



FIGURE 2.8. Loss tangent versus frequency. The loss tangent $\tan \delta_c = \sigma / (\omega \epsilon)$ for selected materials plotted as a function of frequency, assuming that the material constants σ and ϵ are as given in Table 2.2 and that they do not vary with frequency.

TABLE 2.2. Relative permittivity and conductivity of selected materials

Medium	Relative permittivity ϵ_r , (dimensionless)	Conductivity σ , (S-m ⁻¹)
Copper	1	5.8×10^7
Seawater	81	4
Doped silicon	12	10^3
Marble	8	10^{-5}
Maple wood	2.1	3.3×10^{-9}
Dry soil	3.4	10^{-4} to 10^{-2}
Fresh water	81	$\sim 10^{-2}$
Mica	6	10^{-15}
Flint glass	10	10^{-12}

TABLE 2.3. Dielectric properties of selected materials

Material	f (GHz)	ϵ'_r	ϵ''_r	T (°C)
Aluminum oxide (Al ₂ O ₃)	3.0	8.79	8.79×10^{-3}	25
Barium titanate (BaTiO ₃)	3.0	600	180	26
Bread	2.45	4.6	1.20	
Bread dough	2.45	22.0	9.00	
Butter (salted)	2.45	4.6	0.60	20
Cheddar cheese	2.45	16.0	8.7	20
Concrete (dry)	2.45	4.5	0.05	25
Concrete (wet)	2.45	14.5	1.73	25
Corn (8% moisture)	2.45	2.2	0.2	24
Corn oil	2.45	2.5	0.14	25
Distilled water	2.45	78	12.5	20
Dry sandy soil	3.0	2.55	1.58×10^{-2}	25
Egg white	3.0	35.0	17.5	25
Frozen beef	2.45	4.4	0.528	-20
Honey (100% pure)	2.45	10.0	3.9	25
Ice (pure distilled)	3.0	3.2	2.88×10^{-3}	-12
Milk	3.0	51.0	30.1	20
Most plastics	2.45	2 to 4.5	0.002 to 0.09	20
Papers	2.45	2 to 3	0.1 to 0.3	20
Potato (78.9% moisture)	3.0	81.0	30.8	25
Polyethylene	3.0	2.26	7.01×10^{-4}	25
Polystyrene	3.0	2.55	8.42×10^{-4}	25
Polytetrafluoroethylene (Teflon)	3.0	2.1	3.15×10^{-4}	22
Raw beef	2.45	52.4	17.3	25
Snow (fresh fallen)	3.0	1.20	3.48×10^{-4}	-20
Snow (hard packed)	3.0	1.50	1.35×10^{-3}	-6
Some glasses (Pyrex)	2.45	~4.0	0.004 to 0.02	20
Smoked bacon	3.0	2.50	0.125	25
Soybean oil	3.0	2.51	0.151	25
Steak	3.0	4.0	12.0	25
White onion (78.7% moisture)	2.45	53.8	13.5	22
White rice (16% moisture)	2.45	3.8	0.8	24
Wood	2.45	1.2 to 5	0.01 to 0.5	25

TABLE B.2. Relative permittivity and dielectric strength of selected materials

Material	Relative permittivity (ϵ_r) (at room temperature)	Dielectric strength (MV·m⁻¹) (at room temp. and 1 atm)
Air	1	~3
Alumina (Al ₂ O ₃)	~8.8	
Amber	2.7	
Bakelite	~4.8	25
Barium titanate (BaTiO ₃)	1200	7.5
Freon	1	~8
Fused quartz (SiO ₂)	3.9	~1000
Gallium arsenide (GaAs)	13.1	~40
Germanium (Ge)	16	~10
Glass	~4-9	~30
Glycerin	50	
Ice	3.2	
Mica (ruby)	5.4	200
Nylon	~3.6-4.5	
Oil	2.3	15
Paper	1.5-4	15
Paraffin wax	2.1	30
Plexiglass	3.4	
Polyethylene	2.26	
Polystyrene	2.56	20
Porcelain	~5-9	11
Rubber	~2.4-3.0	25
Rutile (TiO ₂)	100	
Silicon (Si)	11.9	~30
Silicon nitride (Si ₃ N ₄)	7.2	~1000
Sodium chloride (NaCl)	5.9	
Styrofoam	1.03	
Sulphur	4	
Tantalum pentoxide (Ta ₂ O ₅)	~25	
Teflon (PTFE)	2.1	
Vaseline	2.16	
Water (distilled)	81	
Wood (balsa)	1.4	

TABLE B.3. Conductivities and temperature coefficients of selected materials

Material	Conductivity σ (S·m ⁻¹) (at 20°C)	Temperature coefficient α_σ [(°C) ⁻¹]
Aluminum	3.82×10^7	0.0039
Bismuth	8.70×10^5	0.004
Brass (66 Cu, 34 Zn)	2.56×10^7	0.002
Carbon (graphite)	7.14×10^4	-0.0005
Constantan (55 Cu, 45 Ni)	2.26×10^6	0.0002
Copper (annealed)	5.80×10^7	0.0039
Dry, sandy soil	$\sim 10^{-3}$	
Distilled water	$\sim 10^{-4}$	
Fresh water	$\sim 10^{-2}$	
Germanium (intrinsic)	~ 2.13	-0.048
Glass	$\sim 10^{-12}$	-0.07
Gold	4.10×10^7	0.0034
Iron	1.03×10^7	0.0052-0.0062
Lead	4.57×10^6	0.004
Marshy soil	$\sim 10^{-2}$	
Mercury (liquid)	1.04×10^6	0.00089
Mica	$\sim 10^{-15}$	-0.07
Nichrome (65 Ni, 12 Cr, 23 Fe)	1.00×10^6	0.00017
Nickel	1.45×10^7	0.0047
Niobium	8.06×10^6	
Platinum	9.52×10^6	0.003
Polystyrene	$\sim 10^{-16}$	
Porcelain	$\sim 10^{-14}$	
Quartz (fused)	$\sim 10^{-17}$	
Rubber (hard)	$\sim 10^{-15}$	
Seawater	~ 4	
Silicon (intrinsic)	$\sim 4.35 \times 10^{-4}$	
Silver	6.17×10^7	0.0038
Sodium	2.17×10^7	
Stainless steel	1.11×10^6	
Sulfur	$\sim 10^{-15}$	
Tin	8.77×10^6	0.0042
Titanium	2.09×10^6	
Tungsten	1.82×10^7	0.0045
Y Ba ₂ Cu ₃ O ₇ (at < 80K)	$\sim 10^{20}$	
Wood	10^{-11} - 10^{-8}	
Zinc	1.67×10^7	0.0037