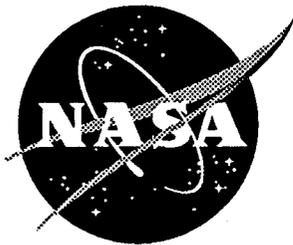


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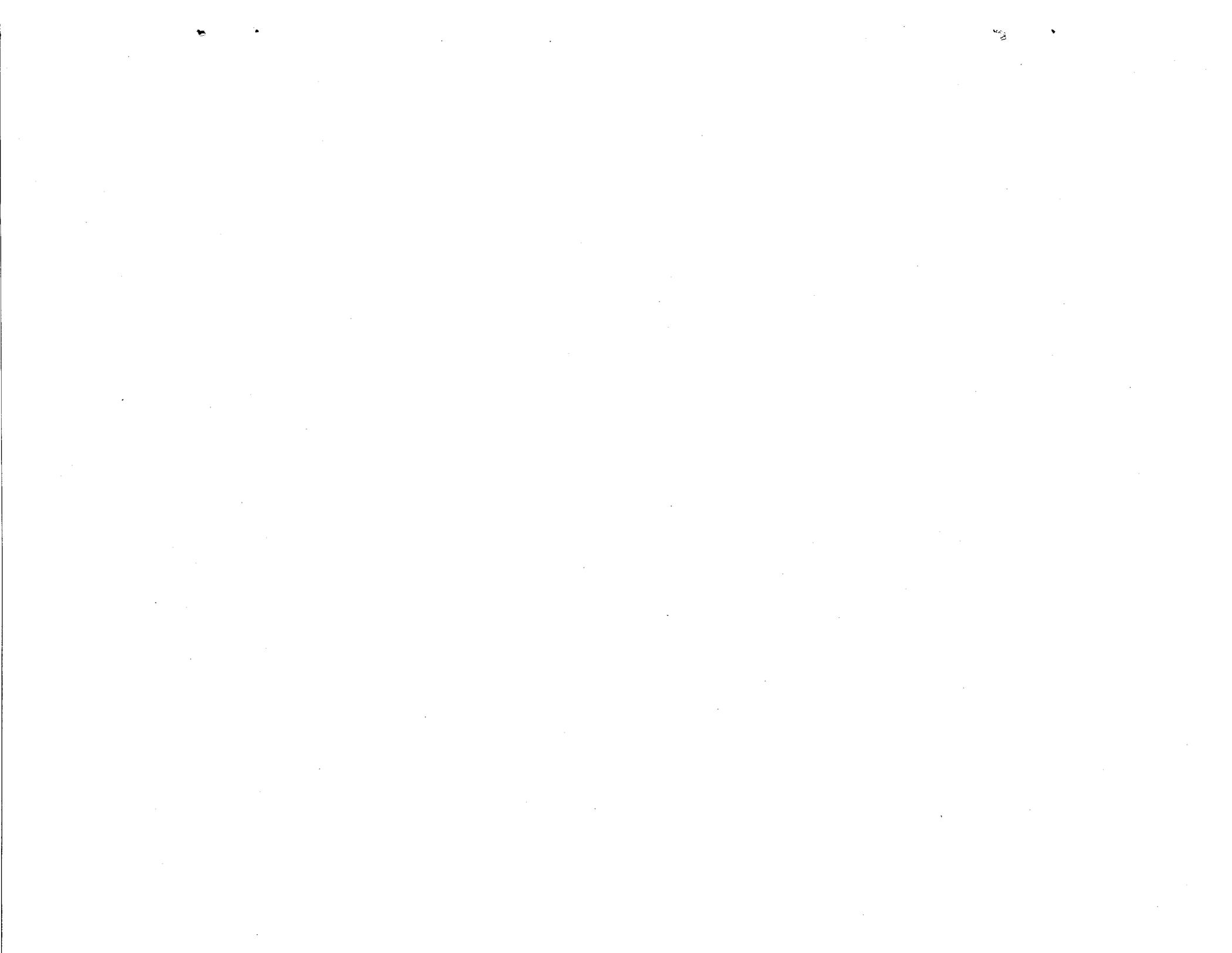


# W-Band Transmission Measurements and X-Band Dielectric Properties Measurements for a Radome Material Sample

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## Introduction

This paper describes measurements which were performed on a sample of radome material in the Electromagnetic Properties Measurements Laboratory (EPML). The purpose of the measurements described in this paper was to determine the one-way transmission loss through the flat panel of radome material for a frequency range of 84 to 94 GHz, for varying incidence angles. The panel, which was manufactured by Norton Performance Plastics Corporation, was provided to the EPML by TRW. The size of the panel is 40" x 36" x 0.422" and consists of a foam material with one side coated with a smooth white coating (this side will be referred to as the front side). The dielectric properties of the foam material from the inside of the panel were also determined at X band (8.2 - 12.4 GHz). The W-band free space measurements are presented first, followed by the X-band dielectric properties measurements.

## W-Band Transmission Measurements

### Measurement Setup.

In this section, a description of the measurement setup will be given, followed by detailed information about the various hardware components comprising the setup. The measurement setup consisted of transmit and receive antennas on opposite sides of the sample. The sample was supported by a rotatable holder. The setup was located on an optical table positioned in front of a millimeter wave network analyzer (see figs. 1 and 2).

The sample holder is constructed of a circular plexiglass base with a low  $\epsilon_r$  foam cradle which supports the sample. The foam cradle is attached to a circular plexiglass platform which fits into the base and rotates. The base is marked with scribe marks to indicate the angular displacement.

The network analyzer used in the measurements is a Hewlett-Packard (HP) 85106C system with WR-10 Test Set Modules which allow operation of the 85106C at frequencies from 75 to 110 GHz. The Test Set Modules can be seen in figs. 1 and 2, as the grey boxes to which the waveguide hardware is attached.

The transmit and receive antennas used in this measurement are scalar horns having an operating frequency range from 75 to 110 GHz, and are symmetrical both physically and electromagnetically. The horns have a 3 dB beamwidth of approximately 23 degrees and gain of 25 dB at 92 GHz. The antennas are connected to the WR-10 Test Set Modules with various WR-10 waveguide sections such that they are located approximately 36 inches apart and approximately 22 inches above the surface of the optical table. With the sample located midway between the antennas and oriented at 0 degrees, (broadside to the antennas) the 3 dB area of illumination was a circle approximately 7.3 inches in diameter (the sample is located in the far field of the antennas). With the sample oriented at 45 degrees, the 3 dB area of illumination was an elliptical spot with a short axis length (vertical direction) of about 7.3 inches, and a long axis length (horizontal direction) of about 8.6 inches.

### **Measurement Procedure.**

Before the measurements were started, an effort was made to isolate and eliminate potential sources of error. The frequency range used for the measurements was 79 to 99 GHz, in order to bracket the desired frequency range of 84 to 94 GHz, and to eliminate band edge errors due to the time domain gating process (which will be explained in more detail below). Two hundred and one frequency points were used, which gave a time domain range of 10 ns. An averaging factor of 64 was used for all measurements.

After the antennas were roughly positioned as described in the previous section, final boresighting was accomplished by observing the S21 response in the time domain (with the sample not present) and moving the antennas slightly until the response was observed to be at a maximum amplitude. The 0 degree position of the sample holder was then set by inserting a 2 foot X 2 foot flat metal plate into the sample holder and observing the S11 response. The sample holder was set to 0° at the position which gave the maximum S11 response from the plate.

During the empty sample holder measurements described above, two symmetrical peaks were observed on either side of the main response. Each of these peaks were separated in time from the main peak by about a nanosecond, with levels at

about 10 dB below that response. It was determined by disassembling the antenna setup and connecting the WR-10 modules directly together that these responses were artifacts of the modules and not multipath reflections. A time domain gate was thus set up around the main response in order to minimize the effects of these responses on the actual measurement. Several tests were also performed to assure that multipath reflections were not present, by placing absorber on the optical table between the WR-10 modules. Test results were the same with or without absorber on the table.

Transmission through the sample was measured for sample positions ranging from broadside ( $0^\circ$ ) to  $45^\circ$ , at angular increments of  $5^\circ$ . The transmit antenna was located on the front side of the sample. For each sample position, an empty sample holder transmission ( $S_{21_{\text{empty}}}$ ) measurement was made and recorded. The sample was then placed in the holder and  $S_{21_{\text{sample}}}$  was recorded. The one-way loss through the sample was calculated as  $S_{21_{\text{sample}}} / S_{21_{\text{empty}}}$ . In order to accomplish positioning repeatability, the sample was measured and marked so that it could be placed in the same position on the sample holder each time. It was found through experimentation that the loss through the sample varied up to 0.2 dB with positional changes, so a consistent measurement position was desirable. This will be discussed further in the Measurement Errors section.

## **Results.**

Measurement results are shown in the following figures (figs. 3-12). For each angle, a plot is given of the one-way loss through the sample in dB (normalized to the loss measurement for the empty sample holder at that angle) versus the frequency in GHz. A table giving the values of the loss for each angle at three specific frequencies (84, 89, and 94 GHz) follows the plots. As can be seen from the plots and table, the measured values for the frequencies of interest generally fall in the range -1 to -2.5 dB.

Angle/Frequency	84 GHz	89 GHz	94 GHz
0 degrees	-2.13819	-2.41679	-2.01011
5 degrees	-1.70333	-2.34551	-1.56844
10 degrees	-1.55315	-2.39826	-1.55299
15 degrees	-1.49053	-2.29234	-1.74277
20 degrees	-1.36397	-2.07975	-2.02596
25 degrees	-1.74227	-1.29429	-2.46704
30 degrees	-1.90319	-1.24839	-2.02137
35 degrees	-1.72674	-1.70018	-1.42950
40 degrees	-1.34114	-2.00248	-1.84097
45 degrees	-1.50155	-1.46395	-2.27118

**Table 1:** Transmission Loss in dB for measured sample positions for selected frequencies

### **Error Discussion.**

A large source of error identified during these measurements was sample positioning. Changes of up to 0.2 dB resulted from moving the sample slightly and repeating the 0 degree measurement. Thus, an effort was made to illuminate the same spot throughout the series of measurements even though the sample had to be removed between the rotations of the sample holder so that a background measurement could be made. The sample was also observed to be non-planar, i.e., to have a slight curvature. Even though the sample was wedged into the sample holder with foam wedges, the curvature of the sample and the inhomogeneities are thought to contribute to the measurement error. If more accurate measurements are desired, a sample holder which surrounds the sample and holds it completely flat is recommended.

## **X-Band Material Properties Measurements**

### **Measurement Setup.**

The material properties measurements of the foam material on the interior of the panel were conducted using an X-band waveguide setup connected to an HP 8510C network analyzer. The X-band waveguide sample holder was 5" in length, and was connected to the network analyzer with Gore flexible cables and coax-to-waveguide adapters (see fig. 13). The sample used was 0.9 inches by 0.4 inches in cross section (to match the waveguide cross section) and was 0.303 inches thick. The foam sample was cut out of the interior part of the radome sample, so the shiny white coating and rough backing had been removed.

### **Measurement Procedure.**

Before the measurements were conducted, a full two-port calibration was performed using a standard waveguide calibration kit. The HP 85071A Materials Measurement software was utilized to compute the dielectric properties of the material from the measured reflection and transmission coefficients. For more detail about this measurement system, see Reference 1.

### **Results.**

Measurement results are shown in figs. 14 and 15. The plots show the real and imaginary parts of the permittivity as a function of frequency, as computed by the HP 85071 software. As can be seen from the plots, the real part of the permittivity for the foam sample is approximately 1.2, and the imaginary part is approximately 0.02.

## **Conclusions**

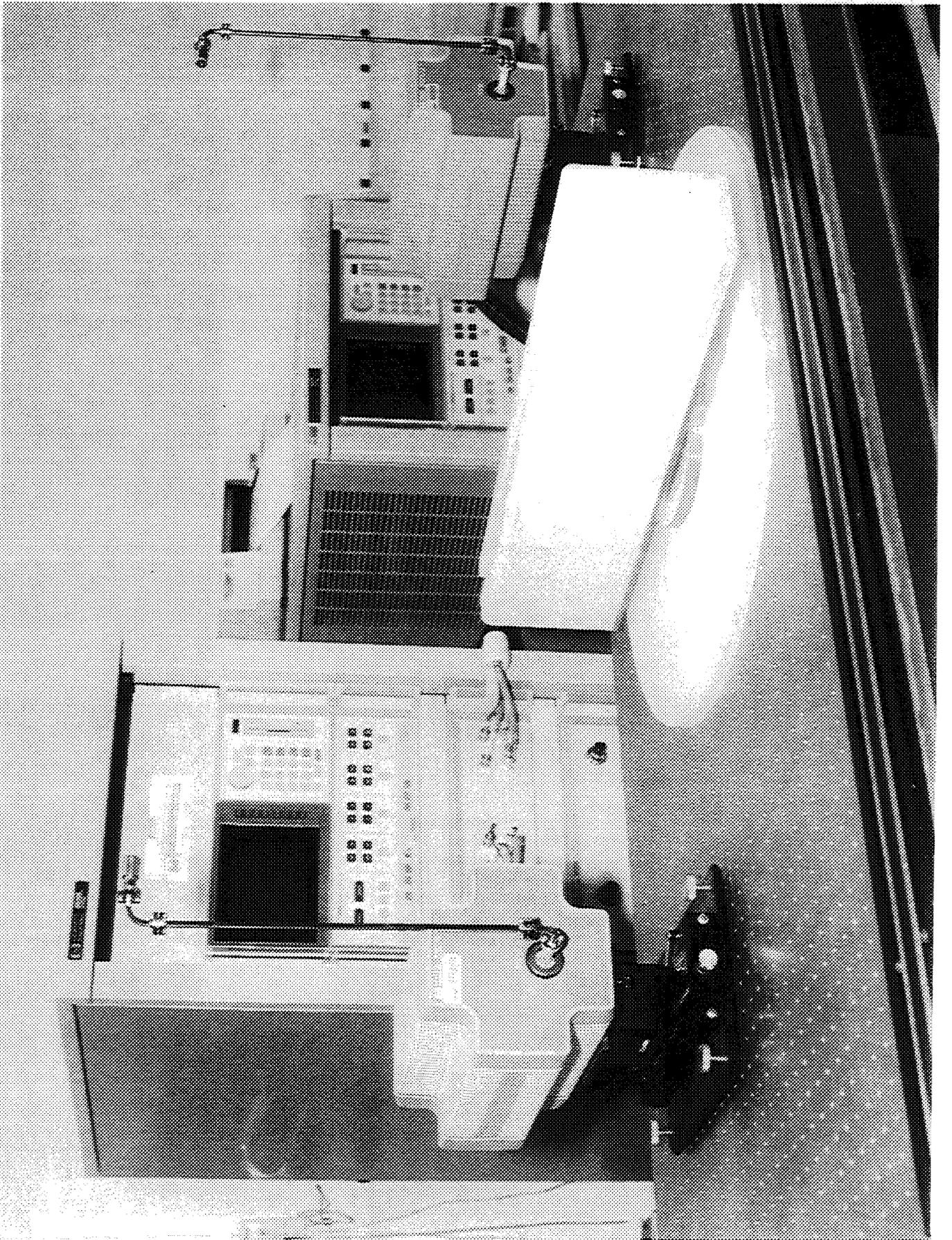
Free space transmission loss measurements at W-band and permittivity measurements at X-band were performed on a sample of radome material provided to the EPML by TRW. The free space measurements showed a one-way transmission loss between -1 and -2.5 dB. The waveguide measurements yielded a permittivity ( $\epsilon_r'$ ,  $\epsilon_r''$ ) value of about (1.2, 0.02).

## **Acknowledgment**

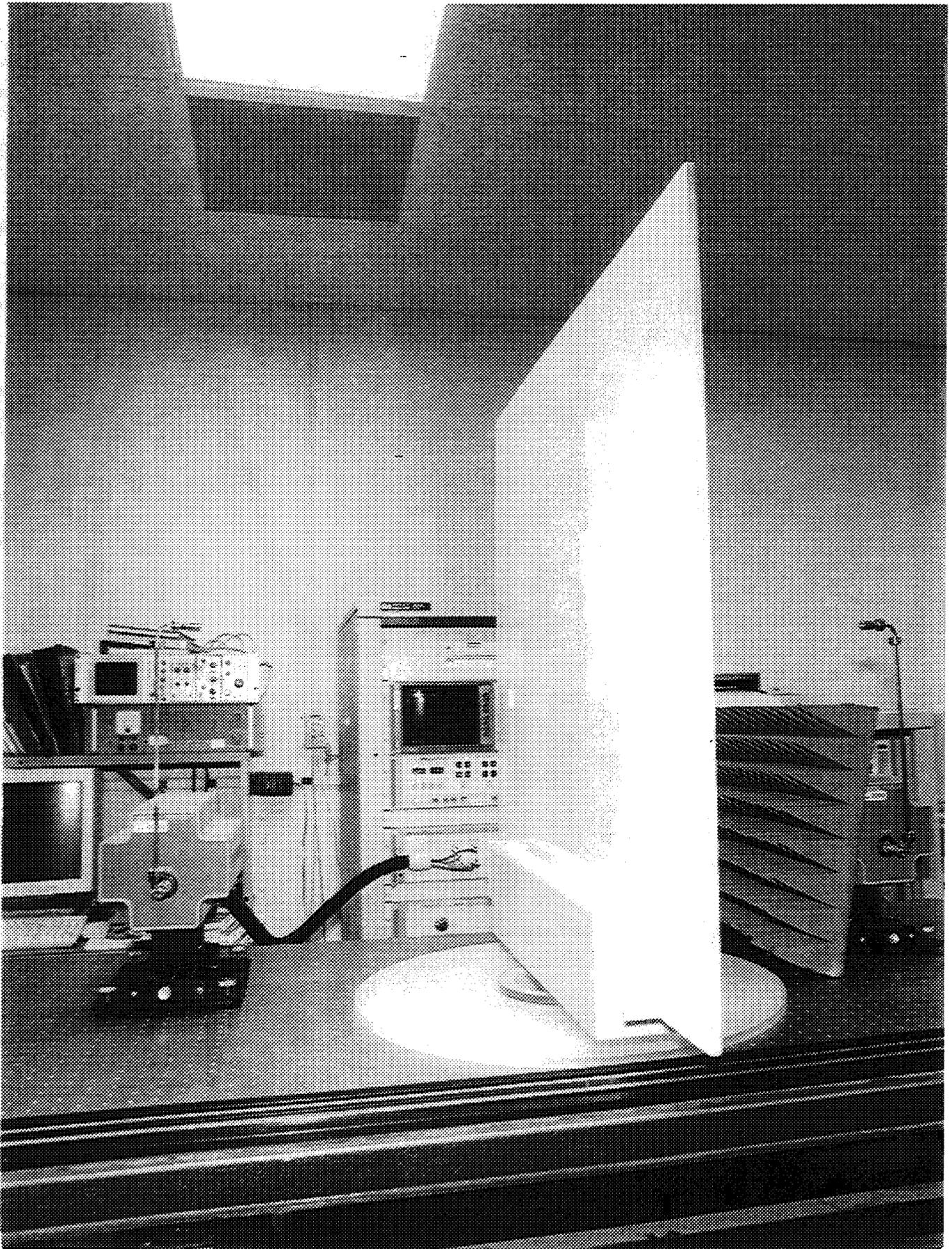
The authors wish to thank Dion Fralick of the Lockheed Engineering and Sciences Company for his expertise and assistance in making these measurements.

## **References**

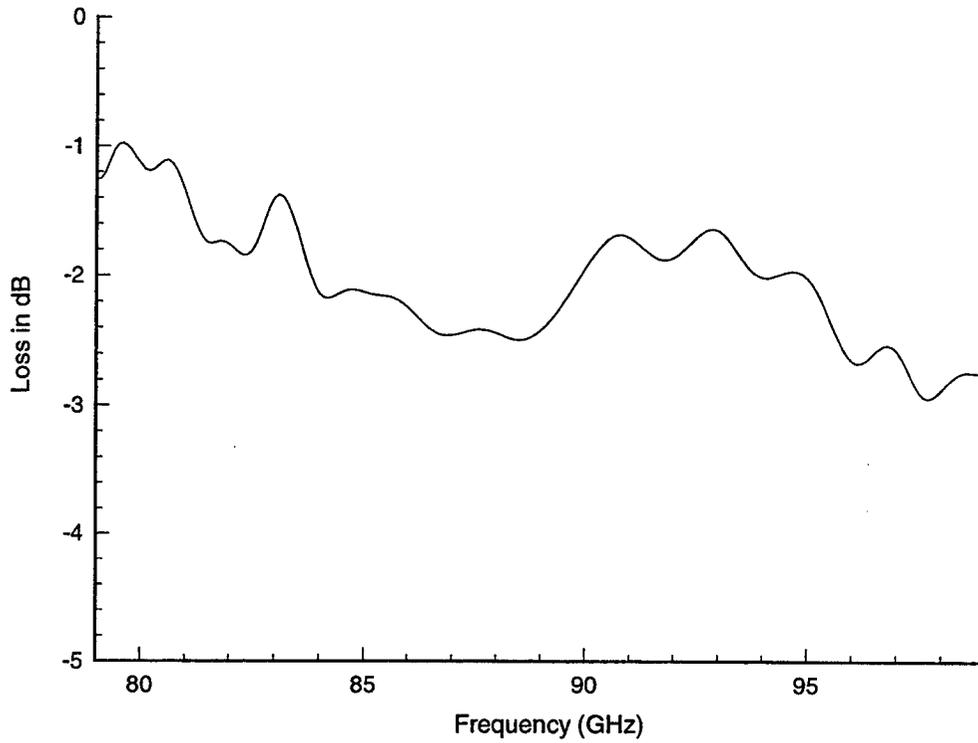
1. Cravey, R. L.; Tiemsin, P. I.; Bussell, K.; and Dudley, K. L.: Dielectric Property Measurements in the Electromagnetic Properties Measurement Laboratory. NASA TM-110147, April 1995.



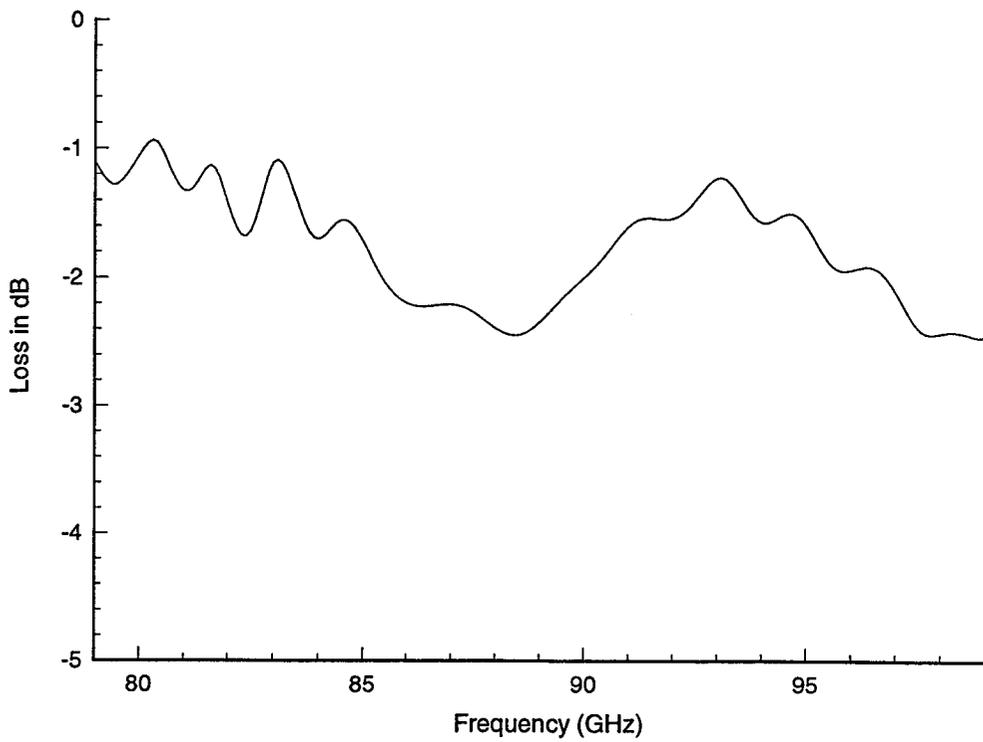
**Figure 1.** W-band free-space measurement setup



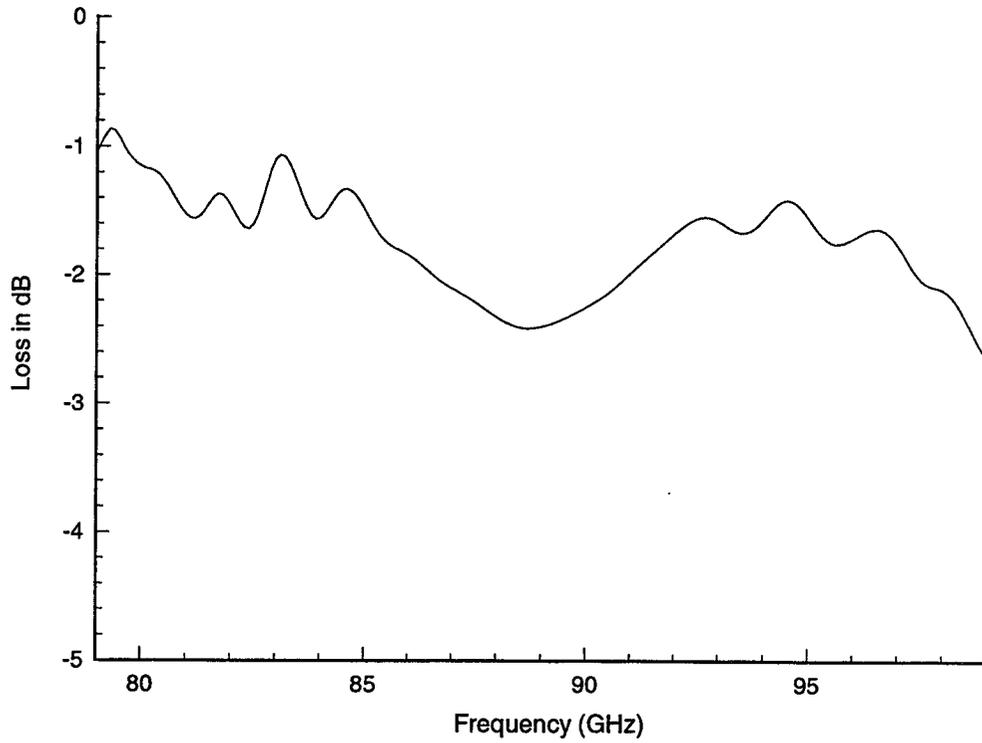
**Figure 2.** W-band free-space measurement setup with sample



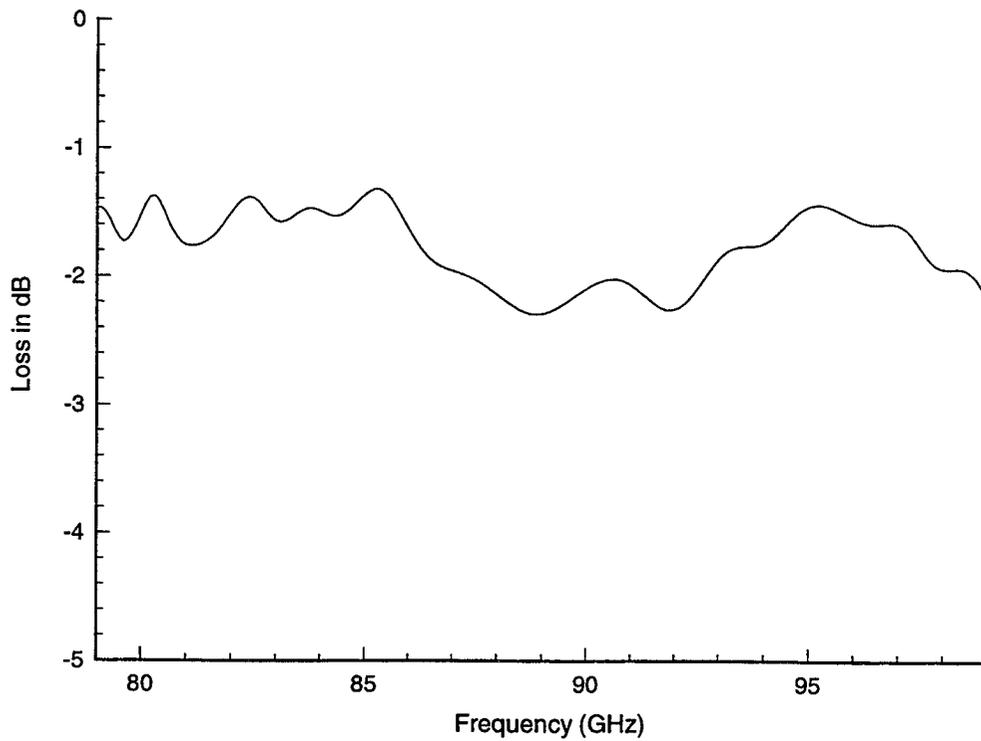
**Figure 3.** One-way loss through panel at 0 degrees (normalized to empty sample holder)



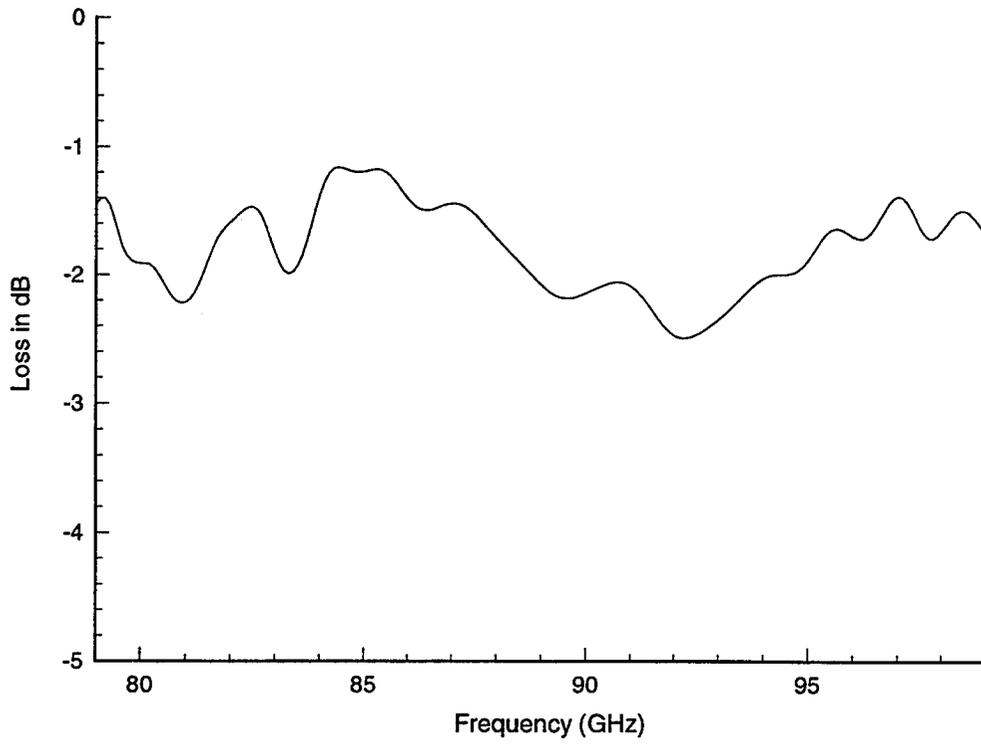
**Figure 4.** One-way loss through panel at 5 degrees (normalized to empty sample holder)



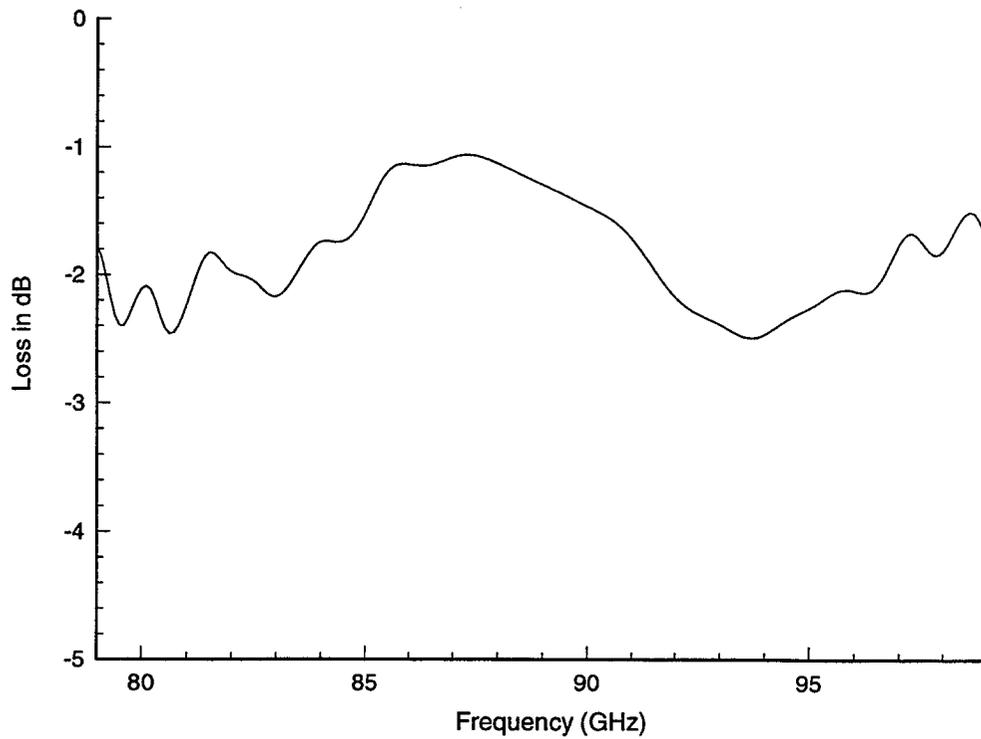
**Figure 5.** One-way loss through panel at 10 degrees (normalized to empty sample holder)



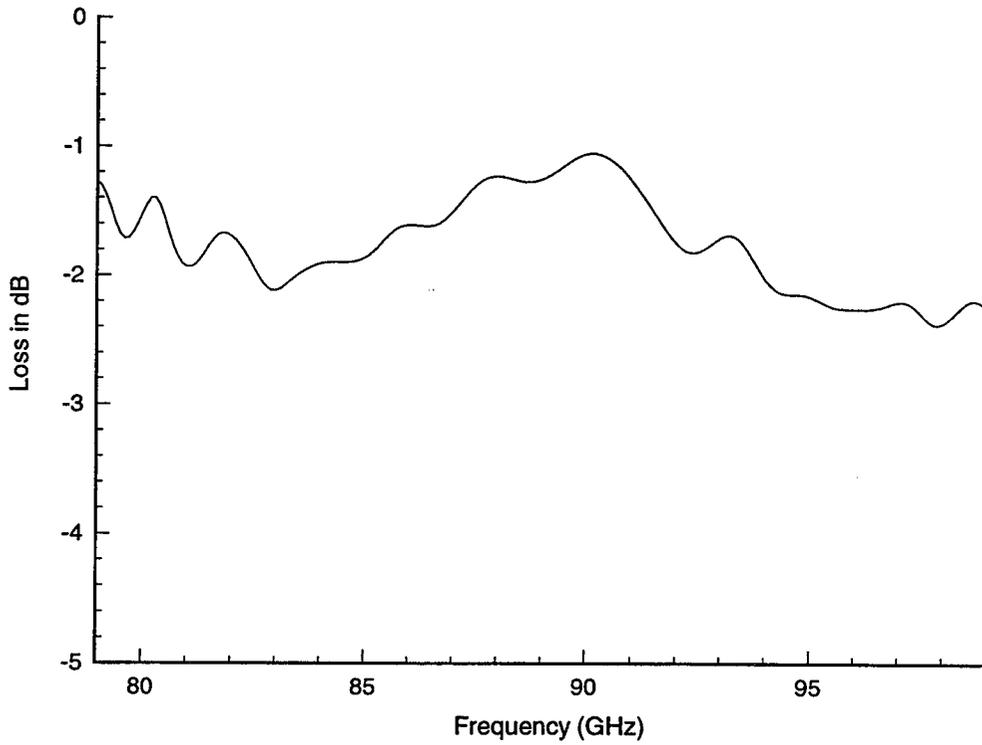
**Figure 6.** One-way loss through panel at 15 degrees (normalized to empty sample holder)



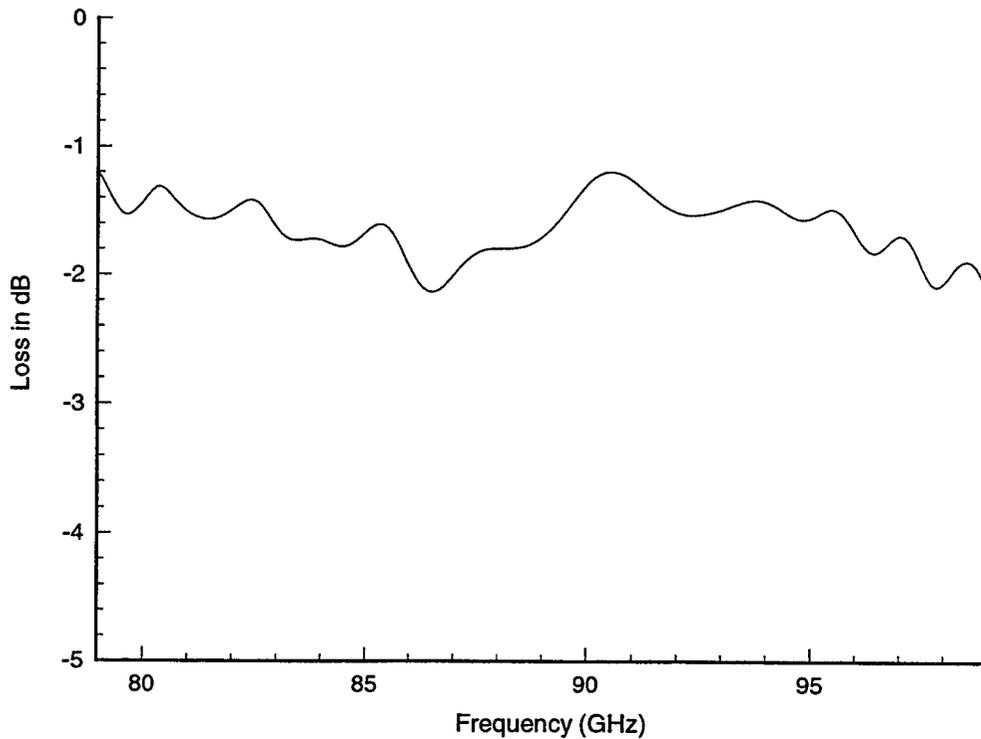
**Figure 7.** One-way loss through panel at 20 degrees (normalized to empty sample holder)



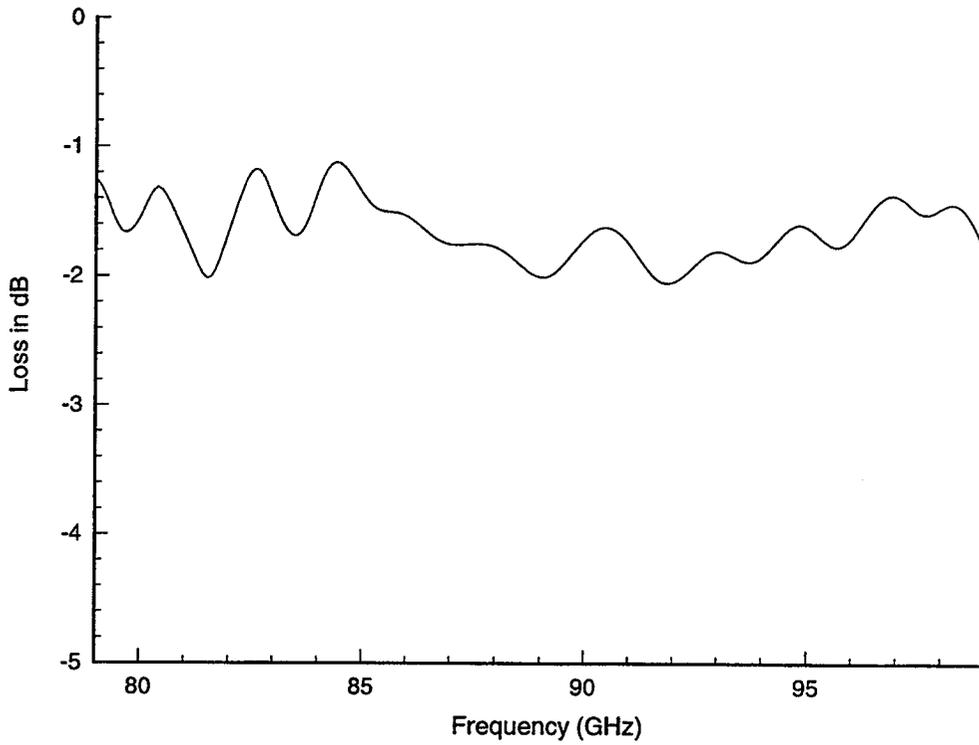
**Figure 8.** One-way loss through panel at 25 degrees (normalized to empty sample holder)



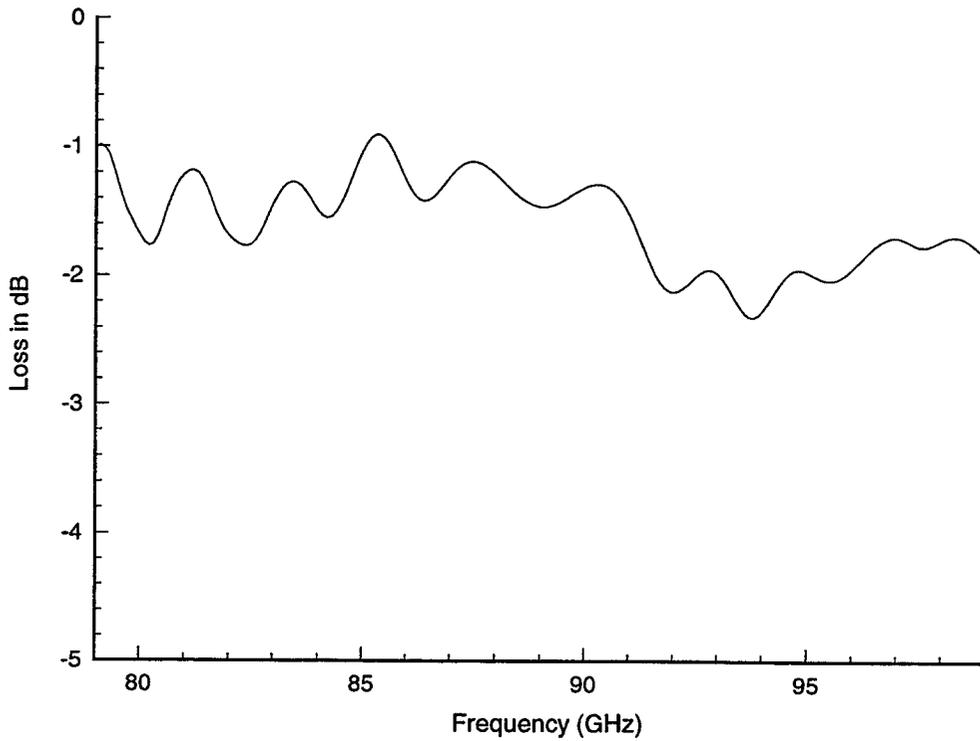
**Figure 9.** One-way loss through panel at 30 degrees (normalized to empty sample holder)



**Figure 10.** One-way loss through panel at 35 degrees (normalized to empty sample holder)



**Figure 11.** One-way loss through panel at 40 degrees (normalized to empty sample holder)



**Figure 12.** One-way loss through panel at 45 degrees (normalized to empty sample holder)

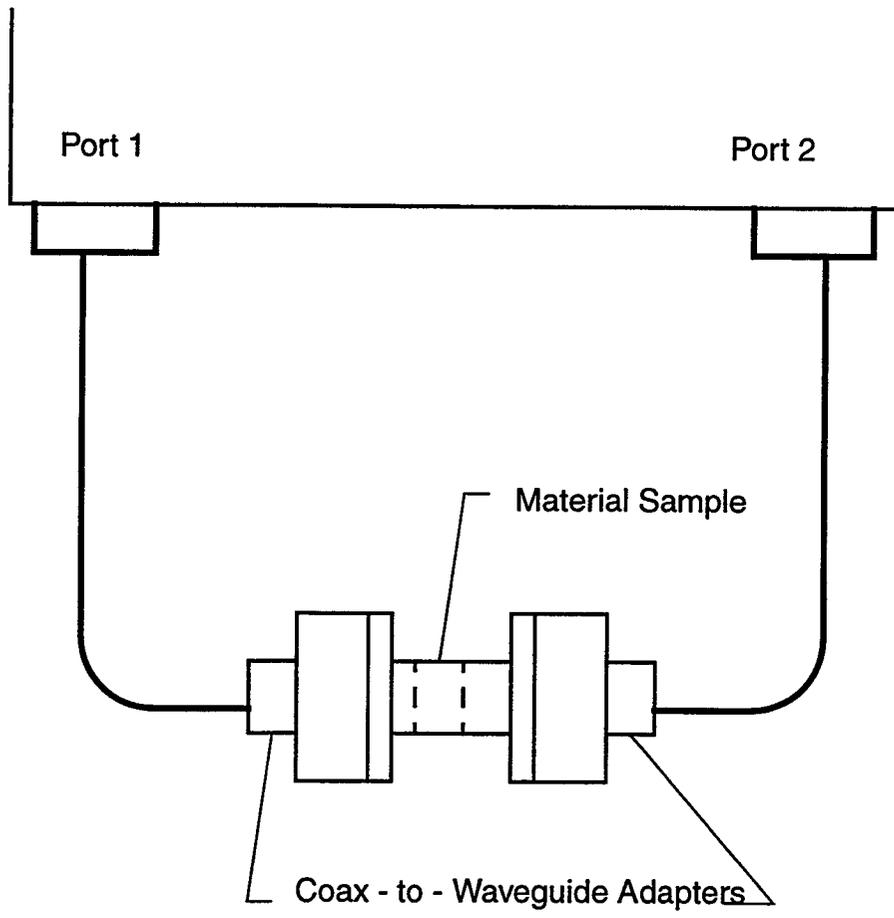


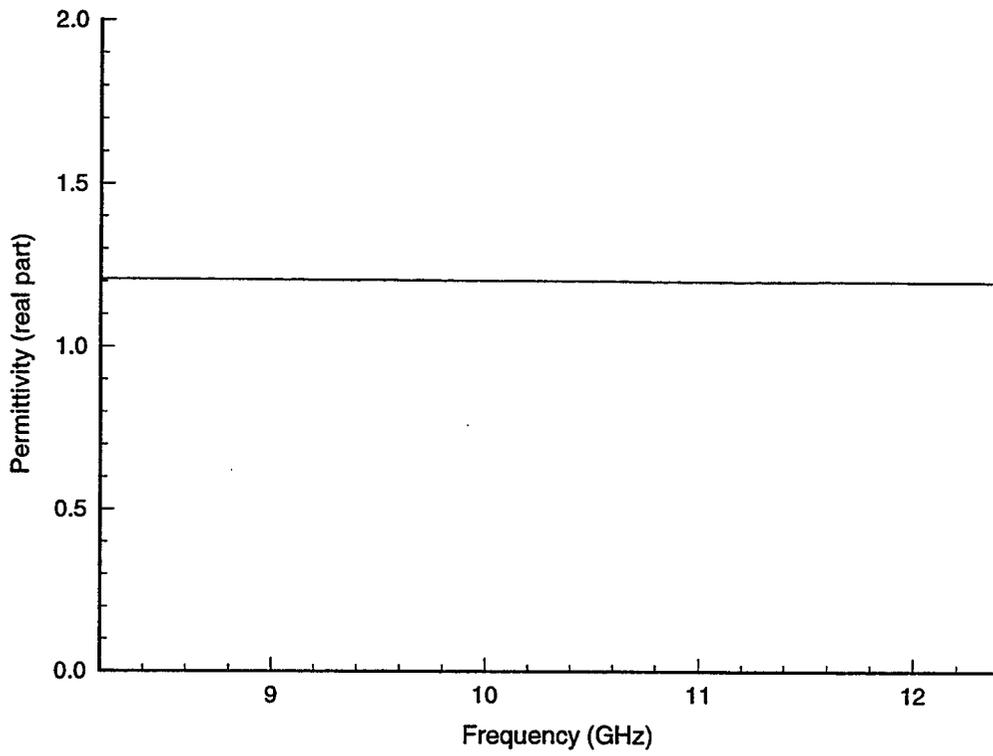
Figure 13. Waveguide Measurement Test Setup

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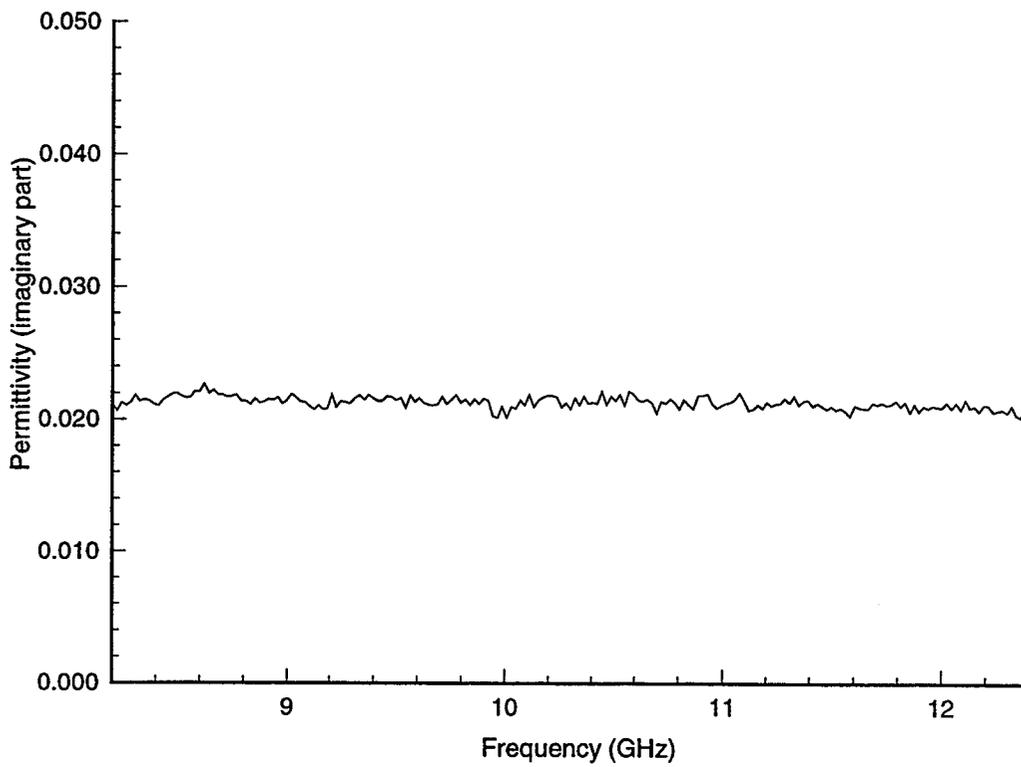
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**Figure 14.** Real part of permittivity of foam from interior of radome material panel



**Figure 15.** Imaginary part of permittivity of foam from interior of radome material panel