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

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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

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Current Technologies

Mechanically Scanned

- Simple
- Inexpensive
- Slow
- Rudimentary capabilities

Electronically Scanned

- Advanced capabilities
- Fast
- Expensive
- Complex

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*
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

Motor to move sheets closer or farther apart

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

Field mostly in air, so low $\varepsilon_{eff}$

Field mostly in dielectric, so high $\varepsilon_{eff}$
Needed Transmission Line Agility

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

For $d = 0.4\lambda$ and $\frac{k_{\text{eff}}}{k_0} = 5$, $\theta = 0^\circ$

For $\theta = -60$ to 60 at $d = 0.25\lambda$, Need $3.1 \leq \frac{k_{\text{eff}}}{k_0} \leq 4.9$
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>
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</thead>
<tbody>
<tr>
<td><img src="image1" alt="Diagram" /></td>
<td><img src="image2" alt="Diagram" /></td>
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</tbody>
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#### Scan Angle vs. $k_{eff}$ and Element Spacing

- **Strip Spacing** $\leq 0.40\text{mm (}\lambda/20@40\text{GHz)}$
  - $t=0.1\text{mm case} \rightarrow$ 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

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

- $t=0.05\text{mm} \quad X: 0.2 \quad Y: 1.791$
- $t=0.10\text{mm} \quad X: 0.2703 \quad Y: 1.476$
22 Element Prototype Design

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

- 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 length

**Operation**

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

**Change of $k_{eff}$ as Gap in Increased**

- Scanning achieved over 60mil rather than 10mil

<table>
<thead>
<tr>
<th>$k_{eff}/k_0$</th>
<th>Gap (mil)</th>
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<tbody>
<tr>
<td>2.5</td>
<td>30</td>
</tr>
<tr>
<td>2.25</td>
<td>40</td>
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<tr>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td>1.75</td>
<td>60</td>
</tr>
<tr>
<td>1.5</td>
<td>70</td>
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<tr>
<td>1</td>
<td>80</td>
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<td></td>
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</table>
Simulated vs. Measured

Simulated Scan Patterns

Realized Gain (dB)

$\theta$ (deg)

Simulated Scan Patterns

Realized Gain (dB)

$\theta$ (deg)
Simulating Known Differences

- Ridge dimensions
- Overetch

Simulated with known differences
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

- Parallel Plate
- Angled Insert CPS
- Square Insert PP - Ka
- Angled Insert CPS - Ka

Graph showing the comparison of TL designs with varying air gaps (mils).

Diagram illustrating different TL designs:
- TMM 13i
- TMM4
- RT6002
- R03010
- PEC
- TMM13i

Metrics and dimensions:
- 150mil
- 60mil
- 10mil
- 5mil
- g
- 75mil
- 50mil
- 25mil
- 5°
Dipole Capacitive Coupling

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

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

\[ D = -0.5 \]
\[ D = 0.2 \]
\[ D = 1 \]
\[ D = 2 \]

Graphs showing:
- Realized Gain (dB)
- Coupled Energy (dB)

* \( A \) 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 \( P_1, P_{47}, \text{and} \ \alpha \)
Mathematical Array Weighting

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

desired excitation profile

$\mathcal{R} = -\sqrt{2}\beta_0$
$\mathcal{R} = -\sqrt{3}\beta_0$
$\mathcal{R} = -2\beta_0$
Double Equation Based Taper

Try two different Tapers

Excitation Taper responds as expected

SLL = –16.6dB

SLL = –17.4dB

SLL = –20dB
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
- ↑ $k_{eff}$ 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
  o ±30° in both directions
• Novel feeding scheme to reduce
  o Weight
    ▪ 250 grams (not including excitation)
  o Complexity
    ▪ 1 excitation and 2 independent phase controls
  o Cost
    ▪ (1) 18”x12”x0.025” Roger’s TMM 3 board
    ▪ (1) 18”x12”x0.125” Roger’s TMM 13i board
    ▪ Actuators
    ▪ Excitation
Questions?