Reconfigurable Wave Velocity Transmission Lines for Phased Arrays

By: Nicholas Host
Advisors: Chi-Chih Chen
John L. Volakis

NASA Mentor: Félix Miranda

Work supported by NSTRF, NASA Grant #NNX11AN16H

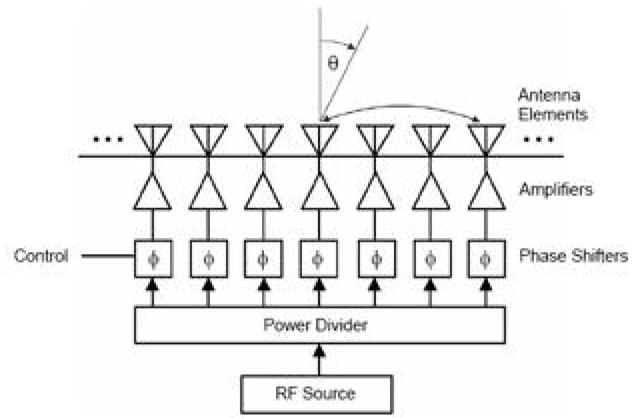
Current Technology

Phased Array Features:

- *Wideband*
  - Element Design allows for wideband operation
- *Beam Scanning Ability*
  - Element phase control allows for beam scanning

Phased Array Challenges:

- *Complex*
  - Backend used to achieve beam steering is very complex
- *Heavy*
  - The backend adds significant weight
- *Costly*
  - Components are very expensive



Addressed by our approach

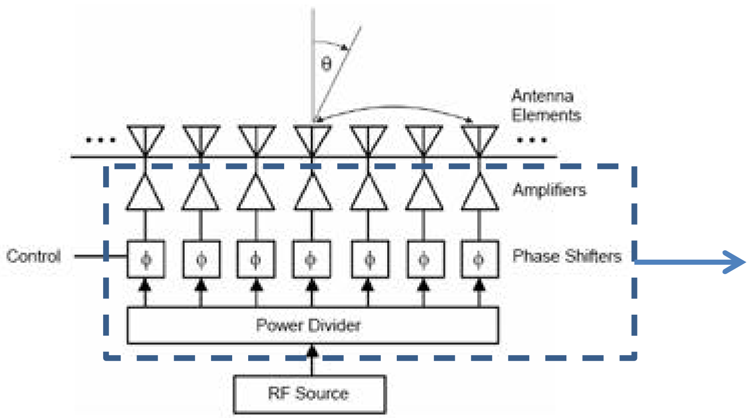
Novel Aspects

Design Goals:

- *Reduce Complexity*
- *Reduce Weight*
  - Large contributions for both come from the backend
- *Reduce Cost*

Methodology:

- *Replace backend with simpler feeding mechanism*



Replace with simpler mechanism

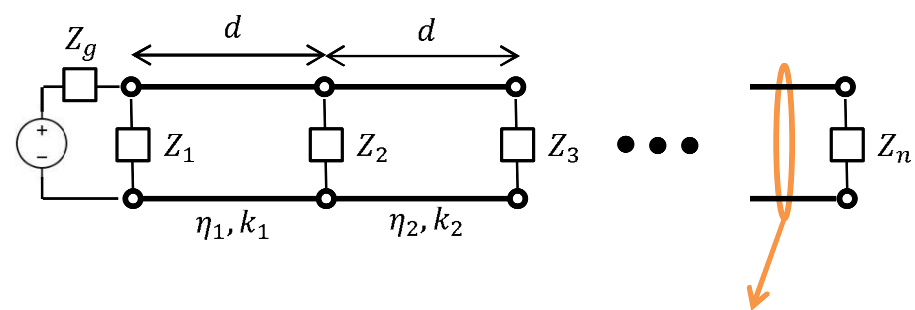
Approach

Replace Backend With Simpler Mechanism

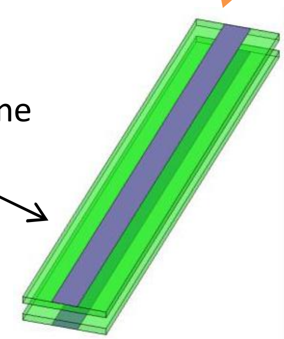
- *Get rid of all splitters, phase shifters, and amps*

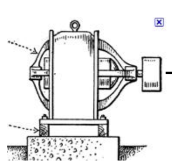
Use Series Fed Array:

- *Array fed at one point (side)*
- *Magnitude at each element controlled by varied mismatch at element terminals*
- *Beam Steering will be accomplished by a controllable propagation constant between elements*
  - A motor can bring two fixed sheets closer to change the effective dielectric constant

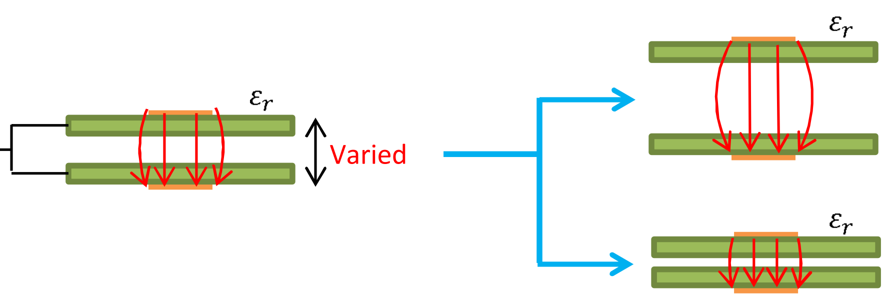


Reconfigurable transmission line





Motor to move sheets closer or farther apart

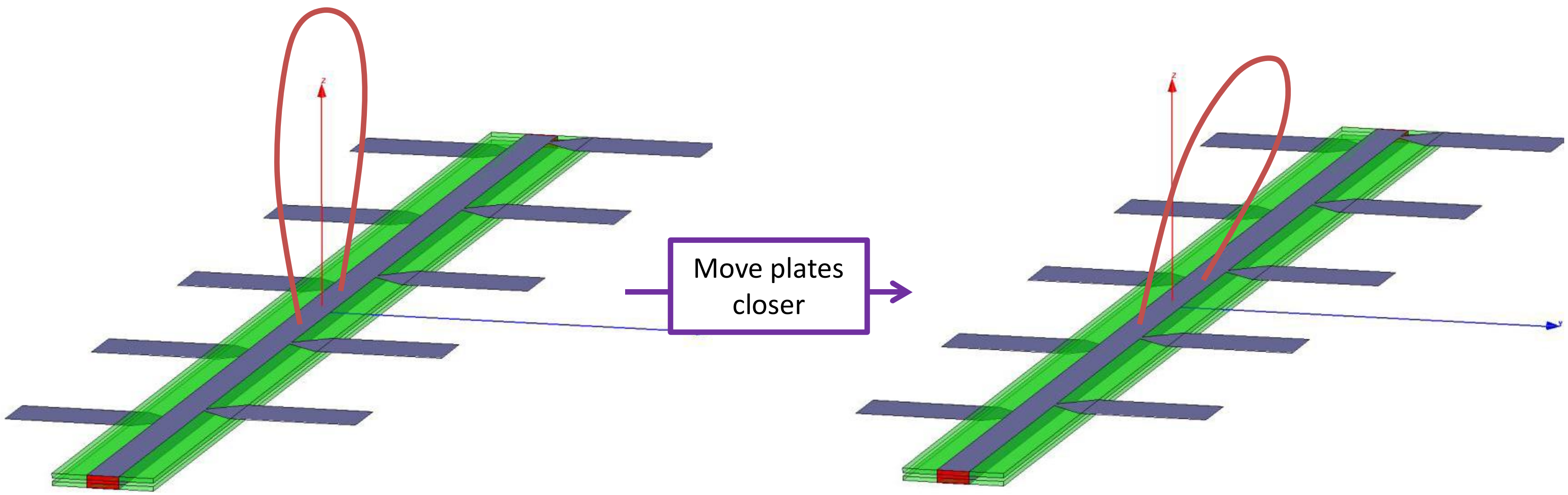


Field mostly in air, so low ε_{eff}

Field mostly in dielectric, so high ε_{eff}

By changing ϕ (through change of k_{eff}) scanning is accomplished:

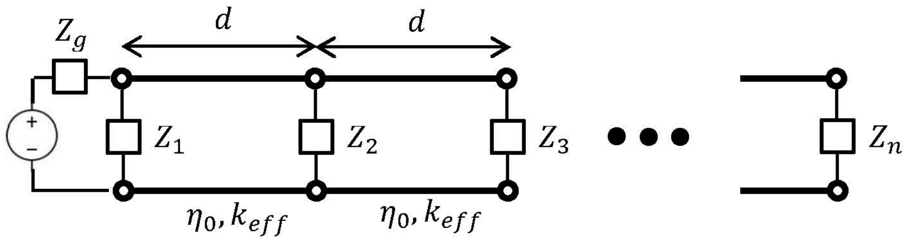
Achieving Scanning

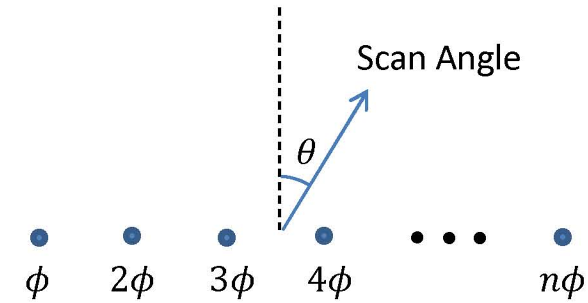


Scanning is achieved with one mechanical motion and no phase shifters

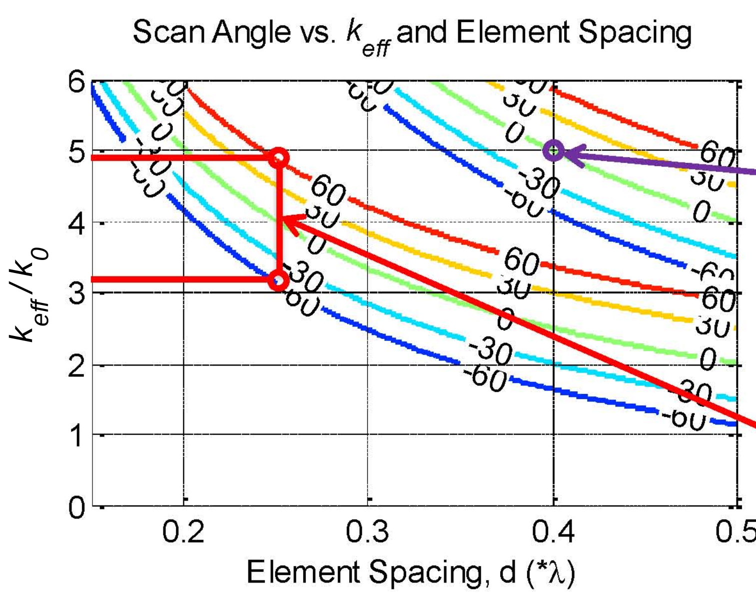
Needed Transmission Line Agility

Assume each transmission line is the same





$$\phi = f(d, k_{eff})$$



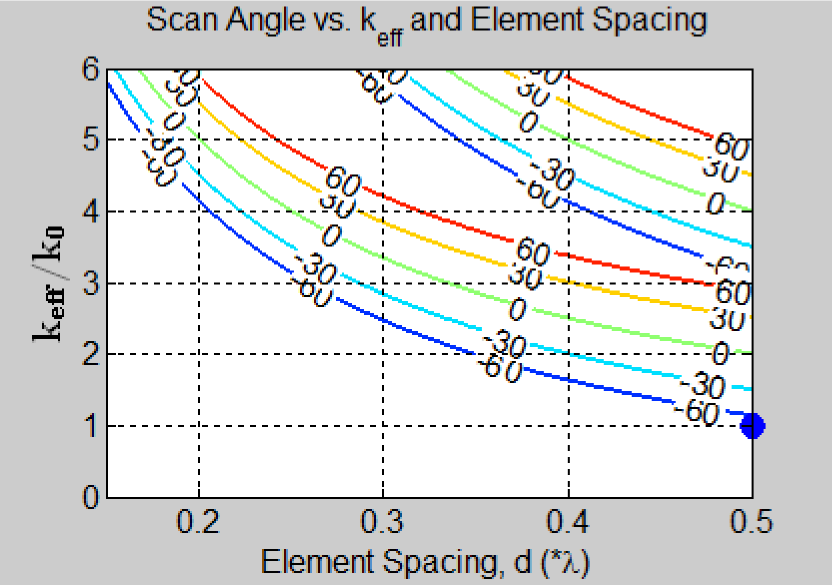
For $d = 0.4\lambda$ and $\dfrac{k_{eff}}{k_0} = 5$ ⇒ $\theta = 0°$

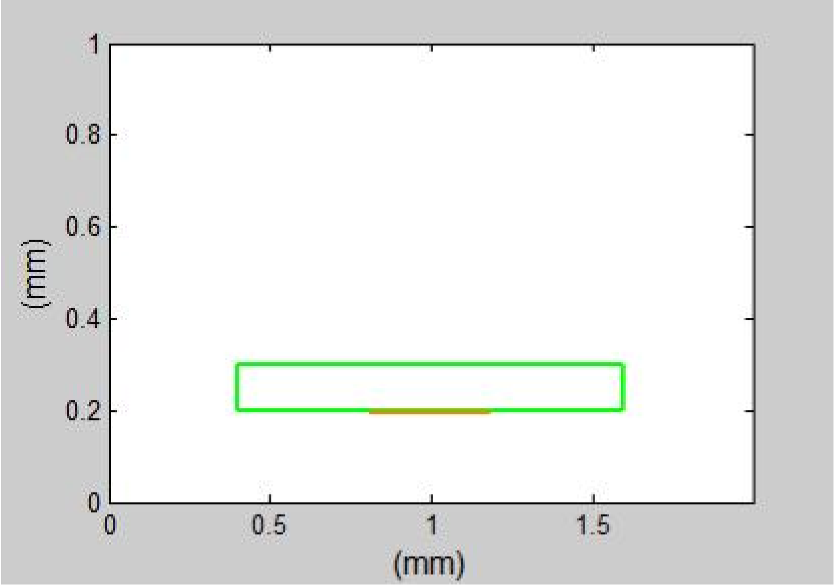
For $\theta = -60$ to 60 at $d = 0.25\lambda$ ⇒ Need $3.1 \leq \dfrac{k_{eff}}{k_0} \leq 4.9$

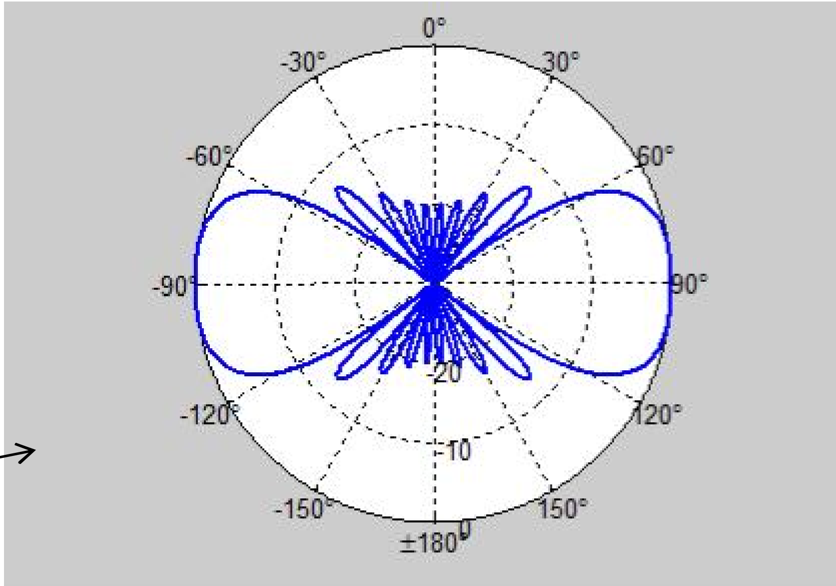
Process to Scan

As the parallel plates close (left)

- $k_{eff} \uparrow$ (right top)
- For given $d = \lambda/2$
  - Scan angle (right top)
  - Pattern (right bottom)

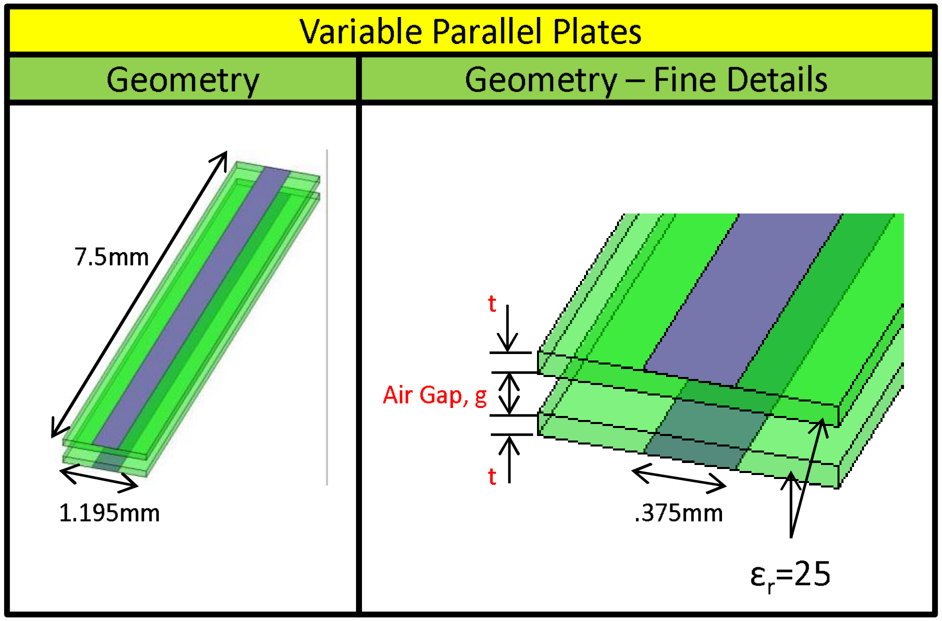


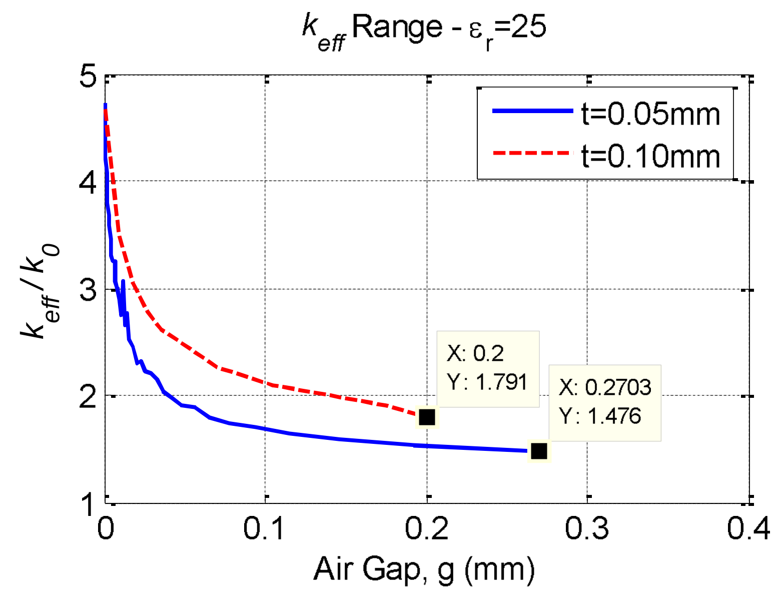


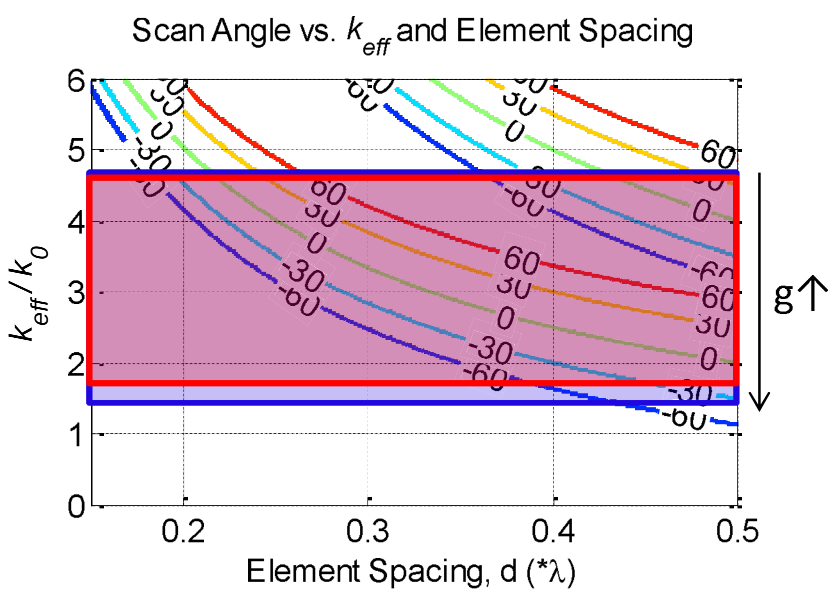


Theoretical 10 Element array with $\lambda/2$ element spacing

Achievable k_{eff} Range - $\varepsilon_r = 25$

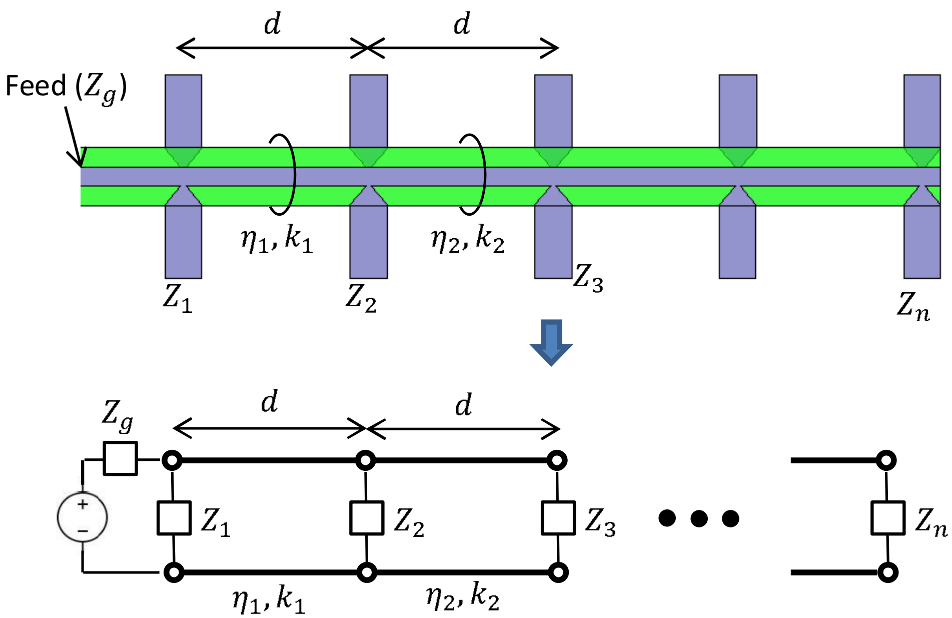






- Strip Spacing ≤ 0.40mm (λ/20 @ 40GHz)
  - t=0.1mm case → lower max g
- t=0.05mm
  - Larger $\varepsilon_{eff}\mu_{eff}$ range
  - More precision needed
- t=0.10mm
  - Smaller $\varepsilon_{eff}\mu_{eff}$ range
  - Less precision needed

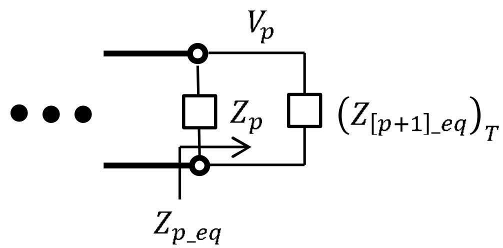
Array as a Circuit Network



- Equal Power Distribution
  - ➢ $P_i \rightarrow$ Power at the i^{th} element
    - ✓ $P_i = P_j$
    - ✓ Uniform pattern
- Matching at Feed
  - ➢ S_{11} minimized at Feed

General Impedance Distribution – n Elements

Equal Power Distribution



$$(Z_{[p+1]\_eq})_T = \frac{Z_p}{n-p}$$

So:

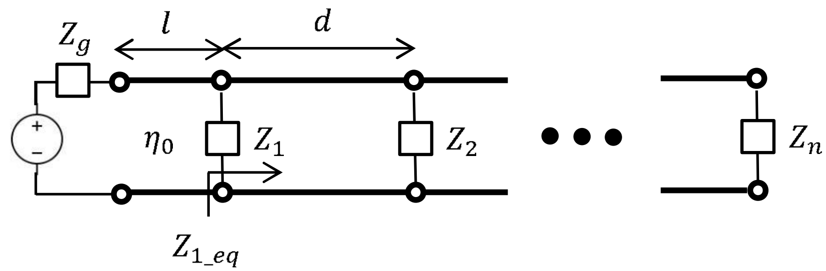
$$Z_{[p+1]\_eq} = Z_0\left(\frac{\frac{Z_p}{n-p}\cos(kd) - j\eta_p\sin(kd)}{\eta_p\cos(kd) - j\frac{Z_p}{n-p}\sin kd}\right)$$

knowing:

$$Z_{[p+1]\_eq} = \frac{Z_{p+1}}{n-p}$$

$$\boxed{Z_{p+1} = Z_0\left(\frac{Z_p\cos(kd) - j(n-p)\eta_p\sin(kd)}{\eta_p\cos(kd) - j\frac{Z_p}{n-p}\sin kd}\right)}$$

Circuit Matching



To be matched:

$$Z_{1\_eq} = Z_0$$ ← Valid for all l

$$Z_{p\_eq} = \frac{Z_p}{n-p+1} \Rightarrow Z_{1\_eq} = \frac{Z_1}{n}$$

$$\boxed{Z_1 = n\eta_0}$$

Or:

$$(Z_{1\_eq})_T = Z_g$$

$$\boxed{Z_1 = n\eta_0\left(\frac{Z_g\cos(kl) - j\eta_0\sin(kl)}{\eta_0\cos(kl) - jZ_g\sin(kl)}\right)}$$

Analytical Formulation of Z_0

Derivation

Equal Power Distribution Condition:

$$Z_{p+1} = \eta_p \left(\frac{Z_p \cos(kd) - j(n-p)\eta_p \sin(kd)}{\eta_p \cos(kd) - j \dfrac{Z_p}{n-p} \sin kd} \right)$$

In This Case:

$Z_{p+1} = Z_p = Z$ Use same antenna element

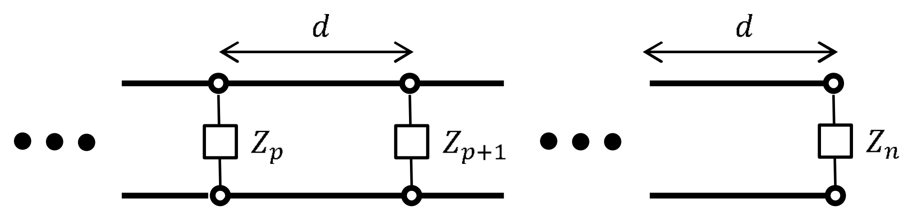
So:

$$Z = \eta_p \left(\frac{Z \cos(kd) - j(n-p)\eta_p \sin(kd)}{\eta_p \cos(kd) - j \dfrac{Z}{n-p} \sin(kd)} \right)$$

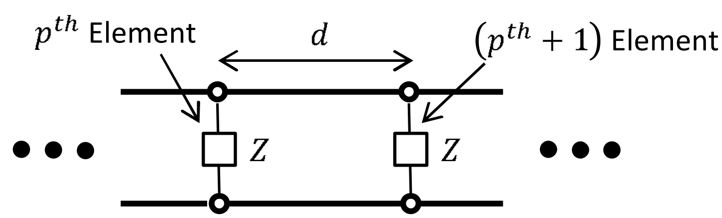
$$\vdots$$

$$\boxed{\eta_p = \pm \frac{Z}{n-p}}$$

Graphical Representation



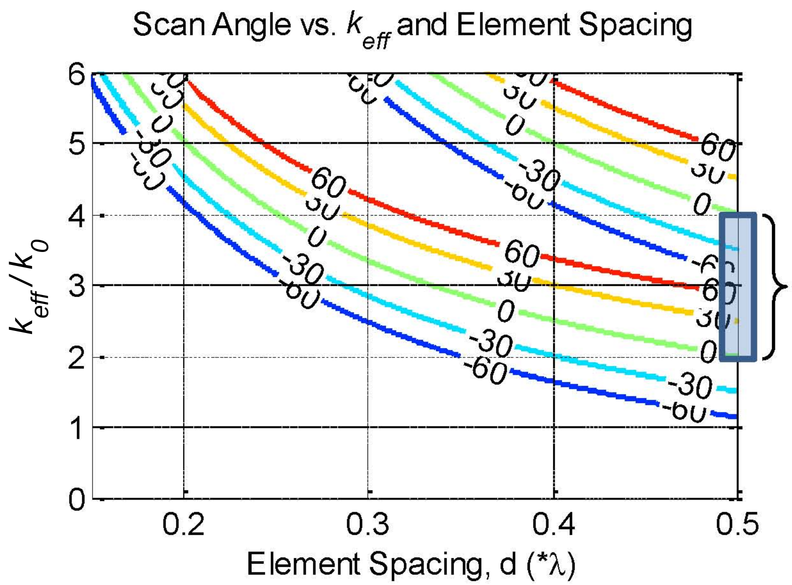
For Equal Power Distribution



$$\eta_p = \frac{Z}{n-p}$$

Not dependent on d

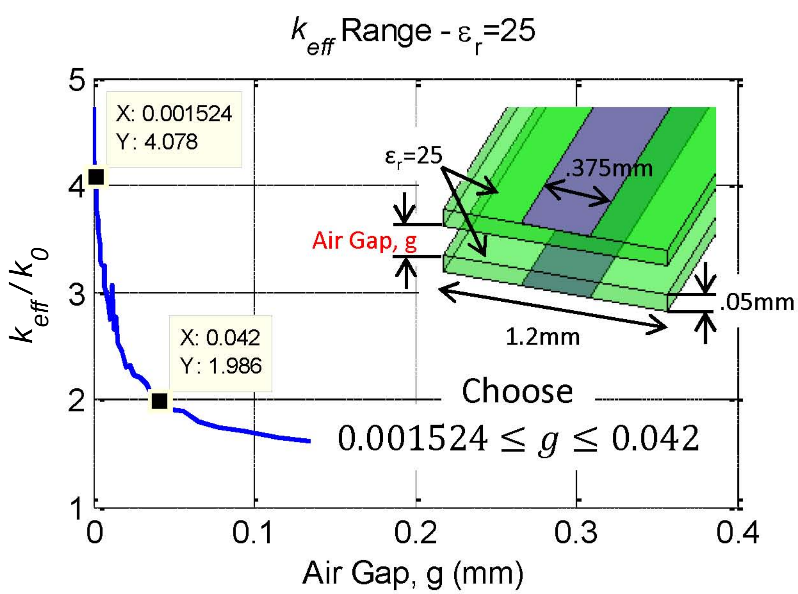
Transmission Line Attributes

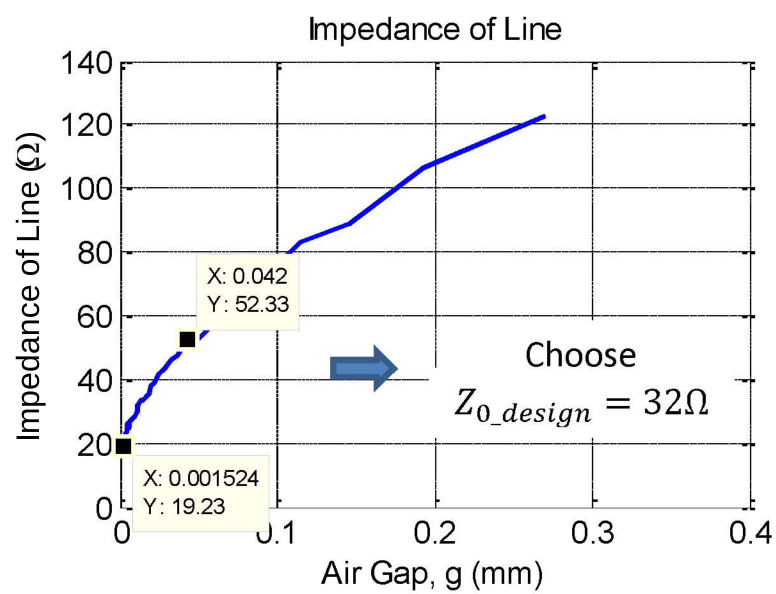


$$d = \frac{\lambda}{2}$$

$$2 \le \frac{k_{eff}}{k_0} \le 4$$

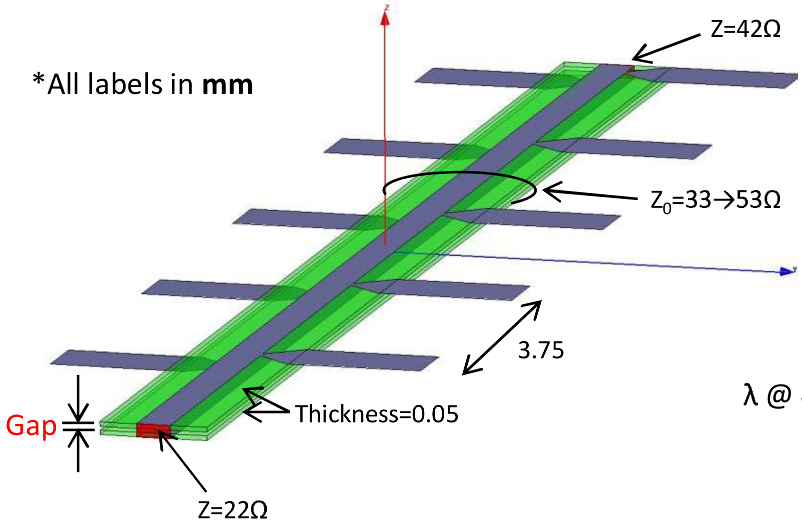
Can scan to all angles

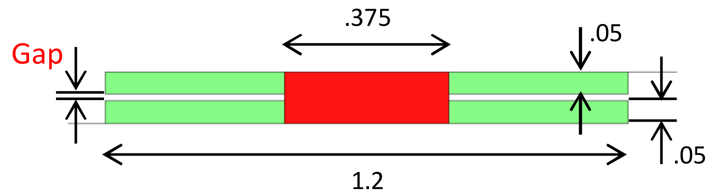




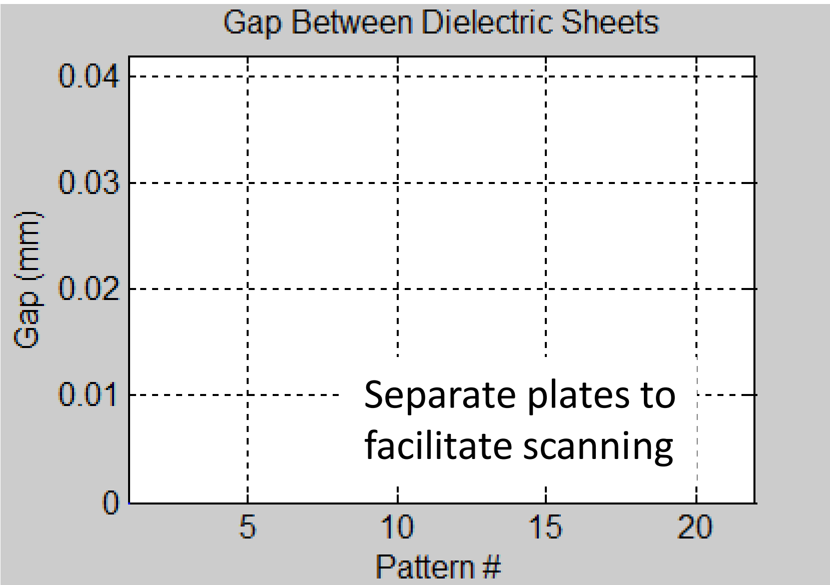
Simulation of Connected Array

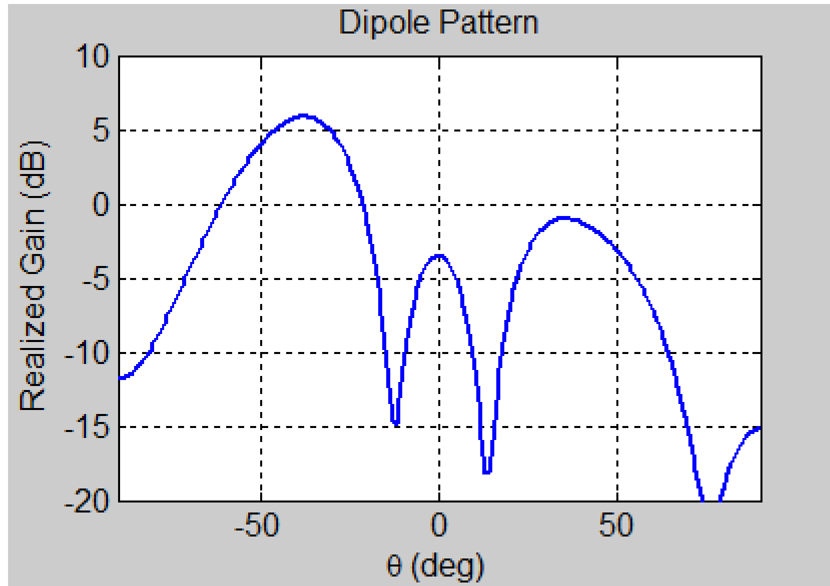
*All labels in **mm**



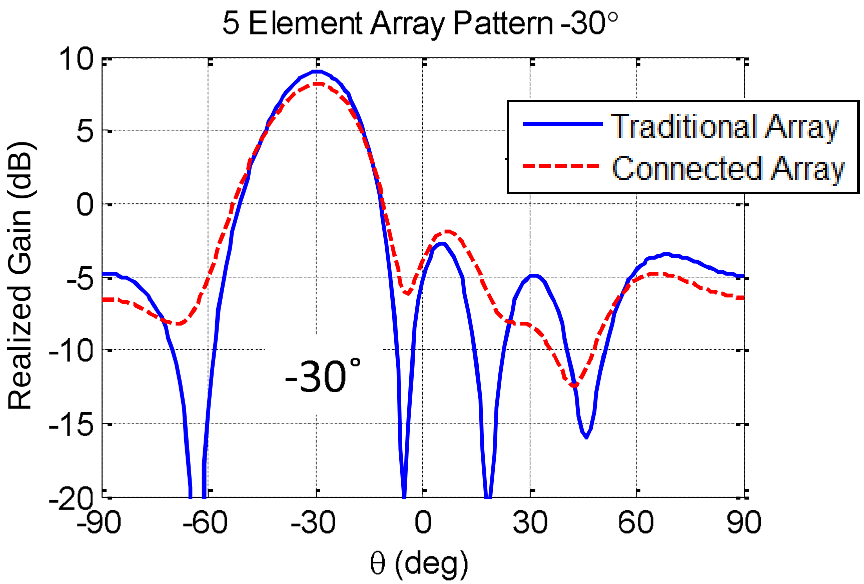


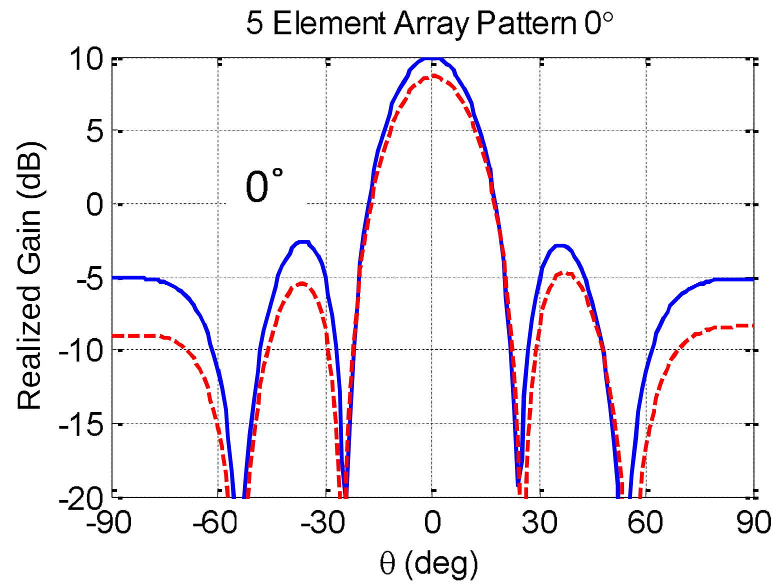
λ @ 40GHz = 7.5mm

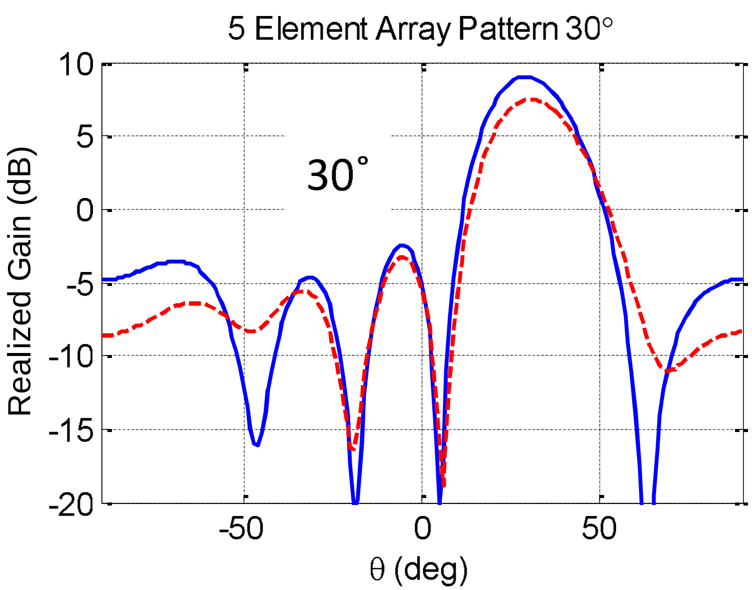


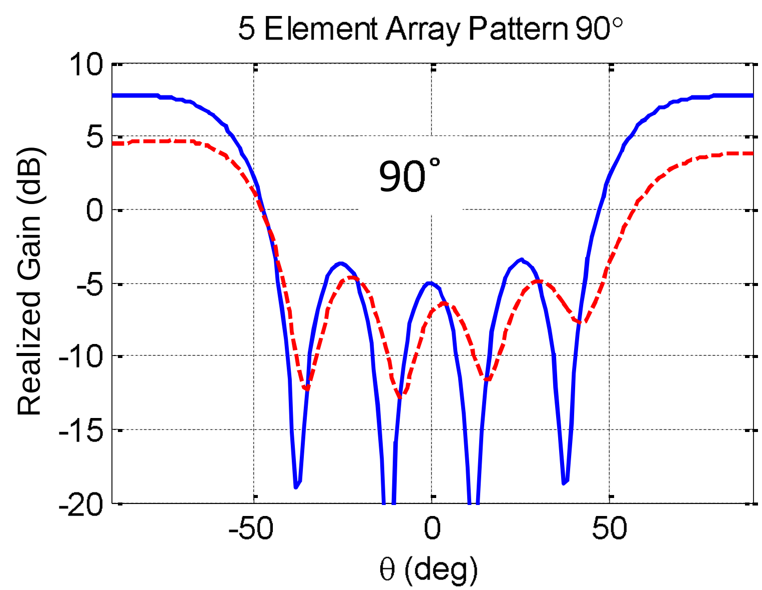


Traditional Array vs. Connected Array

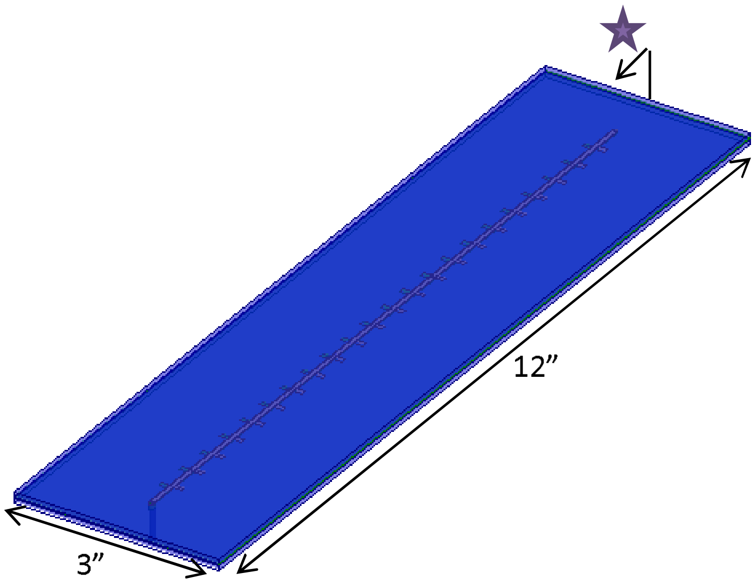


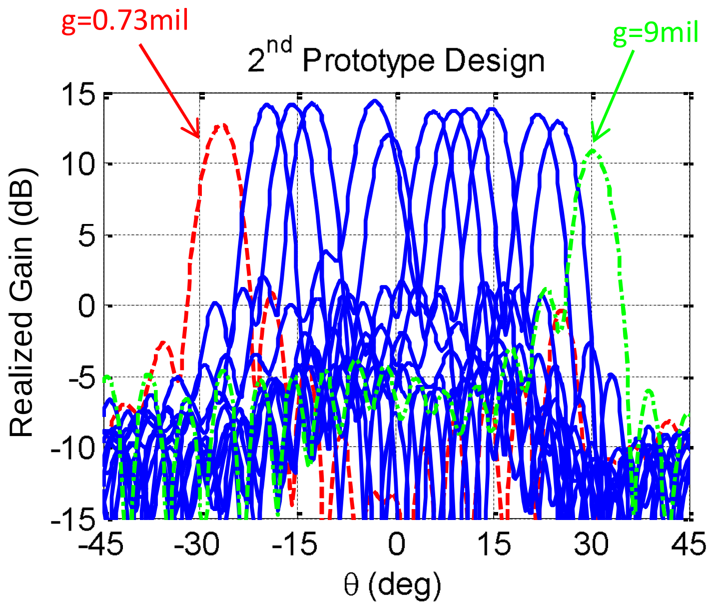


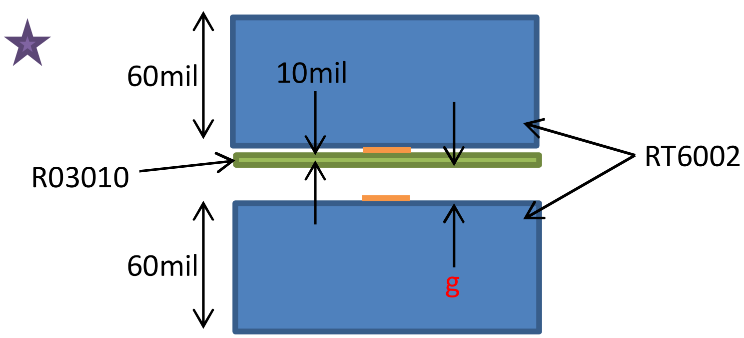




22 Element Prototype Design



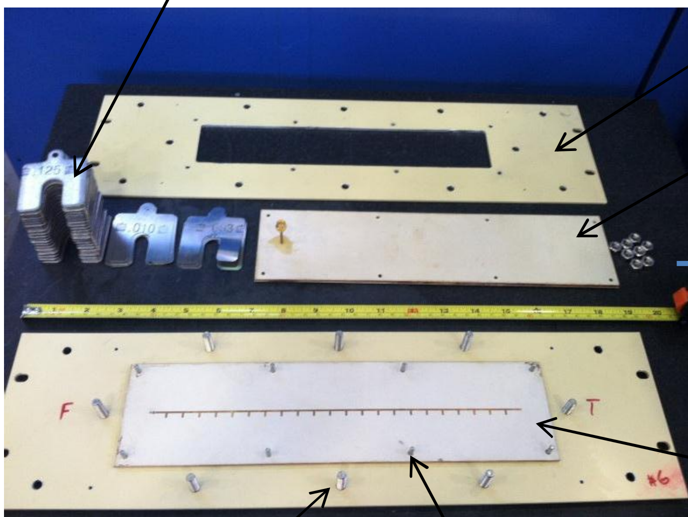




Practical Transmission Line Design
- Circuit printed on two 60mil thick RT6002 boards
  - RO3010 becomes ripply when unsupported
- RO3010 material bonded to inside of one of boards

Assembly of Prototype

Spacing Shims



Compressing Frame

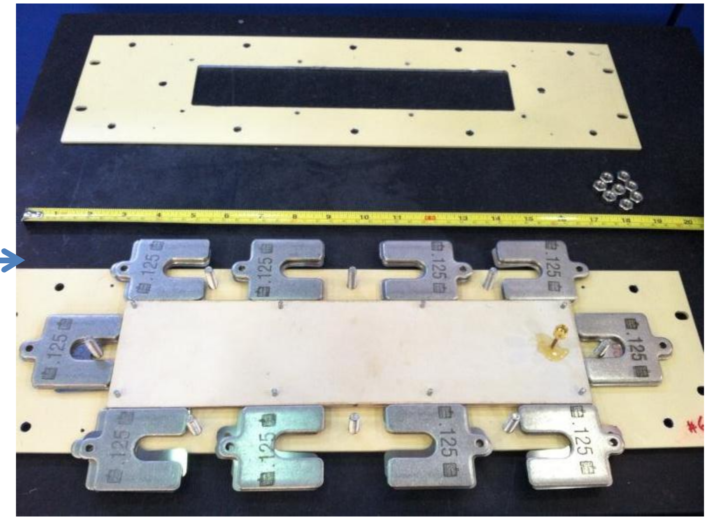
Bottom Dielectric

Top Dielectric

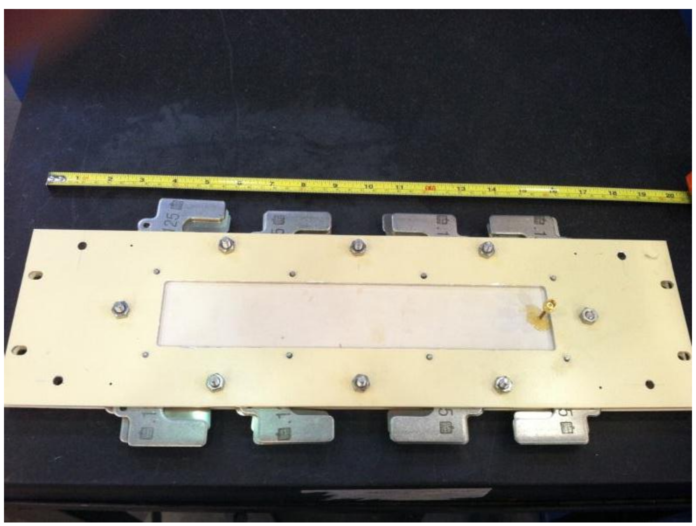
Tightening Bolts

Alignment Pins

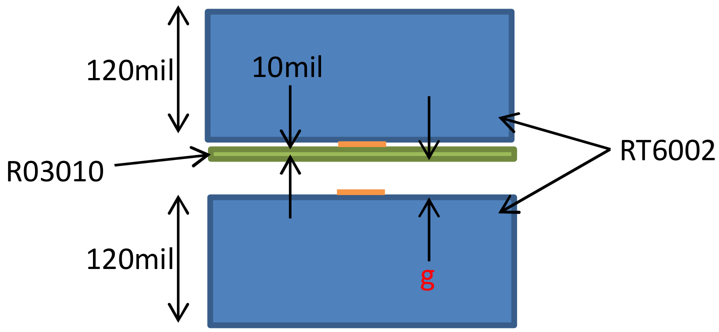
Fit top dielectric on with shims as spacers

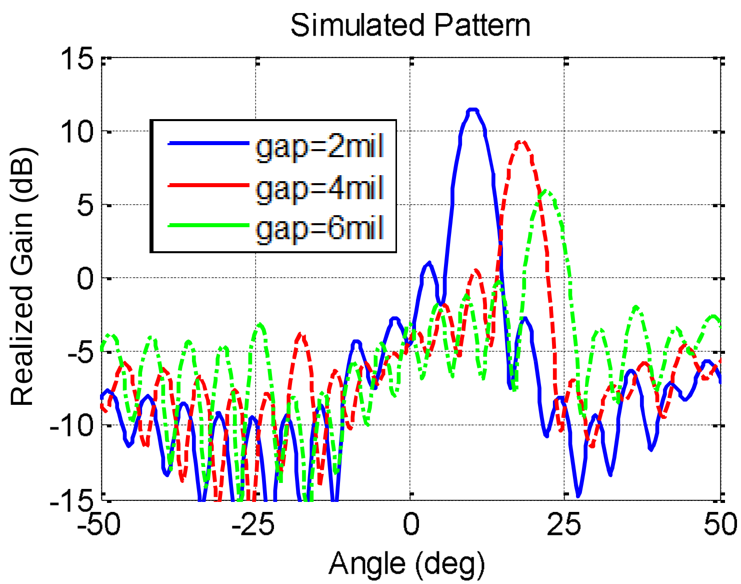


Pinch together two boards with metal frames

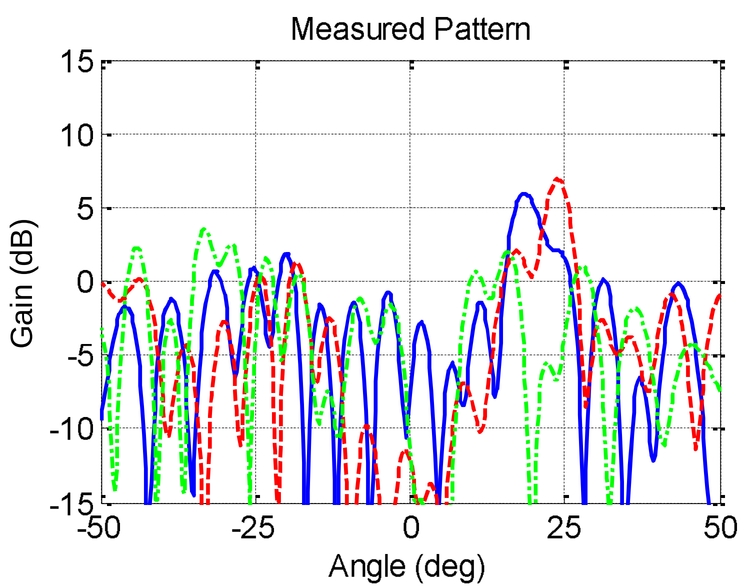


Results





- Scanning Observed
- Achieving gap imprecise
  - Patterns shifted
  - Gain Lowered
- Ways to achieve gap being devised



Future Work

2-D Scanning

- *One feed*
- *Independent control of each scanning axis*
    - Hard with current transmission line

Transmission Line Design

- *Independent control of*
    - Wave Velocity
    - Impedance