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Resistively Loaded FSS Clad Thermal Blankets for Enhanced RF Space Communications

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Abstract—A new concept for improving the performance of radio frequency (RF) space communication systems is described in this paper. This is achieved by employing resistively loaded Frequency Selective Surfaces (FSS) to electromagnetically decouple antennas that are sited above strongly illuminated host spacecraft platforms, that are covered with multilayer thermal insulation material (MLI). The metal backed FSS structures investigated in this study are manufactured using a 1.12 mm thick Polyethylene Terephthalate (PET) sheet, which is suitable for integration into the outermost layer of commercially available thermal blankets which are constructed with the same material. The reduction in scattering, which produces pattern distortion in conjunction with reduced boresight directed gain and enhanced crosspolarisation in the field of view, is illustrated for the case of a low gain bidirectional circular polarized (CP) dipole. The antenna which works at 10 GHz is installed at various distances ranging from one half to five half wavelengths above a typical CubeSat platform.

Index Terms—frequency selective surface, thermal blanket, ultra-thin absorber, radar absorbing material

I. INTRODUCTION

The increase in the stealth budget requirements for many modern RF applications has led to the rapid development of innovative Radar Absorbing Materials (RAM) which are deployed for radar cross-section (RCS) reduction. Much of the recent research effort has focused on creating solutions that are physically thin and hence exhibit desirable aerodynamic properties in conjunction with low weight. A major challenge is to address the conflicting requirements of minimizing the thickness of the structures whilst simultaneously maximizing the reflectivity bandwidth and reducing sensitivity to the angle of incidence. Several different methods for obtaining RCS

reduction have been reported in the literature, such as the use of absorbing paint [1], periodic structures that exhibit random scattering of electromagnetic waves [2], and more recently very thin metal backed resistively loaded FSS [3].

RAM based on the use of resistively loaded FSS are classified as Circuit Analog (CA) absorbers. The physics underpinning their operation is described in [4]. Because of the diversity of the FSS topologies that are available to create this class of material, it offers much more design flexibility than other classical arrangements such as the Salisbury screen [5]. For many applications it is desirable to minimize the thickness of a microwave absorber whilst simultaneously achieving the specified reflectivity bandwidth. For example the electrical thickness of a Salisbury Screen is fixed at $\lambda/4$ and this structure exhibits a -10dB reflectivity bandwidth of 77%, whereas FSS based absorbers have been reported which yield fractional bandwidths and thicknesses (at the center operating frequency) that range from 1.5% ($\lambda/220$) [6] to 107% ($\lambda/9$) [7].

The work reported in this paper exploits the desirable physical properties of resistively loaded FSS to create a novel solution for improving the performance of RF space communications systems. This is achieved by absorbing the backlobe energy which is radiated from antennas that are sited above the host platform. Spacecraft are often covered with a multi-layer thermal insulator blanket which is composed of up to 30 interleaved dielectric and metallic films to create a very thin (typically 3 mm) and flexible heat reflecting sheet. Electromagnetic scattering from space blankets often has a major effect on the electromagnetic performance of low gain antennas [8] and is responsible for pattern ripple, and depolarization in addition to enhanced coupling between ‘on farm’ antennas and the generation of passive intermodulation

products.

Our proposed solution for isolating the antennas from the host space vehicle is simply to modify the outermost layer of the thermal blanket, by printing a resistively loaded FSS on the surface of the first metal backed dielectric layer. In the numerical simulations the periodic array is patterned on a 1.12 mm thick PET sheet which is identical to the material used to construct many commercially available space blankets. To highlight the major performance improvement that can be obtained, numerical simulations are used to compute the radiation pattern of a CP dipole which exhibits a gain of 2.2 dB at 10 GHz and radiates identical but crosspolarized radiation patterns with equal energy in the forward and rear (towards the surface of the CubeSat) hemispheres. The antenna is located at distances $\lambda/2 - 5\lambda/2$ above a 10 cm³ CubeSat to create differences in the illumination of the top surface of the platform. The level of improvement obtained is different for each arrangement studied, however the most significant result is obtained when the antenna is placed $\lambda/2$ above the metal structure. For this case destructive interference reduces the boresight gain to -16 dBic and the crosspolar levels are predicted to increase by more than 14 dB. However, the computed results show that by covering the surface of the spacecraft with a 1.12 mm thick FSS absorber, the shape of the radiation pattern of the antenna in isolation is almost fully recovered in the forward hemisphere. This modification to the space blanket increases the boresight gain by 18.6 dB and reduces the axial ratio of the transmitted signal from 14 dB to 1.74 dB.

II. ABSORBER DESIGN

In this study we evaluate the installed performance of a CP dipole antenna working at 10 GHz and sited $\lambda/2$, $3\lambda/2$ and $5\lambda/2$ above the top surface of a 10 cm³ picosatellite (CubeSat). This ensures realistic simulation times using CST Microwave Studio to compute the radiation patterns with and without the FSS absorber covering the conductive surfaces of the metal structure.

This approach for the suppression of antenna backscatter requires a very thin and lightweight microwave absorber which works over a wide range of angles of incidence for TE and TM waves corresponding to the spatial distribution of the backlobe energy over the surface of the satellite. For the $\lambda/2$ and $5\lambda/2$ arrangements, the edges of the CubeSat are at angle of $\pm 72^\circ$ and $\pm 33^\circ$ respectively, relative to the direction of the peak backlobe radiation (180°).

The FSS unit cell which is depicted in Fig. 1, is composed of a closed packed array of strongly coupled hexagonal patch elements. The periodic array is patterned on a 1.12 mm thick ($\lambda/25$) PET substrate which is often used to manufacture commercially available space blankets. In [9] we show that this topology exhibits a significantly wider reflectivity bandwidth than absorbers constructed with unit cells composed of nested loops [7]. This is because it is impossible to merge the individual narrow reflection nulls that are generated by the loop elements when the FSS thickness is $< \lambda/17$.

Fig. 1: Schematic of the FSS unit cell and side view.

Fig. 2: Computed TE/TM absorbance at normal incidence. Inset illustrates the surface current distribution for the TE wave polarisation.

Fig. 3: Computed TE/TM frequency response for the FSS absorber (a) TE and (b) TM polarised waves.

This material has a permittivity 2.9 and a loss tangent 0.025 [10]. At normal incidence a -10 dB fractional reflectivity bandwidth (FBW) of 16% is obtained at 10 GHz for a periodic array design with dimensions, $t_d = 1.12$ mm, $r = 3.46$ mm, $P = 6.3$ mm, and a surface resistance $R_s = 20 \Omega/sq$. Fig. 2 depicts the computed absorbance of the FSS at normal incidence between 8–12 GHz. The reflectivity results depicted in Fig. 3 show that although the effectiveness of the absorber decreases at higher angles of incidence (θ), at least 75% of the impinging signal is suppressed at 10 GHz for incident angles between $\theta = 0^\circ$ and 60° , and for the case where the dipole is sited $\lambda/2$ above the CubeSat, at least 56% of the energy is absorbed by the FSS placed close to the edge of the satellite platform (74°) for TE waves and 60% for TM waves.

The hexagonal patch array was patterned on a Letter size $140 \mu\text{m}$ PET sheet by digitally configuring the dot density obtained from a desktop inkjet printer in conjunction with selecting a suitable conductive ink/solvent mixture to create self-resonant elements with a $20 \Omega/sq$ surface resistance. The manufacturing technique is discussed in detail in [6] and [11]. Seven identical unpatterned PET sheets were bonded together and inserted between the FSS array and a metal ground plane to complete the construction of the 1.12 mm thick absorber. The reflection coefficient of the structure was measured at normal incidence between 8–12 GHz in an anechoic chamber relative to a $20 \times 22 \text{ cm}^2$ metal plate that was placed 1.3 m distance from the aperture of two 20 dB standard gain horns (Fig. 4a). Time-gating was employed to eliminate unwanted reflections which are mainly attributed to edge diffraction from the support structure. Fig. 4b shows good agreement between the simulated and measured results. The computed -10 dB reflectivity fractional bandwidth (90% absorption), is 16% centered at 9.84 GHz, which compares well to the measured values of 15.4% and 9.91 GHz.

III. EM SIMULATIONS

Fig. 5 shows the predicted RHCP (copolar) and LHCP (crosspolar) plots for the CP cross dipole antenna at 10 GHz. The reference signal is transmitted in the forward hemisphere (towards Earth) centred at 0° and the CubeSat is illuminated by backlobe radiation centred at 180° . The hand of polarisation changes upon single order reflections from the metal surface of the satellite, so degradation of the copolar signal in the forward hemisphere is mainly attributed to the LHCP backlobe whereas scattering of the RHCP signal reduces the polarisation purity of the waves in the boresight direction.

The simulations carried out in CST Microwave Studio were used to compare the installed antenna radiation patterns with the CubeSat covered by (i) a perfect conductor (space blanket) and (ii) the 1.12 mm thick FSS based absorber. Fig. 6 depicts a schematic of the latter arrangement showing the predicted current distribution on the surface of the spacecraft when the antenna is placed $\lambda/2$ above its structure. The centre of the CubeSat is illuminated by the peak of the LHCP beam as shown in Fig. 5, and the numerical results show that the current density is at least 4 times lower at the edges of the top surface.

(a)

(b)

Fig. 4: (a) Photograph of Experimental Set-Up (b) Simulated and measured reflectivity of 1.12 mm thick FSS absorber working at normal incidence.

Fig. 7a shows that the radiation pattern of the CP dipole is significantly degraded by electromagnetic scattering from the conductive spacecraft platform. The antenna is sited $\lambda/2$ above the metal surface to create an equal amplitude antiphase interfering RHCP wave in the boresight direction upon reflection of the LHCP signal. The resultant destructive interference of the copolar signal in conjunction with edge scattering produces an 18.3 dB null thus reducing the gain from 2.2 dB to 16.1 dB. The computer model also shows that the crosspolar signal increases by 14 dB in the boresight direction and the antenna backscatter not only increases the axial ratio from 1.74 dB to 14.38 dB, but when installed on the CubeSat the maximum signal propagates in the LHCP wave mode and not the reference polarisation as shown in Fig. 5.

A remarkable improvement in the antenna performance is illustrated in Fig. 7b which shows the impact of covering the CubeSat with the thin FSS. Absorption of most of the backlobe energy which is incident on the metal surfaces at all incident angles and the two wave polarizations at 10 GHz (Fig. 5), effectively decouples the low gain dipole from the host

platform. The predicted boresight gain (2.7 dB) and the axial ratio 1.74 dB are significantly better than the computed results for the antenna sited on the spacecraft without the 1.12 mm thick resistively loaded FSS. By comparing Fig. 5 and 7(b), it is evident that in the forward hemisphere the beam shape is very similar to the copolar and crosspolar patterns that are generated by the dipole antenna in isolation.

Two more geometrical arrangements were considered for this study, with the antennas placed $3\lambda/2$ and $5\lambda/2$ above the CubeSat (Figs. 8 and 9). The purpose of this investigation

Fig. 5: Simulated radiation (directivity) patterns for the CP dipole antenna in isolation at 10 GHz.

Fig. 6: Current distribution on the CubeSat for RHCP dipole antenna placed $\lambda/2$ above the structure completely covered with the FSS absorber.

Fig. 7: Simulated radiation (directivity) patterns for CP dipole antenna working at 10 GHz and placed $\lambda/2$ above the CubeSat (a) uncovered, (b) covered with absorber.

was to observe the effectiveness of the absorber for different surface illumination factors corresponding to the maximum edge of coverage angle ($\pm 72^\circ$ ($\lambda/2$), $\pm 47^\circ$ ($3\lambda/2$), $\pm 33^\circ$ ($5\lambda/2$)) which is inversely proportion to the height of the dipole antenna above the CubeSat. Fig. 8a and 9a show that the copolar pattern shape in the forward hemisphere is severely degraded by the formation of deep ripples which are caused by scattering from the upper metal surface including the strongly illuminated edges of the satellite. However in both cases the boresight gain of the antenna in isolation and a smooth copolar

Fig. 8: Simulated radiation (directivity) patterns for CP dipole antenna working at 10 GHz and placed $3\lambda/2$ above the CubeSat (a) uncovered, (b) covered with absorber.

Fig. 9: Simulated radiation (directivity) patterns for CP dipole antenna working at 10 GHz and placed $5\lambda/2$ above the CubeSat (a) uncovered, (b) covered with absorber.

Fig. 10: Comparison of axial ratio of CP dipole antenna placed at varying distances above CubeSat with (covered) and without (uncovered) FSS absorber.

pattern is obtained when the metallic structure is covered with the resistively loaded FSS. Fig. 10 summarizes the reduction in boresight axial ratio which is obtained by covering the space vehicle with the 1.12 mm thick absorber. The performance improvement is particularly significant for the configuration where the antenna is closest to the platform. For this case a major reduction in the magnitude of the RHCP signal is mainly responsible for the observed depolarization of the transmitted waves.

IV. CONCLUSIONS

This paper has presented a new technique for improving the performance of RF instruments that deploy low gain antennas in close proximity to host metal structures. The study used numerical simulations to model an extreme case where the primary CP radiating source generates a bidirectional beam so that almost 50% of the energy impinges on the top metal surface of a 10 cm³ CubeSat. It was shown that the major reduction in gain and polarisation purity in the boresight direction is largely removed by deploying a carefully designed resistively loaded FSS which can easily be integrated into the surface of a stratified thermal blanket material. The reflectivity bandwidth could be increased by reducing the angular sensitivity the absorber. This improvement can be implemented by tiling the surface of the spacecraft with dissimilar size periodic elements that are optimised for the angular illumination at each spatial position on the spacecraft. This approach provides a promising solution for enhancing the RF performance of future space borne payload instruments.

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REFERENCES

- [1] J. W. Bond, "Radar attenuating paint," U.S. Patent 4,606,848, 1986.
- [2] J. Xue, W. Jiang, and S. Gong, "Chessboard amc surface based on quasi-fractal structure for wideband rcs reduction," *IEEE Antennas and Wireless Propagation Letters*, vol. 17, no. 2, pp. 201–204, Feb 2018.
- [3] F. Costa, A. Monorchio, and G. Manara, "Analysis and design of ultra thin electromagnetic absorbers comprising resistively loaded high impedance surfaces," *IEEE Transactions on Antennas and Propagation*, vol. 58, no. 5, pp. 1551–1558, May 2010.
- [4] B. A. Munk, *Frequency selective surfaces: theory and design*. John Wiley & Sons, 2005.
- [5] F. C. Seman, R. Cahill, V. F. Fusco, and G. Goussetis, "Design of a salisbury screen absorber using frequency selective surfaces to improve bandwidth and angular stability performance," *IET Microwaves, Antennas Propagation*, vol. 5, no. 2, pp. 149–156, Jan 2011.
- [6] G. G. Machado, R. Cahill, V. Fusco, and G. Conway, "Design and fabrication of inkjet printed ultrathin fss based microwave absorbers," in *The Loughborough Antennas Propagation Conference (LAPC 2018)*, Nov 2018, pp. 1–6.
- [7] S. N. Zabri, R. Cahill, and A. Schuchinsky, "Compact fss absorber design using resistively loaded quadruple hexagonal loops for bandwidth enhancement," *Electronics Letters*, vol. 51, no. 2, pp. 162–164, 2015.
- [8] R. Cahill, I. Cartmell, G. van Dooren, K. Clibbon, and C. Sillence, "Performance of shaped beam quadrifilar antennas on the metop spacecraft," *IEE Proceedings - Microwaves, Antennas and Propagation*, vol. 145, no. 1, pp. 19–24, Feb 1998.
- [9] G. Goncalves Machado, R. Cahill, V. Fusco, and G. Conway, "Comparison of fss topologies for maximising the bandwidth of ultra-thin microwave absorbers," in *13th European Conference on Antennas and Propagation 2019 (EuCAP 2019)*, accepted for publication, Apr 2019.
- [10] Novacentrix. (2019) Novele ij-220. [Online]. Available: https://store.novacentrix.com/v/vspfiles/assets/images/novele%20ij-220_2212.2.pdf
- [11] S. N. Zabri, R. Cahill, G. Conway, and A. Schuchinsky, "Inkjet printing of resistively loaded fss for microwave absorbers," *Electronics Letters*, vol. 51, no. 13, pp. 999–1001, 2015.