ESTIMATION OF NON-CONDUCTIVE PROPERTIES OF SUBSTRATE FOR MICROSTRIP ANTENNA

[1]P.Venu Madhav, [2]A.Ashok Babu
[1,2]Asst. Professor
Dept. of ECE
PVP Siddhartha Institute of Technology, Kanuru, Vijayawada

***Abstract:* To design a microstrip patch antenna at first the designer is to select the substrate material and its thickness. So, if the designer has a clear conception about the effect of changing substrate material and it's thickness on the performance of the antenna, it will be easier to design an antenna.**

Appropriate selection of dielectric material and its thickness is an important task for designing a microstrip patch antenna. Dielectric substrate among the common substrates available gives better performance and the properties of the dielectric substrates affects antenna performance. For lowest cost, microstrip devices may be built on an ordinary FR-4 (standard PCB) substrate. However it is often found that the dielectric losses in FR4 are too high at microwave frequencies, and that the dielectric constant is not sufficiently tightly controlled. This paper discusses and presents a clear understanding of the parameters that are to be considered in the selection of substrate materials.

Key Words: Magnetic Materials, substrates, characteristic impedance, electrical properties, mechanical properties, Thermal conductivity

1. INTRODUCTION

The electromagnetic wave carried by a microstrip line exists partly in the dielectric substrate, and partly in the air above it. In general, the dielectric constant of the substrate will be different (and greater) than that of the air, so that the wave is travelling in an inhomogeneous medium. In consequence, the propagation velocity is somewhere between the speed of radio waves in the substrate, and the speed of radio waves in air. This behavior is commonly described by stating the effective dielectric constant (or effective relative permittivity) of the microstrip; this being the dielectric constant of an equivalent homogeneous medium (i.e., one resulting in the same propagation velocity).

Further consequences of an inhomogeneous medium include that the line will not support a true TEM wave; at non-zero frequencies, both the E and H fields will have longitudinal components (a hybrid mode). The longitudinal components are small however, and so the dominant mode is referred to as quasi-TEM. The line is dispersive. With increasing frequency, the effective dielectric constant gradually climbs towards that of the substrate, so that the phase velocity gradually decreases. This is true even with a non-dispersive substrate material (the substrate dielectric constant will usually fall with increasing frequency).

- The characteristic impedance of the line changes slightly with frequency (again, even with a non-dispersive substrate material). The characteristic impedance of non-TEM modes is not uniquely defined, and depending on the precise definition used, the impedance of microstrip either rises, falls, or falls then rises with increasing frequency. The low-frequency limit of the characteristic impedance is referred to as the quasi-static characteristic impedance and is the same for all definitions of characteristic impedance.
- The wave impedance varies over the cross-section of the line.
- Microstrip lines radiate and discontinuity elements such as stubs and posts, which would be pure reactance in stripline, have a small resistive component due to the radiation from them.

The dielectric loading of a microstrip antenna affects both its radiation pattern and impedance bandwidth. As the dielectric constant of the substrate increases, the antenna bandwidth decreases which increases the Q factor of the antenna and therefore decreases the impedance bandwidth. The most important properties to consider for any dielectric material:

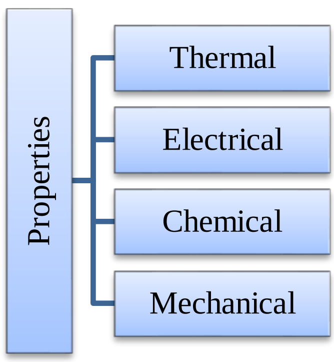

Figure 1 Classification of Non electrical Properties

a) Effects of thermal properties

Under thermal properties the following evaluation need to be performed before selection of the substrate material as it may increase or decrease the performance of the system under consideration.

Glass Transition Temperature (Tg)

Glass transition temperature, or Tg, is the temperature range in which a PCB substrate transitions from a glassy, rigid state to a softened, deformable state as polymer chains become more mobile. When the material cools back down, its properties return to their original states. Tg is expressed in units of degrees Celsius (ºC).

Decomposition Temperature (Td)

Decomposition temperature, or Td, is the temperature at which a PCB material chemically decomposes (the material loses at least 5% of mass). Like Tg, Td is expressed in units of degrees Celsius (ºC).

A material's Td is an important ceiling when assembling PCBs, because when a material reaches or surpasses its Td, changes to its properties are not reversible. Contrast this to Tg, glass transition temperature, where properties will return to their original states once the material cools below the Tg range.

Select a material where you can work in a temperature range That's higher than Tg but well below Td. Most solder temperatures during PCB assembly are in the 200 ºC to 250 ºC range, so make sure Td is higher than this (luckily, most materials have a Td greater than 320 ºC).

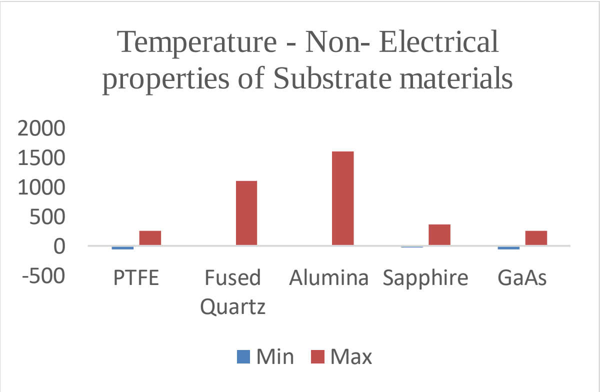

Figure 2 Chart of Temperature variation in substrates

Coefficient of Thermal Expansion (CTE)

The coefficient of thermal expansion, or CTE, is the rate of expansion of a PCB material as it heats up. CTE is expressed in parts per million (ppm) expanded for every degree Celsius that it is heated. As a material's temperature rises past Tg, the CTE will rise as well. The CTE of a substrate is usually much higher than copper, which can cause interconnection issues as a PCB is heated. CTE along the X and Y axes are generally low – around 10 to 20 ppm per degree Celsius.

The woven glass that constrains the material in the X and Y directions, and the CTE does not change much even as the material's temperature increases above Tg. So the material must expand in the Z direction. The CTE along the Z axis should be as low as possible; aim for less than 70 ppm per degree Celsius, and this will increase as a material surpasses Tg.

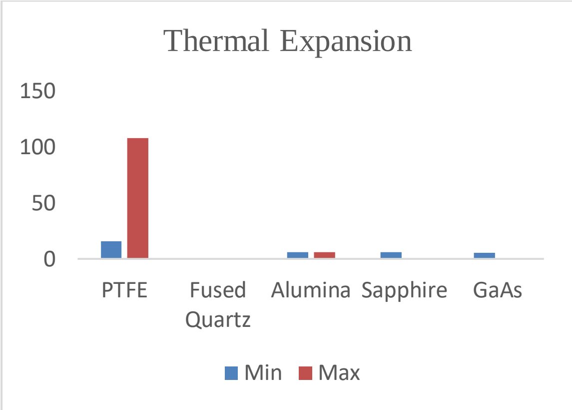

Figure 3 Chart indicating thermal expansion of substrates

Thermal Conductivity (k)

Thermal conductivity, or k, is the property of a material to conduct heat; low thermal conductivity means low heat transfer while high conductivity means high heat transfer. The measure of the rate of heat transfer is expressed in watts per meter per degree Celsius (W/M -ºC). Most PCB dielectric materials have a thermal conductivity in the range of 0.3 to 0.6 W/M-ºC, which is quite low compared to copper, whose k is 386 W/M-ºC. Therefore, more heat will be carried away quickly by copper plane layers in a PCB than by the dielectric material.

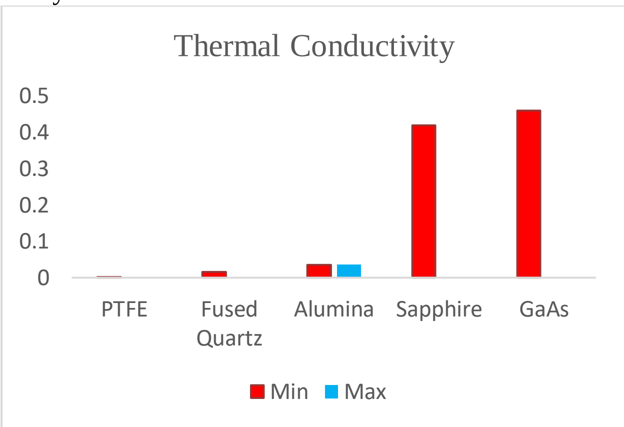

Figure 4 Chart representing thermal conductivity

b) Electrical Properties

Dielectric Constant or Relative Permittivity (Er or Dk)

Considering the dielectric constant of a material is important for signal integrity and impedance considerations, which are critical factors for high-frequency electrical performance.

The εr for most PCB materials is in the range of 2.5 to 4.5. The dielectric constant varies with frequency and generally decreases as frequency increases; some materials have less of a change in relative permittivity than others. Materials suitable for high frequency applications are those whose dielectric constant remains relatively the same over a wide frequency range–from a few 100MHz to several GHz.

Dielectric Loss Tangent or Dissipation Factor (Tanδ or Df): A material's loss tangent gives a measure of power lost due to the material. The lower a material's loss tangent, the less power lost. The Tan δ of most PCB materials range from 0.02 for most commonly used materials to 0.001 for very low-loss high-end materials. It also varies with frequency, increasing as frequency increases.

Loss tangent is not usually a critical consideration for digital circuitry, except at very high frequencies above 1 GHz. However, it is a very important parameter for analog signals, as it determines the degree of signal attenuation and thus affects the signal to noise ratio at various points along signal traces.

Volume Resistivity (ρ)

Volume resistivity, or electrical resistivity (ρ), is one of the measures of the electrical or insulation resistance of a PCB material. The higher a material's resistivity, the less readily it allows the movement of electric charge, and vice versa. Resistivity is expressed in ohm-meters (Ω-m) or ohm-centimeters (Ω-cm).As dielectric insulators, PCB materials are required to have very high values of resistivity, in the order of 10^6 – 10^{10}Megaohm-centimeters. Resistivity is somewhat affected by moisture and temperature.

Surface Resistivity (ρS)

Surface resistivity (ρS) is the measure of the electrical or insulation resistance of the surface of a PCB material. Like volume resistivity, PCB materials are required to have very high values of surface resistivity, in the order of 10^6 — 10^{10}Megaohms per square. It is also somewhat affected by both moisture and temperature.

e. Electrical Strength

Electrical strength measures a PCB material's ability to resist electrical breakdown in the PCB's Z direction (perpendicular to the PCB's plane). It is expressed in Volts/mil. Typical electrical strength values for PCB dielectrics are in the range of 800 V/mil to 1500 V/mil.

Electrical strength is determined by subjecting the PCB material to short high voltage pulses at standard AC power frequencies.

The table1 provides a comparison of various the substrate materials that are available and suitable parametric values for temperature, thermal conductivity and thermal expansion

Table 1 Parameter comparison of substrates

	Temperature		Thermal Conductivity		Thermal Expansion	
	Min	Max	Min	Max	Min	Max
PTFE	-55	260	0.0026		16	108
Fused Quartz		1100	0.017		0.55	
Alumina		1600	0.035	0.037	6.3	6.4
Sapphire	-24	370	0.42		6	
GaAs	-55	260	0.46		5.7	

2. CHEMICAL PROPERTIES

a. Flammability Specs (UL94)

UL94, or the Standard for Safety of Flammability of Plastic Materials for Parts in Devices and Appliances testing, is a plastics flammability standard that classifies plastics from lowest (least flame-retardant) to highest (most flame-retardant).The standards are defined by Underwriters Laboratories (UL). Most PCB materials adhere to UL94 V-0; here are its requirements

1. The specimens may not burn with flaming combustion for more than 10 seconds after either application of the test flame.
2. The total flaming combustion time may not exceed 50 seconds for the 10 flame applications for each set of 5 specimens.
3. The specimens may not burn with flaming or glowing combustion up to the holding clamp.
4. The specimens may not drip flaming particles that ignite the dry absorbent surgical cotton located 300 mm below the test specimen.
5. The specimens may not have glowing combustion that persists for more than 30 seconds after the second removal of the test flame.

Moisture Absorption

Moisture absorption is the ability of a PCB material to resist water absorption when immersed in water. It is given by percentage increase in weight of a PCB material due to water absorption under controlled conditions as per standard test methods. Most materials have moisture absorption values in the range of 0.01% to 0.20%.Moisture absorption affects the thermal and electrical properties of the material, as well as the ability of the material to resist conductive anode filament (CAF) formation when a PCB circuit is powered.

Methylene Chloride Resistance

Methylene chloride resistance is a measure of a material's chemical resistance; specifically, the ability of a PCB material to resist methylene chloride absorption. Just like moisture absorption, it is expressed by percentage increase in weight of a PCB material due to exposure to or soaking in methylene chloride under controlled conditions. Most PCB materials have methylene chloride resistance values in the range of 0.01% to 0.20%.

D. Mechanical Properties

Peel Strength

Peel strength is a measure of the bond strength between the copper conductor and the dielectric material. It is expressed in pounds of force per linear inch (PLI, or average load per conductor width) required to separate bonded materials

where the angle of separation is 180 degrees. Peel strength tests are done on samples of copper traces of 1 OZ thick and ~ 32 to 125 millimeters wide after standard PCB manufacturing processes.
It is completed under 3 conditions:

- After thermal stress: after a sample is floated on solder at 288 ºC for 10 seconds.
- At elevated temperatures: after a sample is exposed to hot air or fluid at 125 ºC.
- After exposure to process chemicals: after a sample is exposed to a specified series of steps in a chemical or thermal process.

Flexural Strength

Flexural strength is the measure of a material's capability to withstand mechanical stress without fracturing. It is expressed in either Kg per square meter or pounds per square inch (KPSI).Flexural strength is generally tested by supporting a PCB at its ends and loading it in the center. IPC-4101 is the Specification for Base Materials for Rigid and Multilayer Printed Boards, and it gives the minimum flexural strength of various PCB materials.

Young's Modulus

Young's modulus, or tensile modulus, also measures the strength of a PCB material. It measures the stress/strain ratio in a particular direction, and some PCB laminate manufacturers give strength in terms of Young's modulus instead of flexural strength. Like flexural strength, it is expressed in force per unit area.
Some PCB laminate manufacturers give the PCB materials strength not in terms of Flexural Strength but in terms of Young's modulus which is a measure of Stress/strain ratio in a particular direction.

Density

The density of a PCB material is expressed in in grams per cubic centimeter (g/cc) or pounds per cubic inch (lb/in^3).

Time to Delamination

Time to delamination measures how long a material will resist delamination—the resin's separation from the laminate, foil, or fiberglass – at a specified temperature. Delamination can be caused by thermal shock, the wrong Tg in the material, moisture, a poor lamination process.

3. CONCLUSION

The points of observation from this paper clearly mention that the antenna designer should Keep in mind that the values for the parameters listed in the table 1 are an example for a certain manufacturer's material. Each manufacturer will have slightly different values for the parameters and must choose wisely while selecting the substrate material into the antenna design.

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