2D Traveling Wave Array Employing a Trapezoidal Dielectric Wedge for Beam Steering

By: Nicholas K. Host\textsuperscript{1}, Chi-Chih Chen\textsuperscript{1}, John L. Volakis\textsuperscript{1}, Félix A. Miranda\textsuperscript{2}

\textsuperscript{1}ElectroScience Laboratory, The Ohio State University, Columbus, OH
\textsuperscript{2}NASA Glenn Research Center, Cleveland, OH
This presentation addresses the progress made so far in the development of an antenna array with reconfigurable transmission line feeds connecting each element in series. In particular, 2D traveling wave array employing trapezoidal Dielectric Wedge for Beam Steering will be discussed. The presentation includes current status of the effort and suggested future work. The work is being done as part of the NASA Office of the Chief Technologist’s Space Technology Research Fellowship (NSTRF).
Acknowledgement

This work was supported by a NASA Office of the Chief Technologist’s Space Technology Research Fellowship (NSTRF), NASA Grant #NNX11AN16H
Current Technologies

Mechanically Scanned

• Simple
• Inexpensive
• Slow
• Rudimentary capabilities

Electronically Scanned

• Advanced capabilities
• Fast
• Expensive
• Complex

Design Goals:

• Reduce Complexity
• Reduce Weight
  ▪ Large contributions for both come from the backend
• Reduce Cost

Methodology:

• Replace backend with simpler feeding mechanism
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

By changing $\phi$ (through change of $k_{eff}$) scanning is accomplished:

Motor to move sheets closer or farther apart
Needed Transmission Line Agility

\[ \phi = f(d, k_{\text{eff}}) \]

For \( d = 0.4\lambda \) and \( \frac{k_{\text{eff}}}{k_0} = 5 \) \( \Rightarrow \theta = 0^\circ \)

For \( \theta = -60 \) to 60 at \( d = 0.25\lambda \) \( \Rightarrow 3.1 \leq \frac{k_{\text{eff}}}{k_0} \leq 4.9 \)
Achieving Scanning

Scanning is achieved with one mechanical motion and no phase shifters.
Comparison of Technologies

- Simple
- Inexpensive
- Slow
- Rudimentary capabilities

- Simple
- Inexpensive
- Fast

- Advanced capabilities
- Fast
- Expensive
- Complex

The technology is a compromise between capability and cost
**Achievable $k_{eff}$ Range - $\varepsilon_r = 25$**

### Variable Parallel Plates

<table>
<thead>
<tr>
<th>Geometry</th>
<th>Geometry – Fine Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Image of Variable Parallel Plates" /></td>
<td><img src="image2.png" alt="Image of Geometry – Fine Details" /></td>
</tr>
</tbody>
</table>

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

---

### Scan Angle vs. $k_{eff}$ and Element Spacing

- ![Graph of Scan Angle vs. $k_{eff}$ and Element Spacing](image3.png)

---

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

- ![Graph of $k_{eff}$ Range - $\varepsilon_r = 25$](image4.png)

- **Variable Parallel Plates**
  - ![Image of Variable Parallel Plates](image1.png)
- **Geometry – Fine Details**
  - ![Image of Geometry – Fine Details](image2.png)
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

1. Pinch together two boards with metal frames.
2. Fit top dielectric on with shims as spacers.
3. Tightening Bolts
4. Spacing Shims
5. Alignment Pins
6. Compressing Frame
7. Bottom Dielectric
8. Top Dielectric

- Metal plates used to ensure rigidness
- Bolts used to squeeze together
- Spacers to achieve gap
Validation

- Scanning Observed
- Achieving gap imprecise
  - Patterns shifted
  - Gain Lowered
CPS Line

**Design**
- TMM 4
- TMM 13i
- 50mil gap
- 100mil height

**Operation**
- Field mostly in dielectric $\rightarrow$ High $\varepsilon_{eff}$
- More field in air $\rightarrow$ Low $\varepsilon_{eff}$

**Graph**
- Change of $k_{eff}$ as gap increased
- $k_{eff}/k_0$ vs Gap (mil)
- Scanning achieved over 60mil rather than 10mil
Prototype Pieces
Simulated vs. Measured

Simulated Scan Patterns

Realized Gain (dB)

$\vartheta$ (deg)

Simulated vs. Measured

Realized Gain (dB)

$\vartheta$ (deg)
Simulating Known Differences

Simulated with known differences

- Ridge dimensions
- Overetch

Reduced scan range

Realized Gain (dB)

Similar to measured
Square Insert Parallel Plate TL

Improvements
• Simpler fabrication
• Built in insert clearance
• Increased $k_{eff}$ control

Operation
• $k_{eff}$ dependent on air to dielectric ratio
• Insert is retracted to induce scanning
Comparison of TL Designs

Graph showing the comparison of TL designs with different air gaps (g mils) and effective keff/ke0 ratios. The designs include Parallel Plate, Angled Insert CPS, Square Insert PP - Ka, and Angled Insert CPS - Ka.

Diagram illustrating the dimensions and configurations of TMM 13i, TMM4, RT6002, TMM3, and PEC layers with specific air gaps and material thicknesses.
Dipole Capacitive Coupling

Excitation via coupling gap, $P$

Control aperture excitation via coupling gap, $P$
$P_1 = 10\text{mil}, P_{47} = 2\text{mil}$

\[ P_n = \frac{A}{n^\alpha} + B \]

* $A$ and $B$ determined by choice of $P_1$, $P_{47}$, and $\alpha$
\( \alpha = 0.2, P_{47} = 2\text{mil} \)

\[ P_n = \frac{A}{n^\alpha} + B \]

* \( A \) and \( B \) determined by choice of \( P_1, P_{47}, \) and \( \alpha \)
Mathematical Array Weighting

Array characteristics
- Kaiser window used for weighting profile
- 47 Elements
- $\theta_{max} = -20^\circ$

Realized Gain (dB)

Coupled Energy (dB)

$SLL = -20 dB$

$SLL = -25 dB$

$SLL = -30 dB$

Desired excitation profile
Double Equation Based Taper

Try two different Tapers

Excitation Taper responds as expected

SLL = $-16.6\, dB$

SLL = $-17.4\, dB$

SLL = $-20\, dB$
Conclusions

Novel Phased Array Feeding Topology
- Low Complexity
- Low Weight
- Low Cost

Parallel Plate Transmission Line
- Large $k_{eff}$ range
- Great $k_{eff}$ sensitivity
  - Degraded performance

Coplanar Stripline
- $k_{eff}$ control
- Successful prototype
  - Smaller scan range
    - Manufacturing error
    - Simulation Validation

Square Insert PPTL
- $\uparrow k_{eff}$ control
- Easier fabrication
- Sidelobe control
Future Work

Finish planar array
- 47x47 element array
- Ka-Band (25.5-27GHz design frequency)
- Ability to scan in both elevation and azimuth directions
  - ±30° in both directions
- Novel feeding scheme to reduce
  - Weight
    - 250 grams (not including excitation)
  - Complexity
    - 1 excitation and 2 independent phase controls
  - Cost
    - (1) 18”x12”x0.025” Roger’s TMM 3 board
    - (1) 18”x12”x0.125” Roger’s TMM 13i board
    - Actuators
    - Excitation
Questions?