AFML-TR-74-250
Part II

DIELECTRIC CONSTANT AND LOSS DATA
Part II

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

DECEMBER 1975

TECHNICAL REPORT AFML-TR-74-250, Part II
INTERIM REPORT FOR PERIOD FEBRUARY 1972 - JANUARY 1975

AIR FORCE MATERIALS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
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JOHN C. OLSON
Project Engineer

FOR THE COMMANDER

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The main body of this report lists dielectric constant and loss data on materials measured in this laboratory in the period 1 Feb 72 through Dec 1974. The main sections are inorganic (arranged in order of chemical name), miscellaneous inorganic, and organic (arranged according to manufacturer or supplier).

The index following the data section is intended to be a complete reference to Vols. IV, V, and VI of the Tables of Dielectric Materials, the 1972 data report (labelled P.R.) and subsequent data (labelled 8).

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PREFACE

The dielectric constant and loss data presented in this report were measured at the Laboratory for Insulation Research of the Massachusetts Institute of Technology, Cambridge, Massachusetts, by W. B. Westphal. This work was performed between 1 Feb 1972 and 30 Dec 1974 under Contract F33615-71-C-1274, Project No. 7371, Task No. 737101, and Contract F33615-75-C-5020, Project No. 7371, Task No. 73710126, for the Air Force Materials Laboratory.

This report was submitted by the author for publication in September 1975.

The work was administered under direction of the AF Materials Laboratory, with Mr. D. J. Evans (AFML/PLJ) acting as project engineer.

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

TABLE OF CONTENTS (cont.)

I. INORGANIC COMPOUNDS

Aluminum oxides

Coors 96% Al_2O_3 ceramic — Coors

T^oC	$1000/T^oK$	Resistivity ρ (ohm-cm)
500	1.29	6.6×10^{8}
400	1.49	2.0×10^{10}
322	1.75	6.0×10^{11}
226	2.00	3.8×10^{13}
158	2.32	8×10^{14}
84	2.80	3×10^{16}
66.5	2.95	2×10^{17}
25	3.36	1.5×10^{18}*

*Extrapolated value, not measured.

Duramic HT-960, 96% Al_2O_3 ceramic — Duramic Products, Inc.

T^oC	Hz	10^2	10^3	10^4	10^5	10^6	10^7	10^9	$3x10^9$
25	κ'	9.33	9.33	9.32	9.32	9.32	9.31	9.29	9.28
	κ"	.00393	.00293	.00182	.00191	.00182	.00233	.00668	.00526
	10^4 tan δ	4.2	3.1	1.95	2.05	1.95	2.5	7.1	5.6
	σ	2.18-13	1.63-12	1.01-11	1.06-10	1.01-9	1.23-8	3.71-6	8.75-6
100	κ'	9.43	9.43	9.42	9.41	9.41	9.40	9.37	
	κ"	.0113	.0065	.0044	.0036	.00272	.00243	.0073	
	10^4 tan δ	11.9	6.9	4.7	3.83	2.9	2.6	7.8	
	σ	6.25-13	3.6-12	2.46-11	2.0-10	1.51-9	1.28-8	4.05-6	
200	κ'	9.59	9.57	9.55	9.55	9.54	9.54	9.50	
	κ"	.0738	.0294	.0102	.0085	.0056	.0040	.0089	
	10^4 tan δ	76.9	30.8	10.7	8.96	5.9	4.2	9.4	
	σ	4.09-12	1.63-11	5.67-11	4.75-10	3.12-9	2.12-8	4.93-6	
300	κ'	10.42	9.95	9.79	9.72	9.69	9.68	9.63	
	κ"	.917	.246	.0759	.0263	.0147	.0103	.0112	
	tan δ	.088	.0247	.00775	.00271	.00152	.00106	.00116	
	σ	5.09-11	1.36-10	4.21-10	1.46-9	8.18-9	5.41-8	6.2-6	
400	κ'	13.26	10.79	10.12	9.96	9.87	9.85	9.79	
	κ"	5.45	1.32	.324	.0972	.0395	.0197	.0137	
	tan δ	.411	.1224	.0321	.00977	.0040	.0020	.00140	
	σ	3.03-10	7.34-10	1.8-9	5.4-9	2.19-8	1.04-7	7.6-6	
500	κ'	21.0	13.96	11.05	10.31	10.11	10.04	9.95	
	κ"	42.4	6.83	1.59	.387	.107	.038	.0172	
	tan δ	2.015	.489	.144	.0375	.0106	.0038	.00173	
	σ	2.35-9	3.73-9	8.85-9	2.14-8	5.95-8	2.-7	9.55-6	

Aluminum oxides

Foam — Supplied by Rockwell International Corp.

T°F		300 MHz	1 GHz	3 GHz	8.52 GHz	14 GHz
-300	κ	1.1171	1.11760	1.11560	1.11370	1.11150
	tan δ	.00015	.00015	.00015	.00007	.000005
-170	κ	1.1165	1.11680	1.11550	1.11320	1.11180
	tan δ	.00012	.00013	.00012	.00011	.00001
74	κ	1.11160	1.11630	1.11550	1.1160	1.11330
	tan δ	.00011	.00008	.00009	.00008	.000038
400	κ	1.1179	1.1180	1.11550	1.11550	1.11410
	tan δ	.00015	.00050	.00035	.00017	.0000015

Mullite, hot-pressed, at 8.52 GHz — Air Force Materials Laboratory

	T°C	κ	tan δ
Dried in vacuum oven at 150°C	25	6.38	.00061
In equilibrium, room humidity	25	6.387	.0021
	98	6.37	.0029
	206	6.39	.0037
	313	6.37	.0052
	451	6.37	.0091
	575	6.41	.0103
	607	6.42	.0101
	746	6.43	.0095
	373	6.38	.0065
	28	6.38	.0020

Alumina cements

At 300 MHz, 25°C

Sample No.	κ	$\tan\delta$	Density (g/cm^3)
1	6.31	.0089	2.707
2	6.19	.0109	2.608
3	6.14	.0110	2.566
25	6.02	.0116	2.453

Green Refractories Co.

Sample No.	κ	$\tan\delta$	Density (g/cm^3)
26	6.24	.0113	2.567
27	6.42	.0119	2.629
28	6.35	.0108	2.622
29	6.58	.0096	2.736

Castolast G at 300 MHz, 25°C

Sample No.	κ	$\tan\delta$	Density (g/cm^3)
R-1	6.87	.0080	2.691
R-2	6.75	.0103	2.682
R-3	6.66	.0096	2.665
I-1	6.83	.0070	2.678

Harbison-Walker Refractories

	κ	$\tan\delta$	Density (g/cm^3)
I-2	6.79	.0073	2.689
I-3	6.75	.0075	2.674
I-4	6.59	.0073	2.664
I-5	6.79	.0077	2.663

Alumina cements, at 300 MHz

Kaiser Refractories

Sample No.	Drying T°F	κ	$\tan\delta$	Density (g/cm^3)
3-8	260	7.07	.0073	2.819
4-7	400	6.27	.0063	2.734
5-7	600	6.25	.0062	2.719
6-6	800	5.95	.0050	2.644
20-1	600	5.78	.0096	2.584
11-1	600	6.22	.0072	2.742
19-5	600	5.97	.0072	2.666

Beryllium oxide plus silicon-nitride ceramic

National Beryllia Corp.

Niberlox, at 8.5 GHz, 25°C

		κ	tan δ	κ	tan δ	κ	tan δ
No. 5	Face 1	7.23	.00124	7.18	.00115		
	2	7.24	.00120	7.18	.00116		
	Average					7.20	.0012
No. 20	Face 1	7.37	.00162	7.32	.00115		
	2	7.36	.00170	7.32	.00114		
	Average					7.34	.0014
No. 100	Face 1	7.94	.00339	7.77	.00355		
	2	7.93	.00170	7.82	.00284		
	Average					7.88	.0030

Niberlox 5, at 8.5 GHz

T°C	κ	tan δ
25	7.29	.00115
132	7.40	.0011
207	7.46	.0011
314	7.56	.0012
494	7.72	.0014
588	7.80	.0015
704	7.91	.0024
781	8.00	.0035
900	8.08	.0046
1002	8.19	.0060

Boron nitride, hot-pressed, with BN fibers, at 8.5 GHz

Carborundum

Sample Pc	T°C		
1	25	3.331	.00015 ± .00006
1, reversed	↓	3.314	.00014 ↓
2	↓	3.323	.00006 ↓
2, reversed	↓	3.330	.00008 ↓
1 + 2 stacked	↓	3.330	.000115 ± .00002
1 + 2 reversed	↓	3.321	.000125 ↓
1 + 2	100	3.33*	.000111 ± .00005
	201	↓	.000107 ↓
	300	↓	.00015 ↓
	373	↓	.00018 ↓
	421	↓	.00017 ↓
	501	↓	.00019 ↓
	600	↓	.00021 ↓
	711	↓	.00024 ↓
	800	↓	.00038 ↓
	31	↓	.00009 ↓

*Limit of error -.01, + 0.5.

Yarn and matrix, Sample BN-3DX-V, at 8.5 GHz

Philco-Ford

		κ	tan δ
25°C, as received,	Face 1	2.862	.00293
	Face 2	2.897	.00334
vacuum dried,	Face 1	2.871	.00012
	Face 2	2.898	.00015

Face 2

T°C	κ	tan δ
25	2.88	.00015
200	2.89	.00011
400	2.88	.00020
600	2.87	.00006
800	2.87	.00011
1000	2.89	.00072
80	2.88	.00007

Cadmium telluride

IRTRAN 6, at 8.52 GHz, 24°C — Eastman Kodak

κ	tan δ	σ [ohm-cm]$^{-1}$
10.45 ± .03	.024 ± .004	1.18 x 10^{-3}

Ferrites — Emerson & Cuming, Inc.

E&C Samples A & B

Sample A

Frequency, MHz	μ'/μ_o	μ''/μ_o	$\varepsilon'/\varepsilon_o$	$\varepsilon''/\varepsilon_o$
1			13.8	.482
18	49.7	44	13.2	.231
55	16.8	30.2	-	-
80	12.8	22.7	-	-
189	12.24	36.6	-	-
300	3.17	26.0	13.01	.195
350	2.93	22.37	-	-
510	1.246	10.17	-	-
580	.905	9.02	-	-
650	.813	8.55	-	-
1000	- .234	7.67	12.34	-

Sample B

Frequency, MHz	μ'/μ_o	μ''/μ_o	$\varepsilon'/\varepsilon_o$	$\varepsilon''/\varepsilon_o$
1	-	-	13.3	.427
18	51.	78.	13.2	.171
55	12.0	32	-	-
80	-	-	-	-
189	-	-	-	-
300	2.39	23.2	13.36	.116
350	-	-	-	-
510	-	-	-	-
580	-	-	-	-
650	.800	8.16	-	-
1000	- .336	7.64	13.28	<.02

Magnesium fluoride, hot-pressed Eastman Kodak

IRTRAN 1

T°C	Hz	10^2	10^3	10^4	10^5	10^6	10^7	$4x10^9$	$8.5x10^9$
25	κ'	5.31	5.31	5.31	5.31	5.30	5.30	5.28	[illegible]
	10^4 κ"	4.8	4.5	3.2	2.0	2.5	2.6	8.5	12.1
	10^4 tan δ	.89	.84	.6	.38	.47	.5	1.6	2.3
	σ	2.7E-14	2.5E-13	1.6E-12	1.1E-11	1.4E-10	1.4E-9	2.E-6	5.4E-6
100	κ'	5.40	5.38	5.36	5.34	5.33	5.33	5.35	
	10^4 κ"	6.05	8.89	7.86	4.89	4.3	4.8	9.1	
	10^4 tan δ	1.12	1.65	1.46	.92	.8	.9	1.7	
		3.3E-14	4.9E-13	4.4E-12	2.7E-11	2.4E-10	2.7E-9	2.1E-6	
200	κ'	5.52	5.45	5.45	5.44	5.44	5.43	5.47	
	10^4 κ"	30.8	17.4	14.3	9.76	6.73	6.0	10.9	
	10^4 tan δ	5.57	3.19	2.62	1.80	1.22	1.1	2.0	
	σ	1.7E-13	9.6E-13	7.9E-12	5.4E-11	3.7E-10	3.3E-9	2.6E-6	
300	κ'	5.69	5.65	5.65	5.63	5.63	5.61	5.59	
	10^4 κ"	293	107	46.7	23.3	12.6	9.0	15.7	
	10^4 tan δ	51.8	18.9	8.26	4.14	2.23	1.6	2.8	
	σ	1.6E-12	6.E-12	2.6E-11	1.3E-10	7.E-10	5.E-9	3.7E-6	
400	κ'	5.85	5.79	5.77	5.76	5.75	5.74	5.72	
	κ"	.149	.034	.0114	.00536	.00276	.00172	22.9	
	10^4 tan δ	254	58.8	19.7	9.31	4.80	3.0	4.0	
	σ	8.3E-12	1.9E-11	6.3E-11	3.E-10	1.5E-9	9.5E-9	5.4E-6	
500	κ'	7.06	6.21	5.99	5.95	5.93	5.91	5.87	
	κ"	10.86	1.29	.202	.0337	.0105	.0067	.0031	
	tan δ	1.538	.209	.0339	.00566	.00177	.00113	.00051	
	σ	6.E-10	7.2E-10	1.1E-9	1.9E-9	5.9E-9	3.7E-8	7.3E-6	
532	κ'							5.91	
	10^4 κ"							34.3	
	10^4 tan δ							5.8	
	σ							8.1E-6	
27	κ'	5.325	5.32	5.32	5.32	5.31	5.31		
	10^4 κ"	17.8	12.9	9.53	7.97	7.31	6.9		
	10^4 tan δ	3.35	2.42	1.79	1.50	1.38	1.3		
	σ	9.9E-14	7.2E-13	5.3E-12	4.4E-11	4.1E-10	3.8E-9		

Magnesium fluoride, hot-pressed

IRTRAN 1 (cont.)

Comparison of 4 samples at 8.5 GHz, 25°C

		κ'	$10^4 \tan\delta$
Sample 1	Face 1 up	5.276	2.3
	Face 2 up	5.275	2.2
Sample 2	Face 1 up	5.276	2.2
	Face 2 up	5.273	2.0
Sample 3	Face 1 up	5.272	2.4
	Face 2 up	5.274	2.0
Sample 4	Face 1 up	5.283	1.9
	Face 2 up	5.285	2.1

The upward face receives incident energy. Sample was reversed and rotated 90° for second measurement.

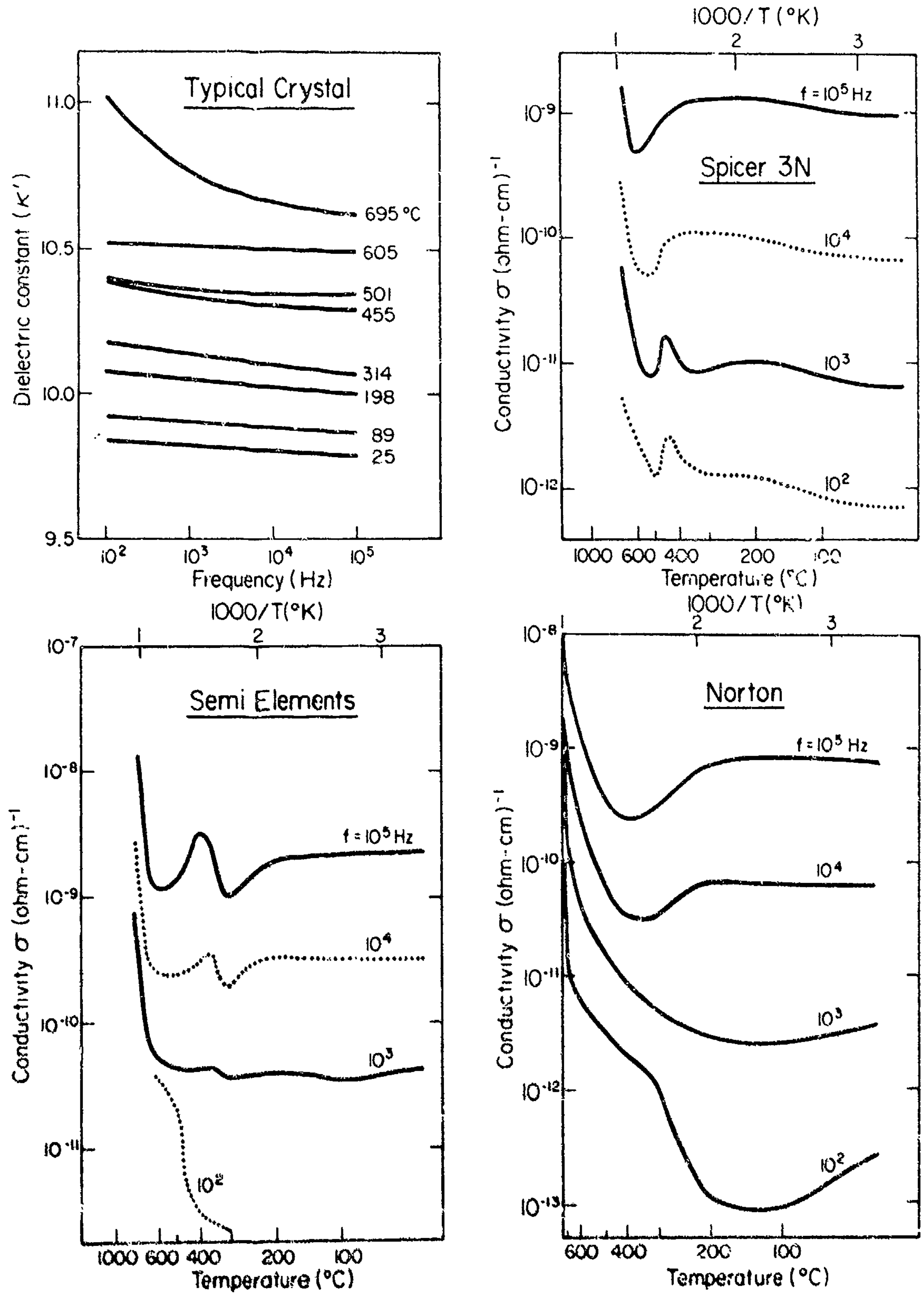
Measured density of sample 1 at 25°C: 3.171 g/cm^3.

Magnesium oxide crystals — Department of Metallurgy, Ceramics Laboratory, MIT

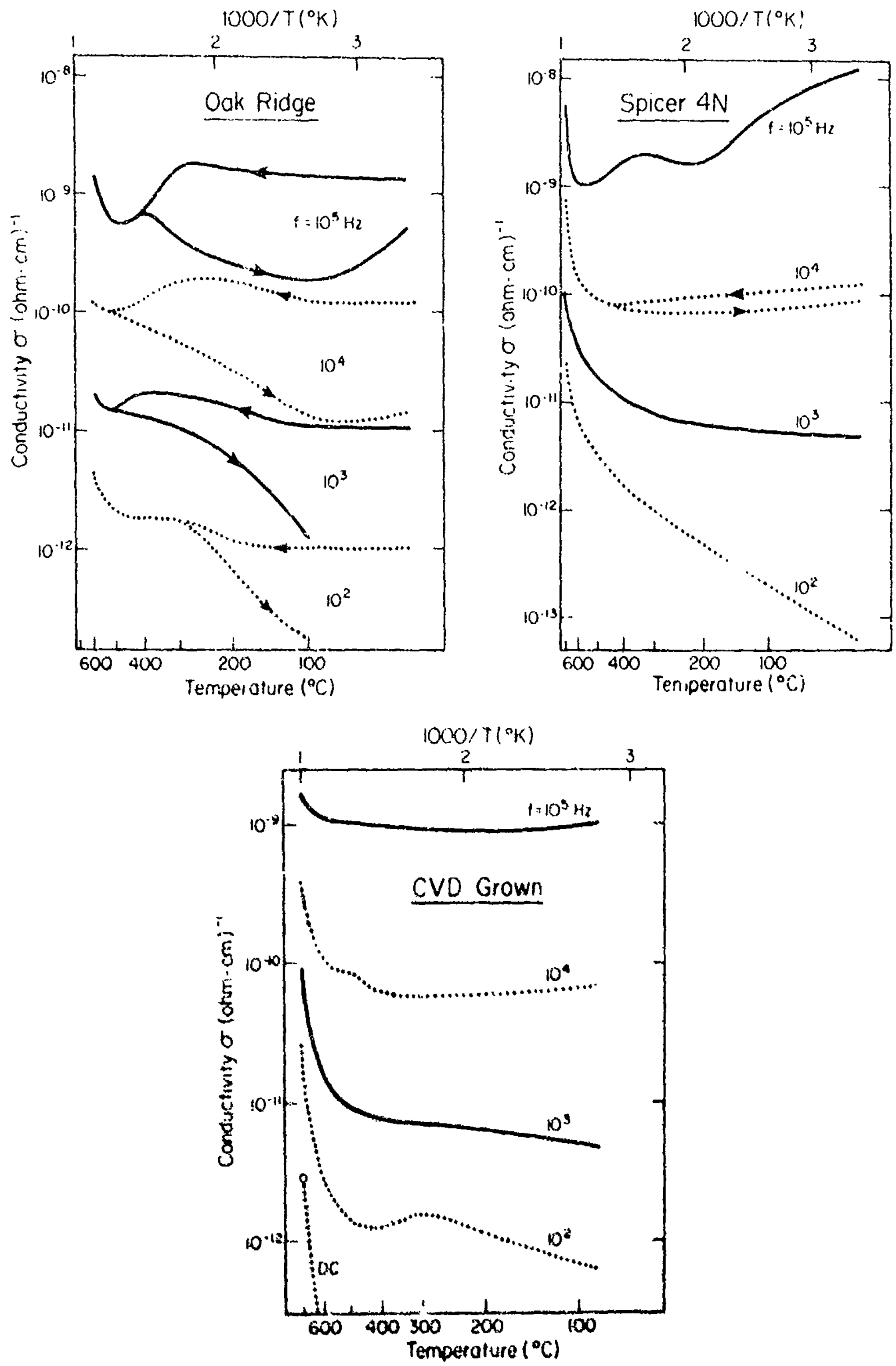
Chemical analysis of single crystals

	Spicer 3-N	Semi-elements	Norton	Oak Ridge	Spicer 4-N	CVD
Al	70 ppm	10 ppm	10 ppm	10 ppm	10 ppm	100 ppm
Ca	100	50	50	5	5	1
Cr	-	-	10	-	-	10
Cu	5	10	10	5	10	10
Fe	20	50	50	10	50	10
Mn	10	10	5	10	-	-
Si	50	50	10	50	5	10
Zr	-	-	-	-	-	-
Total	305	180	145	90	80	140

Magnesium oxide crystals



Magnesium oxide crystals (cont.)



Cr-doped magnesium oxide — University of Colorado

Comparison of pure and Cr-doped magnesium oxide crystals

Dielectric constant (κ)

Sample	Freq.,Hz 100	1 M
Pure	10.13	10.16 ± .15
.068% Cr	-	9.95 ± .2
.3% Cr	10.10	10.07 ± .3

	L	W	T
Pure	1.045	.463	.222-.223
.068% Cr	.8818	.554-.563	.260-.281
.3% Cr	.980	.425-.458	.234

Note: Measurements limited in accuracy by irregular dimensions of samples.

Magnesium oxide — Eastman Kodak

IRTRAN 5, transparent ceramic

Density: 3.57 g/cm^3

At 25°C

Freq., Hz	κ	tan δ
10^2	9.82	.0014
8.5×10^9	9.72	.00045

Spinel, hot-pressed

Coors' magnesium aluminate ceramic, at 4.3 GHz — Coors

$T^{o}F$	κ_{meas}	tan δ
2	8.101	.00012 ± .0005
34	8.119	↓
51.8	8.127	↓
61	8.135	↓
75.8	8.145 ± .01	.00012 ± .0003
96.2	8.155	↓
115.9	8.167	↓
133.2	8.179	↓
149.7	8.191	↓
184	8.217	↓
200.2	8.229	.00012 ± .0005

At $76^{o}F$ $\Delta\kappa/\Delta T$ = $.00060^{o}F$.

Silica

Dynasil 4000, at 3 GHz — Dynasil

$T^{o}F$	κ_{meas}	tan δ
2	3.8205	.00010
33	3.8212	↓
78	3.8225 ± .005	.00010 ± .00002
104.2	3.8232	↓
124.2	3.8237	↓
130.8	3.8240	↓
157.8	3.8245	↓
169	3.8250	↓
199.8	3.8261	.00010

At $78^{o}F$ $\Delta\kappa/\Delta T$ = $.0000268^{o}F$.

<u>Note</u>: The values of κ_{meas} included thermal dimension change effect. The true dielectric constant κ_{corr} can be computed when thermal expansion linear coefficient (α) is known: $\kappa_{corr} = \kappa_{meas}/(1+2\alpha\Delta T)$.

Various experimental samples

	Sample No. 14			Sample No. 15			Sample No. 16			Sample No. 17		
(Density in g/cm^3)		1.558			1.632			1.753			1.611	
	T°C	κ	tan δ	T°C	κ	tan δ	T°C	κ	tan δ	T°C	κ	tan δ
After cutting	25	2.785	.00152	25	2.875	.00189	25	3.058	.00172	25	2.870	.00121
		2.767	.00164		2.929	.00218		3.066	.00159		2.845	.00133
Oven dried	25	2.780	.00146	25	2.869	.00161	25	3.028	.00131	25	2.863	.00129
		2.767	.00147		2.924	.00175		3.033	.00128		2.839	.00122
	104	2.77	.00136	50	2.88	.00192	102	3.05	.00140	102	2.87	.00121
	202	2.78	.00131	103	2.88	.00138	208	3.06	.00143	200	2.88	.00140
	310	2.79	.00139	204	2.90	.00124	301	3.07	.00186	307	2.90	.00137
	407	2.80	.00147	302	2.90	.00118	399	3.08	.00201	399	2.91	.00161
	501	2.81	.00146	400	2.91	.00143	497	3.10	.00228	499	2.93	.00164
	600	2.82	.00193	495	2.92	.00154	600	3.11	.00216	605	2.94	.00307
	709	2.82	.00248	595	2.95	.00172	696	3.12	.00339	691	2.95	.00333
	800	2.84	.00384	699	2.96	.00221	797	3.13	.00439	800	2.97	.00408
	896	2.85	.00526	796	2.97	.00326	897	3.16	.00760	897	2.99	.00575
	25	2.77	.00126	896	2.94	.00443	93	3.06	.00197	28	2.87	.00144
				25	2.88	.00159	25	3.04	.00169			

	Sample No. 18			Sample No. 19			Sample No. 20		
(Density in g/cm^3)		1.729			1.772			1.713	
	T°C	κ	tan δ	T°C	κ	tan δ	T°C	κ	tan δ
After cutting	25	3.244	.000521	25	3.372	.00605	25	3.075	.00416
		3.242	.00590		3.394	.00588		3.095	.00405
Oven dried	25	3.246	.0049	25	3.388	.0057	25	3.089	.00409
	100	3.27	.0039	104	3.35	.0042	99	3.12	.0048
	200	3.30	.0036	201	3.37	.0054	199	3.17	.0060
	299	3.31	.0061	300	3.38	.0095	300	3.18	.0096
	400	3.30	.0104	404	3.39	.0161	403	3.19	.0166
	499	3.33	.0168	501	3.43	.0289	490	3.23	.0241
	597	3.35	.0318	601	3.48	.0498	600	3.28	.0419
	697	3.38	.0565	699	3.54	.113	699	3.31	.077
	798	3.40	.0933	799	3.59	.220	800	3.34	.120
	899	2.42	.141	897	3.22	.797	896	3.40	.228
	25	3.31	.0047	25	3.37	.0054	25	3.16	.00425

Silica fiber AS-3DX

Philco-Ford

Sample, as received, 25°C

		1 GHz		3 GHz	
		κ	tan δ	κ	tan δ
5ZD-1	Face 1	3.130	.00794	3.049	.00826
	Face 2	3.046	.00765	3.051	.00836
2	Face 1	3.001	.00176	2.976	.00183
	Face 2	2.973	.00189	2.964	.00202
3	Face 1	3.159	.00815	3.118	.00850
	Face 2	3.135	.00812	3.106	.00792
4	Face 1	3.031	.00159	3.005	.00212
		3.007	.00151	2.997	.00187

5ZD-1

			1 GHz		3 GHz	
		T°C	κ	tan δ	κ	tan δ
After oven drying	Face 1	25	3.025	.00192	3.013	.00235
		25	2.991	.00238	3.010	.00283
Ambient	Face 1	25	3.025	.00424	2.960	.00479
	Face 2	25	2.966	.00434	2.985	.00458
	Face 1	119	3.047	.00236	3.046	.0032
		215	3.022	.00102	3.025	.00110
		305	3.005	.00105	3.012	.00095
		401	3.003	.00123	3.010	.00108
		500	3.001	.00163	3.007	.00126
		35	3.008	.00114	3.014	.00150

Silica fiber AS-3DX (cont.)

Sample 5ZD-2		$T^{o}C$	1 GHz κ	1 GHz tan δ	3 GHz κ	3 GHz tan δ
After oven drying	Face 1	25	2.950	.00068	2.957	.00093
	Face 2	25	2.993	.00095	2.938	.00131
In H.T. holder	Face 1	25	2.949	.00103	2.953	.00119
		101	2.961	.00085	2.958	.00099
		211	2.955	.00078	2.960	.00086
		301	2.954	.00102	2.962	.00085
		403	2.955	.00115	2.960	.00104
		499	2.956	.00136	2.965	.00116
		19	2.950	.00086	2.955	.00097

Sample		$T^{o}C$	8.52 GHz κ	8.52 GHz tan δ
5ZD-5	Face 1, as received	25	3.131	.00706
	Face 2, " "	25	3.127	.00600
6	Face 1, " "	25	3.068	.00198
	Face 2, " "	25	3.074	.00195
5	Face 1, dried	25	3.071	.00115
	Face 1, ambient	25	3.074	.00332
		38	3.072	.00329
		130	3.061	.00092
		160	3.056	.00078
		212	3.054	.00057
		265	3.049	.00057
		317	3.045	.00065
		373	3.047	.00067
		433	3.053	.00070
		28	3.071	.00086

Silica fiber AS-3DX (cont.)

Sample	T^oC	κ	tan δ
		8.52 GHz	
5ZD-5			
Ambient	25	3.076	.00353
	344	3.041	.00054
	503	3.038	.00060
	604	3.036	.00090
	697	3.033	.00101
	793	3.028	.00124
	22	3.059	.00052
5ZD-6 Oven dried, Face 1	25	3.049	.00074
Face 2	25	3.053	.00077
In H.T. holder, Face 1	25	3.050	.00112
	139	3.050	.00112
	198	3.041	.00051
	313	3.039	.00056
	400	3.035	.00064
	501	3.037	.00074
	609	3.029	.00090
	694	3.026	.00106
	771	3.025	.00123
	22	3.044	.00035
5ZD-7		14 GHz	
As received, Face 1	25	3.082	.0129
rotated 90°	25	3.083	.0117
As received, Face 2	25	3.104	.0069
rotated 90°	25	3.096	.0071
Oven dried, Face 1	25	3.038	.0044
rotated 90°	25	3.040	.0040

Silica fiber AS-3DX (cont.)

Sample		14 GHz	
5ZD-8	T°C	κ	tan δ
As received, Face 1	25	2.983	.0058
rotated 90°	25	2.979	.0071
As received, Face 2	25	2.973	.0034
rotated 90°	25	2.950	.0034
Oven dried, Face 1	25	2.950	.00121
rotated 90°	25	2.948	.00148
	25	2.95	.00096
	112	2.95	.00062
	201	2.94	.00058
	296	2.95	.00061
	370	2.94	.00069
	482	2.94	.00105
	511	2.95	.00112
	50	2.95	.00052
5ZD-9		24 GHz	
As received, Face 1	25	3.116	.01127
rotated 90°	25	3.111	.01155
Oven dried, Face 1	25	3.085	.00358
rotated 90°	25	3.081	.00348
Redried, Face 1	25	3.082	.00321
In H.T. holder	25	3.083	.00495
	110	3.08	.00354
	197	3.07	.00178
	309	3.06	.00197
	408	3.06	.00150
	492	3.05	.00117
	584	3.04	.00093
	676	3.04	.00132
	797	3.03	.00131
	18	3.04	.00071

Silica fiber AS-3DX (cont.)

Sample		24 GHz	
5ZD-10	T°C	κ	tan δ
As received, Face 1	25	3.013	.00317
rotated 90°	25	3.006	.00305
Oven dried, Face 1	25	2.987	.00099
rotated 90°	25	2.999	.00113
Redried, Face 1			
In H.T. holder	25	3.000	.00154
	99	3.002	.00118
	204	3.00	.00064
	289	3.00	.00061
	380	2.99	.00068
	481	2.99	.00064
	598	2.99	.00079
	680	2.99	.00093
	799	2.98	.00128
	17	2.999	.00079

Silica fiber, silicone coated — Raytheon Co.

At 8.5 GHz

As received		Sample F		Sample G	
		κ	tan δ	κ	tan δ
Face 1	min	3.173	.00568	2.966	.00268
	max	3.190	.00557	2.979	.00270
Face 2	min	3.185	.00585	2.987	.00279
	max	3.176	.00601	3.000	.00271
After 24 hrs. 110°C, vac. oven					
Face 1		3.160	.00431	2.985	.00230
Face 2		3.150	.00425	2.990	.00232

Silicates

Borosilicate coating Supplied by Rockwell International Corp.

T^oC		8.52 GHz	14 GHz
-300	κ	2.35	2.30
	tan δ	.0030	.0030
-170	κ	2.40	2.35
	tan δ	.0050	.0050
74	κ	2.45	2.40
	tan δ	.01630	.0160
400	κ	2.50	2.45
	tan δ	.0180	.0200

Corning 7971 Glass Corning

At 4 GHz

T^oF	κ_{meas}	tan δ
4	4.01156	.00014 ± .00003
10.6	4.011182	↓
77.7	4.01456 ± .003	.00015 ± .00003
94.2	4.01530	│
111.2	4.01577	│
127.5	4.01693	│
143.2	4.01740	│
159.4	4.01777	│
173.3	4.01882	│
182.1	4.01935	│
192.3	4.01982	↓
226.1	4.02051	.00016 ± .00003

Note: The values of κ_{meas} included thermal dimension change effect. The true dielectric constant κ_{corr} can be computed when thermal expansion linear coefficient (α) is known: $\kappa_{corr} = \kappa_{meas}/(1+2\alpha\Delta T)$.

The temperature coefficient of dielectric constant $\Delta\kappa_{meas}/\Delta T_{(T=78)}$ = .0000377, which compares favorably with the corresponding values for Corning 7940 fused silica and single-crystal spinel of .0000397 and .000702 respectively.

Silicates

Pennvernon glass — PPG Industries, Inc.

Resistivity in ohm-cm

T°C	60 Hz	1 kHz
21	6.5E10	8.63E9
50	1.7E10	4.03E9
75	6.2E9	1.87E9
100	2.60E9	8.14E8
125	7.8E8	3.65E8
150	2.02E8	1.45E8
175	6.08E7	5.18E7
200	1.88E7	1.78E7
225	6.55E6	6.40E6
250	2.74E6	2.57E6
275	1.20E6	1.12E6
300	5.24E5	5.12E5
325	2.58E5	2.50E5
350	1.43E5	1.37E5

Freq., Hz	60	1 k	1 M
K	8.41	7.74	7.24
P.F.	.059	.0302	.0107

Float Glass

T°C	60 Hz ρ	1 kHz ρ	T°C	60 Hz ρ	1 kHz ρ
25	6.12E10	7.55E9	200	3.85E7	3.8E7
50	3.2E10	4.9E9	225	1.33E7	1.33E7
75	1.2E10	2.65E9	250	5.3E6	5.3E6
100	4.8E9	1.22E9	275	2.15E6	2.15E6
125	1.5E9	5.1E8	300	1.06E6	1.06E6
150	3.8E8	2.17E8	325	4.75E5	4.75E5
175	1.22E8	9.4E7	350	2.55E5	2.55E5

25°C

Freq., Hz	60	1 k	1 M
K	8.38	7.87	7.05
P.F.	.0586	.0302	.0110

Silicates

P-18 PPG Industries, Inc.

T°C	60 Hz	1 kHz
25	5.30E10	7.44E9
50	1.87E10	3.31E9
75	6.34E9	1.56E9
100	2.02E9	6.55E8
125	4.92E8	2.57E8
150	1.18E8	8.09E7
175	3.28E7	3.10E7
200	1.04E7	1.04E7
225	3.68E6	3.68E6
250	1.47E6	1.47E6
275	6.36E5	6.36E5
300	2.90E5	2.90E5
325	1.42E5	1.42E5
350	7.32E4	7.32E4

Freq., Hz	60	1 k	1 M
κ'	8.62	7.96	7.49
P.F.	.0655	.0168	.0115

Silicon nitride ceramic Raytheon Company

	T°C	κ	tan δ
As received	25	4.627, 4.637	.0035, .0028
Partially dried	25	4.606 - 4.613	.00187, .00175
In H.T. holder	25	4.61	.0024
	200	4.60	.0013
	419	4.61	.0011
	607	4.60	.0023
	713	4.62	.0043

Silicon nitride with MgO, hot-pressed Air Force Materials Laboratory

Experimental

At 14 GHz

	Thickness (cm)	T^oC	Against short κ'	Against short tan δ	$\lambda/4$ away κ'	$\lambda/4$ away tan δ
Face 1	.381	25	8.286	.00699	8.26	.00756
Face 2	.381	25	8.289	.00780	8.24	.00793
Face 1	.279	25	8.285	.00645		
Face 2	.279	25	8.286	.00667		
Face 1	.270	108	8.28	.0070		
		197	8.30	.0062		
		308	8.33	.0065		
		403	8.34	.0072		
		494	8.35	.0083		

Silicon nitride, hot-pressed Air Force Materials Laboratory

with 3 w/o MgO + 5 w/o BN, experimental

At 14 GHz

	T^oC	κ	tan δ
Face 1	25	8.295	.0436
face 2	25	8.250	.0440
	98	8.22	.0413
	210	8.21	.0415
	299	8.22	.0418
	396	8.24	.0425
	500	8.36	.0431
	29	8.18	.0404

Zinc selenide Eastman Kodak

IRTRAN 4, at 8.52 GHz, 24°C

κ	tan δ	σ [ohm-cm]$^{-1}$
10.08	.0063	3.0×10^{-4}

Zinc sulfide (95% sphalerite, 5% wurtzite) Eastman Kodak

IRTRAN 2, at 8.52 GHz, 24°C

κ	tan δ	σ [ohm-cm]$^{-1}$
8.62	.00152	6.18×10^{-4}

II. MISCELLANEOUS INORGANICS

Gypsum board (sheet rock) Supplied by The Sippican Corp.

($CaSO_4 \cdot 2H_2O$)

	Freq., Hz	60	50 k	500 k	3 M	100 M
As received	κ	9.7	2.53	2.45	2.34	2.32
	tan δ	.92	.0805	.0225	.0125	.0088
Dried	κ	1.875	1.820	1.802	1.788	1.765
	tan δ	.0172	.00591	.00526	.0050	.0061

Shale rock

Supplied by Raytheon Company

Sample D, E∥

50 Hz			1 MHz			10 MHz		
T°C	κ	tan δ	T°C	κ	tan δ	T°C	κ	tan δ
19.5	417.	.810	19.5	10.3	.316	19.5	7.60	.209
57	640.	.564	57	14.9	.486	57	9.38	.293
82	540.	.710	74	17.54	.591	81	10.2	.429
110	475.	1.27	114	20.4	.660	111	11.0	.435
163	390.	1.17	134	20.9	.646	159	9.30	.554
204	350.	1.31	157	19.9	.597	218	8.20	.264
339	742.	4.75	224	11.9	.360	325	7.42	.213
420	117.*	6.63*	259	10.7	.324	426	9.16	.100
			308	10.5	.195			
			312	10.3	.197			
			432	11.2	.242			

*100 Hz.

Shale rock | Raytheon Company

Sample D, 3 GHz, E

$T^{o}C$	κ	tan δ
25	5.12	.037
100	5.26	.055
200	5.27	.047
250	5.19	.036
299	4.94	.037
352	5.19	.050
400	5.40	.079
450	7.34	.049

Shale rock | Raytheon Company

Various samples, electric field oriented with respect to laminar structure

Sample/Field	Freq., Hz	50	1 M	10 M	30 M	100 M	300 M	1 G	3 G
A, E ∥	κ	-	19.7	14.52	11.5	8.3	5.34	5.24	5.20
	tan δ	-	.212	.257	.276	.309	.0182	.0274	.025
	ρ	3.39E5							
A, E ⊥	κ	9.30	6.37	5.92	5.85	5.80	-	-	-
	tan δ	.171	.0255	.0217	.0181	.0142	-	-	-
B, E ∥	κ	172	11.58	7.30	6.62	6.05	5.44	5.18	4.97
	tan δ	.313	.463	.267	.180	.102	.108	.079	.049
B, E ⊥	κ	102	7.55	5.65	5.50	5.44	-	-	-
	tan δ	.359	.237	.0937	.061	.040	-	-	-
D, E ∥	κ	264	10.9	7.65	6.72	6.90	5.35	5.15	5.12
	tan δ	2.60	.322	.219	.176	.130	.0917	.063	.037
D, E ⊥	κ	55.3	7.62	5.92	5.58	5.30	-	-	-
	tan δ	.556	.236	.139	.140	.067	-	-	-

Shale rock, oil-rich

E ||

Raytheon Company

Freq., Hz	50	1 M	10 M	30 M	100 M	300 M	1 G	3 G
κ	4.68	3.12	2.95	2.88	2.83	2.79	2.76	2.73
tan δ	.118	.0384	.0339	.0312	.0272	.0264	.0261	.0254

III. ORGANICS

Polyimide laminate AL-300

Atlantic Laminates

At 22°C

	3 GHz		8.5 GHz	
	κ	tan δ	κ	tan δ
Best value	4.48	.0132	4.412	.0137

Temperature run on stacked sample, 8.52 GHz

T°C	κ	tan δ	Sample thickness (cm)	Comments
23.5	4.16	.0097	.635	
98	4.30	.0104	.622	
198	4.41	.0116	.611	
284	4.50	.0116	.599	Smoke detectable
336	4.52	.0125	.597	Noticeably soft
426	4.01	.0142	.633	Smoking profusely
458	2.605	.0097	.824	too much smoke, gelatin-like softness, rapidly expanding
261	2.025	.0048	1.003	

Plastic ropes

Condex

At 25°C, electric field parallel to sample axis

Frequencies		Condex Tri-Laminar	Condex Urethane	"Glastran" rope
100 kHz	κ	4.77	4.50	4.88
	tan δ	.043	.047	.0128
1 MHz	κ	4.51	4.22	4.80
	tan δ	.062	.060	.0167
10 MHz	κ	4.07	3.88	4.73
	tan δ	.061	.055	.020
100 MHz	κ	3.78	3.66	4.55
	tan δ	.067	.060	.026
1000 MHz (extra-polated)	κ	3.5	3.4	4.2
	tan δ	.076	.066	.034

Styrofoam FR

Dow-Corning

	Freq., GHz	At 25°C κ	At 25°C tan δ
2 Stacked coax at 1 and 3	1	1.0335	.00005
	3	1.0323	.000077
1 Cylinder	8.5	1.0372	.000109

Sylgard 188 Dow-Corning

	25°C		-55°C	
Freq., Hz	κ	tan δ	κ	tan δ
100	2.858	.00292	3.332	.00239
1000	2.854	.00198	3.330	.00271
1500	2.853	.00197	3.329	.00286
8000	2.849	.00191	3.327	.00329
10000	2.849	.00190	3.326	.00332
10^5	2.844	.00178	3.317	.00318
10^6	2.841	.00152	3.308	.00377
10^7	2.839	.00165	3.301	.00665

Silastics Dow-Corning

Samples E-1600 140 at 8.52 GHz

	A			C	
T°C	κ	tan δ	T°C	κ	tan δ
18	3.046	.0193	25	2.740	.0133
-8		.0234*	0	2.775	.0166
-19	3.128	.0204	-24	2.808	.0191
-40	3.118	.0117	-33	2.813	.0183
-77	3.091	.00653	-42	2.815	.0155
-195	3.126	.00598	-63	2.798	.00846
			-80	2.778	.00428
	B		-100	2.760	.00231
25	2.99	.0118	-130	2.758	.00244
			-151	2.767	.00256
			-195	2.791	.00221

*Estimated value, not measured.

Silicone resin — Dow Corning

At 8.52 GHz, 22°C

Material	κ	tan δ
X-12546	3.381	.00768
XR-43117	2.885	.0176

Fiber samples — E. I. Du Pont de Nemours and Company

At 8.52 GHz

Sample No.	Orientation of electric field to surface fiber direction	T°C	κ	tan δ
5230-126	arbitrary,	75	3.83	.0530
	" , same	150	4.03	.0775
	" , same	300	4.15	.128
126	0°, E ∥	75	4.21	.0263
	90°, E ⊥	75	3.45	.0263
5230-127	arbitrary,	75	3.64	.0286
	" , same	150	3.71	.035
	" , same	300	3.81	.063
127	0°, E ∥	75	3.96	.0236
	30°	75	3.83	.0238
	45°	75	3.55	.0232
	90°, E ⊥	75	3.32	.0209
127	0°, E ∥	300	4.15	.055

Tedlar — E. I. Du Pont de Nemours and Company

At 25°C, 50% R.H.

Freq.	8.5 GHz	14 GHz	24 GHz
κ	4.38	4.32	4.28
tan δ	.044	.0040	.035

"TEFLON" TFE 7A — E.I. Du Pont de Nemours & Company

T°C	Hz	100	1 k	10 k	100 k	1 M	10 M	100 M	300 M	1 G	3 G	8.5 G	14 G	24 G
250	κ	1.91	→						1.91	1.912	1.912	1.912	1.91	1.91
	10^4 tan δ	10.05	1.62	.60	.09	.14	<.1	-	.6	.5	1.3	2.5	2.8	3.3
150	κ	2.00	→					-	2.00	2.002	2.001	2.001	2.000	2.00
	10^4 tan δ	5.00	.69	.13	.08	.16	.23	-	1.0	1.3	3.2	2.7	3.9	3.5
23	κ	2.05	→							2.051	2.050	2.050	2.048	2.047
	10^4 tan δ	.06	.04	.04	.05	.13	.15	1.4	3.2	3.7	3.4	2.3	2.6	3.0

"TEFLON" PFA TE 9704 — E.I. Du Pont de Nemours & Company

T°C	Hz	100	1 k	10 k	100 k	1 M	10 M	100 M	300 M	1 G	3 G	8.5 G	14 G	24 G
23	κ	2.06	→							2.060	2.058	2.055	2.052	2.049
	10^4 tan δ	.27	.20	.23	.35	.80	1.45	4.5	8.4	11.5	14.4	13.6	13.1	12.4
75	κ	-	-	-	-	-	-	-	-	2.043	2.041	2.038	2.036	2.034
	10^4 tan δ	-	-	-	-	-	-	-	-	11.0	14.0	14.7	14.5	14.1
100	κ	2.03	→		-	-	-	-	-	2.031	2.029	2.027	-	2.023
	10^4 tan δ	4.03	.91	.39	-	-	-	-	-	9.4	12.6	14.3	-	15.3
150	κ	2.01	→					-	-	2.010	2.009	2.007	2.004	2.002
	10^4 tan δ	28.6	3.96	.77	.40	.45	1.1	-	5.2	8.3	11.1	13.8	14.6	15.3
200	κ	-	-	-	-	-	-	-	1.98	1.979	1.979	1.977	1.974	1.971
	10^4 tan δ	-	-	-	-	-	-	-	3.1	6.0	9.4	12.2	13.2	14.1
250	κ	1.93	→							1.930	1.929	1.928	1.925	1.922
	10^4 tan δ	33.9	5.38	1.21	.60	.23	.8	-	1.5	4.5	7.2	10.3	11.2	12.5
150*	κ	2.01	-	-	-	-	-	-	-	-	-	-	-	-
	10^4 tan δ	13.6	1.71	.53	.40	.45	1.1	-	-	-	-	-	-	-
23*	κ	2.06	→					-	-	-	-	-	-	-
	10^4 tan δ	.06	.14	.23	.33	.71	1.5	-	-	-	-	-	-	-

*After heating to 250°C.

"TEFLON" FEP 100 — E.I. Du Pont de Nemours & Company

Freq. Hz	23°C κ	23°C 10^4 tan δ	75°C κ	75°C 10^4 tan δ	100°C κ	100°C 10^4 tan δ	150°C κ	150°C 10^4 tan δ	23°C κ	23°C 10^4 tan δ
10^2	2.06	1.21	-	-	2.03	6.01	2.00	32.3	2.06	1.49
10^3	↓	.80	-	-	-	-	↓	4.42	↓	.43
10^4	↓	.89	-	-	-	-	↓	1.14	↓	.13
10^5	↓	2.43	-	-	-	-	↓	1.25	↓	1.72
$5x10^5$	↓	4.59	-	-	-	-	↓	1.59	↓	3.85
10^6	↓	5.30	-	-	-	-	↓	1.73	↓	4.95
$1.5x10^6$	↓	5.8	-	-	-	-	↓	-	↓	5.4
$2x10^6$	↓	5.9	-	-	-	-	↓	-	↓	
$3.5x10^6$	↓	5.6	-	-	-	-	↓	-	↓	5.5
10^7	2.05	5.3	-	-	-	-	↓	2.5	2.05	5.3
10^8	2.05	7.0	-	-	-	-	↓	-	-	-
$3x10^8$	2.05	9.3	-	-	-	-	↓	7.5	-	-
$1x10^9$	2.047	13.7	2.031	13.2	2.022	12.8	1.999	12.3	-	-
$3x10^9$	2.045	11.6	2.029	13.3	2.020	13.8	1.997	13.6	-	-
$8.5x10^9$	2.043	9.0	2.027	10.3	2.018	11.6	1.994	12.8	-	-
$1.4x10^{10}$	2.040	7.5	2.024	9.4	2.013	11.1	1.986	12.4	-	-
$2.4x10^{10}$	2.034	6.7	2.014	8.3	2.000	10.0	1.974	11.2	-	-

"VITON", at 24°C — E.I. Du Pont de Nemours & Company

Freq., Hz	κ	tan δ	σ $(ohm\text{-}cm)^{-1}$
31.4	10.76	.0347	1.03E-11
100	10.37	.0327	3.92E-11
1000	10.19	.0349	1.98E-10
10^4	9.39	.0810	4.23E-9
10^5	8.00	.148	6.56E-8
$5x10^5$	6.60	.198	3.63E-7
10^6	5.99	.213	7.08E-7
$9.5x10^6$	4.27	.194	4.36E-6
$1.8x10^7$	3.95	.176	6.96E-6
$6x10^7$	3.64	.140	1.30E-5
$3x10^8$	3.30	.0951	5.24E-5
$1x10^9$	3.171	.0725	1.27E-4
$3x10^9$	3.057	.0542	2.82E-4
$8.5x10^9$	3.03	.0372	5.25E-4

Standard Conditions

Tedlar both sides	Sample No.	8.5 GHz ε	8.5 GHz tan δ	14 GHz ε	14 GHz tan δ	24 GHz ε	24 GHz tan δ
Single ply	1	2.87	.0181	-	-	2.75	.0129
	2	2.94	.0179	-	-	2.82	.0142
	3	2.90	.0178	-	-	2.76	.0146
	4	2.88	.0174	-	-	2.86	[illegible]
	5	2.88	[illegible]	-	-	[illegible]	[illegible]
	6	2.76	.0172	2.80	.018[illegible]	[illegible]	.0176
	7	2.76	.0175	2.77	.0165	2.82	[illegible]
	8	2.73	.0174	2.75	.0164	[illegible]	.0188
2 Ply same	1	2.86	.0130	2.90	.0127	2.78	[illegible]
	2	2.85	.0132	2.82	.0122	2.87	[illegible]
	3	2.88	.0135	2.75	.0121	2.63	.012[illegible]
3 Ply same	1	2.88	.0118	2.83	.0121	2.69	.0090
	2	2.88	.0121	2.85	.0126	2.84	[illegible]
	3	2.88	.0126	2.85	.0129	[illegible]	.0093
4 Ply same	1	2.88	.0121	2.83	.0116	2.68	[illegible]
	2	2.89	.0122	2.82	.0112	2.71	.0068
	3	2.89	.0120	2.83	.011[illegible]	[illegible]	.0079
3 Ply uncoated	1	2.88	.0108	2.87	[illegible]	2.72	[illegible]
	2	2.93	.0106	2.87	.0098	2.75	.0089
	3	2.86	.0104	2.82	.0096	2.81	.0089

After soaking 24 hrs., distilled water both sides,
then samples punched and measured within two minutes

Tedlar both sides	Sample No.	8.5 GHz ε	8.5 GHz tan δ	14 GHz ε	14 GHz tan δ	24 GHz ε	24 GHz tan δ
Single ply	1	2.89	.0191	-	-	[illegible]	.0118
	2	2.91	.0192	-	-	2.58	.0144
	3	2.90	.0191	-	-	2.67	[illegible]
	4	2.87	.0189	-	-	2.63	.0160
	5	2.86	.0190	-	-	2.71	[illegible]
	6	[illegible]	.0197	2.85	.0191	2.71	.0195
	7	[illegible]	.0202	2.81	.0195	2.70	.0151
	8	2.88	.0198	2.84	.0194	2.79	.0164
2 Ply same	1	2.90	.0182	2.86	.0161	2.60	.0123
	2	2.92	.0183	2.88	.0164	2.78	.0119
	3	2.92	.0184	2.87	.0155	2.77	.0123
3 Ply same	1	2.91	.0163	2.93	.0154	2.80	.0109
	2	2.93	.0164	2.84	.0145	2.79	.0114
	3	2.92	.0167	2.93	.0147	2.86	.0112
4 Ply same	1	2.93	.0138	2.79	.0126	2.72	.0084
	2	2.96	.0145	2.80	.0125	2.79	.0087
	3	2.98	.0148	2.84	.0120	2.83	.0089

Cross-linked polystyrene — General Electric Company

Standard conditions

Freq., GHz	.5	1	3	8.5	14	24	90
κ	2.54	2.539	2.535	2.535	2.535	2.531	2.85 ± .05
tan δ	.00107	.00094	.00063	.00041	.00057	.00084	.0015 ± .0005

After 48 hrs. 30/1 H_2O/NaCl solution

κ	2.54	2.544	2.540	2.538	2.537	2.535
tan δ	.00142	.00127	.00107	.00054	.00083	.00108

Noryl SE-1 — General Electric Company

Freq., MHz	κ	tan δ
100	2.639	.00135
1000	2.635	.00292
3000	2.629	.00545

Noryl SE-1-802 — General Electric Company

Standard Conditions

Freq., GHz	.5	1	3	8.5	14	24	90
κ	2.71	2.706	2.699	2.696	2.691	2.69	2.5 ± .1
tan δ	.0030	.00304	.00319	.00260	.00292	.0034	.005 ± .003

After 48 hrs. 30/1 H_2O/NaCl solution

κ	2.71	2.708	2.705	2.70	2.696	2.69
tan δ	.0031	.00281	.00325	.0031	.0039	.00336

Noryl GFN3 — General Electric Company

Standard Conditions

Freq., GHz	.5	1	3	8.5	14	24	90
κ	3.12	3.11	3.10	3.09	3.08	3.06	2.85 ± .1
tan δ	.0032	.0033	.0037	.00453	.0049	.0053	.008 ± .003

Noryl GFN3 (cont.)

<u>After 48 hrs. 30/1 H_2O/NaCl solution</u>

Freq., GHz	.5	1	3	8.5	14	90
κ	3.13	3.13	3.11	3.10	3.08	3.07
tan δ	.0034	.0036	.0037	.0046	.0053	.0058

Silicone resin laminates — Supplied by Lincoln Lab., MIT

Sample	Freq., GHz	1	3	8.5
581 Astro Quartz	κ	2.27	2.20	2.28
	tan δ	.0015	.0011	.0014
E Glass	κ	3.33	3.42	3.38
	tan δ	.0028	.00403	.0075

Polyester + Al + C — MIT Bio-Medical

Polyester resin (Laminac 4110, American Cyanamid) + 14.5% (Bakers' purified Al powder) + various amounts of acetylene black as indicated

Freq., GHz	1	3	8.5
0.24% C			
κ'	5.70	5.18	4.90
tan δ_d	.167	.122	.088
μ'/μ_o	1.02	.956	.942
tan δ_m	.037	.036	.033
0.48% C			
κ'	7.10	6.10	5.34
tan δ_d	.351	.239	.172
μ'/μ_o	1.036	.962	.937
tan δ_m	.023	.036	.030
0.96% C			
κ'	9.66	7.54	6.02
tan δ_d	.823	.518	.238
μ'/μ_o	1.04	.993	.921
tan δ_m	.023	.043	.046
1.9% C			
κ'	18.7	11.35	8.01
tan δ_d	3.44	.961	.562
μ'/μ_o	1.04	.904	.984
tan δ_m	.021	.038	.061

L-600 Polymer

Monsanto

Temp.	Hz	1	2	5	10	33.3	10^2	10^3	10^4	$2x10^4$	$5x10^4$	10^5	
25°C 77°F	κ	4.23	4.20	4.17	4.11	4.03	3.91	3.67	3.55	3.49	3.42	3.39	
	$\tan\delta$	.0227	.0236	.0264	.0281	.0321	.0380	.0315	.0318	.0299	.0274	.0252	
	Hz	10^6	10^7	$1.8x10^7$	10^8	$3x10^8$	10^9	$3x10^9$	$8.52x10^9$	$2.4x10^{10}$			
25°C	κ	3.29	3.21	3.19	3.15	3.11	3.10	3.0[illegible]	3.084	3.05			
	$\tan\delta$	.0163	.0107	.0099	.0087	.0073	.0072	.00695	.00629	.0083			
	Hz	33	100	333	1000	3333	10^4	10^5	10^6	10^7	10^9		
49.3°C 121°C	κ	4.36	4.26	4.13	4.004	3.86	3.74	3.54	3.39	3.30	3.13		
	$\tan\delta$	.0361	.0414	.0462	.0500	.0509	.0487	.0394	.0283	.0185	.0102		
	Hz	$3x10^9$	$8.52x10^9$	$2.4x10^{10}$									
	κ	3.11	3.10	3.06									
	$\tan\delta$	.0099	.0088	.0087									
	Hz	10^2	10^3	3333	10^4	$2x10^4$	10^5	10^6	10^7	10^9	$3x10^9$	$8.5x10^9$	$2.4x10^{10}$
75°C 167°F	κ	4.65	4.39	4.22	4.06	3.96	3.95	3.50	3.34	3.14	3.12	3.11	3.07
	$\tan\delta$	.0388	.0534	.0607	.0629	.0622	.057[illegible]	.0445	.0287	.0128	.0116	.0110	.0094
	Hz	10^2	10^3	10^4	10^5	10^6	10^7	10^9	$3x10^9$	$8.5x10^9$	$2.4x10^{10}$		
100°C 212°F	κ	6.08	5.46	4.87	4.29	3.82	3.48	3.21	3.15	3.12	3.10		
	$\tan\delta$	.0971	.0860	.0921	.0938	.0773	.050	.0232	.0172	.0141	.012		
	Hz	10^2	10^3	10^4	10^5	10^6	10^7	10^9	$3x10^9$	$8.5x10^9$	$2.4x10^{10}$		
125°C 257°F	κ	19.1	13.5	9.19	6.64	4.96	4.03	3.50	3.30	3.22	3.18		
	$\tan\delta$	.246	.273	.256	.222	.183	.119	.0617	.034	.027	.022		
	Hz	10^2	10^3	10^4	10^5	10^6	10^7	10^9	$3x10^9$	$8.5x10^9$	$2.4x10^{10}$		
150°C 302°F	κ	21.8	20.2	17.15	11.39	7.05	4.58	3.95	3.63	3.42	3.33		
	$\tan\delta$	.765	.139	.195	.299	.314	.206	.167	.109	.048	.037		
175°C 347°F	κ	31	22	19.6	18.4	13.8	8.20	4.19	3.88	3.55	3.42		
	$\tan\delta$	2.9	.55	.087	.094	.252	.368	.231	.59	.070	.051		

Moplen 004 polypropylene　　　　　　　　　　　　　　　　　　Novamont

T^oC	Freq., GHz	1	3	Error limits for both freq.
25	κ	2.260	2.254	$\pm$ .005
	tan δ	.00042	.00036	$\pm$ .00005
100	κ	2.15	2.14	$\pm$ .03
	tan δ	.00060	.00063	$\pm$ .00005

Dialite 55 P687 laminate　　　　　　　　　　　　　　　　　Supplied by RCA

At 300 MHz

T^oC	κ	tan δ	T^oC	κ	tan δ
-143	4.248	.00351	-15.5	4.333	.00594
-128.6	4.257	.00343	- 6.8	4.339	.00550
-119	4.262	.00328	0.6	4.351	.00700
-110	4.266	.00338	14.1	4.362	.00743
-101	4.273	.00371	24	4.370	.00783
- 89.5	4.289	.00397	25.6	4.373	.00790
- 84	4.282	.00449	37.1	4.379	.00857
- 47.6	4.309	.00499	47.3	4.383	.00889
- 39.9	4.316	.00536	58.1	4.399	.00936
- 34.5	4.322	.00507	68.6	4.312	.01015
- 29.7	4.323	.00550	75.2	4.319	.0104
- 23.2	4.328	.00586			

Fluorosint　　　　　　　　　　　　　　　　　　　　　　　Supplied by RCA

At 300 MHz

T^oC	κ	tan δ	T^oC	κ	tan δ
-149	3.468	.00074 $\pm$ .0001	-20.3	3.481	.00074 $\pm$ .0001
-133	3.471	↓	-13.6	3.482	↓
-126.5	3.473	↓	- 4.7	3.483	↓
-116.8	3.472	↓	2.5	3.483	↓
-109	3.473	↓	11.6	3.484	↓
- 89.8	3.475	↓	22.8	3.485	.00074 $\pm$ .00005
- 75.6	3.477	↓	26.5	3.486	↓
- 63.6	3.479	↓	33	3.487	.00074 $\pm$ .0001
- 53.7	3.489	↓	45.7	3.488	
- 46	3.479	↓	54.7	3.489	
- 40.5	3.480	↓	64.2	3.490	
- 33.8	3.481	↓	75.5	3.492	
- 25.8	3.481	↓			

G11 laminate

At 300 MHz

Supplied by RCA

T°C	κ	tan δ	T°C	κ	tan δ
76.7	4.849	.0238	- 40.8	4.453	.0094
68.2	4.812	.0228	- 50.2	4.431	.0088
58.8	4.771	.0218	- 60.	4.415	.0081
48.3	4.731	.0197	- 70.5	4.401	.0076
39.2	4.691	.0190	- 80.9	4.384	.0070
28.4	4.649	.0176	- 90.7	4.373	.0064
12.1	4.593	.0156	-100.6	4.363	.0056
6.8	4.572	.01485	-113.6	4.347	.00494
0	4.555	.0141	-121.1	4.338	.0046
-10.	4.524	.0126	-130.	4.332	.0043
-19.2	4.501	.0119	-140.3	4.322	.0041
-31.	4.472	.0107			

RTV-511, unloaded

At 300 MHz

Supplied by RCA

T°C	κ	tan δ	T°C	κ	tan δ
-146.1	3.202	.0109	- 30	3.409	.0118
-133.8	3.228	.0135	- 20.3	3.385	.0097
-122	3.248	.0154	- 8.1	3.364	.0080
-111	3.266	.0170	+ 1.7	3.347	.0071
-100.8	3.280	.0186	10.8	3.332	.0068
- 89.7	3.310	.0218	22.8	3.309	.00625
- 83.6	3.334	.0272	33.3	3.286	.0059
- 68	3.388	.0269	43.6	3.252	.0054
- 60.6	3.413	.0226	52.7	3.222	.0052
- 50.8	3.423	.0186	63.2	3.155	.00505
- 39	3.419	.0140	73	3.123	.0047

RTV-511, unloaded — Supplied by RCA

At 2.2969 GHz

T^oC	κ	tan δ	T^oC	κ	tan δ
-134.8	3.071	.00190	28.2	3.328	.0270
130	3.073	.00194	19.8	3.335	.0254
119.8	3.090	.0023	- 8.1	3.354	.0215
110	3.109	.0036	+ 2.5	3.324	.0183
98.2	3.142	.0062	12.3	3.309	.0160
89	3.171	.0093	21.8	3.295	.0143
80	3.197	.0130	32.7	3.273	.0124
69.3	3.228	.0178	43.1	3.236	.0112
60	3.254	.0224	52.7	3.194	.0103
50.2	3.281	.0264	64.8	3.145	.0091
41.1	3.307	.0286	72.9	3.133	.0085

RTV-511, 45 parts zinc oxide — Supplied by RCA

At 300 MHz

T^oC	κ	tan δ	T^oC	κ	tan δ
-128.9	3.546	.0036	20.1	3.832	.0108
117.4	3.580	.0061	+ 9.8	3.816	.0092
112.9	3.599	.0080	- 0	3.800	.0084
103.6	3.635	.0109	10.2	3.780	.0075
90	3.706	.0216	21.6	3.745	.0067
79.9	3.750	.0246	31.3	3.727	.0064
68.2	3.808	.0254	42.4	3.671	.0063
59.6	3.838	.0227	51.5	3.640	.00625
51.3	3.853	.0196	62	3.605	.0062
40.6	3.858	.0153	73.2	3.584	.0065
30.2	3.850	.0131			

RTV-511, 45 parts zinc oxide

At 2.2969 GHz

Supplied by RCA

T°C	κ	tan δ	T°C	κ	tan δ
131.2	3.395	.0072	-10.6	3.675	.0275
120.1	3.404	.0077	+ .6	3.666	.0243
111	3.413	.0082	10	3.654	.0221
99.7	3.445	.0099	21.3	3.636	.0196
90.2	3.479	.0134	26.6	3.623	.0183
81.6	3.514	.0171	32.8	3.608	.0172
69.1	3.557	.0236	35.3	3.600	.0168
60	3.587	.0278	45	3.578	.0160
49.7	3.617	.0314	56.2	3.553	.0152
40.6	3.642	.0324	65.2	3.528	.0146
30.5	3.667	.0318	74.7	3.501	.0142
21.2	3.676	.0299			

RTV-511, 90 parts zinc oxide

At 300 MHz

Supplied by RCA

T°C	κ	tan δ	T°C	κ	tan δ
-129.8	4.047	.0214	-19.3	4.118	.0098
-116.8	4.074	.0228	-10.3	4.102	.0086
-103.8	4.099	.0232	1.0	4.083	.00776
- 90.2	4.122	.0218	6.7	4.073	.00750
- 96.1	4.114	.0223	22.6	4.038	.00675
- 78.9	4.132	.0204	33.8	4.008	.00638
- 69.3	4.136	.0190	43.8	3.976	.00630
- 59.7	4.140	.0169	52.9	3.948	.00645
- 50.2	4.141	.0148	62.9	3.923	.00670
- 39.9	4.138	.0130	72.5	3.907	.00732
- 31.2	4.132	.0115			

RTV-511, 90 parts zinc oxide — Supplied by RCA

At 2.2969 GHz

T^oC	κ	tan δ	T^oC	κ	tan δ
-129.2	3.662	.0111	20.5	3.923	.0327
120	3.672	.0116	9.8	3.921	.0298
109.7	3.699	.0131	0	3.917	.0269
102.5	3.712	.0139	9.4	3.908	.0246
90.2	3.770	.0181	16.6	3.897	.0229
80.9	3.803	.0229	21.9	3.888	.0215
71.1	3.828	.0272	28.2	3.872	.0202
58.9	3.858	.0326	42.6	3.834	.0182
50.2	3.881	.0346	51	3.810	.0179
40.3	3.900	.0348	61.9	3.775	.0176
30.2	3.916	.0340	72.8	3.742	.0174

Polyurethane sealant P/N 596927 — Supplied by Raytheon Company

<u>Average values</u>

Freq., Hz	60	1 k	1 M	10 M	30 M
κ	7.05	6.81	4.71	4.02	3.69
tan δ	.0150	.0422	.102	.1135	.1106

<u>At 1 kHz</u>

T^oC	κ	tan δ	T^oC	κ	tan δ
22	6.81	.0422	90	5.72	.0101
30	6.73	.0324	100	5.57	.0140
40	6.62	.0209	110	5.45	.0196
50	6.46	.0145	120	5.34	.0285
60	6.31	.0104	130	5.21	.0391
70	6.12	.0083	140	5.06	.0568
80	5.90	.0086	150	4.84	.0762

Stycast 2651-40 RQ
(Emerson & Cumming)

Supplied by Raytheon Company

Sample No.	Freq., Hz	60	1 k	1 M	10 M	30 M
1	κ	5.09	4.92	4.22	3.96	3.82
	tan δ	.0305	.0231	.0452	.0435	.0515
2	κ	5.18	4.94	4.28	4.06	3.88
	tan δ	.0294	.0231	.0449	.0426	.050
3	κ	5.15	4.97	4.28	4.02	3.86
	tan δ	.0304	.0231	.0451	.0429	.0484
Average	κ	5.14	4.94	4.26	4.01	3.85
	tan δ	.0301	.0231	.0451	.0430	.050

Temperature runs, 1 kHz

Sample No.	1		2		3		Average	
T°C	κ	tan δ	κ	tan δ	κ	tan δ	κ	tan δ
23	4.98	.0247	5.08	.0245	5.06	.0250	5.04	.0247
30	5.05	.0253	5.15	.0251	5.12	.0265	5.11	.0256
40	5.12	.0280	5.22	.0262	5.25	.0291	5.20	.0276
50	5.29	.0318	5.38	.0307	5.36	.0322	5.34	.0316
60	5.59	.0401	5.86	.0438	5.82	.0456	5.76	.0432
70	6.34	.0776	6.41	.0745	6.37	.0715	6.37	.0745
80	6.96	.0998	7.32	.0976	7.16	.0985	7.15	.0985
90	7.42	.110	7.54	.108	7.50	.109	7.49	.109
100	7.55	.157	7.66	.160	7.70	.162	7.65	.159
110	7.50	.282	7.65	.241	7.76	.255	7.63	.259
120	7.41	.468	7.48	.522	7.58	.450	7.49	.482
130	7.35	.838	7.47	.731	7.50	.685	7.44	.751
140	7.40	1.13	7.52	.948	7.32	.914	7.41	.964
150	7.32	1.18	7.43	.998	6.92	1.17	7.22	1.116
26			4.92	.0185				

Honeycomb laminate — Supplied by Rockwell International Co.

Skin, E∥

T^oF	Freq.	3 GHz	8.52 GHz	14 GHz
74	κ	4.14	4.45	4.40
	tan δ	.010	.0120	.0160
-300	κ	-	4.35	4.33
	tan δ	-	.0022	.0025
-170	κ	-	4.40	4.37
	tan δ	-	.0095	.0080
400	κ	-	4.50	4.45
	tan δ	-	.018	.0205

Core (Nomex), E∥

T^oF	Freq.	3 GHz	8.52 GHz	14 GHz
74	κ	1.1250	1.2305	1.1476
	tan δ	.00270	.01040	.00735
-300	κ	-	1.184	1.1315
	tan δ	-	.01500	.00150
-170	κ	-	1.1817	1.1400
	tan δ	-	.00266	.00470
400	κ	-	1.12986	1.12610
	tan δ	-	.00195	.00248

Composite, E∥

T^oF	Freq.	300 MHz	1 GHz	3 GHz
74	κ	1.4756	1.4484	1.4246
	tan δ	.00438	.00499	.00643
-300	κ	1.4283	1.4978	1.3893
	tan δ	.00095	.00087	.00174
-170	κ	1.4550	1.4410	1.4220
	tan δ	.00220	.00240	.00340
400	κ	1.4339	1.4102	1.3920
	tan δ	.00159	.000965	.00202

Nomex felt — Supplied by Rockwell International Corp.

T°F	Freq.	3 GHz	8.52 GHz	14 GHz
74	κ	1.21500	1.24400	1.30850
	tan δ	.00339	.00451	.00560
-300	κ	-	1.22390	1.25780
	tan δ	-	.00086	.00162
-170	κ	-	1.22460	1.27400
	tan δ	-	.00159	.00320
400	κ	-	1.23140	1.27280
	tan δ		.00634	.00516

Silicone RTV — Supplied by Rockwell International Corp.

T°F	Freq.	3 GHz	8.52 GHz	14 GHz
74	κ	3.59000	3.55000	3.50500
	tan δ	.01250	.01850	.021500
-300	κ	-	3.48000	3.63900
	tan δ	-	.003250	.00363
-170	κ	-	3.57000	3.57000
	tan δ	-	.01390	.01500
400	κ	-	3.48000	3.46100
	tan δ	-	.005370	.008970

Glastrate
(O-C Fiberglas) — The Sippican Corp.

Freq., Hz	60	50 k	500 k	3 M	100 M
κ	1.450	1.432	1.417	1.405	1.398
tan δ	.0228	.0039	.0028	.0022	.0012

Infrared windows — Texas Instruments

TI-1173 and TI-20

Sample No.	T^oC	8.5 GHz κ	tan δ
TI-1173	25	9.69 ± .08	.0008 ± .0005
TI-20	25	8.037 ± .04	.00046 ± .00008
	100	8.041	.00057 ± .00012

Diallyphthalate, glass — Upjohn

At 8.5 GHz

Sample No.	Thickness (cm)	T^oF	κ	tan δ
C 1-2	-	77	4.91	.0087
			4.90	.0082
C 3-3	-	77	4.91	.0087
			4.88	.0073
C 5-6	1.4765	77	4.91	.0092
			4.91	.0081
	1.4884	189	4.89	.0117
	1.5347	400	4.85	.0297
	1.554	535	4.83	.0354
	1.4813	77	4.92	.0090
Modified, at 8.5 GHz				
B 1-2	-	77	4.47	.0072
			4.45	.0071
B 3-4	-	77	4.45	.0072
			4.39	.0060
*B 5-6	1.4755	77	4.48	.0073
	1.4846	199	4.49	.0092
	1.5105	400	4.49	.0150
	1.539	539	4.41	.0195
	1.478	77	4.51	.0074

*No appreciable change when sample reversed and rotated 90 degrees.

Epoxy, glass — Upjohn

At 8.5 GHz

Sample No.	Thickness (cm)	T°F	κ	tan δ
R 1-2	-	77	5.03	.0196
			5.07	.0191
R 5-6	-	77	5.05	.0206
			5.07	.0203
*R 3-4	1.221	77	5.04	.0208
	1.240	240	5.03	.0260
	1.259	432	5.09	.0341
	1.299	636	5.17	.0228
	1.223	77	5.01	.0175

*No appreciable change when sample reversed and rotated 90 degrees.

Polybutadiene, glass — Upjohn

At 8.5 GHz

Sample No.	Thickness (cm)	T°F	κ	tan δ
A 1-2	-	77	4.42	.0080
			4.38	.0079
A 5-6	-	77	4.40	.0084
			4.41	.0082
A 3-4	-	77	4.39	.0083
	1.476	77	4.40	.0081
	1.491	200	4.39	.0096
	1.517	401	4.28	.0086
	1.534	561	4.29	.0088
	1.478	77	4.40	.0068

Polyurethane foam — Upjohn

At 300 MHz

2-lb. foam

Sample No.	T^oC	κ	tan δ
1-3	25	1.038	.00070
2-3	↓	1.038	.00072
3-3		1.036	.00072
4-3		1.036	.00074
1-2		1.036	.00068
1-3 + 2-3		1.040	.00068
	100	1.047	.00151
3-lb. foam			
1	25	1.0524	.00109
2	↓	1.0535	.00110

Cyanurate ester resin — Whittaker Corporation

XSR-10500, at 8.5 GHz

	T^oF	κ	tan δ
As received	73	3.143	.00672
As received, reversed	73	3.142	.00668
In temperature holder	140	3.156	.00798
	201	3.171	.00975
	310	3.181	.0125
	400	3.191	.0137
	502	3.193	.0145
	102	3.121	.00668

Polybutadiene-Astroquartz 3.164-11 — Whittaker Corporation

Firestone PM502, at 8.5 GHz

	$T^{o}C$	κ	tan δ
As received	73	3.105	.00301
Reversed	73	3.117	.00379
Over quarter wavelength	73	3.072	.00207
Reversed	73	3.079	.00393
After cutting	73	3.102	.00206
Reversed	73	3.129	.00314
In temperature holder	86	3.098	.00178
	159	3.070	.00174
	199	3.063	.00160
	303	3.058	.00141
	391	3.057	.00137
	516	3.039	.00131
	72	3.088	.00164

Polybutadiene-Kevlar 3.164-10 — Whittaker Corporation

Firestone PM502, at 8.5 GHz

As received	73	3.257-3.261	.9179-.0190
Reversed	73	3.254-3.258	.0176-.0185
Over quarter wavelength	73	3.231-3.230	.0162-.0170
Reversed	73	3.235-3.235	.0163-.0172
After curring	73	3.220-3.253	.0161-.0179
In temperature holder	74	3.188	.0154
	170	3.226	.0322
	211	3.225	.0262
	310	3.107	.0135
	417	3.062	.0117
	515	3.065	.0156
	116	3.062	.00565
	71	3.061	.00483

Polyether sulfone (dry sample) Whittaker Corporation

SN 300-P, 24 GHz, 24°C

κ	tan δ
3.26	.0108

Polyphenylquinoxaline resin Whittaker Corporation

PPQ 401, at 8.5 GHz

	T°F	κ	tan δ
As received	73	3.084	.00392
As received, reversed	73	3.047	.00384
in temp. holder	74	3.052	.00384
	154	3.068	.00481
	208	3.074	.00527
	303	3.045	.00604
	402	3.028	.00608
	505	2.994	.00576
	158	3.031	.00467

Polyphenylquinoxaline-Astroquartz Whittaker Corporation

2256-16A, at 24 GHz

T°C	κ	tan δ
23.5	3.31	.00128
70	3.31	.00149
120	3.29	.00158
176	3.28	.00158
221	3.27	.00158
260	3.25	.00189
112	3.31	.00158

Polyurethane foam (rigid) Witco Chemical Co.

D.C. resistivity = 1.7×10^{15} ohm-cm at 25°C

MATERIALS AND COMPANY INDEX*

*In this index Roman numerals refer to Tables of Dielectric Materials, Vols. IV, V, and VI. P.R. refers to Tech. Rep. AFML-TR-72-39. This report is referenced by Arabic number 8 followed by page numbers.