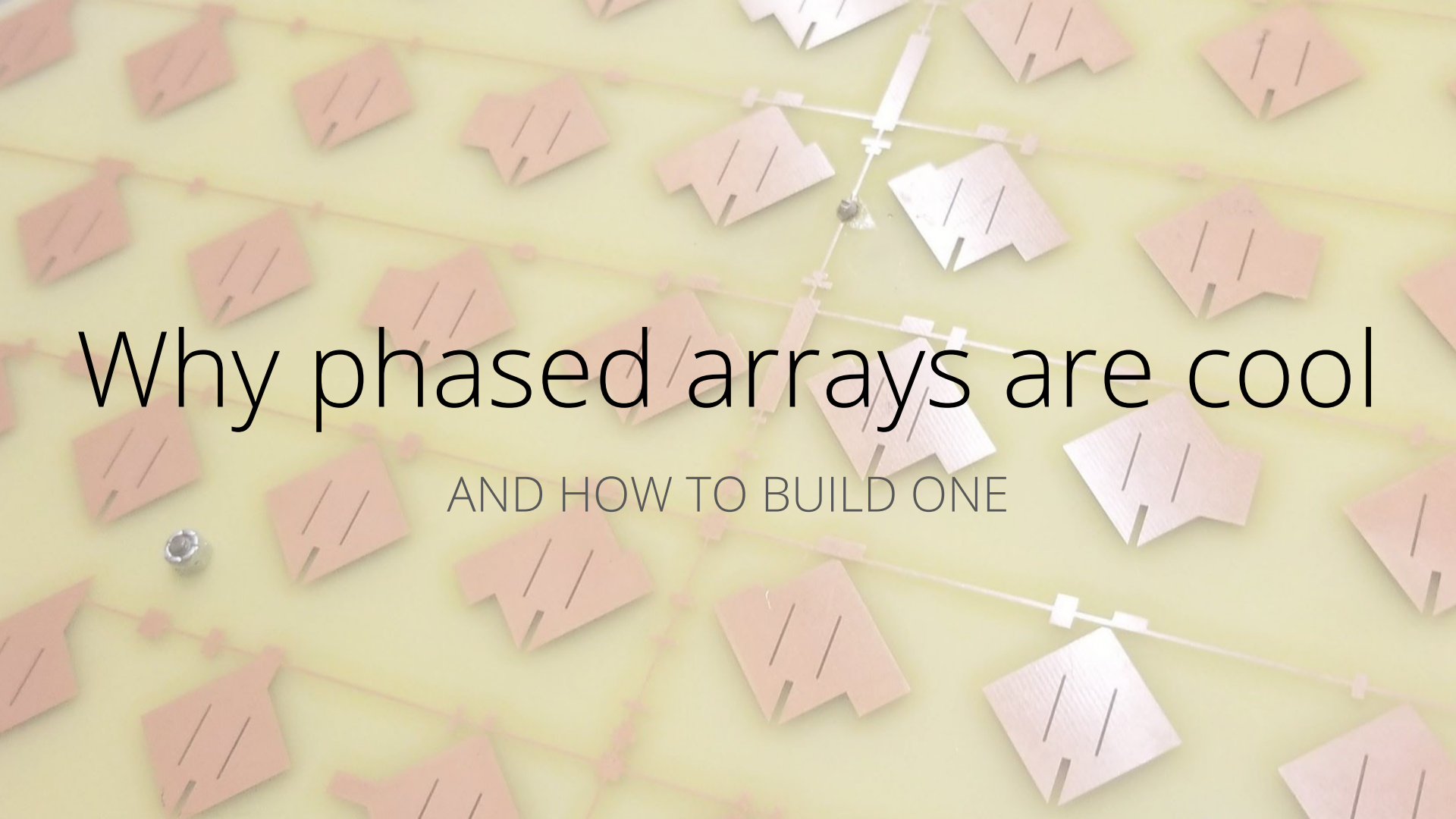


Why phased arrays are cool

AND HOW TO BUILD ONE

What we’re covering

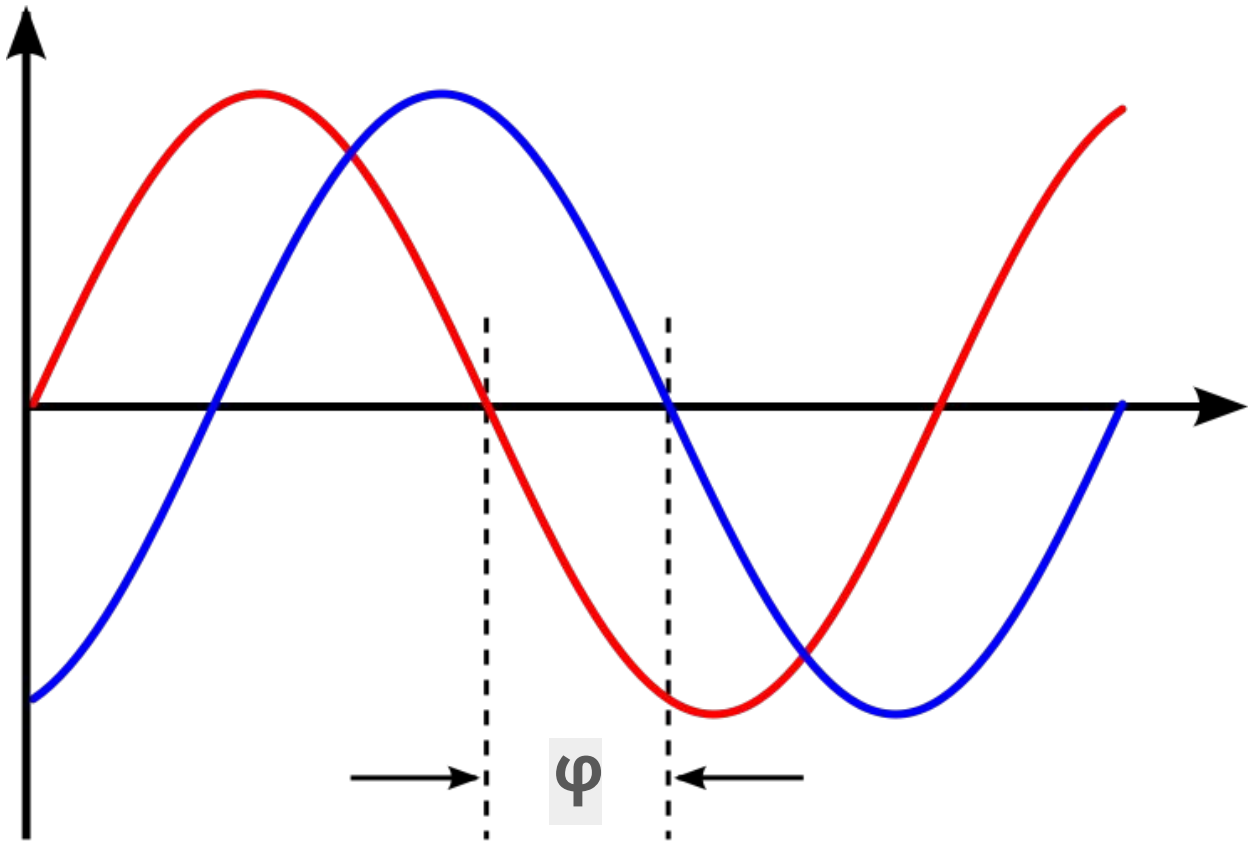
- Basic physics and math of a phased array
- What you can do with a phased array
- Building your own
- Design considerations

Who I am

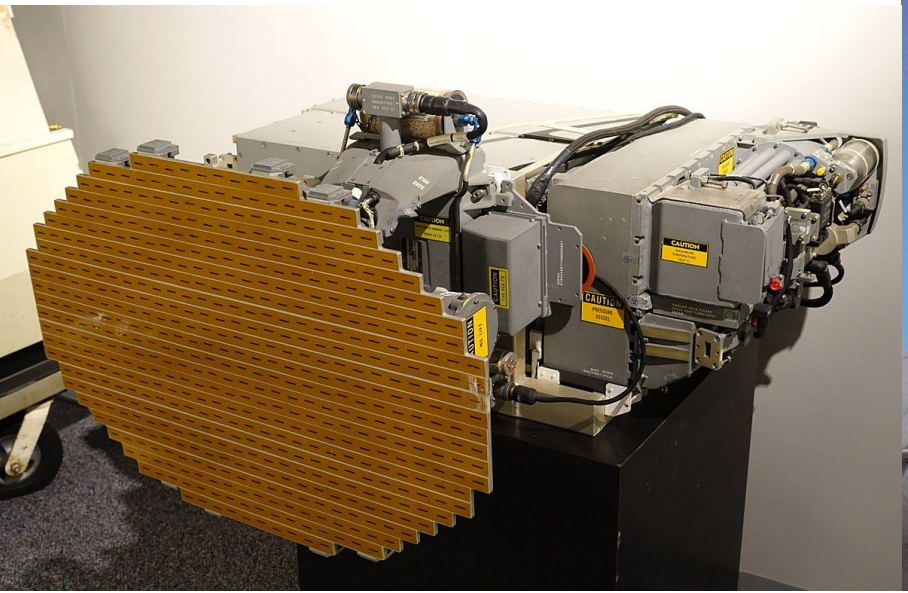
- Hunter Scott
- Director of Hardware Engineering at Reach Labs
- 10 years of hardware design

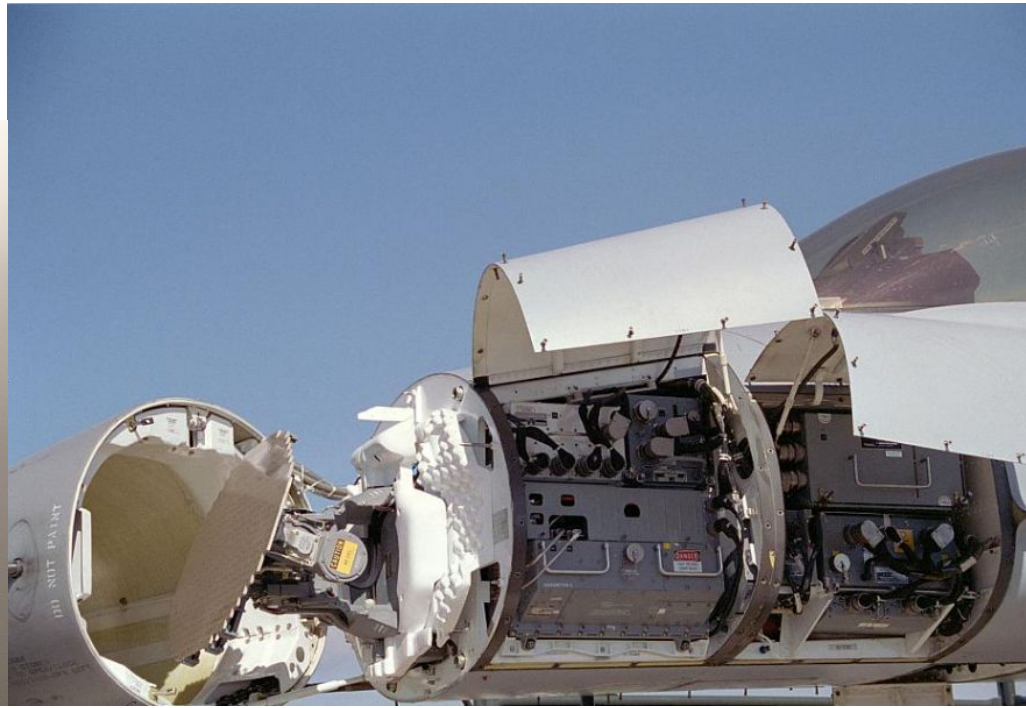
What's phase?

$A*\sin(\omega t + \varphi)$



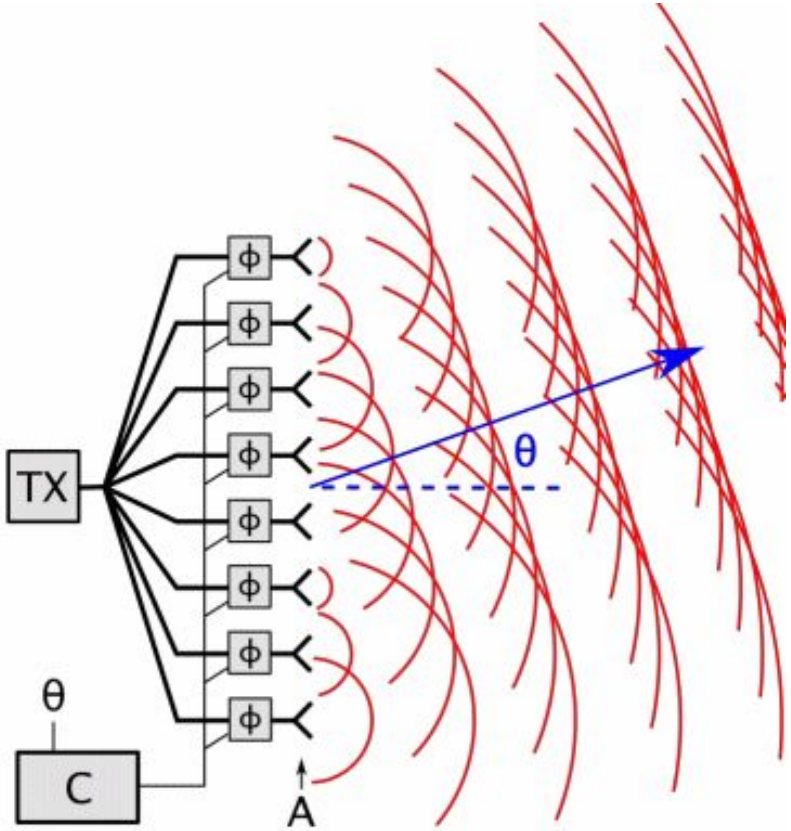
What isn’t a phased array?



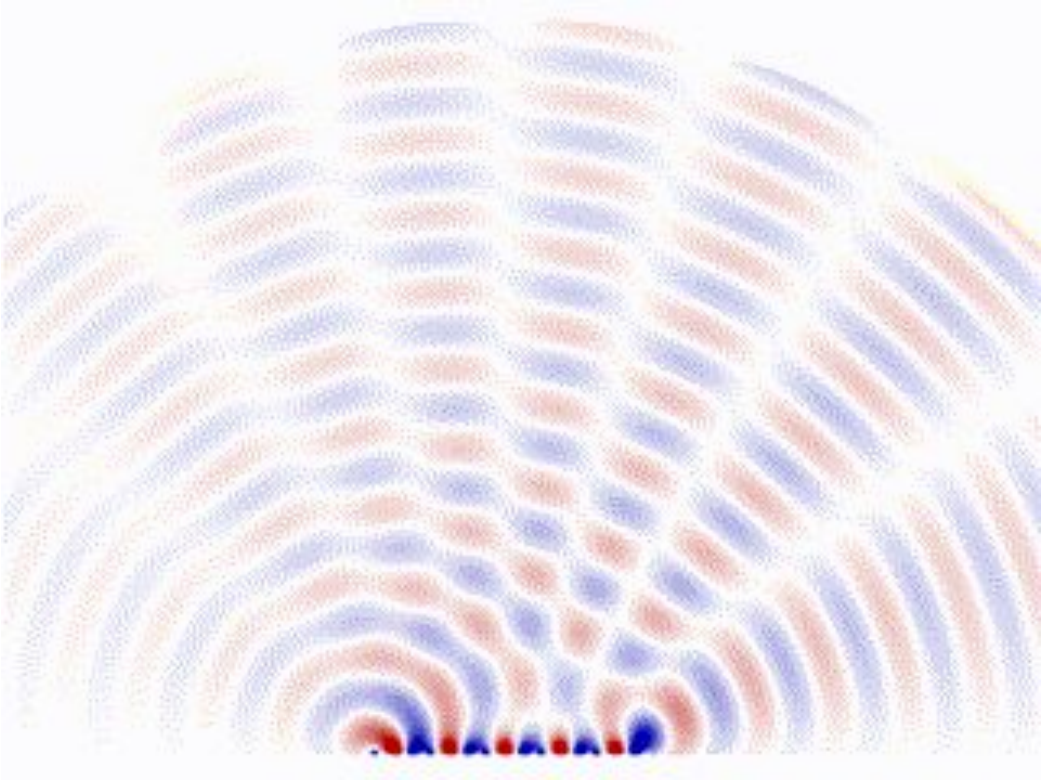


Mechanical steering can have downsides....

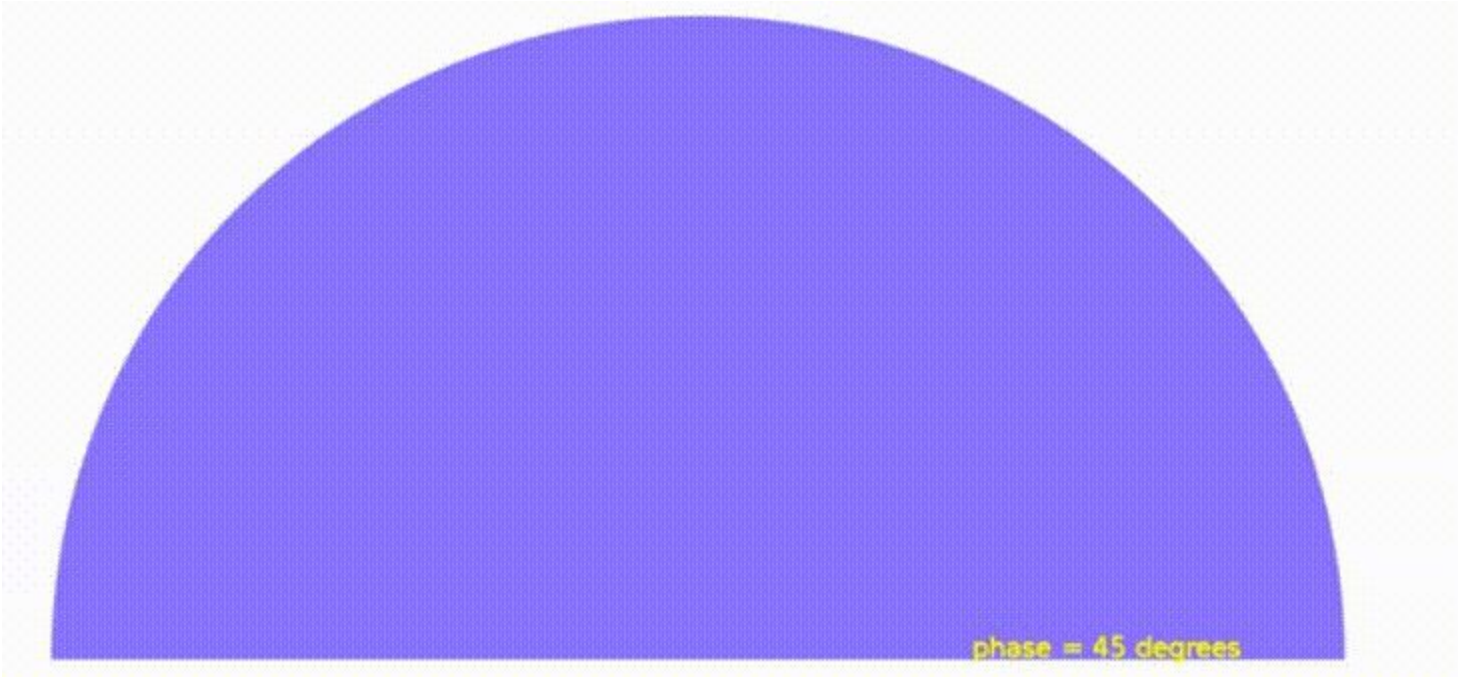
What’s a phased array?



What’s a phased array?



What’s a phased array?



What’s a phased array?

Mark Hickel

What’s a phased array?

Mark Hickel

Big phased arrays

Sea-based X band radar

Big phased arrays

Eglin AFB Site C-6

Big phased arrays

PATRIOT missile

Phased array architecture

An antenna array that allows phase control over each antenna

- **Passive**

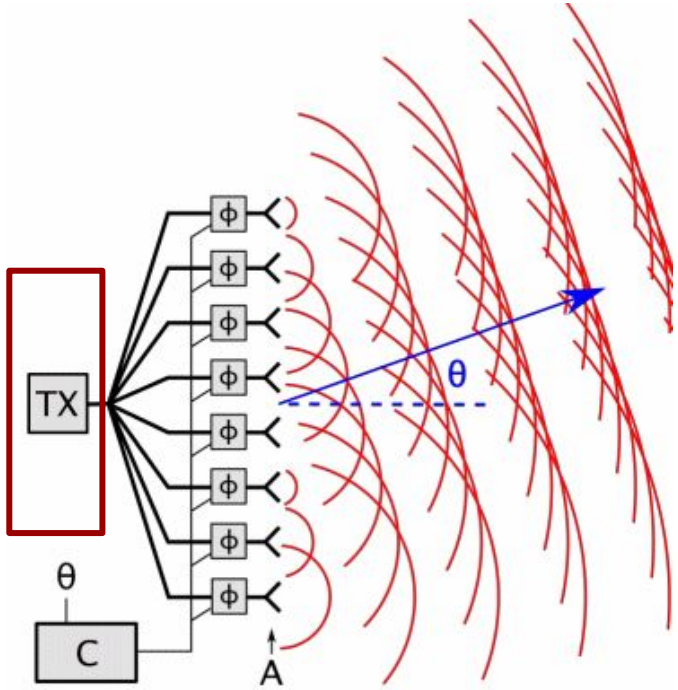
  One frequency source, each element has a phase shifter

- **Active**

  Each element has a VCO and phase shifter. More expensive, better performance.

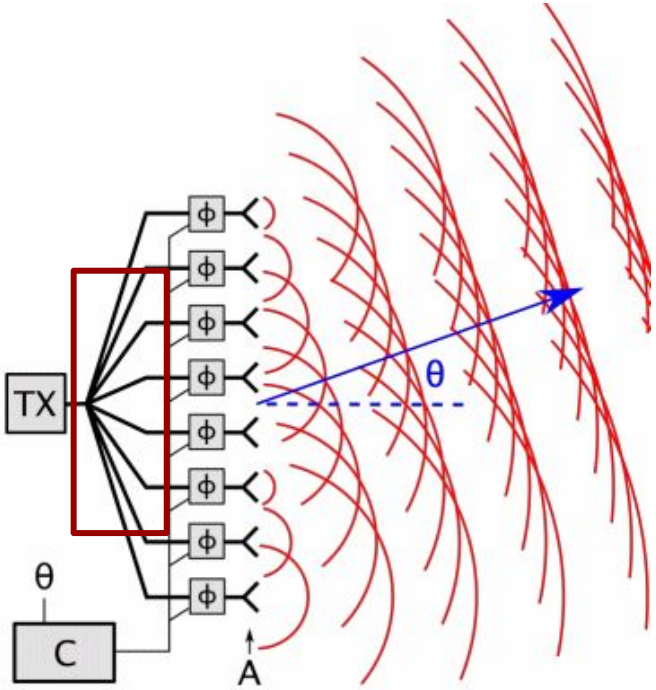
Phased array architecture

- **Passive**



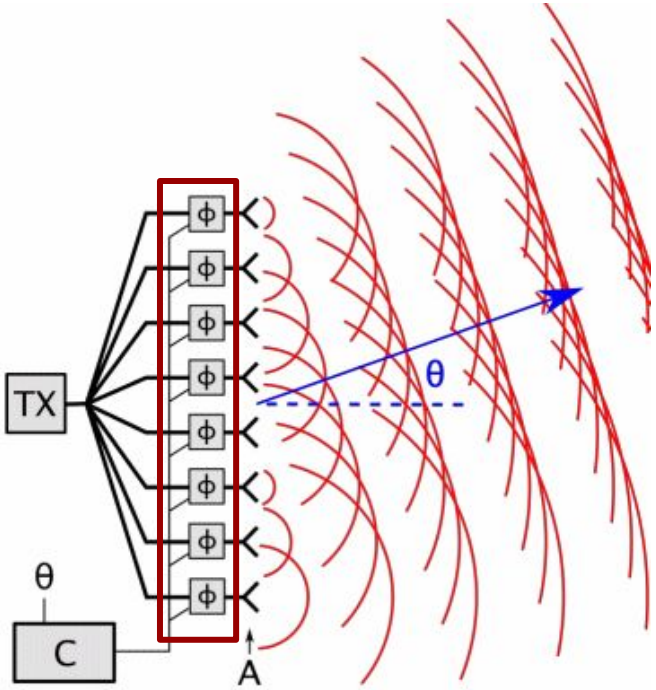
Phased array architecture

- **Passive**



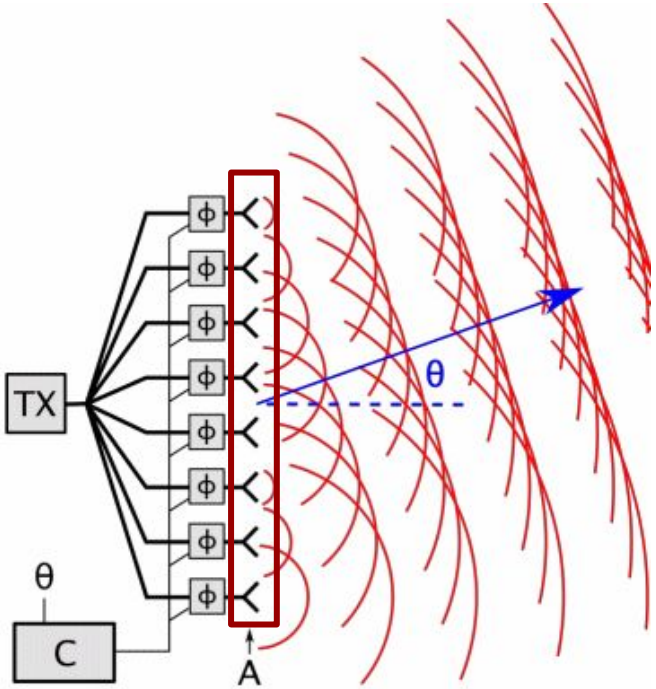
Phased array architecture

- **Passive**



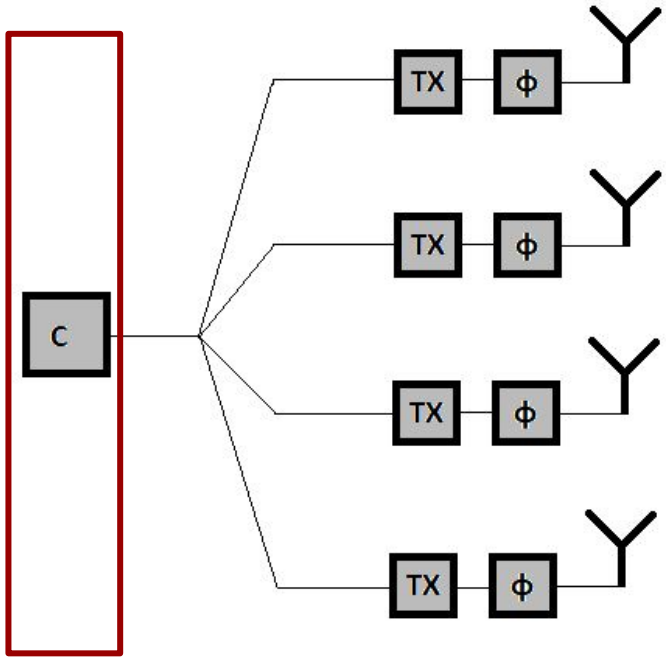
Phased array architecture

- **Passive**



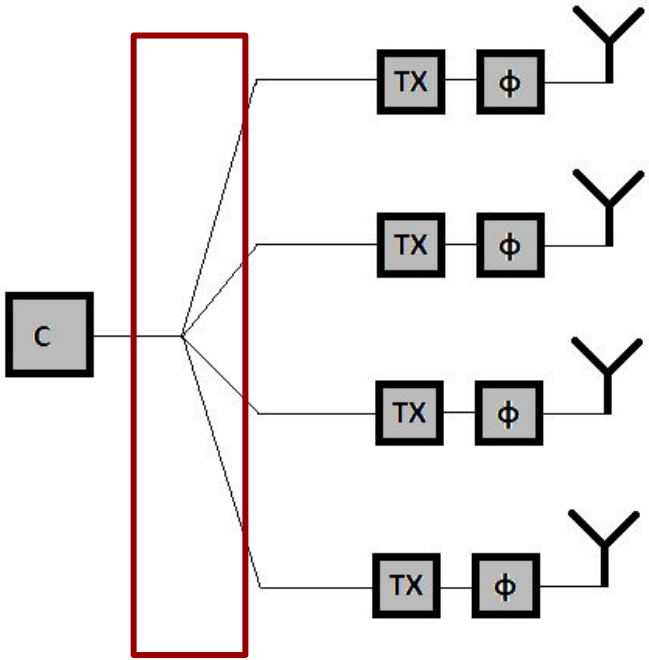
Phased array architecture

- **Active**



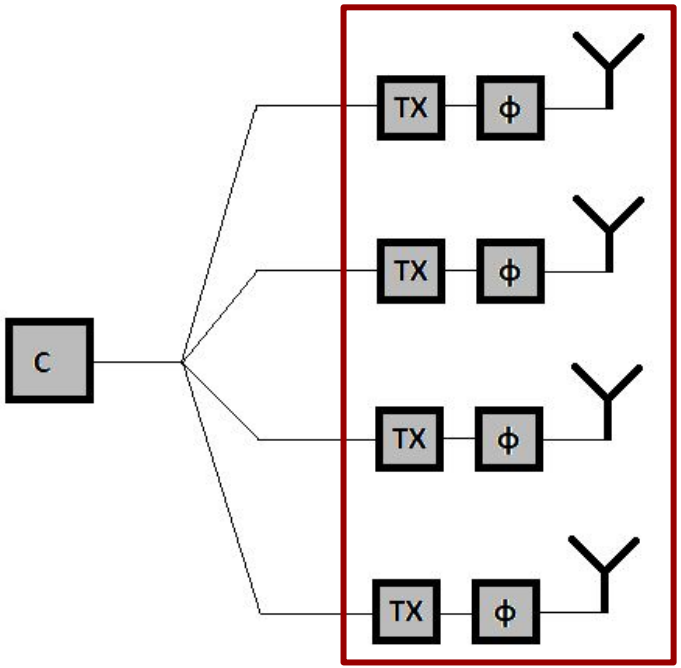
Phased array architecture

- **Active**



Phased array architecture

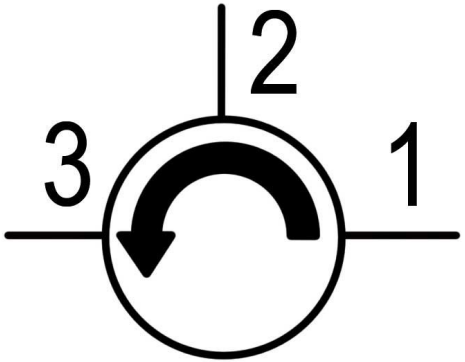
- **Active**



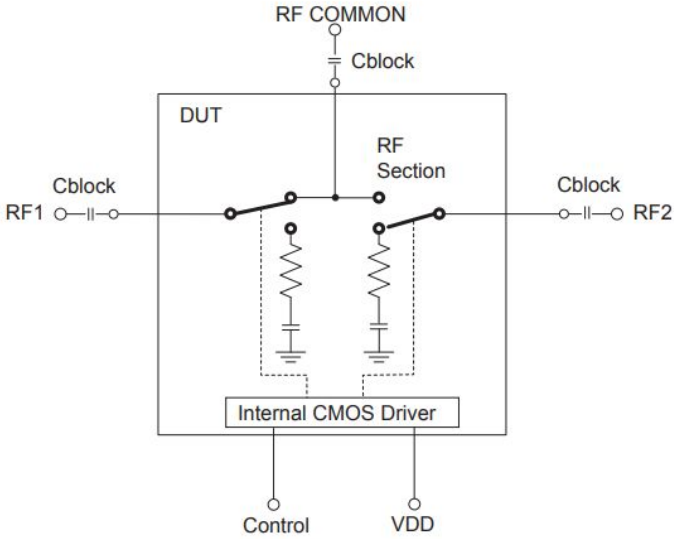
Phased array architecture

Transmit/Receive switching

Circulator:



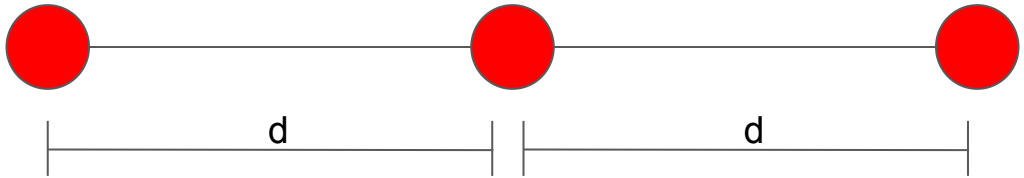
Switch:



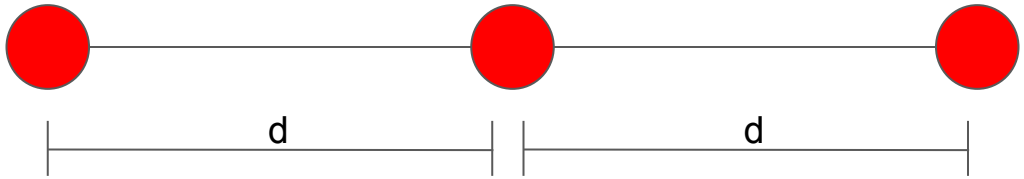
Math!

- How do you know when to emit from each port to get them to line up right?
- Principle of Reciprocity - the transmit case is the same as the receive case
- So let’s look at the receiving version, since it’s a little easier to think about, and it’s exactly the same equations for transmitting.

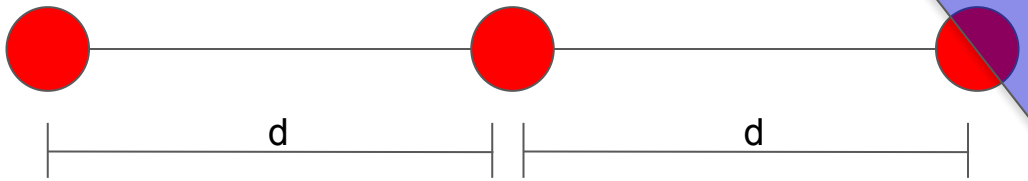
Math!



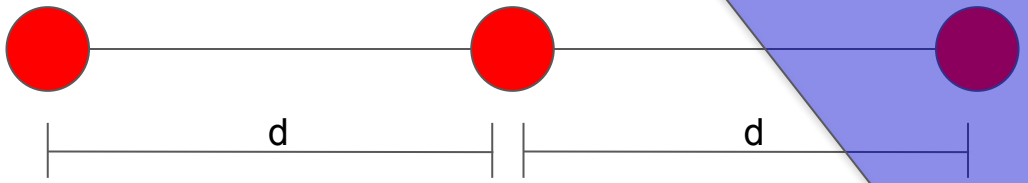
Math!



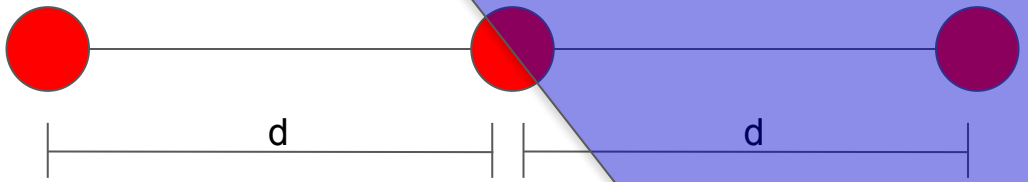
Math!



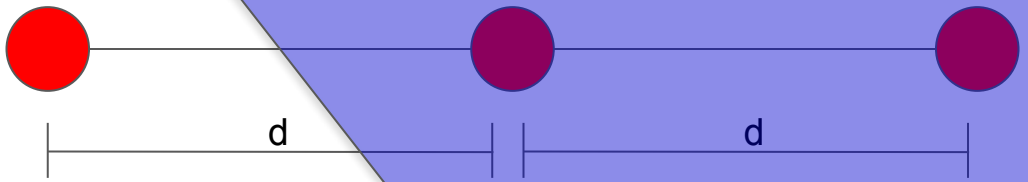
Math!



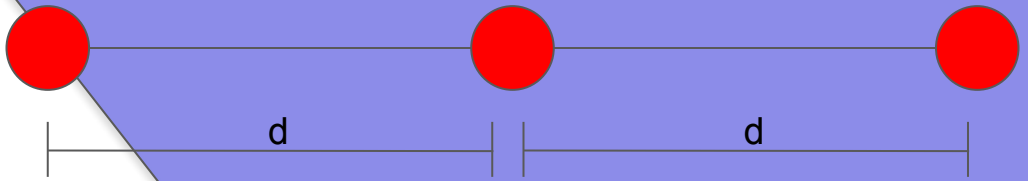
Math!



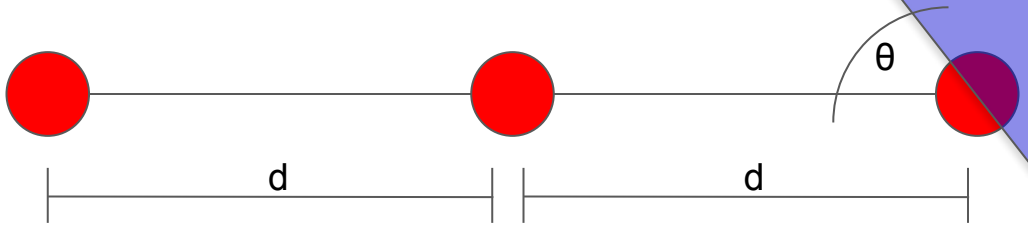
Math!



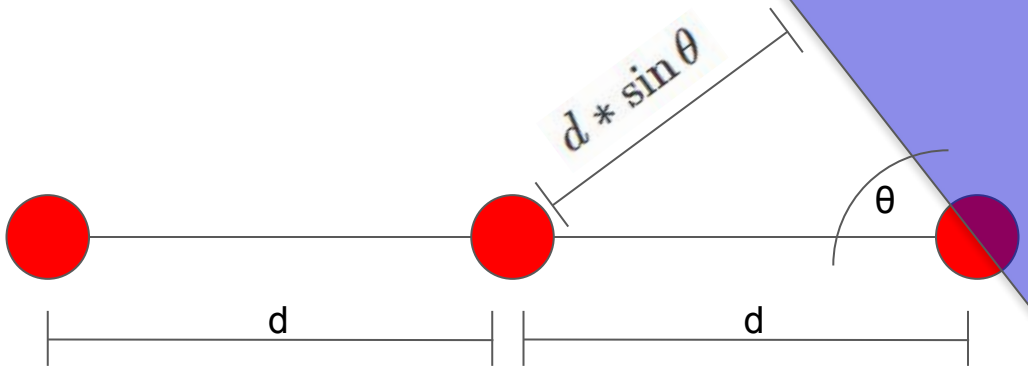
Math!



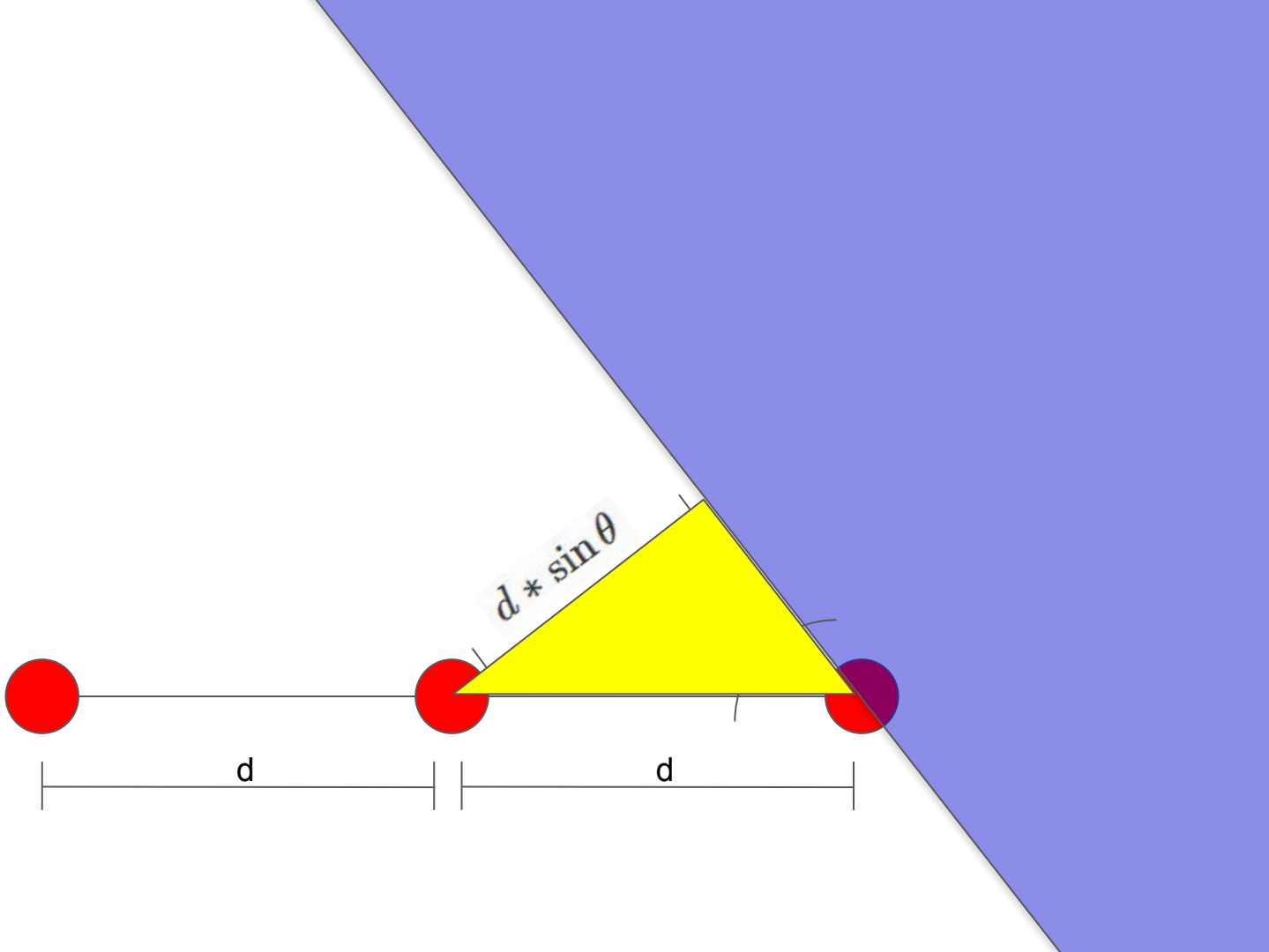
Math!



Math!

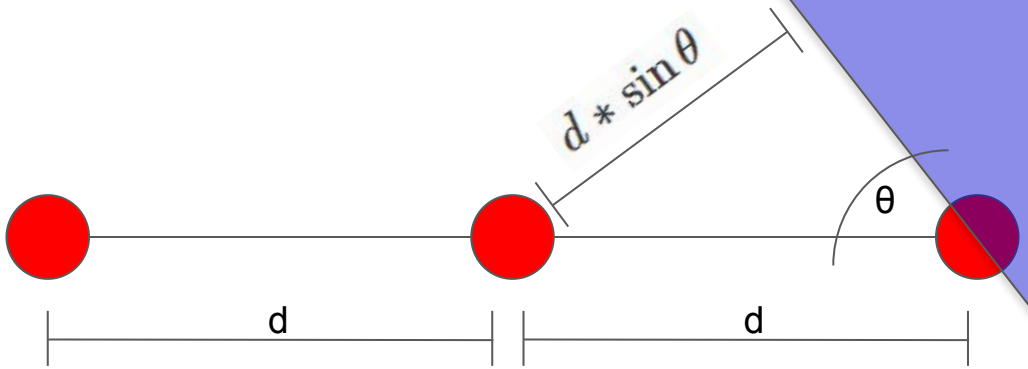


Math!



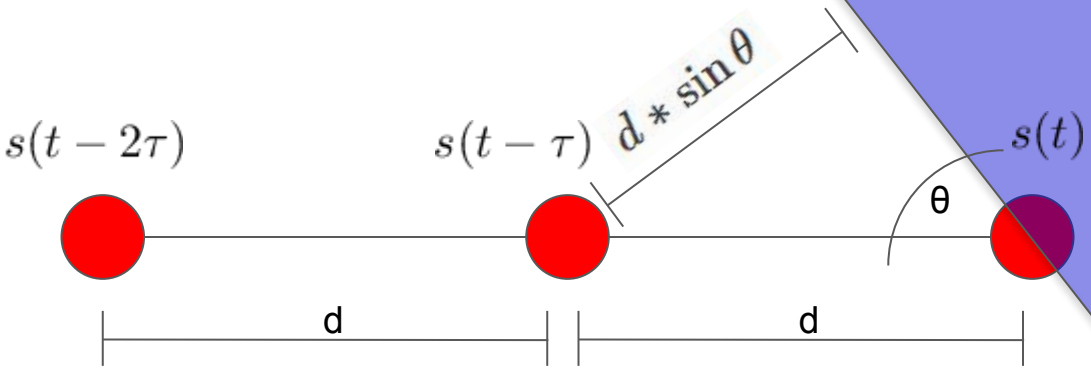
Math!

$$\tau = \frac{d * \sin\theta}{c}$$



Math!

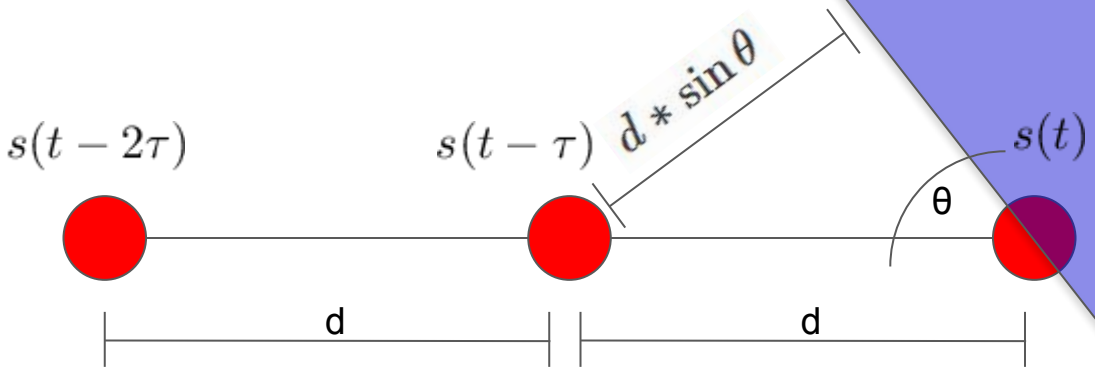
$$\tau = \frac{d * \sin\theta}{c}$$



Math!

$$\tau = \frac{d * \sin\theta}{c}$$

$$y(t) = s(t) + s(t-\tau) + s(t-2\tau) + ...$$

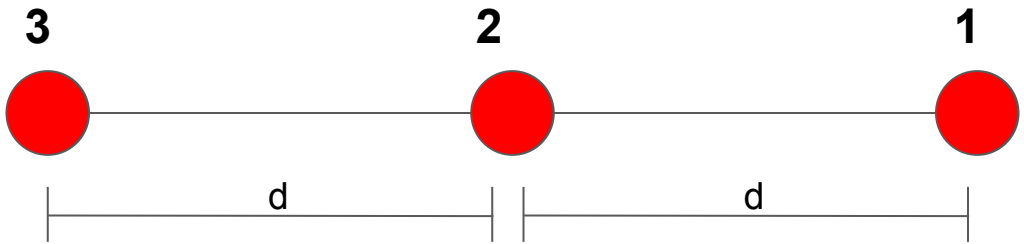


Math!

Example: isotropic elements in a line

$$\Delta\phi = \frac{360^\circ * d * \sin\Theta_s}{\lambda}$$

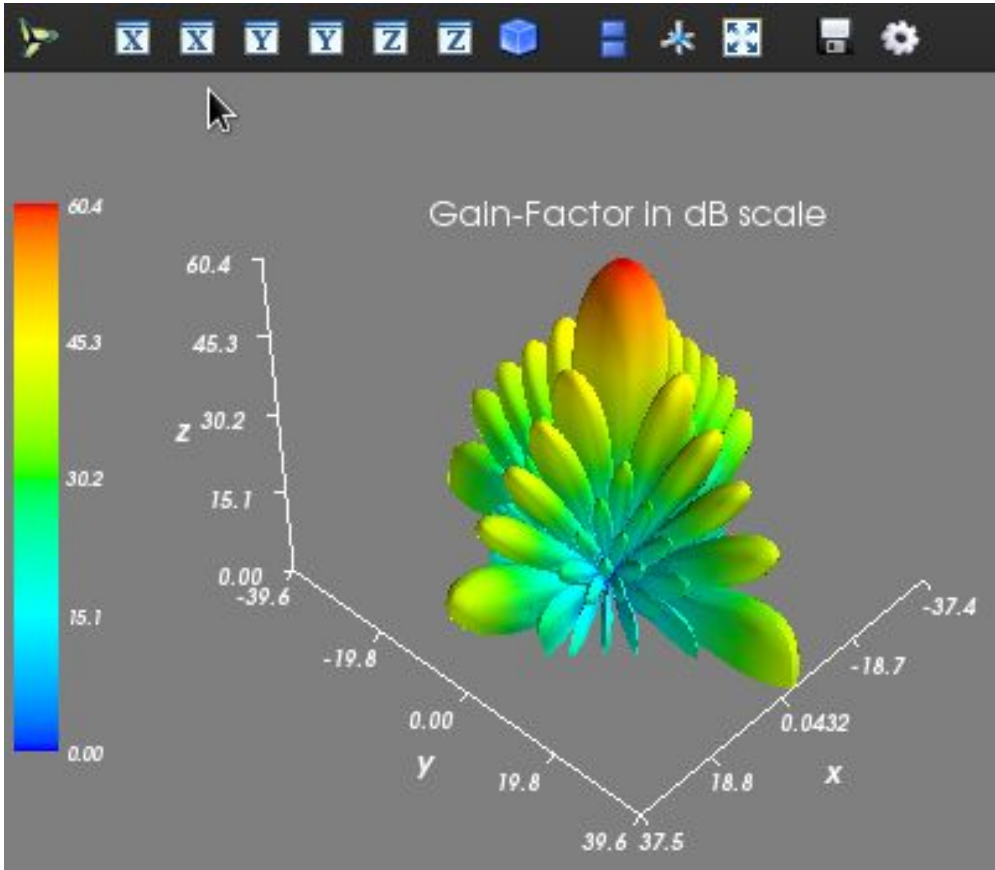
$$(\Delta\phi * n - 1) \mod 360^\circ =$$ Phase to steer out of antenna n to steer to angle Θ_s



Math!

This talk is only 35 minutes,
so please use ArrayTool

https://zinka.github.io/arraytool/



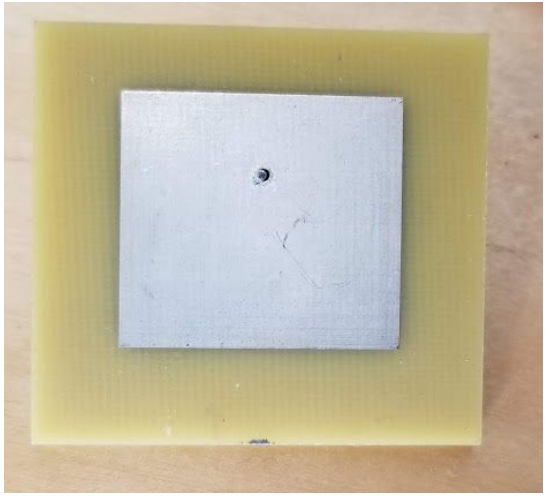
Parts we need (for one design of a phased array)

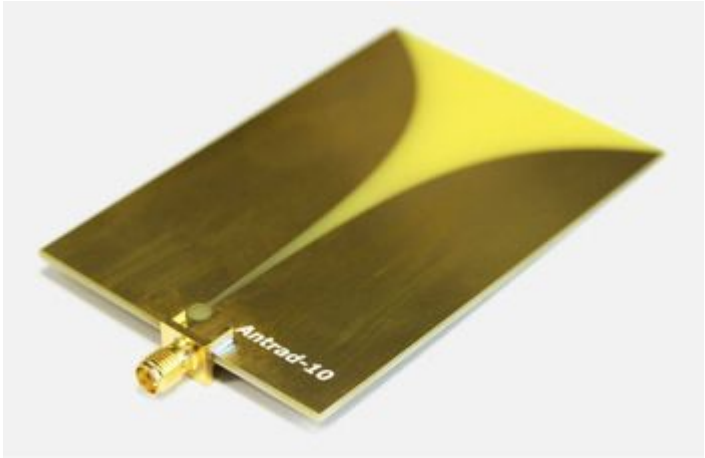
- Antennas
- VCO
- Splitters
- Amplifiers
- Some way to control phase

Parts we need (for one design of a phased array)

Antennas

Two most common are patch and Vivaldi





Parts we need (for one design of a phased array)

VCO

(Voltage controlled oscillator)

Consider output power and frequency range

Example Minicircuits part: ZX95-2500WA-S+

Parts we need (for one design of a phased array)

Splitters

Can use components or a Wilkinson divider in microstrip

Example Minicircuits part: ZN2PD-9G-S+

Parts we need (for one design of a phased array)

Amplifiers (PA/LNA)

Consider distortion, bandwidth, gain, power, stability

Minicircuits PA/LNA example part: ZX60-P103LN+
(can be used for both!)

Parts we need (for one design of a phased array)

Something to shift phase

-Phase shifter! But they’re expensive.

-IQ modulator!

Example IQ modulator dev board: OM7944 (from NXP)

Wait, what's I and Q again?

In phase and quadrature. Can represent any signal with those two things.

More info: https://www.youtube.com/watch?v=RHFZUqUM8DY (W2AEW!)

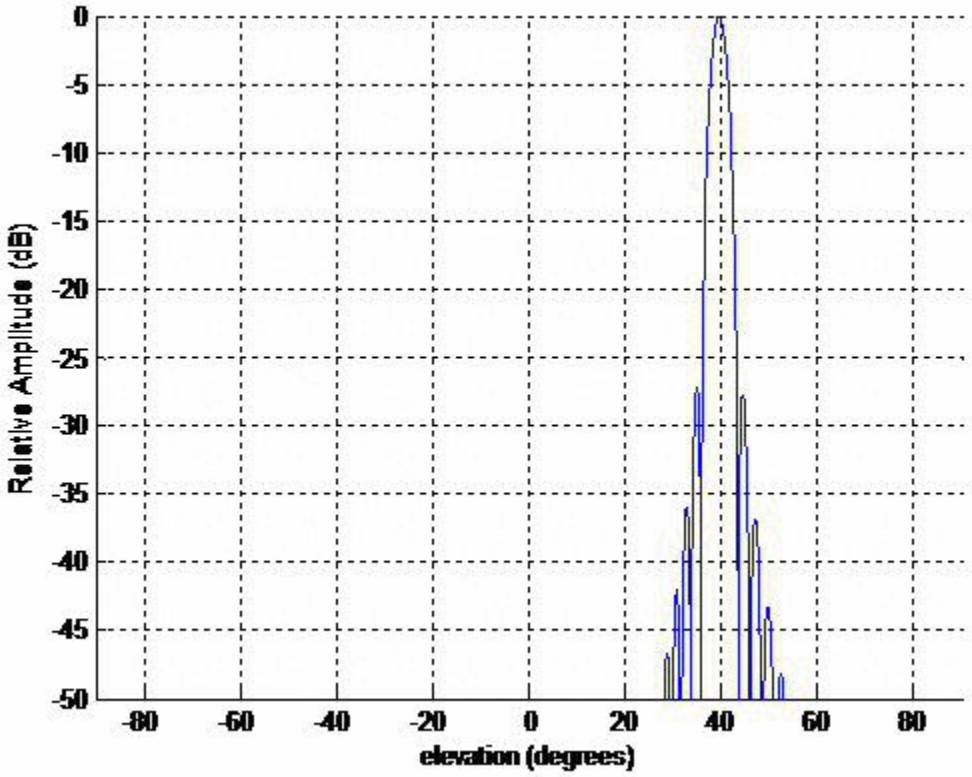
Design considerations

- Start small
- Watch out for feedback/coupling
- Watch out for backplane radiation from antennas into electronics
- Power
- Thermals
- Isolation (especially for TX/RX)
- Phase shift linearity over frequency
- SMA vs RP-SMA

Design considerations

Grating lobes

When you steer too far to one side and the beam appears on the other side.



Build your own

Some links to help kickstart your project:

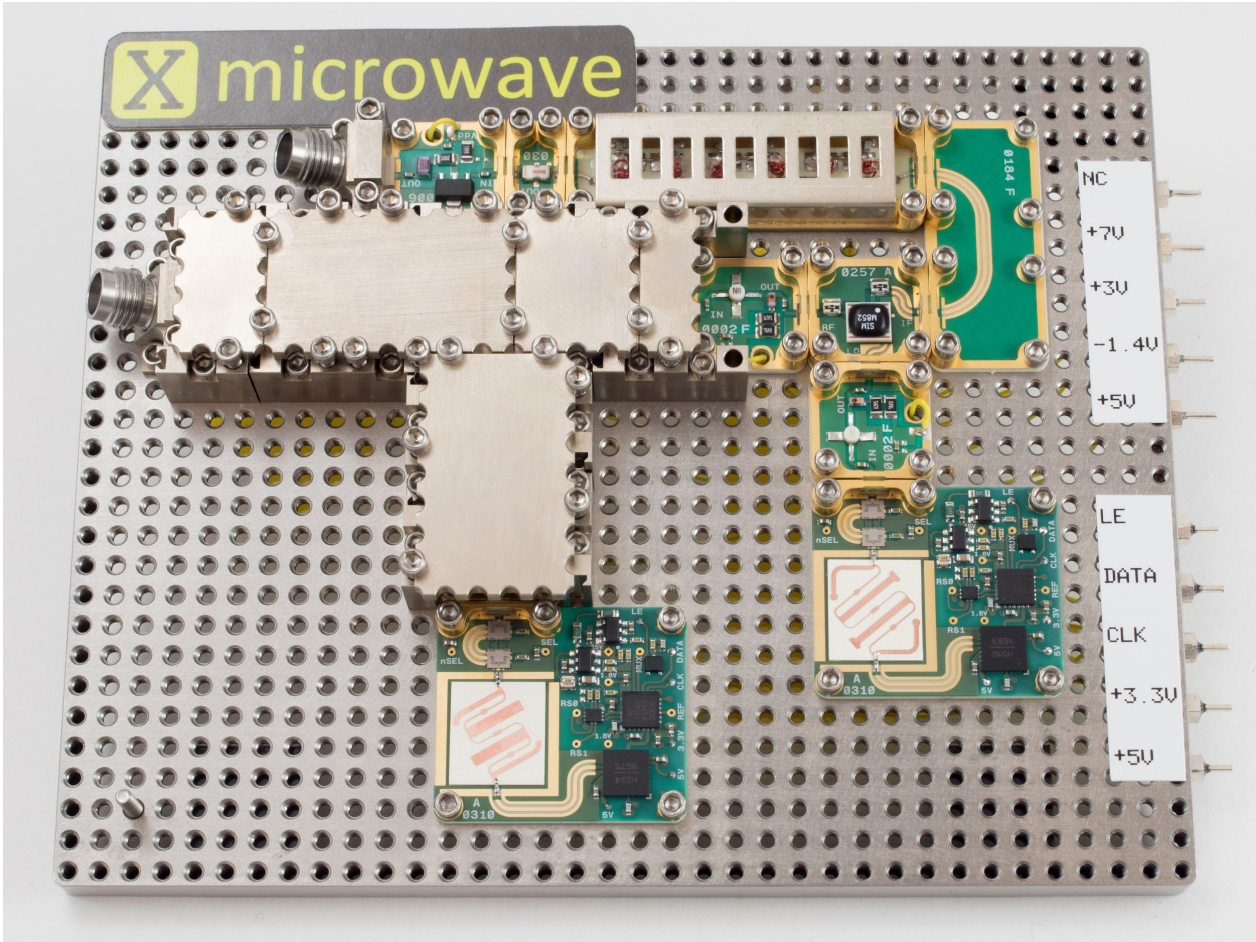
https://coherent-receiver.com/getting-started

http://glcharvat.com/Dr._Gregory_L._Charvat_Projects/S-Band_MIMO_Phased_Array_Radar.html

Build your own

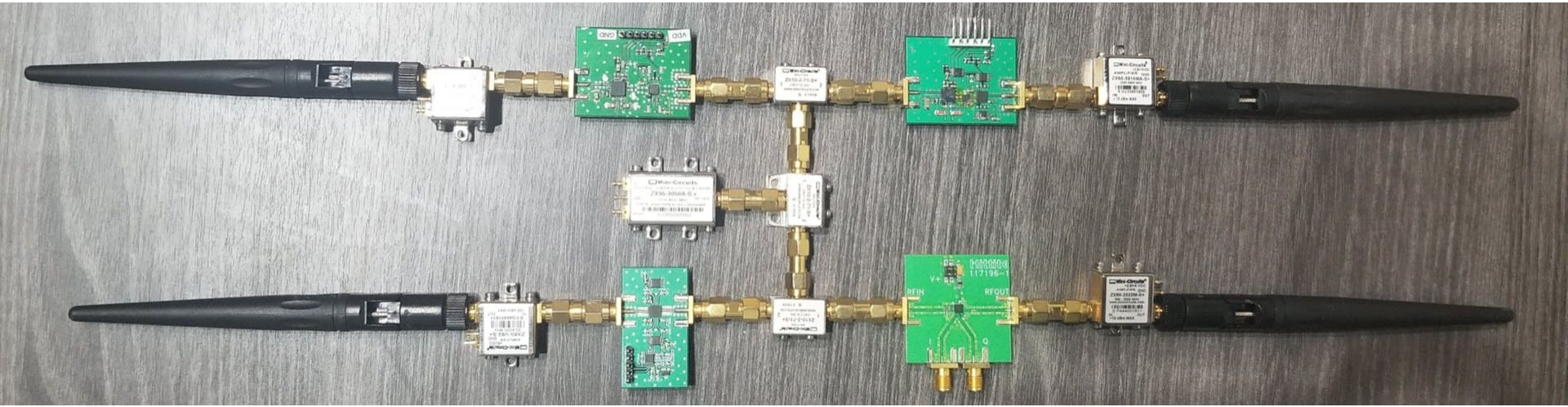
Xmicrowave:

Rapid prototyping for RF



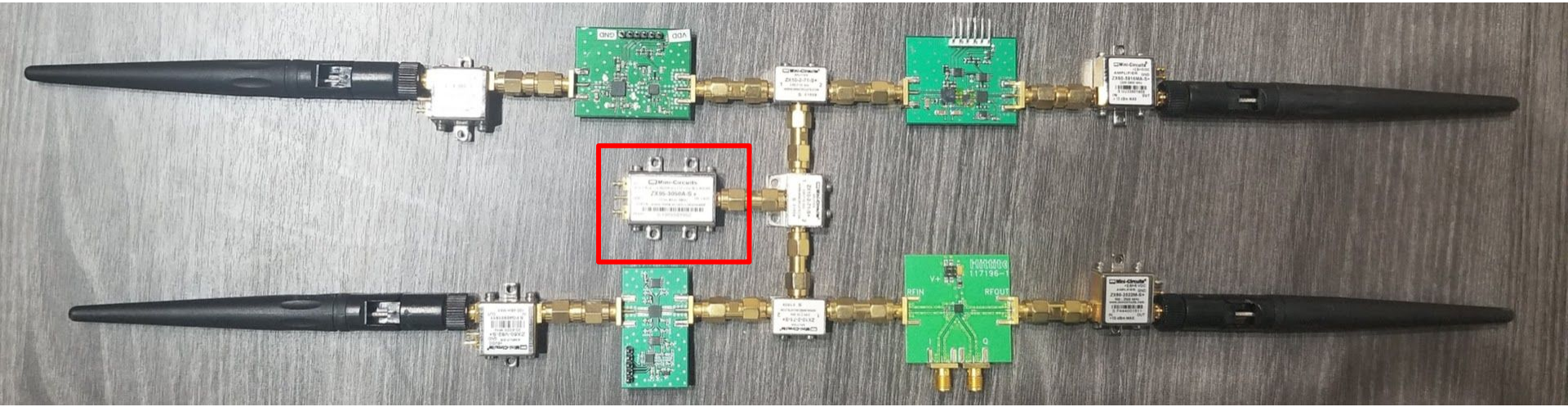
Build your own

2.4 GHz MiniCircuits version



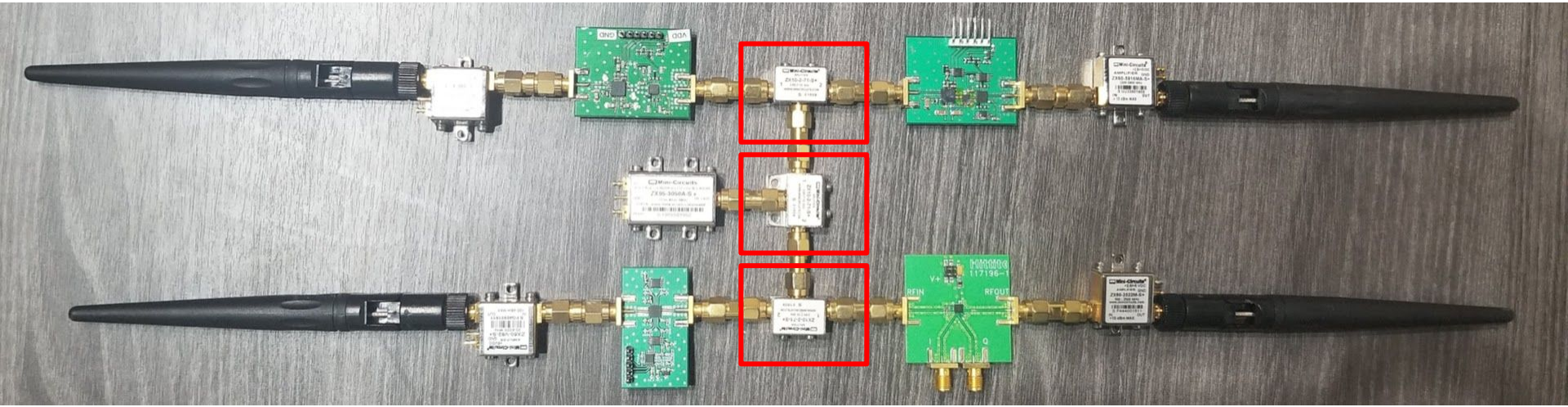
Build your own

2.4 GHz MiniCircuits version



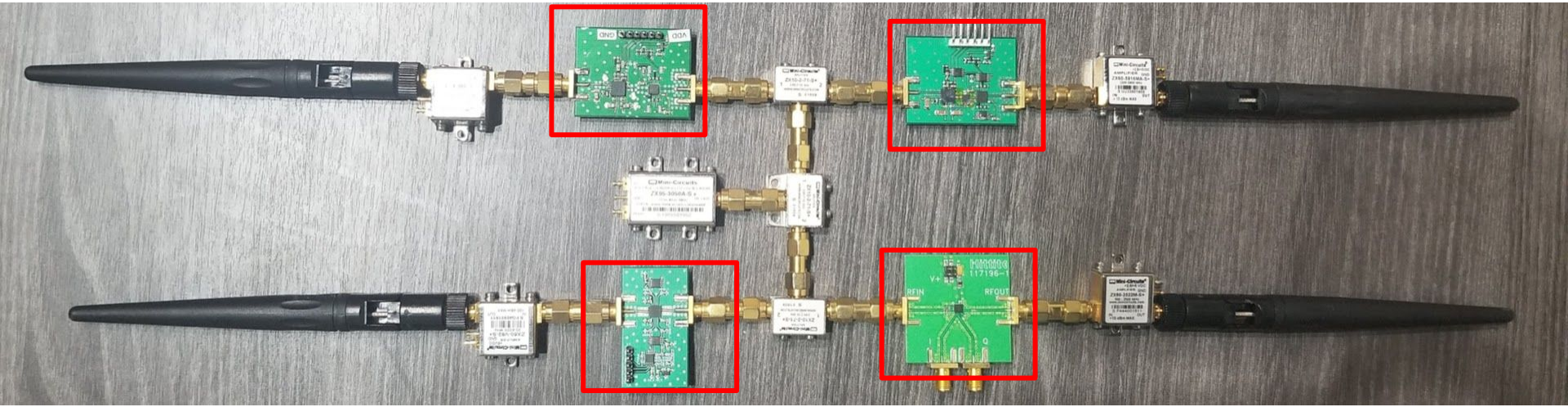
Build your own

2.4 GHz MiniCircuits version



Build your own

2.4 GHz MiniCircuits version



Build your own

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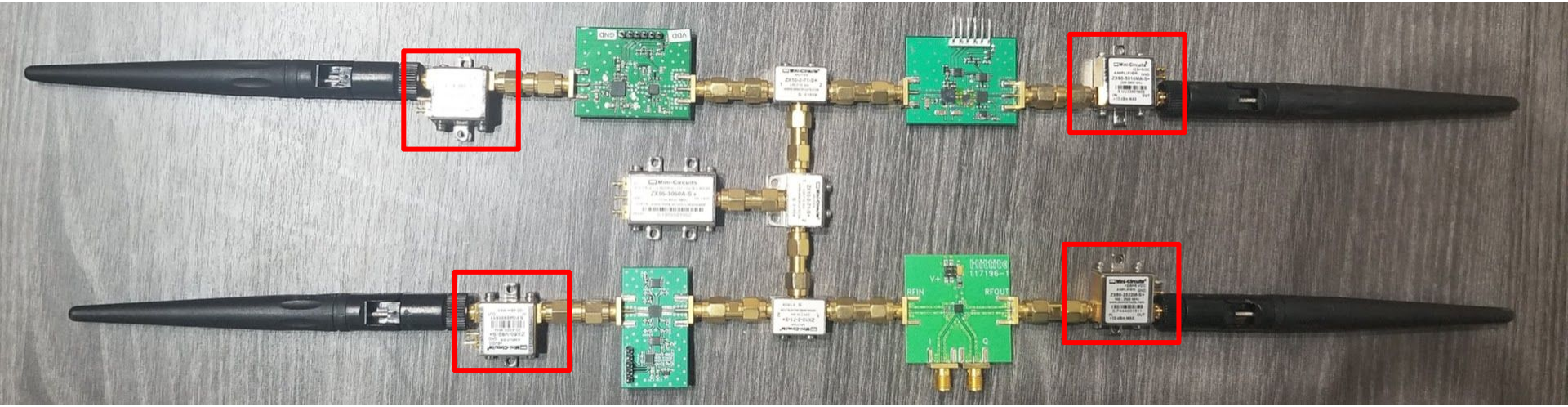
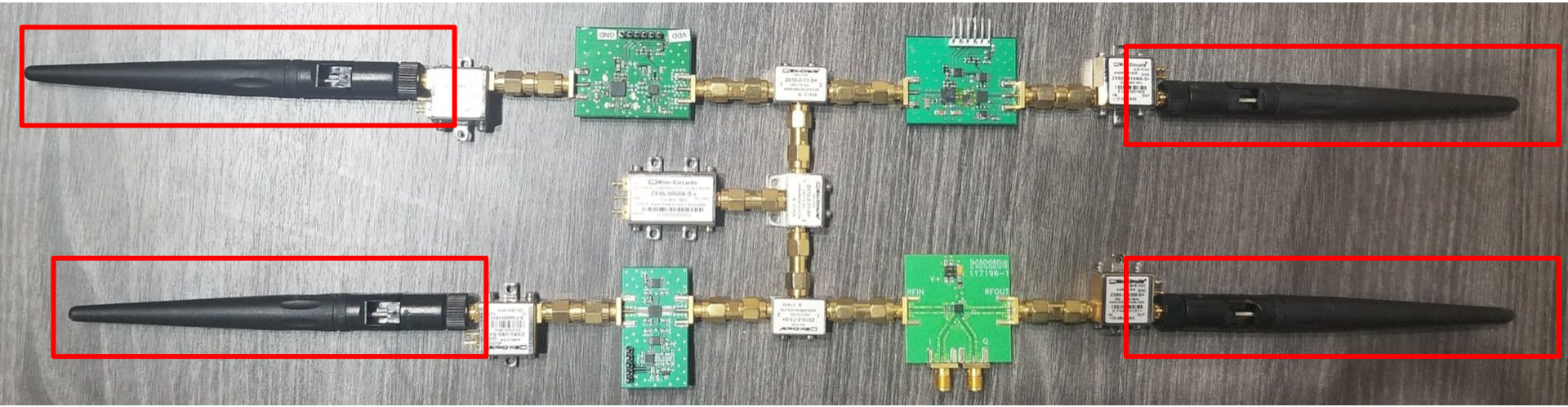


Build your own

2.4 GHz MiniCircuits version

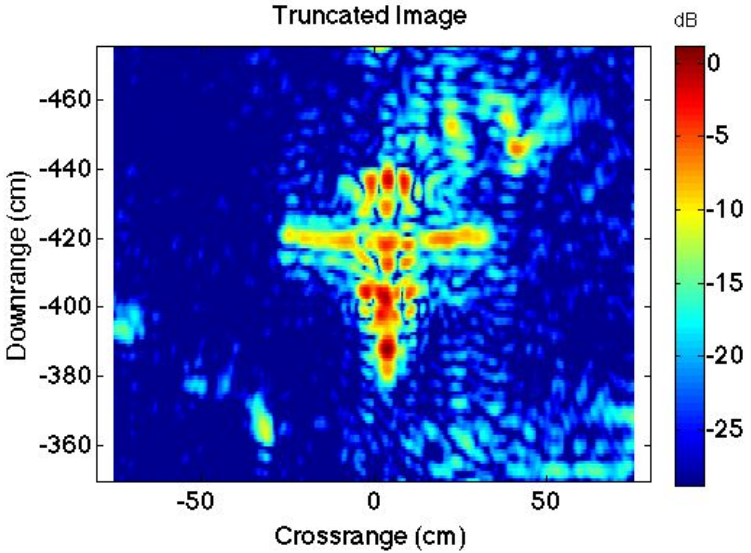


Relevance

- 5G is going to make all of this way easier. More integrated chips.

  Fun activities:

- Build your own SAR!
- Do spatial multiplexing experiments!
- Use magnetrons and precision cook your steaks!



A new project

Want to help build a phased array to make it easier for people to learn and experiment?

I need:

- An FPGA person, experience with RF would be great
- GNURadio integrator expert
- Maybe someone to help with some board design

You will get:

- No money
- The goodwill of dozens of people
- The joy of being a bad influence on today's impressionable youth by getting them interested in RF

Still in the early stages

Thank you!

Slides with links and part numbers:

http://hscott.net/PhasedArray

Contact:
hunter@hscott.net