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SUPPLEMENTARY DIELECTRIC-CONSTANT AND  
LOSS MEASUREMENTS ON HIGH-TEMPERATURE  
MATERIALS

J. Iglesias, et al

Massachusetts Institute of Technology  
Cambridge, Massachusetts

January 1967

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Supplementary Dielectric-Constant and Loss Measurements  
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# SUPPLEMENTARY DIELECTRIC-CONSTANT AND LOSS MEASUREMENTS ON HIGH-TEMPERATURE MATERIALS

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**Abstract:** This is a summary report on dielectric constant and loss measurements made in this laboratory after 1958, excepting high-dielectric-constant materials. The emphasis is on high-temperature materials (those with melting points above  $1200^{\circ}\text{C}$ ), but data on some plastics and liquids are also included. The samples of solids include oxides of Al, Be, Cr, Hf, Mg, Si, Ta, Th, Y, Zr, nitrides of B and Si,  $\text{LaAlO}_3$  and various silicates, rocks, and minerals. Pure samples of  $\text{Al}_2\text{O}_3$ ,  $\text{BeO}$ ,  $\text{MgO}$ ,  $\text{SiO}_2$ , and  $\text{BN}$  all show loss tangents  $< 0.01$  at  $1500^{\circ}\text{C}$  in the microwave region. Various phenomena of electric loss, e. g., transconductance, dipole orientation, and molecular vibrations are clearly discernible. A fundamental analysis will be undertaken in connection with our over-all research program on dielectric spectroscopy.

## General Properties

The obvious prime requisites for any high-temperature solid insulator are high melting point and wide optical-energy gap. The first parameter for most of the elements and compounds of interest is known and available in physics handbooks. The optical-energy gap refers to the one-electron band model and is the energy required to excite an electron into the conduction band.<sup>1)</sup> These ultra-violet absorption data are incomplete. Electrical conduction is often greatly enhanced by impurities and in some materials predominantly ionic; in practice the optical-energy-gap data are only a very rough guide. As has been previously pointed out,<sup>2)</sup> electrical losses in the microwave region in pure materials are due to infrared absorption spectra as well as charge transfer. Materials with impurities show increased losses in three ways: (1) increased conduction, i. e., charge transfer; (2) dipole relaxation losses; (3) broadened infrared spectra. The general appearance of the electrical spectra is illustrated in Fig. 1; in practice the individual loss regions may overlap considerably.

- 
- 1) Technical Report 191, Laboratory for Insulation Research, Massachusetts Institute of Technology, Cambridge, Mass., July, 1964.
  - 2) Summary Technical Report No. 1 (AFML-TR-65-396), November, 1965, Laboratory for Insulation Research, Massachusetts Institute of Technology, Cambridge, Mass.

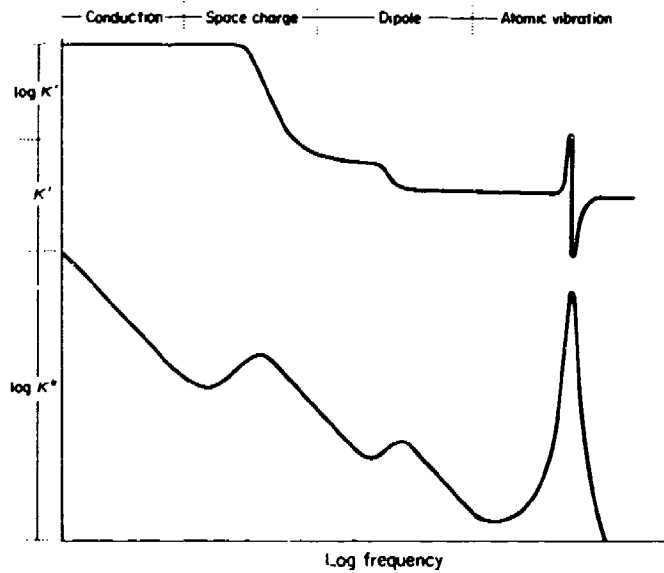


Fig. 1.  
Dielectric spectra.

### Melting Points

A discussion of the factors influencing the melting points of the elements and some of the binary compounds has been given previously.<sup>1)</sup> As there is only one insulating element for high temperatures (diamond), most of the materials of interest are diatomic. The largest category are the oxides; their melting points are arranged according to the periodic chemical table (Table 1). About 25 of these are known to have melting points above  $1600^{\circ}\text{C}$ . The heavy atoms, in general, supply many electrons for conduction at moderate temperatures. All known borides, carbides, halides, nitrides, silicides, and sulfides, with the exception of those listed in Table 2, have melting points (or decompose rapidly) below  $1600^{\circ}$  or are known to exhibit high conduction. Table 2 also lists compounds with 3 or 4 elements which have high melting points. The 25 high-temperature oxides of Table 1 and compounds listed in Table 2 comprise the present chemical list of compounds worthy of consideration. If the temperature limit is raised to  $2000^{\circ}\text{C}$  and the heavy and multivalent atoms are eliminated, the list reduces to C, BeO, MgO,  $\text{Al}_2\text{O}_3$ , CaO,  $\text{Sc}_2\text{O}_3$ , ZnO, SrO,  $\text{Ca}_2\text{SiO}_4$ ,  $\text{MgAl}_2\text{O}_4$ ,  $\text{Be}_3\text{N}_2$ , BN, AlN,  $\text{Si}_3\text{N}_4$ .

### Measurement Techniques

When only small samples were available, two-terminal measurements were made in the lumped-circuit range,  $10^2$  to  $10^7$  Hz, using a laboratory-built bridge.<sup>3)</sup>

3) Tech. Rep. 201, R. E. Charles, K. V. Rao, and W. B. Westphal, Lab. Ins. Res., Mass. Inst. Tech., Cambridge, Mass., October, 1966.

Table 1. Melting points of oxides in degrees centigrade.

Li >1700	Be 2530	B 460	C -566	N -908	O -192	F O <sub>3</sub> -							
Na 1275 <sub>s</sub>	Mg 2800	Al 2015	Si 1713	P 580	S d70 - 95	Cl -							
K 490	Ca 2580	Sc -	Ti 1830 Ti <sub>2</sub> O <sub>3</sub> 2130	V 1970	Cr 2435	Mn 1705	Fe 1565	Co 1935	Ni 1990				
Cu 1326	Zn 1975	Ga 1900	Ge 1115	As 193	Se 350 <sub>s</sub>	Br -							
Rb 570	Sr 2430	Y 2410	Zr 2715	Nb 1780	Mo 795	Tc -	Ru 255	Rh d1100	Pd 870				
Ag d300	Cd d900	In V850	Sn 1127	Sb 656	Te 733	I -							
Cs 490	Ba 1923	La 2315	Hf 2812	Ta 1800	W 1500	Re d1000	Os 500	Ir d1100	Pt d550				
Au -	Hg d500	Tl 717	Pb 888	Bi 860	Po -	At -							
Fr -	Ra -	Ac -											
Ce 2600	Pr -	Nd 1900	Pm -	Sm -	Eu -	Gd -	Tb -	Dy 2340	Ho -	Er -	Tm -	Yb -	Lu -
Th 3050	Pa -	U 2500	Np -										

s = sublimes; d = decomposes.

For larger samples three-terminal measurements could be made, and microwave measurements were performed using the standing-wave method with shorted-line and dielectric-filled resonant cavities.<sup>3)</sup> Materials that are very sensitive to atmosphere are noted in the data section, and more than one set of data is given. The microwave measurements with Pt-foil covered dielectrics are relatively free from atmospheric or diffusion effects. The highest temperature reached was about 1700°C.

Table 2. Binary tri-element compounds.

Tri-element	Melting point (°C)	Binary	Melting point (°C)
BeAl <sub>2</sub> O <sub>3</sub>	1870	CdS	1750 (100 A)
CaAl <sub>2</sub> O <sub>4</sub>	1600	HfN	3305
CaCr <sub>2</sub> O <sub>4</sub>	2090	MgS	d > 2000
Ca <sub>3</sub> (PO <sub>4</sub> ) <sub>2</sub>	1670	Mo <sub>2</sub> C	2687
Ca <sub>2</sub> SiO <sub>4</sub>	2130	SiO	> 1702
CaZrO <sub>3</sub>	2550	SrS	> 2000
LiAlO <sub>2</sub>	1600	ThC <sub>2</sub>	2655
(or Li <sub>2</sub> Al <sub>2</sub> O <sub>4</sub> )		UB <sub>2</sub>	2365
MgAl <sub>2</sub> O <sub>4</sub>	2135		
Mg <sub>2</sub> SiO <sub>4</sub>	1910		
KAlSiO <sub>4</sub>	ca 1800		
SrSiO <sub>4</sub>	> 1750		
SrSO <sub>4</sub>	1605		

Materials Measured and Their General Characteristics

The frequency characteristics of all materials measured under this program show common trends. The dielectric constant  $\kappa'$  (relative to vacuum) increases at low frequencies with high temperatures. The loss factor  $\kappa''$  at high temperatures decreases with increasing frequency but seldom is proportional to  $1/f$ . The slower change implies that the conductivity  $\sigma (= \omega \kappa'' \epsilon_0)$  rises with frequency. Plots of  $\log \sigma$  vs. the reciprocal of absolute temperature show deviations from the straight line given by the relation

$$\sigma = \sigma_0 e^{-A/kT}$$

The microwave temperature runs show the loss tangent steadily rising with temperature except for Brush B-6 beryllia and Carborundum alumina. These have sharp absorptions which look like vibration spectra. Exact interpretation will depend on data taken versus frequency at fixed temperature (given in the Index to the data).

Wide-Band Spectra. The dielectric spectrum of elemental insulators (we need consider only carbon in diamond form) consists ideally of two parts: low-frequency conduction loss due to thermal excitation of electrons from the valence to conduction band and electronic vibration spectrum in the ultraviolet region. In the microwave region conduction losses should predominate; we estimate that the loss tangent should reach 0.01 at about 2100°C.<sup>4)</sup> No data are available to indicate if best crystals approach the ideal, a strongly bonded material (m. p. > 3500°C) with large energy gap (5 to 7 eV).

The cubic diatomic insulators - MgO is the best example - ideally show only three regions of loss. The vibration spectrum of the magnesium-oxygen bond is added to low-frequency conduction loss and electronic ultraviolet spectrum. The optical energy gap of MgO is 8.7 eV. Measurements of conductivity show much lower gaps (2 to 4.6 eV), partly because of impurities and partly because of vacancies existing at high temperatures.

We have data in the far infrared on SrF<sub>2</sub> indicating agreement between extrapolated vibration loss and microwave data (p. 62).

The heavy diatomic insulators - thorium oxide is a cubic example - have strong bonds with many electrons (m. p. = 3000°C), but only moderate temperatures are needed to excite electrons for conduction. Our data on a technical grade ThO<sub>2</sub> ceramic show appreciable conduction at 500°C and a dipolar response at lower temperatures.

The noncubic materials have more than one infrared vibration mode. The reflectivity of hexagonal Al<sub>2</sub>O<sub>3</sub> shows a complicated response with high losses over the region 8 to 30 μ (1 to 3.8 x 10<sup>13</sup> Hz). Optical data indicate a band gap of above 8 eV at 25°, decreasing to about 6.9 eV at 900°C. Conductivity data indicate much lower activation energies, probably due to oxygen vacancies and ready acceptance by the lattice of many metallic impurities.

Another hexagonal oxide, BeO in ceramic form, has recently been measured in this laboratory<sup>5)</sup> and shows very low high-temperature conductivity in agreement with the reported statement that BeO exhibits lower conductivity than any other

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4) Based on the one-electron model, see Ref. 1, pp. 20 and 21, and no change in energy gap with temperature. Measurements on Ge show appreciable reduction gap with temperature.

5) Summary Tech. Rep. No. 1 (AFML-TR-65-396), Lab. Ins. Res., Mass. Inst. Tech., Cambridge, Mass., November, 1965, pp. 18, 19.

oxide. 6)

The heavy noncubic oxides all exhibit high conduction at 500°C. 7)

High-purity yttria<sup>8)</sup> shows lower losses than previously reported for a single crystal; <sup>9)</sup> losses to 500°C are comparable with those of high-purity alumina.

Nitrides of B, Al, Si, and Mg<sub>2</sub>S are of interest for high-temperature work. Data on a commercial ceramic and pyrolytic material of S<sub>3</sub>N<sub>4</sub> have been published previously. <sup>10)</sup>

Summary. Pure oxides of alumina, beryllium, magnesium, and silicon have electrical properties suitable for microwave windows to at least 1500°C. Boron nitride is also suitable and has considerably lower temperature coefficient of dielectric constant. While the dominating microwave loss process is conduction in low-purity materials, the infrared absorptions are also important.

#### Dielectric Data

The following pages of data list materials as inorganic or organic. The first section is arranged alphabetically according to chemical name. The organics are listed alphabetically according to manufacturer or supplier. The data show permittivity relative to vacuum  $\kappa'$  or  $\epsilon'/\epsilon_0$ ; dielectric loss factor  $\kappa''$  or  $\epsilon''/\epsilon_0$ ; loss tangent,  $\tan \delta$ , a. c. conductivity  $\sigma$  in ohm-cm<sup>-1</sup> or a. c. resistivity  $\rho$  in ohm-cm. The magnetic parameters shown are the permeability relative to vacuum  $\kappa'_m$  or  $\mu'/\mu_0$ , magnetic loss factor  $\kappa''_m$  or  $\mu''/\mu_0$ , and magnetic loss tangent  $\tan \delta_m$ . Refer to Tech. Rep. 189 for conversion to other parameters such as attenuation factor, propagation constant, intrinsic impedance, etc. <sup>11)</sup>

In the index are listed many materials measured in our laboratory since 1958. Data already given in our technical reports are not repeated, but references are given. The index also lists the temperature (T°C) at which the microwave loss tangent reached 0.01 in our measurements.

---

6) E. Ryshkewitch, "Oxide Ceramics," Academic Press, New York and London, 1960, p. 330.

7) Ref. 5, p. 24.

8) Ref. 5, p. 25.

9) W. B. Westphal, Tech. Rep. 182, Lab. Ins. Res., Mass. Inst. Tech., October, 1963.

10) Ref. 5, pp. 26, 27.

11) Tech. Rep. 189, Lab. Ins. Res., Mass. Inst. Tech., May, 1964.



I. INORGANIC COMPOUNDS

	T <sup>o</sup> C	T. R. 182	Summary T. R. 1	T. R. 203
<b>Aluminum nitride</b>				
AlN, hexagonal, MP > 2200 (in N <sub>2</sub> )				
Carborundum, hot-pressed	670			15
<b>Aluminum oxide</b>				
Al <sub>2</sub> O <sub>3</sub> , hexagonal, MP 2050 <sup>o</sup> C				
Single crystal				
Linde		24, 25		
Multicrystalline				
Alberox A-950	892			15
A-962	820	45		
American Lava 576	1050	45		
614	1035	45		
719	960	45		
Armour Research, density = 3.32				16, 17
E-11				18, 19
E-20				20
A-76				21-23
A-75				24-26
mixtures				27
Carborundum 1542	1085	46		
Centralab 205				28
206				28
Coors AD-99	1300	46		
AD-995	~1500	46		
MC-2014	-	46		
RR	800	47		
Coors-NBS 10F2	800			28
Diamonite B-890-2	960	47		
P-3662	975	47		
Frenchtown 7225				28
General Electric Lucalox (1965)	365	29, 48		
"    "    "    (1960)	1000			29
Interntl. Pipe & Ceramic V-69				29
"    "    "    TC-301				
"    "    "    TC-302-H	~900			29
"    "    "    TC-351	~1000			30



	T <sup>o</sup> C	T. R. 182	Summary T. R. 1	T. R. 203
Bismuth silicate				35
Boron nitride, hexagonal, 3000 <sup>o</sup> C sub- limes				36
Carborundum, hot-pressed	1130	53		
High-Temperature Materials, pyrolytic		31		37
National Carbon, hot-pressed HBN	1400			38
"        "        "        HD-0056	-			39
"        "        "        HD-0086	940			39
Raytheon, pyrolytic	1740			40
Calcium carbonate				
Single crystal mineral (Calcite), hexagonal, decomposes at 894 <sup>o</sup> C				41
Calcium fluoride				
Single crystal, cubic, m. p. 1360 <sup>o</sup> C				
M. I. T., Crystal Physics Laboratory				42
M. I. T., Ceramics Laboratory				43
Cerium fluoride, m. p. 1460 <sup>o</sup> C				
Ceramic, M. I. T., Lab. Ins. Res.				44
Chromium oxide				
Single crystal, hexagonal, m. p. 1990 <sup>o</sup> C				
Linde		32		
Cobalt oxide				
Single crystal, cubic, m. p. 1935 <sup>o</sup> C				
M. I. T., Crystal Physics Lab.				44
Cobalt oxide/nickel oxide mixed crystal,				
M. I. T., Crystal Physics Lab.				44
Copper halides, m. p. 430 <sup>o</sup> -605 <sup>o</sup> C				
Pressed-powder, M. I. T., Lab. Ins. Res.				44
Hafnium oxide, cubic, m. p. 2810 <sup>o</sup> C				
Multicrystalline				
Zirconia			20, 24	
Hydrogen oxide, glacial, ices, see Sec. II				
Lanthanum aluminate, m. p. 1612 <sup>o</sup> C				
Single crystal				
National Lead		33		
Lead bromide, orthorhombic, m. p. 373 <sup>o</sup> C				
Single crystal, M. I. T., Crystal Physics Lab., also see see Final Report under Contract Nonr-1841(88), March 11, 1965				45
Lead bromide/lead chloride mixed crystals, see above				45
Lead chloride				45

	T <sup>o</sup> C	T. R. 182	Summary	
			T. R. 1	T. R. 203
Magnesium-aluminum silicate (cordierite)				
Multicrystalline, Raytheon	T=550			45
Magnesium carbonate, d 350 <sup>o</sup>				
Pressed powder				45
Magnesium oxide, cubic, m. p. 2800 <sup>o</sup> C				
Multicrystalline				
Kodak Itran-5				46
M. I. T., Lab. Ins. Res.		34, 36		
Minneapolis Honeywell				
Magnesium metasilicate, steatite fired to clinoenstatite, monoclinic, de- composes at 1570 <sup>o</sup> C				
Multicrystalline				
Bell Telephone Labs. F-66	T = 780			46
Internatl. Pipe & Ceramic TC 503				46
Magnesium orthosilicate (fosterite), orthorhombic, m. p. 1890 <sup>o</sup> C				
Multicrystalline				
Steatite-Magnesia AG Frequentia M				47
Magnesium titanate, MgTiO <sub>3</sub>				
Multicrystalline, U.S. Sonics				48
Magnesium fluoride, tetragonal, m. p. 856 <sup>o</sup> C				
Single crystal, Columbia Univ.				49
Nickel oxide, cubic, m. p. 1990 <sup>o</sup> C				49
Rubidium manganese fluoride, RbMnF <sub>3</sub>				
Single crystal, cubic, m. p. 1050 <sup>o</sup> C				
M. I. T., Materials Center				49
Silicon				
Single crystal, cubic, m. p. 1420 <sup>o</sup> C, Brown Univ.				50
M. I. T., Crystal Physics Laboratory				50
Silicon carbide				
Multicrystalline				
Carborundum				51
With BeO				
National Beryllia Corp. Carberlox				52
Silicon dioxide				
Single crystal quartz mineral, hexagonal-cubic; m. p. 1710 <sup>o</sup> C (Prog. Rep. No. XXXIV, L. I. R., p. 65)				52, 53

	T <sup>o</sup> C	T. R. 182	Summary T. R. 1	T. R. 203
Silicon dioxide (cont.)				
Fort Monmouth				
Glasses (glass mica mixtures and glass ceramics, see Sec. II)				
American Optical Amerasil, clear	T >1400	53		
"  transpar.	T =1165	53		
Corning 7940	T >1500			54, 55
C. E. 101	T =1170	38, 39, 55		
Mixed Silicate glasses				
Corning Lab. No. 119BUC				55
Corning, Code 1723				55
Lancaster 7352				56
7357				56
L1957				57
L8100				58
Owens-Corning X 994				59
Pittsburgh Plate Glass, plate glass				59
"          "          "  sheet glass				59
Silicon nitride, sublimes at 1900 <sup>o</sup> C				
Pyrolytic, North American Res.			27	
Ceramic, Haynes Stellite			26	
Silver iodide				
Pressed powder, L. I. R.				60
Sodium chloride + BiCl <sub>3</sub> , M. I. T., Crystal Physics Lab., see Quart. Prog. Rep. No. 8,				
Strontium fluoride, cubic, m.p. > 1450				
Single crystal, M. I. T., Crystal Physics Lab.				61, 62
Tantalum oxide, orthorhombic, de- composes at 1470 <sup>o</sup> C				
Ceramic, Ciba powder, fired at L. I. R.		42		
Thallium bromide crystal, M. I. T., Crystal Physics Lab.				63
bromide-chloride cryst., ditto				63
bromide-iodide          "          "				63
Thallium chloride crystal				63
Thallium fluoride pressed powder				63
Thallium iodide, polycrystalline				63
Thorium oxide, cubic, m.p. 3050 <sup>o</sup> C				
Ceramic, L. I. R., M. I. T.		40, 41		
Zirconia				

	T <sup>o</sup> C	T. R. 182	Summary T. R. 1	T. R. 203
Vanadium oxide (V <sub>2</sub> O <sub>3</sub> ), pressed powder				63
Yttrium oxide (Y <sub>2</sub> O <sub>3</sub> ), m. p. 2410 <sup>o</sup> C				
Single crystal, M. I. T., L. I. R.		43		
Ceramic, Zircoa			25	
Zinc oxide (ZnO), hexagonal, m. p. 1975 <sup>o</sup> C				
Single crystal, Airtron Division, Litton Industries				63
Zirconium oxide (ZrO <sub>2</sub> ), mono. -cubic, m. p. 2715 <sup>o</sup> C				
Ceramic Zircoa, tech. grade			21, 24	
"      "      nuclear grades			22-24	
"Zircolite", AFML				64
Zirconium silicate (zircon)				
Single crystal, mineral				65, 66, 67

## II. MINERALS, ROCKS, SOILS, MISCELLANEOUS INORGANICS

### Single crystal minerals

Apatite				68, 69
Astrophyllite				69
Benitoite				69
Beryl				70, 71
Calcite, see Sec. I				
Neptunite				71
Quartz, see Sec. I				
Spodumene				72, 73, 74
Topaz				75, 76
Tourmaline				76
Zircon, see Sec. I				

### Crushed minerals

Halite				77
Limonite				77
Magnesite				77
Quartz sand				77

### Rocks

Basalt, Hawaiian, dense				78
"      "      porous				78
Granite, Quincy				79
"      Virginia				79

	T. R. 203
Greenstone, Virginia	80
Limestone	80
Rhyolite	81
Sandstone, almond	81
Soils	
Hawaiian	82
Mass. loams	83
Fullers earth, Foxboro	82
Desert sand	83
Miscellaneous inorganics and mixtures	
Ices, glacial	84, 85, 86
CFI 1003, 1006 attenuator materials	87
Corning 7941, 9606, see T.R. 182, p. 55	
Ferrites, General Ceramics:	
3308D, 3310, 3321, 3330, "Q"-3	88
R-1, R-4, R-5, R-6	89, 90
"Havelex" glass-bonded micas:	
Types 1080, 1090, 1101, 2101, 2103, 2801, 2803	91
"Mycalex" 410, 500, 555, 560, 620	91, 92, 93
Asphalt pavement and asphalts	94
Concrete pavement	94

### III. ORGANIC COMPOUNDS

American Cyanamid, cyanoethylated	
cotton molding	95
"Cymac" 325	96
AVCO Research Labs. , polyvinylidene fluoride	97
H. I. Crowley Co. , polyiron attenuator	97
Dow Corning Corp. , molding compound 306	98
"Silastic" RTV 501	
RTV 521	
1602	
RTV 5350	
S-6538	
"Sylgard" 182	
DC-92-007	
Dupont de Nemours and Co. , "H" film	99, 100, 101
"Teflon" FEP	101, 102
"Teflon" TFE	103

"Teflon" 100 ,	102, 103
"Teflon" 9033	102
Electronized Chemical Corp. "Polyguide"	104
Emerson and Cumming, A-19 attenuator material	104
General Electric Silicone Rubber SE 900	105
"Lexan"	105
Minnesota Mining and Metallurgy, "3M" board	106
Nopco Chemical Corp. , polyurethane foam	106
Polymer Corp. , "Fluorosint"	106
Rex, William Brand, Div. American Enka Rexolite, 1422	107
"Rexolite" 2200	108
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Rogers Corp. , "Duroid" 5870	110
Shell Chemical, "Epon" 828 + PMDA epoxies	111, 112
Tellite Corp. , "Tellite" 3A	112
Union Carbide Corp. , Plastics Div. , polysulfone	113
U. S. Air Force Materials Laboratory, Wright-Patterson Air Force Base, Fiberglass laminates	113, 114

IV. LIQUIDS

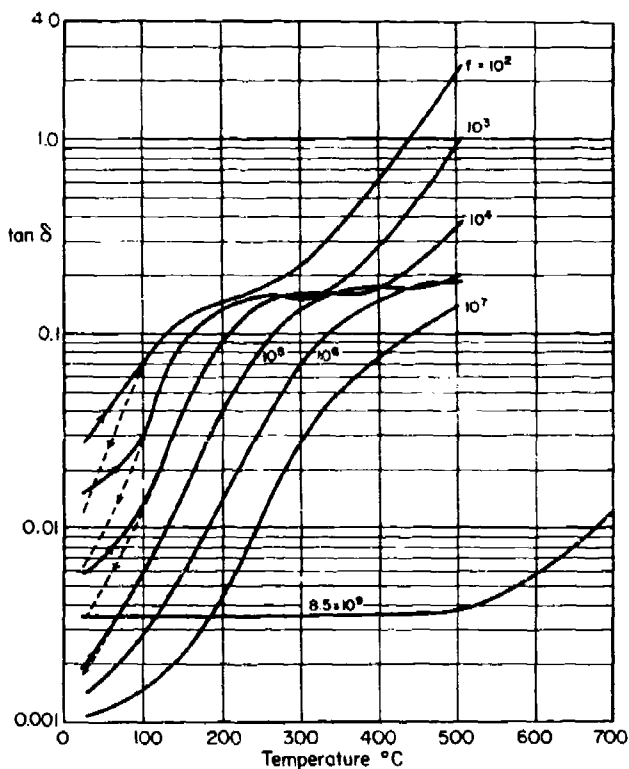
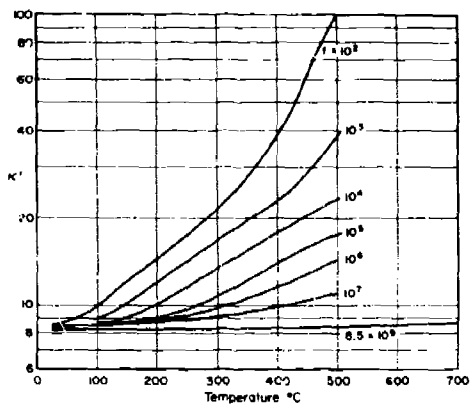
Dow Chemical, "Dowtherm" A	115
Esso, "Teresso" oil	115, 116

V. FOODSTUFFS

Cooking oil, Kremax, Armour	117
Beef steak, lean, frozen and vacuum dried	118
Raw potatoes	118
Potatoe flakes	118
Potatoe chips	118
Instant coffee, powder	119
Instant tea, powder	119
Eggwhite	119
Bread	119
Bread dough	119



Aluminum nitride, hot pressed  
The Carborundum Co.



Aluminum oxide

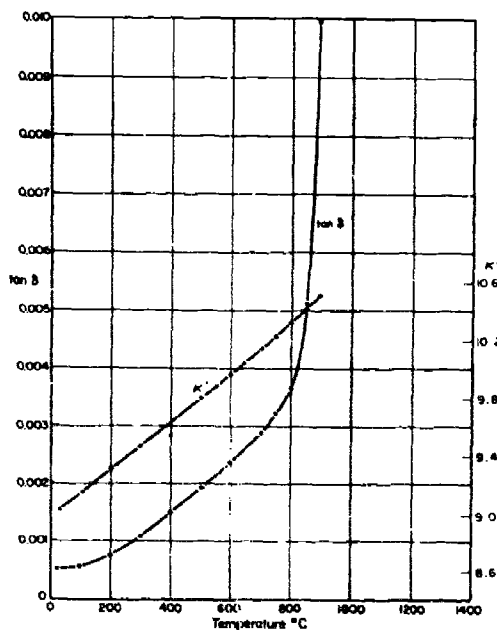
Alberox Corp. A-950  
3.663 g/cm<sup>3</sup>

T <sup>o</sup> C	$\kappa'$	$\tan \delta$
25	9.01	.00051
100	9.14	.00055
200	9.30	.00074
300	9.46	.00108
400	9.53	.00149
500	9.79	.00192
600	9.95	.00237
700	10.13	.00288
750	10.22	.00320
800	10.31	.00367
850	10.41	.0051
892	10.50	.010

3.89 - 3.61 GHz

8.500 GHz

25 8.98 .00058



Alumina, high-purity

Armour Research Foundation

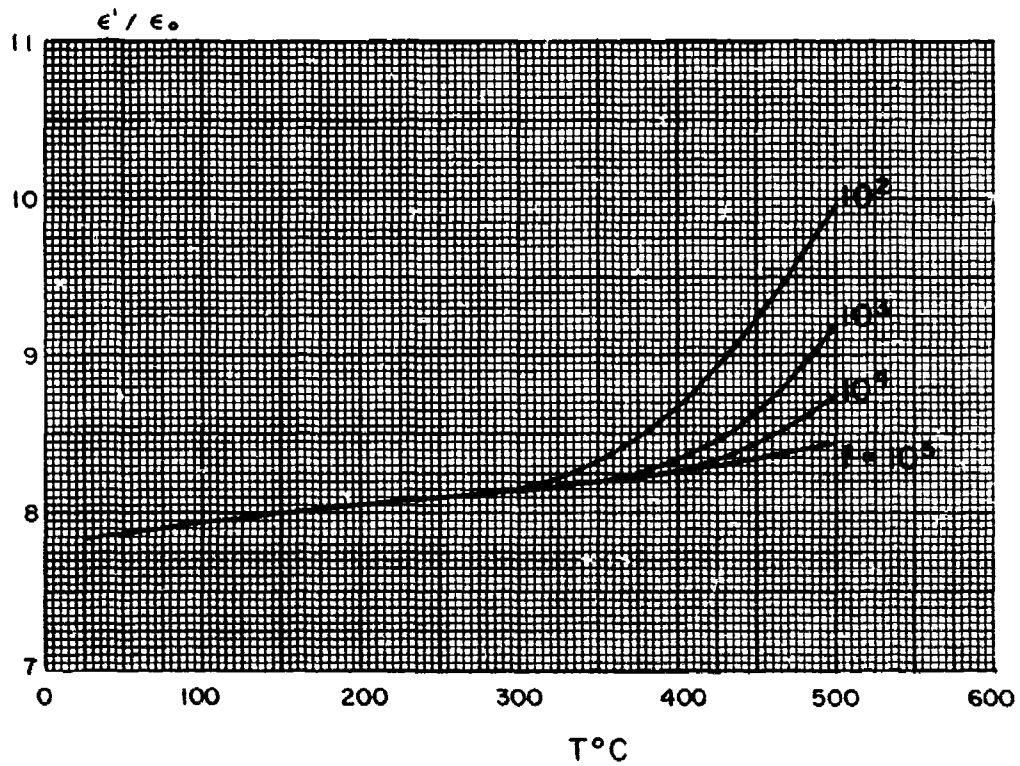
From Alcoa 99.99% Al with HF, fired air 1820°C

Spectrographic analysis: concentration of elements in parts per million:

Si	Mg	Fe	Ca	Cu
111	58	38	3	5

Density 3.32 g/cm<sup>3</sup>

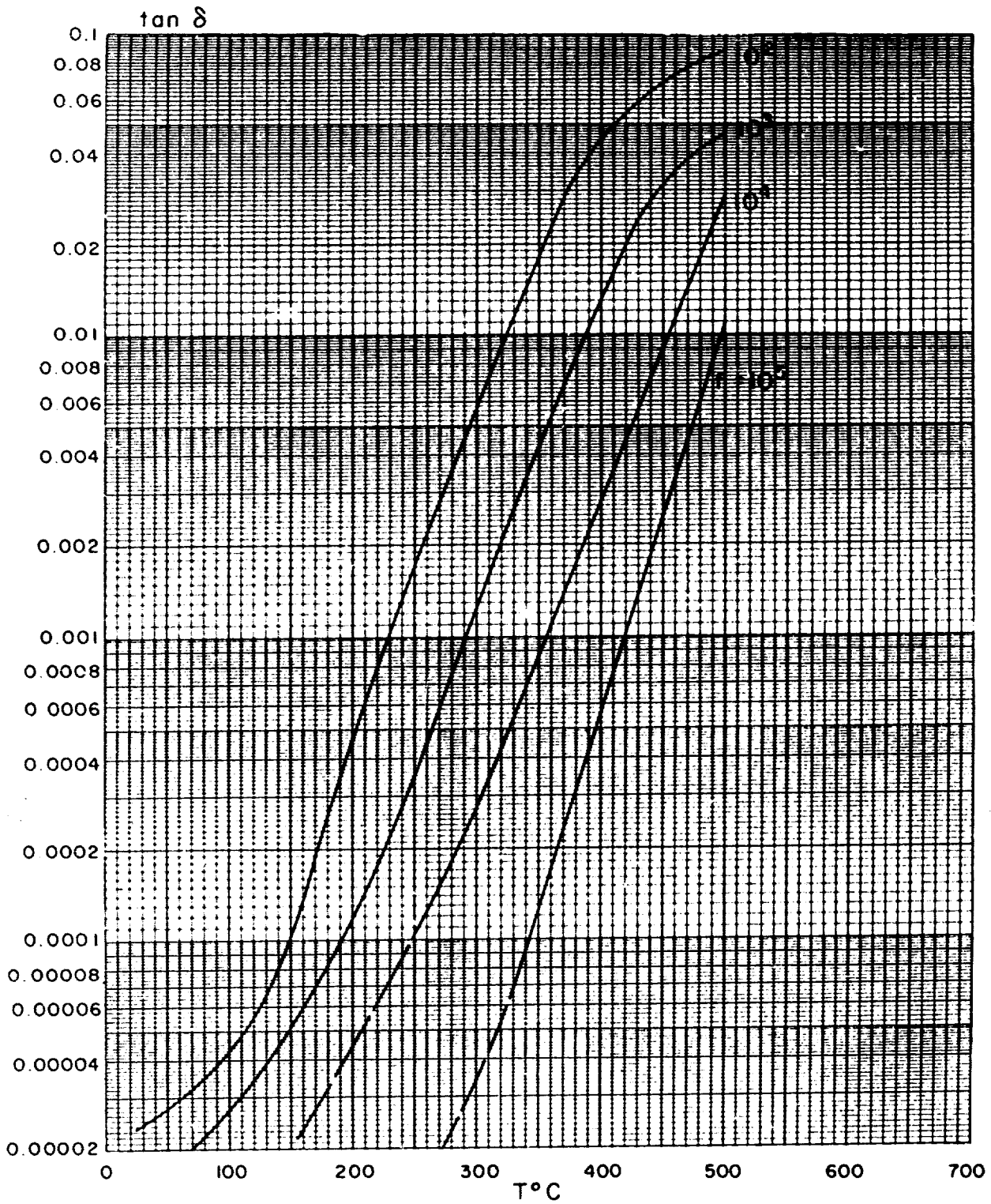
Fired silver electrodes



Alumina (cont.)

Armour Research Foundation

Density 3.32



Alumina, high-purity

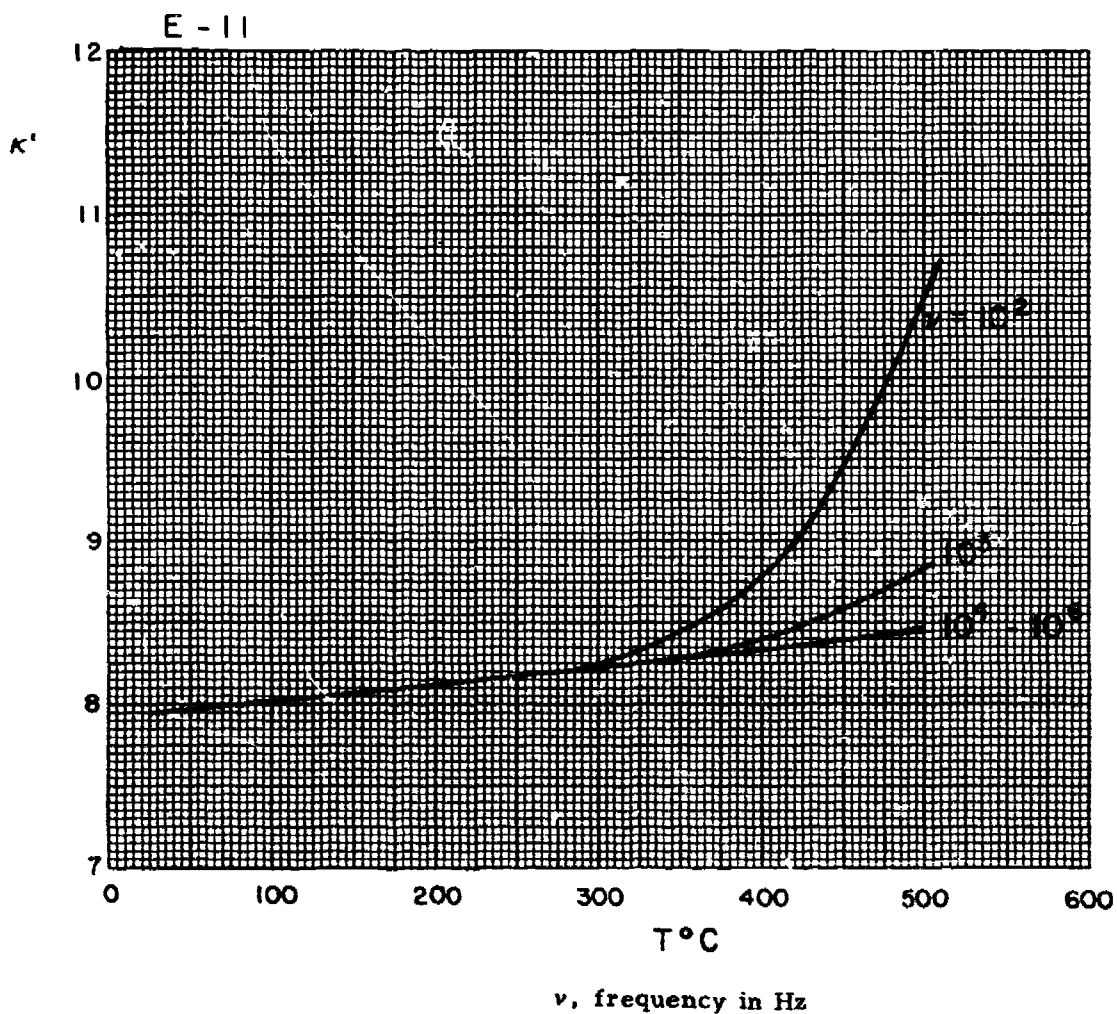
Armour Research Foundation

From Reynolds 99.999% Al with HF, fired air 1840°C

Spectrographic analysis: concentration of elements  
in parts per million:

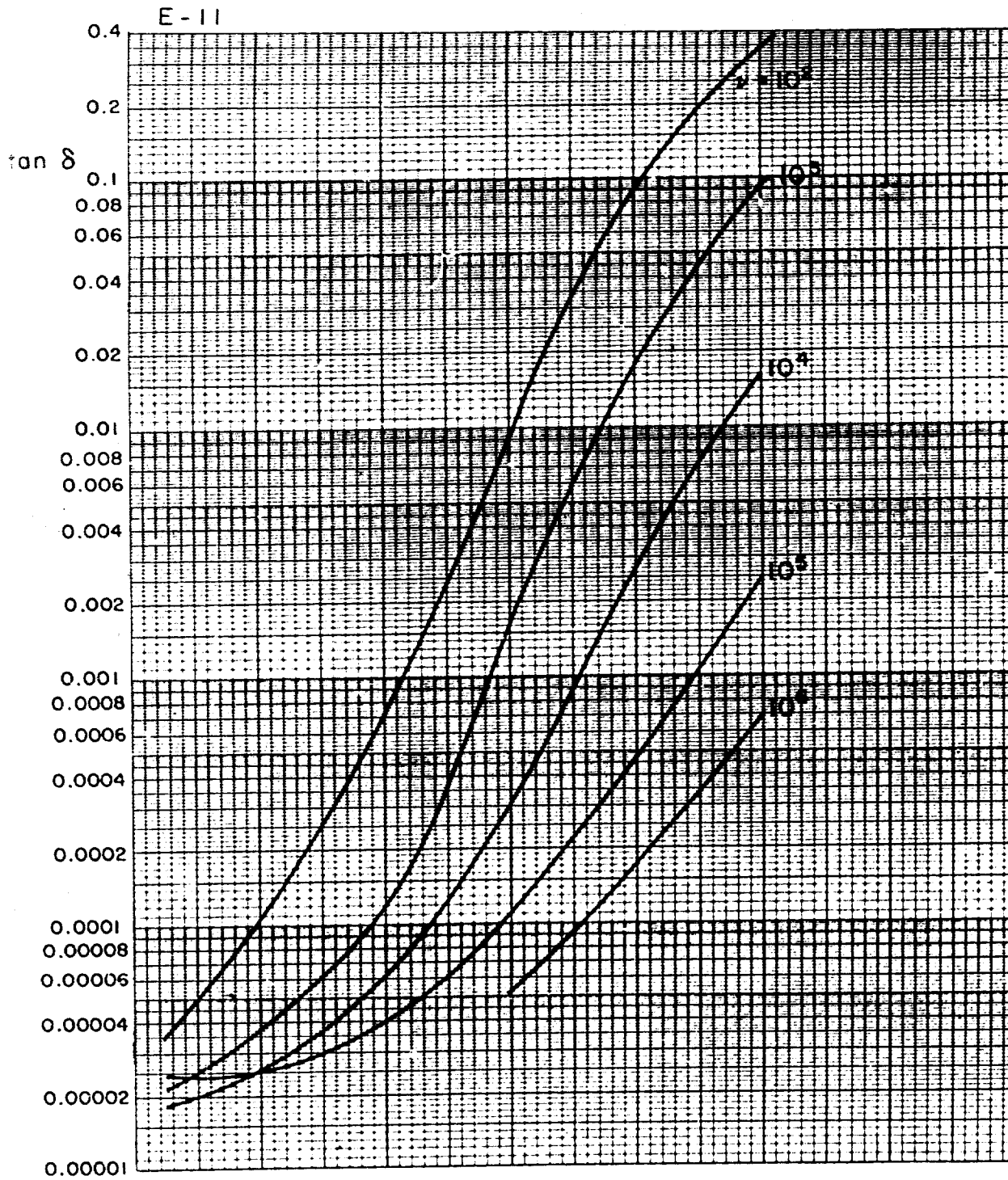
Si	Mg	Fe	Ca	Ni	Cr	Cu
60	30	60	15	5	4	3

Density 3.23 g/cm<sup>3</sup>



Alumina (cont.)

Armour Research Foundation



Alumina oxide with added silicic acid

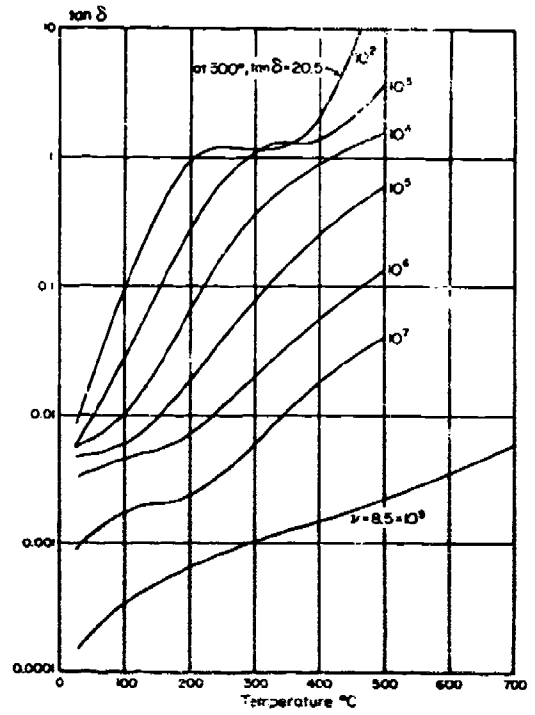
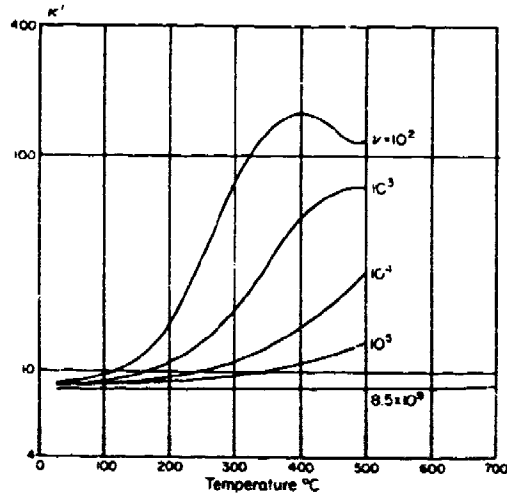
Armour Research Foundation

Fired air 1890°C

850 ppm Si, 550 ppm Na

Fired silver electrodes

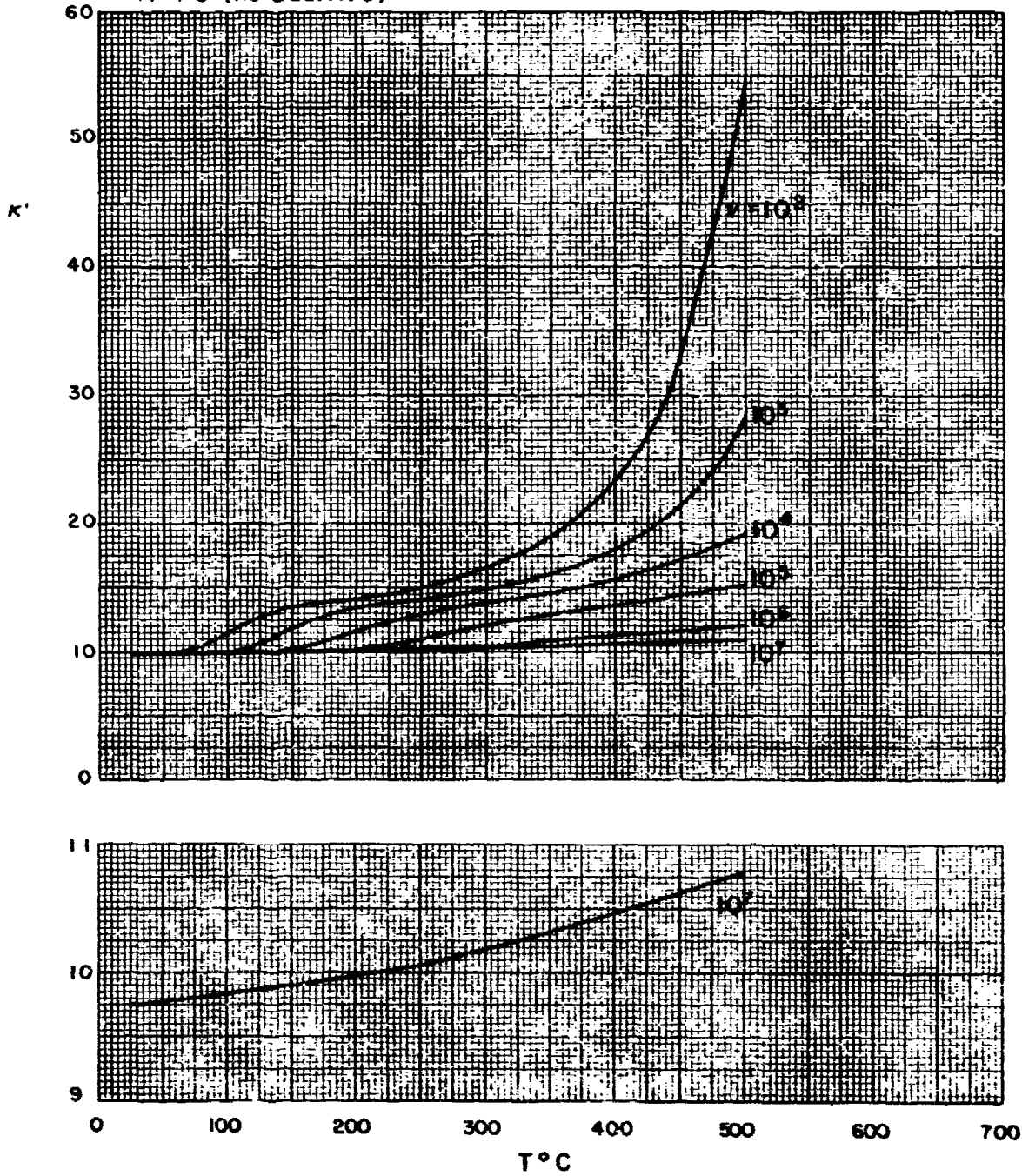
Density 3.49 g/cm<sup>3</sup>



Alumina, high purity, hot-pressed in C  
Density 3.84 g/cm<sup>3</sup>

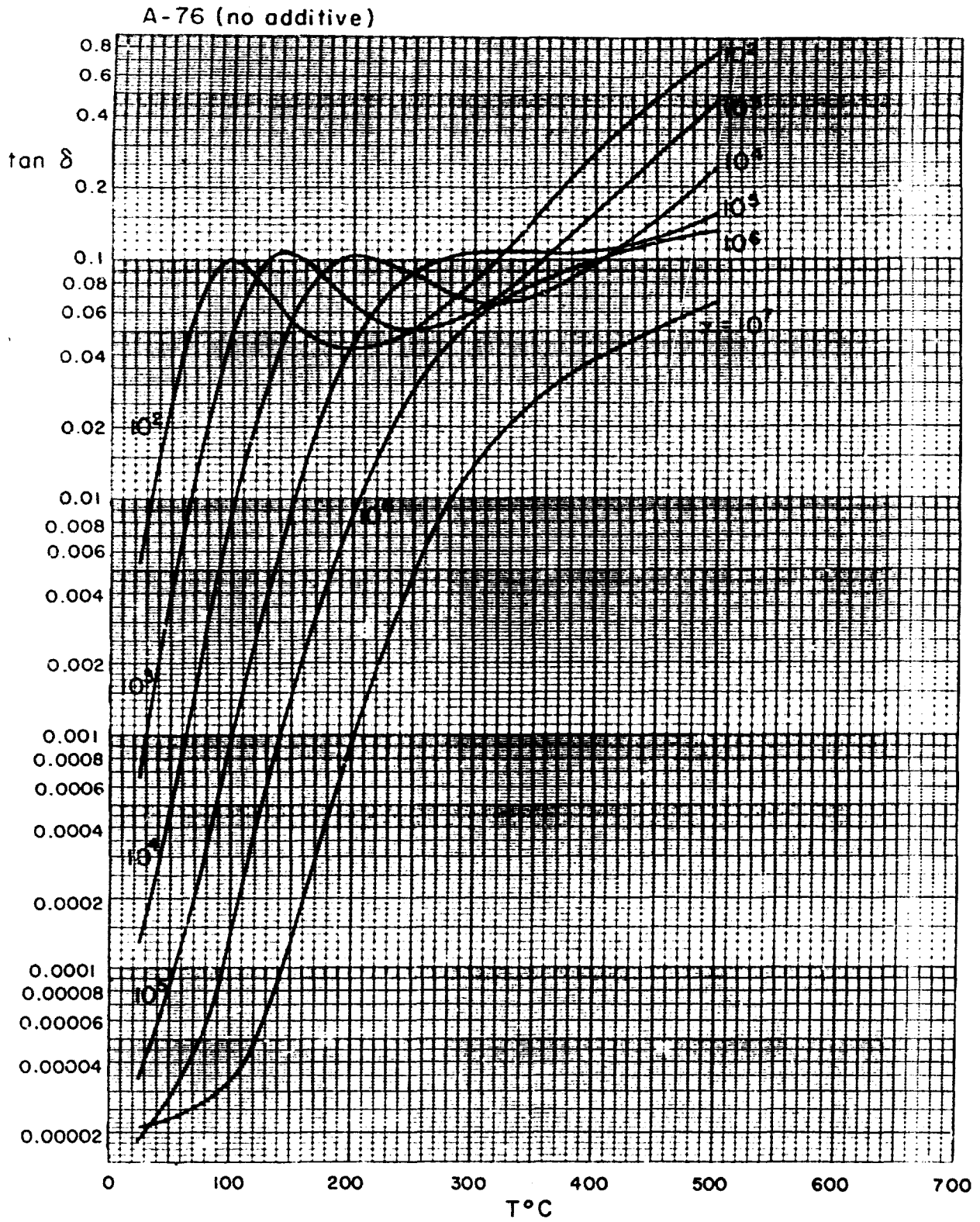
Armour Research Foundation

A-7G (no additive)



Alumina (cont.)

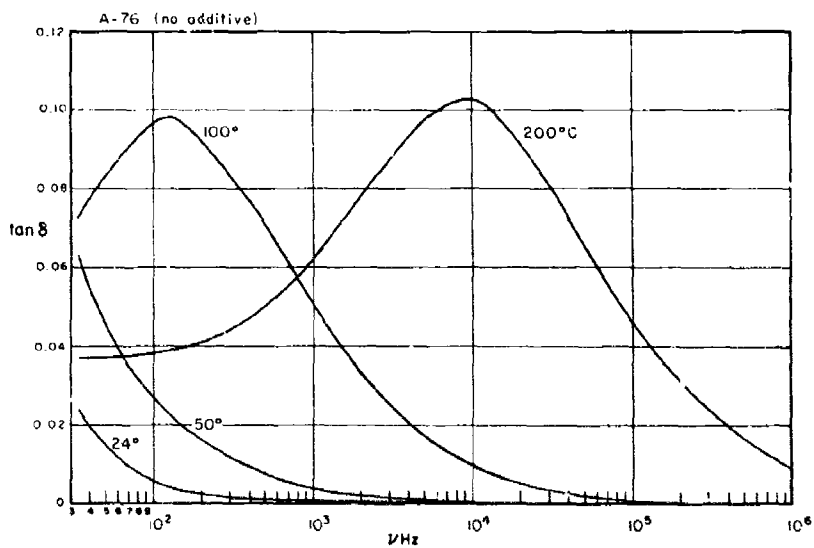
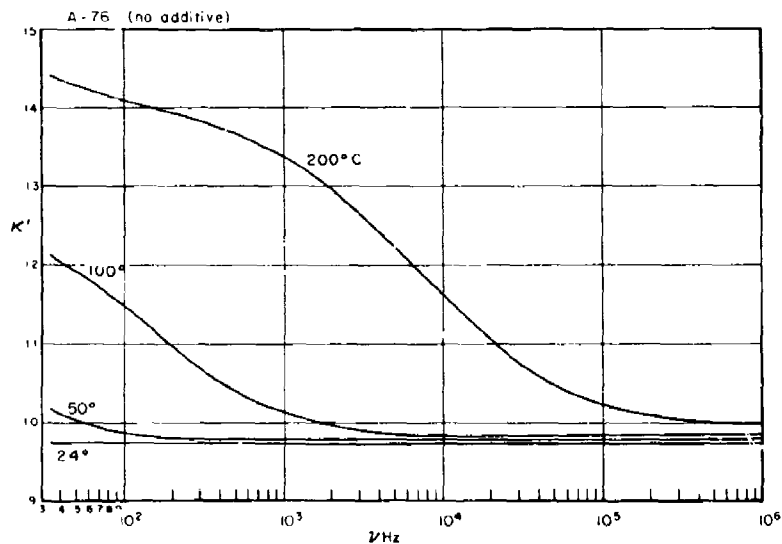
Armour Research Foundation





Alumina, hot-pressed

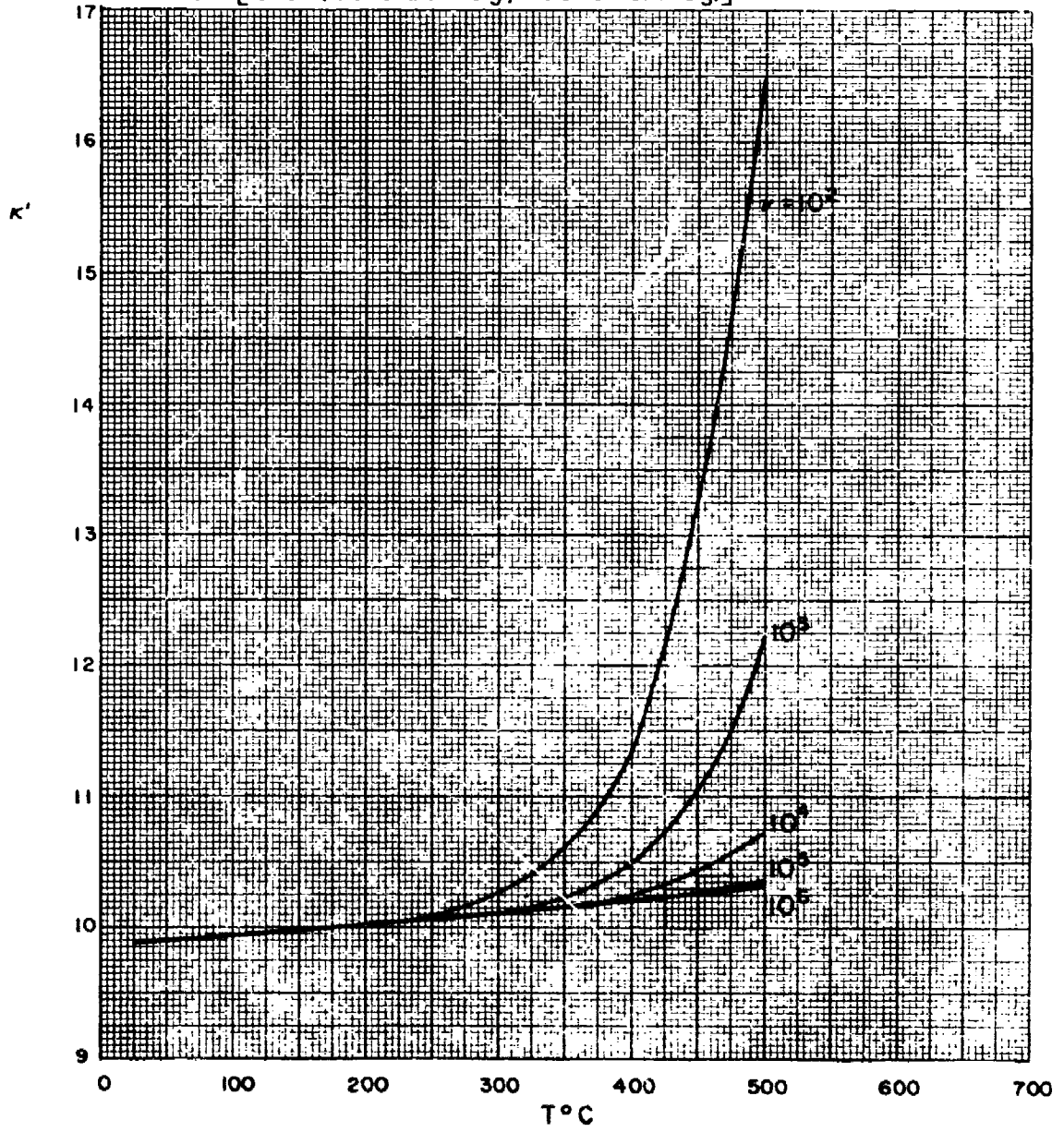
Armour Research Foundation



Alumina with 10% titanate addition

Armour Research Foundation

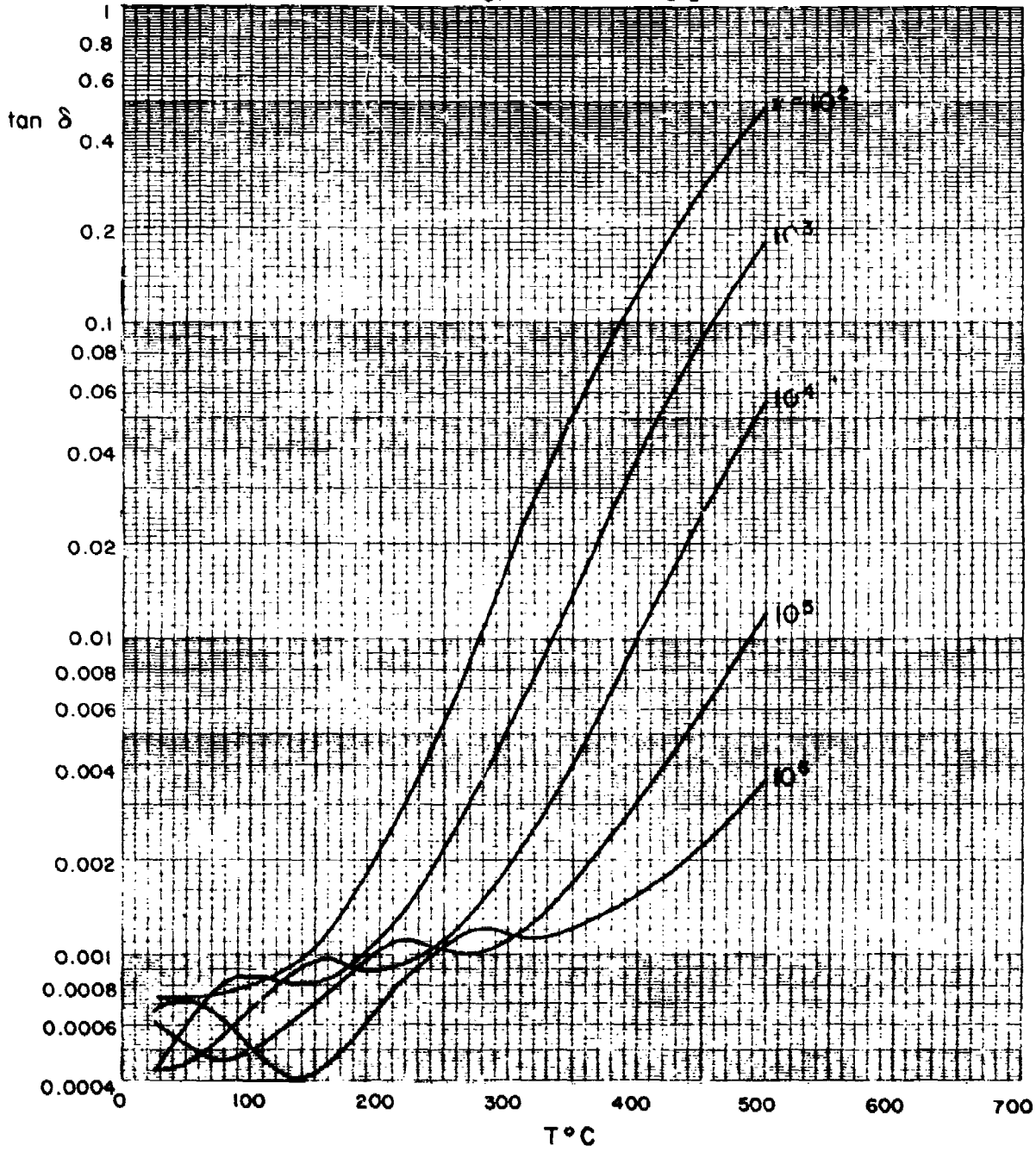
A-75 [10% (50% BaTiO<sub>3</sub>, 50% SrTiO<sub>3</sub>)]

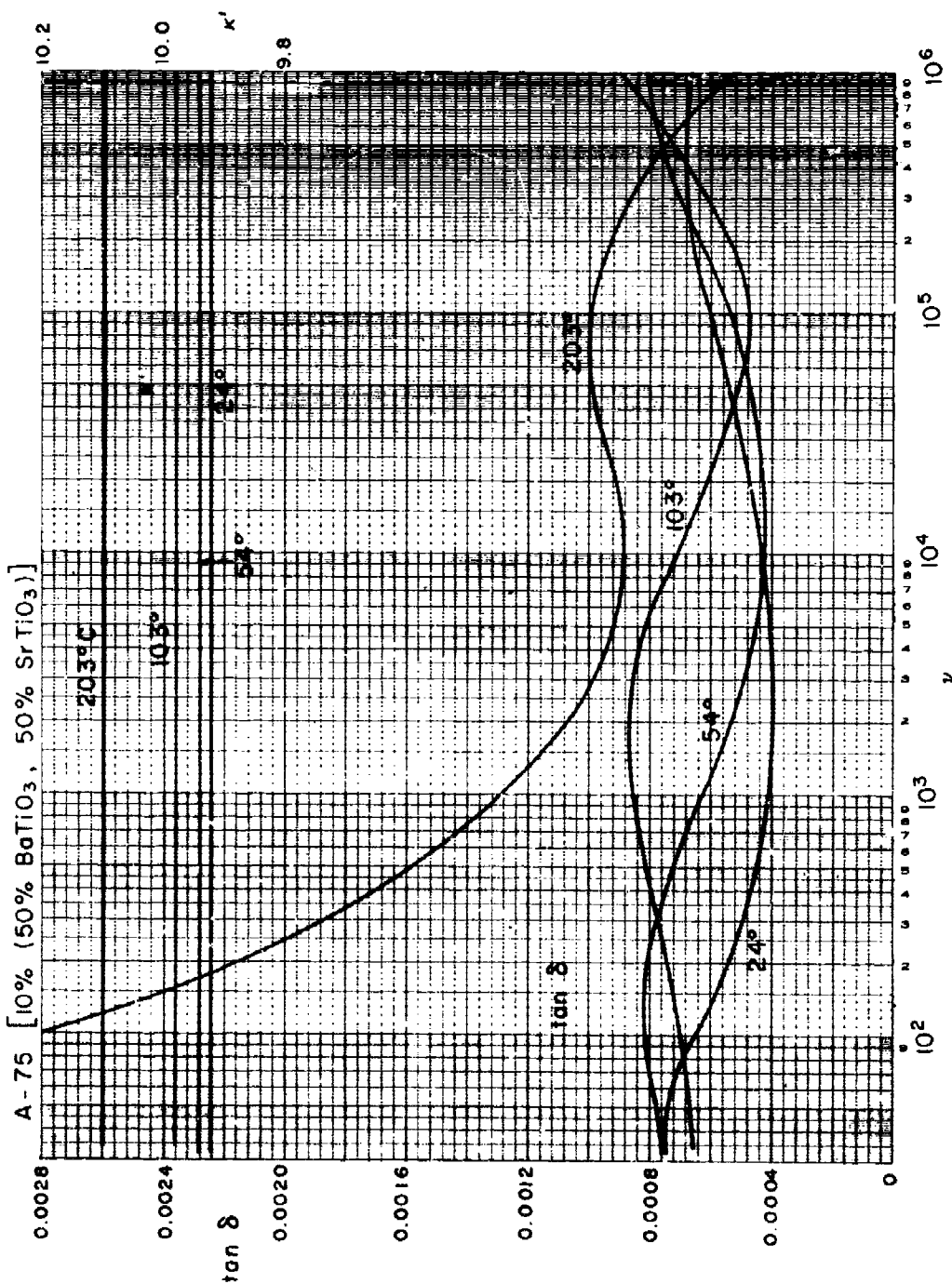


Alumina with 10% titanate addition

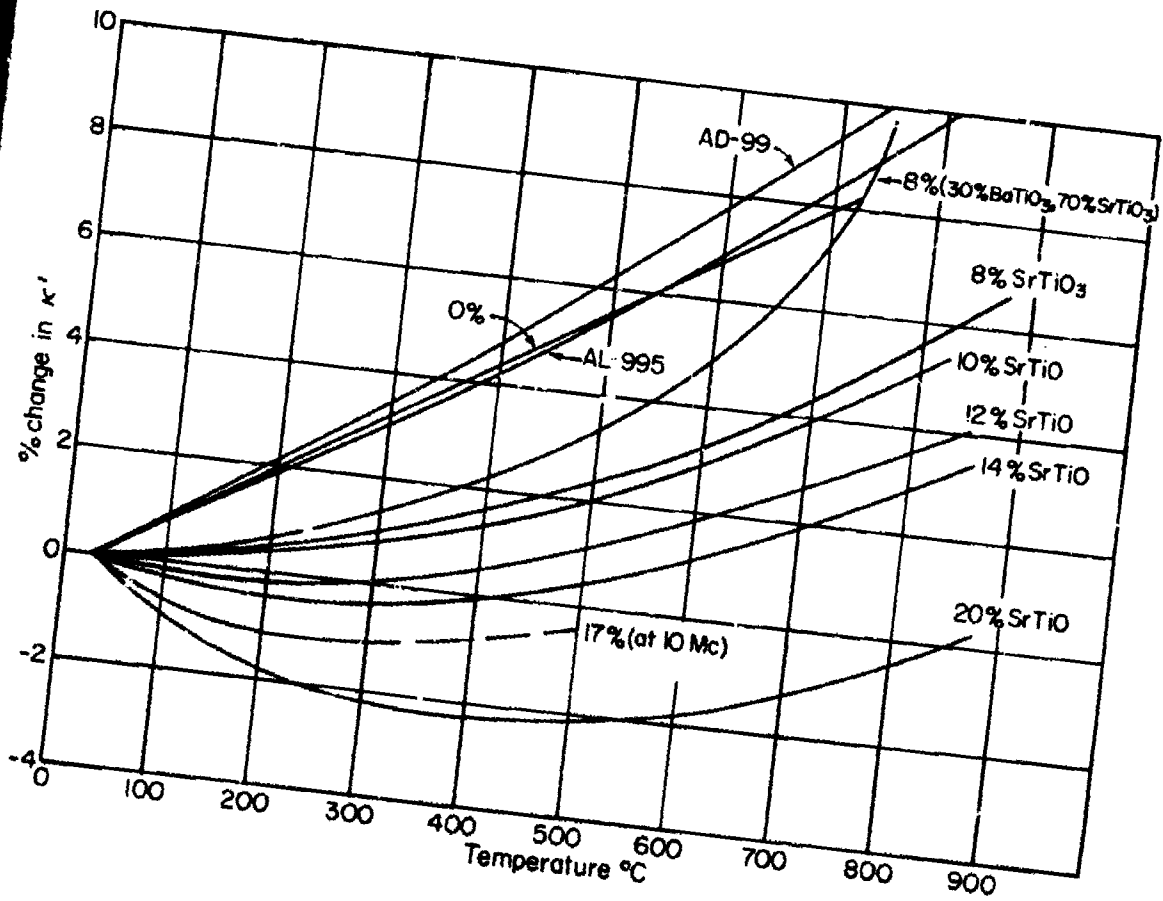
Armour Research Foundation

A-75 [10% (50% BaTiO<sub>3</sub>, 50% SrTiO<sub>3</sub>)]

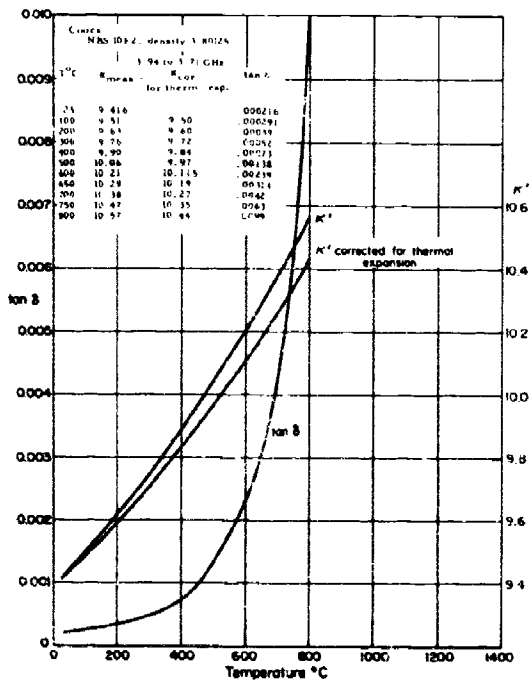
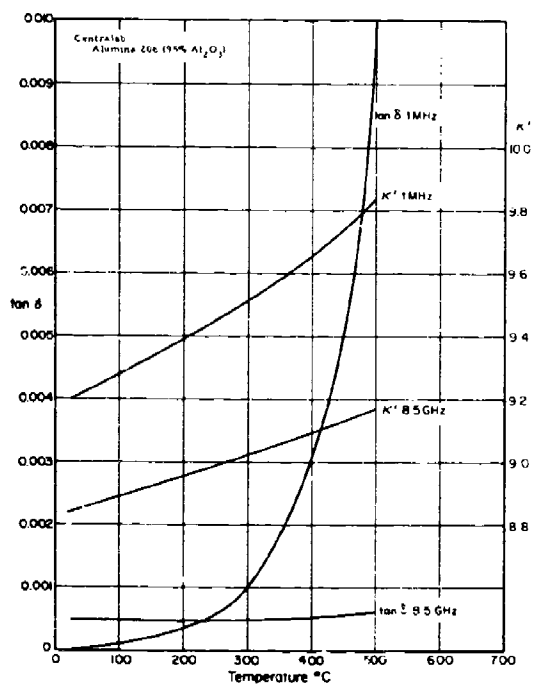
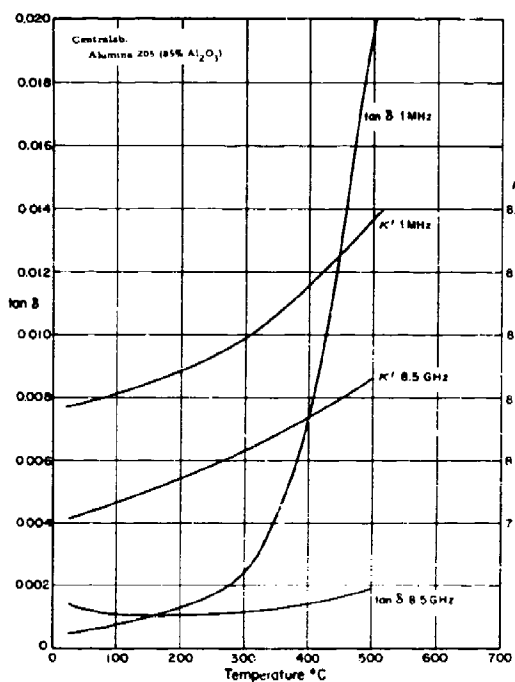




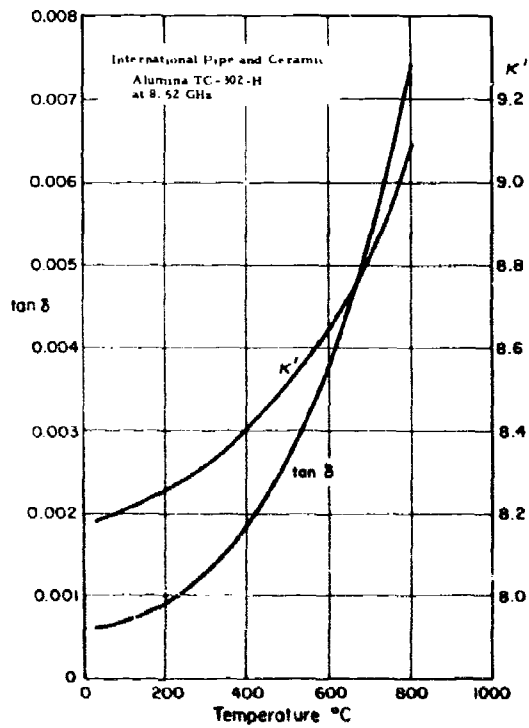
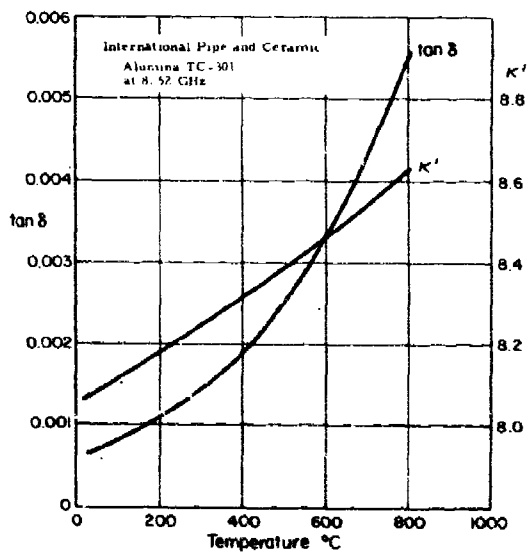
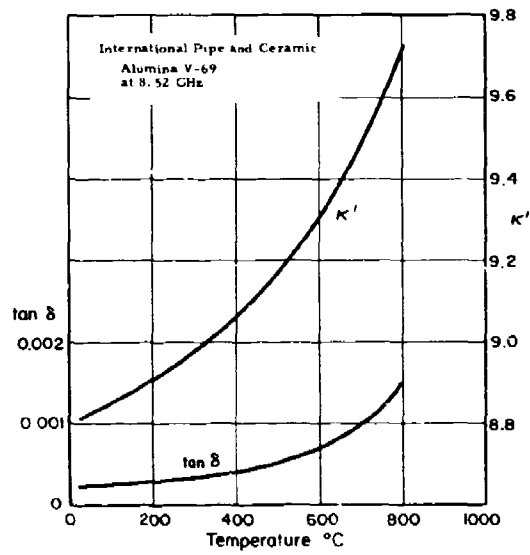
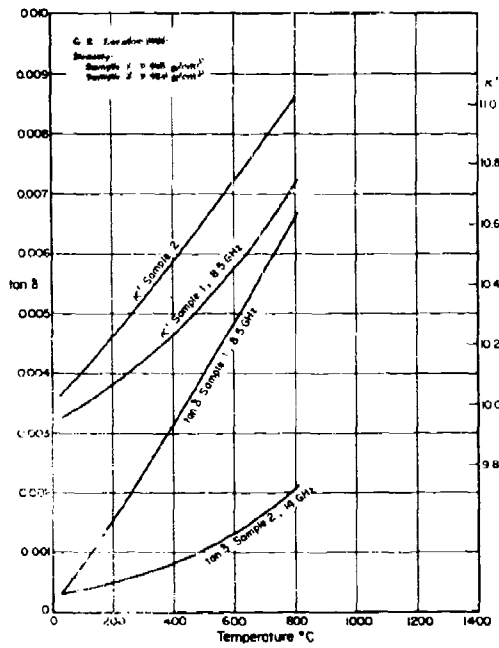
Change in dielectric constant  
with temperature for various  
aluminas at ca. 4000 MHz



Alumina (cont.)

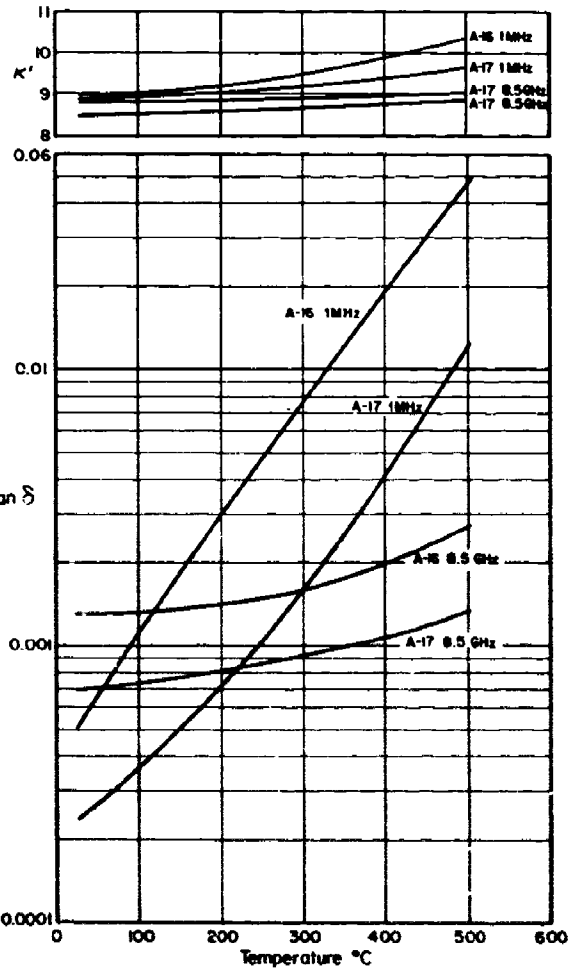
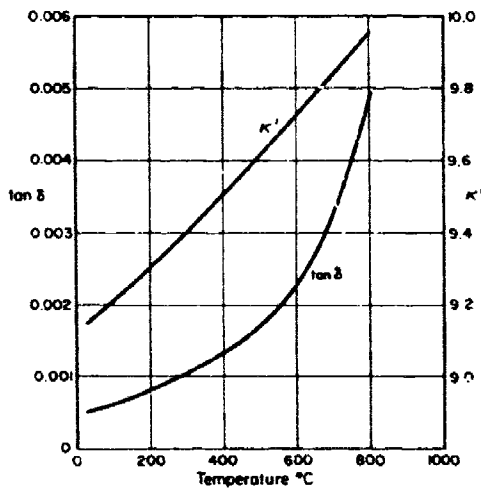


Alumina (cont.)



Raytheon  
Aluminas 1959

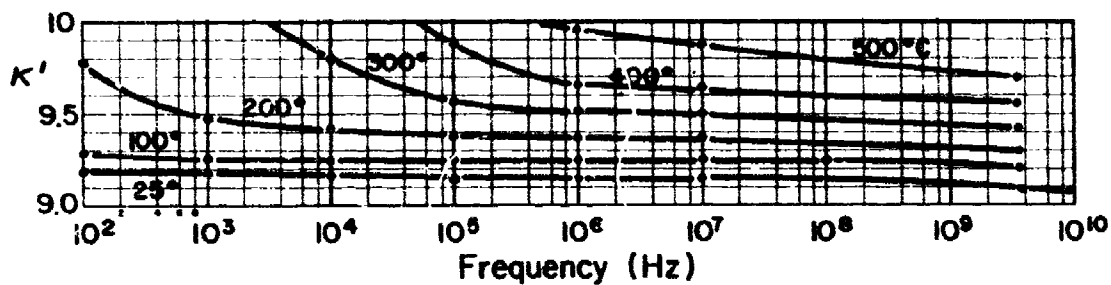
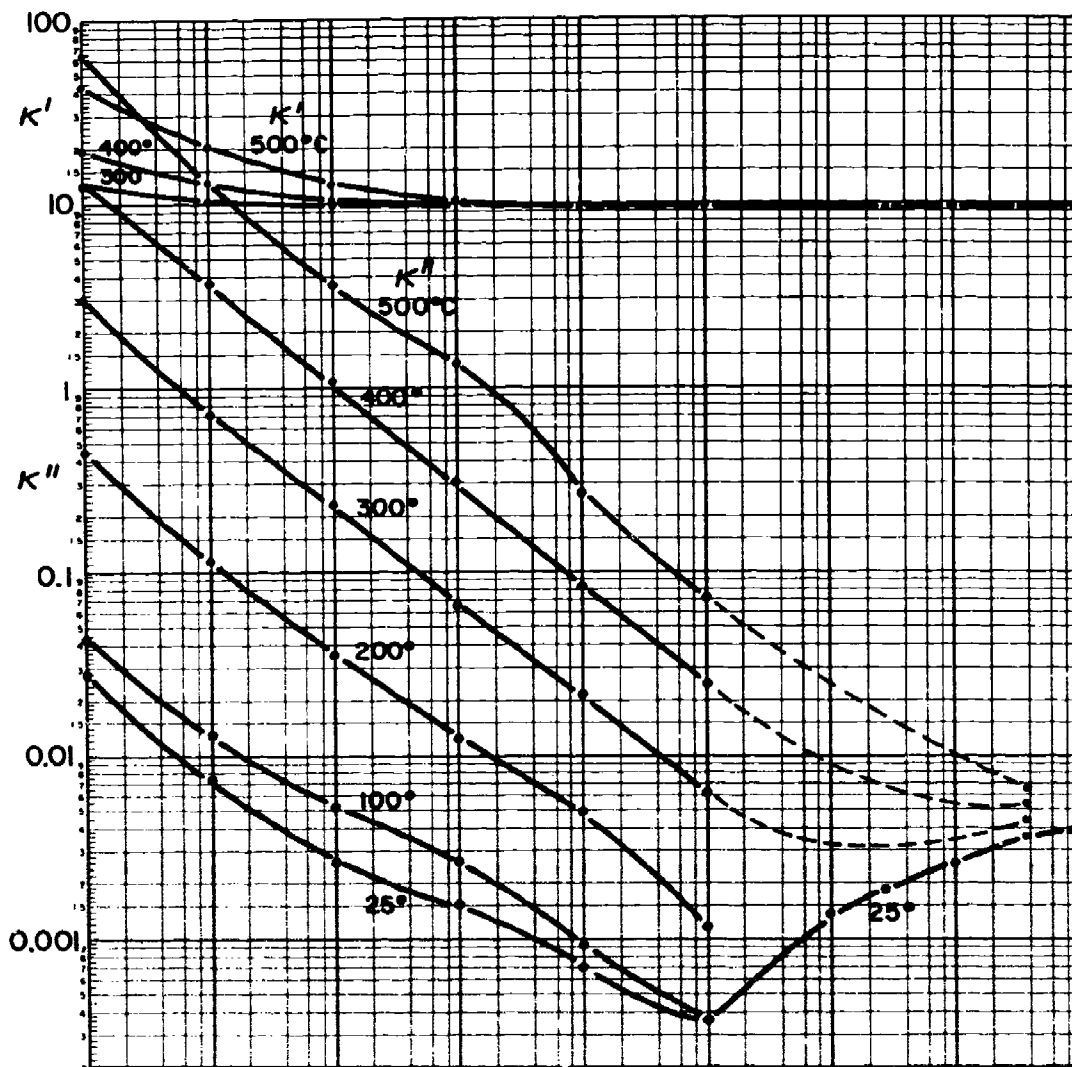
International Pipe and Ceramic  
TC-351  
at 8.52 GHz





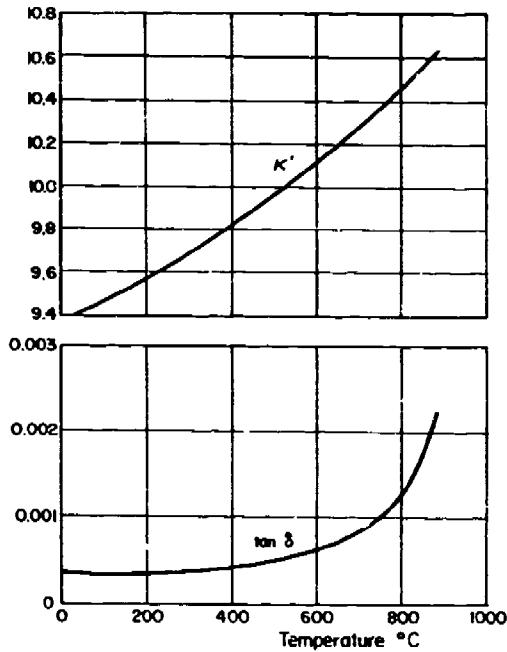
Alumina A-18  
Density 3.676 g/cm<sup>3</sup>

Steatit-Magnesia Aktiengesellschaft



Alumina, Western Gold and Platinum

Al-300 modified  
Density 3.771 g/cm<sup>3</sup>  
4.1 to 3.85 GHz



T <sup>o</sup> C	$\kappa'$	$\tan \delta$
25	9.39	.00037
122	9.48	.00037
185	9.55	.00038
258	9.63	.00038
339	9.74	.00041
393	9.79	.00045
500	9.95	.00055
572	10.08	.00064
788	10.43	.00120
881	10.63	.00219

At 25<sup>o</sup>C

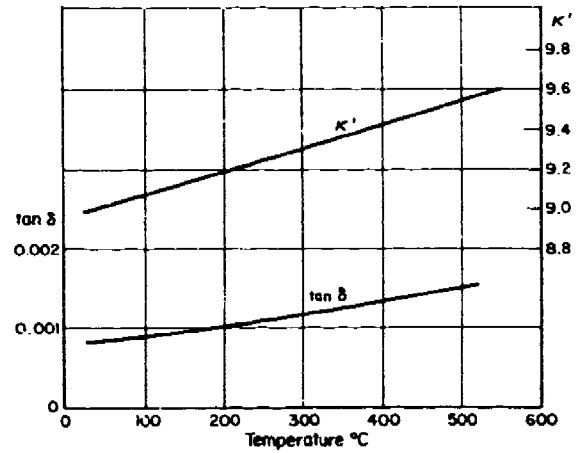
f (Hz)	$\kappa'$	$\tan \delta$
10 <sup>7</sup>	9.44	.00012
10 <sup>9</sup>	9.40	.00035
3x10 <sup>9</sup>	9.39	.00037
8.5x10 <sup>9</sup>	9.38	.00046

Alumina, Western Gold and Platinum

Al-500  
Density 3.665 g/cm

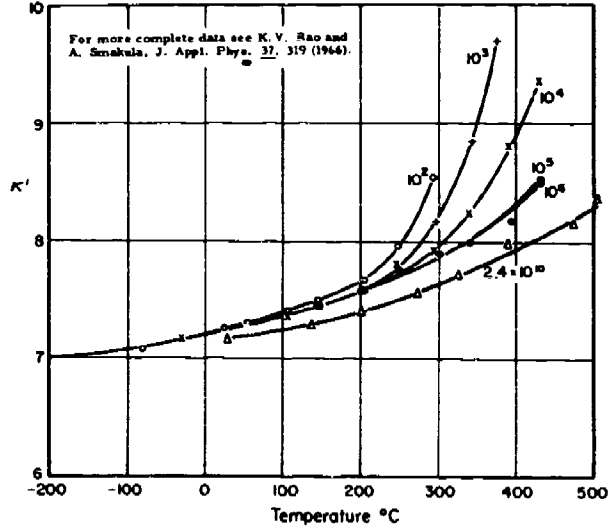
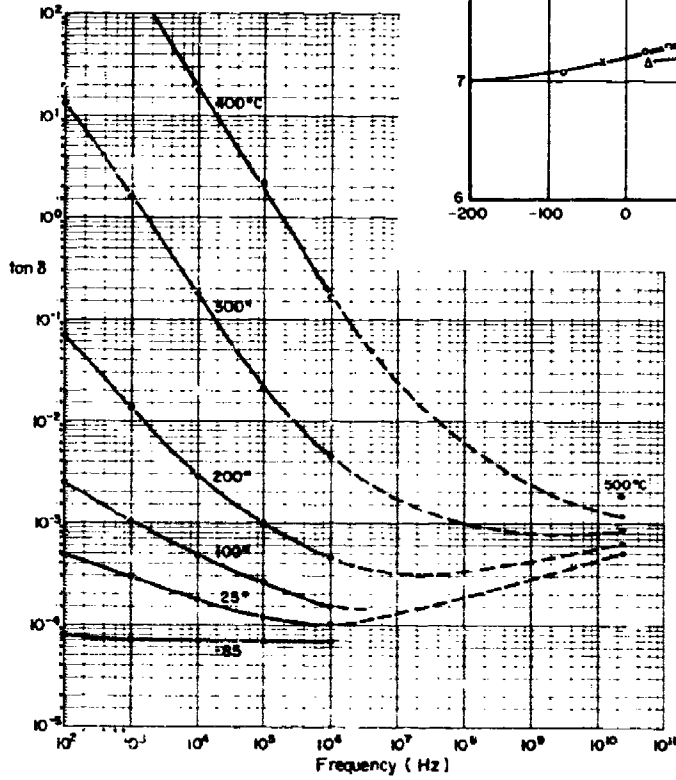
At 25<sup>o</sup>C

f (Hz)	$\kappa'$	$\tan \delta$
10 <sup>7</sup>	9.07	.00026
10 <sup>9</sup>	9.03	.00062
3x10 <sup>9</sup>	9.02	.00070
8.5x10 <sup>9</sup>	see the graph below	

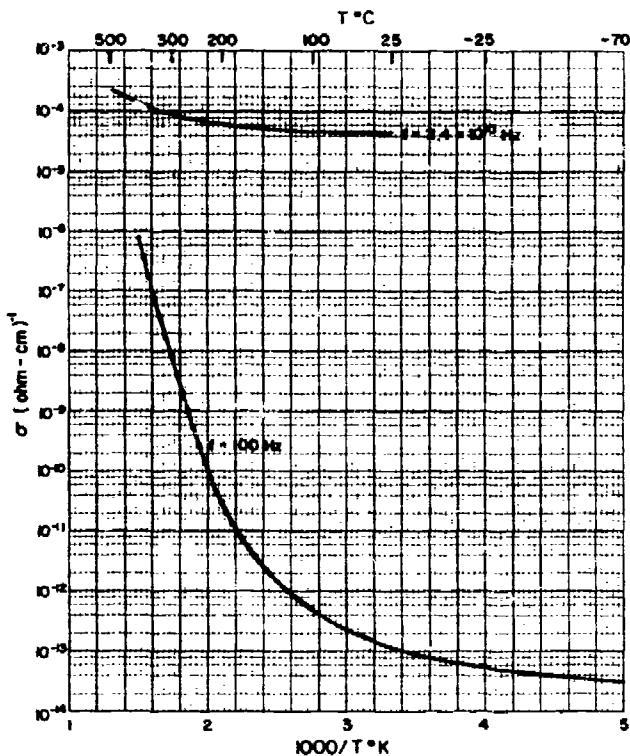


Barium Fluoride

Massachusetts Institute of Technology  
Crystal Physics Laboratory



Barium fluoride (cont.)



Beryllium oxide

BeO crystal KSC 7011A

Electronic Space Products Inc.

E || c axis

$10^2$  to  $10^7$  Hz

$\kappa' = 7.41 \pm 0.1$

$\tan \delta < 0.0006$

American Lava  
AlSiMag 754 (99.5% BeO)  
Density 2.851 g/cm<sup>3</sup>

Coors Porcelain Co.  
Beryllia BD98  
8.52 GHz

National Beryllia Corp.  
Berlox  
8.52 GHz

8.52 GHz			8.52 GHz			8.52 GHz		
T <sup>o</sup> C	$\kappa'$	$\tan \delta$	T <sup>o</sup> C	$\kappa'$	$\tan \delta$	T <sup>o</sup> C	$\kappa'$	$\tan \delta$
25	6.86	.00031	25	6.67	.00050	25	6.64	.00043
300	6.98	.00055	300	6.87	.00072	300	6.77	.00068
500	7.13	.00062	500	7.13	.00102	500	6.98	.00093

Beryllium silicate crystal KSC 7013

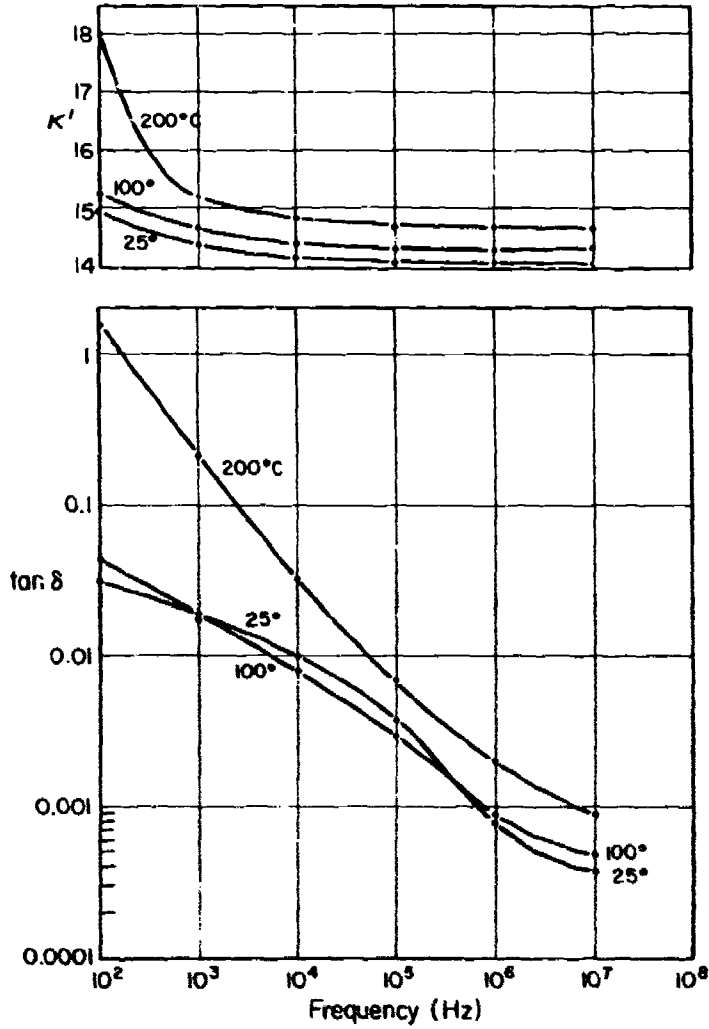
Electronic Space Products Inc.

E || optic axis

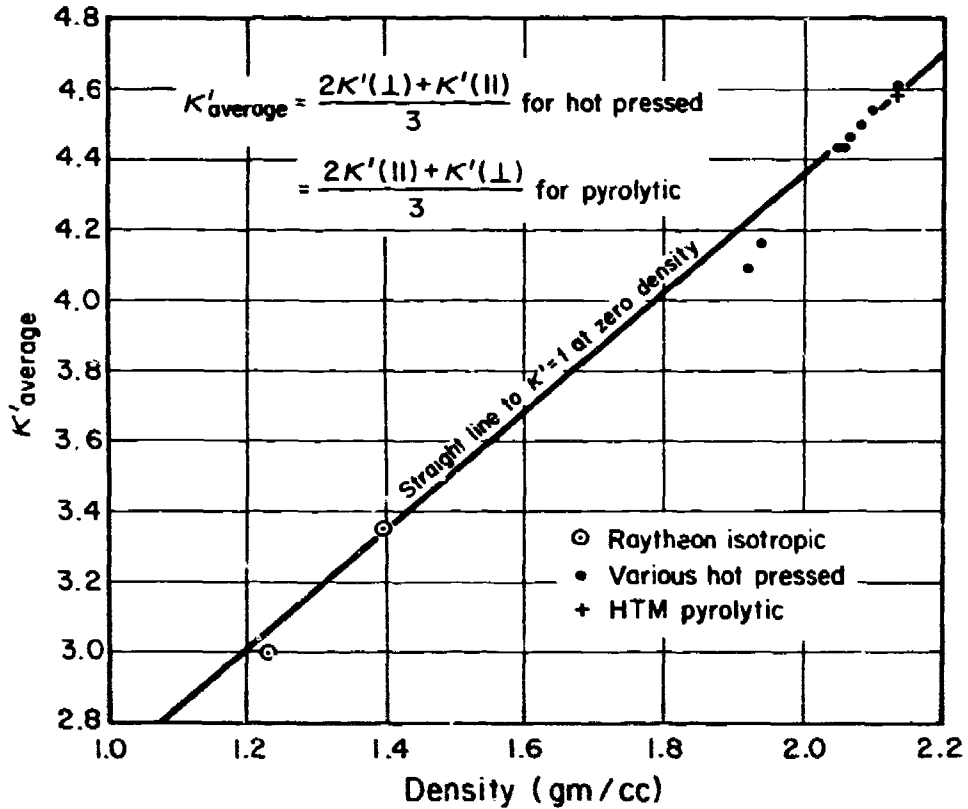
f (Hz)	$\kappa'$	$\tan \delta$
$10^2$	$5.1 \pm .5$	.0025
$10^5$	"	$.0003 \pm 2$

$\text{Bi}_4\text{Si}_3\text{O}_{12}$  ceramic

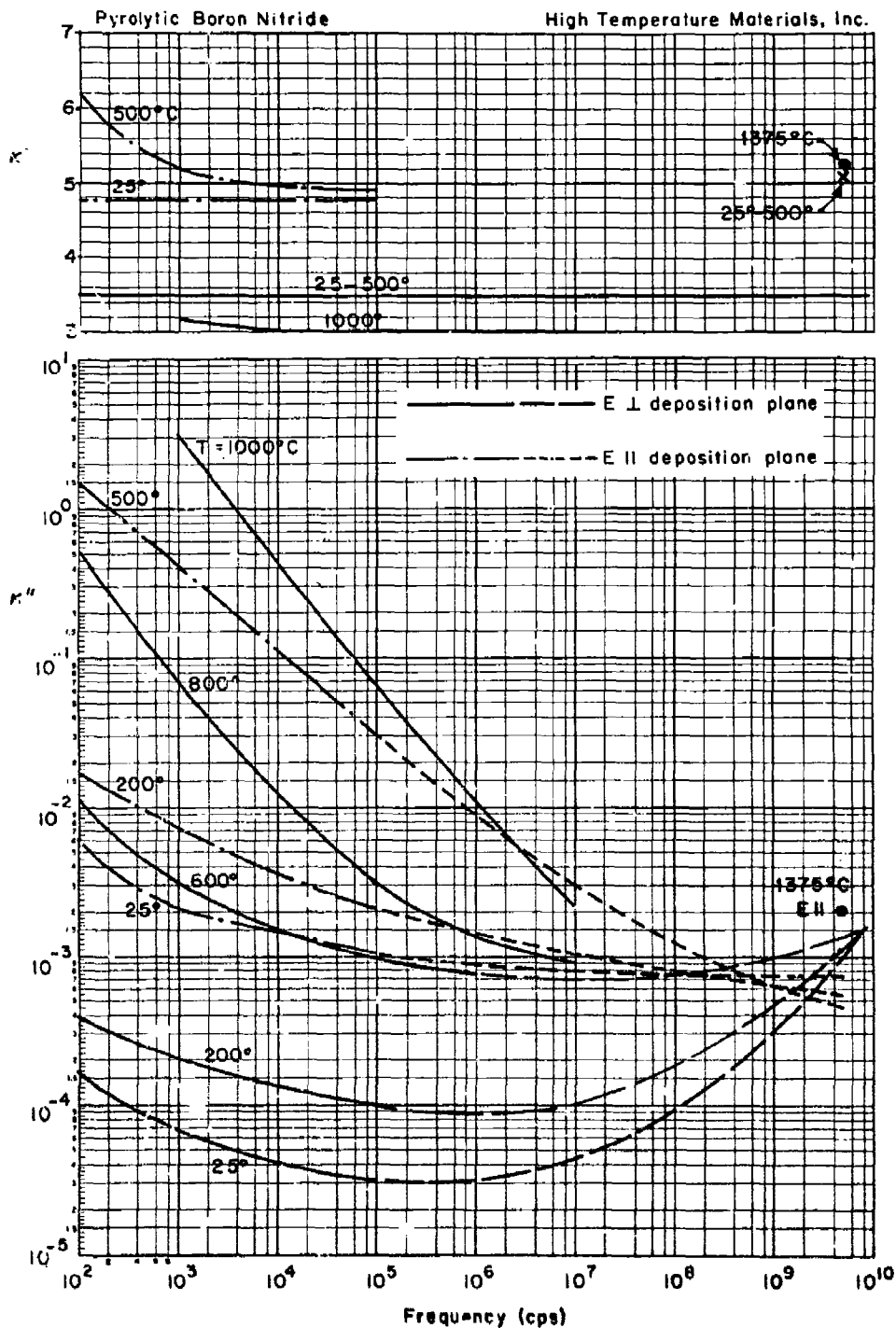
Laboratory for Insulation Research



Boron nitride  
Average dielectric constant versus density  
X-ray density  $2.25 \text{ g/cm}^3$



$\kappa' \perp$  : electric field  $\perp$  direction of unidirectional hot press or electric field  $\perp$  deposition plane.

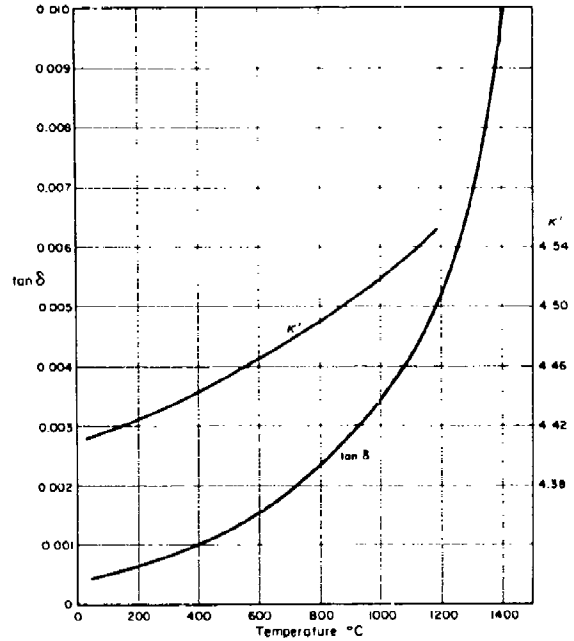
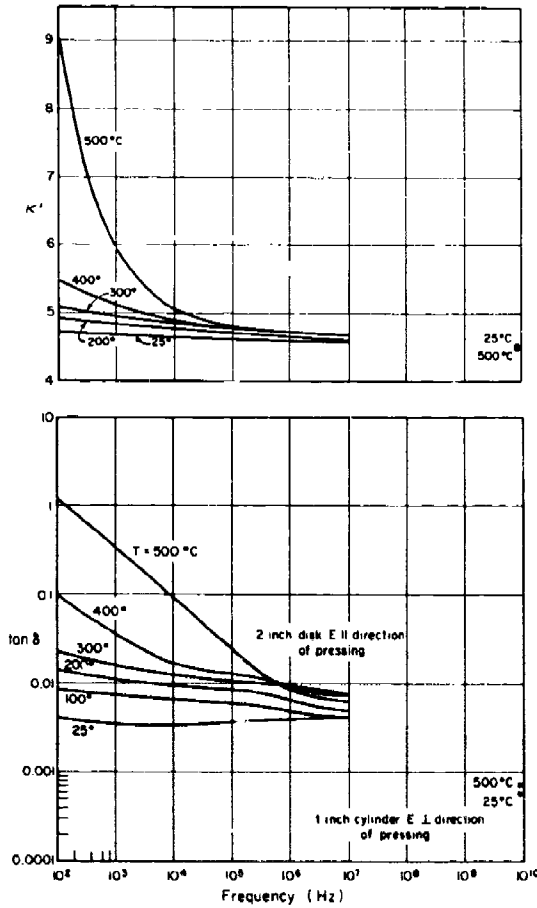


BN, pyrolytically deposited, High-Temperature Materials, Inc., "Boralloy." The microwave data show a small peak possibly due to loss of impurities (perhaps OH ions) at about 800°C. Graphite electrodes and prepurified N<sub>2</sub> used in low-frequency measurements which showed variations among different samples.

Hot-pressed boron nitride, grade HBN

Carbon Products Division  
 Union Carbide Corp.  
 (Formerly National Carbon Co.)

4.95 to 4.88 GHz

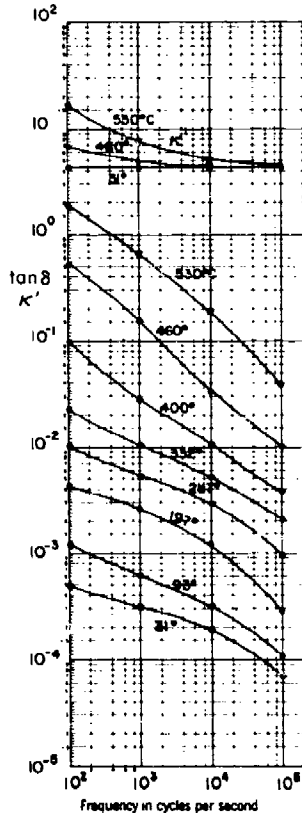


Density 2.054 g/cm<sup>3</sup>  
 1" cylinder, 8.52 GHz

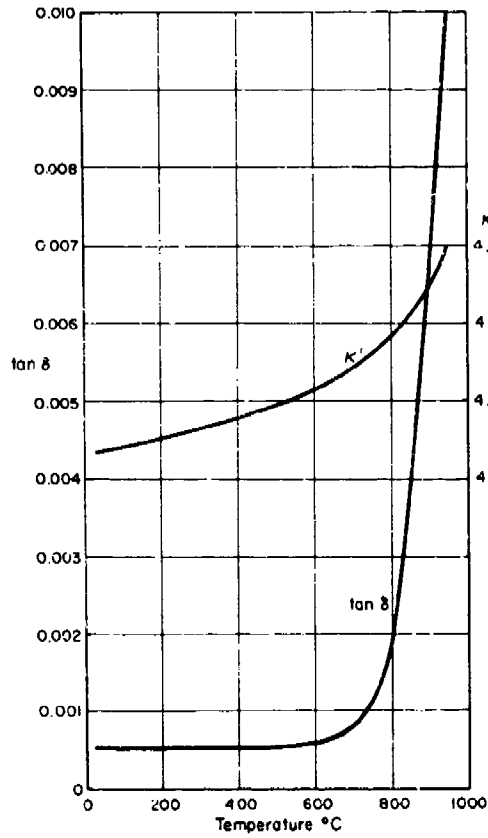
T <sup>o</sup> C	E	κ'	tan δ
25	⊥	4.38	.00050
25		4.52	.00056
100		4.52	.00056
200		4.51	.00061
300		4.50	.00064
400		4.49	.00066
500		4.48	.00073



Hot-pressed boron nitride  
Grade HD0056



Grade HD 0086  
Density 1.940 g/cm<sup>3</sup>  
5.17 to 4.96 GHz



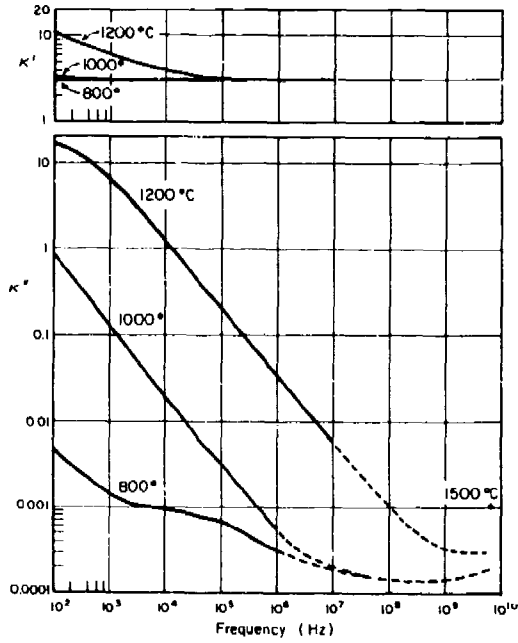
8.52 GHz

T °C	E	K'	tan δ
25		4.31	.00053
25	⊥	4.10	.00055
100	⊥	4.08	.00059
200	⊥	4.07	.00066
300	⊥	4.06	.00075
400	⊥	4.05	.00086
500	⊥	4.05	.00102

Pyrolytic boron nitride

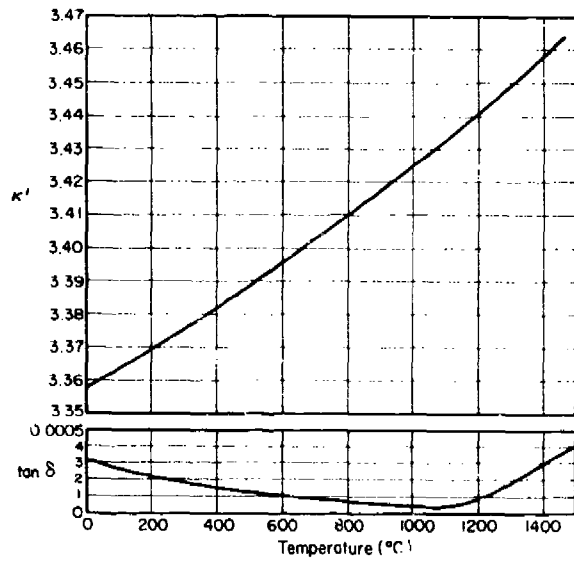
Raytheon

Density 1.23 g/cm<sup>3</sup>



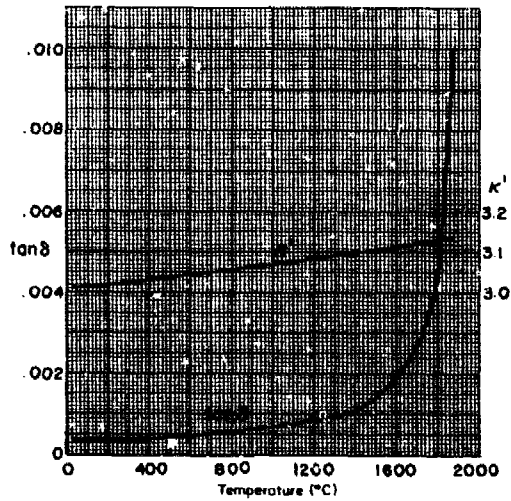
At 5.74 to 5.65 GHz

Density 1.398 g/cm<sup>3</sup>



Density 1.23 g/cm<sup>3</sup>

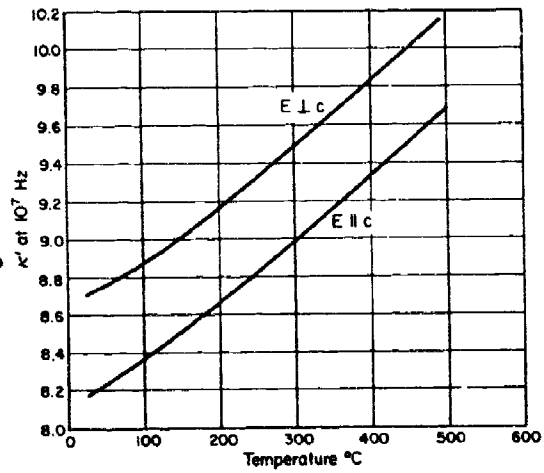
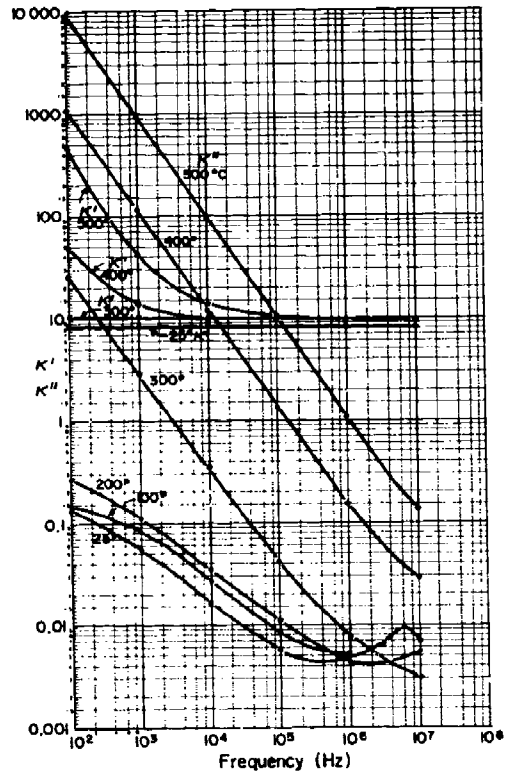
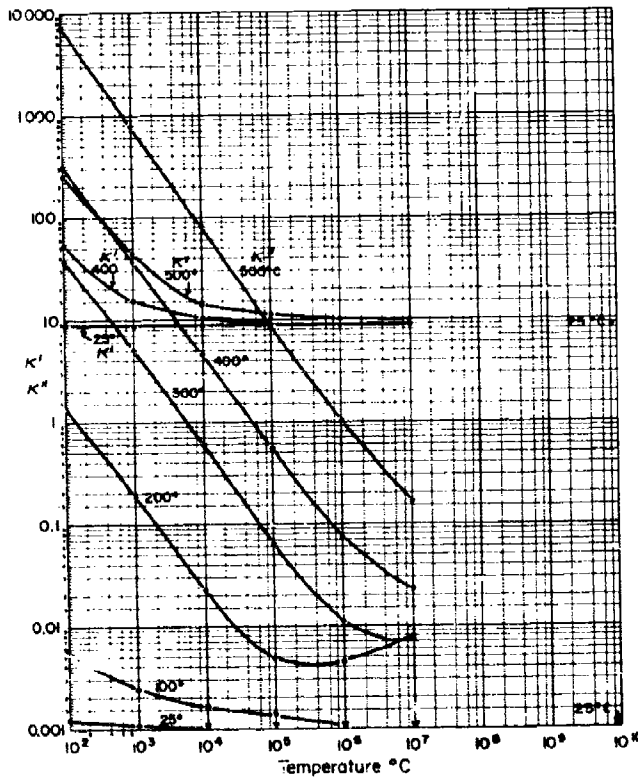
At 9.21 to 9.04 GHz



Calcium carbonate  
Calcite, single crystal mineral

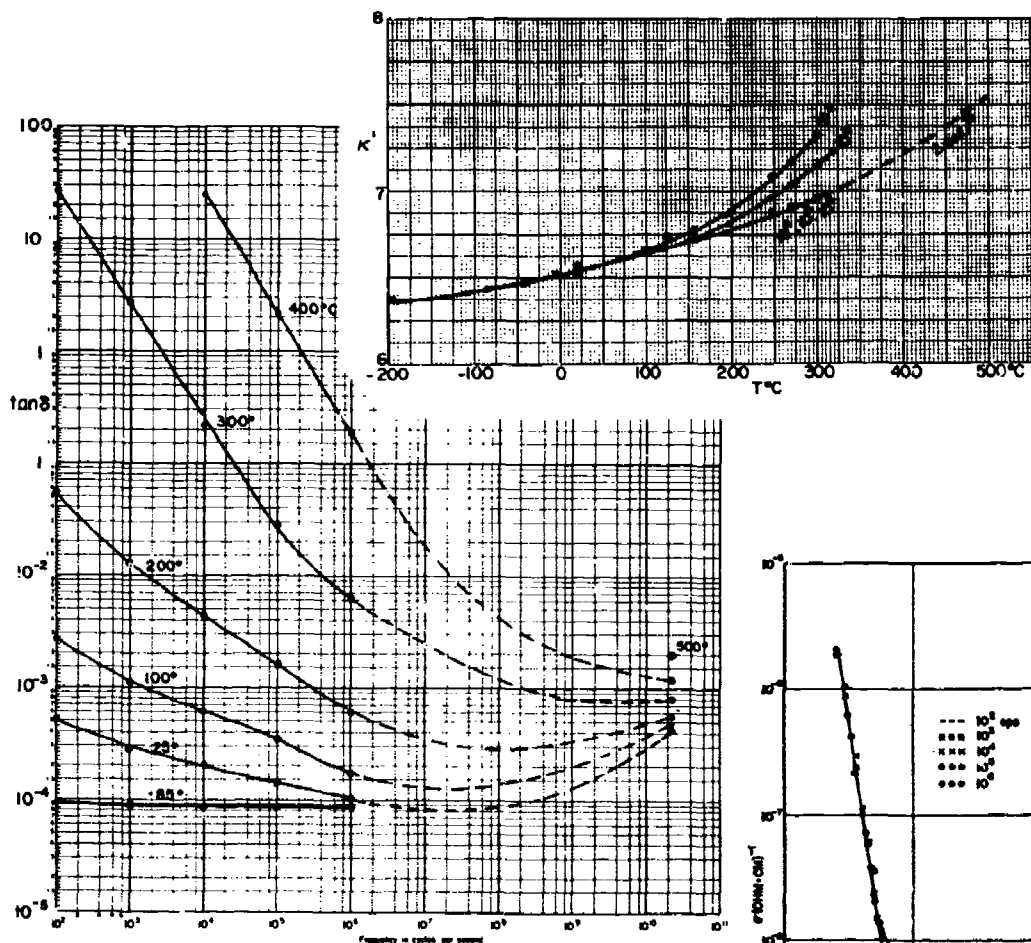
E || c, crystal No. 1

E ⊥ c, crystal No. 2

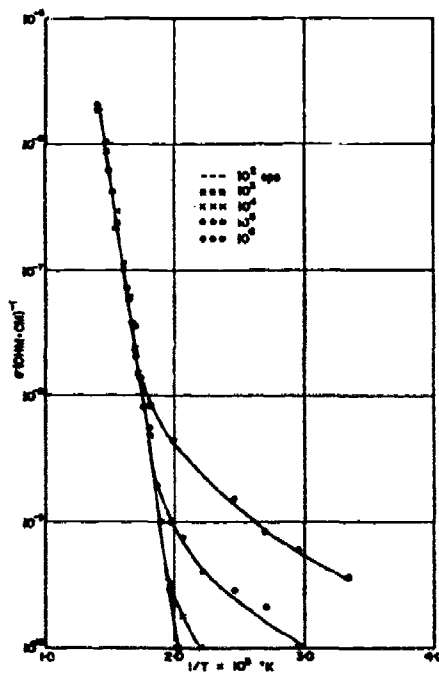


Calcium fluoride crystal

M. I. T., Crystal Physics  
Laboratory

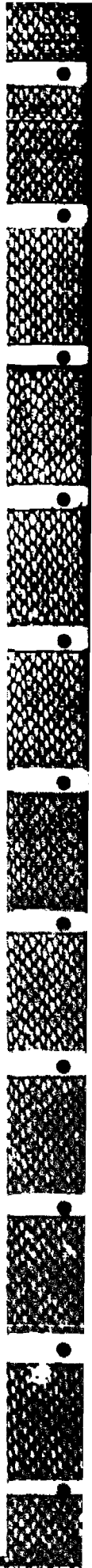
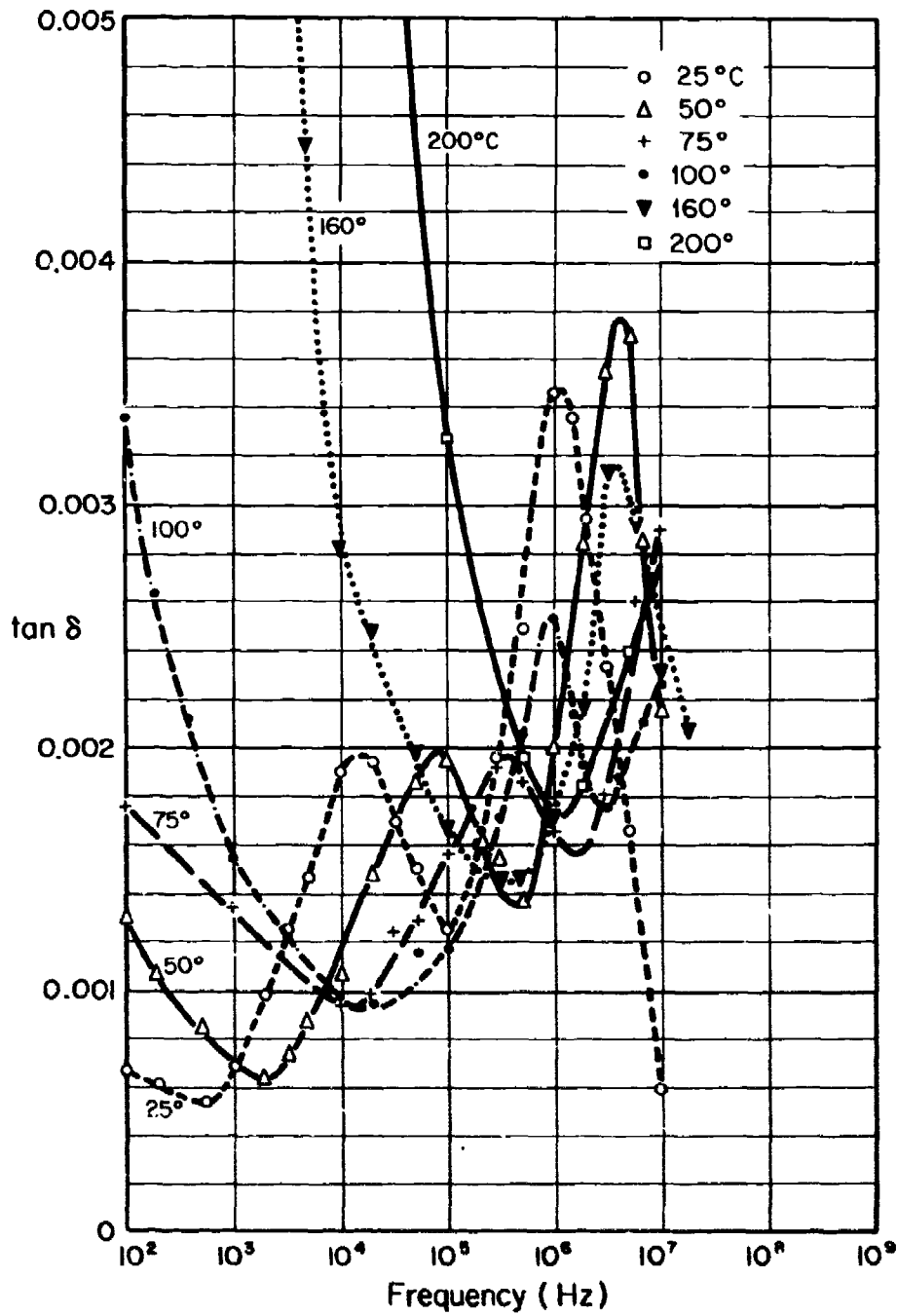


For more complete data see  
K. V. Rao and A. Smakula,  
J. Appl. Phys. 37, 319 (1966).



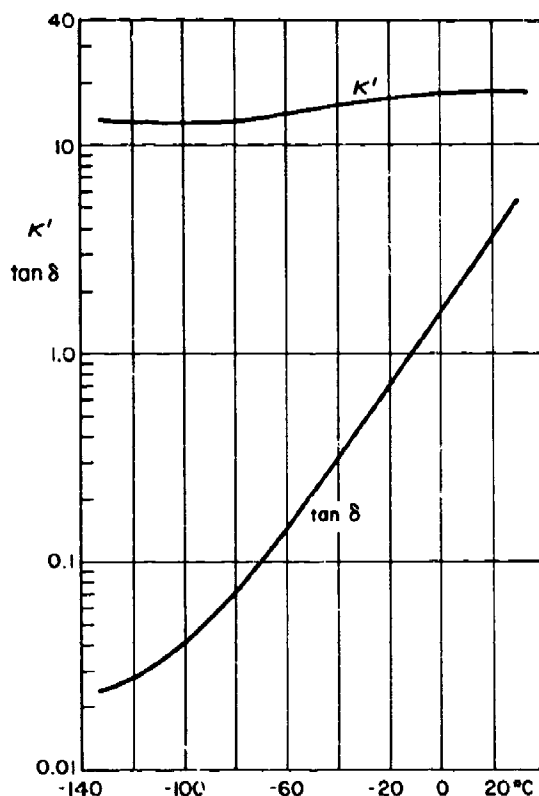
Calcium fluoride doped with  $Y_2O_3$

M. I. T. , Department of Metallurgy, Ceramics Lab.



Cerium fluoride, at 1 MHz

M. I. T., Lab. Ins. Res.



Cobalt oxide M. I. T.,  
Crystal Physics Lab.

Copper halide M. I. T., Lab.  
pressed powders Ins. Res.

Cobalt oxide-nickel oxide

Measured values at 14 GHz

At 25°C, 1 MHz

Sample / X-ray  
density / density

	$\kappa'$	$\tan \delta$
CoO	12.9	.0005
CoO-NiO 50/50 mole percent	40	.39

	$\kappa'$	$\tan \delta$
CuBr	4.85/5.17	6.33 < .001
CuCl	3.68/4.10	6.52 < .001
CuI		27.8 .112

For complete data see:

K. V. Rao and A. Smakula,  
J. Appl. Phys. 36, 2031 (1965).

Lead halides

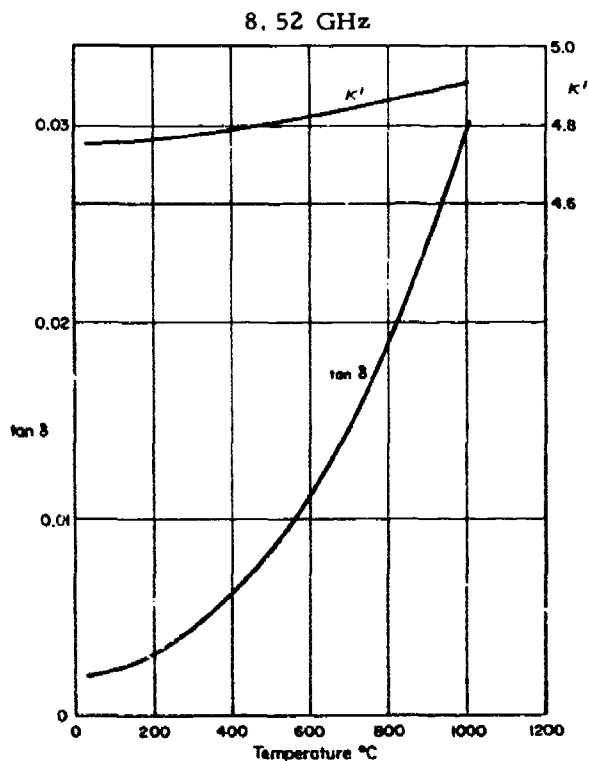
M. I. T. Crystal Physics Laboratory

	Electric field dir. parallel to		At 1 MHz, 25°C		Activation energy for "intrinsic" conduction
			$\kappa'$	$\tan \delta$	
PbBr <sub>2</sub>	a	4.72	52.7	.0052	-
	b	8.06	56.3	.0033	-
	c	9.55	25.3	.0033	-
PbCl <sub>2</sub>	a	4.53	47.4	.11	.30 eV
	b	7.62	51.3	.065	.28 eV
	c	9.05	24.8	.051	.42 eV
PbCl <sub>2</sub> -PbBr <sub>2</sub> c 85/15 mol %			28.5	.016	1.1 eV

For additional data on these materials see: A. Smakula, Tech. Rep. No. 6, (Final Report under Contract Nonr 1841(88)), M. I. T., Crystal Phys. Lab., March 11, 1965.

Magnesium aluminum silicate

Cordierite ceramic, Raytheon Co.



Magnesium carbonate, hard-packed  
fine powder, reagent grade,  
at 8.52 GHz, 25°C:

$\kappa'$        $\tan \delta$   
1.282      .0109

Density .189 g/cm<sup>3</sup>

Transparent MgO ceramic  
IRTRAN-5

Kodak

Density = 3.57 g/cm<sup>3</sup>, 25°C

f (Hz)	$\kappa'$	tan $\delta$
10 <sup>2</sup>	9.82	.0014
8.5 x 10 <sup>9</sup>	9.72	.00045

Magnesium metasilicate,  
multicrystalline, F-66

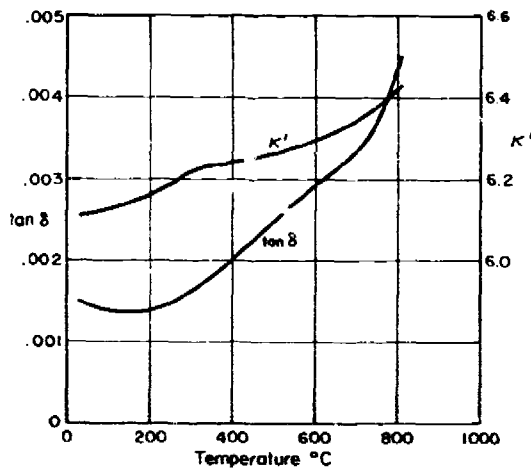
International Pipe and Ceramic Corp.  
(Gladding McBean and Co.)

Bell Telephone Laboratories

Steatite TC-503, 8.52 GHz

14 CHz

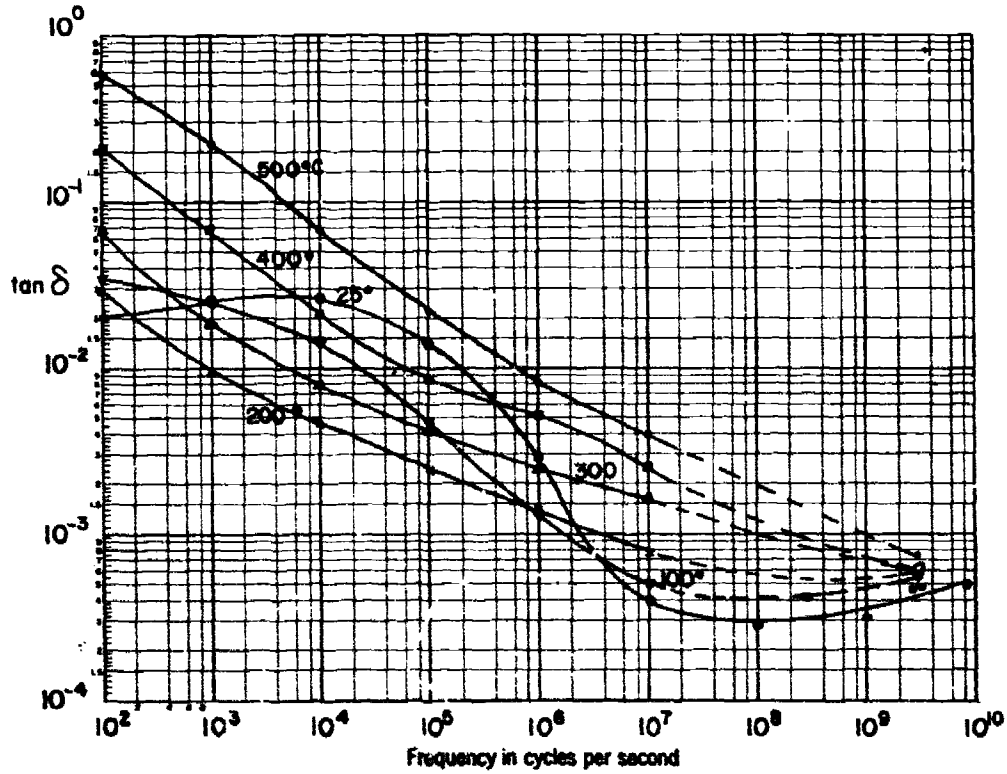
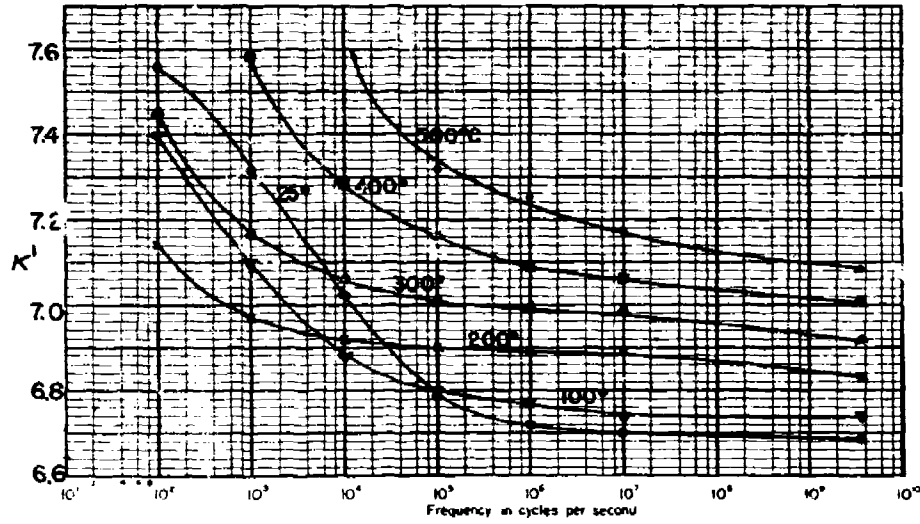
T°C	$\kappa'$	tan $\delta$
25	6.37	.0012
100	6.39	.0012
200	6.43	.0012
300	6.47	.0012
400	6.52	.0013
500	6.58	.0015
600	6.67	.0020
700	6.75	.0047
800	6.85	.0165





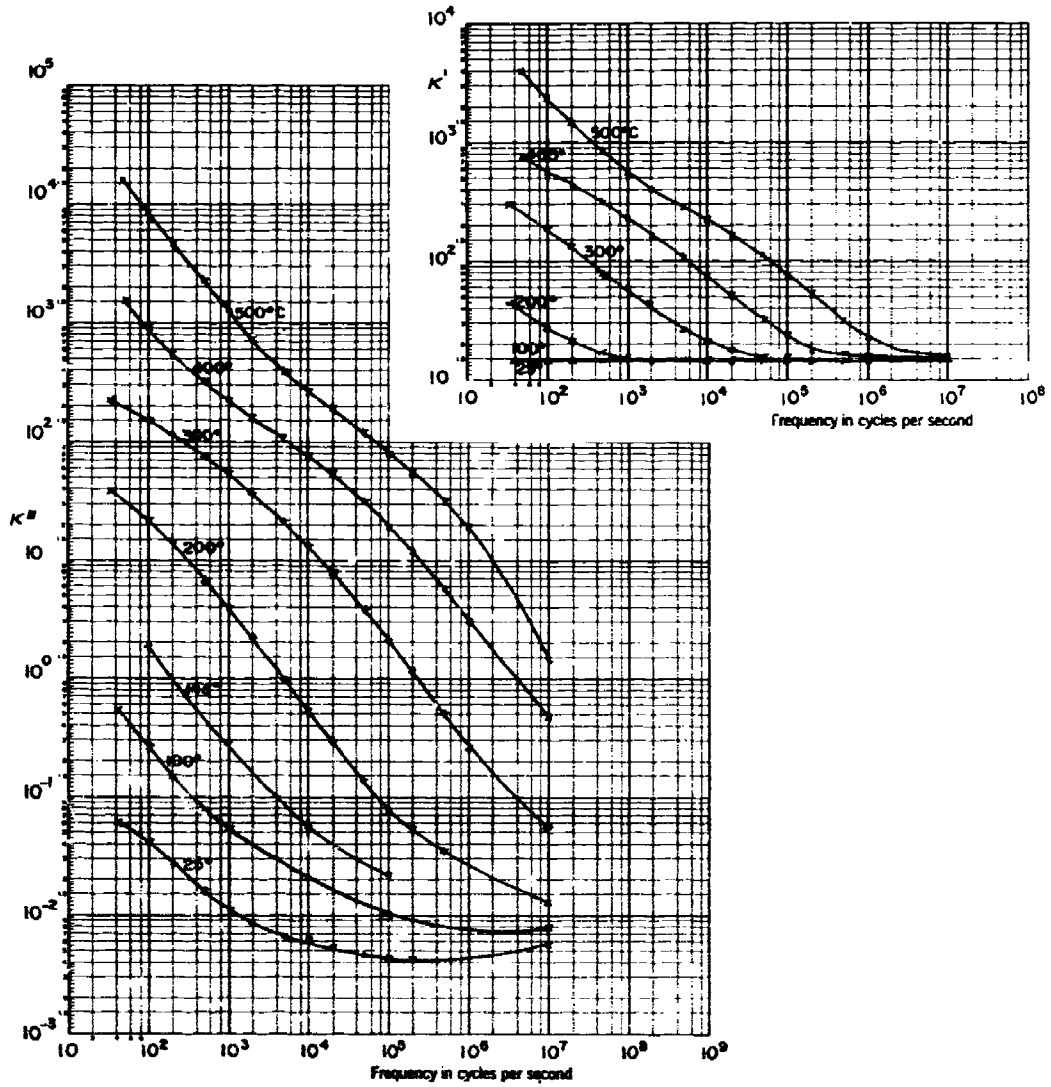
Frequenta M

Steatit-Magnesia Aktiengesellschaft



Magnesium titanate ( $MgTiO_3$ )  
Density  $3.21 \text{ g/cm}^3$

U. S. Sonics



Manganese fluoride crystal ( $MnF_2$ )

Columbia University

f (Hz)       $\kappa'$       tan  $\delta$

$10^3$      $7.2 \pm .2$     .043

$10^7$      $6.7 \pm .2$      $<.004$

E  $\perp$  to platelike, unoriented crystal

Nickel oxide, NiO, single crystal

M. I. T., Crystal Physics Lab.

At 25°C, 1 MHz

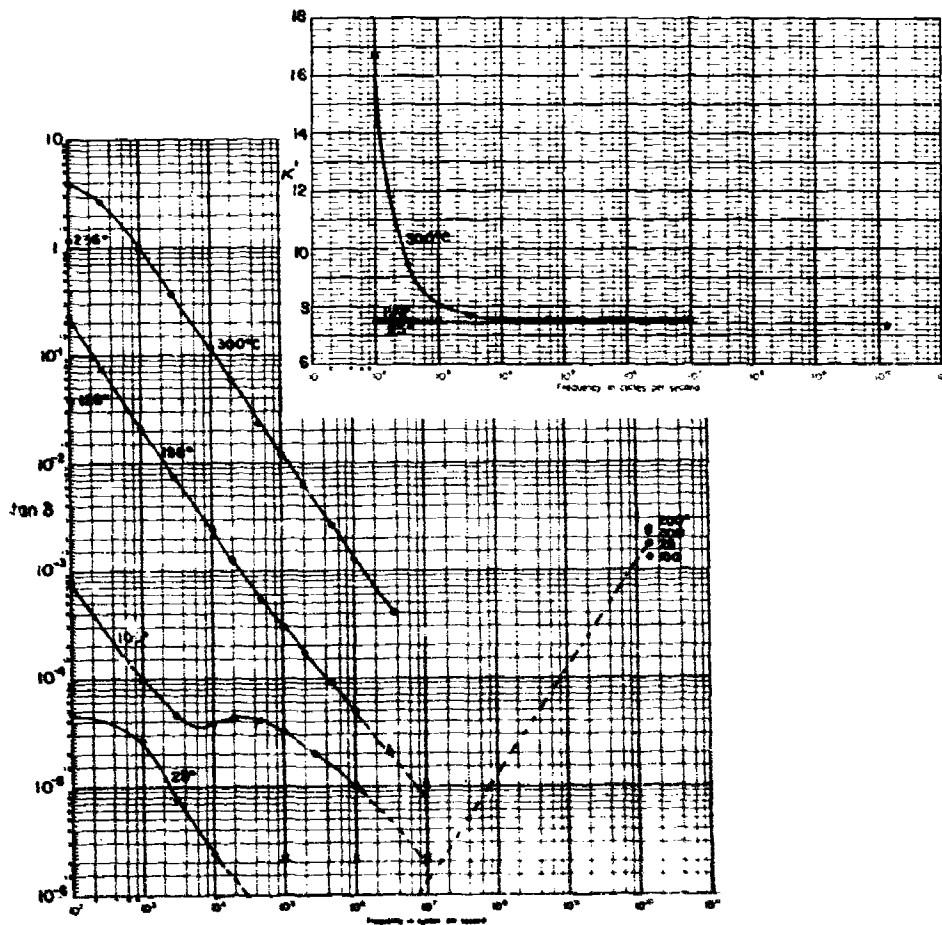
$\kappa' \approx 11.9$

tan  $\delta = .0154$

For complete data see: K. V. Rao and A. Smakula, J. Appl. Phys. 36, 2031-2038 (1965).

Rubidium manganese fluoride

M. I. T., Crystal Physics Lab.



Silicon crystal, intrinsic  
at 25°C

M. I. T., Crystal Physics Lab.

f (Hz)	$\kappa'$	$\tan \delta$	$\rho$ (ohm-cm)
$10^3$	-	-	4100
$1.4 \times 10^{10}$	12.0	.0090	1190

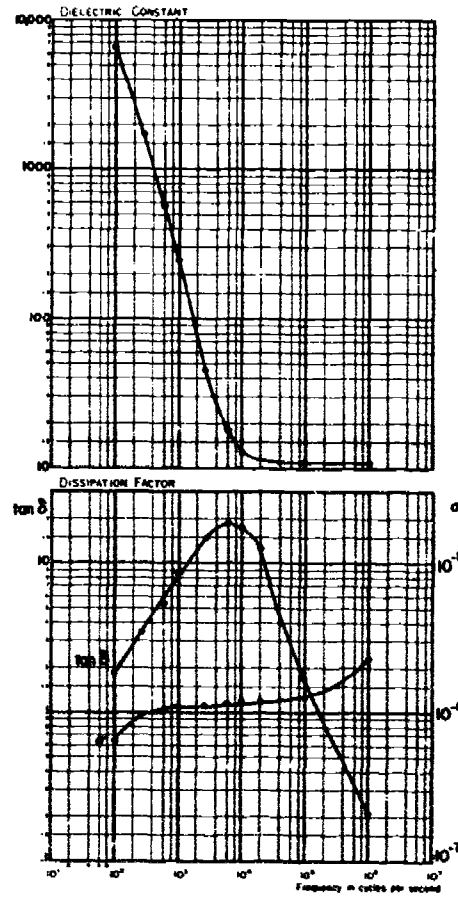
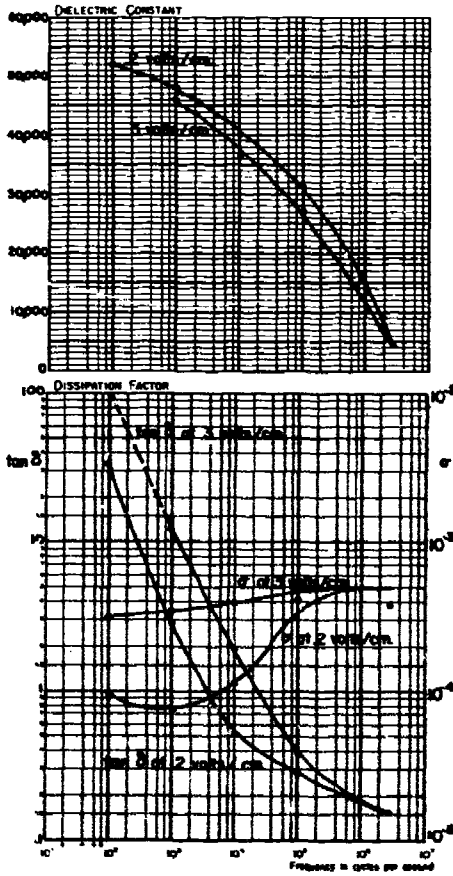
Silicon crystal, undoped

Brown University

Apparent properties of 1 cm cube sample  
with evaporated gold electrodes

Silicon single crystal

Radiation damaged single crystal



Silicon carbide type attenuator materials

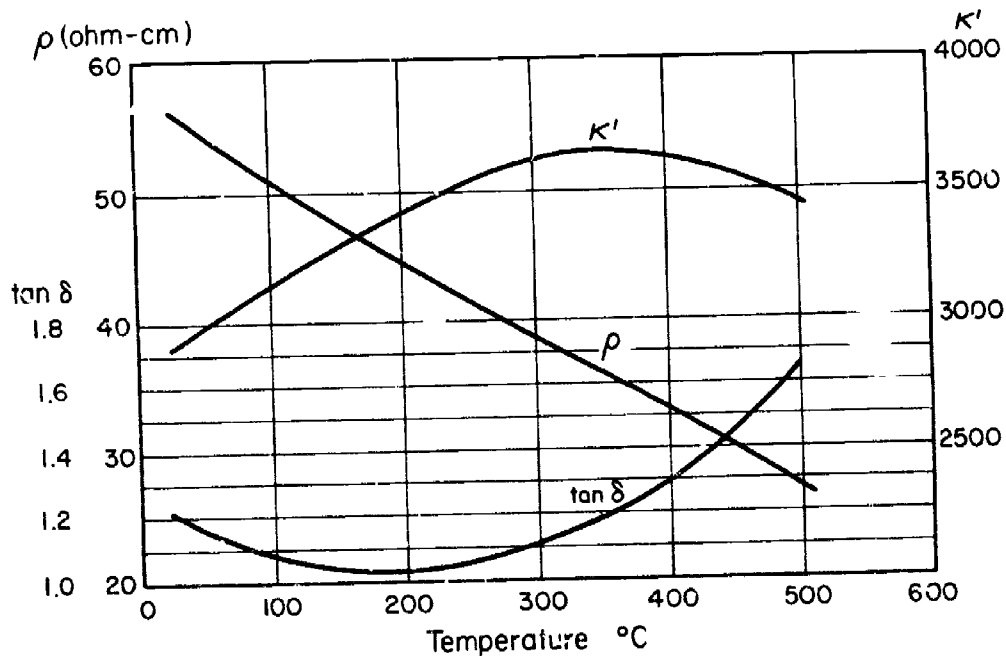
Carborundum

Nominal resistivity (ohm-cm)	Temperature (°C)	f (Hz)	$\kappa'$	$\tan \delta$	Measured resistivity (ohm-cm)
35	25	$3 \times 10^8$	167	0.96	37.2
	25	$10^9$	107	0.686	24.4
	25	$3 \times 10^9$	60	0.58	17.2
	25	$8.5 \times 10^9$	47.7	0.55	8.05
0.1	25	$8.5 \times 10^9$	2130	1.85	0.069
50	25*	$10^6$	10,150	1.17	151
	25**	$10^6$	29,450	1.36	45
	25*	$10^7$	2810	1.21	56.5

\* Two-terminal measurement.

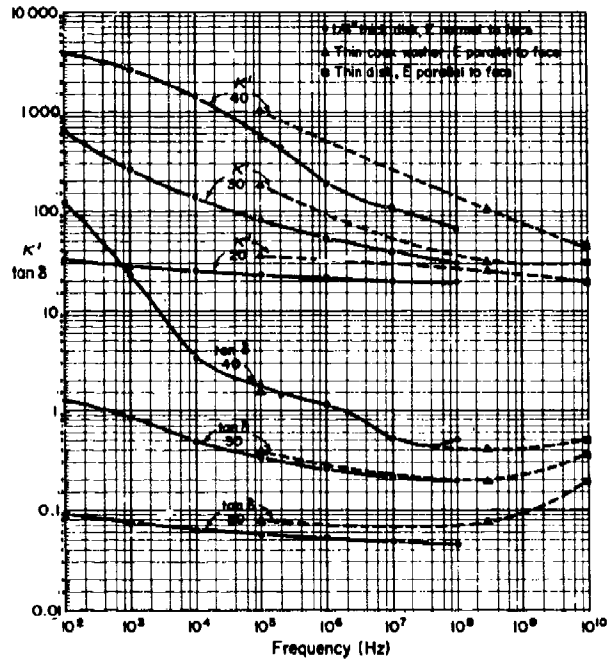
\*\* Four-terminal measurement, different sample

Nominal 50-ohm material at  $10^7$  Hz



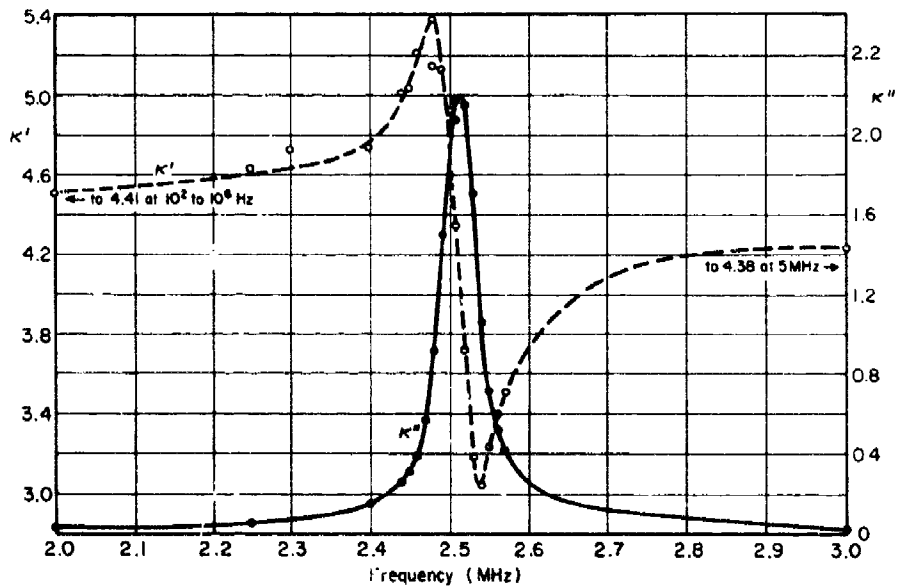
Carberlox 20, 30, 40  
BeO and silicon carbide ceramic

National Beryllia Corp.



Silicon dioxide, natural quartz crystal,  
Y-cut plate, silver paint electrodes, at 25°C

Fort Monmouth



Quartz, continued

Y-cut plate

At 25°C,  $\kappa' = 4.40$

$$1/\kappa' \left( \frac{d\kappa'}{dt} \right) = -2.8 \times 10^{-5} / ^\circ\text{C}$$

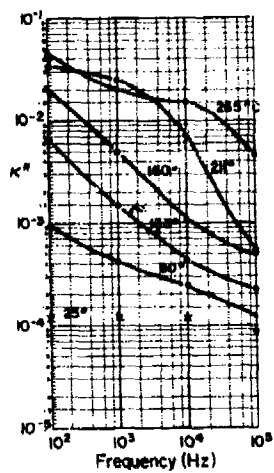
Z-cut plate, E || optic axis

At 25°C,  $\kappa' = 4.64$

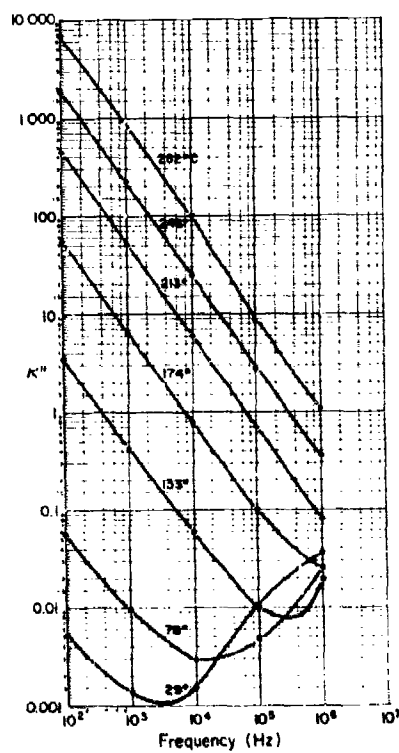
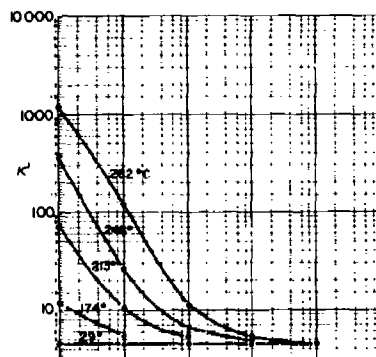
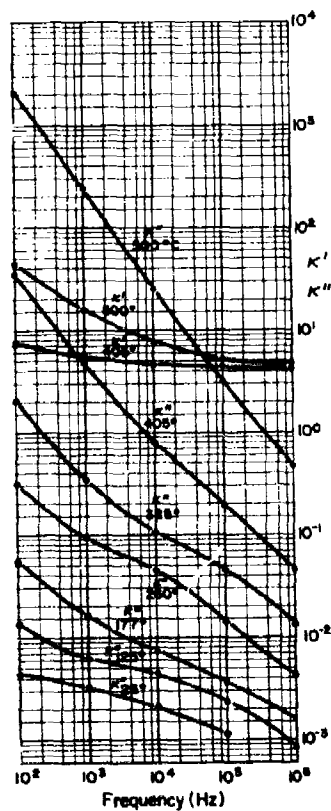
$$1/\kappa' \left( \frac{d\kappa'}{dt} \right) = -3.9 \times 10^{-5} / ^\circ\text{C}$$

Silver electrodes

Silver electrodes

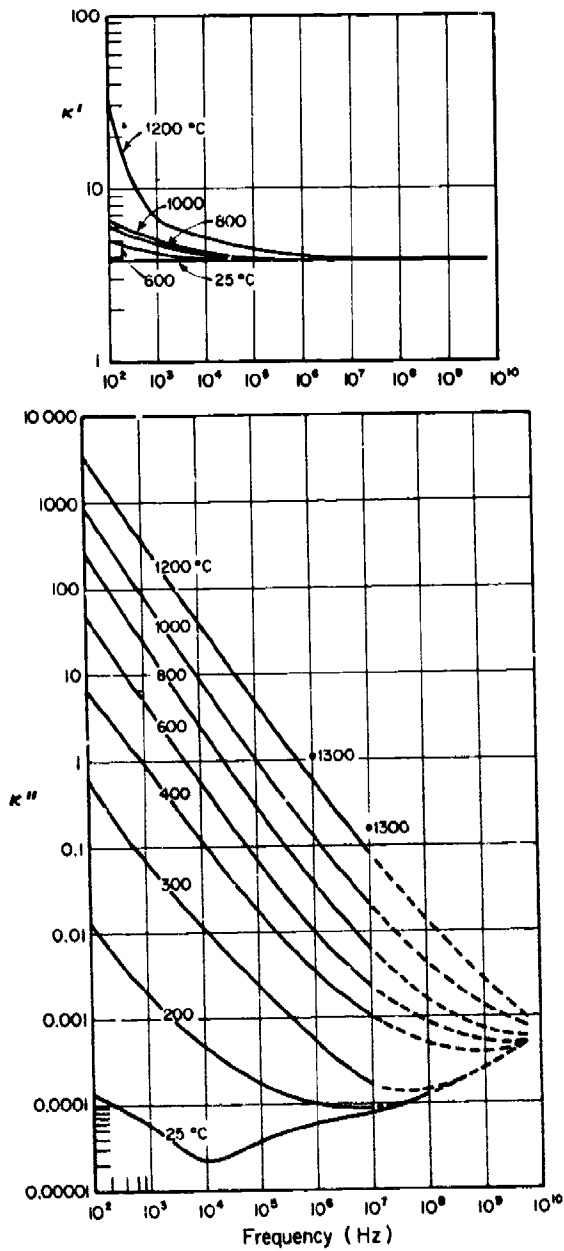


Pt electrodes



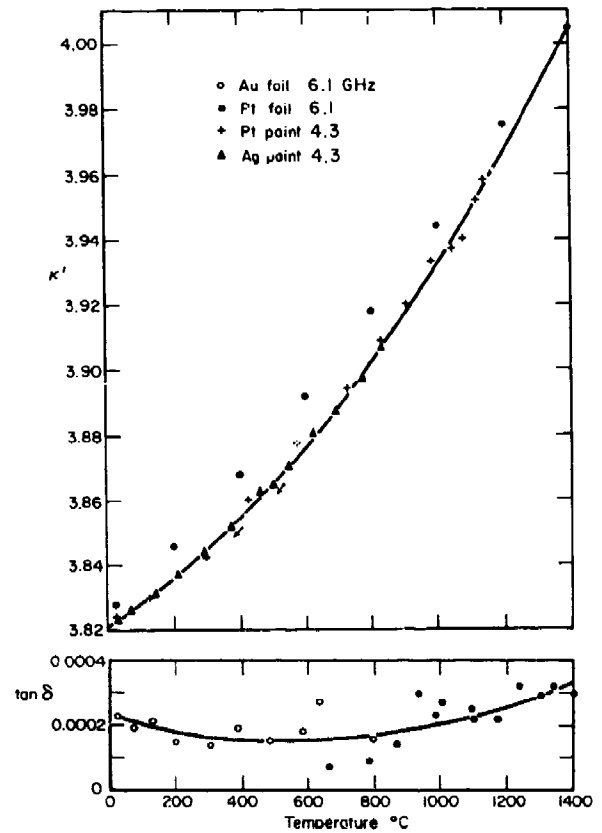
Silicate glasses

Fused silica, Corning 7940



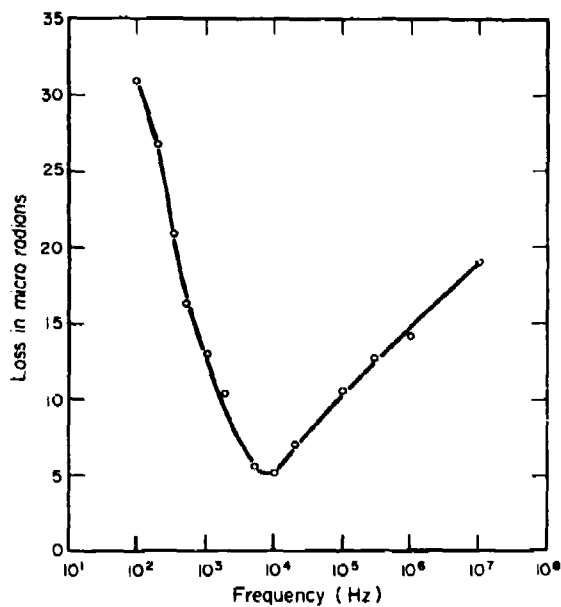
Corning Glass Works

Microwave data on fused silica, Corning 7940, density = 2.20027 g/cm<sup>3</sup>. Data with foil taken on one sample at 6.1 GHz, data with paint taken on second sample at 4.3 GHz.





Corning 7940 continued



Corning Lab. No. 119BUC  
magnetic glass

Corning Glass Works

25°C, 8.52 GHz

$\kappa'$	$\tan \delta$	$\kappa'_m$	$\tan \delta_m$
20.8	0.157	1.006	0.372

Corning Code 1723 glass

14 GHz			24 GHz		
T°C	$\kappa'$	$\tan \delta$	T°C	$\kappa'$	$\tan \delta$
25	6.18	.0069	25	6.13	.0075
85	6.21	.0067	85	6.16	.0075
144	6.24	.0065	155	6.20	.0074
234	6.27	.0063	251	6.24	.0073
305	6.31	.0061	333	6.28	.0074
339	6.33	.0060	419	6.32	.0073
396	6.36	.0059	446	6.35	.0073
464	6.40	.0057	510	6.39	.0074
502	6.43	.0056			

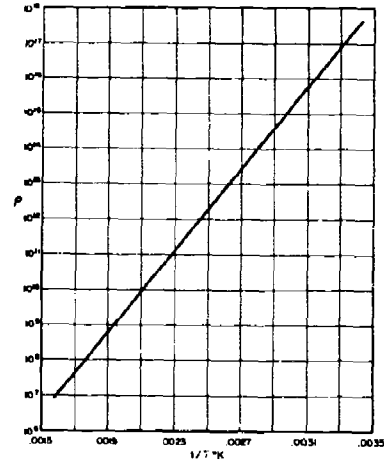
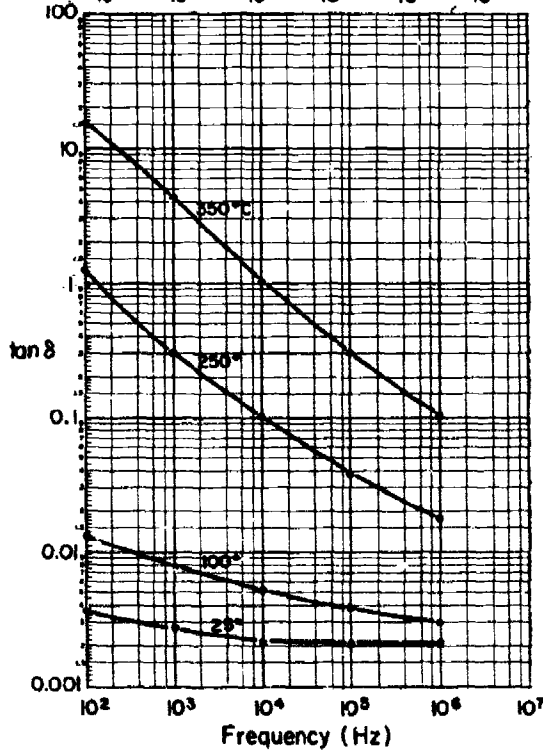
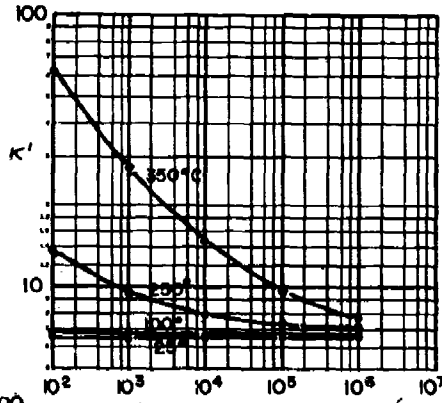
Silica glasses

Lancaster

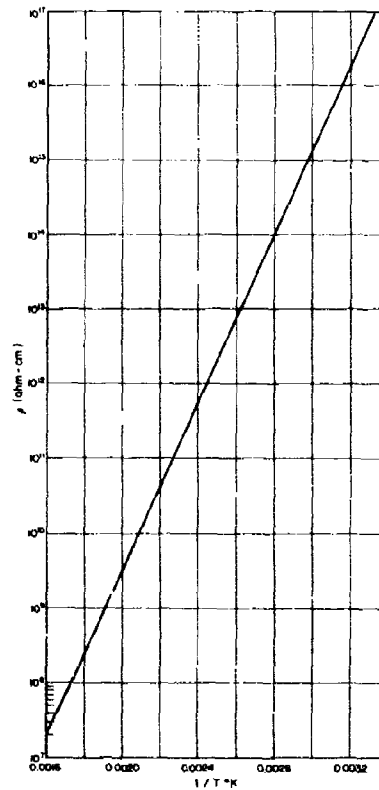
Resistivities measured at 100 Hz

No. 7352

7357

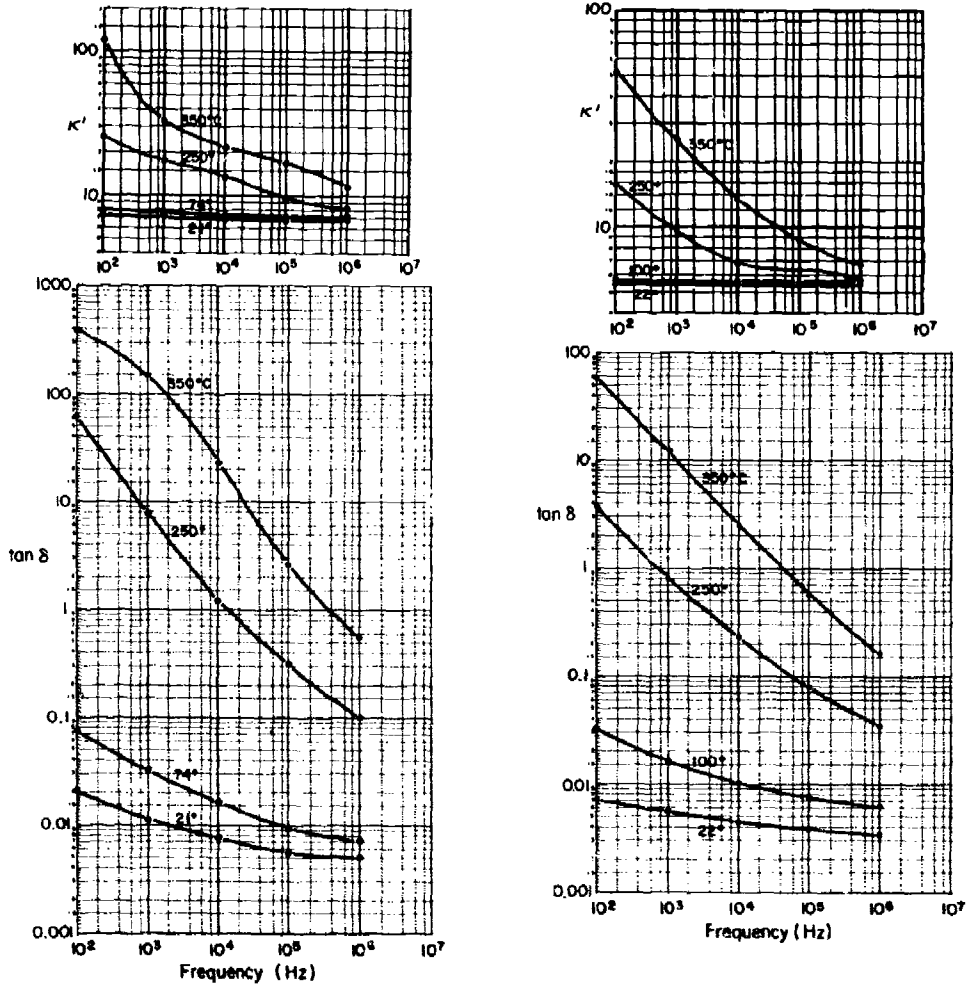


No. 7357



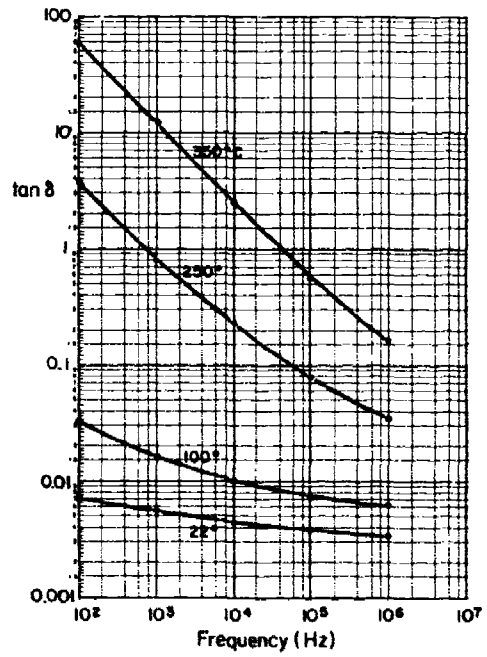
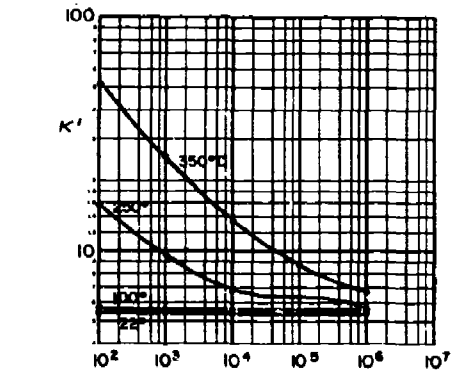
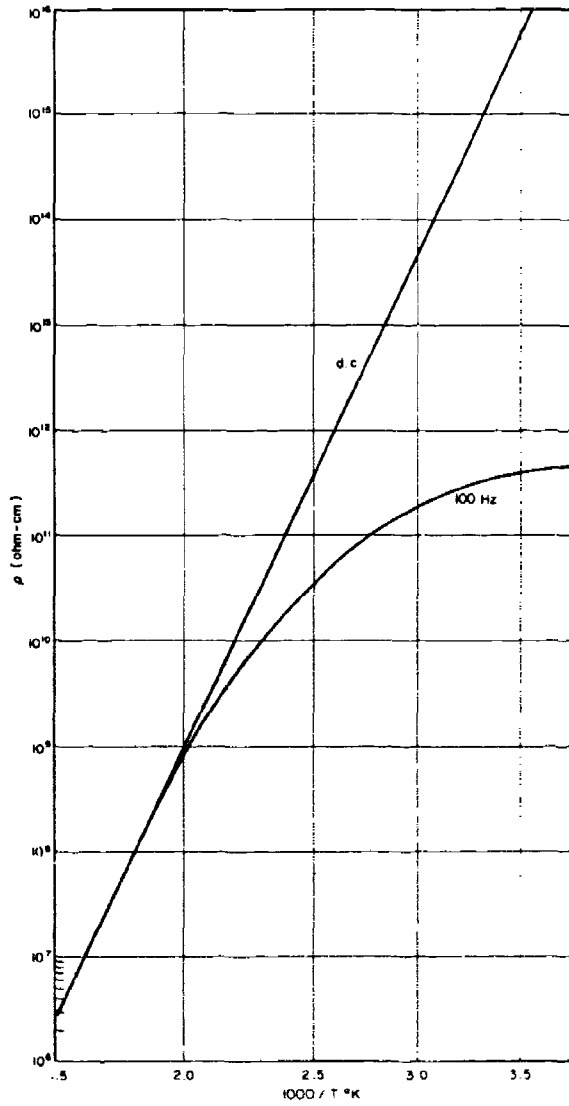
Lancaster glasses (cont.)

L 1957



Lancaster glasses (cont.)

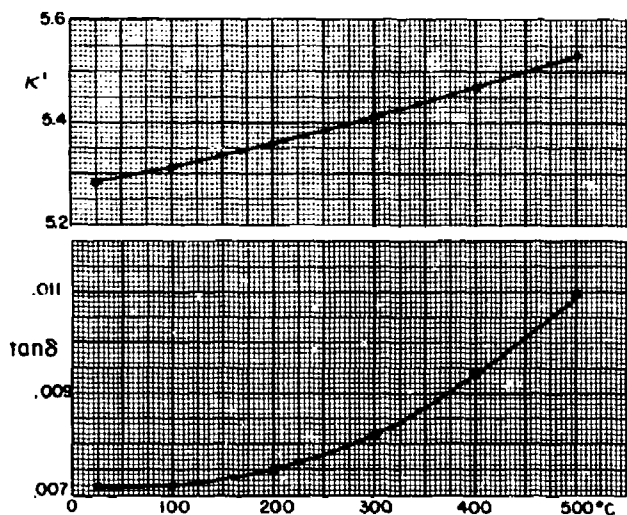
No. L 8100



Silicate glasses (cont.)

X 994

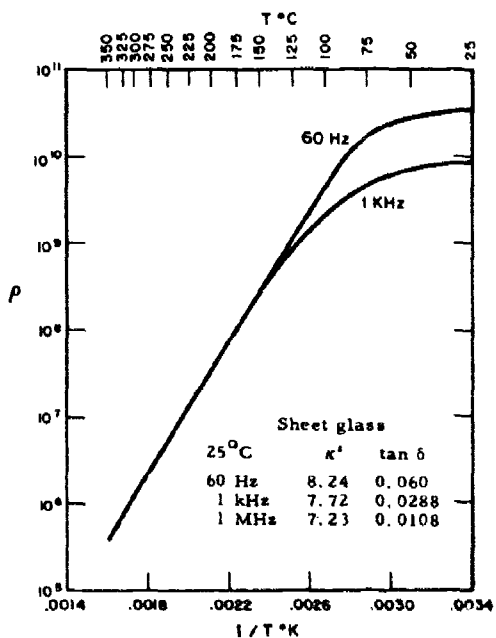
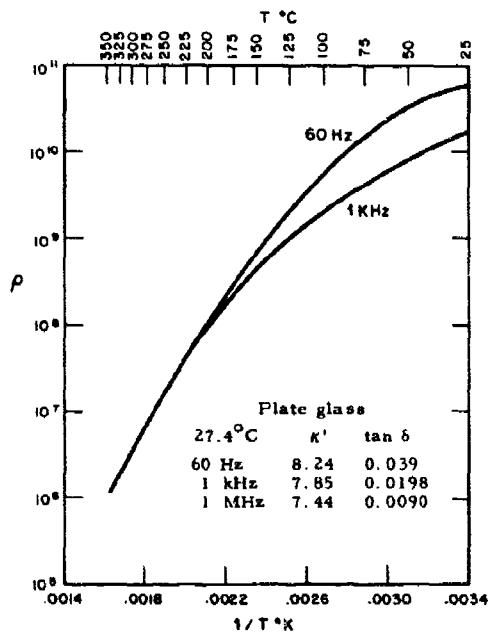
Owens-Corning



Pittsburgh Plate Glass Co.

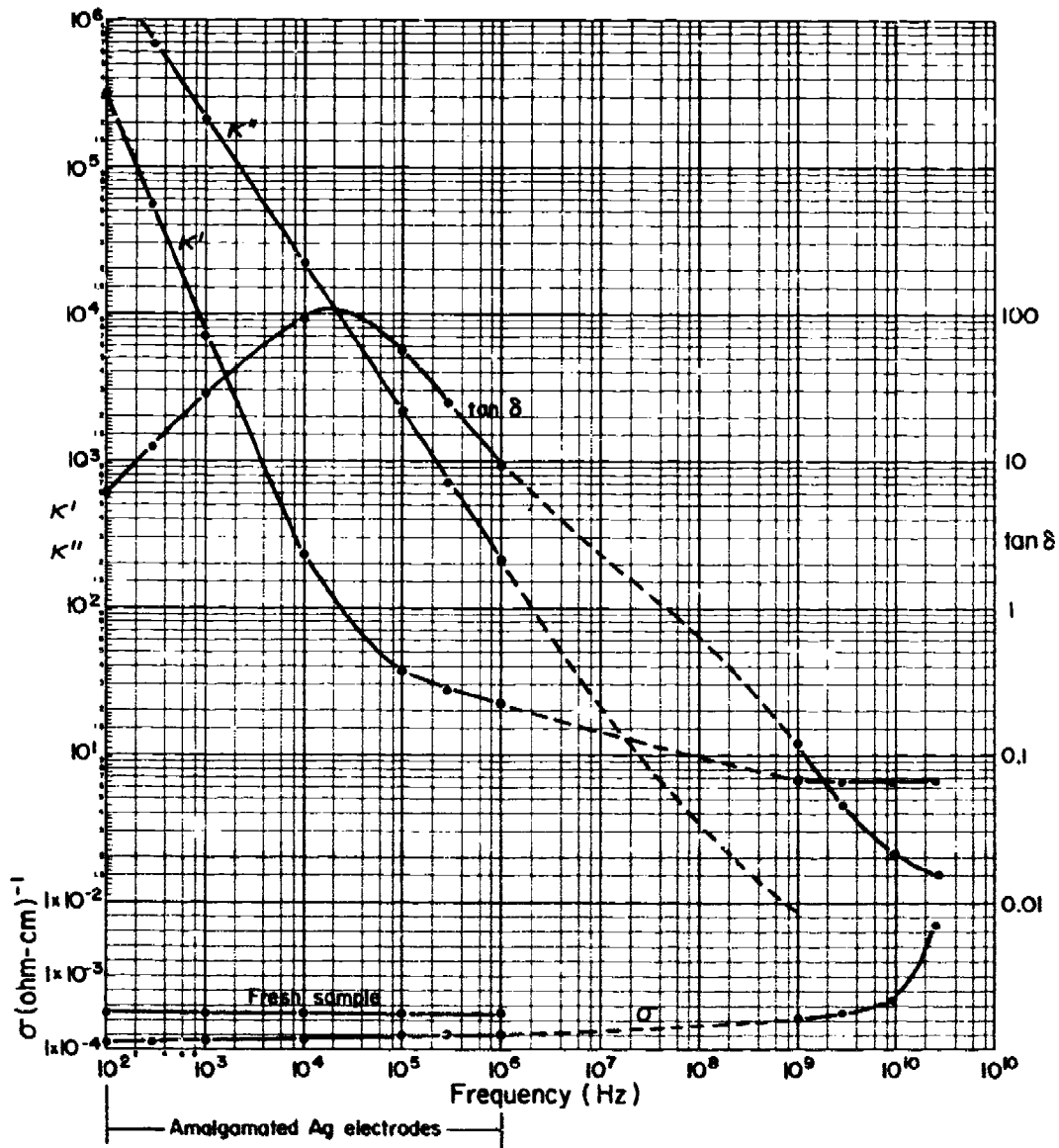
Plate glass

Sheet glass



Silver iodide, pressed powder  
at 10,000 psi, 27°C, aged  
several weeks unless noted

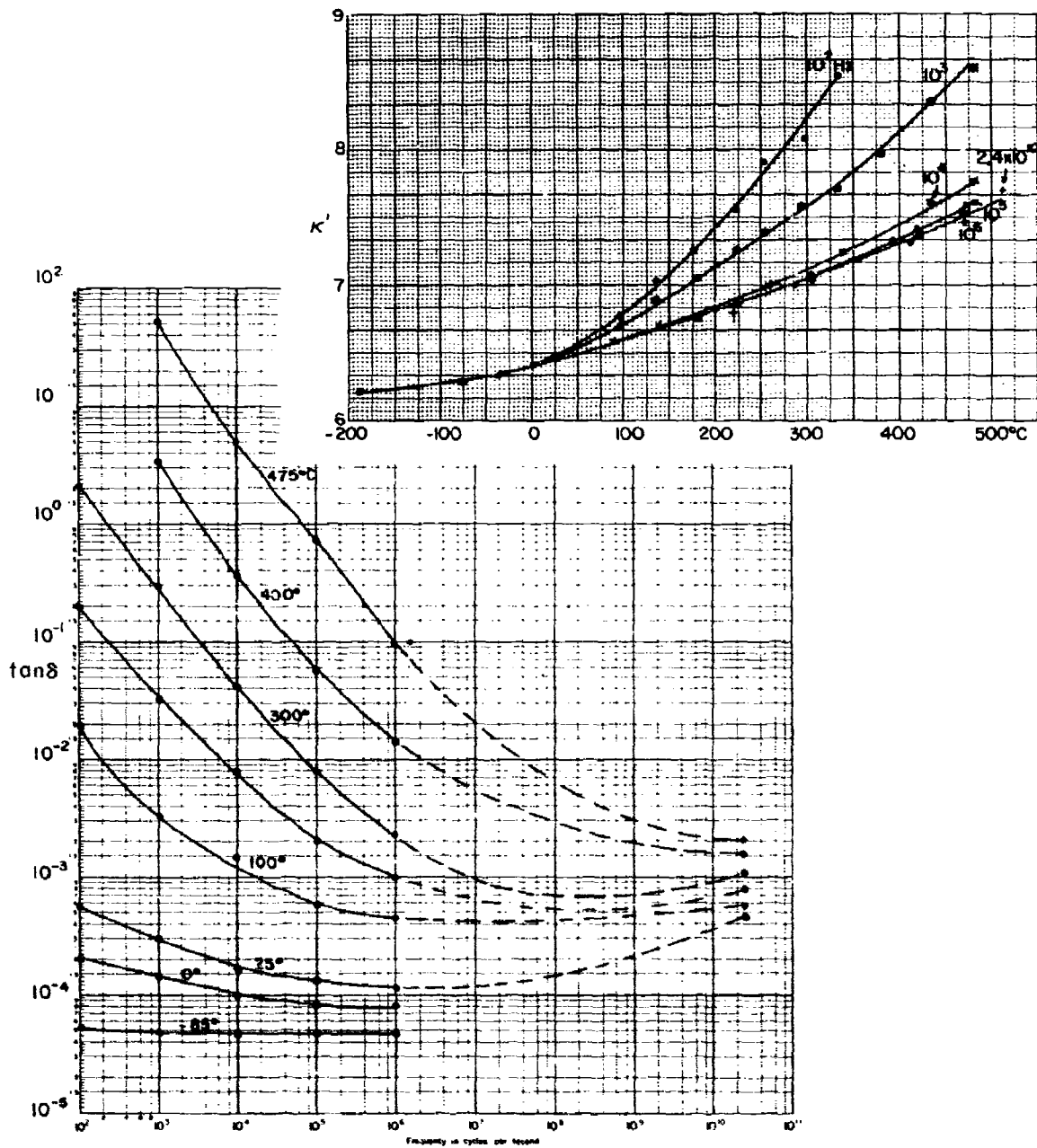
M. I. T., Laboratory for  
Insulation Research

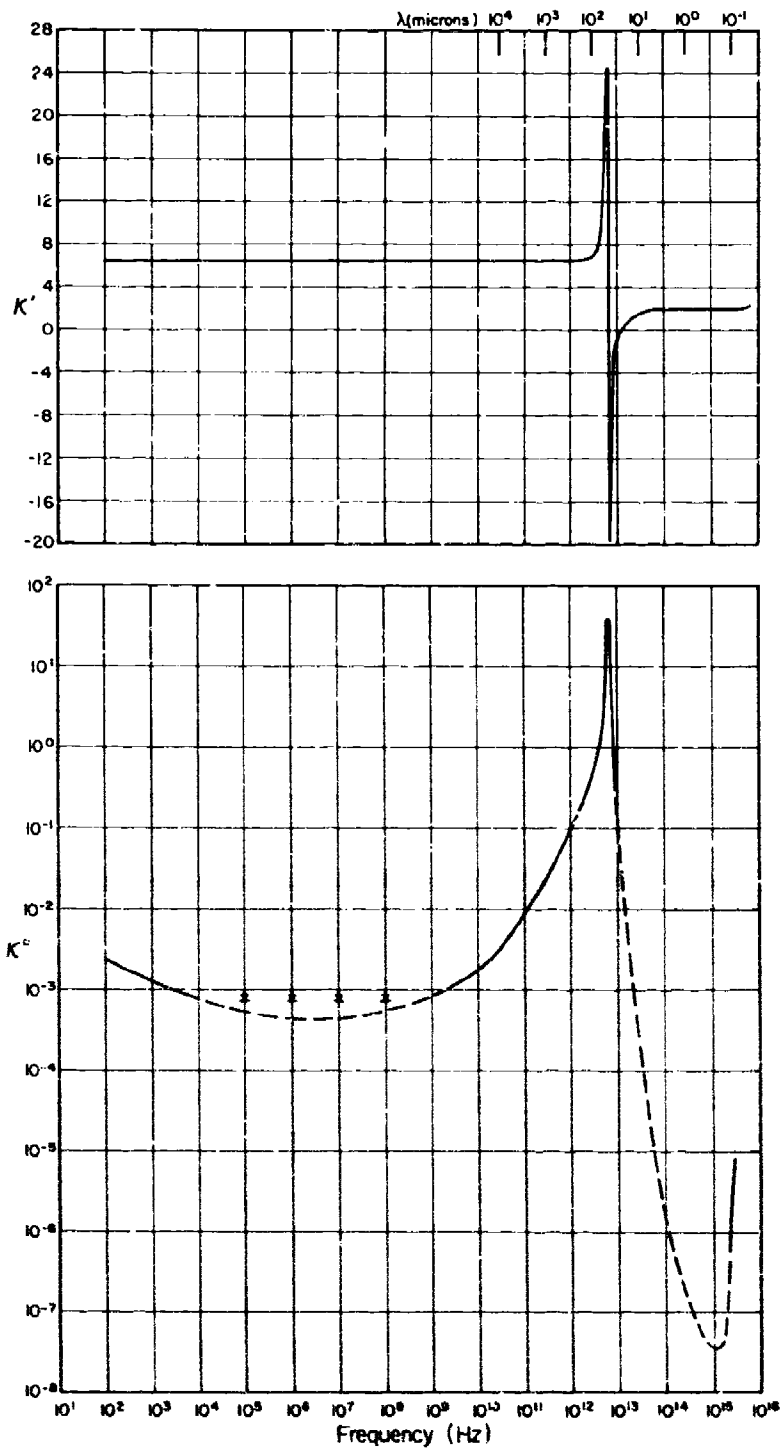


Strontium fluoride

M. I. T. , Crystal Physics Lab.

For more complete data see  
K. V. Rao and A. Smakula,  
J. Appl. Phys. 37, 319 (1966).





Wide-frequency-range data on  $\text{SrF}_2$  crystal. At frequencies above microwaves, reflection data obtained with several optical instruments were combined and Kramer's-Kronig relations used to calculate  $\kappa'$  and  $\kappa''$ .



Thallium halides

M. I. T., Crystal Physics Lab.

Material	$\kappa'$ , 25°C 10 <sup>6</sup> Hz	$\kappa'$ , 4°K	$\tan \delta$ , 25°C 10 <sup>6</sup> Hz	Activation energy for conduction in eV
TlF pressed	19.7	-	.00015	-
TlCl	31.9	-	.00006	.73
TlBr	30.4	-	.00005	.77
TlI polycrystalline	20.4	20.0	.00024	-
KRS6 (TlCl) <sub>.7</sub> -(TlBr) <sub>.3</sub>	32.2	38.4	.000075	.71
KRS5 (TlBr) <sub>.42</sub> -(TlI) <sub>.58</sub>	32.4	-	.00016	.66
TlI + CsI .01	32.5	39.4	.000068	.65

For more complete data see reports under Contract AF 19(628)-395.

Vanadium oxide (V<sub>2</sub>O<sub>3</sub>)

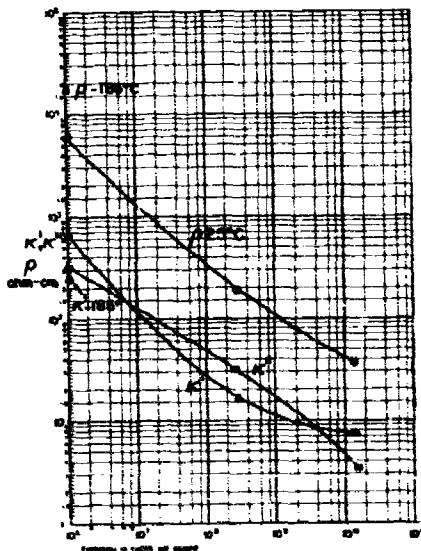
M. I. T., Lab. Ins. Research

Pressed powder samples, -185°C:

f (Hz)	$\kappa'$ meas.	$\kappa'$ corr. to full density	Density g/cm <sup>3</sup>
10 <sup>5</sup>	6.52	15.2	2.60
10 <sup>6</sup>	4.72	14.5	2.28

Zinc oxide

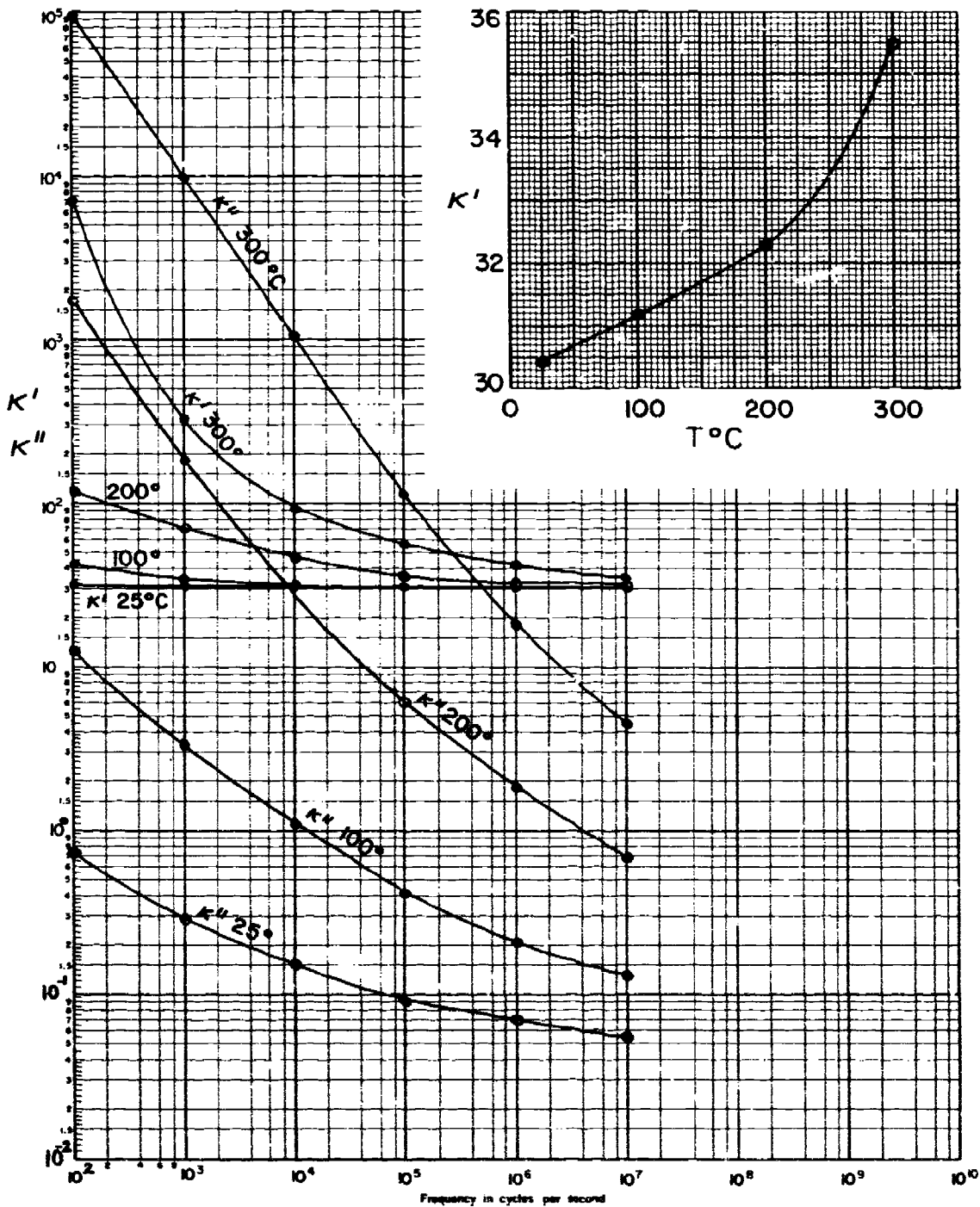
Airtron Div. of Litton Industries



Measurements of 1 and 300 MHz  
with electric field  $\parallel$  to c axis.  
At 1.4 GHz field was perpendicu-  
lar.

Zirconium oxide, "Zirconite" ceramic

Air Force Materials Laboratory  
Wright-Patterson Air Force  
Base, Ohio



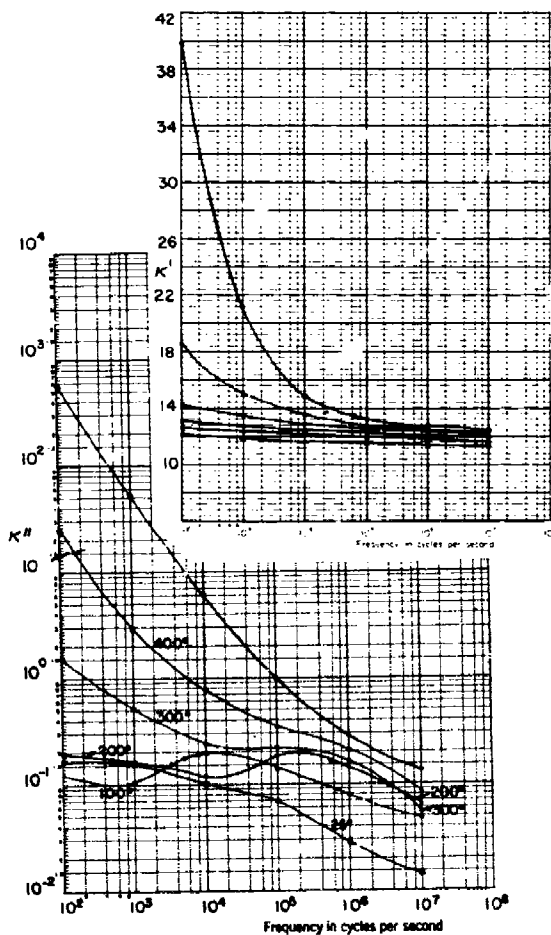
Zirconium silicate (zircon),  $ZrSiO_4$ ,  
all samples from one crystal<sup>4</sup>

E || c

Sample 1, run 1

$N_2$  to 200°C, air to 500°C,

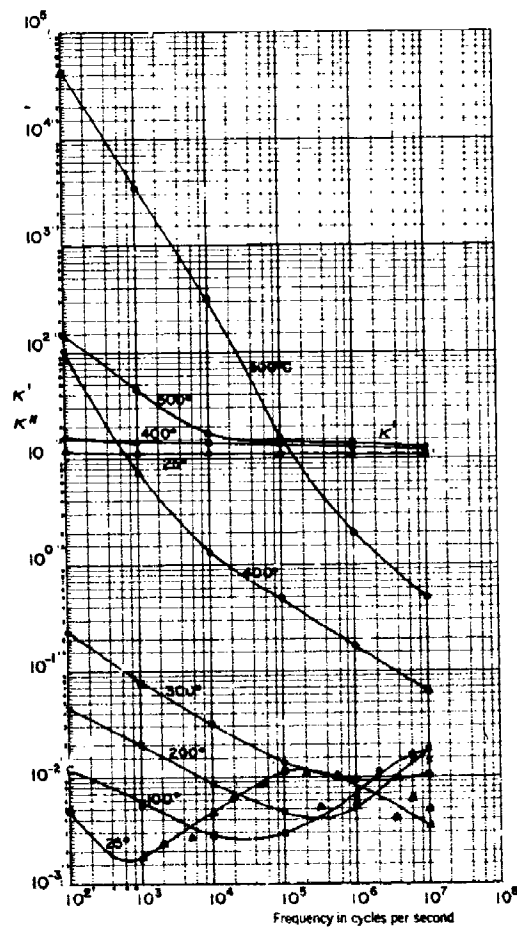
Ag electrodes



E || c

Sample 2, run 1,

same conditions as for Sample 1

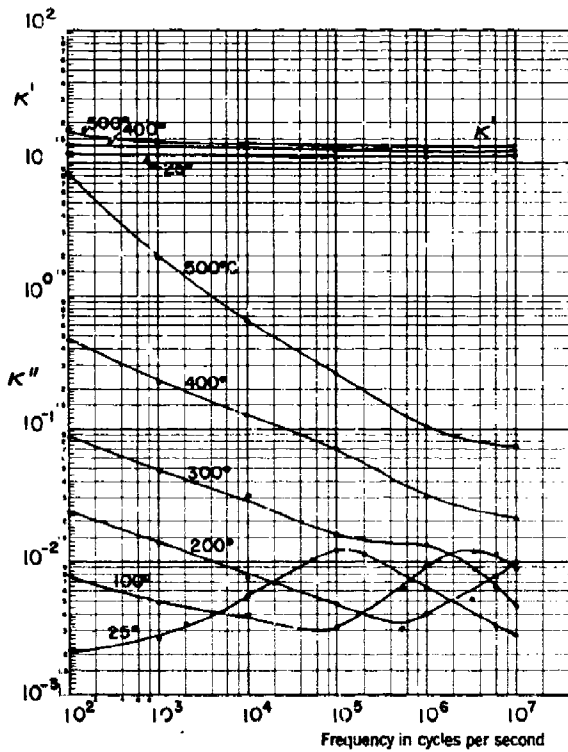


Zircon (cont.)

$E \parallel c$

Sample 2, run 2

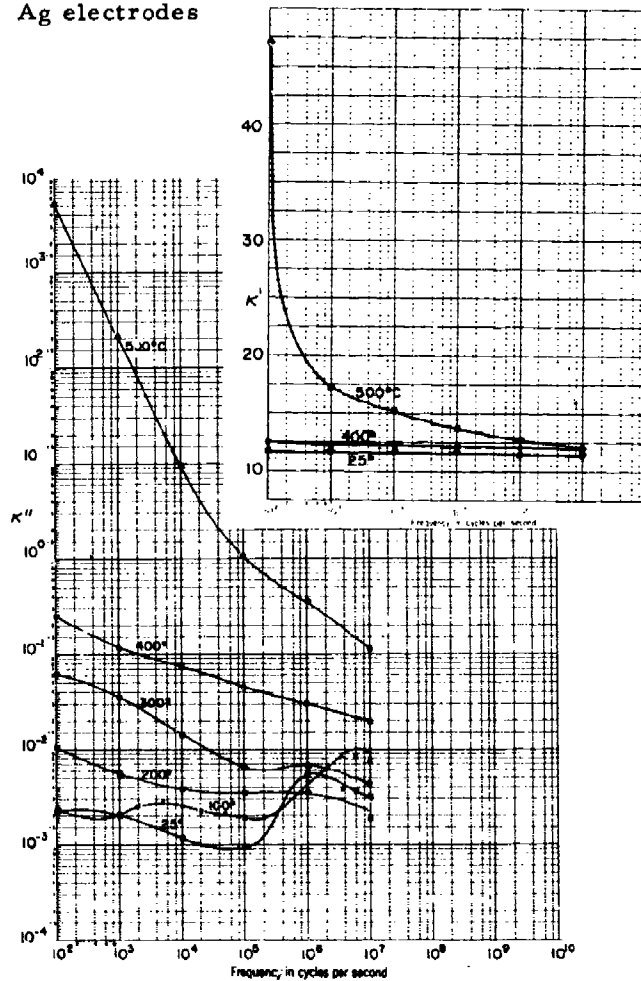
Argon atmosphere throughout  
the run, Ag electrodes



$E \perp c$

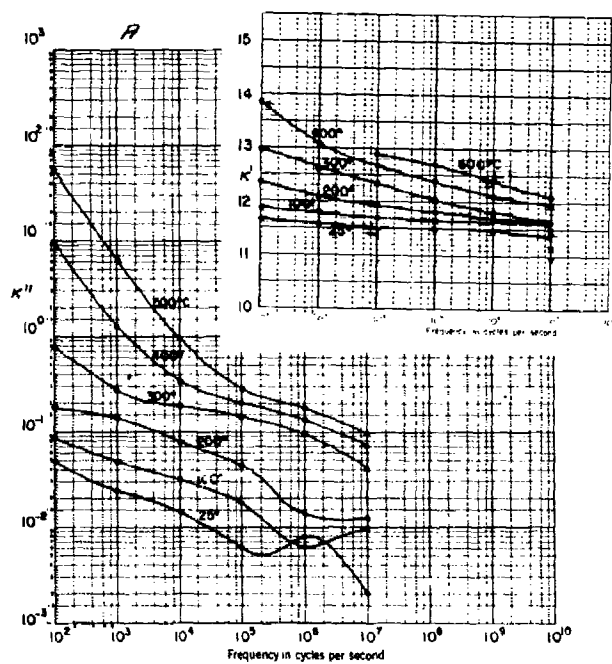
Sample 1, run 1

$N_2$  to 200°C,  
air to 500°C,  
Ag electrodes

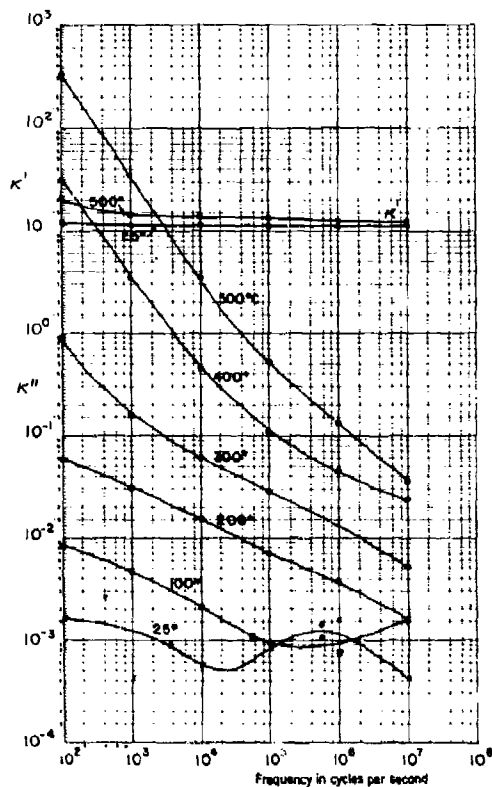


Zircon (cont.)

E ⊥ c  
Sample 1, run 2,  
N<sub>2</sub> to 500°C,  
Ag electrodes



E ⊥ c  
Sample 1, run 3,  
Ar to 500°C, Pt electrodes



II. Minerals, Rocks, Soils, Miscellaneous Inorganics

Single crystal minerals

Apatite

$E \perp c$

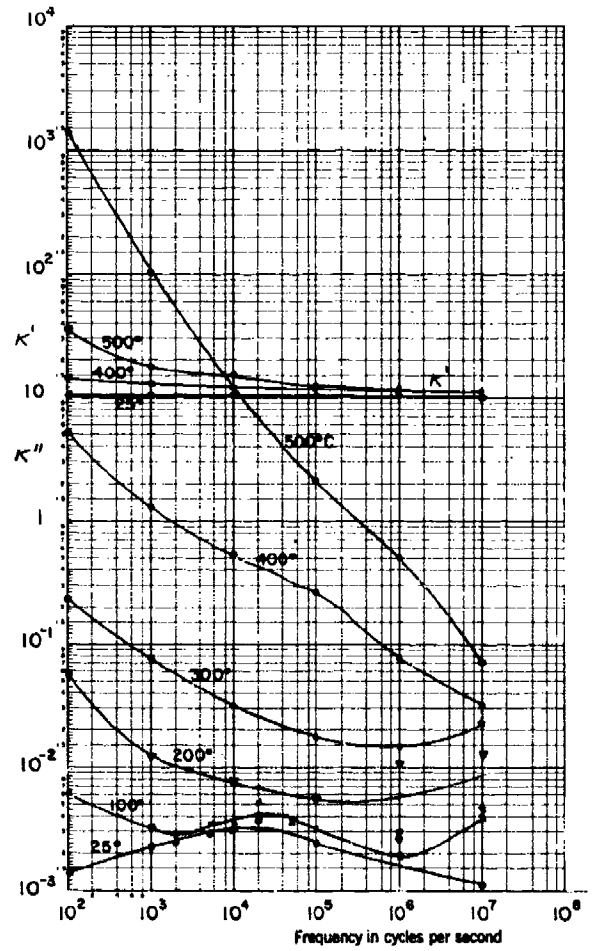
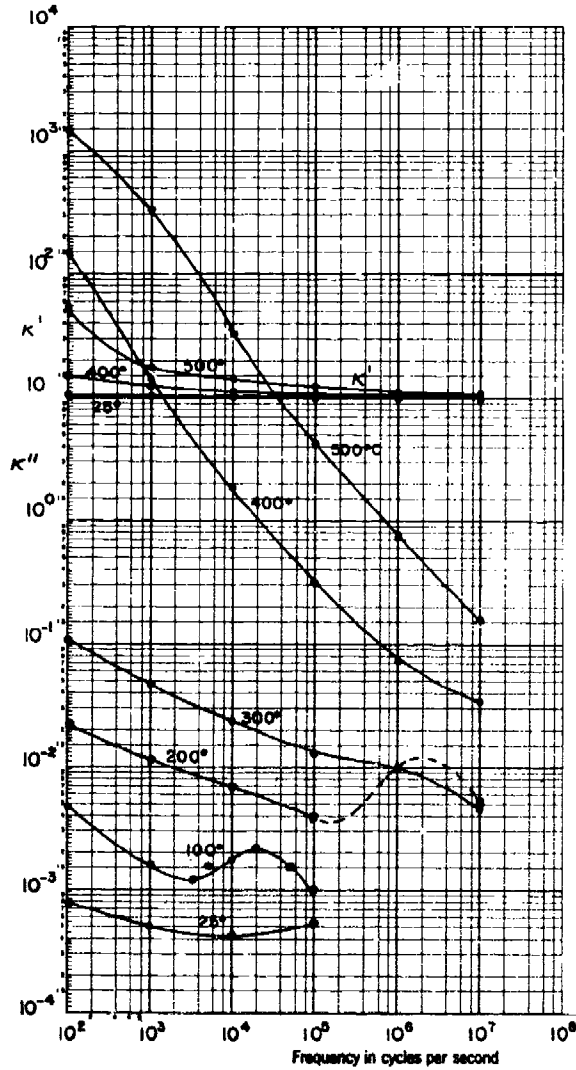
Sample 1, run 1, 25°C

1 MHz,  $\kappa' = 10.1$

$E \perp c$

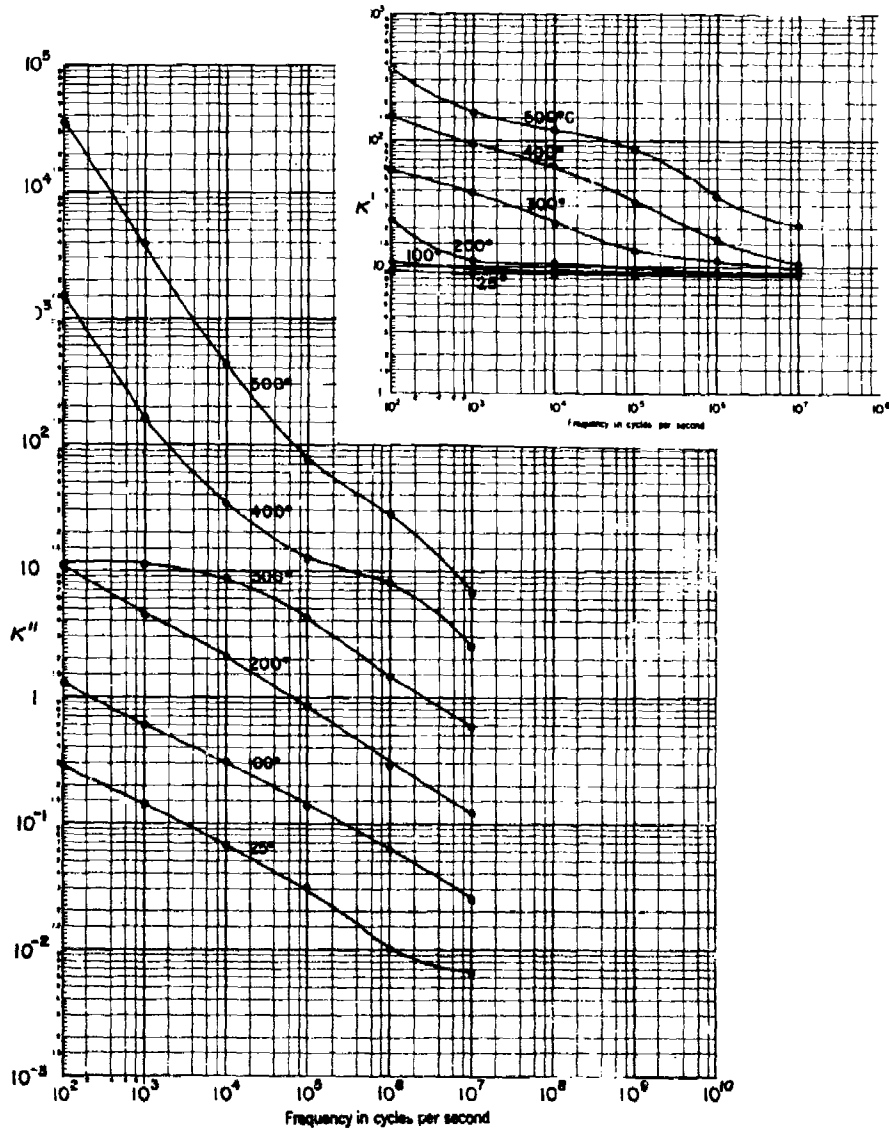
Sample 1, run 2,

repeat of run 1



Apatite (cont.)

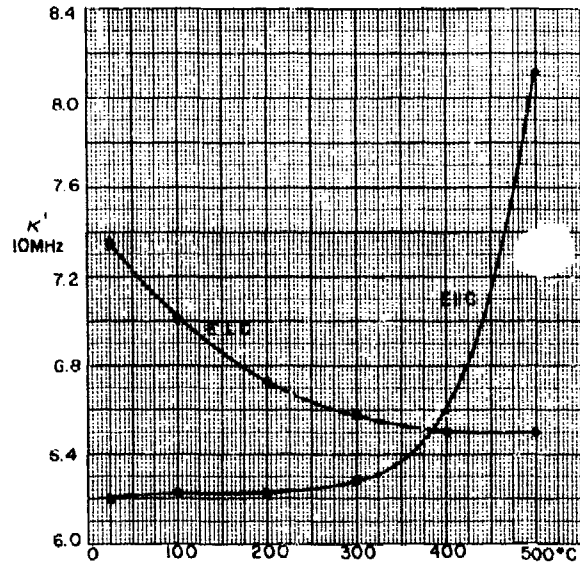
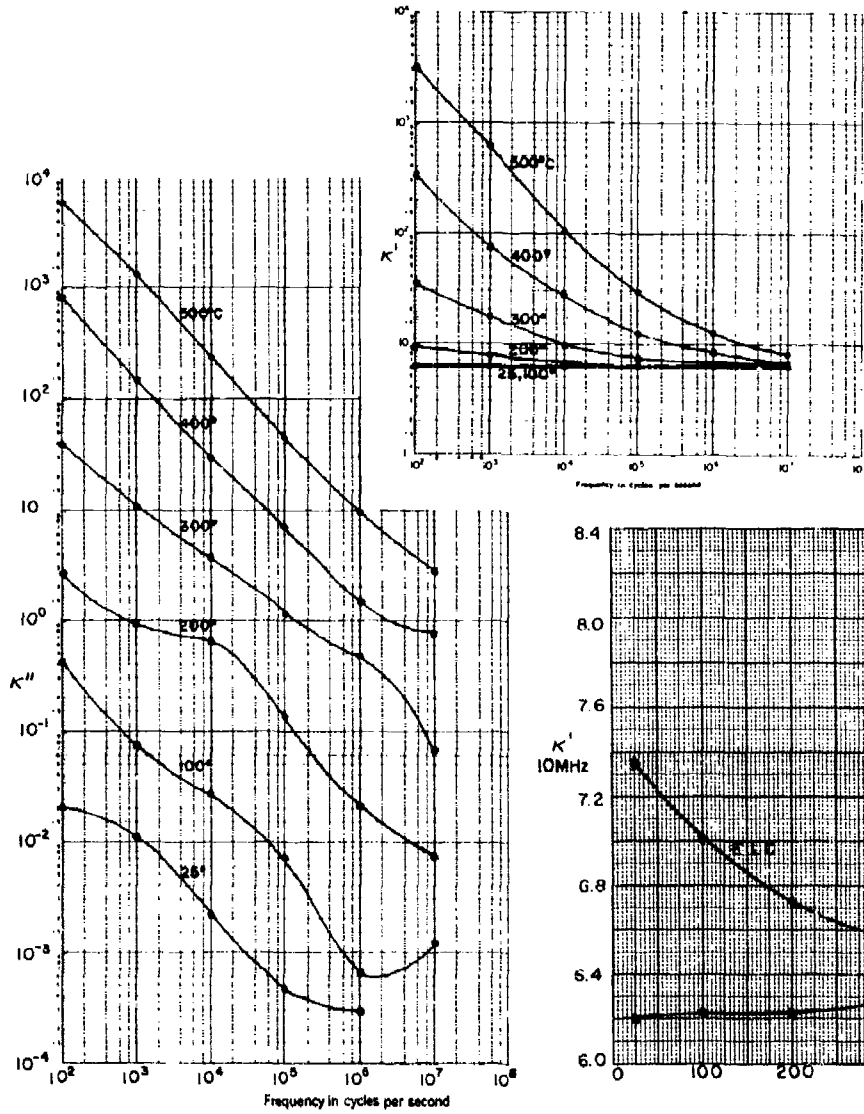
E || c, 25°C, 1 MHz,  $\kappa' = 8.58$



		10 <sup>2</sup> Hz	10 <sup>3</sup> Hz	10 <sup>4</sup> Hz
Astrophyllite				
Unoriented crystal	$\kappa'$	15.42	15.17	14.83
	$\tan \delta$	0.035	0.021	0.014
Benitoite				
BaTiS <sub>3</sub> O <sub>9</sub> , unoriented cryst.	$\kappa'$	23.8	19.6	19.2
	$\tan \delta$	0.374	0.090	0.0195

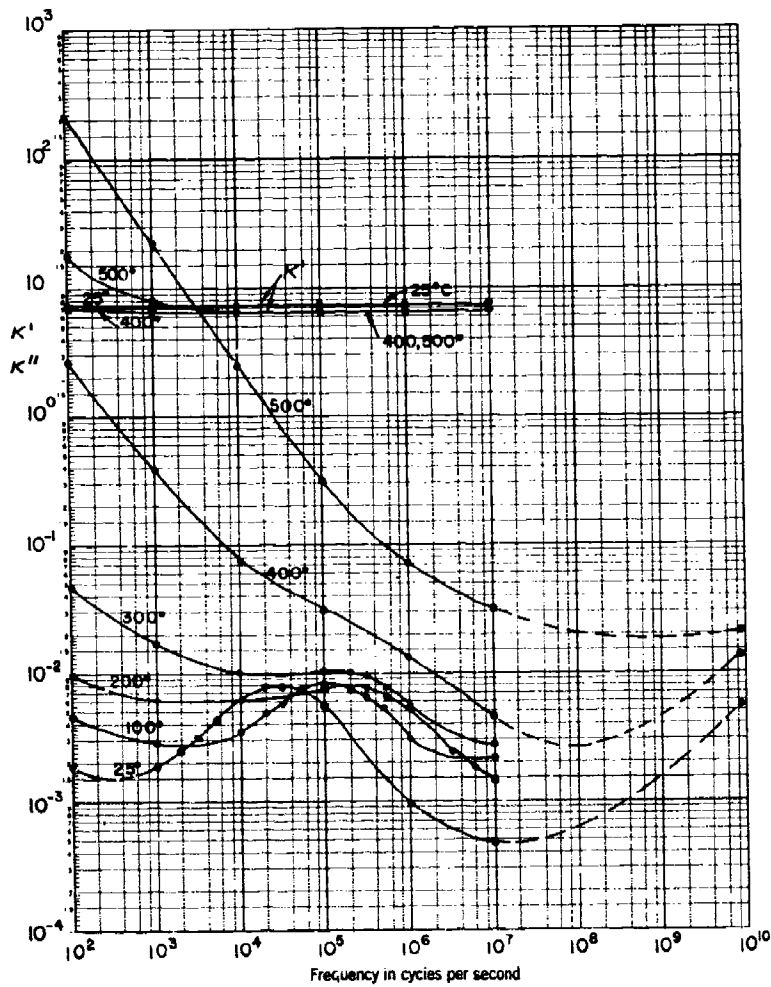
Beryl

E || c





Beryl, E l c



Neptunite,  $(\text{Na}, \text{K})_2(\text{Fe}, \text{Mn})(\text{Si}, \text{Ti})_5\text{O}_{12}$ ,  
 data on unoriented crystal

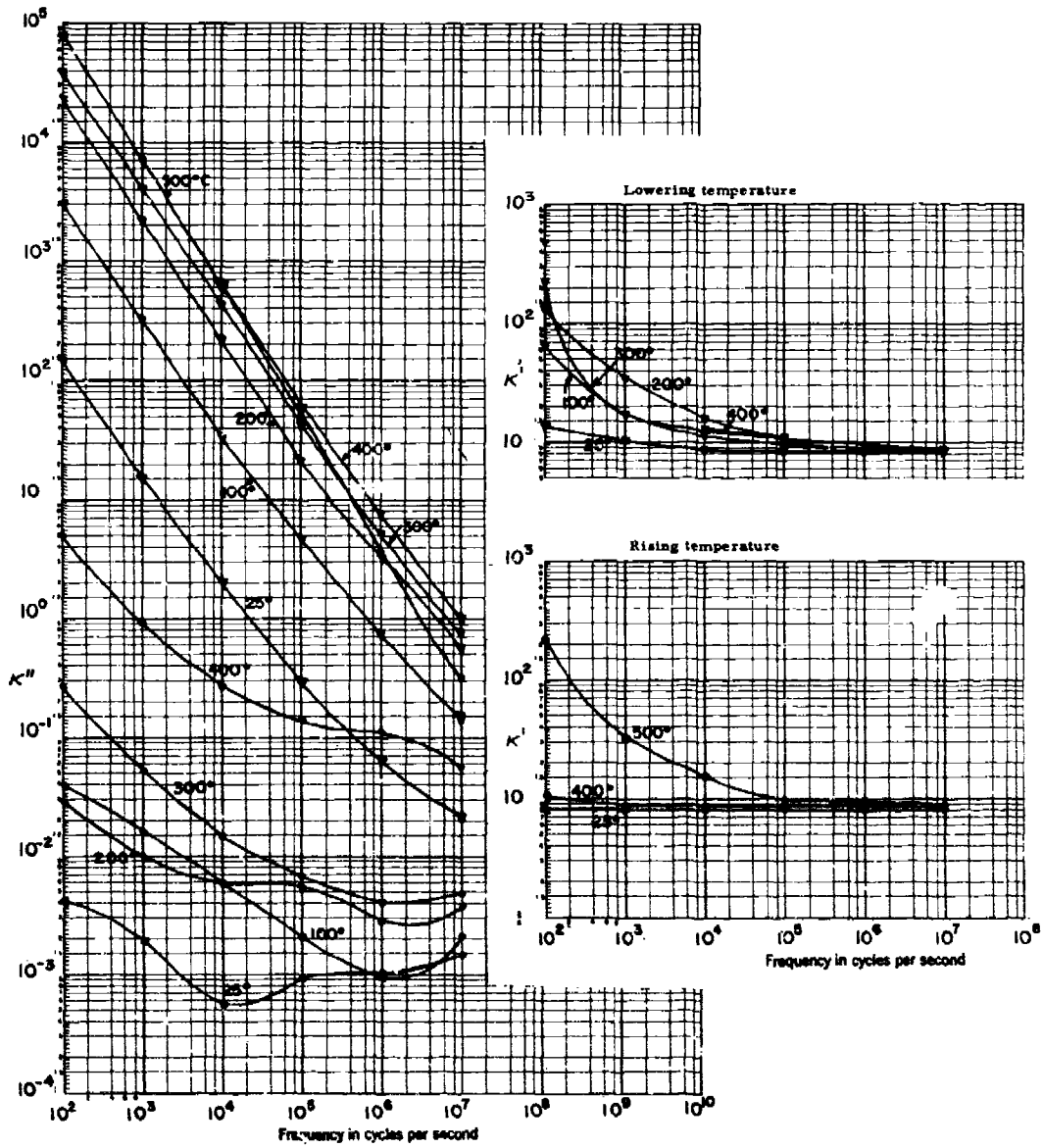
	$10^3$ Hz	$10^4$ Hz
$\kappa'$	8.33	8.19
$\tan \delta$	0.0335	0.068

Spodumene

E || a

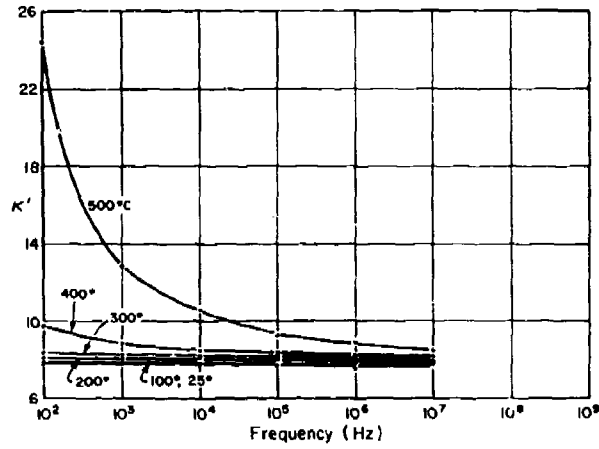
○ rising temperature

▽ lowering temperature

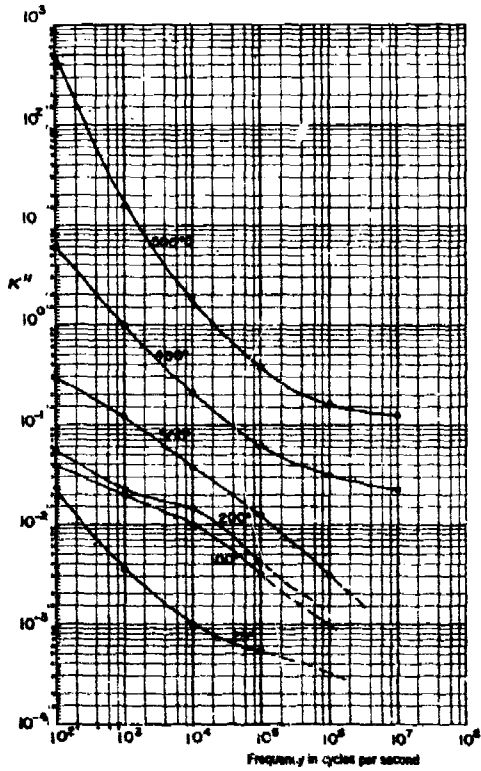


Spodumene (cont.)

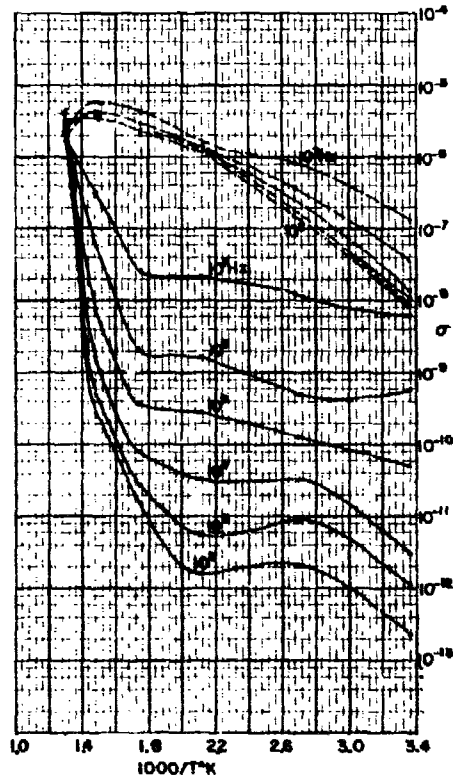
E || b



E || b

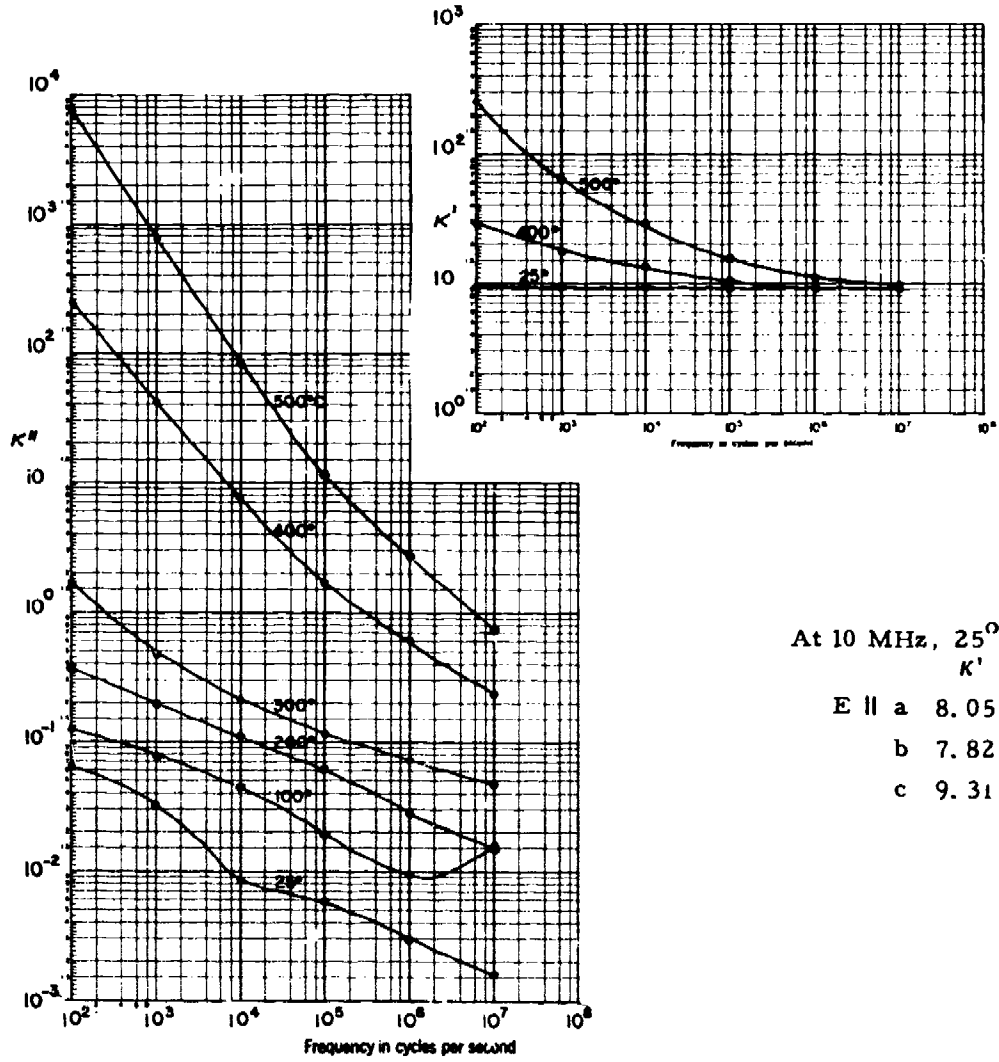


E || a



Spodumene (cont.)

E || c

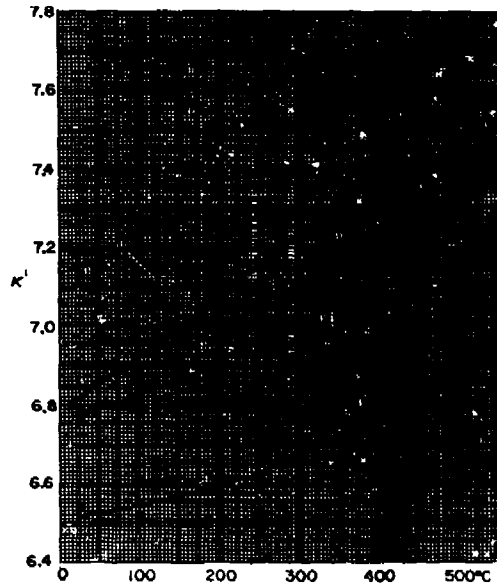


At 10 MHz, 25°C  
 $\kappa'$

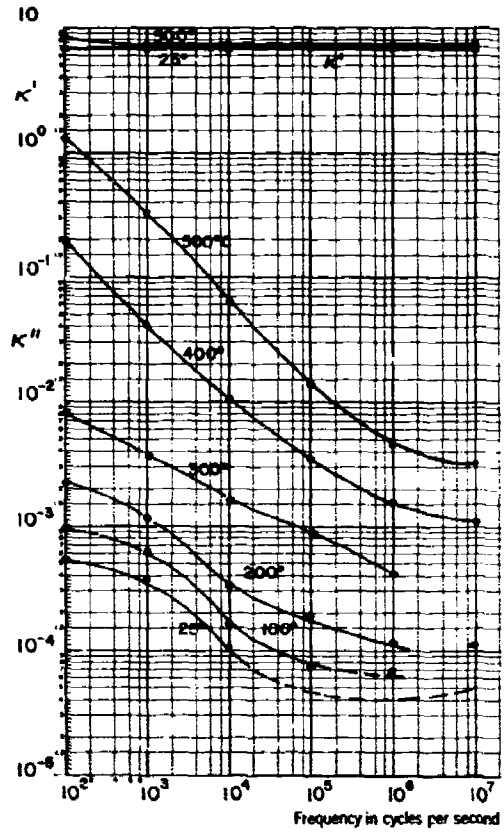
- E || a 8.05
- b 7.82
- c 9.31

Topaz

$\kappa'$  at 10 MHz

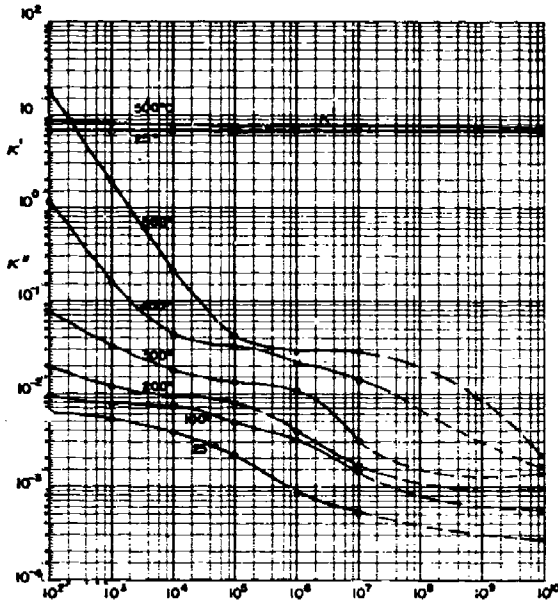


E || a

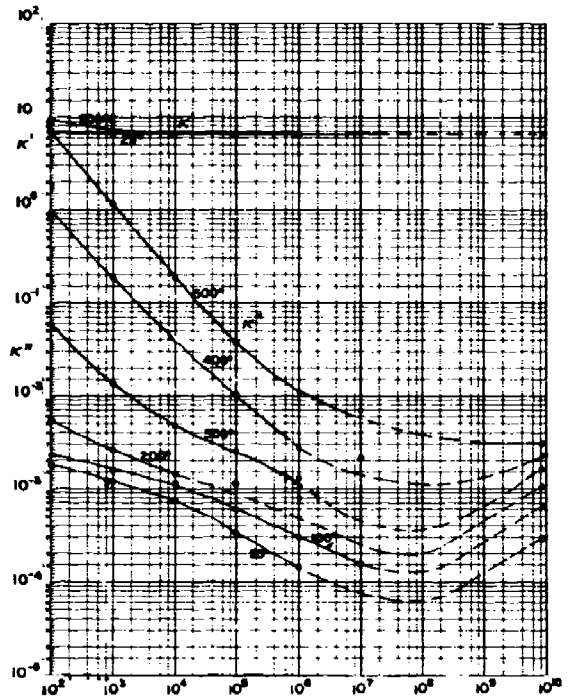


Topaz (cont.)

E || b

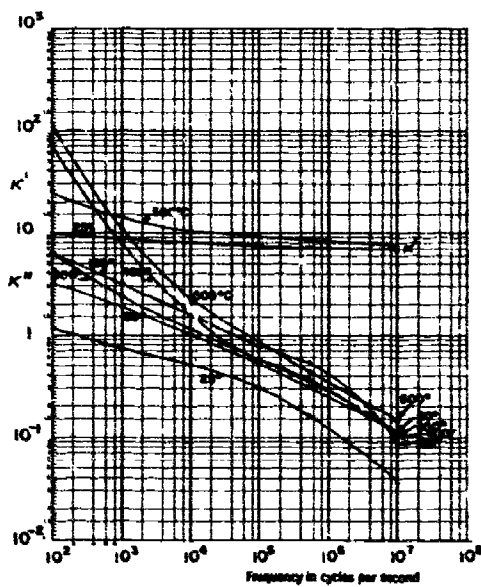


E || c

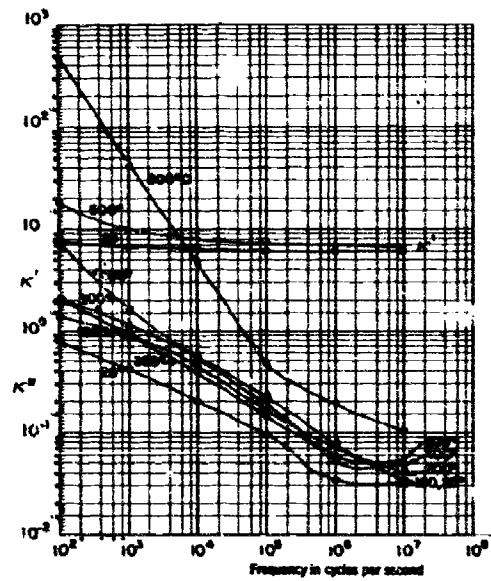


Tourmaline

E  $\perp$  c, piezoelectrically active at 1 MHz



E || c



Multicrystalline minerals

Halite (rock-like pieces of porous salt), at 50% R. H., 25°C, 14 GHz

Sample	$\kappa'$	$\tan \delta$	Density (g/cm <sup>3</sup> )
1, surface	4.52 - 4.63	.0056 - .0057	1.808
2, "	4.68 - 4.82	.0106 - .0103	1.861
3, "	3.81 - 3.83	.0127 - .0109	1.565
4, "	3.95 - 4.00	.0104 - .0134	1.670
5, 1' down	3.69 - 3.94	.0198 - .0125	1.500
6, "	3.25 - 3.50	.0077 - .0113	1.422
7, 3' "	4.17 - 4.18	.036 - .046	1.646
7, dried	4.12 - 4.19	.0193 - .0206	1.640

Limonite, crushed, density 1.733 g/cm<sup>3</sup>

Harvard College Observatory

T°C	10 <sup>9</sup> Hz		3 x 10 <sup>9</sup>	
	$\kappa'$	$\tan \delta$	$\kappa'$	$\tan \delta$
25	4.17	.0108	3.73	.046
475	3.65	.0134	3.63	.0193
404	3.62	.0076	3.60	.0113
325	3.61	.0057	3.58	.0084
250	3.61	.0048	3.57	.0073
185	3.60	.0045	3.56	.0064
107	3.58	.0047	3.55	.0059
22	3.56	.0057	3.53	.0055

Limonite, 8.52 GHz

Sample 1, coarse, 25°C

$\kappa' = 3.95 - 4.01$  depending on rotation  
 $\tan \delta = 0.18 - 0.059$

Sample 2, fine, 25°C

$\tan \delta = 0.0122 - 0.0127$

Sample 3	T°C	$\kappa'$	$\tan \delta$
	25	3.82	.0012
	510	3.60	.0085
	400	3.55	.0047
	300	3.52	.0039
	200	3.50	.0042
	100	3.48	.0043
	25	3.49	.0043

Sample in equilibrium with room humidity approx. 50%.

Magnesite, crushed powder, hard-packed

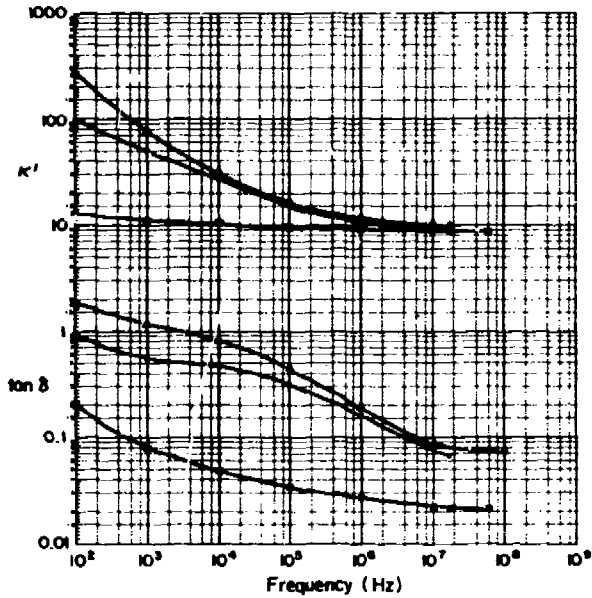
25°C, 50% R. H., 8.52 GHz,  $\kappa' = 3.29$ ,  $\tan \delta = .0054 - .0059$ , density 1.11 g/cm<sup>3</sup>

Quartz powder, 8.52 GHz, pre-dried in oven at 100°C, density 1.22 g/cm<sup>3</sup>

T°K	$\kappa'$	$\tan \delta$
80	2.446	.0021
200	2.460	.0027
300	2.472	.0028
400	2.483	.0027
500	2.495	.0031
600	2.497	.0035

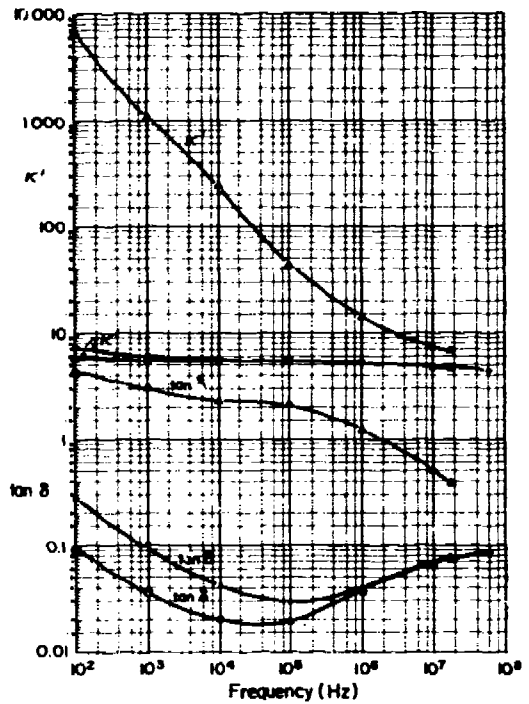
Rocks

Hawaiian, high-density basalt



- % H<sub>2</sub>O on dry weight basis 0.358  
% H<sub>2</sub>O on dry volume basis 0.956  
density 2.6756 g/cm<sup>3</sup>
- Dry after 3 days in oven at 105°C  
density 2.669 g/cm<sup>3</sup>
- ▲ % H<sub>2</sub>O on dry weight basis 0.377  
% H<sub>2</sub>O on dry volume basis 1.005  
density 2.677 g/cm<sup>3</sup>

Hawaiian, low-density basalt

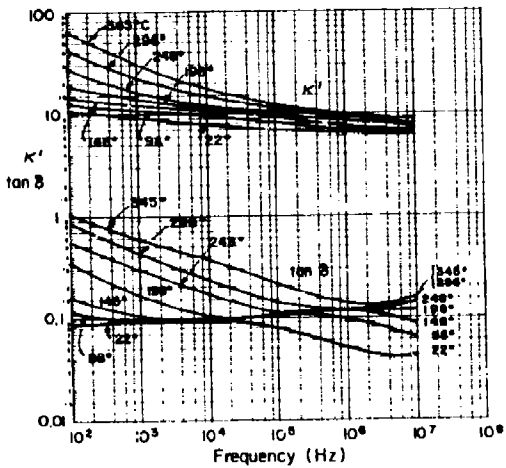


- % H<sub>2</sub>O on dry weight basis 0.441  
% H<sub>2</sub>O on dry volume basis 0.0617  
density 1.401 g/cm<sup>3</sup>
- Dry (after 3 days in oven at 105°C  
density 1.400 g/cm<sup>3</sup>
- ▲ % H<sub>2</sub>O on dry weight basis 2.71  
% H<sub>2</sub>O on dry volume basis 3.79  
density 1.438 g/cm<sup>3</sup>



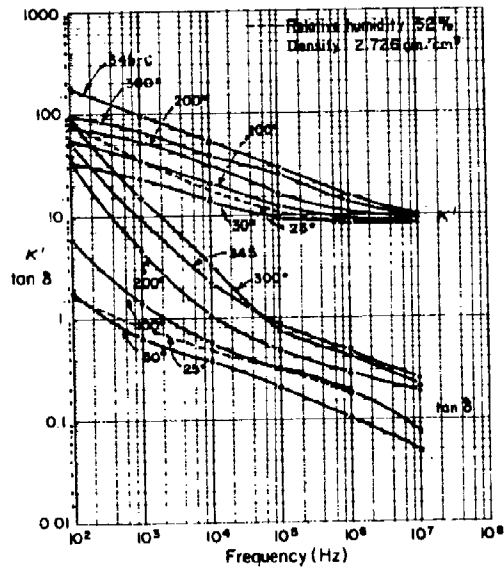
Quincy granite

Density 2.631 g/cm<sup>3</sup>  
Temp. run in dry N<sub>2</sub>



Virginia granite or marble

Temperature run in dry N<sub>2</sub>



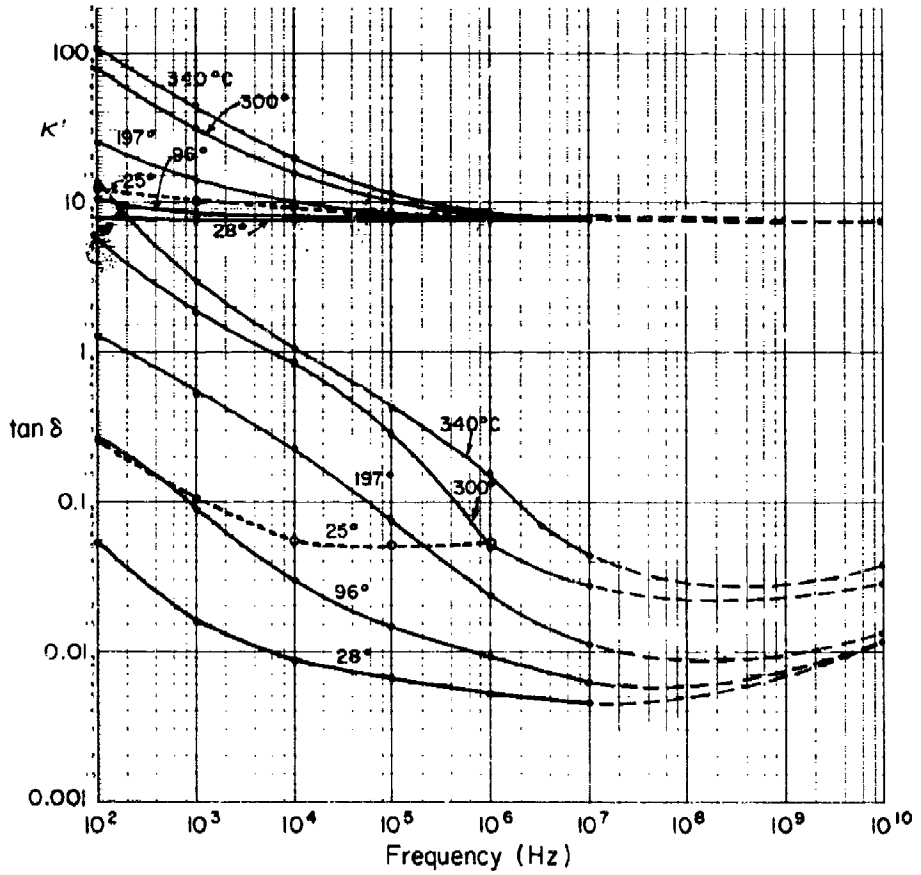
Quincy granite

T <sup>o</sup> C	Frequency (Hz)				T <sup>o</sup> C	1 kHz		
	10 <sup>2</sup> Hz	10 <sup>3</sup> Hz	10 <sup>4</sup> Hz	10 <sup>5</sup> Hz		κ'	σ	
25	κ'	10.5	9.26	8.01	2.06	9.26	4.50 x 10 <sup>-10</sup>	
	tan δ	0.0796	0.0875	0.0875	0.0705	10.3	4.58	
	σ	4.64 x 10 <sup>-11</sup>	4.5 x 10 <sup>-10</sup>	3.9 x 10 <sup>-10</sup>	2.76 x 10 <sup>-8</sup>	105	10.9	4.64
200	κ'	15.4	12.47	11.07	9.78	147	11.5	5.31
	tan δ	0.21	0.121	0.088	0.090	204	12.51	8.61 x 10 <sup>-10</sup>
	σ	1.797 x 10 <sup>-10</sup>	8.37 x 10 <sup>-10</sup>	5.40 x 10 <sup>-9</sup>	4.88 x 10 <sup>-8</sup>	251	14.87	1.85 x 10 <sup>-9</sup>
400	κ'	64.5	32.9	19.42	12.86	305	19.3	3.38 x 10 <sup>-9</sup>
	tan δ	1.02	0.60	0.374	0.252	345	23.4	5.51 x 10 <sup>-9</sup>
	σ	3.65 x 10 <sup>-9</sup>	1.097 x 10 <sup>-8</sup>	4.03 x 10 <sup>-8</sup>	1.757 x 10 <sup>-7</sup>	400	32.9	1.09 x 10 <sup>-8</sup>
600	κ'	293	106	42.5	22.0	466	34.4	9.5 x 10 <sup>-8</sup>
	tan δ	6.85	2.31	1.03	0.54	553	81.3	9.34 x 10 <sup>-8</sup>
	σ	1.114 x 10 <sup>-7</sup>	1.36 x 10 <sup>-9</sup>	2.43 x 10 <sup>-7</sup>	6.60 x 10 <sup>-7</sup>	601	106	1.36 x 10 <sup>-9</sup>
800	κ'	4395	238	4	37.4	700	172	4.25 x 10 <sup>-7</sup>
	tan δ	14.4	9.65	3.05	1.11	806	243	1.313 x 10 <sup>-6</sup>
	σ	1.116 x 10 <sup>-6</sup>	1.275 x 10 <sup>-6</sup>	1.423 x 10 <sup>-6</sup>	2.30 x 10 <sup>-6</sup>	874	26,800	1.84 x 10 <sup>-4</sup>
1000	κ'	47000	6100	710	710	996	45,900	3.57 x 10 <sup>-4</sup>
	tan δ	14.0	12.6	12.4	12.4			
	σ	3.65 x 10 <sup>-4</sup>	4.26 x 10 <sup>-4</sup>	4.89 x 10 <sup>-4</sup>	4.89 x 10 <sup>-4</sup>			

Virginia Greenstone

Density 2.936 g/cm<sup>3</sup>, temperature run in dry N<sub>2</sub>

(-----) R. H. 52%



Limestone, from Lucerne Valley

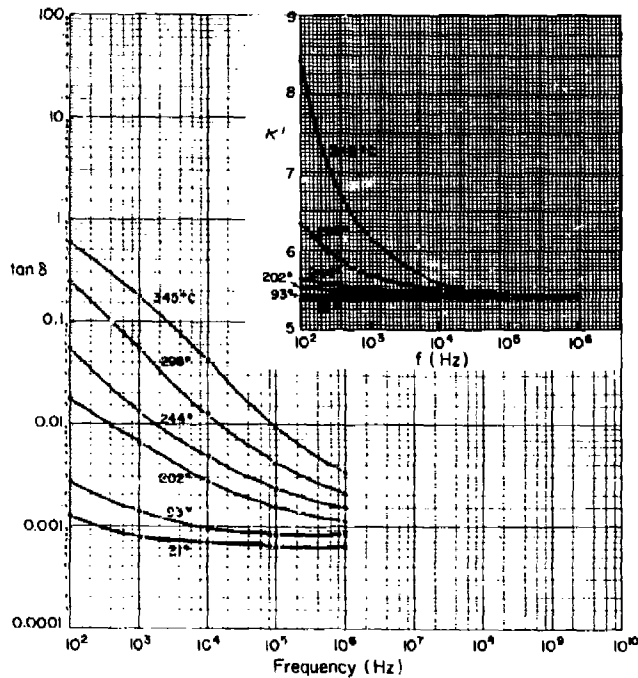
Raytheon

50% R. H., 25°C, 14 GHz

Sample	$\kappa'$	$\tan \delta$	Density
1	8.21 - 8.45	.0038 - .0080	2.667
2	8.62 - 8.64	.0178 - .0189	2.646

Rhyolite

Density 2.655 g/cm<sup>3</sup>, temperature run in dry N<sub>2</sub>



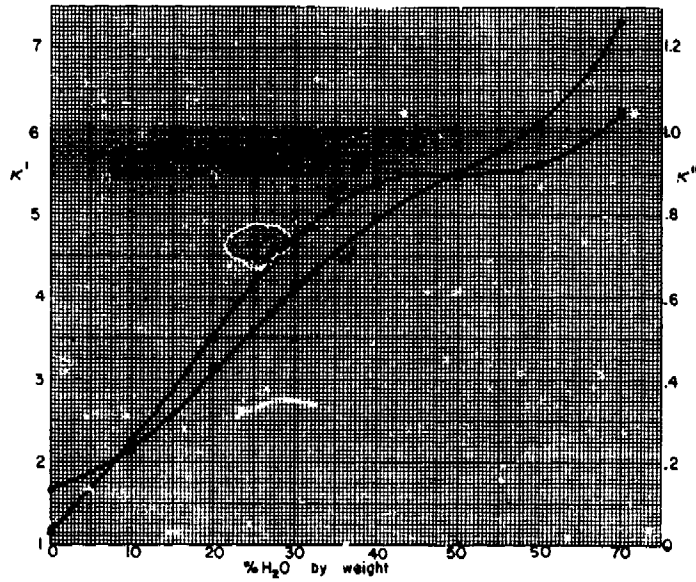
Sandstone, almond, oil-bearing as cored, 25°C

Raytheon

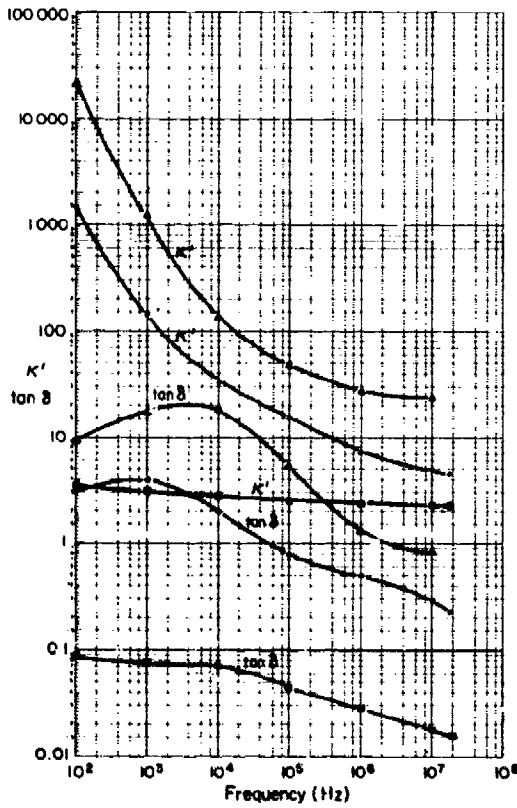
Frequency in MHz

Sample		1	3	10	60	100
1	$K'$	5.64	5.23	4.90	4.55	4.50
	$\tan \delta$	0.131	0.104	0.084	0.059	0.049
2	$K'$	6.13	6.09	6.07	6.06	6.06
	$\tan \delta$	0.0100	0.0084	0.0059	0.0047	0.0051
3	$K'$	6.05	6.04	6.01	5.91	5.87
	$\tan \delta$	0.0068	0.0079	0.00855	0.0095	0.0097
4	$K'$	5.33	5.08	4.92	4.75	4.73
	$\tan \delta$	0.060	0.057	0.051	0.036	0.027
5	$K'$	5.40	5.16	4.93	4.68	4.61
	$\tan \delta$	0.080	0.068	0.058	0.042	0.032
6	$K'$	22.9	11.24	9.20	6.60	6.20
	$\tan \delta$	1.88	1.39	0.68	0.338	0.29
7	$K'$	6.15	6.12	6.10	6.04	6.00
	$\tan \delta$	0.0088	0.0093	0.0096	0.0102	0.0105

Soils  
Fullers Earth, at 8.52 GHz

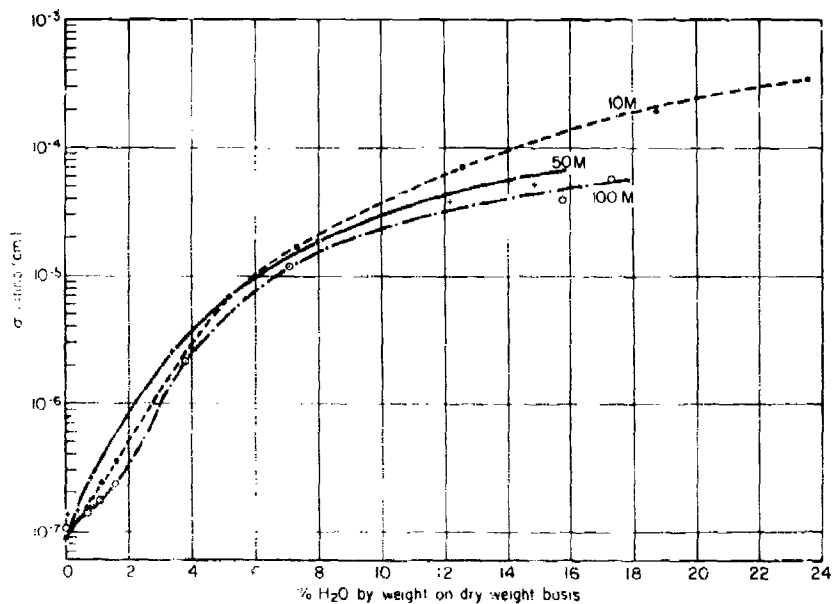
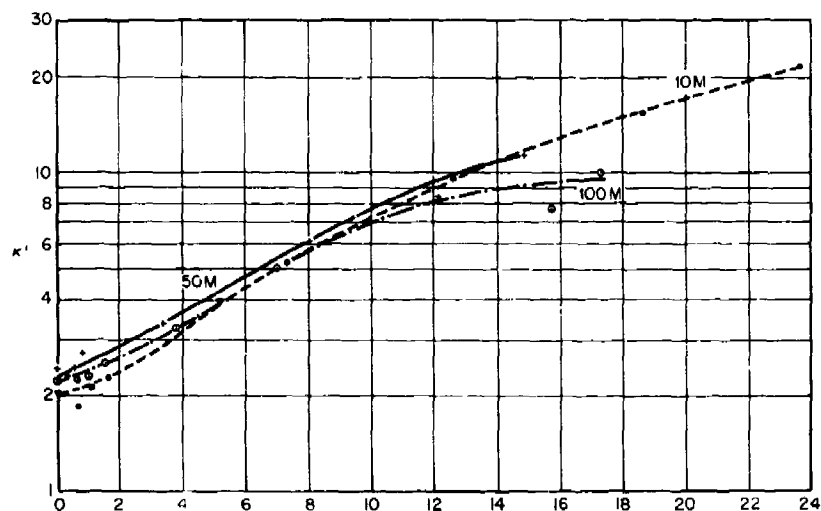


Hawaiian



- % H<sub>2</sub>O on weight basis 20.0  
% H<sub>2</sub>O on volume basis 14.4  
Density 0.8634 g/cm<sup>3</sup>
- Dry after 3 days in oven at 105°C  
Density .7627 g/cm<sup>3</sup>
- ▲ % H<sub>2</sub>O on dry weight basis = 72.27  
% H<sub>2</sub>O on volume basis = 50.60  
Density 1.2133 g/cm<sup>3</sup>

Mass. loams, at 10 MHz, 25°C



Desert sand (Raytheon)

15% R. H. , 25°C, 14 GHz

$\kappa' = 2.86$

$\tan \delta = 0.0116$

Density =  $1.43 \text{ g/cm}^3$



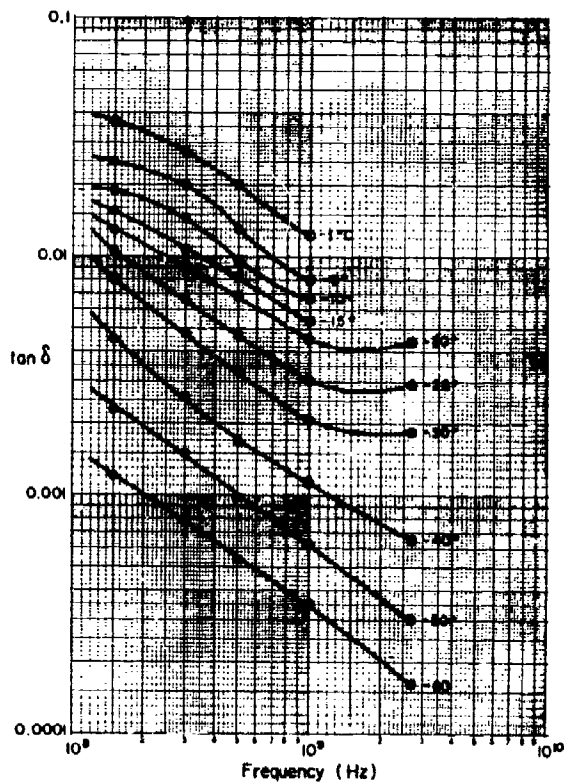
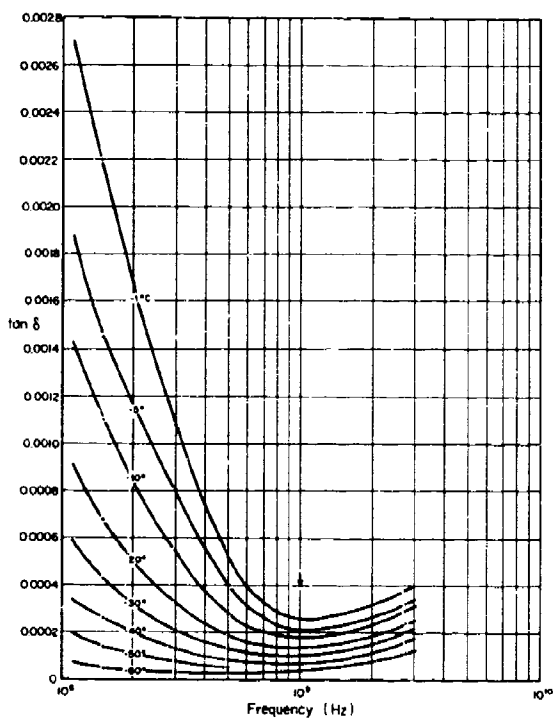
LOSS TANGENT

Sample, Source	Temp. (°C)	Frequency in MHz						
		110 *	150	300	500	1000	2700	
Dartmouth No. 12	-1	.0030	.0022	.00108	.00052	.0004	.00038	
	5	.0019	.00144	.00076	.00040		.00034	
	10	.00145	.00110	.00055	.00028		.00030	
	20	.00092	.00068	.00033	.00019		.00024	
	30	.00059	.00043	.00021	.00013		.00020	
	40	.00034	.00026	.00013	.00008		.00016	
	50	.00020	.00014	.00008	.00005		.00014	
60	.00008	.00005	.00003	.00003		.00013		
Dartmouth No. 14	-1	.039	.037	.0225	.0200	.0122		
	5	.026	.025	.0200	.0130	.0080		
	10	.0195	.0190	.0145	.0097	.0067		
	15	.017	.0157	.0107	.0082	.0054		
	20	.015	.0130	.0091	.0068	.0045	.0044	
	25	.013	.0106	.0067	.0047	.0030	.0029	
	30	.010	.0080	.0048	.0033	.00205	.00185	
	40	.0058	.0045	.0026	.0017	.00112	.00065	
	50	.0028	.0023	.0015	.00098	.00062	.00030	
	60	.0014	.0012	.00078	.00054	.00035	.00016	
Tuto Tunnel		See data for Dartmouth No. 12 (no measurable difference)						
Little America	-1	.0049	.0037	.0018	.00106	.00054	.00038	
	5	.0035	.0026	.0013	.00072	.00037	.00032	
	10	.00286	.00217	.00108	.00056	.00025	.00027	
	20	.0020	.00154	.00078	.00038	.00018	.00024	
	30	.00146	.00116	.00057	.00029	.00014	.00020	
	40	.00105	.00085	.00044	.00025	.00013	.00014	
50	.00076	.00057	.00030	.00021	.00012	-		
* 110 MHz values are extrapolated, not measured.								
Artic	-1						.00033	
	5						.00029	
	10		Cooling failed, sample melted					.00024
	20						.00018	
	30			.00045			.00016	
	40			.00032			.00014	
	60			.00022			.00013	
				.00015			.00013	

Ices

Dartmouth No. 12

Sea ice

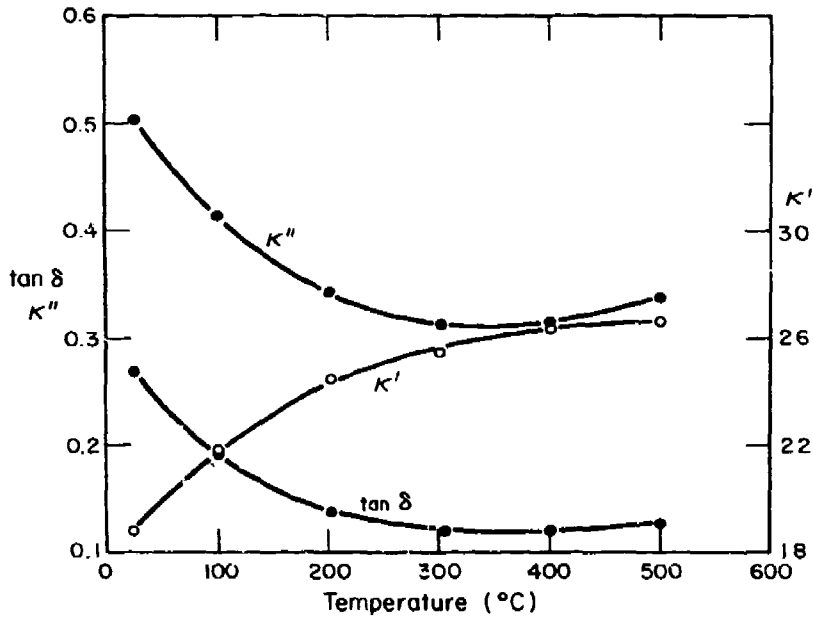




CFI 1003

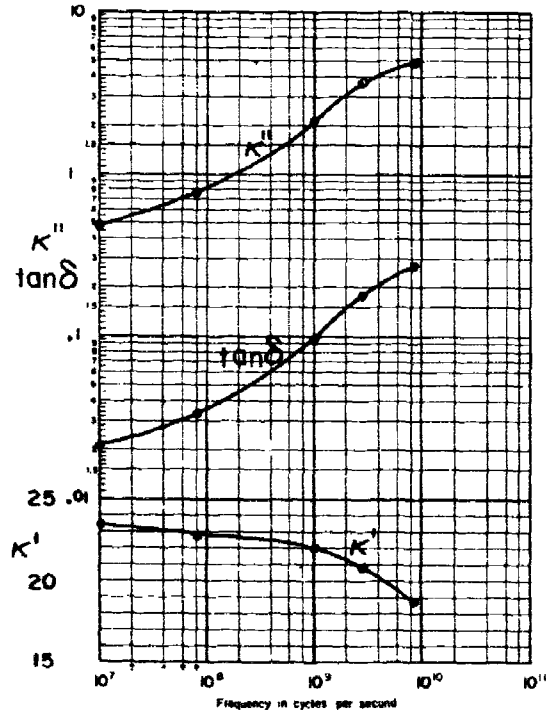
Ceramics for Industry

At 8.52 GHz



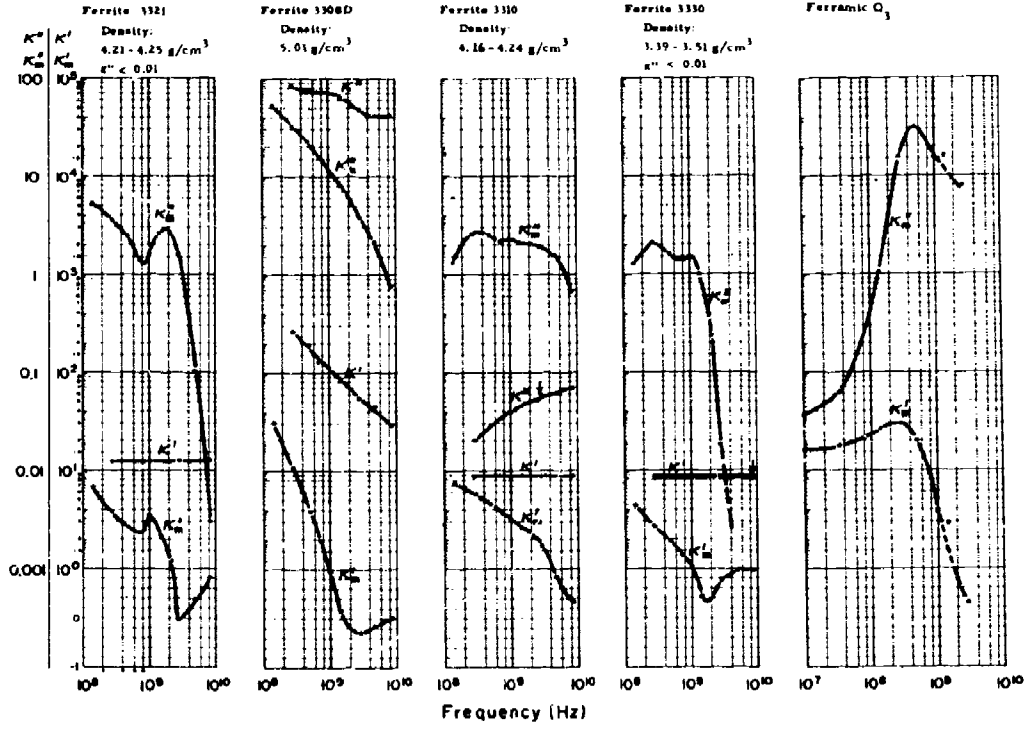
CFI 1006

At 25°C



Ferrites

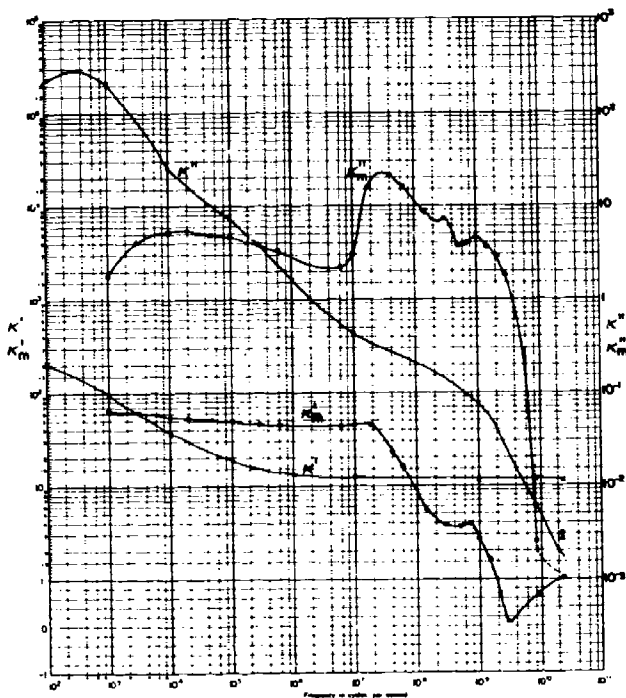
General Ceramics  
Division of Indiana General



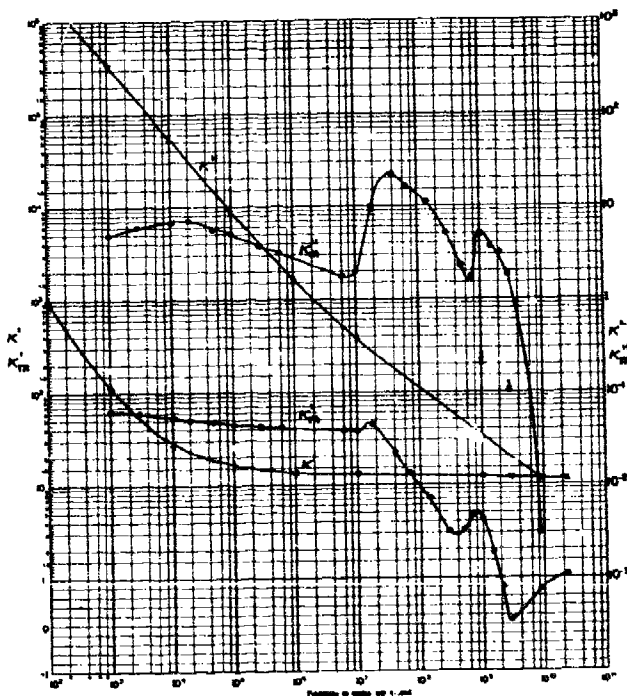
Ferrites (cont.)

General Ceramics  
Division of Indiana General

R-1



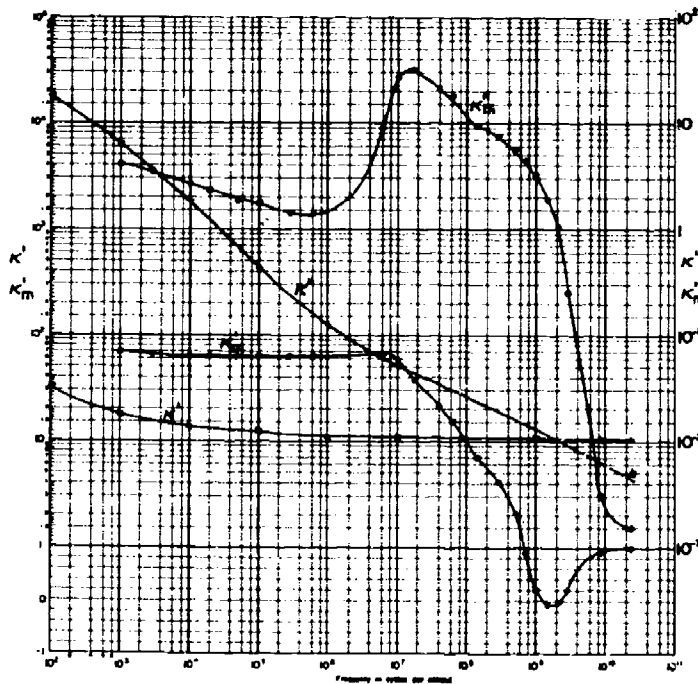
R-4



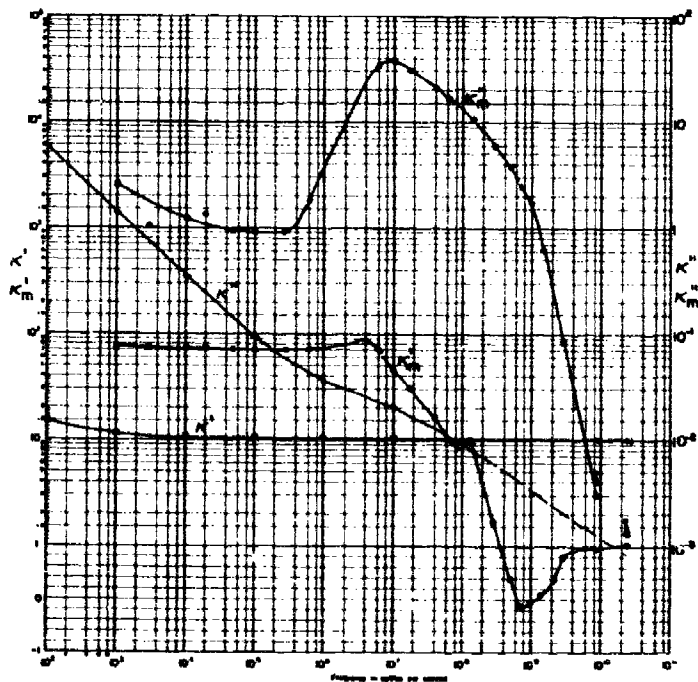
Ferrites (cont.)

General Ceramics  
Division of Indiana General

R-5



R-6

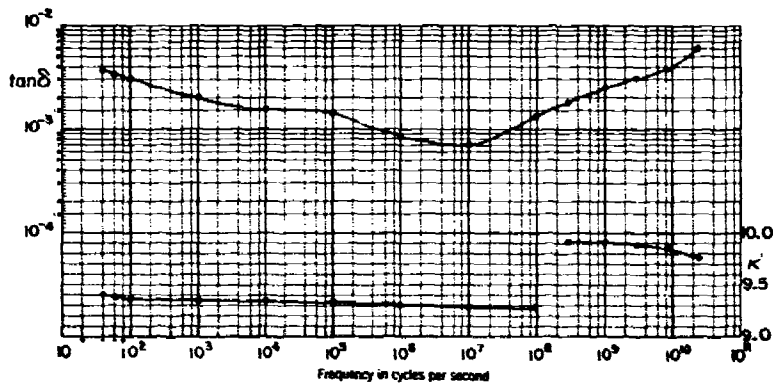


Havelex, glass-bonded mica  
At 8.52 GHz, 25°C

Haveg Industries, Inc.  
Taunton Division

Type	$\kappa'$	$\tan \delta$
1080	6.35	.0025
1090	6.17	.0058
1101	8.89	.0027
2101	6.35	.0013
2103	9.2	.0021
2801	6.35	.0020
2803	6.05 -	.00255 -
	6.39	.0026

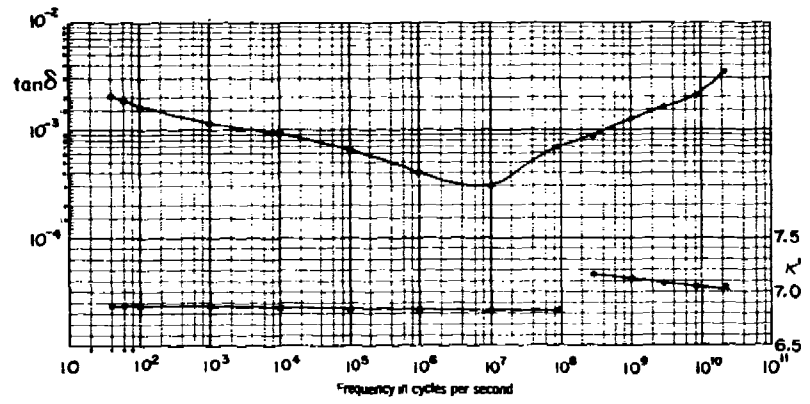
Mycalex 410



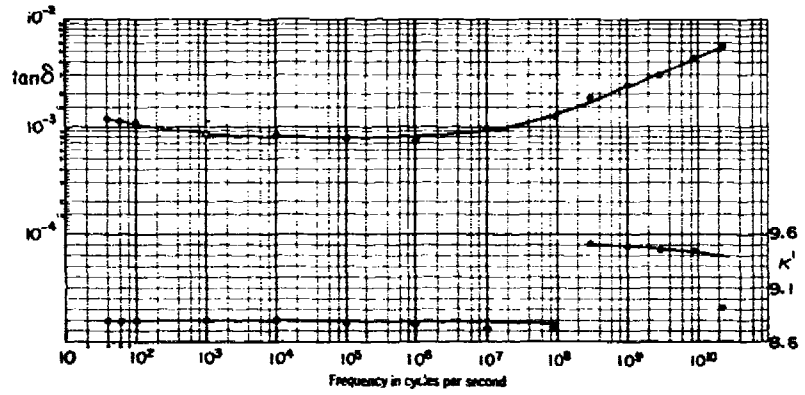
Note: all Mycalex samples from sheet stock.  $10^2$  through  $10^8$  Hz, E  $\perp$  sheet.  
 $3 \times 10^8$  to  $2.4 \times 10^{10}$  Hz, E  $\parallel$  sheet.

Mycalex (cont.)

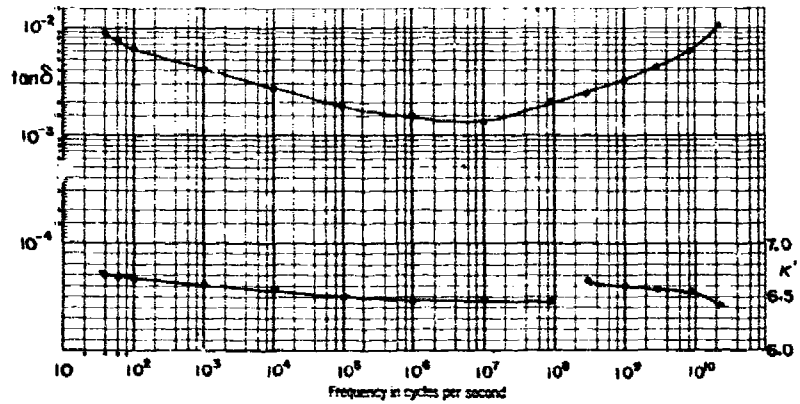
500



555

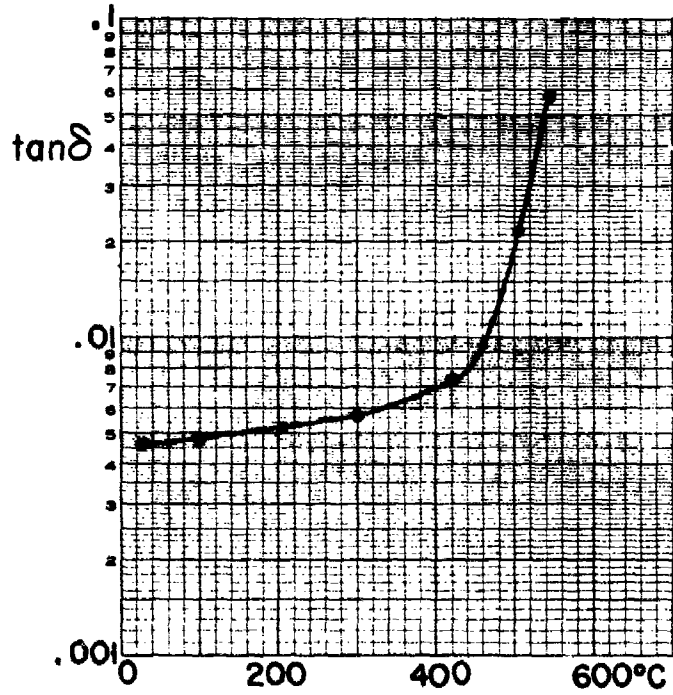
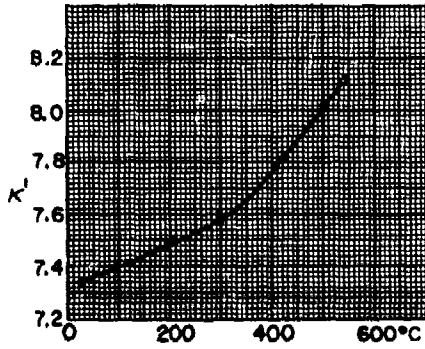
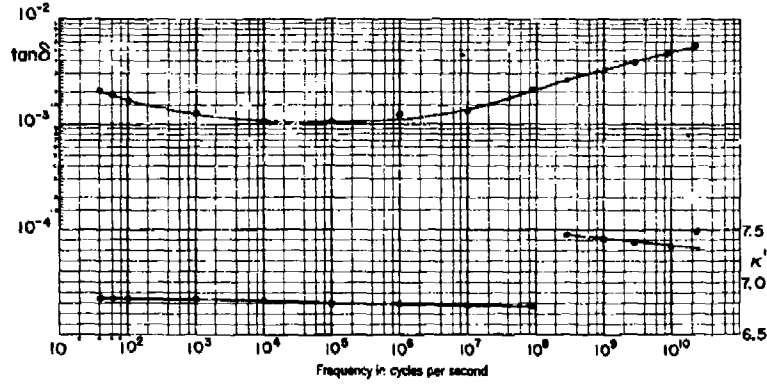


560



Mycalex (cont.)

620



Miscellaneous Inorganics and Mixtures

Raytheon

Asphalt pavement at 40% R. H. , 25°C, 14 GHz

Sample No.	Thickness (cm)	Density (g/cm <sup>3</sup> )	H <sub>2</sub> O (%)	Orientation	$\kappa'$	tan $\delta$
1	0.1			Independent	4.73	.0114
2	0.1			"	4.62	.0103
3	0.1				5.03	.0120
4	0.1				5.48	.0095
5	0.91	2.35	.754	Face 1	6.02	.021
				Face 1, 90°	5.53	.052
				Face 2	5.37	.204
				Face 2, 90°	5.44	.102

Concrete pavement at 40% R. H. , 25°C, 14 GHz

Raytheon

1	0.1			Various	5.03-5.06	.026-.029
2	0.1			Various	5.06-5.17	.034-.030
3	0.335	2.14	2.21	Face 1	5.21	.059
				Face 1, 90°	5.20	.0612
				Face 2	5.30	.0509
				Face 2, 90°	5.26	.0505
4	0.453	2.04	2.81	Face 1	4.71	.0470
				Face 1, 90°	4.60	.0455
				Face 2	4.70	.0487
				Face 2, 90°	4.55	.0487

Liquid asphalt

Esso

f (Hz)	$\kappa'$	tan $\delta$
$1 \times 10^9$	2.46	.0017
$3 \times 10^9$	2.46	.0019
$8.5 \times 10^9$	2.46	.0013

Solid asphalt formed by burning liquid for 2 days at 300°C

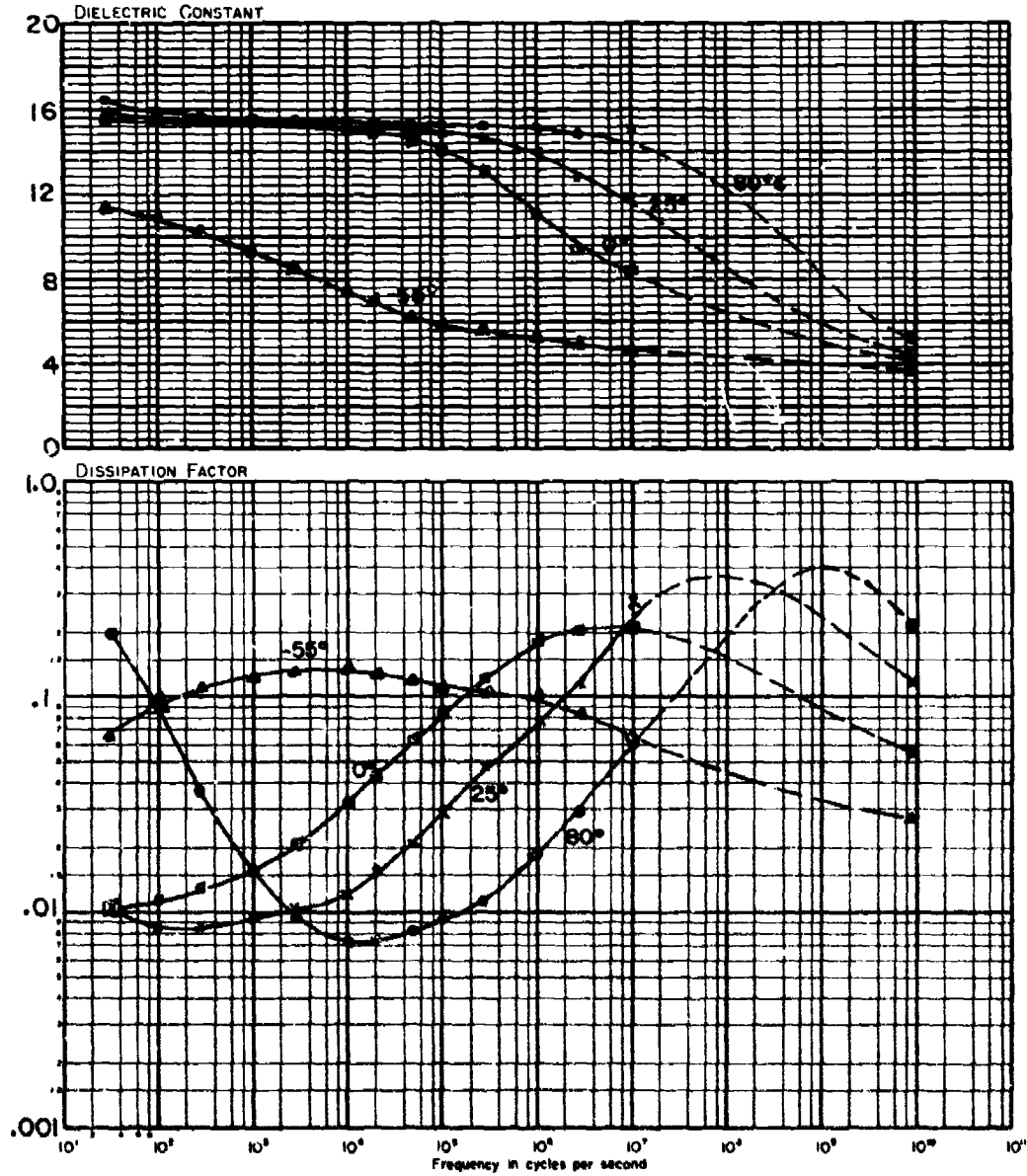
$1.5 \times 10^6$	2.64	.0043
$10^7$	2.64	.0030
$1.8 \times 10^7$	2.64	.0027
$4 \times 10^7$	2.64	.0025
$8.5 \times 10^9$	2.63	.0018



III. ORGANIC COMPOUNDS  
(Listed according to supplier)

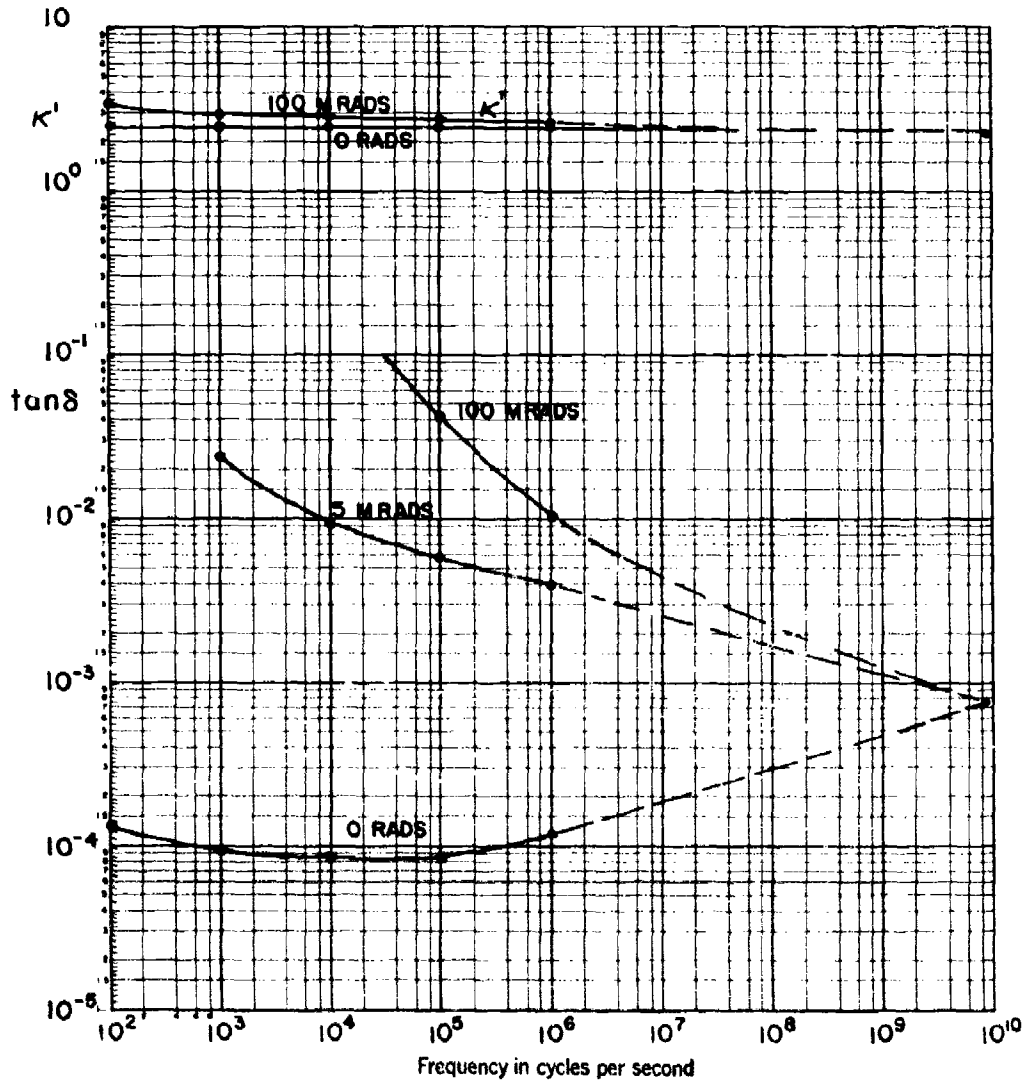
Cyanoethylated cotton moulding  
S4403-160-1

American Cyanamid



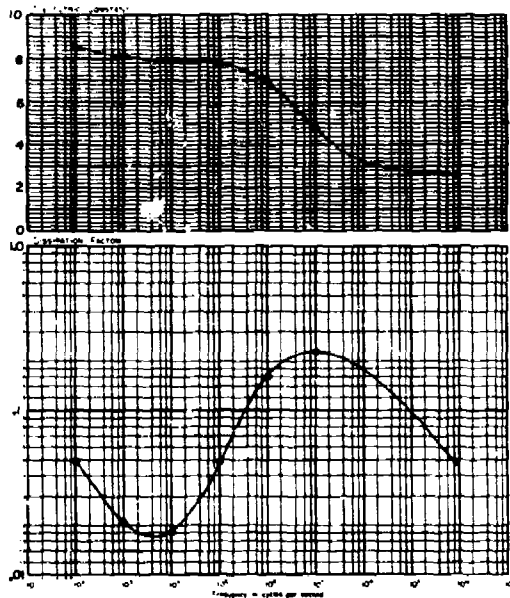
Cymac 325  
including effect of Van De Graaff irradiation

American Cyanamid



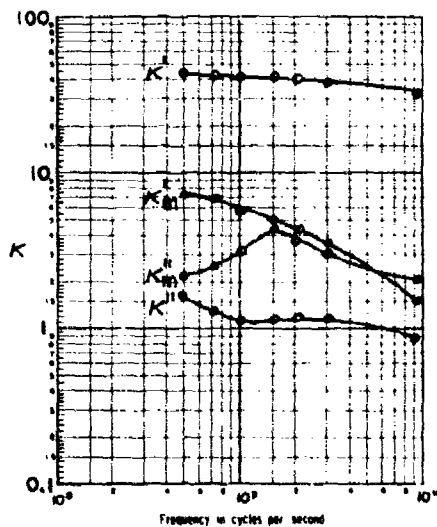
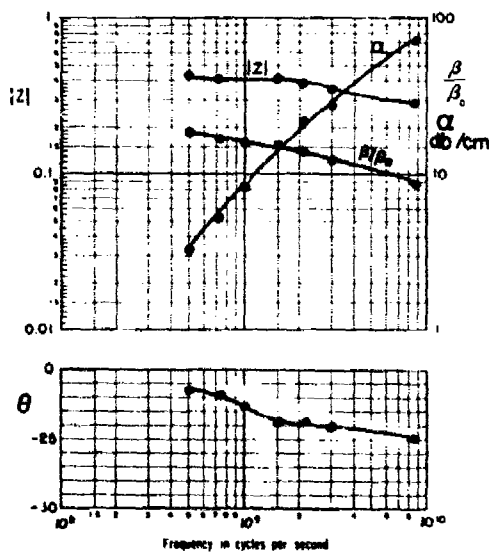
Polyvinylidene fluoride

AVCO Research



Polyiron (Carbonyl)

H. I. Crowley



Moulding compound 306

Dow Corning

T°C	1 GHz		3 GHz		T°C	8.52 GHz	
	$\kappa'$	tan $\delta$	$\kappa'$	tan $\delta$		$\kappa'$	tan $\delta$
25	3.92	.00538	3.87	.00622	-55	3.85	.0060
76	3.91	.0052	3.86	.0058	25	3.84	.0067
103	3.90	.0052	3.85	.0058	61	3.835	.00655
129	3.89	.0051	3.84	.0056	118	3.825	.0064
150	3.87	.0050	3.83	.0055	147	3.82	.00635
216	3.83	.0050	3.78	.0051	199	3.807	.00625
255	3.80	.0052	3.75	.0051	315	3.74	.00615
305	3.77	.0056	3.72	.0054	400	3.66	.0061
410	3.68	.0064	3.63	.0068	499	3.57	.0060
504	3.62	.0058	3.58	.0066	296	3.72	.0061
301	3.75	.0048					

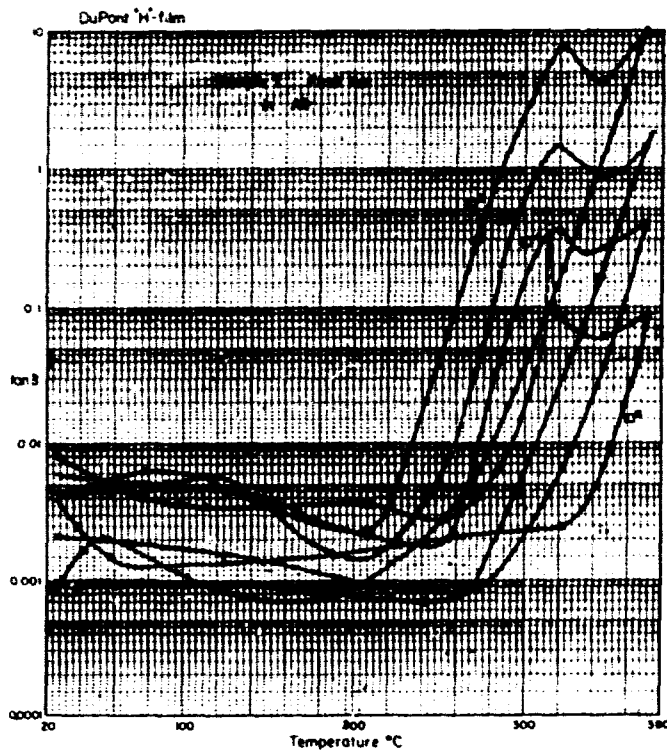
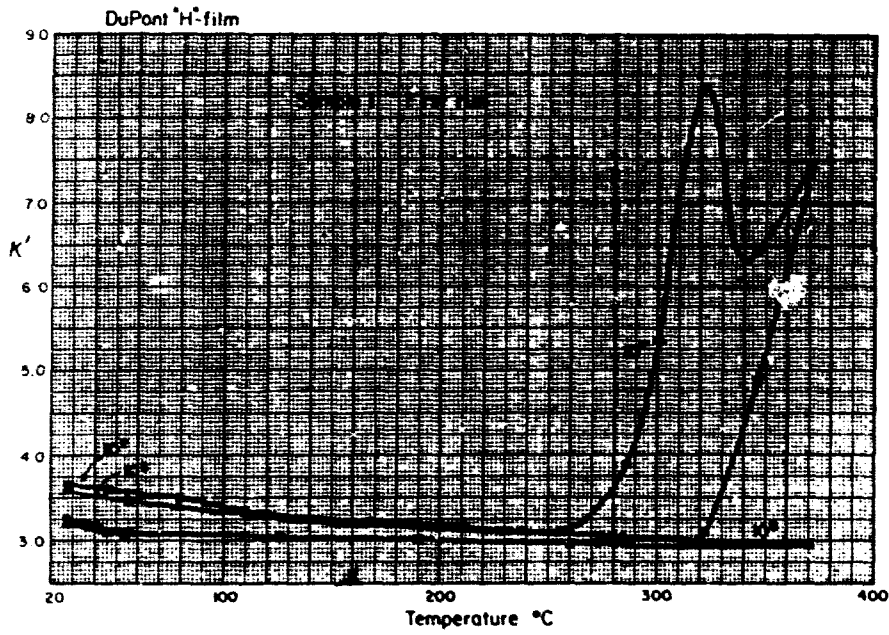
	T°C		1000 MHz	3000 MHz	8500 MHz
Silastic RTV 501	-55	$\kappa'$	3.17	3.07	
		tan $\delta$	0.025	0.037	
	23	$\kappa'$	2.89	2.88	2.87
		tan $\delta$	0.0053	0.0104	0.0175
	150	$\kappa'$	2.62	2.62	
		tan $\delta$	0.042	0.0045	
RTV 521	23	$\kappa'$	3.33	3.32	3.31
		tan $\delta$	0.0086	0.0153	0.0252
RTV 1602	-55	$\kappa'$	3.09	3.03	
		tan $\delta$	0.0220	0.0308	
	23	$\kappa'$	2.93	2.93	2.91
		tan $\delta$	0.0073	0.0117	0.0187
	150	$\kappa'$	2.77	2.75	
		tan $\delta$	0.0044	0.0060	
RTV 5350	-55	$\kappa'$	3.22	3.14	
		tan $\delta$	0.0234	0.0287	
	23	$\kappa'$	3.06	3.05	3.04
		tan $\delta$	0.0043	0.0088	0.0166
	150	$\kappa'$	2.82	2.79	
		tan $\delta$	0.0040	0.0043	
S-6538	-55	$\kappa'$	3.01	2.96	
		tan $\delta$	0.0242	0.0260	
	23	$\kappa'$	2.99	2.98	2.97
		tan $\delta$	0.0069	0.0124	0.0187
	150	$\kappa'$	2.78	2.77	
		tan $\delta$	0.0039	0.0047	
Sylgard 182	-55	$\kappa'$	2.90	2.86	2.81
		tan $\delta$	0.0200	0.024	0.029
	23	$\kappa'$	2.79	2.77	2.73
		tan $\delta$	0.0081	0.0120	0.0199
	150	$\kappa'$	2.50	2.48	2.45
		tan $\delta$	0.0026	0.0040	0.0073

DC-92.007

8.52 GHz, 25°C, 50% R.H.,  $\kappa' = 4.92$ ; tan  $\delta = 0.091$

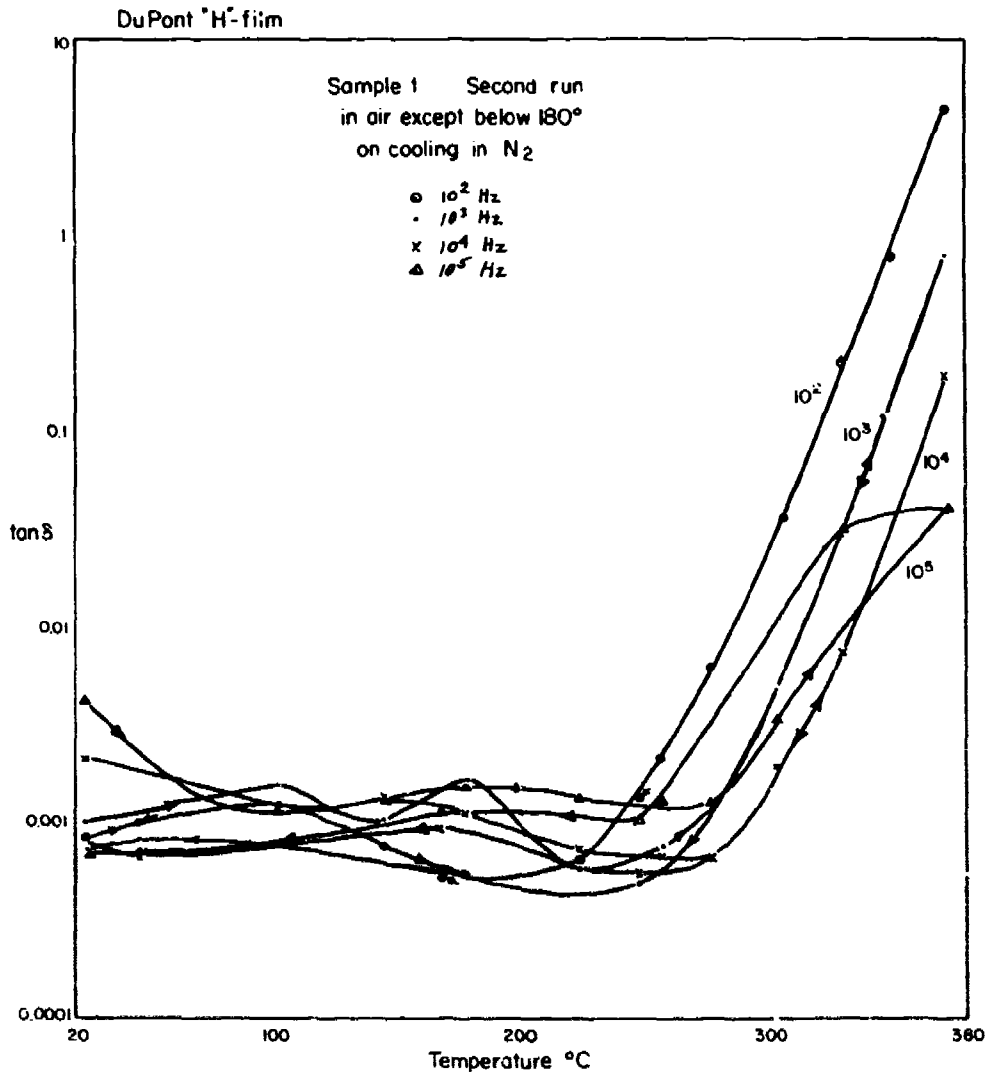
"H"-film

E. I. Dupont de Nemours and Co.



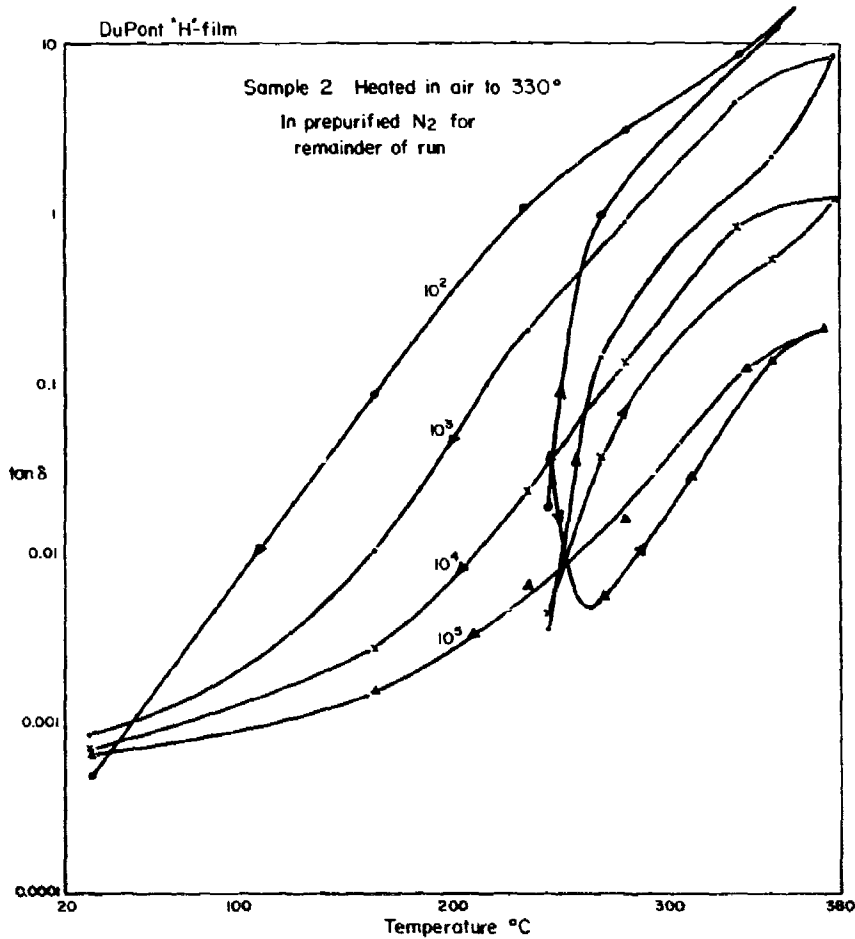
"H"-film (cont.)

E. I. Dupont de Nemours and Co.



H<sup>2</sup>-film (cont.)

E. I. Dupont de Nemours and Co.



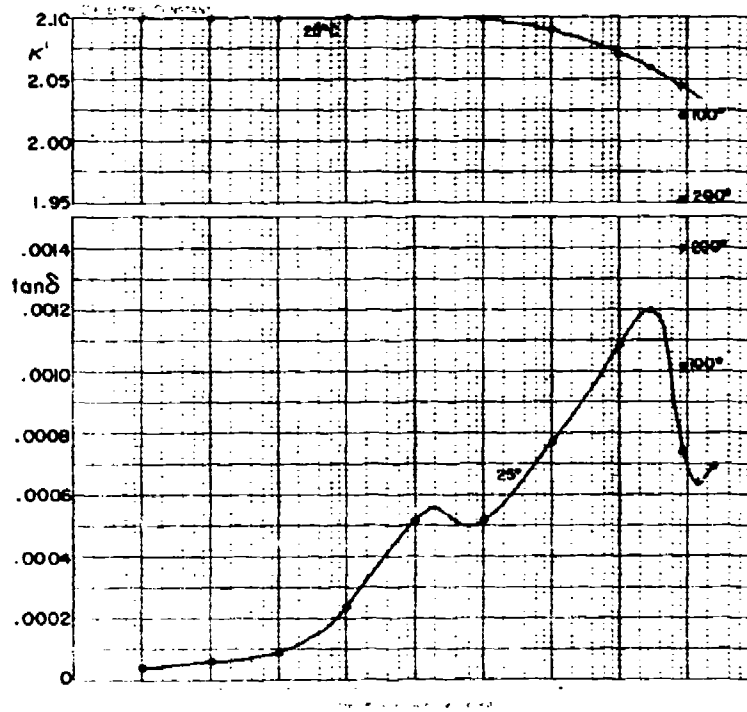
Teflon FEP (1963)

Density = 2.153 g/cm<sup>3</sup>, at 25°C, 8.52 GHz

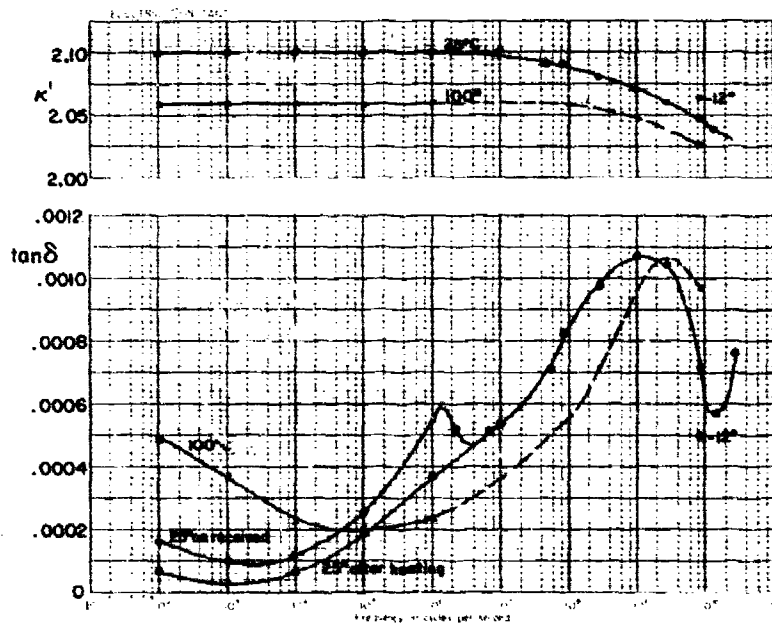
$\kappa'$  = 2.058, tan  $\delta$  = 0.00108

Teflon FEP (1964)

E. I. Dupont de Nemours and Co.



Teflon 9033, Lot 10601, density at 25°C = 2.147, similar for  
 Teflon T-100, Lot 38180, " " " = 2.152

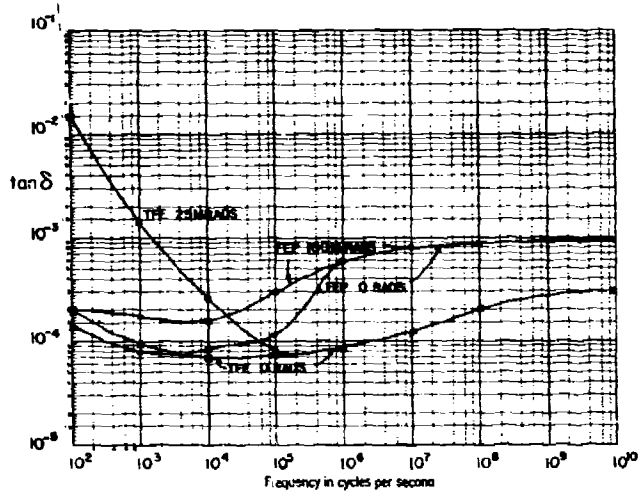




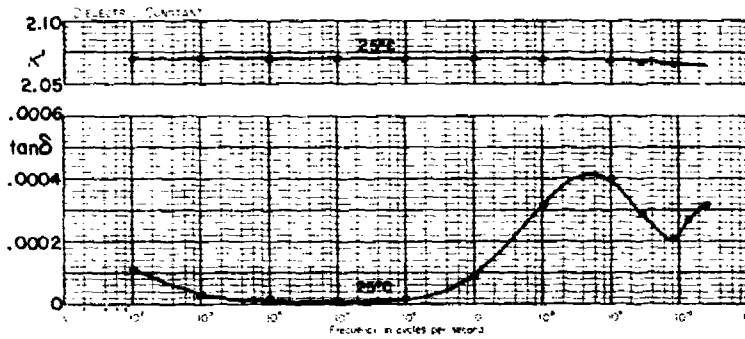
Teflon 100X (FEP) 1960 and TFE

E. I. Dupont de Nemours and Co.

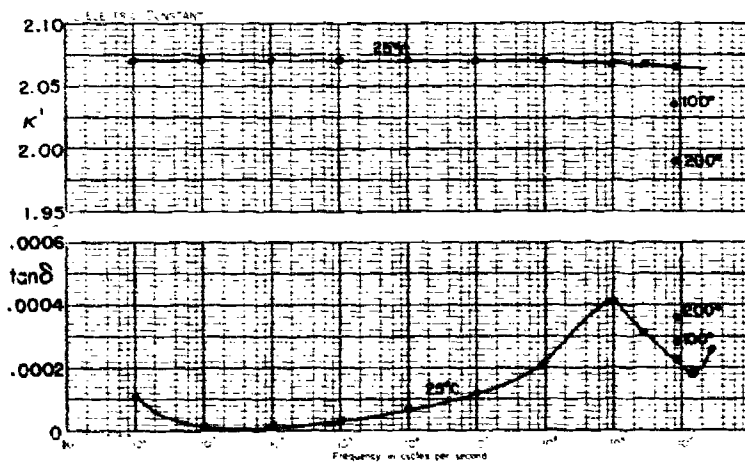
Effect of Van De Graaff irradiation, 25°C



TFE-7 (1964)



TFE-6C (1964)



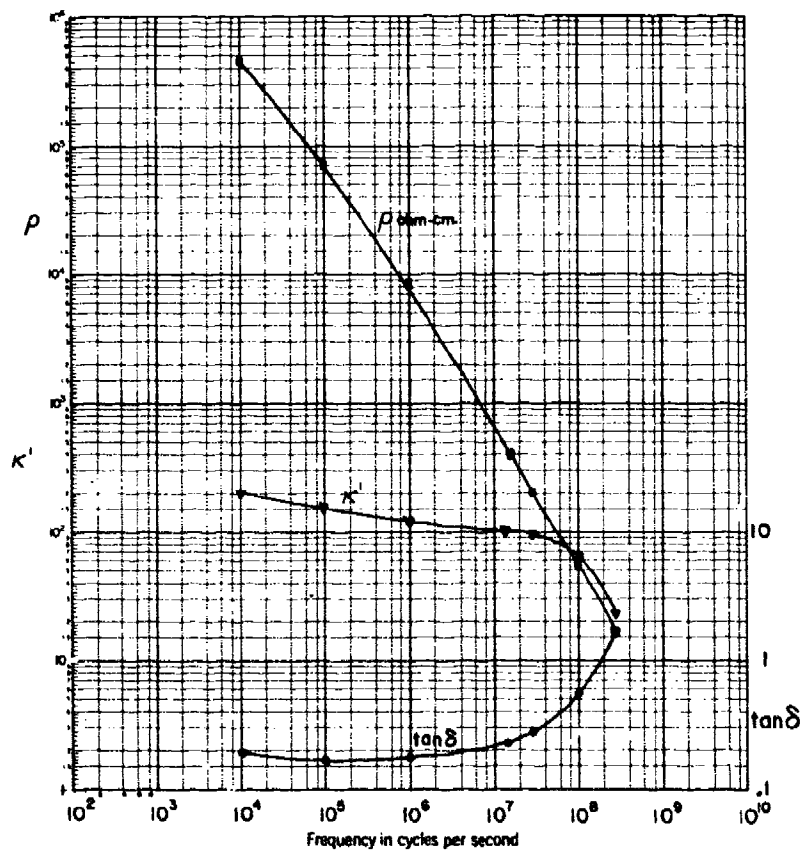
"Polyguide"

Electronized Chemicals Corp.

		3 GHz		8.52 GHz		% wt. increase
		$\kappa'$	$\tan \delta$	$\kappa'$	$\tan \delta$	
As received	25°C	2.32	.00034	2.319	.00030	
	-48°C			2.320	.00017	
	74°C			2.300	.00040	
After 24 hrs. H <sub>2</sub> O		2.32	.00047	2.320	.00038	.007

Emerson and Cumming A-19

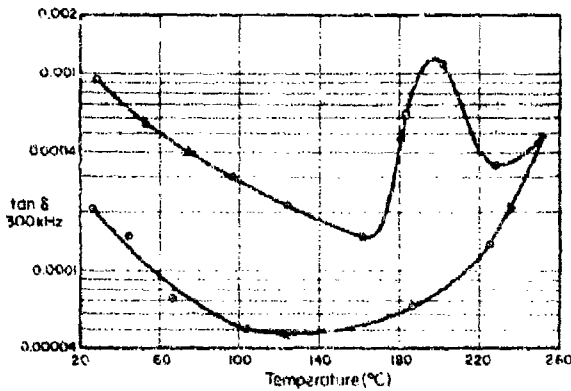
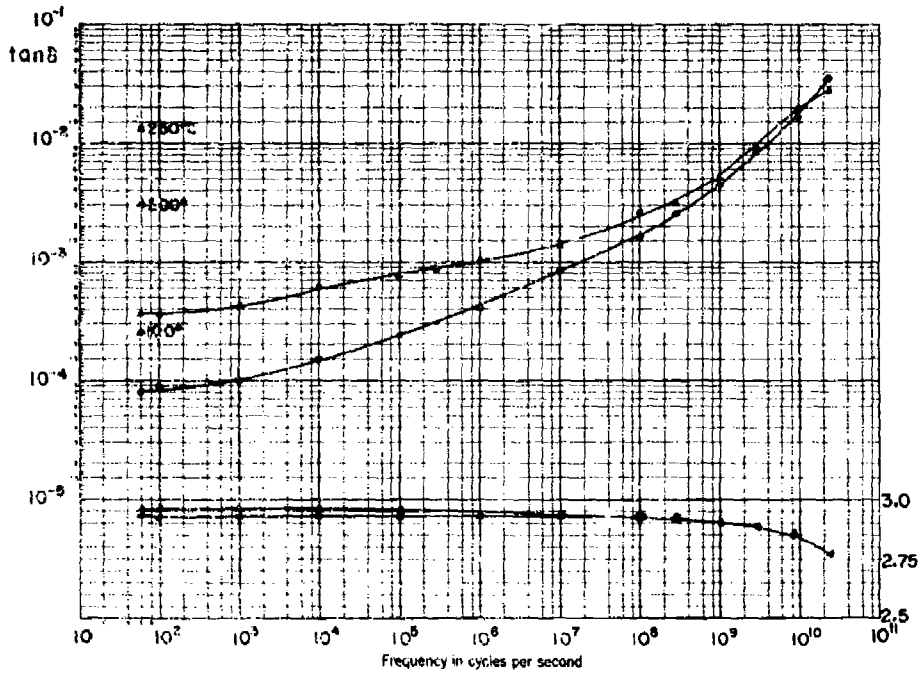
graphite fiber loaded plastic, November 1966



SE 900 Silicone Rubber

General Electric

Δ Sample cured 1 hr at 300°F, measured at 50% R. H.  
 ○ Normal cure



	Lexan	General Electric	
f(Hz)	$\kappa'$	tan $\delta$	
$8.5 \times 10^9$	2.77	.00615	
$2.5 \times 10^{10}$	2.75	.00593	

"3M" board

Minnesota Mining and Metallurgy

	Temperature	3 GHz		8.52 GHz		% wt. increase
		$\kappa'$	$\tan \delta$	$\kappa'$	$\tan \delta$	
As received	25°C	2.32	.00038	2.316	.00037	
	-48°C			2.316	.00015	
	74°C			2.300	.00040	
After 24 hrs H <sub>2</sub> O	25°C	2.32	.00060	2.316	.00043	

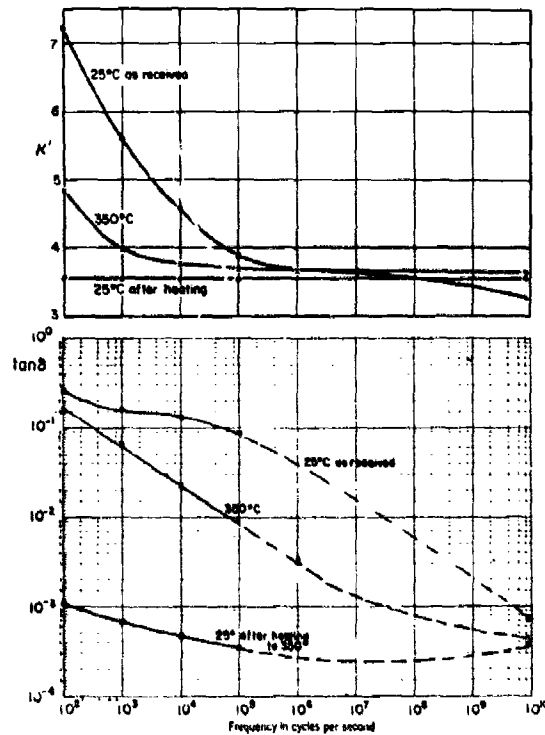
Polyurethane rigid foam, at 399 MHz

Nopco Chemical Corp.

T°F	3.80 lbs/cu. ft		7.54 lbs/cu. ft	
	$\kappa'$	$\tan \delta$	$\kappa'$	$\tan \delta$
77	1.087	.00136	1.165	.00242
116	1.088	.00176	1.170	.00276
164	1.093	.00208	1.175	.00344

Fluorosint (1960)

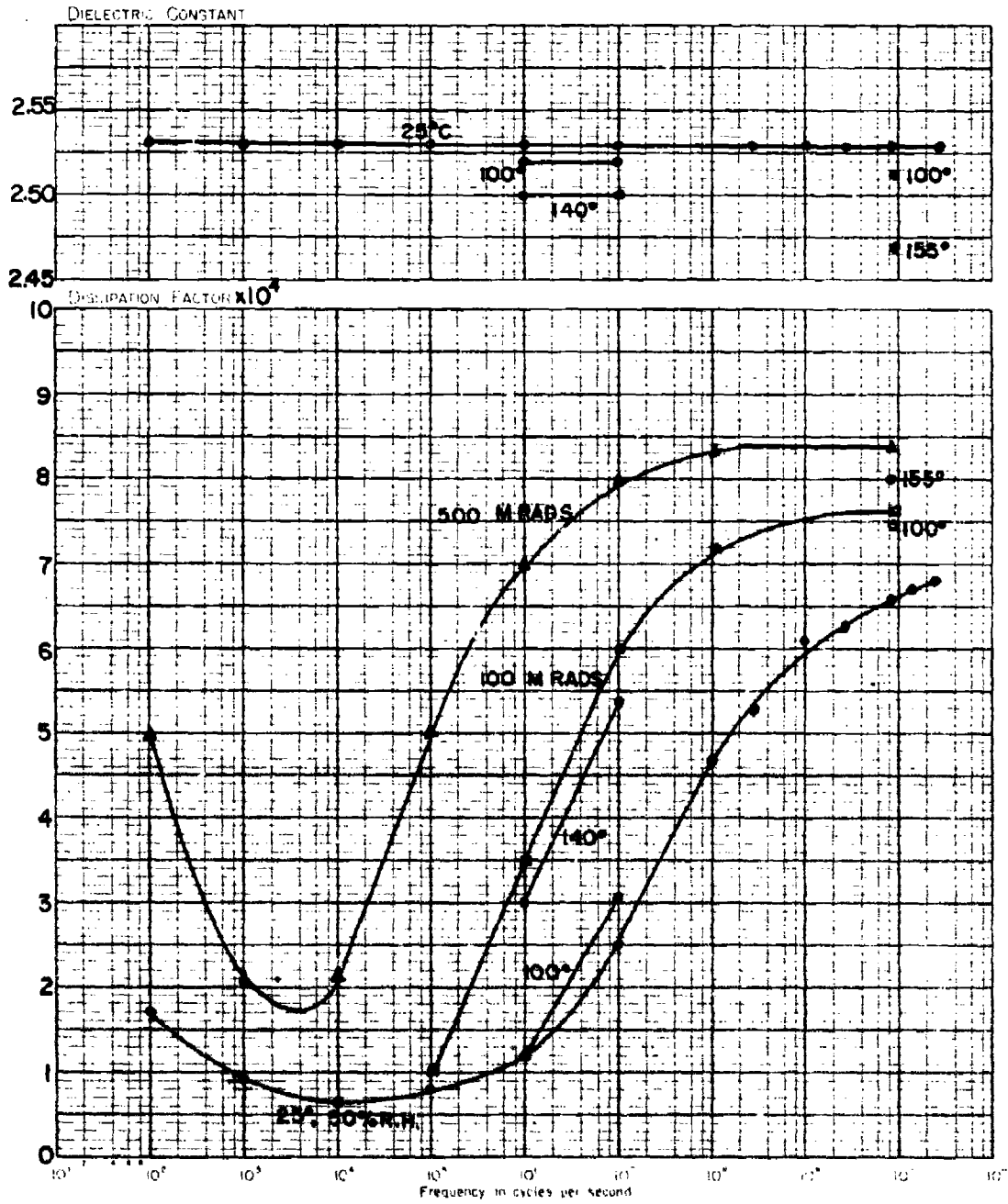
Polymer Corp.



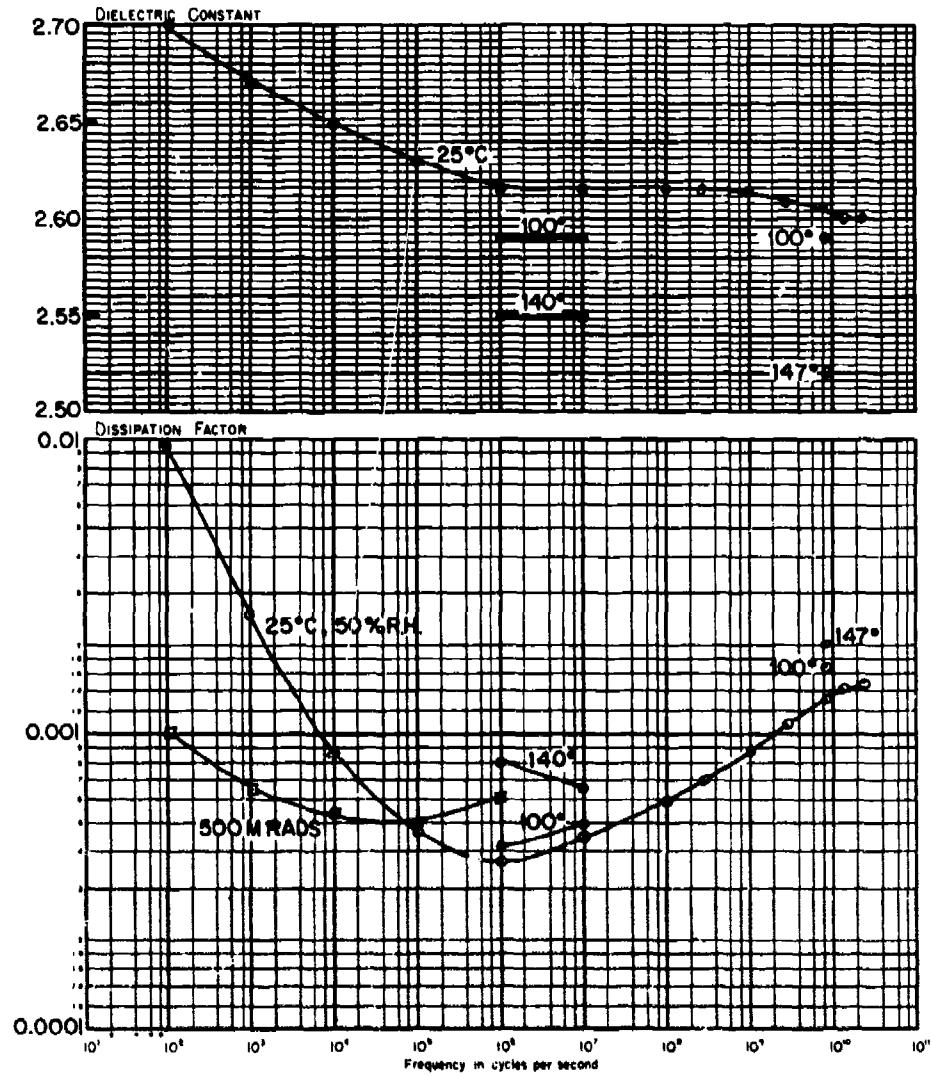
Rexolite 1422 (1964),

Wm. Brand Rex Division  
of American Enka Corp.

including effect of Van De Graaff irradiation (1960)



Rexolite 2200 (1964),  
including effect of Van De Graaff irradiation (1960)

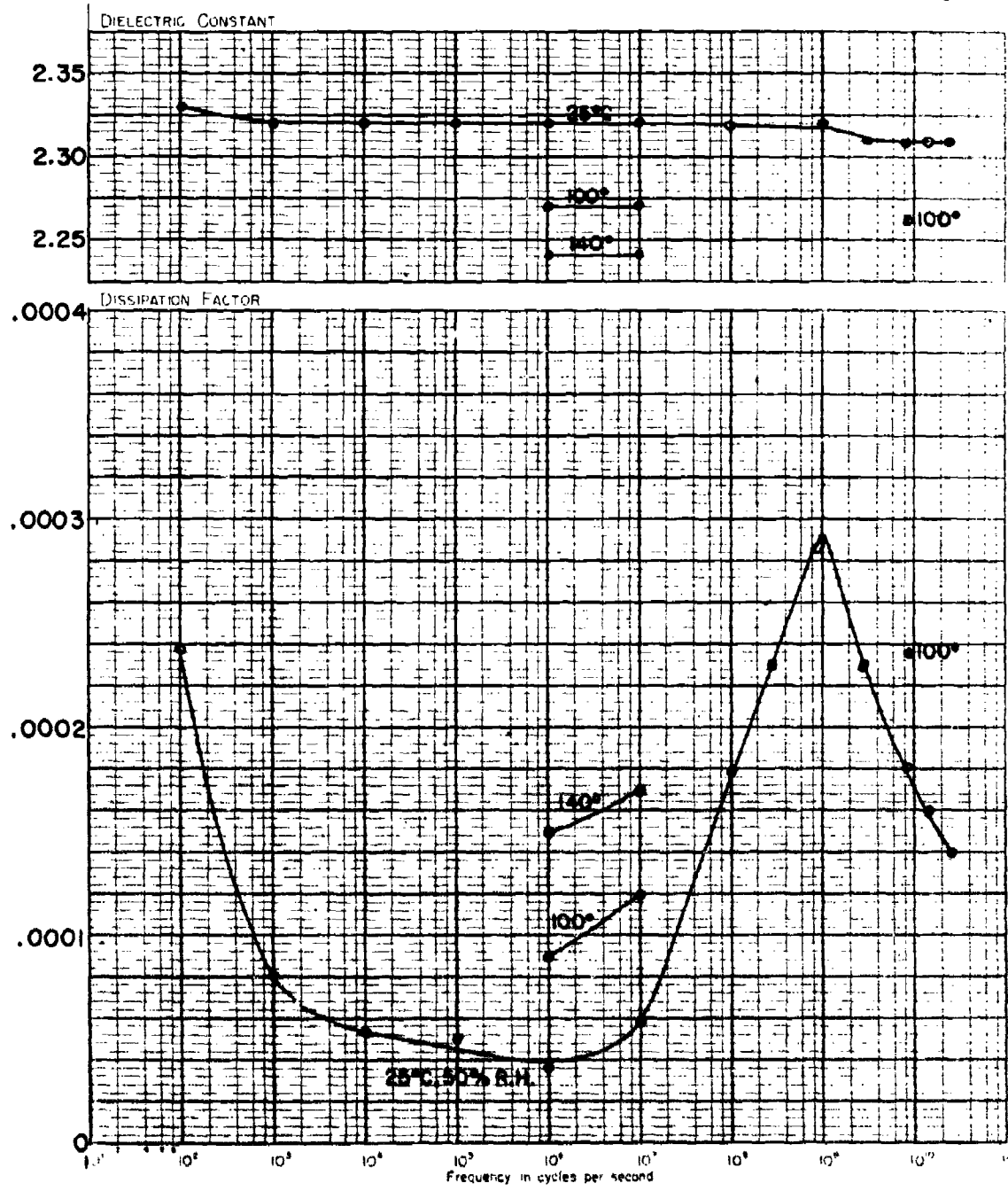


Rexolite 2200 (1965)

	Temperature	3 GHz		8.52 GHz		% wt. increase
		K'	tan δ	K'	tan δ	
As received	25°C	2.65	.00169	2.65	.00170	
	-48°C			2.64	.00110	
	74°C			2.645	.00209	
After 24 hrs. H <sub>2</sub> O	25°C	2.66	.0026	2.66	.00343	.055

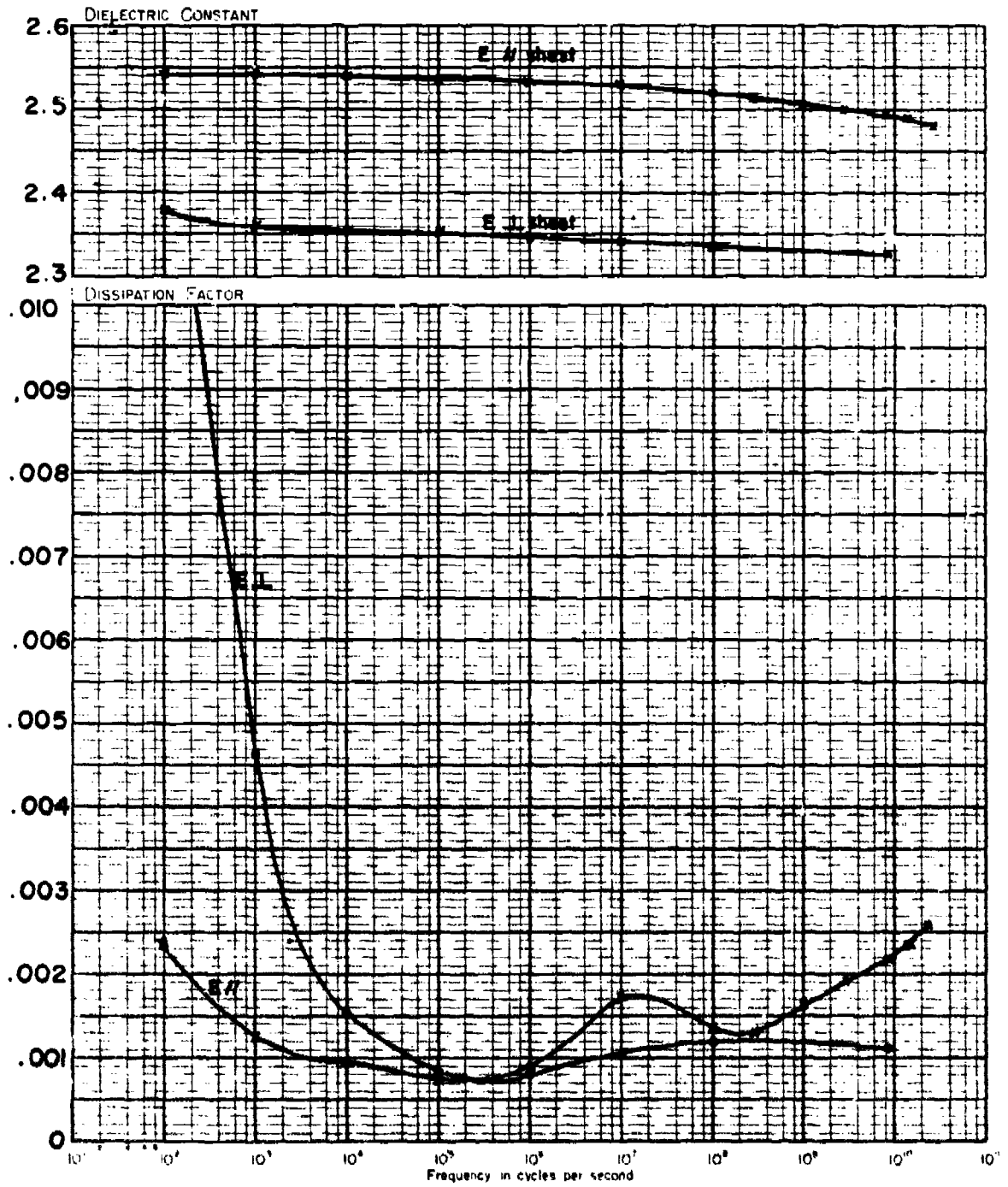
Rexolene P

Wm. Brand Rex Division  
of American Enka Corp.



Duroid 5870 (1966)

Rogers Corp.

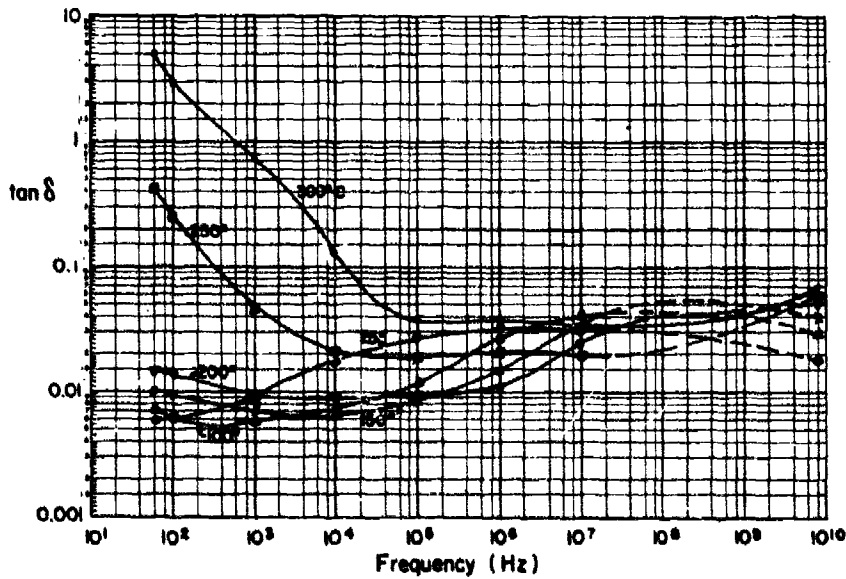
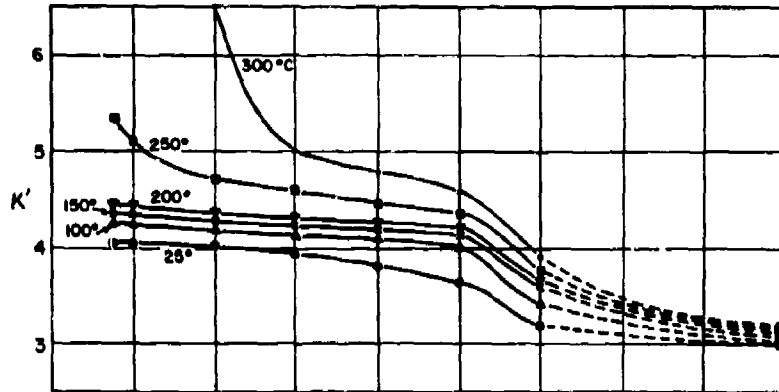




Epon 828/PMDA casting

Shell Chemical Company

156 pts. { Epon 828 epoxy 100 pts. by weight  
          { PMDA (pyromellitic dianhydride) 56 pts. by weight  
plus  
20 pts. { Tetrahydrofurfural alcohol 99 pts. by weight  
          { Dicyandiamide 1 pt. by weight

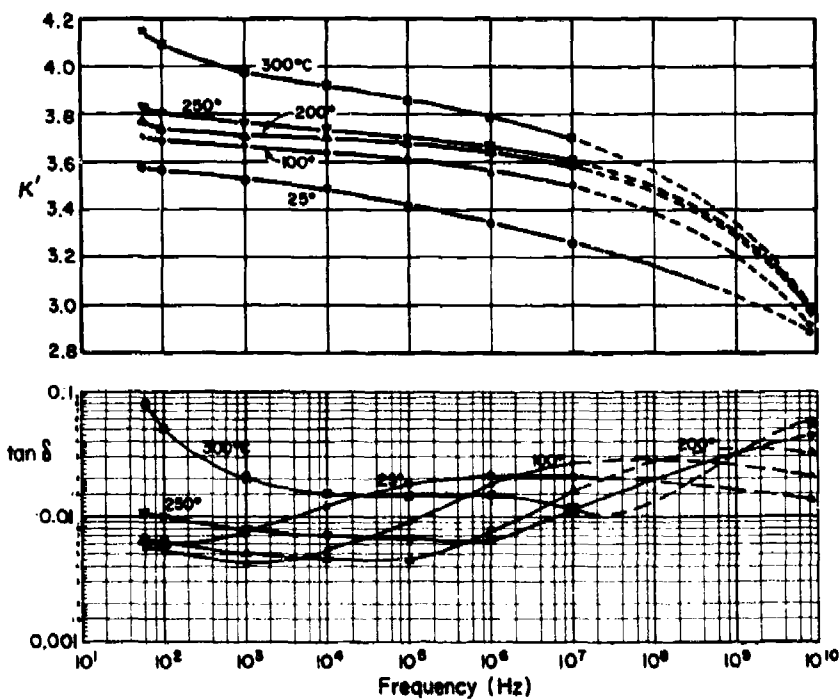


Epon 828/PMDA casting

Shell Chemical Company

Epon 828 epoxy 100 pts. by weight

PMDA (pyromellitic dianhydride) 31 pts. by weight



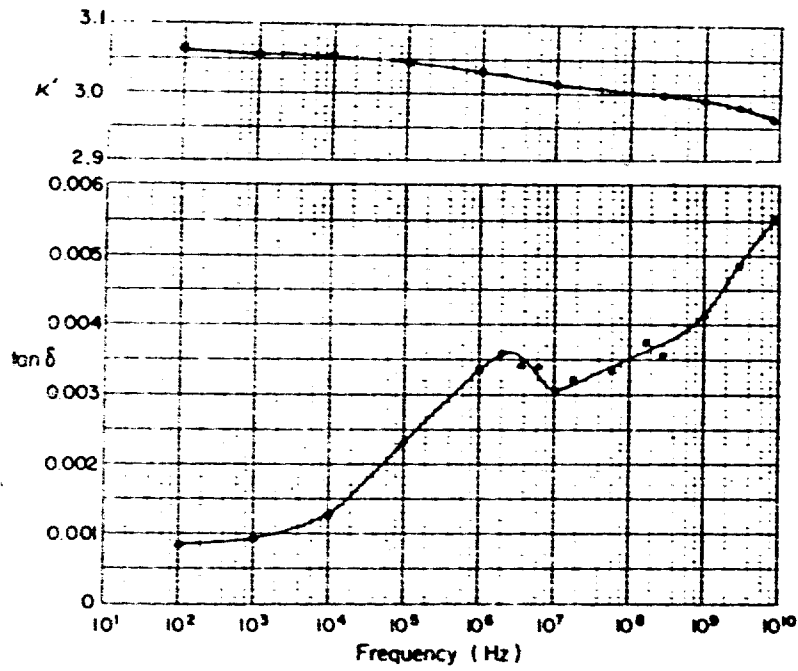
Tellite 3A

Tellite Corp.

	T <sup>o</sup> C	$K'$	$\tan \delta$	$K'$	$\tan \delta$	% weight increase
As received	25	2.31	.00028	2.311	.00022	
	-48			2.318	.00020	
	74			2.294	.00027	
After 24 hrs H <sub>2</sub> O	25	2.31	.00036	2.311	.00032	.003

Polysulfone, 25°C, 50% R. H.

Union Carbide Corp.  
Plastics Division

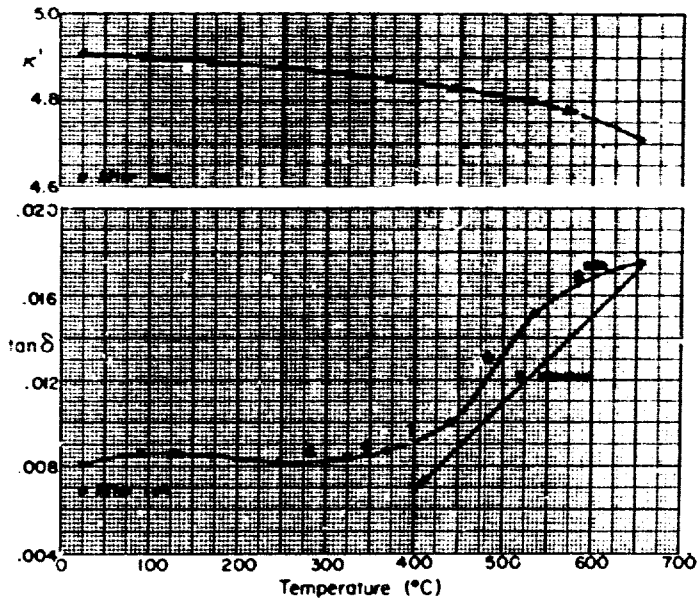


Fiberglass laminate

Air Force Materials Laboratory

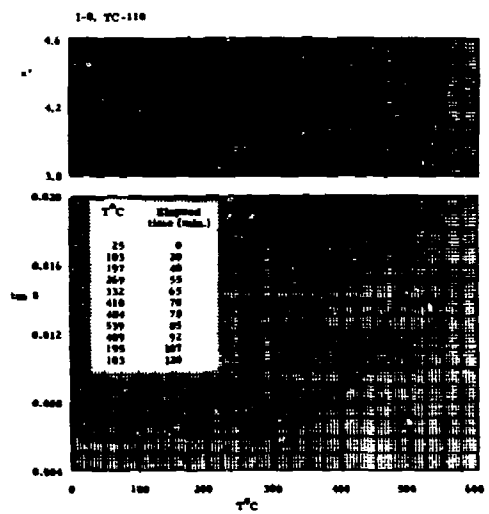
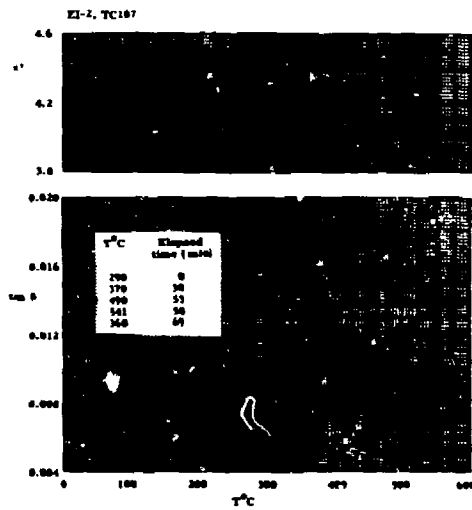
with polybenzimidazole resin (approx. 24%)

density 1.949 g/cm<sup>3</sup>



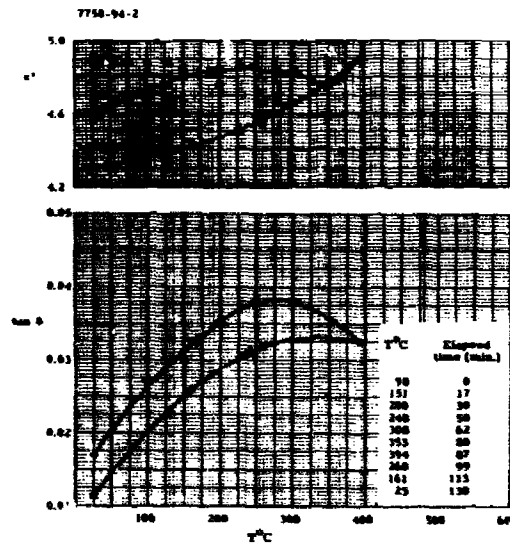
Fiberglass laminates

Air Force Materials Laboratory



Fiberglass laminate with 181 glass cloth and a polyol cross-linked polyimide resin, 8.52 GHz

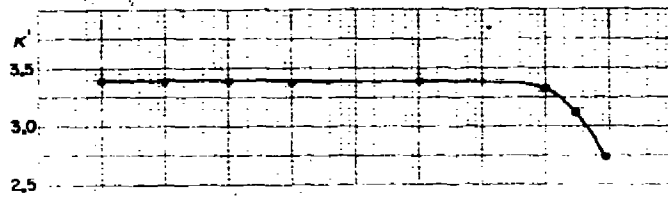
Fiberglass laminate with 181 glass cloth and a polyimide resin, 8.52 GHz



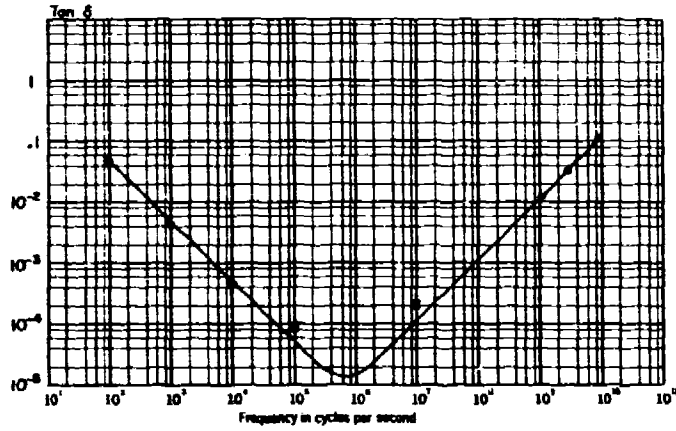
Fiberglass laminate with 181 glass cloth and epoxy resin, 8.52 GHz

### IV. LIQUIDS

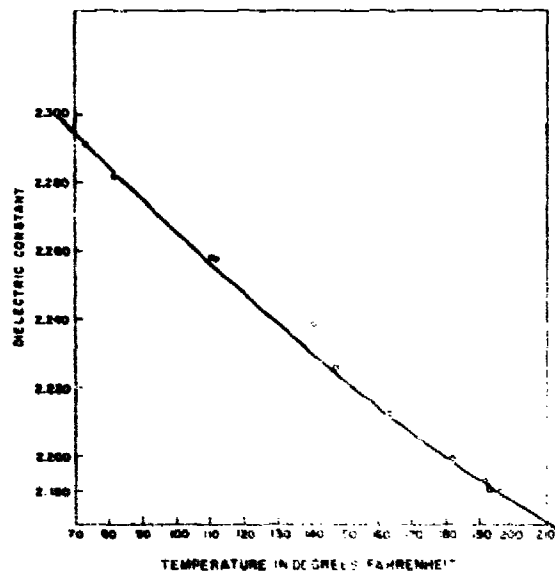
Dowtherm A



Dow Chemical



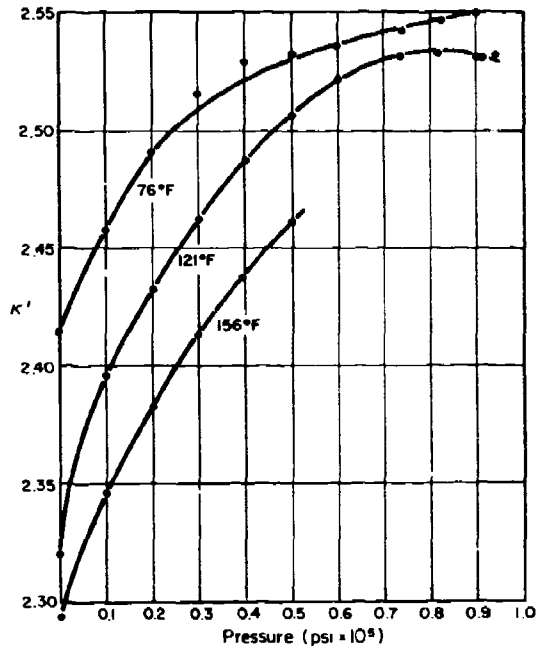
Teresso V-78



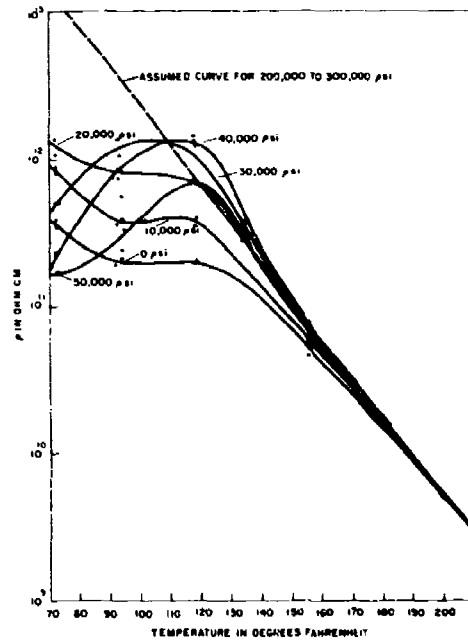
Esso



Teresso V-78 (cont.)



pressure

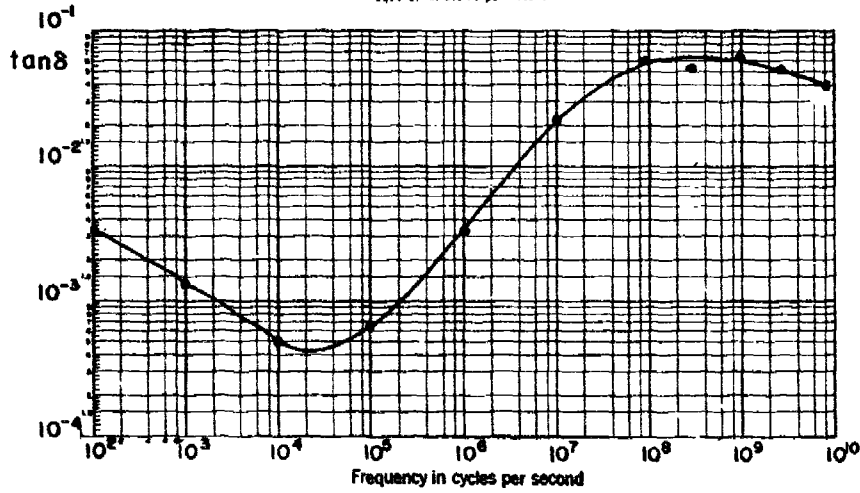
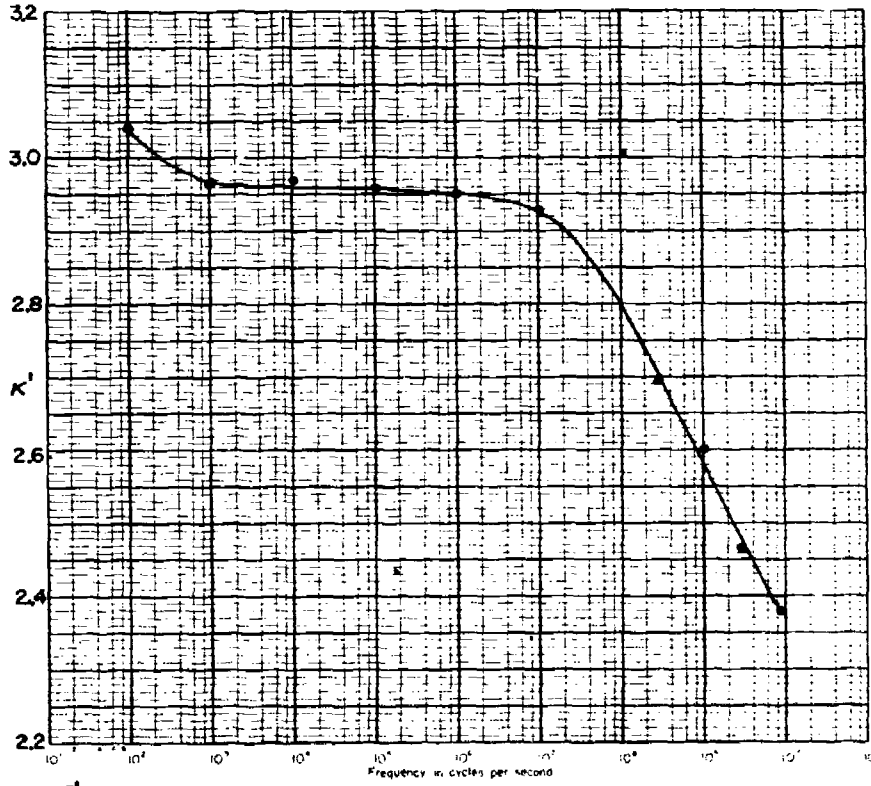


temperature

V. FOODSTUFFS

Kremax

Armour



Frozen lean steak

T <sup>o</sup> F	150 MHz		1000 MHz		3000 MHz	
	κ	tan δ	κ	tan δ	κ	tan δ
-75	3.42	.022	3.33	.0164	3.22	.0105
-60	3.61	.040	3.42	.026	3.40	.014
-50	3.70	.058	3.46	.036	3.44	.0185
-40	3.82	.072	3.51	.050	3.46	.024
-30	3.92	.094	3.60	.066	3.55	.032
-20	4.18	.102	3.80	.089	3.70	.040
-10	4.50	.138	4.10	.12	3.80	.054
0	5.33	.18	4.40	.165	3.95	.076
10	6.35	.24	5.18	.223	4.37	.108
20	9.55	.39	9.50	.203	7.30	.174
30	33	.60	20.8	.254	8.40	.250
40	53.5	.22	33.0	.32	8.30	.208
50	53.0	.21				

Vacuum-dry lean beef

-60			1.495	.00320	1.471	.00335
-40	1.535	.0060	1.497	.00375	1.473	.00395
-20	1.548	.0080	1.502	.00436	1.475	.0047
0	1.562	.0102	1.511	.00535	1.480	.0057
20	1.582	.0132	1.520	.0066	1.483	.0068
40	1.60	.0168	1.530	.0080	1.490	.0082
60	1.62	.0216	1.542	.0096	1.500	.0099
80	1.648	.0264	1.558	.0111	1.509	.0119
100			1.571	.0127	1.522	.0138
120			1.587	.0143	1.535	.0147
140			1.604	.0160	1.545	.0175
160			1.622	.0176	1.560	.0193
180			1.642	.0198	1.590	.0214

Potato (Maine, 78.9% H<sub>2</sub>O), 25°C

f (GHz)	κ'	tan δ
.3	130	.83
1	87	.39
3	81	.38

Potato flakes, density 0.284

.3	1.50	.034
1	1.485	.030
3	1.47	.029

Potato chips

partly cooked	1	5.76	.36
	3	5.18	.55
cooked	1	1.89	.034
	3	1.86	.036



f (Hz)	Nescafe			Nestea		
	$\kappa'$	$\tan \delta$	$\sigma$	$\kappa'$	$\tan \delta$	$\sigma$
$10^2$	1.557	.0115	$9.93 \times 10^{-13}$	1.290	.00442	$3.17 \times 10^{-13}$
$10^3$	1.529	.0113	$9.58 \times 10^{-12}$	1.281	.00384	$2.73 \times 10^{-12}$
$10^4$	1.490	.0103	$8.52 \times 10^{-11}$	1.276	.00301	$2.13 \times 10^{-11}$
$10^5$	1.488	.0090	$7.43 \times 10^{-10}$	1.270	.00245	$1.73 \times 10^{-10}$
$10^6$	1.471	.0089	$7.27 \times 10^{-9}$	1.267	.00230	$1.62 \times 10^{-9}$
$10^7$	1.453	.0093	$7.52 \times 10^{-8}$	1.260	.00196	$1.37 \times 10^{-8}$
$3 \times 10^8$	1.432	.0106	$2.53 \times 10^{-7}$	1.24	.0023	$4.75 \times 10^{-7}$
$10^9$	1.39	.0098	$7.57 \times 10^{-6}$	1.22	.0024	$1.63 \times 10^{-6}$
$3 \times 10^9$	1.36	.0093	$2.11 \times 10^{-5}$	1.21	.0026	$5.25 \times 10^{-6}$
$8.5 \times 10^9$	1.34	.0086	$5.65 \times 10^{-5}$	1.20	.0033	$1.87 \times 10^{-5}$
density $0.241 \text{ g/cm}^3$			density $0.126 \text{ g/cm}^3$			

Eggwhite

Frequency	$\kappa'$	$\tan \delta$	$\rho$
$3 \times 10^9$	35	.5	
$9.2 \times 10^9$	13	1.1	
$10^4, 10^5$			35

Bread

$1.2 \times 10^7$	11	3.35	
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Dough

$10^7$	$2 \times 10^5$	2.25	1
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Unclassified

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DOCUMENT CONTROL DATA - R&D		
<i>(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)</i>		
1. ORIGINATING ACTIVITY (Corporate author)		2a. REPORT SECURITY CLASSIFICATION
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3. REPORT TITLE		
Supplementary Dielectric-Constant and Loss Measurements on High-Temperature Materials		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates)		
Technical Report		
5. AUTHOR(S) (Last name, first name, initial)		
Iglesias, J., and Westphal, W. B.		
6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
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c.		
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10. AVAILABILITY/LIMITATION NOTICES		
Distribution unlimited		
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY
		Office of Naval Research and Air Force Materials Laboratory
13. ABSTRACT		
<p>This is a summary report on dielectric constant and loss measurements made in this laboratory after 1958, excepting high-dielectric-constant materials. The emphasis is on high-temperature materials (those with melting points above 1200°C), but data on some plastics and liquids are also included. The samples of solids include oxides of Al, Be, Cr, Hf, Mg, Si, Ta, Th, Y, Zr, nitriles of B and Si, LaAlO<sub>3</sub> and various silicates, rocks, and minerals. Pure samples of Al<sub>2</sub>O<sub>3</sub>, BeO, MgO, SiO<sub>2</sub>, and BN all show loss tangents &lt; 0.01 at 1500°C in the microwave region. Various phenomena of electric loss, e. g., transconductance, dipole orientation, and molecular vibrations are clearly discernible.</p>		

DD FORM 1473  
1 JAN 64

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Dielectric constants Dielectric losses Dielectric properties of geophysical materials, foods, high-temperature inorganics						

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