An Electrically-Thin, Two-Pole, Bandpass Radome

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Abstract: A two-pole bandpass radome is comprised of an inductive ground plane with symmetric capacitive FSS structures equally spaced on either side. Capacitive patches in these two FSS structures are connected with the ground plane by virtue of plated through holes. Spurious modes are suppressed over a very broad frequency band between the desired passband and the parasitic resonance of the FSS patches, which can be up to an order of magnitude in ratio due to the relatively small size of the patches. Furthermore, the total radome thickness can be designed to be less than \( \frac{\lambda_0}{50} \) at the fundamental passband. An L-band example is fabricated and tested.

I. Introduction

Traditional bandpass filter (BPF) radomes employ a periodic array of resonant \( \frac{\lambda_0}{2} \) slots in a metal screen. However, such radomes may exhibit spurious passbands at odd multiples of the fundamental frequency. One of our goals was to design a radome free of spurious transmissions for a decade or more of bandwidth above the fundamental resonance. In addition, we desired more frequency selectivity than the single pole response obtained from a single slotted screen, but we desired a total radome thickness comparable to a single screen design.

Here we introduce a bandpass radome that exploits a new mode of resonance whereby standing TEM waves are set up internal to the structure in a wave direction normal to the surface. This is possible using an artificial magnetic conductor (AMC) comprised of a “thumbtack structure” originally taught by Sievenpiper [1], which exhibits a high surface impedance at its resonant frequency. In this new concept, we employ back-to-back AMCs whereby RF power is coupled through their common ground plane using very electrically small periodic apertures. Thus the ground plane becomes an inductive grid. Each AMC behaves as a coupled resonator such that the total structure exhibits a two pole response with much sharper transmission skirts than what is available from a single pole slotted radome of similar thickness. Applications include dichroic subreflectors for Cassegrain communications antennas where the uplink and downlink frequencies are closely spaced, such as in the same microwave band.

II. Mechanical Description

This L-band radome is fabricated as a symmetric five-layer printed circuit board (PCB) that includes plated through holes (PTH) drilled through all layers. An edge view is shown in Figure 1 with an exploded view in Figure 2. The period for the square lattice is 12 mm, and the square patches that comprise layers 1,2,4, and 5 are 11.25 mm on a side,
excluding the rebated corners. The four dielectric cores are each Rogers RO4003, where \( t = 0.2 \text{ mm}, \) and \( d_1=d_2=1.524 \text{ mm}. \) The inductive grid contains a uniform periodic array of 2.25 mm square apertures. The total fabricated radome thickness is approximately 4 mm including \( \frac{1}{2} \text{ oz.} \) copper layers plus 3 bonding films. So the fabricated radome is \( \lambda_o/49 \) thick were \( \lambda_o \) is the free space wavelength at the center of the passband: 1550 MHz.

III. Electrical Model

Each side of the inductive grid may be considered a resonator, which is coupled by electrically small \((\lambda_o/90)\) apertures. Figure 3 is an equivalent circuit sufficient to predict the lower frequency, or passband, response. Applying a chain matrix analysis allows transmission loss to be computed as

\[
T = -20 \log \left[ \left( \frac{\eta_o}{2j\omega L_2} \right)^2 + \left( 1 + \frac{L_1}{L_2} + j\omega C_1\eta_o \right)x + \frac{j\omega L_1}{\eta_o}\right] \left( 1 + \frac{L_1}{2L_2} \right) \right]^{(dB)}
\]

where \( x = (1 - \omega^2 L_1 C_1) \). \( C_1 \) is the effective shunt capacitance of each capacitive FSS. \( L_1 \) is the effective series inductance \( \mu_0d \) of an equivalent transmission line between each capacitive FSS and the inductive grid. Transmission is achieved at a center frequency approximately defined by the resonance of \( L_1 \) and \( C_1 \). \( L_2 \) is typically much smaller than \( L_1 \), and it may be estimated from standard formulas \[3\]. In this design, \( L_1 = 1.91 \text{ nH}, \) \( L_2=0.12 \text{ nH}, \) and \( C_1=5.22 \text{ pF.} \) A full-wave TLM simulation (see Figure 4) was also performed which gave excellent agreement with the above transmission formula.

IV. Experimental Results

Figure 4 shows the predicted transmission loss at normal incidence, which is computed from a TLM full wave simulation. Material losses were not included in the simulation. Figure 4(a) shows that the simulated transmission is a 2-pole Butterworth response with the center frequency near 1550 MHz. The 3 dB passband bandwidth is 132 MHz, or 8.8%. Above band, the first 6 overtones of 1550 MHz are predicted to be suppressed. However, several spurious transmission responses do occur between 12 GHz and 16 GHz due to patch resonances.

Transmission measurements of the fabricated design, shown in Figure 5, support these predictions. However, the center frequency is too low by about 100 MHz, or 6.5%. This difference is due to added thickness of prepreg layers not included in the simulation. Furthermore, we required an additional prepreg layer on one side of the grid \( d_1 \) was not equal to \( d_2 \), which created an asymmetric passband. The passband transmission loss is approximately \(-3 \text{ dB}\) for this prototype radome, which may be improved by increasing and equalizing the dimensions \( d_1 \) and \( d_2 \). Regarding the above-band transmission, measurements show the suppression of spurious responses just as predicted up to 12 GHz. Thus a broad stopband is observed from about 2 GHz to 12 GHz, which may be extended even further by using smaller patches and a thinner FSS dielectric. Oblique incidence measurements were not pursued due to resource limitations.

V. Conclusions

We have shown that a two-pole bandpass radome can be constructed whose total thickness is approximately \( \lambda_o/50 \) at the center of the fundamental passband: 1550 MHz.
It is comprised of two capacitive FSS structures symmetrically located on either side of an inductive grid. Plated through holes connect the FSS patches to the grid, and small square apertures ($\lambda_o/90$) in the grid allow coupling. However, the period of the unit cell is so small ($\lambda_o/16$) that spurious responses are suppressed for approximately an order of magnitude above the center frequency of the fundamental passband.

VI. References

Figure 3. A simple equivalent circuit for this bandpass radome is comprised of five lumped elements, only three of which are unique.

Figure 4. Predicted transmission loss and return loss at normal incidence using a full wave simulation: (a) between 1400 MHz and 1600 MHz, (b) between 0 and 18 GHz.

Figure 5. Measured transmission loss at normal incidence: (a) between 1 GHz and 2 GHz, and (b) between 2 GHz and 18 GHz.