A Dual Band Circularly Polarized Microstrip Antenna on an EBG Substrate

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Abstract-- A novel circularly polarized (CP), single-fed microstrip antenna on an electromagnetic band gap substrate (EBG) is presented. The antenna consists of stacked structure of almost square patches and an EBG substrate for the lower patch. The proposed design has a reduced antenna size as compared to the conventional CP microstrip antenna at a given operating frequency and of lightweight. The impedance and axial ratio bandwidths are large and CP radiation quality is excellent over the entire upper hemisphere. The antenna features about 11dBi gain. The proposed antenna is suitable for global positioning system (GPS) applications.

Introduction

In general, a microstrip antenna has a narrow frequency bandwidth; therefore, in the practical design of circularly polarized antennas, techniques for achieving wide band polarization characteristics, as well as wide band impedance characteristics are important. Some of the single feed microstrip antennas as nearly square, corner chopped square, square or circle with a slot or patch with a notch etc.are described in literature [1-2]. On technique for achieving wide band antennas is by the use of stacked elements. If excited at the symmetry axis of a driven patch, linearly polarized, high gain antennas with good bandwidth can be achieved. In order to apply this approach for circular polarization, the probe must be displaced off the symmetry axis.

A stacked structure giving CP is reported in [3]. In the proposed structure since the lowe patch is ring and that also on a high ε_r substrate the antenna real estate is actually small. The ring geometry introduces additional parameters to the antenna that can be used to control its impedance, resonant frequency and bandwidth. In addition because the feed is located close to the perforated area, it is possible to place the feeding network or a MMIC at the center of the ring. This may be a useful feature in integrating the antenna with its electronics or placing beamforming network components within the array element. A common property of most microstrip antennas is that the antenna element launche surface wave modes, in addition to the fields radiated into the space. Suppression or reduction of surface waves improves antenna efficiency and reduces side lobe level. EBG materials also known as photonic crystals (PC) can offer a real solution to the surfac wave problem [4]. PCs are a class of periodic metallic, dielectric or composite structure that exhibit pass and stop bands in their frequency response. Because of this they offer the property to forbid the propagation of the electromagnetic waves whose frequency is included within their stop band-so called Electromagnetic Band Gap (EBG). Hence if th substrate is periodically loaded to create an EBG crystal in such a way that the frequency of the substrate mode overlaps the stop band frequency of the crystal, the excited substrate mode exponentially decays thus reducing the energy lost into the substrate. Thus an increased amount of radiated power couples to space waves and this mechanis has the effect of reshaping the antenna pattern and increasing the gain. In this paper, a

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stacked structure of nearly square patches for CP radiation is analyzed and its performance improvement with EBG substrate is investigated.

Antenna Design

The antenna consists of a probe-fed stacked patch configuration of a rectangular patch over a rectangular ring; both the patches are nearly square in dimension. The stacked structure has to be considered as two coupled cavities. Because of the coupling th parameters affected mainly are the effective values of th ε_r and the dimensions of th antenna especially that of the upper patch. To produce CP radiation, the antenna should be excited such that the resonant frequencies of the two cavities should be very near or there should be a mutual resonance so that at a particular frequency these two modes have equal magnitudes and a phase difference of 90^0. The two orthogonal modes ar excited in the upper and lower cavities. The effective value of the dielectric constant, ε_{rc} for a stacked structure is given by,

$$\varepsilon_{rc} = \frac{\sum_{i=1}^{n} h_i}{\sum_{i=1}^{n} \frac{h_i}{\varepsilon_{ri}}}, \qquad (1)$$

where, n is the number of layers in the structure

The lower and upper cavity parameters are to be analyzed separately. The analysis is done assuming that the lower cavity resembles an antenna covered by a dielectric neglecting the effects of the upper patch since the fields are concentrated in the region between the lower patch and the ground plane. When analyzing the upper patch the effects of coupling are to be taken into account. So the effective dimension of the upper patch is to be found by taking the extension of the lower patch also. In resonant frequency calculation of both the patches the ε_{reff} is found out using the value of ε_{rc} in place of ε_r. i.e.

$$\varepsilon_{reff} = \frac{\varepsilon_{rc}+1}{2} + \frac{\varepsilon_{rc}-1}{2}\left[1+\frac{12.0h}{L}\right]^{-\frac{1}{2}}, \qquad (2)$$

where, h is the total thickness of the substrate and L is the dimension for that patch.

The path of the surface current excited in the fundamental mode in the rectangular ring is expected to be longer than the path in the rectangular solid patch. This characteristic makes the required antenna size of the proposed CP antenna smaller than that of th conventional design. A large number of parameters like thickness and dielectric constants of the substrates, size and nature of the patches and position of the feed influence th operation of the antenna. It should be obvious that a purely empirical design with such a large number of strongly dependent parameters is practically impossible. A large parameter study has been made and on the basis of these results the proposed CP antenna is designed.

The proposed antenna consists of a stacked structure of a rectangular patch over a rectangular ring .The details of the antenna are given in Fig.1. The feed position shown in the figure is for obtaining RHCP. The probe in the other diagonal gives LHCP. The top patch is in the inverted configuration. The upper substrate actually works as a superstrate. The dimensions of the patches and the thickness and dielectric constant of the substrates are optimized to achieve good aspect ratio and impedance bandwidth using Empipe3D and HFSS 5.6. It provides a CP bandwidth of 18.4%. Next step is to convert the lower substrate into an EBG structure to reduce the surface wave effects. This is done by drilling triangular lattice of holes in it (Fig.2). The lattice constant (a) and the diameter of the holes (d) are selected such as to obtain a stop band centered on 2GHz. The maximum gap is obtained when introducing the array of air and perfectly conducting cylinders (PEC) in the lattice. In this structure 'a' is chosen as 38mm and 'd' as 18mm which is found to give an almost stop band in the frequency range from 1.86 to 2.52 GHz.

Simulation Results

Simulations are performed for both the structures; one with normal substrate and th other with EBG with all the other parameters remaining the same. Fig. 3 shows the return loss characteristics for both the structures. An impedance bandwidth with the input VSWR being < 2 of 440MHz is obtained for the normal antenna and of 490MHz for EBG substrate with a slight shift in center frequency. Because of the surface wav reduction the antenna with EBG gives more bandwidth, 25.79% compared to 22.92% for the normal antenna. Fig.4 shows the impedance charts for the CP antenna. The loop in the input impedance is caused by the existence of two spatially orthogonal degenerate modes. Very good matching of the input was obtained. The axial ratio of CP radiation for both the structures are shown in Fig.5, in which the CP bandwidth, determined from 3-dB AR, is found to be about 370 MHz for a normal antenna and 320 MHz for an EBG antenna. This means CP bandwidth of 18.4% and 16.84% respectively with respect to the center frequencies (the frequencies with minimum AR). The antenna gain in the broad side direction against operating frequency is also plotted in Fig.5. There is a 2dB improvement in maximum gain for the EBG antenna. The radiation patterns in two orthogonal planes at 2.02GHz are also plotted in Fig.6. Good RHCP radiation is obtained. We can see a 2dB reduction in side radiation with EBG substrate. Though the AR remains less than 3 dB in the whole band the phase shift varies from the required $\pm 90^0$ in the middle of the band. So this antenna is suitable for dual band CP applications.

Conclusion

A reduced size stacked antenna using a single probe feed has been investigated and the performance improvement is studied with an EBG substrate. An easier CP is obtained by using a stacked structure of two almost square patches. Using an EBG substrate the antenna is found to give more impedance bandwidth and more gain with reduced side radiation. The proposed antenna is shown to be able to give a 3-dB axial ratio bandwidth of 16.84% and more than 11dBi gain.

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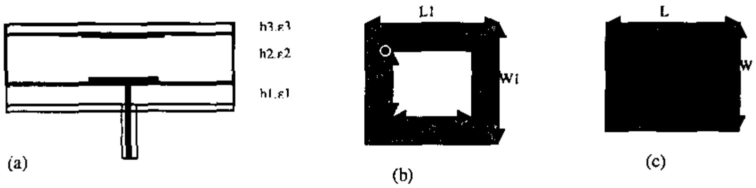

Fig.1 (a) Geometry of the antenna (b) Lower patch (c) Upper patch
Parameters:$h1=2.54mm\ (0.017\lambda_0)$,$h2=9.5mm(0.063\lambda_0)$,$h3=0.254mm$,
$\varepsilon1=9.8$,$\tan\delta1=0.002$,$\varepsilon2=1.05$,$\tan\delta2=0.0012$,$\varepsilon3=4.8$,$\tan\delta3=0.0009$,
$L1=19mm$,$W1=22mm$,$L1/L2=W1/W2=3$,$L=45mm$,$W=47.5mm$

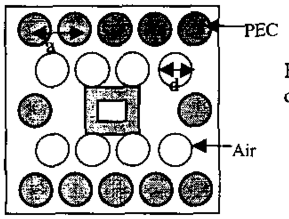

Fig.2 EBG Structure as lower substrate
$d=18mm$,$a=38mm$

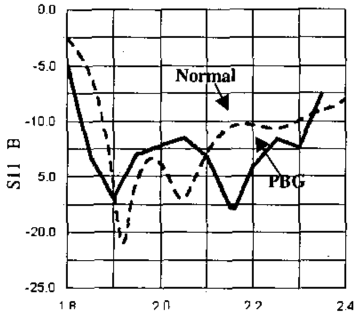

Fig.3 Return loss characteristics

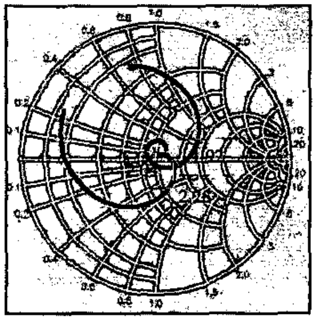

Fig.4 Impedance characteristics

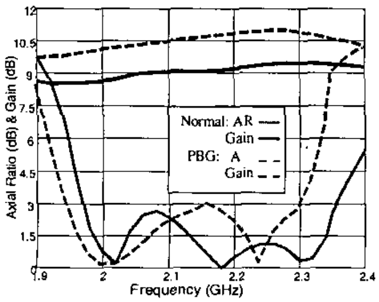

Fig.5 Axial ratio characteristics

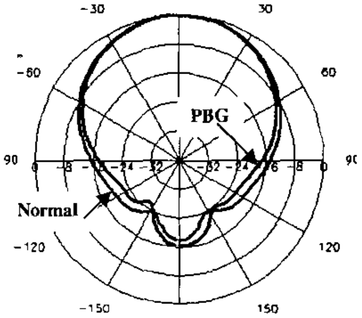

Fig.6 Comparison of radiation patterns