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Suppression of Antenna Backscatter on a Nanosat Using a Resistively Loaded FSS Absorber

Gabriel G. Machado, Robert Cahill, Vincent Fusco, Gareth A. Conway

Abstract—A very thin microwave absorber which can be integrated into the outermost layer of thermal blankets is proposed as a means to electromagnetically decouple payload antennas from spacecraft platforms. The effectiveness of this concept is evaluated for a critical test case where a linearly polarised dipole antenna working at 10 GHz is placed at three different distances above the surface of a 10 cm Nanosat mock-up. This scenario is chosen as the dipole will radiate into both half spaces and any reflections from the vehicle onto which it is mounted will significantly affect its behavior. A resistively loaded Frequency Selective Surface (FSS) absorber is employed to suppress the energy contained in the antenna backlobes, and it is shown that the installed performance for all three geometries closely resembles the beam shape of the antenna in isolation. Experimental results have been obtained for one arrangement to confirm that the directive gain is increased by 18 dB in the boresight direction. The FSS absorber is composed of an array of resistively loaded hexagonal patches which are patterned on a 1.12 mm ($\lambda/25$) thick foil backed Polyethylene Terephthalate (PET) sheet to replicate the physical construction of commercially available space blankets.

Index Terms—Frequency selective surfaces, Microwave absorbers, Ink jet printing.

I. INTRODUCTION

Electromagnetic scattering from the conductive surfaces of a spacecraft can degrade the performance of radio frequency (RF) instruments, mainly those that deploy low gain antennas. These interference effects are responsible for distortion of the beam shape, gain and polarization purity reduction, and also undesirable RF coupling in antenna farms. For example in [1] it is shown that the gain of an isotropic UHF communications antenna is significantly increased by coupling to the deployable payload sensor booms on a weather nanosatellite. Numerical simulations reported in [2] demonstrated that the undesirable pattern nulls can be removed by encasing each of the four sensors with a cylindrical shaped metasurface composed of thin metals strips. More generally, the authors [3] have shown that electromagnetic scattering from a large spacecraft platform can reduce the gain of a quadifilar helix antenna (15 dB front to back ratio) by 2 dB. To mitigate these effects, the European Space Agency (ESA) has recently identified a need for the RF enhancement of thermal blankets using metasurfaces as a means to suppress undesirable reflections from satellite platforms [4].

The stringent physical thickness limitation imposed on the construction of composite space blankets requires a solution which differs from most previously published work on metamaterials. Moreover in order to facilitate flexibility in the physical layout of the payload, the structure must provide electromagnetic decoupling of antennas which are positioned at

different heights above the spacecraft platform. Currently the only mechanically suitable arrangement that has been reported is a structure composed of a metal backed aperiodic array of conductive patches [5]. The elements forming this class of FSS can be printed on the outermost surface of space blankets which are composed of multiple layers of thin interleaved foil backed dielectric sheets that spread the energy out upon reflection by randomly phased scattering. The design strategy described in this paper is very different, because instead of randomising the back scattered energy, our proposed solution works by strongly absorbing the antenna backlobe radiation. This is achieved by exploiting the physical properties of a thin metal backed resistively loaded FSS [6], [7] which is suitable for integration into the uppermost surface of this material [8]. The periodic array is patterned on a 1.12 mm thick foil backed PET substrate and is therefore compatible with the material type and physical dimensions of the cover layer. The purpose of this letter is to demonstrate the effectiveness of this approach by simulating the radiation patterns of a bidirectional dipole antenna operating at a center frequency of 10 GHz and placed at three different heights ($\lambda/4$, $\lambda/2$ and λ) above the top surface of a 10 cm (side) mock-up of a Nanosat. The latter two arrangements were selected to highlight the major performance improvements that are achieved by removing the deep copolar null on boresight which is attributed to ground plane induced destructive interference. Computed results are also employed to show that a similar performance improvement is obtained for circular polarization wave propagation, which is normally employed for spacecraft communications payloads [9].

In this study a close packed array of hexagonal patch elements has been engineered [10] for normal incidence operation. For this geometrical arrangement, the entire top surface of the metal plate is illuminated by the dipole and we show that a major reduction in pattern degradation is achieved when it is covered with the absorber. The numerical simulations for the worst case arrangement ($\lambda/2$) are validated by measured results using a mock-up of a Nanosat with the top surface covered with a resistively loaded FSS patterned using an ink jet printer.

II. DESIGN OF FSS ABSORBER AND SIMULATED PERFORMANCE

The reflectivity bandwidth that is achievable from this class of absorber is proportional to the thickness of the material [6], [11], [12]. The CST Microwave Studio simulator [13] was used to maximise the 90% absorbance (-10 dB reflectivity) bandwidth for a FSS printed on a 1.12 mm thick PET substrate

($\epsilon_r = 2.9$, $\tan \delta = 0.025$). The optimum design for normal incidence operation at 10 GHz was obtained from the unit cell arrangement simulated using Floquet Ports, assuming TE/TM plane wave illumination over the infinite array. The unit cell topology is shown in the inset of Fig. 1a, where $a = 3$ mm, $p = 10.9$ mm and $g = 0.3$ mm. The surface resistance of the close packed array of hexagonal shaped patches is $20 \Omega/sq$ [10].

Numerical simulations showing the absorbance of the infinite size FSS working at normal incidence are depicted in Fig. 1. The results show that the reflectivity bandwidth is 16.9% centred at 10 GHz, but the oblique incidence performance is not as good in both TE and TM plane. In the latter case this is mainly attributed to an upward frequency shift in the absorption peak which as explained in [14], is attributed to the large variation in the impedance presented to the incident waves for this orientation.

III. INSTALLED ANTENNA PATTERN PREDICTIONS

In the numerical model a center fed half-wavelength dipole was placed at a distance of $\lambda/4$, $\lambda/2$, and λ (7.5, 15 and 30 mm) above the surface of the Nanosat mock-up, which was modeled using copper to emulate the external layer of a thermal blanket. Scattering from a small platform was studied in order to reduce computing resources and a simple dipole with a gain of 2.4 dB was deployed for the primary radiating source because it radiates equal power in the forward and rear (towards the platform) hemispheres and therefore facilitates a major test of the ability of the FSS to decouple the antenna from the metal structure. In common with most published work [6], [7], [10], the results depicted in Fig. 1 assume that the FSS is infinite in extent and illuminated by plane waves. However in our pattern prediction study the electromagnetic environment is finite in size and the spatial distribution of the backlobe energy corresponds to an amplitude weighted angular spectrum of waves in a field of view of $\pm 80^\circ$, $\pm 72^\circ$, $\pm 58^\circ$, for a spacing of $\lambda/4$, $\lambda/2$, and λ , respectively. Although the FSS was optimized for normal incidence operation, Fig. 1 verifies that moderate absorption of TE and TM waves occurs at other angles. Figs. 2a,c show that the antenna beam shape is significantly modified by backlobe energy reflected from the metal platform. For the $\lambda/4$ geometry, the energy reflected in the boresight direction is in phase with the reference signal and constructive interference yields a 5.2 dB increase in the peak gain. For the other two cases studied, destructive interference produces a deep null in the boresight direction and the predicted gain of the antenna is reduced from 2.4 dB to -18.4 dB ($\lambda/2$) and -10.8 dB (λ) where the edges of the platform are more strongly illuminated in the E plane. When the top surface of the Nanosat is covered with the thin FSS absorber the computed results (Figs. 2b,d) in the forward hemisphere show that the deep nulls observed in the boresight direction are filled in and for all three cases studied the installed performance more closely resembles the patterns predicted for the dipole antenna in isolation. The results obtained from these test cases show that the decoupling effect of the FSS is independent of the position of the antenna

Fig. 1. Computed TE/TM absorbance at normal and oblique incidence for the FSS absorbers (a) TE, (b) TM. Experimental results are shown for normal incidence only. Inset depicts a unit cell.

above the space vehicle. Table I summarizes the predicted boresight gain for the dipole placed above the uncovered and FSS covered mock up of the Nanosat.

Most modern satellite and terrestrial point-to-point communications systems use circular polarization (CP) wave propagation as a means to maximize the polarization efficiency component of the link budget [9]. At normal incidence the topology of the hexagonal patches is symmetrical and the impedance presented by the FSS absorber shown in Fig. 1 is therefore identical when exposed to TE and TM waves. However the phase and amplitude of the more weakly reflected orthogonally orientated signals are different for oblique incidence operation and therefore this has the potential to degrade the beam shape and polarization purity [9] of the antenna pattern in the forward hemisphere. Therefore to verify that the proposed concept is also a feasible solution for CP wave operation, a 10 GHz crossed dipole was designed in CST and placed $\lambda/2$ above the Nanosat. For this arrangement the beam shape in the forward and rear hemispheres are identical, but

TABLE I
SUMMARY OF COMPUTED BORESIGHT DIRECTIVITY COMPARISON FOR THE UNCOVERED AND FSS COVERED NANOSAT.

Height	Gain (dB) Uncovered	Gain (dB) FSS Covered
$\lambda/4$	7.6	4.8
$\lambda/2$	-18.4	4.0
λ	-10.8	2.8

Fig. 2. Computed normalized directivity pattern of dipole antenna at 10 GHz in isolation and mounted at different heights above Nanosat mock-up (a) without and (b) with the FSS absorber for H-Plane, (a) without and (b) with the FSS absorber for E-Plane. The directivities are normalized to the dipole in free space 2.4 dB_i gain.

are of the opposite polarisation, and the single order reflected waves undergo polarization hand reversal. This results in the 3D copolar (RHCP) pattern exhibiting an 18.3 dB deep null, but as illustrated in Fig. 3, the null is removed by placing the FSS absorber on the upper surface of the vehicle. Moreover the crosspolar (LHCP) signal which is predicted to increase by 14 dB in the boresight direction (not shown for brevity)

Fig. 3. Computed 3D directivity pattern at 10 GHz for a RHCP polarized cross dipole placed $\lambda/2$ above the (a) uncovered and (b) FSS covered Nanosat.

and is higher than the reference signal, is suppressed by the FSS absorber which reduces the axial ratio from 14.4 dB to 1.74 dB. The radar backscatter suppression obtained from the FSS is therefore sufficient to isolate CP antennas from the host platform.

A. Experimental Results

An Epson Stylus C88+ inkjet printer with a specified maximum DPI of 600 was employed to pattern the periodic array in a single pass trace on the surface of a letter size 140 μm thick mm Novele IJ-220 PET substrate [15]. Eight sheets of the available material were bonded together using a 3M scotch welding spray glue to form the 1.12 mm thick absorber. As reported in [10] the spray creates an extremely thin layer of bonding film which does not affect the absorber performance, and therefore is not modeled in CST. As a general observation, the formation of air-bubbles must be avoided to prevent a large shift in the resonant frequency. The use of an inkjet printer to pattern the FSS is compatible with the topology of thermal blankets and moreover it provides a precise means to achieve the required surface resistance value given that the loss tangent of the PET material is fixed and the strategic placement of lumped element resistors on the periodic elements [16] is mechanically unsatisfactory. The surface resistance of the physical features was obtained by controlling the digital settings of the printer to adjust the dot density by manipulating the grayscale (or RGB code to 13,13,13) of the printer, in conjunction with the use of a 1:7 volume solution of Metalon™ JS-B25P nano silver ink [17] and Metalon™ aqueous vehicle [10], [18]. The bistatic measurement set-up described in [10] was used to verify the performance of the printed absorber. Time gated swept frequency measurements were carried out in the range 8 – 12 GHz, with the FSS absorber and the reference metal plate positioned 1.3 meters distance from two standard gain horns. For brevity Fig. 1 only shows the experimental results obtained at normal incidence. A photograph of the mock-up model of the Nanosat is depicted in Fig. 4. The structure was manufactured by soldering five copper clad boards to form a hollow metal cube with side lengths of 10 cm.

For simplicity a linear polarized dipole antenna was fabricated by soldering the 0.53 mm thick wire arms and the folded balun to the center conductor and outer jacket of a 1.9 mm diameter semi rigid cable. E and H plane radiation patterns

were measured in a 10 meter long anechoic chamber with the mock up model of the Nanosat mounted on a precision azimuth turntable and the antenna sited 15 mm above the top surface of the mock-up. The significant improvement which occurs when the metal structure is covered with the 306 element FSS absorber is shown in Fig. 5. In general the agreement between the numerical simulations and experimental results is quite good. The minor discrepancies that are observed in the plots can be accounted for by various factors that are not included in the computer model, including: (i) amplitude ripple which is imposed on the freespace antenna patterns because of unavoidable backscatter from the support jig, and azimuth turntable, (ii) the aperture which is inserted in the FSS to enable the antenna to be connected to the microwave receiver,

Fig. 4. Photograph of the Nanosat mock-up covered with a 1.12 mm thick FSS absorber.

Fig. 5. Normalised measured and simulated copolar radiation patterns of dipole antenna at 10 GHz in isolation and mounted $\lambda/2$ above Nanosat mock-up with and without the FSS absorber (a) H Plane, (b) E Plane.

and (iii) the impact of the semi rigid cable transmission line which is placed in close proximity to the absorber.

IV. CONCLUSION

Numerical and experimental results have been employed to demonstrate the feasibility of improving the installed radiation pattern performance of a low gain antenna which is sited in close proximity to the host metal platform. The physical thickness and material type used to design the thin FSS absorber are compatible with the construction of thermal blankets. By printing the resistively loaded elements on the surface of the outer foil backed dielectric cover sheet, we have shown that it is possible to change the electromagnetic behaviour of the structure from one presenting an almost perfect reflecting surface to a material that absorbs the impinging energy, therefore the strongly illuminated vehicle has minimal impact on the antenna gain. An important outcome from this work is the demonstration that resistively loaded FSS modelled in an infinite size and plane wave electromagnetic environment, perform well when exposed to impinging RF energy from a low gain antenna over a wide range of angles on the surface of a small platform. In addition, the test cases studied show that significant suppression of backscatter is obtained when the FSS is positioned in both the near ($\lambda/4$) and far field (λ) of the antenna, and this therefore enables the physical layout of the payload instruments to be adjusted without the need for costly design iterations. Although the physical thickness of the outermost dielectric layer of space blankets is generally fixed, the topology of the periodic array can be modified to match the design frequency of the individual payload antennas [19], but as shown in [10] the bandwidth is proportional to the electrical thickness of the structure, ranging from 2% ($\lambda/213$) to 16.9% ($\lambda/25$). A good performance was obtained when the top surface of the nanosatellite mock-up was covered with an array of 306 unit cells. However, future work could consider the study of FSS designs with smaller periodic elements in order to reduce sensitivity to the incident angle and wave polarisation [20]. This is an attractive low cost solution which would enable the space blanket to protect the payload from the hostile thermal environment and simultaneously improve the RF performance of the antennas.

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REFERENCES

- [1] J. Tresvig and T. Lindem, "Investigating the Coupling Effects Between CubeSTAR's Communication Antenna and Deployable Payload Sensors [Measurements Corner]," *IEEE Antennas and Propagation Magazine*, vol. 58, no. 1, pp. 90–129, Feb. 2016.
- [2] S. Vellucci, A. Monti, M. Barbuto, A. Toscano, and F. Bilotti, "Satellite Applications of Electromagnetic Cloaking," *IEEE Transactions on Antennas and Propagation*, vol. 65, no. 9, pp. 4931–4934, Sep. 2017.

- [3] R. Cahill, I. Cartmell, G. v. Dooren, K. Clibbon, and C. Sillence, "Performance of shaped beam quadrifilar antennas on the METOP spacecraft," *Antennas and Propagation IEE Proceedings - Microwaves*, vol. 145, no. 1, pp. 19–24, Feb. 1998.
- [4] ESA/IPC/THAG, "IPC Technology Harmonisation Report: RF Metamaterials and Metasurfaces," European Space Agency, Technology Harmonization Advisory Group, Tech. Rep., 2016.
- [5] A. Mazzinghi, M. Sabbadini, and A. Freni, "Enhanced RF Behavior Multi-Layer Thermal Insulation," *Sci Rep*, vol. 8, no. 1, pp. 1–10, Jan. 2018. [Online]. Available: <https://www.nature.com/articles/s41598-017-18337-3>
- [6] 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.
- [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] Dunmore, "Multi layer Insulation & Multilayer Film Materials | Dunmore." [Online]. Available: <https://www.dunmore.com/products/multi-layer-films.html>
- [9] B. Y. Toh, R. Cahill, and V. F. Fusco, "Understanding and measuring circular polarization," *IEEE Transactions on Education*, vol. 46, no. 3, pp. 313–318, Aug 2003.
- [10] G. G. Machado, R. Cahill, V. Fusco, and G. Conway, "Resistively loaded ultra-thin fss absorbers for radio-frequency enhancement of spacecraft thermal blankets," *IET Microwaves, Antennas Propagation*, vol. 13, no. 11, pp. 1928–1933, 2019.
- [11] K. N. Rozanov, "Ultimate thickness to bandwidth ratio of radar absorbers," *IEEE Transactions on Antennas and Propagation*, vol. 48, no. 8, pp. 1230–1234, Aug. 2000.
- [12] G. G. Machado, R. Cahill, V. Fusco, and G. Conway, "Comparison of FSS Topologies for Maximising the Bandwidth of Ultra-Thin Microwave Absorbers," in *2019 13th European Conference on Antennas and Propagation (EuCAP)*, Mar. 2019, pp. 1–5.
- [13] D. Systemes, "CST Studio Suite – 3d EM analysis software - SIMULIA by Dassault Systemes." [Online]. Available: <https://www.3ds.com/products-services/simulia/products/cst-studio-suite/>
- [14] F. Costa, S. Genovesi, A. Monorchio, and G. Manara, "A Circuit-Based Model for the Interpretation of Perfect Metamaterial Absorbers," *IEEE Transactions on Antennas and Propagation*, vol. 61, no. 3, pp. 1201–1209, Nov. 2012.
- [15] Novacentrix, "Novele IJ-220." [Online]. Available: https://store.novacentrix.com/v/vspfiles/assets/images/novele%20ij-220_2212.2.pdf
- [16] S. Ghosh, S. Bhattacharyya, D. Chaurasiya, and K. V. Srivastava, "A broadband polarization-insensitive circuit analog absorber using lumped resistors," in *2015 IEEE Applied Electromagnetics Conference (AEMC)*, Dec 2015, pp. 1–2.
- [17] Novacentrix, "Metalon JS-B25P." [Online]. Available: http://store.novacentrix.com/v/vspfiles/assets/images/Metalon%20JS-B25P_1.pdf
- [18] 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.
- [19] A. C. Lepage, Y. Pinto, O. Rance, X. Begaud, and N. Capet, "Lightweight and wide-angle metamaterial absorbing material concept," in *12th European Conference on Antennas and Propagation (EuCAP 2018)*, April 2018, pp. 1–3.
- [20] S. D. Assimonis and V. Fusco, "Polarization Insensitive, Wide-Angle, Ultra-wideband, Flexible, Resistively Loaded, Electromagnetic Metamaterial Absorber using Conventional Inkjet-Printing Technology," *Sci Rep*, vol. 9, no. 1, p. 12334, Dec. 2019. [Online]. Available: <http://www.nature.com/articles/s41598-019-48761-6>