A Wideband Multilayer Microstrip Patch Antenna for Telemetry Applications

BAZEYI HATEGEKIMANA
JEYASINGH NITHIANANDAM
Electrical and Computer Engineering Department
Morgan State University
1700 East Cold Spring Lane
Baltimore, MD 21251, USA
bhateg@hotmail.com; jeyasingh.nithianandam@morgan.edu

Abstract: This research paper reports a design of a wide band microstrip patch antenna (MSPA) for L frequency band. The results reported here were obtained using a full wave finite element computer simulation of the antenna with Ansoft HFSS software. The antenna uses a stacked dielectric layer structure and has desired wide bandwidth. In the design of the wide band antenna feed position of the coaxial connector probe, widths of square patches and height of a foam layer in the multilayer were varied and optimized to achieve desired performance for the antenna. A 10-dB bandwidth of 16% was achieved for the antenna in the L-band.

Key-Words: Bandwidth, optimization, probe feed, parasitic patch, driven patch, foam, multilayer patches.

1. Introduction

Microstrip patch antennas have various system applications. Some of the applications are radar systems, missiles telemetry systems, aircraft communications systems, satellite communications and mobiles handsets. Microstrip Patch Antennas (MSPAs) have the advantage of small size and low profile allowing them to be easily integrated in the body of aircrafts, missiles or computers. Microstrip patches can be fabricated easily at low cost. The disadvantage of a MSPA is its small bandwidth of 1 to 2% around the resonant frequency. Analysis and design of wideband low profile antennas are currently an important research area.

This work consists of a MSPA design for Integrated Network Enhanced Telemetry (INET) program that requires a wideband patch antenna in the L frequency band. We present a multilayer or stacked layer structure that involves a primary patch radiator element and a parasitic patch element. We used ansoft HFSS software simulation to achieve a design that provides a wide band behavior in the L frequency band.

2. MSPA Design

The stacked patches analyzed in this project are made of a driven and a parasitic square patches with a Rohacell foam in between them. The sides of the patches are basically half wavelength of the operating frequency. This first approximation of MSPA dimensions emanates from basic equations for microstrip patch antenna design. However the presence of additional dielectric substrates above the main patch causes a shift of the operating frequency.
Many researchers have addressed the problem of effective dielectric constant of multilayer structures for antenna applications. Bernard and Toussignant [1] utilized conformal mapping technique to obtain expressions for the effective filling fractions and effective dielectric constant. Their work is applied to a multilayer antenna structure in figure 1 and used it to compute the dimensions of the patches.

![Multilayer Patch Antenna](image)

Figure 1. A schematic diagram of a multilayer patch antenna

### 2.1 Effective dielectric constant and filling fractions $q_1$, $q_2$, $q_3$, $q_4$

The effective dielectric constant and width of the patches are given by the following:

\[
\varepsilon_{\text{eff}} = \varepsilon_2 q_{1} + \varepsilon_1 \left( 1 - q_1 \right)^2
\]

\[
\times \left[ \varepsilon_2 g_{2} q_3 + \varepsilon_3 \left( q_3 q_4 + \left( q_3 + q_4 \right)^2 \right) \right]
\]

\[
\times \left[ \varepsilon_2 g_{2} q_3 q_4 + \varepsilon_1 \left( \varepsilon_2 q_3 + \varepsilon_3 q_4 \right) \left( 1 - q_1 - q_4 \right)^2
\]

\[
+ \varepsilon_2 \varepsilon_3 q_4 \left( q_2 q_4 + \left( q_3 + q_4 \right)^2 \right) \right]^{-1}
\]

\[w_{\text{eff}} = \frac{\varepsilon_{\text{eff}}}{\varepsilon_{\text{eff}} - 1} \left[ w + 0.882 h_1 + 0.164 \frac{h_1 (\varepsilon_{\text{eff}} - 1)}{(\varepsilon_{\text{eff}})^2} \right]^{1/2}
\]

\[+ \frac{\varepsilon_{\text{eff}} h_1 (\varepsilon_{\text{eff}} + 1)}{\pi \varepsilon_{\text{eff}}} \left[ \ln \left( \frac{w}{2 h_1} + 0.94 \right) + 1.451 \right]
\]

The filling factors are given by the following expressions:

\[q_1 = 1 - \frac{1}{2} h_1 - \frac{h_1 - v_{\varepsilon} \times \Theta_{\varepsilon}}{w_{\text{eff}}}
\]

\[\Theta_{\varepsilon} = \ln \left[ \pi \frac{w_{\text{eff}}}{h \left( h - \frac{1}{2} \right) + \frac{v_{\varepsilon} \pi}{2 h}} \right]
\]

\[q_3 = \frac{1}{2} h_1 - \frac{v_{\varepsilon} \times \Theta_{\varepsilon}}{w_{\text{eff}}}
\]

\[q_4 = \frac{h}{2 w_{\text{eff}}} \ln \left( \frac{\pi}{2} - \frac{h_1}{2 w_{\text{eff}}} \right)
\]

\[q_2 = 1 - q_1 - q_3 - 2 q_4
\]

\[q_1' = q_1 - q_4
\]

\[q_2' = 1 - q_{1\text{new}} - q_3 - 2 q_4
\]

\[\varepsilon_{\text{eff}} = \frac{2 \varepsilon_{\text{eff}} - 1 + A}{1 + A}
\]

\[A = \left( 1 + \frac{10 h_1}{w_{\text{eff}}} \right)^{1/2}
\]

### 2.2 The Size of the patches

The lengths of a side of the square patches are computed by using the expression (12). $\Delta L$ is given by the expressions from the work of Kirschning and coworkers [2]. $W$ in expression (2) is made to be equal to $L$ because the designed patch has the shape of a square.

\[f_r = \frac{c}{2(L + 2\Delta L)\sqrt{\varepsilon_{\text{eff}}}}
\]
2.3 Electrical displacement $\Delta L$ of an open end microstrip

From reference [2] we have the following expressions

$$\frac{\Delta L}{h} = (\xi_1 \xi_2 \xi_3 / \xi_4)$$  \hspace{1cm} (13)

$$\xi_1 = 0.434907 e^{0.81 \frac{w}{h}} + 0.26 e^{0.8544 \frac{w}{h}} + 0.236$$  \hspace{1cm} (14)

$$\xi_2 = 1 + \frac{w}{h}$$  \hspace{1cm} (15)

$$\xi_3 = 1 + \frac{0.5274 \arctan \left( 0.084 \frac{w}{h} \right)}{\varepsilon_{eff}}$$  \hspace{1cm} (16)

$$\xi_4 = 1 + 0.0377 \arctan \left[ 0.067 \left( \frac{w}{h} \right)^{1.456} \right]$$

$$\times \left\{ 6 - 5 e^{(0.036(1-\varepsilon_{eff}))} \right\}$$  \hspace{1cm} (17)

$$\xi_5 = 1 - 0.218 e^{-7.5 \frac{w}{h}}$$  \hspace{1cm} (18)

2.5 Square Patches

The primary patch element is a square patch and $W=L$ (figure 2). We used a coaxial probe to feed RF signal to the primary patch. The position $X_p$ of the probe on the $X$-axis is calculated by using formulas from reference [3].
3.2 The Stacked Patch Antenna

The antenna was designed by using the substrate RT/duroid 5880 with dielectric constant $\varepsilon_r = 2.2$, loss tangent $\tan\delta = 0.0009$ and thickness $h_1 = 3.175\text{mm}$ for the parasitic and driven patch. The thickness of Rohacell foam is 10mm.

3.3 Calculations and Optimization

The calculations based on the equations (1) to (18) at 1.8 GHz gave the length of a side of the square patch as $L = 53.27\text{mm}$, and the probe position as $X_p = 24.6\text{mm}$ and effective dielectric constant for the dielectric multilayer structure as $\varepsilon_{\text{eff}} = 2.1$.

Numerical computer calculations were made with Ansoft HFSS (figure 3) to find an optimum position of the coaxial probe on the primary patch feed and the length of the square patches elements. The results are shown in figure 4. The sides of the patches were varied from 50mm to 56mm. The probe position was varied from 21mm to 26mm. The values of $L$ and $X_p$ that give the best return loss and bandwidth at $-10\text{dB}$ around 1.8GHz are $L = 53.5\text{mm}$ and $X_p = 25\text{mm}$.

3.4. Results

3.4.1. Optimization

Several curves for the return loss were obtained by varying $L$ and $X_p$ around the calculated values. The results from computations are shown in figure 4.

3.4.2 Return Loss and Bandwidth

The return loss $= -10 \log(|S_{11}|)$ and its value in figure 5 at 1.884 GHz is $-27.3\text{dB}$. The "upper frequency" at $-10\text{dB}$ was found as 1.9452GHz and the "lower frequency" was found as 1.6538GHz. The "center frequency" of the antenna is 1.80GHz and its bandwidth is 291 MHz and it is 16.1% at center frequency.
3.4.3. Radiation Pattern of the MSPA

I) $E_{\theta}$ Field Cut

Figure 6. Radiation patterns at frequency of 1.8 GHz. Dotted curve is plot of $E_{\theta}$ at $\phi = 0^\circ$ and continuous curve is a plot of $E_{\phi}$ at $\phi = 90^\circ$.

II) $E_{\phi}$ Field Cut

Figure 7. Radiation patterns at frequency of 1.8 GHz. Dotted curve is plot of $E_{\phi}$ at $\theta = 0^\circ$ and continuous curve is a plot of $E_{\phi}$ at $\theta = 90^\circ$.

4. Conclusion

The stacked patch antenna was designed using RT/duroid 5880. The substrate chosen has a relatively low dielectric constant $\varepsilon_r = 2.2$ and a height of 3.175mm. By using a low dielectric constant, a thick substrate and thick foam we were able to improve the bandwidth from 1.5% to 16%. The maximum return loss for the designed antennas is around -27dB.

This work was completed under an INET program research contract with "Test and Evaluations" division of DOD, Scientific Research Corporation and Computer Science Corporation.

References:


