SAR Imager

Senior Design Project: Northrop Grumman

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2016 Team

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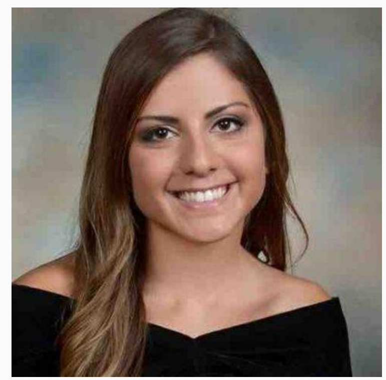
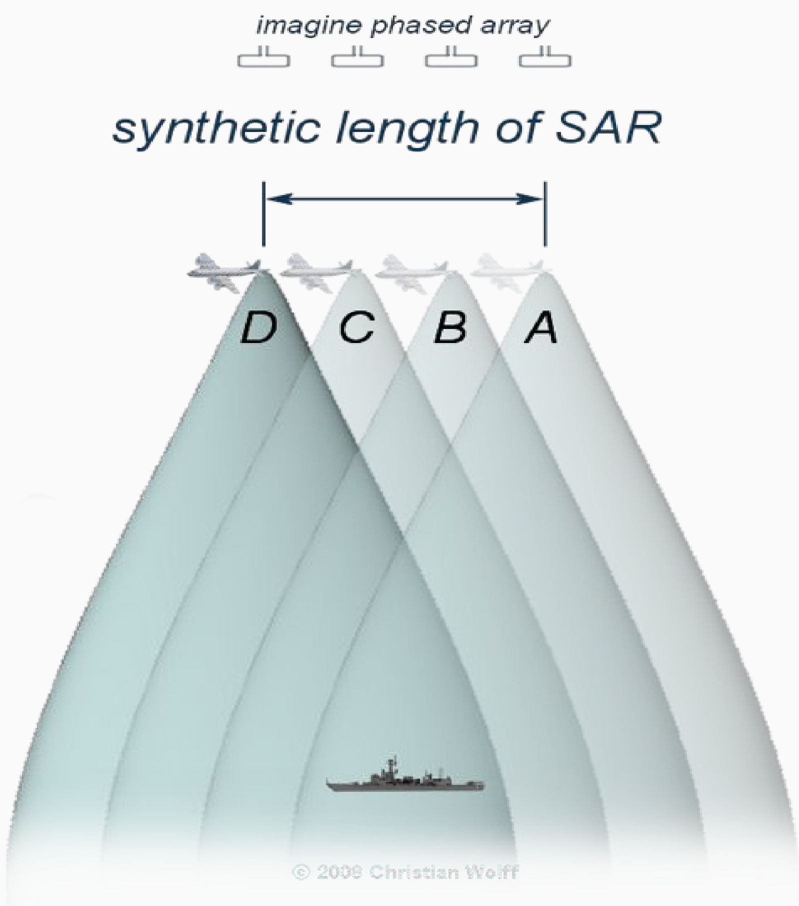
			
Computer Engineering Project Manager	**Electrical Engineering**	**Electrical Engineering**	**Computer Engineering**

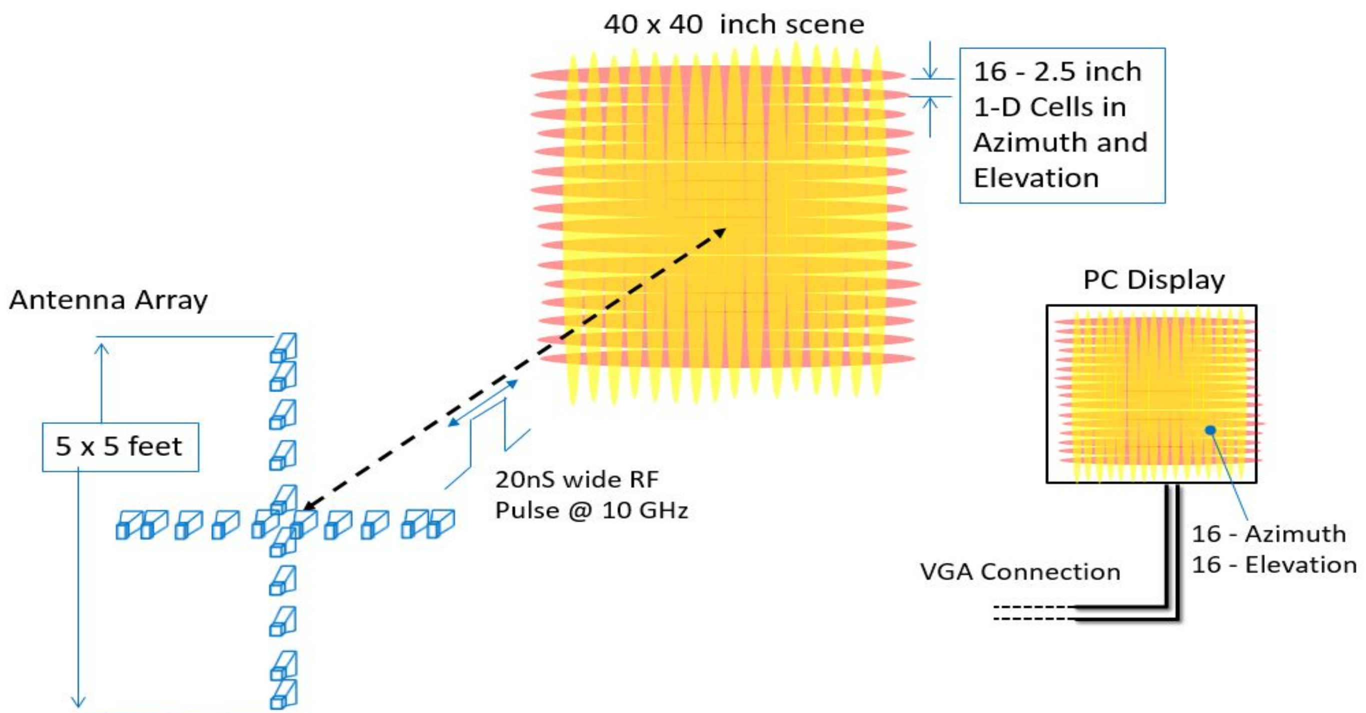
Synthetic Aperture Radar (SAR)

- SAR is a radar system that is commonly on board a moving aircraft (or other far-field application), the system typically consists of a single antenna mounted to a moving object that transmits and receives multiple signals to form an image.

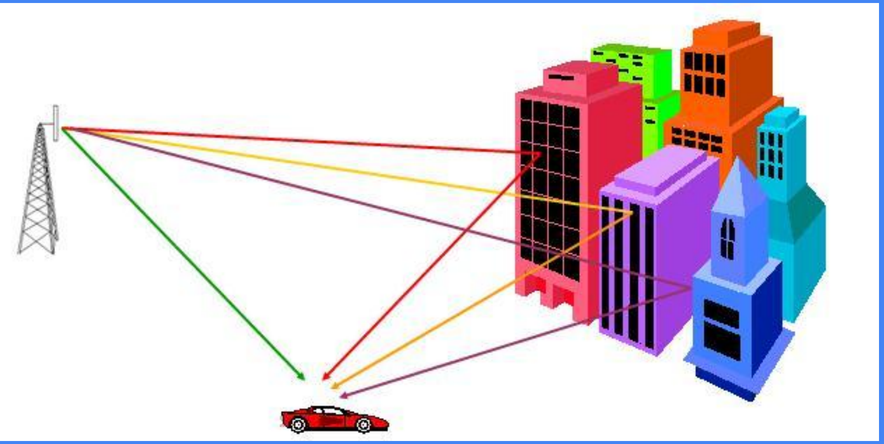


Project Scope

Our SAR Imager is intended to detect metal weapons from a distance. Rather than using a single antenna and multiple signals, our design uses multiple antennas each propagating their own signal.



Problem Statement



When echo is emitted from radar transmitter, it bounces off objects in the surrounding area and is received by receiver.

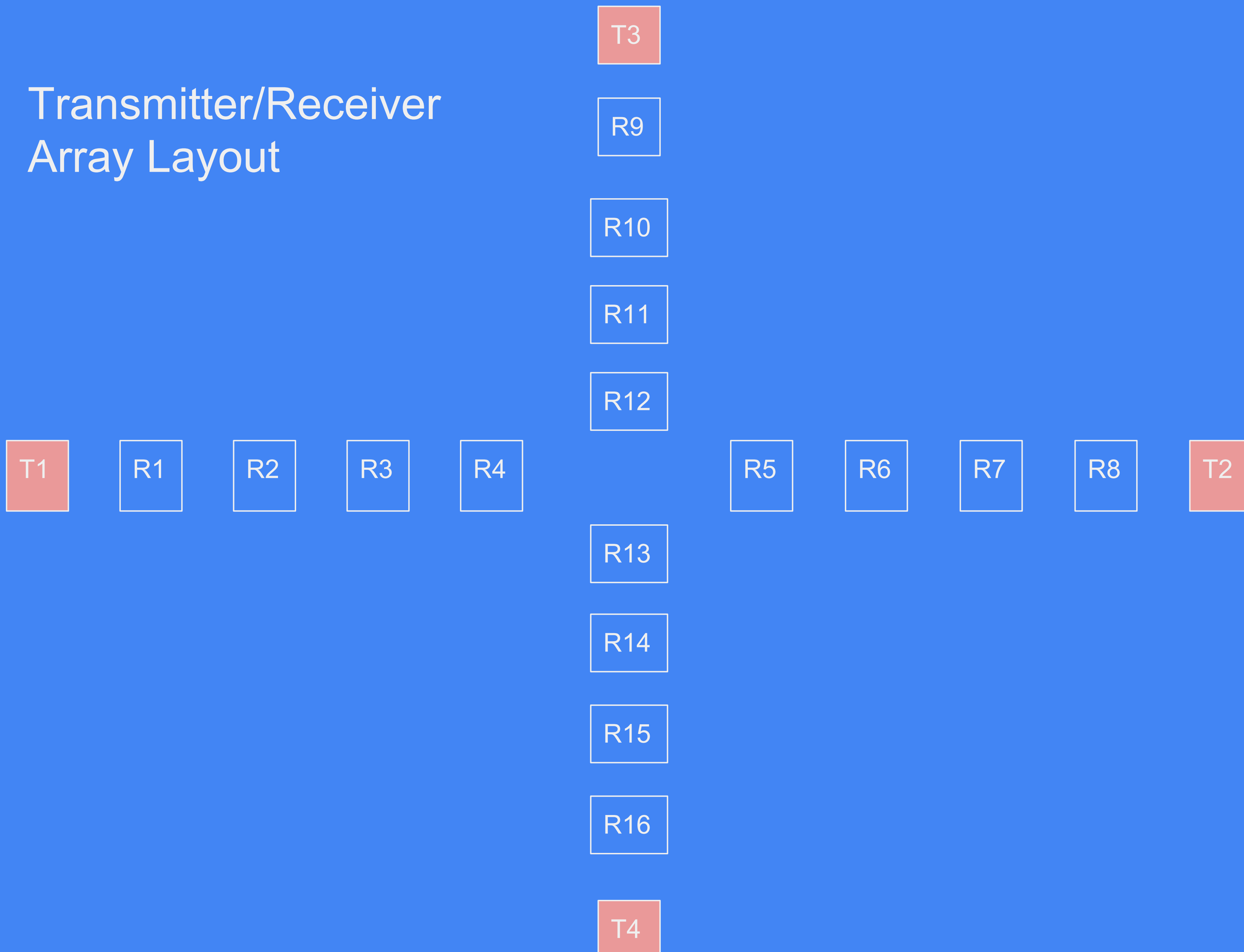
Main problem being the reflection off of the same metal object that are trying to be detected.

How is this problem detrimental to the project and how can it be resolved?

Previous Work

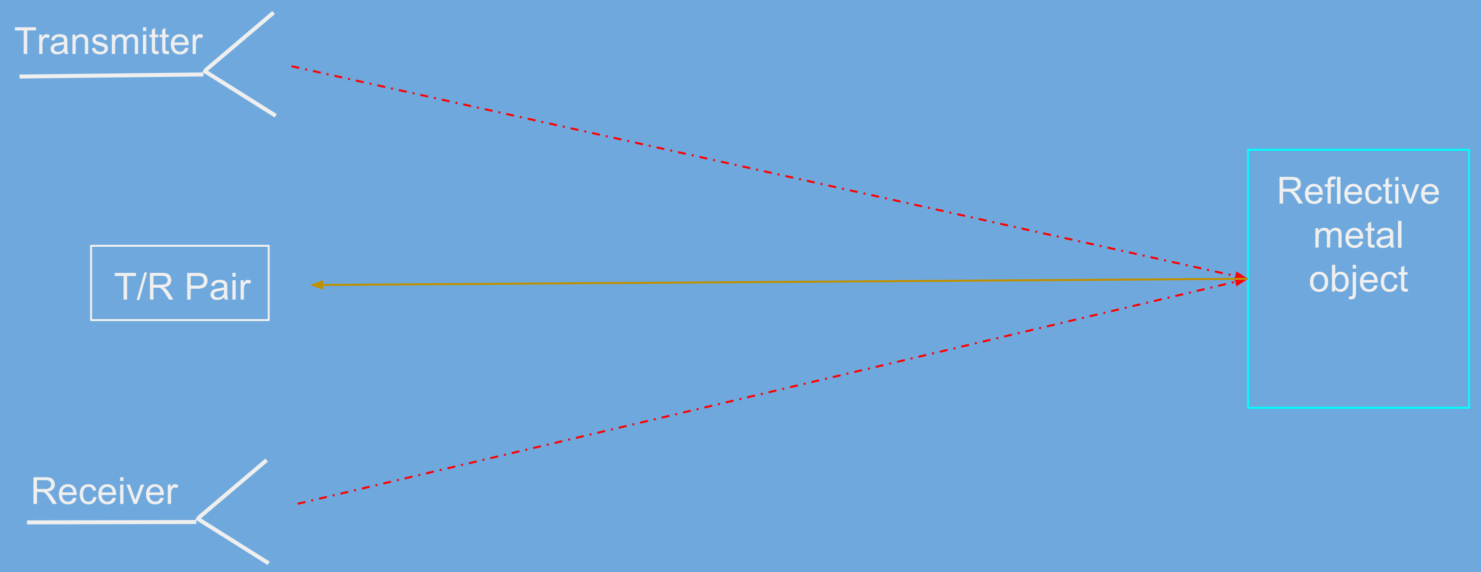
- Current Functionality
  - Radar successfully transmits / receives signals
    - 1.20 ns wide RF pulsed signal at 10 GHz
  - Structure has been improved for better mobility
    - New structure with wheels
    - Switched material from Steel → Aluminum for lighter weight
- New objectives
  - Minimize noise by integrating a feedback drain
    - Using switches
  - Create a successful emulation to validate theoretical basis
  - Create a target simulator for hardware troubleshooting

Transmitter/Receiver Array Layout

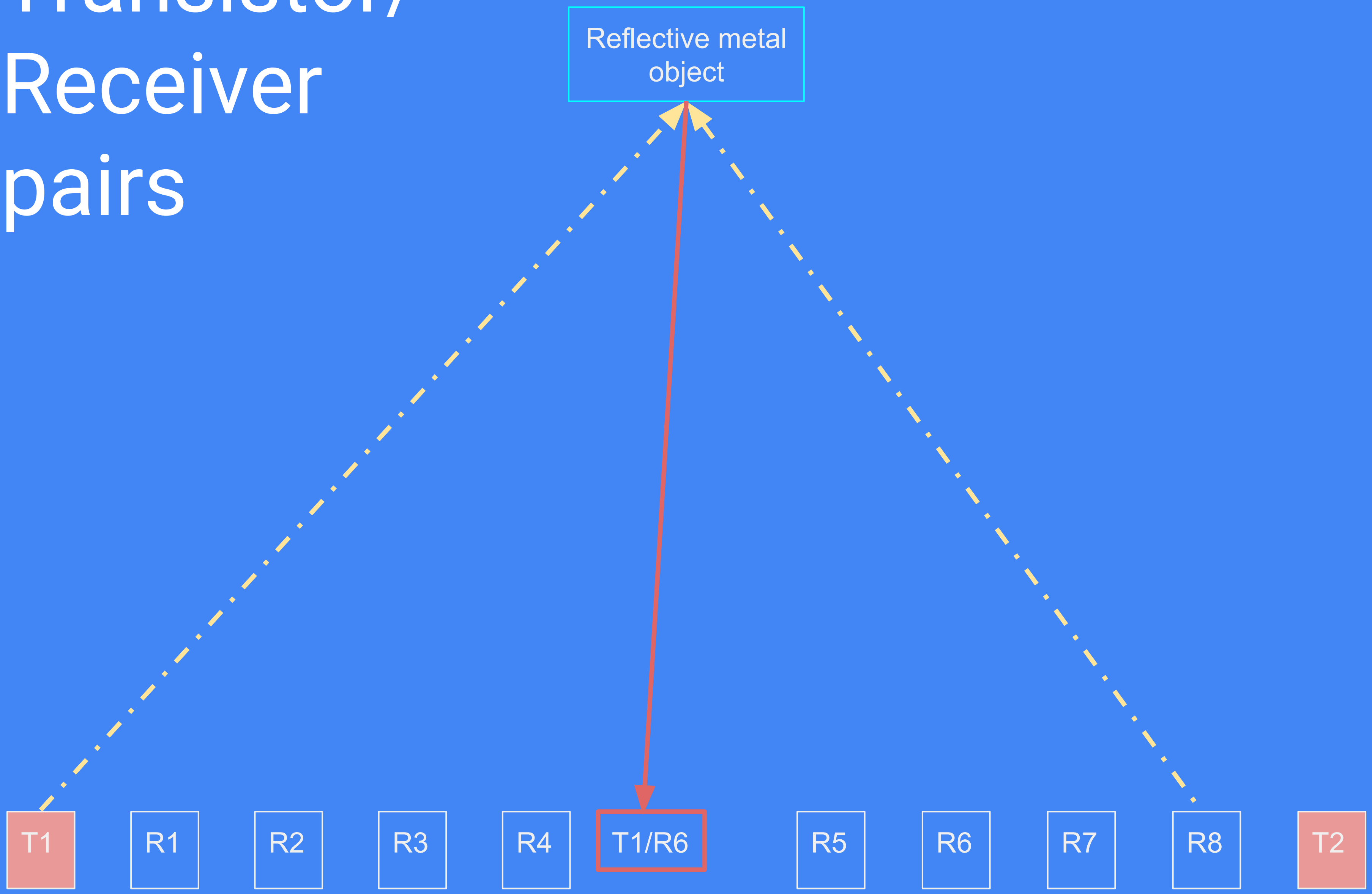


Phase Centers

- Each antenna pair is simulated by a transmitter and a receiver component, which create a "phase center"



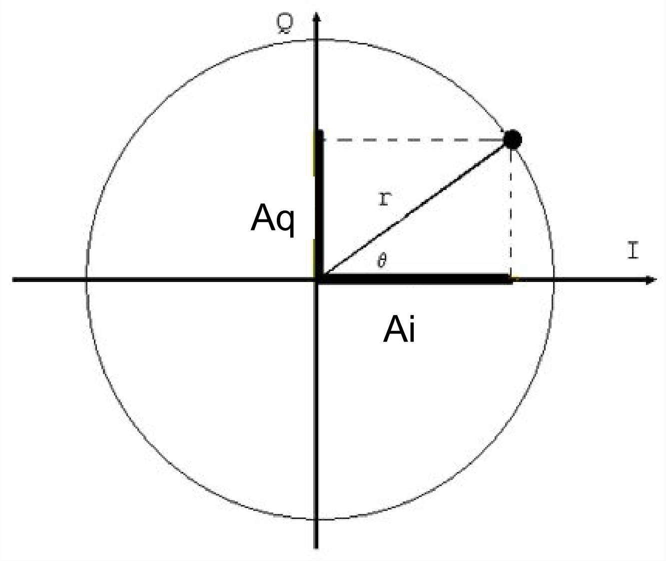
Transistor/ Receiver pairs



In-phase and Quadrature components of signal

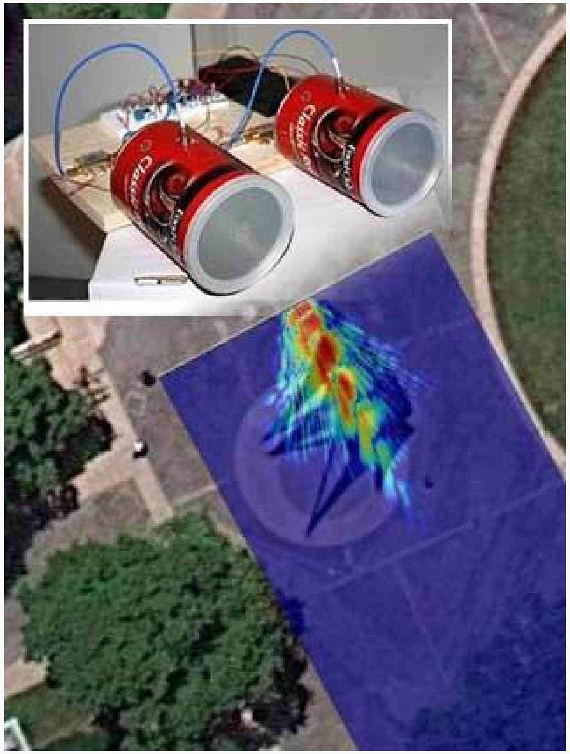
- Multiply signal with sine and cosine functions for amplitudes in Q and I
- The angle is relative to other transmitter and receiver pairs
- Corrected theta from the system center point can be found

$$tan^{-1}\left(\frac{Aq}{Ai}\right) = \theta$$



Idea for Noise Filtering:

Separate the tasks of detecting an object from denoting metallic properties



- Detecting an object using other forms of technology to describe an object's distance and denote its metallic properties based on the receiver's response in that direction.

- This way the signal received can distinguish the specific details from the signal it wants.

How to use the sensor?

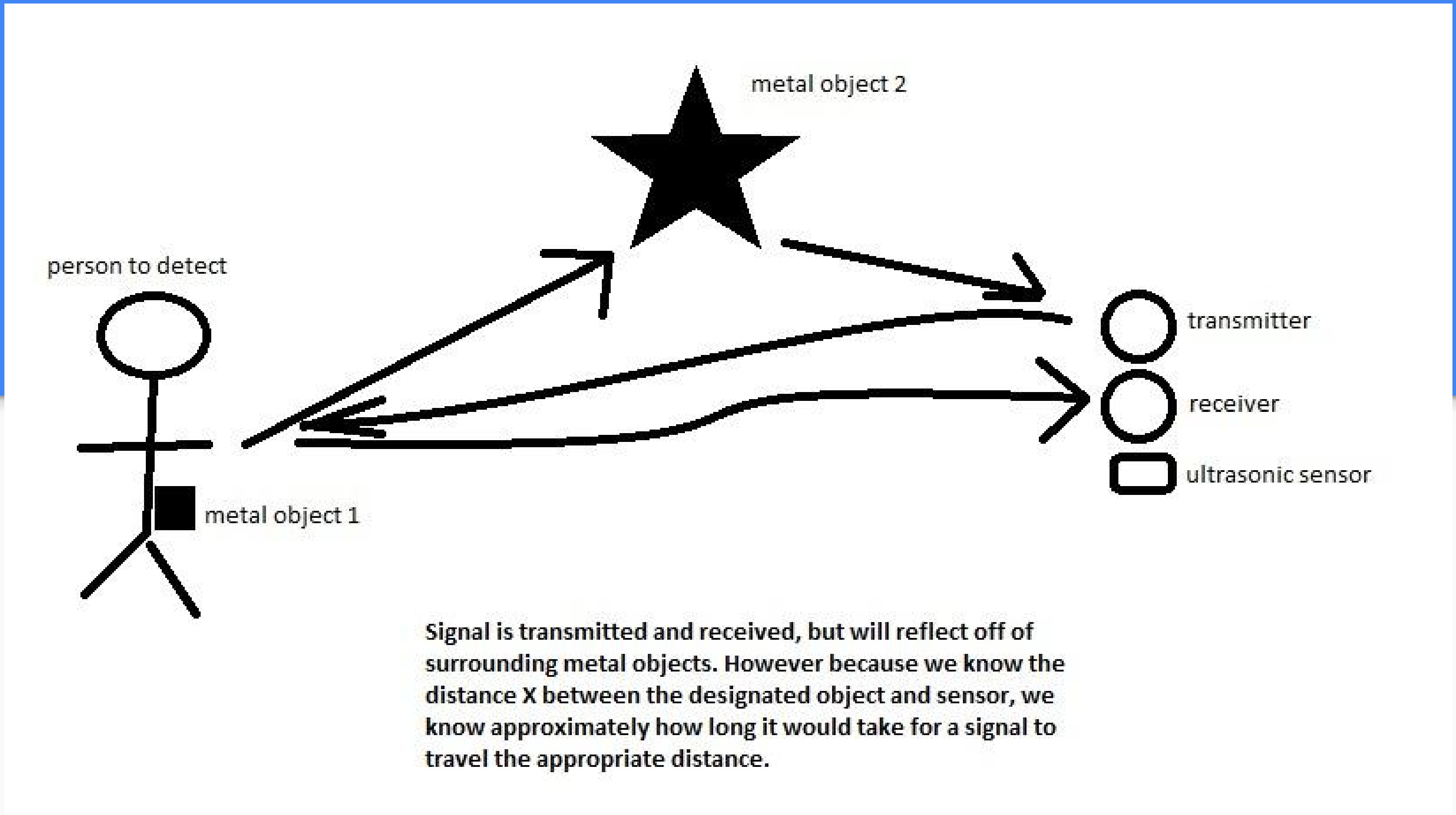
- If the sensor can clearly describe the distance between the radar and the designated object, proper filtering can handle the rest of the job.
- To do this some assumptions must be made:
  - Objects in the room are static or moving at a negligible speed so the doppler effect can be ignored.
  - For the sake of this project we assume there is a single target(person with or without detectable metal object) in front of a radar and separate sensor.
  - Although it is possible to use IR sensors to denote the distance of an object, ultrasonic sensors will be used for simplicity.

What is the purpose of the sensor?

- To differentiate frequencies received by one object and another, we use the static object assumption which leads to the possibility of only a minor frequency returned from any objects that reflect thi transmitted electromagnetic wave.
- If we multiplex the outgoing signal as a function of time, we can use the received signal at time t_n and filter out other signals that would have been transmitted at separate times and reflected off of surrounding metallic objects.
- If distance can be detected using an ultrasonic sensor, we can then know at what distance is the object ahead, and use distance as a function of time to determine what time a suspected frequency should return.

Use of an ultrasonic sensor:

- Ultrasonic sensor can be any generic Ultrasonic Distance Sensor such as the HC-SR04.
- The sensor can detect reflected sound waves and calculate the appropriate distance by multiplying the time taken for the signal to be transmitted by the speed of sound.



A frequency transmitted and received will be the same for the person as from the metal object. However, knowing the distance allows you to know which signal you are looking for.

Holes in this Design

1. A transmitted signal may negate an incoming signal.
2. To calculate the distance an object is from the radar in this model uses ultrasonic waves. Depending on the layout of the area where the radar is located there could be redundancies and complications in the system.
3. Speed being used to measure is so quick that the difference in depth is impossible to calculate

Option for Expansion-Machine Learning

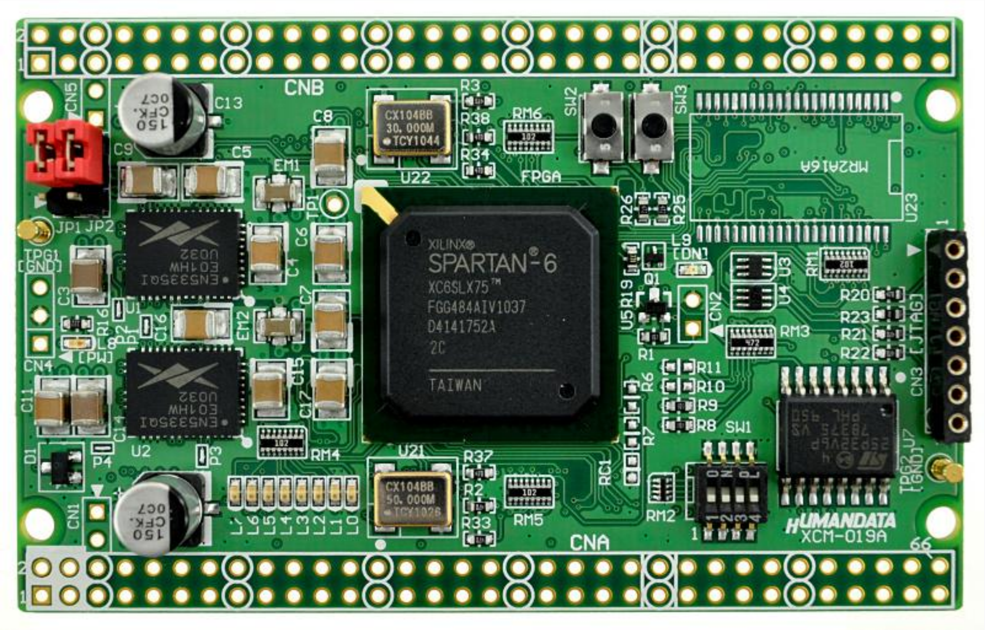
- Implement with a lookup table in the FPGA that would process the signals in real time to develop a real time filter for received phase values.
- Weights for Neural Network filter to be determined outside of runtime using simulation and emulation.
    - Another filtering possible error calculations in the horns

Possible use of Motion Sensor

- Phase determines where the detected object is within a 360° range.
  - If an object is outside at 360 degrees, its location can be interpreted as 0°, and the data can therefore be skewed.
- Use a motion sensor to determine if an object is outside of 360°.

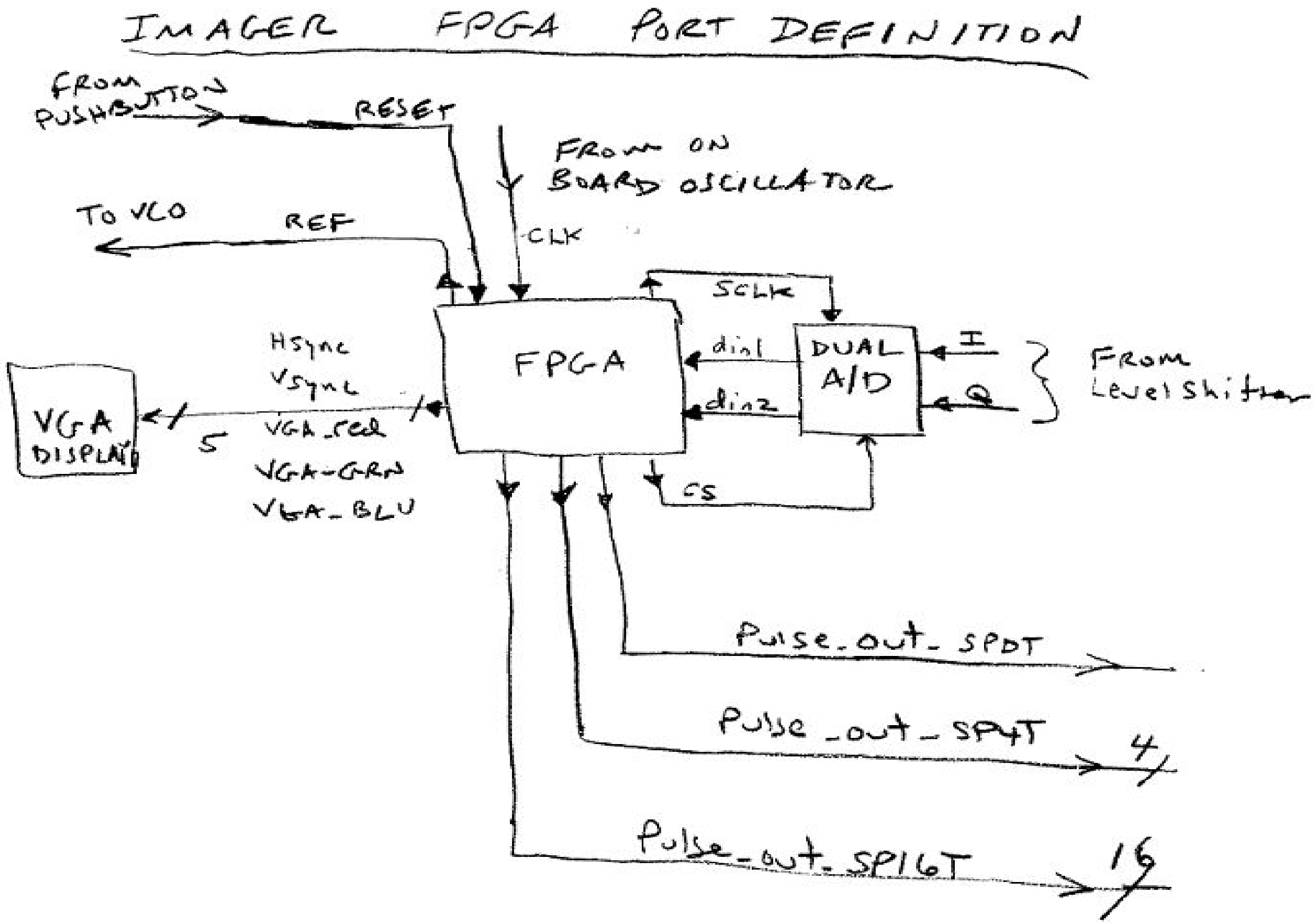
Why Spartan 6

- Speed
  - A standard CPU can't perform the operations with the speed we can get from an FPGA
- I/O capability
  - Although Cyclone 2 does have enough options, Spartan 6 I/O are better quantified and therefore easier to use.
- Past years have used Spartan 6 in design



FPGA Tasks

- A to D conversion and storage of values in memory
- Math Computations inside the FPGA with values stored in memory
- Timing discrete generation that switches the RF path between transmit and receive phase centers.
- Generate a fast pulse signal through VHDC connection
- Displaying math computation results real time on the VGA display.


IMAGER FPGA PORT DEFINITION
FROM PUSHBUTTON
RESET
FROM ON BOARD OSCILLATOR
CLK
TO VCO
REF
SCLK
FPGA
din1
din2
DUAL A/D
I
Q
FROM Level Shifter
Hsync
Vsync
VGA_red
VGA-GRN
VGA_BLU
VGA DISPLAY
5
CS
Pulse_out_SPDT
Pulse_out_SP4T
4
Pulse_out_SP16T
16

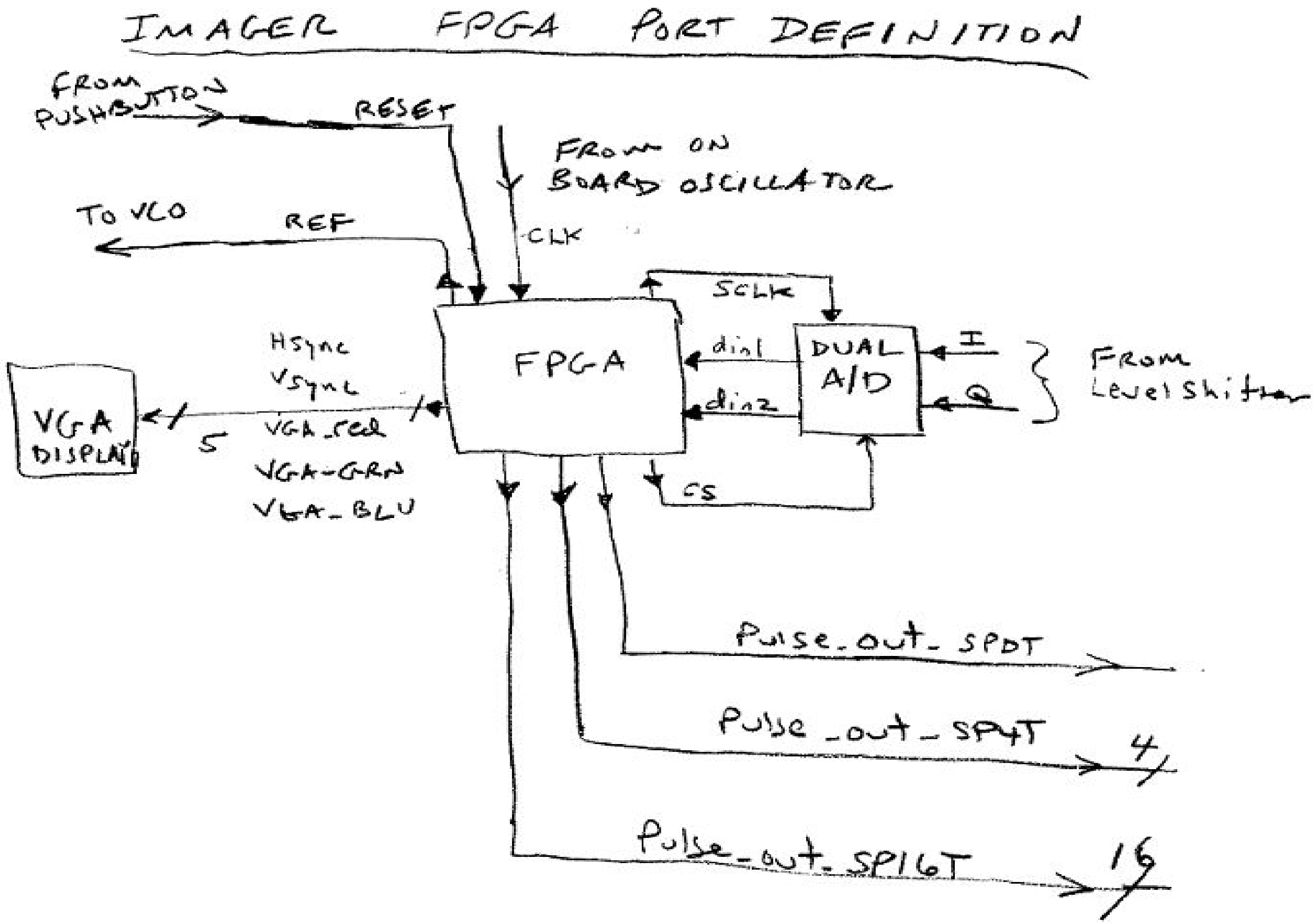
Math Computations

Using the 4 Digital Signals from ADC: I, I’, Q, Q’

- Perform a complex multiply where
  - Real Part = (IxQ) + (I’xQ’)
  - Imaginary Part = (IxQ’)+(I’xQ)
- Do this for each receiver (16 times)
- Square the sum of the real and imaginary parts(M) for each receiver.
- Convert to db using the equation:
  - 20*Log(Sqrt(M))

Pulse Generation

- Generate a 50 MHz pulse
- Switch between Transmit/Receive cycles on rising clock edge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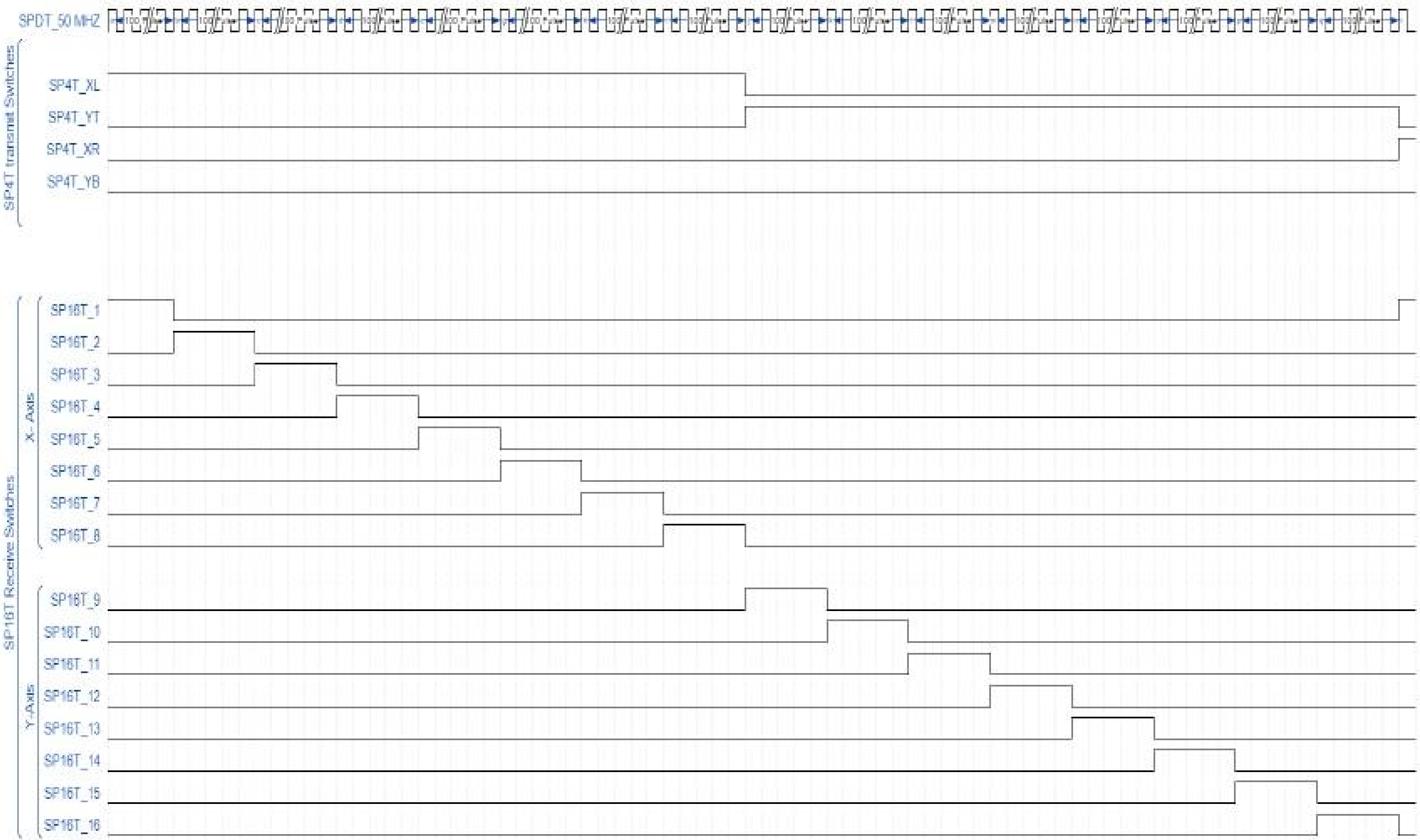
VGA-GRN
VGA_BLU
5
VGA DISPLAY
CS
Pulse_out_SPDT
Pulse_out_SP4T
4
Pulse_out_SP16T
16

System Timing Diagram

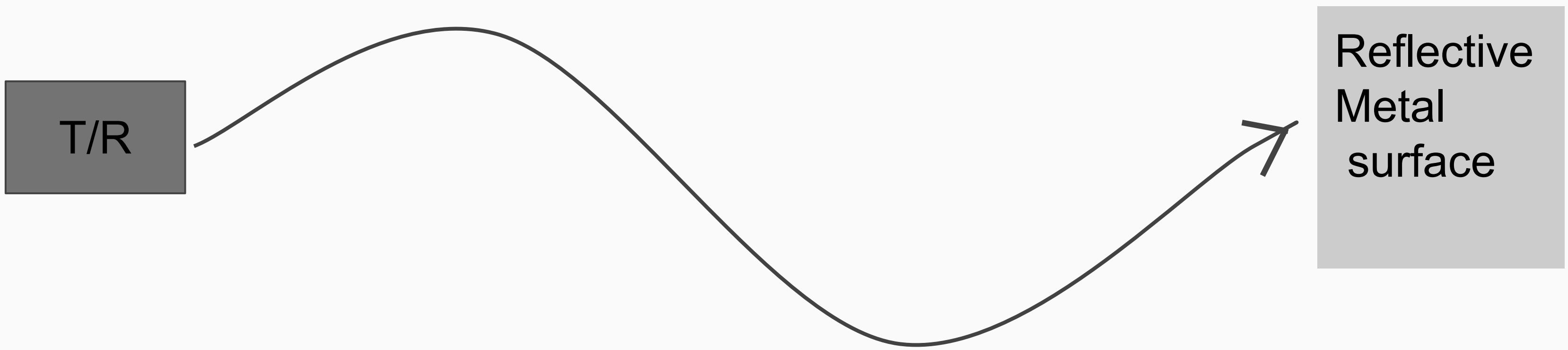


Fast TR Pulse Design

- Designing a circuit that level shifts the output of the FPGA to 0 to5 V
- This ensures 20 nS pulse is properly accommodated
- Maintain pulse fidelity
- Use of MOSFET for fast switching

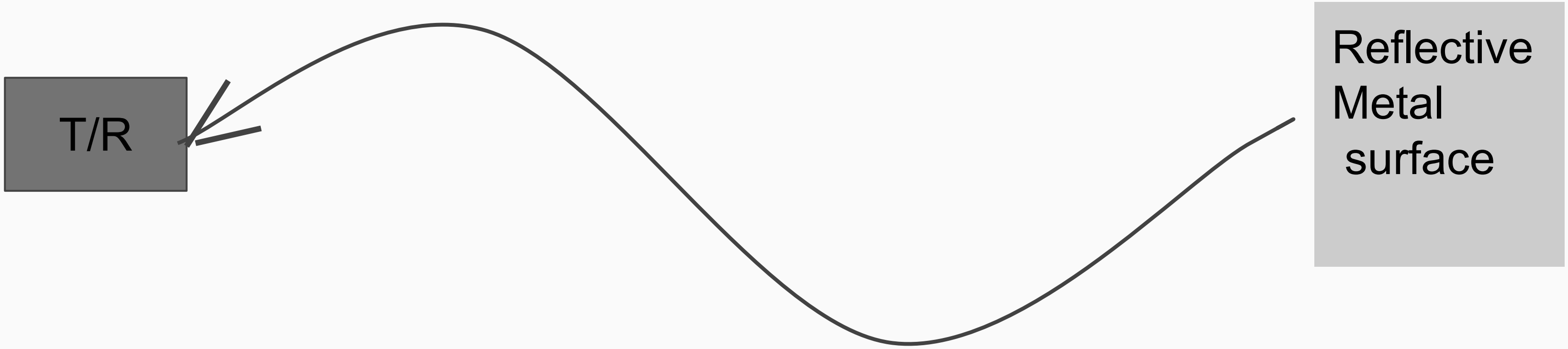
Traveling Wave Signal in Spatial Domain

- Signal will be 20 feet in spatial domain
- Image at t = 20 nS



Traveling Wave Signal in Spatial Domain

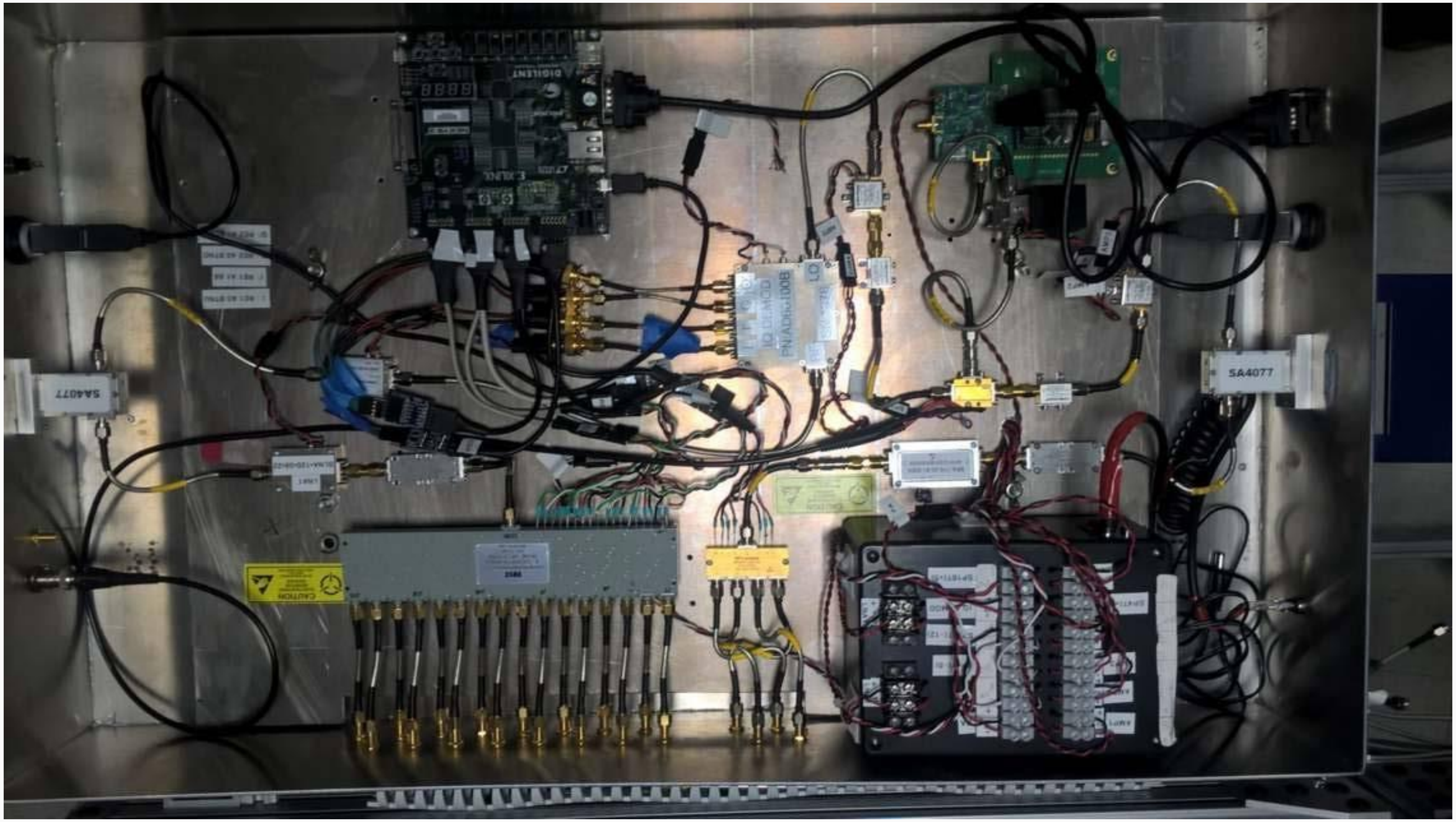
- Image at t = 40 nS



VGA Display

- 16 blocks wide
- Using db values from FPGA
  - Based on the response, area of the display will be lit to denote that what is in front of the screen in that area is carrying a metal object.
- The phase of the signal that is returned can determine the angle an object is away from boresight.

Current Design



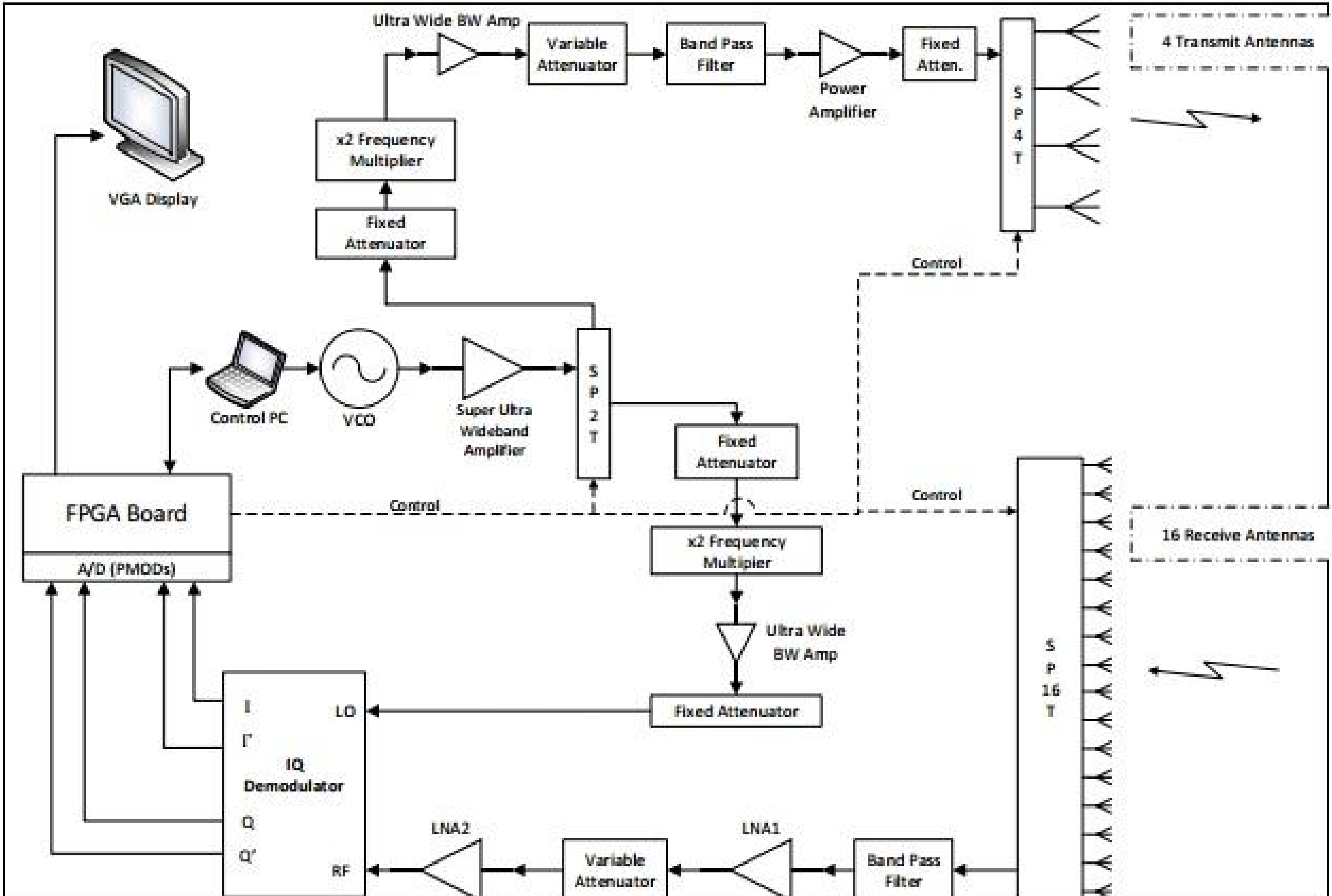
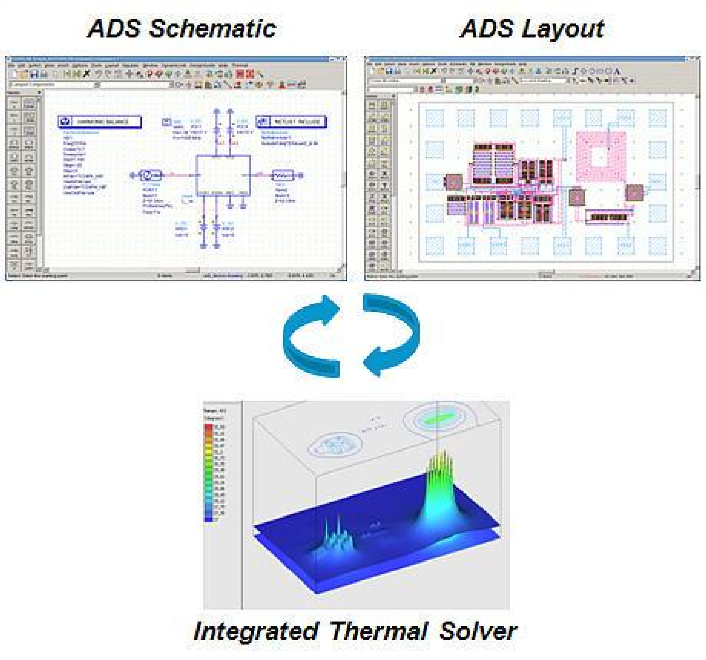


Figure 1.2 : Top-down block diagram

ADS

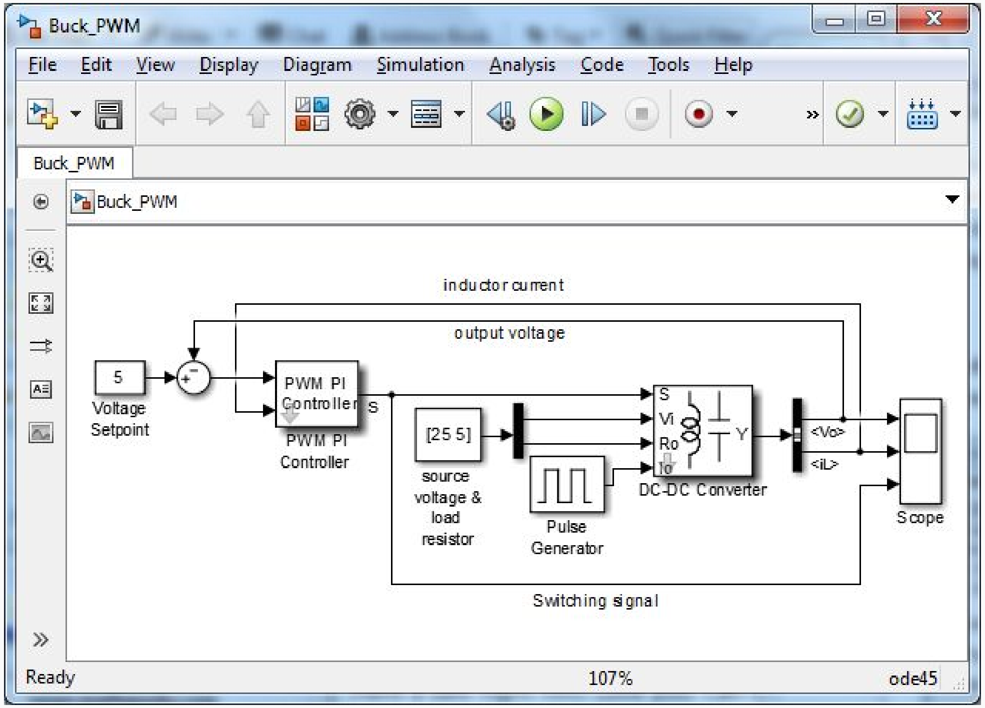
- Used for building layouts, and producing time, frequency, and electromagnetic field simulations.

- Will use ADS to simulate entire system to analyze the RF performance
  - Transmit path
  - LO path
  - Receive path



Simulink

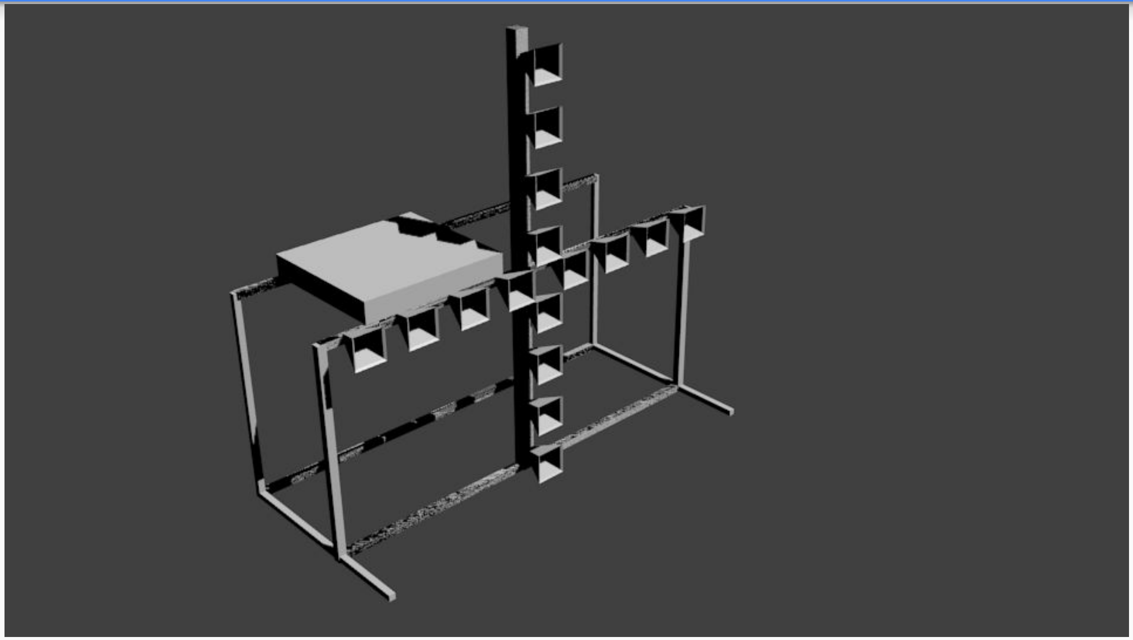
- Extension of MATLAB commonly used in DSP for multidomain simulation
- Will use Simulink to model
  - Pulse modulation
  - Baseband pulse modulation characteristics



Why Emulation?

- Theoretically, the design should work. Should the electronic design in previous years not work, or a component of the system need adjustment, the emulation will show which component needs calibration.

Other Objectives



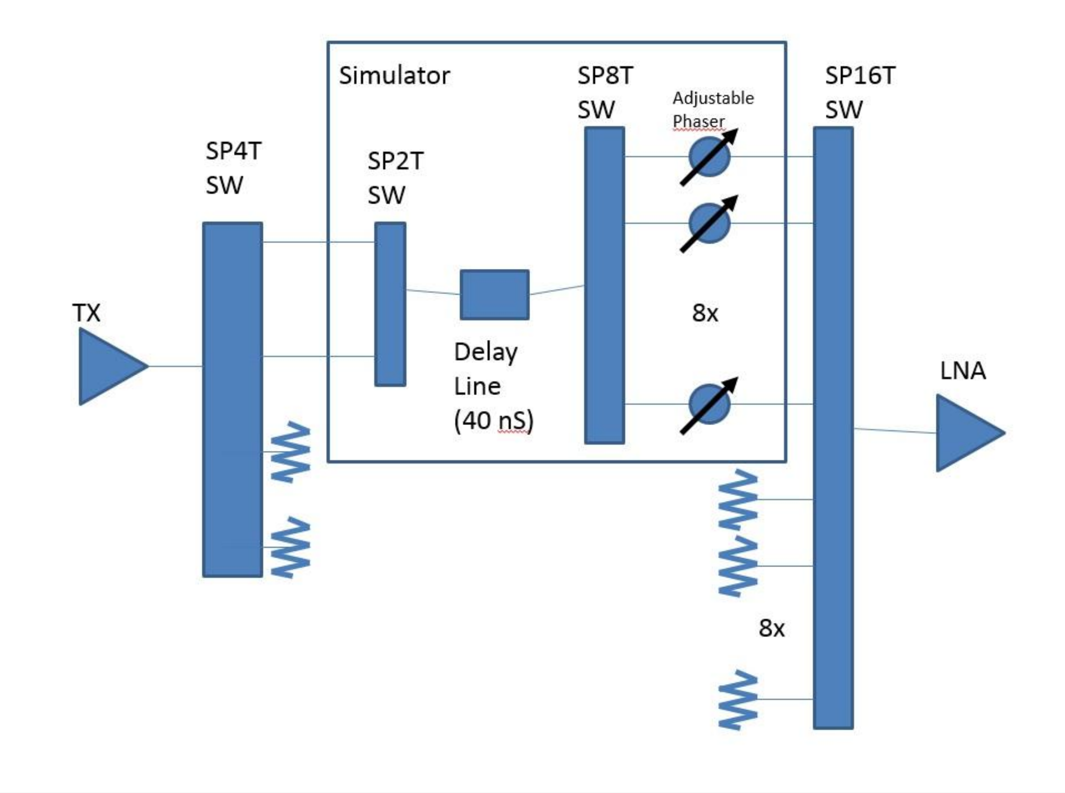
- Software simulation the performance of the mechanism as a whole.
- Simulation will be performed using CUDA for computation of wave behavior and OpenGL for visual rendering.

OpenGL Emulation

- Goals are to understand the absolute behavior of the design, and to be able to simulate it in an environment (wave based simulation similar to agilent simulations) where any user can see the project's objectives.
  - Simulate circumstances such as different metal objects entering and leaving the area in front of the SAR.
  - Shaders and kernel functions used for hardware performance.
- The idea is to show anyone how the project is supposed to determine where an object is and how the phase domain is used to approximate the location of an object.
- Also, won't cost any money!

Test Bench, Emulation

- Emulate the pulse timing.
- The reason for this expensive investment, is to make sure that the hardware in the circuit does the same thing that.



Budget

Vendor	Desc	P/N	Qty	$ each
Fairview Microwave	Phase Trimmer	SMP 2046	4	$110.00
Fairview Microwave	Phase Trimmer	SMP2018	6	$190.00
DOW	SP8T Switch	Quote pending	1	$960.00
DOW	SP2T Switch	Quote pending	1	$519.00
Minicircuits	20 dB Atten	FW-204	25	$18.95
	MOSFET	Si1553cdl	5	$ 25.00
	MOSFET Board	SC70-6	5	$ 25.00
Analog Devices	Spare TR Switch	HMC-C011	1	$ 1,800.00
			TOTAL	$ 6,082.75

Questions?

Budget

About $6,100

- Switch to drain the signal from the receiver:
  - High performance switch with proper capability is 1800
- Rest of the budget goes into Test Bench Emulation
  - Switches were chosen based on compatibility to FPGAs
  - Accept coaxial inputs instead of regular pulses
  - Not many options available, but is a Low cost
  - $440.00
  - $1,140.00
  - $960.00
  - $519.00
  - $473.75
  - $125.00
  - $125.00
  - $1,800.00
  - $ 500.00
  - $6,082.75