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W-band Free Space Permittivity Measurement Setup for Candidate Radome Materials

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Introduction

A system to characterize the permittivity of candidate radome materials for the passive millimeter wave (PMMW) camera experiment was developed in support of the NASA LaRC Electromagnetics Research Branch (ERB). The PMMW camera is a new technology sensor, with goals of all-weather landings of civilian and military aircraft. The sensor is being developed under a NASA Technology Reinvestment Program (TRP) with TRW, McDonnell-Douglas, Honeywell, and Composite Optics, Inc as participants. The camera operates at W-band, in a radiometric capacity and generates an image of the viewable field. Because the camera is a radiometer, the system is very sensitive to losses. The transmission loss through the radome at the operating frequencies, 84 GHz - 94 GHz, was of particular interest to the camera developers. As a goal, the PMMW camera designers assigned a transmission loss figure of 1.0 dB through the radome to be used during the flight test. A test of the NASA LaRC B-757 radome, at the PMMW camera operating frequencies, generated transmission losses between 7.0 and 8.0 dB, well above the tolerable loss for this new sensor. Development and characterization of low-loss composite materials, at W-band frequencies, became crucial to the successful development and flight testing of the PMMW Camera.

System Design

Because of the severe time constraint associated with this task, a robust, precision system which had been under design was temporarily tabled in favor of a system that could be put together quickly, for little cost, with reasonable accuracy. The accuracy requested by the radome designers was 10% in ϵ' , with no particular preference provided for ϵ'' .

A free-space technique was used for its obvious advantages over waveguide techniques at W-band frequencies. In addition, all of the pieces necessary to build this "short-term" solution were already branch resources except for the sample holder. The measurement system was centered around the HP 85106 mmW Measurement System, W-band external mixers for the same, and Millitech Gaussian optics lens antennas. The antennas used were standard, off-the-shelf, WR-10 fed, conical horns with 3 inch diameter lenses with infinite focal lengths. A table which had been fabricated previously for the W-band transmission loss measurements on the NASA

LaRC B-757 radome was used to support the antennas, waveguide and mixers. A simple sample holder was then designed and fabricated on-site at NASA LaRC to complete all the components necessary for this system.

A picture of the complete system set-up is shown in figure 1. The antennas were separated by a distance of approximately 40 inches. This would allow the sample to be illuminated by a column of rays with a diameter approximately the size of the 3 inch aperture of the antennas.¹ A sample size of 12 inches square was used based upon the Gaussian optics lens antenna parameters and the separation distance. A sample this size would be large enough so the edges would not be greatly illuminated and essentially all of the power radiated would propagate through the sample. A simple isolation test with a 12 inch square piece of 4 inch thick absorber provided an isolation of greater than 70 dB and verified the above assumption. Still, not having adequate hardware to verify the cross section of the beam at the sample plane, the sample holder was designed such that the edges of the sample would be overlapped by about 1/4 inch of absorber. This would reduce diffraction from the sample edges in the event they were illuminated at greater levels than assumed. The absorber plugs which were cut out and removed from each side of the sample holder were saved for use as calibration standards. After the sample holder was in place, a more rigorous isolation test was performed using the cut out plugs. This produced an isolation level of better than 78 dB, which was more than sufficient for measuring low loss materials. Sample frames were made from, General Plastics Manufacturing Co., Last-A-Foam® to support the samples during the measurement process.

System Alignment

Although there's really no substitute for precision, the lack of precision was made up for, in part, by very careful procedure. The alignment of the sample holder and boresighting of the antennas was very tedious and accomplished to our satisfaction only after several trials and several hours of work. The alignment of the sample holder to the beam was accomplished with a reflecting plate and the boresighting was accomplished by peaking the receiving signal level using a thru measurement.

System Calibration

A technique to calibrate the system was necessary for operation of the free-space measurement set-up. Other free-space systems that have been developed^{2,3} have successfully used a thru-reflect-line (TRL)⁴ method as a calibration technique. The drawback of the TRL method for our application was that the "line" calibration standard required changing the path length between the horn antennas by $\lambda/4$ at mid-band. Since several hours had been spent tweaking the boresight, and precision adjustments were not available, the desire was to not move the antennas after the system was peaked. These facts and the reality that $\lambda/4$ was on the order of 0.025 inches at the frequencies of operation led us to use a similar technique, the thru-reflect-match (TRM)^{3,4} technique. The TRM technique allowed us to not move the antennas after boresighting and utilize a "match" calibration standard in place of the "line" standard. The match standard was accomplished by inserting the absorber plugs, which had been cut out to form the sample opening, as mentioned earlier. The reflect standard was a nominally 3/8 inch thick aluminum plate with its opposite faces milled flat and parallel. This was the same plate used to align the sample holder as discussed earlier. The thru standard was simply the empty sample holder. The standards were defined to the HP 8510 based system using the internal TRL/TRM measurement model.

Operation

Once calibrated, the measurement system was operated under PC based control using the HP 85071 Material Measurements Software. Several measurement models exist within this software package. The precision and fast models were exercised and results compared. The precision model was chosen for the measurements of the candidate radome materials and coatings since it appeared to perform better for the low loss materials and provided more consistent results for the imaginary portion of the permittivity. Time domain gating was used to reduce the effect of multiple reflections between the sample faces and the transmit horns.

To verify adequate calibration and operation, samples with (relatively) known permittivities were measured. Air, a 0.062 inch thick sample of DuPont Teflon® and a sample of 0.1 inch thick acrylic sheet were measured. Results of some of these measurements are shown in figures 2(a), 2(b), 3(a), 3(b), 4(a), 4(b). Each of the figures shows data from two or

three independent measurements. The accepted value for air is 1.0006 for the real part and zero for the imaginary part, for all frequencies. The measured values shown in figures 2(a) and 2(b) are very close to these values. The values, both real and imaginary, for Teflon® are very close to those accepted for this material at much lower frequencies and are shown in figures 3(a) and 3(b). A small sample, cut from the same sheet, of acrylic was sent to Claude Weil at the National Institute of Standards and Technology. He performed permittivity measurements using a cavity resonance technique in the 60 GHz range and provided the data⁵ for comparison. His measurements indicated a real value of permittivity around 2.62 - 2.64 and an imaginary value ranging from 0.018 to 0.020. The measured values for the acrylic sample are shown in figures 4(a) and 4(b) and agree closely but are slightly higher than those provided by Weil. This could be due to the different frequency range since permittivity does change slightly with frequency or simply measurement error due to our system set up.

The candidate radome materials and coating materials were then measured. The results of these measurements are documented and discussed in reference 6. Calibrations were re-accomplished and verified on a regular basis throughout the performance of the measurements due to the observed sensitivity to temperature and surroundings.

Conclusions

A W-band free space permittivity measurement set-up was designed and constructed for little cost and was operational in just two weeks. This measurement system met the requirements put forth by the radome designers for the PMMW camera experiment. This will allow for the successful design and construction of a radome to be used for the PMMW camera flight tests later this year.

References

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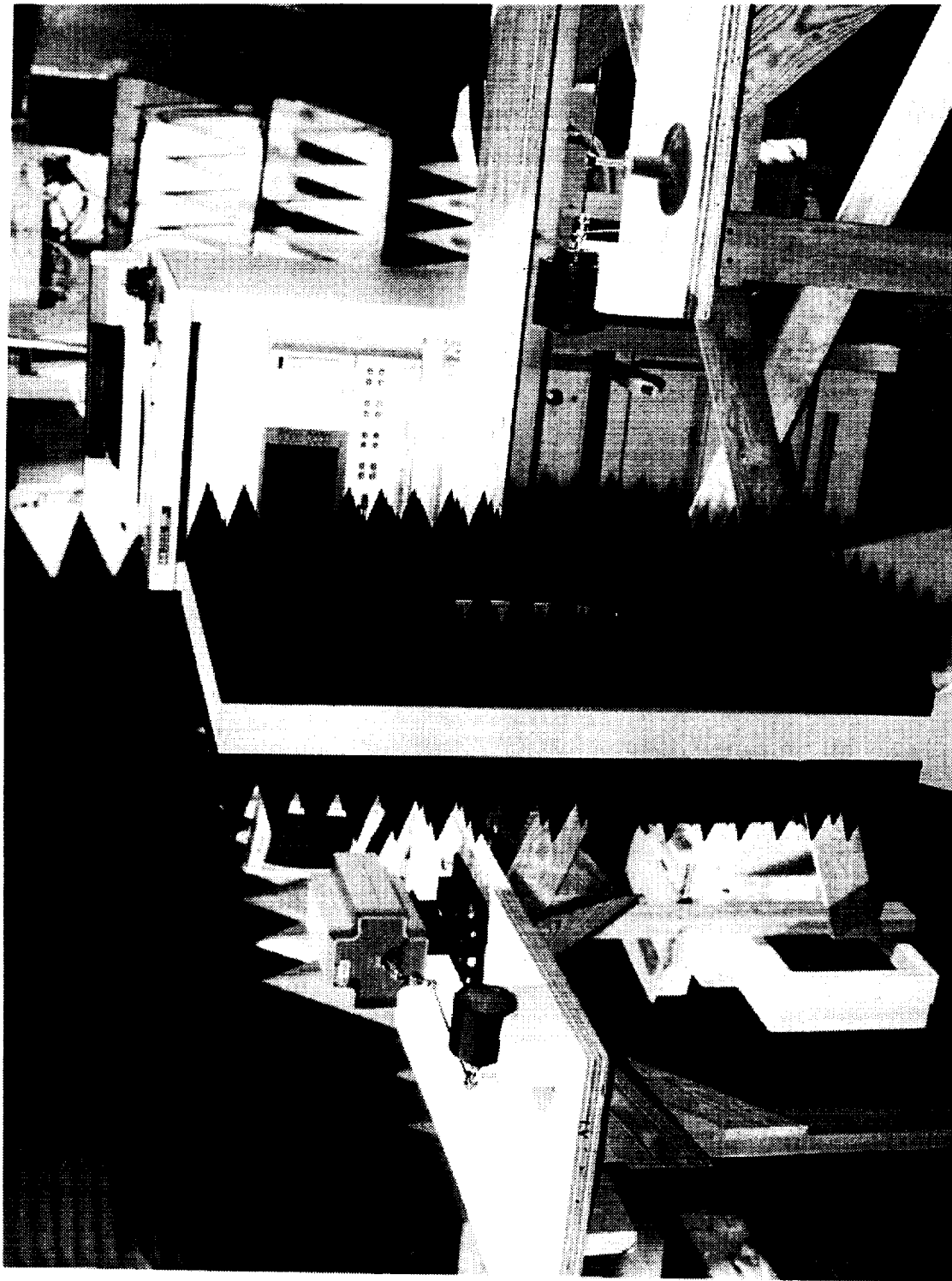


Figure 1 W-Band Free Space Measurement Set-Up

Air

Real Permittivity

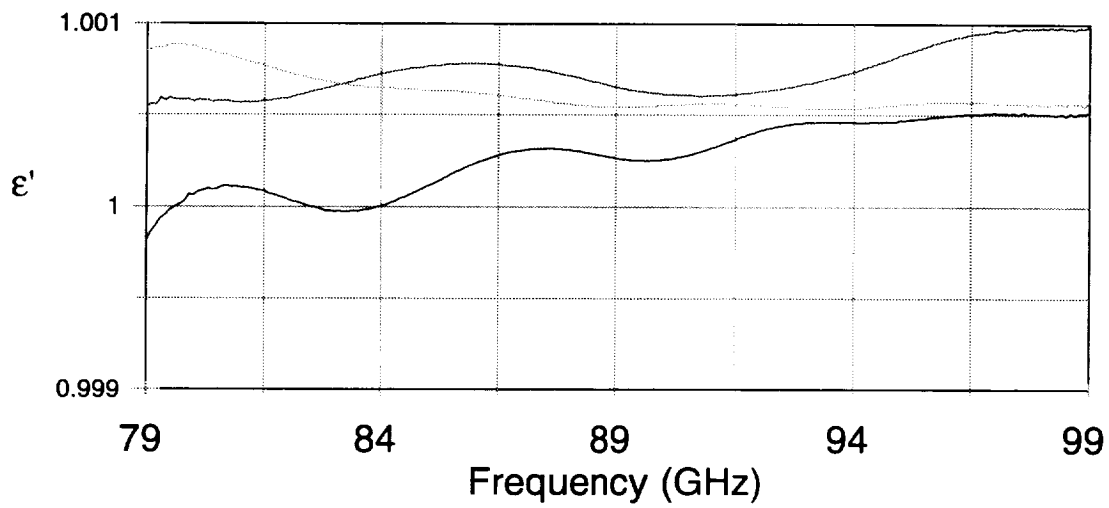


Figure 2a

Air

Imaginary Permittivity

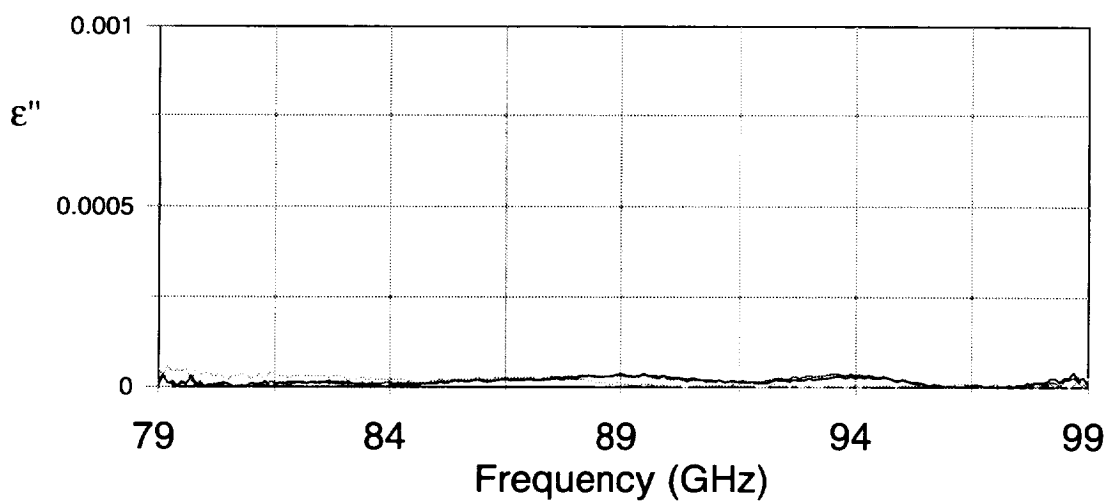


Figure 2b

Teflon®

Real Permittivity

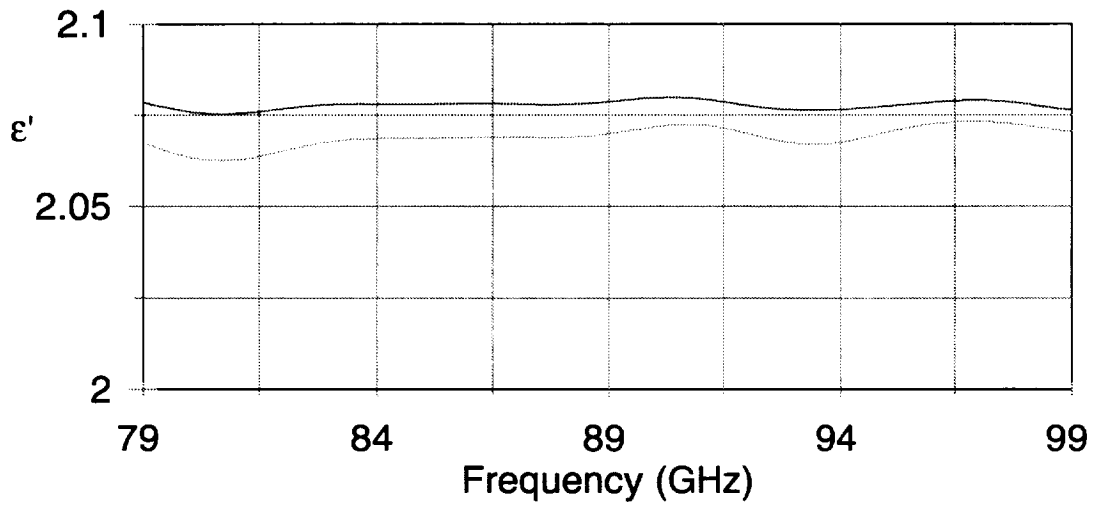


Figure 3a

Teflon®

Imaginary Permittivity

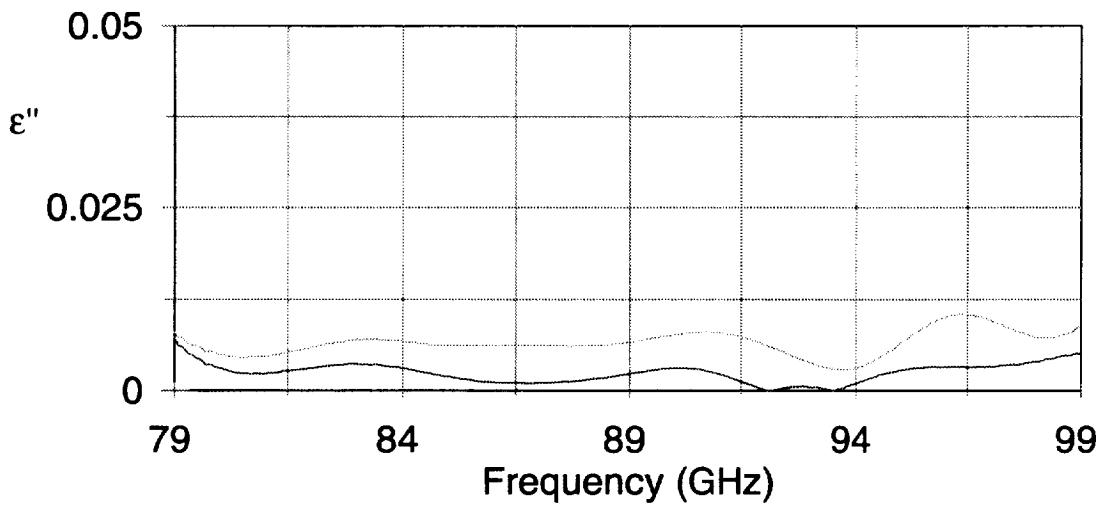


Figure 3b

Acrylic Sheet

Real Permittivity

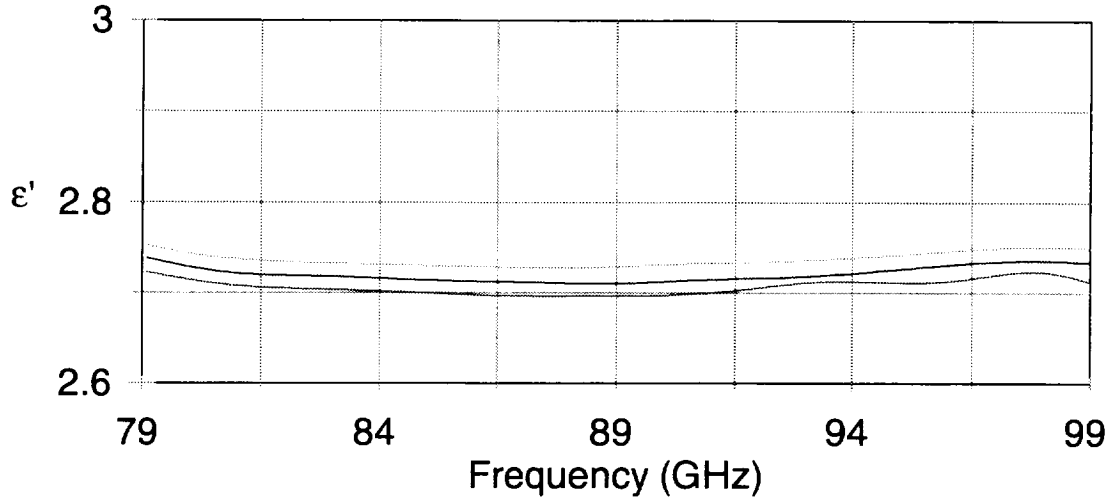


Figure 4a

Acrylic Sheet

Imaginary Permittivity

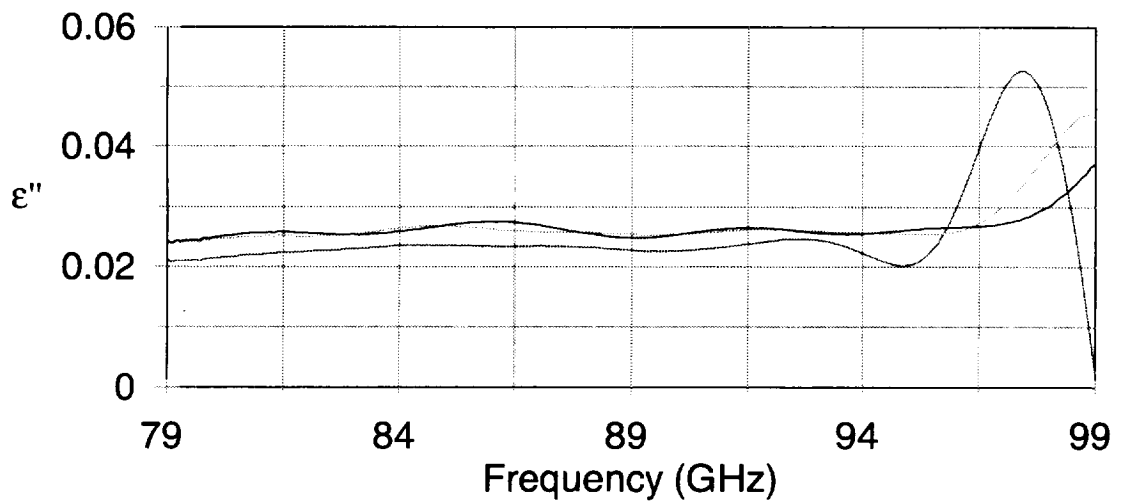


Figure 4b

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