# ANALOG DEVICES

## 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

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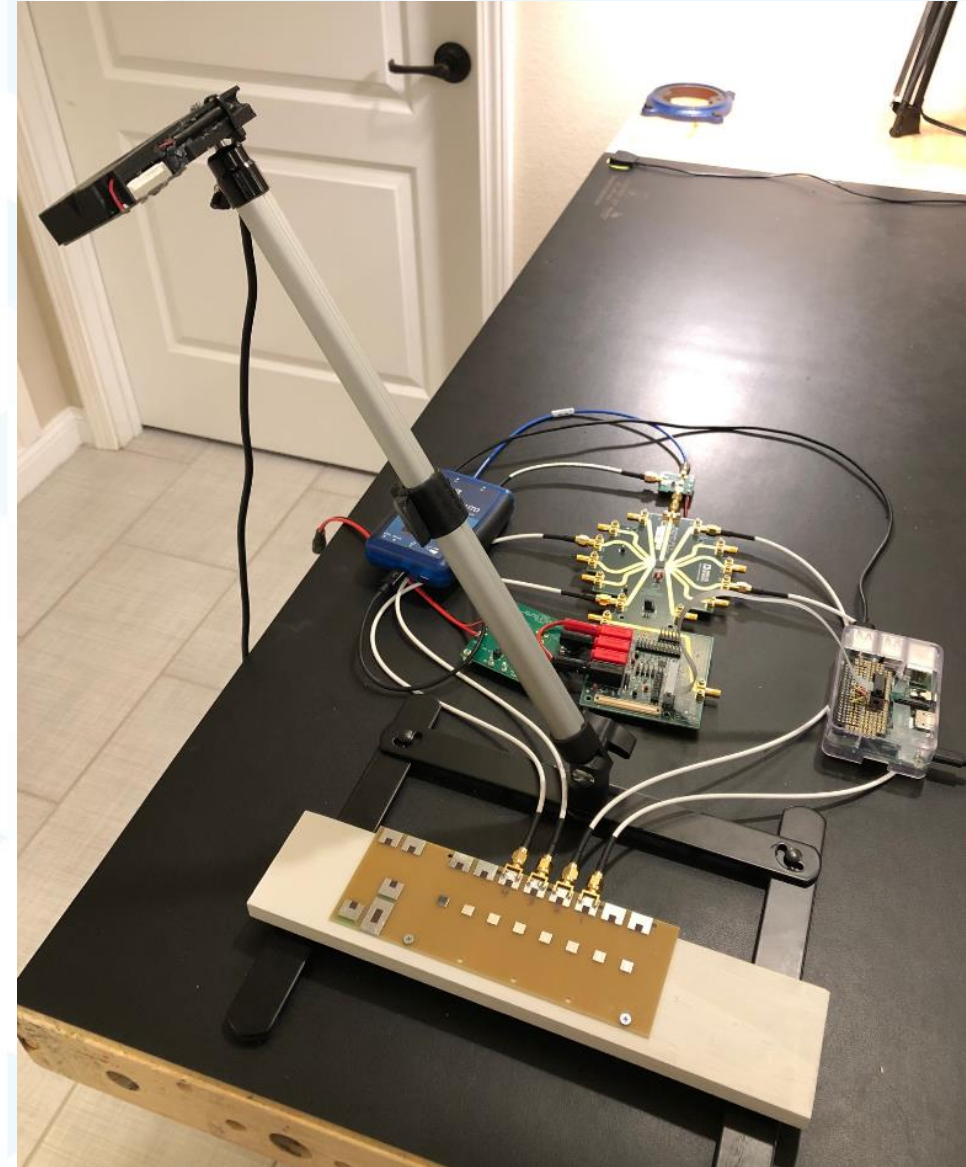
# Intro to ADAR1000 and Lab Setup

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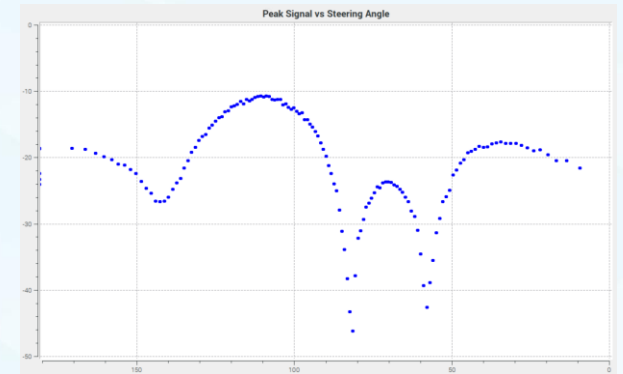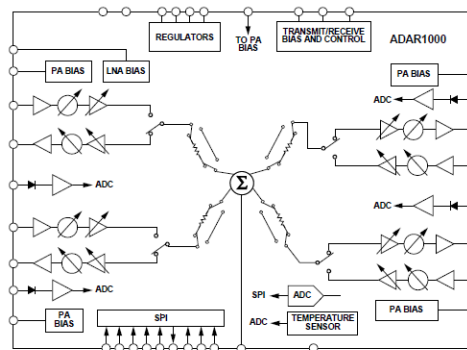
# Phased Array Lab Setup

▶ The lab consists of:
- A 10 GHz spacing (d=0.015m) 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)
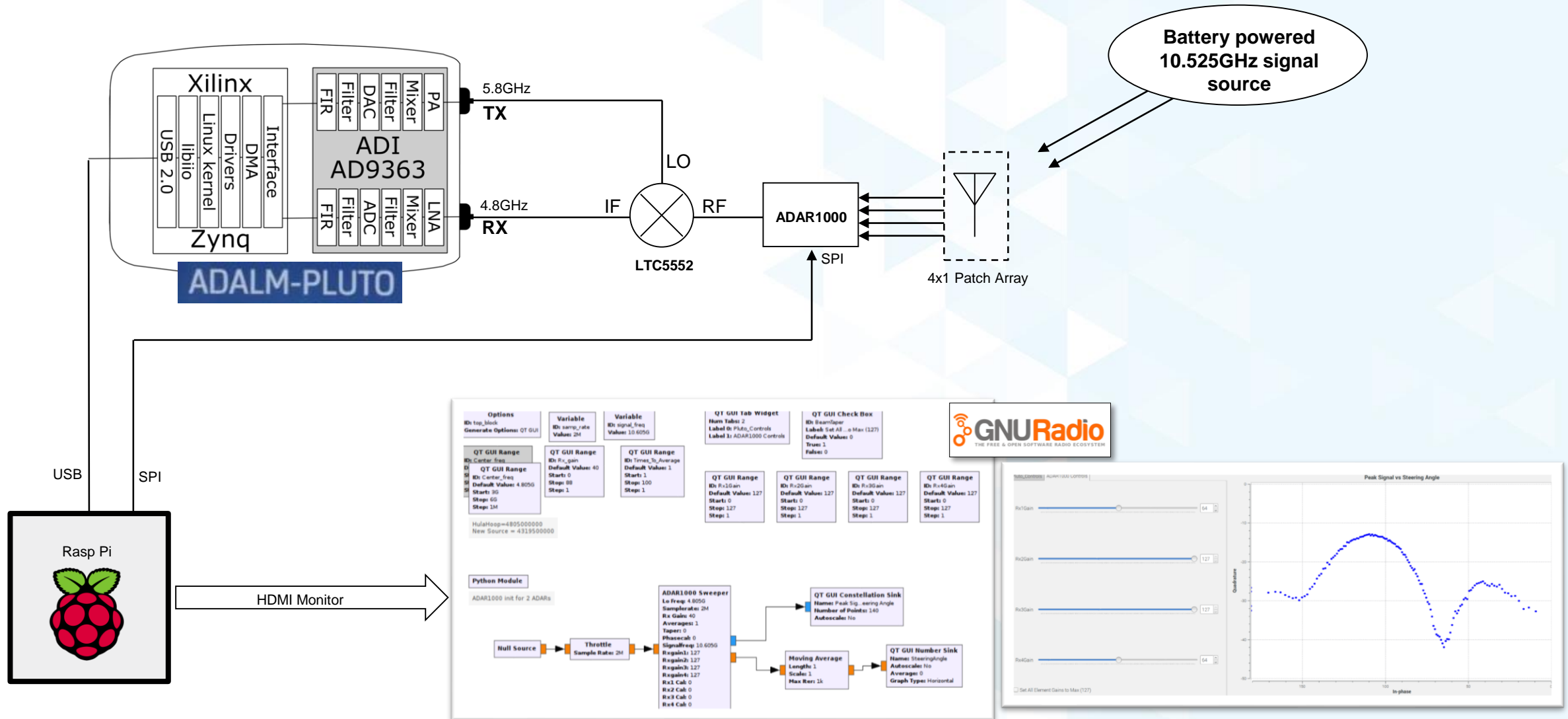  - Displays received data from Pluto



Peak Signal vs Steering Angle

**4 Patch Antenna**     **ADAR1000**

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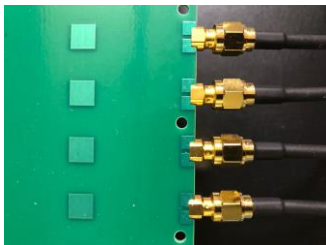
# Phased Array Lab Setup: Tracking an RF Source

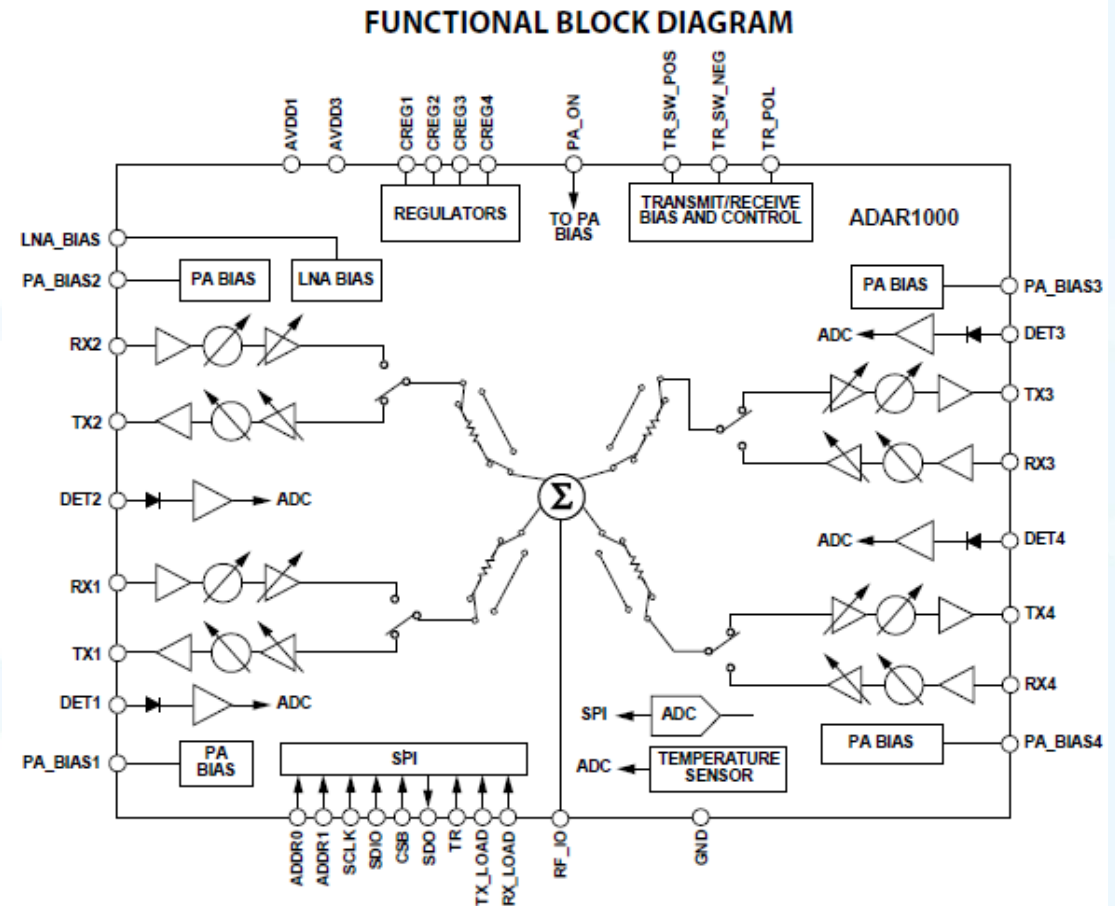©2019 Analog Devices, Inc. All rights reserved.

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# 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
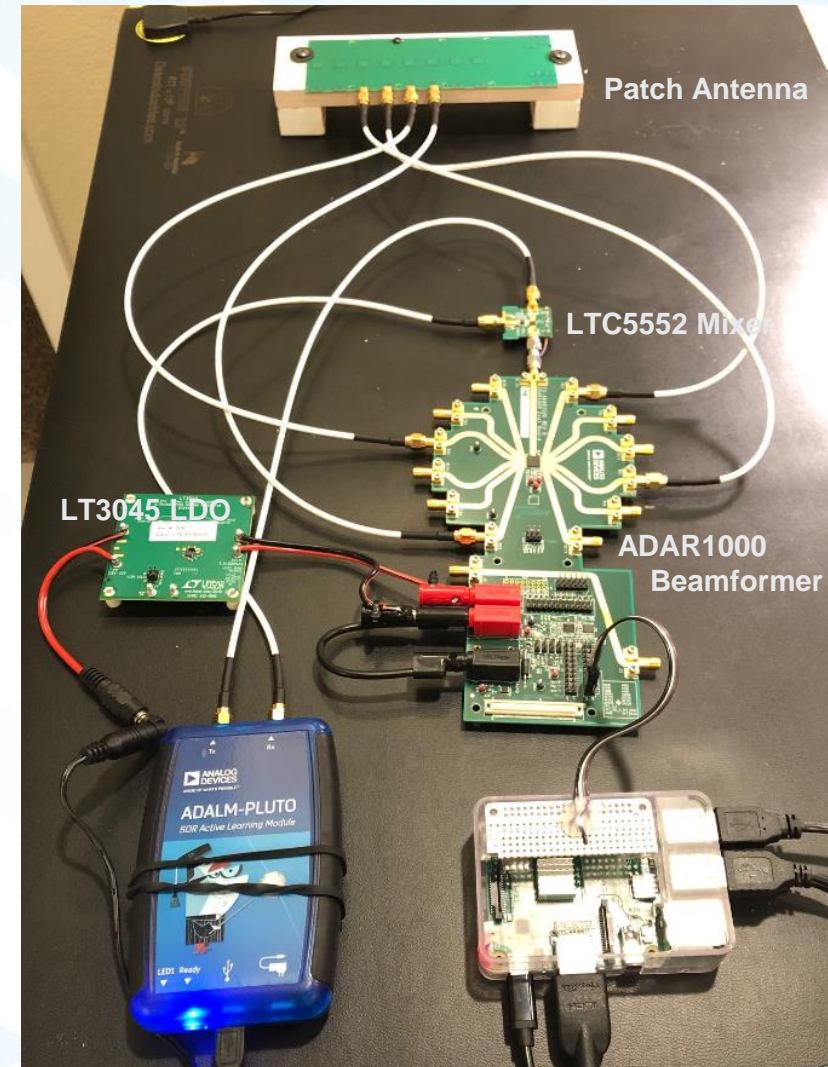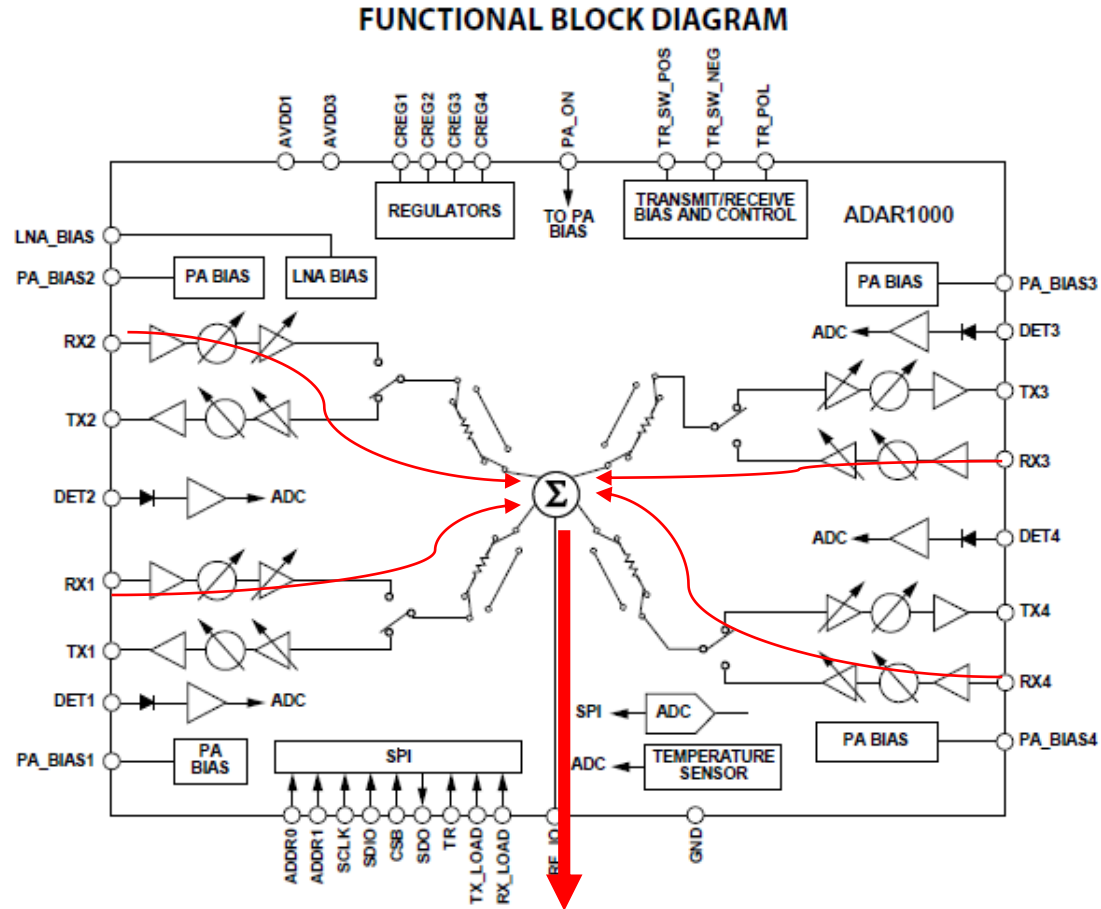- ▶ 88-terminal, 7 mm × 7 mm LGA package

## 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
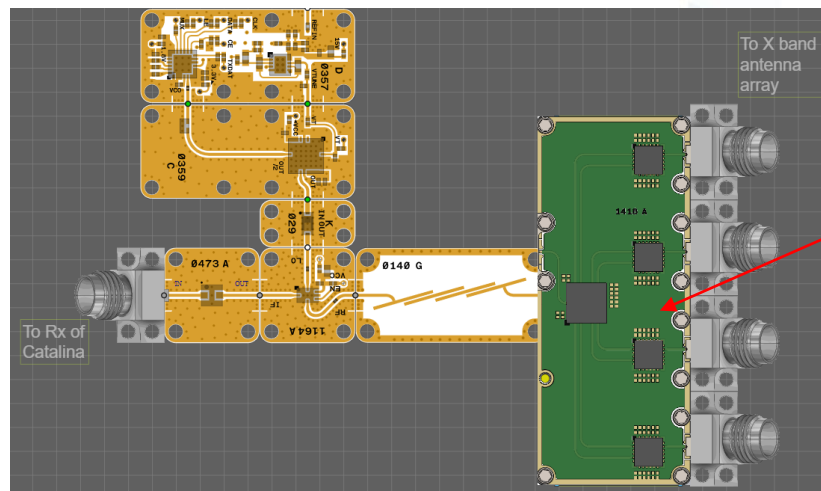- ▶ Support low power bias mode with 50% reduction in power consumption



FUNCTIONAL BLOCK DIAGRAM

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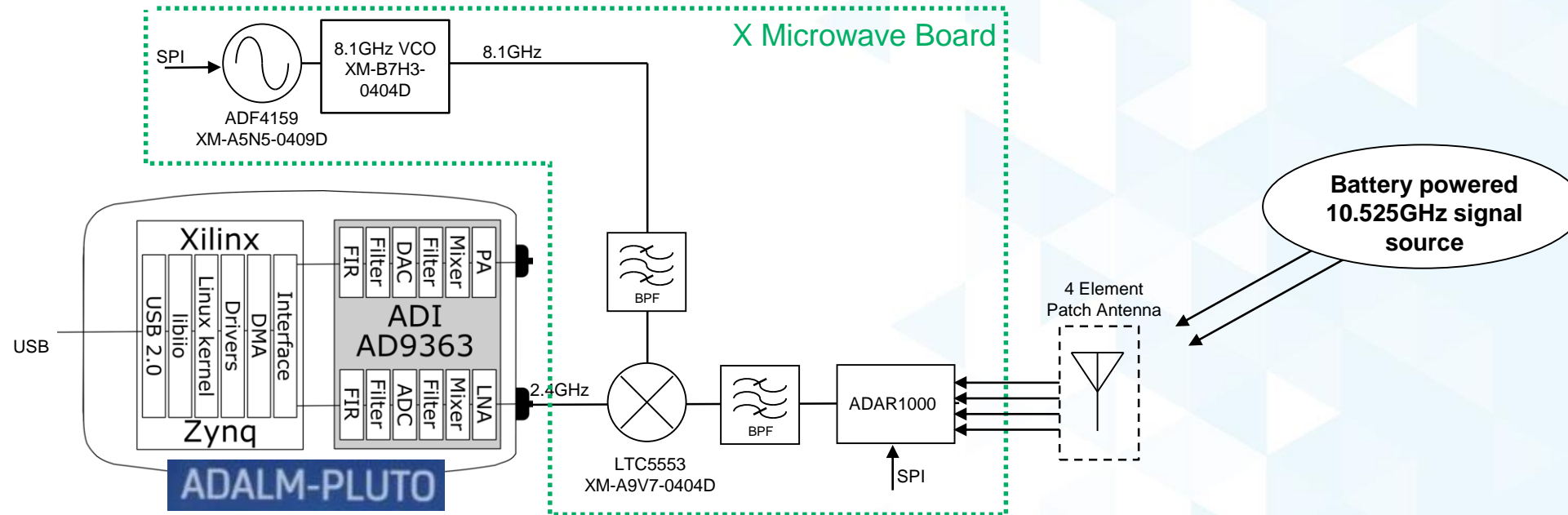# ADAR1000: 4 Channel Analog Beamformer

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



FUNCTIONAL BLOCK DIAGRAM



Patch Antenna
LTC5552 Mixer
LT3045 LDO
ADAR1000 Beamformer
ADALM-PLUTO

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# 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

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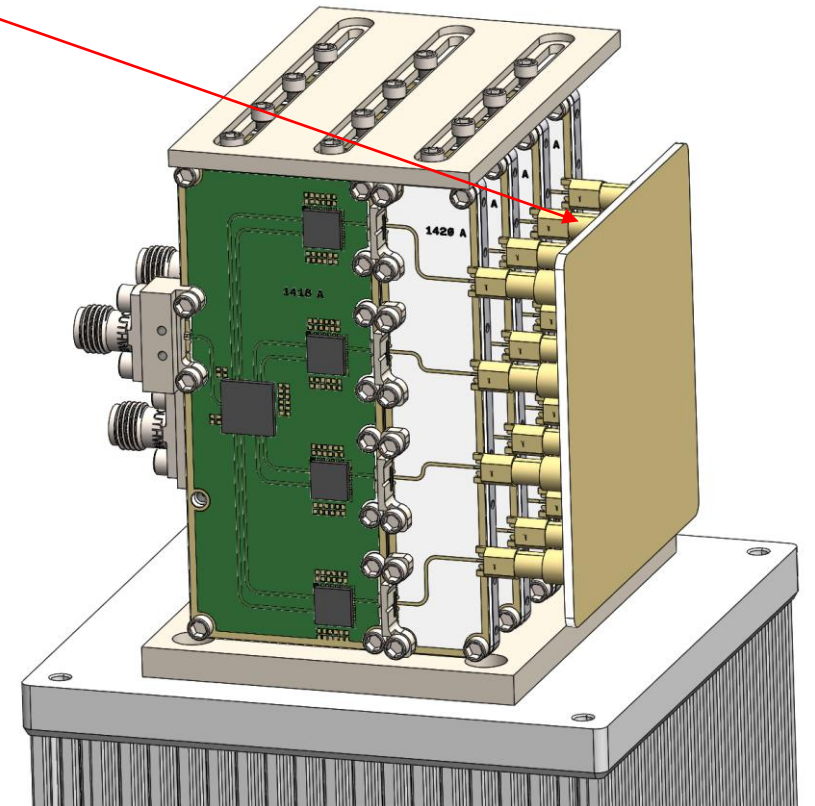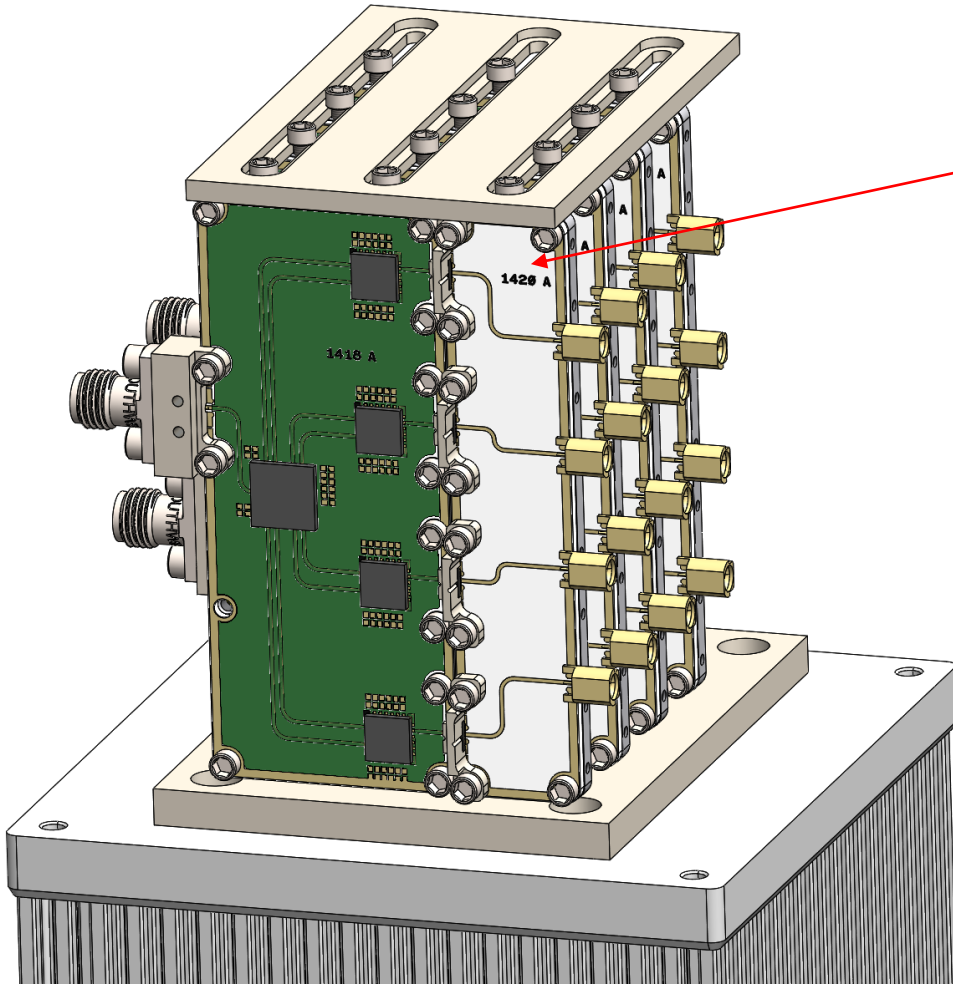
# Bill of Materials:

## Beamformer, Mixer, and SDR

| Qty | Description | Other info | Part Number | Link |
|---|---|---|---|---|
| 1 | ADAR1000 Eval Board | | EVAL-ADAR1000 | https://www.analog.com/en/design-center/evaluation-hardware-and-software/evaluation-boards-kits/EVAL-ADAR1000.html#eb-overview |
| 1 | Pluto SDR | | ADALM-Pluto | https://www.analog.com/en/design-center/evaluation-hardware-and-software/evaluation-boards-kits/ADALM-PLUTO.html |
| 1 | LTC5552 Mixer | | DC2668A | https://www.analog.com/en/design-center/evaluation-hardware-and-software/evaluation-boards-kits/dc2668a.html |
| 1 | LT3045 3.3V LDO Board | | DC2491A | https://www.analog.com/en/design-center/evaluation-hardware-and-software/evaluation-boards-kits/dc2491a.html |
| 6 | 18" SMA Cable | | 415-0033-018 | https://www.digikey.com/product-detail/en/cinch-connectivity-solutions-johnson/415-0033-018/J10114-ND/457274 |
| 1 | SMA  Connector | | ACX1240-ND | https://www.digikey.com/product-detail/en/amphenol-rf/132168/ACX1240-ND/1011917 |
| 1 | AC to DC wall wart | 5V output | PSAC05A-050L6 | https://www.digikey.com/product-detail/en/phihong-usa/PSAC05A-050L6/993-1330-ND/5418482 — https://www.amazon.com/gp/product/B01N7RS0NG/ref=ppx_yo_dt_b_asin_title_o09_s00?ie=UTF8&psc=1 |
| 1 | 2.1x5.5mm barrel jack wires | | | https://www.amazon.com/gp/product/B07CWQPPTW/ref=ppx_yo_dt_b_asin_title_o05_s00?ie=UTF8&psc=1 |
| 1 | Banana Jack | Red | 108-1082-001 | https://www.digikey.com/product-detail/en/108-1082-001/J460-ND/35155/?itemSeq=307381256 |
| 1 | Banana Jack | Black | 108-1083-001 | https://www.digikey.com/product-detail/en/108-1083-001/J461-ND/35158/?itemSeq=307381098 |
| 10 | Bumper feet for eval boards | | SJ5746-0-ND | https://www.digikey.com/product-detail/en/3m/SJ61A1/SJ5746-0-ND/1768456 |
| 1 | Raspberry Pi 3B+ | | Rasp Pi 3 B+ | https://www.digikey.com/product-detail/en/pimoroni-ltd/PIM337/1778-1195-ND/8574322 |
| 1 | Raspberry Pi breakout board for SPI | | PROTO-001 | https://www.digikey.com/products/en?keywords=protozero — https://www.amazon.com/gp/product/B07BF8Z3HS/ref=ppx_yo_dt_b_asin_title_o00_s03?ie=UTF8&psc=1 — https://www.amazon.com/gp/product/B01M27459S/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1 |
| 2 | Polarity key for rectangular ribbon cable connector | Optional | 15040292 | https://www.digikey.com/products/en?keywords=wm1033-nd |
| 1 | Ribbon cable connector | | ED1543-ND | https://www.digikey.com/product-detail/en/on-shore-technology-inc/302-S101/ED1543-ND/2178422 |

## Antenna Board, RF Source, and Stand

| Qty | Description | Other info | Part Number | Link |
|---|---|---|---|---|
| 4 | CONN SMA JACK STR 50OHM EDGE MNT | | 314-1703-ND | https://www.digikey.com/product-detail/en/BU-1420701851/314-1703-ND/9950117/?itemSeq=310517966 |
| 1 | 8 element 10.525GHz Patch Antenna | | | |
| 1 | 10.525GHz RF Source | | | https://www.amazon.com/gp/product/B00FFW4AZ4/ref=ppx_yo_dt_b_asin_title_o00_s01?ie=UTF8&psc=1 |
| 1 | Power cable for RF Source | | AE10621-ND | https://www.digikey.com/product-detail/en/assmann-wsw-components/AK670-OE-BLACK/AE10621-ND/2391700 |
| 1 | Stand for RF Source | | | https://www.amazon.com/gp/product/B07JR2Q1G1/ref=ppx_yo_dt_b_asin_title_o00_s01?ie=UTF8&psc=1 |
| 1 | Adapter to hold RF Source to Stand | | | https://www.amazon.com/gp/product/B07RJW34WB/ref=ppx_yo_dt_b_asin_title_o00_s02?ie=UTF8&psc=1 |
| 4 | Magnet to hold antenna to stand | | 469-1063-ND | https://www.digikey.com/product-detail/en/radial-magnet-inc/8221/469-1063-ND/5400502 |

# Eval Board Assembly

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# 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
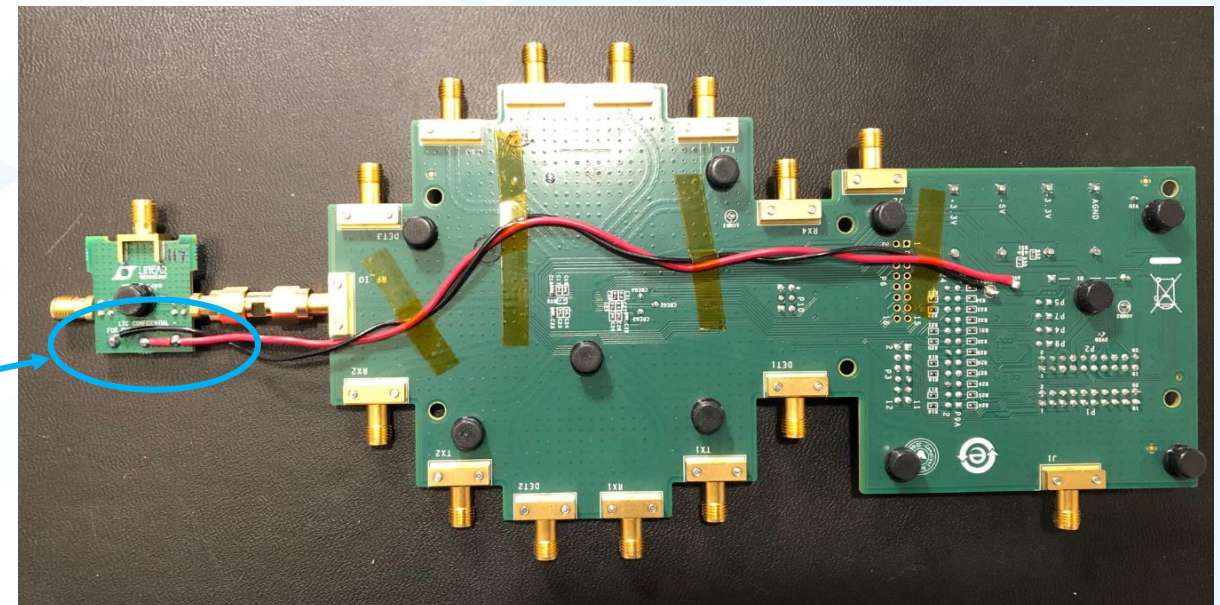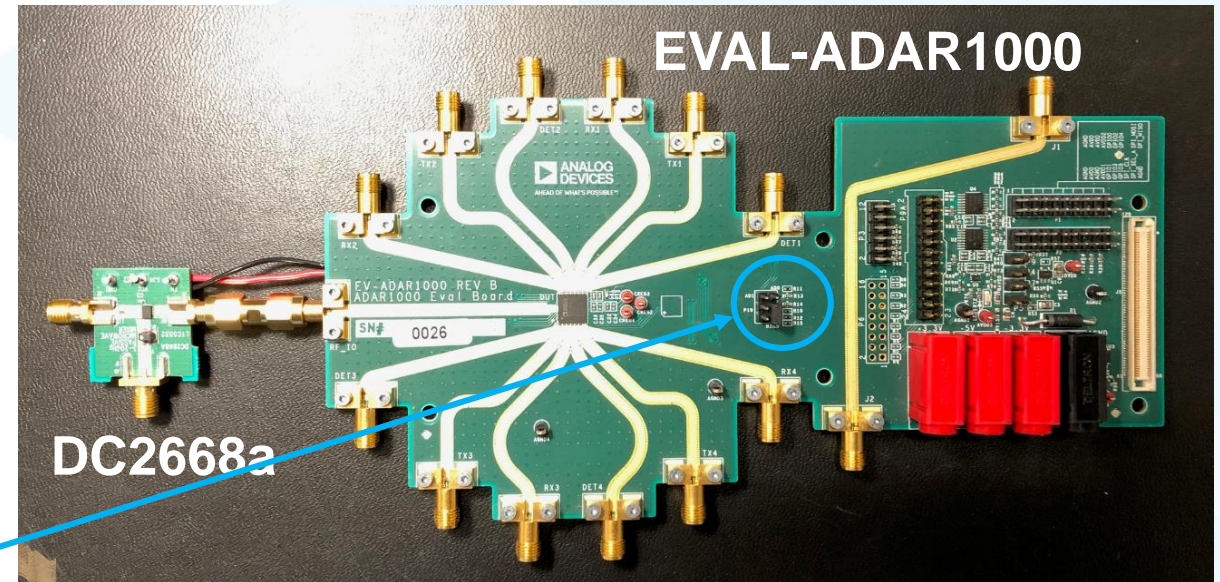
- ► Set the correct SPI Address
  - Default for my programs is 0x20 as shown

- ► Both boards are powered by 3.3V
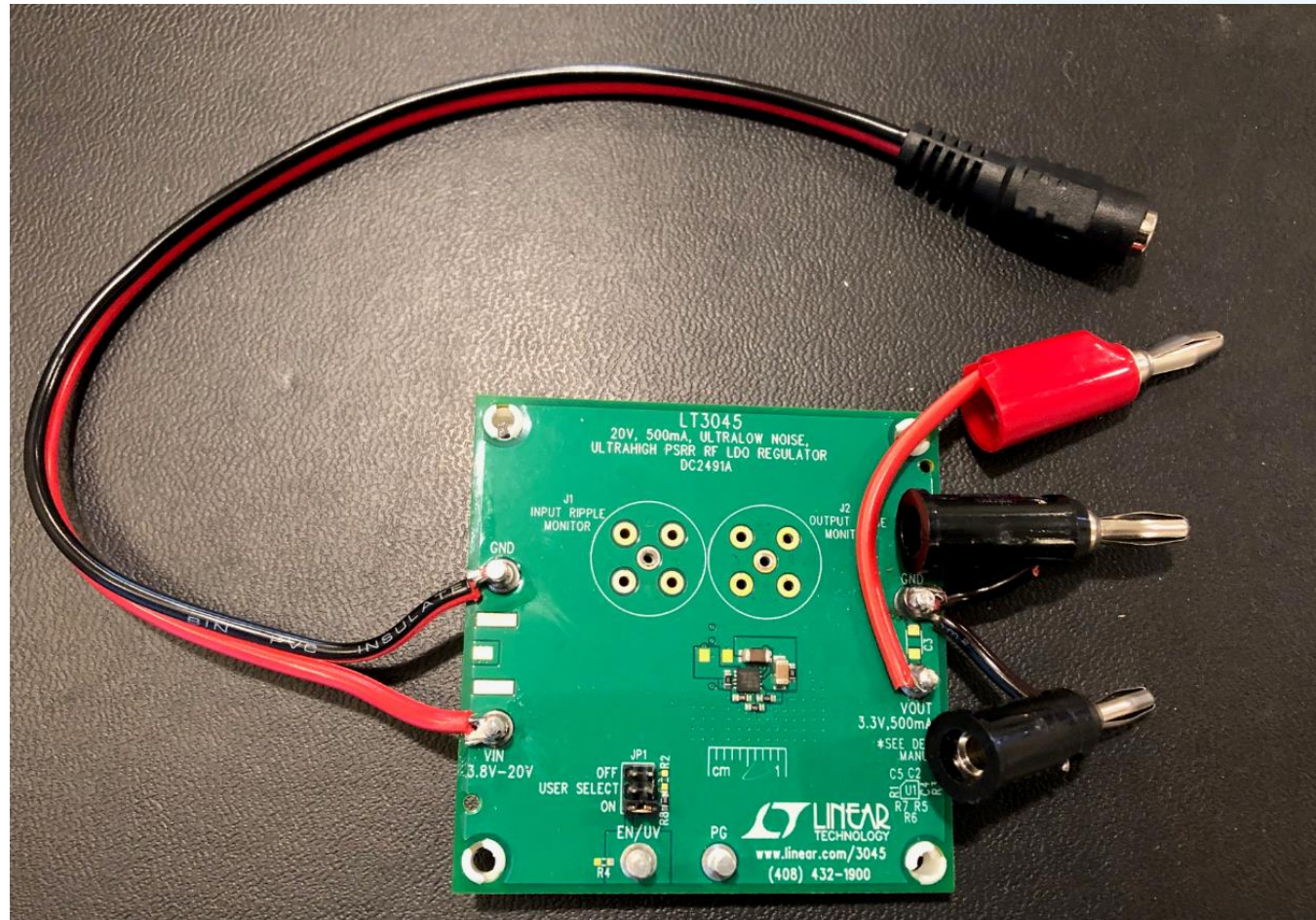  - Red and Black wires connect GND and 3.3V

- ► "EN" pin on LTC5552 board also needs to be pulled to 3.3V, so be sure to connect it also



EVAL-ADAR1000

DC2668a

# 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

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# 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/PhasedArrayLab/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
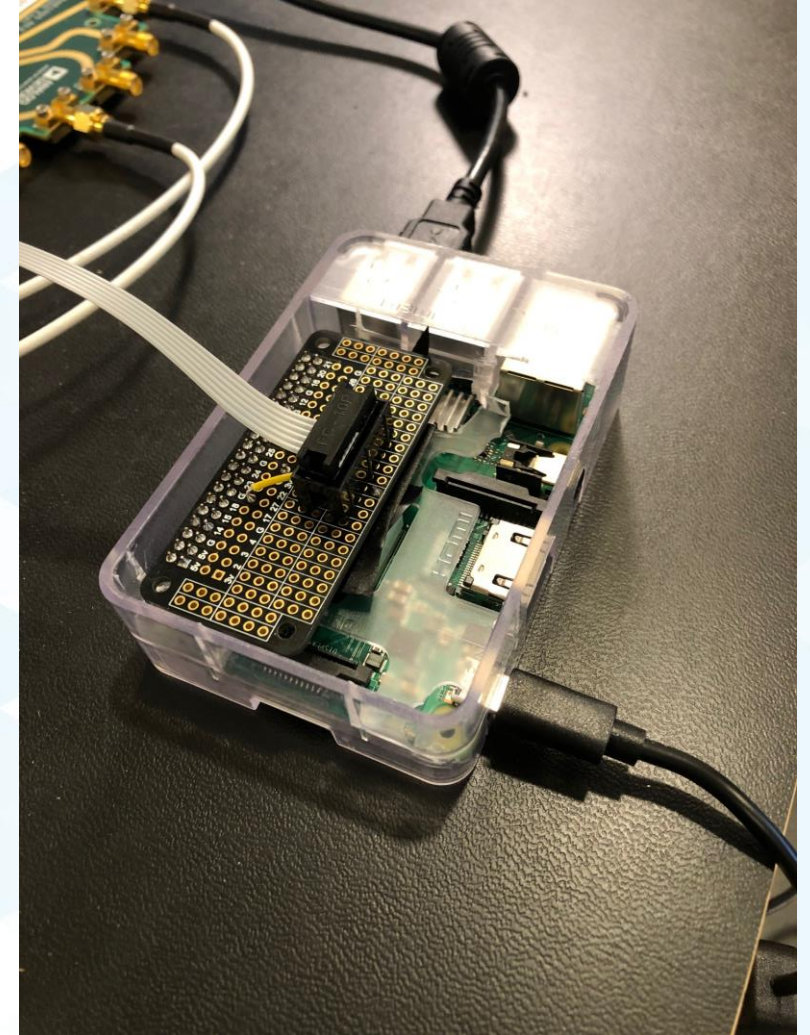
# Rasp Pi SPI Breakout Board

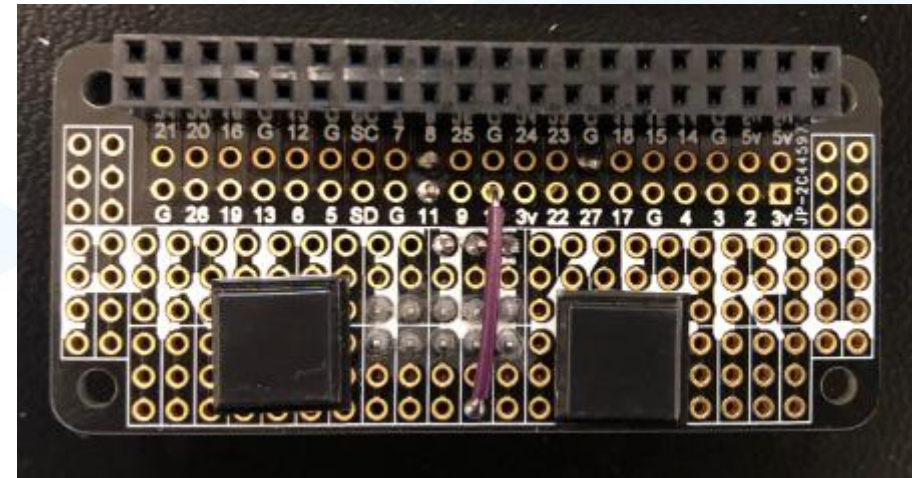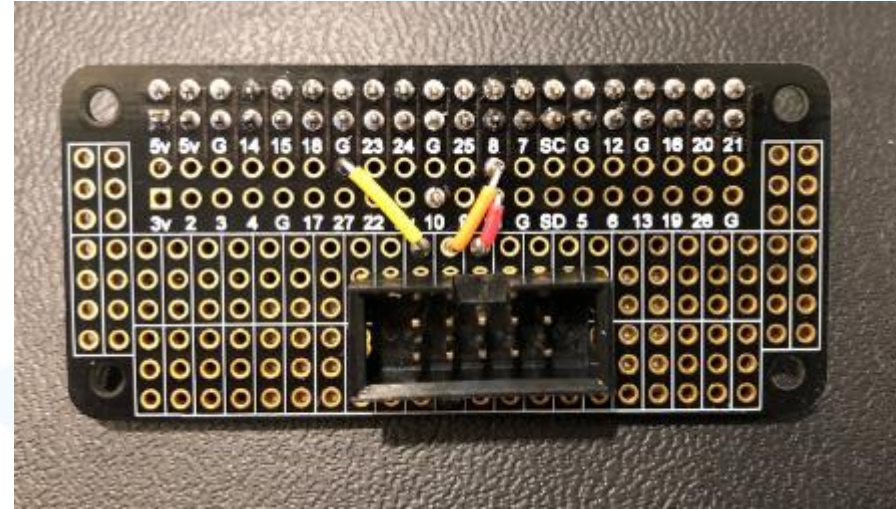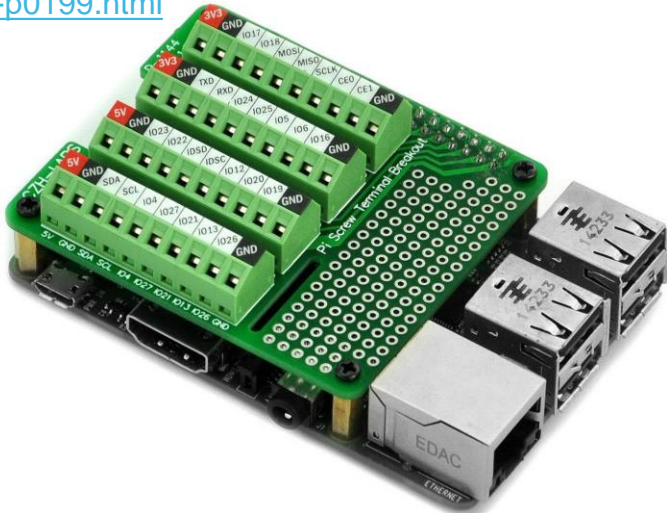- ► Connect SPI to ADAR1000 Ribbon Cable
    - Use Pimoroni ProtoZero board:
        - https://shop.pimoroni.com/products/protozero

- ► Or use Electronics-Salon Terminal Block:
    - https://czh-labs.com/czh-labs-pi-screw-terminal-block-breakout-module-for-raspberry-pi-p0199.html
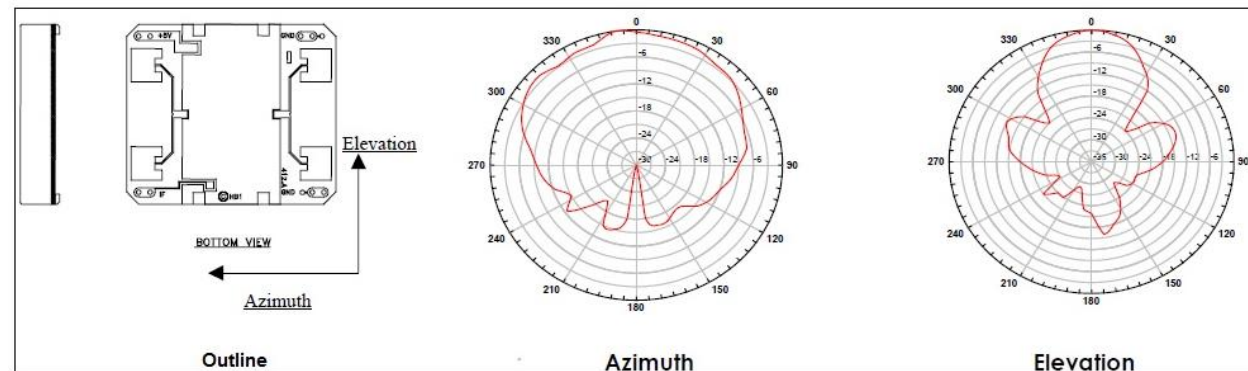
# RF Source Assembly

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# 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/
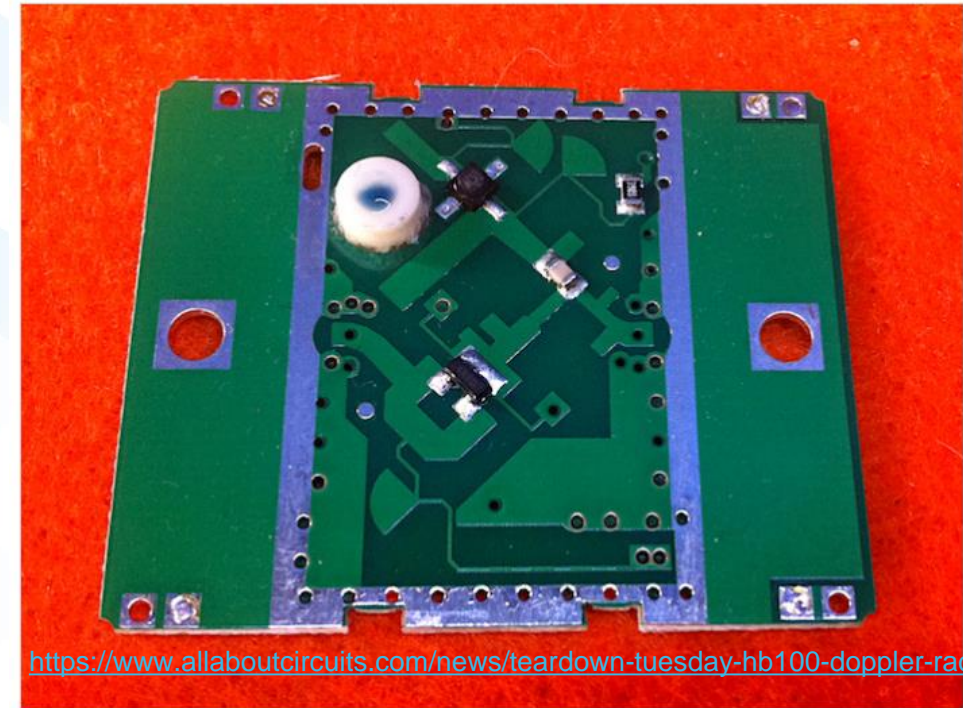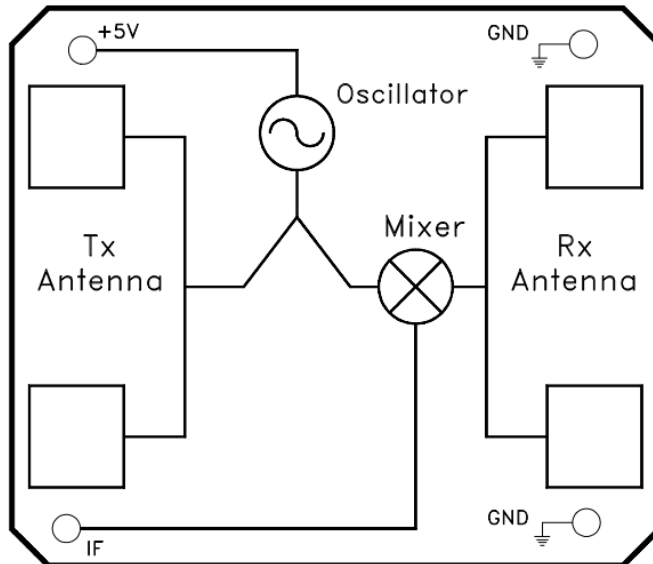
*What sorcery is this?*





https://www.limpkin.fr/public/HB100/HB100_Microwave_Sensor_Application_Note.pdf

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# 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

- Then attach it with a 3D printed holder
  - .stl file available at www.github.com/jonkraft/phasedarray
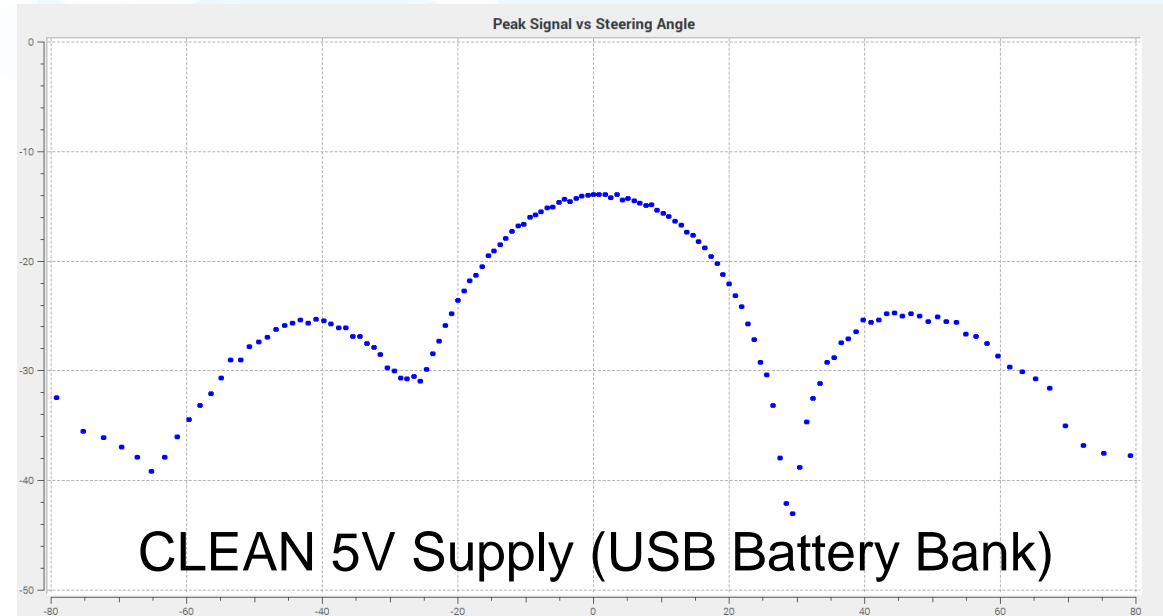  - or use the "cell phone" holder generally included with the stand
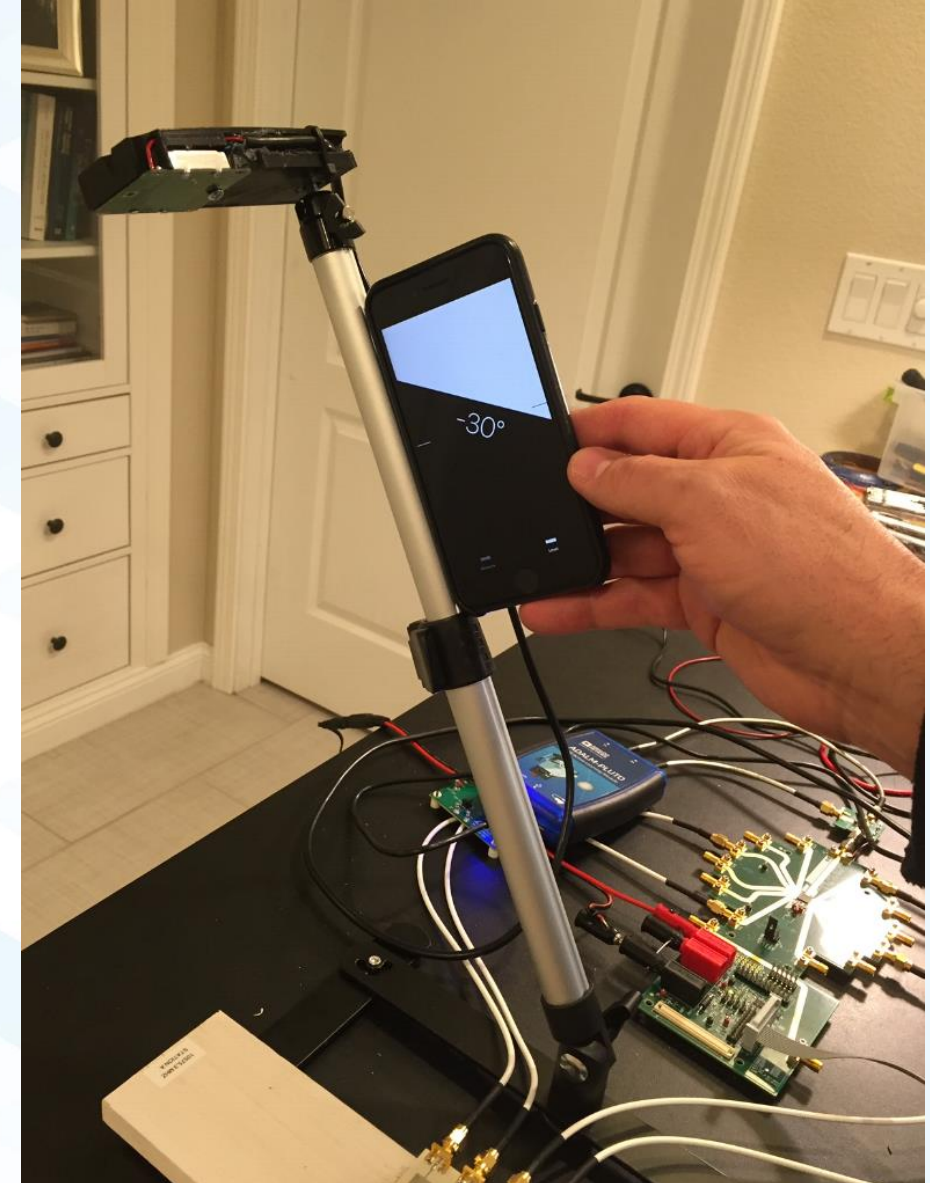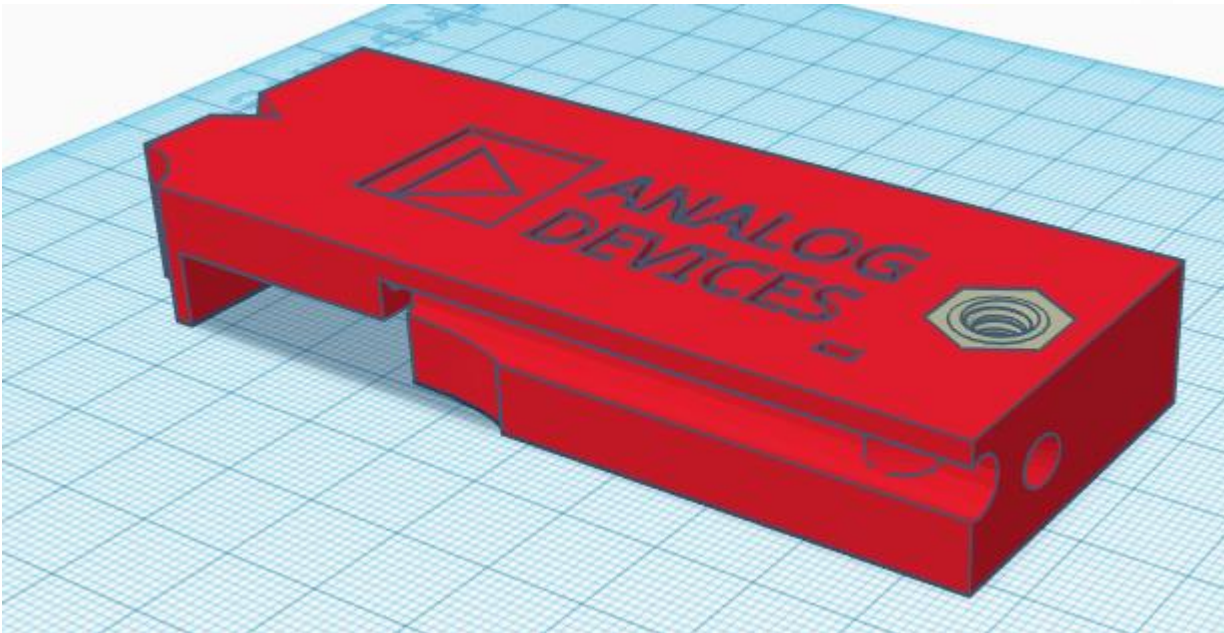
# HB100 RF Source:  The Power Supply Matters!

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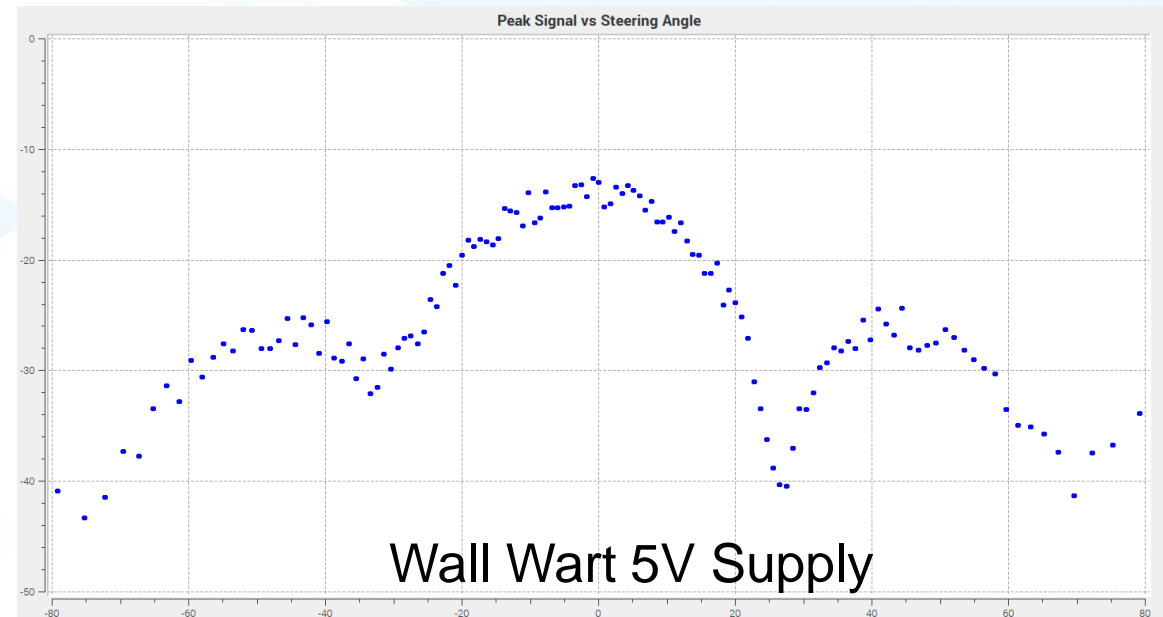
► But a noisy 5V will mean a noisy FFT Plot!

► These are **GOOD** power sources:
  - LT3045 LDO
  - Battery Pack or USB Battery Bank
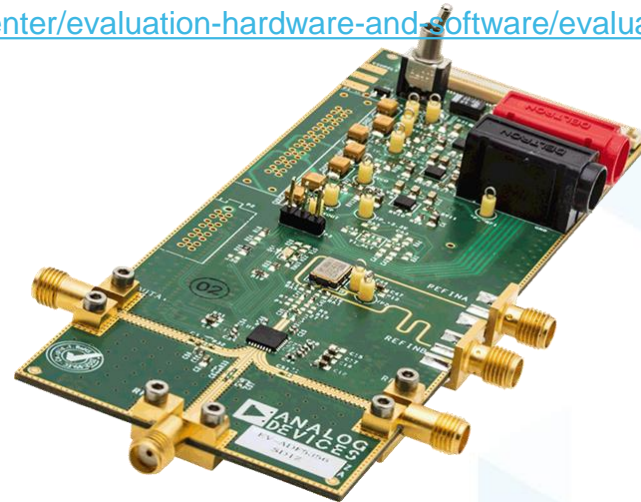  - Good Quality USB Phone Changer

► These are **BAD** power sources:
  - Raspberry Pi USB port
  - Wall Wart



Peak Signal vs Steering Angle

CLEAN 5V Supply (USB Battery Bank)



Peak Signal vs Steering Angle

Wall Wart 5V Supply

# 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

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# Antenna Assembly

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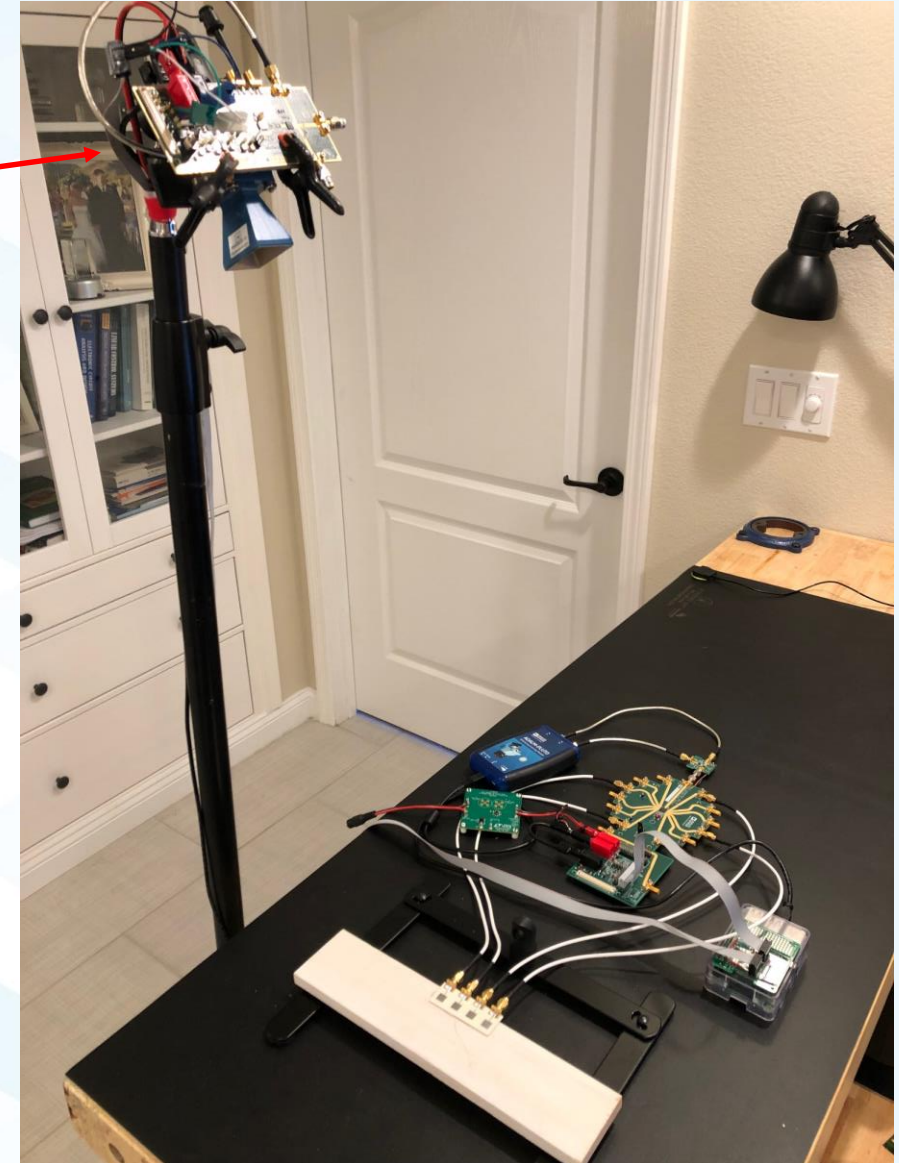
# Patch Antenna

- 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

- 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



14.28 mm element to element spacing

# Configure Pluto

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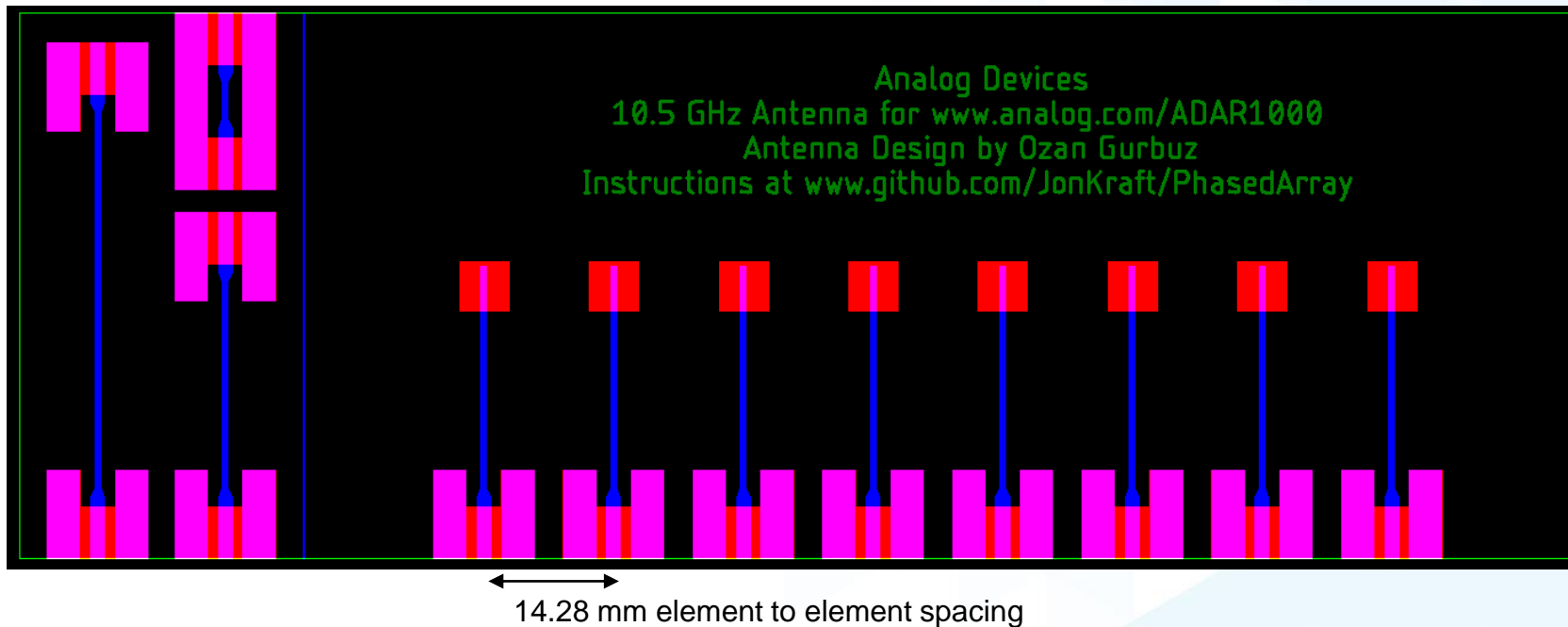
# Upgrade Pluto



- 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

# Put it All Together!

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# Fully Assembled Lab Station:



Patch Antenna

LTC5552 Mixer

LT3045 LDO

ADAR1000 Beamformer

ADALM-PLUTO
SDR Active Learning Module

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