A Novel Compact Artificial Magnetic Conductor Based on Multiple Non-grounded Vias

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Abstract — In this paper a novel compact artificial magnetic conductor based on multiple non-grounded vias (MNGV) is introduced. This structure has more bandwidth in comparison with other compact structures neither use magnetic materials nor NICs presented recently and exhibits an acceptable stability of resonance frequency for the complete angular spectrum of incident plane waves. The unit cell size is decreased 81.6% by MNGV-AMC with single grounded via compared with the similar Sievenpiper AMC structure. Therefore antennas and microwave integrated circuits performance can be improved by increasing the number of cells in a finite space, especially in mobile communications.

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1. INTRODUCTION

In order to miniaturize mobile communication devices, it is necessary to incorporate the antenna with the printed circuit board. Because the substrate thickness is usually much smaller than the wavelength in dielectric medium, the ground plane destroys the antenna performance. To overcome this problem, in the late 1990s, Sievenpiper proposed a mushroom-like high impedance surface or AMC structure that reflects the plane wave in-phase and suppresses surface wave [1–3]. Consequently it can be placed very close to the antenna instead of the ground plane. But for low frequency band, i.e., wireless communication band (GSM, PCS and ISM), the unit cell size is large and it is not possible to use AMC in low profile and low frequency devices. Magnetic loading of AMC [4] and NICs [5] are used for decreasing the resonance frequency and enhancing the bandwidth. Multi-layer AMC structures are proposed for GSM applications [6–8]. However these methods are very difficult to implement and not applicable with conventional two-layer printed circuit boards with dielectric substrates. Some methods for reducing the cell size of two-layer AMC structures are introduced [9], but none of them can decrease the cell size better than 40%. An IE-AMC [10] is presented with about 70% reducing the cell size, but its bandwidth is 2.3%. This paper introduces a new compact MNGV-AMC structure having stable resonance with respect to polarization and incidence angle. The size of the unit cell is decreased 81.6% in MNGV-AMC with single grounded via compared with Sievenpiper AMC and the bandwidth is increased by a factor of 1.52 in MNGV-AMC without grounded via in comparison with IE-AMC.

2. STRUCTURE DESIGN

The conventional Sievenpiper AMC and its equivalent circuit are shown in Figs. 1(a) and (b) respectively. The resonance frequency is determined by $1/2\pi\sqrt{LC}$ and the bandwidth is proportional to $\sqrt{L/C}$. Increasing the inductance or the capacitance of the structure leads to lower resonance frequency. But if the capacitance is increased, the bandwidth suffers. Therefore it is favorable to increase the structure inductance rather than the capacitance. As for Sievenpiper AMC and IE-AMC, the inductance $L = \mu h$, but in IE-AMC the capacitance is increased greatly and the bandwidth is decreased consequently. In order to increase the inductance without changing the capacitive layer, a thicker substrate must be used. But a thicker substrate occupies more space and makes the device enlarged. One way to increase the structure inductance is using a frequency selective surface with a series LC equivalent circuit instead of a conventional patch. Now the resonance frequency is determined by $1/2\pi\sqrt{(L + L_s)C_s}$. In other words, the surface inductance is added to the previous inductance and the total structure inductance is increased. Therefore a high inductance FSS is required to be placed as the top layer instead of the patch which acts as a capacitive surface. A well-known structure which has this kind of equivalent circuit with high inductance is a square-loop shown in Fig. 2. It is notable that there are other frequency selective surfaces with series LC equivalent circuit and high inductance. But Most of them are complicated.
Figure 1: (a) Top view of conventional Sievenpiper AMC and (b) its equivalent circuit.

Figure 2: (a) Top view of AMC with the Square loop as the top FSS and (b) its equivalent circuit.

For simplicity the so-called structure is chosen. Since the inductance of the square loop is inversely proportional to the loop width, a narrow loop is used.

However because the square loop capacitance isn’t high, the structure capacitance is not changed greatly. By adding new capacitive layers the structure capacitance can be increased. It is important to note that adding a new inductive surface between the ground and the top surface reduces the total structure inductance because it is parallel with the top surface inductance. If the microwave integrated circuit is a two-layer structure, it is difficult to integrate a multi-layer structure with a two-layer one. Also any change in the top surface configuration leads to the surface inductance reduction. Therefore an alternative approach is to create multiple non-grounded vias on the square-loop as shown in Fig. 3(a). The capacitance between the adjacent cells vias and between the vias in a cell is very high and the resonance frequency decreases without reducing the total structure inductance. So the bandwidth is more than IE-AMC. The more the vias, the more the resonance frequency reduction. Also if the length of the vias is taken larger, the capacitance is higher. Because of the narrow bandwidth, the resonance frequency stability in different incidence angles is very important. For a good performance, the maximum shift in resonance frequency at various incidence angles must be lower than half of the bandwidth. Since the vias are not grounded, the structure exhibits an acceptable stability of resonance frequency for the complete angular spectrum.

Figure 3: (a) Geometry of MNGV-AMC structure (b) MNGV-AMC structure with single grounded via.
of incident plane waves.

If the single grounded via in Sievenpiper AMC structure which is in the center of the unit cell is shifted to the corner of the cell, the resonance frequency is decreased about 30%. Applying this technique to the MNGV-AMC structure shows the similar effect. It means that if only one corner via in MNGV-AMC is grounded as shown in Fig. 3(b), the resonance frequency is reduced about 30% compared with MNGV-AMC with no grounded via. But the bandwidth and resonance frequency stability suffers a little in this case.

For creating non-grounded vias in fabrication process, an easy method is dividing the dielectric substrate into two layers. The top layer thickness is equal to vias length and the bottom layer is without via as shown in Fig. 4. In other words, first, the vias are created in the top layer and then the two layers are connected to each other. Finally the vias are metalized.

![Figure 4: Dividing the dielectric substrate into two layers to provide an easiness of fabrication.](image)

3. RESULTS AND DISCUSSIONS

We consider a unit cell size of 7.2 × 7.2 mm² with a substrate thickness of 2 mm for comparing the results with the analogous Sievenpiper and IE-AMC structures. The relative permittivity of the dielectric slab is 2.65. The diameter and the length of vias are 0.2 mm and 1.8 mm respectively. The distance between the centers of two adjacent vias is 0.335 mm. The width of the square loop is 3 mm. Finite difference time domain method is used for the structure simulation. Fig. 5 shows the reflection phase of MNGV-AMC structure for various incidence angles. The resonant frequency of the analogous Sievenpiper AMC is 6.15 GHz. By applying this structure the resonant frequency is reduced to 1.66 GHz with 3.5% bandwidth at normal incidence and the maximum shift in resonance frequency (∆f/f₀) in different plane wave incidence angles is 0.8%. It means that the bandwidth is increased by a factor of 1.52 in comparison with the analogous IE-AMC that is 2.3% at 1.7 GHz.

![Figure 5: Reflection Phase of MNGV-AMC shown in Fig. 3(a) for different incidence angles.](image)

![Figure 6: Reflection Phase of MNGV-AMC with single grounded via shown in Fig. 3(b) for different incidence angles.](image)
In other words, the total structure inductance is approximately doubled.

If only one of the corner vias is grounded, the resonance frequency is reduced to 1.13 GHz at normal incidence, which is 81.6% and 31.95% lower than Sievenpiper AMC structure and MNGV-AMC respectively. Fig. 6 illustrates the reflection phase of MNGV-AMC structure with single grounded via for different incidence angles. As it shows, the bandwidth is decreased to 1.9% at normal incidence and stability to resonance angle suffers a little in TM case which was predictable because of the grounded via. The maximum shift in resonance frequency ($\Delta f/f_0$) in MNGV-AMC with single grounded via is 1.1%.

4. CONCLUSIONS

In this paper a novel compact two layer MNGV-AMC structure and a MNGV-AMC with single grounded via are presented. Through applying these configurations not only the resonance frequency is decreased 81.6% and 10% compared with Sievenpiper and IE-AMC structures respectively but also the bandwidth is increased by a factor of 1.52 in comparison with IE-AMC structure. Also the maximum shift in resonance frequency is 0.8% for MNGV-AMC that is acceptable for 3.5% bandwidth. The MNGV-AMC with single grounded via is more compact but suffers from bandwidth and resonance frequency stability. This problem can be solved by a thicker substrate. Therefore this structure can be used in low-frequency and low-profile mobile communication devices with narrow bandwidth to improve the antenna performance by using more unit cells in a finite space, especially in mobile cell phones.

REFERENCES