Meander Line Antennas for RF and Wireless Communications

By

Chun-Wen Paul Huang, Atef Z. Elsherbeni, Jiang-Bin James Chen, and Charles E. Smith

Electrical Engineering Department
The University of Mississippi
MEANDER LINE ANTENNAS

- Introduction
- Methodology
  FDTD with Perfectly Matched Layer (PML)
- Verifications
- Results
- Conclusions
Advantages of Printed Antenna Over Wire Antenna in PCS

• Small size

• Light weight

• Better integration with the interior circuitry

• Low fabrication cost

• Low specific absorption rate (SAR)
Recent Applications of Internal Printed Antennas

Cordless Phone

Wireless Data Communications

Introduction and Designs Goals

• Small size
• Easily fabrication
• Operating frequency between 0.9-2.5 GHz
• 50 Ohm input impedance
• Dual or multiple operating bands
• Circularly polarized
• Omidirectional radiation pattern
• Wide band
Proposed Designs

Unilaterally printed meander line antenna

Bilaterally printed meander line antenna with meander extension
Methodology and Analysis procedure

_methodology_

The Finite Difference Time Domain Features
- Perfectly Matched Layer (ABC)
- Voltage Source Modeling (Excitation)
- Voltage and Current Sampling for Impedance Computation
- Near-to-far Field Frequency Domain Transformation

_analysis procedures_

- Vary the Lengths or Material Parameters One at a Time
- Apply Trend Lines for Obtaining Empirical Expressions
Resistive Voltage Source Model

\[ \nabla \times H = \frac{\partial D}{\partial t} + J_c + J_L \]

\[ J_L = \frac{I_z}{\Delta x \Delta y} \]

\[ I_{z, n+1}^{i, j, k} = \frac{\Delta z}{2R_s} \left( E_{z, n+1}^{i, j, k} + E_{z, n}^{i, j, k} \right) + \frac{V_{s, n+1}^{i, j, k}}{R_s} \]

\[ E_{z, n+1}^{i, j, k} = \left[ 1 - \frac{\Delta t \Delta z}{2R_s \varepsilon_o \Delta x \Delta y} \right] E_{z, n}^{i, j, k} \]

\[ + \left[ \frac{\Delta t}{\varepsilon_o} \frac{\Delta t \Delta z}{1 + \frac{\Delta t \Delta z}{2R_s \varepsilon_o \Delta x \Delta y}} \right] \]

\[ + \left[ \frac{\Delta t}{R_s \varepsilon_o \Delta x \Delta y} \right] \left[ \frac{\Delta t \Delta z}{1 + \frac{\Delta t \Delta z}{2R_s \varepsilon_o \Delta x \Delta y}} \right] \frac{V_{s, n+1}^{i, j, k}}{ \Delta y} \]

\[ H_{y, n+1}^{i, j, k} - H_{y, n+1}^{i-1, j, k} = \frac{\Delta z}{\Delta x} \]

\[ H_{x, n+1}^{i, j, k} - H_{x, n+1}^{i, j-1, k} = \frac{\Delta x}{\Delta y} \]
**S\textsubscript{11} Calculation**

**Method**

- **Voltage or Current ratio**
- **Power ratio**
- **Impedance Method**

**Formulation**

\[
S_{11} = \frac{V^{\text{ref}}}{V^{\text{inc}}}
\]

\[
S_{11} = -\frac{I^{\text{ref}}}{I^{\text{inc}}}
\]

\[
|S_{11}| = \left|\frac{P^{\text{ref}}}{P^{\text{inc}}}\right|
\]

\[
S_{11} = \frac{(Z_{\text{in}} - Z_{o})}{(Z_{\text{in}} + Z_{o})}
\]

Voltage and Current Sampling Procedure

Voltage

\[ V(t) = -\int_{a}^{b} \vec{E}(t) \cdot d\vec{l} \]

\[ \equiv -\sum_{i=1}^{N} \vec{E}_i(t) \cdot d\vec{l}_i \]

Current

\[ I(t) = -\oint_{cdef} \vec{H}(t) \cdot d\vec{l} \]

\[ \equiv -\left[ \vec{H}_{cd}(t) \cdot d\vec{l}_{cd} + \vec{H}_{de}(t) \cdot d\vec{l}_{de} ight. \\
\left. + \vec{H}_{ef}(t) \cdot d\vec{l}_{ef} + \vec{H}_{fc}(t) \cdot d\vec{l}_{fc} \right] \]

Input Impedance

\[ Z_{in}(f) = \frac{V(f)}{I(f)} \]

Return Loss

\[ RL_{dB}(f) = 20\log \left| \frac{Z_{in}(f) - Z_o}{Z_{in}(f) + Z_o} \right| \]
Computation of Input Impedance

(1) \[ Z_1(w) = \frac{V^n_k(w)}{I^{n+1/2}_k(w)} \]

(2) \[ Z_2(w) = \frac{2V^n_k(w)}{I^{n+1/2}_k(w) + I^{n+1/2}_{k-1}(w)} \]

(3) \[ Z_3(w) = \frac{2V^n_k(w)e^{-j\omega \Delta t/2}}{I^{n+1/2}_k(w) + I^{n+1/2}_{k-1}(w)} \]

(4) \[ Z_4(w) = \frac{V^n_k(w)e^{-j\omega \Delta t/2}}{\sqrt{I^{n+1/2}_{k-1}(w)I^{n+1/2}_k(w)}} \]

Modified expressions based on
J. Fang and D. Xeu, MWGWL vol. 5, no. 1, pp. 6-8, 1995
Frequency Domain Near Field to Far Field Transformation

Time domain

Equivalent $J_S, M_S$

DFT

Frequency domain

Equivalent $J_S, M_S$

Far field $E_\theta, E_\phi$

$$J_S(t), M_S(t)$$

$$J_S(w_1), M_S(w_1)$$

$$N = \iint_s J_s e^{jk \tilde{r}' \cos \psi} \ d s'$$

$$L = \iint_s M_s e^{jk \tilde{r}' \cos \psi} \ d s'$$

$$E_\theta (\omega_1, \theta, \phi) = -\frac{jke}{4\pi \frac{r}{r}} (L_\phi + \eta_0 N_\theta)$$

$$E_\phi (\omega_1, \theta, \phi) = +\frac{jke}{4\pi \frac{r}{r}} (L_\theta - \eta_0 N_\phi)$$
Verification for The $|S_{11}|$
Calculation Procedure

Radiation Pattern of a Quarter Wavelength Dipole Antenna

\( \theta \)-Plane  
(x-z plane)

\( \phi \)-Plane  
(x-y plane)
2W=1.22m, f = 1 GHz.
Δx=Δy=15.25mm, Δz=15mm
The length of monopole antenna is 75mm.
**Numerical Results**

**Design Parameters**

- Dielectric Constant
  \[ \varepsilon_r = 2.2 - 10.2 \text{ (with } \sigma = 0.0034558) \]
- Thickness \( t_s = 0.794 - 6.35 \text{ mm} \)
- Line Width \( S = 1 \text{ mm} \)
- Substrate Width \( W_s = 11 - 41 \text{ mm} \)
- \( e_1 = e_2 = 3 \text{ mm} \)
- Ground plane: \( 59 \times 25.4 \text{ mm}^2 \)
Solution Method

Solution Technique: FDTD
Excitation: A resistive voltage source
Waveform: Gaussian pulse
ABC: Berenger’s PML
Magnitude of Reflection Coefficients of Meander Line Antennas Versus $L_{ax}$

- **28 mm Meander Line Antenna**
- **46 mm Meander Line Antenna**
- **73 mm Meander Line Antenna**

The University of Mississippi
Input Impedance of Meander Line Antenna With Dual Sleeves

Real Part

Imaginary Part
The Resonant and Operating Frequencies Versus $L_{ax}$

- **Empirical Formula**

\[
\begin{align*}
    f_{op1} &= 10.03 - 2.0143 \ln(L_{ax}) \\
    f_{op2} &= 18.152 - 3.7251 \ln(L_{ax})
\end{align*}
\]
The Resonant Impedance and Operating Bandwidth Versus $L_{ax}$

**Empirical Formula**

\[
R_{o3} = 9.8226 \times 10^{-8} (L_{ax})^6 - 2.5210 \times 10^{-5} (L_{ax})^5 + 0.0025026 (L_{ax})^4 + 0.0096 (L_{ax})^2 - 0.7454 (L_{ax}) + 49.261 - 0.11898 (L_{ax})^3 + 2.6549 (L_{ax})^2 - 20.48 (L_{ax})
\]
The Effects of Slab Permittivity $\varepsilon_r$

($L_{ax} = 73$ mm and Dual 37 mm Sleeves)
The Effects of Slab Thickness $t_s$
$(L_{ax} = 73 \text{ mm and Dual 37 mm Sleeves})$

**Empirical Formula**

\[
\begin{align*}
    f_{op1} &= 1.5814 - 0.064 \ln(t_s) \\
    f_{op2} &= 2.5353 - 0.0577 \ln(t_s) \\
    R_{o3} &= -0.012729(t_s)^6 + 0.15862(t_s)^5 - 0.51952(t_s)^4 \\
        &\quad + 0.84411(t_s)^2 + 46.647 \\
    R_{o5} &= 0.004196(t_s)^6 - 0.0051357(t_s)^5 + 0.16667(t_s)^4 \\
        &\quad - 0.47453(t_s)^2 + 46.998
\end{align*}
\]
The Effects of Slab Width $W_s$
($L_{ax} = 73$ mm and Dual 37 mm Sleeves)

\*Empirical Formula\*

\[
\begin{align*}
    f_{op1} &= 1.5262 - 0.0193 \ln(W_s) \\
    f_{op2} &= 2.6080 - 0.0552 \ln(W_s) \\
    R_{o3} &= 1.4673 \times 10^{-7} (W_s)^6 - 1.6513 \times 10^{-3} (W_s)^5 + 5.8583 \times 10^{-4} (W_s)^4 \\
         &\quad - 0.001680 l(W_s)^3 - 0.33882l(W_s)^2 + 7.0505l(W_s) \\
    R_{o5} &= -1.0341 \times 10^{-6} (W_s)^6 - 1.4712 \times 10^{-4} (W_s)^5 - 8.2505 \times 10^{-3} (W_s)^4 \\
         &\quad + 0.2304 l(W_s)^3 - 3.3021l(W_s)^2 + 21.699l(W_s)
\end{align*}
\]
Radiation Directivity of Antenna
\( (L_{ax} = 73 \text{ mm and Dual 37 mm Sleeves}) \) at 1.5 GHz

X-Y Plane  
X-Z Plane  
Y-Z Plane
Radiation Directivity of Antenna
($L_{ax} = 73$ mm and Dual 37 mm Sleeves) at 2.48 GHz

**X-Y Plane**

**X-Z Plane**

**Y-Z Plane**
Future Work

1. Polarization.
2. Larger bandwidth.
3. Multiple operating frequencies.
Conclusions

The meander line antenna with dual sleeves is suitable for the 2nd and 3rd generation personal wireless applications.

Designs for lower frequency PCS applications can be achieved by increasing $L_{ax}$ and the dielectric constant of the substrate.

The input impedance can be tuned to match the feeding network by adopting dual sleeves.

The meander line antenna with dual sleeves provides a wide bandwidth of 120-340 MHz.