



AHEAD OF WHAT'S POSSIBLE™

# Build Your Own Phased Array System!

## INSTRUCTIONS

Jon Kraft

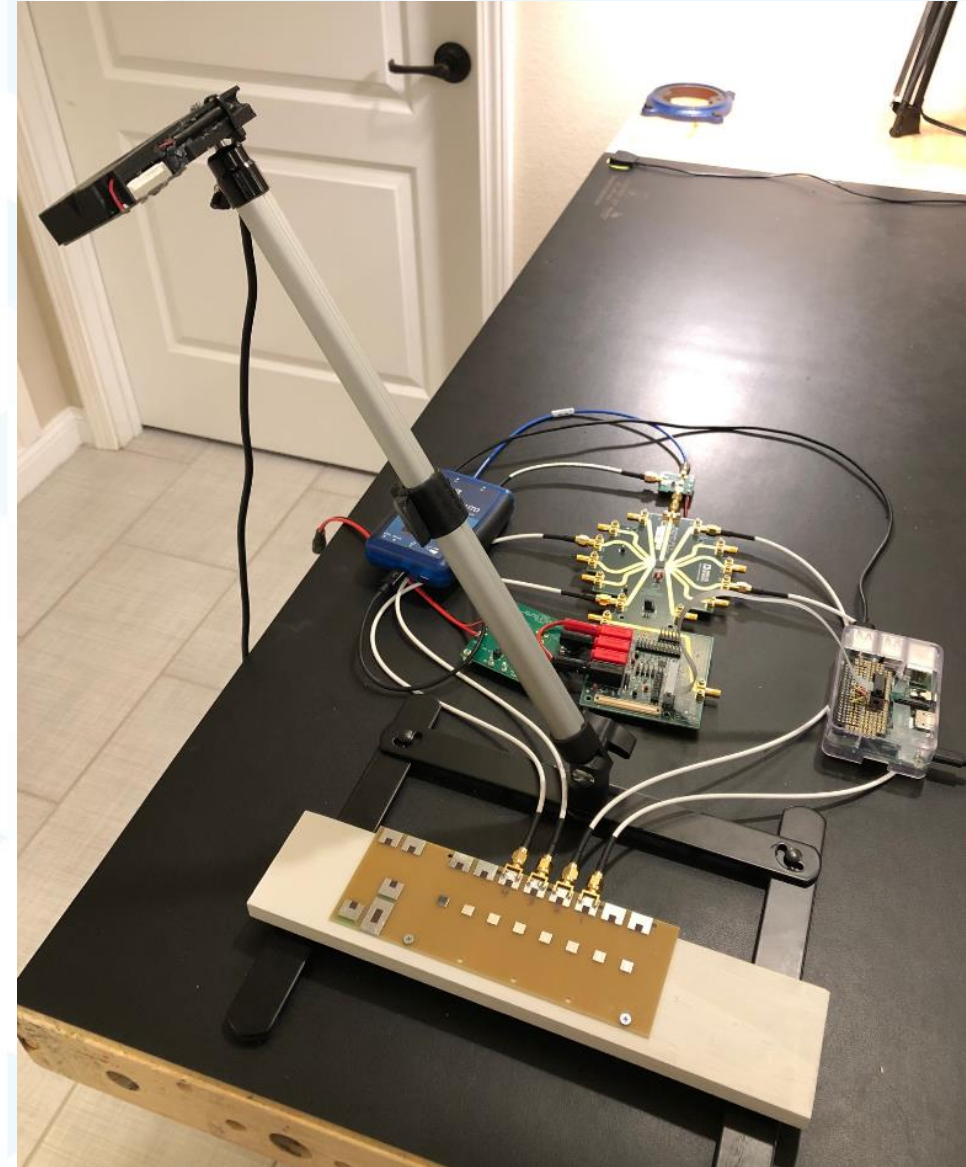
<http://www.github.com/jonkraft/phasedarray>

“Anytime you have to compensate for the speed of light,  
you’re probably doing something cool.”



# Overview of Building Instructions:

- ▶ ADAR1000 Intro and Lab Setup
- ▶ Bill of Materials (BOM)
- ▶ Assemble the Eval Boards
- ▶ Raspberry Pi Setup
- ▶ RF Source Assembly
- ▶ Antenna Assembly
- ▶ Configure Pluto
- ▶ Put it All Together



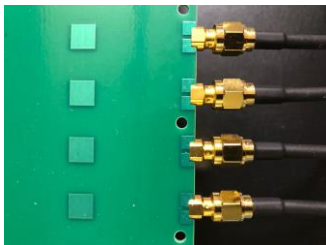
# Intro to ADAR1000 and Lab Setup



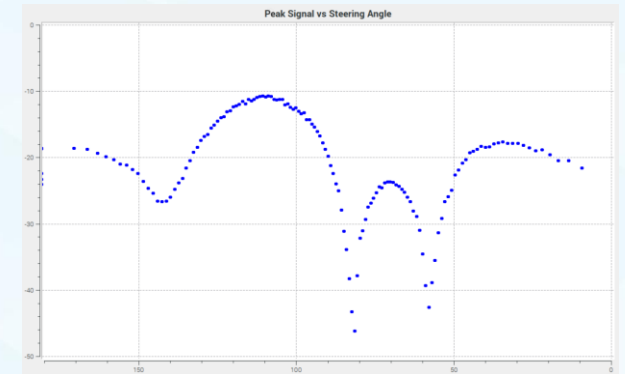
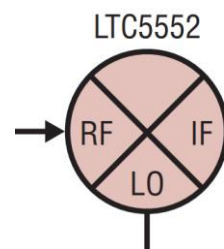
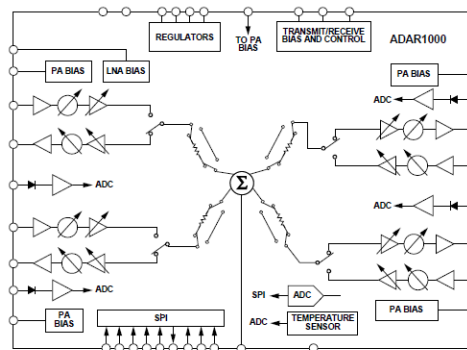
# Phased Array Lab Setup

- ▶ The lab consists of:
  - A 10 GHz spacing ( $d=0.015\text{m}$ ) 4 element linear patch antenna
  - ADAR1000 X Band Analog Beamformer
  - LTC5552 2-18 GHz Active Mixer
  - ADALM-Pluto (AD9363) Software Defined Radio
  - LT3045 3.3V LDO (to power the ADAR1000 and LTC5552)
  - Raspberry Pi running GNURadio
    - Controls ADAR1000 via Python SPI commands
    - Controls Pluto via USB (IIOLIB)
    - Displays received data from Pluto

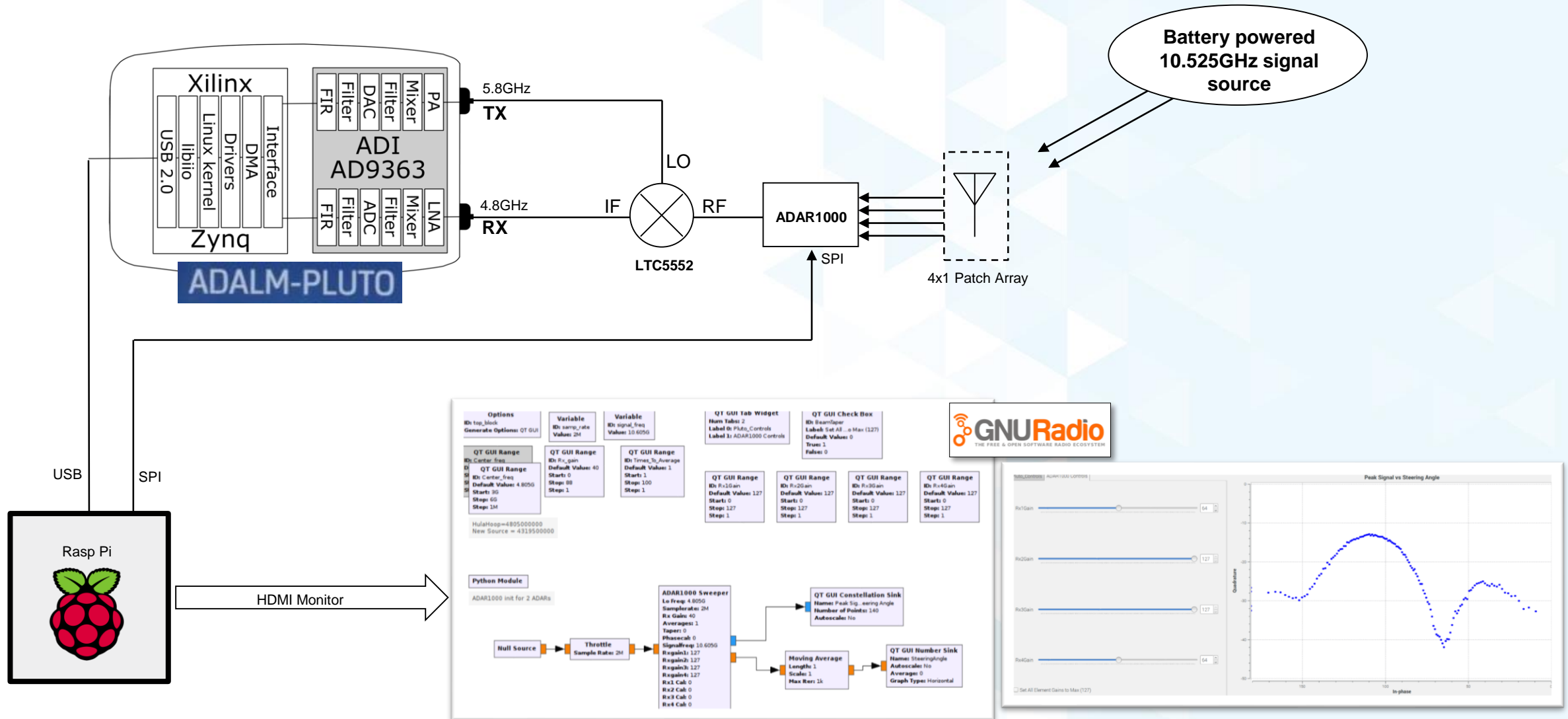
4 Patch Antenna



ADAR1000



# Phased Array Lab Setup: Tracking an RF Source



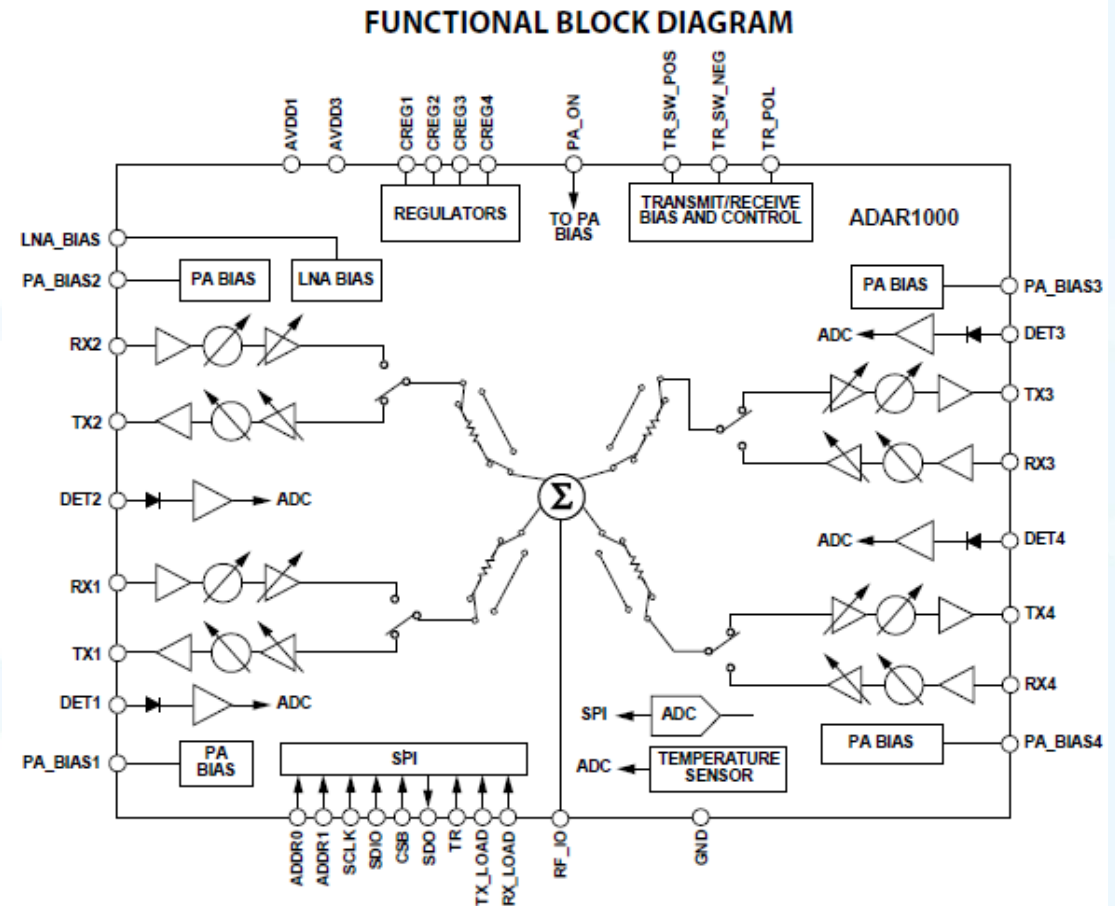
# ADAR1000: 4 Channel Analog Beamformer

## Key Features

- ▶ 8 GHz to 16 GHz frequency range
- ▶ Single-pin transmit and receive control
- ▶ 360° phase adjustment range
- ▶ 2.8° phase resolution
- ▶ ≥31 dB gain adjustment range
- ▶ Bias and control for external transmit and receive modules
- ▶ Memory for 121 prestored beam positions
- ▶ Four -20 dBm to +10 dBm power detectors
- ▶ 88-terminal, 7 mm × 7 mm LGA package

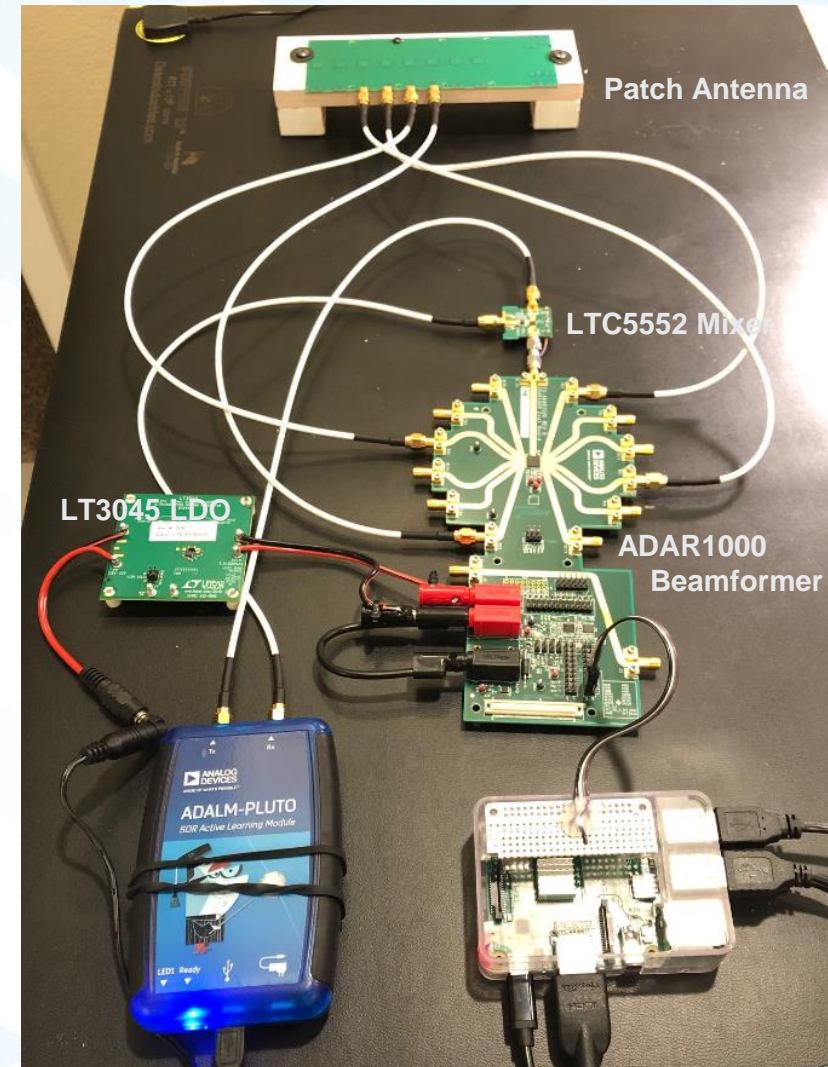
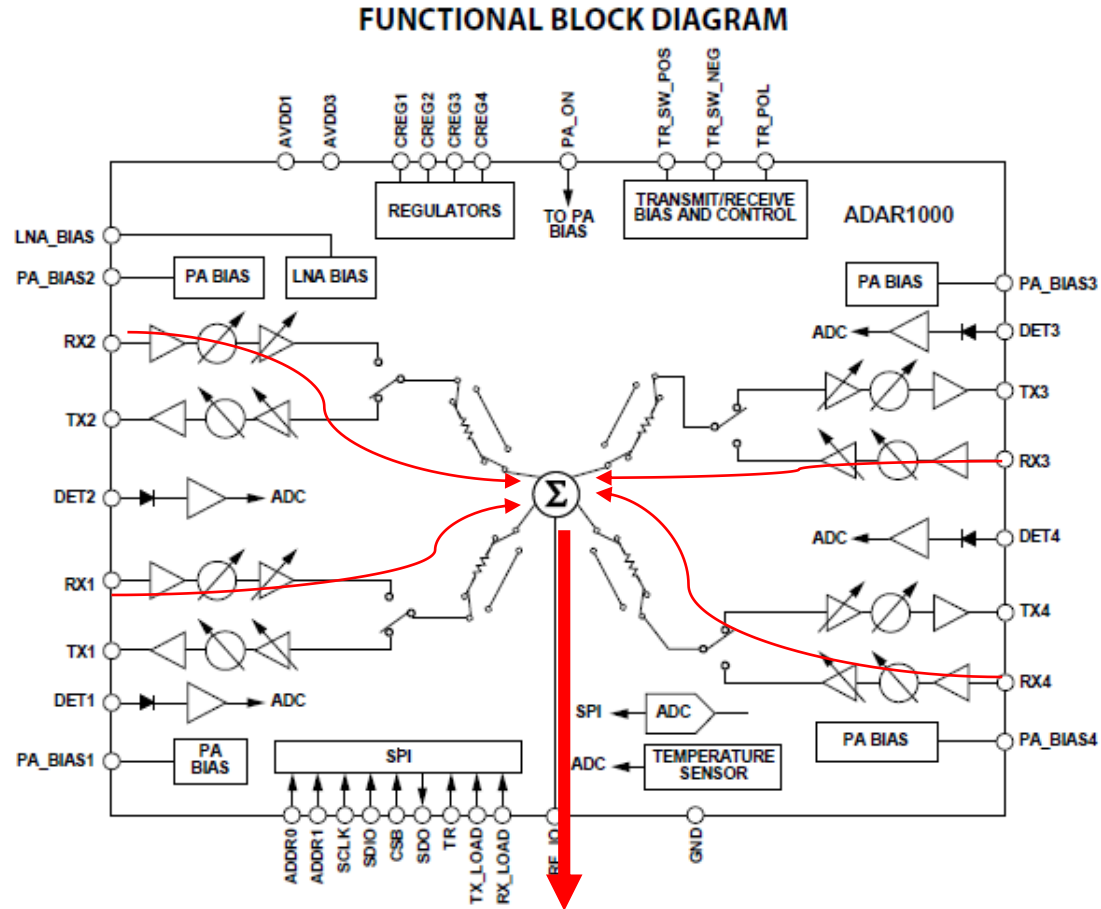
## Key Benefits

- ▶ Compact form factor for electronically steered analog beamformer
- ▶ Negative bias voltage from integrated DAC intended for gate bias of GaAs or GaN amplifier
- ▶ Support low power bias mode with 50% reduction in power consumption



# ADAR1000: 4 Channel Analog Beamformer

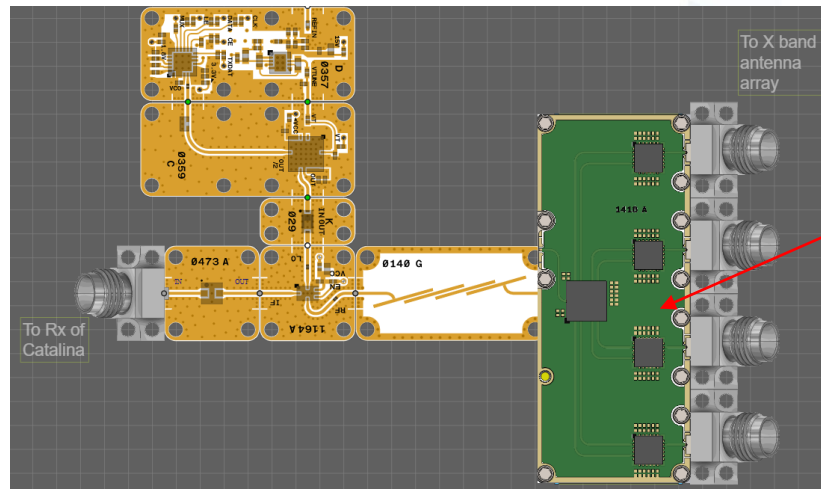
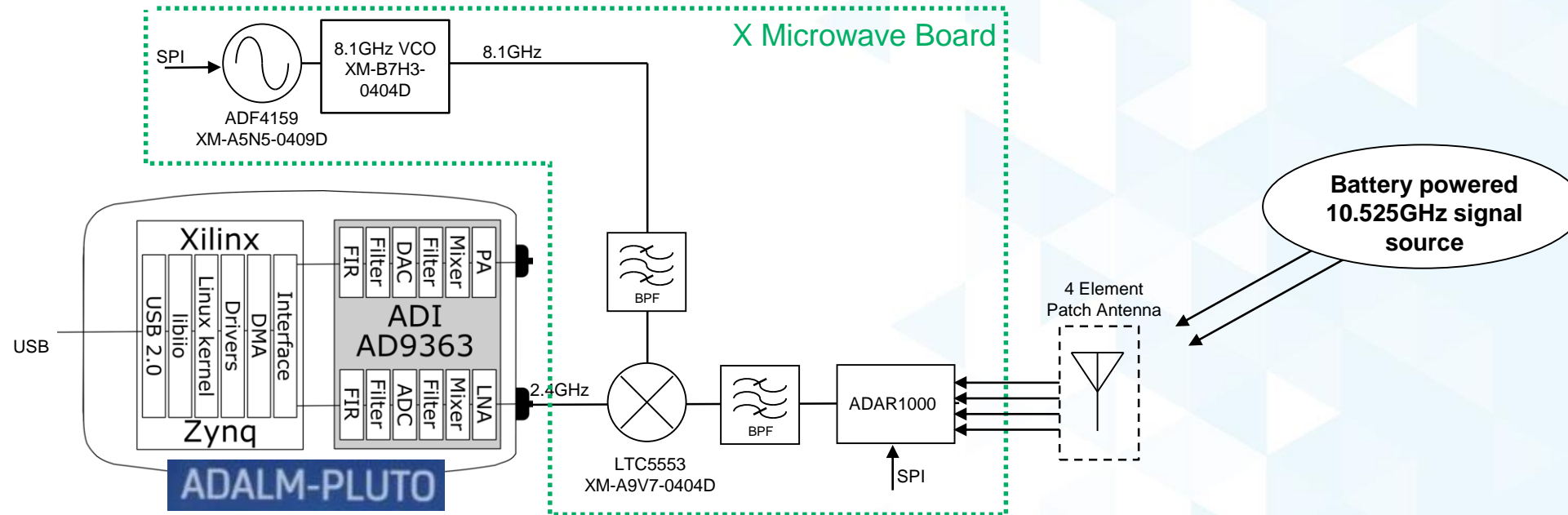
- ▶ We'll only be using the receive path, for this lab





# Declutter this Setup with X Microwave!

<https://www.xmicrowave.com/>



ADAR1000 + 4 ADTR1107 (TR Modules—i.e. PA/LNA/Switch)

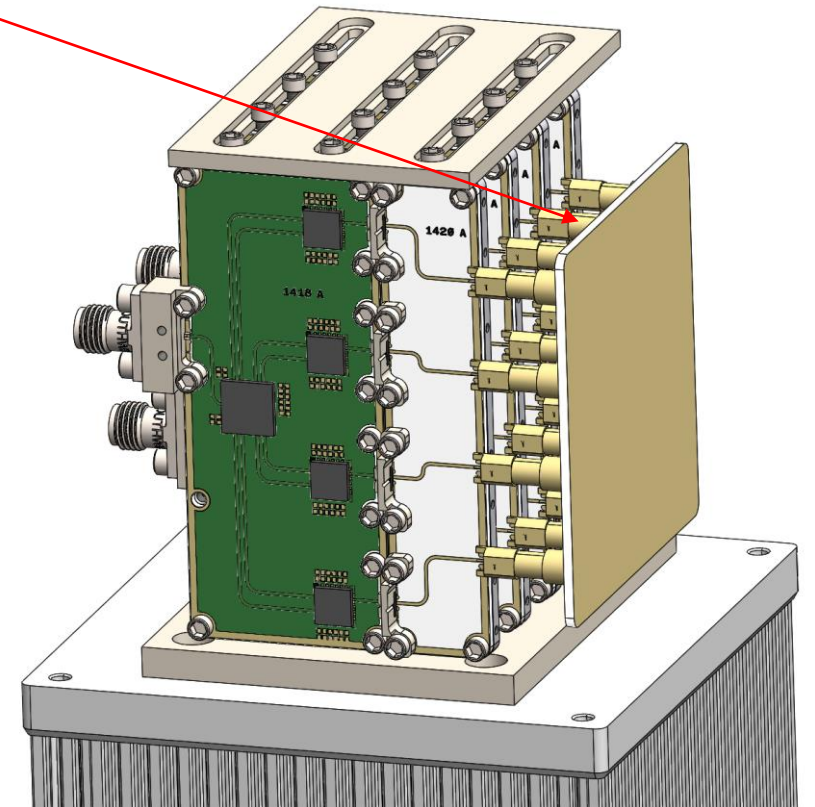
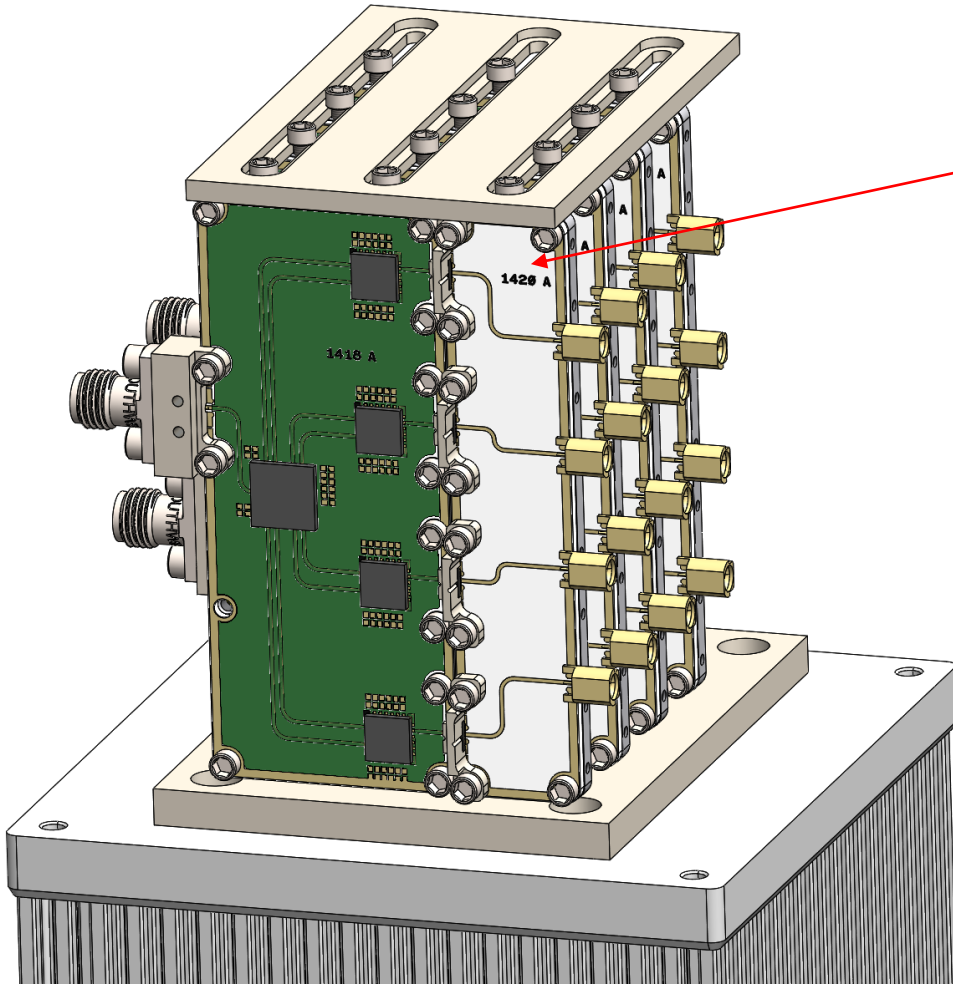


# Stack ADAR1000 Modules Together for the Phased Array Cube:

<https://www.xmicrowave.com/>

## Stack 4 together to create a 4x4 array

- Interposer board to fit whatever lattice spacing
- Antenna snaps on



# Bill of Materials

# Bill of Materials:

Beamformer, Mixer, and SDR				
Qty	Description	Other info	Part Number	Link
1	ADAR1000 Eval Board		EVAL-ADAR1000	<a href="https://www.analog.com/en/design-center/evaluation-hardware-and-software/evaluation-boards-kits/EVAL-ADAR1000.html#eb-overview">https://www.analog.com/en/design-center/evaluation-hardware-and-software/evaluation-boards-kits/EVAL-ADAR1000.html#eb-overview</a>
1	Pluto SDR		ADALM-Pluto	<a href="https://www.analog.com/en/design-center/evaluation-hardware-and-software/evaluation-boards-kits/ADALM-PLUTO.html">https://www.analog.com/en/design-center/evaluation-hardware-and-software/evaluation-boards-kits/ADALM-PLUTO.html</a>
1	LTC5552 Mixer		DC2668A	<a href="https://www.analog.com/en/design-center/evaluation-hardware-and-software/evaluation-boards-kits/dc2668a.html">https://www.analog.com/en/design-center/evaluation-hardware-and-software/evaluation-boards-kits/dc2668a.html</a>
1	LT3045 3.3V LDO Board		DC2491A	<a href="https://www.analog.com/en/design-center/evaluation-hardware-and-software/evaluation-boards-kits/dc2491a.html">https://www.analog.com/en/design-center/evaluation-hardware-and-software/evaluation-boards-kits/dc2491a.html</a>
6	18" SMA Cable		415-0033-018	<a href="https://www.digikey.com/product-detail/en/cinch-connectivity-solutions-johnson/415-0033-018/J10114-ND/457274">https://www.digikey.com/product-detail/en/cinch-connectivity-solutions-johnson/415-0033-018/J10114-ND/457274</a>
1	SMA Connector		ACX1240-ND	<a href="https://www.digikey.com/product-detail/en/amphenol-rf/132168/ACX1240-ND/1011917">https://www.digikey.com/product-detail/en/amphenol-rf/132168/ACX1240-ND/1011917</a>
1	AC to DC wall wart	5V output	PSAC05A-050L6	<a href="https://www.digikey.com/product-detail/en/phi hong-usa/PSAC05A-050L6/993-1330-ND/5418482">https://www.digikey.com/product-detail/en/phi hong-usa/PSAC05A-050L6/993-1330-ND/5418482</a>
1	2.1x5.5mm barrel jack wires			<a href="https://www.amazon.com/gp/product/B07CWQPPTW/ref=ppx_yo_dt_b_asin_title_o05_s00?ie=UTF8&amp;psc=1">https://www.amazon.com/gp/product/B07CWQPPTW/ref=ppx_yo_dt_b_asin_title_o05_s00?ie=UTF8&amp;psc=1</a>
1	Banana Jack	Red	108-1082-001	<a href="https://www.digikey.com/product-detail/en/108-1082-001/J460-ND/35155/?itemSeq=307381256">https://www.digikey.com/product-detail/en/108-1082-001/J460-ND/35155/?itemSeq=307381256</a>
1	Banana Jack	Black	108-1083-001	<a href="https://www.digikey.com/product-detail/en/108-1083-001/J461-ND/35158/?itemSeq=307381098">https://www.digikey.com/product-detail/en/108-1083-001/J461-ND/35158/?itemSeq=307381098</a>
10	Bumper feet for eval boards		SJ5746-0-ND	<a href="https://www.digikey.com/product-detail/en/3m/SJ61A1/SJ5746-0-ND/1768456">https://www.digikey.com/product-detail/en/3m/SJ61A1/SJ5746-0-ND/1768456</a>
1	Raspberry Pi 3B+		Rasp Pi 3 B+	<a href="https://www.digikey.com/product-detail/en/pimoroni-ltd/PIM337/1778-1195-ND/8574322">https://www.digikey.com/product-detail/en/pimoroni-ltd/PIM337/1778-1195-ND/8574322</a>
1	Raspberry Pi breakout board for SPI		PROTO-001	<a href="https://www.digikey.com/products/en?keywords=protozero">https://www.digikey.com/products/en?keywords=protozero</a>
2	Polarity key for rectangular ribbon cable connector	Optional	15040292	<a href="https://www.digikey.com/products/en?keywords=wm1033-nd">https://www.digikey.com/products/en?keywords=wm1033-nd</a>
1	Ribbon cable connector		ED1543-ND	<a href="https://www.digikey.com/product-detail/en/on-shore-technology-inc/302-S101/ED1543-ND/2178422">https://www.digikey.com/product-detail/en/on-shore-technology-inc/302-S101/ED1543-ND/2178422</a>
Antenna Board, RF Source, and Stand				
Qty	Description	Other info	Part Number	Link
4	CONN SMA JACK STR 50OHM EDGE MNT		314-1703-ND	<a href="https://www.digikey.com/product-detail/en/BU-1420701851/314-1703-ND/9950117/?itemSeq=310517966">https://www.digikey.com/product-detail/en/BU-1420701851/314-1703-ND/9950117/?itemSeq=310517966</a>
1	8 element 10.525GHz Patch Antenna			
1	10.525GHz RF Source			<a href="https://www.amazon.com/gp/product/B00FFW4AZ4/ref=ppx_yo_dt_b_asin_title_o00_s01?ie=UTF8&amp;psc=1">https://www.amazon.com/gp/product/B00FFW4AZ4/ref=ppx_yo_dt_b_asin_title_o00_s01?ie=UTF8&amp;psc=1</a>
1	Power cable for RF Source		AE10621-ND	<a href="https://www.digikey.com/product-detail/en/assmann-wsw-components/AK670-OE-BLACK/AE10621-ND/2391700">https://www.digikey.com/product-detail/en/assmann-wsw-components/AK670-OE-BLACK/AE10621-ND/2391700</a>
1	Stand for RF Source			<a href="https://www.amazon.com/gp/product/B07JR2Q1G1/ref=ppx_yo_dt_b_asin_title_o00_s01?ie=UTF8&amp;psc=1">https://www.amazon.com/gp/product/B07JR2Q1G1/ref=ppx_yo_dt_b_asin_title_o00_s01?ie=UTF8&amp;psc=1</a>
1	Adapter to hold RF Source to Stand			<a href="https://www.amazon.com/gp/product/B07RJW34WB/ref=ppx_yo_dt_b_asin_title_o00_s02?ie=UTF8&amp;psc=1">https://www.amazon.com/gp/product/B07RJW34WB/ref=ppx_yo_dt_b_asin_title_o00_s02?ie=UTF8&amp;psc=1</a>
4	Magnet to hold antenna to stand		469-1063-ND	<a href="https://www.digikey.com/product-detail/en/radial-magnet-inc/8221/469-1063-ND/5400502">https://www.digikey.com/product-detail/en/radial-magnet-inc/8221/469-1063-ND/5400502</a>

# Eval Board Assembly



# ADAR1000 + Mixer Assembly

## ▶ ADAR1000 Eval Board:

- <https://www.analog.com/en/design-center/evaluation-hardware-and-software/evaluation-boards-kits/EVAL-ADAR1000.html#eb-overview>

## ▶ LTC5552 Eval Board:

- <https://www.analog.com/en/design-center/evaluation-hardware-and-software/evaluation-boards-kits/dc2668a.html>

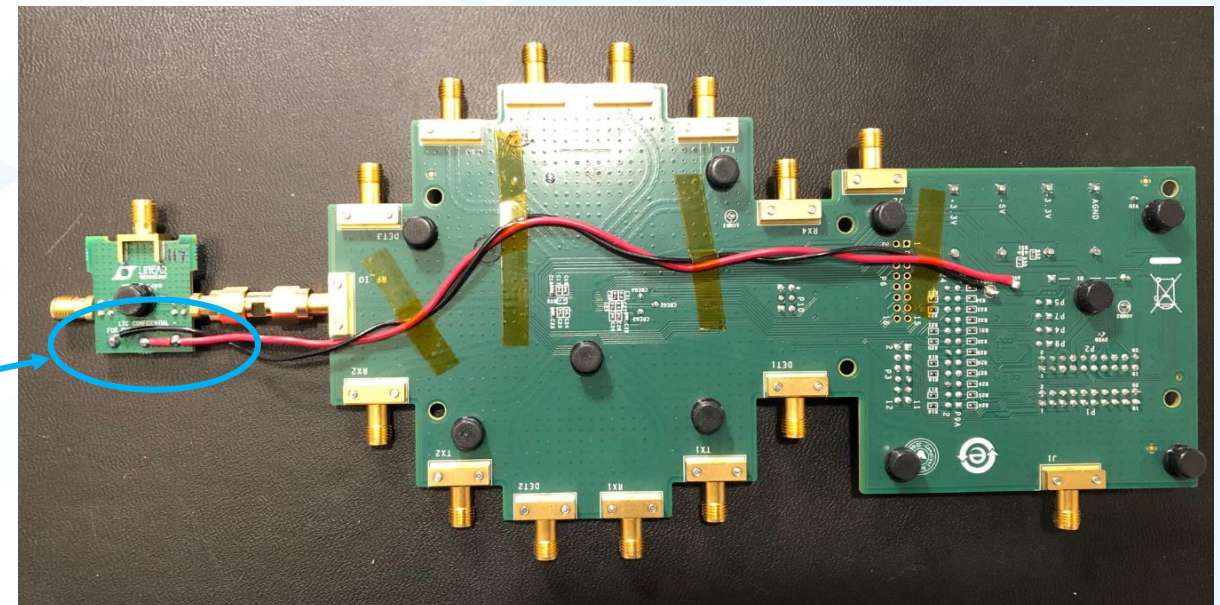
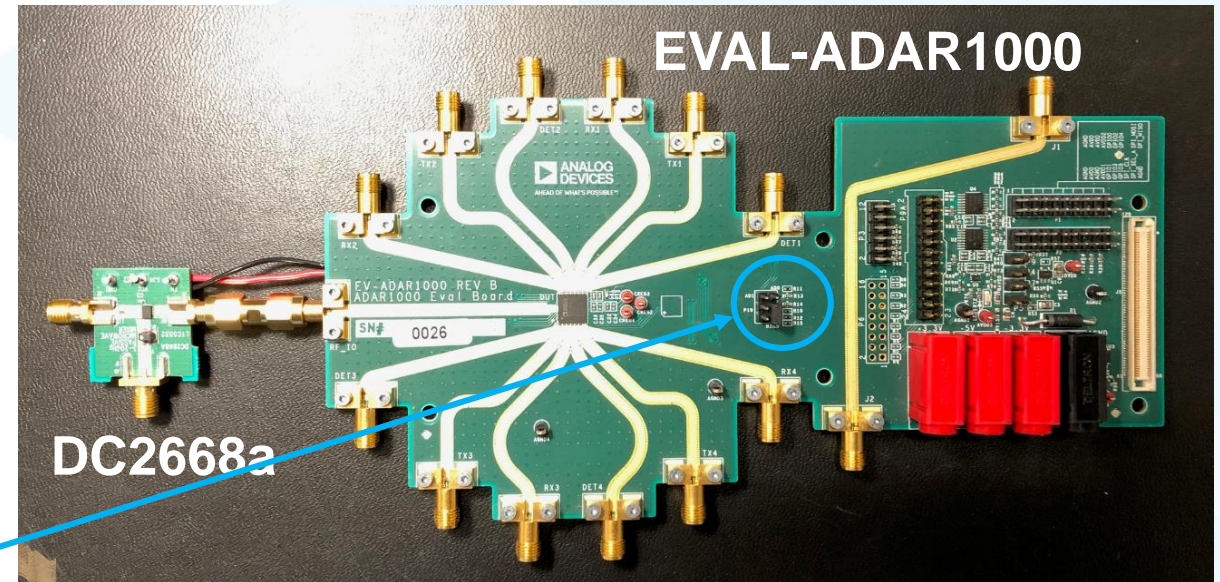
## ▶ Set the correct SPI Address

- Default for my programs is 0x20 as shown

## ▶ Both boards are powered by 3.3V

- Red and Black wires connect GND and 3.3V

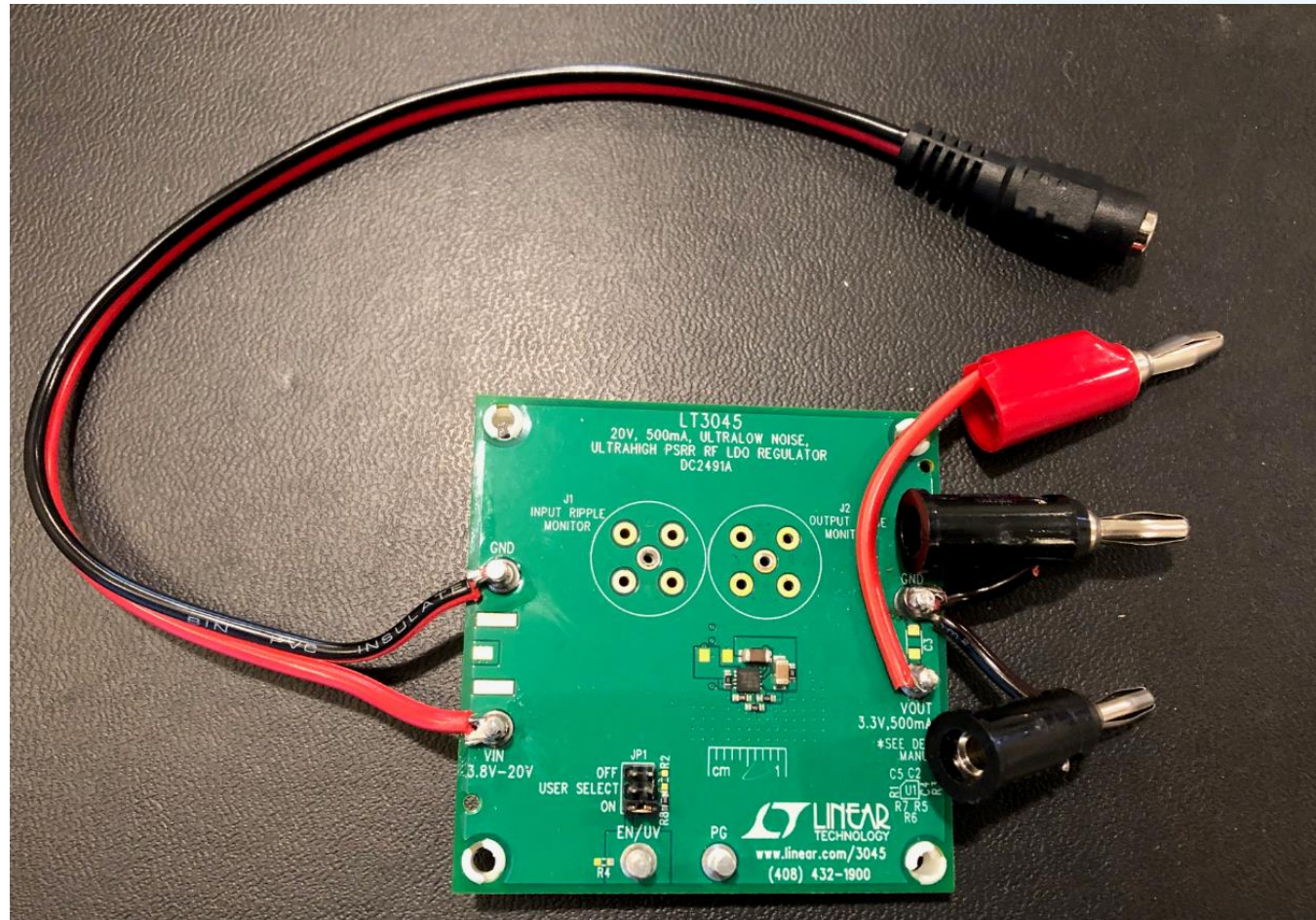
## ▶ “EN” pin on LTC5552 board also needs to be pulled to 3.3V, so be sure to connect it also





# LDO Assembly

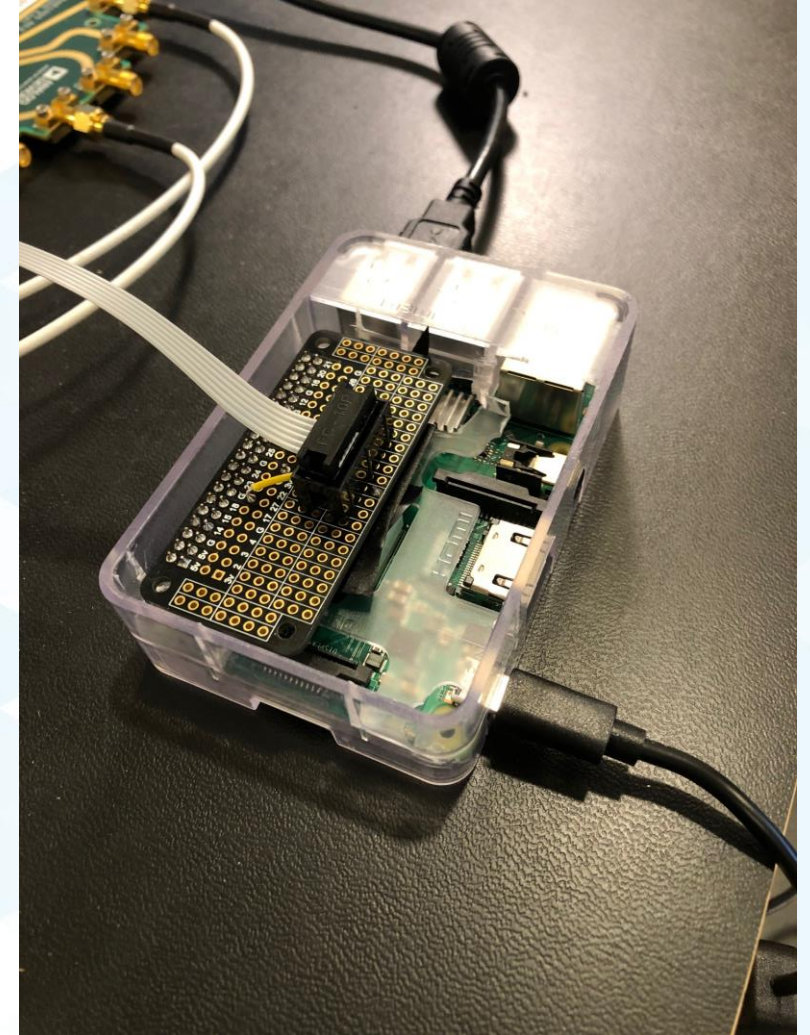
- ▶ Both the LTC5552 and the ADAR1000 are powered by 3.3V
  - Use the ultra low noise LT3045! This is the ideal LDO for powering RF circuitry.
  - <https://www.analog.com/en/design-center/evaluation-hardware-and-software/evaluation-boards-kits/dc2491a.html>



# Raspberry Pi Setup

# Raspberry Pi Setup

- ▶ Raspberry Pi 3B+
  - Other Pi versions may work also
  - Raspbian Stretch Recommended
  - But Pi 4 (running Raspbian Buster) may stumble on some of the GNU radio GUI objects (like the DOA Compass)
- ▶ Download the entire PI SD Card image here:
  - <https://download.analog.com/phased-array-lab/raspi>
  - No other installs are required, it'll work out of the box!
- ▶ Or, do your own install by following these instructions:
  - <https://github.com/jonkraft/Pluto-Install-for-Raspberry-Pi>
- ▶ To interact with the Pi:
  - Option 1: Use HDMI Monitor and Keyboard/Mouse
  - Option 2: Use VNC Viewer





# Rasp Pi SPI Breakout Board

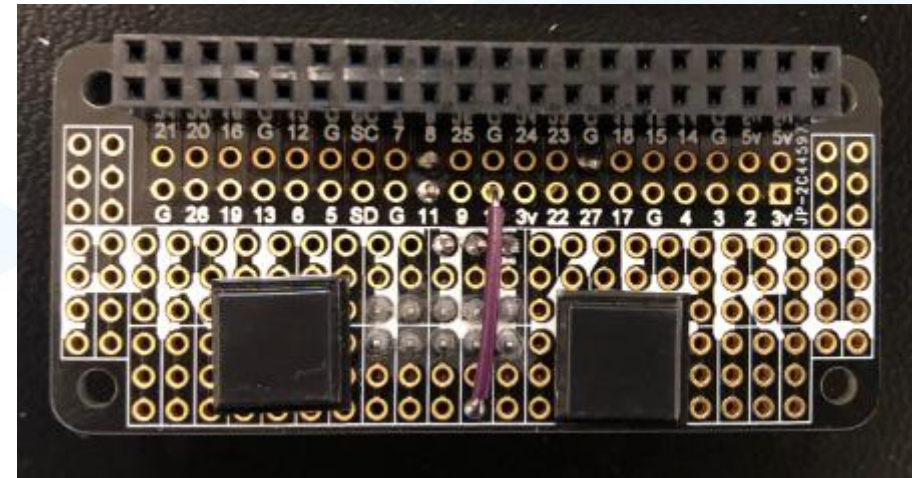
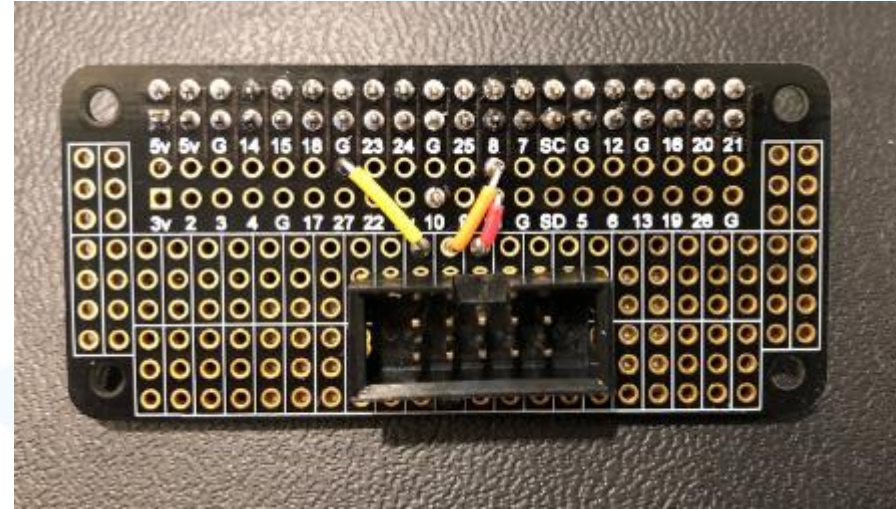
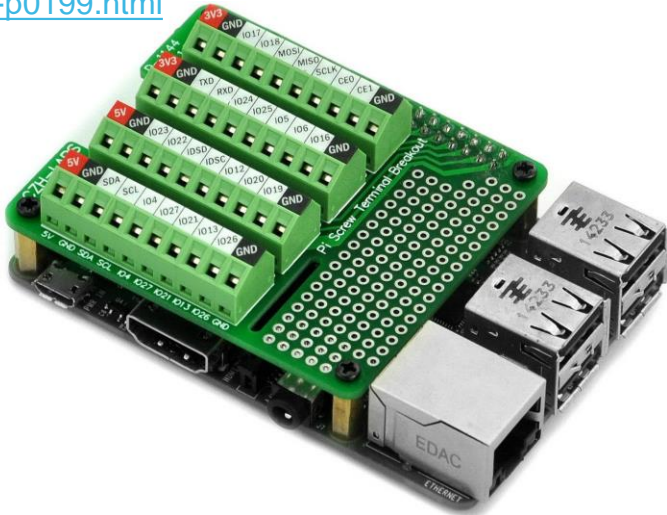
- ▶ Connect SPI to ADAR1000 Ribbon Cable

- Use Pimoroni ProtoZero board:

- <https://shop.pimoroni.com/products/protozero>

- ▶ Or use Electronics-Salon Terminal Block:

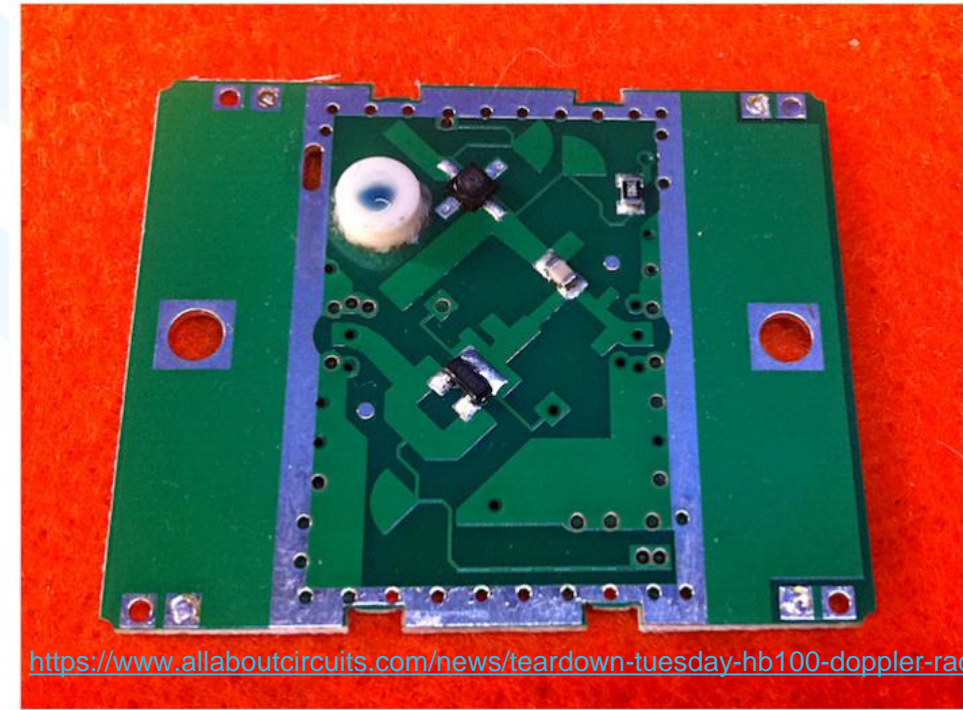
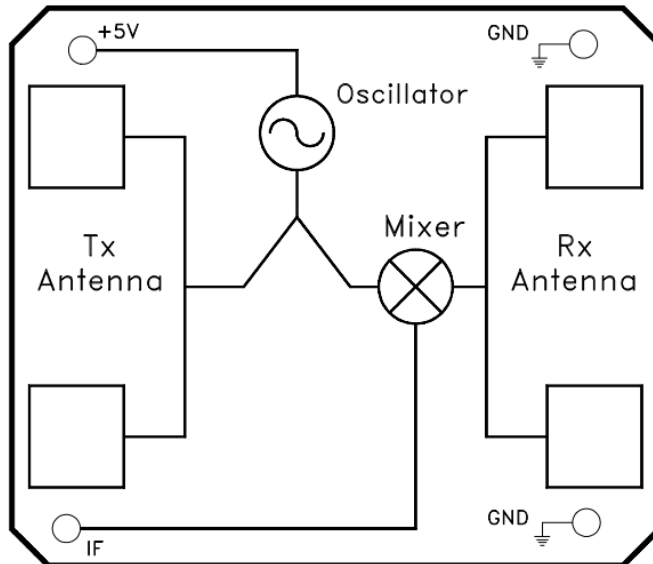
- <https://czh-labs.com/czh-labs-pi-screw-terminal-block-breakout-module-for-raspberry-pi-p0199.html>



# RF Source Assembly

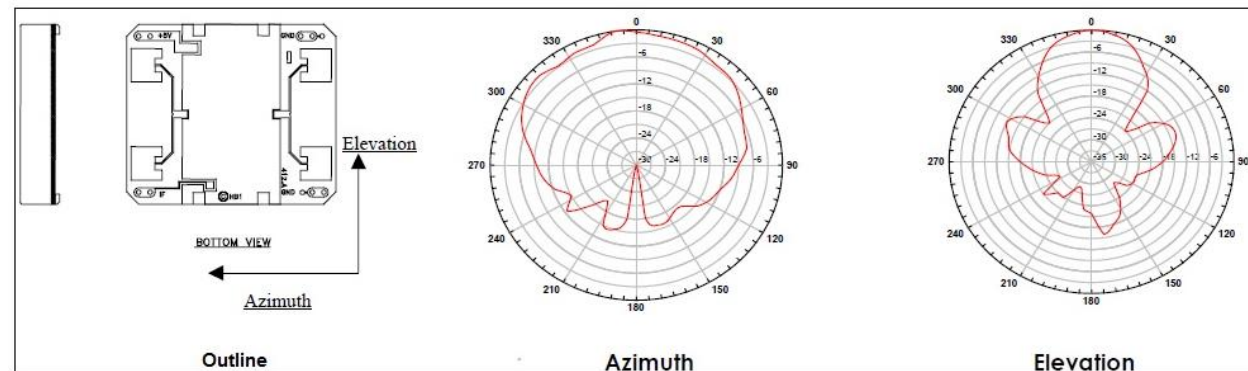
# 10.5GHz RF Source

- ▶ Use the ultra fun HB100!
  - \$3 (includes shipping!) on Ebay
  - Draws 40mA from 5V
  - You MUST use a **CLEAN** 5V Supply (like LDO or battery)
- HB100 generates a poor quality 10.5GHz tone
  - It's good enough for us though!



<https://www.allaboutcircuits.com/news/teardown-tuesday-hb100-doppler-radar-module/>

What sorcery is this?

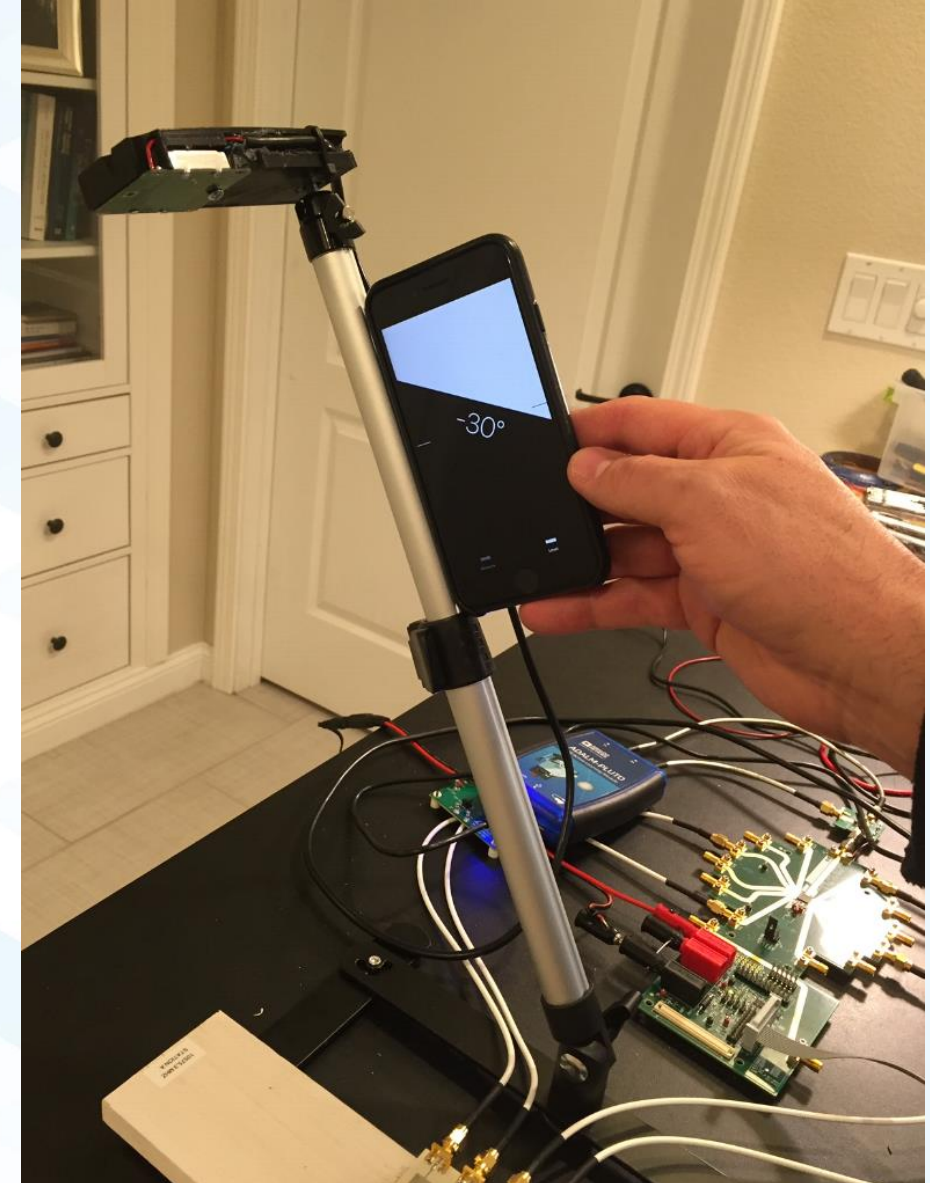
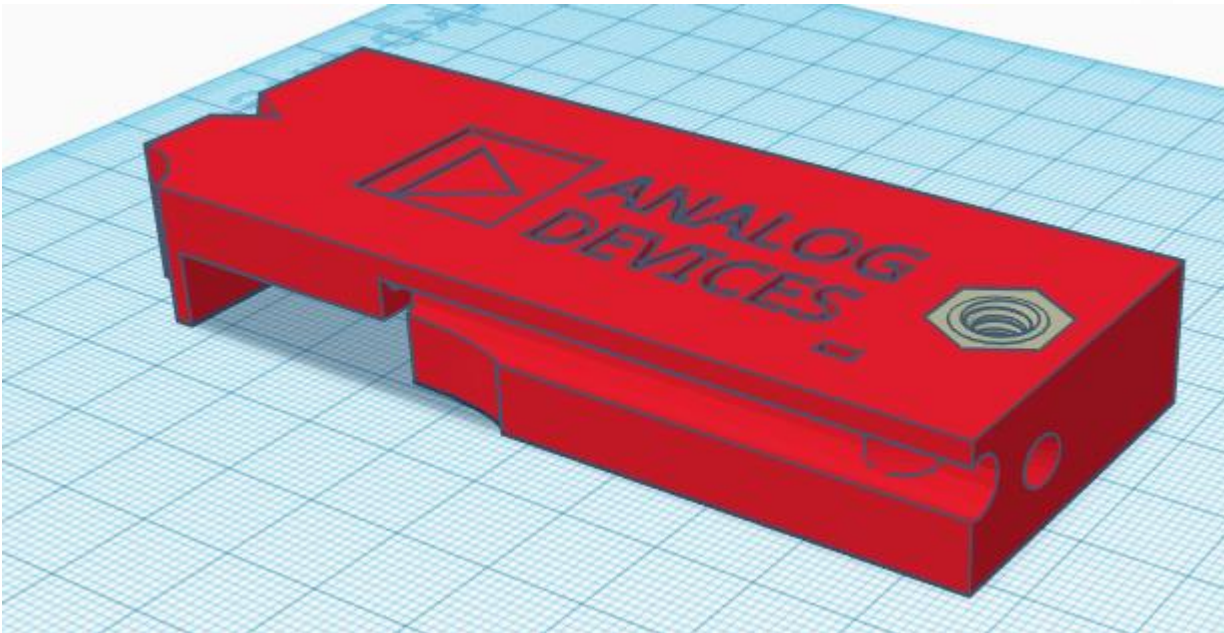


[https://www.limpkin.fr/public/HB100/HB100\\_Microwave\\_Sensor\\_Application\\_Note.pdf](https://www.limpkin.fr/public/HB100/HB100_Microwave_Sensor_Application_Note.pdf)



# HB100 RF Source Setup

- ▶ Add wires to 5V and GND (see next slide)
- ▶ Mount it to a stand:
  - This one works well:
  - [https://www.amazon.com/gp/product/B07JR2Q1G1/ref=ppx\\_yo\\_dt\\_b\\_asin\\_title\\_o00\\_s01?ie=UTF8&psc=1](https://www.amazon.com/gp/product/B07JR2Q1G1/ref=ppx_yo_dt_b_asin_title_o00_s01?ie=UTF8&psc=1)
- ▶ Then attach it with a 3D printed holder
  - .stl file available at [www.github.com/jonkraft/phasedarray](http://www.github.com/jonkraft/phasedarray)
  - or use the “cell phone” holder generally included with the stand



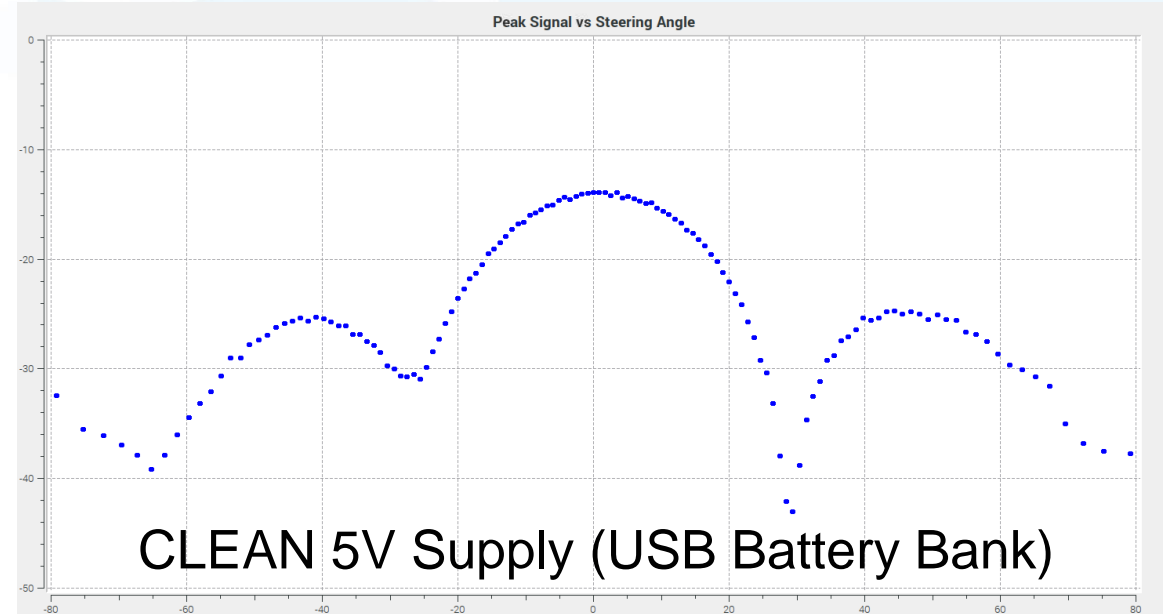


# HB100 RF Source: The Power Supply Matters!

- ▶ HB100 must be supplied with 5V
- ▶ But a noisy 5V will mean a noisy FFT Plot!

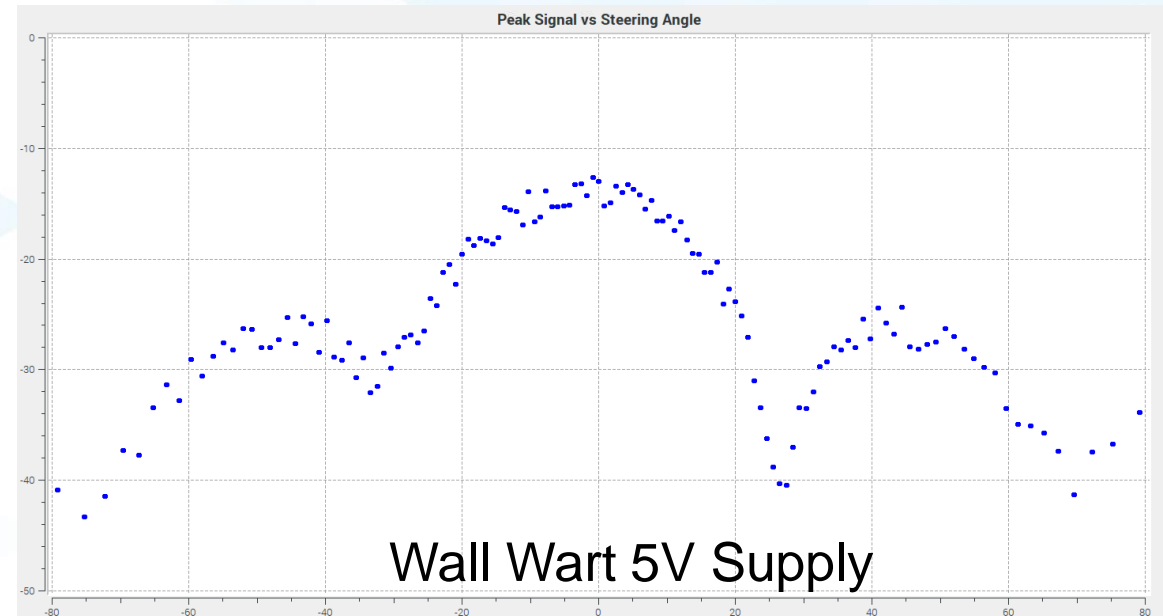
- ▶ These are **GOOD** power sources:

- LT3045 LDO
- Battery Pack or USB Battery Bank
- Good Quality USB Phone Changer



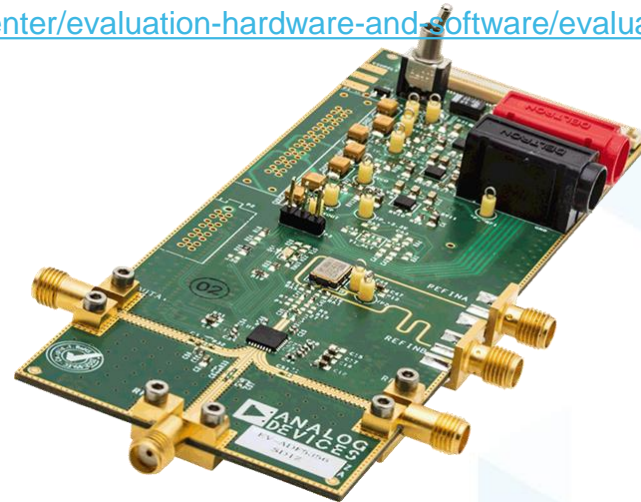
- ▶ These are **BAD** power sources:

- Raspberry Pi USB port
- Wall Wart



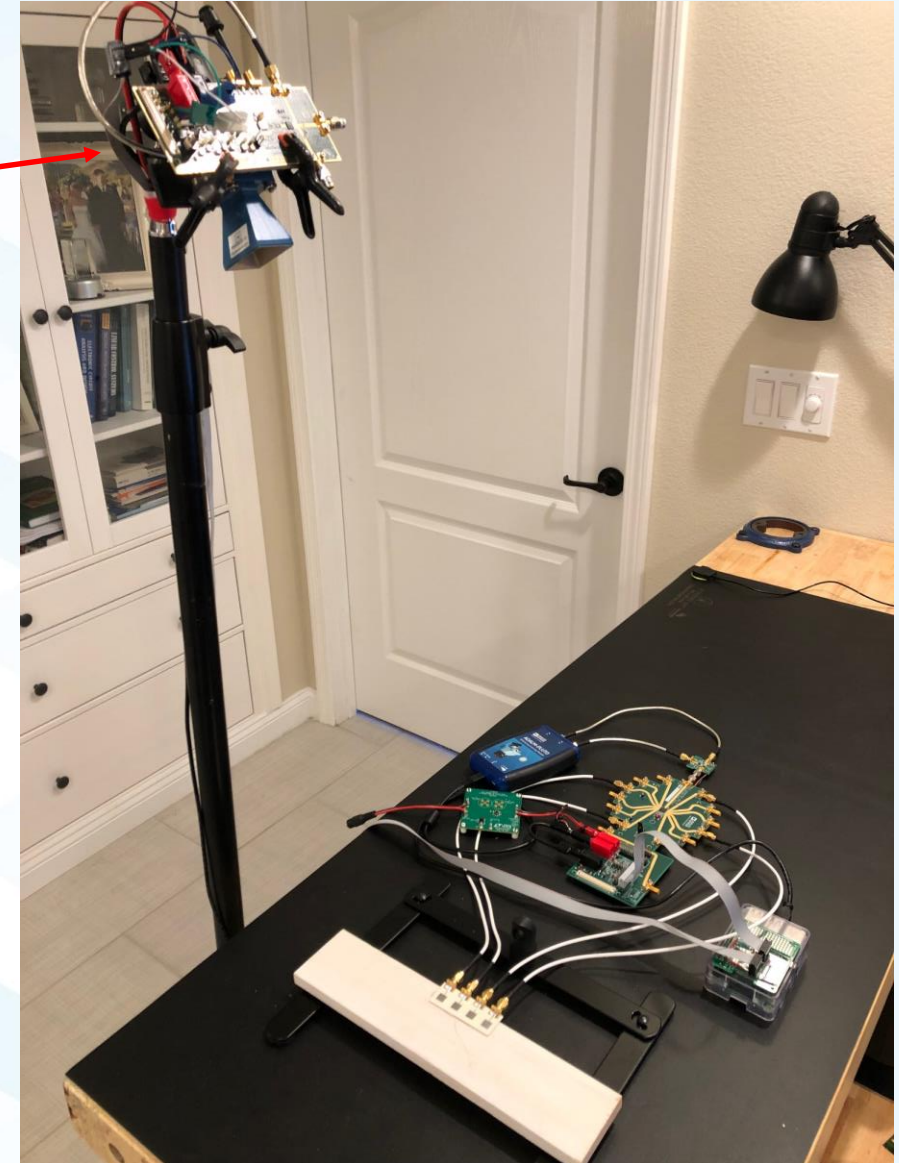
# A MUCH Better RF Source

- ▶ Alternatively, use an ADI Synthesizer to generate the X band signal source
- ▶ The ADF5356 Works Great for this!
  - <https://www.analog.com/en/design-center/evaluation-hardware-and-software/evaluation-boards-kits/EVAL-ADF5356.html>



- ▶ Transmit Antenna:

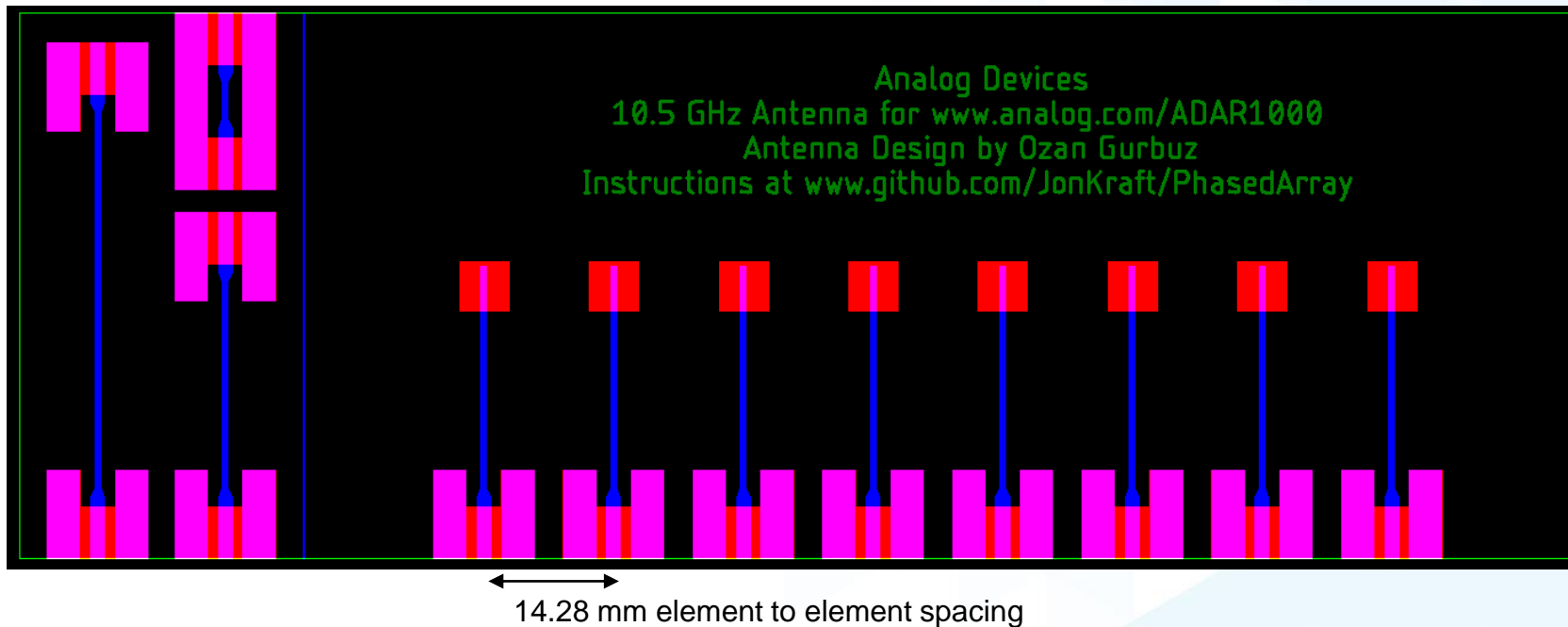
- <https://www.pasternack.com/standard-gain-horn-waveguide-size-wr90-10-db-gain-sma-female-pe9856sf-10-p.aspx>



# Antenna Assembly

# Patch Antenna

- ▶ A 10.5GHz patch antenna has been specifically designed for this lab by Ozan Gurbuz
- ▶ The gerber files, to make your own, are available at:
  - [www.github.com/jonkraft/phasedarray](https://www.github.com/jonkraft/phasedarray)
- ▶ Or contact your local Analog Devices FAE! They can probably find you one.
- ▶ This antenna can also be ordered directly from PCBWAY:
  - Use this link: [https://www.pcbway.com/project/shareproject/10\\_5GHz\\_X\\_Band\\_Patch\\_Antenna.html](https://www.pcbway.com/project/shareproject/10_5GHz_X_Band_Patch_Antenna.html)





# Configure Pluto

# Upgrade Pluto

- ▶ ADALM-PLUTO is an AMAZING Software Defined Radio!

- <https://wiki.analog.com/university/tools/pluto>

- ▶ Unbox it, and perform these two steps:

- Update Firmware:

- Download firmware here:

- <https://github.com/analogdevicesinc/plutosdr-fw/releases/latest>

- Install on Pluto:

- <https://wiki.analog.com/university/tools/pluto/users/firmware#windowsosx>

- Upgrade Pluto to higher freq range and wider BW:

- This is required for the frequency and sample rates used in the lab:

- [https://wiki.analog.com/university/tools/pluto/users/customizing#updating\\_to\\_the\\_ad9364](https://wiki.analog.com/university/tools/pluto/users/customizing#updating_to_the_ad9364)



# Put it All Together!

# Fully Assembled Lab Station:

