A Minimal Software-Defined Radio VHF/UHF/SHF Transceiver

KD2TAI, Zhemin Zhang
hisenzhang01@gmail.com

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Speaker Bio

Hisen, KD2TAI.

Officially known as Zhemin Zhang.

Currently pursuing a B.S. in Computer Science dual Computer and Systems Engineering, focusing on digital communication and AI technologies.

President of the W2SZ college amateur radio club at RPI. Licensed as an Amateur Extra class operator since 2022.

ZHEMIN ZHANG
hisenzhang01@gmail.com

Agenda

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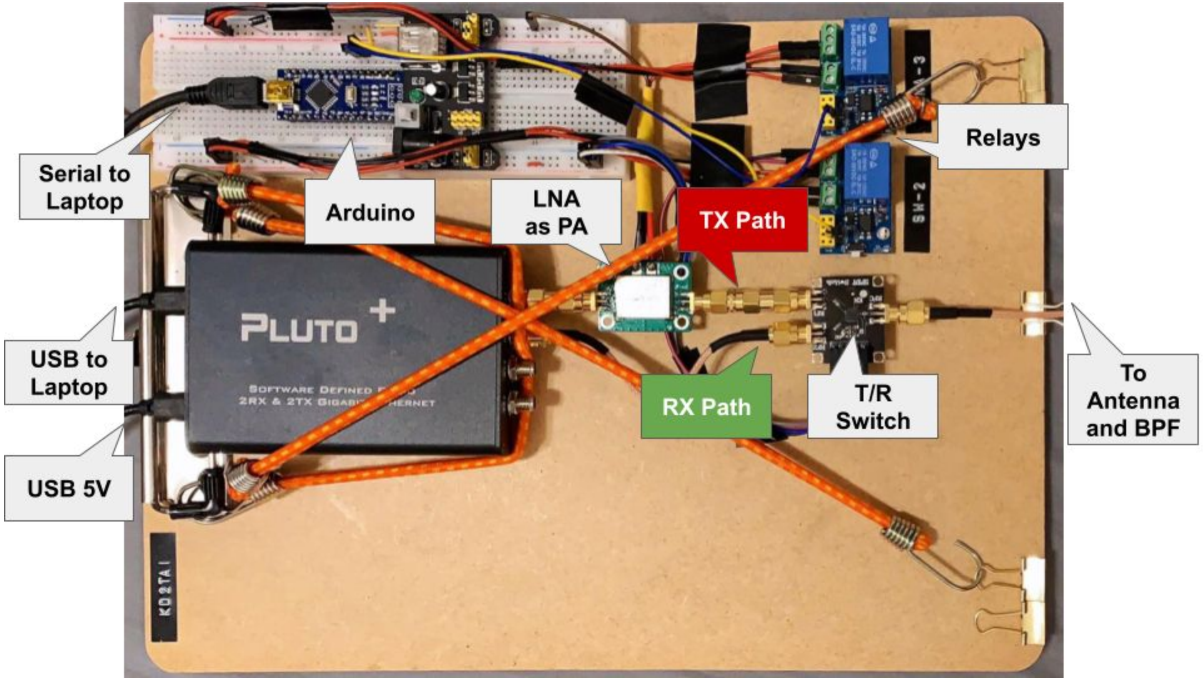
   b. New Mode
   c. MIMO



Background

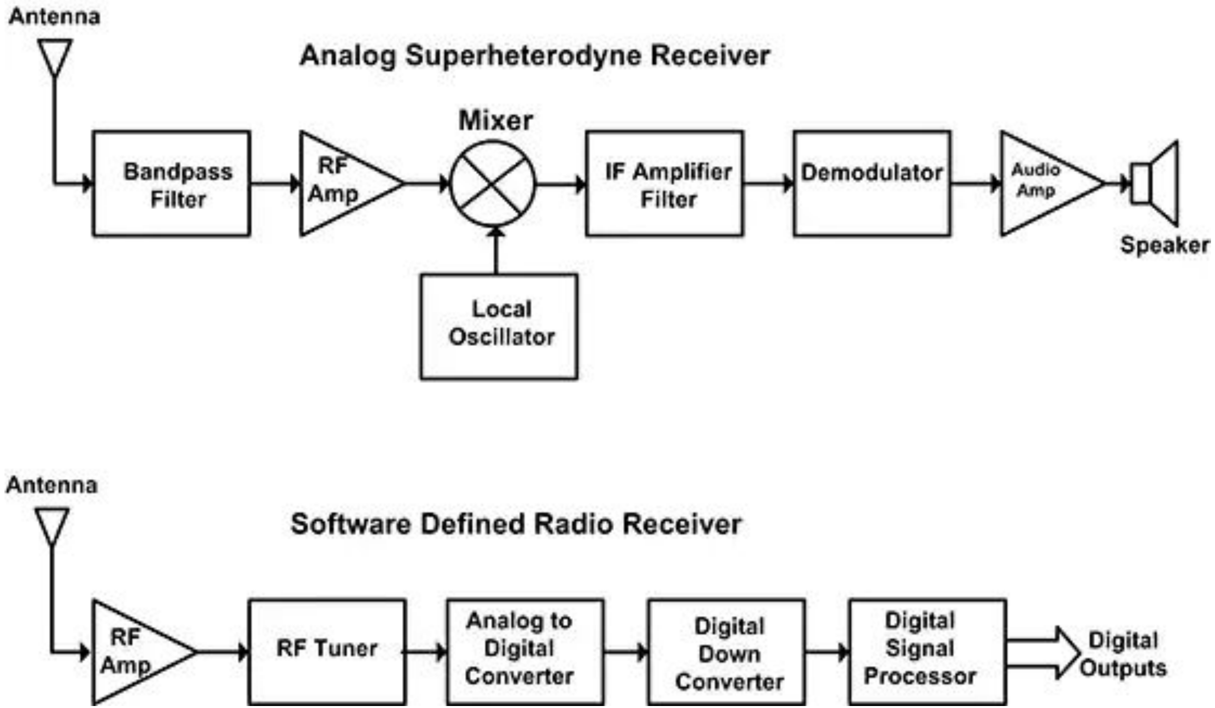
Software-Defined Radio

Software-defined radio (SDR) technology is becoming increasingly popular in amateur radio due to its:

- Flexibility
  - All processing are done by software
- Versatility
  - All modes, all bands
- Higher bandwidth
  - Make no assumption about the signal

Traditional Receiver vs. SDR Receiver

Image by Digi-Key Electronics with permission to reprint



Existing Designs

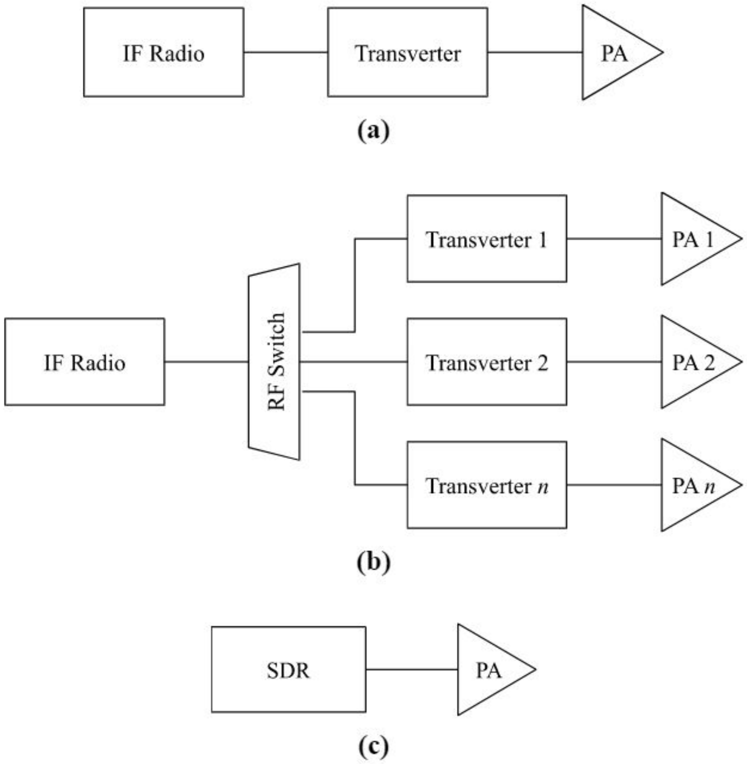


Figure II. Microwave Radio Architectures **(a)** Transverter **(b)** Transverter, Multiple Bands **(c)** SDR

Existing Designs: Transverters

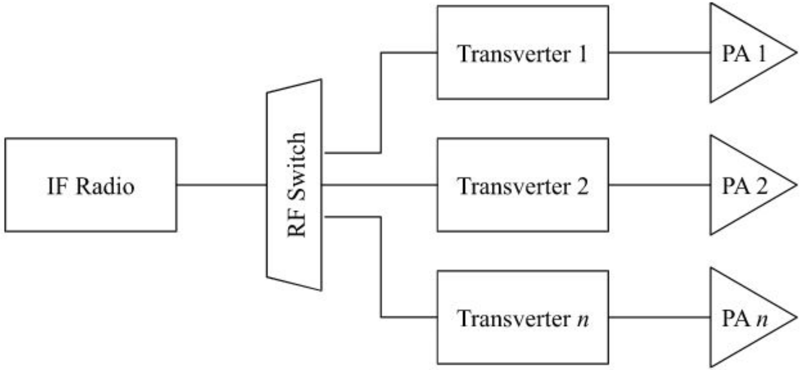
The current popular amateur microwave transceivers are mainly homemade with

- a commercially available ("off-the-shelf") intermediate frequency (IF) transceiver,
- an *n*-way RF switch, connected to
- transverters working on *n*-desired bands

IF ⇐ (transverter) ⇒ microwave

The RF switch activates one transverter at a time.

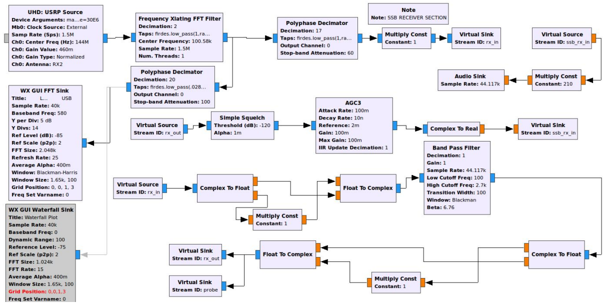
E.g., **W1GHZ** A four-band transverter solution for microwave rovers

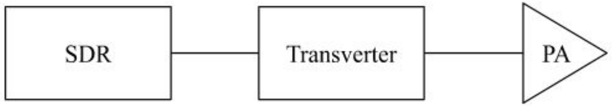


(b)

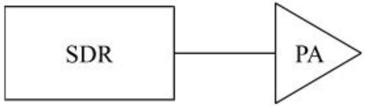
Existing Designs: Software-Defined Radios

W7FU Universal Microwave SSB/CW Transceiver (IF SDR)





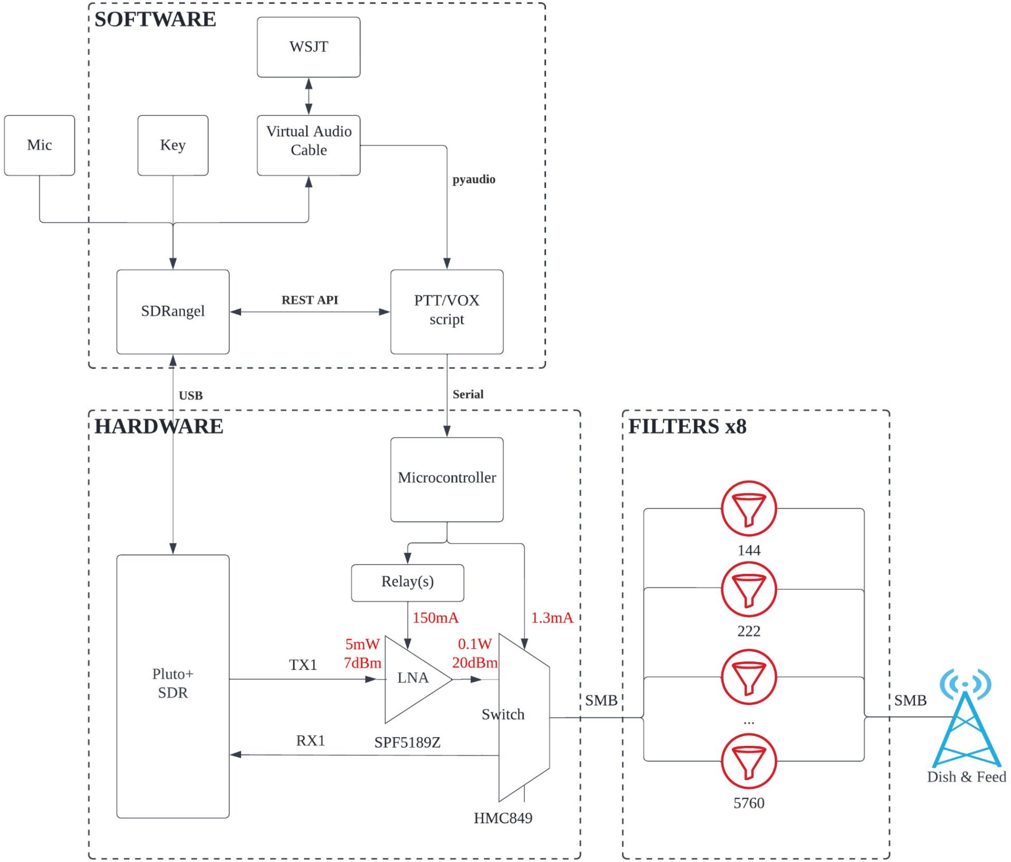
G4EML Langstone project (Full SDR)



System Design

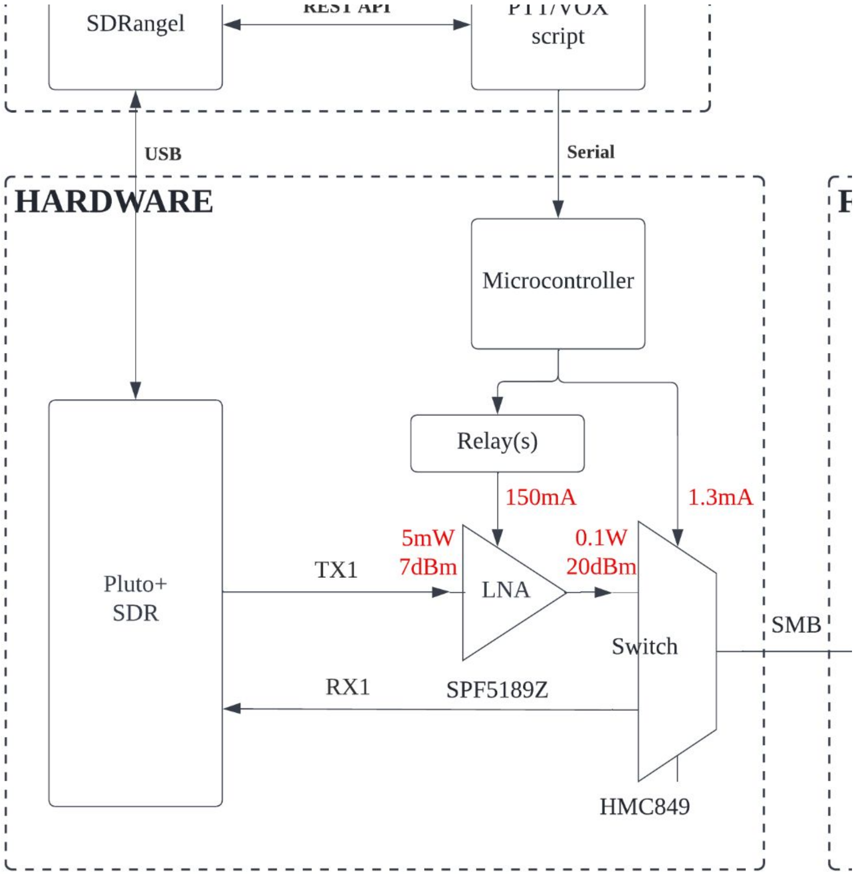
System Design Overview

- "Less is more"
  - reduced component count and costs
  - improved robustness
- 144 MHz to 5.7 GHz
  - support mainstream amateur modes
- Dimensions
  - LxWxH 32x23x3 cm
  - weight 0.7 kg


SOFTWARE
WSJT
Mic
Key
Virtual Audio Cable
pyaudio
SDRangel
REST API
PTT/VOX script
USB
Serial
HARDWARE
Microcontroller
Relay(s)
150mA
1.3mA
5mW
7dBm
0.1W
20dBm
Pluto+ SDR
TX1
LNA
Switch
RX1
SPF5189Z
HMC849
SMB
FILTERS x8
144
222
...
5760
SMB
Dish & Feed

Hardware

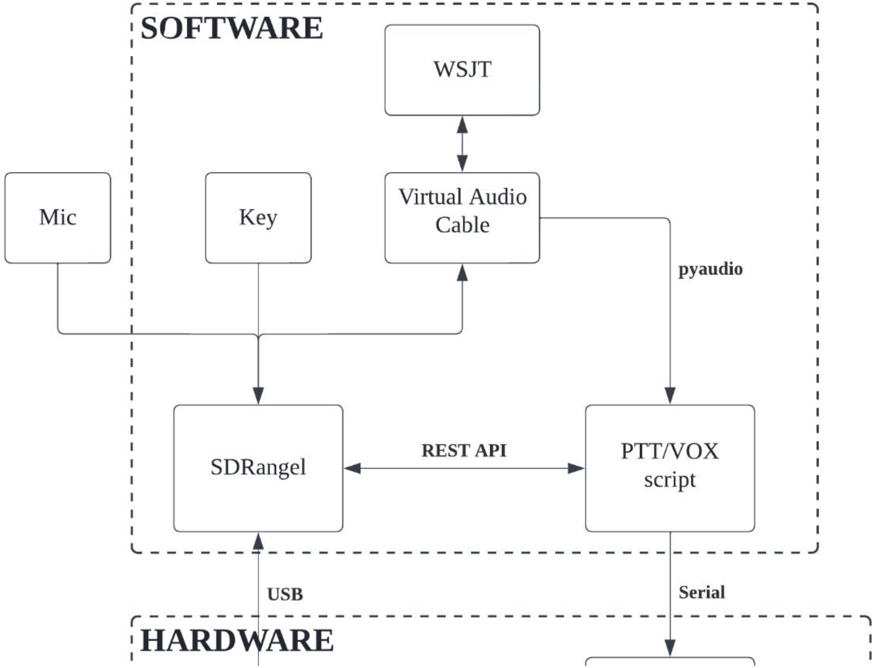
- Pluto+ SDR, AD9363: 2x2 MIMO, 12-bit DACs and ADCs.
- SPF5189Z as the PA
- HMC849 as the T/R switch
- An Arduino toggling the switch and PA



Software

The kit running on a laptop includes:

- SDRangel as the interface
- A controller script as PTT or VOX
- A two-way API for T/R switching
- VB-CABLE redirecting audio
- WSJT-X as the modem for digital modes



Antenna and Filter

- Manual filter switching
  - SMB connectors
  - Snap-on for quick rewiring
- Two antennas:
  - A whip for 144 MHz and 432 MHz
  - A log periodic yagi PCB for 800 MHz - 6 GHz.

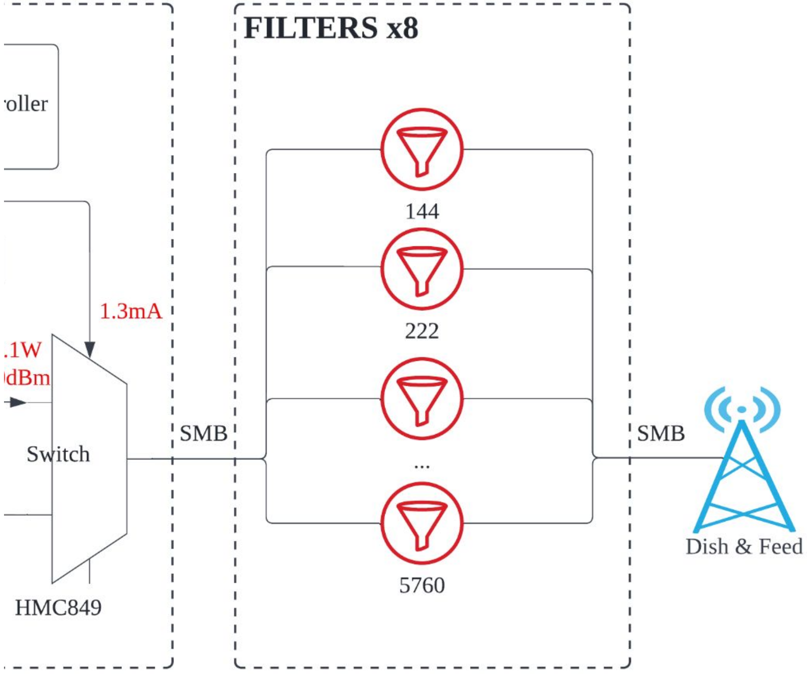


Figure V. Antenna for Field Test (left) and Full System in Operation (right)

Evaluation

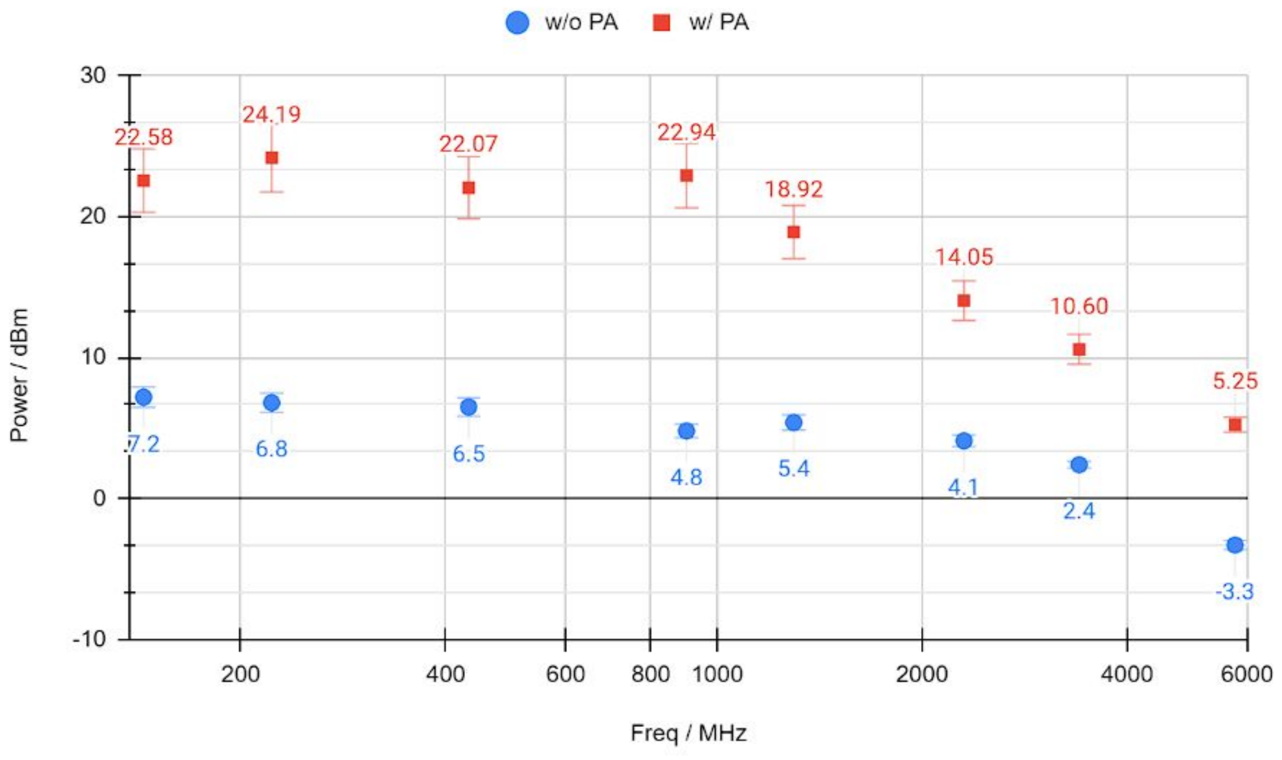


Figure VI. Tx Power vs. Frequency

Spurious Emission

- Output has strong odd harmonics
- Filtering is necessary
- Exploiting the harmonics…
  - to transmit on frequencies above the hardware limit (Langstone project)

Tx_att = 10dB @ 500MHz

- 1st 500MHz -1.8dBm
- 2nd 1GHz -51dBm
- 3rd 1.5GHz -11.2dBm
- 4th 2GHz -54dBm
- 5th 2.5GHz -18.6dBm

Source: https://www.eevblog.com/forum/rf-microwave/adalm-pluto-sdr/msg1290682/#msg1290682

Field Test

In the best case:

- FT8 on 902 and 1296 MHz over 132 miles
- CW from 432 through 3400 MHZ over 106 miles

For around 100mW, the system supports decent signal quality for SSB mode up to 66 miles and CW mode over 100 miles of line-of-sight path.

- 2, 1, and 0 stand for good, fair, and poor communication quality.
- “B” means the other station was too busy to answer.

Grid / miles	FN32	FN33	FN22	FN23	FN31	FN42	FN21	FN34
Freq / MHz	36	37	50	53	65	65	66	106
144	B	2	2	2	B	B	2	0
222	2	2	2	2	2	1	2	0
432	2	2	2	2	2	2	2	1
902	2	2	2	2	2	2	2	1
1296	2	2	2	2	2	2	2	1
2304	2	2	2	2	2	2	2	1
3400	2	2	2	2	2	2	2	1
5760	2	2	2	2	1	1	1	0

Figure VII. Signal Quality Heatmap[3]

Application

STEM Education

- Pluto SDR is an affordable and simple system suitable for school projects.
- The system has official Python, MATLAB, and Simulink support and teaching resources for STEM education.
- Pluto SDR is compatible with GNU Radio, an open-source radio framework for fast prototyping.

Preliminary Equipment Testing

- SDR's wide operating frequency and modulation support make it suitable for simple equipment testing.
- It can benchmark the receiving performance of a handheld transceiver (HT) and test a desktop unit's sideband output, all in one device.
- However, SDR setups cannot replace lab-grade instruments for limited precision and accuracy.

Amateur Radio Contesting

- Microwave stations are relatively rare in contests due to the high barrier of entry (equipment and knowledge).
- Rover stations are common in VHF contests to activate additional bands and locations by traveling to multiple geographical grids and operating portable equipment.
- The proposed setup powered by a standard 5V supply is lightweight and small enough for portable operations.

Future Work

Hardware Upgrade

GPSDO - Mini Precision GPS Reference Clock

Typical phase noise at 10MHz output:

- -70 dBc/Hz at 1 Hz
- -100 dBc/Hz at 10 Hz
- -125 dBc/Hz at 100 Hz
- -145 dBc/Hz at 1 kHz
- -150 dBc/Hz at 10 kHz
- -153 dBc/Hz at 100 kHz
- -155 dBc/Hz at 1 MHz

Power Amplifier - TBWA2/20dB

Noise Figure @ 2GHz: 4.5 … 5 dB

Freq	**Gain dB**	**Freq**	**Gain dB**
1M	14.8	1G	19.8
10M	20.2	2G	19
100M	20.2	3G	17.6
500M	20	4.5G	17.4
		6G	15.4

Software Upgrade

Developing dedicated software kits yields several benefits:

- Easier system configuration
- Reduced system performance requirements
- Reduced power consumption

Spread Spectrum Modes

- Better interference rejection
- Lower power density
- Bandwidth on microwave bands
  - Legal limit: 100kHz
  - AFSK: 2.8kHz

Shannon-Hartley theorem:

$$C = B\log_2\left(1+\frac{S}{N}\right)$$

- B - bandwidth in hertz
- S, N - power in watts for received signal and noise

MIMO - Multiple Input, Multiple Output.

Improves capacity, range, and reliability

- Increase throughput in multipath channels
- Beam steering

THE END.