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DEVELOPMENT OF DIELECTRIC WINDOWS FOR SPACECRAFT ANTENNAS

Third Quarterly Report Covering Period
1 January 1964 to 31 March 1964

AEROSPACE GROUP

HUGHES

HUGHES AIRCRAFT COMPANY
CULVER CITY, CALIFORNIA

DEVELOPMENT OF DIELECTRIC WINDOWS FOR SPACECRAFT ANTENNAS

by

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George C. Marshall Space Flight Center
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FOREWORD

This report was prepared by the Hughes Aircraft Company under contract number NAS 8-11026, "Development of Dielectric Windows for Spacecraft Antennas," for the George C. Marshall Space Flight Center of the National Aeronautics and Space Administration. The work was administered under the technical direction of the Propulsion and Vehicle Engineering Division, Engineering Materials Branch of the George C. Marshall Space Flight Center with Mr. E.C. McKannan acting as Project Manager.

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ABSTRACT

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Screening tests of a number of reinforced plastics have been completed with the exception of the determination of the effect of ultraviolet irradiation on the dielectric properties. Dielectric measurements conducted with the resonant cavity dielectrometer in a vacuum chamber demonstrated the practicality of making high vacuum dielectric measurements. At the same time, difficulties experienced in the vacuum stabilization of reinforced plastics dielectric specimens showed the necessity for equipment especially designed to perform high vacuum dielectric measurements.

INTRODUCTION

The principal objective of this program is the development and qualification testing of materials to be used in the fabrication of radomes for spacecraft antennas. These materials must be low in dielectric loss, strong, rigid, creep resistant, low in permeability to gases, and relatively stable to the space environment. Since no one material can be expected to be ideal in all respects, compromises will have to be made and probably materials of composite construction will be required in order to meet all of the requirements.

VACUUM CONDITIONING OF DIELECTRIC SPECIMENS

A series of reinforced plastics dielectric specimens based on DC 2106 (silicone), P680 (DAIP polyester), P631 (TAC polyester), and Imidite 1850 (reinforced in one case with E glass and in the other with J.P. Stevens quartz cloth) was stabilized under vacuum at high temperature. The specimens were stabilized over a period of 12 days at 10^{-6} torr at a temperature of 350°F. A mercury diffusion pump with a nominal capacity of 75 liters per second was used along with a liquid nitrogen trap. Relatively large quantities of water and other volatile substances were trapped during this period.

Following vacuum stabilization, both faces of each specimen were ground to ensure flatness and parallelism within 0.001 inch. All specimens were approximately one-half wavelength thick.

The dielectric constant and loss tangent of each specimen was calculated from resonant cavity measurements made at 9280 mc. The dielectric properties obtained are given in the following table:

Material	Dielectric Constant		Loss Tangent	
	Side 1	Side 2	Side 1	Side 2
DC 2106	4.27	4.27	0.0064	0.0065
P 680	4.46	4.46	0.0090	0.0091
P 631	5.06	5.08	0.0092	0.0090
Imidite 1850 (E glass)	4.65	4.65	0.0069	0.0066
Imidite 1850 (Quartz)	3.38	3.38	0.0056	0.0063

Following the measurement of the initial dielectric properties, an attempt was made to vacuum stabilize the two types of Imidite specimens in small irradiation chamber - ion pump assemblies. After several days pumping, it did not appear practical to stabilize these specimens using these small ion pumps. Pressures in the 10^{-4} torr range have been obtained after several days pumping at room temperature. The specimens cannot be heated to promote outgassing since this procedure will result in flooding the ion pumps with the attendant heating.

The difficulties being experienced indicate the need for making dielectric measurements in vacuum. This is discussed at length in the section on High Vacuum Dielectric Measurements.

HIGH VACUUM DIELECTRIC MEASUREMENTS

The Hughes X-band resonant cavity dielectrometer is designed to operate at atmospheric pressure. This is a serious disadvantage when attempting to investigate the effect of simulated space conditions (hard vacuum and solar radiation) on the dielectric properties of reinforced plastics. All of the plastics being considered in this program absorb a varying amount of moisture under ordinary atmospheric conditions. Since the effect of simulated solar radiation under hard vacuum is being investigated, it becomes necessary to vacuum stabilize the material following each dielectric measurement prior to irradiation. Making dielectric measurements at atmospheric pressure also introduces an unknown variable into the test results, that is the effect of absorbed moisture on the dielectric properties.

The foregoing considerations prompted the investigation of the practicability of operating a resonant cavity type dielectrometer under conditions of hard vacuum. Dielectric measurements were made at atmospheric pressure and under hard vacuum on two standard ceramic dielectric specimens, fused silica and pyroceram. Plastics specimens were not measured to avoid possible contamination of the vacuum chamber.

Figure 1 gives a block diagram of the equipment used in making the measurements. In Figure 2, the vacuum chamber is open to show the resonant cavity. In Figure 3, the vacuum chamber is shown closed and ready for measurement. The micrometer drum was rotated by means of shaft extending through a hermetic rotating seal mounted in the wall of the vacuum chamber and connected to a right angle drive mechanism. A small periscope was mounted in the vacuum chamber to enable reading the micrometer through the vacuum chamber viewing port.

All measurements were made at a frequency of 9280 ± 1 mc. The cavity temperature was monitored by means of a thermocouple. All measurements were made in the temperature range of 72.5^{o} to 75.5^{o}F.

The results of a total of 38 measurements, 17 on the pyroceram and 21 on the fused silica, showed no significant difference in the calculated values of the dielectric properties. The table which follows

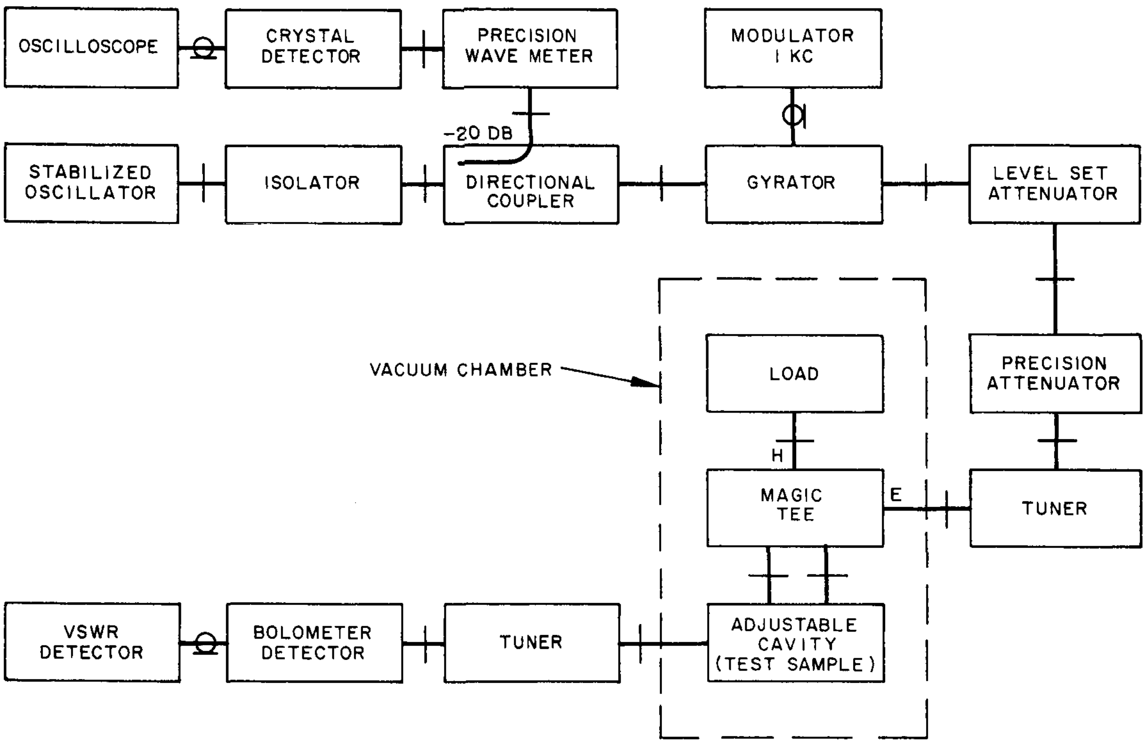

Figure 1. Block diagram for measuring dielectric constant and loss tangent.

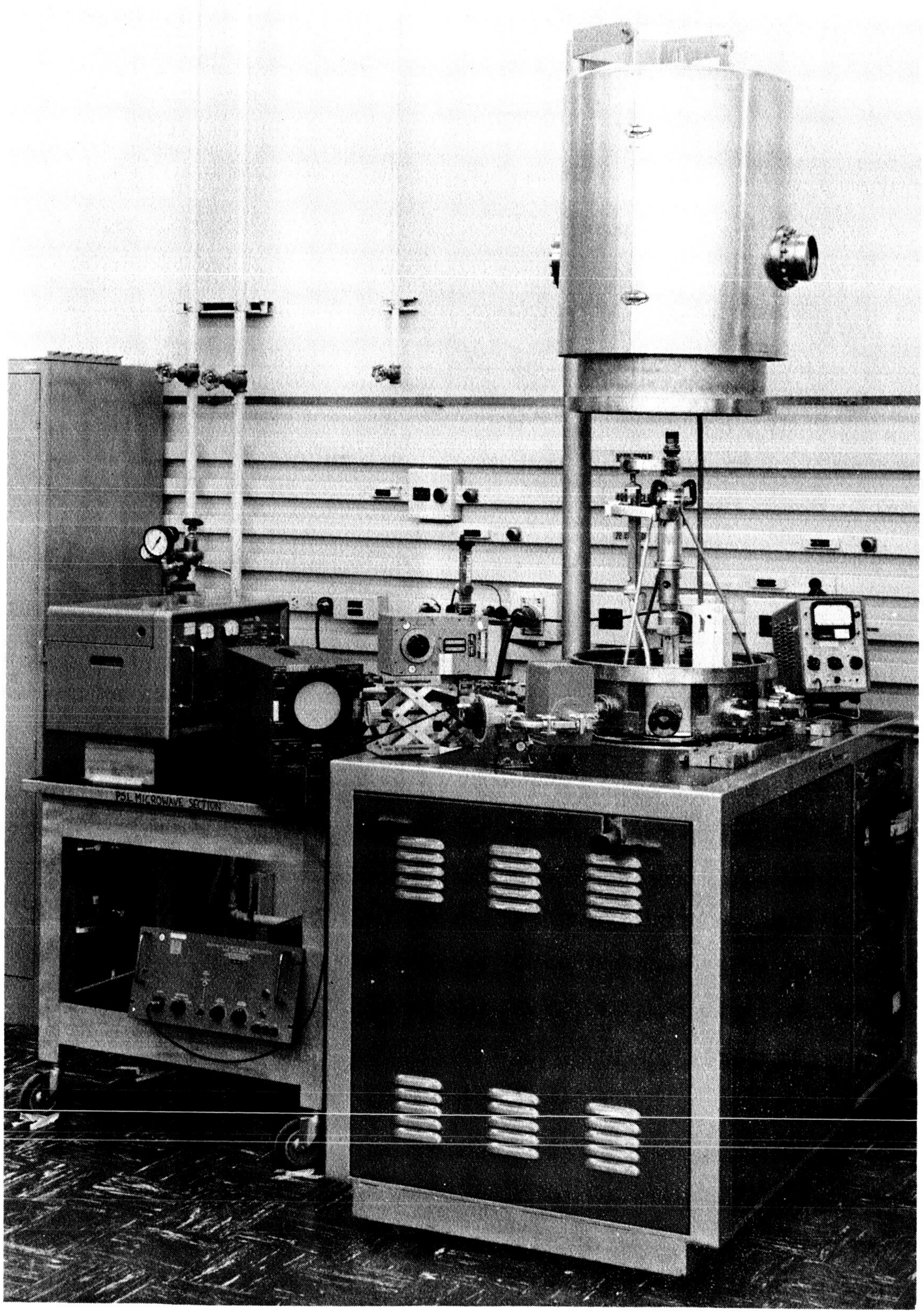

Figure 2. High vacuum dielectrometer – chamber open.

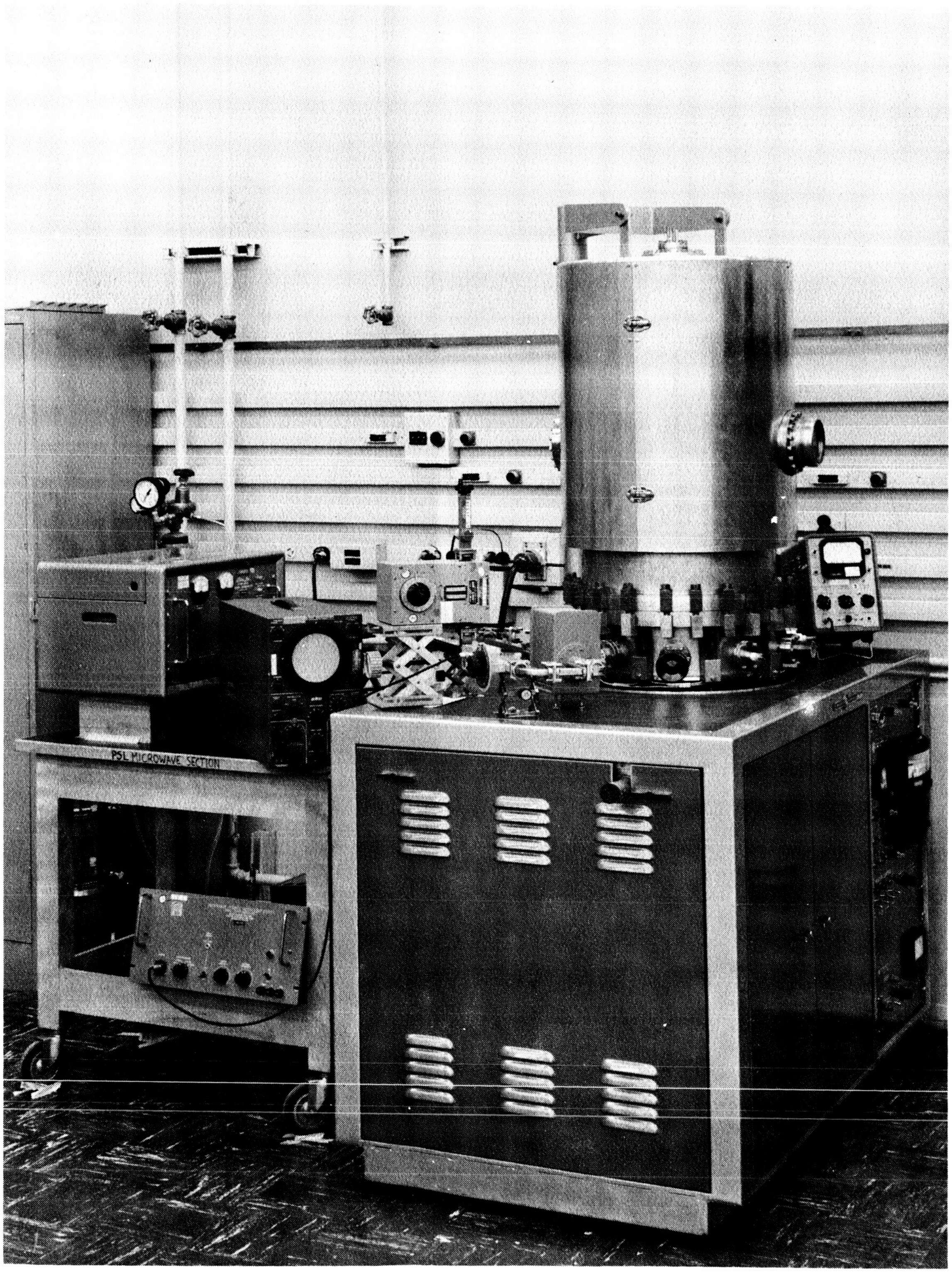

Figure 3. High vacuum dielectrometer – chamber closed.

given the average values of dielectric constant and loss tangent for the two specimens for each pressure (the complete results recorded in the order corresponding to that in which the original measurements were made are tabulated in the Appendix).

Specimen Type	Pressure, Torr	Dielectric Constant	Loss Tangent, x 10^4
Pyroceram	760	5.7442	4.44
	10^{-8}	5.7451	4.50
Fused Silica	760	3.8296	1.48
	10^{-8}	3.8298	1.62

It may be concluded from the foregoing results that the operation of a resonant cavity-type dielectrometer in a hard vacuum is practical. However, the use of a conventional resonant cavity in a vacuum chamber would still require transfer of the specimens from the cavity to the radiation cell with the attendant absorption of moisture. A good solution would be the fabrication of a high vacuum resonant cavity with provisions for irradiation of the specimen while in position in the cavity. Dielectric measurements could be made before, during and after exposure to ultraviolet. The dielectrometer could be designed to allow exposure of the dielectric specimen to various types of particle radiation.

EFFECT OF LOW LOSS REINFORCEMENT ON DIELECTRIC PROPERTIES OF PLASTIC LAMINATES

The dielectric constant and loss tangent at 9280 mc were determined for DC 2106 laminates reinforced with S (994) glass cloth and D (556) glass cloth. The results were compared with those obtained previously for DC 2106 laminates reinforced with E glass cloth and quartz cloth (General Electric). The following table gives the dielectric properties for each type of DC 2106 laminate.

Type of Reinforcement	Dielectric Constant	Loss Tangent
E glass	4.27	0.0065
Quartz cloth	3.30	0.0035
D (556) glass	3.39	0.002
S (994) glass	3.74	0.0085

The dielectric properties were also calculated from measurements made at 9280 mc on specimens prepared from Imidite laminates, one containing 181 E glass cloth and the other containing style 581 quartz cloth supplied by J. P. Stevens. Surprisingly, the loss tangent of the quartz-reinforced Imidite was only slightly lower than that of the E glass-reinforced Imidite (0.0059 versus 0.0067). The dielectric constant of the quartz laminate was much lower than that of the E glass laminate (3.38 versus 4.65), as was expected. Both laminates contained nominally 20 weight percent resin.

POLYIMIDE RESIN

The screening evaluation of PI-2101, a polyimide resin supplied by DuPont, is in progress. A series of laminates was made and test specimens were machined for the determination of dielectric properties, gas transmission, vacuum stability and ultraviolet resistance.

Several discs, nominally 1/8 inch thick by 7/8 inch in diameter were stabilized under hard vacuum at a temperature of 350°F. The total weight loss (0.63%) under vacuum occurred at a pressure of 5×10^{-6} torr at room temperature. No further weight loss took place upon heating to 350°F while pumping down to 1×10^{-8} torr.

The solar absorptance and infrared emittance of laminated PI-2101 were determined prior to ultraviolet irradiation and found to be 0.75 and 0.87 respectively. Irradiation at 5 times solar intensity for 1000 solar equivalent hours reduced the solar absorptance from 0.75 to 0.72, possibly due to a bleaching effect.

An attempt was made to determine the air transmission rate for a PI-2101 laminate in the as-molded condition and after being post-cured. Both test specimens leaked too rapidly to allow an accurate determination of the leak rate to be made. An estimate of the percentage of voids in the resin matrix was calculated from the density and composition of the laminate and found to be about 50 volume percent. Optimization of processing conditions will undoubtedly reduce the degree of porosity.

CERAMICS EVALUATION

Three commercial ceramics from American Lava Corporation, AlSiMag 243 (forsterite), AlSiMag 748 (98% alumina) and AlSiMag 753 (99.5% alumina) were tested for stability to ultraviolet. Discs of these materials 1/8 inch thick and 7/8 inch in diameter were exposed to 5 times solar radiation for periods up to 1000 solar equivalent hours and the effect on the solar absorptance determined. Since a different specimen was taken for each exposure time, a "before" and "after" value of solar absorptance is given for each exposure time for each material. The solar absorptance measurements were made in a Gier-Dunkel reflectometer integrating sphere over the wavelength range from 0.3 to 2.7 microns in 10% incremental steps following the Johnson curve. The reflectance standard used was magnesium oxide.

During the ultraviolet exposure, the forsterite yellowed slightly, while both types of alumina turned lemon yellow. The solar absorptance of the forsterite was virtually unaffected by the ultraviolet exposure. The relatively pure alumina (AlSiMag 753) was affected more than the AlSiMag 748. The complete results are tabulated in the following table.

Effect of ultraviolet on solar absorptance of ceramics.

	Solar Absorptance					
	10 S.E.H.		100 S.E.H.		1000 S.E.H.	
	Before	After	Before	After	Before	After
AlSiMag 243 (forsterite)	0.47	0.46	0.46	0.47	0.46	0.47
AlSiMag 753 (99.5% Al_2O_3)	0.20	0.32	0.17	0.30	0.18	0.33
AlSiMag 748 (98% Al_2O_3)	0.19	0.27	0.18	0.25	0.16	0.25

Specimen Type	Temperature, °F	Pressure, Torr	Dielectric Constant	Loss Tangent x 10^{-4}
Pyroceram	73.0	760	5.7450	5.13
	73.5	8×10^{-9}	5.7421	4.14
	73.5	8×10^{-9}	5.7421	4.14
	73.5	8×10^{-9}	5.7480	3.81
	73.5	8×10^{-9}	5.7429	5.44
	73.5	760	5.7433	3.51
	73.5	760	5.7438	5.13
	74.0	9×10^{-9}	5.7460	4.47
	74.0	760	5.7440	3.51
	74.0	760	5.7444	4.16
	74.0	760	5.7460	5.45
	74.0	760	5.7434	4.48
	74.0	760	5.7435	4.16
	74.5	9×10^{-9}	5.7462	4.79
	75.0	9×10^{-9}	5.7460	4.47
	75.0	9×10^{-9}	5.7464	5.12
	75.5	9×10^{-9}	5.7458	4.14
Fused Silica	72.5	760	3.8303	1.50
	72.5	760	3.8292	1.50
	73.0	760	3.8304	1.43
	73.5	8×10^{-9}	3.8294	1.63
	73.5	8×10^{-9}	3.8295	1.63
	73.5	760	3.8286	1.51
	73.5	760	3.8286	1.51
	73.5	760	3.8297	1.50
	74.0	8×10^{-9}	3.8295	1.63
	74.0	9×10^{-9}	3.8296	1.63
	74.0	760	3.8298	1.50
	74.0	760	3.8300	1.31
	74.0	760	3.8295	1.44
	74.0	760	3.8292	1.63
	74.5	9×10^{-9}	3.8298	1.63
	74.5	9×10^{-9}	3.8297	1.63
	75.0	9×10^{-9}	3.8298	1.63
	75.0	9×10^{-9}	3.8298	1.63
	75.0	9×10^{-9}	3.8300	1.50
	75.0	9×10^{-9}	3.8302	1.63
	75.5	9×10^{-9}	3.8302	1.63

Calculated dielectric properties of dielectric standards measured under atmospheric pressure and hard vacuum.