L-BAND COPLANAR SLOT LOOP ANTENNA FOR INET APPLICATIONS

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ABSTRACT

In this article we present a design of an L-band slot loop antenna with a dielectric loaded conductor backed coplanar waveguide (CBCPW) feed. The coplanar slot loop antenna has a transmission line resonator in series. We used full wave electromagnetic simulations with Ansoft’s high frequency structure simulator (HFSS) software in the design of the coplanar slot loop antenna. The series transmission line resonator helps to tune the coplanar slot loop antenna and reduce its size. We present here results on return loss and radiations patterns of coplanar slot loop antenna obtained from HFSS simulations.

Key Words: slot loop, coplanar waveguide, return loss, bandwidth, radiation pattern

INTRODUCTION

Phased array antennas that are small in size and weight are needed for aeronautical telemetry applications. Antenna elements such as microstrip patches, dipoles, and slots are large in size at L-band frequencies and they are usually half the size of wavelength of electromagnetic waves at their resonant frequencies. It is desirable to use small size antenna elements that have high gain and high band width in a phased array antenna that would be useful for aeronautical telemetry applications. A coplanar slot loop antenna is smaller in size than a microstrip patch antenna. A slot loop antenna in a coplanar waveguide configuration has bidirectional radiation patterns [1]. Adding a conductor backing to coplanar waveguide would change the radiation pattern of the slot loop antenna. In this paper a novel design of a compact square shaped slot loop antenna that is formed on a dielectric loaded conductor backed coplanar waveguide structure is presented. Full wave finite element electromagnetic simulations were performed on the coplanar slot loop antenna element with Ansoft HFSS software. Calculated return loss and radiation patterns of the coplanar slot loop antenna are presented.
GEOMETRY AND STRUCTURE

The basic building block of coplanar slot loop antenna element is a dielectric loaded conductor backed coplanar waveguide. Figure 1 shows a diagram of a dielectric loaded CBCPW that has finite upper ground planes. This transmission line consists of a substrate of height $h_1$ and relative permittivity of $\varepsilon_{r1}$. A signal conductor line of width $2S$ is sandwiched between two finite ground planes. The distance between the two ground planes is $2(S+G)$. The coplanar transmission line has a bottom ground conductor. The upper ground planes and bottom ground conductor layer are joined using via cylinders. A dielectric material of height $h_2$ and relative permittivity $\varepsilon_{r2}$ covers the two upper ground planes and signal conductor. The permittivity of dielectric cover layer is higher in value than the permittivity of the bottom substrate. In a conventional CBCPW RF power leaks from dominant coplanar waveguide modes to unwanted parallel plate modes. In order to suppress leakage of RF power to parallel plate electromagnetic modes, we used a dielectric cover layer in addition to via cylinders. A Rogers Duroid 5880 substrate of thickness 1.57 mm is used as the bottom substrate and its relative permittivity is $\varepsilon_{r1} = 2.2$ and its loss tangent is $\tan \delta_1 = 0.0009$. A planar dielectric layer without copper cladding is used to cover the upper ground planes and signal conductor in the CBCPW transmission line. The permittivity of dielectric cover layer is $\varepsilon_{r2} = 3.27$ and its loss tangent is $\tan \delta_2 = 0.002$. The thickness of the dielectric cover layer is 0.381 mm.

![Figure 1. Schematic diagram of a dielectric loaded CBCPW.](image)

DESIGN OF A FEED FOR ANTENNA ELEMENT

The effective relative permittivity of the transmission line shown in Fig.1 is given by the following expressions:

$$\varepsilon_{eff} = 1 + q_1(\varepsilon_{r1} - 1) + q_2(\varepsilon_{r2} - 1) \quad (1)$$

$$q_1 = \frac{K(k_1)}{K(k'_1)} \left[ \frac{K(k_1)}{K(k'_1)} + \frac{K(k_0)}{K(k'_0)} \right] \quad (2)$$

$$q_2 = \frac{K(k_2)}{K(k'_2)} \left[ \frac{K(k_2)}{K(k'_2)} + \frac{K(k_0)}{K(k'_0)} \right] \quad (3)$$
Here \( \varepsilon_{r1} \) is relative permittivity of bottom substrate and \( \varepsilon_{r2} \) is relative permittivity of the dielectric layer that covers signal conductor and ground planes of CBCPW. The filling factors for the dielectric loaded CBCPW are \( q_1 \) and \( q_2 \). The functions \( K(k_i) \) with \( i = 0,1,2 \) in equations 1 and 2 are complete elliptic functions of first kind \( K(k_i) \). The arguments of the complete elliptic functions of first kind are given by expressions given below:

\[
k_o = \frac{S}{S+G}
\]

\[
k_1 = \frac{\sinh \left( \frac{\pi S}{2h_1} \right)}{\sinh \left( \frac{\pi(S+G)}{2h_1} \right)}
\]

\[
k_2 = \frac{\sinh \left( \frac{\pi S}{2h_2} \right)}{\sinh \left( \frac{\pi(S+G)}{2h_2} \right)}
\]

The characteristic impedance of a CBCPW loaded with a dielectric layer is given by the expression:

\[
Z_o = \left( \frac{60\pi}{\sqrt{\varepsilon_{reff}}} \right) \left[ \frac{1}{\frac{K(k_1)}{K(k_o)} + \frac{K(k_o)}{K(k_2)}} \right]
\]

These expressions were obtained by conformal mapping method and they are discussed in detail in reference [2].

Matlab software has a subroutine on complete elliptic function of first kind and a Matlab program was developed to perform design calculations for a dielectric loaded CBCPW. A dielectric loaded CBCPW feed with a characteristic impedance of 50 ohm was designed with the Matlab program. A signal conductor of width \( 2S = 12.35 \) mm and a gap with a width of \( G = 1 \) mm provided a characteristic impedance value of 50 ohms for the dielectric loaded CBCPW feed. Effective permittivity of dielectric loaded CBCPW was also calculated and it is \( \varepsilon_{reff} = 3.8 \). The values of \( 2S \) and \( G \) were used in the design of a dielectric loaded CBCPW feed line to a square shaped slot loop radiating element as shown in Fig. 2.
SQUARE SHAPED COPLANAR SLOT LOOP RADIATING ELEMENT

Resonant frequency \( f_{\text{res}} \) of a square shaped coplanar slot-loop antenna depends on the length of its circumference. The wavelength of guided waves in the slot loop radiating element was calculated using an expression given below:

\[
\lambda_g = \frac{c}{f_{\text{res}} \sqrt{\epsilon_{\text{eff}}}}
\]

\[
\epsilon_{\text{eff}} = \frac{\epsilon_{\text{eff}} + 1}{2}
\]

Here \( c \) is the velocity of electromagnetic waves in free space.

A coplanar slot loop antenna with a dielectric loaded CBCPW feed line is shown in Fig. 2. The guided wavelength in the antenna is 121.8 mm when \( f_{\text{res}} = 1.7 \) GHz and \( \epsilon_{\text{eff}} = 2.1 \). The length of an outer side of the square shaped slot loop radiating element is 25 mm. The width of the slot of the loop is 1 mm. The patch region is 24 mm x 24 mm in size. The dielectric loaded CBCPW feed line has a length of 30 mm. A SMA type coaxial connector is fixed to the bottom of the lower substrate. The cylindrical signal conductor of SMA connector is attached to the signal conductor of the dielectric loaded CBCPW feed line and it is at a distance of 5.75 mm from the bottom of the patch enclosed by the square slot loop. The slot loop radiating element with feed transmission line section has an additional dielectric loaded CBCPW transmission line of length 24.25 mm below the SMA connector. This additional dielectric loaded CBCPW transmission line section is in series with the square slot loop antenna and it serves as a resonator. The upper ground plane surrounds completely the dielectric loaded CBCPW transmission line. The slot-loop antenna was printed on 85 mm X 90 mm Rogers Duroid 5880 substrate.

Figure 2. A square shaped slot loop antenna with a dielectric loaded CBCPW feed.
FULL WAVE ELECTROMAGNETIC CALCULATIONS

A detailed study of the square shaped slot-loop antenna with CBCPW feed and a series resonator was carried out by performing full wave finite element electromagnetic calculations using HFSS software. A diagram of the geometry of the setup used in our computer simulations is shown in Fig.3. The upper ground plane of CBCPW structure of the antenna is connected to the bottom ground plane of RT Duroid 5880 substrate by using four copper via cylinders of radius 0.5 mm in the feed region and four additional copper via cylinders in the slot loop element region. The vias along with dielectric loading of the CBCPW feed significantly suppressed excitation and propagation of unwanted parallel plate modes in the antenna structure. Radiation boundary conditions, excitation at SMA connector and a frequency sweep was set up in HFSS software and electromagnetic calculations were performed on the antenna structure in Fig.3.

Figure 3. Diagram of the square shaped slot-loop radiating element with a dielectric loaded CBCPW feed in Ansoft HFSS software.

RESULTS

The return loss as a function of frequency for the square shaped slot-loop antenna is shown in Fig. 4. A plot of real and imaginary parts of input impedance of the coplanar slot loop antenna is shown in Fig.5. The resonant frequency of square shaped slot-loop antenna is 1.7 GHz. and its return loss at the resonant frequency is -21 dB. The coplanar slot loop antenna has a bandwidth of 107.3 MHz at return loss value of -10 dB. The -10 dB bandwidth of the antenna is 6.3%.
Figure 4. Return loss of square shaped coplanar slot-loop antenna as a function of frequency.

Figure 5. Plots of real (green) and imaginary (blue) parts of input impedance of slot-loop antenna.

Far field radiation patterns of the coplanar slot loop antenna were calculated with Ansoft HFSS. Polar plots of $E_\theta$ at $\phi = 0^\circ$ and $\phi = 90^\circ$ are shown in Fig.6. Polar plots of $E_\phi$ at $\phi = 0^\circ$ and $\phi = 90^\circ$ of the antenna are shown in Fig.7.
Figure 6. Calculated $E_\theta$ radiation patterns of coplanar slot loop antenna at $\phi = 0^\circ$ and at $\phi = 90^\circ$ and at 1.7 GHz.

Figure 7. Calculated $E_\phi$ radiation patterns of coplanar slot loop antenna at $\phi = 0^\circ$ and at $\phi = 90^\circ$ and at 1.7 GHz.
DISCUSSION

In order to understand the role of the section of the dielectric loaded CBCPW transmission line that lies below the center of the SMA connector in Fig.2, we plotted electric field vectors at 1.7 GHz on the coplanar antenna printed on the Rogers Duroid 5880 substrate using HFSS. The E-field vector plot showed that this additional transmission line section acts as a resonator. The length of the slot of the resonator section of the transmission line is 60.85 mm and it is half the guided wavelength of EM waves at 1.7 GHz. When the length of the transmission line section was reduced, the resonant frequency of the slot loop antenna increased to slightly higher frequency value in our simulations. The transmission line resonator is useful to tune the resonant frequency of coplanar slot loop antenna.

The sum of the length of the square shaped slot loop and the dielectric loaded CBCPW feed line upto the center of SMA connector is slightly smaller than one guided wavelength at 1.7 GHz. Moreover the center of the SMA connector is at a distance of 30.25 mm from the mid point of the top slot of the square shaped radiating element and this distance is about $\frac{\lambda_g}{4}$. The E field vector plot on the radiating element also showed that a quarter wavelength EM wave fits in this region of Fig.2. The E-field magnitude is nearly zero at the center of the SMA connector and it has maximum positive amplitude at the top slot of the square shaped radiating element and a maximum negative amplitude at the bottom of the resonator section. The observed E field vector plot for the coplanar slot loop antenna of this paper is different from the electric field distribution described for a rectangular coplanar slot loop antenna in reference [1]. The antenna in reference [1] has a different type of feed and it does not have a series transmission line resonator. The square shaped coplanar slot loop antenna on a dielectric loaded CBCPW structure proposed in this paper is small in size and it has desirable radiation pattern for telemetry applications. It is planned to fabricate this antenna and measure its return loss and radiation patterns in future.

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