UNIVERSIDADE ESTADUAL DE CAMPINAS
FACULDADE DE ENGENHARIA ELÉTRICA E DE COMPUTAÇÃO
IE766 - GUIAMENTO E RADIAÇÃO DE ONDAS

Design and Simulation of a Band-pass Filter of 10GHz

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1 Introduction

A microstrip line is a primary transmission line, manufactured by lithography and easily minutiarized. It is a mixed dielectric system, with a solid dielectric below and on top, usually air. These systems can only support a multimodal propagation behavior at a particular frequency, the structure is not compatible with the pure TEM wave, that is, they have a "quasi-TEM" propagation. [1]. As you can see in the fig. 1.

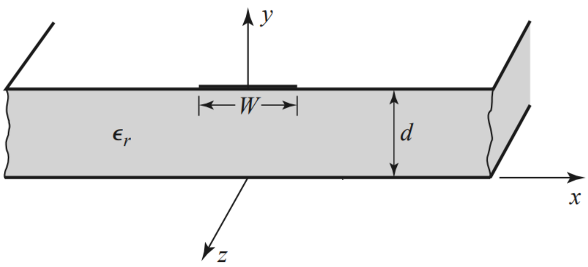

Figure 1: Microstrip Line. [1]

Coupled Line Band-pass Filter is manufactured with sections of lines in cascade, these lines are coupled in parallel forming a system in TEM mode with half wavelength [2]. As you can see in the fig. 2.

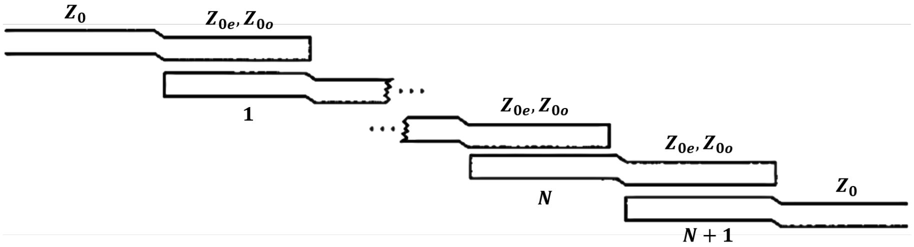

Figure 2: Coupled Line Band-pass Filter [1]

2 Design

When working with parts of flattened parallel lines, as shown in the fig. 2, we must define the type of filter (Chebyshev) to perform, the order and the ripple. Specifications for the band pass filter are shown in table 1. Based on the known parameters, the proposed procedure has the following steps.

Table 1: Pass-band Filter design specifications.

Parameter	Symbol	Value
Centre frequency	f	10GHz
Band	Δ	10%
Substrate permitivity (Rogers-RT5880)	ϵ_r	2.2
Substrate thickness	h	0.79mm
Metal thickness	t	0.035mm
Ripple	R	3dB
Rejection(11GHz)	r	20dB
Impedance	Z_0	50Ω

2.1 Find physical width and length

We start with the respective table for a ripple of 3dB fig. 3. Obtaining the values for the Chebyshev filter of order 5.

From this, we must find the even and odd impedances for each line and later we will find the physical dimensions.

We use the equations provided by Pozar, to be able to design the filter. [1]

$$Z_0 J_1 = \sqrt{\frac{\pi\Delta}{2g_1}}, n = 1 \tag{1}$$

$$Z_0 J_n = \frac{\pi\Delta}{2\sqrt{g_{n-1}g_n}}, n = 2, ..., N \tag{2}$$

$$Z_0 J_n = \sqrt{\frac{\pi\Delta}{2g_{n-1}g_n}}, n = N + 1 \tag{3}$$

With this we calculate the impedances for each line.

$$Z_{0e} = Z_0(1 + J_i Z_0 + (J_i Z_0)^2) \tag{4}$$

$$Z_{0o} = Z_0(1 - J_i Z_0 + (J_i Z_0)^2) \tag{5}$$

In this way we obtain the impedances as shown in the table 2 and using the code in MATLAB.

Low-Pass Chebysev Filter Coefficients – 3 dB Ripple

N	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
1	1.9953	1.0000									
2	3.1013	0.5339	5.8095								
3	3.3487	0.7117	3.3487	1.0000							
4	3.4389	0.7483	4.3471	0.5920	5.8095						
5	3.4817	0.7618	4.5381	0.7618	3.4817	1.0000					
6	3.5045	0.7685	4.6061	0.7929	4.4641	0.6033	5.8095				
7	3.5182	0.7723	4.6386	0.8039	4.6386	0.7723	3.5182	1.0000			
8	3.5277	0.7745	4.6575	0.8089	4.6990	0.8018	4.4990	0.6073	5.8095		
9	3.5340	0.7760	4.6692	0.8118	4.7272	0.8118	4.6692	0.7760	3.5340	1.0000	
10	3.5384	0.7771	4.6768	0.8136	4.7425	0.8164	4.7260	0.8051	4.5142	0.6091	5.8095

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Figure 3: 3dB Ripple [1]

```
clear;
format long e;
n=5;z0=50;
f2=10.5*1e9;
f1=9.5*1e9;
w2=2*pi*f2;
w1=2*pi*f1;
w0=sqrt(w2*w1);
delta=(w2-w1)/w0;
g=[3.4817 0.7618 4.5381 0.7618 3.4817 1];
j1z0=sqrt((pi*delta)/(2*g(1)))
j2z0=(pi*delta)/(sqrt(2*g(1)*g(2)))
j3z0=(pi*delta)/(sqrt(2*g(2)*g(3)))
j4z0=sqrt((pi*delta)/(2*g(3)*g(4)))
j5z0=sqrt((pi*delta)/(2*g(4)*g(5)))
j6z0=sqrt((pi*delta)/(2*g(5)*g(6)))
zoe1=z0*(1+j1z0+(j1z0)^2)
zoe2=z0*(1+j2z0+(j2z0)^2)
zoe3=z0*(1+j3z0+(j3z0)^2)
zoe4=z0*(1+j4z0+(j4z0)^2)
zoe5=z0*(1+j5z0+(j5z0)^2)
zoe6=z0*(1+j6z0+(j6z0)^2)
zoo1=z0*(1-j1z0+(j1z0)^2)
zoo2=z0*(1-j2z0+(j2z0)^2)
zoo3=z0*(1-j3z0+(j3z0)^2)
zoo4=z0*(1-j4z0+(j4z0)^2)
```

```
zoo5=z0*(1-j5z0+(j5z0)^2)
zoo6=z0*(1-j6z0+(j6z0)^2)
```

Listing 1: Impedances Calculation

Table 2: Pass-band Filter Impedances.

Symbol	Value	Symbol	Value
Z_{0e1}	62.8855	Z_{0o1}	41.63172
Z_{0e2}	57.7612	Z_{0o2}	44.10398
Z_{0e3}	56.6967	Z_{0o3}	44.73426
Z_{0e4}	62.9392	Z_{0o4}	41.61007
Z_{0e5}	65.1403	Z_{0o5}	40.78937
Z_{0e6}	62.8855	Z_{0o6}	41.63172

We use the calculated coupled lines that HFSS provides in its toolbox fig. 4.

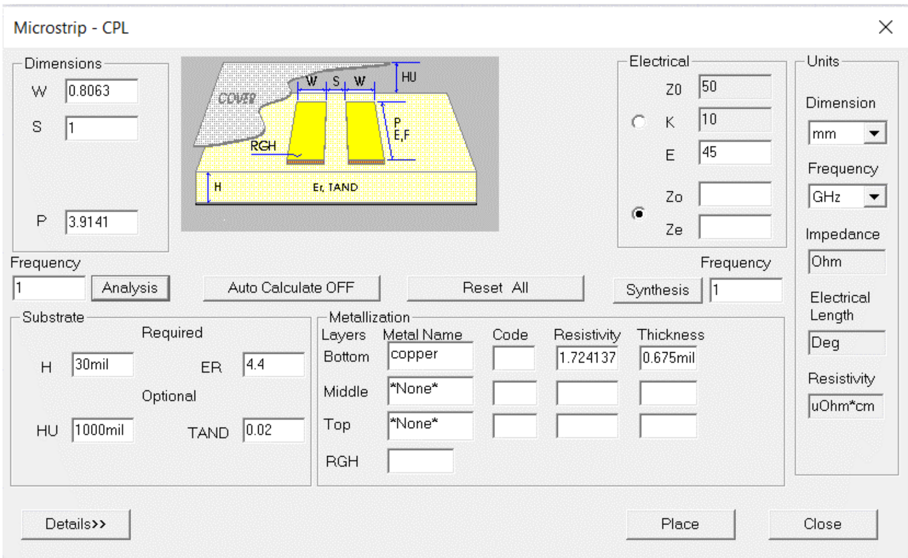

Figure 4: HFSS ToolBox

So we have the initial physical values for the filter.

2.2 Circuit Model

The objective of the circuit simulation is to determine the dimensions of the coupled parallel lines that optimize the given requirements. Using the previously found parameters, we proceed to carry out a circuit model in order to speed up the simulation and to be able to find the appropriate values before carrying out the simulation in 3 dimensions.

Table 3: Initial Values for Band-pass Filter.

Parameter	Value	Parameter	Value	Parameter	Value
W_{Z00}	2.34011mm	L_{Z0}	5.43013mm		
W_{Z11}	2.08691mm	L_{Z11}	5.48693mm	S_1	0.347782mm
W_{Z12}	2.08691mm	L_{Z12}	5.48693mm		
W_{Z21}	2.23343mm	L_{Z21}	5.45551mm	S_2	0.69865mm
W_{Z22}	2.23343mm	L_{Z22}	5.45551mm		
W_{Z31}	2.25805mm	L_{Z31}	5.44978mm	S_3	0.830218mm
W_{Z32}	2.25805mm	L_{Z32}	5.44978mm		
W_{Z41}	2.08523mm	L_{Z41}	5.48727mm	S_4	0.345565mm
W_{Z42}	2.08523mm	L_{Z42}	5.48727mm		
W_{Z51}	2.01541mm	L_{Z51}	5.50058mm	S_5	0.269675mm
W_{Z52}	2.01541mm	L_{Z52}	5.50058mm		
W_{Z01}	2.34011mm	L_{Z0}	5.43013mm		

Using Ansys Electronic Desktop (AED), we assembled the circuit with the calculated dimensions, as shown in the fig. 5.

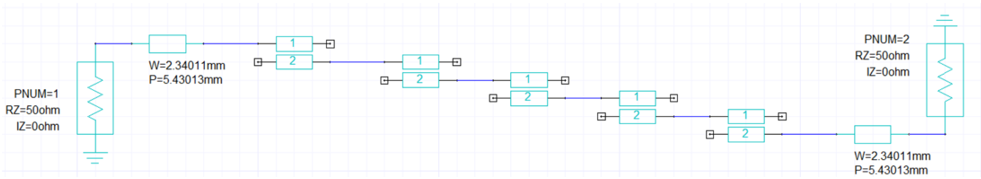

Figure 5: Circuit Simulation.

The result of the circuit gives us an operation in 10GHz, as seen in the fig. 6, but one must seek to optimize these values to meet what is required.

We update the parameters within an acceptable range of $\pm 10\%$ and independently simulate each variable to find the best values that optimize the device's performance at 10GHz and meet the requirements. (fig. 7)

The graphs of the parameter S in the fig. 7 show the results of the band pass filter. Configured as shown in fig. 6, the "sweep" function was used to produce the graphs of the S parameter for each variable. The dimensions were then adjusted accordingly to obtain the optimal coupling coefficient and insulation values. The objective was to obtain a reflection of 20dB at 11 GHz for the coefficient S_{21} and a band from 10%. In this way, our most optimal results are:

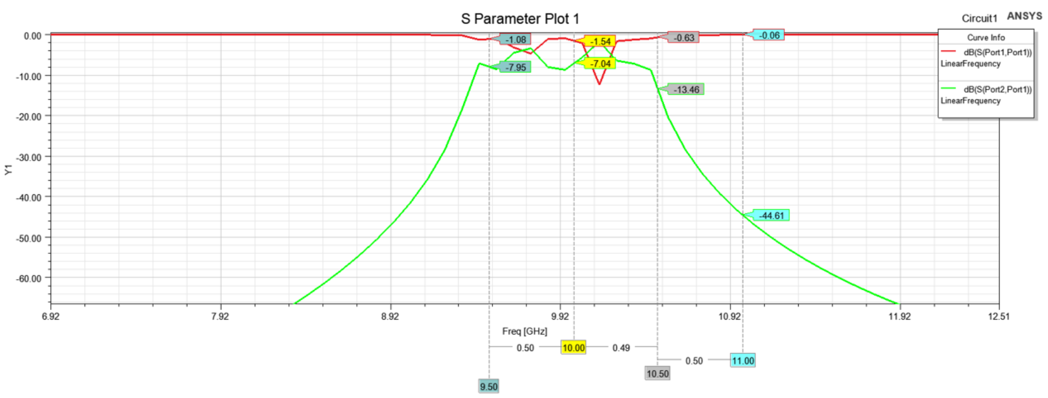

Figure 6: First result - Circuit Simulation.

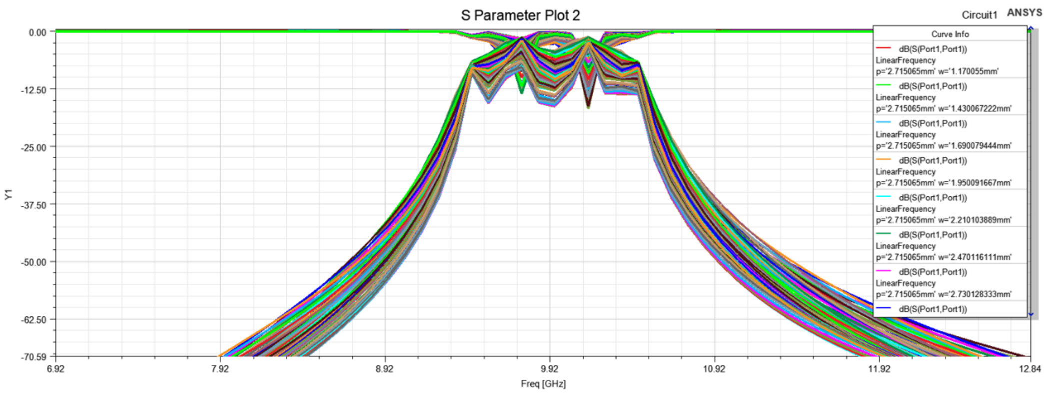

Figure 7: Sweep parameter - Circuit Simulation.

Table 4: Final Values for Band-pass Filter.

Parameter	Value	Parameter	Value	Parameter	Value
W_{Z00}	2.20mm	L_{Z0}	5.00mm		
W_{Z11}	0.55mm	L_{Z11}	6.58mm	S_1	0.20mm
W_{Z12}	0.55mm	L_{Z12}	6.58mm		
W_{Z21}	1.32mm	L_{Z21}	5.33mm	S_2	0.20mm
W_{Z22}	1.32mm	L_{Z22}	5.33mm		
W_{Z31}	2.03mm	L_{Z31}	5.84mm	S_3	0.40mm
W_{Z32}	2.03mm	L_{Z32}	5.84mm		
W_{Z41}	2.56mm	L_{Z41}	4.60mm	S_4	0.40mm
W_{Z42}	2.56mm	L_{Z42}	4.60mm		
W_{Z51}	1.37mm	L_{Z51}	5.88mm	S_5	0.20mm
W_{Z52}	1.37mm	L_{Z52}	5.88mm		
W_{Z01}	2.20mm	L_{Z0}	5.00mm		

3 Simulation

Through the circuit model, the optimal measurements have been found and with that we proceeded to make the 3D model, following the diagram of the fig. 8. With these dimensions, we ensure the operation of the simulation from 9.5 to 10.5 GHz.

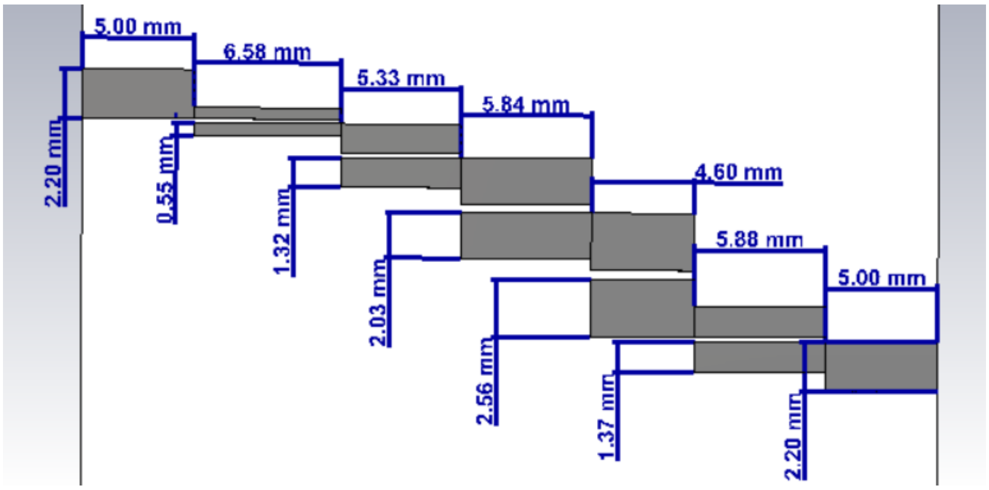

Figure 8: Band-pass Filter Measurements.

A very important procedure, in all types of simulation, is to specify the boundary conditions. For the case studied, the environmental condition is considered in the air, with the device's radiation medium.

4 Results and Discussion

The main parameters to measure the performance of a filter are, the reflection coefficient (S_{11}), which measures return loss and transmission coefficient (S_{12}), which measures insertion loss. An optimal filter has high return loss and low insertion loss. The filter operates around 10GHz and with a bandwidth of 1GHz, this is useful to pass frequencies between 9.5GHz to 10.5GHz (fig. 9). Additionally, the filter has a return loss of 22dB for 11GHz and an insertion loss close to zero. (fig. 10).

An interesting point is in the 3d design, to adjust the measurements and the final result had to eliminate the last couple of coupled lines. In this way, a result much closer to the circuit design was obtained. Possibly the incompatibility between HFSS and CST is great or the optimized measurements require an update.

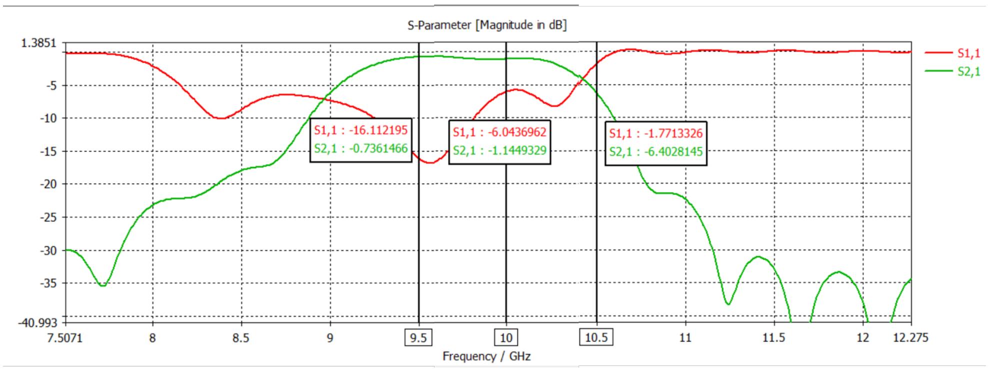

Figure 9: S-parameter with center at 10GHz.

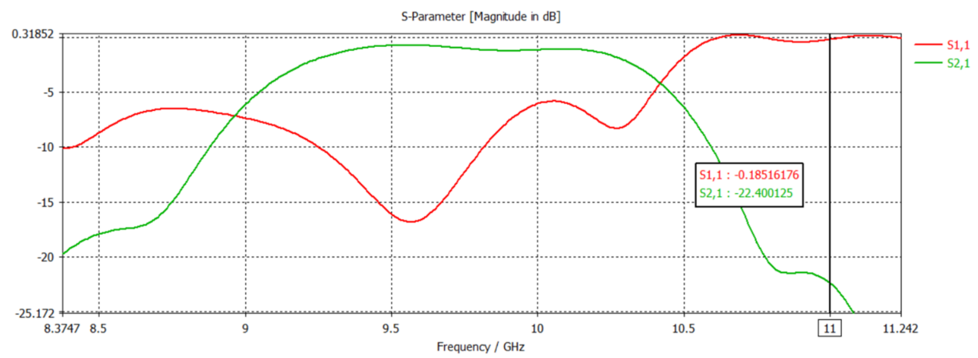

Figure 10: Reflection.

5 Conclusions and Recommendations

In the report presented, the design and simulation of a Band-pass Filter with parallel lines coupled with a working frequency of 10GHz was carried out. The Band-pass Filter is designed using low loss microstripline design theory on a small ROGERS RT-5880 substrate. The results of the simulation of the Band-pass Filter have been obtained using HFSS for the circuitry part and CST for the 3D simulation. The current design can be improved through metaheuristic algorithms and adjusted to meet the requirements.

References

[1] D. M. Pozar, *Microwave engineering.* John wiley & sons, 2011.

[2] A. R. Othman and C. Wasli, "2.4 ghz microstrip bandpass filter," in *The 1st International Conference on Engineering and ICT, Melaka, Malaysia*, 2007.

ROGERS CORPORATION

Data Sheet

RT/duroid® 5870 /5880

High Frequency Laminates

RT/duroid® 5870 and 5880 glass microfiber reinforced PTFE composites are designed for exacting stripline and microstrip circuit applications.

The randomly oriented microfibers result in exceptional dielectric constant uniformity.

The dielectric constant of RT/duroid 5870 and 5880 laminates is uniform from panel to panel and is constant over a wide frequency range.
Its low dissipation factor extends the usefulness of RT/duroid 5870 and 5880 laminates to Ku-band and above.

RT/duroid 5870 and 5880 laminates are easily cut, sheared and machined to shape. They are resistant to all solvents and reagents, hot or cold, normally used in etching printed circuits or in plating edges and holes.

Normally supplied as a laminate with electrodeposited copper of ½ to 2 ounces/ft.^{2} (8 to 70μm) or reverse treated EDC on both sides, RT/duroid 5870 and 5880 composites can also be clad with rolled copper foil for more critical electrical applications. Cladding with aluminum, copper or brass plate may also be specified.

When ordering RT/duroid 5870 and 5880 laminates, it is important to specify dielectric thickness, tolerance, rolled, electrodeposited or reverse treated copper foil, and weight of copper foil required.

Features:

- Lowest electrical loss for reinforced PTFE material
- Low moisture absorption
- Isotropic
- Uniform electrical properties over frequency
- Excellent chemical resistance

Some Typical Applications:

- Commercial Airline Broadband Antennas
- Microstrip and Stripline Circuits
- Millimeter Wave Applications
- Military Radar Systems
- Missile Guidance Systems
- Point to Point Digital Radio Antennas

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PROPERTY	TYPICAL VALUES				DIRECTION	UNITS[3]	CONDITION	TEST METHOD
	RT/duroid 5870		RT/duroid 5880					
[1]Dielectric Constant, ε_r Process	2.33 2.33 ± 0.02 spec.		2.20 2.20 ± 0.02 spec.		Z Z	N/A	C24/23/50 C24/23/50	1 MHz IPC-TM-650 2.5.5.3 10 GHz IPC-TM 2.5.5.5
[4]Dielectric Constant, ε_r Design	2.33		2.20		Z	N/A	8 GHz - 40 GHz	Differential Phase Length Method
Dissipation Factor, tan δ	0.0005 0.0012		0.0004 0.0009		Z Z	N/A	C24/23/50 C24/23/50	1 MHz IPC-TM-650, 2.5.5.3 10 GHz IPC-TM-2.5.5.5
Thermal Coefficient of ε_r	-115		-125		Z	ppm/°C	-50 - 150°C	IPC-TM-650, 2.5.5.5
Volume Resistivity	2 X 10^7		2 X 10^7		Z	Mohm cm	C96/35/90	ASTM D257
Surface Resistivity	2 X 10^7		3 X 10^7		Z	Mohm	C/96/35/90	ASTM D257
Specific Heat	0.96 (0.23)		0.96 (0.23)		N/A	J/g/K (cal/g/C)	N/A	Calculated
Tensile Modulus	Test at 23 °C	Test at 100 °C	Test at 23 °C	Test at 100 °C	N/A	MPa (kpsi)	A	ASTM D638
	1300 (189)	490 (71)	1070 (156)	450 (65)	X			
	1280 (185)	430 (63)	860 (125)	380 (55)	Y			
ultimate stress	50 (7.3)	34 (4.8)	29 (4.2)	20 (2.9)	X			
	42 (6.1)	34 (4.8)	27 (3.9)	18 (2.6)	Y			
ultimate strain	9.8	8.7	6.0	7.2	X	%		
	9.8	8.6	4.9	5.8	Y			
Compressive Modulus	1210 (176)	680 (99)	710 (103)	500 (73)	X	MPa (kpsi)	A	ASTM D695
	1360 (198)	860 (125)	710 (103)	500 (73)	Y			
	803 (120)	520 (76)	940 (136)	670 (97)	Z			
ultimate stress	30 (4.4)	23 (3.4)	27 (3.9)	22 (3.2)	X			
	37 (5.3)	25 (3.7)	29 (5.3)	21 (3.1)	Y			
	54 (7.8)	37 (5.3)	52 (7.5)	43 (6.3)	Z			
ultimate strain	4.0	4.3	8.5	8.4	X	%		
	3.3	3.3	7.7	7.8	Y			
	8.7	8.5	12.5	17.6	Z			
Moisture Absorption	0.02		0.02		N/A	%	.062" (1.6mm) D48/50	ASTM D570
Thermal Conductivity	0.22		0.20		Z	W/m/K	80°C	ASTM C518
Coefficient of Thermal Expansion	22 28 173		31 48 237		X Y Z	ppm/°C	0-100°C	IPC-TM-650, 2.4.41
Td	500		500		N/A	°C TGA	N/A	ASTM D3850
Density	2.2		2.2		N/A	gm/cm^3	N/A	ASTM D792
Copper Peel	27.2 (4.8)		31.2 (5.5)		N/A	pli (N/mm)	1 oz (35mm) EDC foil after solder float	IPC-TM-650 2.4.8
Flammability	V-0		V-0		N/A	N/A	N/A	UL94
Lead-Free Process Compatible	Yes		Yes		N/A	N/A	N/A	N/A

[1] Specification values are measured per IPC-TM-650, method 2.5.5.5 @ ~10GHz, 23°C. Testing based on 1 oz. electrodeposited copper foil. ε_r values and tolerance reported by IPC-TM-650 method 2.5.5.5 are the basis for quality acceptance, but for some products these values may be incorrect for design purposes, especially microstrip designs. We recommend that prototype boards for new designs be verified for desired electrical performance.
[2] Typical values should not be used for specification limits, except where noted.
[3] SI unit given first with other frequently used units in parentheses.
[4] The design Dk is an average number from several different tested lots of material and on the most common thickness/s. If more detailed information is required, please contact Rogers Corporation. Refer to Rogers' technical paper "Dielectric Properties of High Frequency Materials" available at http://www.rogerscorp.com.

Standard Thickness	Standard Panel Size	Standard Copper Cladding	Non-Standard Copper Cladding
0.005" (0.127mm) 0.031" (0.787mm) 0.010" (0.254mm) 0.062" (1.575mm) 0.015" (0.381mm) 0.125" (3.175mm) 0.020" (0.508mm) Non-standard thicknesses are available	18" X 12" (457 X 305mm) 18" X 24" (457 X 610mm) Non-standard sizes are available up to 18" X 48" (457 X 1219 mm)	½ oz. (18µm) and 1 oz. (35µm) electrodeposited and rolled copper foil	¼ oz. (9 µm) electrodeposited copper foil ½ oz. (18µm), 1 oz. (35µm) and 2 oz. (70µm) reverse treat copper foil 2 oz. (70µm) electrodeposited and rolled copper foil
		Thick metal claddings may be available based on dielectric and plate thickness. Contact customer service for more information on available non-standard and custom thicknesses, claddings and panel sizes	

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