North Texas NTMS Microwave Society

Multi-band SDR microwave radios

Jim McMasters KM5PO

January 18th, 2025

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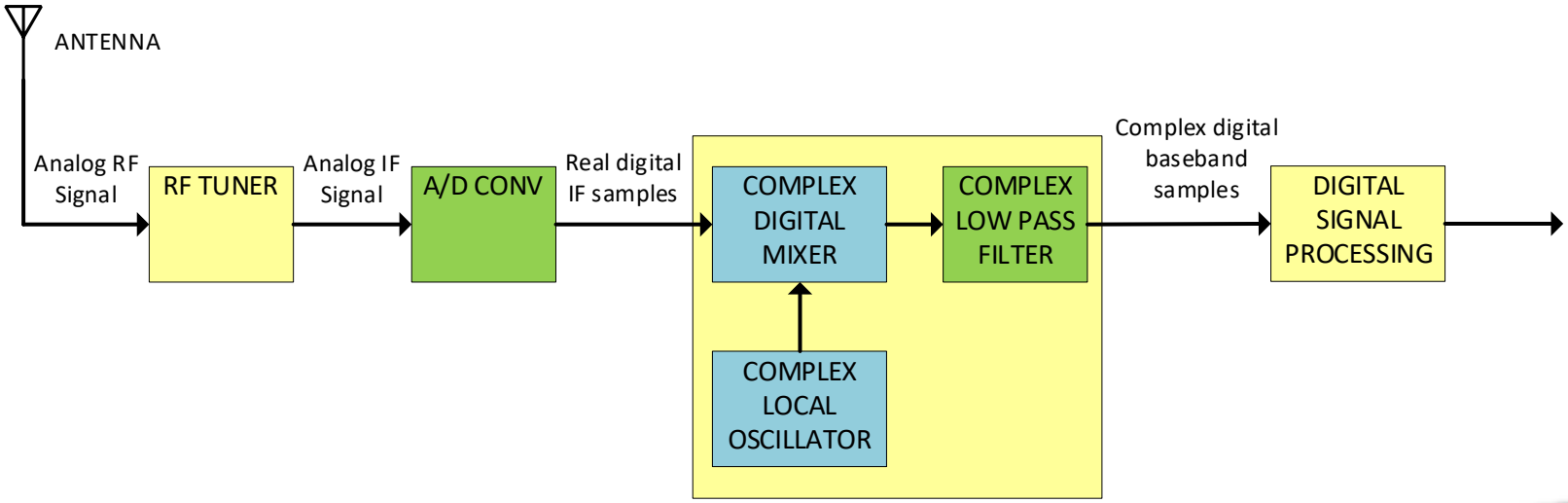
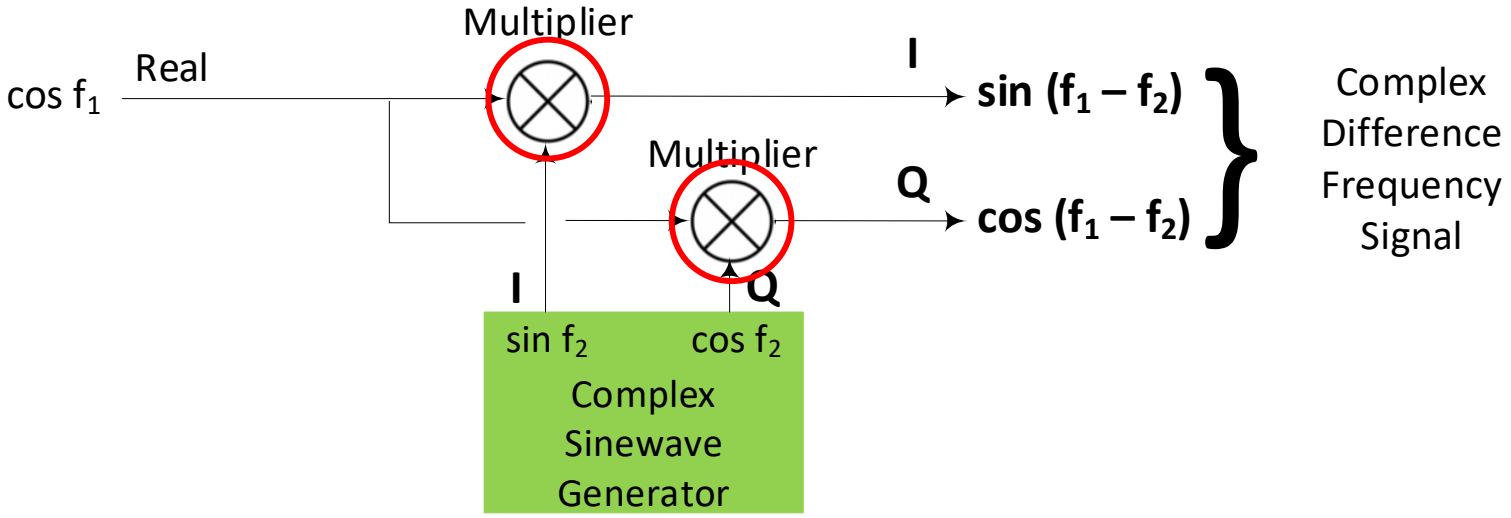
Software Radio Receiver

- RF Tuner down converts analog RF signals to analog IF frequencies
- A/D converter digitizes the IF signal creating real digital samples
- Digital Mixer & Local Oscillator translate digital IF to complex baseband
- Complex digital FIR low pass filter limits the baseband signal bandwidth
- The Mixer, Local Oscillator and Down sampling Low Pass Filter could be named a Digital Down Converter
- Digital signal processing stage performs signal demodulation, etc.



How to make a Complex signal

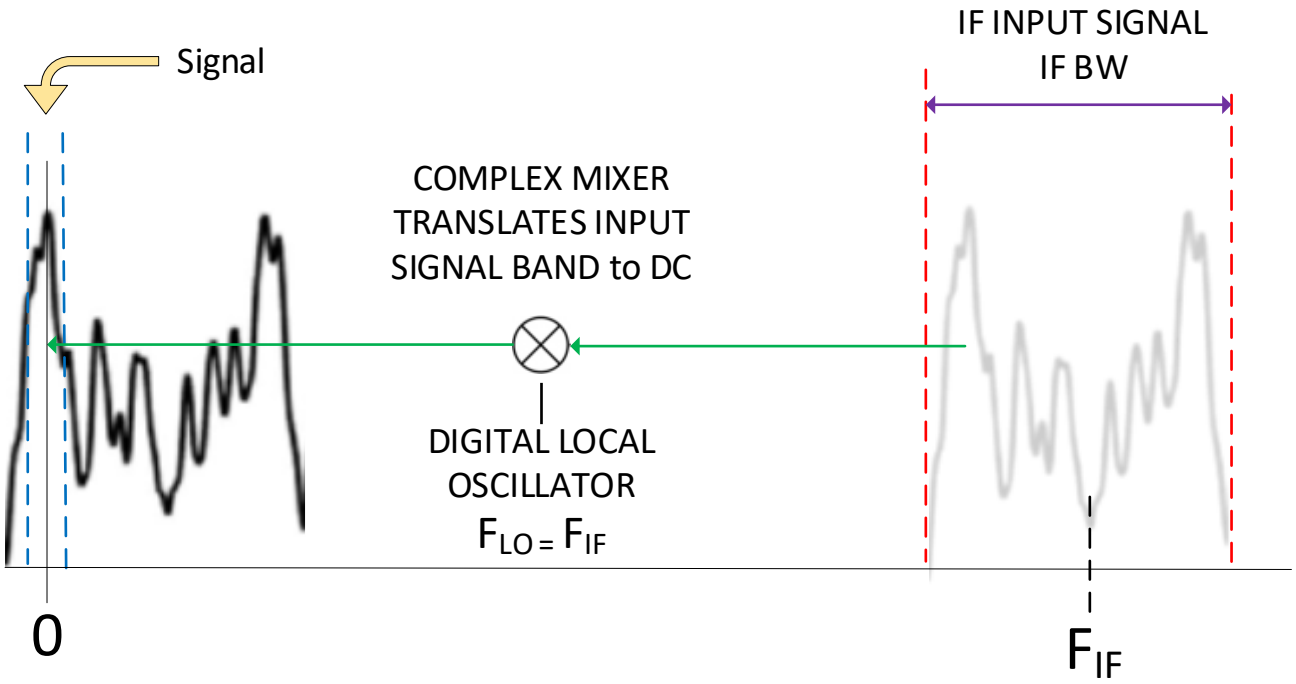
- Multiply a real signal (f_1) by a complex sinewave signal generator (f_2)



- From math class
  - $\cos f_1 \times \sin f_2 = \frac{1}{2}\{\sin (f_1 - f_2) - \sin (f_1 + f_2)\}$
  - $\cos f_1 \times \cos f_2 = \frac{1}{2}\{\cos (f_1 - f_2) + \cos (f_1 + f_2)\}$
- Remove the higher frequency sum components
- Complex multiplication performs two operations
  - Translates the input signal (f_1) down to the difference frequency ($f_1 - f_2$)
  - Converts the real input signal to a complex difference frequency signal

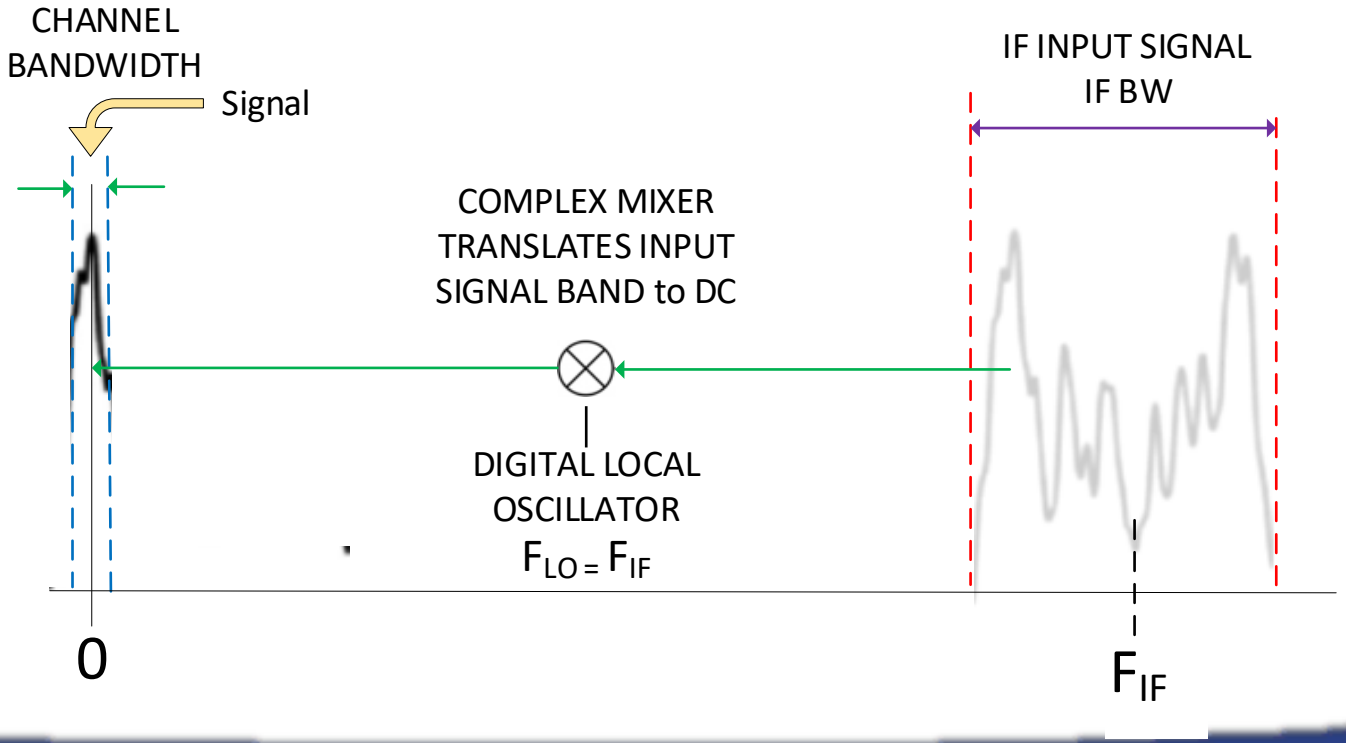
Complex Digital Translation

- IF band contains many signals within its bandwidth
- Digital complex mixer translates desired input signal within the IF band directly down to 0 Hz or DC as a complex signal



Filter Bandlimiting

- Complex Low Pass Filter bandwidth is set to match desired bandwidth of received channel
- At the output of the Low Pass Filter, the complex baseband signal bandwidth has been reduced



Software Radio Transmitter

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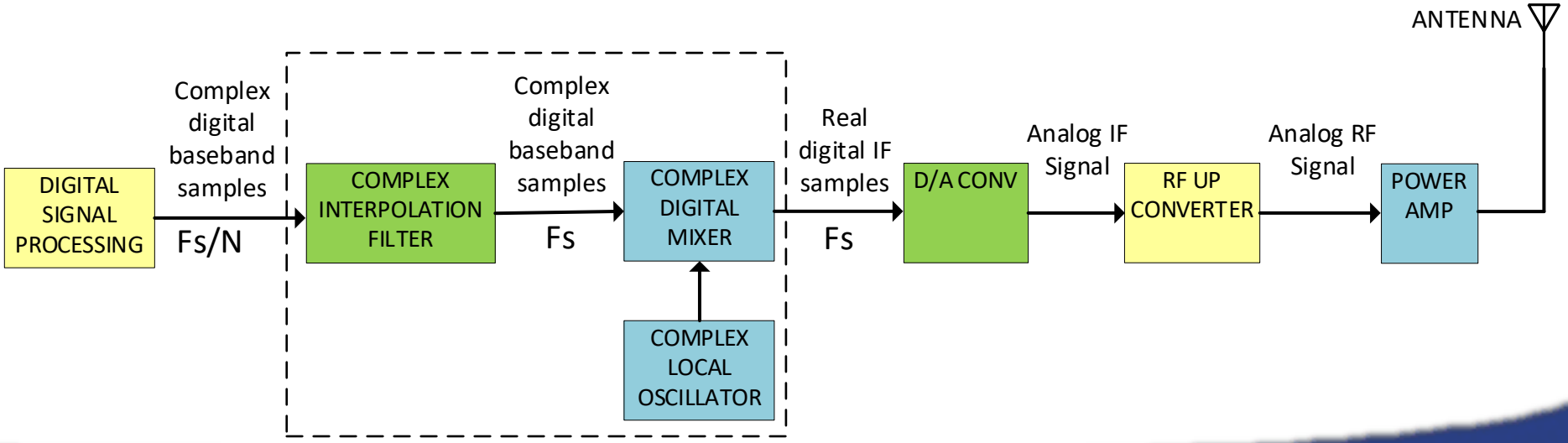
- DSP stage generates complex digital baseband signal samples
- Digital up converter translates complex digital baseband to real IF
- D/A converter converts real digital IF samples to analog IF signal
- RF upconverter translates analog IF frequencies to analog RF frequencies
- Power amplifier boosts signal energy to antenna



Pluto block diagram

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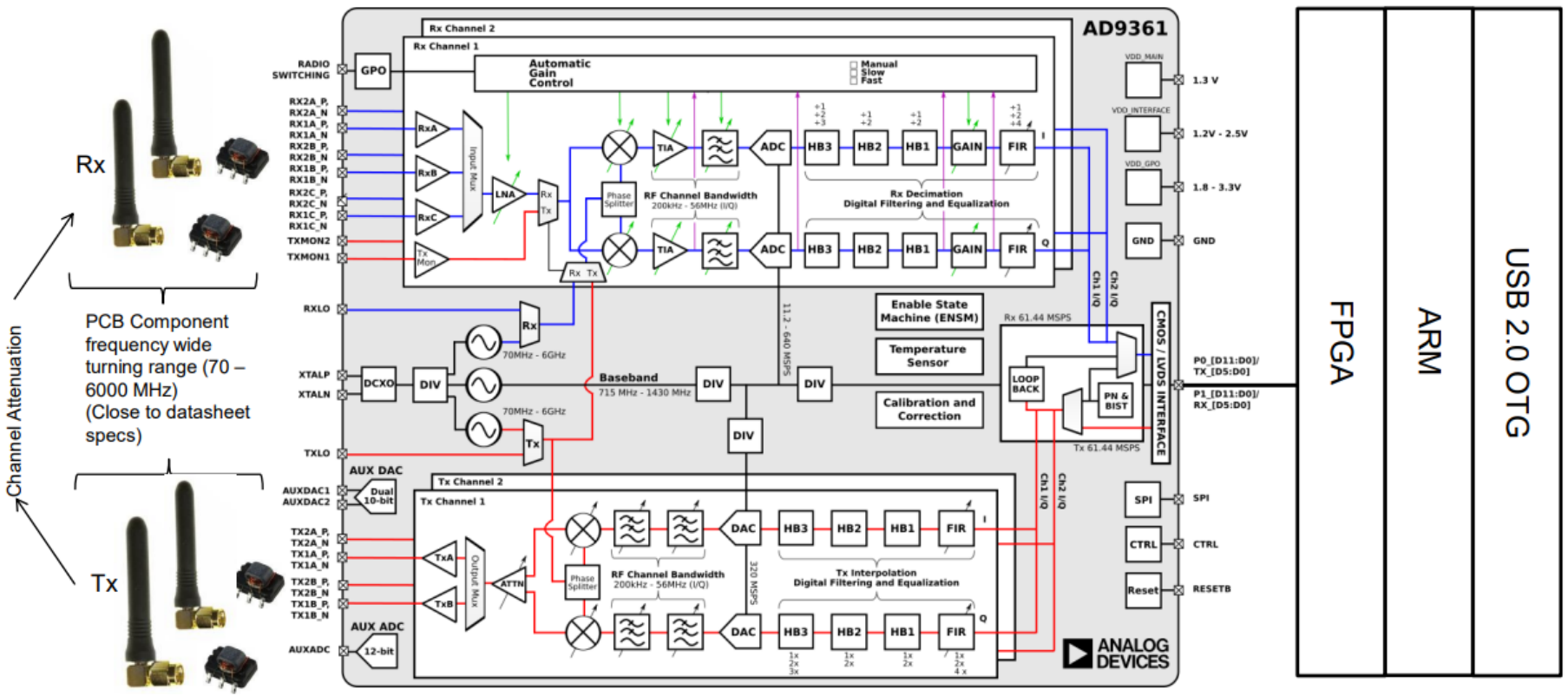

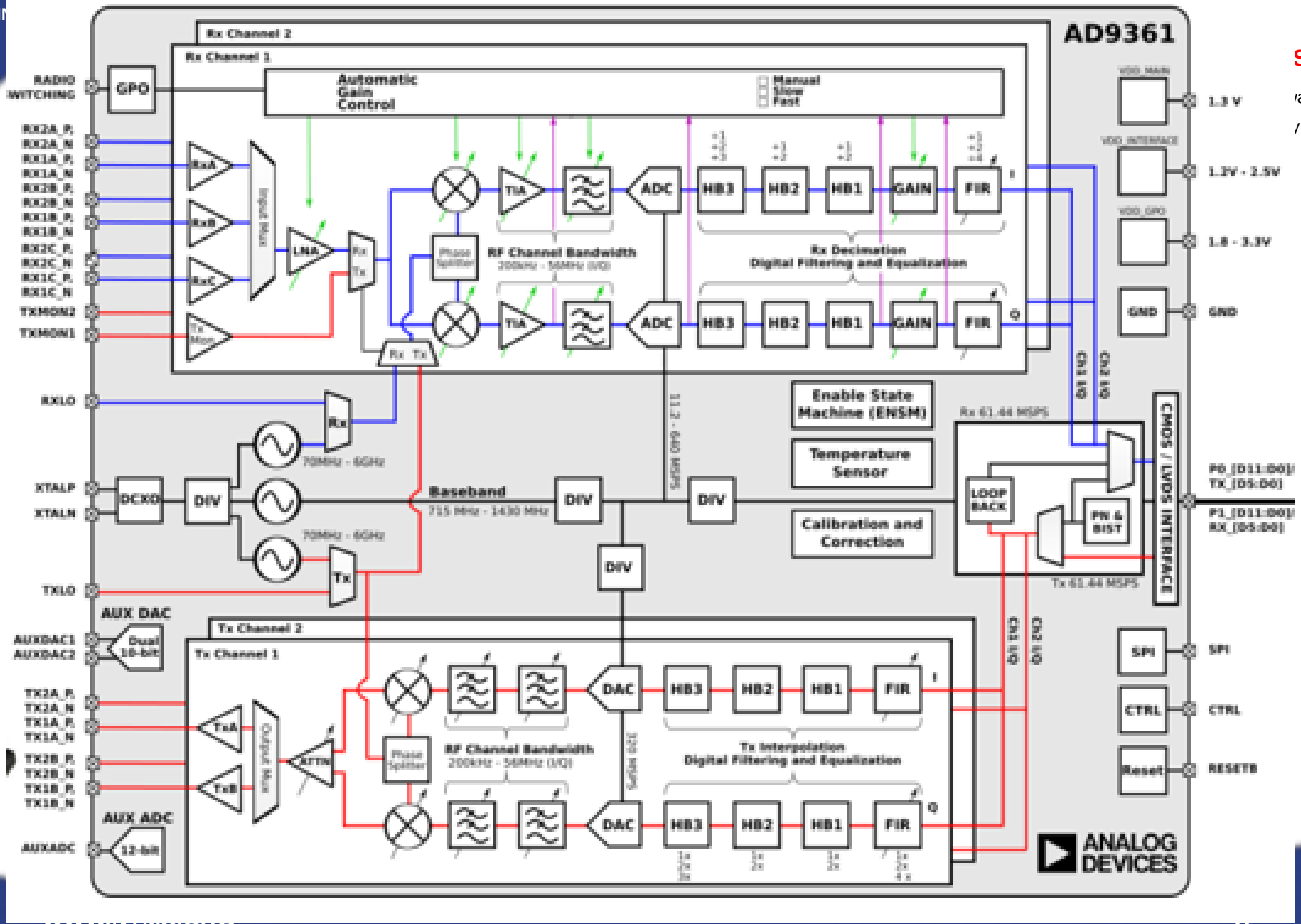
AD9361
Rx Channel 2
Rx Channel 1
Automatic Gain Control
Manual
Slow
Fast
RADIO WITCHING
GPO
RX2A_P
RX2A_N
RX1A_P
RX1A_N
RX2B_P
RX2B_N
RX1B_P
RX1B_N
RX2C_P
RX2C_N
RX1C_P
RX1C_N
TXMON2
TXMON1
RxA
RxB
RxC
Digital Step
LNA
Rx Tx
Phase Splitter
TIA
ADC
HB3
HB2
HB1
GAIN
FIR
I
Q
RF Channel Bandwidth
200kHz - 56MHz (I/Q)
Rx Decimation
Digital Filtering and Equalization
Rx Tx
RXLO
Rx
70MHz - 6GHz
XTALP
XTALN
DCXO
DIV
Baseband
715 MHz - 1430 MHz
1132 - 640 MSPS
Enable State Machine (ENSM)
Temperature Sensor
Calibration and Correction
Rx 61.44 MSPS
LOOP BACK
PN & BIST
Tx 61.44 MSPS
CMOS / LVDS INTERFACE
P0_[D11:D0]
TX_[D5:D0]
P1_[D11:D0]
RX_[D5:D0]
CH1 IQ
CH2 IQ
TXLO
Tx
AUX DAC
AUXDAC1
AUXDAC2
Dual 10-bit
Tx Channel 2
Tx Channel 1
TX2A_P
TX2A_N
TX1A_P
TX1A_N
TX2B_P
TX2B_N
TX1B_P
TX1B_N
TxA
TxB
Output Mux
ATTN
DAC
Tx Interpolation
Digital Filtering and Equalization
AUX ADC
AUXADC
12-bit
1.3 V
1.3V - 2.5V
1.8 - 3.3V
GND
SPI
CTRL
Reset
RESETB
ANALOG DEVICES

SDR Clinics

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- Please sign-up on interest list if you would like to know more about SDR.
- NTMS will sponsor a series of clinics free of charge to provide more information/teaching on SDR topics:
  - Installing GNURadio or other SDR software clients such as SDR#, SDR Console, SDR Angel
  - Basic SDR theory and basic match
  - Deeper dive into SDR theory and math
  - Practical application and building complete systems
- Watch the ntms.org home page link to SDR Clinics for schedules of Zoom meetings and optional in-person meetings.

Broad band SDR

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- SDR radios and software can cover vast amount of spectrum.
- Opened up Pluto and HackRF radios cover all of HF up to 6 GHz.
- Other low cost radios cover HF up to 1.5 GHz.
- This RF front end design allows RX and TX in a large number of unlicensed and licensed frequency bands. More on that later.

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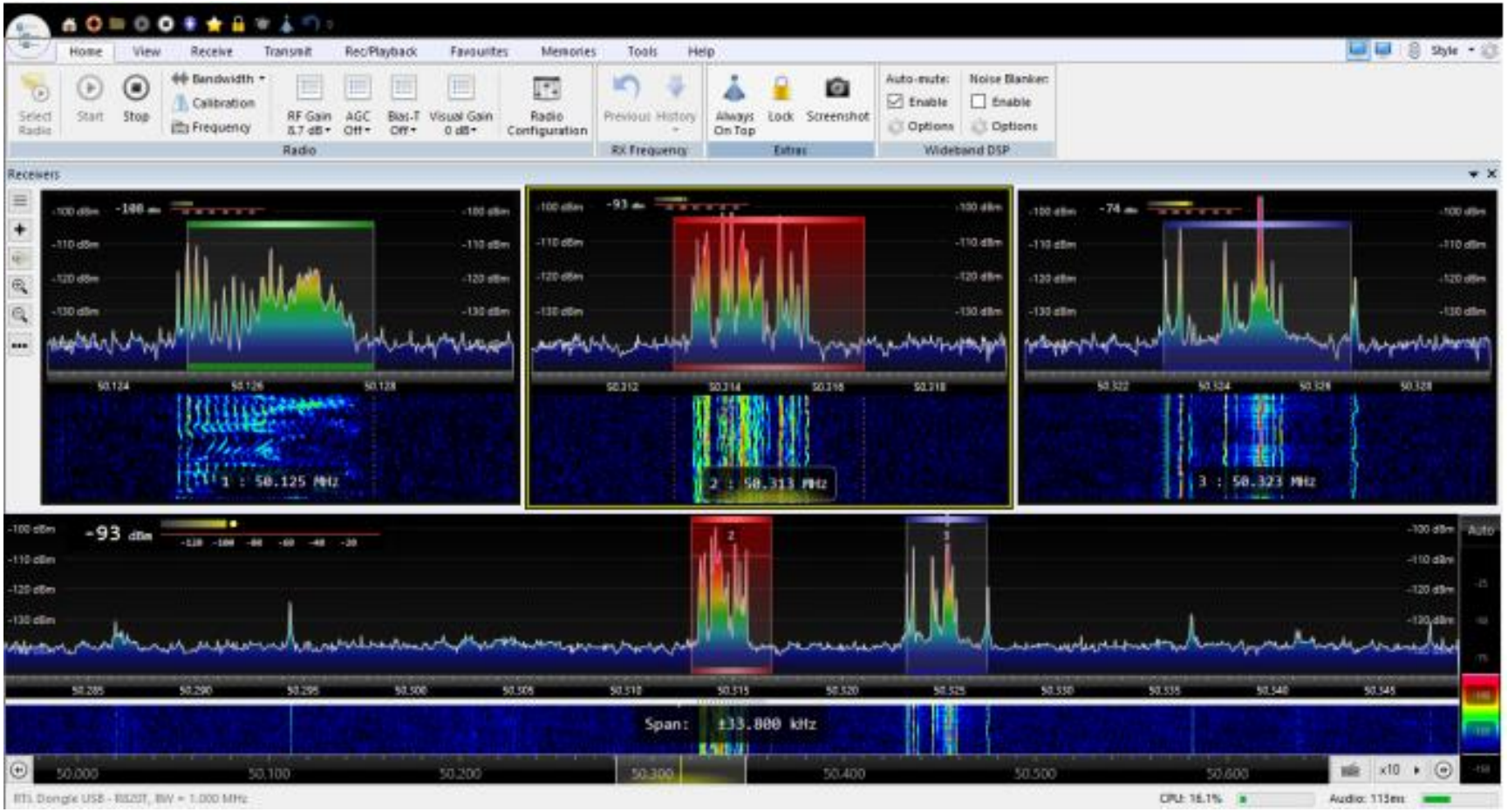
K5ND monitoring 6 meters



KM5PO – 5 RX – 20m/AC/FMBB

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Multi-band operation

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- One SDR radio is capable of multi-band microwave operation.
  - Hardware on the SDR radio is broadband by design but will have some efficiency roll off.
  - With a broadband design the inputs and outputs are unfiltered.
    - Receiver reciprocal mixing and high receiver noise floor could be encountered. HPF would suffice.
    - Transmitter output has harmonics. Any system that will employ external TX amps needs to be filtered.
  - The complexity of a computer and software interface is offset by the frequency flexibility of the hardware design and the multitude of software features that permit enhanced operational performance.
  - Side mention: as a bench top test instrument, the SDR and software offers an alternative to signal generators/modulators.

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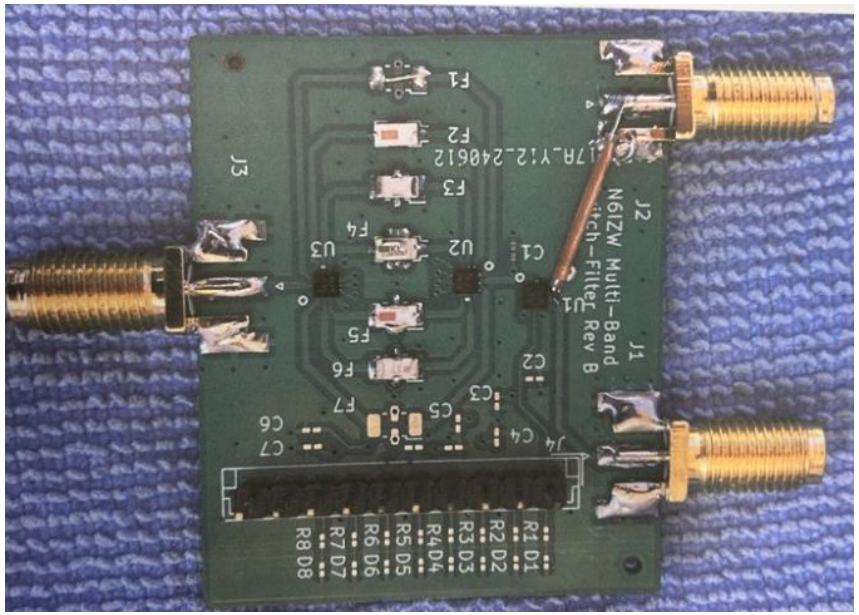
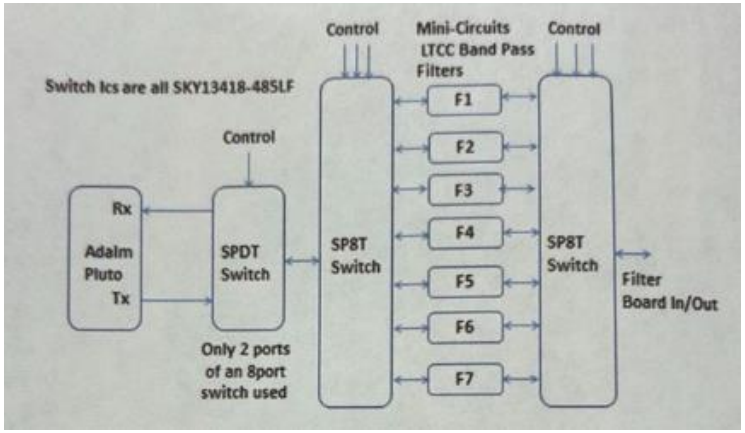
TX filter ideas

- For microwave bands < 5 GHz





Mini-Circuits filters used	Ins loss
1296 MHz band BFCN-152W-75	5 dB
2304 MHz band BFCN-2275+	5 dB
3446 MHz band BFCN-3600+	7 dB
5.7 GHz band BFCN-5750+	15 dB

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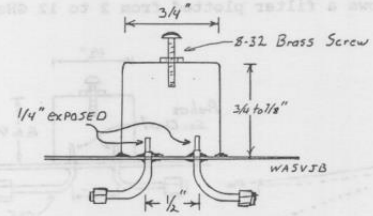
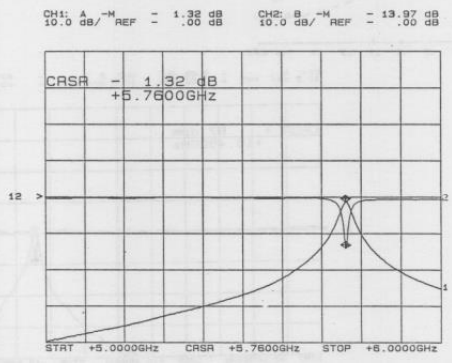
TX filter ideas

- For microwave bands > 3 GHz

5760 MHz 3/4" Filter

This was one of the filters I was fortunate to get plotted on some really fancy equipment. I didn't get an opportunity to build a family of these filters before the proceedings deadline, but my first try seems to have done pretty well. Again a 5760 MHz transverter using a 144 MHz I.F. would have about 20 dB rejection of the L.O. and almost 30 dB image rejection with less insertion loss than the 1" filter.





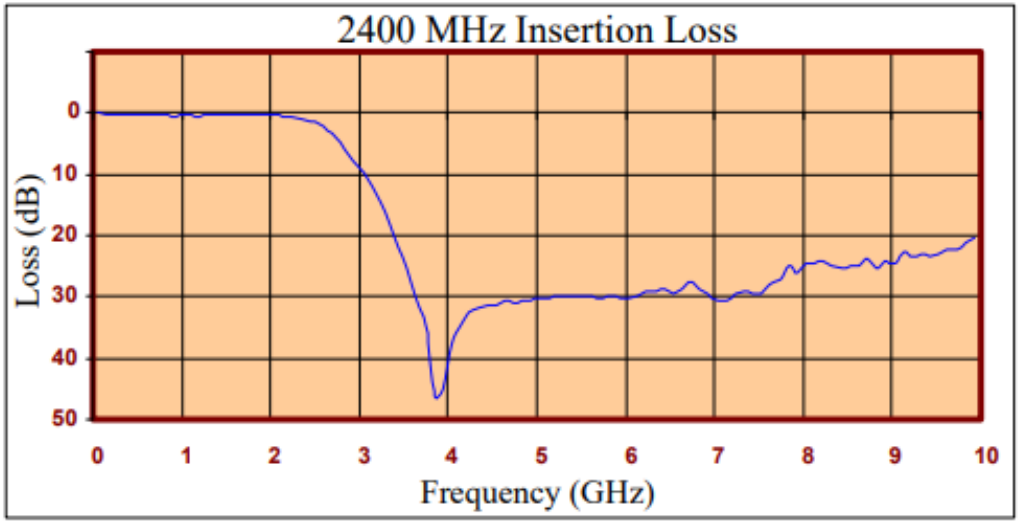
TX filter ideas

- For 2.3 GHz band – Paul KI5EMN is using these on TX side

CLPFL-2400

CRYSTEK MICROWAVE
A Division of Crystek Corporation

Low Pass Filter
CLPFL-2400



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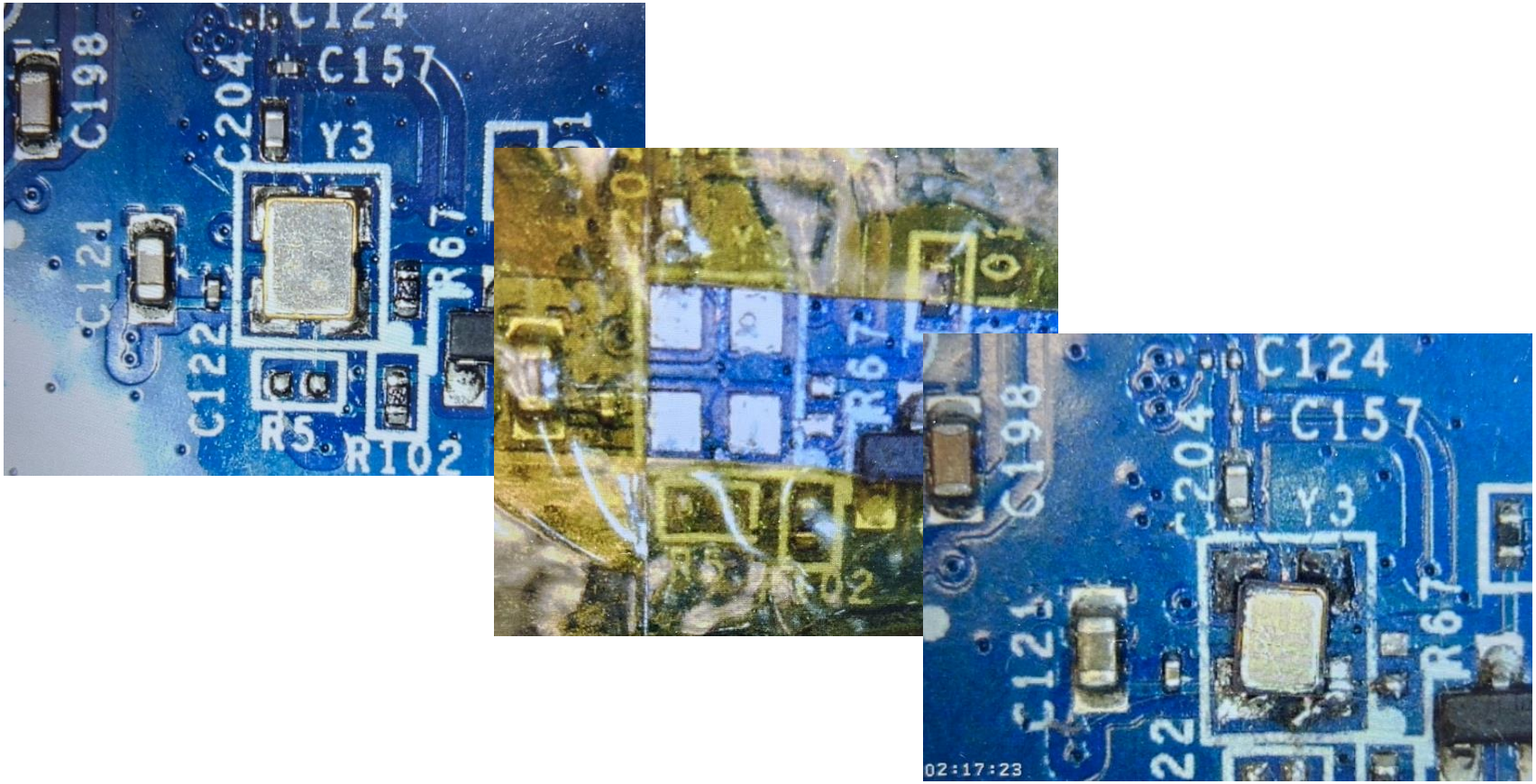
Pluto TCXO mod

- Stability modification to Pluto – necessary for uwave operation



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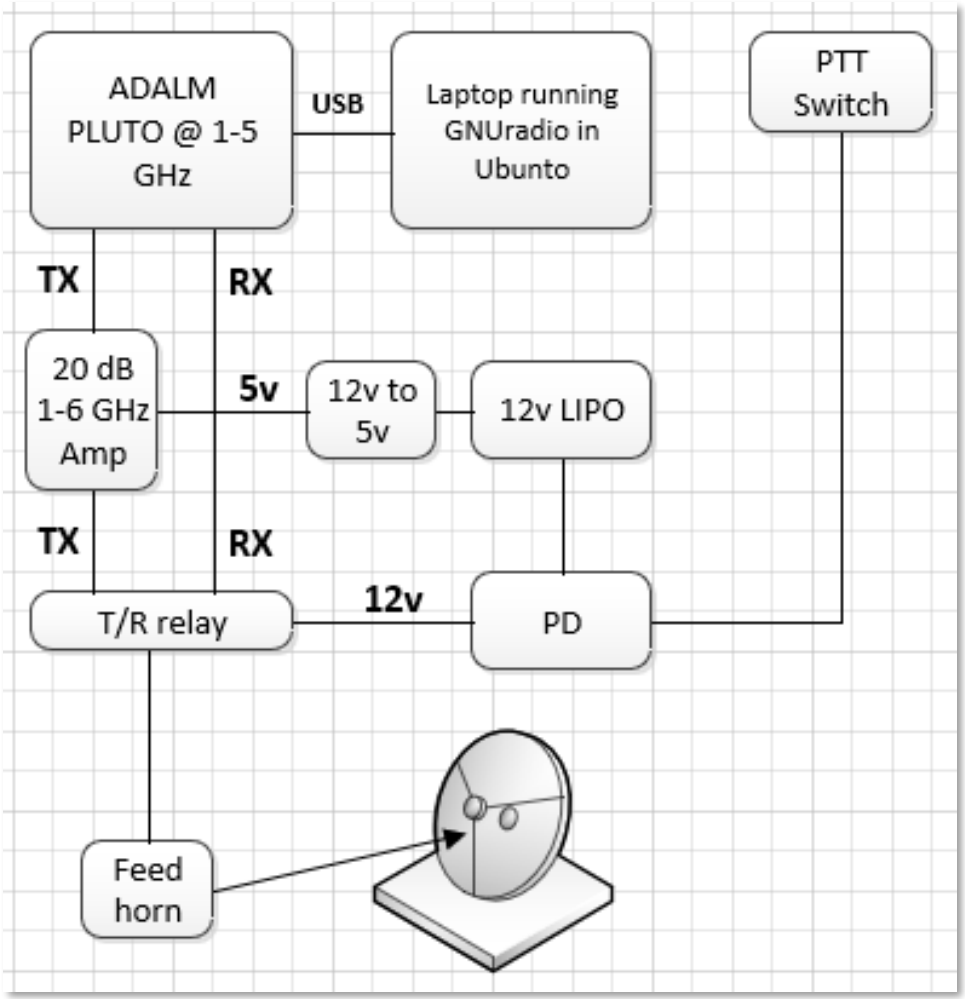
Hamfest 5 GHz system



Hamfest uWave system

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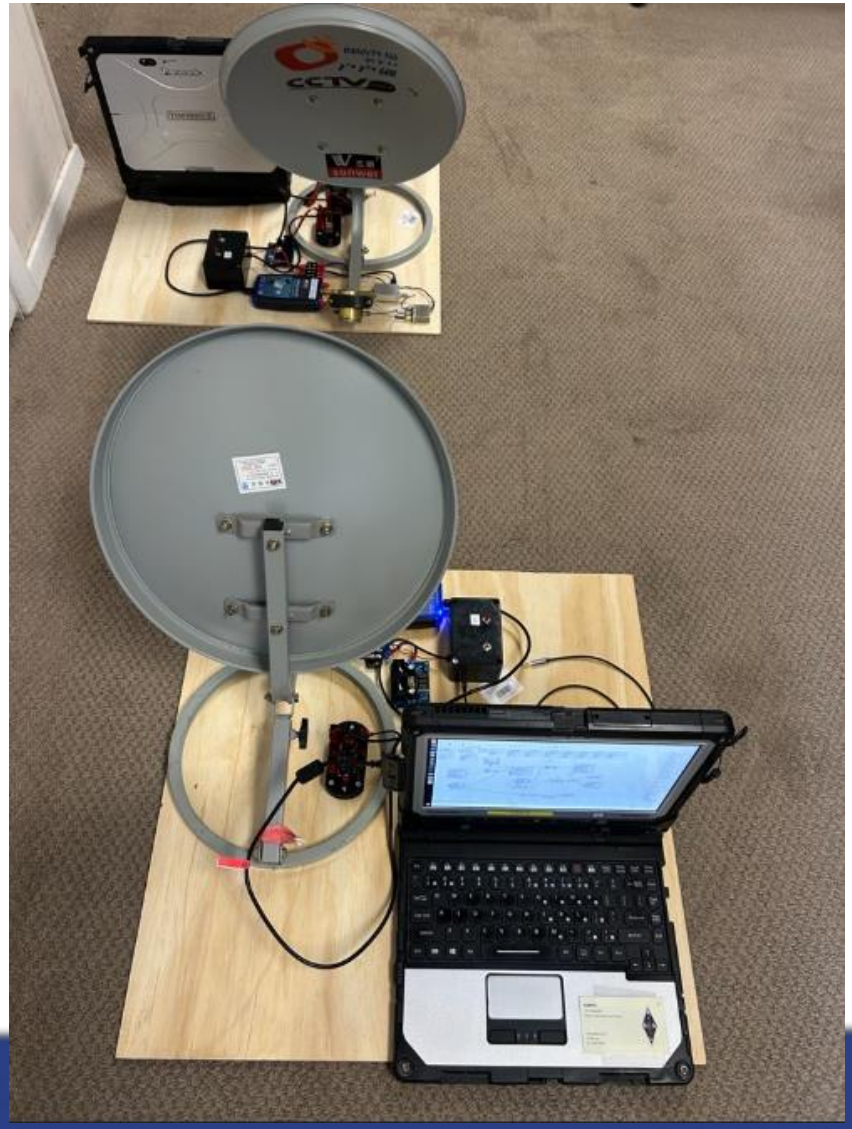

GNU Radio

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GNU Radio is a free & open-source software development toolkit that provides signal processing blocks to implement software radios.

It can be used with readily-available low-cost external RF hardware to create software-defined radios, or without hardware in a simulation-like environment.

It is widely used in research, industry, academia, government, and hobbyist environments to support both wireless communications research and real-world radio systems.

GNU Radio

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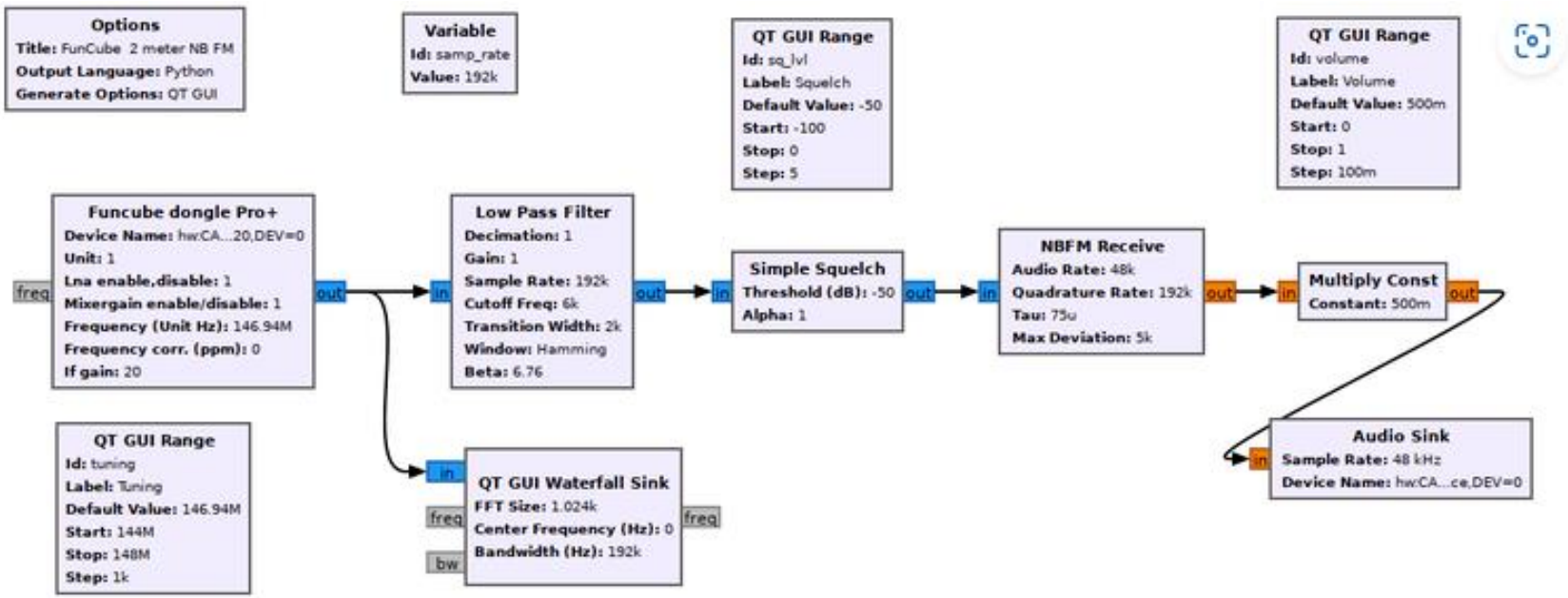
Flowgraph system of functional blocks



GNU Radio

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Windows download.
Scroll down to "Assets" & make sure to click on the "Show all assets" hotspot to find the latest Windows installer or other OS versions.

GNU Radio may be run from within Oracle virtualbox

GNU Radio may be run from a flash drive under embedded Ubunto OS on the flash drive (this is the method we will use for hamfest demos)

Help wanted

North Texas NTMS Microwave Society

- SDR or “Signal processing Engineers” are in demand

Software Defined Radio (SDR) Engineer

Caliola Engineering, LLC
Colorado Springs, CO

What we require:

- MS OR BS plus 2 years' experience in Electrical Engineering, Mathematics or Physics or a related professional technical
- Experience solving technical problems in the areas of wirel processing, and signals collection.
- Strong background in scientific programming using languages such as C, C++, Python.
- Experience developing communication system components for SDR frameworks like GNU Radio.
- Experience with standard RF lab equipment (e.g., oscilloscopes, spectrum analyzers, signal generators, etc.).
- Experience integrating SDR components with external systems and software.
- Experience with wireless digital communication systems, in particular modern digital modulation techniques and modem design.
- Proven track record of being resourceful and creative, and willing to contribute to a multidisciplinary and face-paced engineering environment.
- Awareness of relevant industry standards, regulations and best practices in RF design and safety.
- This position requires the ability to obtain and maintain a security clearance, which is issued by the U.S. Government. Security clearances may only be granted to U.S. citizens. In addition, applicants who accept a conditional offer of employment may be subject to government security investigation(s) and must meet eligibility requirements for access to classified information.

Software Defined Radio (SDR) Engineer
Caliola Engineering, LLC — Colorado Springs, CO
At Caliola, SDR engineers are problem solvers who enjoy solving hard technical problems quickly and creativity and applying innovative approaches to solve...
$90,788 - $177,158 a year Quick Apply

North Texas NTMS Microwave Society

Help wanted

KRATOS

Digital Signal Processing Engineer

Kratos Defense - 3.3

Colorado Springs, CO

Apply Now

Experience and Skills:

- Must be a self-starter and able to work closely in a fast paced, small engineering team which includes other software engineers, DSP engineers, hardware engineers, systems engineers, and test engineers
- Must have an active Top-Secret security clearance with the ability to obtain an SCI
- Education and/or background in digital signal processing and satellite communications specifically in modulation detection and characterization
- Team player and capable of working in a fast paced, team environment

Preferred Skills and Experience

- Satellite communications, geolocation, or other RF communications experience
- Familiarity and experience with Linux operating systems
- Familiarity with GNU Radio and Software Defined Radios (SDR)
- Software development experience with languages such as C or C++, or Python, or Cuda
- Familiarity with containerized environments such as Docker
- Experience with common engineering lab and test equipment such as oscilloscopes and spectrum analyzers
- Experience with Agile program execution methodologies

#LI-Onsite

Competitive salary based on experience and education

Salary Range: $130,000-$170,000

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Help wanted

Signal Processing Specialist - Geospatial Intelligence

Muon Space
Mountain View, CA

Apply Now

Qualifications

- Experience with digital signal processing techniques related to RF instruments
- Experience developing algorithms using data from RF instruments
- Exceptional skills in python-based development and analysis
- Ability to work with a distributed, interdisciplinary team (scientists, engineers, data support, all working at different locations)

Preferred Qualifications

- Experience with problems requiring precision timing
- Experience with geolocation of RF transmitters
- Experience with GNU Radio
- Experience developing retrieval algorithms from satellite Earth observations
- Understanding of the principles of scientific instruments
- Familiarity with cloud native systems (AWS, Flyte)

Salary

The salary range for this role is $95K- $195K and will depend on a candidate's skills, geographic location, qualifications, and experience as defined during the interview process.

About Muon Space

Founded in 2021, Muon Space is an end-to-end Space Systems Provider that designs, builds, and operates LEO satellite constellations delivering mission-critical data. Our

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Help wanted

SDR SW Engineer (GNU Radio)

Comcentric Inc. - 3.9 ★
Austin, TX

Quick Apply

Full Job Description

We are seeking a **SDR SW Engineer** for a long term remote contract - goal is to convert contractors to perm employees..

Looking for US Citizens.

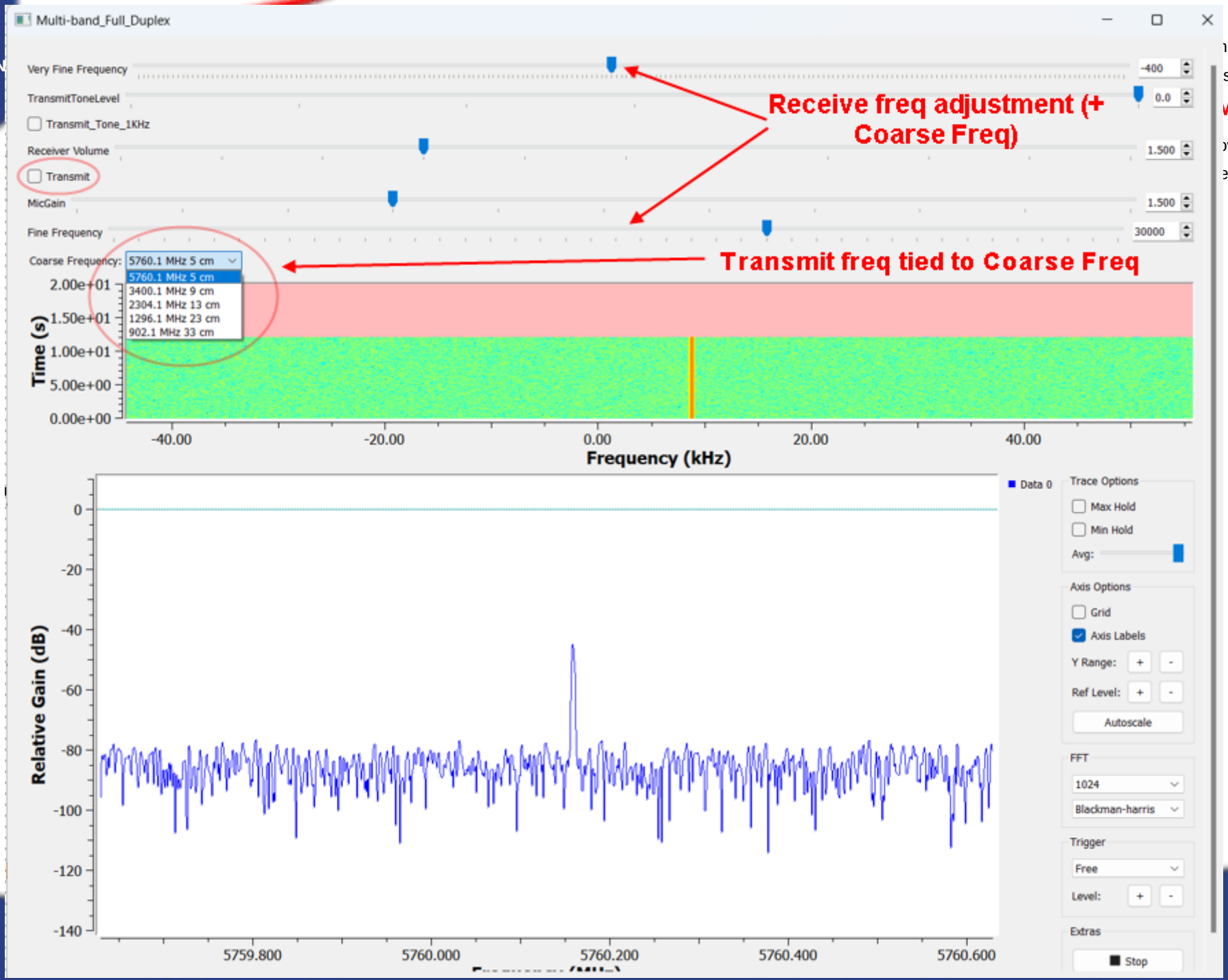
Responsibilities

- Analyze and Design SDR systems
- Develop a real-time capable transceiver in GNU Radio + FPGA based hardware
- Work with a test engineer to validate the design
- Work with an application engineer to support customer demos and requested capabilities
- Support implementing and improving new algori
- Support IP development and packaging for futur

Qualifications

- BS in Computer Science or related field (MS or Ph
- Experience with Linux, C++, and Python
- Git experience, or equivalent source code manag
- Experience with modern software development practices and Continuous Integration/Continuous Development (CI/CD)
- Experience with open-source GNU Radio software and/or Software Defined Radio

SDR SW Engineer (GNU Radio)
Comcentric Inc. — Austin, TX 3.9 ★
BS in Computer Science or related field (MS or PhD highly preferred). Work with a test engineer to validate the design. Analyze and Design SDR systems.
Estimated: $108K - $137K a year Quick Apply


Multi-band_Full_Duplex
Very Fine Frequency
-400
TransmitToneLevel
0.0
Transmit_Tone_1KHz
Receiver Volume
1.500
Transmit
MicGain
1.500
Fine Frequency
30000
Coarse Frequency:
5760.1 MHz 5 cm
5760.1 MHz 5 cm
3400.1 MHz 9 cm
2304.1 MHz 13 cm
1296.1 MHz 23 cm
902.1 MHz 33 cm
Receive freq adjustment (+ Coarse Freq)
Transmit freq tied to Coarse Freq
Time (s)
2.00e+01
1.50e+01
1.00e+01
5.00e+00
0.00e+00
-40.00
-20.00
0.00
20.00
40.00
Frequency (kHz)
Relative Gain (dB)
0
-20
-40
-60
-80
-100
-120
-140
5759.800
5760.000
5760.200
5760.400
5760.600
Data 0
Trace Options
Max Hold
Min Hold
Avg:
Axis Options
Grid
Axis Labels
Y Range:
Ref Level:
Autoscale
FFT
1024
Blackman-harris
Trigger
Free
Level:
Extras
Stop

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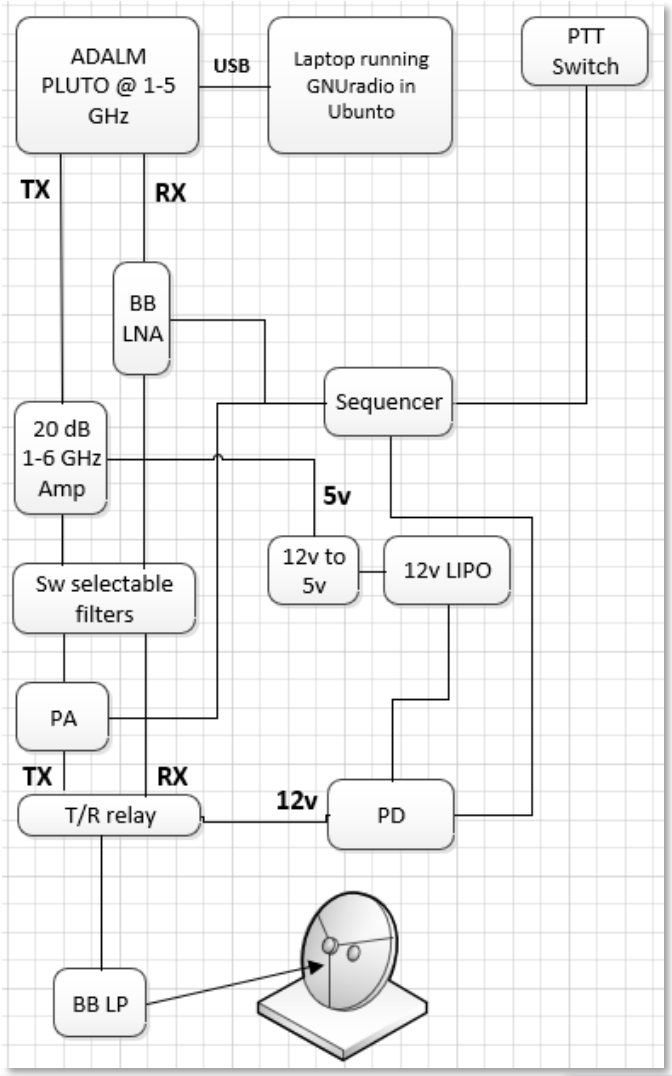
Improved MBMW system



SDR uWave designs seen at MUD 2024 Vancouver

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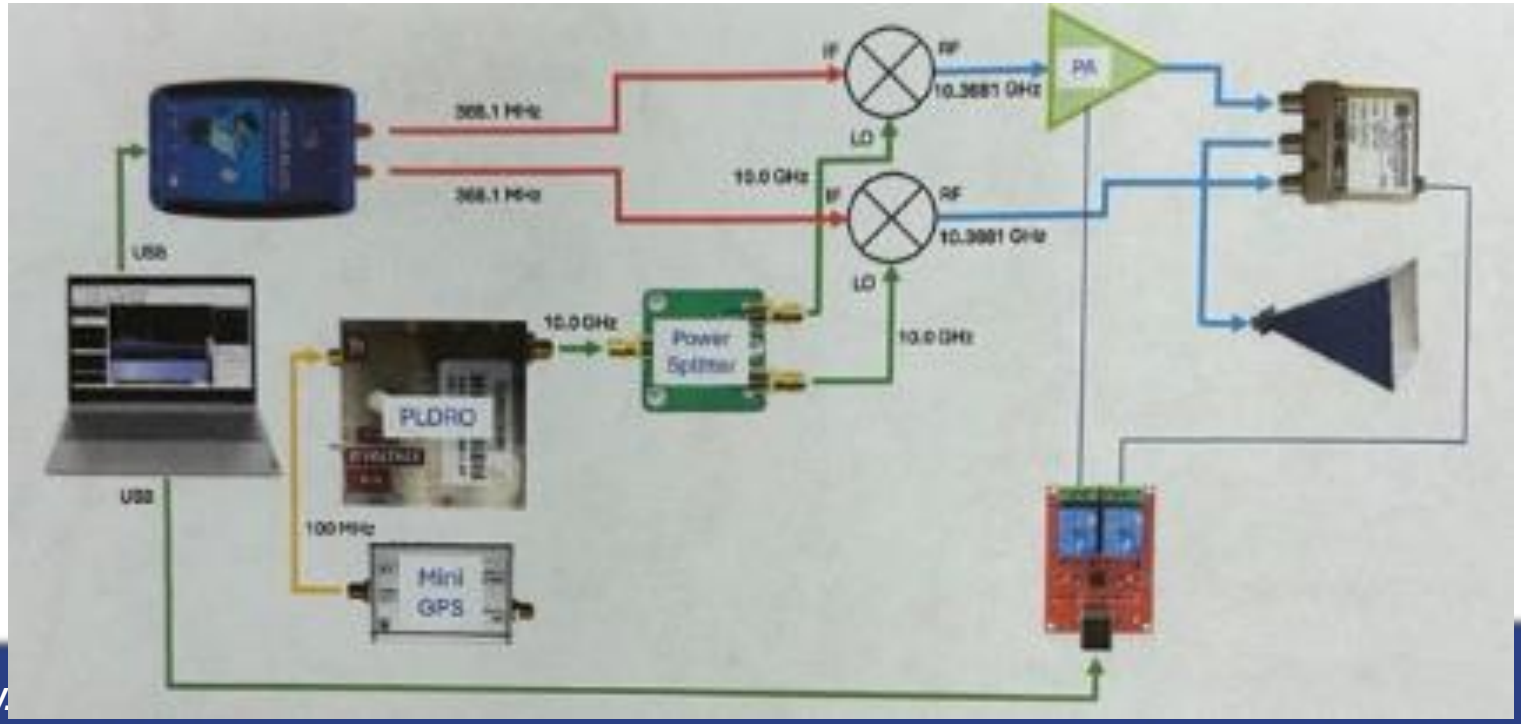
- SDR is used as an IF operating at 368.1
- PLDRO - Phase Locked Dielectric Resonator Oscillator operates at 10.000 GHz.
- Dual mixer strategy



Unlicensed TX operation

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- Transmitting on-the-air with SDR
  - If you are not licensed then you may use the following frequencies

Type of band	Frequency range		Power	Usage	Range
Family Radio Service (FRS)	462-467 MHz	UHF	.5 to 2 watts	Short-range comms for families, hiking, campling, local comms	A few miles in open areas
Multi-Use Radio Service (MURS)	151-154 MHz	VHF	2 watts	Small business and personal comms, external antennas allowed. Driveway alarms, handheld radios, farm comms	A few miles in open areas
Citizen Band (CB) Radio	26.965-27.405 MHz	HF	4 watts AM, 12 watts SSB	Truckers/hobbyists	Several miles, E layer skip possible
Wireless Microphones/Intercoms	49 and 902-928 MHz	HF/VHF		Microphones, baby monitors and intercom	Close range
Industrial, Scientific and Medical (ISM) Band	902-928 MHz	UHF		Wi-Fi, Bluetooth and RFID	Close range
Industrial, Scientific and Medical (ISM) Band	2.4-2.5 GHz	uWave		Wi-Fi, Bluetooth and RFID	Close range
Industrial, Scientific and Medical (ISM) Band	5.725-5.875 GHz	uWave		Wi-Fi, Bluetooth and RFID	Close range

With a ham radio license

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- Transmitting on-the-air with SDR
  - As a “Technician” class licensee you have the following VHF/UHF/uWave privileges (plus some HF band usage)

Ham band	Main propagation	other propagation
6 meters (50 MHz – 54 MHz)	Groundwave & Ionospheric reflection	Moonbounce/meteor scatter
2 meters (144 MHz – 148 MHz)	Groundwave & Ionospheric reflection (rare)	Moonbounce/meteor scatter
1.25 meters (222 MHz – 225 MHz)	Groundwave & Ionospheric reflection (rare)	Moonbounce/meteor scatter
70 centimeters (420 MHz – 450 MHz)	Ground wave	Moonbounce
33 centimeters (902 MHz – 928 MHz)	Ground wave	Moonbounce
23 centimeters (1.24 GHz – 1.3 GHz)	Ground wave	Moonbounce
13 centimeters (2.3 GHz – 2.45 GHz)	Ground wave	Moonbounce/rain scatter
9 centimeters (3.3 GHz – 3.5 GHz)	Ground wave	Moonbounce/rain scatter
6 centimeters (5.65 GHz – 5.925 GHz)	Ground wave/tower & building scatter	Moonbounce/rain scatter
3 centimeters (10.00 GHz – 10.500 GHz)	Ground wave/tower & building scatter	Moonbounce/rain scatter
1.2 centimeters (24.00 GHz – 24.25 GHz)	Ground wave/tower & building scatter	Moonbounce/rain scatter
6 mm (47.0 GHz – 47.2 GHz)	Ground wave/tower & building scatter	Moonbounce/rain scatter

Obtaining a license

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- Cowtown Amateur Radio Club (K5COW) testing
  - Testing for ham radio licensing is conducted at the Cowtown ARC club house twice a month (2nd and 4th Thursday at 7pm).
  - Prefer pre-registration however walk-ins are welcome
  - K5COW - Cowtown Amateur Radio Club - Get Your License

Todays Demos

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- Monitor from 1000 – 6000 MHz with TinySA spectrum analyzer
- Paul KI5EMN is running a 2304.234 MHz SDR Beacon (cw) across the hamfest venue.
  - The transmitter is a Pluto SDR driven by a laptop running GNUradio on Ubunto. Power output is in milliwatts range.
  - The receiver here in the room is a Pluto SDR driven by a laptop running GNUradio on Ubunto.
- Demo voice (SSB) comms on:
  - 5760 MHz
  - 3400 MHz
  - 2304 MHz
  - 1296 MHz
  - 902 MHz
  - Using the dish-based systems depicted on previous pages

NTMS Beacons

North Texas Microwave Society area Beacon Status updated October 30, 2022

Freq (MHz)	Call	Grid	Power	Antenna	Height above Ground	Status		Frequency Stabilization	Freq Reference	Keying
50.073	W5HN/B	EM13sj	.5 W	Halo	180 ft	OFF THE AIR (1)	HB	Crystal	12.51825 MHz	on/off
144.280.2	W5HN/B	EM13sj	1.5 W	Halo	180 ft	ON THE AIR	HB	Crystal	12.0233 MHz	on/off
222.060	AA5C/B	EM13se	8 W	Folded Dipole	53 ft	ON THE AIR	HB	PLL	10 MHz	on/off
432.370	N5PYK/B	DM93bm	50 W	Yagi towards DFW	70 ft	ON THE AIR		XCVR		on/off
432.380	W5HN/B	EM13kf	.8 W	Halo	280 ft	ON THE AIR	HB	ADF4351	10 MHz OCXO	on/off
903.050	W5HN/B	EM13kf	9 W	Alford Slot	280 ft	ON THE AIR	HB	N5AC PLL	10 MHz OCXO	on/off
1296.375	W5HN/B	EM13kf	3 W	Alford Slot	280 ft	ON THE AIR	HB	N5AC PLL	10 MHz OCXO	on/off
2304.366	W5HN/B	EM13kf	4 W	Alford Slot	280 ft	ON THE AIR	HB	Crystal		FSK
3456.380	W5HN/B	EM13kf	250 mW	Alford Slot	280 ft	OFF THE AIR	DB6NT	Crystal X 27	128.014 MHz	FSK
3400.380	W5HN/B	EM13kf	250 mW	Alford Slot	280 ft	BEING UPGRADED (2)	DB6NT	ADF4351	125.94 MHz	on/off
5760.364	W5HN/B	EM13kf	158 mW	Alford Slot	280 ft	ON THE AIR	DB6NT	Crystal X 48	120.0079 MHz	FSK
10368.368	W5HN/B	EM13kf	2.5 W	Alford Slot	280 ft	ON THE AIR	DB6NT	Crystal X 96	108.00395 MHz	FSK
24192.300	AA5C/B	EM13sf	500 mW	16-slot WR42	75 ft	ON THE AIR	HB	Crystal	112.0015 MHz	on/off
24192.380	W5HN/B	EM13kf		10 slot Alford	280 ft	Under Construction (3)	HB	ZL PLL		on/off
47088.300	W5HN/B	?				Under Construction				

Actual 10 digit grid squares
EN13sj = EM13sj91mr
EM13se = EM13se55vi
DM93bm = DM93bm46su
EM13kf = EM13kf45pb
EM13sf= EM13sf89tb

Notes
(1) Waiting for a tower climb to put antenna back up at 60ft
(2) Working on cleaning up spurs
(3) ETA 2023

Reference

- Pipe cap filters :https://www.w1ghz.org/filter/Pipe-cap_Filters_Revisited.pdf

Questions?

North Texas NTMS Microwave Society