Magnetic Loading of Artificial Magnetic Conductors for Bandwidth Enhancement

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1. Introduction

A magnetically loaded artificial magnetic conductor (AMC) providing enhanced bandwidth has been developed. The design is a variation of the Sievenpiper [1] "thumbtack" structure, which makes use of a low-loss, aligned, barium-cobalt hexaferrite material in the spacer layer. The design has been carefully engineered to align the high impedance and surface wave bandgap frequency bands. The demonstrated result is greater than four times improvement in bandwidth relative to a conventional structure of the same thickness.

2. Magnetic Material

The magnetic material used to load the spacer layer of the AMC is barium cobalt hexaferrite, $Ba_3Co_2Fe_{24}O_{41}$ (Co_2Z), first presented by Smit and Wijn in 1959 [2]. During the fabrication process, the magnetic moments can be aligned to produce a bi-uniaxial magnetic material with $\mu_{r,xy} \approx 30 - j\ 1.0$ and $\mu_{r,z} \approx 1.0 - j\ 0.03$ at approximately 200 MHz. Air gaps can then be introduced into the material to increase the resonant frequency at the expense of initial permeability according to Snoek's law. The effective transverse material parameters are given by the Claussius-Mosotti equations shown below. (where Vf is the volume fraction of ferrite).

$$\mu_{xyeff} = [(1+V_f(\frac{\mu_{xy}-1}{\mu_{xy}+1}) \Big/ (1-V_f(\frac{\mu_{xy}-1}{\mu_{xy}+1})] \quad (1a)$$

$$\varepsilon_{xyeff} = \varepsilon_{host} \cdot [(1+V_f(\frac{\varepsilon_{xy}-\varepsilon_{host}}{\varepsilon_{xy}+\varepsilon_{host}}) \Big/ (1-V_f(\frac{\varepsilon_{xy}-\varepsilon_{host}}{\varepsilon_{xy}+\varepsilon_{host}})] \quad (1b)$$

while the axial parameters are given by:

$$\mu_{zeff} = 1+V_f\mu_z\,, \quad \varepsilon_{zeff} = 1+V_f\varepsilon_z \quad (2)$$

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3. AMC Design

The magnetically loaded AMC (Mag-AMC) was designed to operate with a band-center at 315 MHz and 2:1 instantaneous bandwidth in a 1” thick form factor. A drawing of the AMC is shown in Fig. 1 and a close-up of the magnetic material geometry is shown in Fig. 2. The complexity of the design was necessary to achieve a surface wave bandgap over the entire high-impedance frequency band of the AMC – defined as the +/-90° reflection phase band. As described further below, certain specific aspects of the design are chosen to minimize loss and obtain the proper high impedance band, while others are primarily associated with TM surface wave cutoff, and still others principally affect the TE surface wave cutoff [3,4].

The TM surface wave cutoff is determined by the via spacing in the upper and lower spacer layer regions. For the upper region containing the Rohacell foam the vias are placed at the center of every third FSS unit cell. However, in the lower region containing the ferrite tiles a much closer via spacing is required because of the high transverse permittivity and permeability resulting in vias placed at the center of each ferrite tile. In the final design the vias are spaced 9 times closer together in the ferrite tile region than in the Rohacell region.

The high permeability of the Co_2Z perturbs the magnetic field components of the TE surface wave near the capacitive FSS layer and encourages energy to become bound to the surface. To counteract this effect, the magnetic material should be as far as possible from the FSS layer, and its normal permeability should be minimized. This is shown in the construction photo and final version photo of the Mag-AMC - Figs. 3 and 4, respectively. The AMC shown in Fig. 4 was has a form factor of 16.2” x 16.2” x 1.3” and weighs 18 lbs.

4. Simulation and Measurement Results

A comparison of simulated and measured results for the Mag-AMC and a standard foam core AMC is shown in Fig. 5. The simulated result for the foam core AMC is based on a simple circuit model. The simulated result for the Mag-AMC was generated using KCC Microstripes with an effective medium model of the AMC. The Mag-AMC has a simulated ±90° reflection phase bandwidth of 246 MHz compared to a measured bandwidth of 167 MHz. The foam core AMC has a simulated bandwidth of 62 MHz and a measured bandwidth of 35 MHz. These discrepancies may be due to edge diffraction effects which are important here given the limited electrical size of the substrate. For both AMC realizations the measured bandwidth was about 30-40% smaller than predicted by the simulations. However, both sets of results show more than a factor of four increase in reflection phase bandwidth for the magnetically loaded case. Note: It was not possible to obtain a clean surface wave measurement for this structure given the limited substrate size, so the predicted surface wave bandgap has not yet been verified.

5. Conclusions

The use of magnetic loading in AMC structures for bandwidth enhancement has been successfully demonstrated in this paper. More than a factor of four increase in reflection phase bandwidth is achievable with a magnetically loaded AMC compared to a conventional foam core AMC. Using the Mag-AMC it is possible to build an antenna to instantaneously cover the UHF LOS frequency band in a depth of about 1.5”.

6. Acknowledgements

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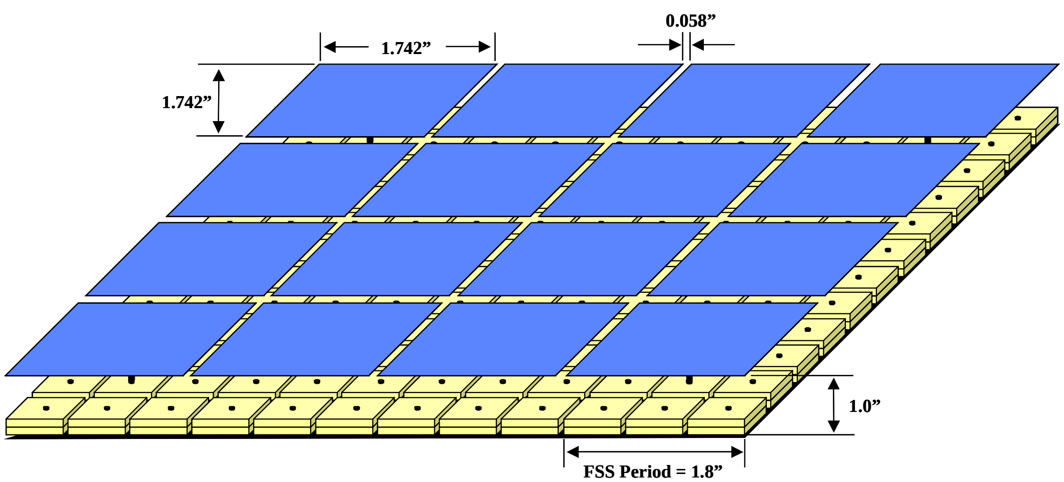


Figure 1. Magnetically Loaded AMC Geometry

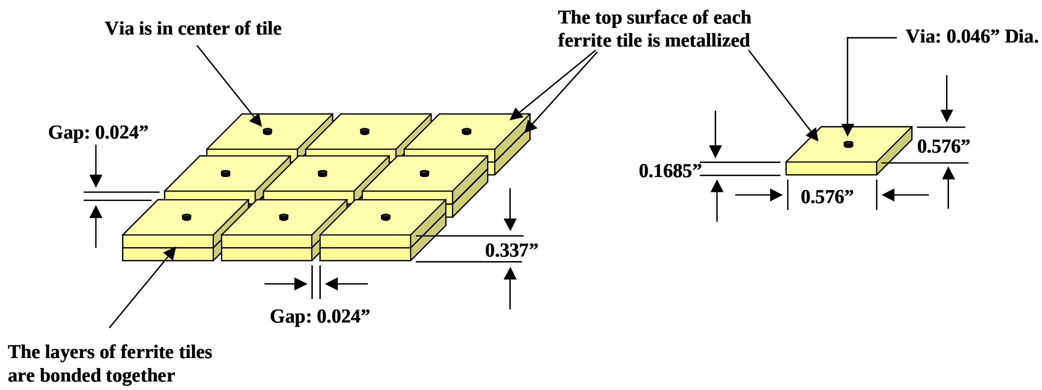
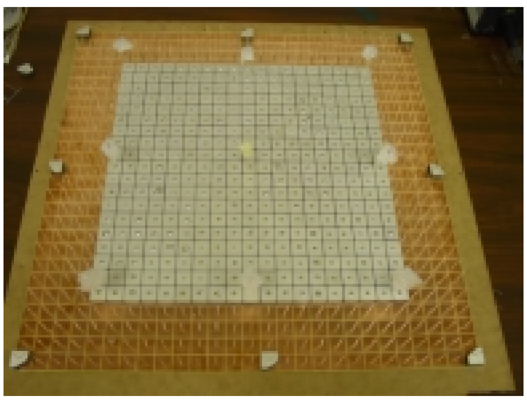


Figure 2. Ferrite Tile Geometry



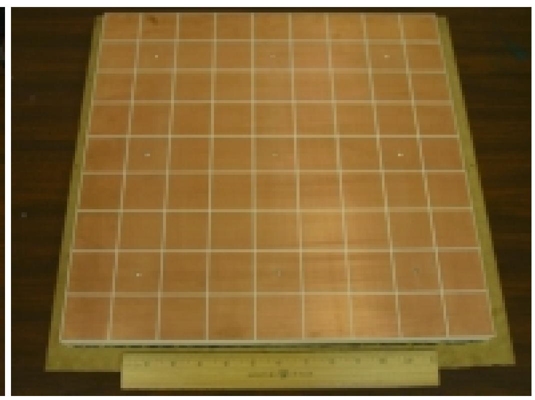


Figure 3. Construction photo of Mag-AMC ferrite tile layer.

Figure 4. Completed Mag-AMC photo

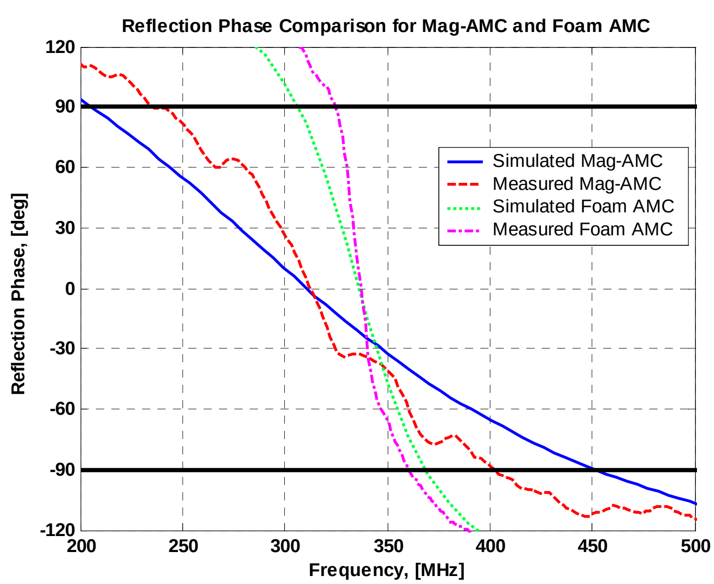


Figure 5. Reflection Phase Comparison for Mag-AMC and Foam Core AMC