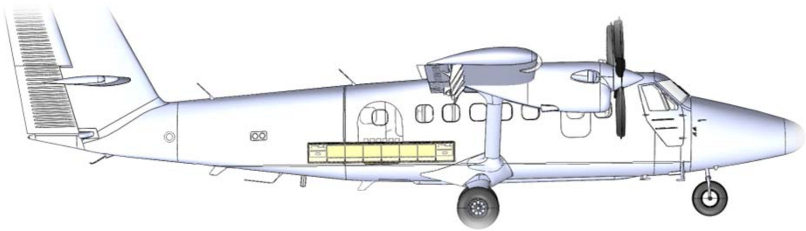
Airborne Radar Testbed Radio Frequency Calibration: WPI MQP 2016



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WPI

Presentation Outline

- **Presentation Outline**
- **Problem Statement**
- **Design**
- **Verification Results**
- **Experimental Results**
- **Conclusion**

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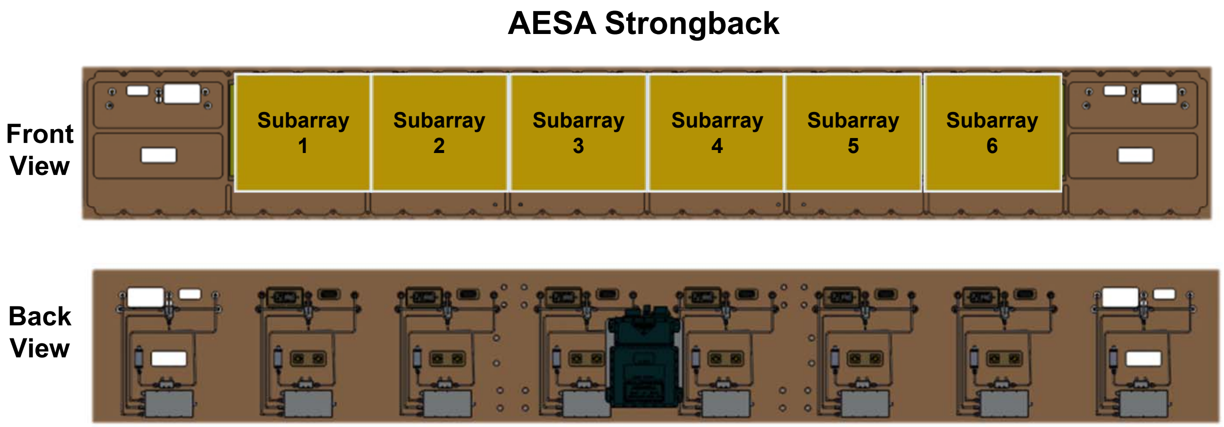
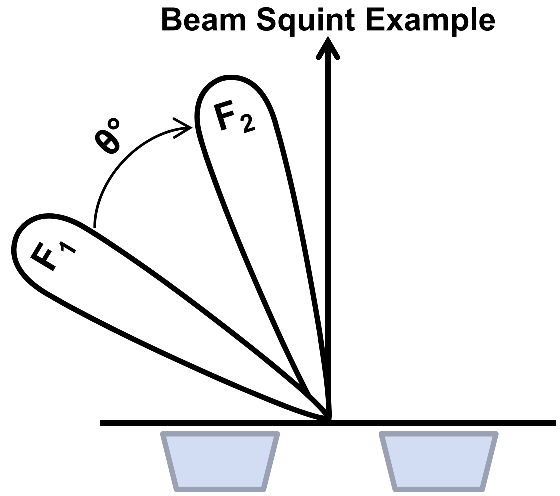
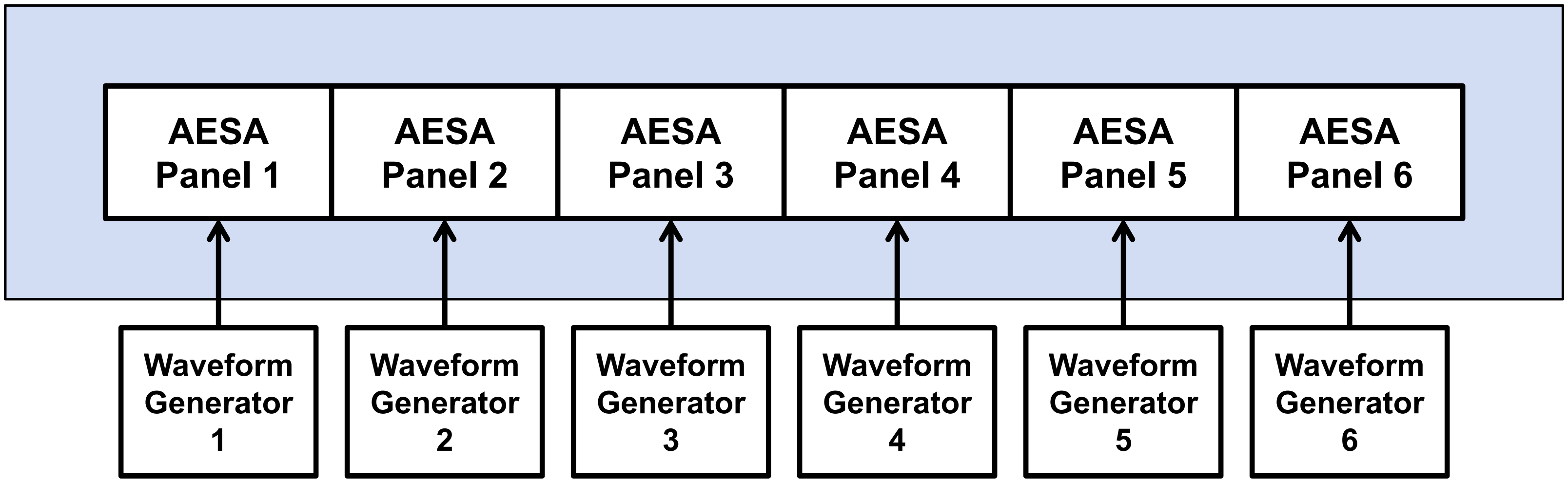
Background:
Active Electronically Scanned Arrays



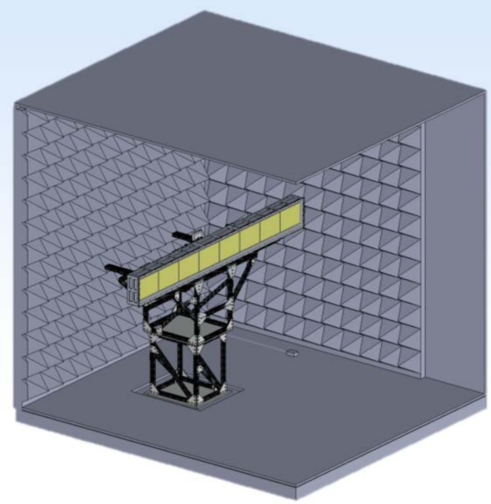


- **AESA's** utilize **phase shifters** for beam steering as opposed to **time delay circuits**
  - More appealing: size, complexity, cost
  - Side effect: **beam squint**
- The antenna system is divided into a series of **sub-arrays**
  - Each sub-array driven with a **unique RF waveform generator** allows for **time delay beam steering**

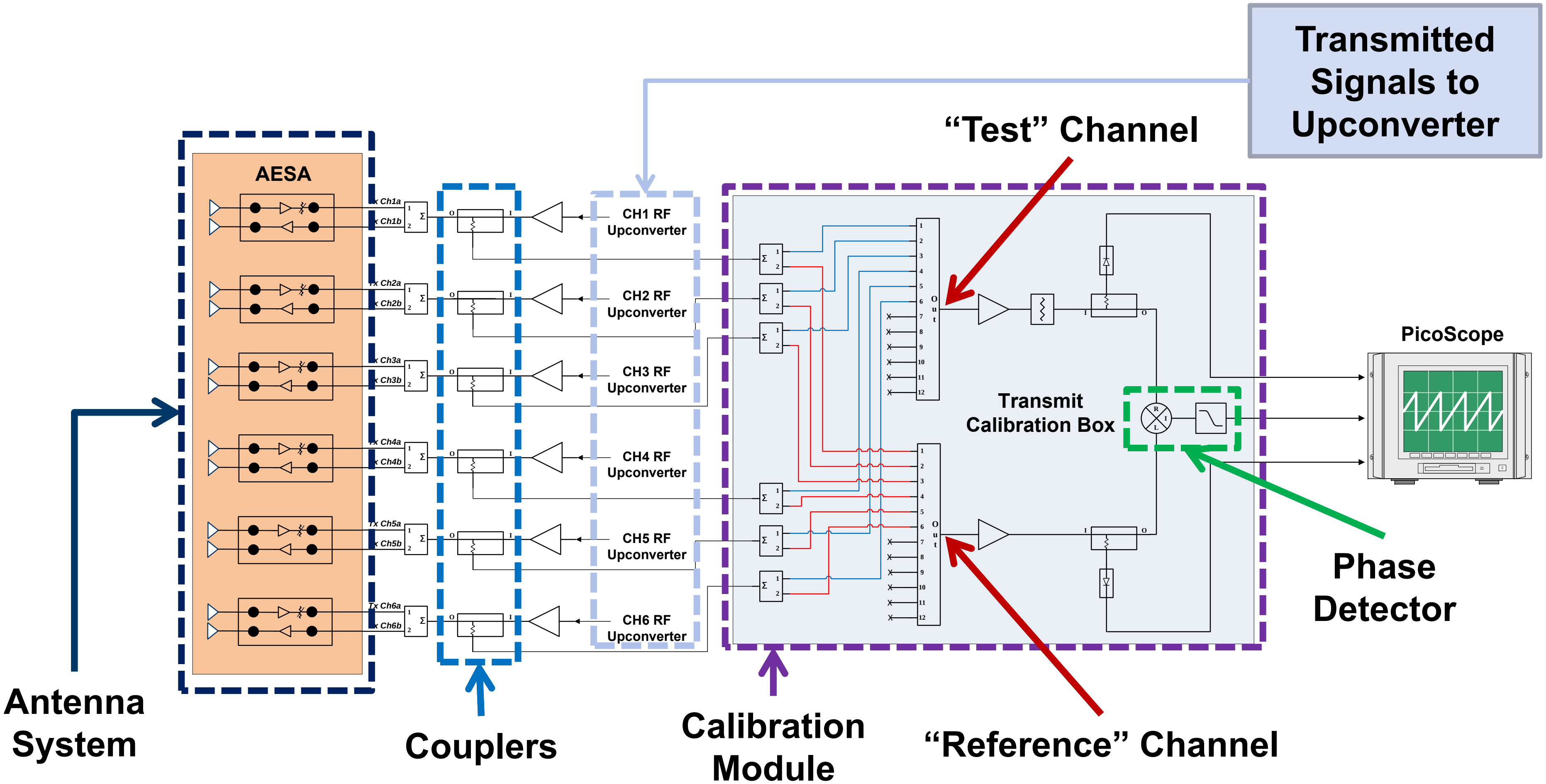
Phase Stability & Calibration Concern



- Realize the **effective time offset** between channels
- Achieve a **known phase** at the input to the sub-arrays

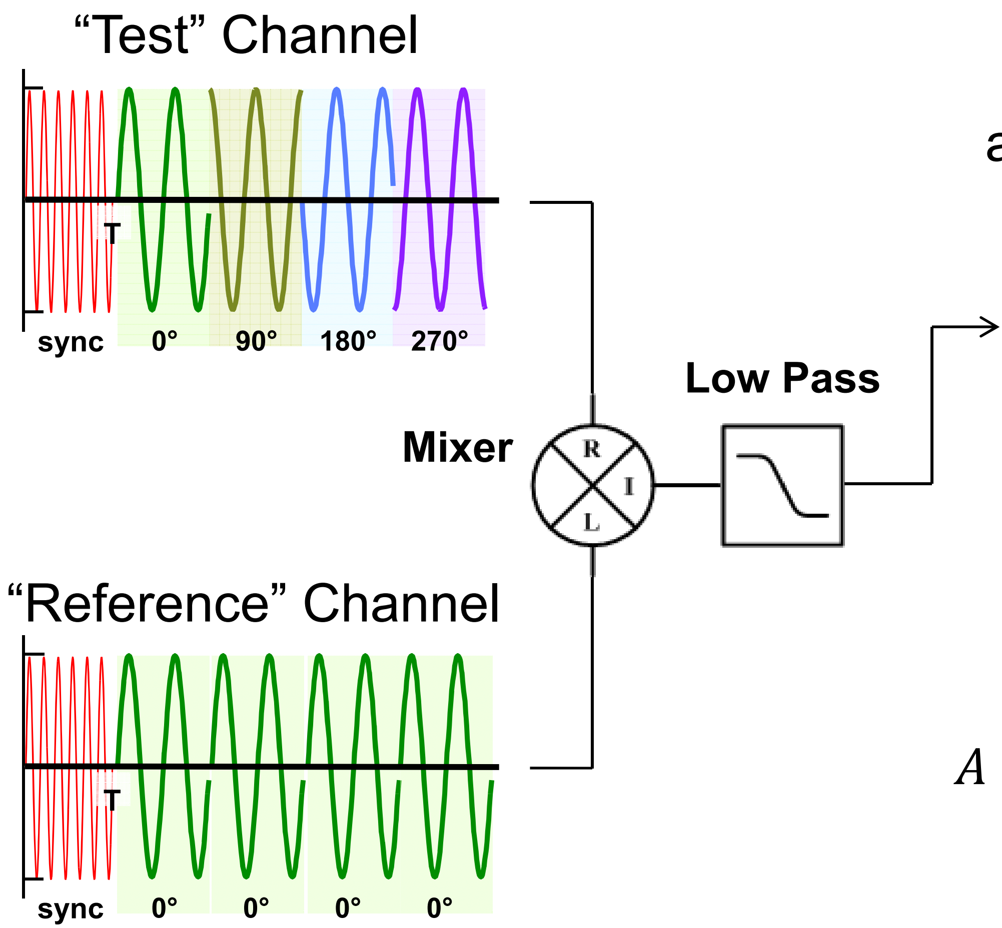


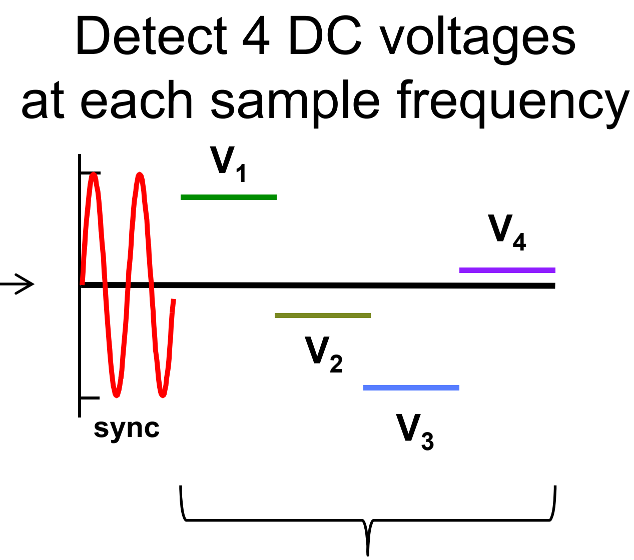
Calibration Module
Detail



Concern: How consistent and accurate is the calibration system?
Goal: Characterize the calibration system under operational conditions

How calibration works
Detecting amplitude and phase





$$A = \frac{1}{2}\sqrt{(V_3 - V_1)^2 + (V_4 - V_2)^2}$$

$$\phi = \tan^{-1}\frac{V_4 - V_2}{V_1 - V_3}$$

Source: Jerry Benitz

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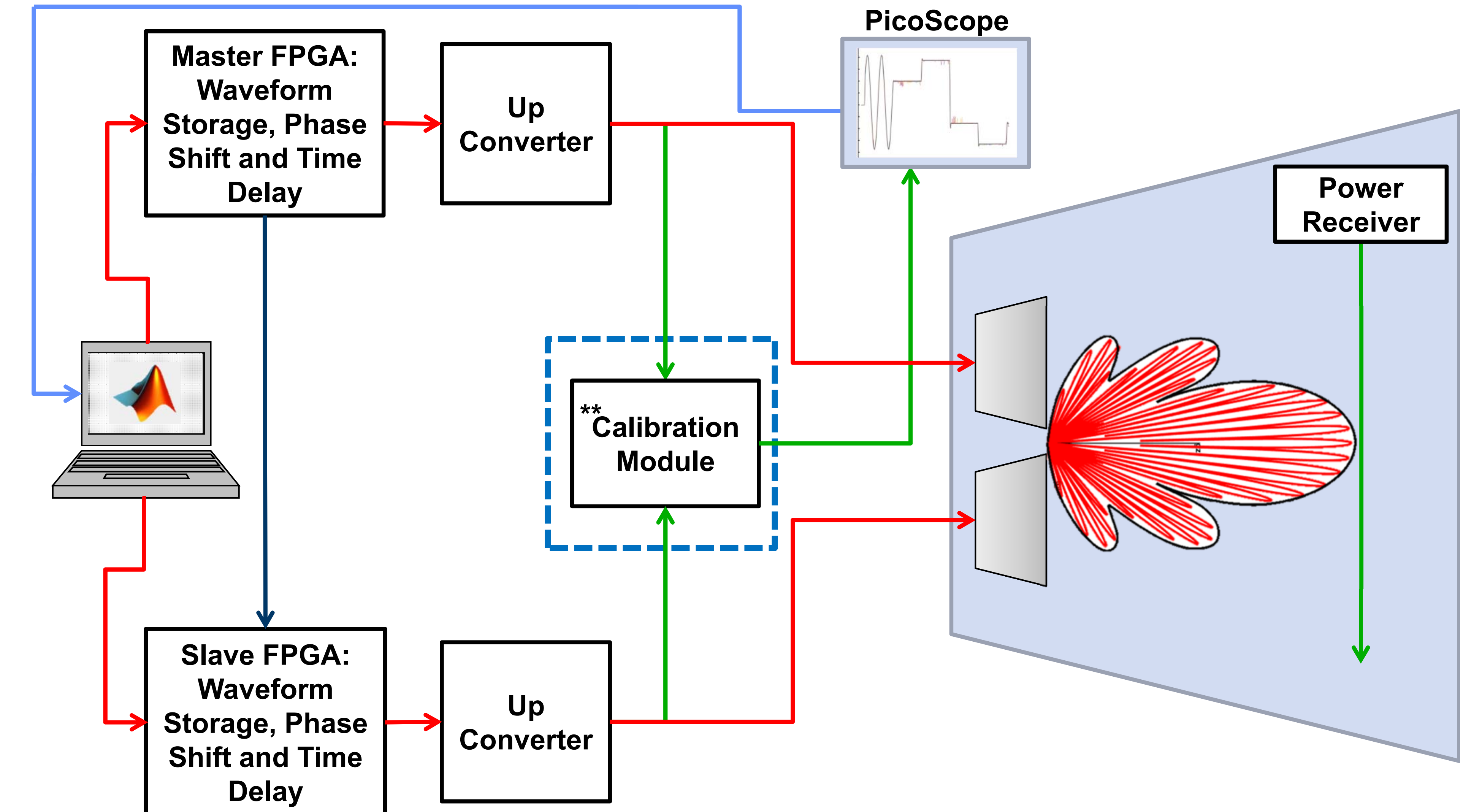
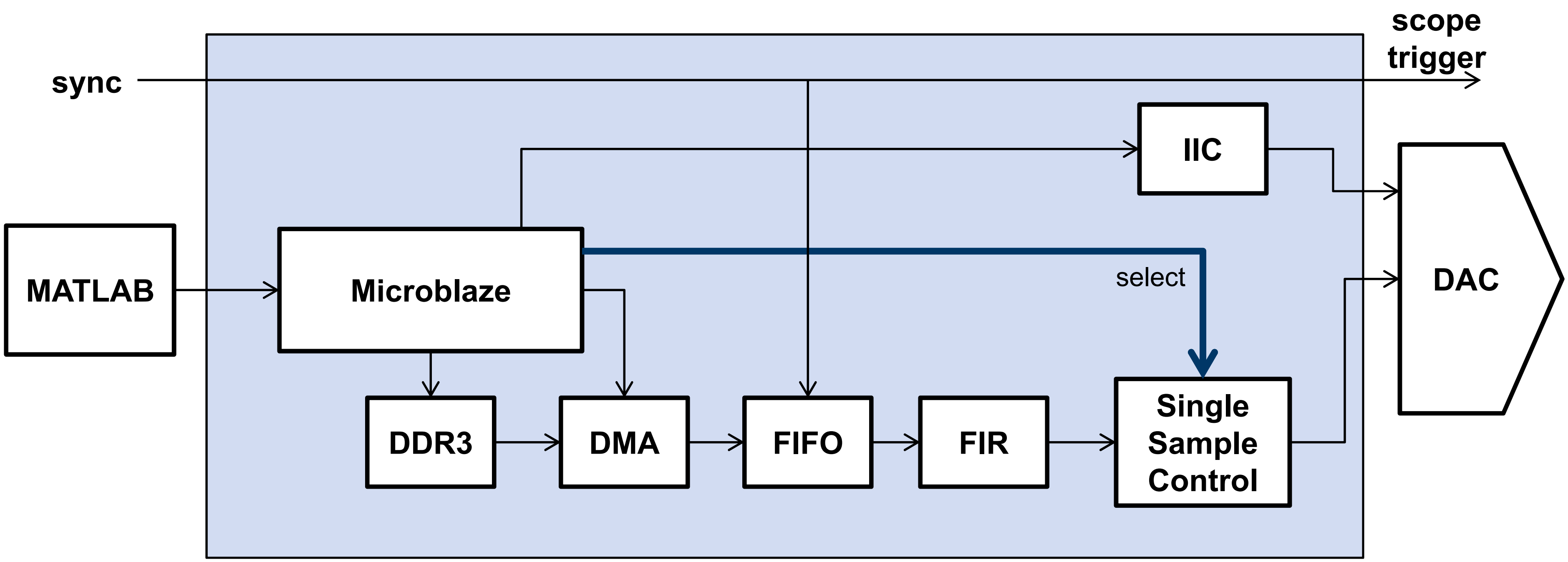
Test System: High Level Diagram



** ----- Device Under Test (DUT)

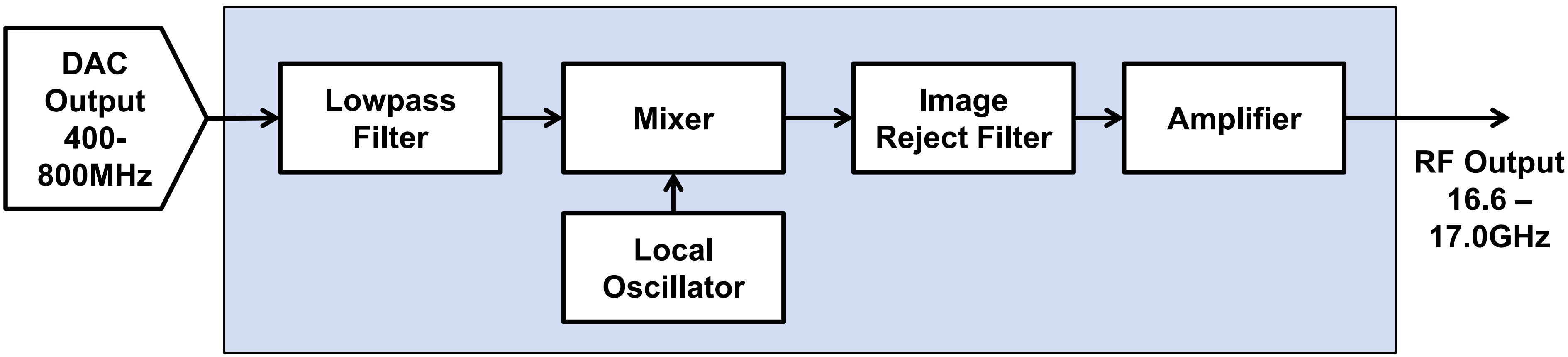
FPGA Design Overview for Both FPGAs



- **Synchronized** transmission between multiple waveform generators
- **Time delay** for subsample resolution and continuous **phase control**
- **Single sample control** given DAC sampling frequency of 2.8 Gsps

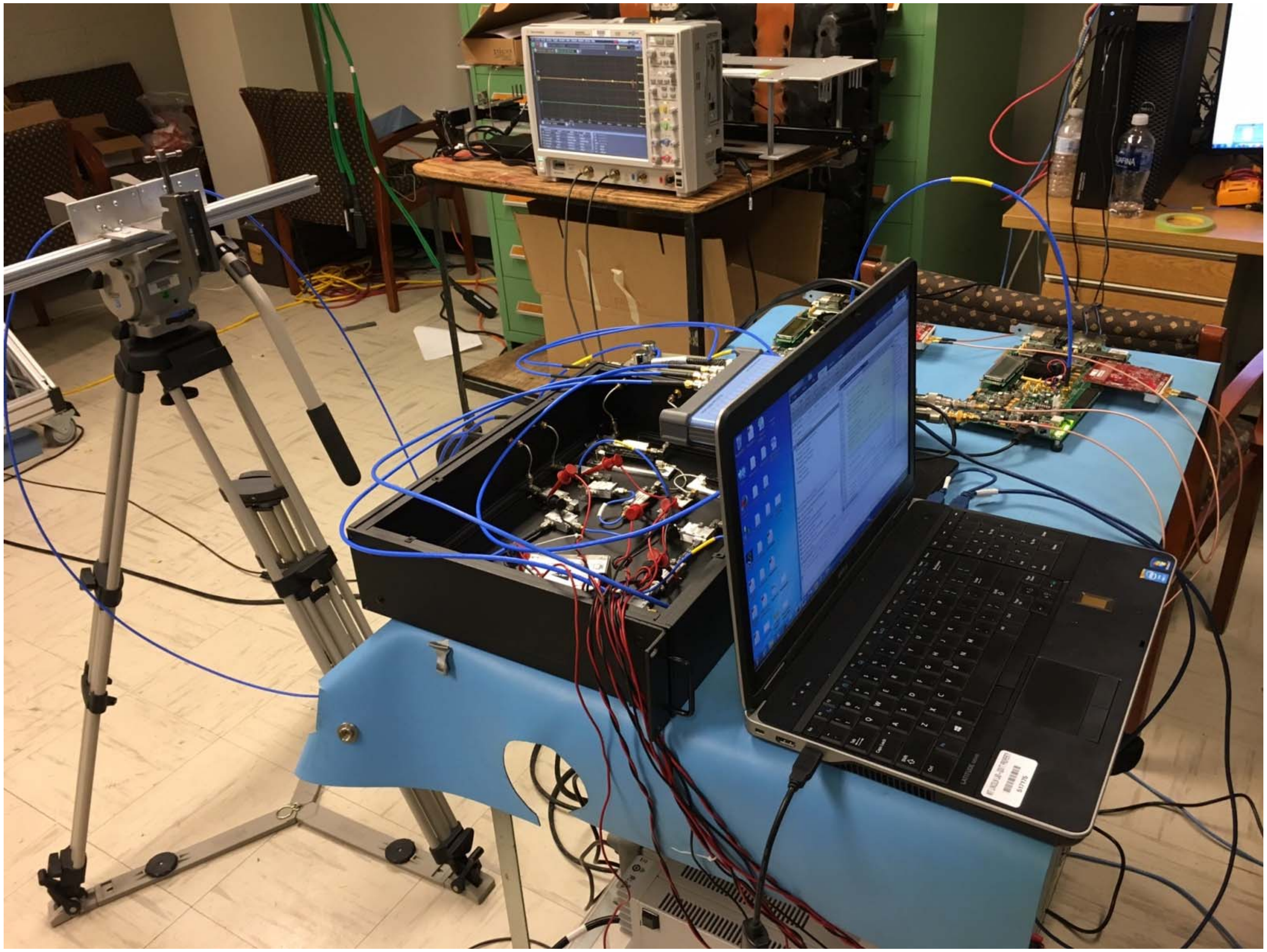
RF Design: Upconversion

Purpose: Convert from intermediate frequency to Ku band RF output



- **Solution** because actual upconversion hardware was not ready
- **Range:** 400-800 MHz to 16.6-17.0 GHz
- **Test Frequency:** 700 MHz --> 16.7 GHz

Final Product



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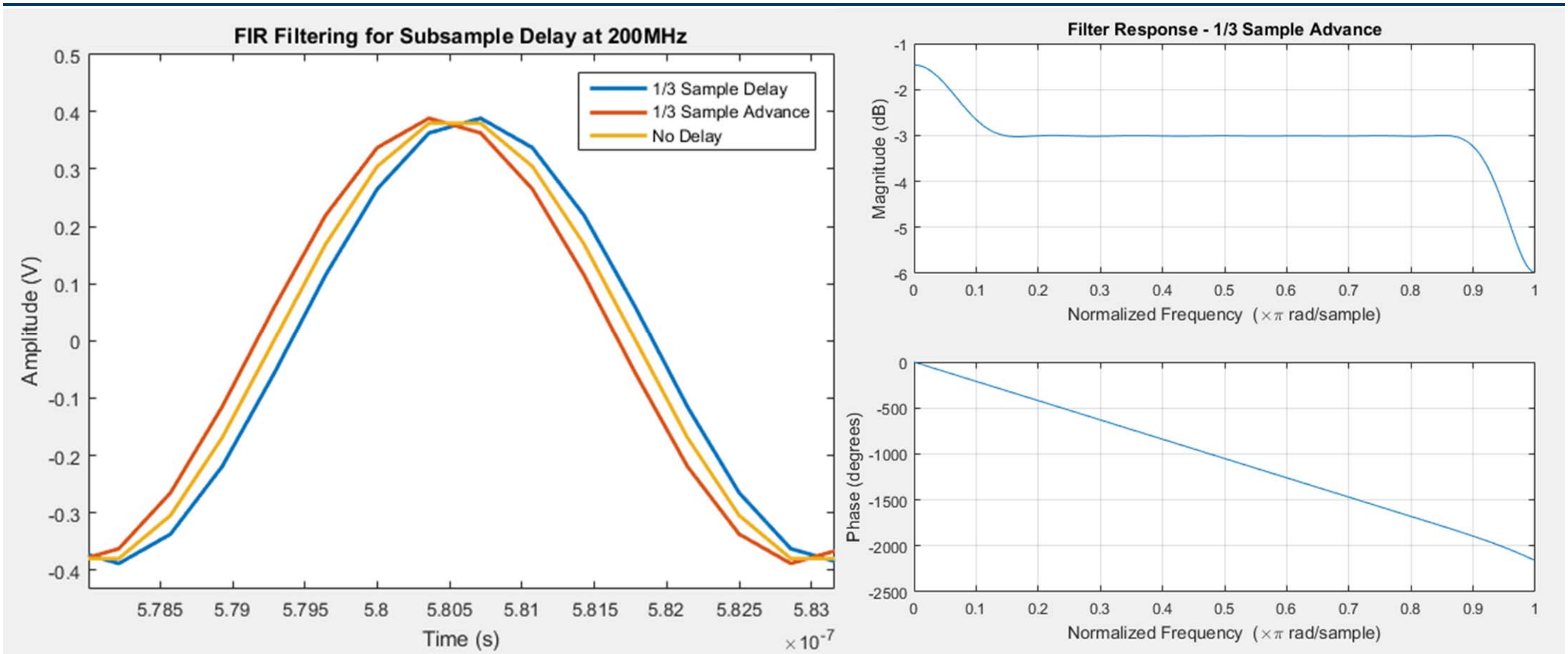
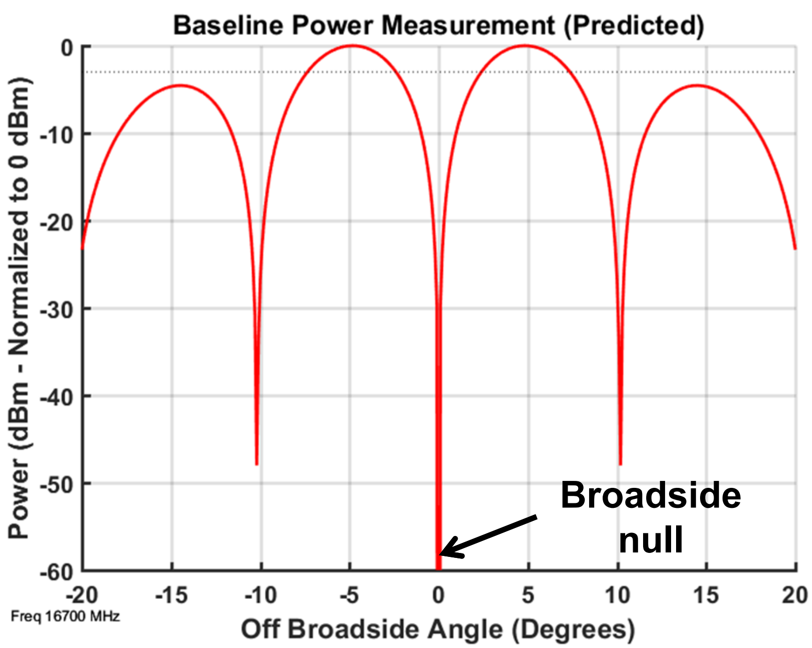
FIR Filtering

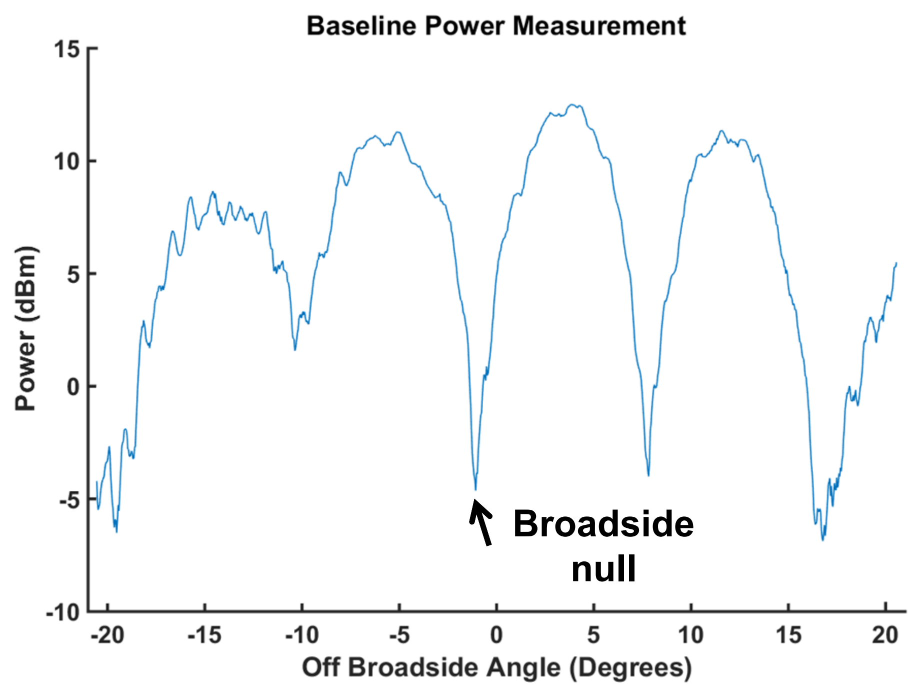
- Control **phase, delay** and **gain**
  - allows for **subsample delay control** (1/3, 1/12, etc.)
  - Also supports **continuous phase control**



Interferometer: Broadside Null

- Interferometer: 1 antenna 180° out of phase --> destructive interference
- Simulated expected antenna pattern in MATLAB
- In lab, interferometer antenna pattern worked for producing nulls
- Multi-path effects from test environment visible in measurements
  - However, broadside null is consistent





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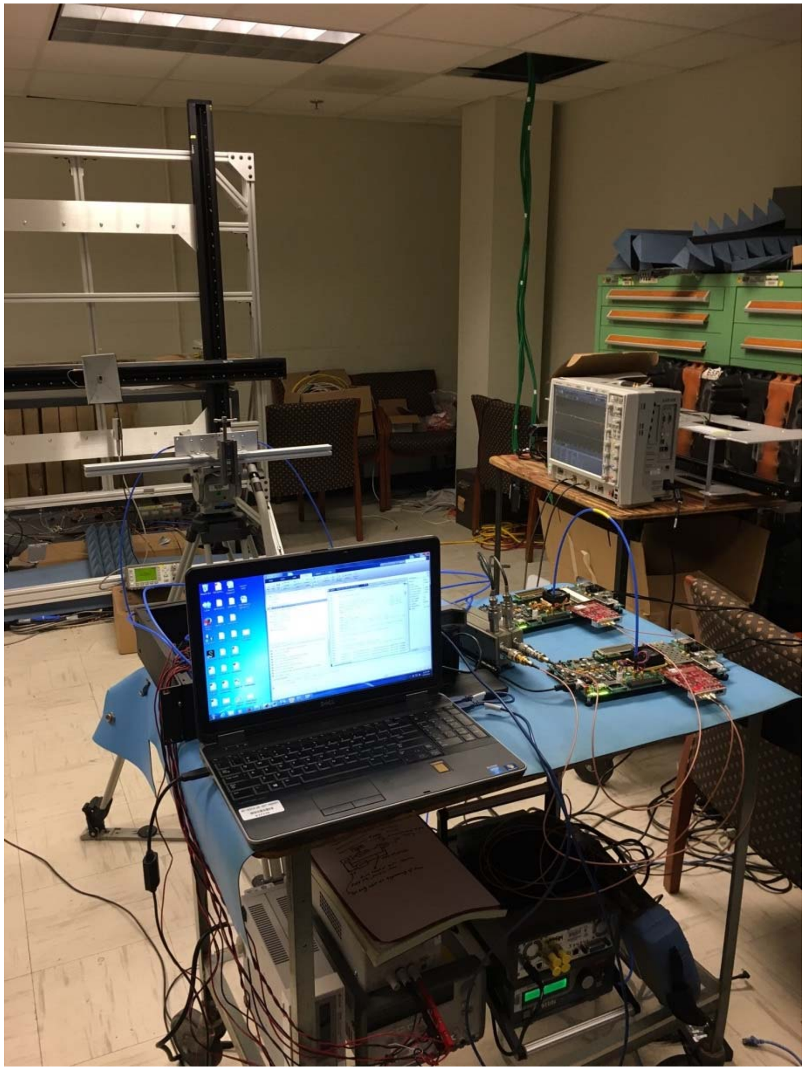
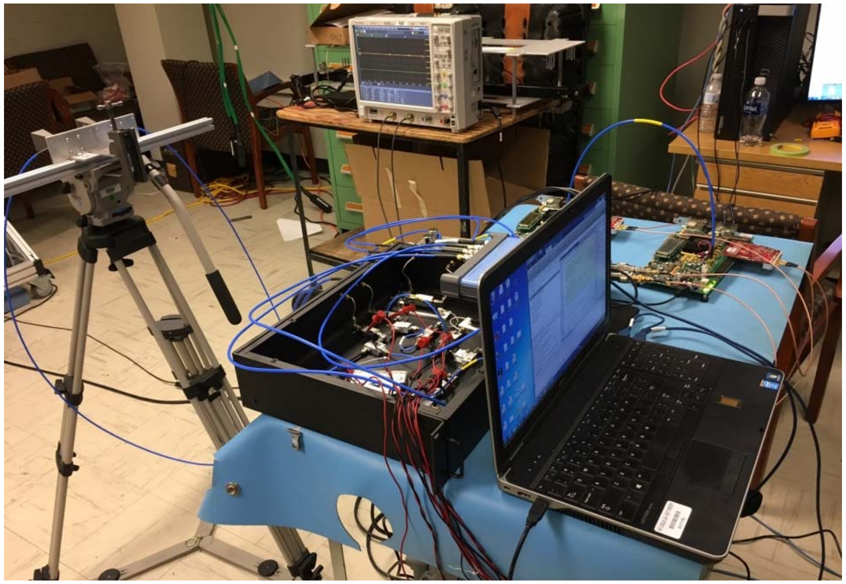
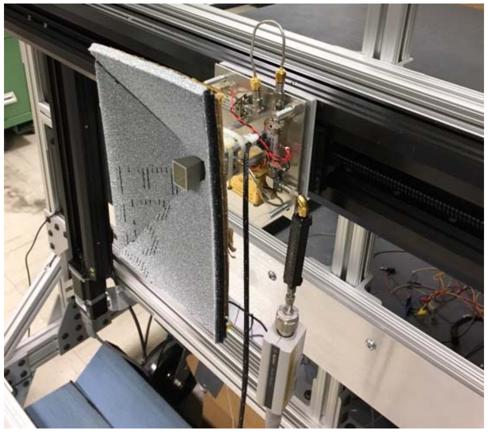
Test Setup





- Transmit waveform data
- Utilize antennas and receiver as feedback loop
- Analyze data in Matlab

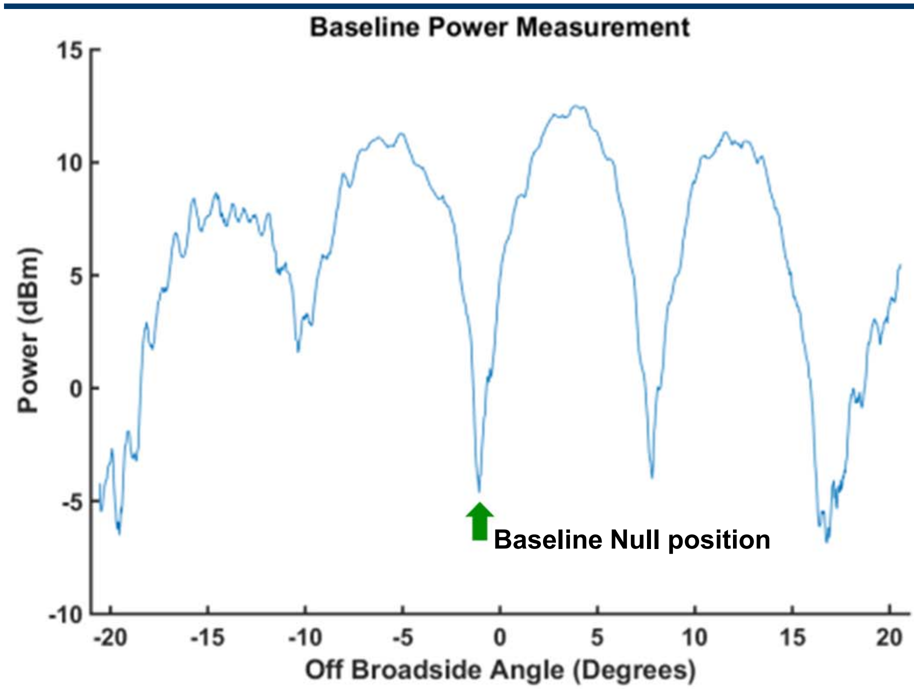


Test Protocol: Step 1

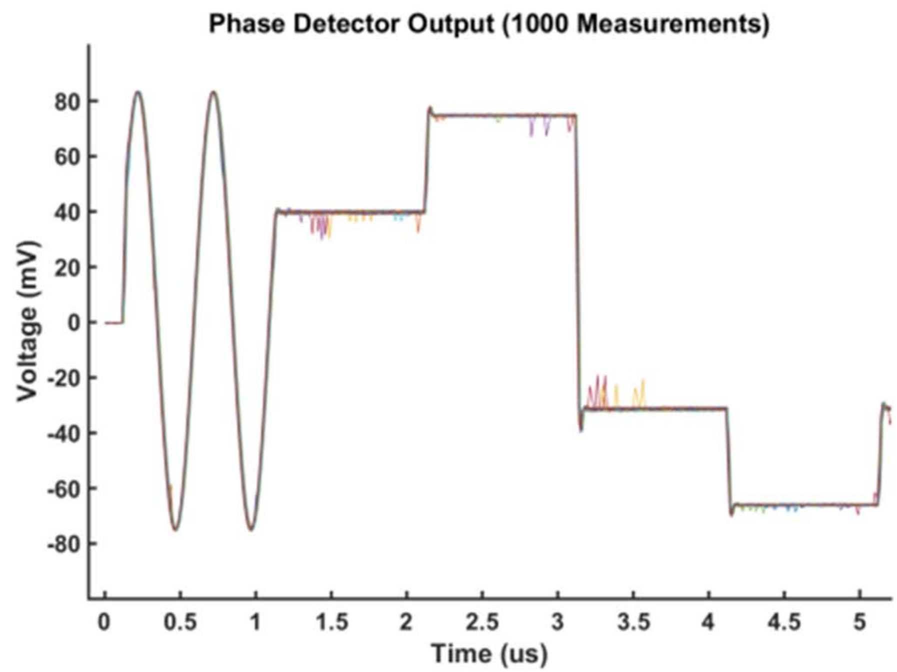
Step 1: Established a baseline null position and phase difference

- Tuned test channel
- Examined consistency

Baseline Interference Pattern



Baseline Phase Detector Output

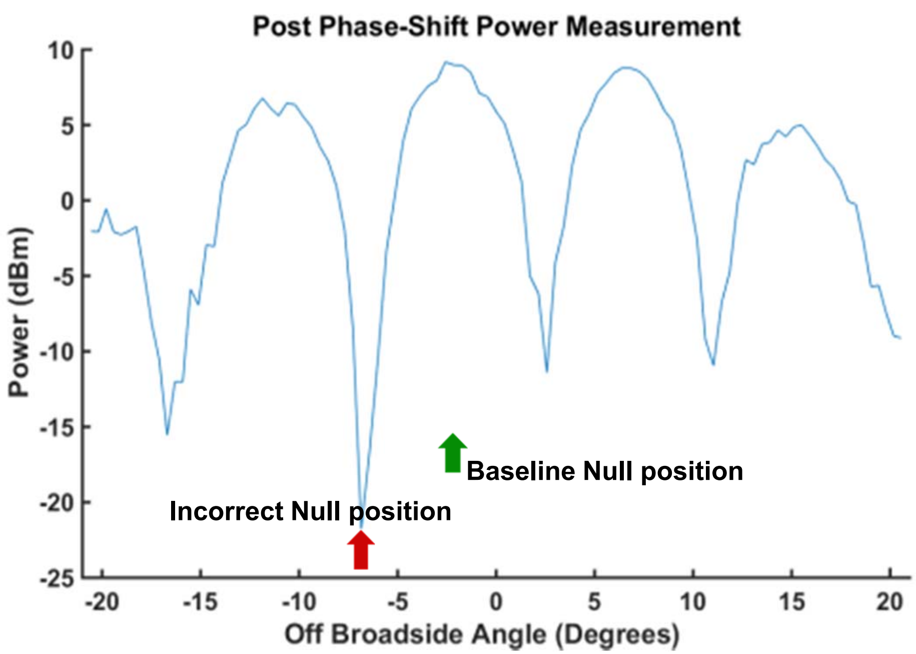


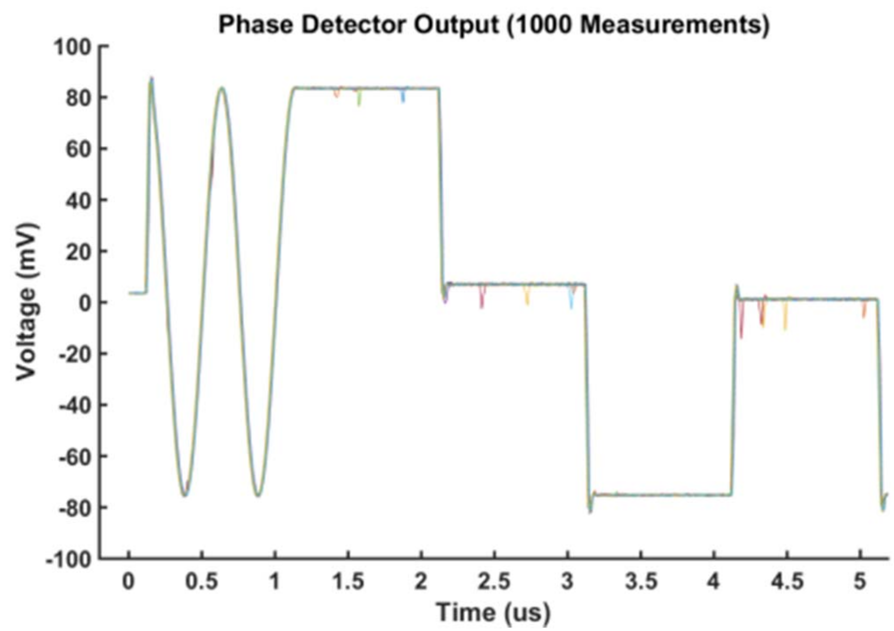
Test Protocol: Step 2

<u>Step 2:</u> Used phase shifter to intentionally put the system out of calibration

- **Measured resulting null position and phase difference**

Uncalibrated Interference Pattern	Uncalibrated Phase Detector Output



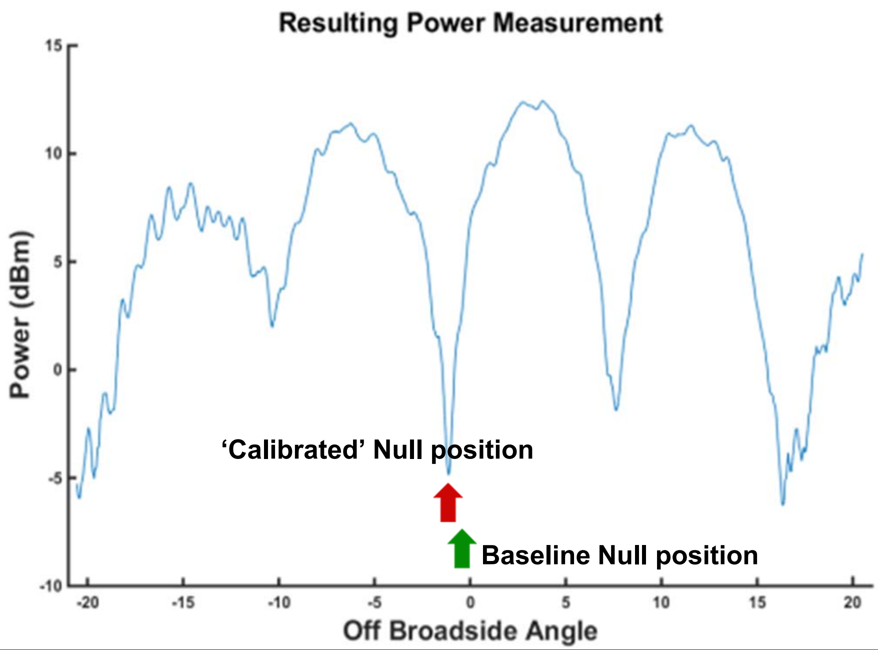


Test Protocol: Step 3

<u>Step 3:</u> Used new phase difference measurement to change the phase of the test channel input signal

- **Measured resulting null position and phase difference**

Interference Pattern After Re-Calibration	**Restored Phase Detector Output After Re-Calibration**



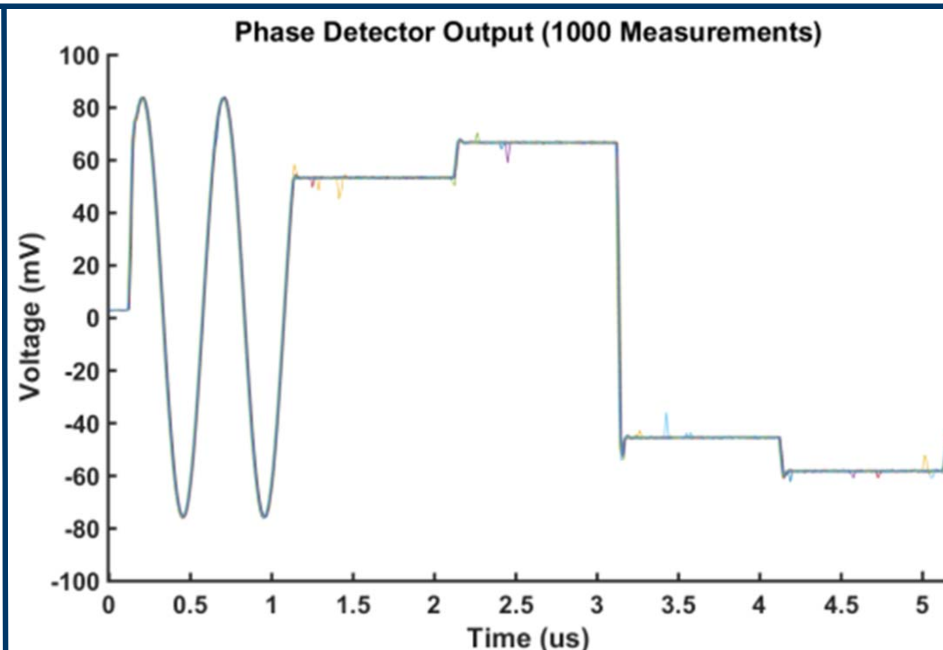


Figure of Merit: How close was the recalibrated null to the original baseline null?

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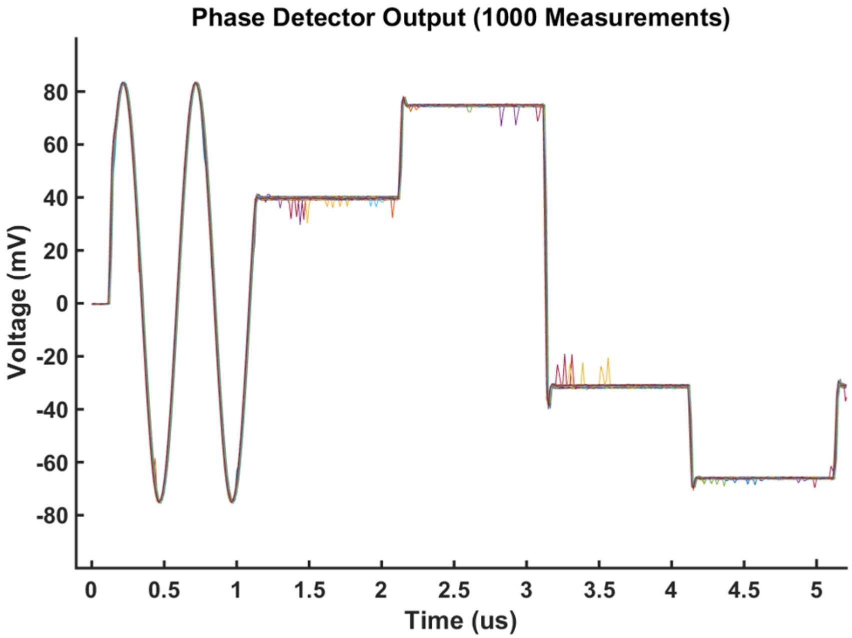
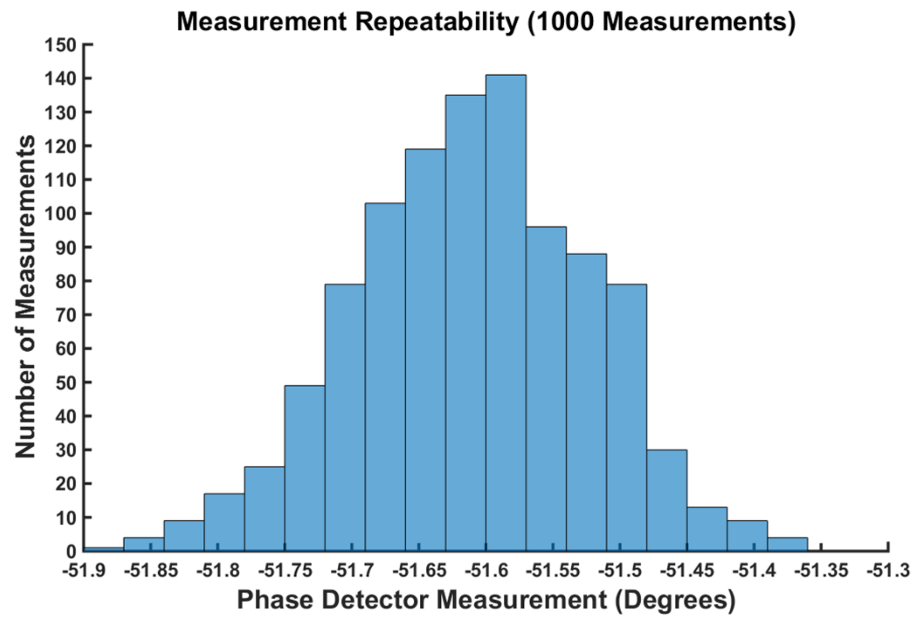
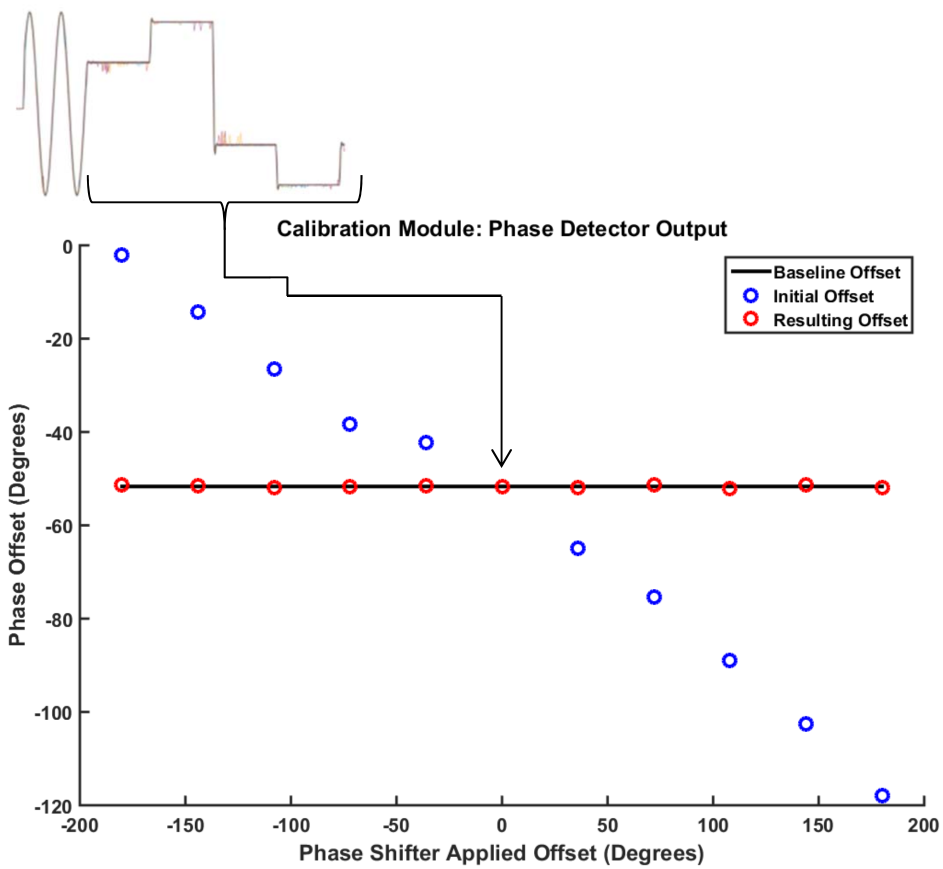
Measurement Repeatability

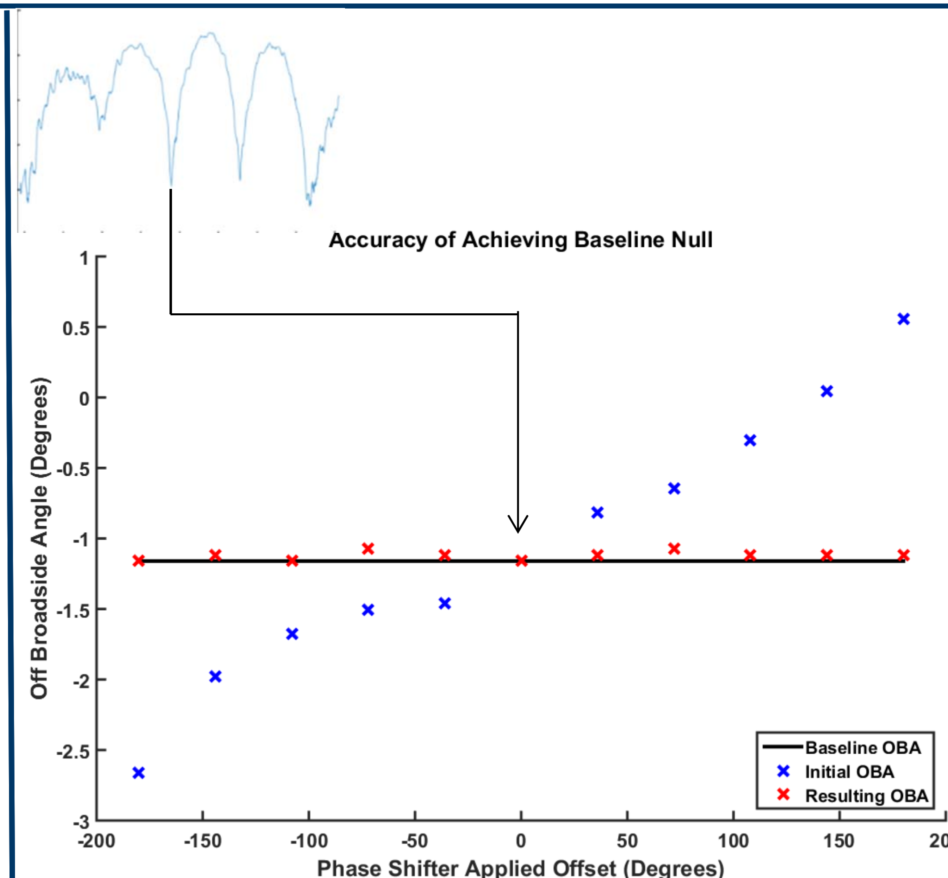




Over 1000 measurements for a set of 5 full system resets, the phase detector output was determined to be reliable within ~1°.

Accuracy of Calibration Module





Digitally steering back to a baseline position using the calibration module output to revise waveforms achieves accuracy within 0.15° at OBA.

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Conclusion

- **Main concern: accuracy and consistency of calibration module**
- **Developed test system simulating transmission side of ARTB with calibration module as DUT**
- **Utilized power receiver and horn antennas as feedback loop**
- **Ran statistical analysis of calibration and received power data**

The ARTB calibration module can consistently and accurately provide calibration data to revise waveforms within 0.15° of the baseline beam angle.

Future Work

- Run in near-field chamber
- Test at full 1 GHz bandwidth
- Examine effects of temperature changes on calibration consistency and accuracy

Acknowledgements

Andy Messier

Edward Clancy

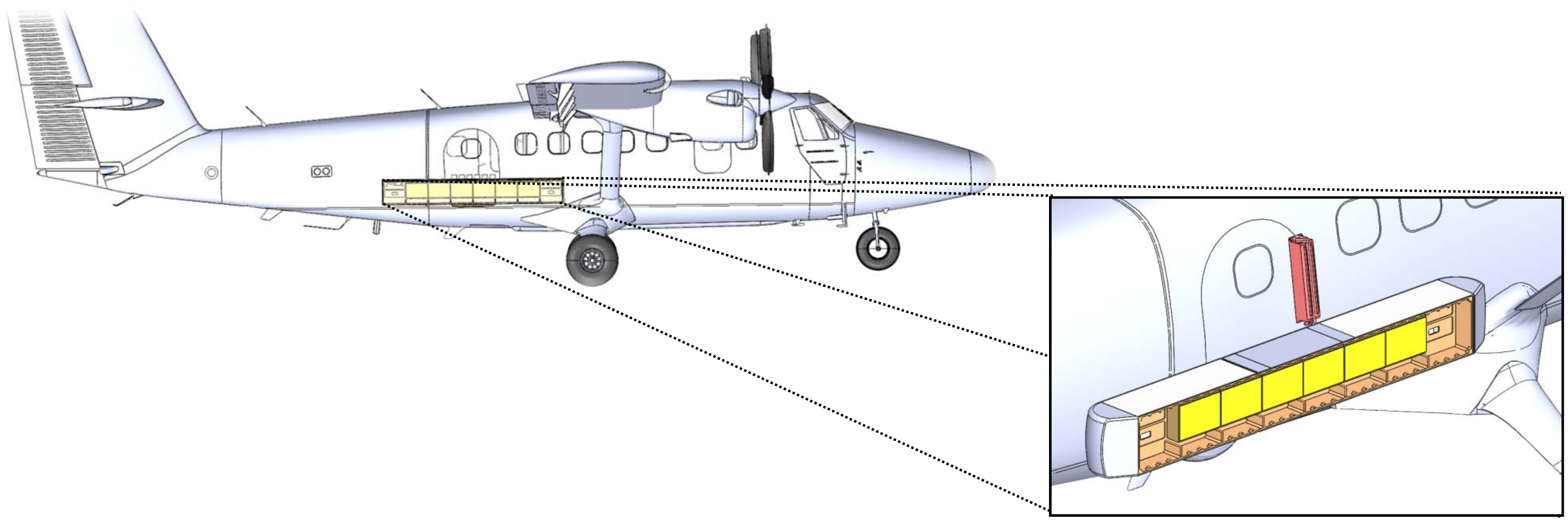
Jeffery Blanco

Tasadduq Hussain

Matt Calderon

Gerald Benitz

Questions?



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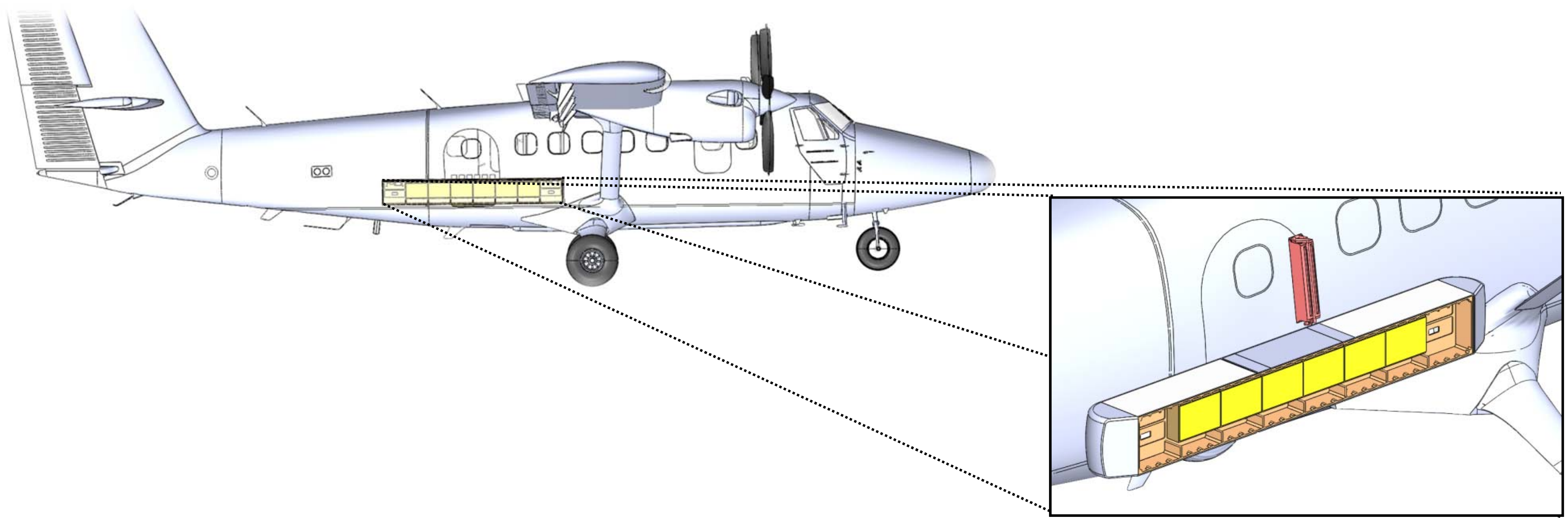
Additional Detail



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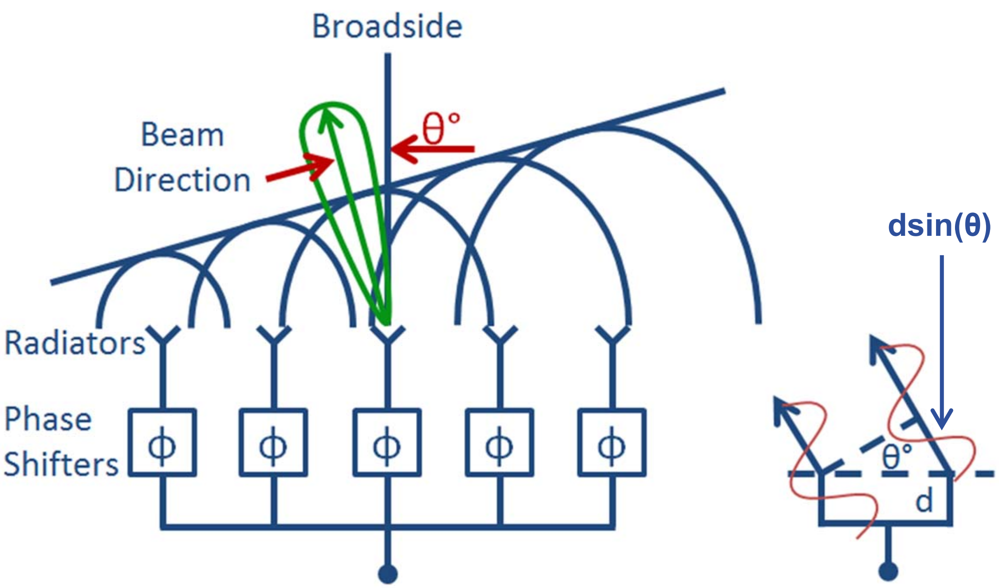
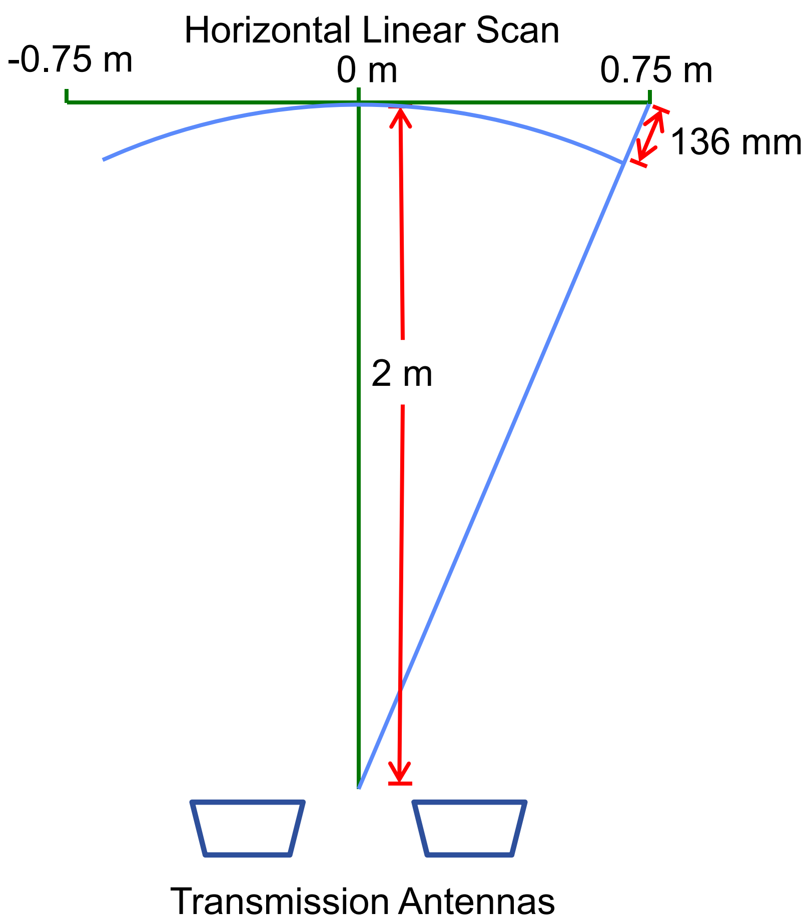
Additional Information:
Beam Squint



$$\Delta t = \frac{d\sin(\theta)}{c} \longrightarrow \Delta\phi = 2\pi f \Delta t = \frac{2\pi d\sin(\theta)}{\lambda}$$

- Using phase shifters for beam steering induces beam squint over wide bandwidths
- Wave must travel an additional dsin(θ) for each successive antenna element
- Phase shift is frequency dependent, but time delay is not

Additional Detail:
Horizontal Linear Scan

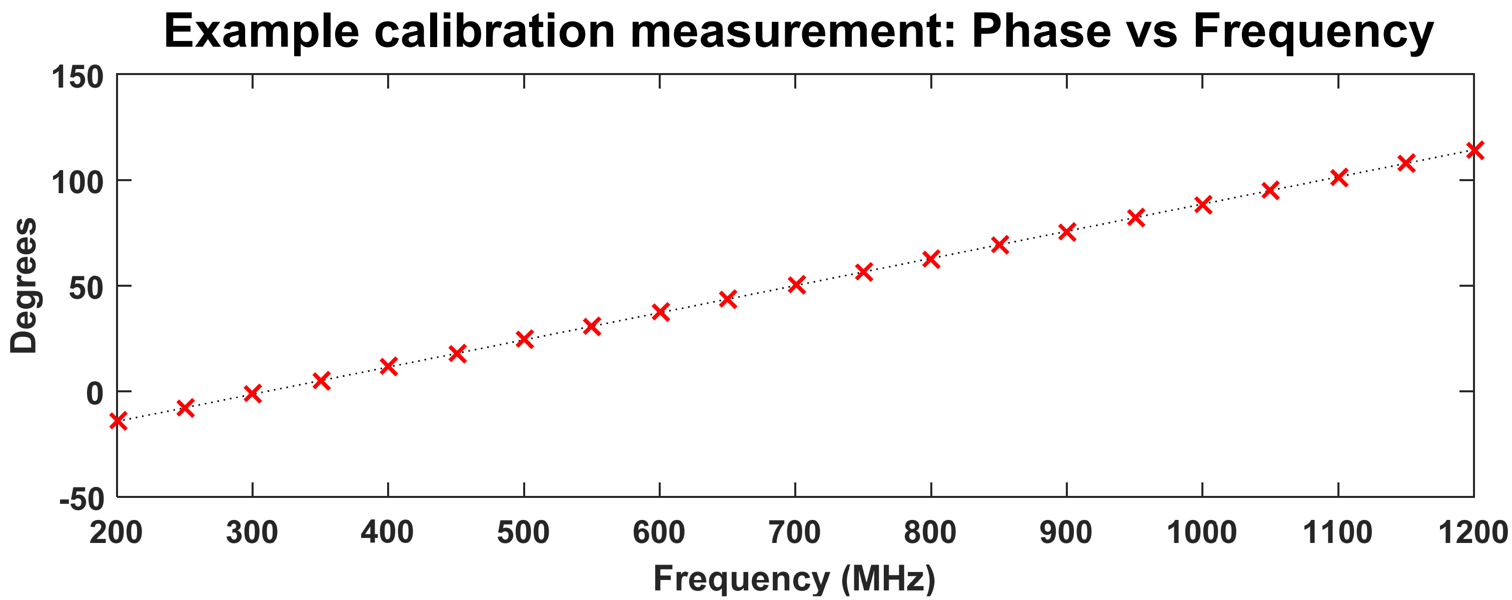


- Use of a horizontal linear scan results in additional path length as the scan angle moves away from broadside
- Additional phase shift not relevant for power measurement
- From Friis Equation, additional power loss is 0.1dB at the scan edges

Friis Equation:

$$Pr = Pt + Gt + Gr + 20log\left(\frac{\lambda}{4\pi\Delta r}\right)$$

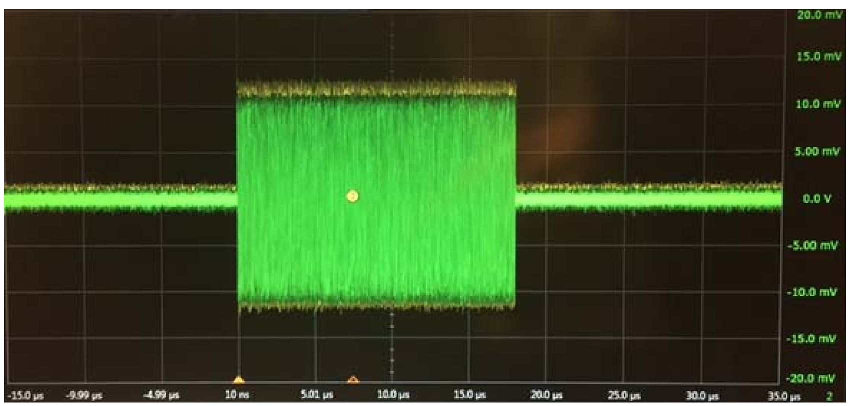
Additional Information: Full 1GHz Bandwidth

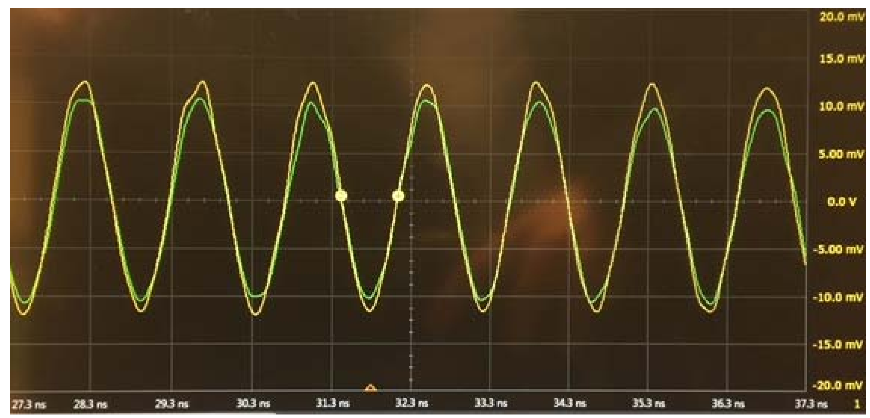


- **Slope indicates delay**
  - **Example: Test signal is exactly 1 DAC sample ahead**
- **Midband phase may require correction**
  - **Example: Phase is lagging 40° vs 1 DAC sample advance**

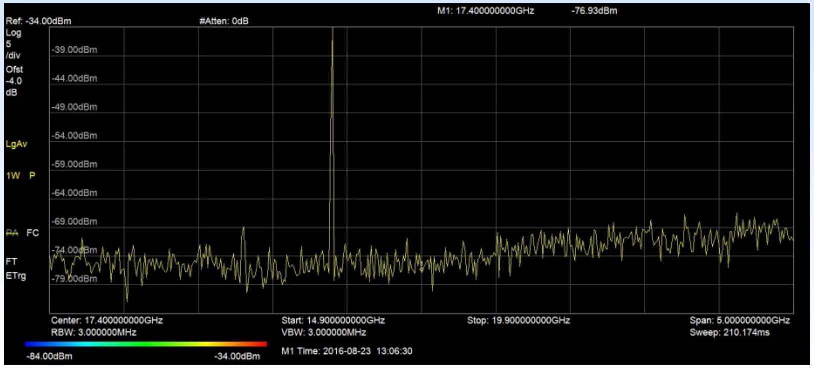
Additional Information:
Synchronization

- Master board **triggers** slave board for **synchronization**
  - **Deterministic**: able to use filtering to align phase of waveforms





Additional Information:
Full Upconverter



16.2 GHz Spur

16.8 GHz RF Frequency

Upconversion from 600 MHz to 16.8 GHz

Center Frequency: 17.4 GHz

Span: 5 GHz