NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

*Technical Report 32-1433*

*Revision 1*

# *Dielectric Constant and Loss Tangent of Eccofoam PT, at 2.3 GHz, for Various Packing Densities*

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JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA
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# Preface

The original issuance of this document reported on work done in support of the Capsule System Advanced Development (CSAD) project. It included a corrected curve for dielectric constant versus density for Eccofoam PT. This revision is issued to (1) report additional data obtained since the conclusion of the CSAD project which substantiates the earlier experimental data, (2) delete the corrected curve which now appears to be invalid, and (3) make minor editorial changes.

The work described in this report was performed by the Applied Mechanics Division of the Jet Propulsion Laboratory.

All of the physical and electrical testing upon which this report is based was accomplished by A. G. Young.

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## Abstract

The dielectric constant and loss tangent for Eccofoam PT, at various densities, are determined; the resulting density gradients are provided. The range of densities over which the dielectric constant and loss tangent are determined are from ~320 to 1280 $kg/m^3$ (20 to 80 $lb/ft^3$).

# Dielectric Constant and Loss Tangent of Eccofoam PT, at 2.3 GHz, for Various Packing Densities

## I. Introduction

A dielectrically loaded, cavity type of antenna design was used on the Capsule System Advanced Development (CSAD) Lander at the Jet Propulsion Laboratory. The work described herein established the relationships of relative dielectric constant and loss tangent to density for Eccofoam PT (Emerson and Cuming, Inc., Canton, Massachusetts), a light-weight, syntactic, epoxide foam, at frequencies in the vicinity of 2.3 GHz. It was determined that this material, packed to a nominal density of 457 kg/m$^3$ (28.5 lb/ft$^3$), would satisfy the design requirement that the loading material have a relative dielectric constant of 1.70. In the results reported here, values in customary units are included in parentheses after values in SI (International System) units if the customary units were used in the measurements or calculations.

Since Eccofoam PT has the consistency of damp sand, it is difficult to distribute evenly within a cavity and around an antenna probe. Uneven distribution causes density variations; furthermore, the areas of the different densities possess different dielectric constants. For most general applications, the desired situation would be a homogeneous density throughout the loaded device, thereby affording the same dielectric constant in all areas of the cavity. This work established the magnitude of the local density variations that resulted when Eccofoam PT was packed by means of a particular procedure, and permitted calculation of the resulting variations in dielectric constant. These are considered acceptable in the CSAD antenna application.

The initial measurements made during the CSAD project showed the dielectric constant to increase almost linearly with density within the range of investigation, whereas prior experience had led the investigators to expect that it would tend to level off at the higher densities. Since this was the unconfirmed result of a single set of measurements, a mathematically corrected curve of relative dielectric constant versus density was also included in the original report. When the opportunity later arose, a second set of measurements was made on the higher density specimens. These confirmed the earlier experimental data, and the corrected curve is therefore deleted from this revision.

**Table 1. Density vs dielectric constant and loss tangent of Eccofoam PT**

| Specimen set | Target density, kg/m$^3$ (lb/ft$^3$) | Density before machining, kg/m$^3$ (lb/ft$^3$) | Density after grinding, kg/m$^3$ (lb/ft$^3$) | Relative dielectric constant $\epsilon'_r$ | Loss tangent, $\delta\epsilon$ | Test frequency, MHz |
|---|---|---|---|---|---|---|
| 1 | 320 (20.0) | 319 (19.9) | 322.0 (20.10) | 1.489 | 0.00606 | 2279.6 |
| | 457 (28.5) | 453 (28.3) | 457.6 (28.57) | 1.733 | 0.00696 | 2284.8 |
| | 641 (40.0) | 636 (39.7) | 635.6 (39.68) | 2.050 | 0.00735 | 2277.6 |
| | 801 (50.0) | 798 (49.8) | 801.4 (50.03) | 2.390 | 0.00820 | 2215.7 |
| | 961 (60.0) | 960 (59.9) | 959.8 (59.92) | 2.733 | 0.00815 | 2071.8 |
| | 1280 (80.0) | 1270 (79.3) | 1288 (80.41) | 3.501 | 0.00876 | 1782.1 |
| 2 | 801 (50.0) | 823 (51.4) | 831.2 (51.89) | 2.423 | — | 2173.9 |
| | 961 (60.0) | 988 (61.7) | 994.7 (62.10) | 2.816 | — | 2040.0 |
| | 1280 (80.0) | 1290 (80.4) | 1314 (82.04) | 3.649 | — | 1777.1 |

**Table 2. Machined dimensions of Eccofoam PT specimens**

| Specimen set | Target density, kg/m$^3$ (lb/ft$^3$) | Anticipated dielectric constant $\epsilon'_r$ | Outer diameter, cm (in.) | Inner diameter, cm (in.) | Length, cm (in.) |
|---|---|---|---|---|---|
| 1 | 320 (20.0) | 1.45 | 2.096 $+0.000$ $-0.008$ (0.8250) $\begin{pmatrix}+0.0000\\-0.0003\end{pmatrix}$ | 0.9151 $+0.008$ $-1.000$ (0.3603) $\begin{pmatrix}+0.0003\\-0.0000\end{pmatrix}$ | 5.410 ± 0.013 (2.130 ± 0.005) |
| | 457 (28.5) | 1.70 | | | 5.004 ± 0.013 (1.970 ± 0.005) |
| | 641 (40.0) | 2.00 | | | 4.610 ± 0.013 (1.815 ± 0.005) |
| | 801 (50.0) | 2.10 | | | 4.508 ± 0.013 (1.775 ± 0.005) |
| | 961 (60.0) | 2.20 | | | 4.394 ± 0.013 (1.730 ± 0.005) |
| | 1280 (80.0) | 2.40 | | | 4.394 ± 0.013 (1.730 ± 0.005) |
| 2 | 801 (50.0) | 2.18 | | | 4.417 ± 0.013 (1.739 ± 0.005) |
| | 961 (60.0) | 2.22 | | | 4.374 ± 0.013 (1.722 ± 0.005) |
| | 1280 (80.0) | 2.09 | | | 4.506 ± 0.013 (1.774 ± 0.005) |

## II. Objectives

The objectives of this program were (1) to determine the relative dielectric constant and loss tangent of Eccofoam PT at approximately 2.3 GHz, when packed at selected densities, and (2) to determine the density gradients at various depths in the specimens, resulting from the use of a particular packing procedure. This information makes it possible to selectively tailor the material properties to meet a range of electrical requirements. In addition, density gradient data can be used to develop practical and reproducible fabrication procedures.

## III. Testing

### A. Specimen Preparations

Duplicate sets of cylindrical Eccofoam PT specimens were prepared at densities of 320, 457, 641, 801, 961, and 1280 kg/m$^3$ (20, 28.5, 40, 50, 60, and 80 lb/ft$^3$). One of the specimen sets was intended as a spare, to be used in the event of damage to the first set; however, this eventuality did not occur. Thus, this second, unused set was available, and the 801, 961, and 1280 kg/m$^3$ (50, 60, and 80 lb/ft$^3$) specimens were used for the additional dielectric constant and density measurements that were made later.

Each specimen was packed in layers to a specified density. In order to accomplish this, an accurately known quantity of Eccofoam PT was placed into a mold and slowly compressed by a ram until the layer was 1.27 cm 0.5 in.) high. This procedure was repeated for each layer until five layers were compressed, for a total specimen length of 6.35 cm (2.5 in.)

After packing, all specimens were cured in a forced-draft oven for 1 h at 121°C (250°F). After curing and removal from their molds, the approximate density of each specimen was determined (Table 1). Specimens were precision ground to the dimensions shown in Table 2. The outer- and inner-diameter dimensions allow the specimens to be lightly pressed into an adjustable reactance line for electrical testing. The specimen length is determined from an anticipated value of dielectric constant and the desired test frequency. In the usual case, the dielectric constant is not exactly as anticipated; the test frequency must be changed slightly to compensate for the error in the specimen length caused by the difference between the anticipated and the actual dielectric constant. In this case, it will be noted that there is, at the higher densities, a large disparity between the measured dielectric constant and that which was anticipated on the basis of prior work with similar materials.

### B. Test Procedure

After machining, the density of each specimen was accurately determined by micrometer measurements and by weighing on an analytical balance.

The dielectric constant and loss tangent determinations were performed using two SLRD Generators and an LMD Precision Slotted line (Rohde and Schwarz, Inc., Munich, Germany). The generators and slotted line were operated in a typical heterodyne setup with an MRAL Mixer and a Type 1236 I-F Amplifier Detector (General Radio Co., West Concord, Mass.). The specimen container was an Adjustable Reactance Line (Rohde and Schwarz).

After the electrical determinations were completed, each specimen of the first set of PT specimens was sectioned, as shown in Fig. 1, and densities of each piece were accurately determined. Table 3 presents the density of each sectioned piece versus the dielectric constant, as taken from the curve in Fig. 2.

Additional data points at 801, 961, and 1280 kg/m$^3$ (50, 60 and 80 lb/ft$^3$), obtained from the second set of PT specimens, increase the confidence one might have in the curve of Fig. 2, which was plotted using the data from the first set of PT specimens. This is especially true since the densities and, therefore, the resulting test fre-

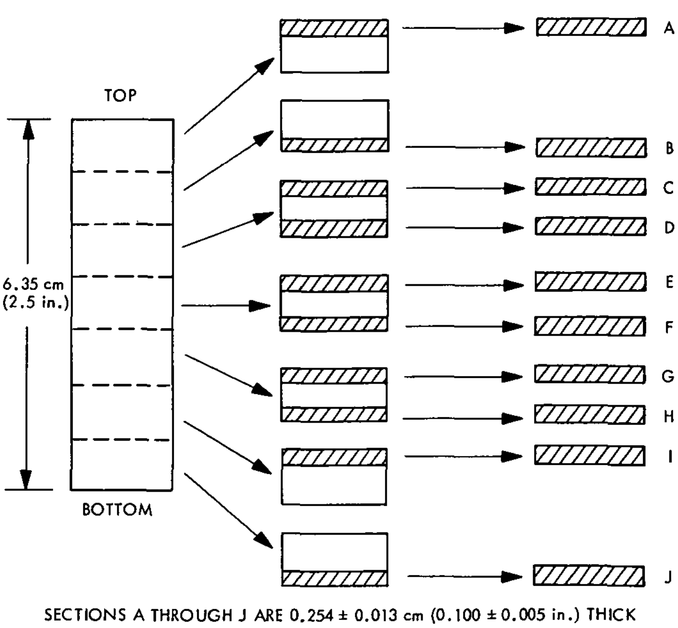


**Fig. 1. Sectioning of specimens after electrical determinations**

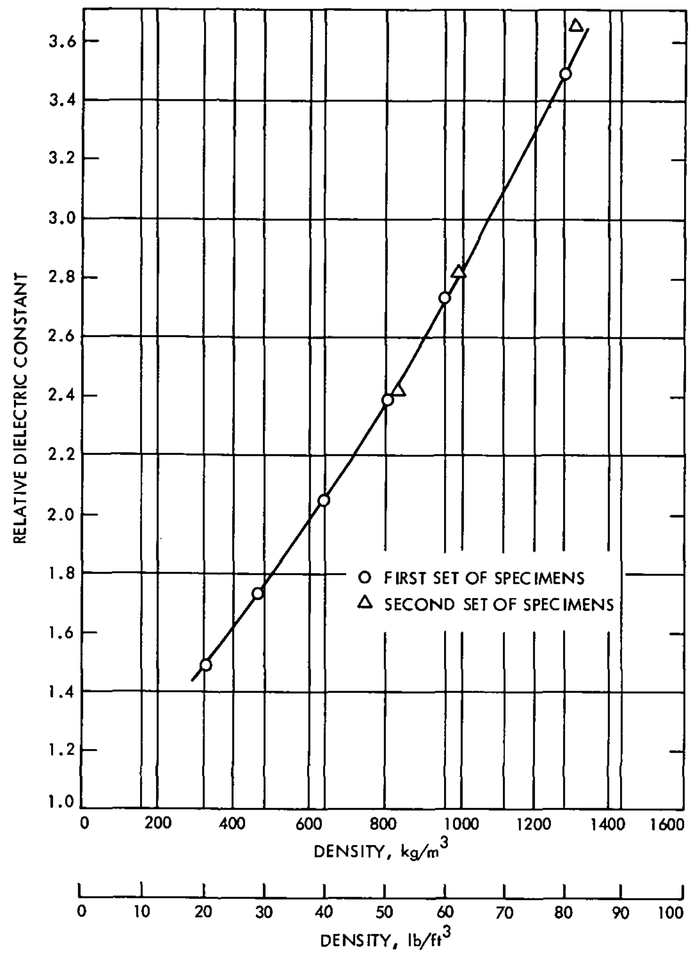


**Fig. 2. Dielectric constant vs density of Eccofoam PT**

quencies for the second set of specimens were slightly different from the corresponding densities and test frequencies of the first set of PT specimens.

## IV. Conclusions

Within the selected density ranges tested, the dielectric constant of PT increases without leveling off.

The tangent of the loss angle for Eccofoam PT increases with increasing density, as shown in Table 1.

An analysis of the data in Table 3 indicates that practical deviations of dielectric constants (caused by density gradients) can be expected to be less than 0.074 for each of the packing densities between ~320 and 1280 kg/m$^3$ (20 and 80 lb/ft$^3$).

**Table 3. Density gradients vs dielectric constants**

| Target density, kg/m$^3$ (lb/ft$^3$) | Specimen location (Fig. 1) | Density, kg/m$^3$ (lb/ft$^3$) | Corresponding dielectric constant from curve in Fig. 2 |
|---|---|---|---|
| (20.0) 320 | A | 319.7 (19.96) | 1.480 |
| | B | 320.8 (20.03) | 1.490 |
| | C | 317.3 (19.81) | 1.475 |
| | D | 321.8 (20.09) | 1.490 |
| | E | 319.9 (19.97) | 1.480 |
| | F | 312.8 (19.53) | 1.470 |
| | G | 321.6 (20.08) | 1.490 |
| | H | 322.1 (20.11) | 1.490 |
| | I | 321.2 (20.05) | 1.490 |
| | J | 318.9 (19.91) | 1.475 |
| (28.5) 457 | A | 480.2 (29.98) | 1.765 |
| | B | 472.2 (29.48) | 1.755 |
| | C | 479.4 (29.93) | 1.765 |
| | D | 456.5 (28.50) | 1.725 |
| | E | 468.5 (29.25) | 1.750 |
| | F | 444.5 (27.75) | 1.705 |
| | G | 458.9 (28.65) | 1.730 |
| | H | 468.5 (29.25) | 1.745 |
| | I | 472.4 (29.49) | 1.755 |
| | J | 443.07 (27.66) | 1.700 |
| (40.0) 641 | A | 661.2 (41.28) | 2.100 |
| | B | 612.5 (38.24) | 2.010 |
| | C | 646.0 (40.33) | 2.070 |
| | D | 625.0 (39.02) | 2.040 |
| | E | 614.9 (38.39) | 2.020 |
| | F | 615.3 (38.41) | 2.020 |
| | G | 646.5 (40.30) | 2.070 |
| | H | 632.4 (39.48) | 2.050 |
| | I | 656.1 (40.96) | 2.090 |
| | J | 618.8 (38.63) | 2.020 |
| (50.0) 801 | A | 817.3 (51.02) | 2.410 |
| | B | 798.0 (49.82) | 2.380 |
| | C | 792.9 (49.50) | 2.370 |
| | D | 794.4 (49.59) | 2.380 |
| | E | 821.4 (51.28) | 2.425 |
| | F | 781.7 (48.80) | 2.345 |
| | G | 803.6 (50.17) | 2.410 |
| | H | 799.5 (49.91) | 2.380 |
| | I | 787.8 (49.18) | 2.355 |
| | J | 800.4 (49.97) | 2.380 |
| (60.0) 961 | A | 1002 (62.53) | 2.805 |
| | B | 974.8 (60.86) | 2.755 |

Table 3. (contd)

| Target density, kg/m³ (lb/ft³) | Specimen location (Fig. 1) | Density, kg/m³ (lb/ft³) | Corresponding dielectric constant from curve in Fig. 2 |
|---|---|---|---|
| (60.0) 961 (contd) | C | 958.1 (59.81) | 2.720 |
| | D | 941.1 (58.75) | 2.680 |
| | E | 945.9 (59.05) | 2.695 |
| | F | 930.8 (58.11) | 2.660 |
| | G | 952.5 (59.46) | 2.710 |
| | H | 956.6 (59.72) | 2.720 |
| | I | 1005 (62.76) | 2.825 |
| | J | 968.8 (60.48) | 2.735 |
| (80.0) 1280 | A | 1304 (81.40) | 3.545 |
| | B | 1273 (79.47) | 3.460 |
| | C | 1274 (79.53) | 3.465 |
| | D | 1268 (79.16) | 3.455 |
| | E | 1311 (81.84) | 3.565 |
| | F | 1264 (78.91) | 3.440 |
| | G | 1302 (81.28) | 3.540 |
| | H | 1280 (79.91) | 3.480 |
| | I | 1312 (81.90) | 3.560 |
| | J | 1273 (79.47) | 3.460 |


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