Application of Artificial Magnetic Conductor in Aperture-coupled Microstrip Antenna

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Abstract— A new technology of the slot waveguide transmission line has been concerned. The application of this technology in aperture of coupled microstrip antenna is studied in this paper. The dispersion characteristics are analyzed in the communication bands. The design and analysis of aperture-coupled microstrip antenna adding Artificial Magnetic Conductor (AMC) has been done. The numerical results show that the antenna structure is well to achieve the expected design requirements.

1. INTRODUCTION

In the millimeter-wave technology, in order to overcome the problem of transmission loss of traditional transmission lines, a new technique has been widespread concern. The new technique is slot waveguide transmission line. Quasi-TEM waves can be transmitted in this transmission line over a wide bandwidth. Slot waveguide technology was first proposed as the range of 30 GHz to THz transmission line in the literature [1]. Application of traditional transmission line is limited by the transmission performance, device integration and cost in this frequency range. Slot waveguide transmission line is used to solve this problem.

The first planar waveguide is constituted by two parallel plates. Electromagnetic wave that perpendicular to the plane of the waveguide can be propagated in this waveguide. If one of the conductors in the planar waveguide is replaced by magnetic conductor, electromagnetic wave can't be propagated when the distance between the planar waveguide is less than the 1/4 wavelength. Conductor transmission line is added between the perfect conductor and the perfect magnetic conductor. This conductor transmission line just likes a slot in the perfect conductor plane. This slot can be used to propagate Quasi-TEM waves.

Electromagnetic characteristics of Artificial Magnetic Conductor (AMC) can be changed by artificially [2]. The formula about the surface impedance of AMC was proposed in literature [3]. Literature [4] studied the dispersion characteristics of the slot waveguide. Literature [5] studied the impedance characteristics of the slot waveguide. Application of the slot waveguide in millimeter-wave devices was studied in literature [6]. Application of package in monolithic microwave integrated circuit (MMIC) was proposed in literature [6].

Aperture-coupled microstrip antenna was used very widely in wireless communication. But this antenna has radiation effects on the back. This drawback limits the application of this antenna in communication. In order to overcome the back radiation effects, the traditional method is to add a reflective plate or cavity on the back. However, the reflective plate tends to produce unwanted effects of radiation. And cavity produces high order mode of electromagnetic radiation. This paper studies the application of AMC in aperture-coupled microstrip antenna. AMC is added on back of antenna. The radiation effect on the back can be reduced.

2. STRUCTURE OF WAVEGUIDE

Planar waveguide consists of two parallel metal planes. When the spacing between two parallel metal planes is less than 1/2 wavelength, TEM electromagnetic waves can propagate perpendicular to the surface. If the planar waveguide be made by a metallic conductor and a magnetic conductor. When the spacing between two parallel planes is less than 1/4 wavelength, the electromagnetic wave can't propagate in such a planar waveguide.

Development of meta-material technology provides a new method to achieve AMC. The dispersion characteristics of the planar waveguide which made by a metallic conductor and AMC were discussed in literature [4]. AMC is made by periodic array of metal wires. Effective permittivity is shown in Formula (1).

$$\vec{\vec{\varepsilon}}(\omega, k_z) = \varepsilon_0\varepsilon_h \left[\hat{x}\hat{x} + \hat{y}\hat{y} + \varepsilon_{zz}\left(\omega k_z\right)\hat{z}\hat{z}\right] \tag{1}$$

where,

$$\varepsilon_{zz}(\omega k_z) = 1 - \frac{k_p^2}{k_h^2 - k_z^2}, \quad k_h = \sqrt{\varepsilon} k \tag{2}$$

$$k_p = \frac{1}{a}\sqrt{\frac{2\pi}{\ln(a/2\pi b) + 0.5275}} \tag{3}$$

a is the period of the array, b is the radius of the wire. When the height of the wire is 1/4 wavelength, the wire array and the air interface can be considered as a magnetic conductor. Electromagnetic waves can't propagate in this waveguide from 10 GHz to 20 GHz [4]. In this paper, aperture of coupled microstrip antenna operates at 2.3 GHz. The structure of the planar waveguide must be re-designed so that electromagnetic waves can't propagate in waveguide at 2.3 GHz. The radius of the wire is 2 mm. The height of the wire is 31.25 mm.

Dispersion analysis of wave propagation is calculated using the model shown in Figure 1. X direction and Y direction are the periodic boundary conditions. Z direction is perfect boundary conditions for the conductor.

Figure 2 gives the dispersion curve. Electromagnetic waves don't have propagation modes from 1.9 GHz to 4.36 GHz.

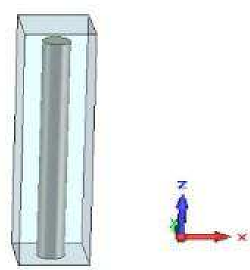

Figure 1: Periodic structural unit.

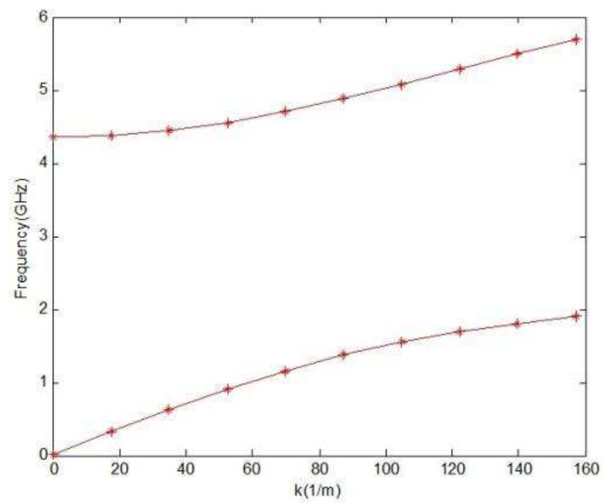

Figure 2: Dispersion curve.

3. APERTURE-COUPLED MICROSTRIP ANTENNA

Feeder and microstrip antenna are electrically isolated by technology of aperture-coupled microstrip antenna. They are coupled through a slot on the ground plane. Therefore, feeder and antenna elements can be optimized separately. Coupling aperture is $0.141\lambda \times 0.019\lambda$. An aperture-coupled microstrip antenna working at 2.3 GHz is shown in Figure 3. There is AMC at back of the antenna. AMC and the metal surface form a planar waveguide structure. According to Section 2, electromagnetic waves can't propagate in this structure at 2.3 GHz. So back radiation effects are reduced. The size of the microstrip patch is 30 mm $*$ 40 mm. The size of coupling slot is 14mm $*$ 1.55 mm. Permittivity of the dielectric substrate is 2.2. The distance between the microstrip antenna and the metal ground is 1.6 mm. The distance between the feeder and the metal ground is 1.6 mm.

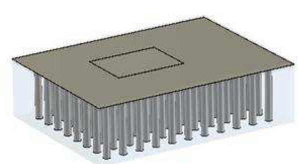

Figure 3: Aperture-coupled microstrip antenna with AMC.

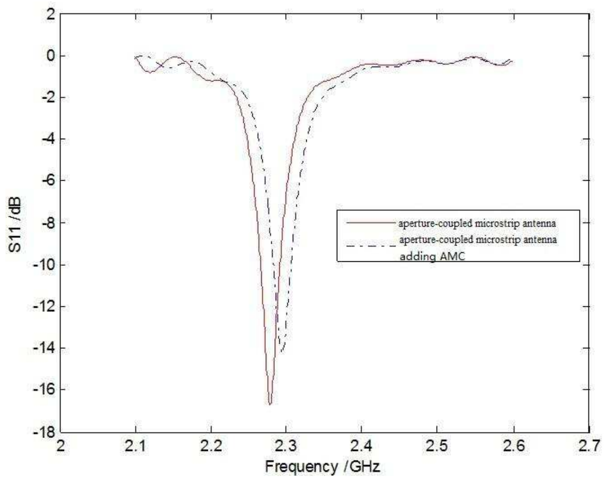

Figure 4: S_{11}.

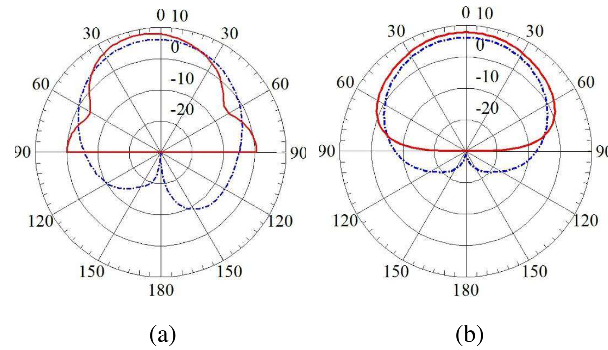

Figure 5: (a) X-Z antenna gain. (b) Y-Z antenna gain.

4. CONCLUSION

An aperture-coupled microstrip antenna is shown in Figure 3. Since the number of unknown variables is large, I simulated this structure by finite difference time domain (FDTD). The simulation results are shown in Figures 4 and 5.

S_{11} don't change a lot with AMC from Figure 4. Both of them have the same variation. Just the best match frequency shift position slightly. The reason is some parasitic reactance component by adding AMC. The size of the periodic array can be adjusted to improve the result of antenna.

The solid line is the gain curve with AMC. The dotted line is the gain curve without AMC. The gain has a small increase by adding AMC. The back radiation is greatly reduced at the same time.

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