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Passive Intermodulation Generation in Wire Mesh Deployable Reflector Antennas

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Gregory M. Turner

Harris Corporation
P. O. Box 94000, Melbourne Florida 32902
phone: (407)727-4857, fax: (407)727-4430

abstract- Deployable reflector antennas represent a proven technology with obvious benefits for mobile satellite applications. Harris Corporation has provided deployable reflector antennas for NASA's Tracking and Data Relay Satellite System (TDRSS). These antennas utilize a rigid, radial rib unfurlable reflector with a wire mesh surface. This type of mesh has been identified as a potential design risk for multi-channel communications applications based on the potential for generation of Passive Intermodulation (PIM). These concerns are based on the existence of numerous, nonpermanent metal to metal contacts that are inherent to the mesh design. To address this issue, Harris has an ongoing IR&D program to characterize mesh PIM performance. This paper presents the results of the investigation into mesh PIM performance to date and provides background information on the design and performance of the Harris radial rib deployable reflector.

INTRODUCTION

The gain that is available from a spacecraft antenna is a critical parameter in the design and ultimate capability of any satellite communications network. The use of a deployable reflector antenna for these applications provides a high gain, lightweight system that can be compactly stowed for launch, then deployed on orbit. The surface material is a critical component in the deployable reflector design. The surface material is required to provide the desired electrical performance as well as the mechanical properties that are necessary to deploy and maintain the reflector surface on orbit. Of particular interest in multi-channel communications applications is the generation of PIM products at the reflector surface that can result in interference in the receive frequency band.

DEPLOYABLE REFLECTOR DESIGN

Harris Corporation has provided deployable reflector antennas for NASA's TDRSS program that utilize a wire mesh reflector surface. The performance of the TDRSS Single Access (SA) antennas provides a credible indication of the performance achievable for similar designs for mobile satellite applications(see reference [1]). Each TDRSS spacecraft has two SA antennas (reference Figure 1) that are used for communication with user satellites in low earth orbit. Ten of these antennas are currently on orbit and operational with no failures or performance degradation since the first deployment in April of 1983. The SA antennas are dual shaped reflector systems operating at S and Ku band with a deployable 4.9 meter main reflector. Total weight, including the cassegrain feed is less than 55 pounds. The deployed reflector surface accuracy is maintained at approximately .025 inches rms.

The radial rib design concept results in a controlled precision deployment of the umbrella-like rib structure. The radial ribs are deployed from a central hub structure by a motorized deployment mechanism. The mesh surface is held above the ribs by fixed standoffs and a network of dimensionally stable cords and ties. The surface attachment system is fully adjustable, allowing optimization of the surface during the manufacturing process. The key to the surface stability is that the surface shape is determined and maintained by the ribs and backup structure and is not dominated by the mechanical characteristics of the mesh.

The mesh surface is formed by interconnected, gore shaped panels as shown in Figure 2. The mesh is attached to rigid boundary strips along the radial dimension of the panels. The panels join together along the edge strips which are attached to the supporting structure. Front cord assemblies aligned circumferentially along the mesh surface are connected with ties to rear cords that are tensioned between the ribs. These ties are adjustable, allowing the surface to be shaped with precision. The mesh surface effectively floats over a rigid and thermoelastically stable structure of ribs, cords, and ties.

The radial rib design can be adapted to a wide range of antenna diameter versus stowed envelope and surface accuracy requirements. The SA antennas utilize fixed ribs which limit the stowed axial dimension to near the radius of the reflector. Mature design concepts exist for multi-section folding rib systems that avoid this limitation. Demanding surface accuracy requirements can be accommodated by choosing the appropriate number of cords and ties per unit area to provide the required surface adjustability.

WIRE MESH DESCRIPTION

The mesh surface material consists of 1 mil diameter, gold plated molybdenum wire in a tricot knit. The tricot knit results in a complex pattern as shown in Figure 3. Surface currents induced on the mesh must flow over numerous bends and crossover junctions. It is well known that electrical performance characteristics of the mesh are largely dependent on the conditions at these crossover junctions [2]. Any condition that impedes the flow of current through these junctions will result in poor reflectivity performance and substantial loss due to transmission leakage through the mesh. Successful implementation of a deployable reflector design using wire mesh requires strict attention be paid to the wire plating and knitting processes to ensure good electrical performance.

The existence of nonpermanent metal to metal contacts at the crossover junctions in the mesh is the root of concerns over PIM generation. Indeed, eliminating this type of condition is a basic design principle for microwave systems with PIM requirements.

There are properties of the mesh design however, that tend to preclude sensitivity to PIM generation and may provide an explanation for the favorable experimental results presented in the next section. Another design guideline for avoiding PIM is to reduce current densities at potentially sensitive areas. For the case of a wire mesh reflector, the transmit power is distributed over a large surface area that is extremely dense with conductive wires. Mesh knit at 18 openings per inch has over 13 feet of wire and 1000 crossover junctions per square inch.

Another key factor influencing PIM generation at metal to metal contacts is the amount of oxides or other contaminants between the conductors. Gold, which is used to plate the mesh wire, does not oxidize in air like other metals. In fact, gold plating is commonly used to avoid PIM at coaxial connector interfaces. The contact pressure at metal to metal interfaces is also important since high pressure can displace any contaminants that do exist and ensure a clean contact (see references [3] for discussion on PIM dependence on metallic composition and contact pressure). For wire mesh, the contact area that results when 1 mil diameter round wires are in contact is extremely small so that minimal planar tension in the mesh will result in high pressure at the junction contact areas.

EXPERIMENTAL RESULTS

Interest in mesh PIM performance has increased in the 1990's with growth in the market for large deployable reflectors for multi-channel communications applications. Over the past several years Harris has performed a series of tests at L and X band on the standard wire mesh like that used for the TDRSS SA antennas. These tests were performed on planar mesh samples using a test set-up similar to that shown in Figure 4. The samples were 18 x 18 inches of mesh bonded to wooden frames. The sample under test was illuminated by two carriers which are transmitted using separate antennas. A third antenna is used to monitor PIM generation. Extensive filtering and low noise amplification of the receive signal are required to eliminate harmonics and achieve the required measurement sensitivity.

A summary of the test results is listed in Table 1. The first series of tests were for 7th order PIM at L-band. The mesh samples were the standard 10 opening per inch (opi) mesh like that used on the TDRSS SA antennas. Additional samples with surface hardware and edge terminations were also tested. The results showed that PIM generated by mesh alone was not measurable while inclusion of the standard termination and surface hardware components tended to increase PIM susceptibility.

The second series of tests were for 3rd order PIM at X-band. The objective for the X-band tests was to compare the relative performance of different types of mesh so a lower order PIM was chosen to enhance sensitivity. The samples consisted of 10 opi, 18 opi, and conditioned 18 opi mesh. The conditioned samples were exposed to simulated operational environments prior to PIM testing including random vibration, thermal vacuum, and thermal strain (the thermal strain associated with the calculated orbital temperature cycling was simulated by a repetitive, induced mechanical displacement at the center of the sample). The objective of conditioning the samples was to determine if operational environment effects would influence conditions at the wire crossover junctions, and specifically whether they would increase PIM levels. The conclusions drawn from these tests were that the conditioning did not have significant effects on PIM generation and that there is an inverse relationship between mesh density and PIM generation levels. This relationship supports the theory that the distribution of currents over a large number of wire crossover junctions in the mesh reduces PIM sensitivity.

The third series of tests involved measuring 18 opi mesh for 7th and 5th order PIM at L-band over a thermal profile. Temperature can effect PIM generation at metal to metal contacts by changing the junction properties including the contact pressure which varies due to differential contraction and expansion. This type of test addresses an important question regarding conditions at the wire crossover junctions as temperature changes on orbit. No measurable PIM was generated.

While further testing is required to fully characterize mesh PIM performance, these results suggest that implementation of a wire mesh deployable reflector for multi-channel satellite communications applications is feasible. One area that requires more testing and development work is the design of mesh edge terminations and surface hardware interfaces. Test results indicate that the standard designs like those used on TDRSS are susceptible to PIM and will require modification. This issue does not warrant the level of concern that the PIM performance of the mesh itself does since it represents a more treatable problem. These aspects of the design can be addressed with relatively minor modifications using standard PIM mitigation techniques like avoiding metal to metal contacts (isolating or using non-conductive interface components) and shielding sensitive areas.

Extrapolating system performance predictions from these test results requires some subjective judgements and is unique for each system. In general, results from this type of test should be used conservatively to estimate system level PIM performance. The assumption is made that the sample and test conditions are representative of the final system implementation. A example system performance prediction based on sample level test results is shown in Table 2.

CONCLUSIONS

While wire mesh has been considered "PIM sensitive" based on an abundance of nonpermanent metal to metal contacts that are fundamental to the mesh design, careful consideration of the mesh characteristics and aspects of the deployable reflector design implementation reveal conditions that may reduce mesh PIM susceptibility. Experimental results presented in this paper indicate that PIM generation in the type of wire mesh supplied by Harris Corporation for the TDRSS program may be well within the requirements for typical systems. In view of the well established flight record of the Harris radial rib deployable reflector, consideration of its use for applications with PIM requirements is certainly warranted.

REFERENCES

[1] B. Tankersley, H. Bartlett,"Tracking and Data Relay Satellite Single Access Deployable Antenna",*NTC Conference Record*, 1977.

[2] W. Imbriale, V. Galindo-Israel, Y. Rahmat-Samii, "On the Reflectivity of Complex Mesh Surfaces", *IEEE Transactions on Antennas and Propagation*, Vol. 39, No. 9, September 1991.

[3] F. Arazm, F. Benson,"Nonlinearities in Metal Contacts at Microwave Frequencies", *IEEE Transactions on Electromagnetic Compatibility*, Vol. 22, No. 3, August 1980.

Table 1. Mesh PIM Test Results

NOTE: "<" indicates no PIM measured over the noise floor.

Sample Type	Number of samples	Maximum PIM Flux Density
Test Series I: L-band, 7th order PIM, 52 mW/cm^2 combined incident power, 35 cm from sample to measurement plane		
10 opi mesh	6	<-159 dBW/m^2
10 opi mesh with edge terminations and surface hardware	5	-123 to -159 dBW/m^2
18 opi mesh	1	<-159 dBW/m^2
Test Series II: X-band, 3rd order PIM, 23 mW/cm^2 combined incident power, 60 cm from sample to measurement plane		
18 opi mesh	4	-122 dBW/m^2
conditioned 18 opi mesh	2	-118 dBW/m^2
10 opi mesh	2	-90 dBW/m^2

Test Series III: L-band, 5th and 7th order PIM, 21 mW/cm^2 combined incident power, 60 cm from sample to measurement plane

Sample Type	Number of samples	Maximum 5th order PIM Flux Density	Maximum 7th order PIM Flux Density
18 opi mesh	3	<-154 dBW/m^2	<-169 dBW/m^2

Table 2. Example System Performance Prediction from Sample Test Results

INCIDENT POWER DENSITY		
Maximum operational incident power flux density	5 mW/cm^2	
Sample test incident power flux density	20 mW/cm^2	
Incident power density margin	**6 dB**	minimum of 3 dB recommended
PIM INTERFERENCE LEVEL		
Measured sample PIM power flux density	-160 dBW/m^2	
Sample vs. system mesh surface area	+19 dB	0.5 x 0.5 meter sample and 5 meter reflector
Sample test vs. system effective mesh to receive antenna separation	-24 dB	30 cm vs. 5 meters
System receive antenna effective area	-30 $dB{\cdot}m^2$	-5 dBi effective gain in the direction of the transmit reflector surface
PIM power at receive antenna output	**-195 dBW**	

NOTE: A conservative assumption is made that PIM generated over the reflector surface will add coherently and the difference between modulated and CW carriers is not accounted for.

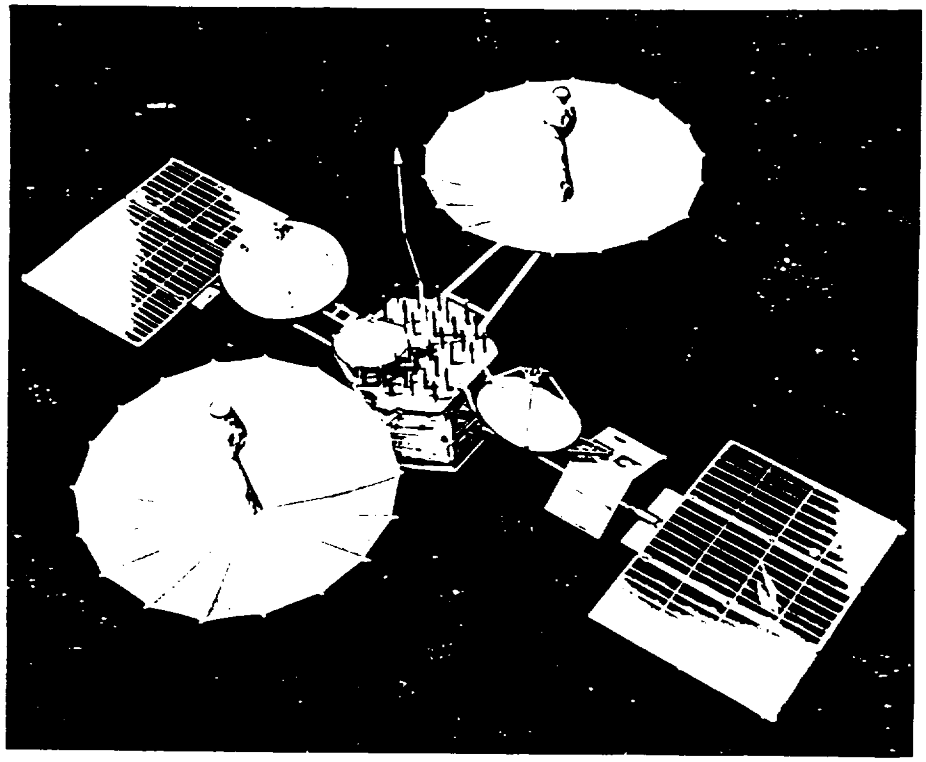

Figure 1. TDRSS Satellite

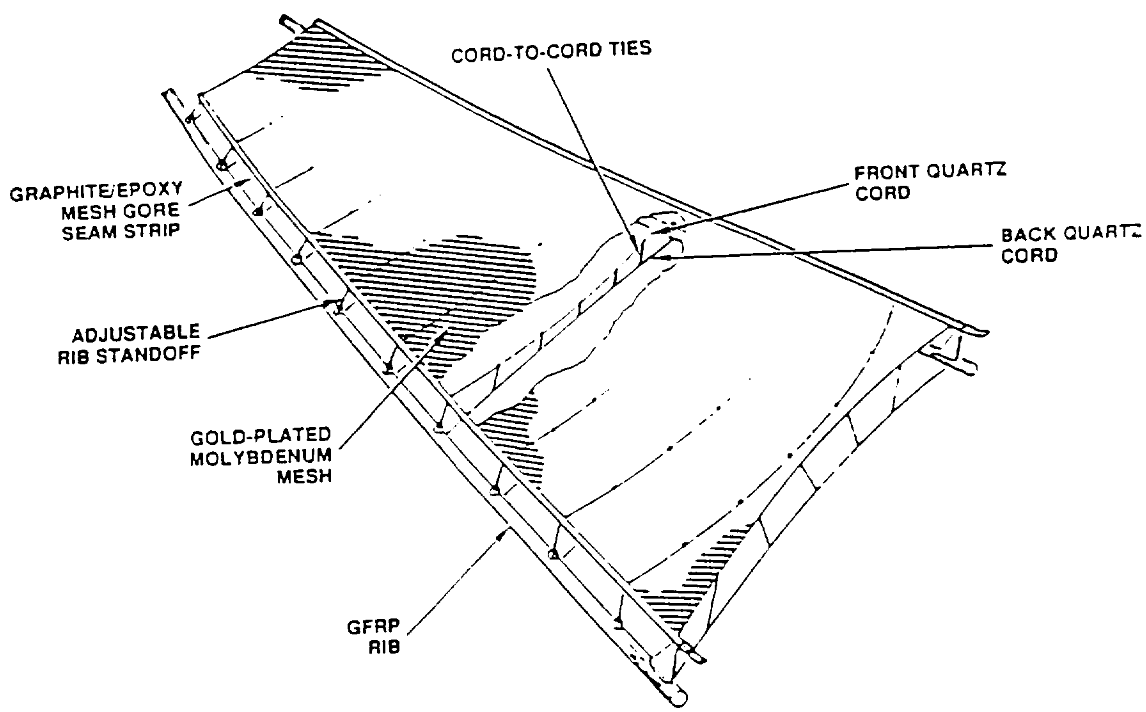

Figure 2. TDRSS SA Antenna Deployable Reflector Design

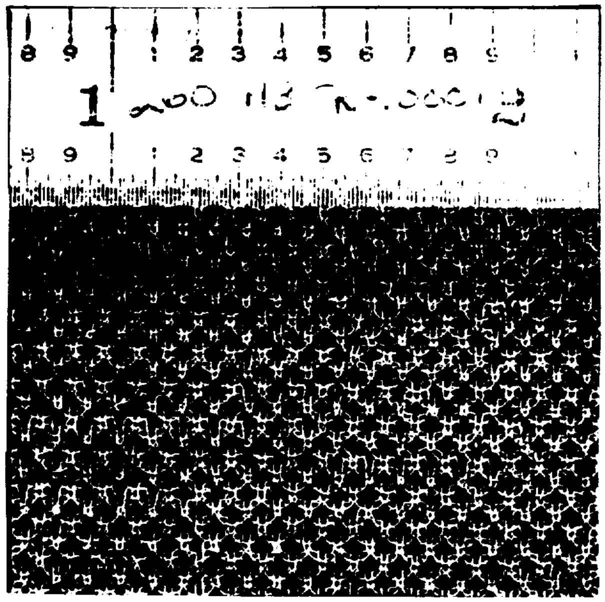

Figure 3. Harris 18 opi Wire Mesh

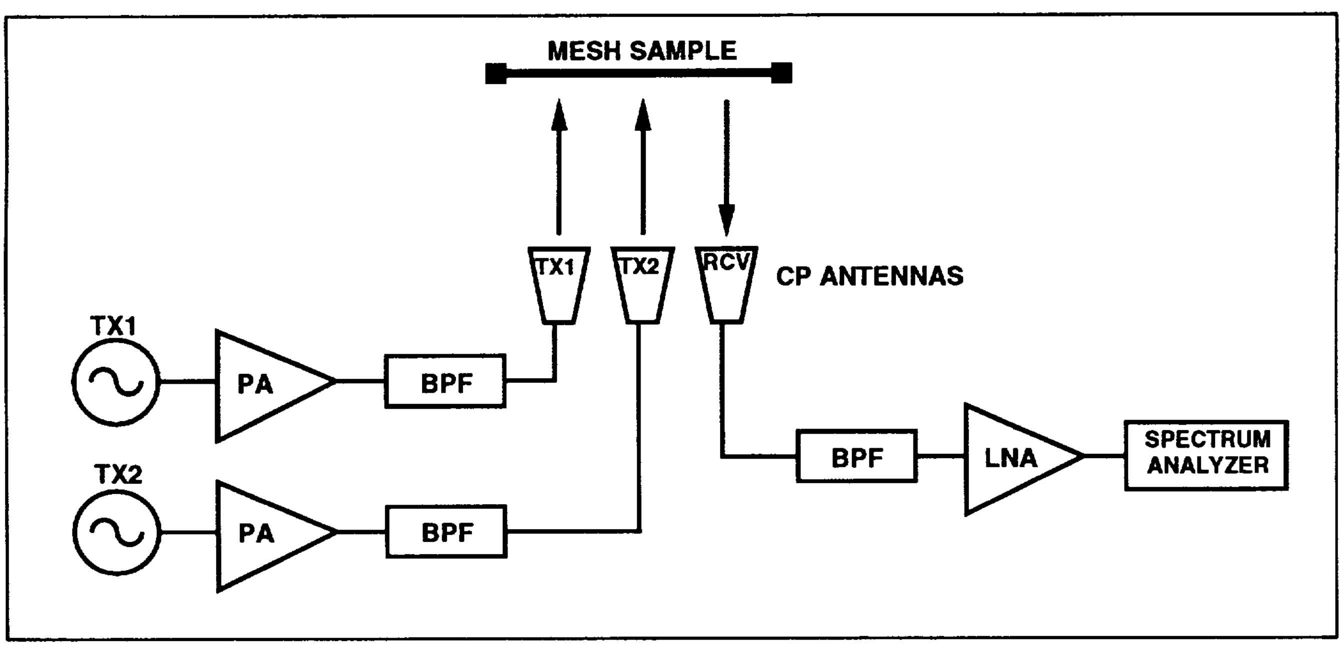

Figure 4. Mesh PIM Test Configuration