Measurements of Complex Dielectric Constants of Paints and Primers for DSN Antennas: Part II

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In Part I of this article, complex dielectric constant values in the frequency range of 24 through 34 GHz were presented for paints and primers currently being used as well as for candidate replacements. Tables of complex dielectric constant values were given for (1) Triangle no. 6 white flat paint, (2) zinc chromate primer, (3) 18FHR6 white water-based paint, and (4) 283 water-based (Aquapoxy) primer.

In this article, Part II, complex dielectric constants are presented for 500FHR6 acrylic urethane-based paint and Triangle no. 710 white glossy paint. In addition, this article gives plots of the real part of the complex dielectric constants and loss tangents of most of the above-mentioned paints and primers. These plots enable quick comparisons to be made of the dielectric properties of the paints and primers in the region of 32 GHz. A final part of the paint study, to be done in the near future, will be to use these complex dielectric constants to compute noise-temperature degradations that occur when various paints and primers are applied to antenna reflector surfaces.

I. Introduction

A paint study was initiated to determine how much degradation of noise temperature and gain occurs as functions of paint and primer thicknesses when applied to antenna reflector surfaces. Part I [1] of this study discussed a waveguide method by which the complex dielectric constants of paints and primers could be measured at frequencies of interest. Then, after the complex dielectric constants were determined, theoretical calculations could be made of degradations of antenna gains and noise temperatures due to paint/primer thicknesses as functions of incident wave polarization and incidence angles in free space. Equations were presented in [1] to enable calculation of these noise-temperature degradations.

In Part I [1], measured complex dielectric constants over a frequency range of 24 through 34 GHz were given for (1) Triangle no. 6 white flat paint, (2) zinc chromate primer, (3) 18FHR6 white water-based paint, and (4) 283 water-based (Aquapoxy) primer. The last two test samples, (3) and (4), are candidate replacements for (1) and (2), which are, respectively, the paint and primer currently being used on main reflector and subreflector surfaces of DSN antennas.

[1] Communications Ground Systems Section.

In this article, results of additional test-sample measurements are presented. Measured complex dielectric constant data will be given for Triangle 500FHR6 and Triangle no. 710 paints. Triangle 500FHR6 is an acrylic urethane-based white paint that appears to be an excellent candidate replacement paint for Triangle no. 6 paint. Triangle no. 710 paint is a glossy white paint that is used primarily on antenna backup and support structures.

The following section is included in this article because it was suggested by the Hewlett-Packard Measurement Center that the methodology being used in Part I [1] should be verified by one additional method to ensure validity of the values already obtained for test samples that are many (more than 5) waveguide wavelengths long.

II. Additional Verification of Measurement Method

The method for obtaining complex dielectric constants from measured S-parameter data of paint samples was discussed previously in [1] and will not be repeated here. The purpose of this section is to discuss another independent method that was used to verify the results already reported in Part I [1].

It is known that S-parameter measurements give phase values to modulo 360 degrees and, therefore, multiples of 360 degrees are not included. For example, if the correct electrical S21 phase is $20.0 + N \times 360$ degrees (where N is an integer $0, 1, 2 \cdots$), the S-parameter phase value output from a network analyzer is a phase value of 20.0 degrees. Since a multiplicity of complex dielectric constant solutions are possible from the measured S-parameters, it is necessary to determine the correct electrical phase lengths of test samples that are several waveguide wavelengths long.

A method was discussed in [1] for finding the correct multiples of 360 degrees to add in to the modulo 360 phase-length value, but this method is valid only if the waveguide test sample is non-ferrous. Group-delay measurements provide a means to determine the correct electrical length for a general case, but the group-delay method becomes somewhat inaccurate when the group delay value is only a few tenths of a nanosecond. Stoyan Ganchev of the Hewlett-Packard Measurement Center in Englewood, Colorado, suggested another method for verifying that the correct solution is found. His suggestion was to make measurements on two different physical lengths of the same dielectric material. If the same complex dielectric constant is obtained for the two different-length samples by the method discussed in [1], one can be sure that the correct solution was determined.

For testing paint samples of two different physical lengths, it is necessary to make the samples from the same paint batch and drying times. Otherwise, differences in drying times and ongoing residual chemical changes could cause small but significant differences in the complex dielectric constants that are measured. The method used to ensure that paint samples were made from the same paint batch and drying times was as follows. After first testing a test paint sample that was several waveguide wavelengths long (for example, the Triangle no. 6 paint sample in a 2.54-cm-long WR28 guide), the second sample was made from the original waveguide sample by machining off one-half of the thickness of each flange of the waveguide sample holder with the paint sample still inside the waveguide. Two waveguide samples tested were shortened by approximately 0.381 cm (0.150 in.) total. When the test-sample length-shortening process was done for Triangle no. 6 and 500FHR6 paint test samples, the measured complex dielectric constants for each paint of the two different lengths agreed to within 1 and 7 percent, respectively, for the real and imaginary parts of the complex dielectric constants. This is the kind of repeatability that is obtainable with this S-parameter measurement method using the Hewlett Packard 8510C (HP 8510C) network analyzer to obtain complex dielectric constants of waveguide paint samples. Perhaps better repeatability might have been obtained had paint samples been placed in precision WR28 waveguide sections with alignment pin holes on the flanges. By performing this additional verification testing, it can be concluded that all paint and primer test results reported in Parts I and II are correct.

III. Test Results

Table 1 shows the results obtained for a 500FHR6 acrylic urethane-based paint made by Triangle Coating, Inc. The measured average complex dielectric constants are given for a total frequency range of 23 through 35 GHz and tabulated for intervals of 2-GHz-wide subfrequency ranges. As can be seen in Table 1, very little change of the complex dielectric constant values is observable over the total frequency range. This paint has the reputation of being robust and has withstood harsh environmental conditions in West Virginia. It currently is being used on reflector surfaces of the National Radio Astronomical Observatory (NRAO) antennas.

Table 2 shows the results for Triangle no. 710 glossy white paint that is being used on Cassegrain cone surfaces, microwave test packages, and exterior antenna support structures. Triangle no. 710 paint is not intended for use on reflector surfaces, but the measured complex dielectric constant data are included in

Table 1. Summary of 500FHR6 acrylic urethane-based white paint test results (average values over specified frequency ranges).[a]

Frequency, GHz	Number of points	Data file	ε_r'	ε_r''	Loss tangent
23-25	401	(S11,S21)	4.7069 0.0026 SD	0.1132 0.0019 SD	0.0240 0.0004 SD
23–25	401	(S22,S12)	4.6922 0.0034 SD	0.1176 0.0029 SD	0.0251 0.0006 SD
25–27	401	(S11,S21)	4.7013 0.0025 SD	0.1142 0.0023 SD	0.0243 0.0005 SD
25–27	401	(S22,S12)	4.6918 0.0024 SD	0.1169 0.0028 SD	0.0249 0.0006 SD
27–29	401	(S11,S21)	4.6918 0.0033 SD	0.1125 0.0023 SD	0.0240 0.0005 SD
27–29	401	(S22,S12)	4.6865 0.0019 SD	0.1148 0.0020 SD	0.0245 0.0004 SD
29–31	401	(S11,S21)	4.6896 0.0017 SD	0.1090 0.0014 SD	0.0233 0.0003 SD
29–31	401	(S22,S12)	4.6850 0.0008 SD	0.1120 0.0012 SD	0.0239 0.0003 SD
31–33	401	(S11,S21)	4.6934 0.0011 SD	0.1087 0.0011 SD	0.0232 0.0018 SD
31–33	401	(S22,S12)	4.6883 0.0020 SD	0.1124 0.0018 SD	0.0240 0.0004 SD
33–35	401	(S11,S21)	4.6921 0.0009 SD	0.1092 0.0008 SD	0.0233 0.0004 SD
33–35	401	(S22,S12)	4.6885 0.0018 SD	0.1114 0.0017 SD	0.0238 0.0004 SD

[a] SD = the standard deviation of the average based on the number of frequency points.

Complex relative dielectric constant = $(\varepsilon_r' - j\ \varepsilon_r'')$.

Loss tangent = $\varepsilon_r''/\varepsilon_r'$.

Frequency range = 23–35 GHz.

WR28 test-sample length = 2.545 cm (1.002 in.).

Complex relative permeability = $(1.0 - j\ 0.0)$.

Table 2. Summary of Triangle no. 710 glossy white paint test results (average values over specified frequency ranges).[a]

Frequency, GHz	Number of points	Data file	ε_r'	ε_r''	Loss tangent
23-25	401	(S11,S21)	6.0750 0.0070 SD	0.1284 0.0025 SD	0.0211 0.0004 SD
23–25	401	(S22,S12)	6.0786 0.0089 SD	0.1271 0.0026 SD	0.0209 0.0004 SD
25–27	401	(S11,S21)	6.0668 0.0022 SD	0.1265 0.0011 SD	0.0209 0.0002 SD
25–27	401	(S22,S12)	6.0686 0.0019 SD	0.1257 0.0007 SD	0.0207 0.0001 SD
27–29	401	(S11,S21)	6.0476 0.0013 SD	0.1277 0.0012 SD	0.0211 0.0002 SD
27–29	401	(S22,S12)	6.0388 0.0022 SD	0.1275 0.0014 SD	0.0211 0.0002 SD
29–31	401	(S11,S21)	6.0430 0.0017 SD	0.1269 0.0014 SD	0.0210 0.0002 SD
29–31	401	(S22,S12)	6.0347 0.0020 SD	0.1265 0.0010 SD	0.0210 0.0002 SD
31–33	401	(S11,S21)	6.0396 0.0021 SD	0.1261 0.0013 SD	0.0209 0.0002 SD
31–33	401	(S22,S12)	6.0313 0.0012 SD	0.1248 0.0012 SD	0.0207 0.0002 SD
33–35	401	(S11,S21)	6.0356 0.0022 SD	0.1253 0.0011 SD	0.0208 0.0002 SD
33–35	401	(S22,S12)	6.0273 0.0008 SD	0.1242 0.0011 SD	0.0206 0.0002 SD

[a] SD = the standard deviation of the average based on the number of frequency points.
Complex relative dielectric constant = $(\varepsilon_r' - j\ \varepsilon_r'')$.
Loss tangent = $\varepsilon_r''/\varepsilon_r'$.
Frequency range = 23–35 GHz.
WR28 test-sample length = 2.555 cm (1.006 in.).
Complex relative permeability = $(1.0 - j\ 0.0)$.

this article for interest and completeness. Comparisons show that, for the 31- through 33-GHz frequency region, the average complex dielectric constant value of $(6.04 - j\ 0.125)$ for Triangle no. 710 glossy paint is not too different from the complex dielectric constant value $(5.91 - j\ 0.148)$ for the flat white Triangle no. 6 paint.

Figures 1 through 10 show 32-GHz frequency-region plots for ε_r' (the real part of the relative complex dielectric constant) and loss tangents for the paints and primers currently being used and also for the candidate replacements. The averages and standard deviations (SDs) for these plots were obtained by taking the average value of ε_r' obtained from S11,S21 and S22,S12 data sets at each frequency point and then calculating the overall average and standard deviations for 401 frequency points within the 2-GHz-wide frequency range. Similarly, the same averaging technique was used to obtain the average loss tangent values over the same frequency range.

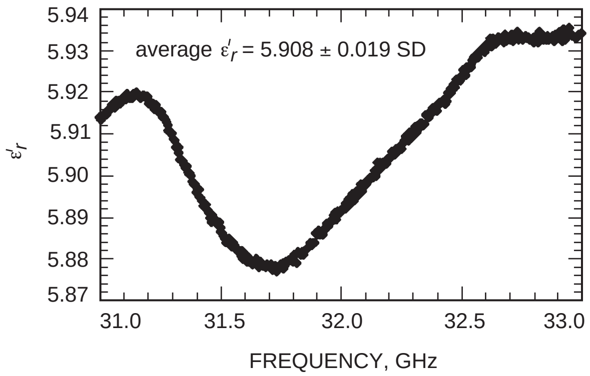

Fig. 1. The real part of the relative complex dielectric constant of Triangle no. 6 paint over the 31- through 33-GHz frequency range.

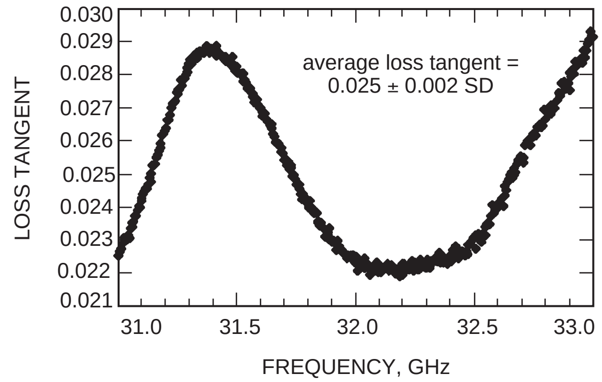

Fig. 2. The loss tangent of Triangle no. 6 paint over the 31- through 33-GHz frequency range.

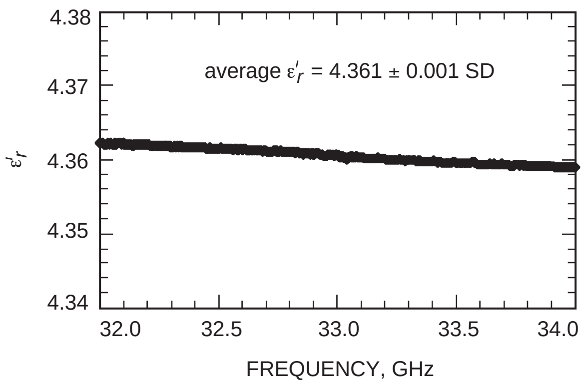

Fig. 3. The real part of the relative complex dielectric constant of zinc chromate primer over the 32- through 34-GHz frequency range.

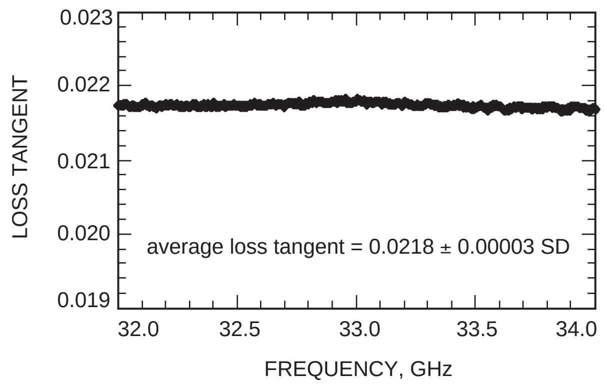

Fig. 4. The loss tangent of zinc chromate primer over the 32- through 34-GHz frequency range.

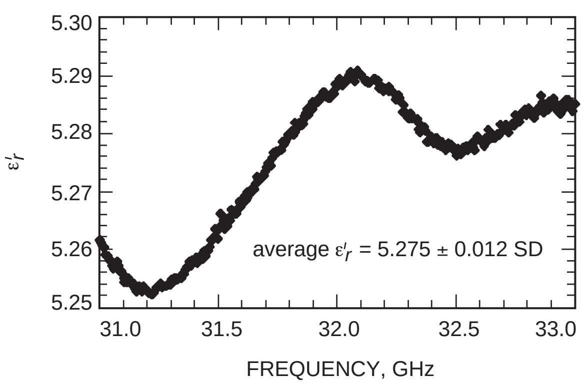

Fig. 5. The real part of the relative complex dielectric constant of 18FHR6 paint over the 31- through 33-GHz frequency range.

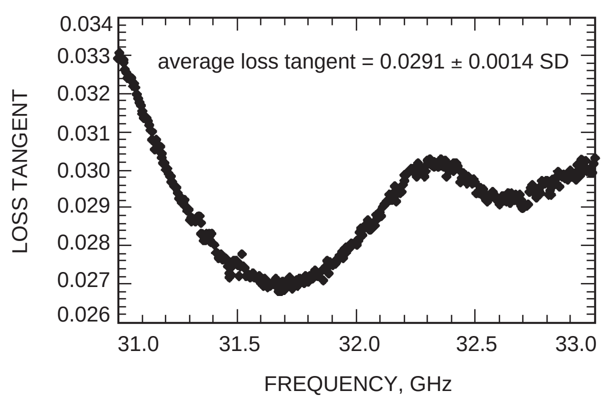

Fig. 6. The loss tangent of 18FHR6 paint over the 31- through 33-GHz frequency range.

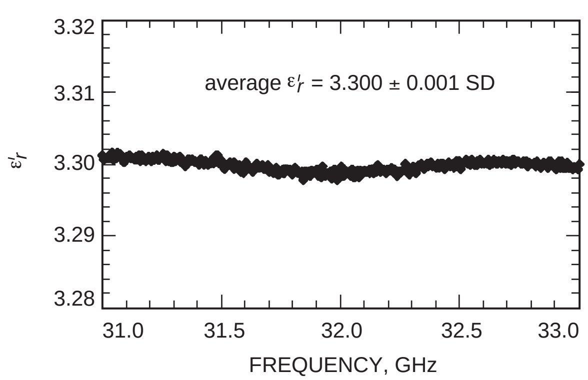

Fig. 7. The real part of the relative complex dielectric constant of 283 primer over the 31- through 33-GHz frequency range.

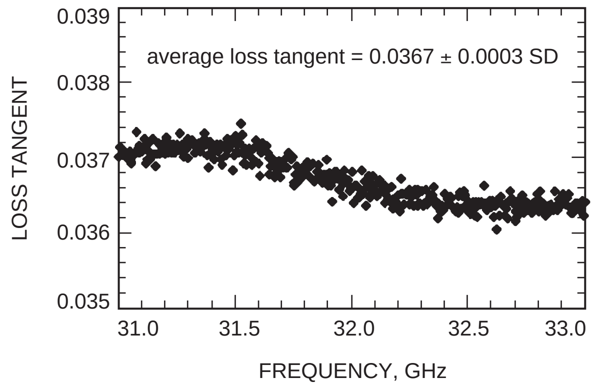

Fig. 8. The loss tangent of 283 primer over the 31- through 33-GHz frequency range.

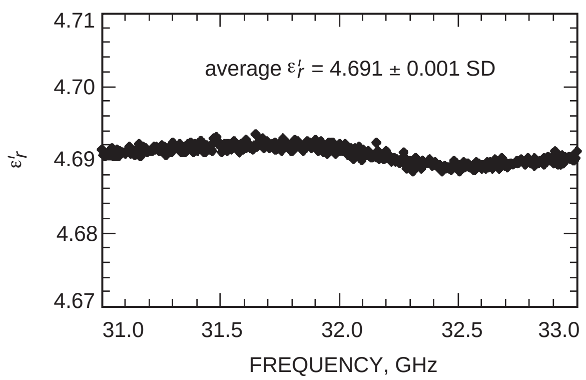

Fig. 9. The real part of the relative complex dielectric constant of 500FHR6 paint over the 31- through 33-GHz frequency range.

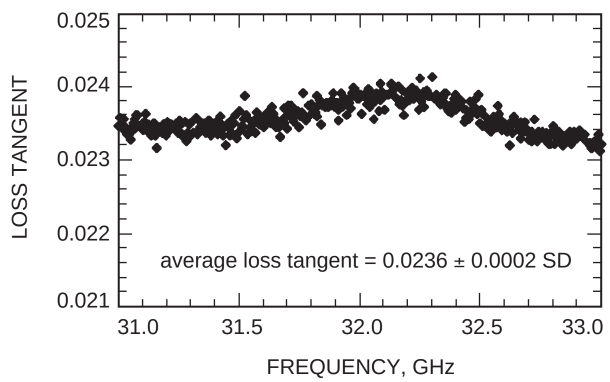

Fig. 10. The loss tangent of 500FHR6 paint over the 31- through 33-GHz frequency range.

For summary purposes, the average ε'_r values shown on the plots are tabulated in Table 3. From both the plots and the table, it can be seen that the 500FHR6 paint has the lowest ε'_r value and the smallest variation with frequency of the three types of paints tested. Triangle no. 6 and the 18FHR6 paints had noticeably large variations of ε'_r and loss tangents with frequency. It also can be seen from the plots that zinc chromate and 283 primers have small variations of ε'_r with frequency. The values shown in this table may be slightly different from those previously reported in [1] because the measurements were repeated on all paint samples over a frequency range of 31 through 35 GHz, and the new final values are given in Table 3 and in Figs. 1 through 10.

IV. Concluding Remarks

Measurements of complex dielectric constants of paints and primers are now complete. Through the use of equations presented in [1], the noise-temperature contributions of various primer and paint layers of interest will be computed as functions of thickness, frequency, polarization, and incidence angle. These results will be presented in an article that will be forthcoming.

Table 3. Average paint/primer values in the 32-GHz frequency region.

Paint or primer	Frequency, GHz	ε'_r	ε''_r	Loss tangent	Electrical conductivity,[a] mhos/m
Triangle no. 6 paint	31–33	5.908 0.019 SD	0.148 0.014 SD	0.025 0.002 SD	0.2631
Zinc chromate primer	32–34	4.361 0.001 SD	0.0949 0.0001 SD	0.0218 0.00003 SD	0.1687
18FHR6 paint	31–33	5.275 0.012 SD	0.153 0.008 SD	0.0291 0.0014 SD	0.2720
283 primer	31–33	3.300 0.001 SD	0.121 0.001 SD	0.0367 0.0003 SD	0.2151
500FHR6 paint	31–33	4.691 0.001 SD	0.111 0.001 SD	0.0236 0.0002 SD	0.1973

[a] Electrical conductivity = $\varepsilon''_r \times$ frequency(GHz)/18. For this table, frequency(GHz) = 32.0 was used.

Reference

[1] T. Y. Otoshi, R. Cirillo, Jr., and J. Sosnowski, "Measurements of Complex Dielectric Constants of Paints and Primers for DSN Antennas: Part I," *The Telecommunications and Mission Operations Progress Report 42-138, April–June 1999*, Jet Propulsion Laboratory, Pasadena, California, pp. 1–13, August 15, 1999. http://tmo.jpl.nasa.gov/tmo/progress_report/42-138/138F.pdf