Near Earth Propagation with Arbitrary Antenna Patterns

Kyle L. Labowski
Christopher W. Penney
R. Ryan Ohs
Ruth S. Belmonte
Background on MWFDTD

• Moving Window Finite Difference Time Domain
  – Applies material properties to 2-D Yee cell problem space
    • Terrain Profile, dielectrics, etc
  – Solves Maxwell’s Equations over entire problem space
  – Excites model and records response
• This presentation describes work performed under sponsorship of NRL to develop the capability to model arbitrary transmitting antennas within MWFDTD
Issues

• FDTD is mainly used to physically model an antenna
  – 2-D or 3-D model set up with dielectric properties
  – Model analyzed for time domain response
    • SWR, Input resistance, Far Field Pattern, Near Field, etc.

• MWFDTD does not account for non-dipole antennas
  – Would require actual antenna to be modeled
  – Very fine grid required
  – Time lost making sure antenna is ‘correct’ before propagation down range

• The imported pattern is gain at an angle
  – Antenna model not present to shape the energy distribution
  – Near field data not present
Approach

- Apply Woodward Lawson Array Synthesis technique to 2-D FDTD space
- Approach is well documented in antenna literature for pattern synthesis
- Basic idea:
  - Take in an antenna pattern slice
  - Process the pattern strength at each angle off of the vertical axis to determine the current at the transmitter location over some aperture length (further explanation will follow)
  - Set the fields along a vertical line at the transmitter location based on the calculated current
Woodward-Lawson Sampling

- The sampling of the pattern is determined by the desired aperture size
  - Larger than one wavelength
  - Testing revealed decent results at three wavelengths
  - $L$ – length of aperture in wavelengths
  - Number of samples = $2L + 1$

- $\theta_m = \arccos(m\lambda/L)$; $m=0, 1, 2, \ldots$
  - $\theta_m$ - Pattern sample angle
  - $B_m$ - Value of pattern at angle

- For example:
  - $L=3\, \lambda$ aperture; 7 samples
  - $\theta_m = \arccos(m\, \lambda/(3\, \lambda))$
  - $\theta_m = 0, 48.79, 70.53, 90, 109.47, 131.81, 180$
Woodward-Lawson Aperture

- $B_m$-match point at angle $\theta_m$ (green line)
- The resulting pattern (magenta line) is thought of as a summation of individual sinc functions (red Lines)
- Sampling focuses on main beam
  - Larger aperture means more main beam samples
- The equation for the estimated resulting pattern $S_m(\theta)$ is:

$$S_m(\theta) = \sum_{m=-M}^{M} B_m \left( \frac{\sin \left( \frac{k l}{2} \left( \cos \theta - \cos \theta_m \right) \right)}{\frac{k l}{2} \left( \cos \theta - \cos \theta_m \right)} \right)$$
Current Distribution

- The sampled points determine the current across the aperture, which is the source excitation:

\[ I(z') = \frac{1}{l} \sum_{m=-M}^{M} B_m e^{-j k z' \cos(\theta_m)} \]
Strengths and Weaknesses

**Pros:**
- Method established in the literature
- Recreates the main beam well without requiring a huge aperture
  - Initial testing shows good results with 3 $\lambda$ array
  - Assuming main beam primary concern for down range propagation
- Relatively simple to implement

**Cons:**
- Does not reconstruct side lobes well
- Requires a larger aperture for more resolution
- Creates an aperture larger than original antenna
XFDTD Results Rectangular Horn

Woodward Results - Red

Desired Pattern - Blue

- Woodward Lawson method implemented in XFDTD 7
- Simulation Implemented using waveguides (aperture antenna)
- Half Wavelength separation
- Total length of array $10 \lambda$
XFDTD Results Rectangular Aperture

Woodward Results - Red

Desired Pattern - Blue

- Woodward Lawson method implemented in XFDTD 7
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XFDTD Results Circular Aperture

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- Woodward Lawson method implemented in XFDTD 7
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MWFDTD Results Antenna on Humvee

Woodward Results - Red

Desired Pattern - Blue

- Woodward Lawson method implemented in 2-D MWFDTD
- Simulation implemented using 2-D waveguides (aperture antenna)
- Half Wavelength separation
- Total length of array 10 \( \lambda \)
MWF DTD Results Circular Aperture

Woodward Results - Red
Desired Pattern - Blue

- Woodward Lawson method implemented in 2-D MWF DTD
- Simulation Implemented using 2-D waveguides (aperture antenna)
- Half Wavelength separation
- Total length of array 10 \( \lambda \)
MWF DTD Results Rectangular Horn

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Summary

• There are standard approaches to applying an arbitrary far field antenna pattern to a 2-D FDTD grid

• Antenna Synthesis methods allow the reproduction of arbitrary antenna patterns in the 2-D FDTD framework
  – Main beam gain is reproduced
    • Important for down range propagation
  – Side lobes not reproduced as well
    • Depends on aperture size – larger aperture = more sample points