Rectangular Patch Antenna Based on TE Modes Supported by Artificial Magnetic Conducting Surfaces

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Abstract

A new type of patch antenna, which could excite the TE modes, is presented. The electric conductive patch and ground plane of the antenna is replaced by the magnetic conductive patch and ground plane. The structure of the antenna basically follows the conventional designs by applying duality theorem. In order to effectively excite the patch, a horizontally bended probe is used. A low profile design ($h=0.04\lambda_0$) is presented in this paper, and an impedance bandwidth of about 14% and a gain of about 8dBi are attained.

1. Introduction

Microstrip patch antennas (MPA) [1]-[2] have been researched and developed extensively in the last three decades. They have become favorites among antenna designers and have been used in many applications in wireless communication systems. The idea of microstrip patch antennas arose from utilizing printed circuit technology not only for the circuit components and transmission lines but also for the radiating elements of an electronic system. It was first proposed by Deschamps (1953). However, little attention was paid to his idea until 1970's. Since then, MPA has been the subject of intensive research and development. The basic structure of the MPA consists of an area of rectangular electric conductor (patch) supported above an electric conductive ground plane by a dielectric substrate. The antenna is fed against the ground at an appropriate location. Electromagnetic energy is first guided or coupled to the region under the patch, which acts like a resonant cavity with open circuits on the sides. Some of the energy leaks out of the cavity and radiates into space, resulting in an antenna.

On the other hand, Electromagnetic bandgap (EBG) [3]-[4] structures exhibit several unique electromagnetic properties, which led to a wide range of applications in microwave circuits and antennas [5]-[7]. For example, EBG structures could be integrated with patch antennas for surface wave suppression, or use as the ground plane of horizontal monopole and spiral antenna to achieve low profile designs. The frequency bandgap of the structure could block the surface wave propagate in the horizontal plane and this could improve the radiation patterns when they are integrated with antenna. Moreover, the structure has a high impedance surface characteristic across a particular frequency band, which inhibits the tangential magnetic field, even there is strong electric field along the surface. The structure could induce in-phase electric image current across its bandgap frequency, and due to this characteristic, the EBG structure is sometime called "artificial magnetic conductor" (AMC).

The conventional MPA uses electric conductor as patch and ground plane, which can only excite TM modes within the cavity, and the radiation from this antenna is due to the equivalent magnetic currents at the patch edges (radiating edges). In this paper, the electric conductive patch and ground plane are replaced by magnetic conductive patch and ground plane. The basic design and some preliminary results of this new antenna are presented. The antenna could excite TE modes and has a number of advantages over the conventional MPA.

2. Antenna structure and Results

In order to simplify the design, an antenna with perfect magnetic conductor patch model will be presented first. A practical design will follow based on the use of artificial magnetic conductor. The geometry and results of the antenna using artificial magnetic conductor will be demonstrated.

2.1 Perfect Magnetic Conducting Patch

For simplicity and providing approximate dimensions for the new antenna, an ideal model is considered. In a dual form to the conventional microstrip antenna that can be analyzed using the cavity model, which is bounded by two perfect electric conductors from the top and the bottom and magnetic walls from the sides along the patch edges. Here the cavity is represented by perfect magnetic conductors from the top and the bottoms and perfect electric conductors from the sides as shown in Fig. 1. Free space is used inside the cavity. The fields of the fundamental mode inside the cavity are calculated by Ansoft HFSS, and they are shown in Fig. 2. It is observed that a TE_{10} mode is excited within the cavity. The duality theorem could be applied to this antenna design. Therefore, the radiation is due to the fringing magnetic field lines that has equivalent electric currents. For this particular structure, the cavity has a dimension of 39.6mm (W) x 19.8mm (L) x 3mm (H), and the resonant frequency of the first four modes are: 3.785GHz, 7.5617GHz, 7.5656GHz and 8.4523GHz.

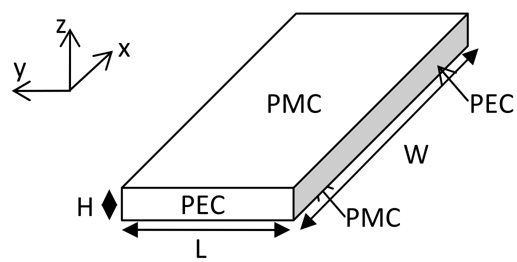


Fig. 1 The geometry of the proposed microstrip patch antenna cavity with PMC as patch and ground plane.

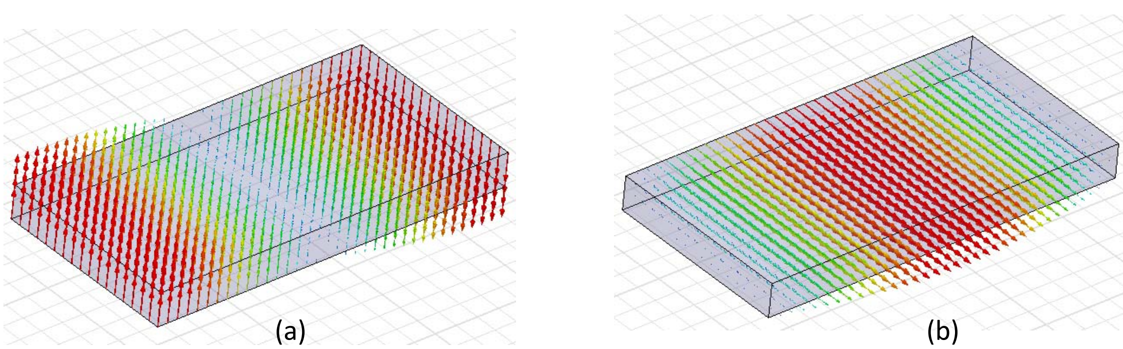


Fig. 2 The fundamental mode field distribution of the proposed antenna cavity (a) H-field and (b) E-field.

2.2 Artificial Magnetic Conductor (AMC) Realization

In order to realize the magnetic conductor properties on the patch and on the ground plane, EBG structure is used. The EBG structure could produce in-phase electric current image across its bandgap, and this AMC characteristic is limited by its bandgap. A wideband uniplanar compact (UC)-EBG [7] is used in this paper. For brevity, the structure of this wideband UC-EBG structure is not reproduced here. This EBG structure attains a bandgap from 3.01GHz to 5.28GHz, which corresponds to a bandwidth of about 54.8%. The wide forbidden bandwidth could provide a wide range for tuning the proposed antenna, and could be used in future wideband TE mode patch antenna designs. Moreover, this EBG structure does not use shorting vias and this could reduce the cost of fabrication.

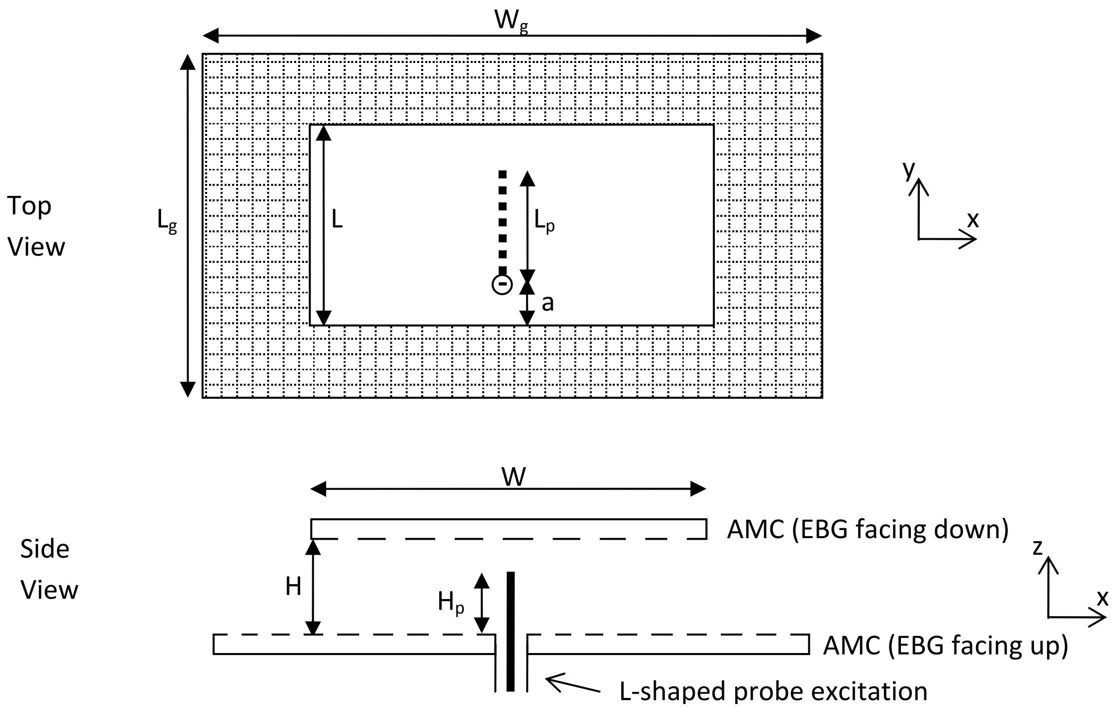
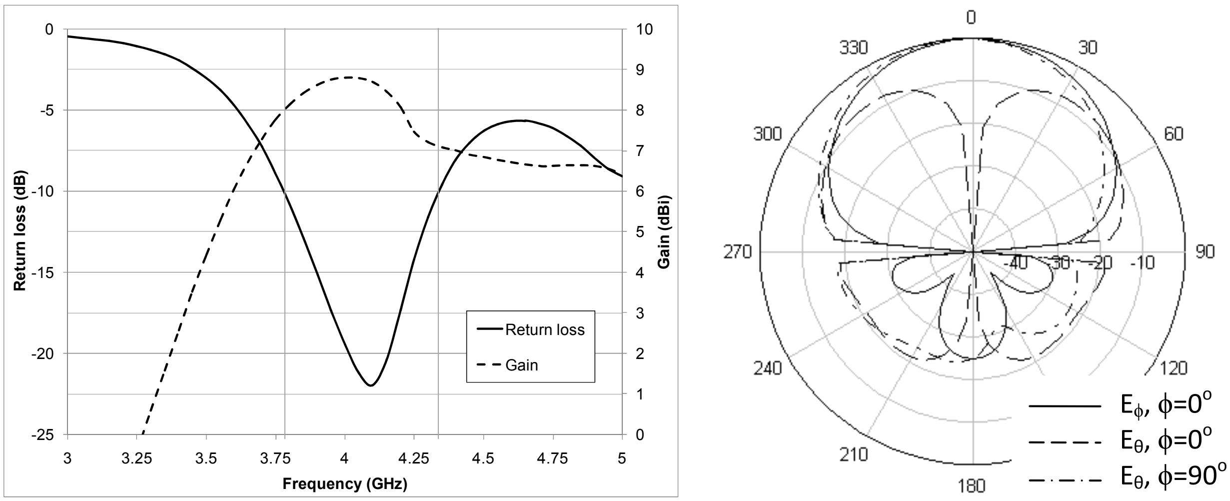


Fig. 3 Geometry of the proposed antenna with AMC as patch and ground plane.

The geometry of the proposed antenna is shown in Fig. 3. AMC material is used on the patch and the ground plane, the EBG structures are arranged to face inside the cavity. The air-filled cavity has a thickness (H) of 3mm, and the AMC patch has a dimension of 39.6 mm (W) x 19.8 mm (L). The AMC ground plane has a dimension of 52.8 mm (W_g) x 26.4 mm (L_g). The AMC ground plane is placed on top of a PEC with dimensions of 80 mm x 80 mm. In order to excite TE mode inside the cavity, an L-shaped probe [9] is used. The probe is placed 0.9mm from the lower edge of the patch (a), it has a height of 2.1 mm (H_p) and a length of 12.5 mm (L_p). This antenna is simulated by MoM based simulation software, Zeland IE3D version 12, and infinitely large dielectric material is used as the substrate of the AMC structure.

The simulated return loss and gain are shown in Fig. 4(a). The antenna attains an impedance matching (return loss <-10dB) frequency band from 3.78 -4.34 GHz, which is equivalent to a bandwidth of 13.8%. This antenna has a wider impedance bandwidth than the conventional MPA with a cavity thickness (H) of about $0.04\lambda_0$. (λ_0 is the free space wavelength calculated at the center frequency (4.06 GHz).) Within the impedance matching bandwidth, the antenna attains a simulated gain of about 8dBi, which is higher than the conventional MPA. The radiation pattern at 4.1 GHz is shown in Fig. 4(b). A symmetry broadside radiation is obtained. Nulls are obtained at phi = 90^0 and 270^0, this is due to the use of infinite large substrate in the simulation. With reference to the trend near phi = 90^0 and 270^0, the H-plane (xz plane) has weak intensity in the phi = 90^0 and 270^0 directions, a high isolation could then be obtained when linear H-plane array is constructed. The antenna has a small backlobe radiation of -20dB. The cross polarization level is quite large, which is about -8dB. The polarization impurity could be due to the vertical portion of the L-shaped feeding probe. Further investigation will be carried out to figure out the source of the cross polarization. Due to the duality theorem, the E-field in conventional MPA is changed into H-field, the magnetic current ($\overrightarrow{M}$) is changed into electric current ($\vec{J}$). The resonant frequency of the antenna is determined by the width of the patch, where the H-field varies along the x-axis and keeps constant along the y-axis.



(a) (b)

Fig. 4 (a) Simulated return loss and gain and (b) radiation pattern at 4.1 GHz.

3. Conclusions

A new type of patch antenna which excites the TE modes was introduced. It was achieved by replacing the PEC patch and ground plane with AMC structure. The performance of an antenna cavity using PMC and a proposed antenna using AMC were demonstrated. L-shaped probe was used to excite the newly proposed antenna. The antenna was found to have higher gain, wider impedance matching bandwidth, smaller intensity in the H-plane endfire direction, and smaller size ($L<\lambda_0/2$, $W\approx \lambda_0/2$) than the conventional MPA which excites the TM mode. A low profile antenna ($h=0.04\lambda_0$) attains a bandwidth of about 14% and a gain of about 8dBi was presented.

4. References

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