



Advanced Circuit Materials Division

Advanced Circuit Materials Division
100 S. Roosevelt Avenue
Chandler, AZ 85226
Tel: 480-961-1382, Fax: 480-961-4533
www.rogerscorporation.com

High Frequency Circuit Materials Properties Guide

Featured in this guide:

- Key Properties Definitions
• Key Properties Aliases
• Symbols
• Units of Measure
• Target Ranges
• Test Methods
• Design Criteria
• Conversion Tables

Rogers RT/duroid® laminates, TMM® laminates, RO3000® materials and RO4000® materials have key electrical and mechanical properties designers use to select the ideal material for a particular application. These properties are listed on our data sheets, selector guide and website. For those who are not design engineers, what the values and units represent may not be easily understood. The test methods used to determine these values might not be known, and the impact these properties have on design may not be readily evident. The purpose of this properties guide is to define each key property, how we test it and how each property is critical to design.

Table of Contents

Dielectric Constant page 2
Dissipation Factor page 2
Insulation Resistance page 3
Volume Resistivity page 3
Surface Resistivity page 3
Thermal Coefficient of Dielectric Constant page 4
Dielectric Strength page 4
Young’s Modulus page 5
Compressive Modulus page 5
Flexural Modulus page 5
Moisture Absorption page 6
Thermal Conductivity page 6
Coefficient of Thermal Expansion page 7
Peel Strength page 7
Glass Transition Temperature page 8
Dimensional Stability page 8
Flammability Rating page 9
Impact, Notch Izod page 9
Acknowledgements page 9
Conversion Tables page 10
Key Properties Main Chart page 11

DIELECTRIC CONSTANT and DISSIPATION FACTOR

KEY PROPERTY	ALIAS	SYMBOL	UNIT OF MEASURE	UNITS
Dielectric Constant	Relative Permittivity	K', DK, ϵ_r	Ratio of the permittivity of a substance to the permittivity of free space.	None
Dissipation Factor	loss tangent $\tan\delta$, approx power factor	$\tan \delta$ DF K''/K'	Ratio of loss to capacity	None

DEFINITIONS

Dielectrics are materials that do not conduct electricity, that is, they are insulators. In the most fundamental electrostatic terms, two quantities of electrical charge, Q and Q' , in free space (vacuum) at a given distance, r , will repel each other with a mechanical force, F , by the relationship

$$F = \frac{QQ'}{r^2 \epsilon}$$

where the value of ϵ is the absolute permittivity of free space, ϵ_0 , that is, the smallest possible value. Replacing free space with a dielectric reduces the force in proportion to its value of ϵ . If Q and Q' have the same sign (+ or -), then the value of F is positive, indicating repulsion. If they differ, then F is negative, indicating attraction. The ratio of ϵ to ϵ_0 is called the relative permittivity or dielectric constant, Dk . Any dielectric other than a vacuum has the internal capability of responding by limited charge separation to the electric field imposed by the Q and Q' charges, thus reducing the force. This charge separation is also called a dipolar response.

Another way to view this is to imagine two metal plates at a fixed separation in a vacuum with a constant voltage from an external source between them. Voltage represents potential energy of an electrical charge. Current represents the movement of electrical charge. Move the plates closer and current must flow to increase the charge to keep the same voltage. Move a high dielectric

constant insulator between them and again current must flow to keep the same voltage. The ratio of electrical charge to voltage is referred to as capacitance of the system of plates and separation. Dielectric constant is the ratio of capacitance for a system having a dielectric insulator versus having a vacuum.

Suppose an alternating sinusoidal voltage is applied to the plates. The amount of alternating current associated with the voltage is proportional to the capacitance. At an instant when the voltage is greatest the current is at zero and changing direction, and when the current is greatest the voltage is at zero and changing sign. Current and voltage are out of phase by one quarter of the sinusoidal cycle in an ideal system with no dissipation of energy. In a real system there will be some degree of electrical energy converted to heat because of resistance to current flow in the conductors and of resistance to dipolar response to voltage in the insulator. The loss in the insulator is referred to as dissipation factor. It is the ratio of energy loss in the dielectric to energy stored in the dielectric per cycle.

The frequency of the alternating voltage and current is the number of sinusoidal cycles per unit of time. As frequency is increased, we can expect to see changes in the way the insulation responds and thus the values for dielectric constant and dissipation factor can vary with frequency. This is why we measure insulating materials near the frequency at which they are to be used.

DIELECTRIC CONSTANT and DISSIPATION FACTOR - continued

TESTING

There are several methods for measuring dielectric constant and dissipation factor at the microwave frequencies of interest including:

- ❑ Stripline Resonator Method, IPC-TM-650 2.5.5.5 (8-12.4 GHz)
- ❑ Long Stripline (LSL), IPC-TM-650 2.5.5.5.1 (1-14 GHz)
- ❑ Full Sheet Resonance (FSR), IPC-TM-650 2.5.5.6
- ❑ Damaskos, Inc. Cavity Resonator

Rogers Corporation utilizes the Stripline Resonator Method (IPC-TM-650 2.5.5.5) when testing production laminates for quality control purposes. This method is considered the "standard" test method for most of the high frequency industry due to the ability to perform rapid measurements with the same test set-up. The stripline circuit consists of a resonator pattern card between two laminate samples etched to remove cladding. Advantages of this method include the ability to perform rapid measurements, an uncomplicated procedure and being operator independent.

DESIGN

G. Robert Traut (who developed the Long Stripline test method) explains why measurements matter:

"Users fabricate our microwave circuit materials into devices which guide and process cyclic microwave signals whose wavelength is small compared to the device... Many design features are built around the expected wavelength and won't work as planned if the wavelength deviates from the expected value... In almost every microwave system, it is very desirable to keep dissipation of energy down to minimize heat generation, to avoid more costly components for signal generation or amplification, to raise the sensitivity or signal to noise ratio.

For transmission line elements in a device, [dielectric constant] affects both wavelength and characteristic impedance (Z_0), with an inverse square root proportionality. Changes in Z_0 give rise to reflections of the signal...

Thus successful products for these users must have low [dissipation factor] and tightly controlled [dielectric constant] values."

In other words, tightly controlled dielectric constant values are required because it affects wavelength and characteristic impedance, two critical components when designing RF circuitry. A large K' tolerance could cause unwanted reflections within the design. Dissipation factor must be minimized to avoid heat generation and having to add extra components.

INSULATION RESISTANCE/VOLUME RESISTIVITY/SURFACE RESISTIVITY

KEY PROPERTY	ALIAS	SYMBOL	UNIT OF MEASURE	UNITS
Insulation Resistance	-	-	Resistance	Gohm
Volume Resistivity	-	ρ_v	Resistance length	Mohm-cm
Surface Resistivity	-	ρ_s	Resistance	Mohm

DEFINITION

Insulation resistance is the measure of the material's ability to resist the flow of current through it. Surface resistivity is the resistance to leakage current along the surface of an

insulating material. Volume resistivity is the resistance to leakage current through the body of an insulating material. The higher the surface/volume resistivity, the lower the leakage current and the less conductive the material is.

TESTING

Surface and volume resistivity are measured using the test method specified by IPC-TM-650 2.5.17.1. This test method involves a sample etched with a specified conductor pattern and test electrodes attached. A potential of 500 volts direct current is supplied to the sample in a controlled environment (due to correlation between resistivity and temperature/humidity) and the surface and volume resistivity is measured. The surface and volume resistivity values are then calculated using these measured values.

DESIGN

Resistivity of a dielectric material is critical to design because it affects electrical performance of the signal. The important factor is to ensure there is no leakage through the dielectric, so high values of resistivity are ideal. The composition of the dielectric material will determine the surface and volume resistivity.

THERMAL COEFFICIENT OF DIELECTRIC CONSTANT

KEY PROPERTY	ALIAS	SYMBOL	UNIT OF MEASURE	UNITS
Thermal Coefficient of Dielectric Constant	Thermal Coefficient of ϵ_r	TCK'	Concentration per temperature	ppm/°C

DEFINITION

TCK' is a measure of how the relative permittivity (dielectric constant) is affected by changes in temperature.

thermostatically controlled oven programmed to vary in steps from minus 50°C to plus 150°C.

DESIGN

Temperature changes can greatly affect the dielectric constant property depending on the dielectric material used in the laminate. Changes in the dielectric constant can affect signal integrity and cause unstable performance within the design.

TESTING

The Stripline Resonator Method, IPC-TM-650 2.5.5.5 is used to measure the dielectric constant where the test fixture is mounted in a

DIELECTRIC STRENGTH

KEY PROPERTY	ALIAS	SYMBOL	UNIT OF MEASURE	UNITS
Dielectric Strength	Electrical Strength	-	Voltage per length	V/mil

DIELECTRIC STRENGTH - continued

DEFINITION

Dielectric strength is the voltage gradient an insulating material can withstand before dielectric breakdown occurs. Dielectric breakdown is the point at which large amounts of electrons are suddenly excited to energies within the conduction band, i.e. failure of the insulating material to withstand current flow. Once the breakdown occurs the insulation is degraded permanently.

TESTING

Dielectric strength is tested using IPC-TM-650 2.5.6.2. Dielectric breakdown utilized IPC-TM-650 2.5.6.

DESIGN

The dielectric strength value represents the magnitude of an electric field necessary to produce breakdown of the dielectric, so when designing a circuit board it is imperative to ensure the potential applied never reaches the dielectric strength value. If it does, the dielectric material becomes conductive and localized heating may occur. Factors that affect dielectric strength include thickness, frequency and environment (especially adsorbed or absorbed moisture).

TENSILE (YOUNG'S) MODULUS / COMPRESSIVE MODULUS / FLEXURAL MODULUS

KEY PROPERTY	ALIAS	SYMBOL	UNIT OF MEASURE	UNITS
Young's Modulus	Modulus of Elasticity	E	Force per area	Mpa or Kpsi
Compressive Modulus	-	-	Force per area	Mpa or Kpsi
Flexural Modulus	-	-	Force per area	Mpa or Kpsi

DEFINITION

These material properties describe how the material reacts under mechanical loading conditions. Strain is the ratio of change in dimension to the original dimension. Stress is the force per unit of cross-sectional area. The modulus of elasticity in tension, also known as Young's Modulus (E), is the ratio of stress to strain along the loading direction in tension. The compressive modulus represents the relationship of stress to strain when the material is in compression. The flexural modulus is the ratio of flexural stress to strain.

TESTING

Young's Modulus is measured using test method ASTM D638 and is described as the

steepest region of the stress/strain curve that is in tension for X and Y axes, and compression for Z axis by ASTM D695 on a 12.7 x 12.7 x 25.4 mm stacked specimen. The compressive modulus is determined using ASTM D695, and the flexural modulus is found using ASTM D790.

DESIGN

The values for these three modulus properties describe how the material behaves under loading conditions. Young's Modulus is defined as the slope of the linear region of the stress/strain curve. It is a measure of the stiffness of the material; the higher the value of E, the more rigid the material is. The stiffness of the material is important in certain applications and should be considered when rigidity of design is a requirement.

MOISTURE ABSORPTION

KEY PROPERTY	ALIAS	SYMBOL	UNIT OF MEASURE	UNITS
Moisture Absorption	-	-	Percentage of moisture absorbed	%

DEFINITION

The amount of moisture, in percentage, that a material will absorb under specified conditions.

TESTING

The test method for measuring moisture absorption is IPC-TM-650 2.6.2.1. A 2 inch x 2 inch sample etched free of copper is weighed and then submerged for 24 hours in distilled water at 23°C. After the 24-hour soak the sample is weighed to find the increase in

weight and the moisture absorption value is calculated.

DESIGN

Moisture absorption can affect the electrical properties of the fabricated printed circuit board. Water has a dielectric constant of approximately 80, so water within the laminate will raise dielectric constant of the PCB and consequently affect the wavelength of the signal as well as the characteristic impedance. A low moisture absorption value is recommended.

THERMAL CONDUCTIVITY

KEY PROPERTY	ALIAS	SYMBOL	UNIT OF MEASURE	UNITS
Thermal Conductivity	-	k	Ratio of dimensional change to temperature change	W/m/K

DEFINITION

The thermal conductivity of a material is equivalent to the quantity of heat that passes in unit time through unit area of a plate of unit thickness, when its opposite faces are subject to unit temperature gradient.

TESTING

The test method Rogers Corporation uses for thermal conductivity is ASTM C518.

DESIGN

Heat dissipation is a primary concern for printed circuit boards. The higher the value of thermal conductivity the more heat will be conducted through the dielectric and away from the copper transmission lines.

COEFFICIENT OF THERMAL EXPANSION

KEY PROPERTY	ALIAS	SYMBOL	UNIT OF MEASURE	UNITS
Coefficient of Thermal Expansion	CTE	CTE, α	Dimensional change to temperature change	% or ppm/°C

DEFINITION

A material's fractional change in length for a given unit change of temperature.

TESTING

The test method used to measure coefficient of thermal expansion is ASTM D3386-94. The values listed on the Product Selector Guide are averaged over the selected temperature range (0-100°C) and are not necessarily linear. However, for RT/duroid 6002® and TMM® material grades the response of CTE from 0-100°C is essentially linear.

DESIGN

The CTE values should be listed in the x-y-z planes for the laminate material. CTE is important during fabrication of laminates where variations in temperature are unavoidable. Ideally, the CTE in the x-y axis would be matched to the bonded metal, usually copper, which has a CTE of approximately 17 ppm/°C. In multi-layer applications, a CTE in the z-axis should ideally be zero to avoid failures of plated through holes connecting layers of circuitry.

PEEL STRENGTH

KEY PROPERTY	ALIAS	SYMBOL	UNIT OF MEASURE	UNITS
Peel Strength	Bond Strength	-	Force per length	N/mm or lb/in

DEFINITION

Measure of the strength of an adhesive bond. It is the average load per unit width of bond line required to part bonded materials.

TESTING

The test method used to measure peel strength for metal clad laminates is IPC-TM-650 2.4.8. The sample is etched to reveal traces of 0.125-inch width. A force gauge is used to measure the vertical force applied to lift the copper from the dielectric. The force values are averaged over a specified length and a value in lbs/in is calculated.

DESIGN

Bond between copper and dielectric is of primary concern when designing RF circuitry. The bond must be strong enough to withstand processing, such as ENIG, HASL and NiAu. These fabrication techniques may require high temperatures that can degrade bond strength. Also, bond strength comes into play when mounting components and re-workability of the laminate. Factors that can reduce bond strength in an application are oxidation and the thermal environment.

GLASS TRANSITION TEMPERATURE

KEY PROPERTY	ALIAS	SYMBOL	UNIT OF MEASURE	UNITS
Glass Transition Temperature	Heat distortion temperature	Tg	Temperature	°F, °C or K

DEFINITION

The glass transition temperature (Tg) is the temperature at which the amorphous phase of a polymeric material changes from its lower temperature glassy state to its higher temperature rubbery state. This is marked by a change in coefficient of thermal expansion and by a change in the specific heat.

measuring the coefficient of thermal expansion (CTE) as the polymer changes its molecular state from crystalline to an elastic state. DMA determines the glass transition temperature using changes in mechanical behavior (modulus or damping) as a function of temperature, time, frequency, stress or strain or combinations of these parameters.

TESTING

There are various methods for measuring the glass transition temperature including:

- Differential Scanning Calorimetry (DSC)
- Thermo-mechanical Analysis (TMA)
- Dynamic Mechanical Analysis (DMA)

DSC is a technique that measures a change in the specific heat to identify the glass transition temperature. TMA identifies the Tg by

DESIGN

The glass transition temperature plays a major role in the fabrication of circuit board laminates, especially for multi-layer applications. A high Tg is preferred so less z-axis thermal expansion movement occurs within the dielectric material during fabrication in multi-layer constructions, which equates to better plated through hole (PTH) reliability.

DIMENSIONAL STABILITY

KEY PROPERTY	ALIAS	SYMBOL	UNIT OF MEASURE	UNITS
Dimensional Stability	-	-	Length per length	mils/in or mm/m

DEFINITION

Dimensional stability represents the ability of a dielectric material to resist changes in its dimensions due to temperature, moisture or physical stress changes.

DESIGN

Dimensional stability is important when considering what fabrication processes the laminate will experience. Processes such as plating or etching can change the material dimensions and thus affect the original design of the circuit board causing degradation in performance.

TESTING

Dimensional stability is tested using IPC-TM-650 2.4.3.9 or 2.2.4 The values for dimensional stability are dependent on material thickness and etch process, which are standardized within the IPC test method.

FLAMMABILITY RATING

KEY PROPERTY	ALIAS	SYMBOL	UNIT OF MEASURE	UNITS
Flammability Rating	UL94	-	-	-

DEFINITION

UL 94 Flame Class - this classification of material is based on flame tests conducted in accordance with UL 94 (a gas-burner test on a small-scale specimen). UL 94 flame testing relates to a material's behavior when introduced to a flame source. Burn time of material when in contact with a flame determines the UL flame classification. For example, to achieve a rating of 94V-0, a material must self-extinguish within 10 seconds and not drip resin or flame while burning. Burn time in excess of 10 seconds may achieve ratings such as V-1 or V-2 based on their time to burn.

TESTING

Underwriters Laboratories Inc. (UL) specifies the flammability rating in specification UL 94. During this test, a sample of material is held over a Bunsen burner, ignited, and allowed to burn. When the sample is removed from the flame, the fire must self extinguish within 10 seconds and show no signs of dripping burning resin in order to achieve a 94V-0 rating. If material continues to burn or if it drips resin or flame, it cannot be rated 94V-0.

DESIGN

The application of the PCB design may require a self-extinguishing material due to the environment. A rating of UL 94V-0 is one of the classes of a self-extinguishing substrate.

IMPACT, NOTCH IZOD

KEY PROPERTY	ALIAS	SYMBOL	UNIT OF MEASURE	UNITS
Impact Notch Izod	Impact Resistance	-	Impact energy per length	J/m or ft-lb/inch

DEFINITION

This is a method for measuring the impact resistance of materials.

TESTING

To measure the impact resistance of plastics, Rogers Corporation utilizes ASTM D256A.

DESIGN

PCB designers can use the information for impact resistance to determine how the material will perform at stress concentration points, such as a corner or notch.

ACKNOWLEDGEMENTS

- Traut, G.R., "Microwave Measurements at Rogers Corp. in Simple Terms" Lurie R&D Center, Rogers, CT 06263.
- Horn, Allen F., "Dielectric Properties from 1 to 50 GHz of High Frequency Circuit Substrates"

CONVERSION TABLES

FROM	TO	EQUATION
lb/in	N/mm	$N/mm = (.175)*lb/in$
N/mm	lbs/in	$lbs/in = (5.710)*N/mm$
ftlb	Nm	$Nm = (.738)*ft-lbs$
Nm	ft-lb	$ft-lb = (1.383)*Nm$
lb	kg	$kg = (.454)*lb$
kg	lb	$lb = (2.205)*kg$
MPa	kpsi	$kpsi = (6.895)*MPa$
kpsi	MPa	$MPa = (.145)*kpsi$
J/g/K	BTU/lb/°F	$BTU/lb/°F = (4.187)*J/g/K$
BTU/lb/°F	J/g/K	$J/g/K = (.239)*BTU/lb/°F$
Pa	N/m ²	$N/m^2 = (1)*Pa$
N/m ²	Pa	$Pa = (1)*N/m^2$
V/mil	kV/mm	$kV/mm = (25.4)*V/mil$
kV/mm	V/mil	$V/mil = (.0394)*kV/mm$
mil/in	mm/m	$mm/m = (1)*mil/in$
mm/m	mil/in	$mil/in = (1)*mm/m$
%	ppm/°C	$ppm/°C = (10,000*%)/\text{temperature range}$

**multiply*

ONE OF THESE	TRANSLATES TO
lb/in	.175 N/mm
Pa	1 N/m ²
psi	6894.76 Pa
psi	6.89476 kPa
kpsi	6.89476 MPa
lbm	.454kg
MPa	.145 kpsi
J/g/K	.239 BTU/lb/°F
mil	.001 inches
mm	40 mils
mil	.025 mm

FROM	TO	EQUATION
Celsius	Fahrenheit	$F = 9/5C + 32$
Celsius	Kelvin	$K = C + 273.15$
Fahrenheit	Celsius	$C = 5/9*(F-32)$
Fahrenheit	Kelvin	$K = 5/9F + 255.37$
Kelvin	Celsius	$C = K - 273.15$
Kelvin	Fahrenheit	$F = 9/5K - 459.67$

KEY PROPERTIES CHART

KEY PROPERTY	ALIAS	SYMBOL	UNIT OF MEASURE	UNITS
Dielectric Constant	Relative Permittivity	K' , DK, ϵ_r	Ratio of the permittivity of a substance to the permittivity of free space.	None
Dissipation Factor	loss tangent $\tan\delta$, approx power factor	$\tan\delta$ DF K''/K'	Ratio of loss to capacity	None
Thermal Coefficient of Dielectric Constant	Thermal Coefficient of ϵ_r	TCK'	Concentration per temperature	ppm/ $^{\circ}$ C
Insulation Resistance	-	-	Resistance	Gohm
Volume Resistivity	-	ρ_v	Resistance length	Mohm-cm
Surface Resistivity	-	ρ_s	Resistance	Mohm
Young's Modulus	Modulus of Elasticity	E	Force per area	Mpa or Kpsi
Compressive Modulus	-	-	Force per area	Mpa or Kpsi
Flexural Modulus	-	-	Force per area	Mpa or Kpsi
Moisture Absorption	-	-	Percentage of moisture absorbed	%
Thermal Conductivity	-	k	Ratio of dimensional change to temperature change	W/m/K
Coefficient of Thermal Expansion	CTE	CTE, α	Dimensional change to temperature change	% or ppm/ $^{\circ}$ C
Peel Strength	Bond Strength	-	Force per length	N/mm or lb/in
Dimensional Stability	-	-	Length per length	mils/in or mm/m
Dielectric Strength	Electrical Strength	-	Voltage per length	V/mil
Glass Transition Temperature	Heat distortion temperature	Tg	Temperature	$^{\circ}$ F, $^{\circ}$ C or K
Flammability Rating	UL94	-	-	-
Impact Notch Izod	Impact Resistance	-	Impact energy per length	J/m or ft-lb/inch

CONTACT INFORMATION:

USA:	Rogers Advanced Circuit Materials	Tel: 480-961-1382	Fax: 480-961-4533
Belgium:	Rogers NV - Gent	Tel: 32-9-2353611	Fax: 32-9-2353658
Japan:	Rogers Japan Inc.	Tel: 81-3-5200-2700	Fax: 81-3-5200-0571
Taiwan:	Rogers Taiwan Inc.	Tel: 886-2-86609056	Fax: 886-2-86609057
Korea:	Rogers Korea Inc.	Tel: 82-31-716-6112	Fax: 82-31-716-6208
Singapore:	Rogers Technologies Singapore Inc.	Tel: 65-747-3521	Fax: 65-747-7425
China:	Rogers (Shanghai) International Trading Co., Ltd	Tel: 86-21-63916088	Fax: 86-21-63915060

The information contained in this Properties Guide is intended to assist you in designing with Rogers' laminates. It is not intended to and does not create any warranties, express or implied, including any warranty of merchantability or fitness for a particular application. The user should determine the suitability of Rogers' circuit materials for each application.

These commodities, technology and software are exported from the United States in accordance with the Export Administration regulations. Diversion contrary to U.S. law prohibited.

RT/duroid, ULTRALAM, TMM, RO3000, RO4000 and DUROID are licensed trademarks of Rogers Corporation.

"The world runs better with Rogers" is a licensed trademark of Rogers Corporation in the USA.

© 2004 Rogers Corporation, Printed in U.S.A. All Rights Reserved.

0678-804-5CC Publication #92-602