



# Calibration Procedures for Picosecond Electronic Beam-steering

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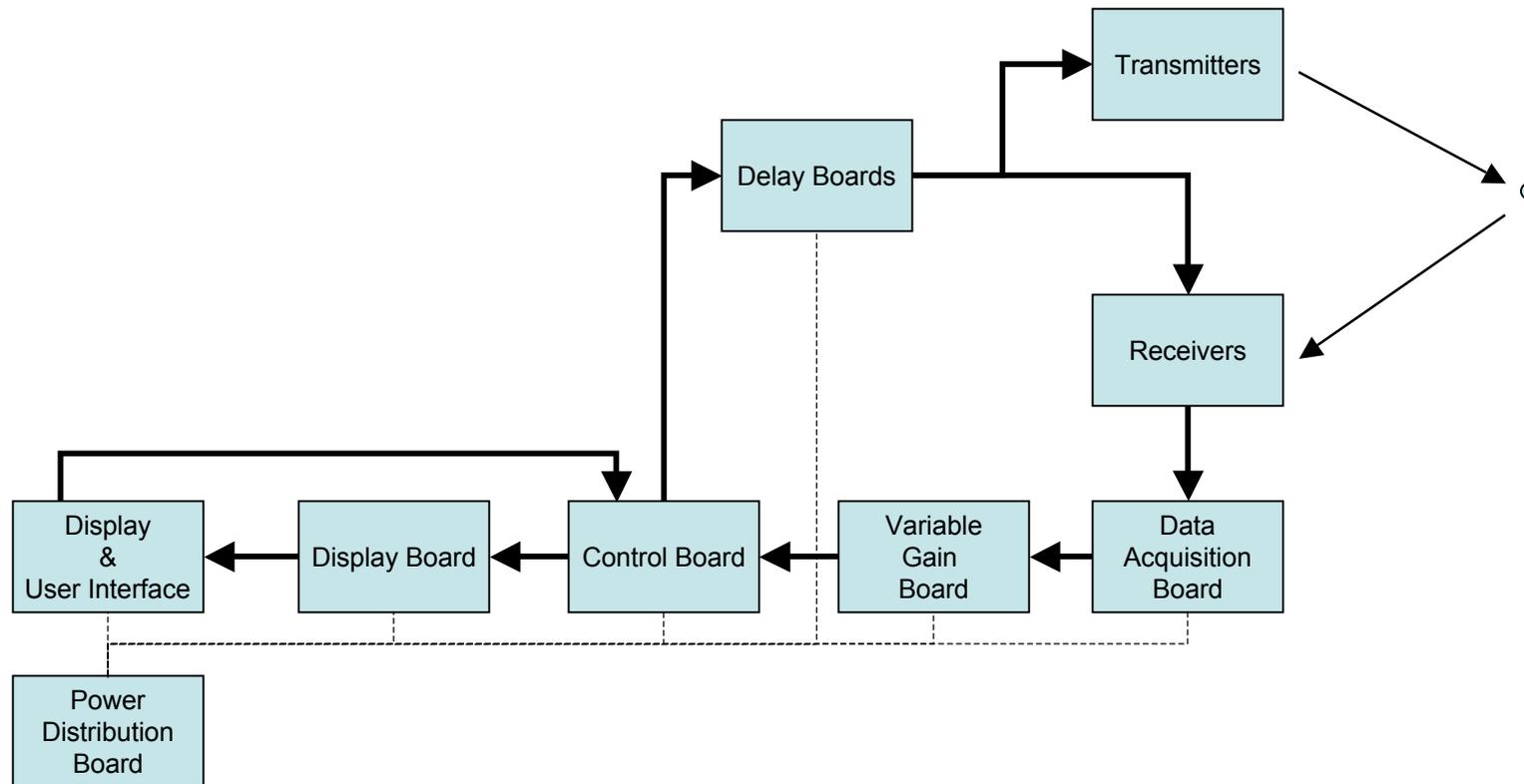


# Radar Camera Images

- Beam-steering Modalities:
  - Coherent addition of pulses at target
  - Non-coherent addition in post-processing
- Image quality depends on ability to precisely and accurately focus UWB pulses



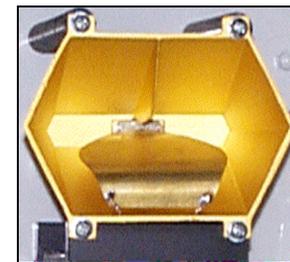
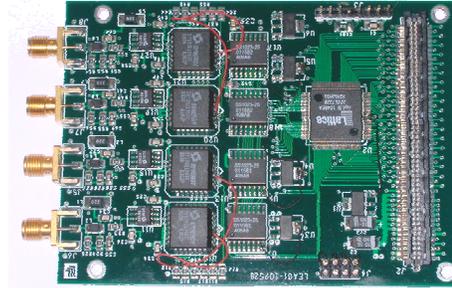
# Hardware Implementation





# Sources of Error

- Digital Delay Generation
  - Step size variation
  - Jitter
  - Temperature drift
- Transmitters and Receivers
  - Temperature drift
  - Delay and Gain Mismatch
- Antennas
  - Angular dependencies





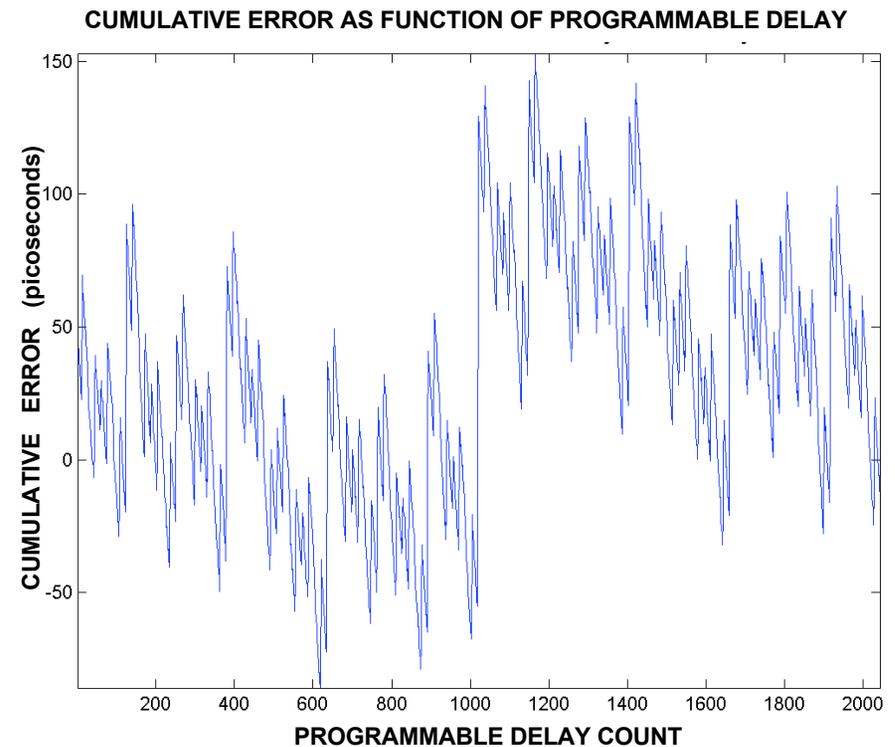
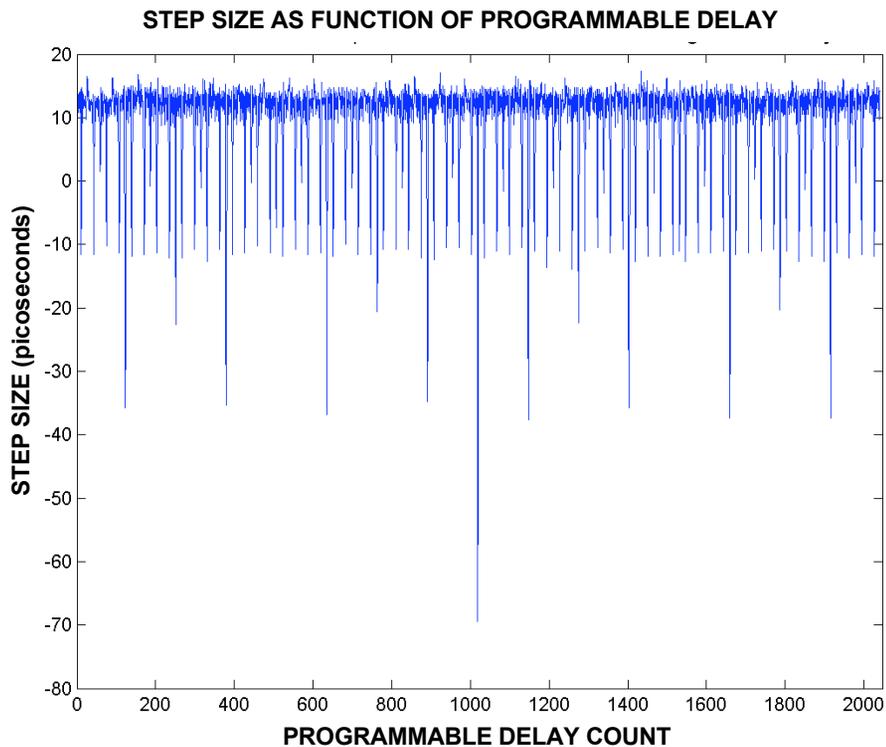
# How much timing error is acceptable?

- Error tolerance is dependent on:
  - bandwidth
  - number of transmitters and receivers
  - array configuration
  - desired spot size
  - range
- For a 3dB beam focus attenuation:
  - ~ 100 ps random jitter
  - ~ 30 ps systematic delay offset



# Step Size Variation

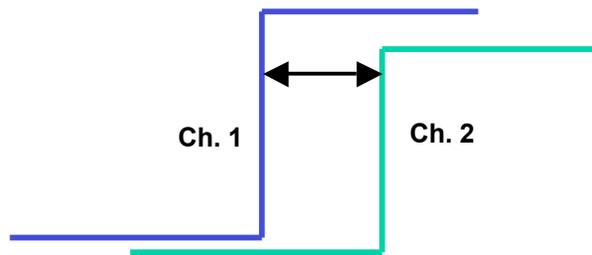
- Programmable Delay Chips have ideal step size of 10ps
- In reality, step size is variable and non-monotonic
- Fortunately, behavior is repeatable



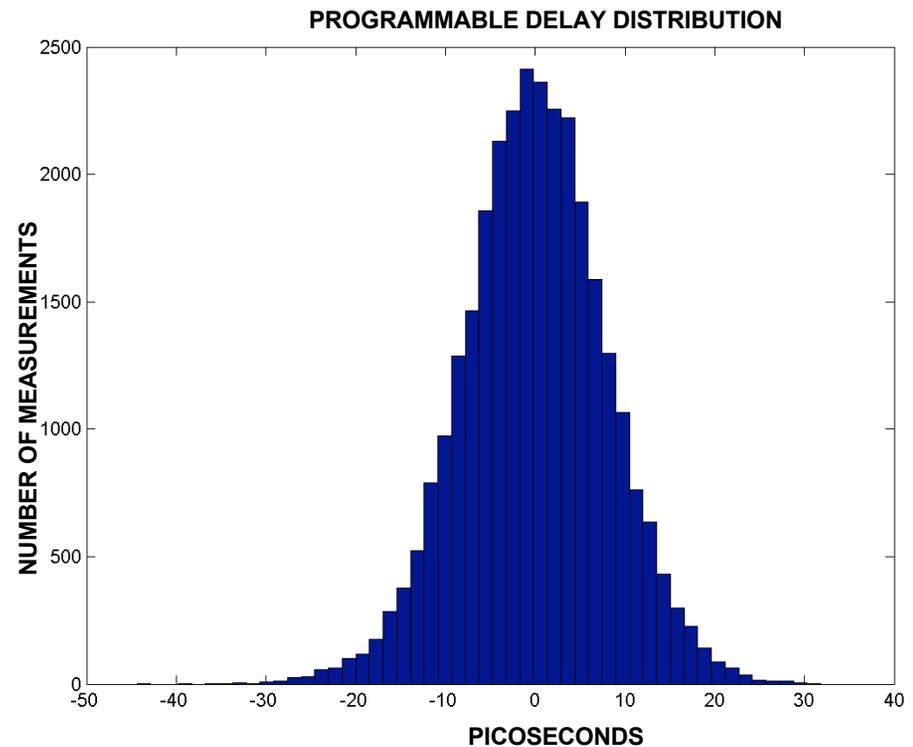


# Jitter

- RMS relative jitter between delay channels
- Measured with an SR620 Time Interval Counter



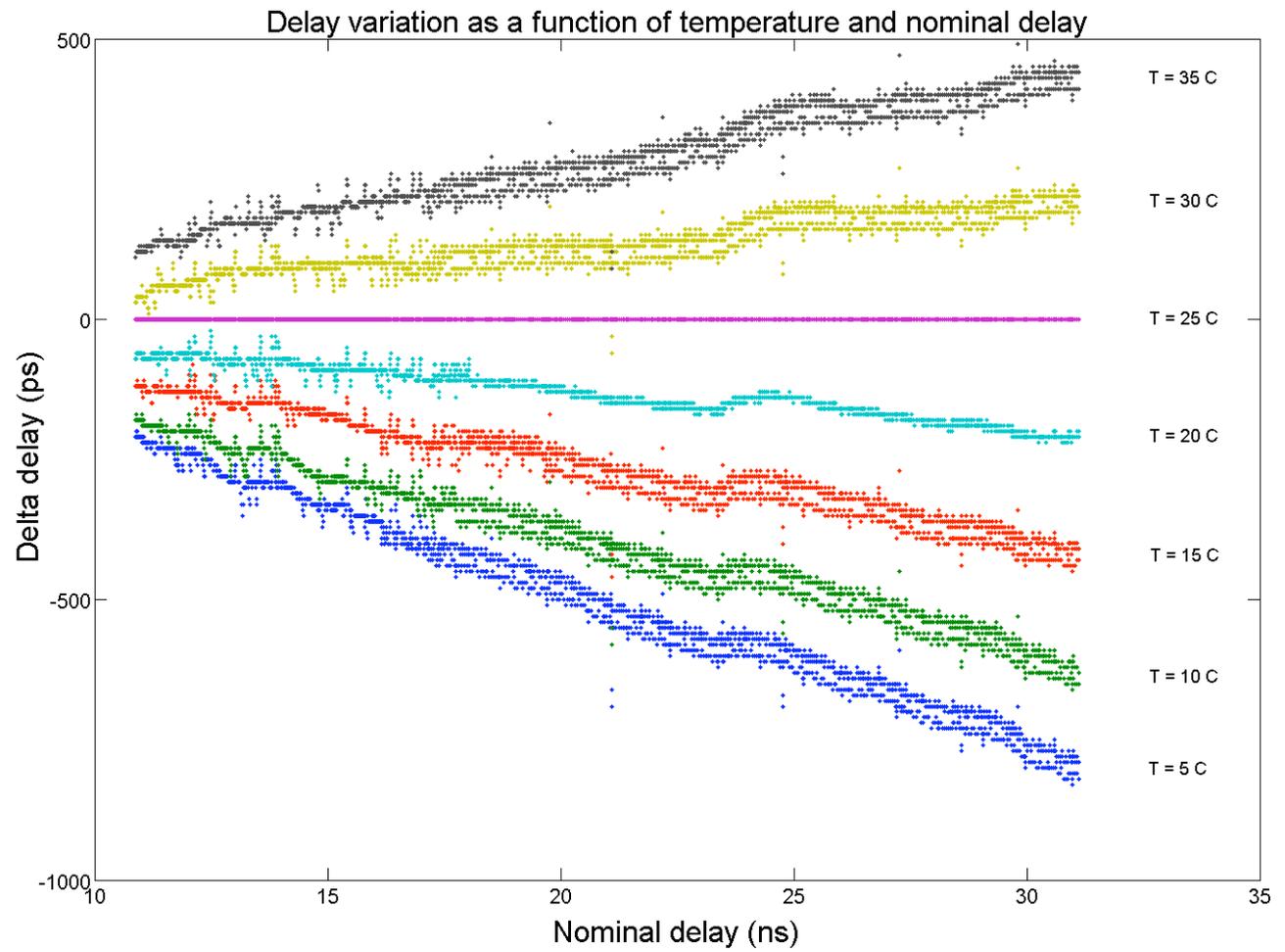
- Jitter:  $\sim 10$  ps





# Temperature Dependence

- 400 ps error over operating range 20°C to 30°C
- 0.15% delay error per °C





# Compensation Schemes for Systematic Error

- Step Size Variation
  - Lookup tables
  - Custom delay characterization board
- Temperature correction
  - Delay increases 0.15% per °C
  - Use an affine model:

$$\text{delay}(T) = \text{delay}(T_o) \left[ 1 + 0.0015(T - T_o) \right]$$



# Performance of Compensation Schemes

<b>Scheme</b>	<b>RMS Error</b>
Uncompensated	165 ps
Lookup Table	115 ps
Lookup Table with Temp Correction	25 ps

\* Assuming a temperature operating range of 20 to 30\_C

Future Work:

- Include temperature dependencies of other components (transmitters, receivers)
- Integrate temperature sensors with hardware