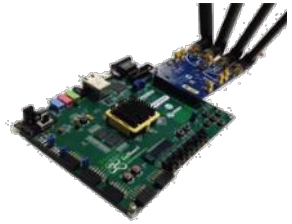
Different Needs / Different Teams / Different HW

ANALOG DEVICES
AHEAD OF WHAT'S POSSIBLE™

Figure out Signal processing

Get Signal processing embedded

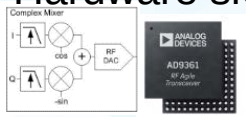
Research → Algorithm Development → Design Elaboration → Prototype → Production

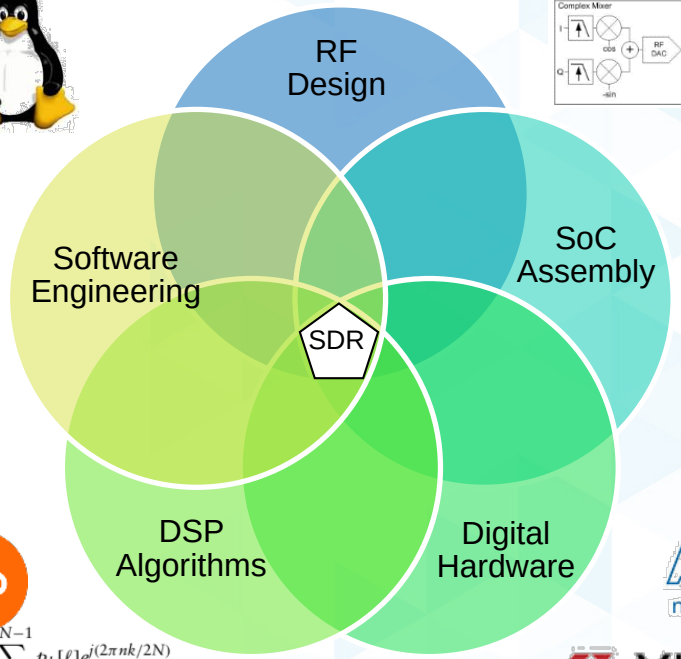


C/C++

$$s[2\ell N+n]=\frac{1}{2N}\sum_{k=0}^{2N-1}p_k[\ell]e^{j(2\pi nk/2N)},$$

RF Hardware skills





VIVADO

QUARTUS™

SYNOPSYS®
Silicon to Software™

ALTERA
now part of Intel

XILINX

GRCon

Hard to talk about in abstract

- Use an Example: ADS-B Squitter

Radar

- Large areas of airspace are not covered by radar. Radar installations are expensive!
- The Air Traffic Control (ATC) depends on "secondary radar".
- A ground station (interrogator) transmits an interrogation to a special receiver inside the aircraft, a transmitter in the aircraft answers by sending a replay back to the ground station.
- If the ground station employs a directional antenna and measures the time delay from interrogation to the answer, then it can predict direction and range to the aircraft - like a real radar. Of course this works only, if the aircraft has the necessary hardware (receiver-transmitter, called transponder) and if this transponder is switched on.

ADS-B Squitter

Automatic Dependent Surveillance–Broadcast

- A secondary radar ground station is much cheaper then a real radar. Another feature is, that the answering aircraft can insert additional helpful information into the answer.

  For several years a new generation of transponders is in use, they support the new Mode-S. This kind of transponder sends more data (ADS-B-data) then the previous types. And they transmit data even if they are not interrogated.
- This feature is called squitter. Everybody can receive this squitter-information and create an own virtual radar picture with the position (and additional information) of all squittering aircraft.
- Close to 100 percent of all aircraft transmit such information. Thus the virtual radar gives you a good idea about the air traffic

GPS

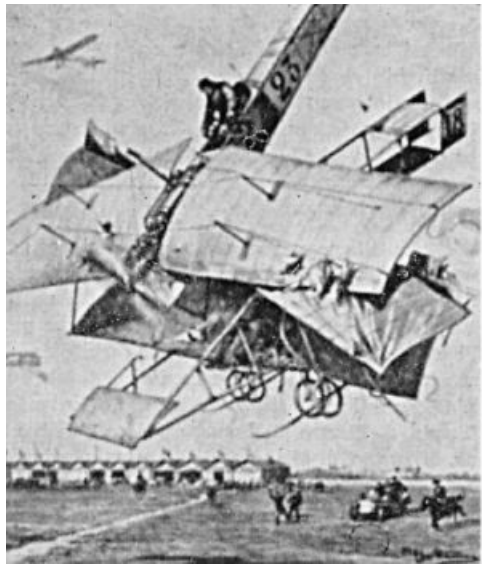
Airspace Requirements

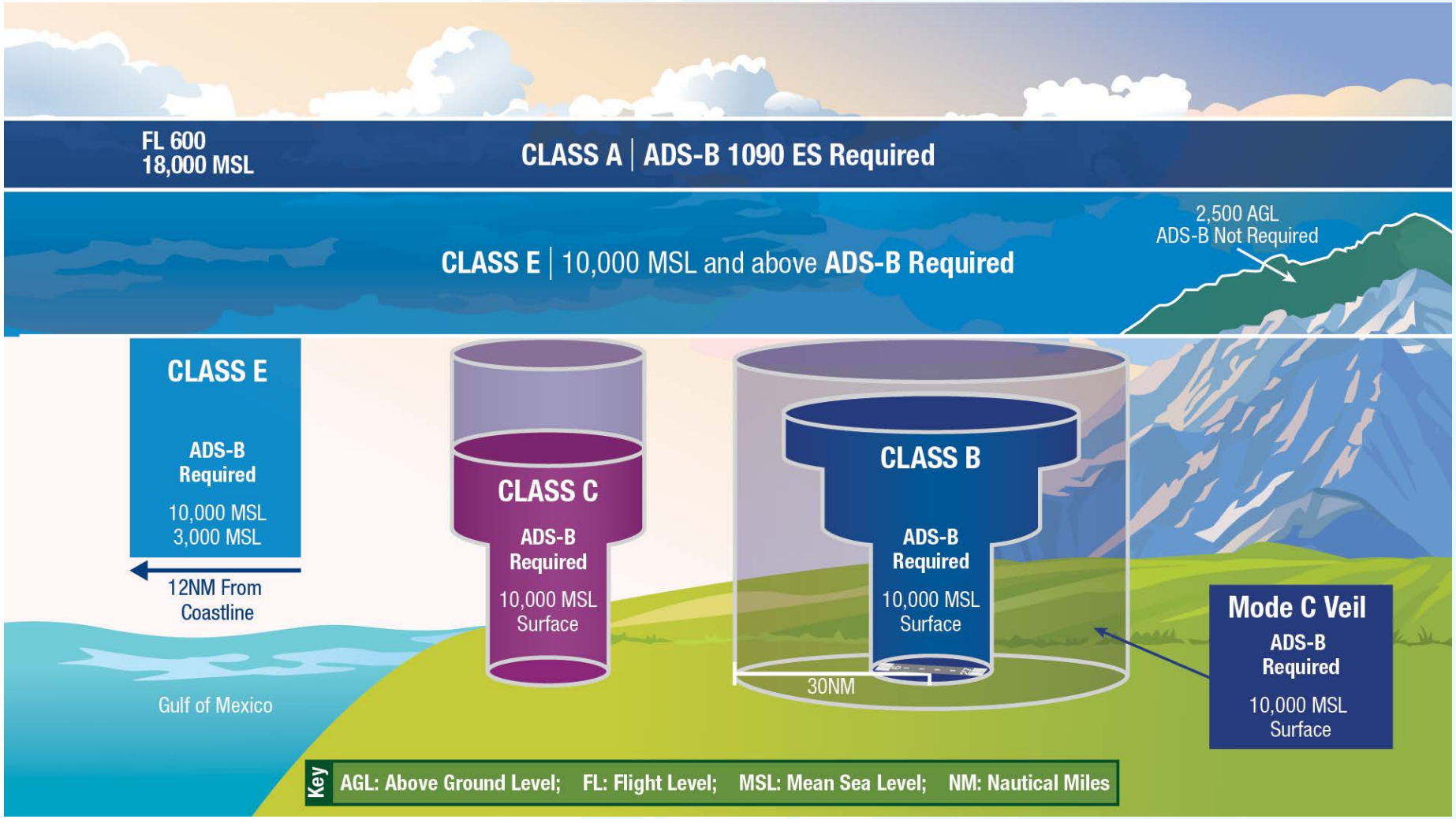
https://www.faa.gov/nextgen/equipadsb/research/airspace/media/airspaceRequirements.jpg

Published May 27, 2010, Starting January 1, 2020, you must be equipped with ADS-B Out to fly in most controlled airspace

https://en.wikipedia.org/wiki/Mid-air_collision

The first recorded mid-air collision was 1910 during a air race in Italy



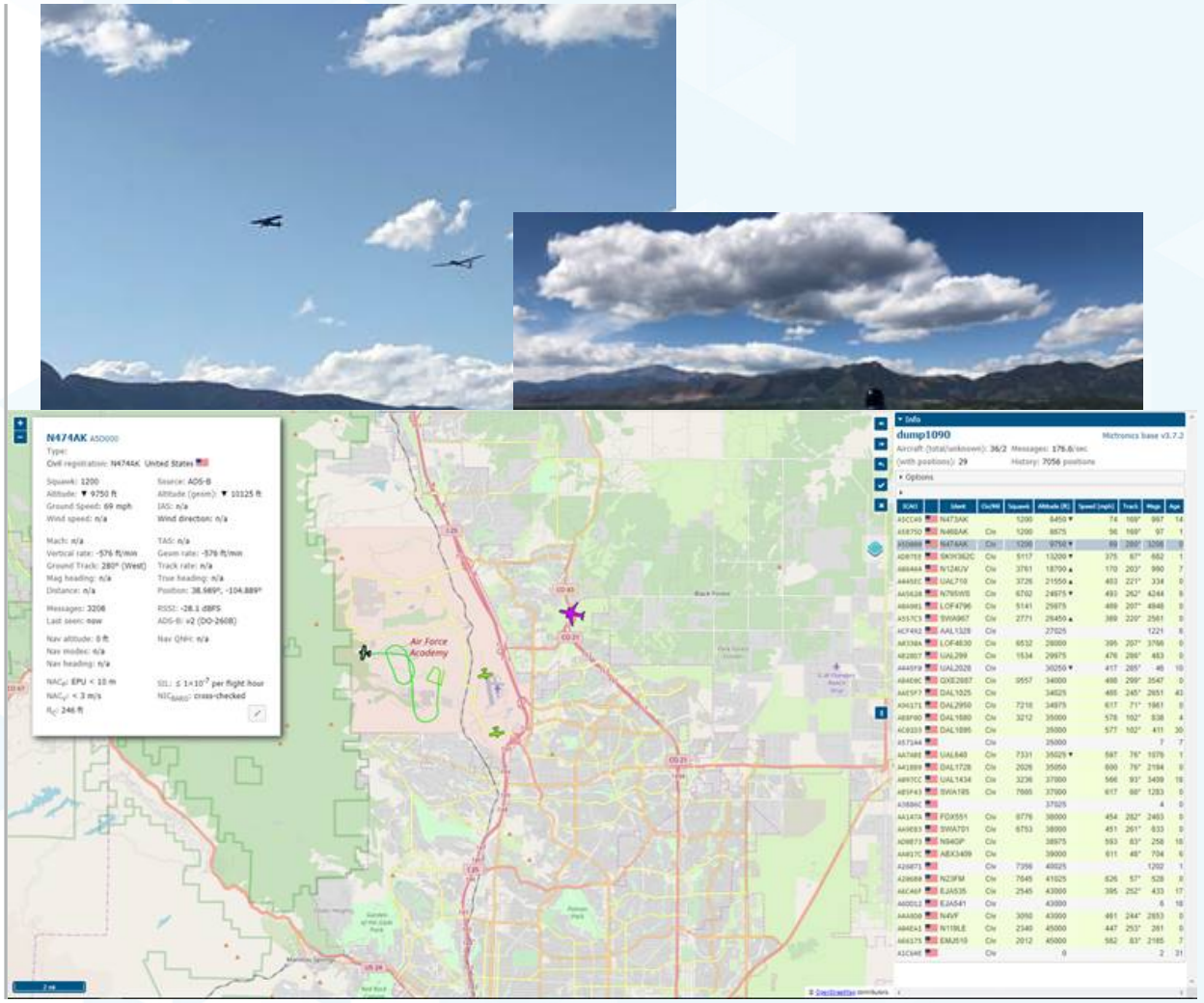


Exceptions

- Airframes without batteries or an electric starter would not be required to equip for ADS-B Out.
  - balloon, or gliders
  - Vintage aircraft (piper cub 1938 – 1947)

- The regulation 14 CFR 91.225(e) allows aircraft not certificated with an electrical system (including balloons and gliders) not equipped with ADS-B Out to operate within 30 nautical miles of a Class B primary airport—basically, within its Mode C veil—while remaining outside of any Class B or Class C airspace.

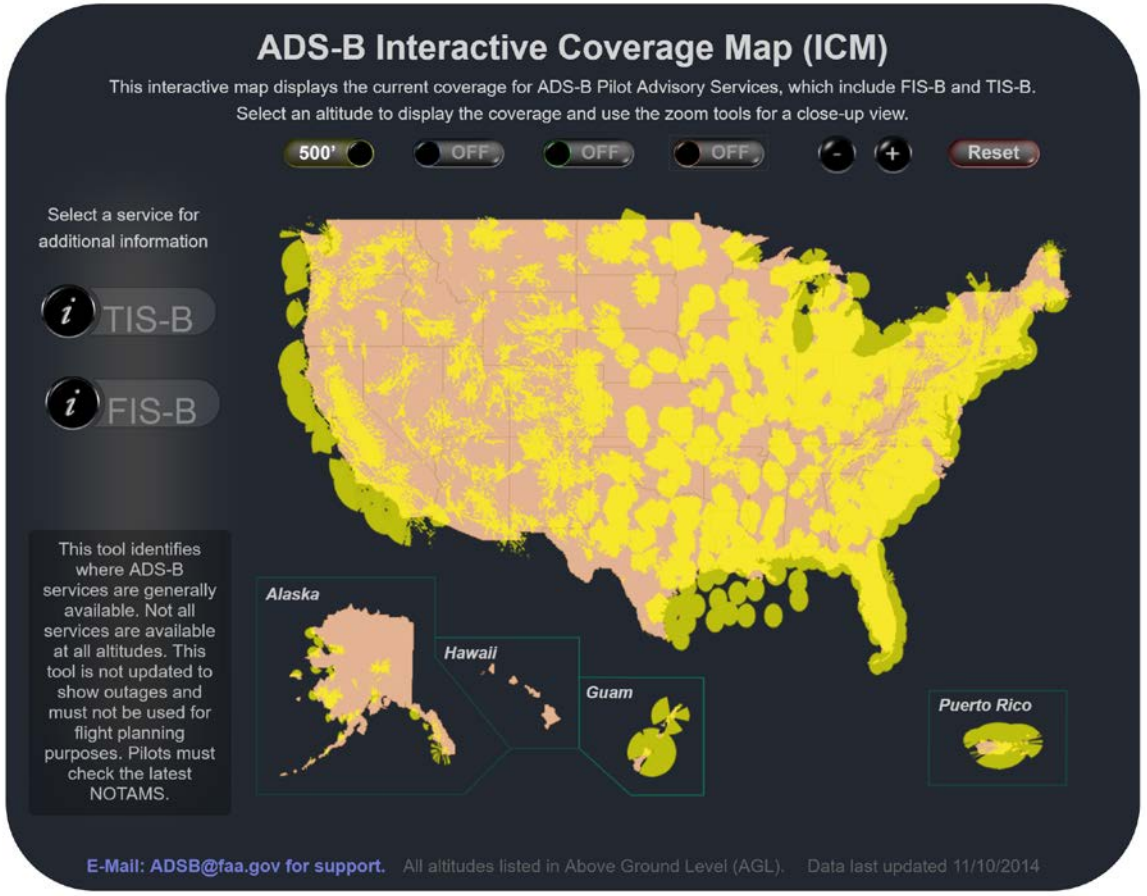
- Any aircraft can ask for permission to fly under a waiver without ADS-B. That's intended to allow a pilot to fly the plane to a repair station if the ADS-B breaks down.



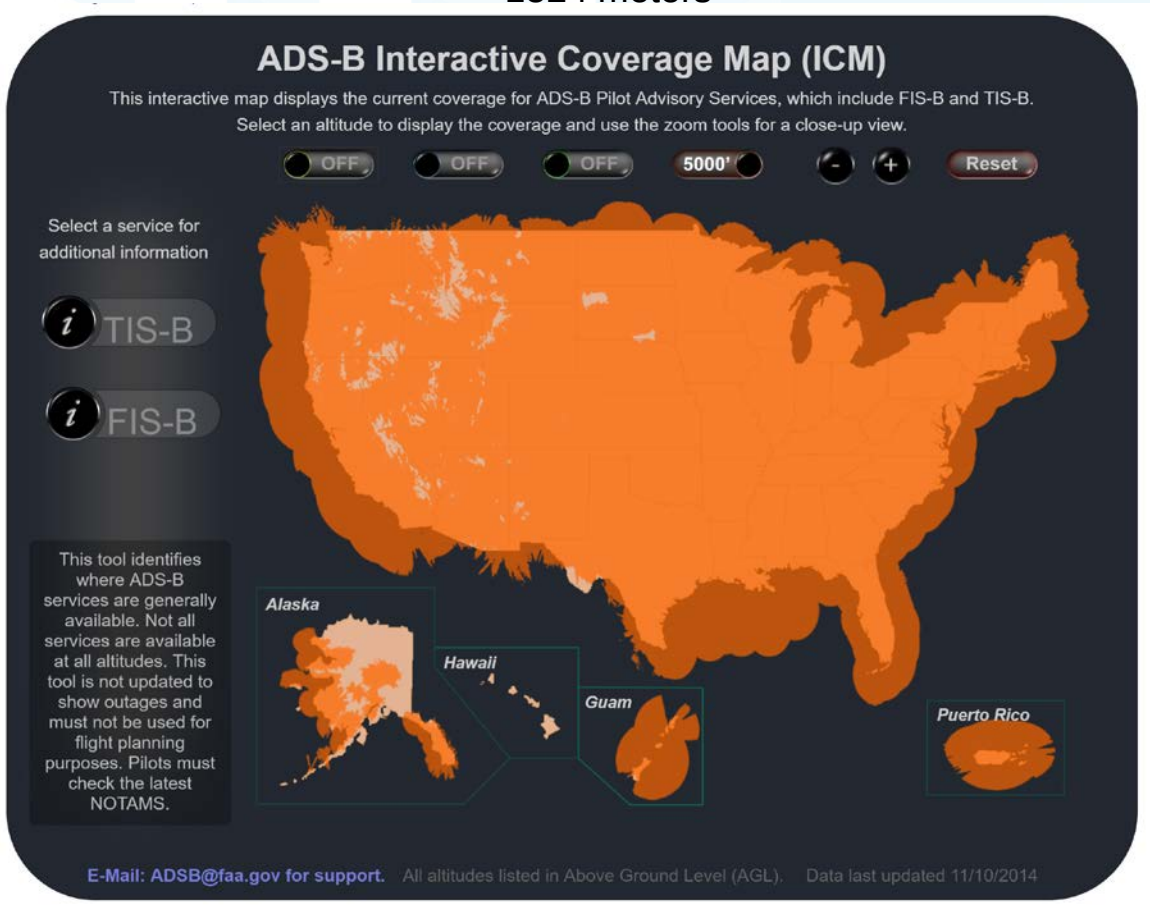
Coverage Map

https://www.faa.gov/nextgen/programs/adsb/ICM/

152.4 meters



1524 meters



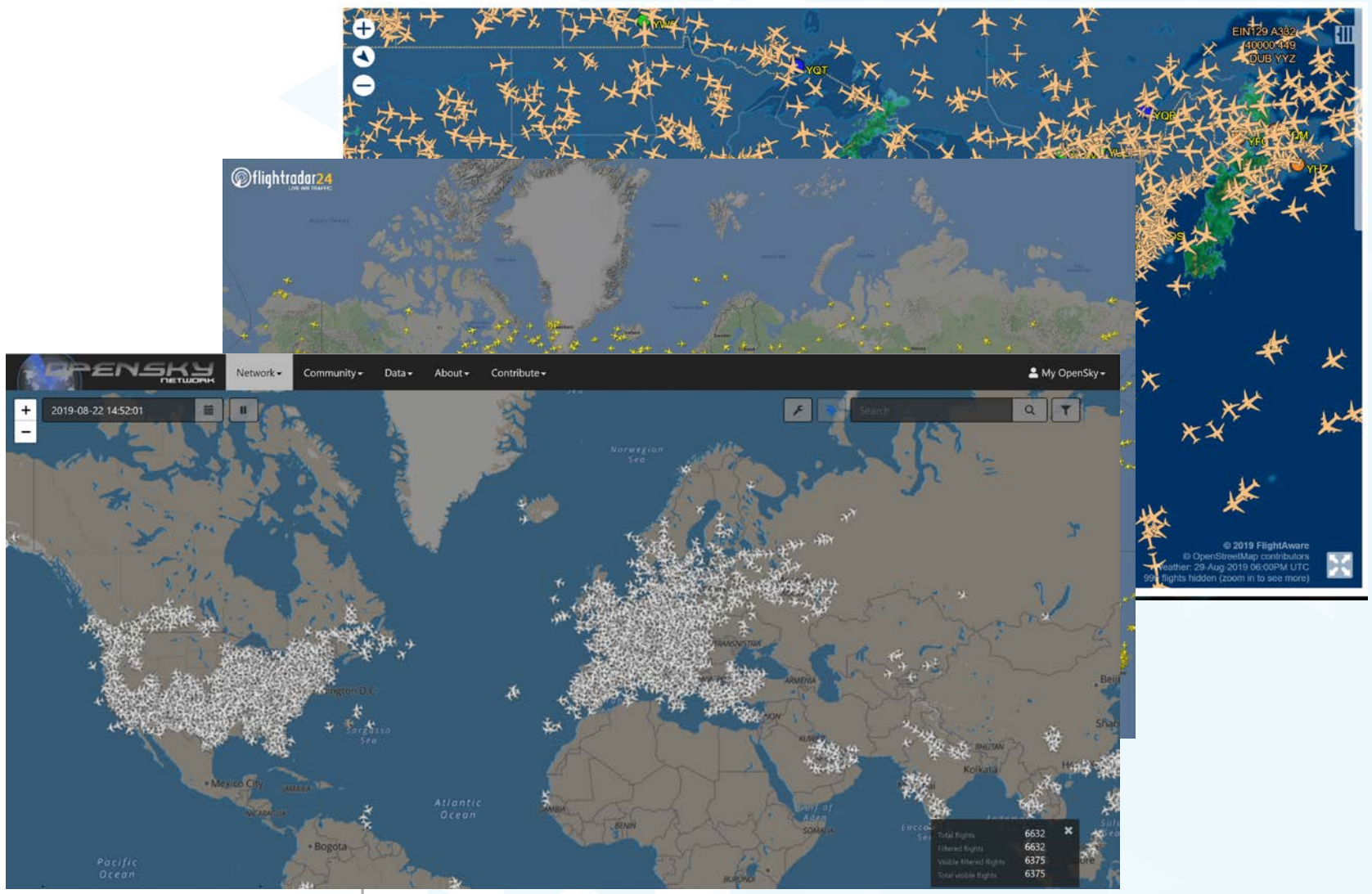
World Wide

- https://flightaware.com/live/
  - FlightAware is a digital aviation company and operates the world's largest flight tracking and data platform

- https://www.flightradar24.com
  - is a flight tracking service that provides you with real-time info about thousands of aircraft around the world.

- https://opensky-network.org/

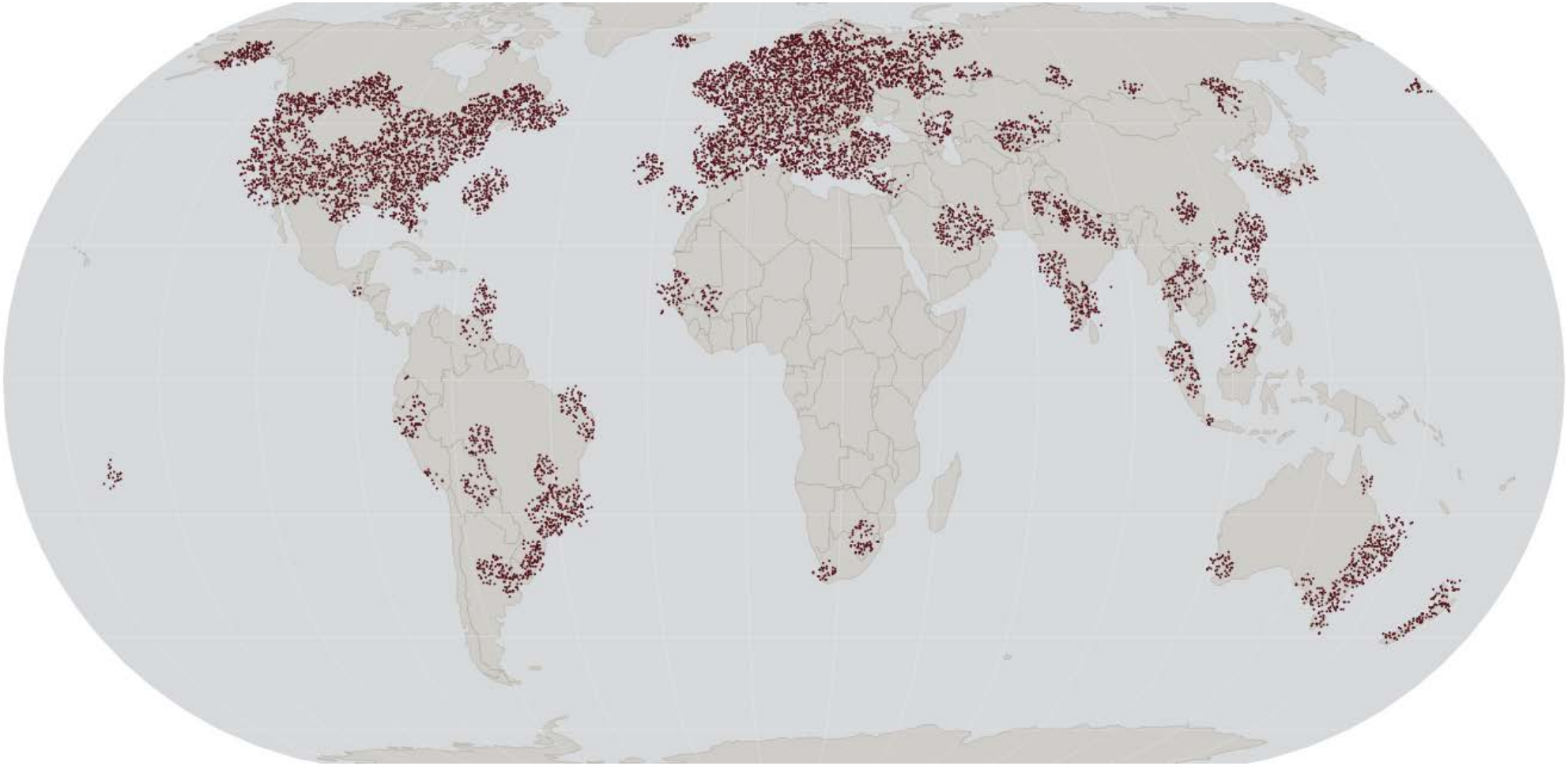
- Opensky
  - started in 2012 as a research project between armasuisse (Switzerland), University of Kaiserslautern (Germany), and the University of Oxford (UK))
  - receiver network which continuously collects air traffic surveillance data. OpenSky keeps the collected raw data forever and makes it accessible to researchers.
  - With over ten trillion messages collected from more than 1000 sensors around the world, the OpenSky Network exhibits the largest air traffic surveillance dataset of its kind.



Courtesy of OpenSky-Network

Nerd Density Chart

opensky-network.org/api/range/coverage



The result is a list of triples (lat, lon, alt). Each triple represents a position bucket/area with an altitude. The altitude is the lowest received at the given day for this area.

you need access to a location with:

- power supply,
- Internet connection
- a good line of sight in all directions
- A radio + ARM

Why?

- Improved safety
  - Reduced separation between aircraft
  - Automated safety alerts for ATC
  - Situational awareness for ATC
  - Improved Search & Rescue
  - Less transactional work for ATC/Pilots
- Improved efficiency for users
  - Reduced & more flexible separation standards
  - More clearances to requested route/level
  - Reduced stepped climb/descent
  - Increased flexibility in poor weather
  - Less delay
  - Lower pilot & ATC workload
  - Reduced fuel burn & operating time
    - Reduced environmental impact
- Planes travel fast
  - Today's standard : 30–80 nautical miles of separation
  - ADS-B-equipped aircraft ~15 nautical miles of separation
  - 553.02 miles/hour = 480.561241 nm/hr = 8.0 nm/min

- Radar Station:
  - ~ $1M - $4M USD

- ADS-B :
  - ~ $100K-$400K USD

FAA estimates that the ADS-B benefits will total about $5.9 billion through 2035.

https://www.icao.int/APAC/Meetings/2012_SEA_BOB_ADSB_WG8/SP01_AUS%20-%20ADS-B%20Basics.pdf

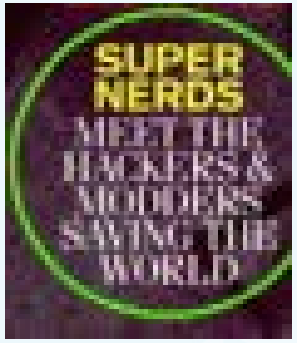
Actual Specifications

Reference	Name of the document	Origin
DO-260 September 13, 2000	Minimum Operational Performance Standards (MOPS) for 1090 MHz Automatic Dependent Surveillance – Broadcast (ADS-B)	RTCA
DO-260A April 10, 2003	Minimum Operational Performance Standards (MOPS) for 1090 MHz Extended Squitter Automatic Dependent Surveillance – Broadcast (ADS-B) and Traffic Information Services – Broadcast (TIS-B)	RTCA
DO-260B December 2, 2009	Minimum Operational Performance Standards (MOPS) for 1090 MHz Extended Squitter Automatic Dependent Surveillance – Broadcast (ADS-B) and Traffic Information Services (TIS-B)	RTCA

RTCA is a private, not-for-profit association founded in 1935 as the Radio Technical Commission for Aeronautics, now referred to simply as “RTCA”. A Public-Private Partnership venue for developing consensus among diverse, competing interests on critical aviation modernization issues in an increasingly global enterprise

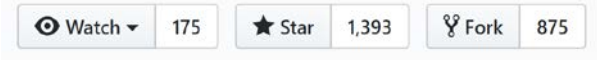
Open Source ADSB Code (Smattering)

- Modez & Aviation Mapper
  - Balint Seeber 2010-2011
  - http://spench.net/drupal/research/mode-s
- Dump1090
  - https://github.com/antirez/dump1090
  - Salvatore Sanfilippo initial commit Jan 5, 2013, Jan 9, 2017 (last commit)
  - specifically designed for RTLSDR devices.
- GNU Radio OOT module for demodulating ADS-B
  - https://github.com/mhostetter/gr-adsb
  - Matt Hostetter initial commit Apr 7, 2016, still maintained (last commit July 30, 2019)
- Gnuradio Mode-S/ADS-B radio
  - https://github.com/bistromath/gr-air-modes
  - Nick Foster initial committed on Sep 15, 2010 (last commit Sep 2017)
- AirplaneJS, RTLSDR ADS-B decoder and plotter in your browser
  - https://github.com/watson/airplanejs
  - (all in Javascript) Thomas Watson
- PyModeS Python Decoder for ADS-B (DF17) and Mode-S Comm-B (DF20/21)
  - Junzi Sun initial commit Mar 17, 2015, still maintained (last commit Aug 22, 2019)
  - https://github.com/junzis/pyModeS & https://mode-s.org
- 1090ES ADS-B Out : ADS-B encoder for Tx-capable SDR hardware.
  - Linar Yusupov
  - https://github.com/lyusupov/ADSB-Out

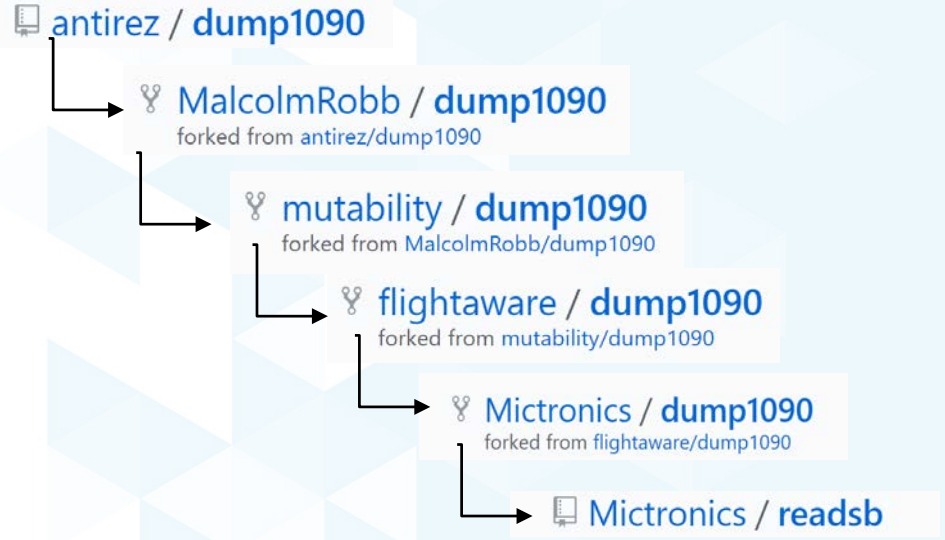


Robin's Rant!

- Don't' fork something unless you are going to add to it.
  - Fork and make it private
- If you like it, - "star it'



- If you have a public fork, update the readme to say why?
- Push changes upstream
- Remove your fork
- End Users:
  - Have one place for bugs
  - Have one place for feature requests
  - Have one place for getting the latest release
  - Everyone (all developers) are working on the same thing



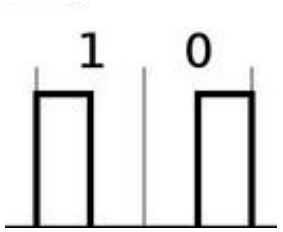
torvalds / linux

Roughly 15,600 developers since 2005

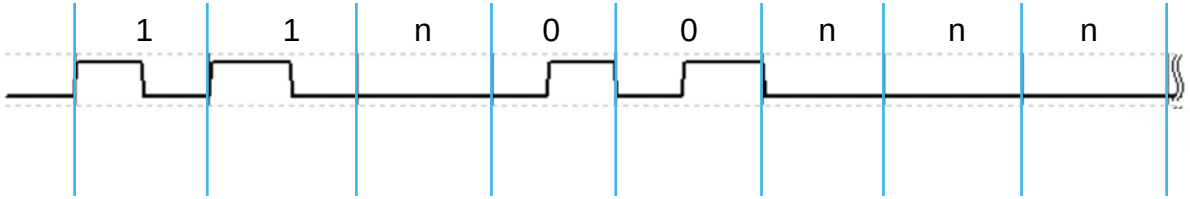
https://techgaun.github.io/active-forks/index.html

ADS-B Data Format

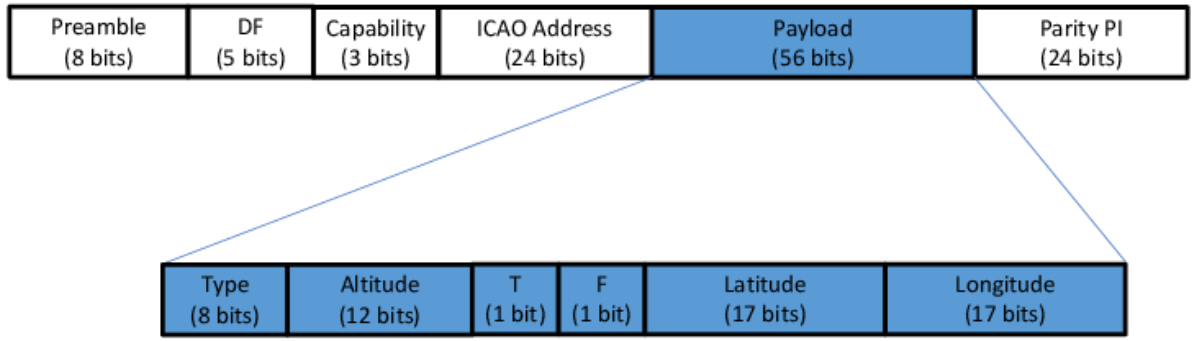
- Pulse Position Modulation (PPM) is a form of signal modulation in which message bits are encoded by transmitting a single pulse in one of N possible required time shifts.
- For ADS-B, there are 2 bits, (1 and 0), and therefor two positions



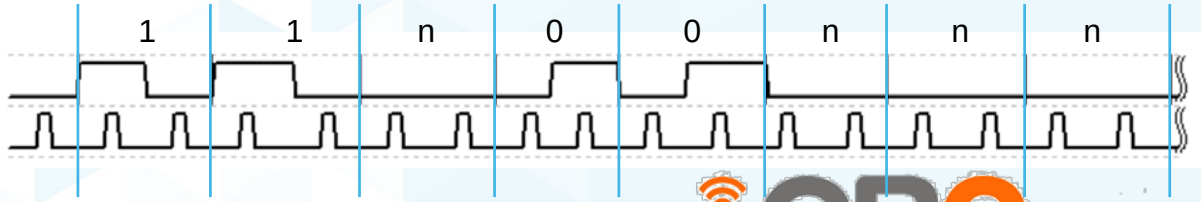
- Each “bit” is 1µs long, the pulse is 0.5 µs.
- 8-bit preamble of “11n00nnn”



- Short squitters are 56bits (8bits Control, 24bits address, 24bits parity check)
- Long squitters are 112bits (8 bits preamble + 8bits control, 24bits address, 56bits ADS message, 24bits parity)



- Sample each bit twice (every 0.5 µs), or 2 MSPS



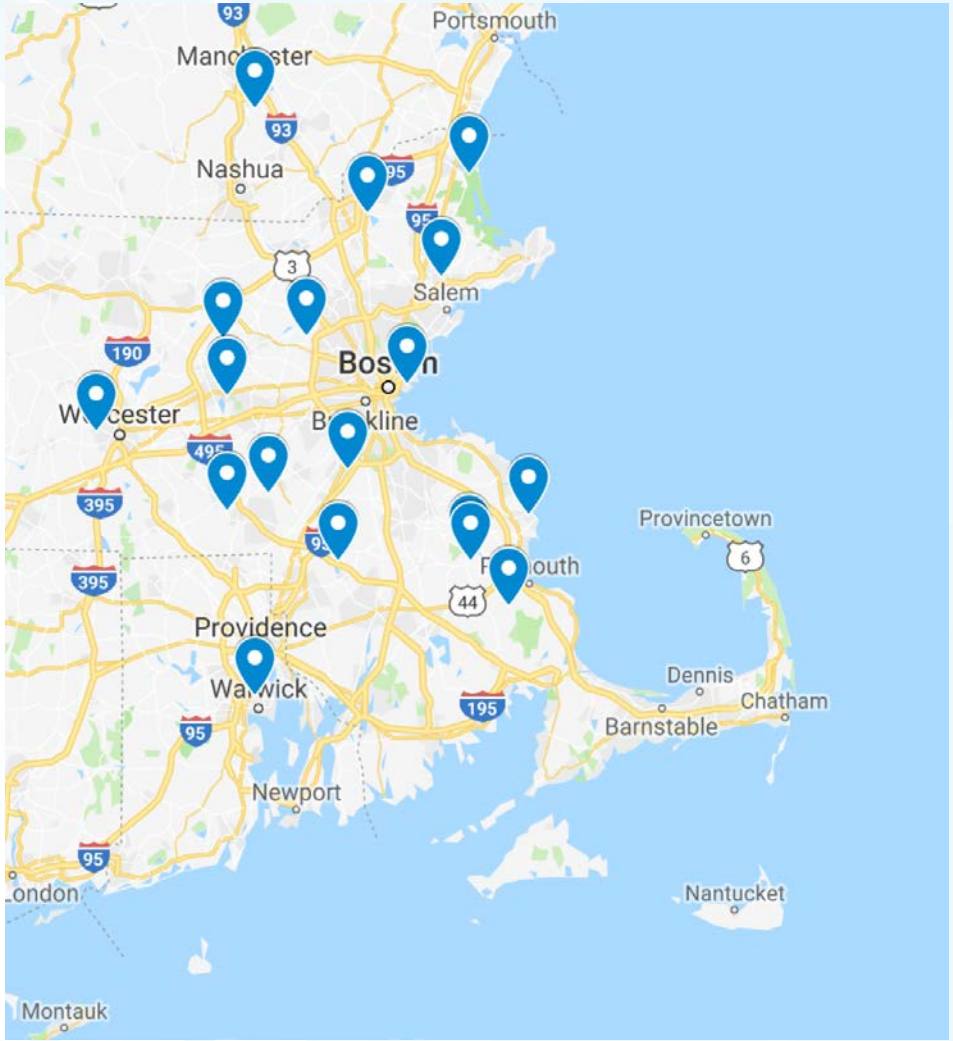
Step 1: Decide on Receiver Quality Metrics

- Number of good packets received?
  - Nope – Not an analog/radio metric
- Bit Errors
  - Nope – Not an analog/radio metric
- CRC errors
  - Nope – Not an analog/radio metric
- Distance to airplane

Distance from airplanes

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

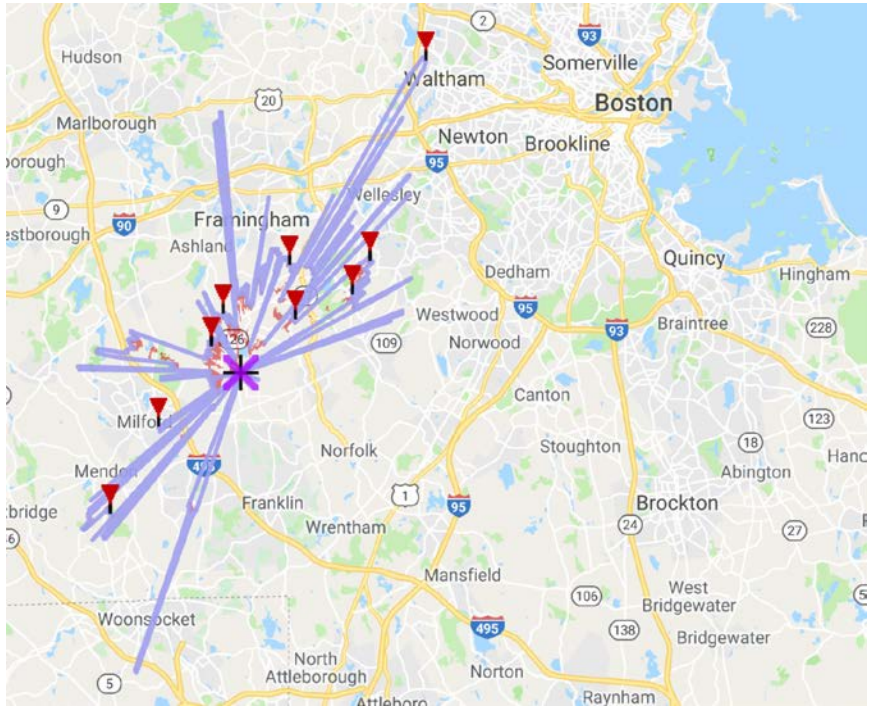
- Commercial
  - Logan International Airport (KBOS), East Boston
  - Worcester Regional Airport (KORH), Worcester, Massachusetts
  - Manchester-Boston Regional Airport (KMHT), Manchester, New Hampshire
  - T. F. Green Airport (KPVD), Warwick, Rhode Island
- Public
  - Beverly Municipal Airport (KBVY)
  - Hanscom Field (KBED)
  - Norwood Memorial Airport (KOWD)
  - Plum Island Airport (2B2)
  - Lawrence Municipal Airport (KLWM)
  - Minute Man Airfield (6B6)
  - Marlboro Airport (9B1)
  - Hopedale Industrial Park Airport (1B6)
  - Mansfield Municipal Airport (1B9)
  - Cranland Airport (28M)
  - Marshfield Municipal Airport (KGHG, formerly 3B2)
  - Plymouth Municipal Airport (KPYM)
- Seaplane bases
  - Monponsett Pond Seaplane Base (MA6)



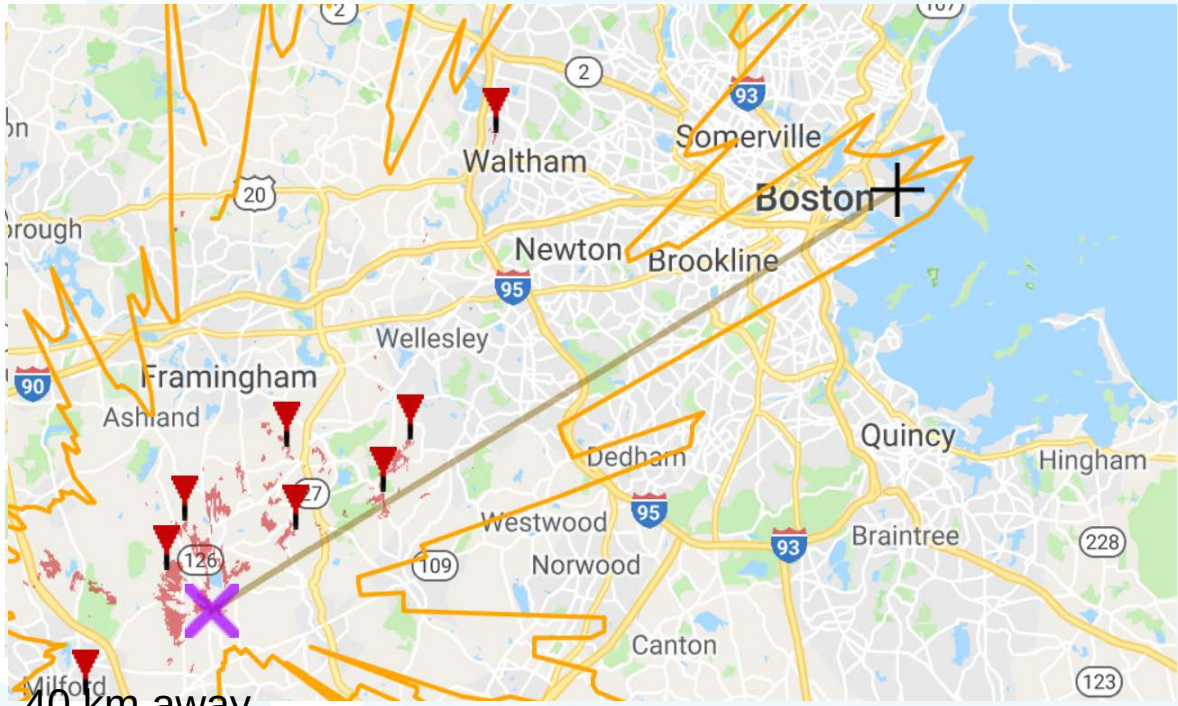
Distance limits

- http://heywhatsthat.com/
  - Click “new Panorama”
  - Enter address or coordinates, height of antenna
  - Click “submit request”

Horizon

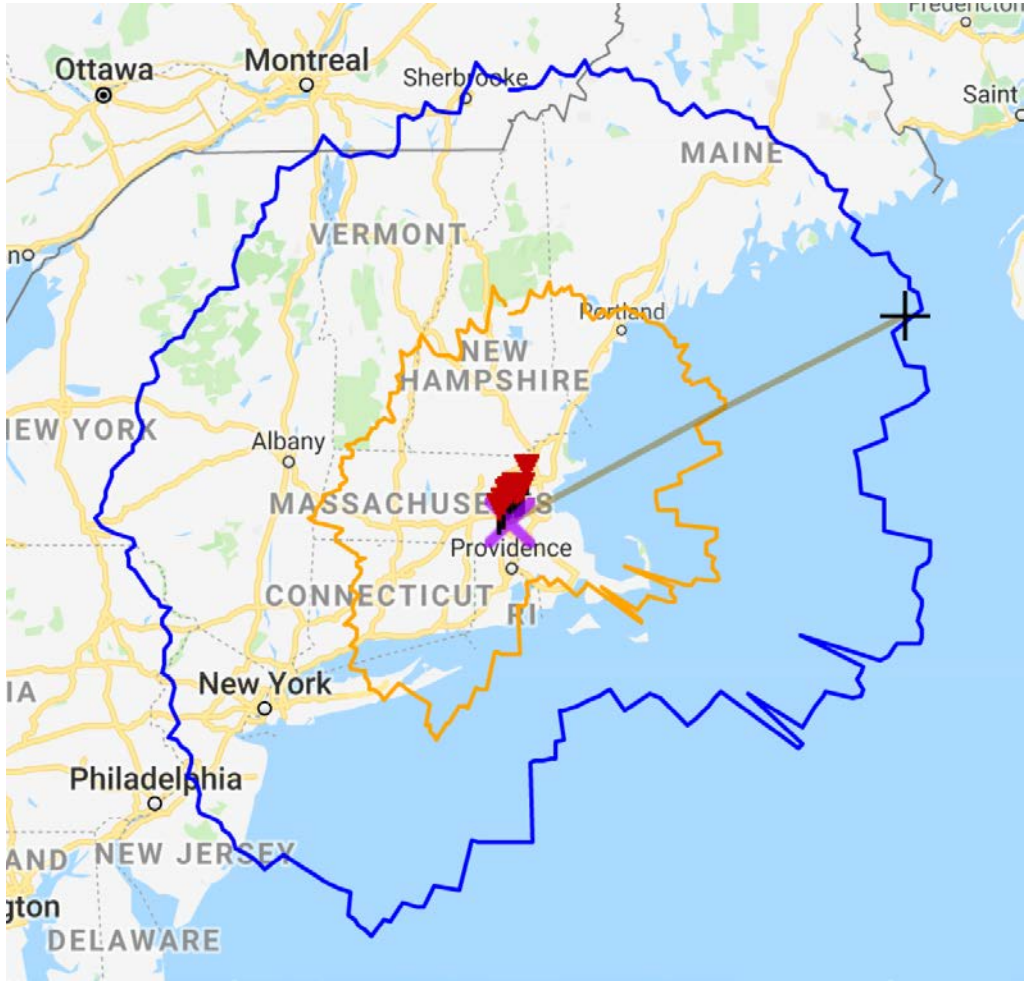


200 m “in the air” line



40 km away

Distance calculations – sort of meaningless



http://heywhatsthat.com/
Blue = 10668 m (35,000 ft)
Orange = 3048 m (10,000 ft)

DATA SOURCE	VIEW
ADS-B	383
SATELLITE	0
MLAT	20
RADAR	24
FLARM	0
ESTIMATED	0
TOTAL	427

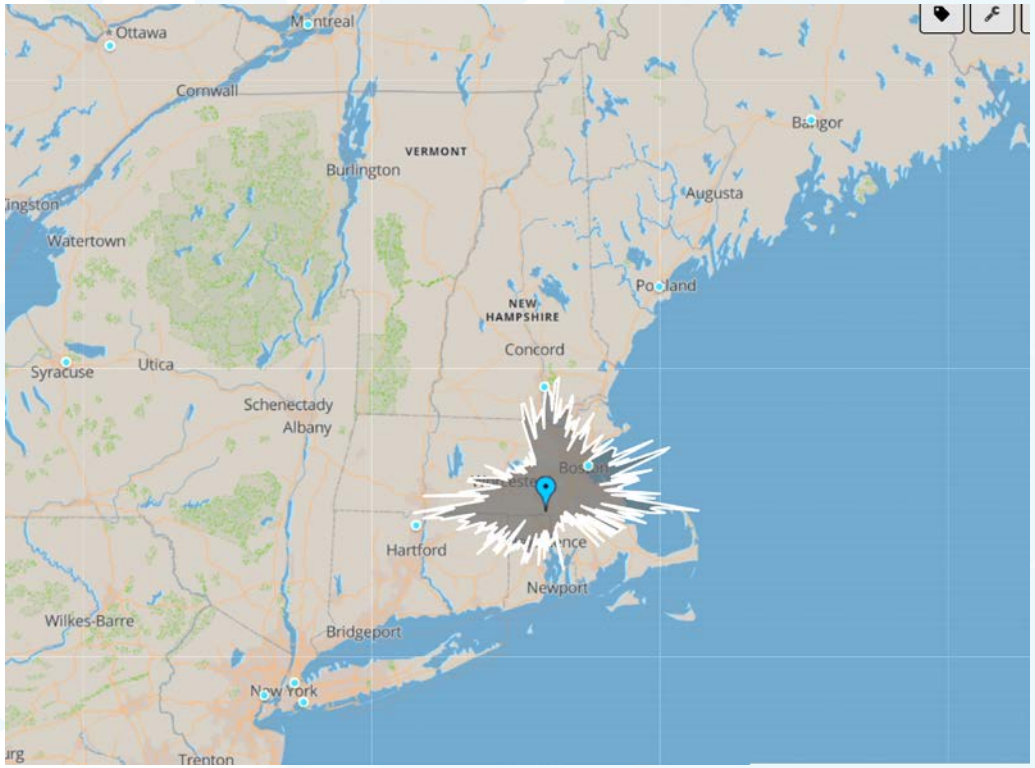
Courtesy https://www.flightradar24.com

112 µS per message

8928.5 messages per second max

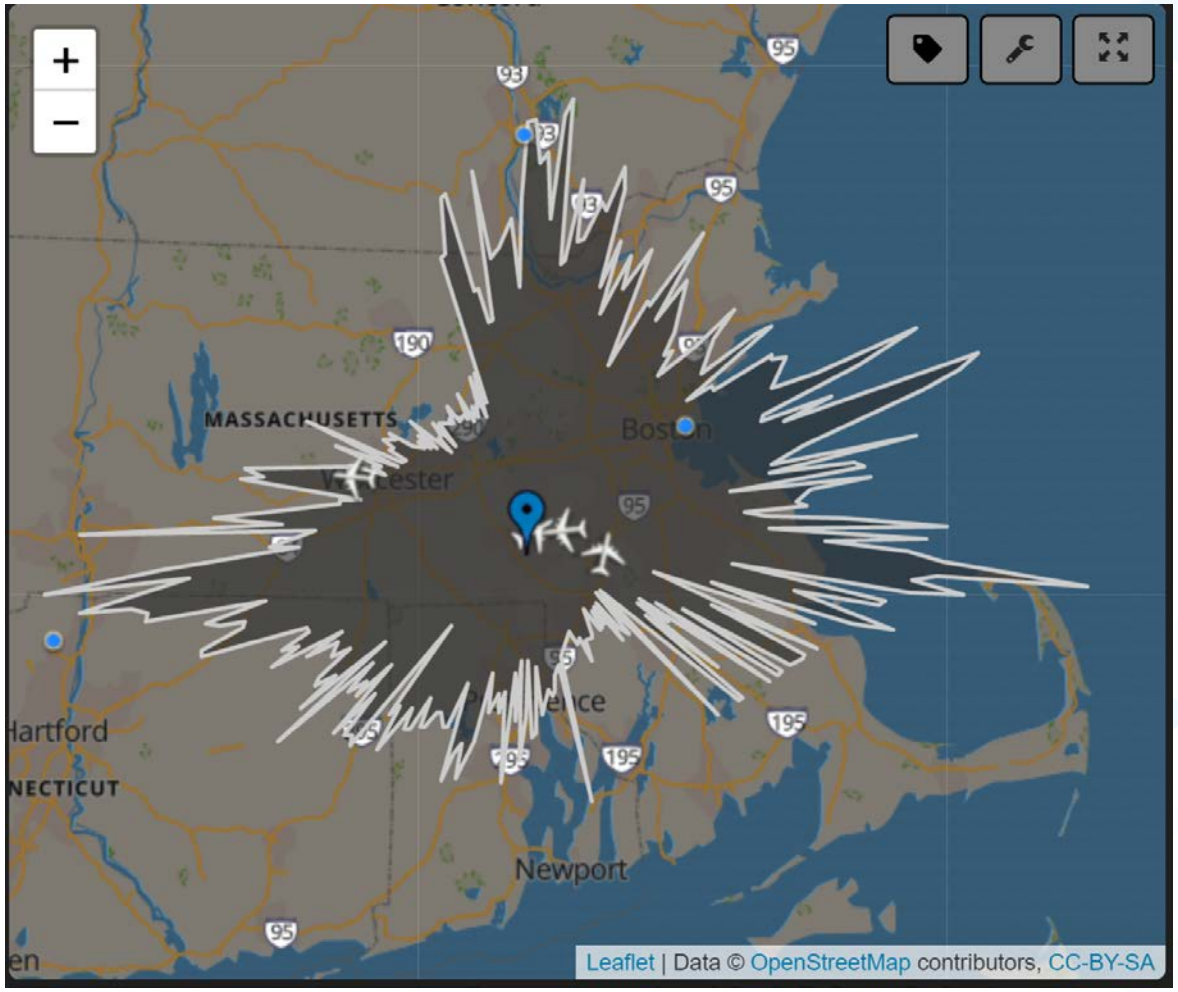
383 aircraft can generate 3400+ messages per second

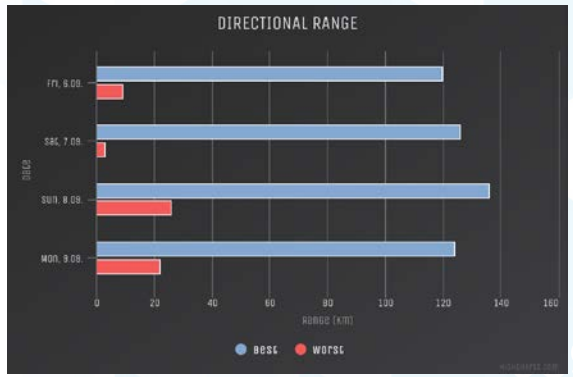
Distance calculations – sort of meaningless

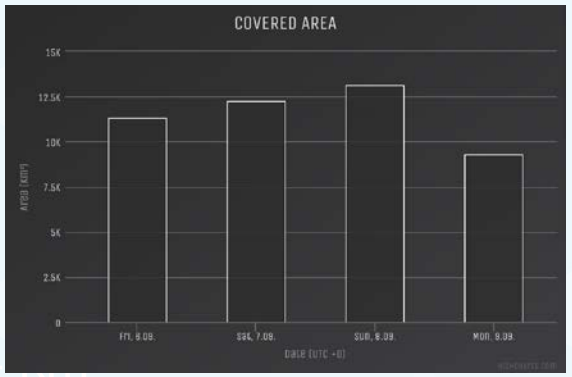


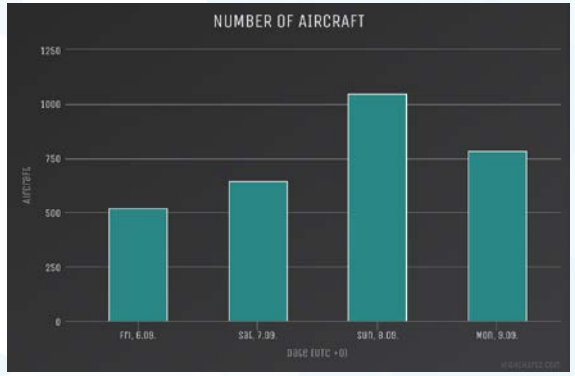
Blue = 10668 m (35000 ft)
Orange = 3048 m (1000 ft)

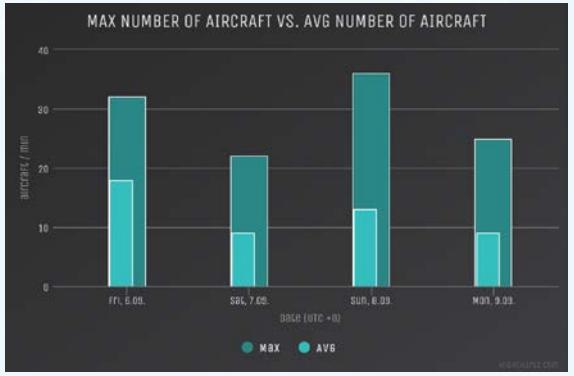
Benchmark



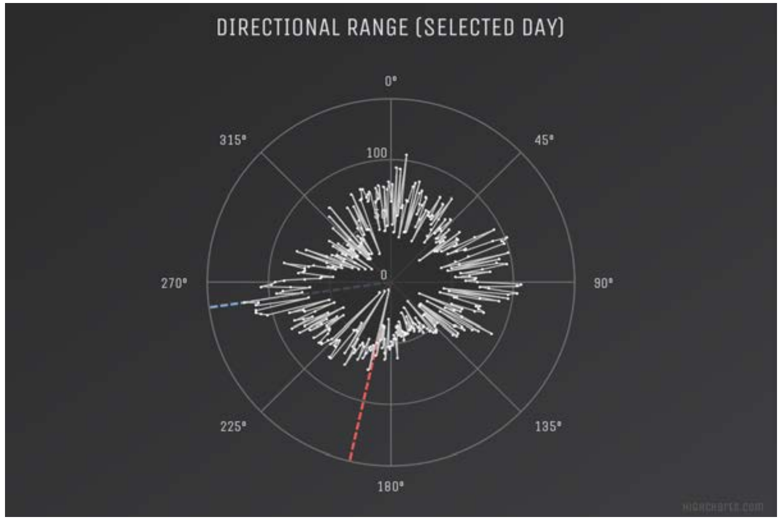


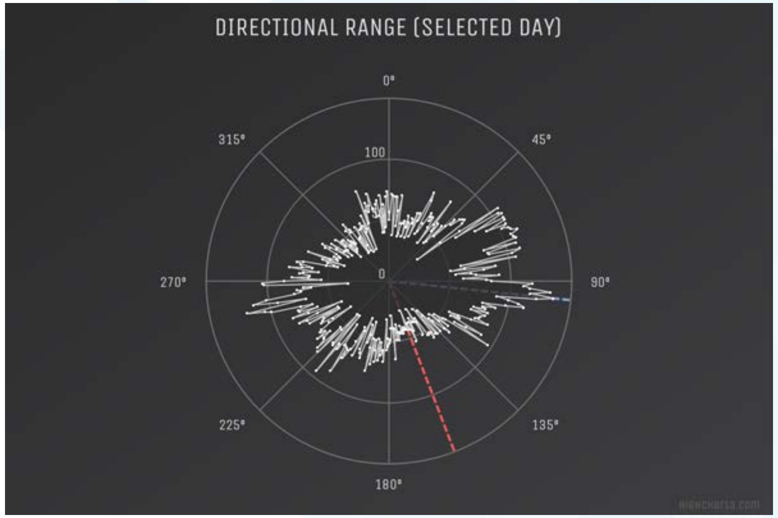


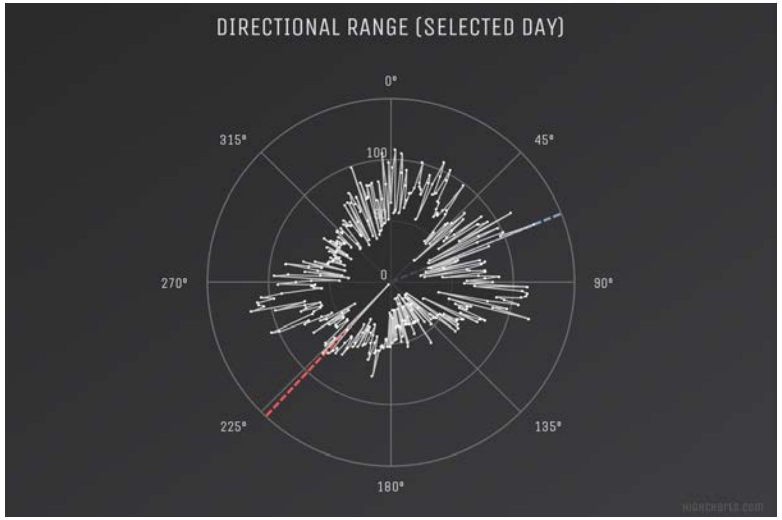


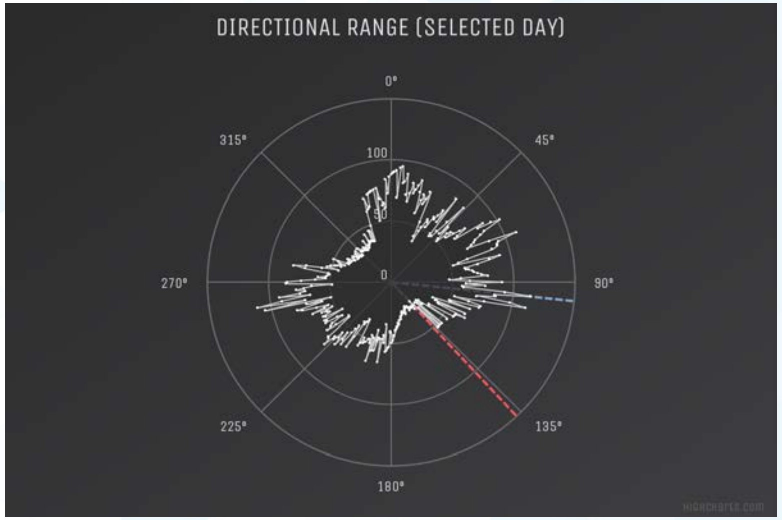


Distance as a metric?





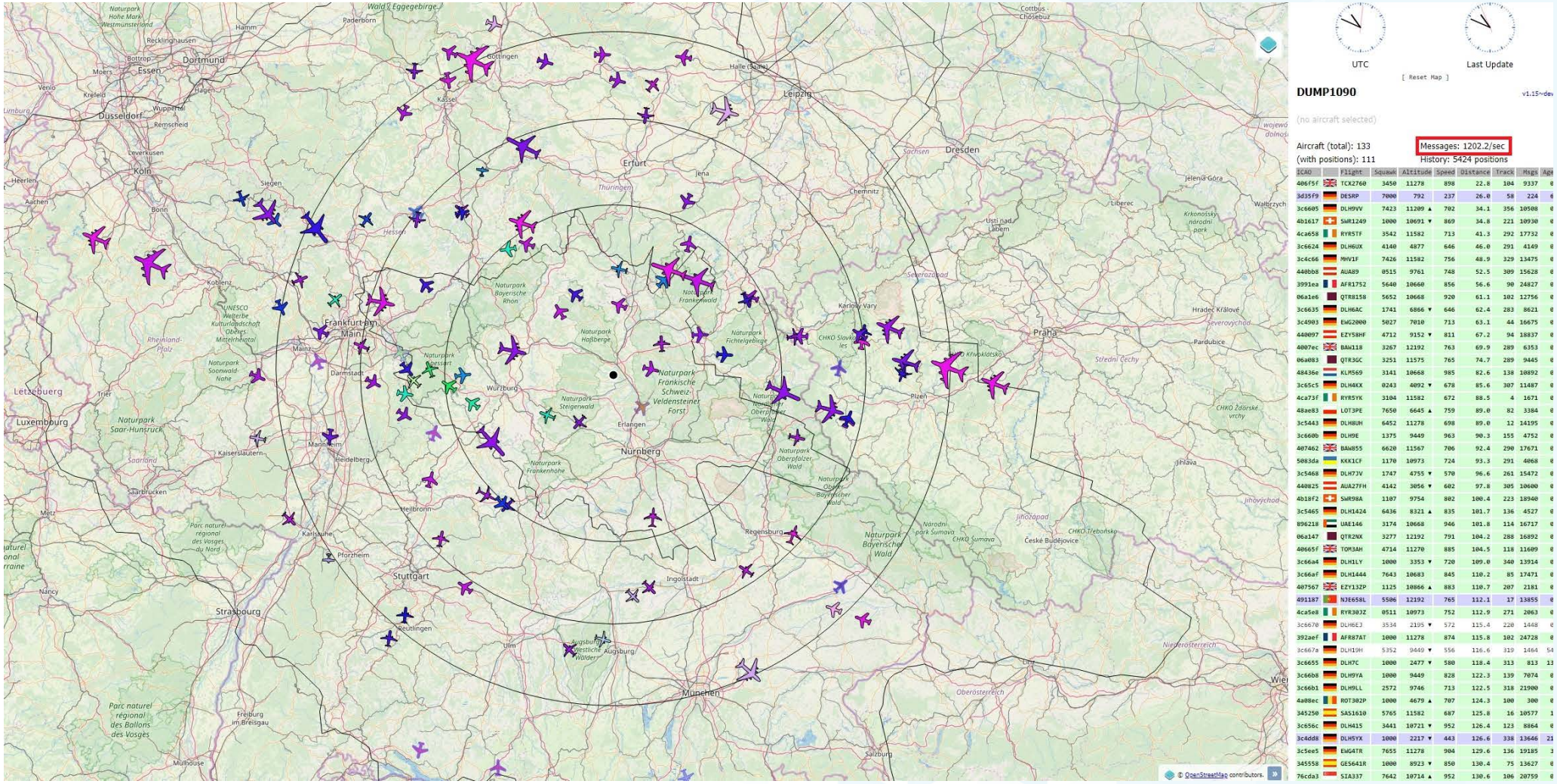




Trees!

It’s possible

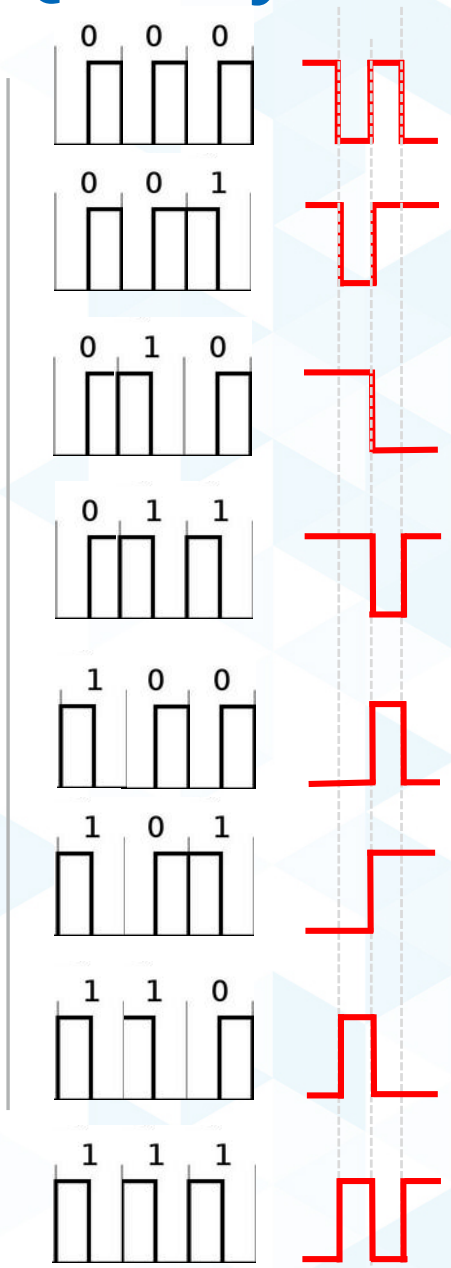
1200 messages/second from 133 aircraft (10 messages/second per aircraft)

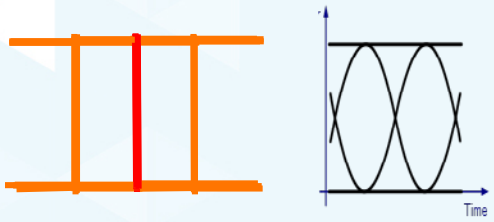


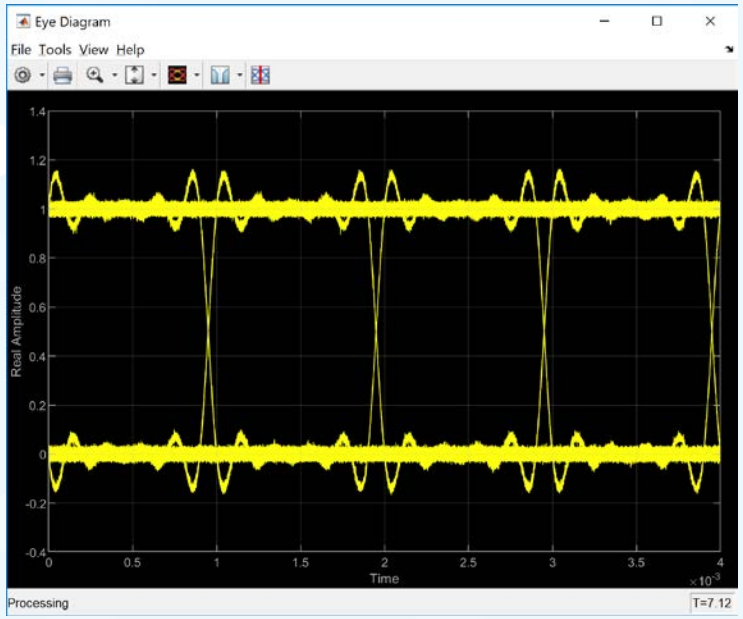
Source : https://www.reddit.com/user/TheFox720p/

Step 1: Decide on Receiver Quality Metrics

- Number of good packets received?
  - Nope – Not an analog/radio metric
- Bit Errors
  - Nope – Not an analog/radio metric
- CRC errors
  - Nope – Not an analog/radio metric
- Distance to airplane
  - Nope – super subjective
- Eye diagram, with constant/controlled transmitter

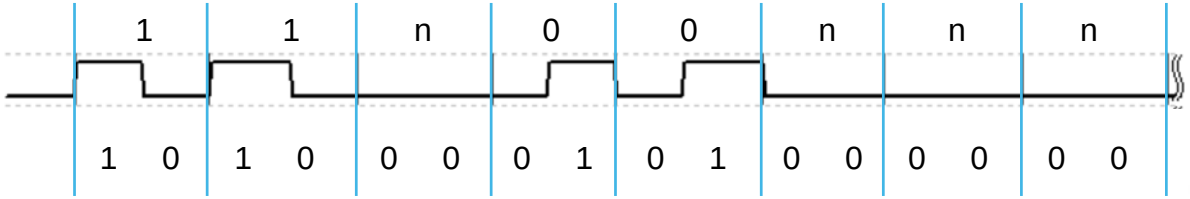






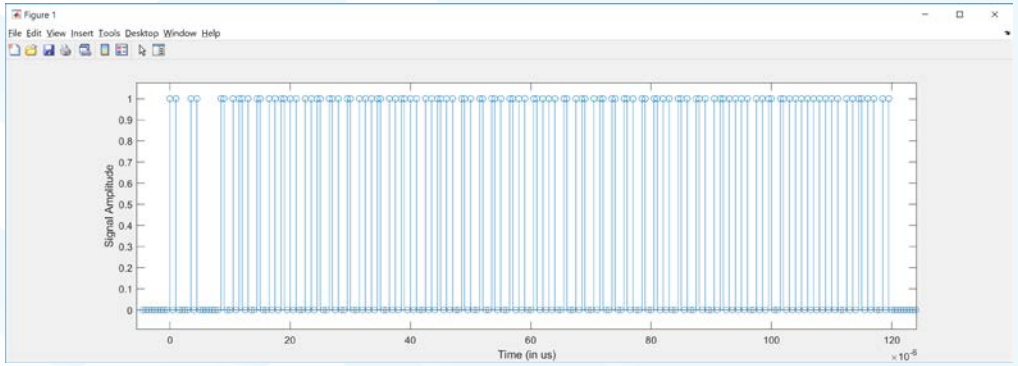
Step 1(a) : Build a transmitter

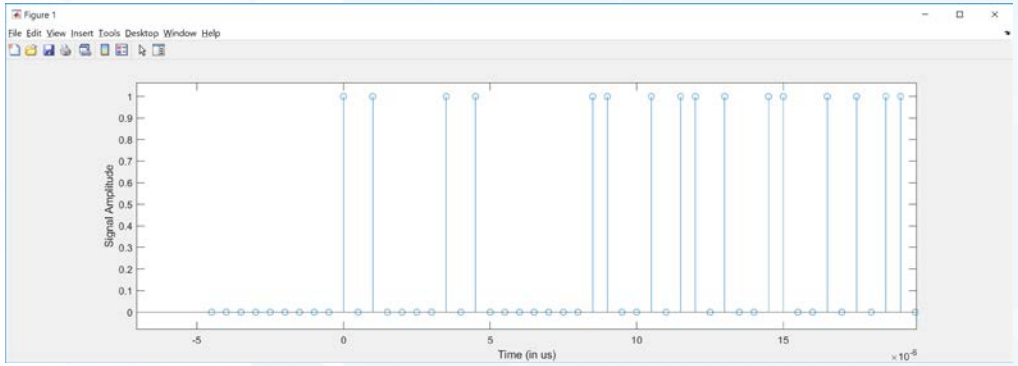
- Pretty trivial:
  - Build a bitstream:
  - Preamble:

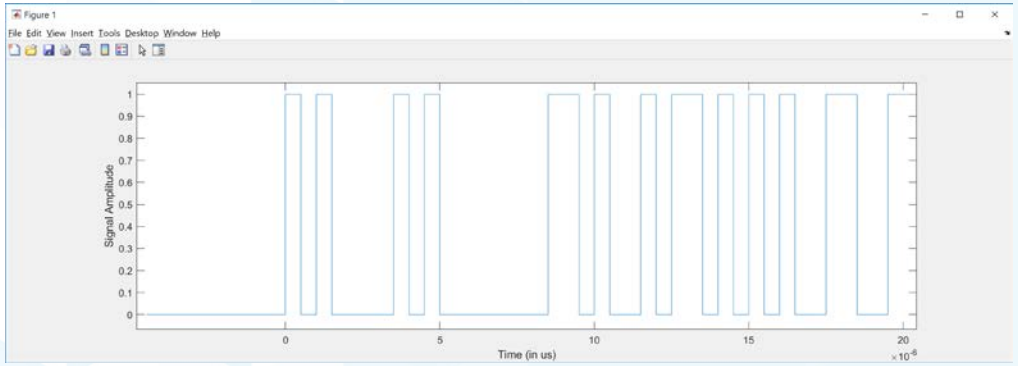


  - Add 96 random bits of ones (“01”) or zeros (“10”)
  - Add 24 parity bits (so actual receivers work)
  - Should end up with 240 “bits” to transmit

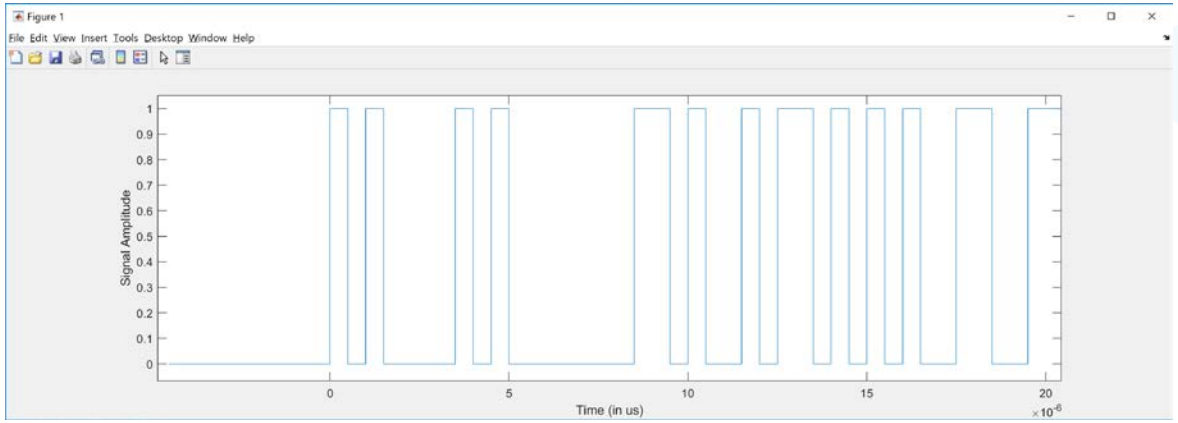
```
data_rand = randi([0,1],1,96);
%% preamble
data_out = [1 0 1 0 0 0 0 1 0 1 0 0 0 0 0 0 ];
data_out = [zeros(1,9), data_out];
for i = 1:length(data_rand);
    if data_rand(i) == 0
        data_out = [data_out, 1 0];
    else
        data_out = [data_out, 0 1];
    end
end
```

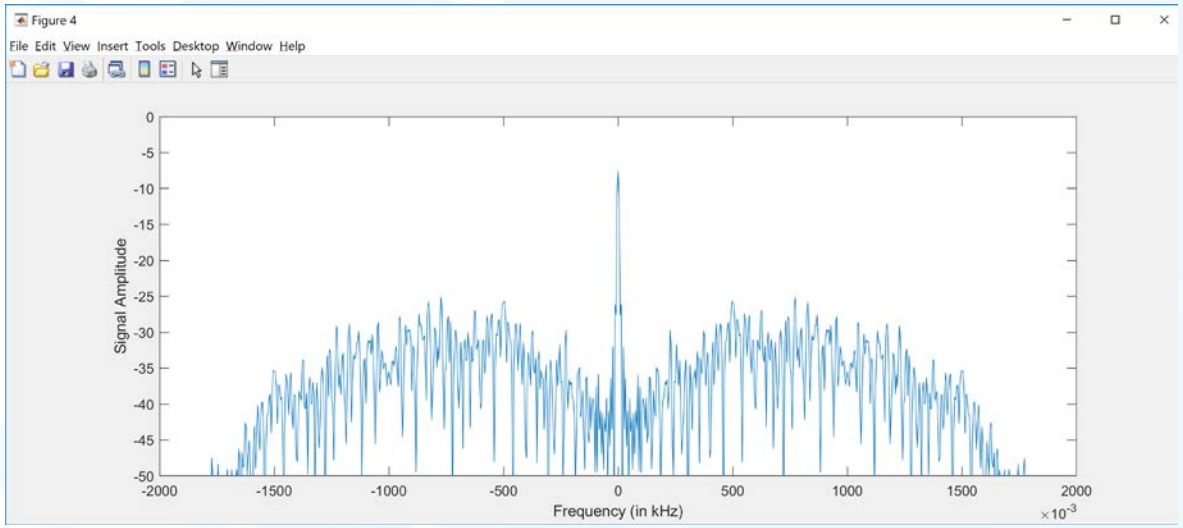


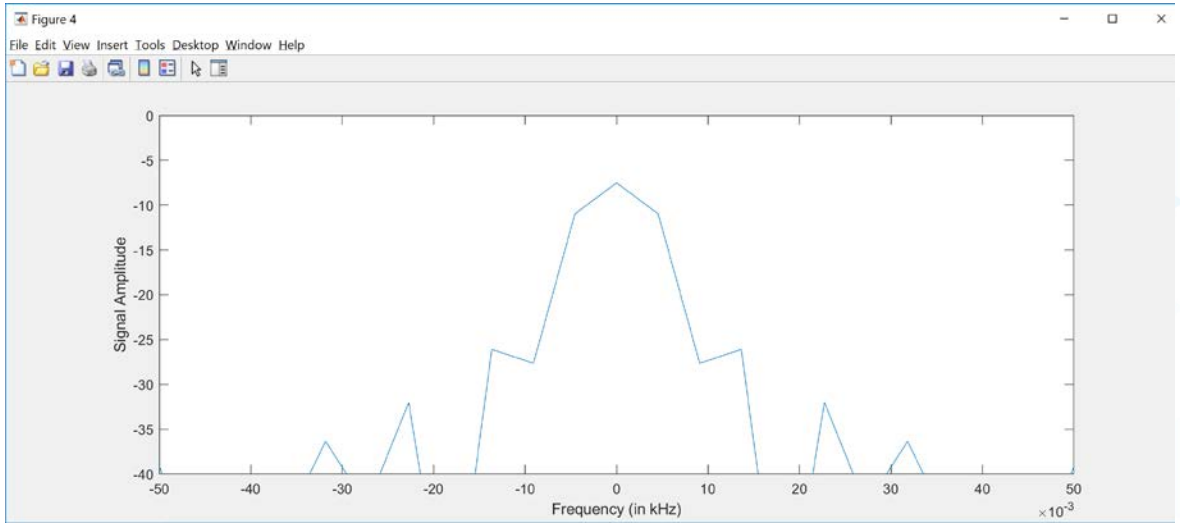


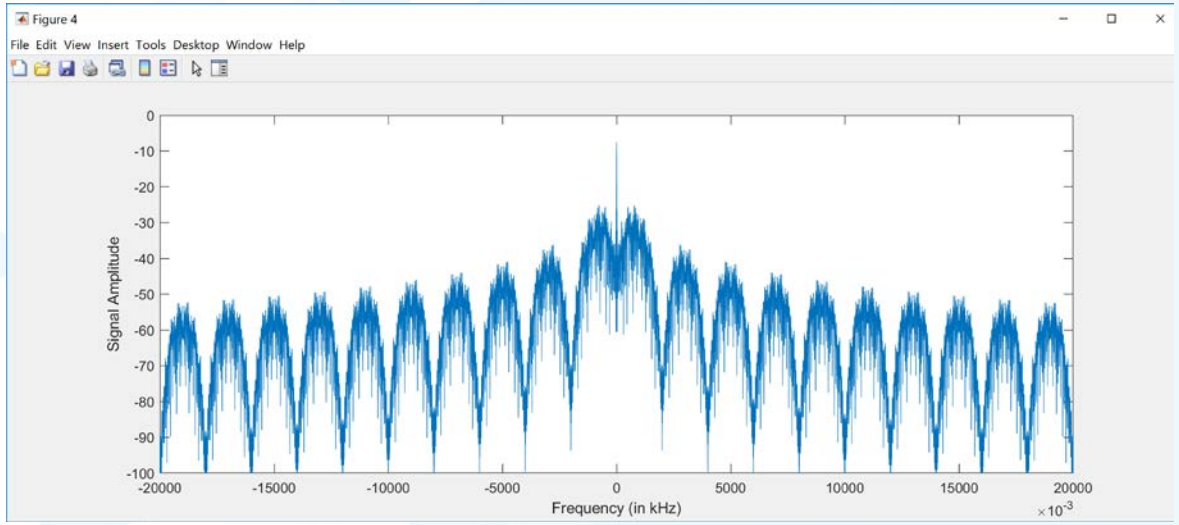


What does this look like spectrally?



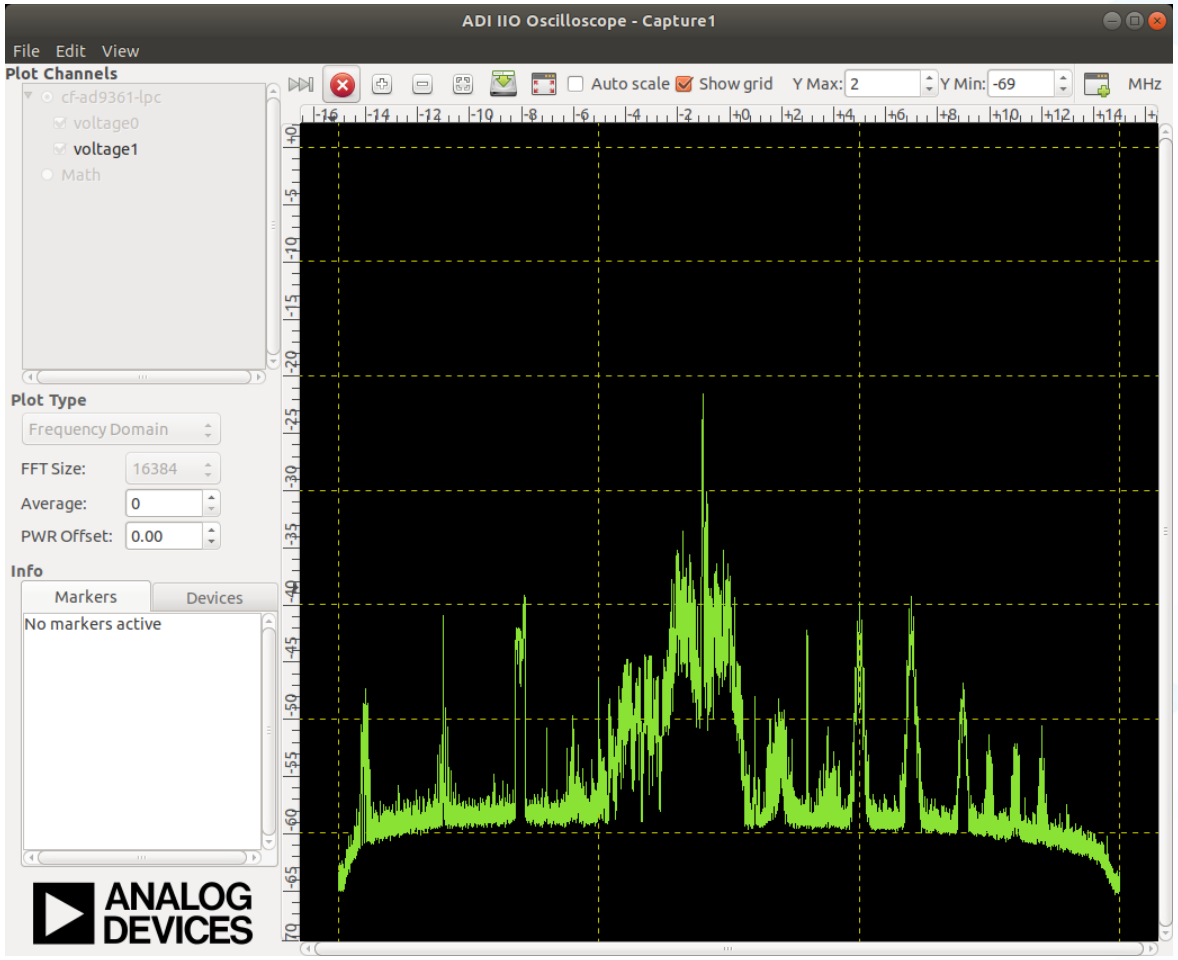


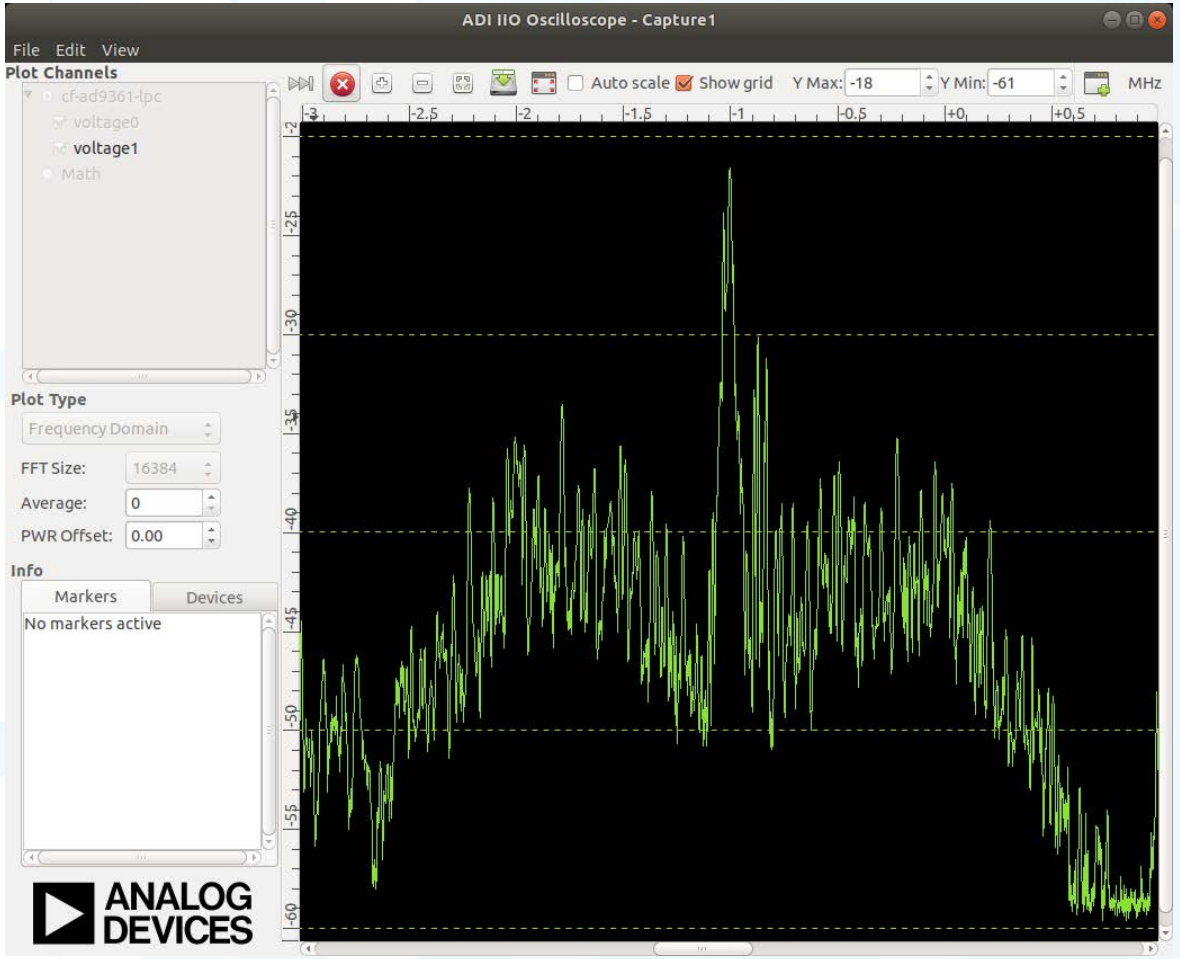




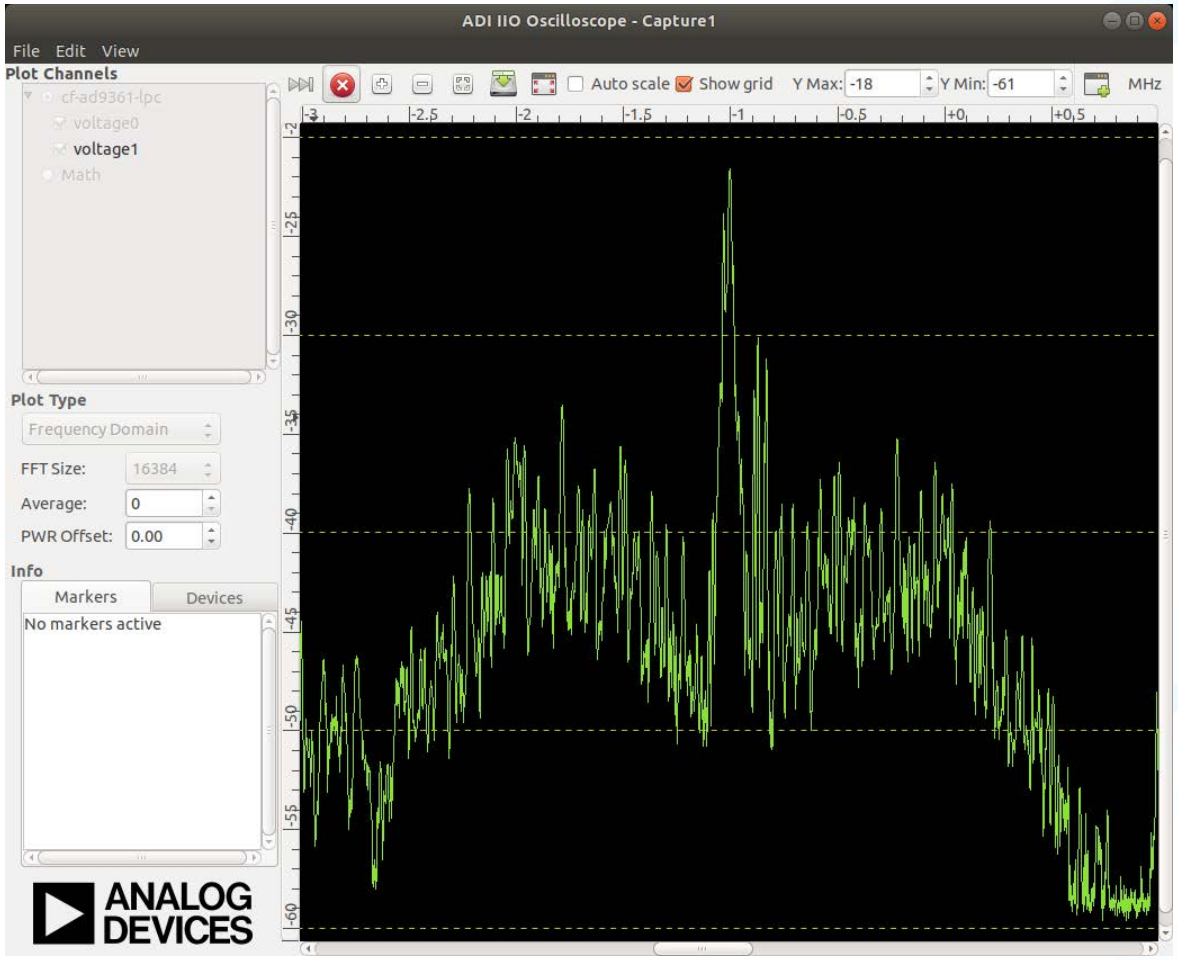
Signals (captured off the air)

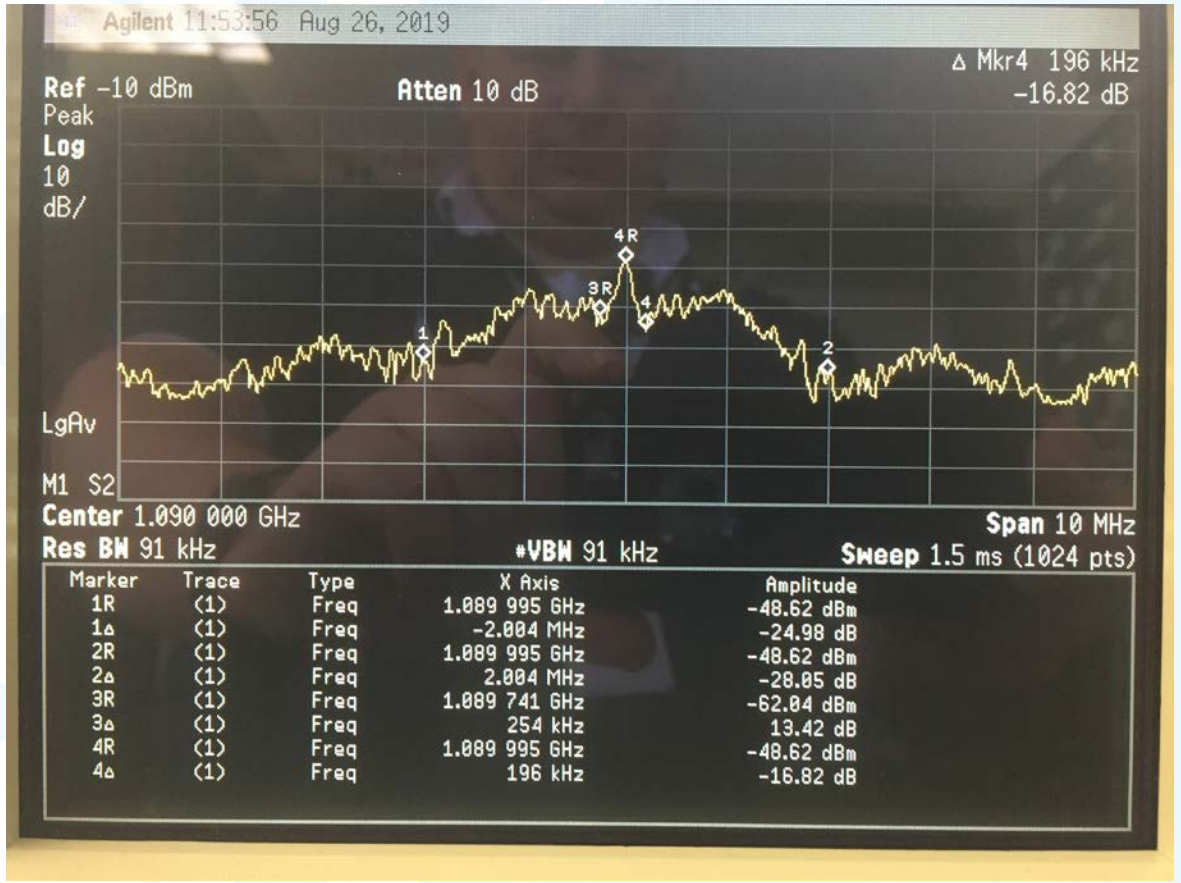
Center Frequency 1091 MHz (no DC correction issues)





Not the Equipment....





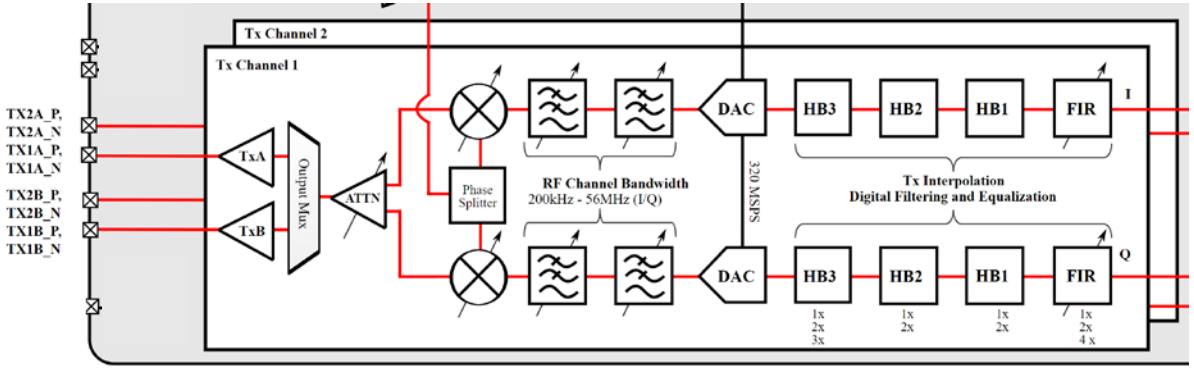
Robin's Rant #2

- Section 922 of the *Dodd-Frank Wall Street Reform and Consumer Protection Act* provides that the Securities and Exchange Commission the authority to pay awards to eligible whistleblowers who voluntarily provides the SEC with original information that leads to a successful enforcement action:
  - *March 19, 2018 :* two whistleblowers sharing a nearly $50 million award and a third whistleblower receiving more than $33 million.
  - SEC has awarded more than $262 million to 53 whistleblowers since 2012

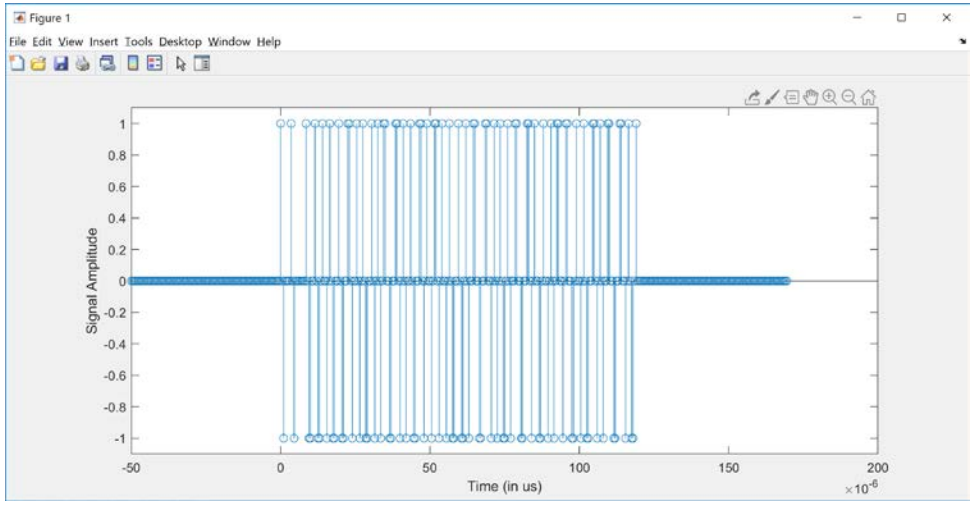
- My (and likely your) degree is not in forensic accounting.
- Call your member of congress, tell them this would be a great idea for the FCC enforcement office.
- https://www.fcc.gov/enforcement
  - Enforcement Bureau (EB) is the primary FCC unit responsible for enforcing the provisions of the Communications Act, the Commission's rules, orders, and various licensing terms and conditions. EB's mission is to investigate and respond quickly to potential unlawful conduct to ensure: (1) consumer protection in an era of complex communications; (2) a level playing field to promote robust competition; (3) efficient and responsible use of the public airwaves; and (4) strict compliance with public safety-related rules.

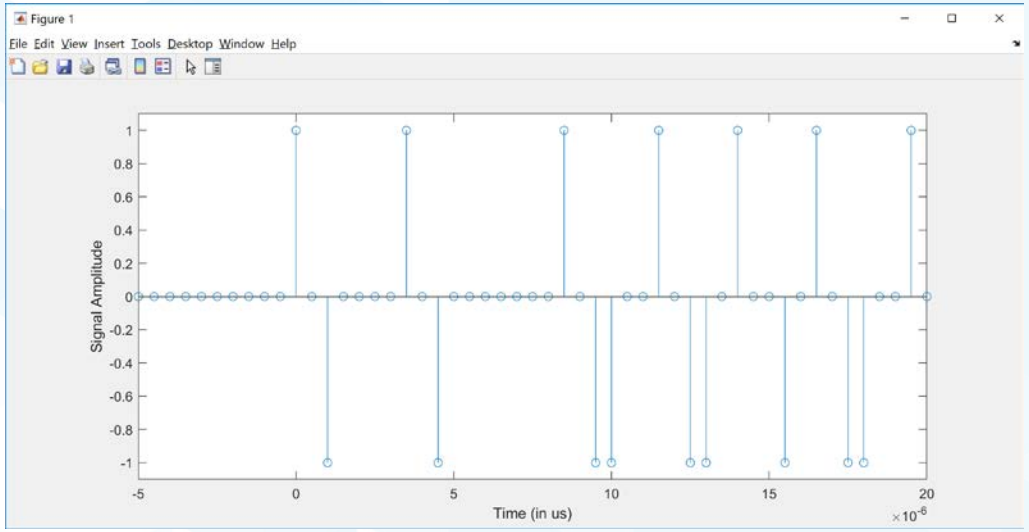
Practical Transmitter

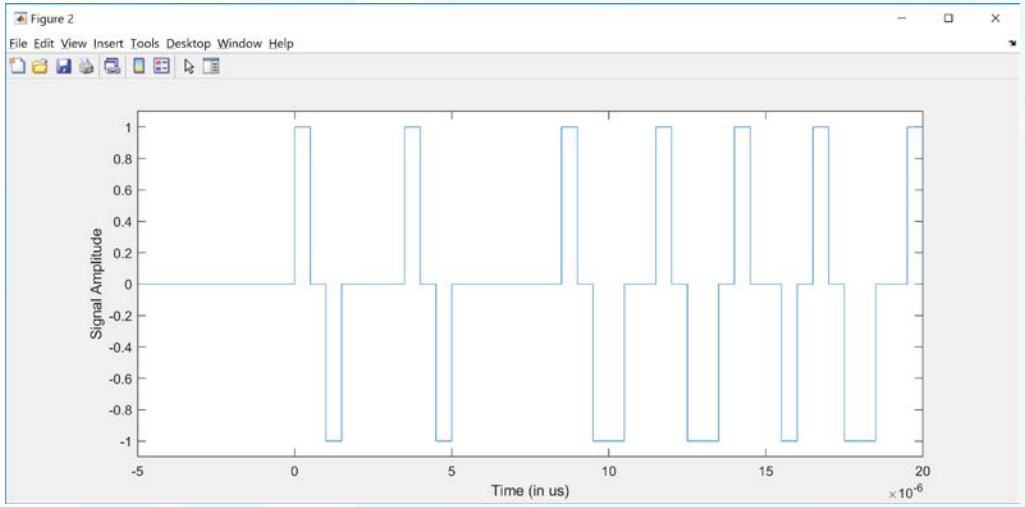
- Can’t transmit “0” and “1” in time domain



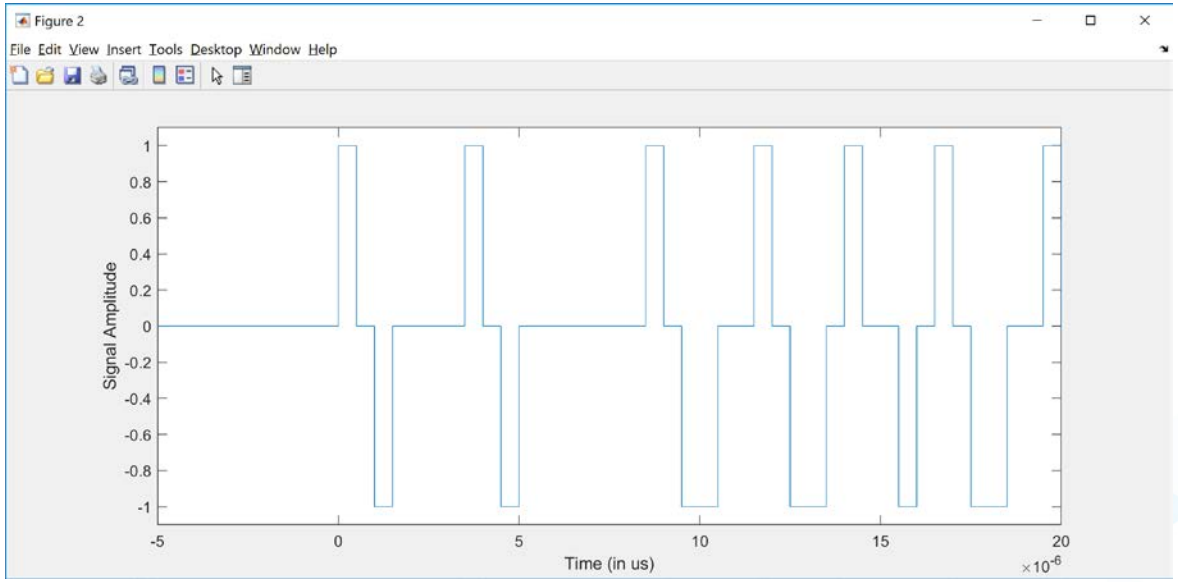
- Need to “normalize” it to “1”, “0” and “-1”

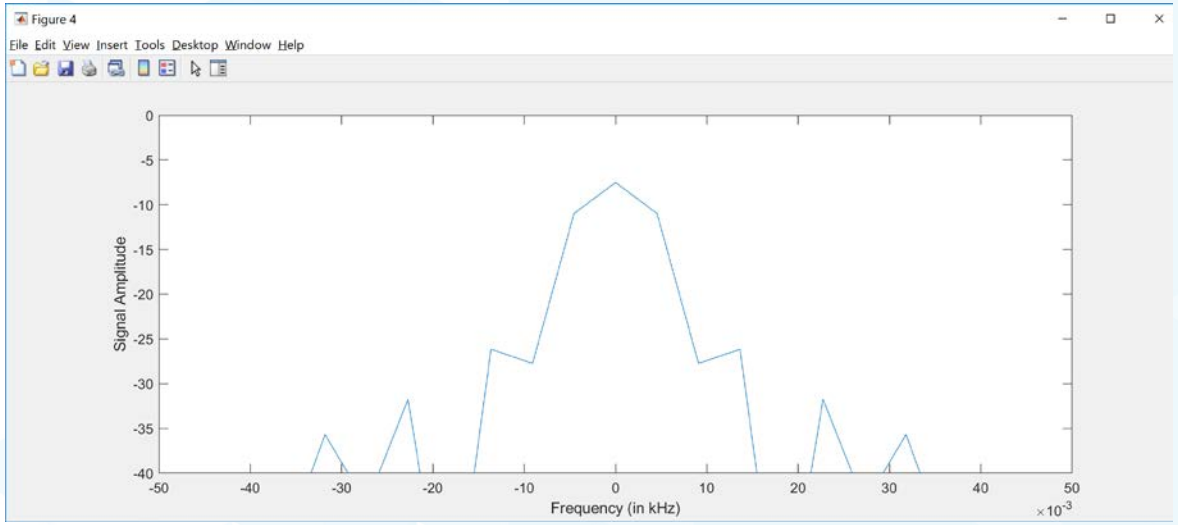


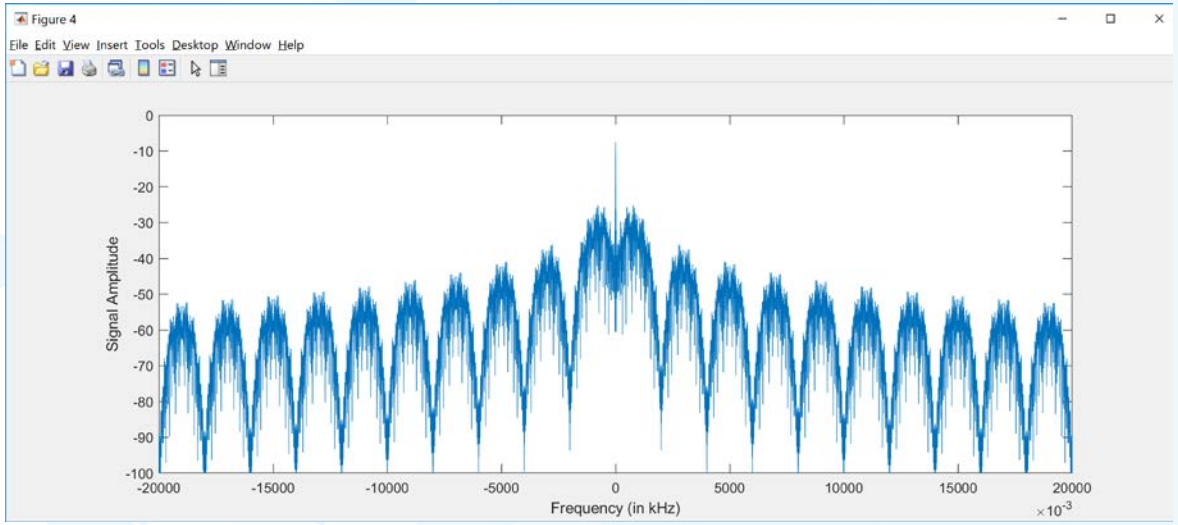




What does this look like spectrally?

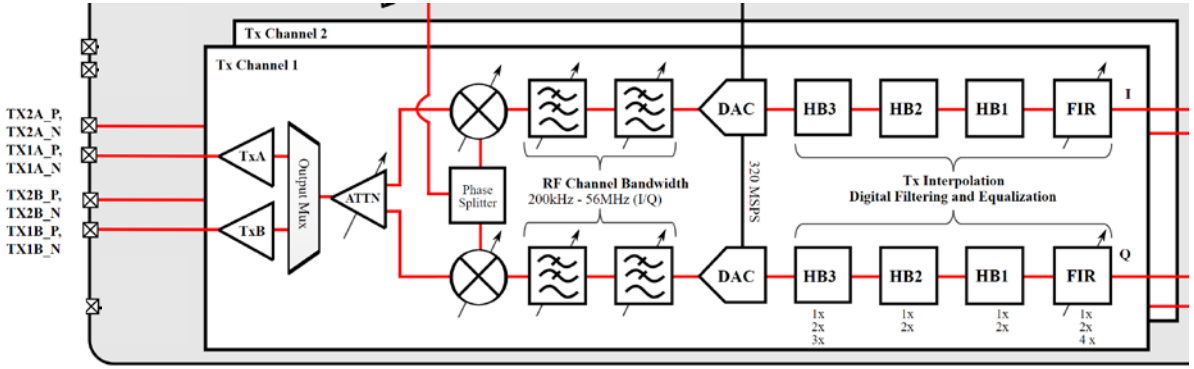




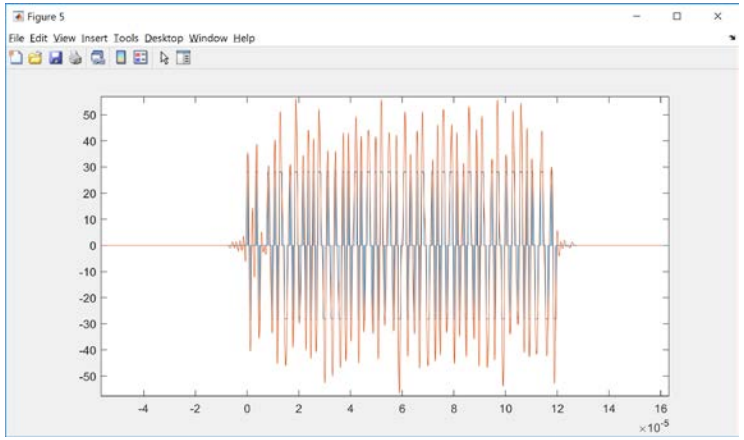


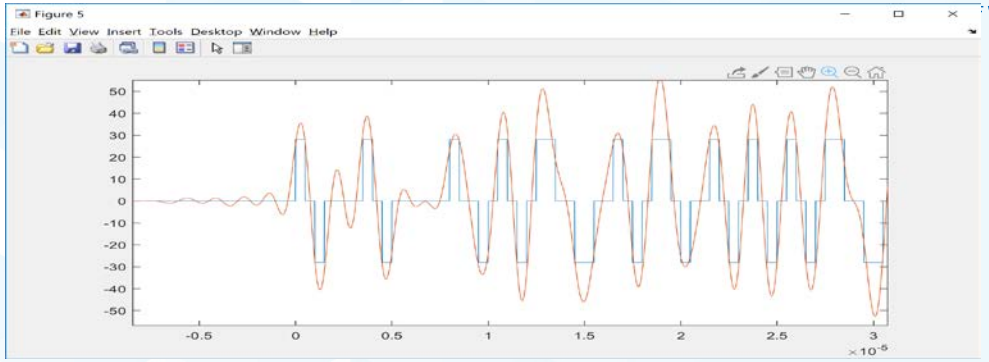
Practical Transmitter

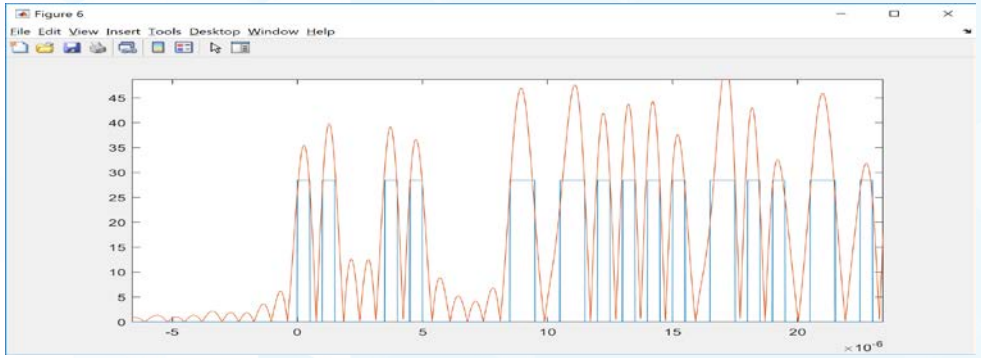
- Can’t transmit “-1” and “1” in time domain

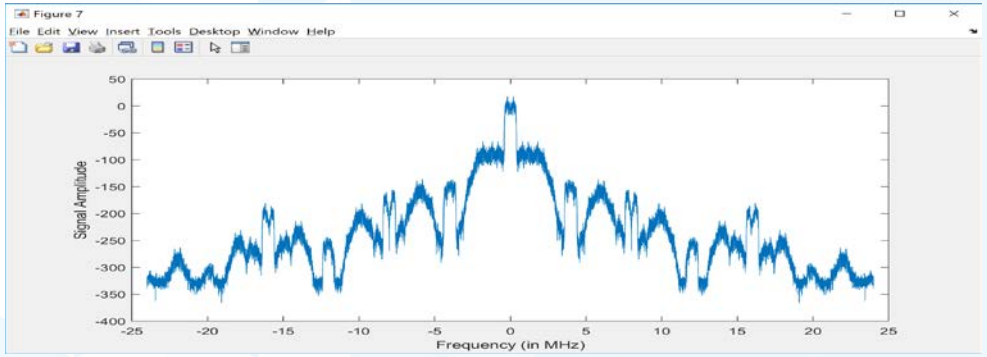


- Need to up sample, filter (bandwidth limit)

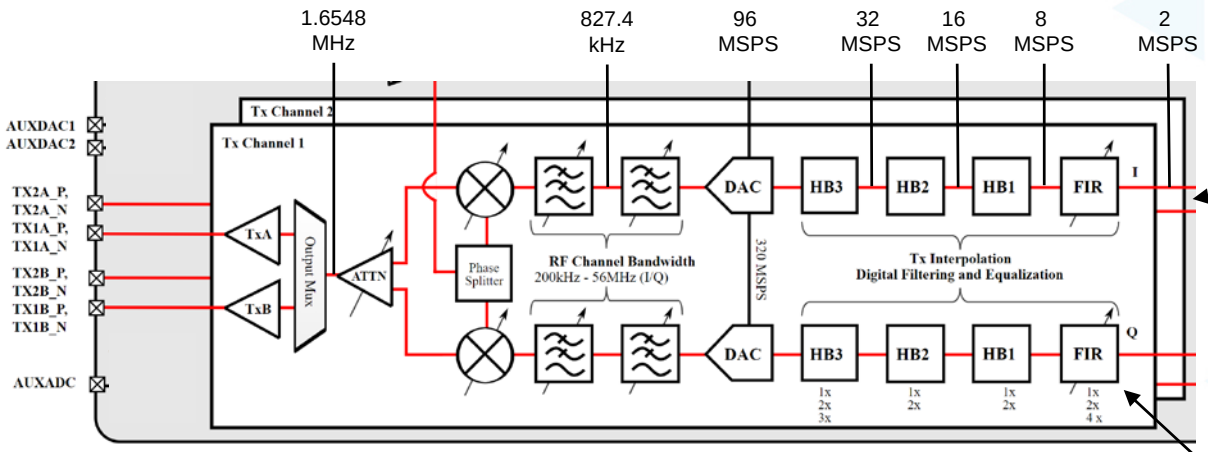


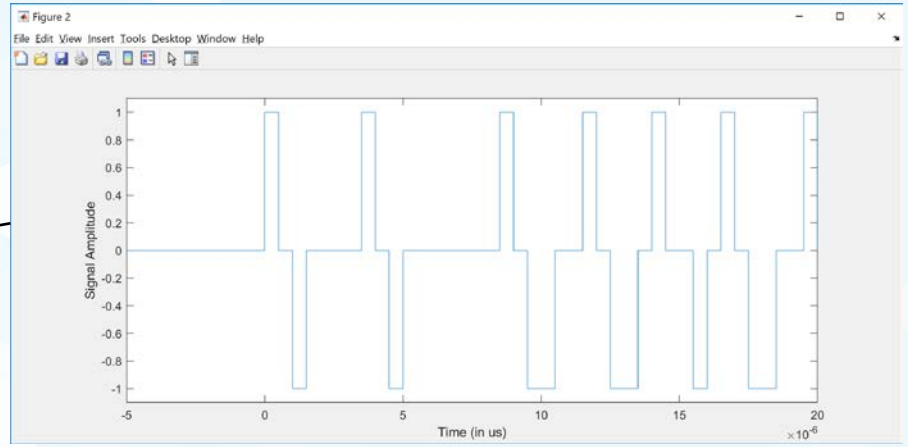


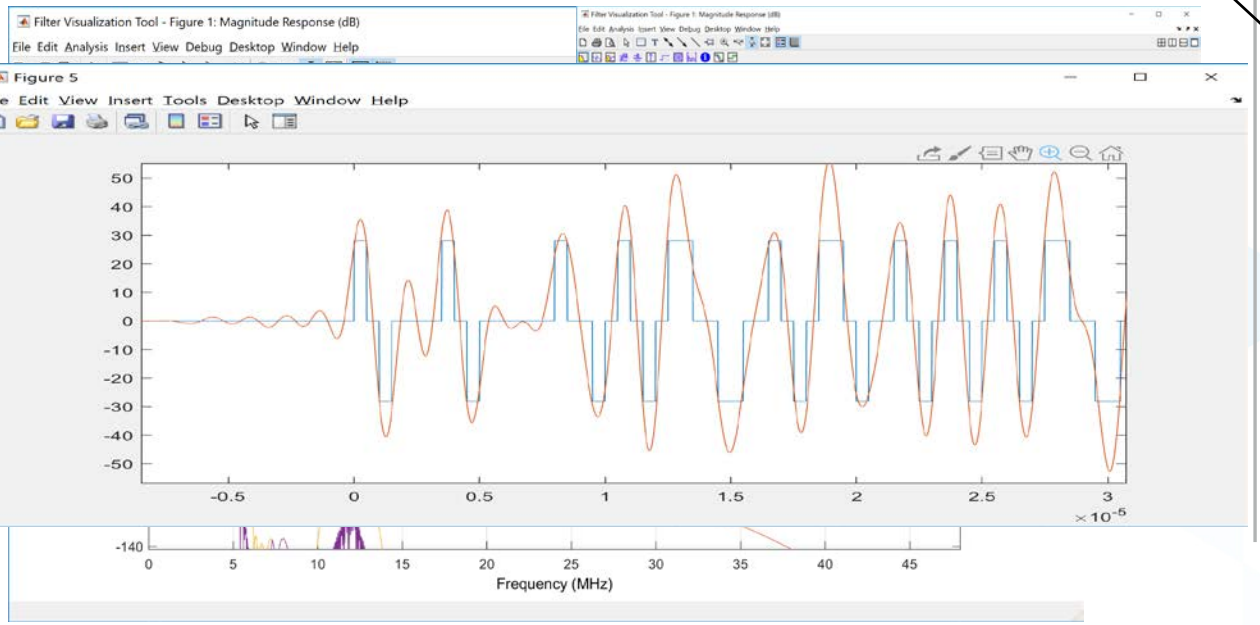


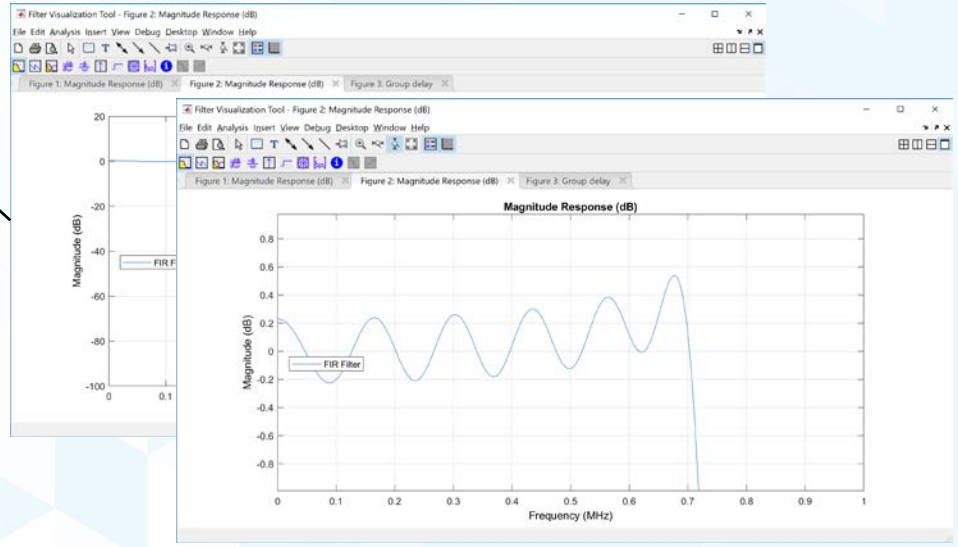


What's going on?

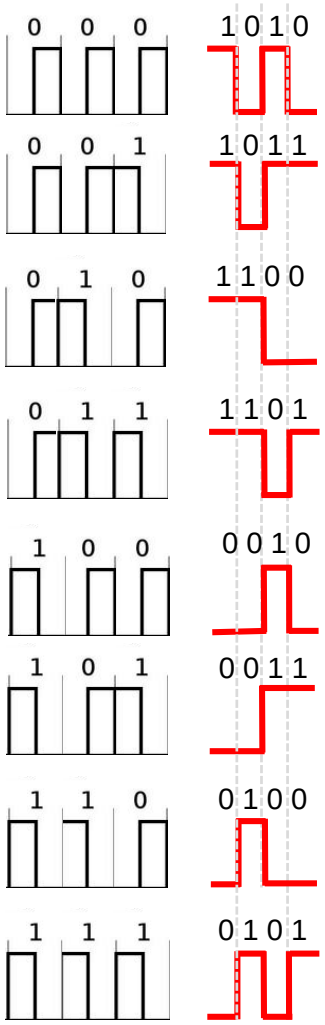


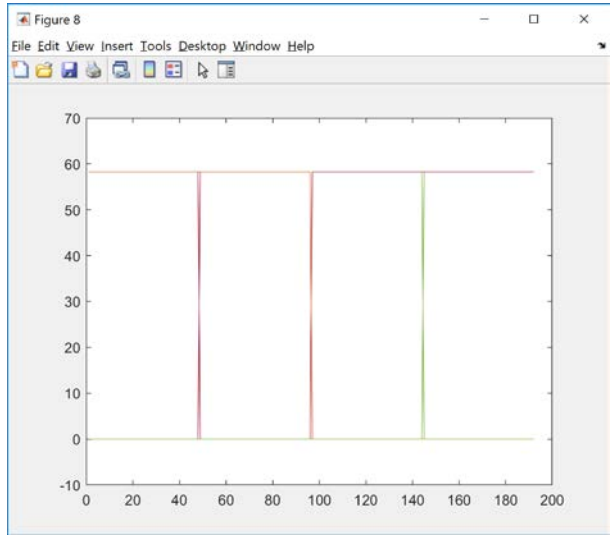


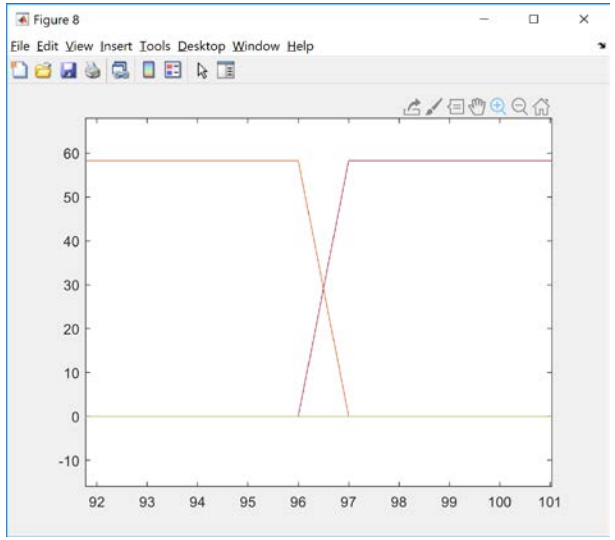


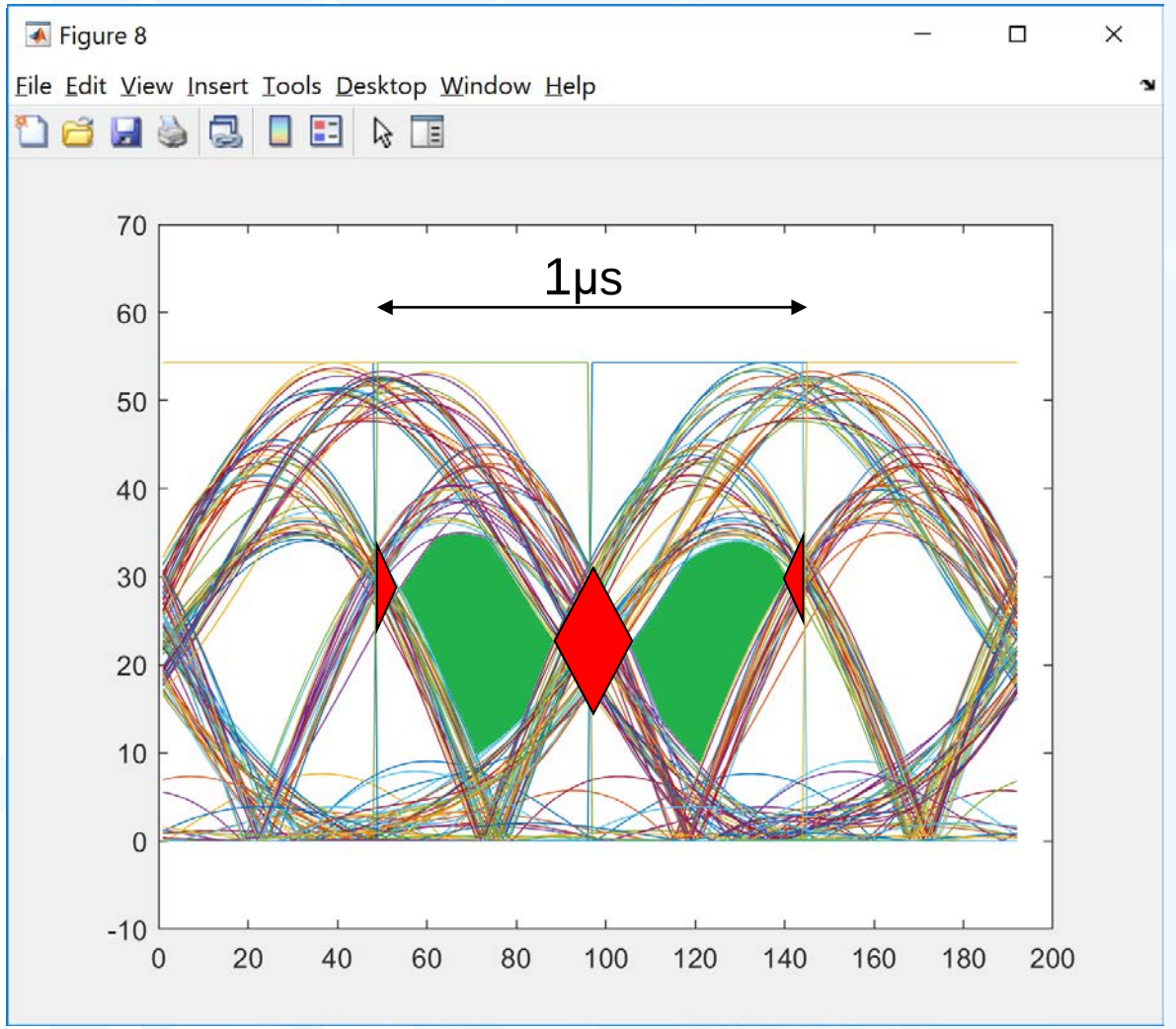


What do things really look like?



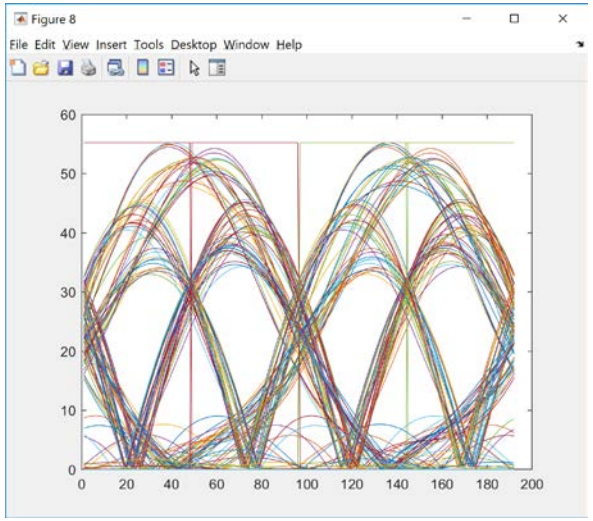


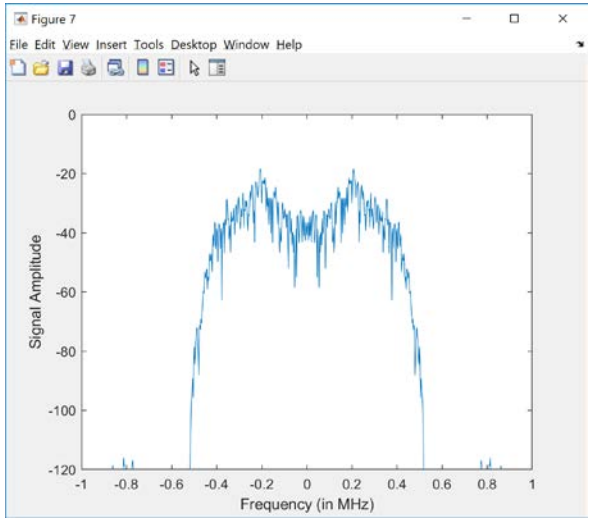




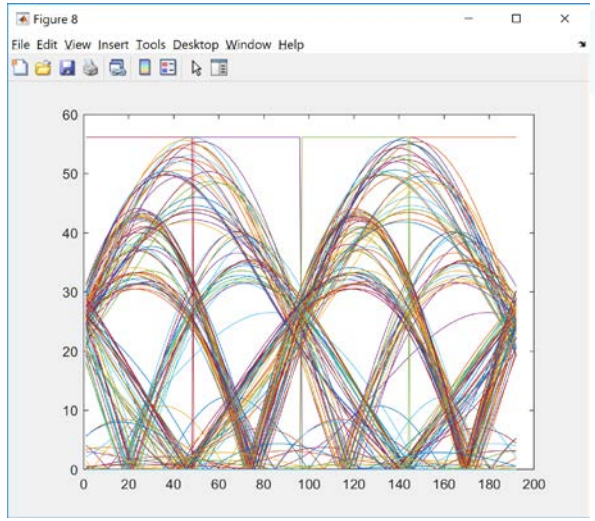
Different FIR Filter Bandwidths

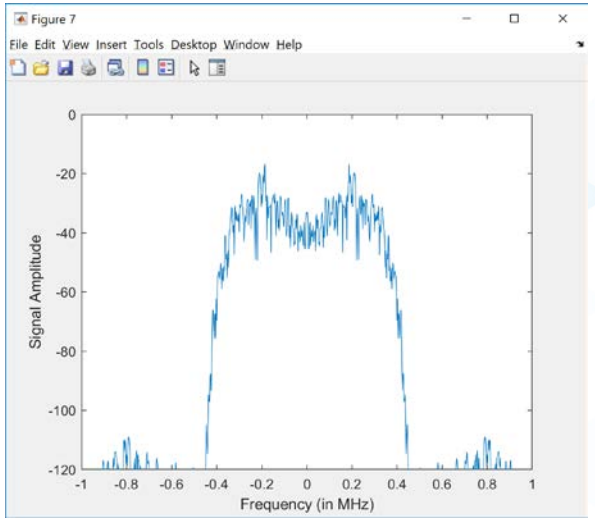
700 kHz



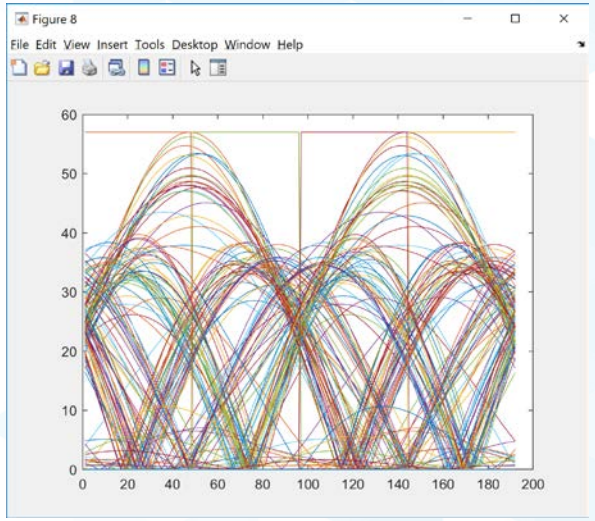


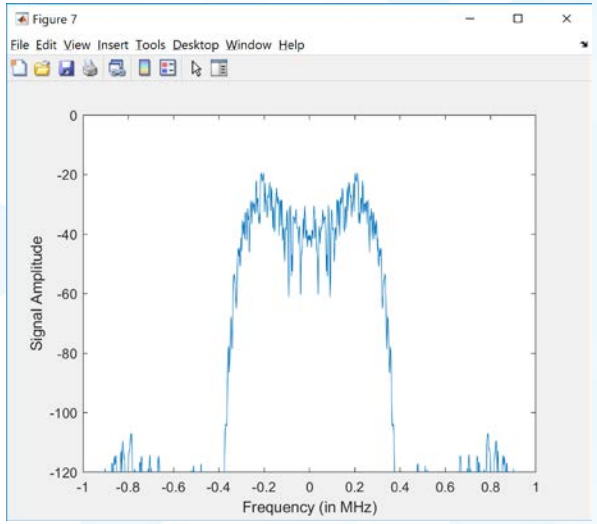
600 kHz



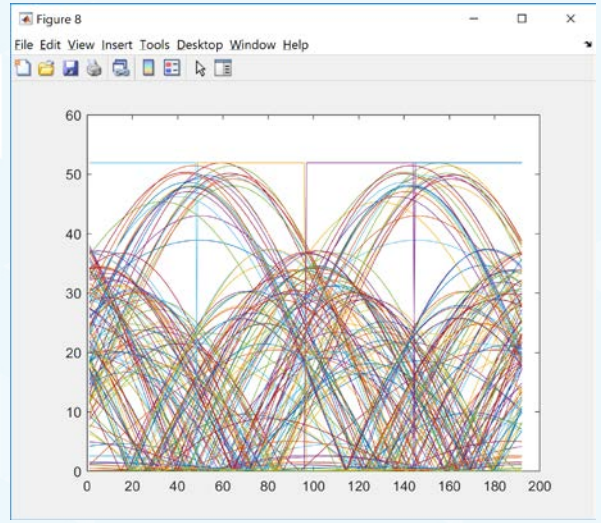


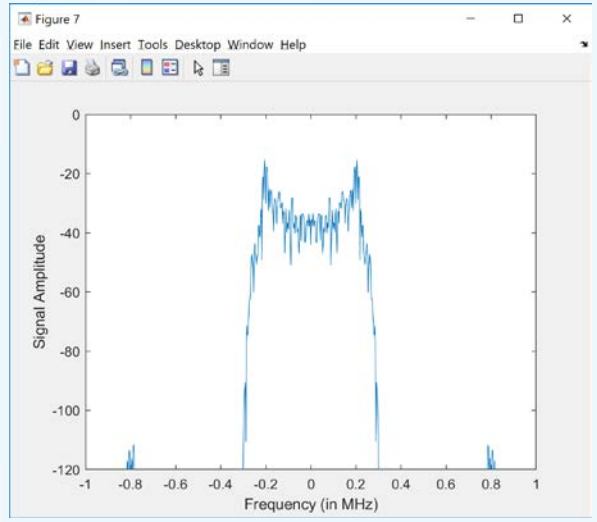
500 kHz



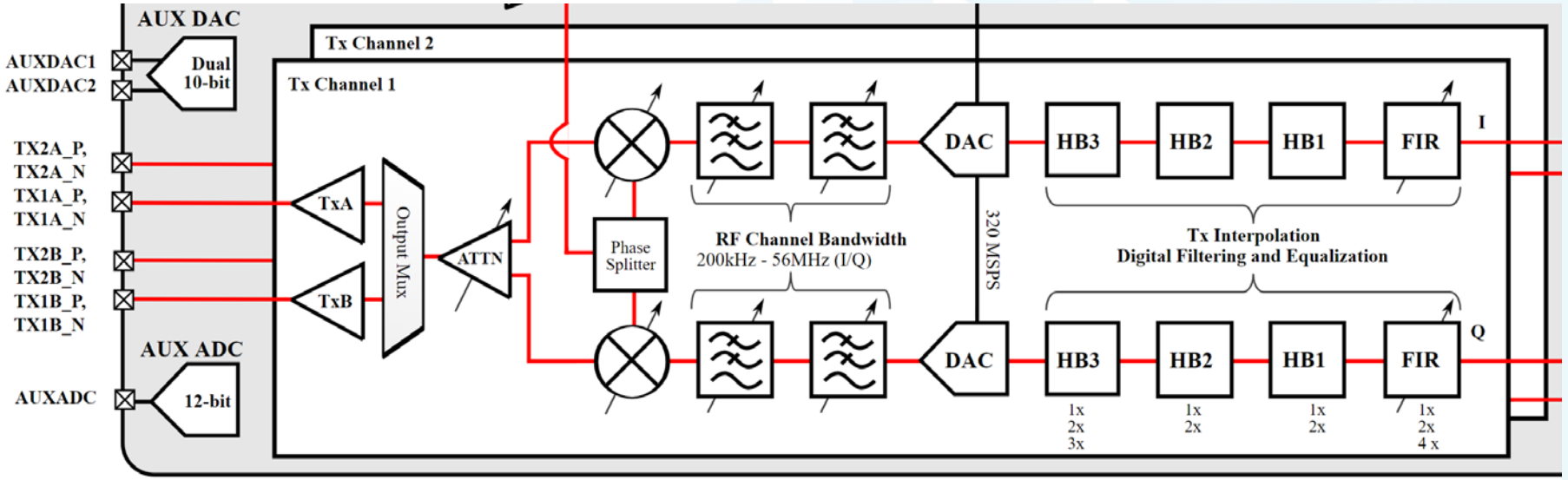


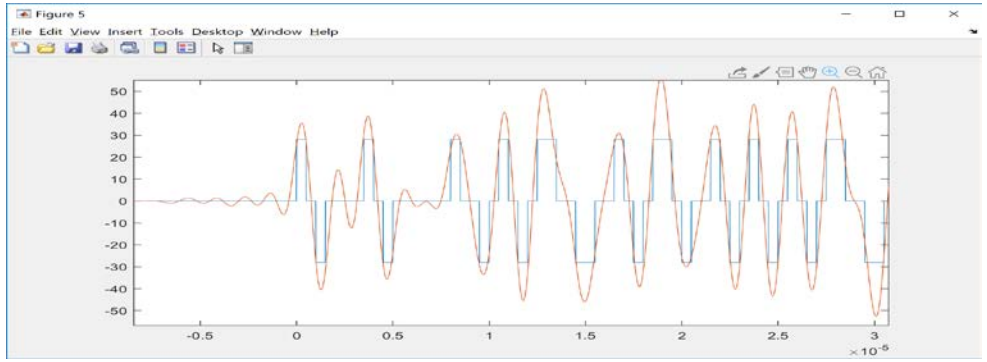
400 kHz

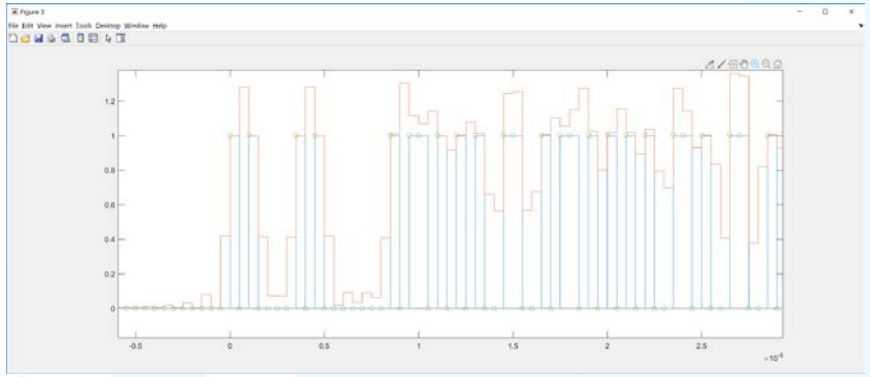




Real Signal -> complex







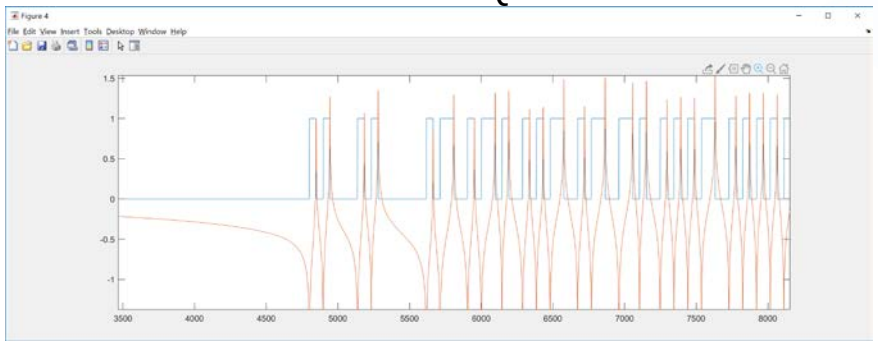
I = Q

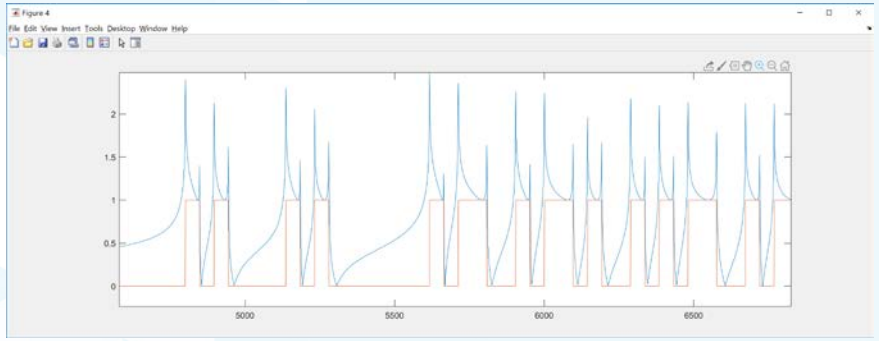
Why not Hilbert?

I / Q

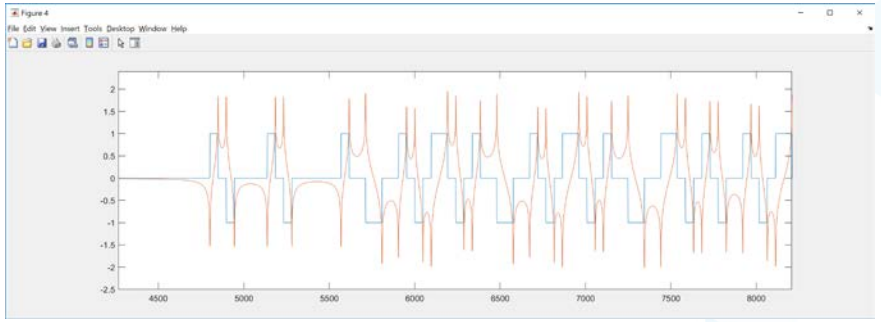
abs(original signal) & abs (I/Q)

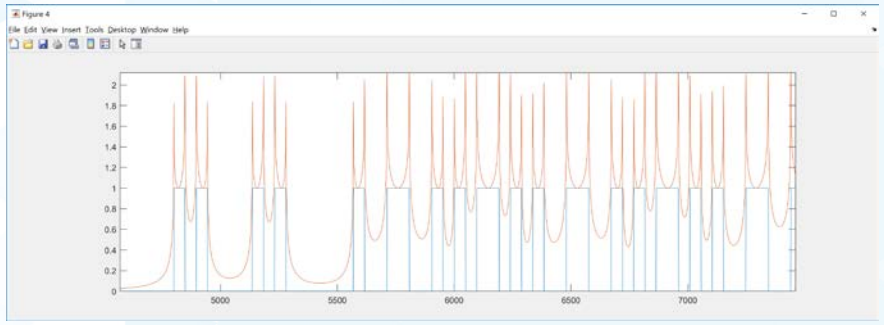
Hilbert on over sampled data



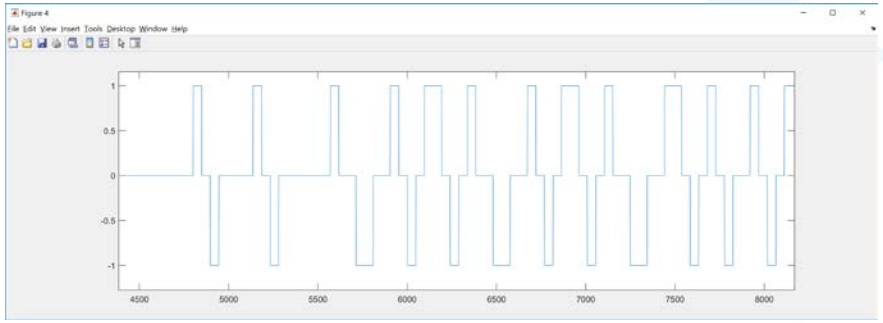


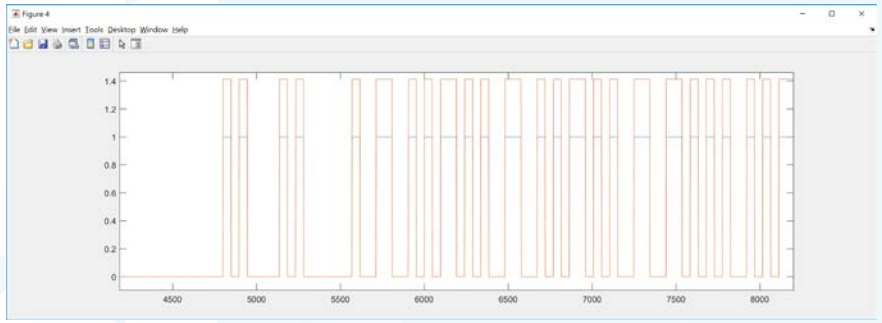
Hilbert on over sampled data



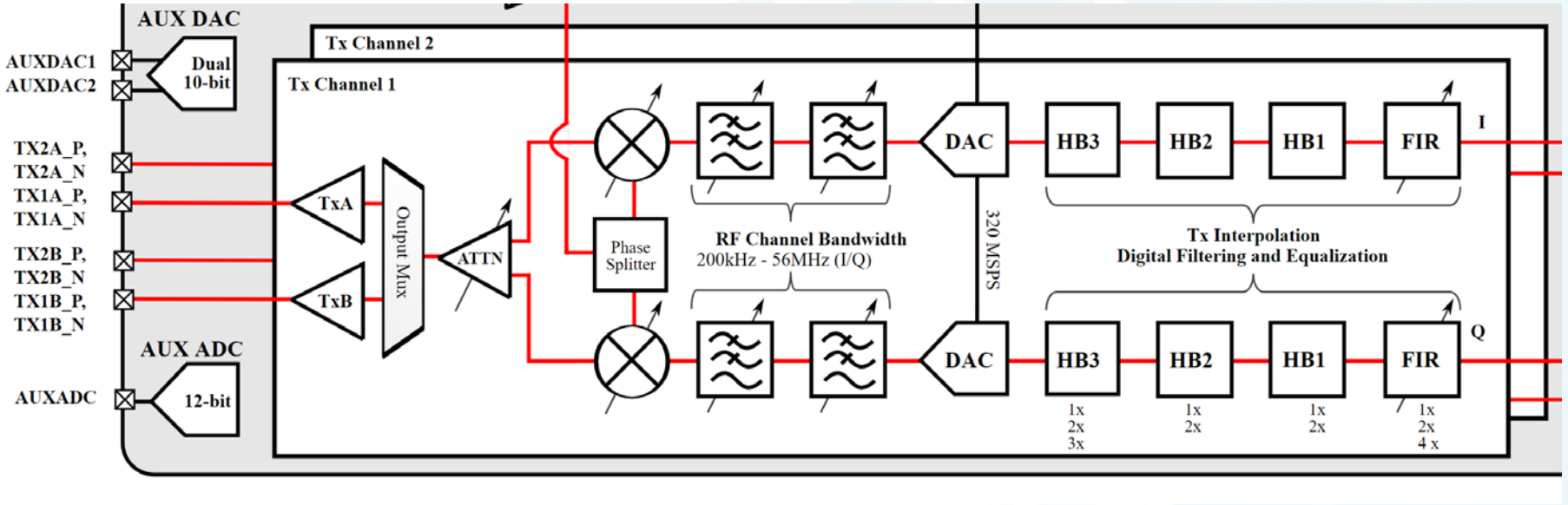


I=Q



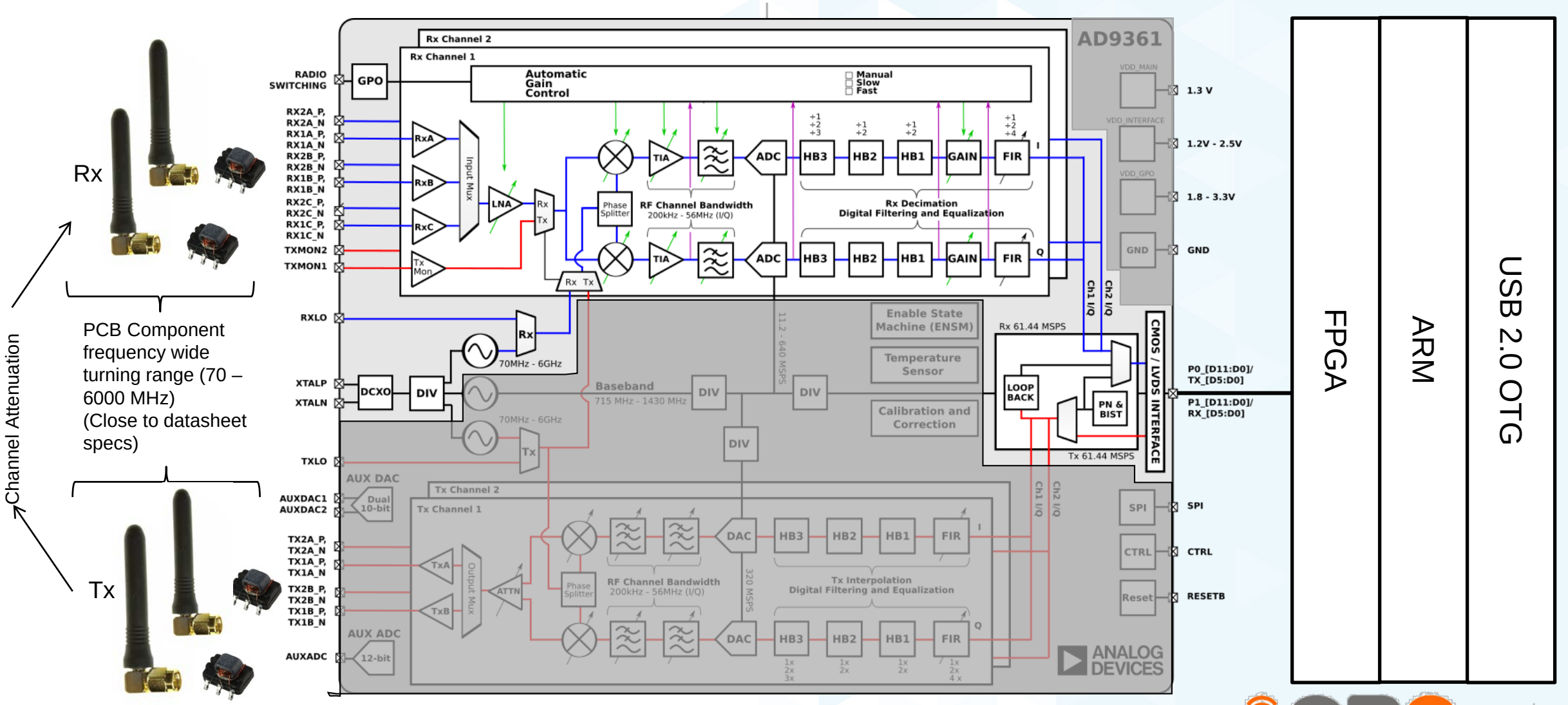


What does this mean?



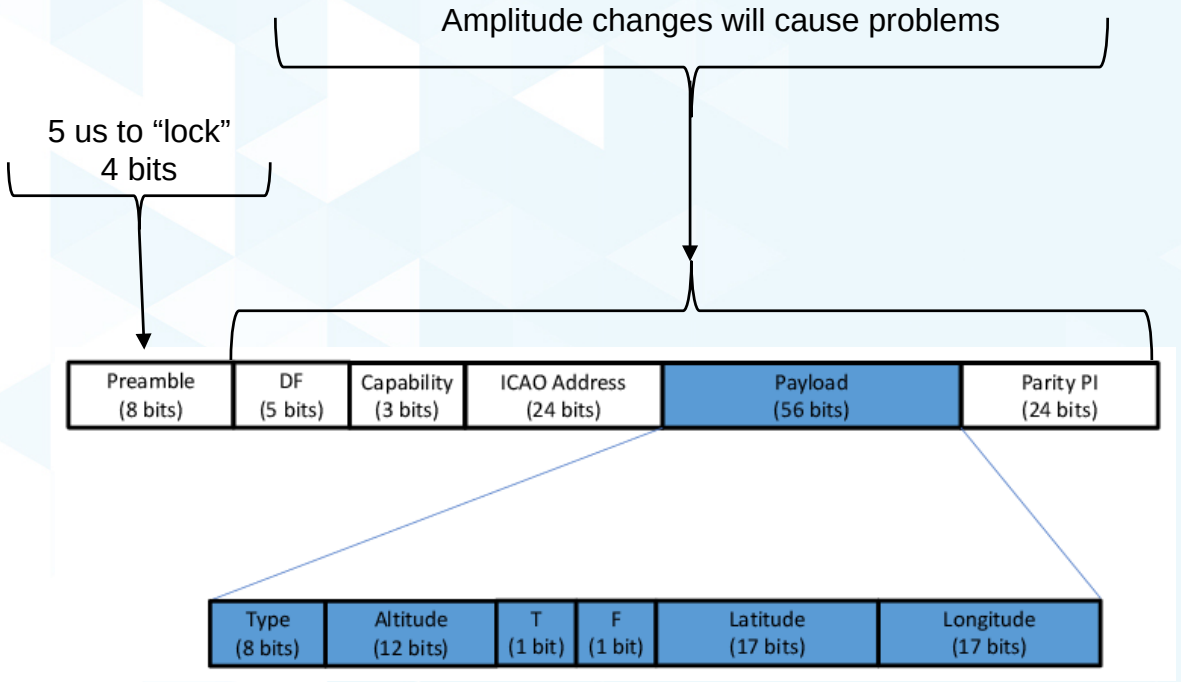
- Not changing the input to the DAC, just FIR, HB & Analog Filter settings
- If you aren't setting them – someone else is.
  - May not be "optimal" for your application/waveform

Step 2 : Optimize device settings



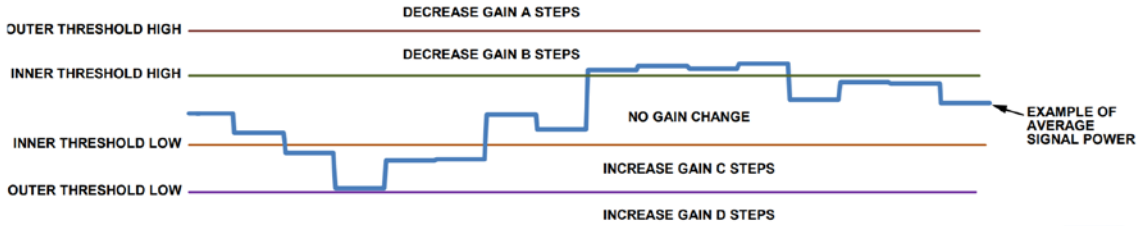
Gain Settings

- Manual?
- Automatic?
- Dynamic Range?

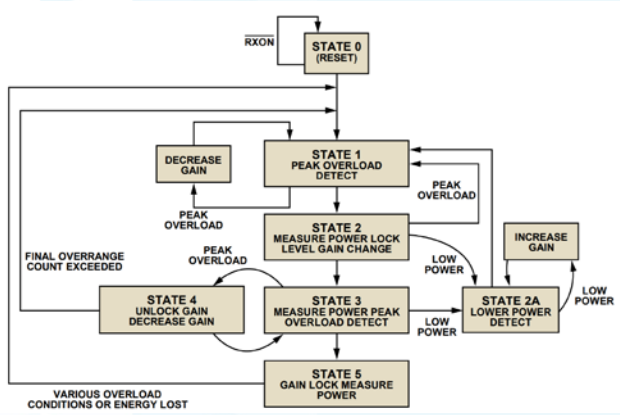


Fast and Slow

- Slow Attack
- Slow attack mode is intended for slowly changing signals such as those found in some FDD applications.
- Will only update after the gain update counter expires. The counter is clocked at the ClkRF rate (the input rate of the RFIR).



- Fast Attack
- Fast attack AGC mode is intended for waveforms that burst on and off, such as those found in TDD applications or GSM/EDGE FDD applications.
- The AGC responds very quickly to overloads at the start of a burst so that the AGC can settle to an optimum gain index by the time the data portion of the signal arrives.

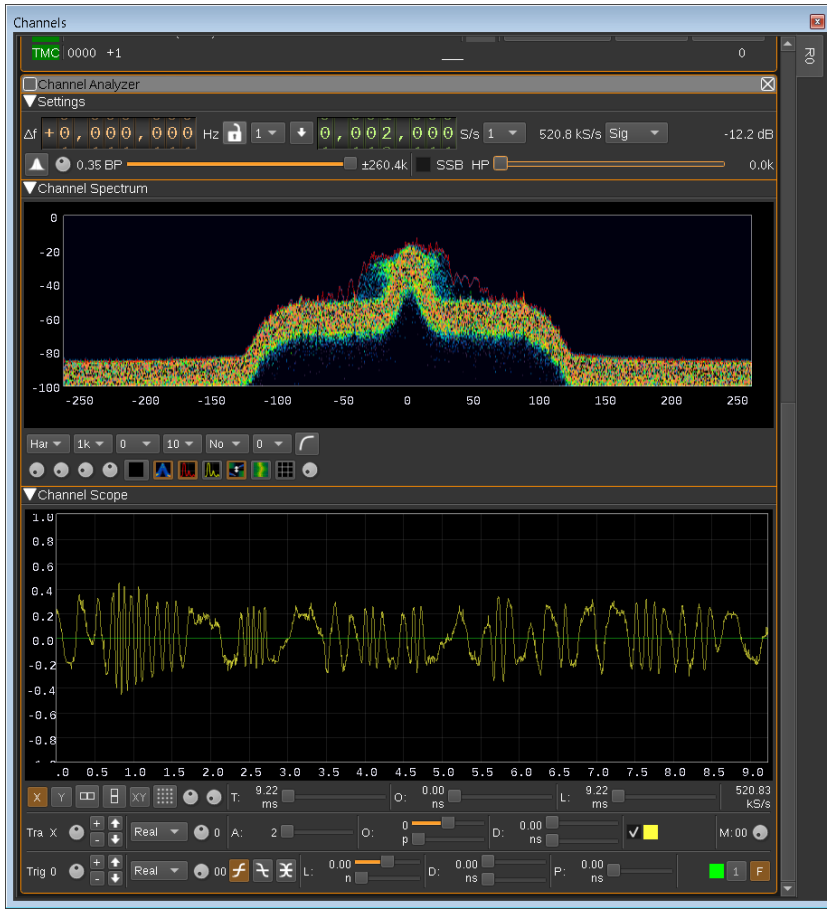


Optimizing Target Average Power

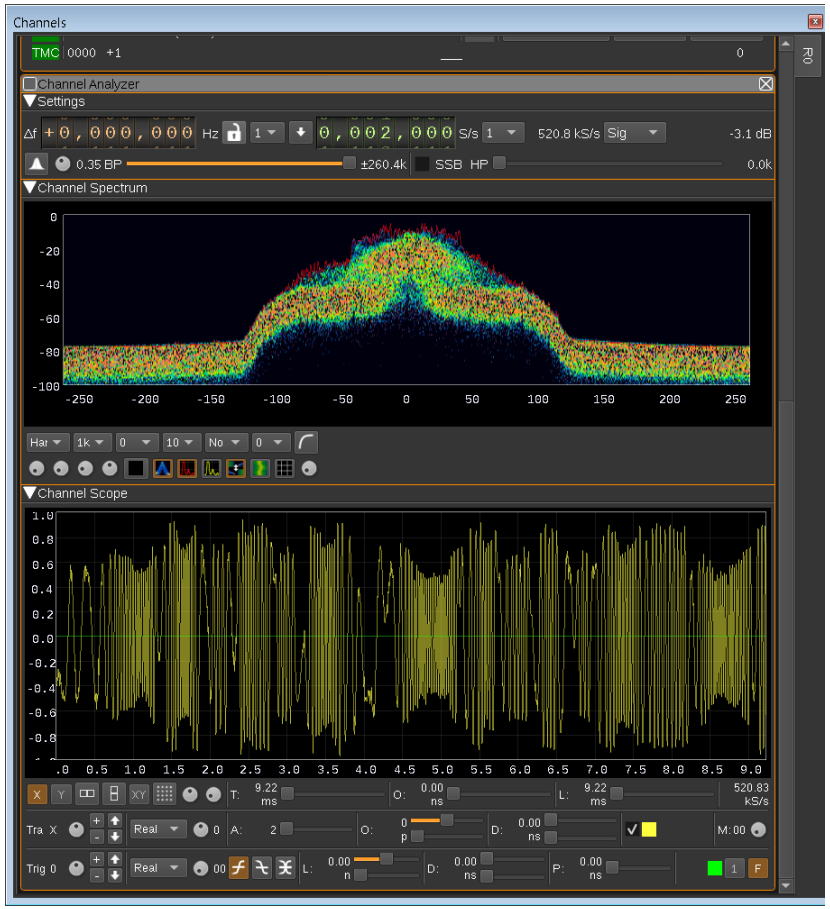
Managing Dynamic Range

Wave Type	RMS Value	Crest Factor	PAPR (dB)
DC	1	1	0.0
Sine Wave	$\frac{1}{\sqrt{2}} = .707$	$\sqrt{2}$ = 1.44	3.01 dB
QPSK	1	1	1.76 dB
8PSK			3.3 dB
64 QAM	$\sqrt{\frac{3}{7}} = 0.654$	$\sqrt{\frac{7}{3}} = 1.542$	3.7 dB
OFDM			~ 12 dB

FM Radio Default Slow Attack



FM Radio Target Adjusted

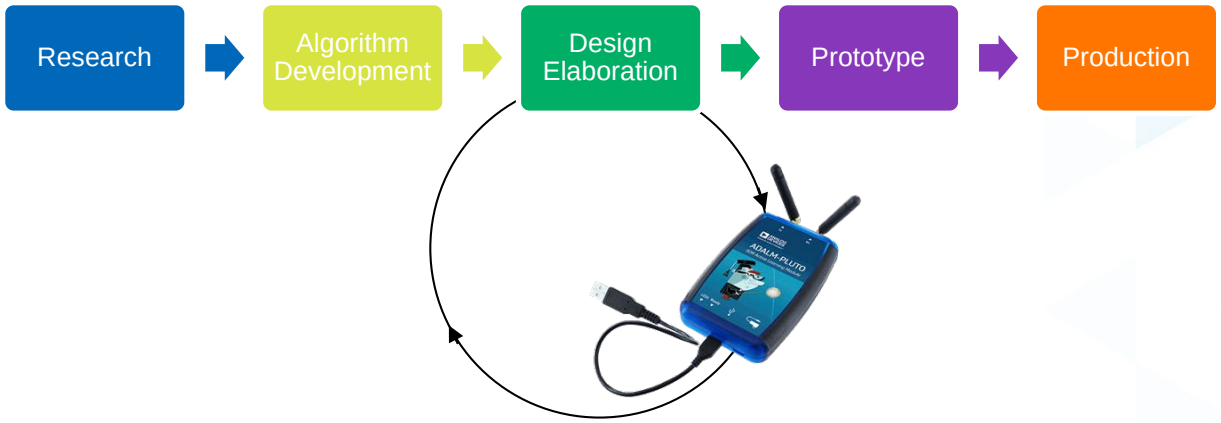


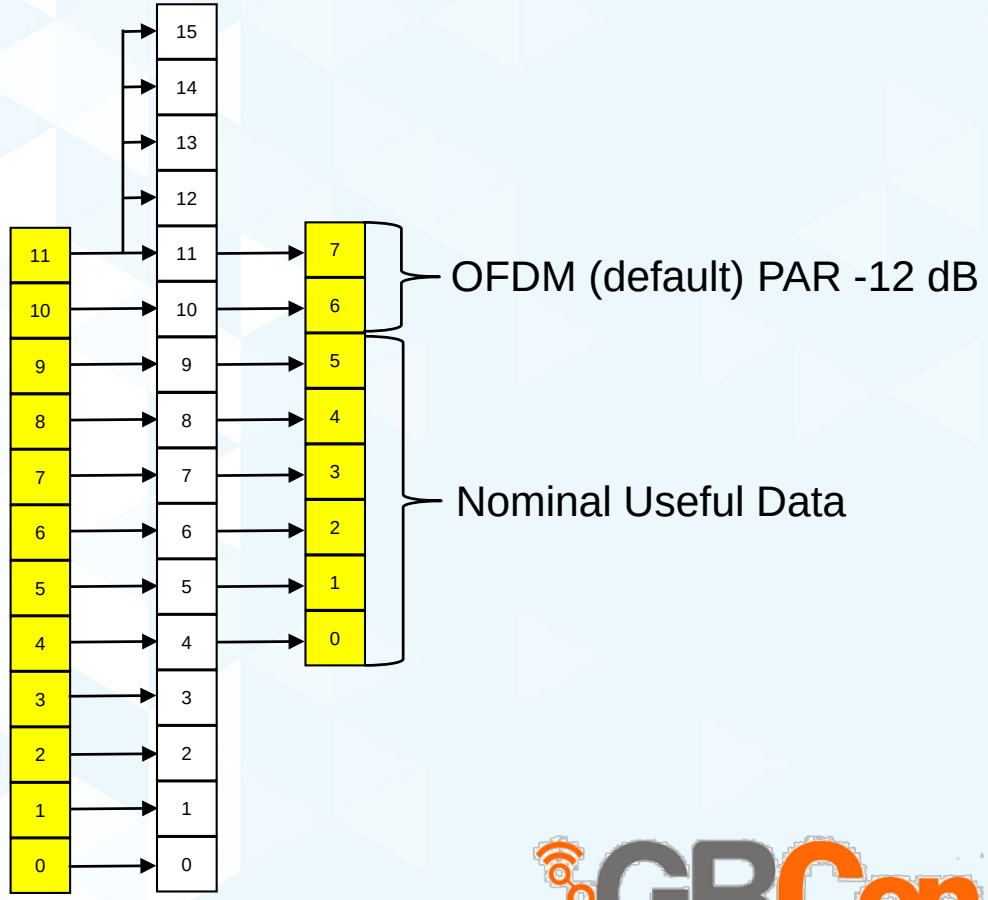
-12dB = ~2 bits

dump1090

https://github.com/PlutoSDR/dump1090/blob/master/dump1090.c#L502

```
for(p_dat = iio_buffer_first(Modes.rxbuf, Modes.rx0_i); p_dat < p_end; p_dat += p_inc){
    const int16_t i = ((int16_t*)p_dat)[0]; // Real (I)
    const int16_t q = ((int16_t*)p_dat)[1]; // Imag (Q)
    cb_buf[j*2]   = i >> 4;
    cb_buf[j*2+1] = q >> 4;
    j++;
}
```



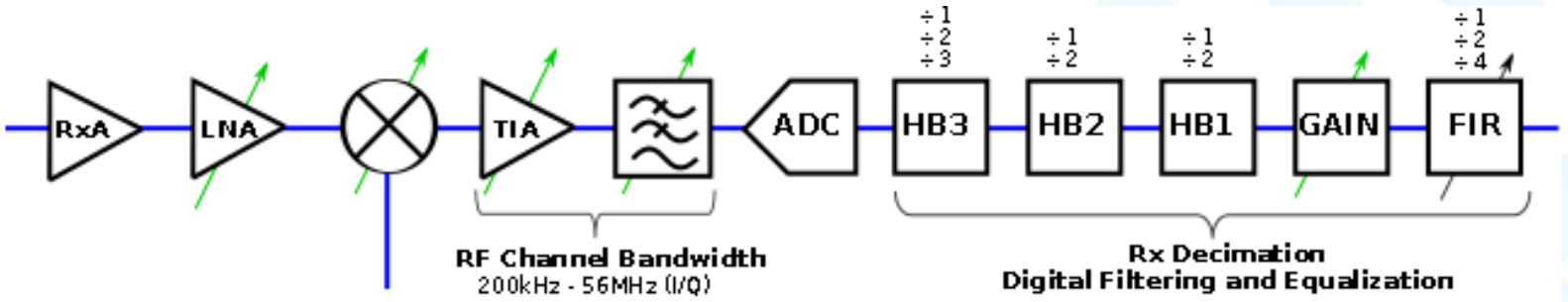


readsb

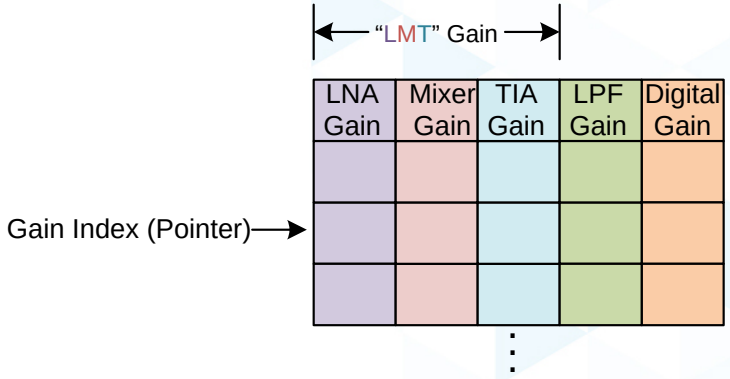
https://github.com/Mictronics/readsb/blob/master/sdr_plutosdr.c

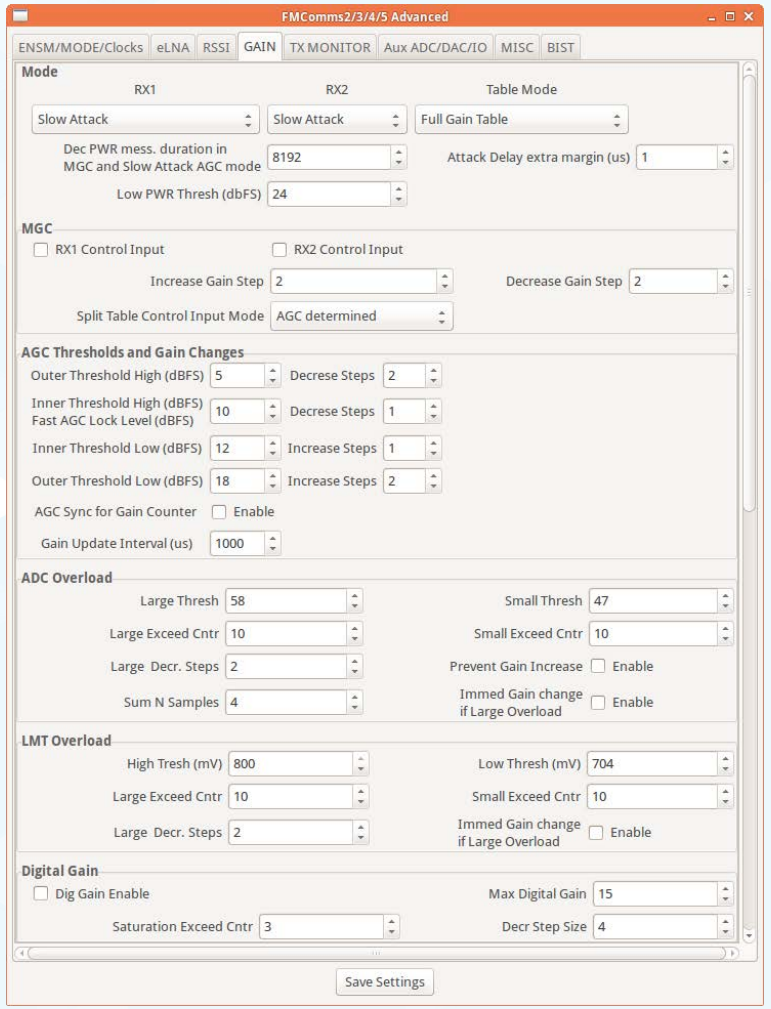
```
if (Modes.gain == MODES_AUTO_GAIN) {
        iio_channel_attr_write(phy_chn, "gain_control_mode", "slow_attack");
    } else {
        // We use 10th of dB here, max is 77dB up to 1300MHz
        if (Modes.gain > 770)
            Modes.gain = 770;
        iio_channel_attr_write(phy_chn, "gain_control_mode", "manual");
        iio_channel_attr_write_longlong(phy_chn, "hardwaregain", Modes.gain / 10);
    }
```

GAIN TABLES

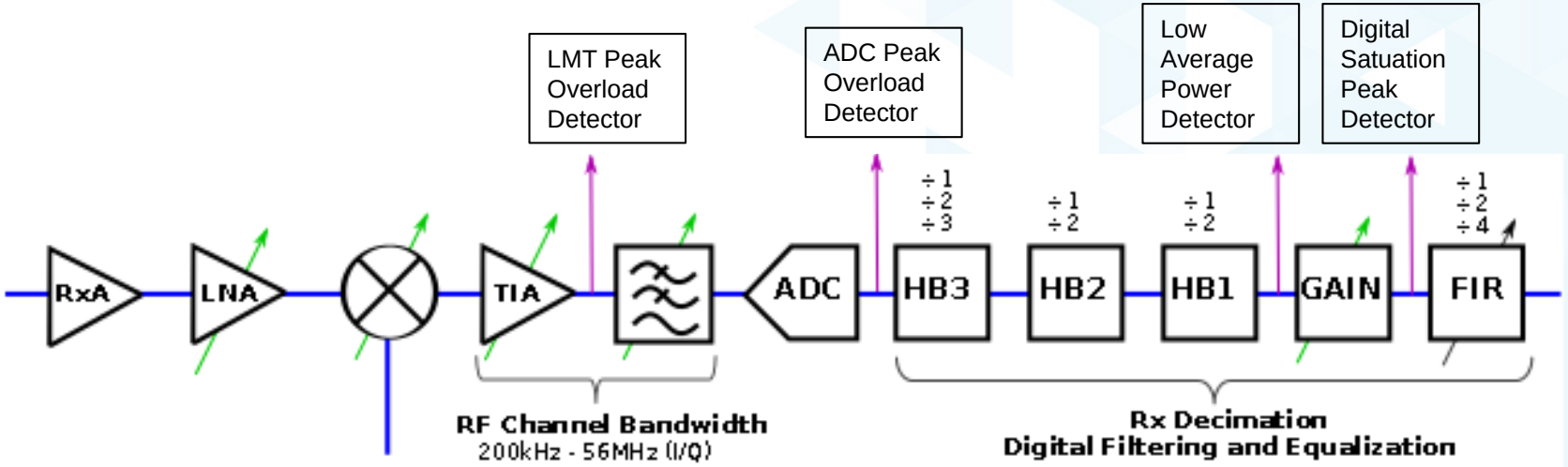


- Gain is variable in all stages with green arrows
- Two separate but identical receive paths
- Each Rx has own programmable HW gain table and index pointers.
- Pointer moves up and down the table, which changes the gain in one or more of the blocks shown left.
- Full Table and Split Table mode
- Fast, Slow and Manual Modes





GAIN CONTROL THRESHOLD DETECTORS



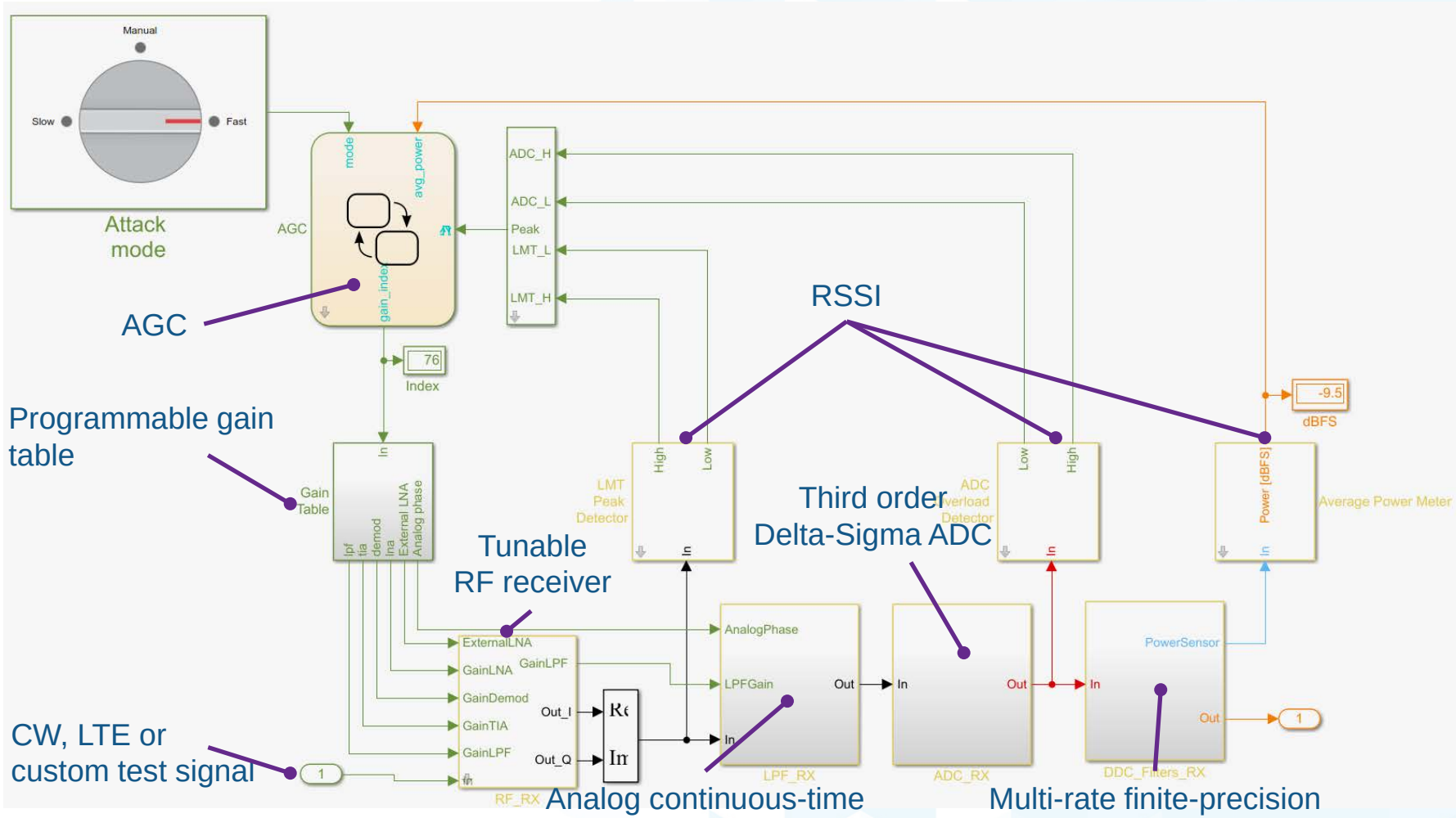
- Detectors are used:
  - Determine if the received signal is overloading a particular block
  - If the signal has dropped below programmable thresholds
- “LMT” and “ADC” Overload/Peak detectors react to nearly instantaneous overload events. (LMT is analog signal)
- In contrast - A digital power measurement in the AD9361 occurs over 16 or more Rx samples.

AD936X AGC Settings

```
# ls -C | grep agc
adi,2rx-2tx-mode-enable
adi,agc-adc-large-overload-exceed-counter
adi,agc-adc-large-overload-inc-steps
adi,agc-adc-lmt-small-overload-prevent-gain-inc-enable
adi,agc-adc-small-overload-exceed-counter
adi,agc-attack-delay-extra-margin-us
adi,agc-dig-gain-step-size
adi,agc-dig-saturation-exceed-counter
adi,agc-gain-update-interval-us
adi,agc-immed-gain-change-if-large-adc-overload-enable
adi,agc-immed-gain-change-if-large-lmt-overload-enable
adi,agc-inner-thresh-high
adi,agc-inner-thresh-high-dec-steps
adi,agc-inner-thresh-low
adi,agc-inner-thresh-low-inc-steps
adi,agc-lmt-overload-large-exceed-counter
adi,agc-lmt-overload-large-inc-steps
adi,agc-lmt-overload-small-exceed-counter
adi,agc-outer-thresh-high
adi,agc-outer-thresh-high-dec-steps
adi,agc-outer-thresh-low
adi,agc-outer-thresh-low-inc-steps
adi,agc-sync-for-gain-counter-enable
adi,aux-adc-decimation
adi,aux-adc-rate
adi,fagc-allow-agc-gain-increase-enable
adi,fagc-dec-pow-measurement-duration
adi,fagc-energy-lost-stronger-sig-gain-lock-exit-cnt
adi,fagc-final-overrange-count
adi,fagc-gain-increase-after-gain-lock-enable
adi,fagc-gain-index-type-after-exit-rx-mode
adi,fagc-lmt-final-settling-steps
adi,fagc-lock-level-gain-increase-upper-limit
adi,fagc-lock-level-lmt-gain-increase-enable
adi,fagc-lp-thresh-increment-steps
adi,fagc-lp-thresh-increment-time
adi,fagc-lpf-final-settling-steps
adi,fagc-optimized-gain-offset
adi,fagc-power-measurement-duration-in-state5
adi,fagc-rst-gla-adc-pulled-high-enable
adi,fagc-rst-gla-energy-lost-goto-optim-gain-enable
adi,fagc-rst-gla-engergy-lost-sig-thresh-below-ll
adi,fagc-rst-gla-engergy-lost-sig-thresh-exceeded-enable
adi,fagc-rst-gla-if-en-agc-pulled-high-mode
adi,fagc-rst-gla-large-adc-overload-enable
adi,fagc-rst-gla-large-lmt-overload-enable
adi,fagc-rst-gla-stronger-sig-thresh-above-ll
adi,fagc-rst-gla-stronger-sig-thresh-exceeded-enable
adi,fagc-state-wait-time-ns
adi,fagc-use-last-lock-level-for-set-gain-enable
adi,gpo3-slave-tx-enable
adi,gpo3-tx-delay-us
adi,mgc-dec-gain-step
adi,mgc-inc-gain-step
adi,mgc-rx1-ctrl-inp-enable
adi,mgc-rx2-ctrl-inp-enable
adi,mgc-split-table-ctrl-inp-gain-mode
adi,gpo-tracking-slow-mode-enable
adi,rf-rx-bandwidth-hz
adi,rf-tx-bandwidth-hz
adi,rssi-delay
adi,rssi-duration
adi,rssi-restart-mode
adi,rssi-unit-is-rx-samples-enable
adi,rssi-wait
adi,rx-fastlock-delay-ns
adi,rx-fastlock-pincontrol-enable
adi,rx-rf-port-input-select
adi,rx-rf-port-input-select-lock-enable
adi,rx1-rx2-phase-inversion-enable
adi,split-gain-table-mode-enable
adi,tdd-skip-vco-cal-enable
adi,tdd-use-dual-synth-mode-enable
adi,temp-sense-decimation
adi,temp-sense-measurement-interval-ms
#
```

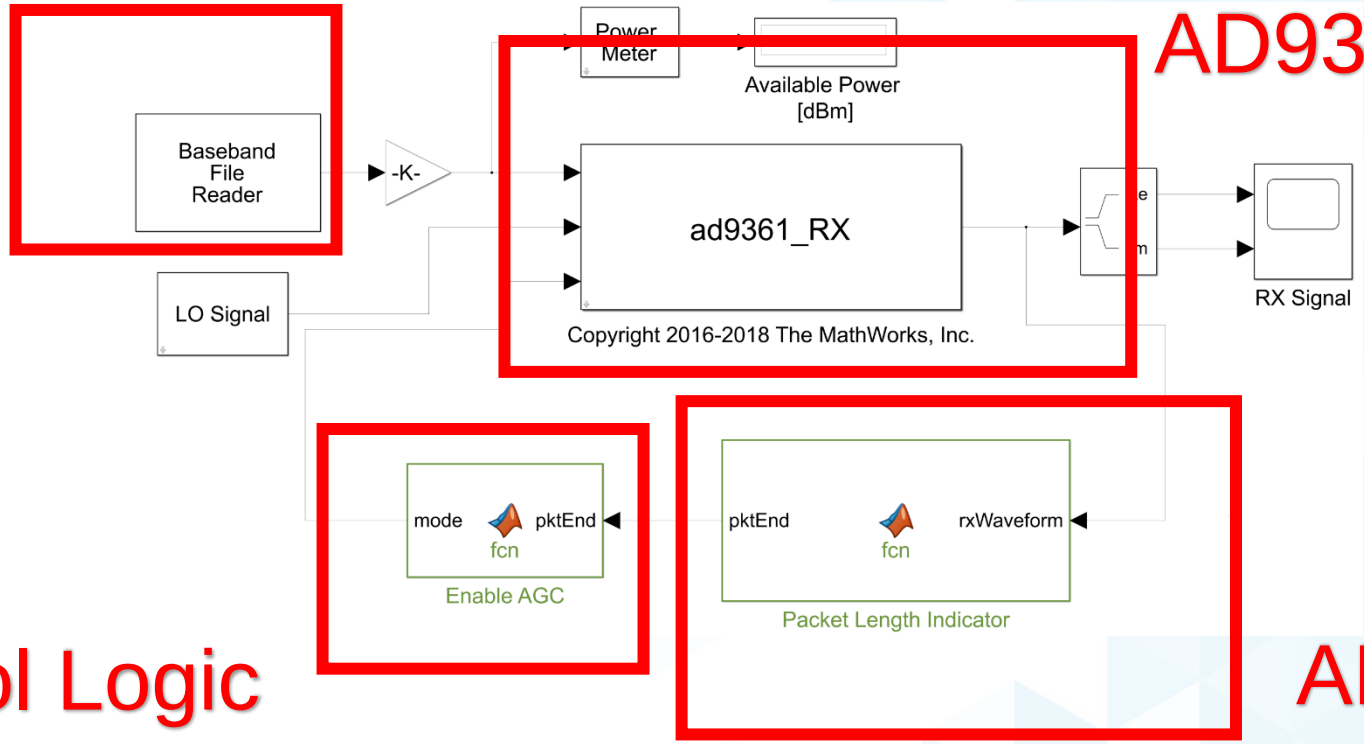
Too many settings to optimize!!

AD936X RF Model



Simulation Setup

Generated Waveforms

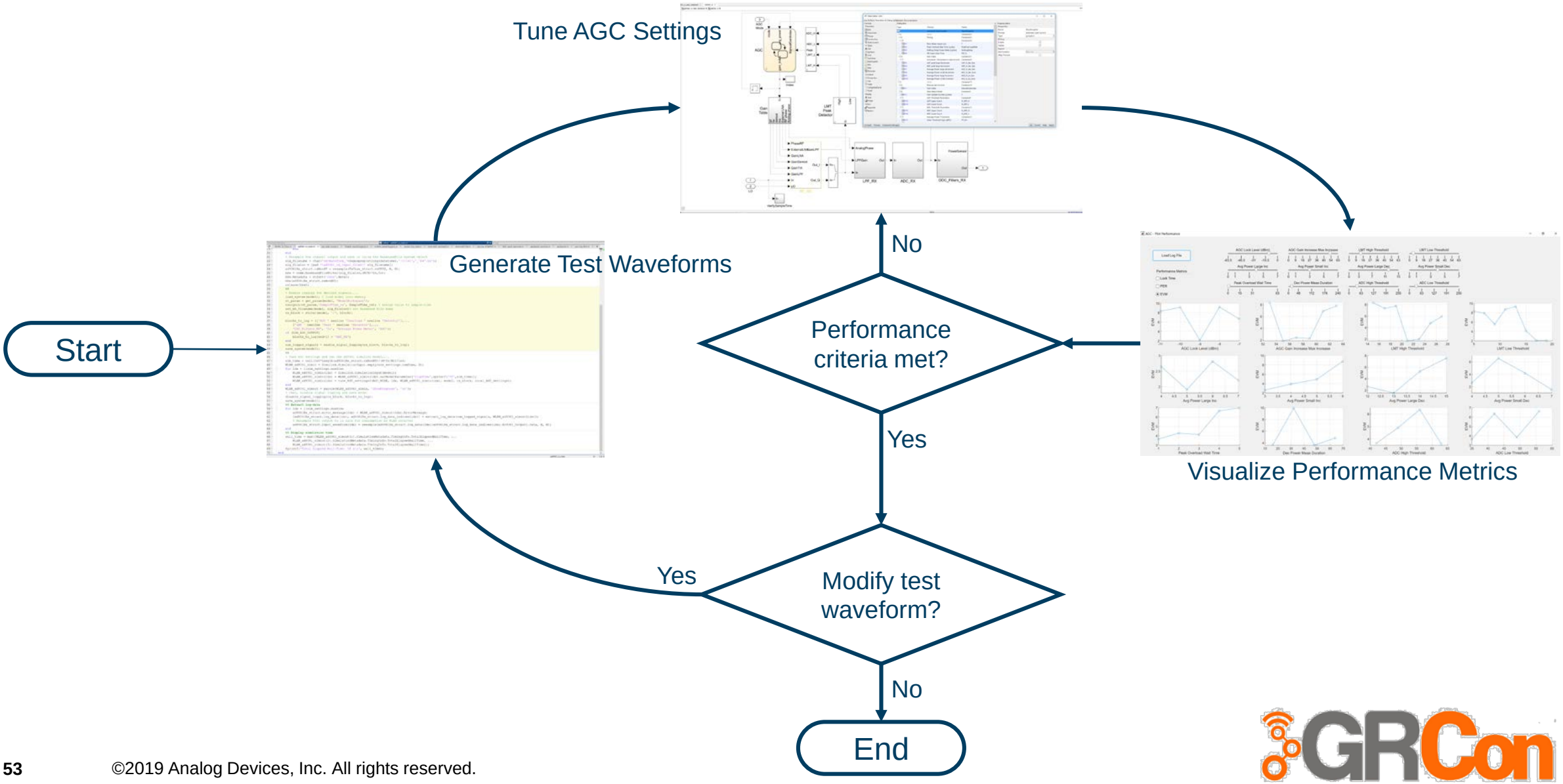


AD9361 Rx Model

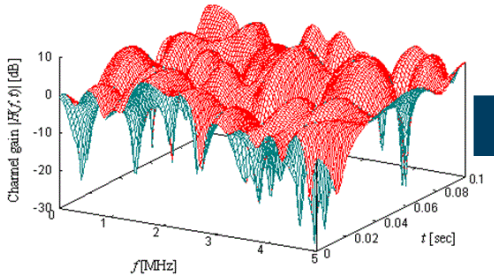
AGC Control Logic

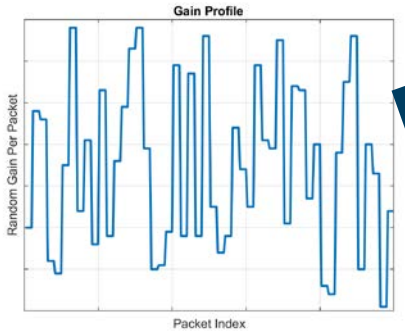
ADS-B Receiver

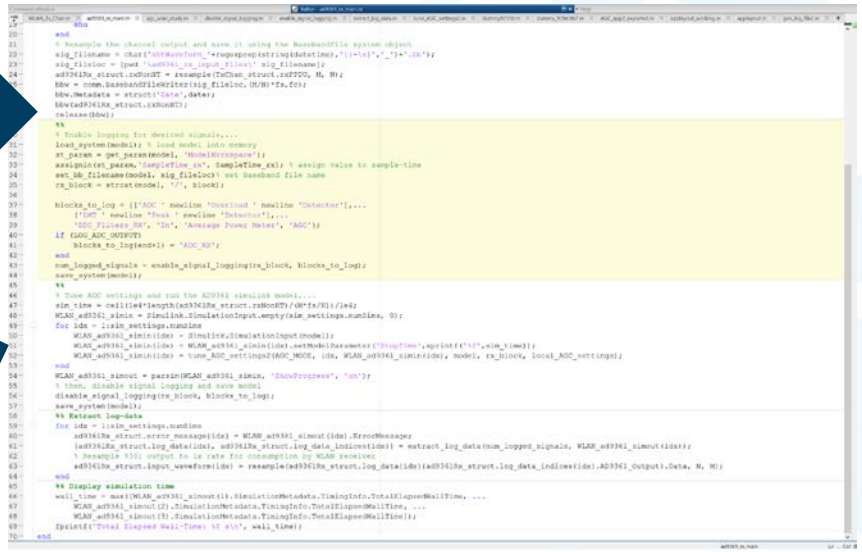
AGC Optimization Using Search Approach

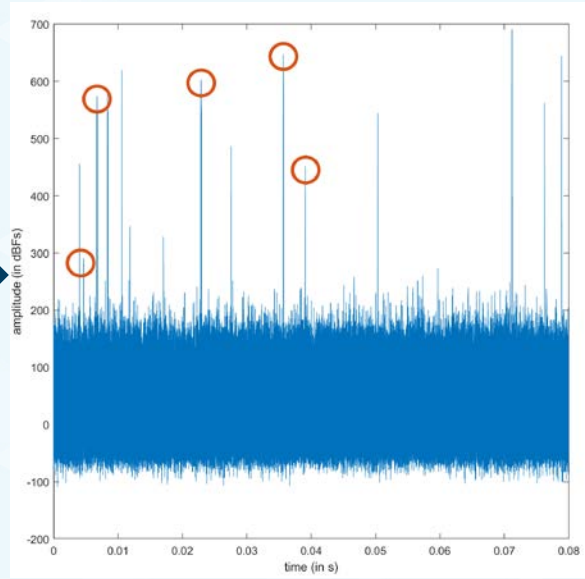


Test Waveform Generation: Example – ADSB





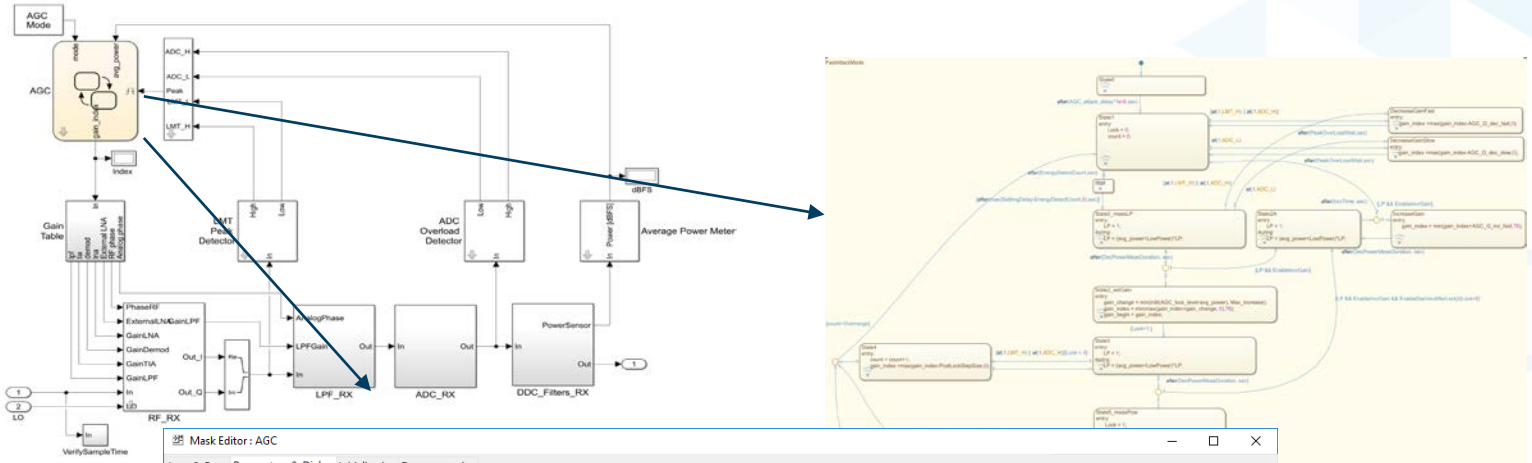


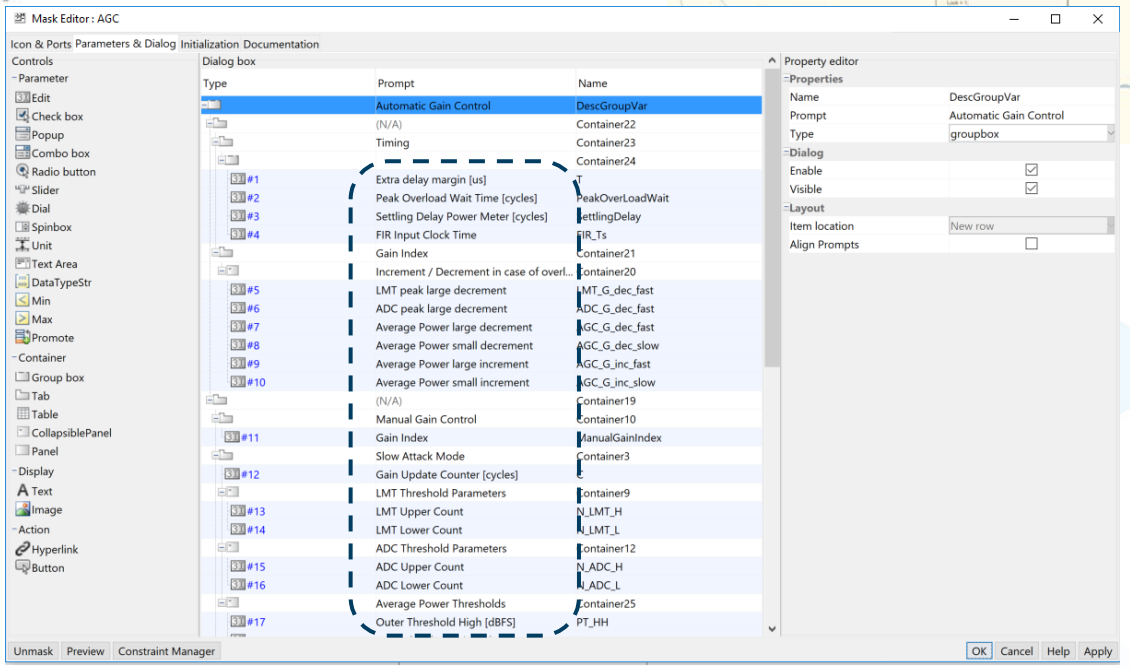


- Test waveforms are generated taking into account
  - modulation
  - packet structure
  - channel characteristics
  - gain profile

all of which influence AGC tuning.

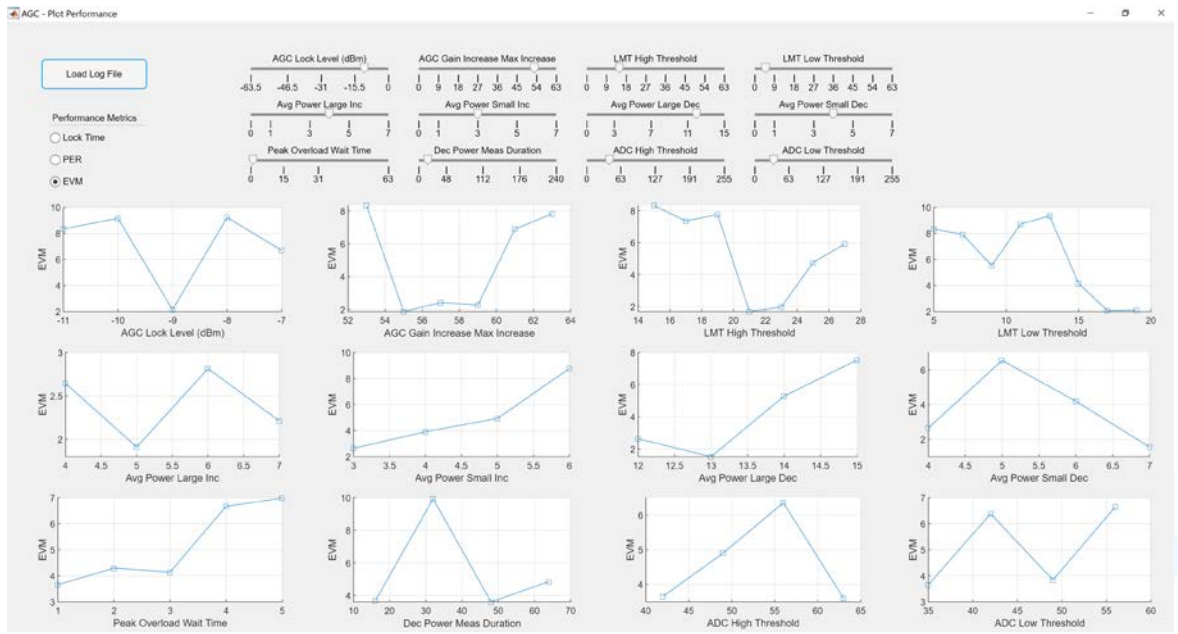
Tune AGC Settings





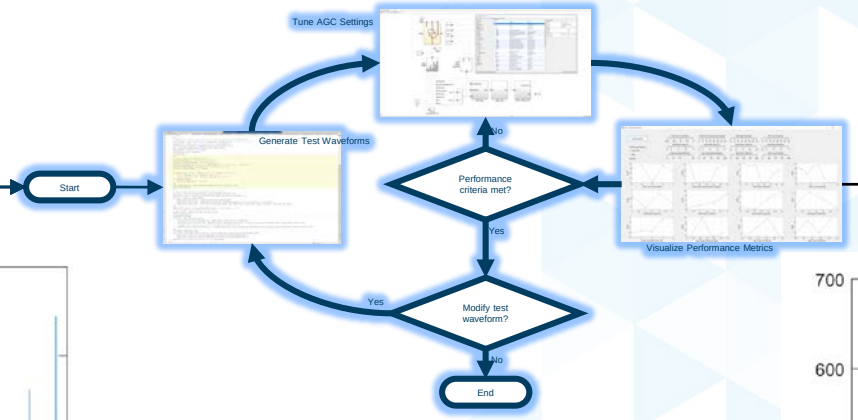
- AGC state machine is implemented using Stateflow.
- Settings can be tuned programmatically to create a flexible debug environment that relates the effect of various combinations of parameters over AGC lock time.
- The number of control inputs that can be logged using the model is not limited, unlike the physical device.
- Several signals that cannot be probed using the physical device can be visualized.
- AGC optimization requires iteratively tuning the parameters and identifying the specific combination that meets your performance criteria.

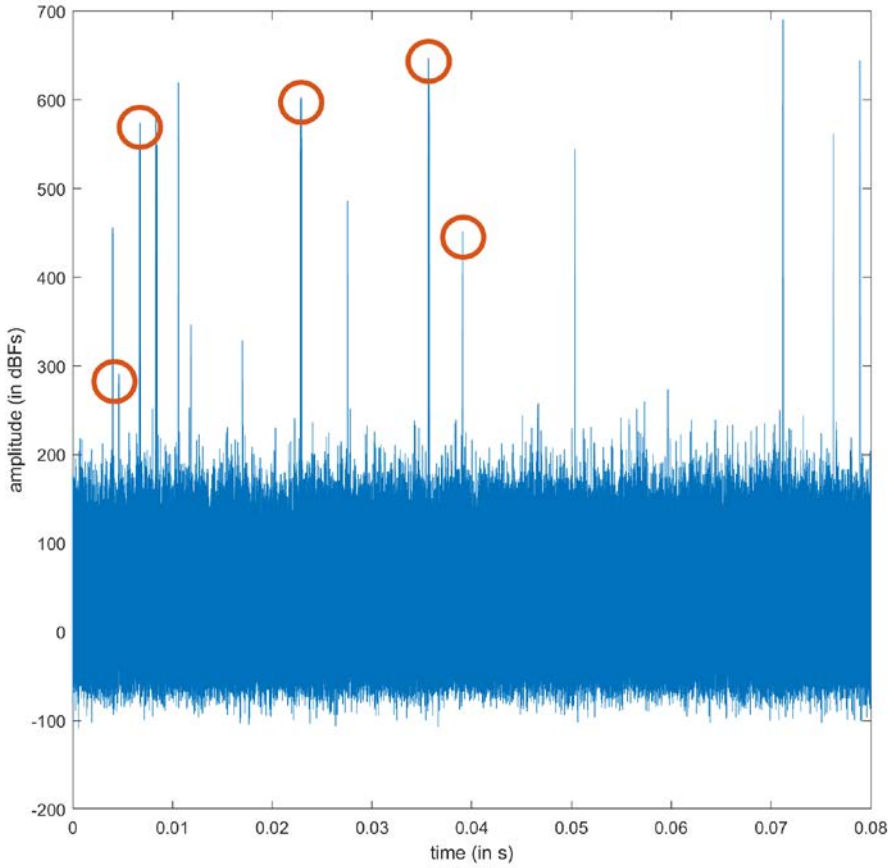
Performance Visualization

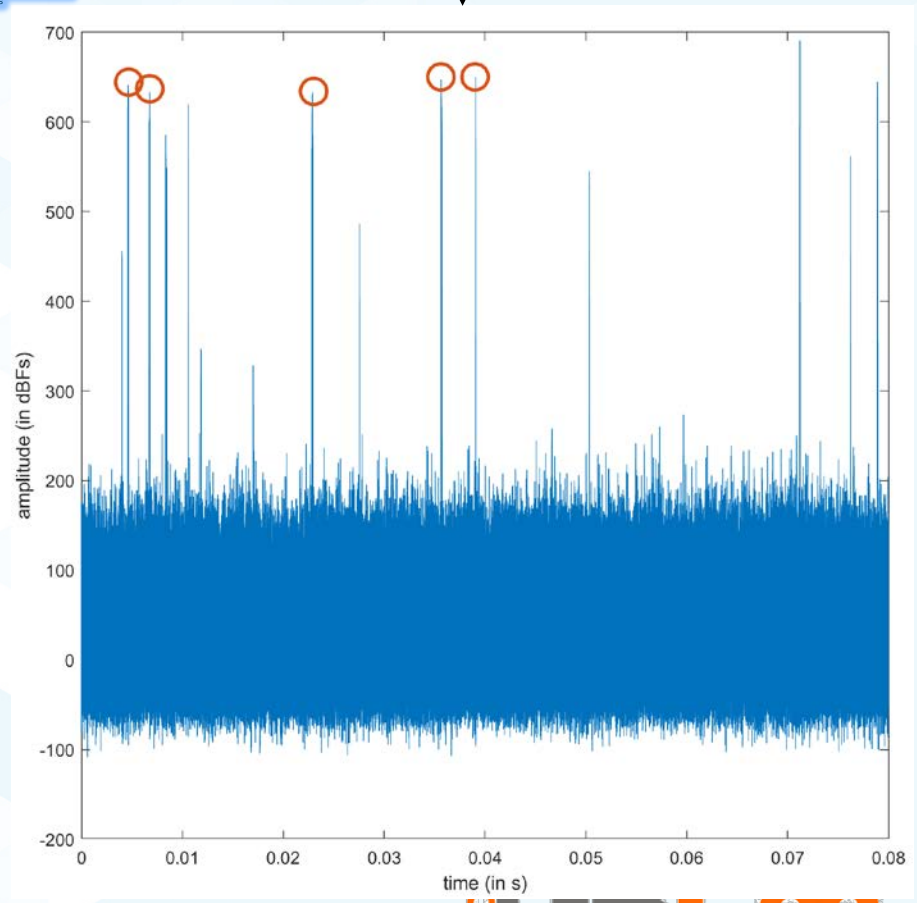


- AGC contains numerous settings, most of them allowing independent tuning over a wide range and fine grain step-sizes - a discrete multi-dimensional optimization problem.
- But, their effect on AGC optimization lends to classification.
- Therefore, the list of tunable AGC settings can be pruned and the tunable range of the remaining can be constrained in a methodical way.
- Consequently, we need a dynamical app that can be configured based on the settings selected for tuning.
- AD9361 AGC Wizard will help visualize the inter-dependent relationship between different settings and their affect on user-defined performance metrics such as AGC lock time, PER, EVM etc.

AGC Optimization Using Monte-Carlo Approach



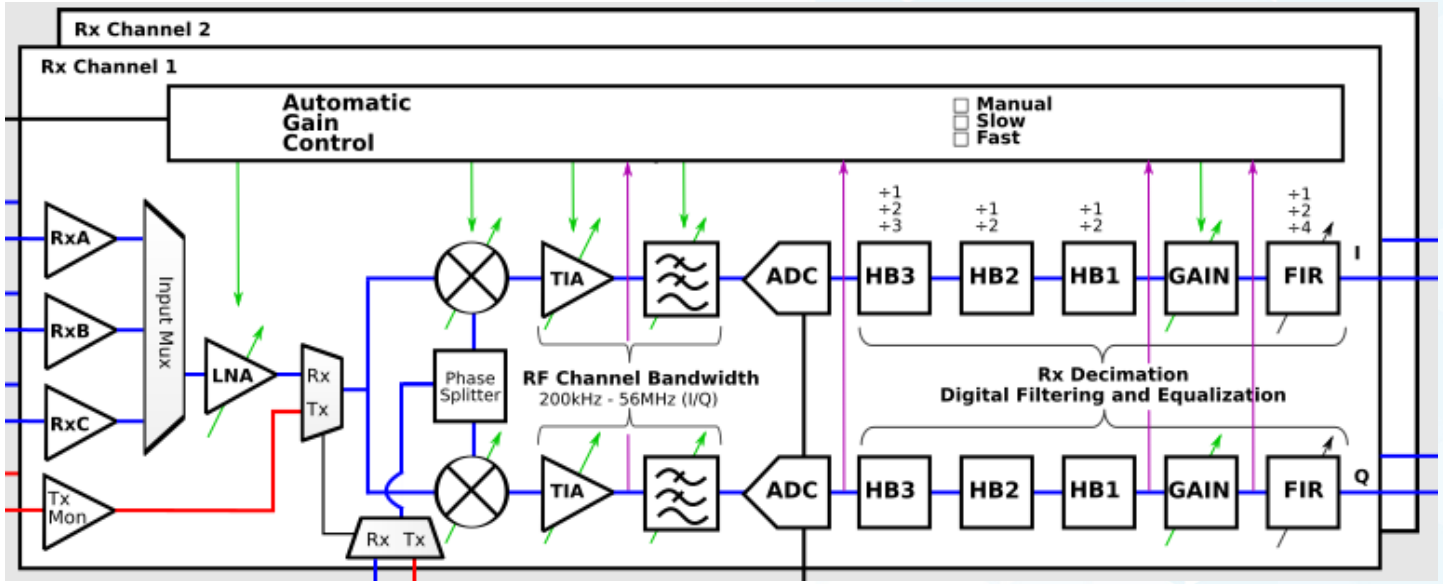




Example results

Model Name	Device Tree/Debug fs	Register	Value
LMT Peak Detector, High Threshold	adi,gc-lmt-overload-high-thresh	0x108[D5:D0]	30
LMT Peak Detector, Low Threshold	adi,gc-lmt-overload-low-thresh	0x108[D5:D0]	25
ADC Peak Detector, Number of Integration Cycles	adi,gc-adc-ovr-sample-size	0x0FC[D2:D0]	4
ADC Peak Detector, High Threshold	adi,gc-adc-large-overload-thresh	0x105	63
ADC Peak Detector, Low Threshold	adi,gc-adc-small-overload-thresh	0x104	56
Average Power Meter, Number of Integration Cycles	adi,gc-dec-pow-measurement-duration	0x15C[D3:D0]	16
Low Power Threshold	adi,gc-low-power-thresh	0x114[D6:D0],	40
Energy Lost Level	adi,fagc-rst-gla-engergy-lost-sig-thresh-below-ll	0x112[D5:D0],	3
AGC Max Increase	adi,fagc-lock-level-gain-increase-upper-limit	0x118[D5:D0]	63
Average Power Large Increment	adi,fagc-lp-thresh-increment-steps	0x117[D7:D5],	7
Average Power Large Decrement		0x106[D6:D4]	7
Average Power Small Decrement	adi,agc-lmt-overload-large-inc-steps	0x103[D4:D2]	3
AGC Lock Level		0x101[D6:D0]	11

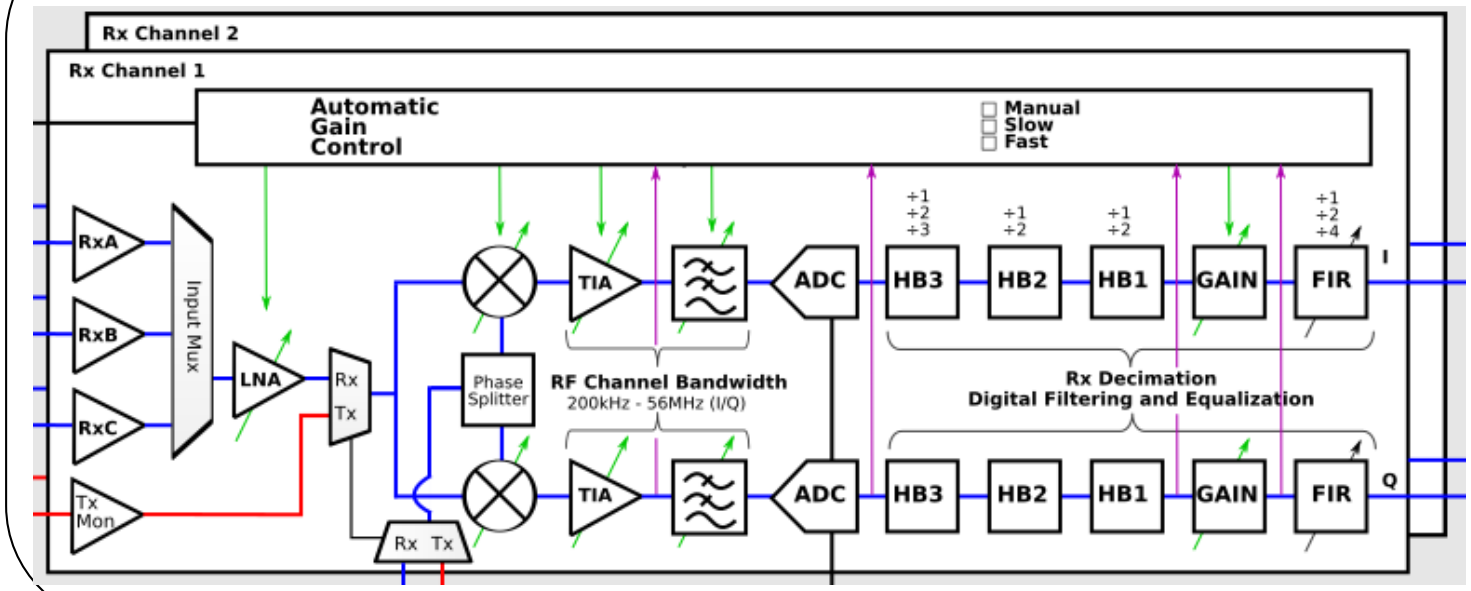
Receiver Settings



- Receiver Analog Filters, Digital Filters, need settings too.
  - No point in over filtering (throw away data that makes it easier to decode)
  - Don’t let noise into system
  - Does not need to be the same as Tx

Reciever

ADALM-PLUTO



12 MSPS

FPGA

correlators

gate

Decimation by 5 or 6

2.4 or 2.0 MSPS

ARM

decode

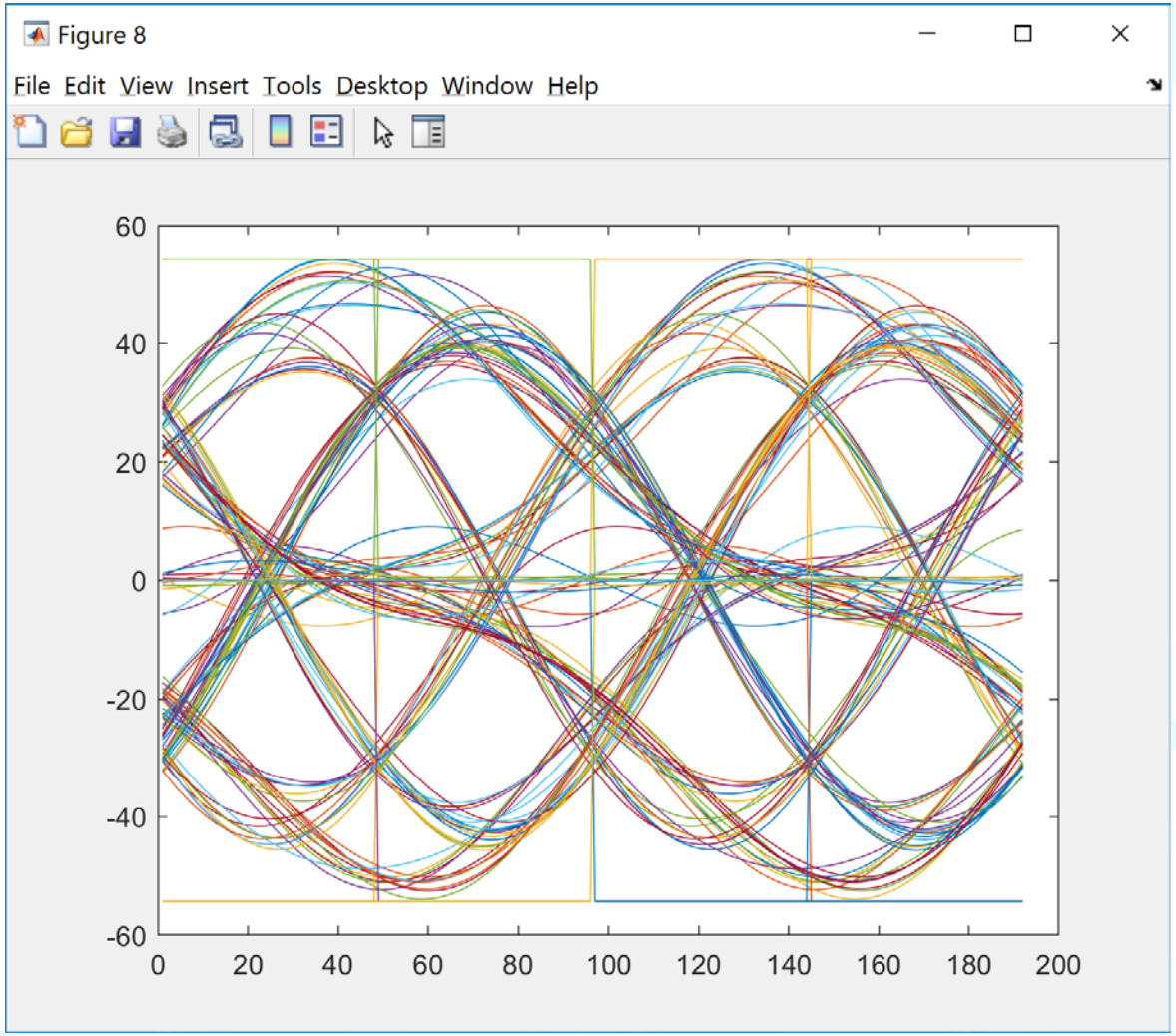
Open-sky Network

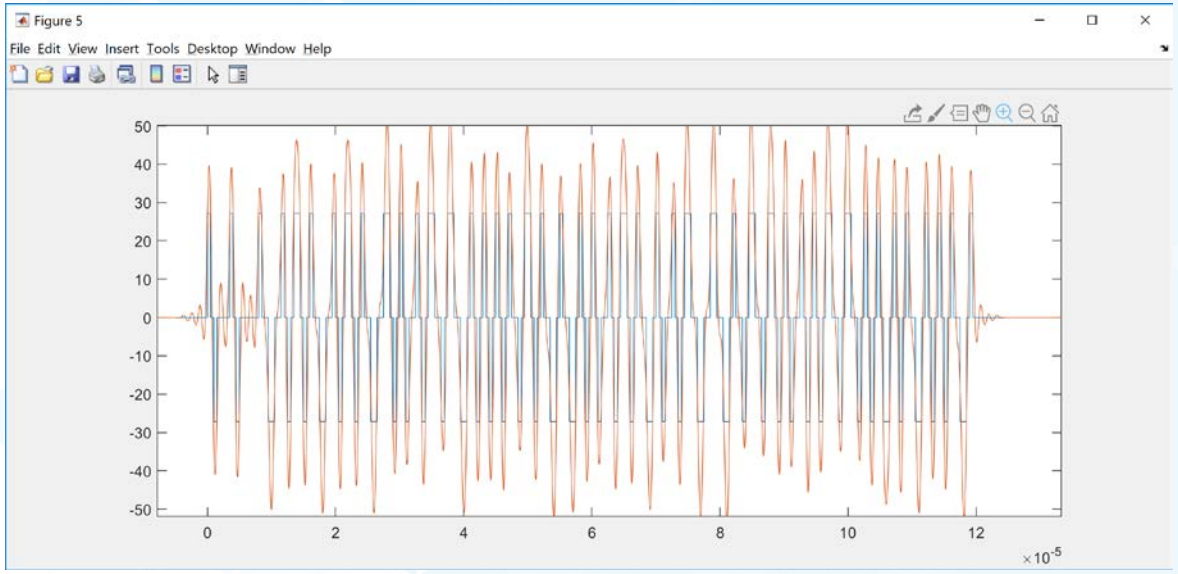
USB Ethernet

Internet

- Output data rate of 12 MSPS, use FPGA to search for pre-amble, and align samples to the correct phase
- https://wiki.analog.com/resources/eval/user-guides/picozed_sdr/tutorials/adsb

Step 3: Optimize algorithm





- Signal is 48x oversampled (at 2MSPS),
  - 48 different phases to look at
- Signal is 40x oversampled (at 2.4 MSPS)
  - 40 different phases to look at

Algorithm Improvements

https://github.com/mutability/dump1090

- Moved Sample Rate to 2,400,000
  - Upper limit of RTLSDR

- When sampling at 2.4MHz we have exactly 6 samples per 5 symbols.
  - Each symbol is 500ns wide, each sample is 416.7ns wide
  - We maintain a phase offset that is expressed in units of 1/5 of a sample i.e. 1/6 of a symbol, 83.333ns
  - Each symbol we process advances the phase offset by 6 i.e. 6/5 of a sample, 500ns
  - The correlation functions below correlate a 1-0 pair of symbols (i.e. manchester encoded 1 bit) starting at the given sample, and assuming that the symbol starts at a fixed 0-5 phase offset within m[0]. They return a correlation value, generally interpreted as >0 = 1 bit, <0 = 0 bit

Testing is easy

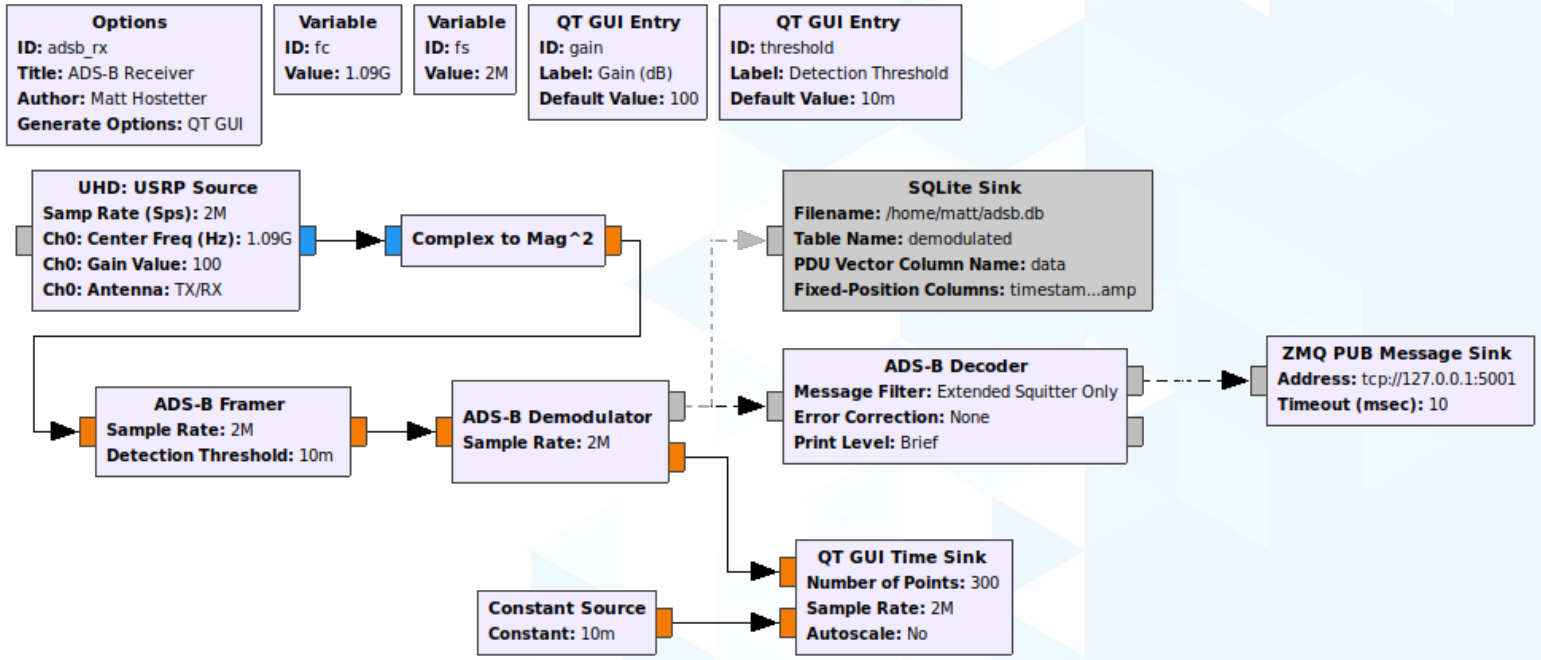
```
ifile-specific options (use with --ifile)

   --ifile <path>          read samples from given file ('-' for stdin)
   --iformat <type>        set sample format (UC8, SC16, SC16Q11)
   --throttle              process samples at the original capture speed
```

gr-adsb

A GNU Radio out-of-tree (OOT) module to demodulate and decode Automatic Dependent Surveillance Broadcast (ADS-B) messages.

https://github.com/mhostetter/gr-adsb




```
# Calculate the samples/symbol
# ADS-B is modulated at 1 Msym/s with Pulse Position Modulation, so the effective
# required fs is 2 Msps
self.fs = fs
assert self.fs % SYMBOL_RATE == 0, "ADS-B Demodulator is designed to operate on an integer number of samples per symbol, not %f sps" % (self.fs / SYMBOL_RATE)
self.sps = int(fs // SYMBOL_RATE)
```

Step 4: Optimize external Rx path

(a) Make signal louder, and (b) only Receive at 1090 MHz

- Contains Outdoor Vertical External 1090 MHz Antenna with respective cable to connect to your device
- Gain 7dBi, Impedance 50Ω±5Ω, Vertical Polarization
- Fiberglass and Aluminum Alloy
- Weatherproof tested in extreme conditions

https://www.amazon.com/AirNav-ADS-B-Outdoor-Antenna-Connector/dp/B07K7YW1XJ/ref=asc_df_B07K7YW1XJ

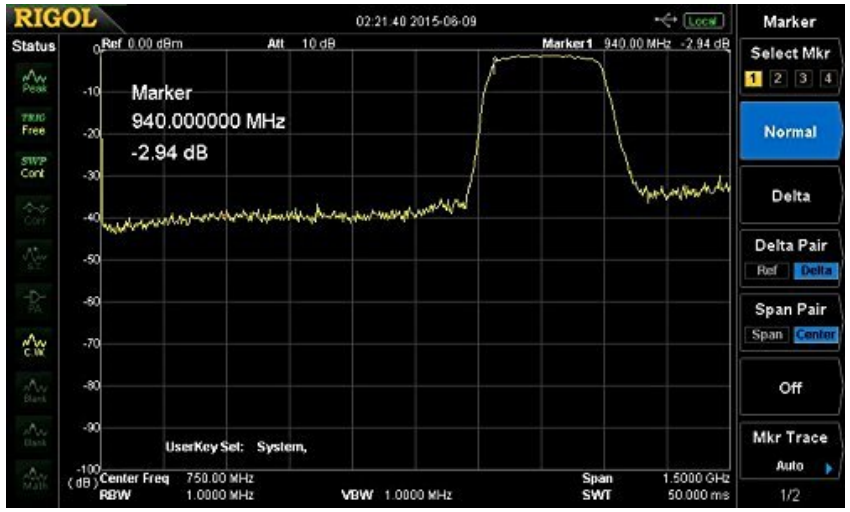
RAMI AV-22 TRANSPONDER ANTENNA

AV-22 is a rod style transponder antenna utilizing its BNC connector for mounting to the airframe. The antenna is designed to operate at speeds up to 350 mph and altitudes up to 50,000 feet.

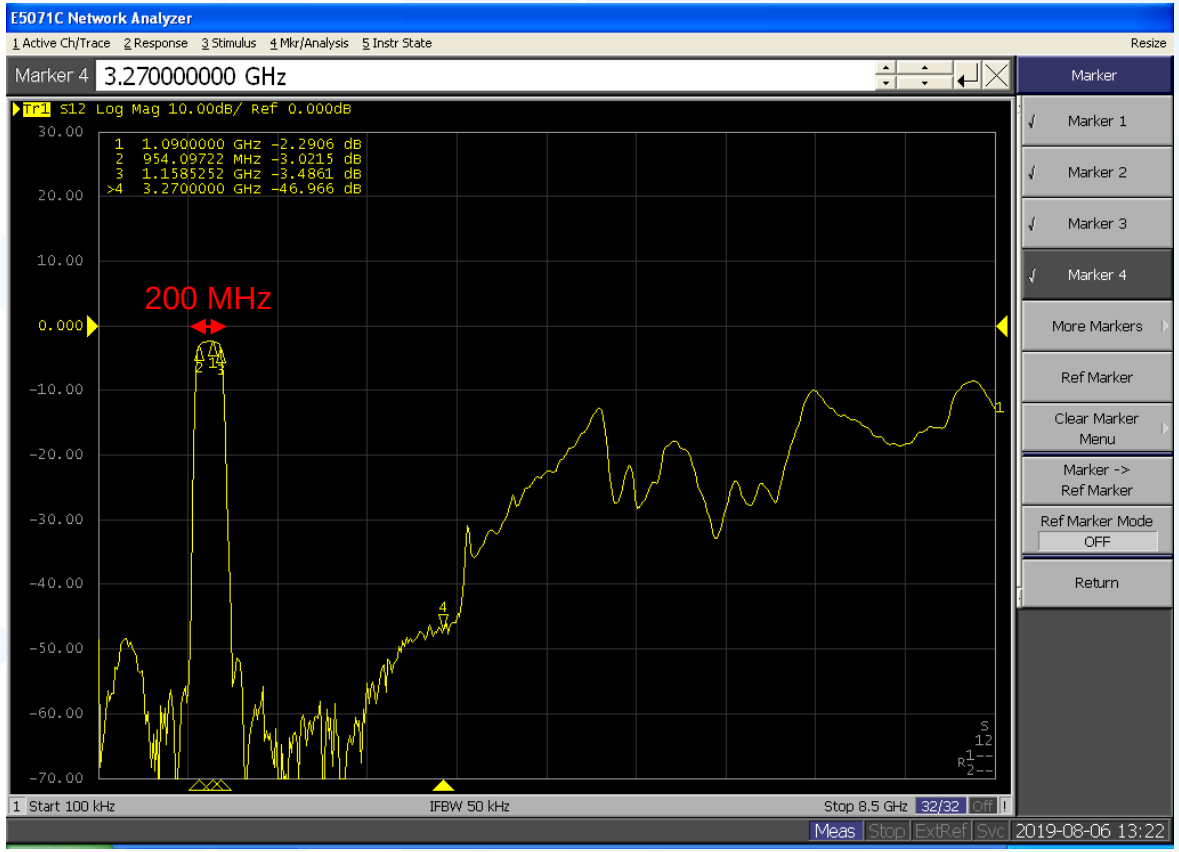
https://discussions.flightaware.com/t/three-easy-diy-antennas-for-beginners/16348/3

FlightAware filter

https://www.amazon.com/ADS-B-1090MHz-Band-pass-SMA-Filter/dp/B010GBQXK8

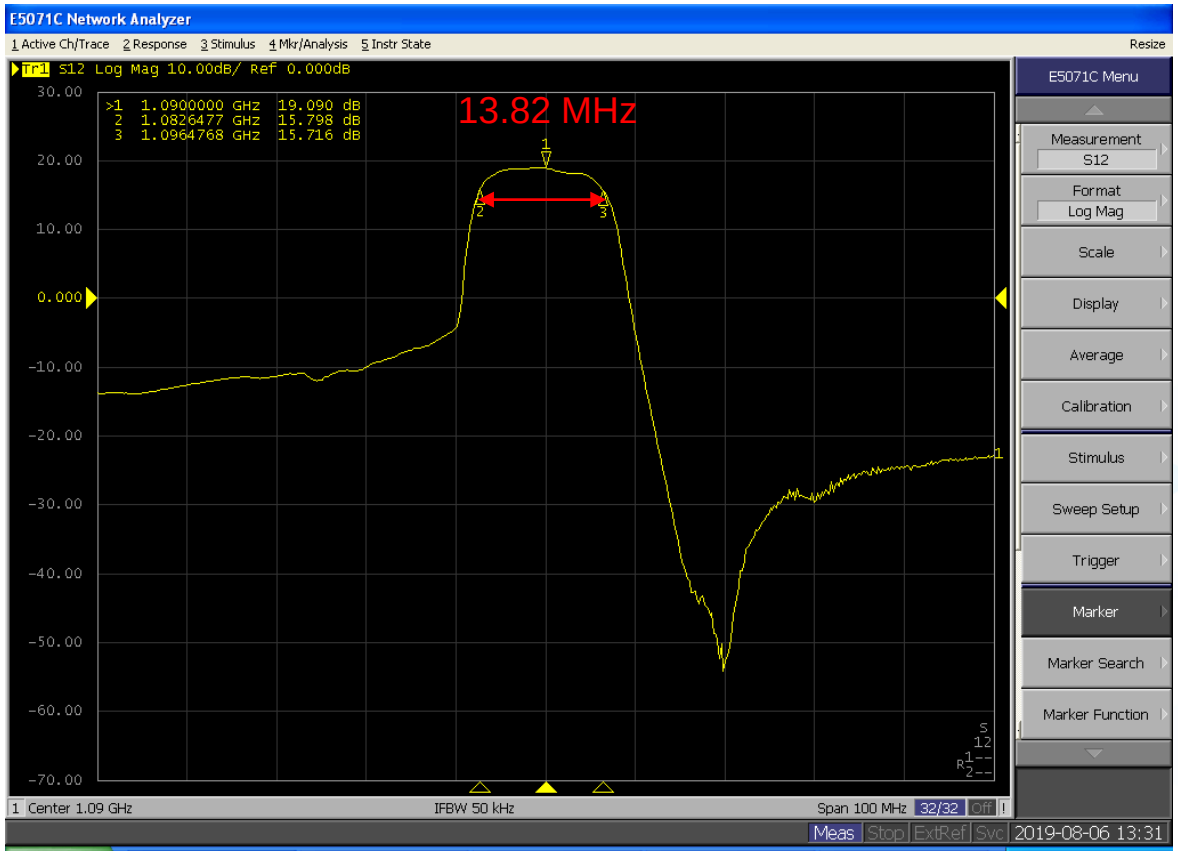


My measurement -2.2 dB insertion loss

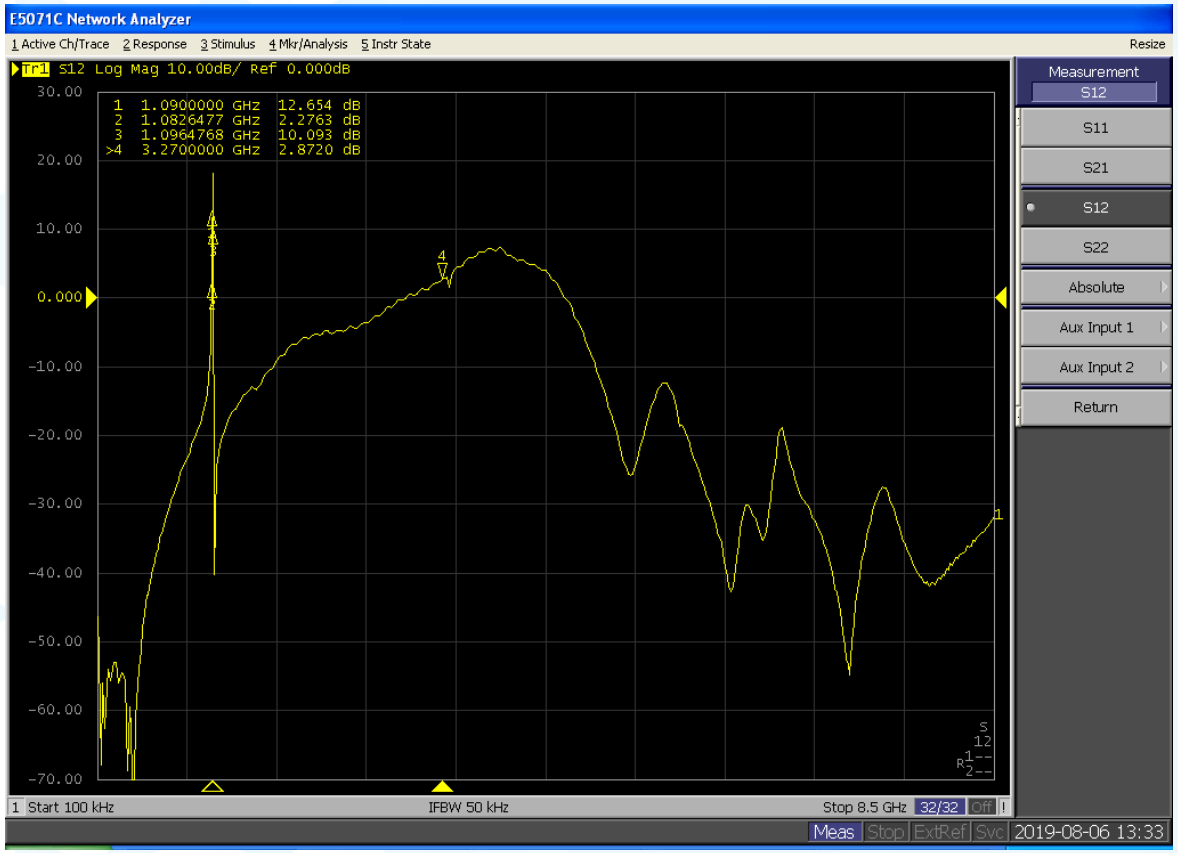


SMAKN 1090M ADS-B Filter +LNA

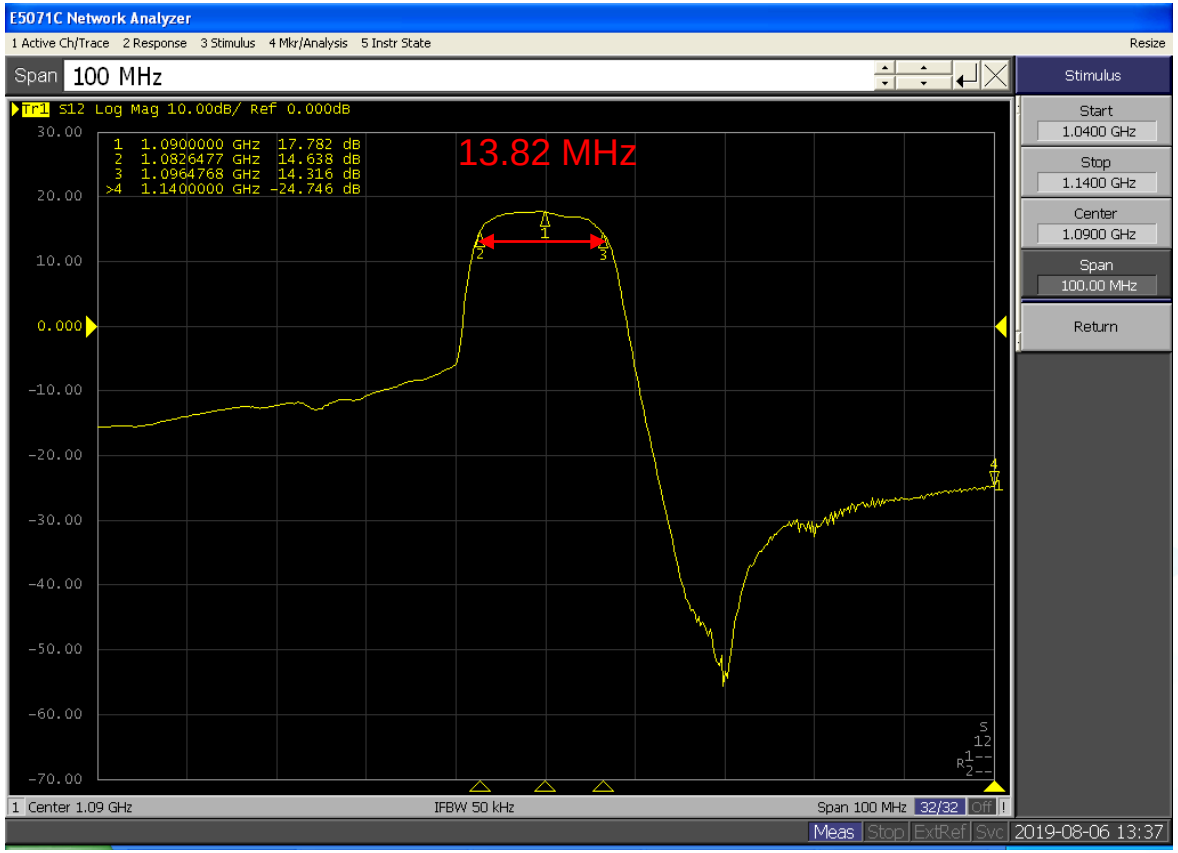
https://www.amazon.com/gp/product/B07M5JRDD4/ref=ppx_yo_dt_b_asin_title_o01_s00

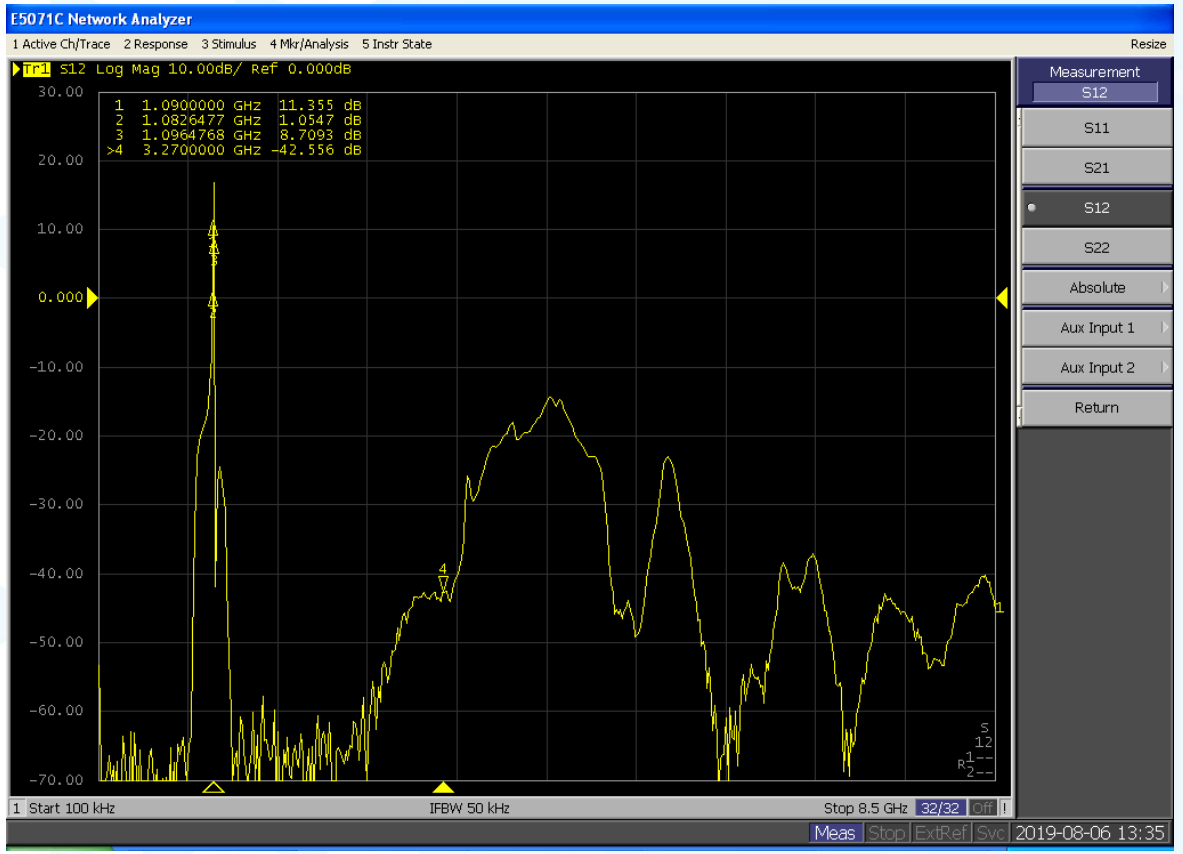


Gain at the 3rd harmonic (3.72 GHz)



Both 1090 solutions together

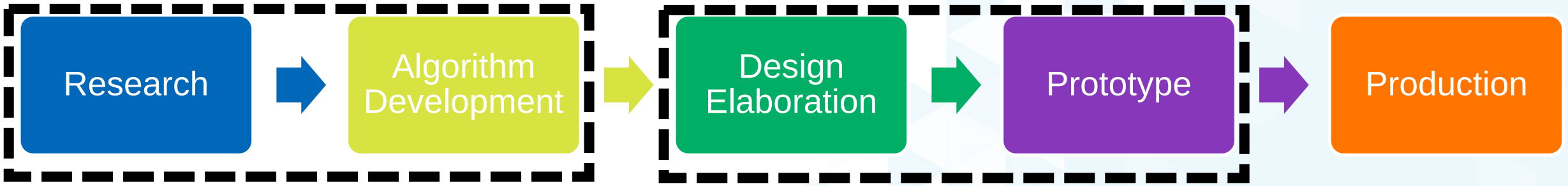


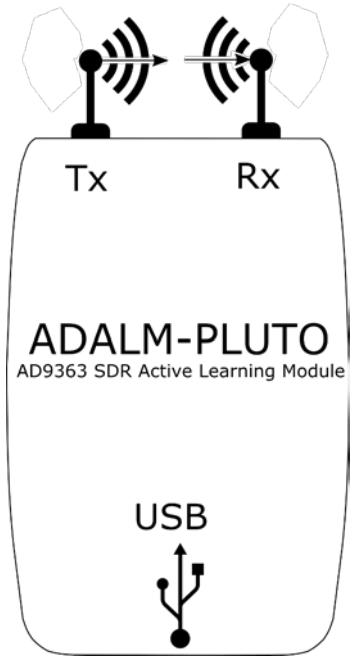


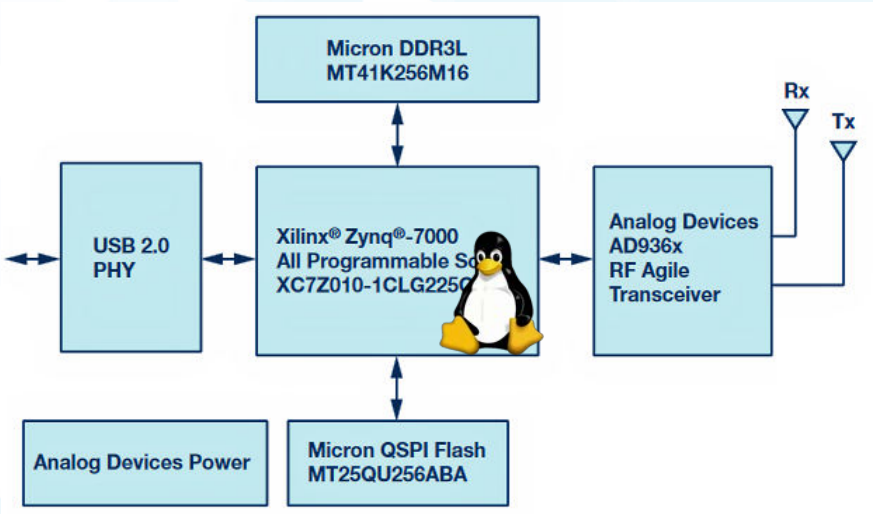
Step 5 : Production

Figure out Signal processing

Get Signal processing embedded







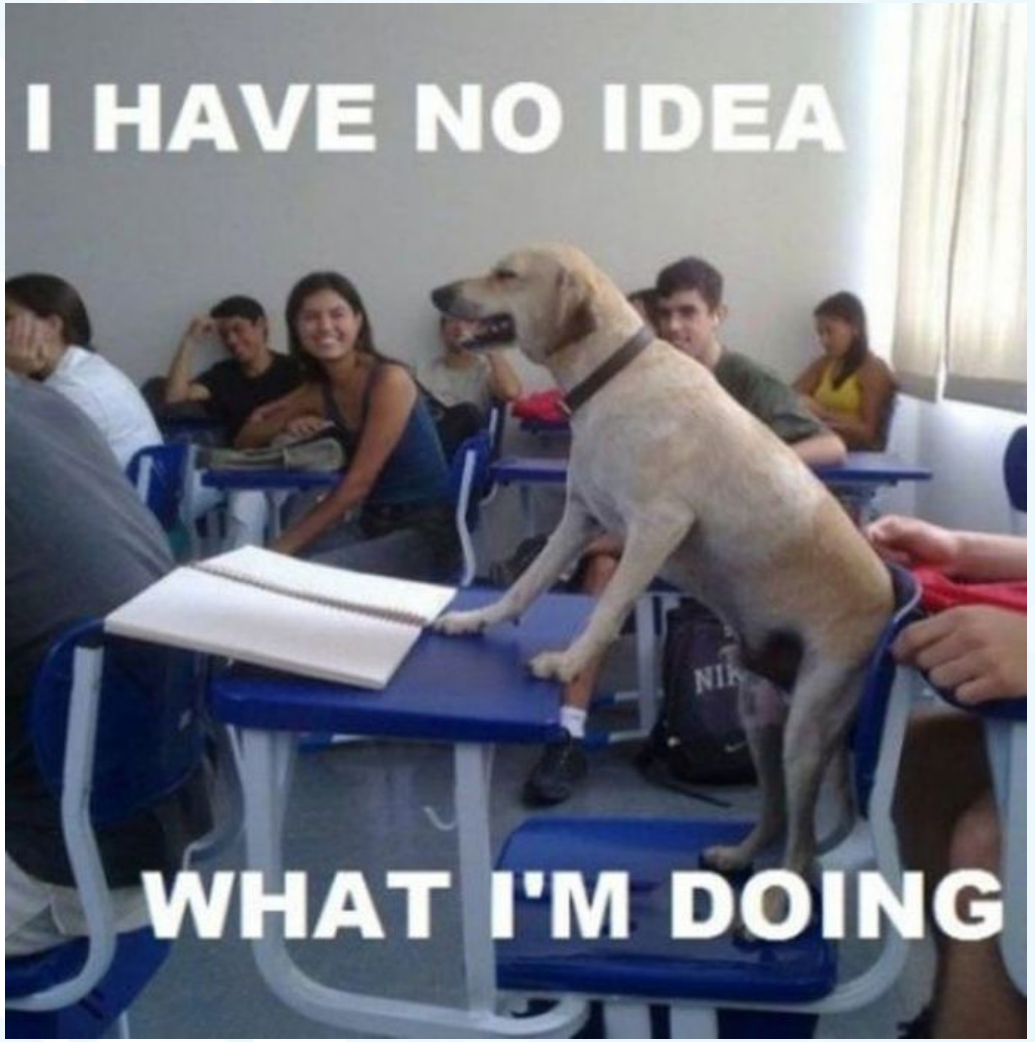
Pretty Easy

1. Cross Compile dump1090 for ARM (pluto)
2. Feed to opensky-network
   - Only a .deb for pi exists?
   - Extract it and manually install it it on plutosdr
     - armhf is same
     - uClibc vs glibc – shouldn't matter if everyone does their job proplery

- Create a small cgi / shell script to turn it on/off

Step 6: Maintenance and improvements

- Software maintenance costs will typically form 75% of TCO.
  - https://galorath.com/software-maintenance-costs/
- when it comes to software, 60% costing is for maintenance
  - Mr. Robert Glass, writer of the ‘Facts and Fallacies of Software Engineering’
- Lack of test cases – makes long term maintenance worse



Things to do

- Send patches upstream
- Make firmware public

- Add more modern communications DSP to decode algorithms, at higher rates
- Implement preamble detection in HDL at high rates, so picking the right phase is done at high speed.

- Fix the web interface so it doesn't need an internet connection

- https://www.tsa.gov/travel/security-screening/whatcanibring/items/radio

Radio

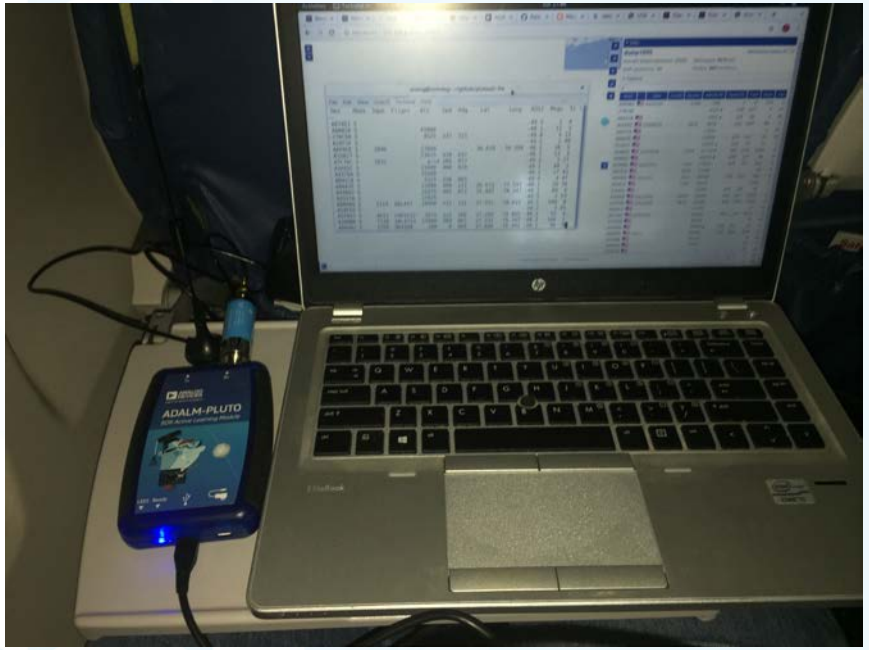
Carry On Bags: Yes

Checked Bags: Yes

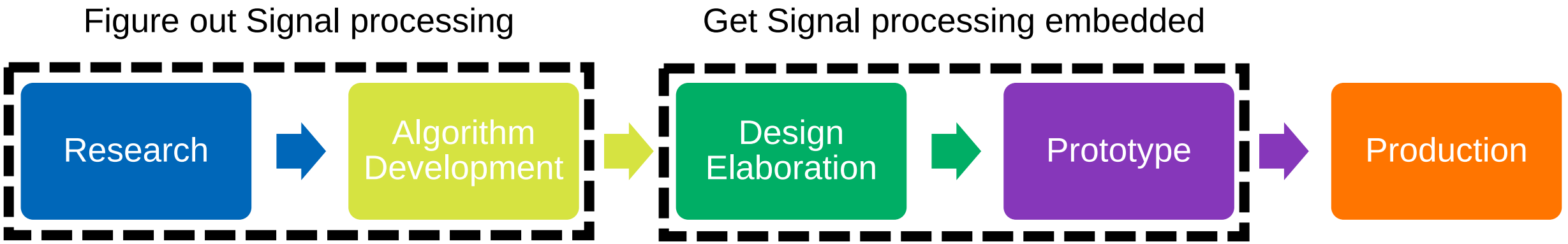
You may transport this item in carry-on or checked bags. For items you wish to carry on, you should check with the airline to ensure that the item will fit in the overhead bin or underneath the seat of the airplane.

For more prohibited items, please go to the 'What Can I Bring?' page.

The final decision rests with the TSA officer on whether an item is allowed through the checkpoint.



Thanks



- Real World Communications Systems are all about the weakest link.
  - Environment
  - Antenna / LNA / PA
  - SDR
  - SDR Setup / Configuration
  - Algorithm
  - Implementation

Any Questions?