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A Multi-Band Artificial Magnetic Conductor Comprised of Multiple FSS Layers

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Abstract: A multi-band artificial magnetic conductor (AMC) is described wherein *N* capacitive frequency selective surfaces (FSS) are employed to realize a zero degree reflection phase at *N* non-harmonically related resonant frequencies. A simple Cauer Type I *LC* network is proposed to model the plane wave reflection coefficient for this type of multi-band AMC. As an example, a dual band AMC (*N=2*) is fabricated and tested to demonstrate the concept. Both a reflection phase resonance and a surface wave bandgap are demonstrated in the GSM 850 MHz band and the PCS 1900 MHz band.

I. Introduction

An AMC is a reactive surface that exhibits a reflection phase of close to zero degrees, but over a limited range of frequencies. For certain low-profile multi-band antenna applications, it is desirable to create multi-band AMCs. We propose that a class of multi-band AMCs can be modeled for plane wave reflection phase by using a Cauer Type I ladder network [1], as shown in Figure 1. This model consists of *N* shunt capacitors and *N* series inductors. The input impedance Z_{in} for this *N* pole network can be written as a continued fraction expansion:

$$Z_{in}(s) = \cfrac{1}{sC_N + \cfrac{1}{sL_N + \cfrac{1}{sC_{(N-1)} + \cfrac{1}{sL_{(N-1)} + \dots}}}} .$$

For practical cases of *N=2* or *3*, this continued fraction can be reduced to a rational function. The roots of the denominator identify the AMC resonant frequencies. Note that for the special case of a single band AMC (*N=1*), the model reduces to a simple parallel LC circuit as originally described by Sievenpiper [2]. One advantage of modeling multi-layer AMCs using equivalent networks is that existing linear circuit simulators can be used to rapidly synthesize the circuit values of multi-layer, multi-band AMCs.

II. Dual-band Example

For the case of N=2, the input impedance of the equivalent circuit in Figure 1 is given by:

$$Z_{in}(s) = \frac{s\left(L_1 + L_2 + s^2 L_1 L_2 C_1\right)}{s^4 L_1 C_1 L_2 C_2 + s^2\left(L_1 C_1 + L_1 C_2 + L_2 C_2\right) + 1} .$$

where $s=j\omega$. Solving for the roots of the denominator of the input impedance yields the two AMC resonant frequencies. The presence of the $L_1 C_2$ term in the denominator of the input impedance indicates that the two resonant frequencies cannot be adjusted independently of each other simply by defining the products L_1C_1 and L_2C_2. The physical structure is illustrated in Figure 2. We approximated the series inductances as $L_n = \mu_o d_n$, *n=1 or 2* where d_n is the height of the corresponding dielectric spacer layer. Capacitors *C1* and *C2* are each realized by a two metal layer FSS comprised of overlapping copper patches in a square lattice separated by a polyimide dielectric (ε_{r3} ~ 3.3) of nominal thickness t =2 mils. The capacitive values can be approximated by the parallel plate capacitance of the shaded area in Figure 3. For the upper FSS: *C2* = 1.8 pF/sq, period P = 294 mil, chamfer = 112 mil, g = 15 mil and for the lower FSS: *C1* = 6 pF/sq, P = 294 mil, chamfer = 35 mil, g = 15 mil. The thickness of the dielectric spacer layers between the lower FSS layer and the ground plane is 124 mils, and between the FSS layers it is 155 mils. Plated through holes of 50 mil diameter connect the center of each patch to the ground plane. This dual-band AMC was designed using a commercial linear circuit simulator, and the predicted reflection phase was optimized to achieve a +/- 90^o phase bandwidth over both the GSM 850 MHz and PCS 1900 MHz bands.

III. Experimental Results

Dual-band AMC panels of size 10” x 16” were fabricated as shown in Figure 4. The total thickness is 314 mils, or $\lambda_o/44$ where λ_o is the free space wavelength at the low band resonance of 825 MHz. Figure 5 shows measured results for the reflection phase (black curve) where the reflection phase of zero degrees occurs at about 825 MHz and 1875 MHz. Surface wave coupling measurements are made using a pair of broadband horns with the AMC panel under test placed in a tunnel lined with absorber. The TM mode coupling curve (in red) measures transmission of the vertical (normal) electric field polarization relative to a metal surface (0 dB) the same size as the AMC panel. The TM mode cutoff frequencies of about 800 MHz and 1825 MHz are clearly seen where the coupling curve crosses 0 dB. The TE mode coupling curve (in blue) measures transmission for the horizontal (tangential) electric field polarization. We consider the TE mode cutoff to be the frequency at which beating (ripple) begins in the S21 response. This beating is caused by bound TE modes reflecting between parallel edges of the AMC panel under test. So the TE mode cutoff frequencies are near 900 MHz and 2000 MHz. Most of the range of frequencies over which a +/- 90^o phase response is observed is contained within the surface wave bandgaps of 800-900 MHz and 1825-2000 MHz.

IV. Conclusions

We have demonstrated a multi-band AMC concept comprised of N capacitive FSS layers with plated through holes extending through all layers. The plane wave reflection coefficient can be predicted using a Cauer Type I LC network with N shunt capacitors and N series inductors, which yields N non-harmonically related resonant frequencies. As an example, we fabricated and tested a dual-band AMC with desired resonances in the GSM 850 MHz band and the PCS 1900 MHz band. Through surface wave coupling measurements, we have also demonstrated that this dual-band AMC exhibits a surface wave bandgap over essentially the same range of frequencies where a high surface impedance surface (+/- 90^o reflection phase response) is observed.

V. References:

[1] Aram Budak, *Passive and Active Network Analysis and Synthesis*, Houghton Mifflin Company, Boston, 1974, pp. 93-94.
[2] Daniel F. Sievenpiper, “High-Impedance Electromagnetic Surfaces,” Ph.D. dissertation, UCLA, 1999.

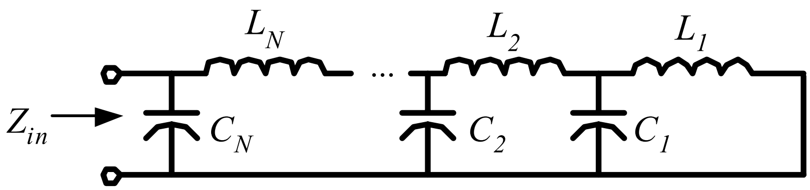

Figure 1. A Cauer Type I LC network is an equivalent circuit for TEM mode reflection at normal incidence.

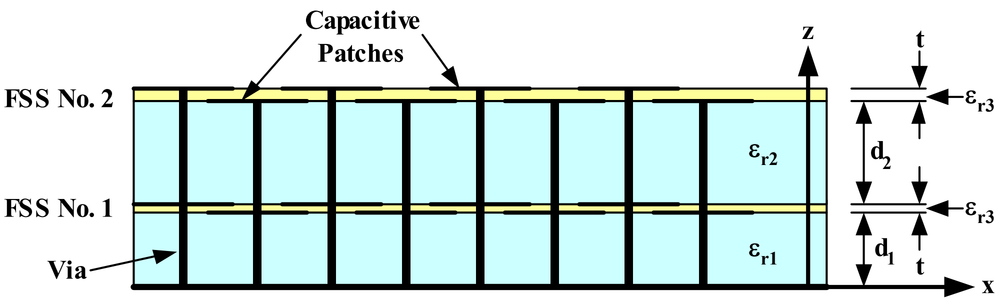

Figure 2. A cross sectional view of a dual-band AMC.

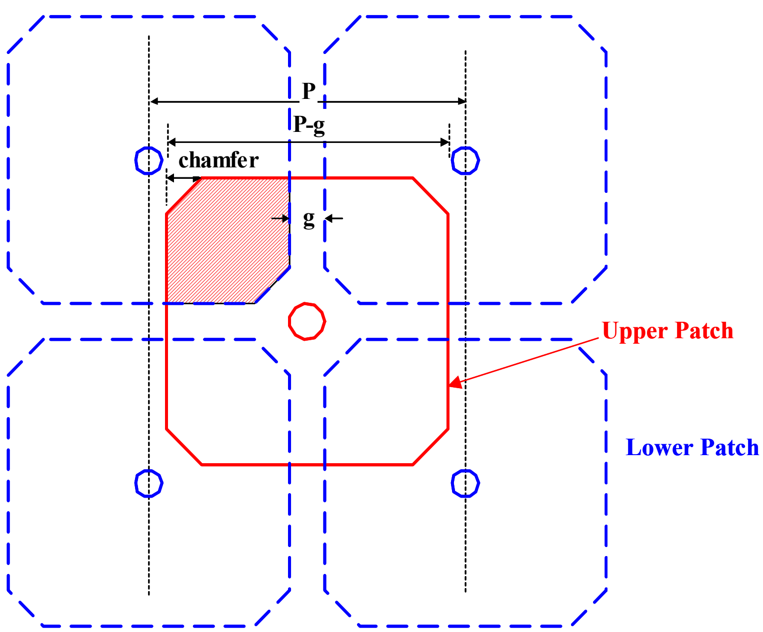

Figure 3. Each capacitive FSS consists of two layers of overlapping square patches.

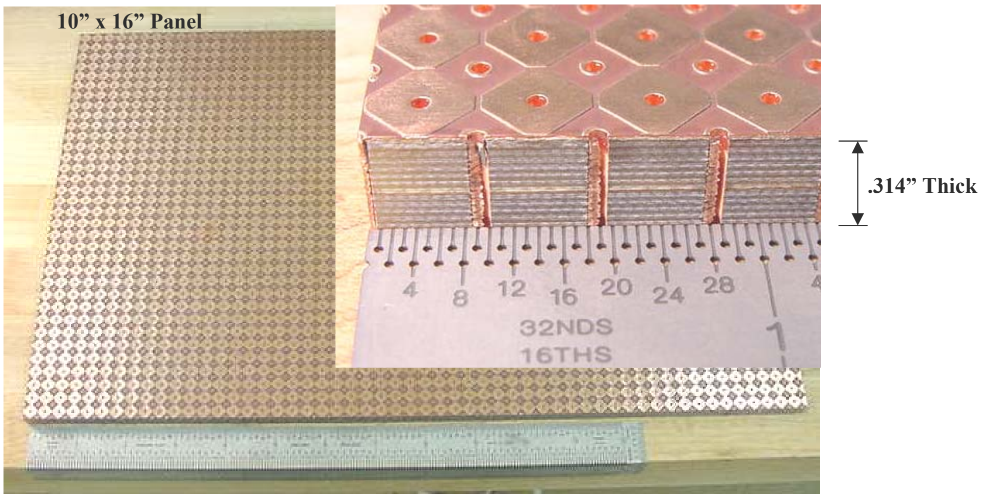

Figure 4. Photographs of a dual-band 850/1900 MHz AMC panel.

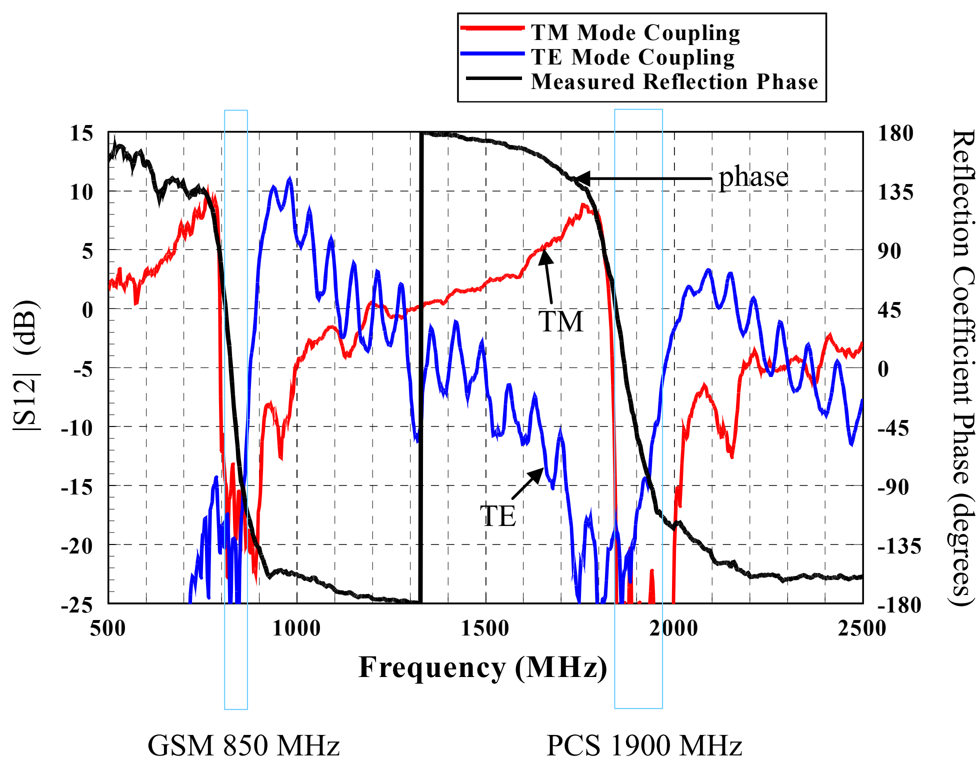

Figure 5. Measured reflection phase, TE mode coupling, and TM mode coupling.