Slot-loaded Dual-layer Artificial Magnetic Conductor

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Abstract

A dual-band artificial magnetic conductor (AMC) composed of two metallic patch layers with slot-loading is proposed. The slots inserted in the patches lengthen the current path on the patches, which increases the equivalent inductances. The equivalent circuit model of the dual-layer AMC is modified by the additional inductances due to the slot-loading, and the reflection phases calculated using the model is compared with full wave analysis results. The effects of the slot-loading on the reflection phase are discussed using the results. The method of controlling the reflection phase of the dual-layer AMC using slot-loading is expected to increase the degree of freedom in designing both AMC and electromagnetic gradient surface (EGS) structures.

1. Introduction

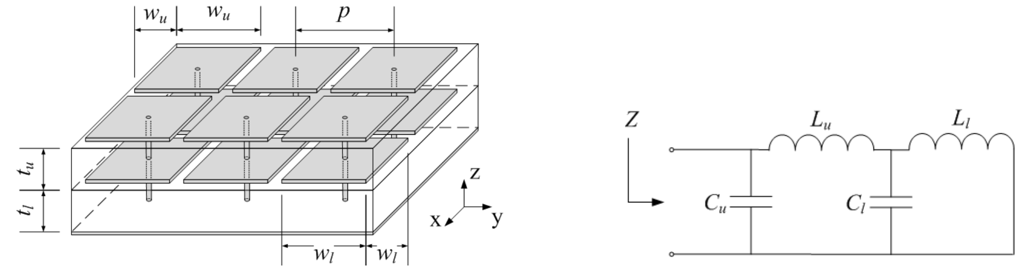
Artificial surfaces with unusual electromagnetic characteristics have been drawn attention for years. One of them is high impedance surface (HIS) composed of subwavelength mushroom type unit cells, which was proposed by D. Sievenpiper in 1999 [1]. Near the resonant frequency of the unit cell, the surface exhibits high surface impedance and it suppresses the propagation of the surface wave on it. Since the reflection phase of the surface at the resonant frequency 0°, which is a characteristic of magnetic conductor, it is normally called artificial magnetic conductor (AMC). Due to the surface wave suppression and the 0° reflection phase characteristics, it has been used as a reflector of antennas to achieve low-profile design with improved side lobe level and front to back ratio characteristics [2].

There have been researches to design multiband AMC [3]. In designing multiband AMCs, it is desirable to control the each resonant frequency and the bandwidth respectively for practical applications. Especially for electromagnetic gradient surface (EGS) design [4], it is desirable to have various reflection phase control methods to increase the degree of freedom in designing [3]. The bandwidth of AMC is defined as the frequency range where the reflection phase is between -90° and +90° [1]. In [3], a method of controlling reflection phase of a dual-band AMC composed of two metallic patch layers by adding multi-via holes has been proposed.

In this paper, a novel method of controlling reflection phase of dual-band AMC composed of two metallic patch layers by inserting slot-loadings. The slots lengthen the current path on the patches, which increases the equivalent inductance. The equivalent circuit model of the dual-band AMC in [3] is modified with the increased inductances, and the calculated reflection phases are compared with full wave analysis results. With the results, the effects of slots on the reflection phase are analyzed.

2. Dual-layer AMC with slot-loading

In Fig. 1 (a), the unit cell of dual-band AMC composed of two metallic patch layers and a via hole connecting the patches to the ground. The equivalent circuit model of the AMC is shown in Fig. 2 (b), and from the model, the reflection phase Φ_Γ and two resonant frequencies, f_l and f_h, where the reflection phase becomes 0° can be calculated as follows [3],



(a) The dual-band AMC with two metallic patch layers (b) The equivalent circuit model

Fig. 1: The structure and the equivalent circuit model of the dual-band AMC.

$$\phi_\Gamma = \mathrm{Im}\left[\ln\left(\frac{Z-\eta}{Z+\eta}\right)\right], \quad \text{where} \quad Z = \frac{j\omega(L_l + L_u - \omega^2 L_l L_u C_l)}{1-(\omega/\Delta)^2 + (\omega/\omega_\Delta)^4} \tag{1}$$

$$f_l = \frac{1}{2\pi}\sqrt{\frac{\omega_\Delta^4}{2}\left(\frac{1}{\Delta^2} - \sqrt{\frac{1}{\Delta^4} - \frac{4}{\omega_\Delta^4}}\right)}, \qquad f_h = \frac{1}{2\pi}\sqrt{\frac{\omega_\Delta^4}{2}\left(\frac{1}{\Delta^2} + \sqrt{\frac{1}{\Delta^4} - \frac{4}{\omega_\Delta^4}}\right)} \tag{2}$$

where η is intrinsic impedance of free space, $\Delta = \left(L_l C_l + L_l C_u + L_u C_u\right)^{-1/2}$ and $\omega_\Delta = \left(L_l L_u C_l C_u\right)^{-1/4}$. The C_l (C_u) is mainly determined from the gap between the lower (upper) patches, and L_l (L_u) is determined from the thickness of the lower (upper) substrate layer [3]. Therefore from (1) and (2), it is observed that the f_l and f_h, and the bandwidths near the resonant frequencies, can only be controlled by the gap between the patches and the thickness of the layers.

If slots are added to the metallic patches of either or both layers, the reflection phase can be further controlled without changing the gap between the patches or the thickness of the layers. The slots can have various shapes, and a sample used in this research is shown in Fig. 2. The role of the slots is increasing the length of the current patch on the patches, and therefore, increasing the equivalent inductance of the patches. If the slots are added to the upper (lower) patches, the equivalent circuit model in Fig. 1 (a) is modified by additional inductance connected in series to C_u (C_l).

(a) Patch without slots (b) Patch with four triangular slots

Fig. 2: The shape of the patch with slot-loading for reflection phase control of dual-band AMC.

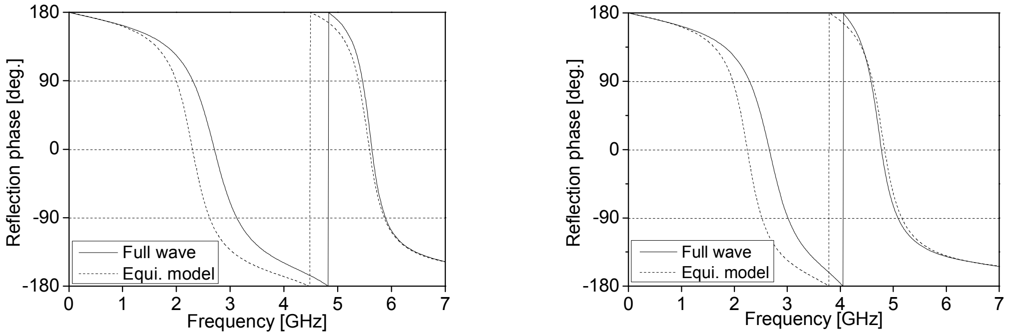
3. Reflection phase comparison

In Fig. 3, the reflection phases of the dual-band AMC are presented for four cases: (a) Without slots (conventional rectangular patch), (b) Slots in the patches of the lower layer only, (c) Slots in the patches of the upper layer only, and (d) Slots in the patches of the both layers. The reflection phases calculated using the modified equivalent models and simulated using full wave analysis are presented together, and they show good agreement. The results are listed in Table. 1.

The inserted slots decrease f_l and f_h for all three cases in Fig. 3 (b) – (d). However, when the slots are inserted to the lower patches, the f_h is reduced while the bandwidth of upper band is increased, which is opposite to the case when the slots are inserted to the upper patches only, which increases the degree of designing both dual-band AMC and EGS structures.

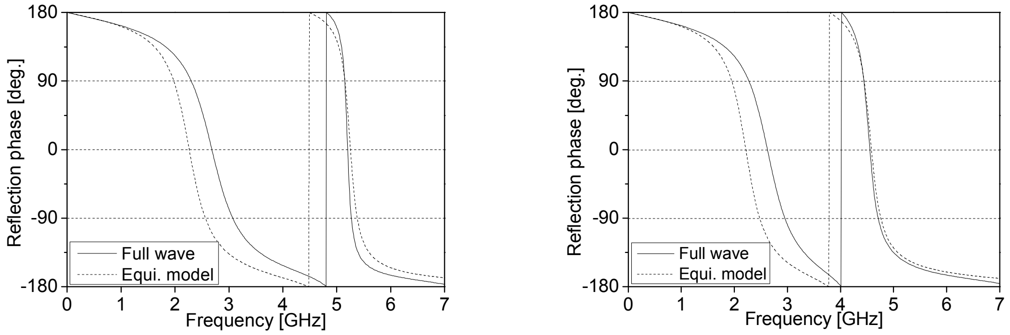
4. Conclusion

The effects of the slot-loading on reflection phase of the dual-band AMC are discussed. The proposed



(a) Without slots

(b) Slots in lower patches



(c) Slots in upper patches

(d) Slots in both patches

Fig. 3: The reflection phases of the dual-band AMC with slot-loaded patches.

Table. 1: The reflection phase characteristics of the dual-band AMC with slot-loadings

	f_l [GHz]	f_h [GHz]	Lower bandwidth [GHz]	Upper bandwidth [GHz]
(a) Without slots	2.71	5.64	0.82	0.42
(b) Slots in lower patches	2.66	4.78	0.74	0.51
(c) Slots in upper patches	2.68	5.20	0.78	0.12
(d) Slots in both patches	2.63	4.55	0.69	0.27

method is expected to increase the degree of freedom in designing both AMC and EGS structures, combined with other methods such as inserting multi-via holes. Although the shape of slot used in this research is triangular, other shapes which further increases the equivalent inductance can be adopted, depending on the design specifications. In the conference, examples of using the slot-loading in designing dual-band AMC and EGS, and their application to antennas will be presented.

Acknowledgement

This work was supported by Defense Acquisition Program Administration and Agency for Defense Development under the contract UD090088JD.

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