N94- 35546

TDA Progress Report 42-117

May 15, 1994

The Electrical Conductivities of Candidate Beam-Waveguide Antenna Shroud Materials

T. Y. Otoshi and M. M. Franco
Ground Antennas and Facilities Engineering Section

The shroud on the beam-waveguide (BWG) antenna at DSS 13 is made from highly magnetic American Society for Testing and Materials (ASTM) A36 steel. Measurements at 8.42 GHz showed that this material (with paint) has a very poor electrical conductivity that is 600 times worse than aluminum. In cases where the BWG mirrors might be slightly misaligned, unintentional illumination and poor electrical conductivity of the shroud walls can cause system noise temperature to be increased significantly. This potential increase of noise temperature contribution can be reduced through the use of better conductivity materials for the shroud walls. An alternative is to attempt to improve the conductivity of the currently used ASTM A36 steel by means of some type of plating, surface treatment, or high-conductivity paints. This article presents the results of a study made to find improved materials for future shrouds and mirror supports.

I. Introduction

The technique used to measure the resistivity of flat stock materials at microwave frequencies was the cavity technique described in [1,2]. Resistivity data on previously measured samples of various metals and plated surfaces have been previously presented in [1–4]. Figure 1 shows the X-band cavity that was used for these measurements. The measurement technique involves placing a flat plate sample of the material to be tested on top of an open cylindrical cavity operating in the TE_{011} mode. Resistivity is determined from measured loaded- and unloaded-Q at a nominal frequency of 8.420 GHz. Slight deviations from perfect flatness of the test sample will cause this center frequency of the test to deviate slightly from nominal. Electrical conductivity is calculated from the measured resistivity using an equation given in [2]. Although electrical conductivities of metals theoretically are frequency independent, in practice when surface roughness becomes a significant fraction of skin depth, the electrical conductivities (that are determined from measured resistivities) could be somewhat frequency dependent.

II. Test Sample Description

Some of the samples tested are shown in Figs. 2 and 3. The ASTM A36 steel samples shown in Fig. 2 were cut from a section of the former bypass shroud on the BWG antenna. It was previously reported [2] that bare-metal-surface ASTM A36 samples had average conductivity values of about 0.01×10^7 mhos/m, while samples painted with thermal diffusive white paint had worse conductivities of about 0.0036×10^7 mhos/m.

For this article, a study was made to find ways to improve the electrical conductivity of ASTM A36 steel by treating the surface with (1) a zinc-plating process and (2) spray painting with cold galvanized paint. For the zinc-plating process, a black-colored dye was used. The use of black dye color was arbitrary, and clear zinc plating could have been specified instead.

Another steel material tested was type 1018 steel (see Fig. 3). This material was used to simulate flat surfaces of steel mirror-support structures in the BWG antenna in some of the shroud noise temperature tests performed at the Microwave Test Facility (MTF) at Goldstone, California. This material was used for these MTF tests because it was known to have dc conductivity and magnetic properties similar to ASTM A36 steel. It was also used because it was readily available in flat sheet stocks at Goldstone. This material was tested with and without white diffusive thermal paint.

Aluminum material is sometimes treated with a type of surface treatment to prevent oxidation. Two types of aluminum samples with surface treatments were fabricated and tested. These samples of aluminum were treated with (1) irriditing and (2) anodizing processes (Fig. 3). In this article, the term "irridite" will be used to describe the surface treatment of aluminum samples or parts by a chemical dipping process. Not generally well known is the fact that irridite, yellow chemical film, and alodine are trade terms referring to identical surface-treatment processes. Confusion sometimes occurs between the terms alodine and anodize, which are not equivalent processes. The former involves a chemical dipping process, while the latter refers to an electrochemical-oxidizing surface-treatment process.

III. Test Results

Table 1 shows a summary of the test results of the described samples. As may be seen in Table 1, the type 1018 steel conductivities for unpainted and painted samples were measured to be 0.0226×10^7 and 0.0081×10^7 mhos/m, respectively, at 8.420 GHz. These results may be compared to 0.01×10^7 and 0.004×10^7 mhos/m for the ASTM A36 structural steel unpainted and painted samples, respectively.

The zinc-plating process on ASTM A36 steel improved the conductivity from 0.01×10^7 to about 0.44×10^7 mhos/m, but it is still about 5 times worse than type 6061 aluminum. As may be seen in the table, for two of the samples, the galvanized-paint process made the conductivity much worse than that for bare ASTM A36 steel and even worse than ASTM A36 steel painted with thermal diffusive white paint. It is suspected that galvanized spray paint is not purely metallic and has lossy epoxy compounds to make the surface more like a lossy dielectric surface. It might seem that if the paints were more highly conductive, then better results would be obtained. However, it was shown in a previous article [2] that a very high grade of silver paint only improved the conductivity from 0.01×10^7 mhos/m for bare metal ASTM A36 steel to 0.022×10^7 mhos/m when silver painted.

Table 1 also shows the results of aluminum samples with surfaces treated with (1) irriditing and (2) anodizing processes. Irriditing caused no noticeable change in the conductivity properties of bare aluminum, while anodizing only degraded the conductivity from 2.31×10^7 to 1.96×10^7 mhos/m, which is still acceptable. From previous tests [2], it was found that primer and thermal diffusive white paint also did not significantly degrade the resultant electrical conductivity of aluminum, but did significantly degrade the conductivity of ASTM A36 steel.

Relative permeability values (relative to air) of the test samples are shown in Table 1. It can be seen that the steel materials are highly magnetic with relative permeabilities being in the 9000–10,000 range. For comparison, aluminum and copper have relative permeabilities of unity, while most types of stainless steel have relative permeabilities of less than 1.10 [2].

It was pointed out by Vane [5] that conductive metals having high permeability tend to have poor *effective* conductivities due to the fact that high permeabilities cause the skin depth to become very small. The effects of surface roughness and surface layers (of paints and oxides) are accentuated because, when skin depth is small, most of the RF currents will tend to flow along the irregular surfaces and even partially inside the treated layers (oxides and paints). Hence, it is not surprising that highly magnetic materials such as ASTM A36 and type 1108 steel with painted layers and poor surface finishes tend to have very poor conductivities. For materials with relative permeabilities close to unity, the skin depth is larger, and RF currents will tend to flow through more volume of the conductor rather than just at the surface. An equation showing the relationship between skin depth and relative permeability was given in [2].

IV. Conclusions

Test results showed that zinc plating the surface of ASTM A36 steel improved the electrical conductivity of bare metal from 0.01×10^7 to 0.44×10^7 mhos/m. For comparison, the conductivity was 0.0036×10^7 mhos/m for a sample of this steel that was primed and painted with thermal diffusive white paint. Even with this improvement, the zinc-plated samples were still about 5 times worse than aluminum. Galvanized spray paint is not recommended because galvanized-painted ASTM A36 samples resulted in conductivities about the same or much worse than samples with thermal diffusive white paint. It can be stated that for highly magnetic steels with rough surfaces, the plating process will help to improve the conductivity significantly, but painting the surfaces with cold conductive paints will not.

Either an irriditing or an anodizing process should be considered for preventing oxidation of aluminum shrouds or mirrors. If anodized aluminum material is chosen as the material for future BWG shrouds, then it is recommended that, for better optical lighting purposes, a clear dye anodizing process should be specified.

Acknowledgment

Pablo Narvaez of the JPL Magnetics Laboratory measured the relative permeabilities of the steel samples.

References

[1] R. C. Clauss and P. D. Potter, *Improved RF Calibration Techniques—A Practical Technique for Accurate Determination of Microwave Surface Resistivity*, Technical Report 32-1526, vol. XII, Jet Propulsion Laboratory, Pasadena, California, pp. 54–67, December 15, 1972.

[2] T. Y. Otoshi, M. M. Franco, and H. F. Reilly, Jr.,"The Electrical Conductivities of the DSS-13 Beam-Waveguide Antenna Shroud Material and Other Antenna Reflector Surface Materials," *The Telecommunications and Data Acquisition Progress Report 42-108, vol. October–December 1991*, Jet Propulsion Laboratory, Pasadena, California, pp. 154–163, February 15, 1992.

[3] E. H. Thom and T. Otoshi, "Surface Resistivity Measurements of Candidate Subreflector Surfaces," *The Telecommunications and Data Acquisition Progress Report 42-65, vol. July–August 1981*, Jet Propulsion Laboratory, Pasadena, California, pp. 142–150, October 15, 1981.

[4] H. F. Reilly, J. J. Bautista, and D. A. Bathker, "Microwave Resistivity of Several Materials at Ambient Temperature," *The Telecommunications and Data Acquisition Progress Report 42-80, vol. October–December 1984*, Jet Propulsion Laboratory, Pasadena, California, pp. 8–11, February 15, 1985.

[5] A. B. Vane, *Measurements of Effective Conductivity of Metallic Surfaces at 3000 Megacycles and Correlation with Surface Conditions and DC Conductivity*, Stanford Microwave Laboratory Report No. 4:III-9, Palo Alto, California, pp. 72–78, 1949.

Table 1. Summary of test results of the cavity samples.

Description	Relative perme-ability[a]	Number of samples tested	Average surface roughness, μm	Test frequency, GHz	Average surface resistivity, ohms/square	Effective conductivity, mhos/m	Comments
Type 1018 steel	>9000	2	1.47 (58 μin.)	8.42221	0.38350	0.02261 x 10^7	
Type 1018 steel, same as above except painted with primer and Triangle #6 thermal diffusive white paint	>9000	1	0.64 (25 μin.)	8.40200	0.63861	0.00813 x 10^7	Paint had a big effect.
BWG antenna shroud ASTM A36 bare steel	9985	1	>6.35 >(250 μin.)	8.42049	0.57737	0.00997 x 10^7	This compares well with the 0.01 x 10^7 value in [2].
BWG antenna shroud ASTM A36 bare steel, with rust spots	9985	2	12.7 (500 μin.)	8.42124	0.63401	0.00830 x 10^7	
BWG antenna shroud ASTM A36 bare steel, rust spots partially removed	9985	1	12.7 (500 μin.)	8.42176	0.63288	0.00830 x 10^7	Rust removal had no effect.
BWG antenna shroud ASTM A36 steel, primer only	9985	1	1.78–2.62 (70-103 μin.)	8.41173	0.63859	0.00814 x 10^7	Compare this with 0.01 x 10^7 for bare metal.
BWG antenna shroud ASTM A36 steel, primer and Triangle no. 6 thermal diffusive white paint	9985	1	2.36 (93 μin.)	8.43990	0.91065	0.00400 x 10^7	Compare this with 0.0036 x 10^7 reported in [2].
BWG antenna shroud ASTM A36 steel, zinc plating (with black dye)	9985	3	6.35 (250 μin.)	8.41959	0.08650	0.4442 x 10^7	Significant improvement over bare metal.
BWG antenna shroud ASTM A36 steel, cold galvanized spray paint	9985	2	2.79–4.27 (110–168 μin.)	8.41544	3.36860	0.000293 x 10^7	Very bad conductivity might be due to surface roughness and paint.
BWG antenna shroud ASTM A36 steel, cold galvanized spray paint	9985	3	3.18 (125 μin.)	8.41399	0.85831	0.00451 x 10^7	About the same as with thermal diffusive white paint.

[a] The relative permeability values are relative to air.

Table 1 (cont'd)

Description	Relative permeability[a]	Number of samples tested	Average surface roughness, μm	Test frequency, GHz	Average surface resistivity, ohms/square	Effective conductivity, mhos/m	Comments
Copper	1.000	3	0.71 (28 μin.)	8.42033	0.02666	4.6770 $\times 10^7$	
Brass	1.000	1	0.53 (21 μin.)	8.42443	0.05020	1.3197 $\times 10^7$	
Aluminum 6061-T6	1.000	2	0.33 (13 μin.)	8.42422	0.03792	2.3129 $\times 10^7$	
Aluminum 6061-T6, irridite	1.000	1	0.41 (16 μin.)	8.42485	0.03790	2.3159 $\times 10^7$	
Aluminum 6061-T6, black anodized type II[b]	1.000	1	0.46 (18 μin.)	8.42458	0.04122	1.9574 $\times 10^7$	
Aluminum 6061-T6, black anodized type III[c]	1.000	1	0.46 (18 μin.)	8.42358	0.04121	1.9585 $\times 10^7$	

[b] Type II refers to an anodizing process that treats the surface only.
[c] Type III refers to an anodizing process that typically goes about 0.013 mm (0.5 mil) into the metal.

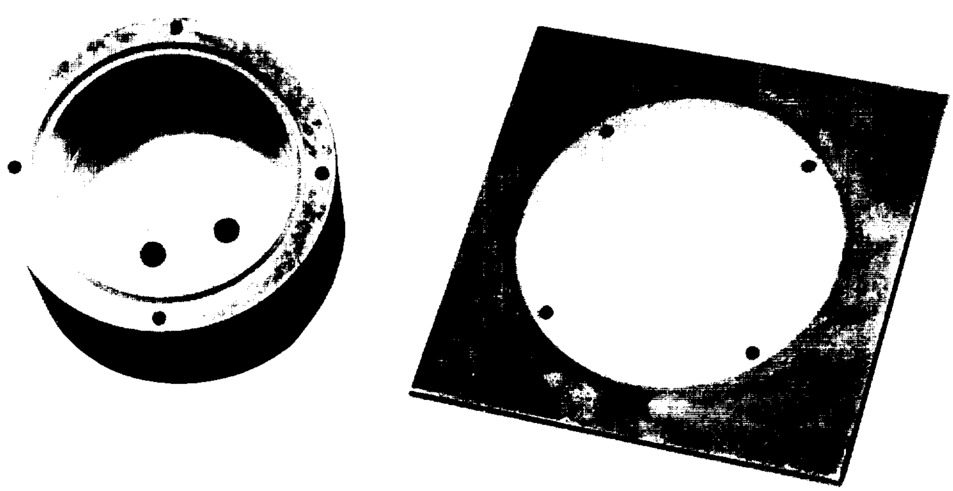

Fig. 1. The X-band cavity.

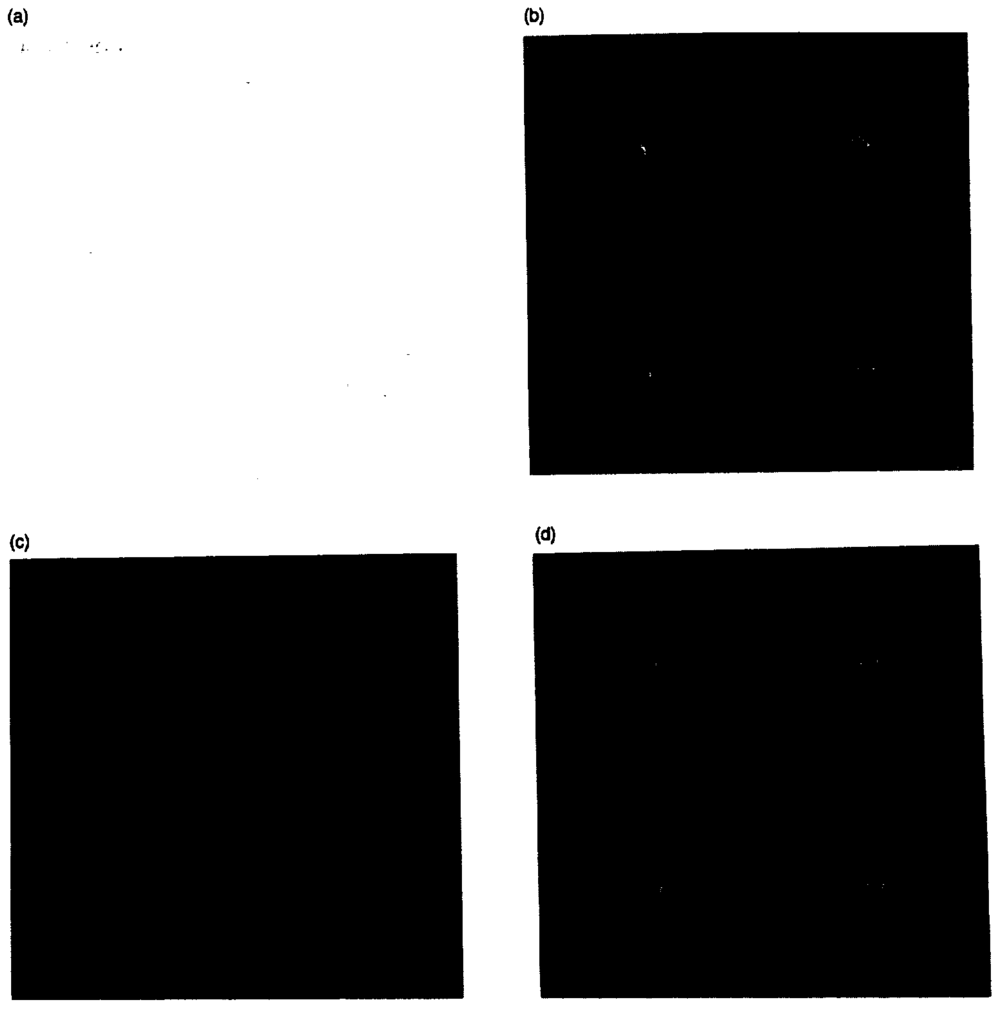

Fig. 2. Samples of the tested ASTM A36 shroud material (10.16 cm x 10.16 cm): (a) painted with primer and Triangle #6 thermal diffusive white paint; (b) bare metal; (c) zinc-plating (with black dye) surface treatment; and (d) galvanized spray-painted surface.

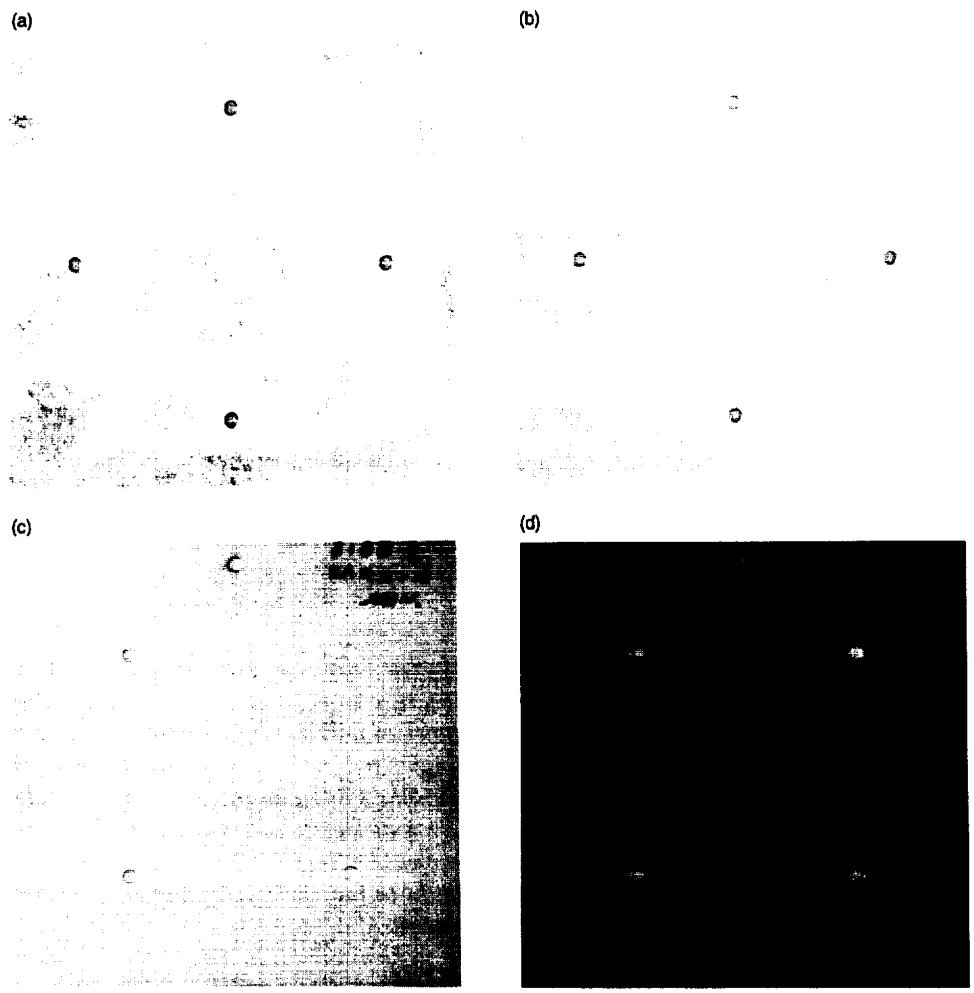

Fig. 3. Other sample candidate shroud materials tested (10.16 cm x 10.16 cm): (a) type 1018 steel bare metal; (b) aluminum 6061; (c) aluminum 6061 with irridite surface treatment; and (d) aluminum 6061 with black anodized surface treatment.

55-32
N94- 35547
TDA Progress Report 42-117 May 15, 1994

Thin-Ribbon Tapered Coupler for Dielectric Waveguides

C. Yeh[1]

T. Y. Otoshi
Ground Antennas and Facilities Engineering Section

F. I. Shimabukuro
Aerospace Corporation
Los Angeles, California

A recent discovery shows that a high-dielectric constant, low-loss, solid material can be made into a ribbon-like waveguide structure to yield an attenuation constant of less than 0.02 dB/m for single-mode guidance of millimeter/submillimeter waves. One of the crucial components that must be invented in order to guarantee the low-loss utilization of this dielectric-waveguide guiding system is the excitation coupler. The traditional tapered-to-a-point coupler for a dielectric rod waveguide fails when the dielectric constant of the dielectric waveguide is large. This article presents a new way to design a low-loss coupler for a high- or low-dielectric constant dielectric waveguide for millimeter or submillimeter waves.

I. Introduction

A recent discovery shows that a high-dielectric constant, low-loss, solid material, such as TiO ($\epsilon_1/\epsilon_0 = 100$, $\tan\delta = 0.00025$) or Rexolite ($\epsilon_1/\epsilon_0 = 2.55$, $\tan\delta = 0.001$), can be made into a ribbon-like waveguide structure to yield an attenuation constant of less than 0.02 dB/m for single-mode guidance of millimeter or submillimeter waves [1]. This discovery provides the impetus to perfect a practical low-loss guided transmission system for these short wavelengths. As a comparison of loss, the attenuation constant of a WR28 copper waveguide is 0.58 dB/m at 32 GHz. One of the crucial components that must be invented in order to guarantee the low-loss utilization of this dielectric-waveguide guiding system is the excitation coupler.

A conventional technique to minimize the coupling loss of an excitation coupler is to taper the coupling end of a dielectric waveguide to a very narrow, sharp apex [2]. However, this method fails when the relative dielectric constant of the dielectric waveguide is much greater than unity, the free-space value. Another technique is to shape the coupling end of the dielectric waveguide into a cusp-like form [3]. This cusp design, which is based on the direct ap-

[1] Independent consultant to the Ground Antennas and Facilities Engineering Section.