Build Your Own Phased Array System

INSTRUCTIONS

Jon Kraft, Analog Devices

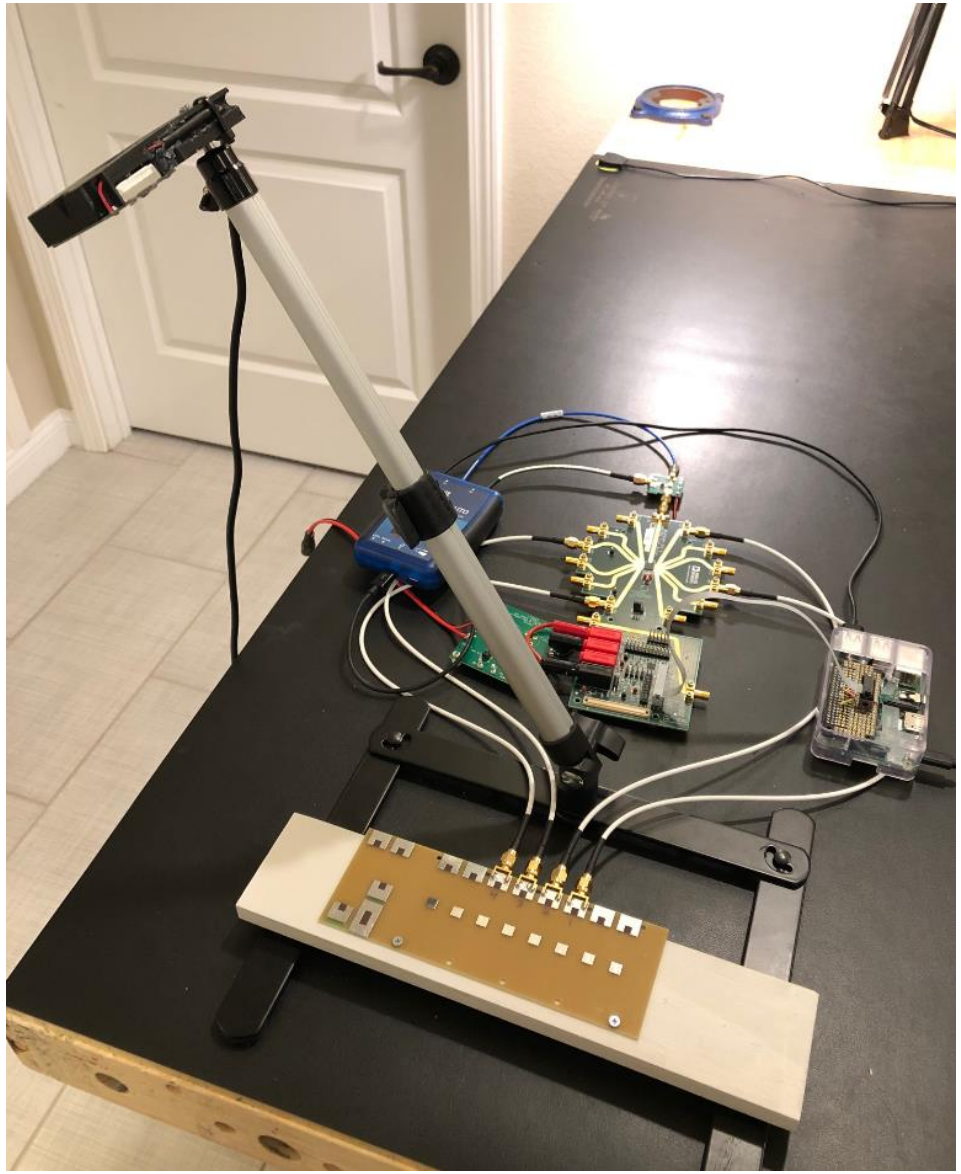
Sept 17, 2020

Overview of Building Instructions:

- Bill of Materials (BOM)
- Assemble the Eval Boards
- Raspberry Pi Setup
- RF Source Assembly
- Antenna Assembly

YOU CAN BUILD THIS!

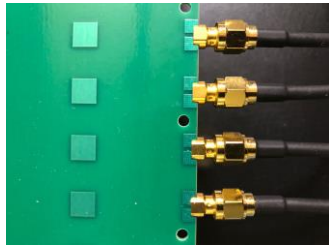
Instructions at:
http://www.github.com/JonKraft/PhasedArray



Simple Phased Array Setup

- Can we build our own beamformer and see this math “Hands On”?
- How would we do that?
  - Antenna
  - Beamformer
  - Mixer (for higher frequencies)
  - Transceiver (or data converter)
  - And don’t forget SOFTWARE!!!!

4 Patch Antenna



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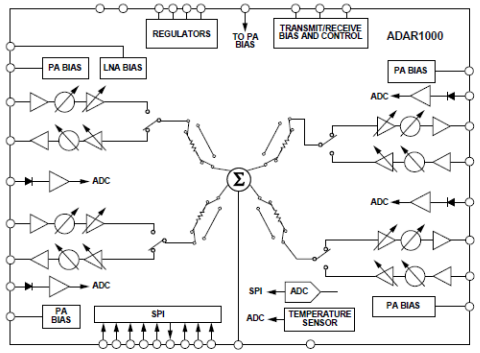
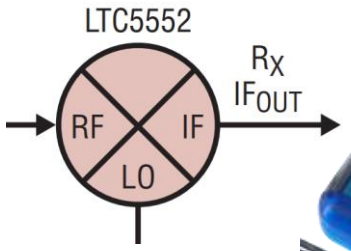
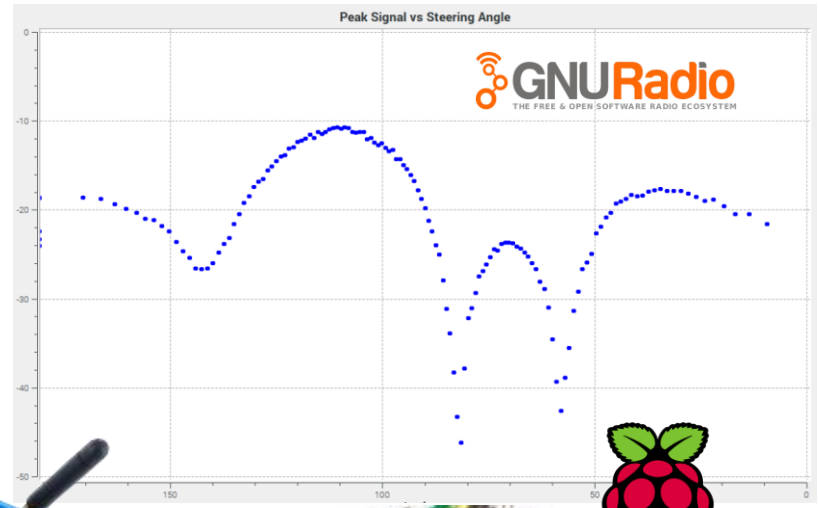
ADAR1000

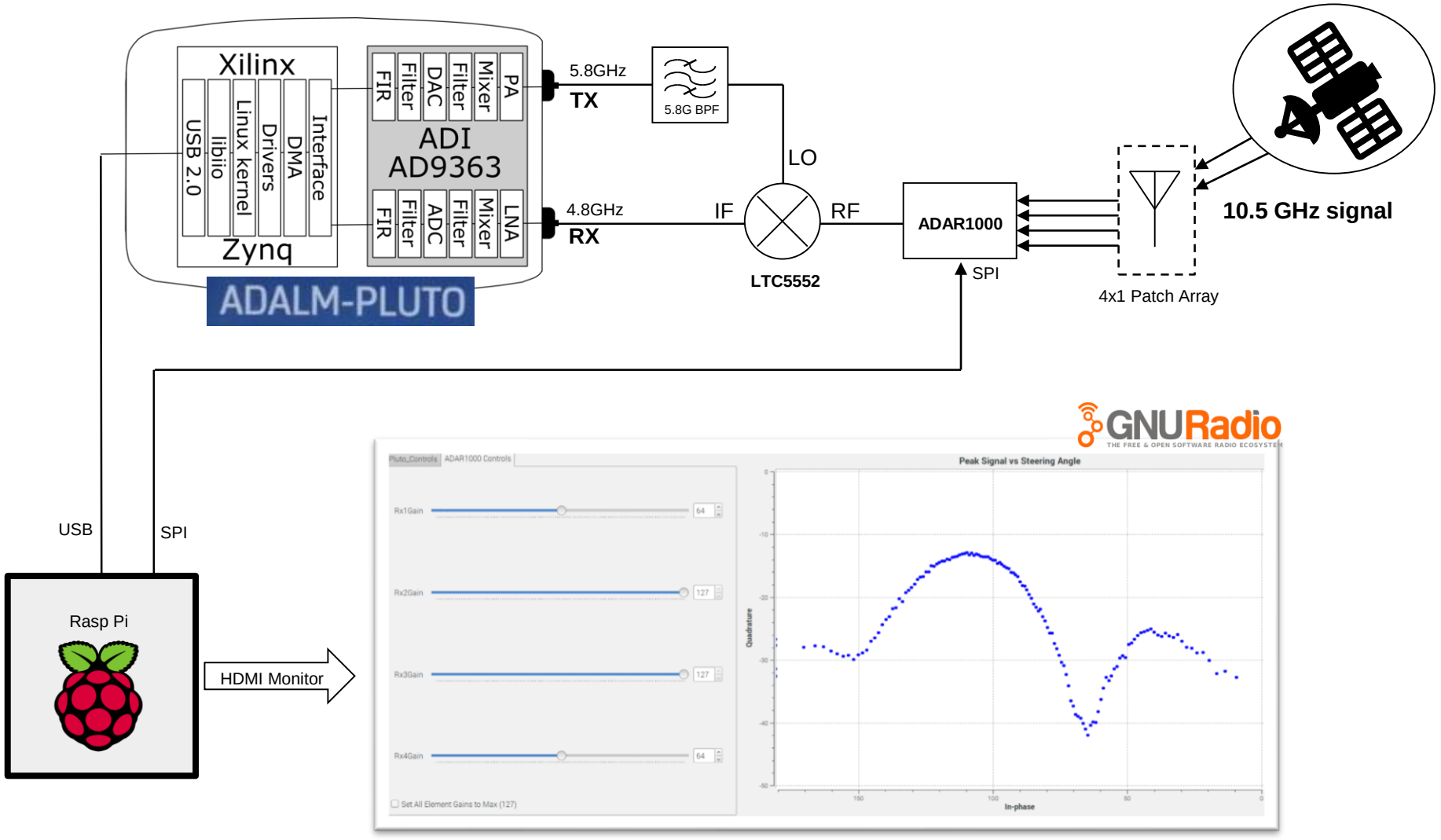


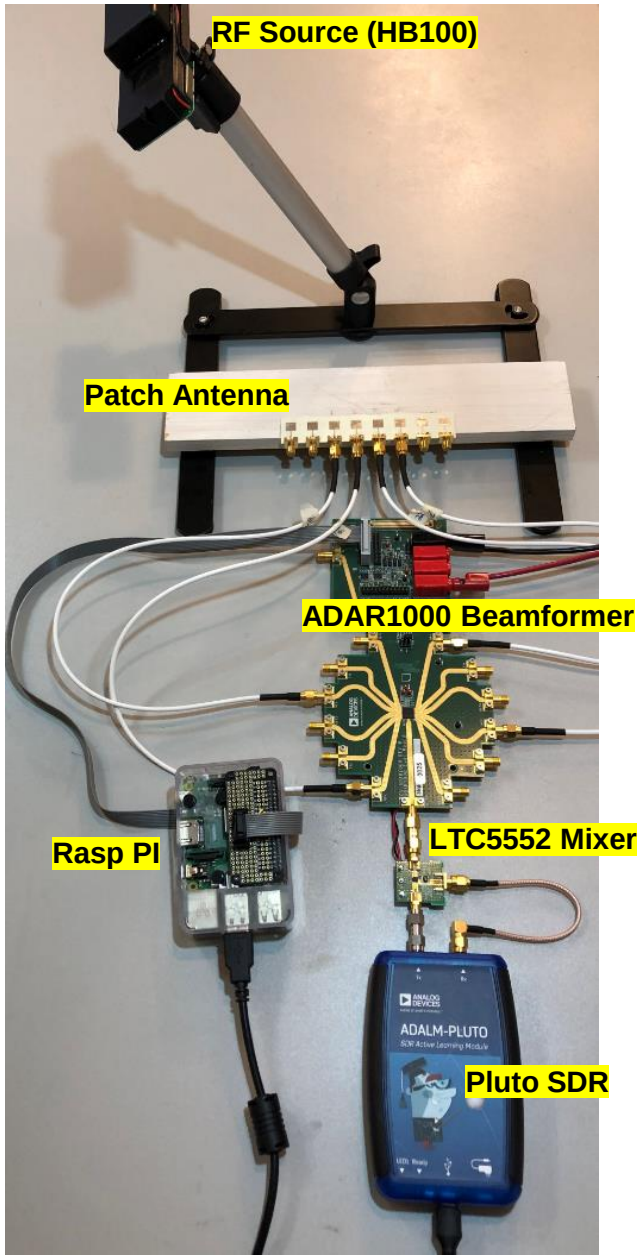




YOU CAN BUILD THIS! Complete step by step instructions, with software, at www.github.com/jonkraft/phasedarray

Simple Phased Array Setup





Bill of Materials:

ANALOG DEVICES
AHEAD OF WHAT'S POSSIBLE™

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/amphenol-rf/415-0033-018/ARX1240-ND/457274
1	SMA Connector		ARX1240-ND	
1	AC to DC wall wart			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			
1	Banana Jack			
1	Banana			
10	Bum			
1	Raspbe			
1	Raspber			https://www.amazon.com/gp/product/B01M27459S/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1
2	Polarity k rectangular connector			
1	Ribbon cable connector			

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

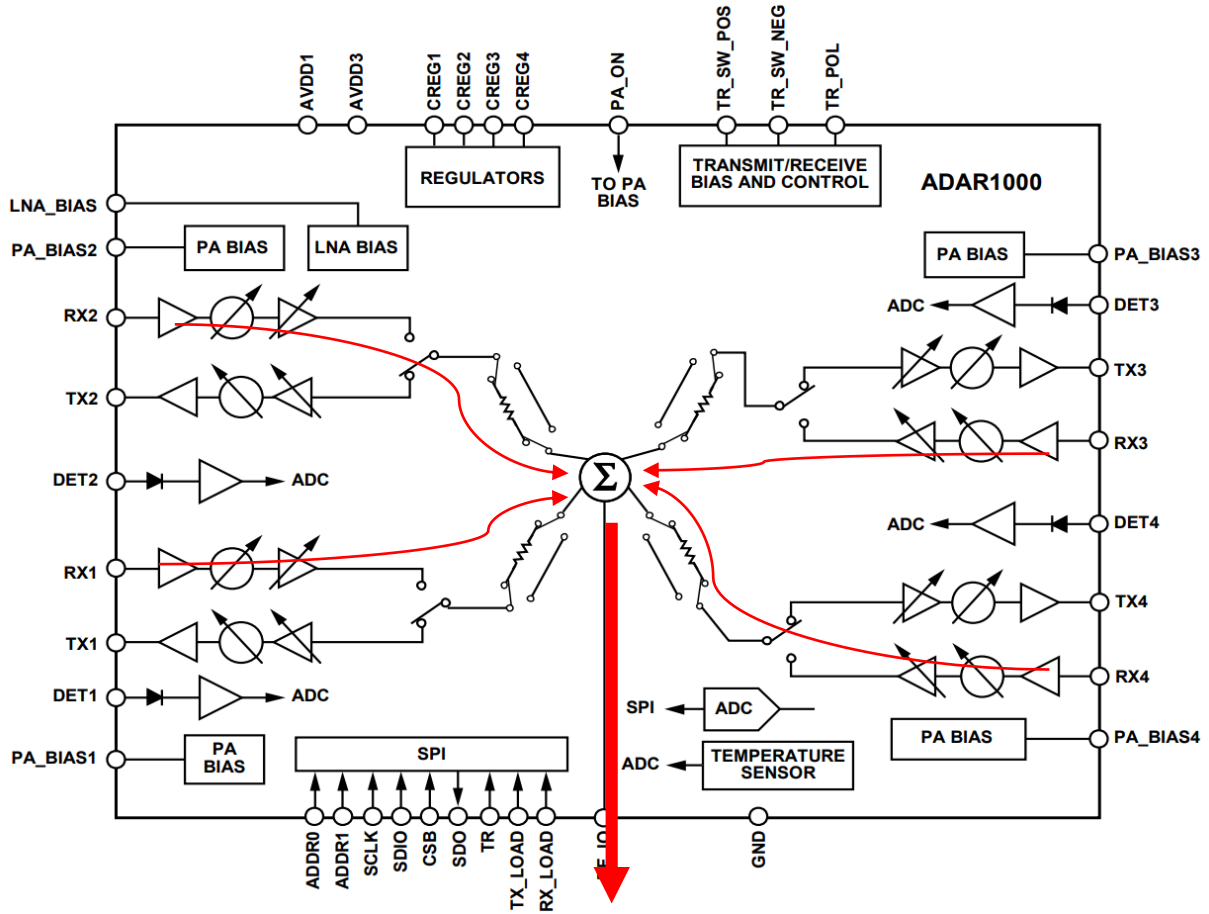
YOU CAN BUILD THIS!

Instructions at:
http://www.github.com/JonKraft/PhasedArray

ADAR1000: 4 Channel Analog Beamformer

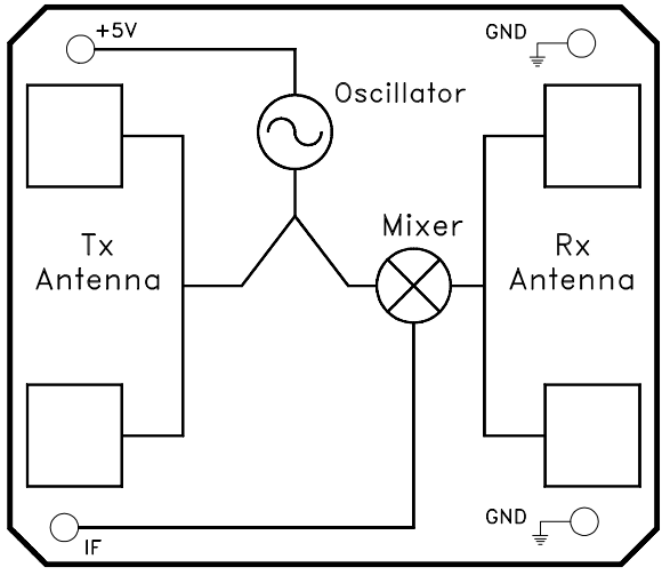
ADAR1000 Features

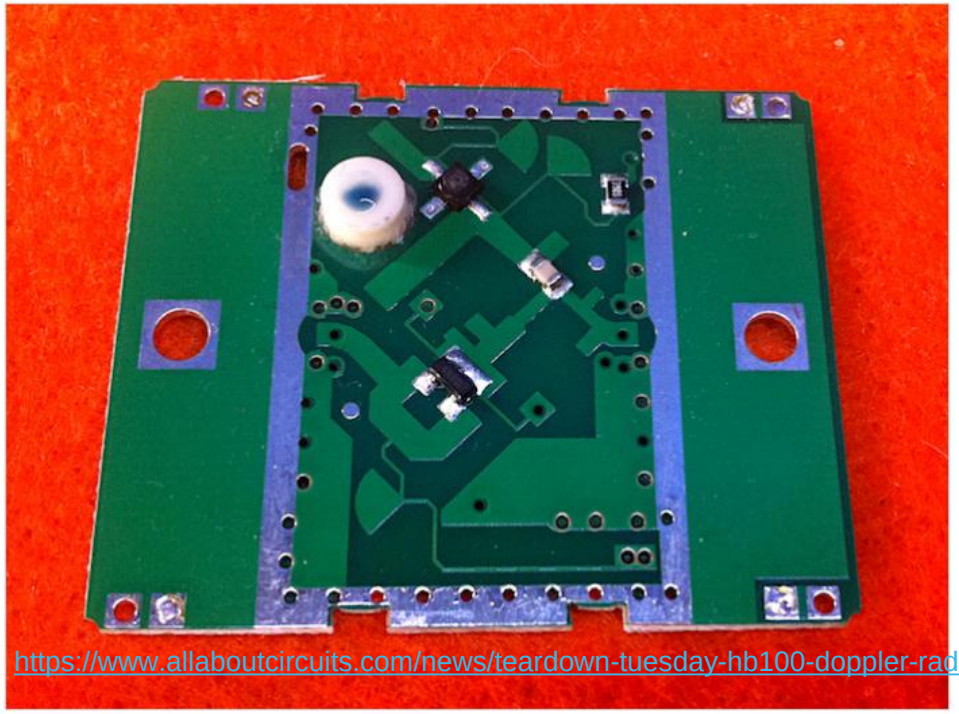
- 8 GHz to 16 GHz frequency range
- 360° phase adjustment range
- 2.8° phase resolution
- ≥31 dB gain adjustment range



10.5GHz RF Source

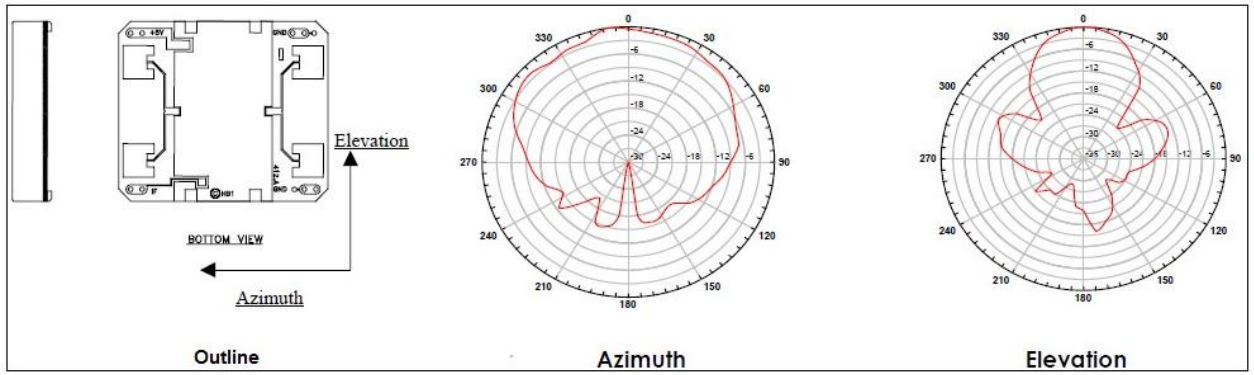
- Use the ultra fun HB100!
  - $3 (includes shipping!) on Ebay
  - Draws 40mA from 5V
  - Generates a poor quality 10.5GHz tone
  - It's good enough for us though!





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

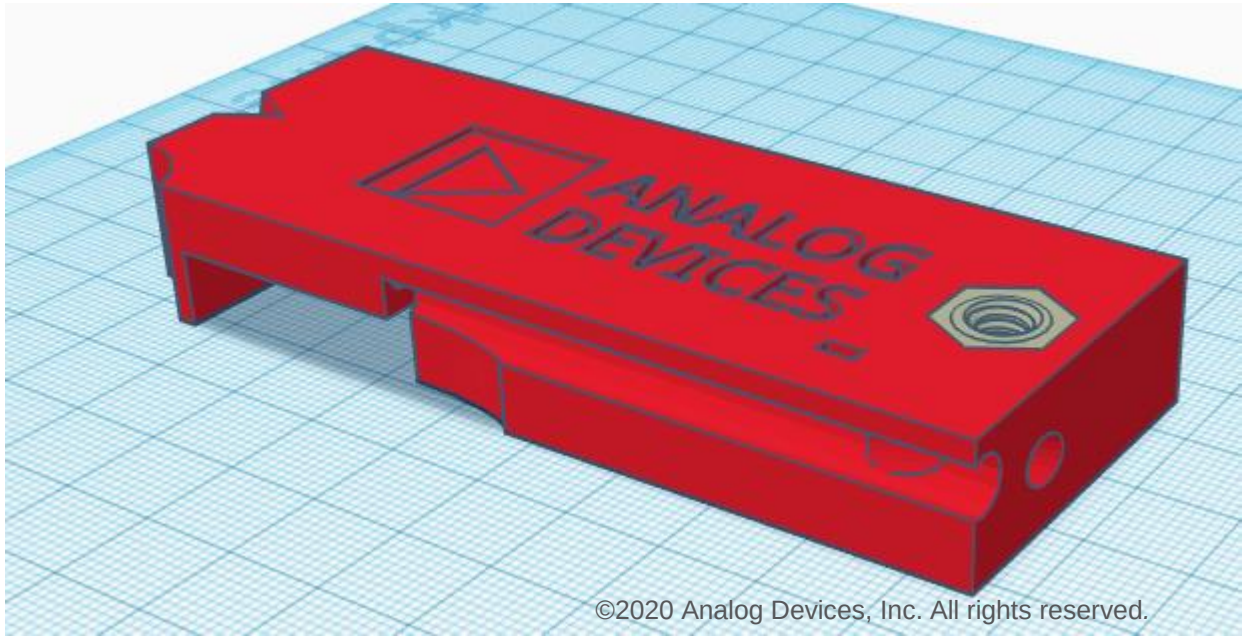
What sorcery is this?



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

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



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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 3 or 4		Rasp Pi 3 or 4	
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
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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

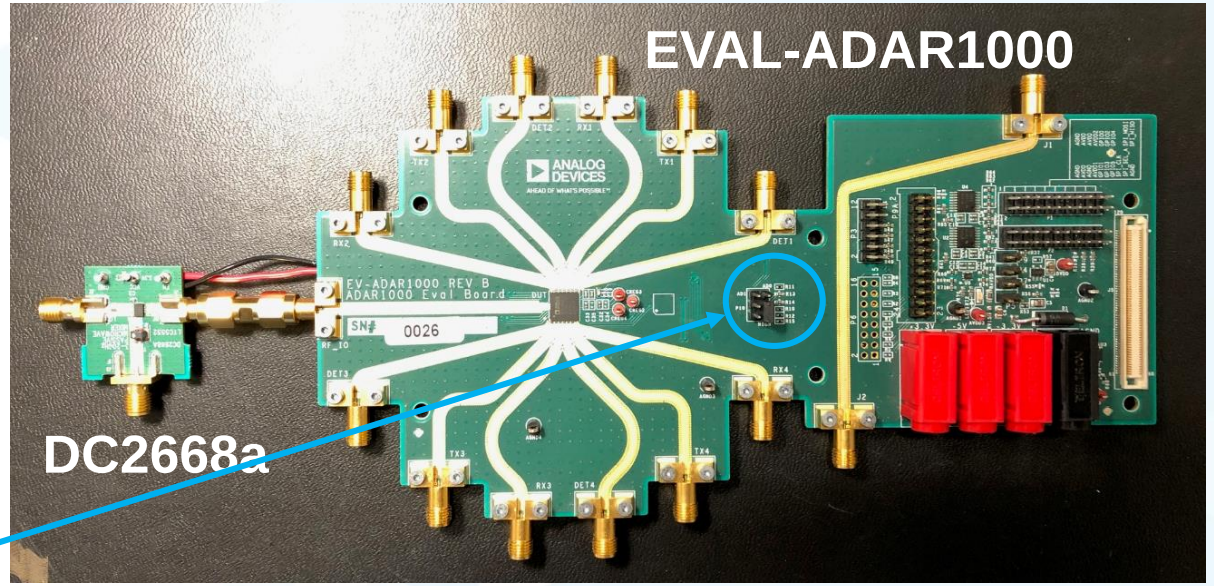
Eval Board Assembly

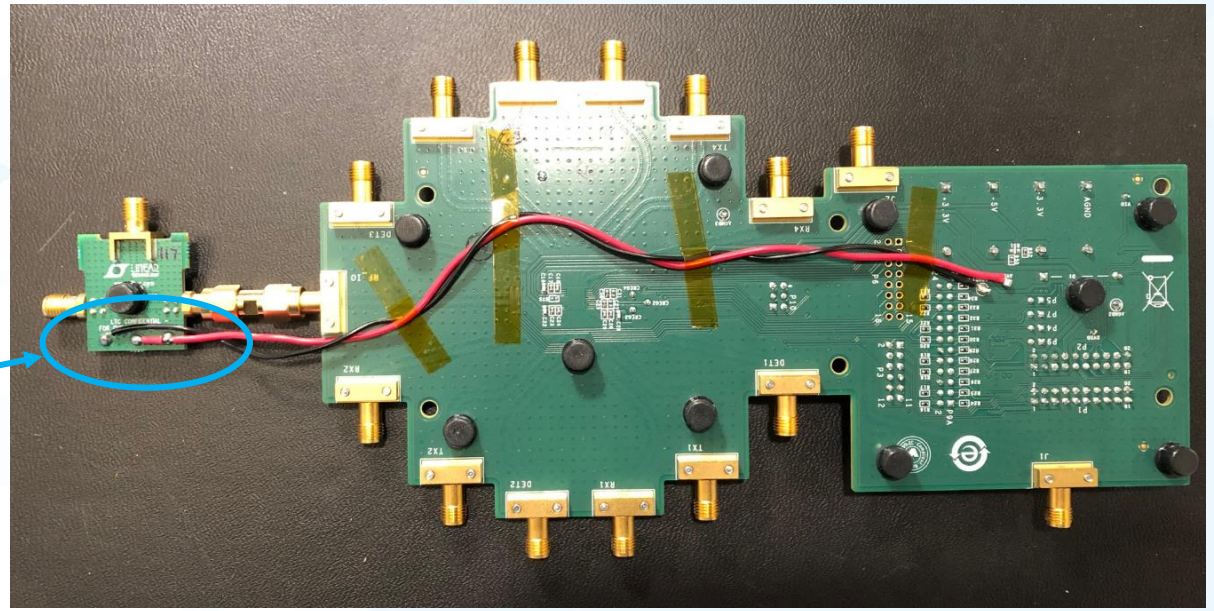
ADAR1000 + Mixer Assembly

- 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

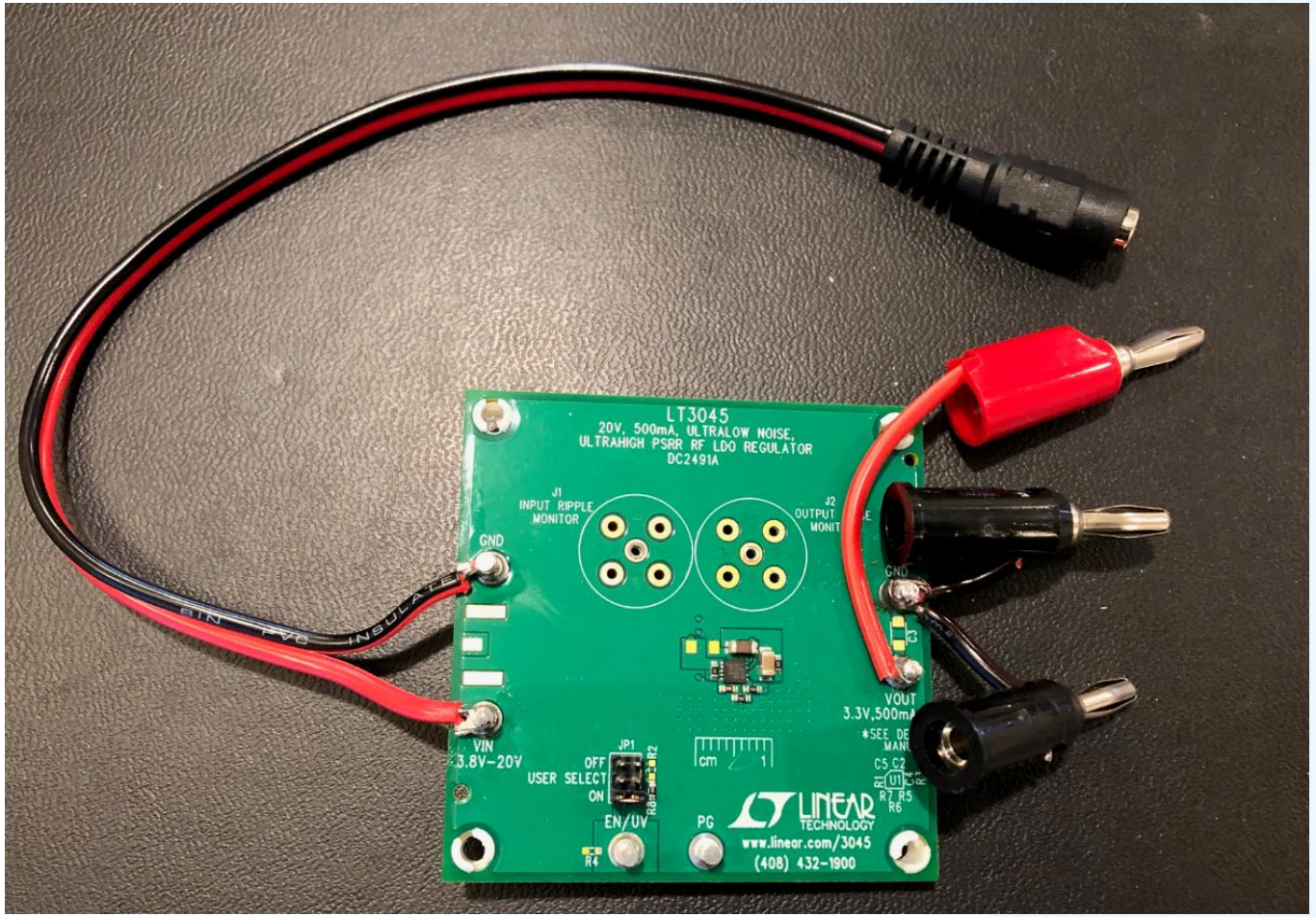
- Both boards are powered by 3.3V
  - Red and Black wires connect GND and 3.3V
- "EN" pin on LTC5552 board also needs to be pulled to 3.3V, so be sure to connect it also





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

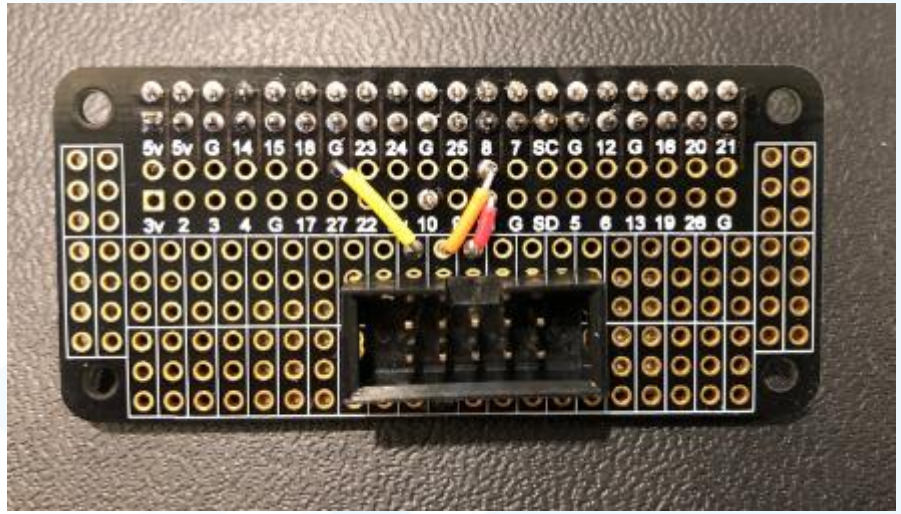
Raspberry Pi Setup

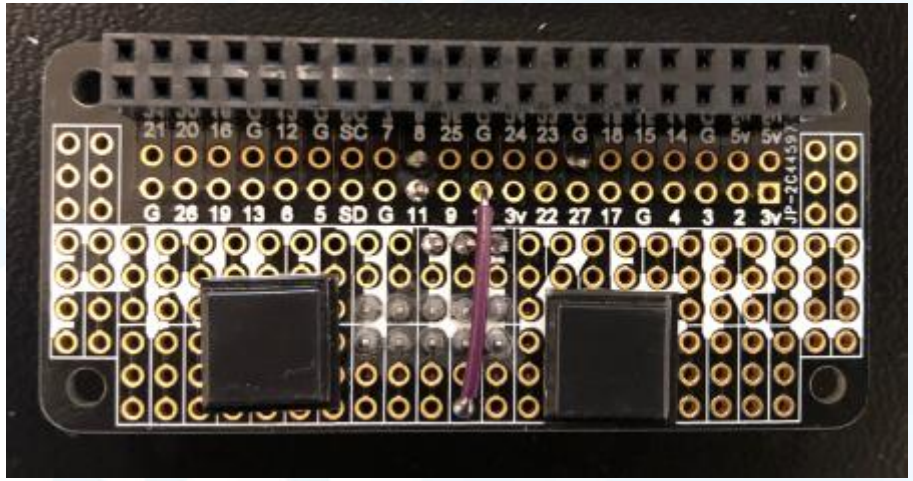
- Raspberry Pi 3 or 4 will work.
- 3 Options for Install
  - Install Manually:
    - https://github.com/jonkraft/Pluto-Install-for-Raspberry-Pi
  - Use ADI-Kuiper-Linux
    - Everything is preinstalled: GNURadio 3.8, IIO scope, LIBIIO, LIBM2K, PYADI-IIO, etc.
    - https://wiki.analog.com/resources/tools-software/linux-software/adi-kuiper_images
  - Complete out of the box, ready to go:
    - https://download.analog.com/phased-array-lab/raspi.7z
    - This has everything you need, including all GNU Radio 3.8 files, already loaded in there. No other installs are required, it'll work out of the box!

For more info on Kuiper, please watch Mark Thoren's GRCon 2020 "Python for the Rest of Us"

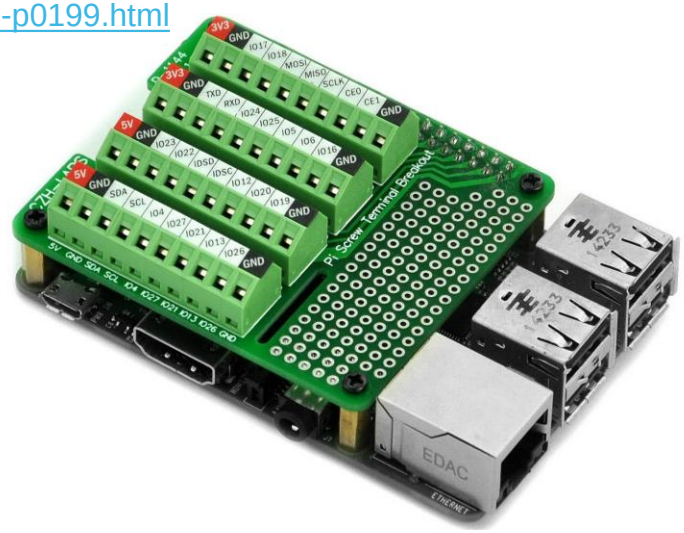
Rasp Pi SPI Breakout Board

- 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

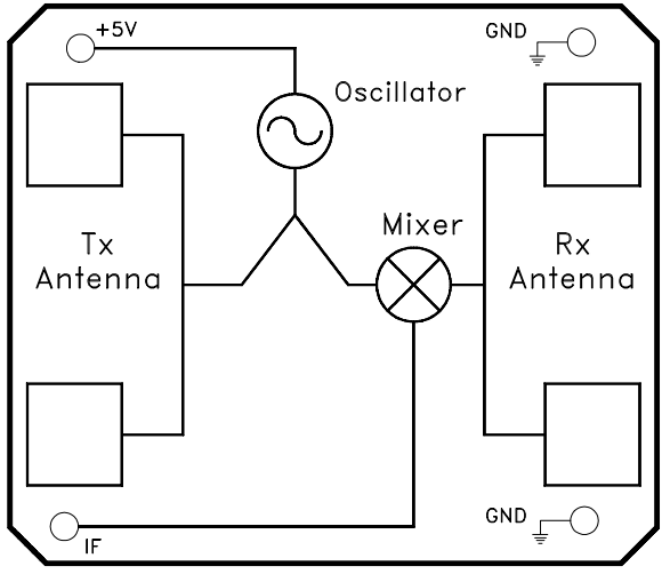


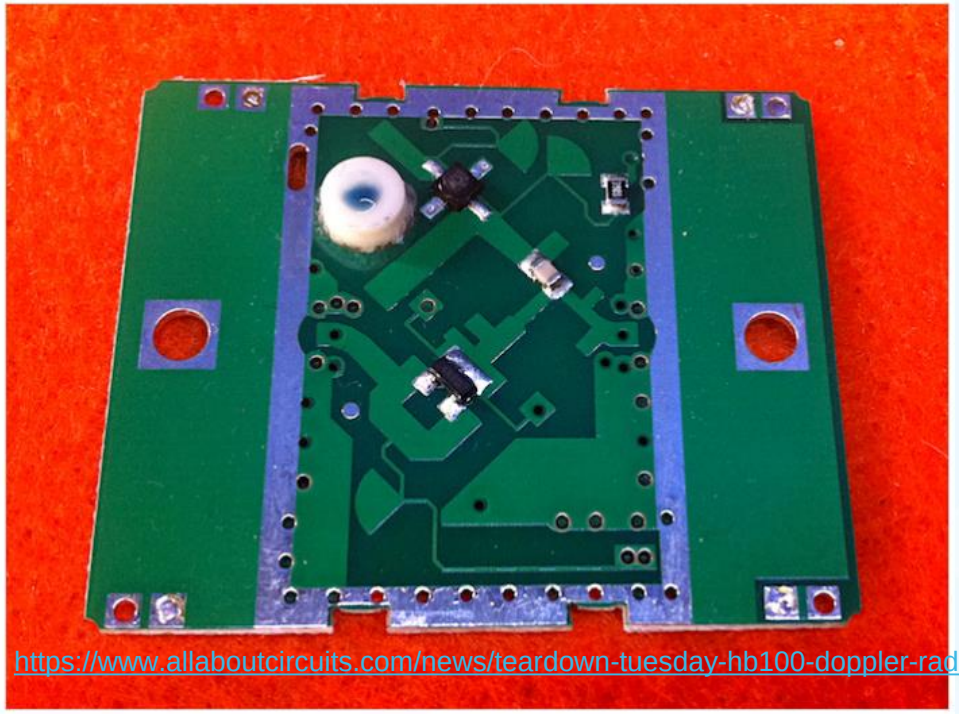
RF Source Assembly

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!





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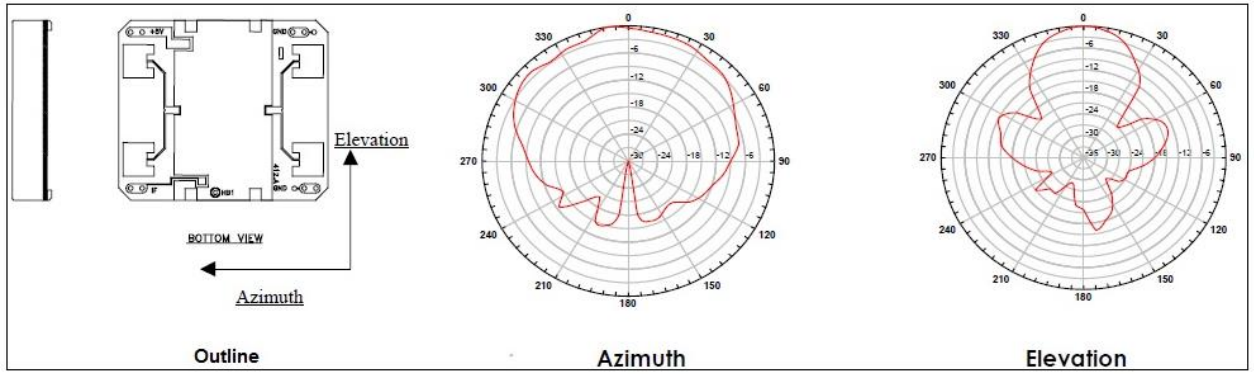
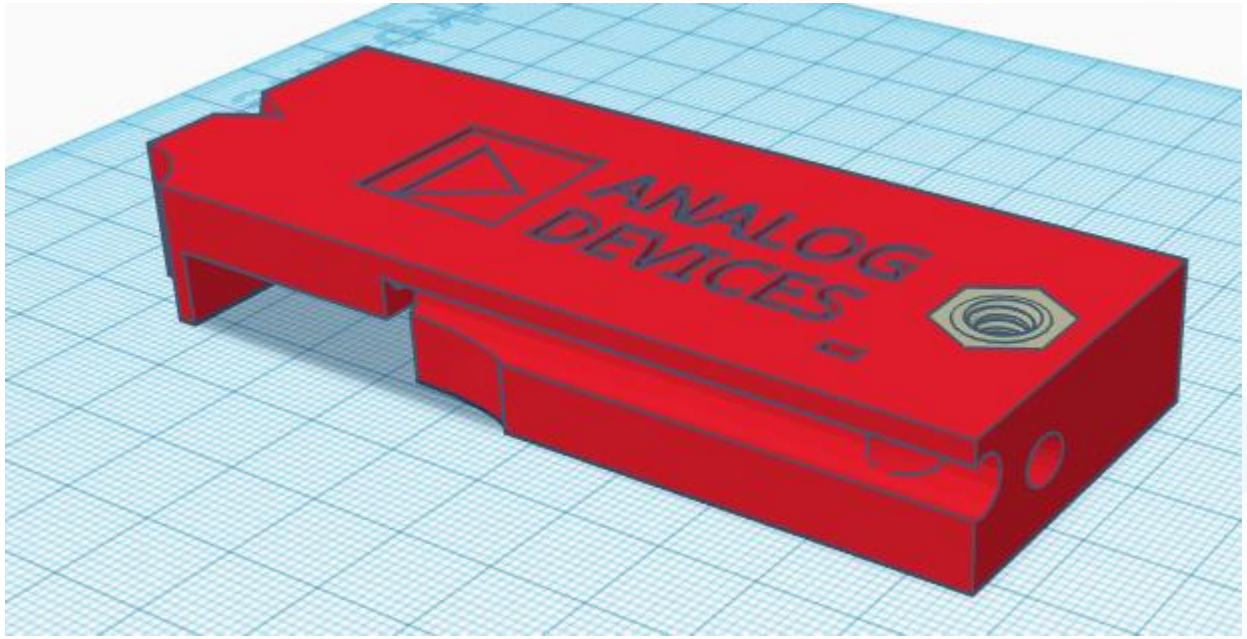


https://www.limpkin.fr/public/HB100/HB100_Microwave_Sensor_Application_Note.pdf

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
- 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

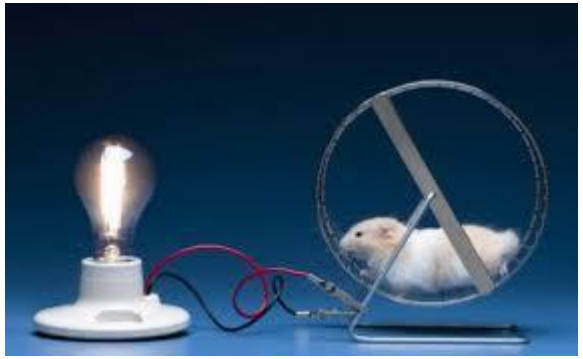


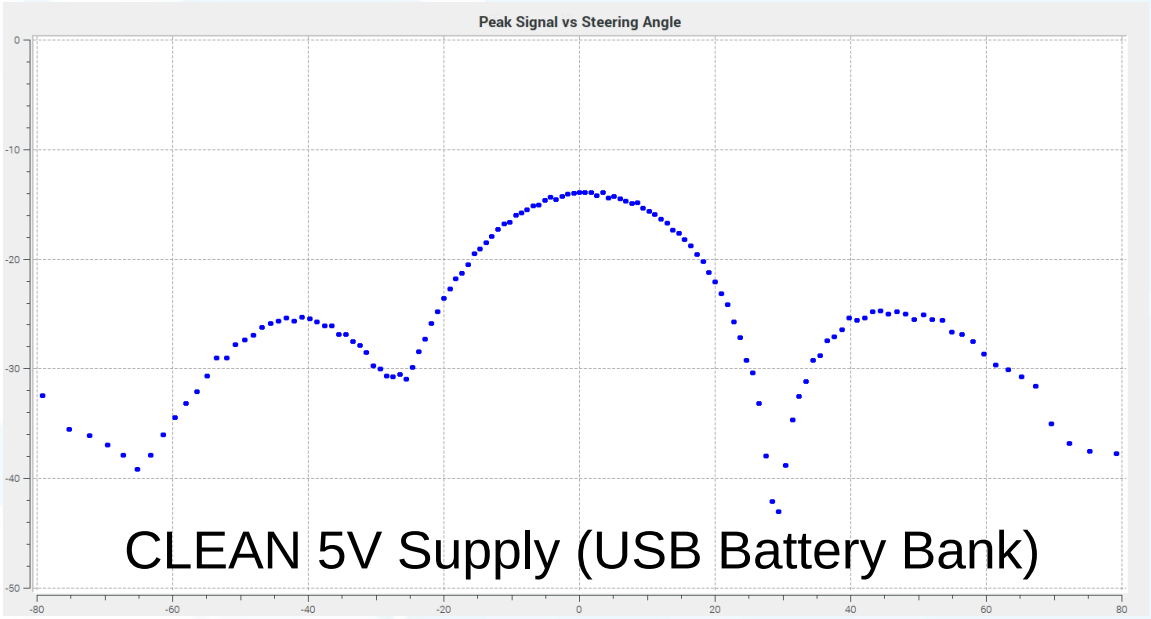
HB100 RF Source: The Power Supply Matters!

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

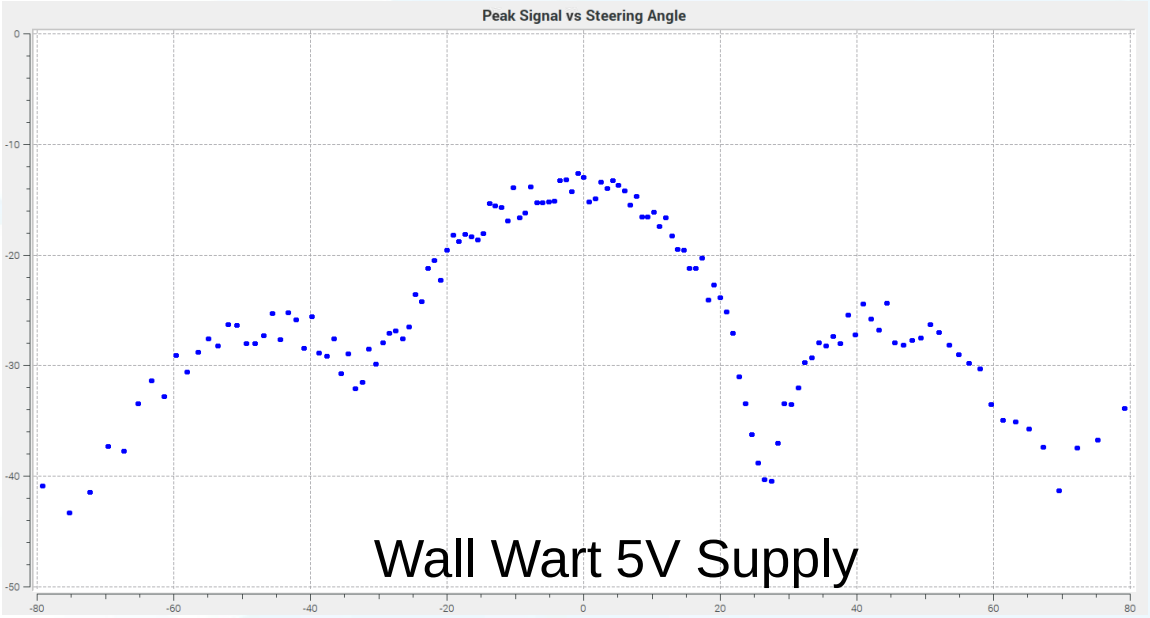
- These are **GOOD** power sources:
  - LT3045 LDO
  - Battery Pack
  - Good Quality USB Phone Changer

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





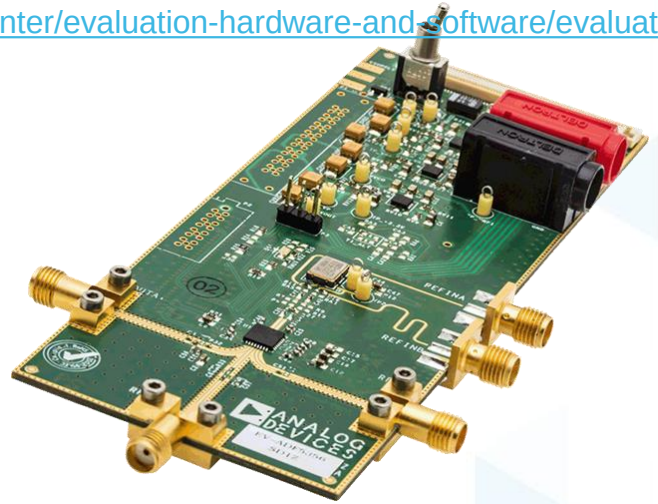
CLEAN 5V Supply (USB Battery Bank)



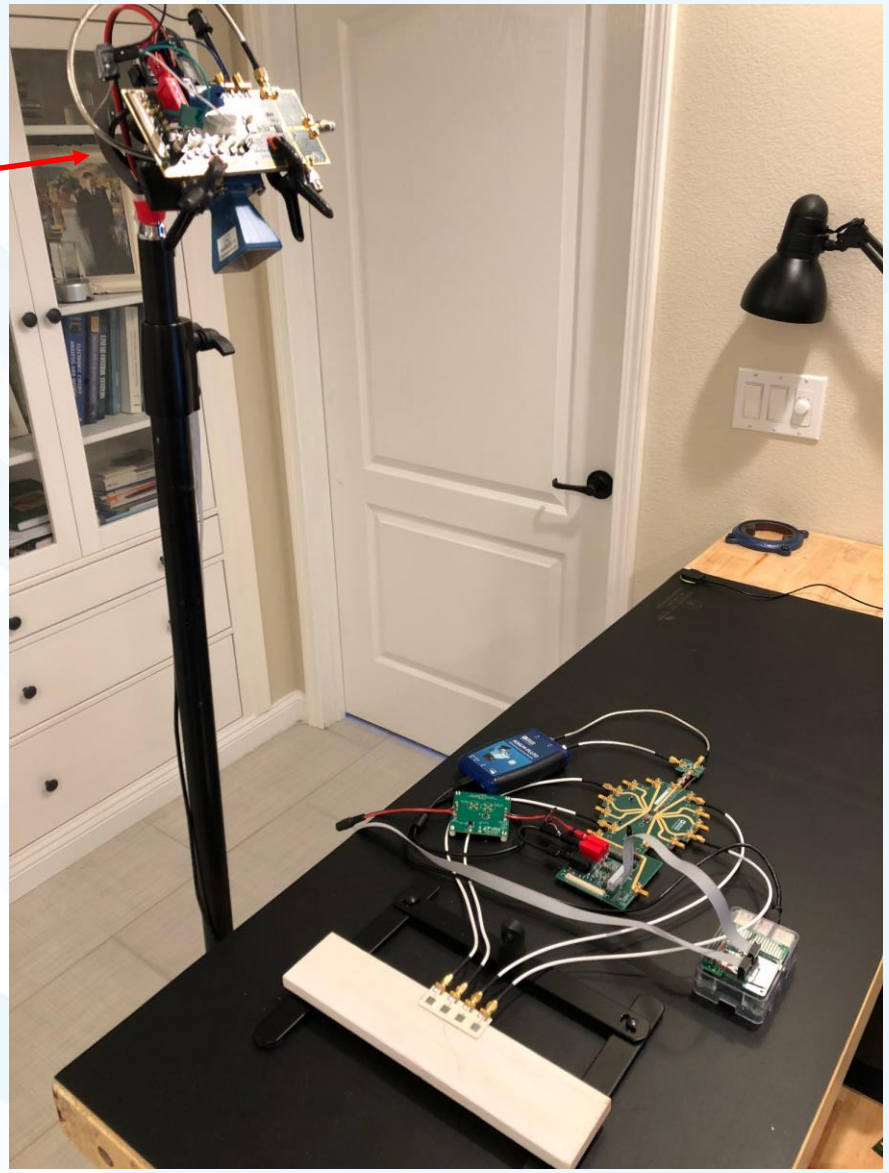
Wall Wart 5V Supply

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



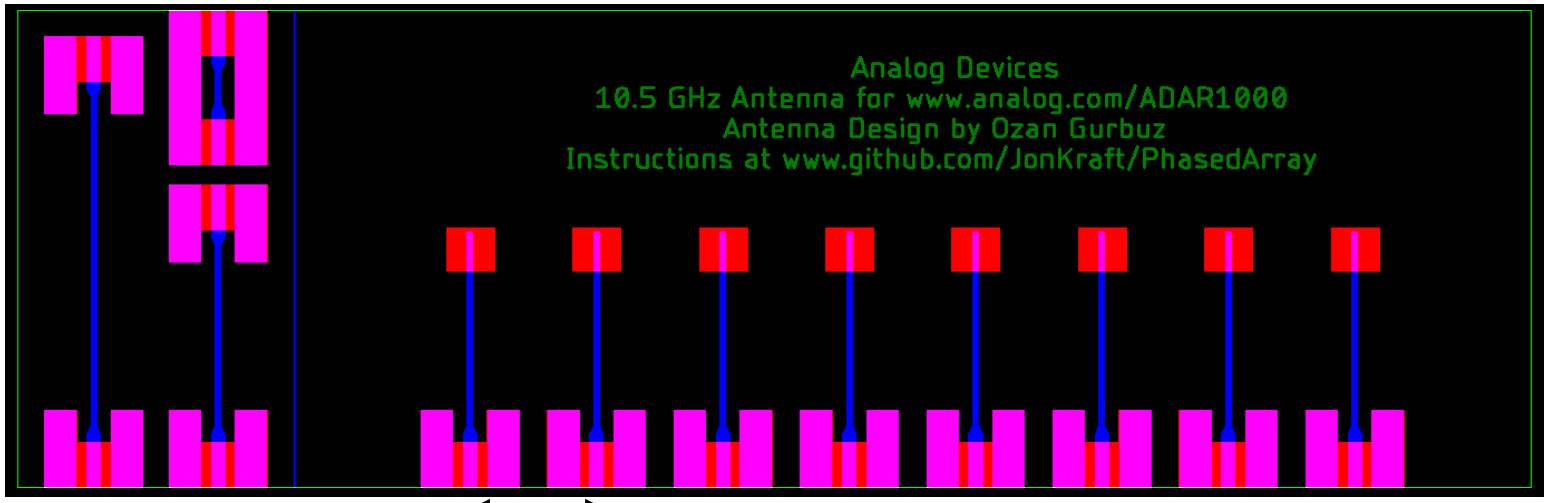
- Transmit Antenna:
  - https://www.pasternack.com/standard-gain-horn-waveguide-size-wr90-10-db-gain-sma-female-pe9856sf-10-p.aspx



Antenna Assembly

Patch Antenna

- A 10.5GHz patch antenna, designed for this lab by Ozan Gurbuz
- Contact your local Analog Devices sales person! They can get you one.
- The gerber files, to make your own, are available at:
  - www.github.com/jonkraft/phasedarray
- 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



- Also thanks to Kent Britain www.wa5vjb.com who made a fantastic 10GHz antenna for this
  - He does amazing custom antenna designs and is very reasonably priced and approachable.

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

Put it All Together!

Fully Assembled Lab Station: