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

Design and Simulation of a Dual Branchline Hybrid Coupler of 10 GHz

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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.

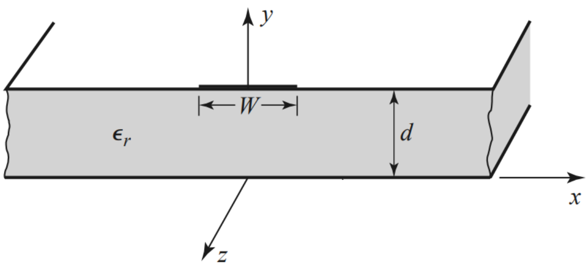


Figure 1: Microstrip Line. [1]

Dual Branch Line Hybrid Couple consists of three transmission lines alternately connected by sections with length $\lambda/4$ and branches in series. Analysis of this structure leads to a class of directional couplers of which parallel transmission line and band slot types can be considered special cases. From the available design data, a series of 3.8 dB-band slot couplers can be constructed in the Coupling-band with performance close to what is expected [2]. As you can see in the fig. 2.

2 Design

The geometry of a parallel coupled line directional coupler is as shown in fig. 1. As described in the introductory section, we assume that the Zo port

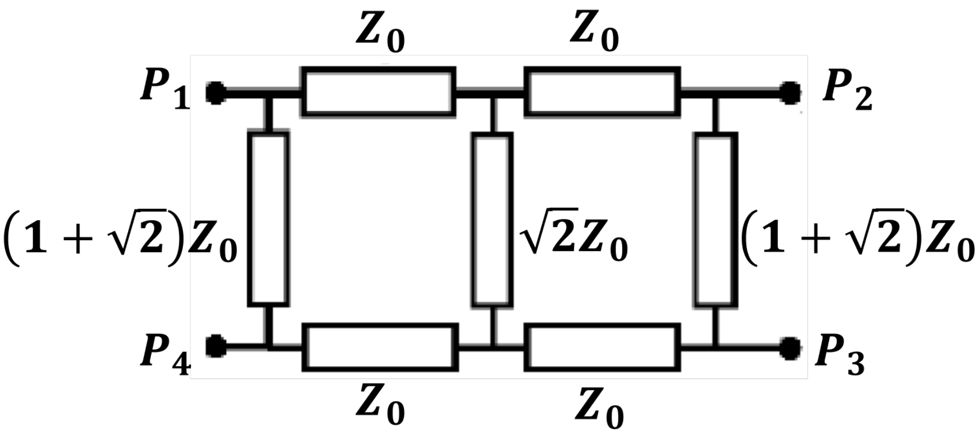


Figure 2: Dual Quadrature Branch Line Couple [1]

impedance, coupling, and operating frequency are known parameters at the beginning of the design. Initial specifications for the designed directional couple are shown in the table 1. Based on the known parameters, the proposed procedure has the following steps.

Table 1: Directional coupler design specifications.

Parameter	Symbol	Value
Coupling	C	3.8dB
Centre frequency	f	10GHz
Substrate permitivity (Rogers-RO4350B)	ϵ_r	3.66
Substrate thickness	h	0.508mm
Coupler thickness	t	0.0175mm
Impedance	Z_0	50Ω

2.1 Find physical width and length

We start with the equations of a microstrip to be able to have the initial parameters and later optimize it. We use the data of the characteristic impedance, the dielectric permittivity constant of the substrate and the given coupling. We use the equations provided by Pozar to design the microstrip. [1] The eq. (1) refers to the effective permittivity from the relative permittivity and a ratio of the length to width of the microstrip.

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + 10\frac{h}{W}}}\right) \tag{1}$$

The ratio between the length and width of the microstrip maintains conditions, as can be seen in the eqs. (2) and (3).

For $W/h \leq 1$

$$Z_0 = \frac{60}{\sqrt{\epsilon_r}} ln\left(\frac{8h}{W} + \frac{W}{4h}\right) \tag{2}$$

For $W/h \geq 1$

$$Z_0 = \frac{120\pi}{\sqrt{\epsilon_r}[\frac{W}{h} + 1.393 + 0.667 ln(\frac{W}{h} + 1.444)]} \tag{3}$$

We begin by finding a ratio between the length and width of the microstrip for Z_0. For this reason we recreate a python file in COLAB, we form the inhomogeneous equation and we find the relation $x = W/h$.

```
import numpy as np
from sympy import *
#x=W/h
x = symbols('x')
f1 = Z0-(60/((er+1)/2+((er-1)/2)*(1+12*1/x)**(-0.5))**0.5)*log
    (8/x+x/4)
fderivative1 = f1.diff(x)
fderivative1.evalf(subs= {x:1})
#initial value
xn = 3
for i in range(20):
    #Newton-Raphson
    xn = xn - np.float(f1.evalf(subs= {x:xn})) / np.float(
    fderivative1.evalf(subs= {x:xn}))
    print(f'The {i+1} iteration xn is {xn:.2} and f(xn) is {np.
    float(f1.evalf(subs= {x:xn})):.2}')
```

Listing 1: Newton-Raphson

For the given data and the calculations performed, we have the following proportions: For $Z_0 = 50\Omega$ con $\frac{W_1}{h} \geq 1$

$$\frac{W_1}{h} = 2.3$$

For $\sqrt{2}Z_0 = 70.71\Omega$ con $\frac{W_2}{h} \leq 1$

$$\frac{W_2}{h} = 0.016$$

For $(1+\sqrt{2})Z_0 = 120.71\Omega$ con $\frac{W_3}{h} \leq 1$

$$\frac{W_3}{h} = 0.093$$

Using these proportions and the information in the datasheet, we take 0.508mm as the substrate thickness. We proceed with the calculations of the physical lengths per line, so we carry out other codes to calculate what we are looking for.

From eq. (1),

```
def fun_eff(W,er,h):
  eff=(er+1)/2+((er-1)/2)*(1+12*h/W)**(-0.5)
  print("eff value is: ",eff)
  return eff
```

Listing 2: Effectivity Permitivity

We calculate the wavelength for each line, according to:

$$\lambda_g = \frac{300}{f_{GHz}\sqrt{\epsilon_{ff}}} \tag{4}$$

and we create the function:

```
def fun_plegth(eff,f):
  lambdax = 300/(f*np.sqrt(eff))
  lent=lambdax/4
  print("lamnda value is: ",lambdax)
  print("lent value is: ",lent)

  return lent,lambdax
```

Listing 3: Wavelength

Finally, the length for each line will depend on Z_0 and a quarter of the wavelength:

$$L_{Z_0} = \frac{\lambda_{Z_0}}{4} \tag{5}$$

With what we have the initial values, calculated through Python, for our simulation.

Table 2: Initial Values for Hybrid Coupled.

Parameter	Value
Frequency (f)	10GHz
Substrate thickness (h)	0.508mm
Dielectric Permitivity (ϵ_r)	3.66
Impedance (Z_0)	50Ω
Width (W_1)	1.1684mm
Length (L_1)	4.432214mm
Width (W_2)	0.008128mm
Length (L_2)	4.863028mm
Width (W_3)	0.047244mm
Length (L_3)	4.794869mm

2.2 Circuit Model

The goal of the circuit simulation is to determine the dimensions of the branchline directional couple that will provide the optimal coupling coefficient and insulation values. 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. Using Ansys Electronic Desktop (AED), we assembled the circuit with the calculated dimensions, as shown in the fig. 3.

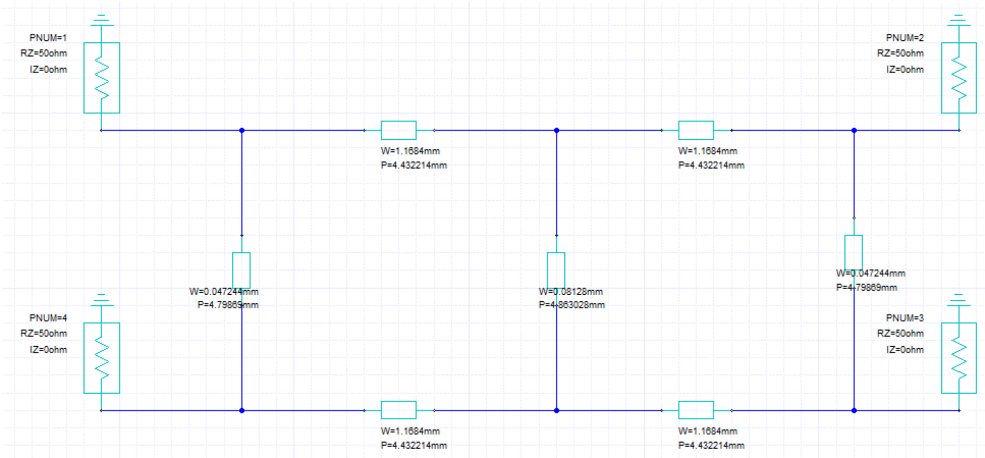


Figure 3: Circuit Simulation.

The first circuit results in a 10GHz operation, as seen in the fig. 4, but one must seek to optimize these values to meet the requirements.

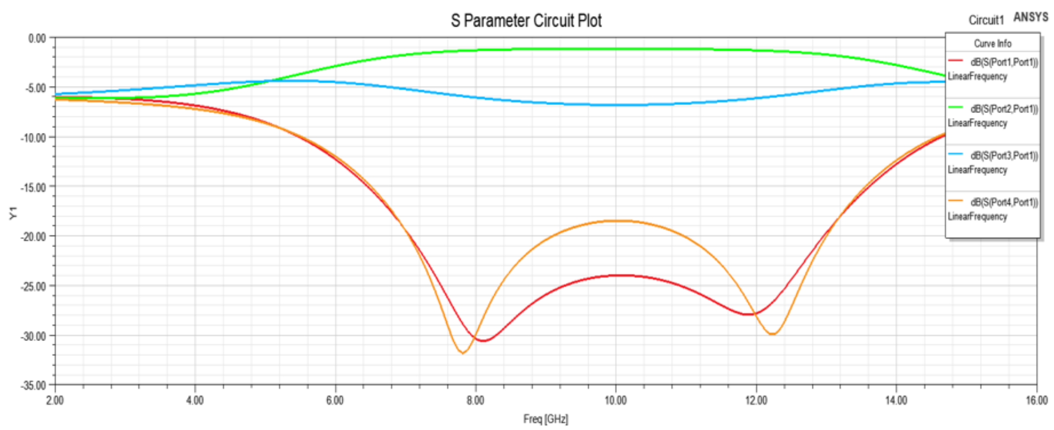


Figure 4: First result - Circuit Simulation.

We update the parameters within an acceptable range of ±10% and independently simulate each variable to find the best values that optimize device performance at 10GHz. (fig. 5)

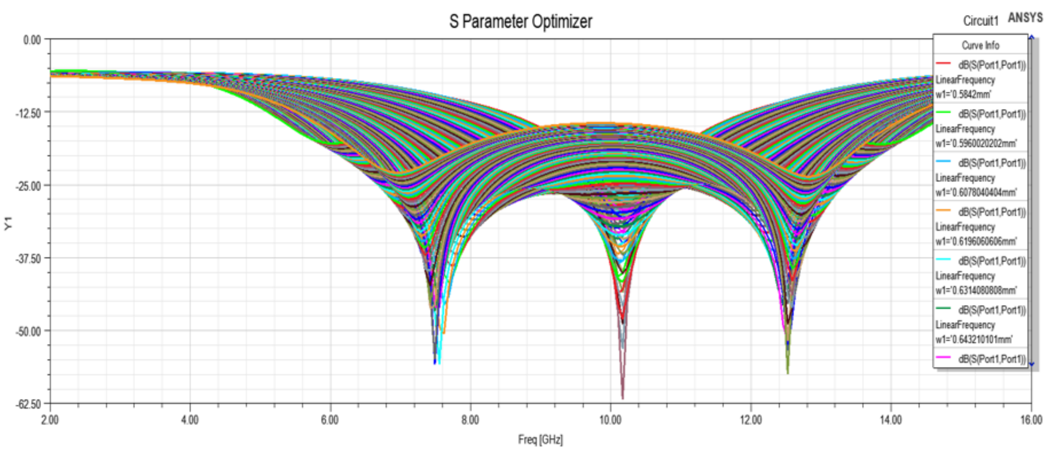


Figure 5: Sweep parameter - Circuit Simulation.

The graphs of the parameter S in the fig. 5 show the results of the directional coupler of the band line on the simulated band line in AED. Configured as shown in fig. 4, 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 goal was to get 3.8 dB for the coupling coefficient and -20 dB for the reflection. In this way, our most optimal results are:

Table 3: Final Values for Hybrid Coupled.

Parameter	Value
Frequency (f)	10GHz
Substrate thickness (h)	0.508mm
Coupler thickness (t)	0.0175mm
Dielectric Permitivity (ϵ_r)	3.66
Impedance (Z_0)	50Ω
Width (W_1)	1.112mm
Length (L_1)	4.7425mm
Width (W_2)	0.35mm
Length (L_2)	3.998mm
Width (W_3)	0.155mm
Length (L_3)	3.998mm

3 Simulation

Through the circuit model, the optimal measurements have been found and with that we proceeded to make the three-dimensional model, following the scheme of fig. 6. With these dimensions, we ensure the operation of the simulation from 9 to 11 GHz. Port 1 is the input, port 3 is coupled and the isolated port is port 4.

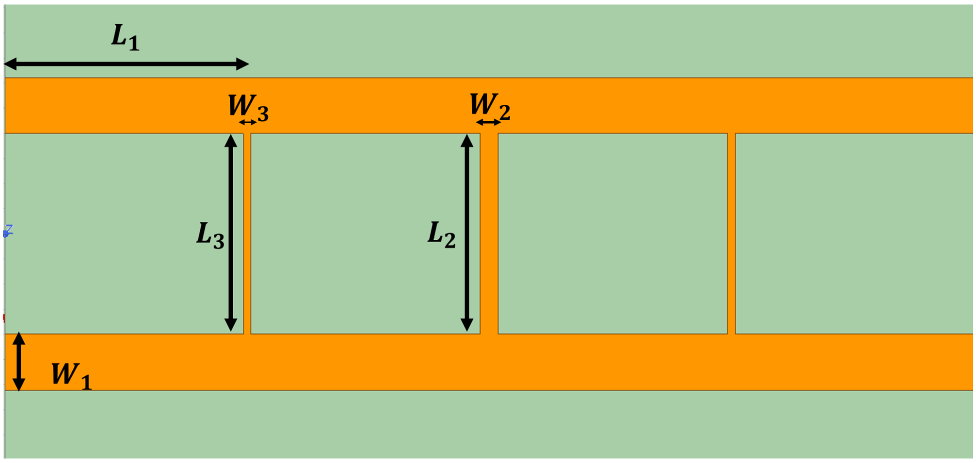


Figure 6: Dual Hybrid Coupled Measurements.

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

Using adaptive meshing, you establish an initial mesh, resolve the fields, and then mesh again based on where the fields have a high gradient. Each re-meshing step is called an "adaptive pass". In each step, the dispersion parameters are evaluated in each port and compared with the previous step, specifically by Max Delta (Mag S), which is the difference of the magnitudes of two consecutive S matrices, $Max(MagS_{ij}^{N} - MagS_{ij}^{N-1})$. With this we ensure convergence in the simulation. fig. 7

The Dual Quadrature Branchline has four ports. Port 1 is the input, it has a reflection in the whole band (9-11GHz) less than -20dB fig. 8. Port 2 is where the energy flows out, and with loss of energy less than 3.8dB fig. 9. Port 3 is the mated port where equal power is polarized 90 degrees. This can be shown in fig. 11 where the phase difference at 10 GHz is 89.53^{o}. Port 4 is isolated, no power flows through it. Here the return loss must be less than -20dB fig. 10.

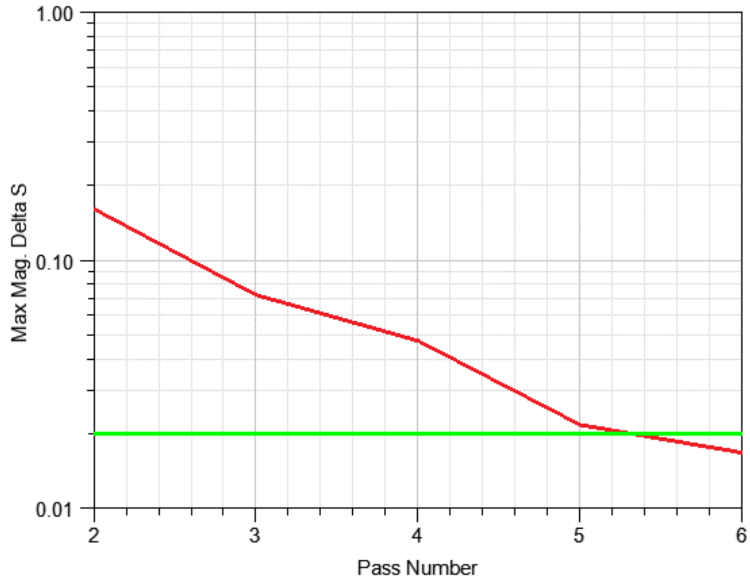


Figure 7: Convergence.

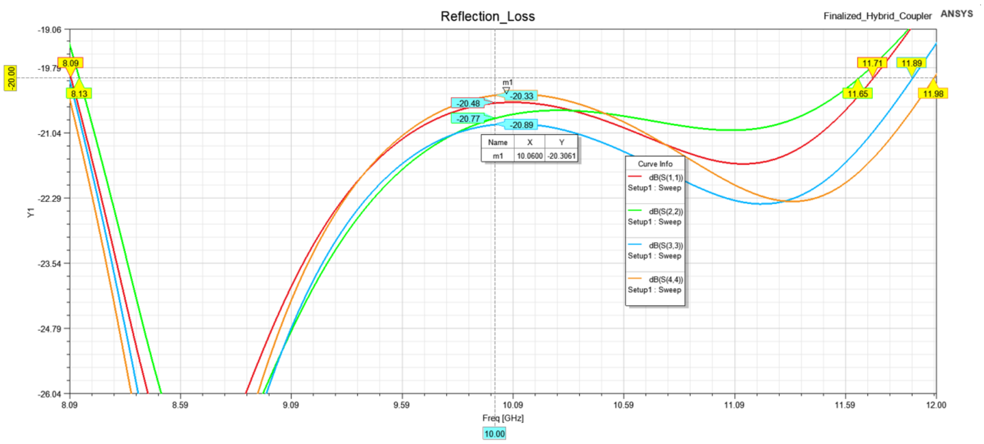


Figure 8: Reflection.

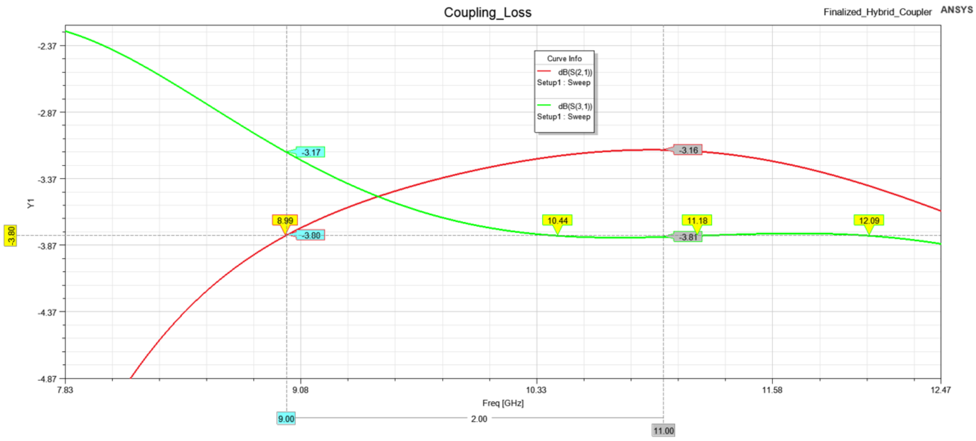


Figure 9: Coupling.

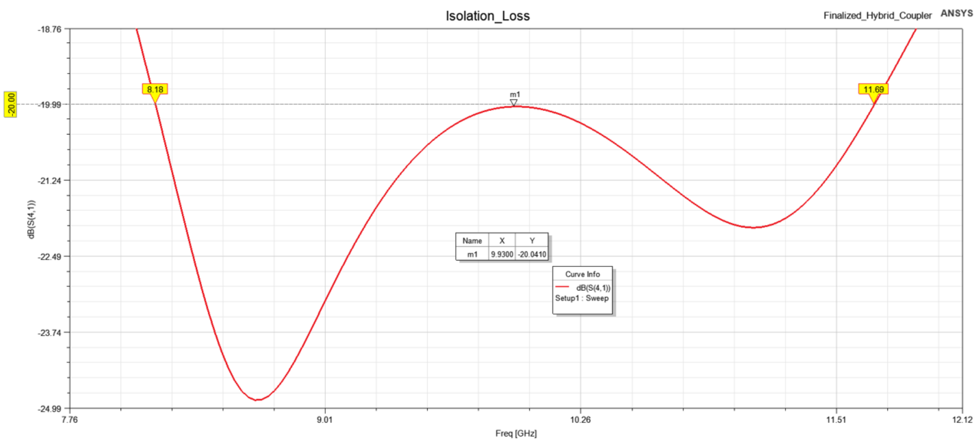


Figure 10: Isolation.

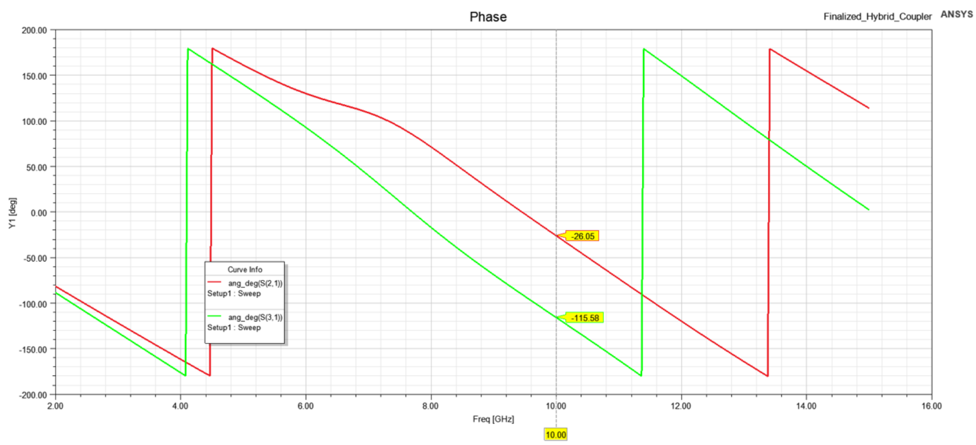


Figure 11: Phase.

5 Conclusions and Recommendations

In the report presented, the design and simulation of a Dual Quadrature BranchLine coupled with a working frequency of 10GHz was carried out. A Dual quadrature microstrip line was designed with a Rogers-RO4350B substrate. Microstripline design theory was used to find and optimize design values that meet specific requirements, such as physical length, wavelength, directional coupler width, effective permittivity, and width of the substrate that was unique to the datasheet. 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] B. Schiek, "Hybrid branchline couplers-a useful new class of directional couplers," *IEEE Transactions on Microwave Theory and Techniques*, vol. 22, no. 10, pp. 864–869, 1974.

ROGERS CORPORATION

Data Sheet

RO4000® Series
High Frequency Circuit Materials

RO4000® hydrocarbon ceramic laminates are designed to offer superior high frequency performance and low cost circuit fabrication. The result is a low loss material which can be fabricated using standard epoxy/glass (FR-4) processes offered at competitive prices.

The selection of laminates typically available to designers is significantly reduced once operational frequencies increase to 500 MHz and above. RO4000 material possesses the properties needed by designers of RF microwave circuits and matching networks and controlled impedance transmission lines. Low dielectric loss allows RO4000 series material to be used in many applications where higher operating frequencies limit the use of conventional circuit board laminates. The temperature coefficient of dielectric constant is among the lowest of any circuit board material (Chart 1), and the dielectric constant is stable over a broad frequency range (Chart 2). For reduced insertion loss, LoPro® foil is available (Chart 3). This makes it an ideal substrate for broadband applications.

RO4000 material's thermal coefficient of expansion (CTE) provides several key benefits to the circuit designer. The expansion coefficient of RO4000 material is similar to that of copper which allows the material to exhibit excellent dimensional stability, a property needed for mixed dielectric multi-layer boards constructions. The low Z-axis CTE of RO4000 laminates provides reliable plated through-hole quality, even in severe thermal shock applications. RO4000 series material has a Tg of >280°C (536°F) so its expansion characteristics remain stable over the entire range of circuit processing temperatures.

RO4000 series laminates can easily be fabricated into printed circuit boards using standard FR-4 circuit board processing techniques. Unlike PTFE based high performance materials, RO4000 series laminates do not require specialized via preparation processes such as sodium etch. This material is a rigid, thermoset laminate that is capable of being processed by automated handling systems and scrubbing equipment used for copper surface preparation.

RO4003C™ laminates are currently offered in various configurations utilizing both 1080 and 1674 glass fabric styles, with all configurations meeting the same laminate electrical performance specification. Specifically designed as a drop-in replacement for the RO4003C™ material, RO4350B™ laminates utilize RoHS compliant flame-retardant technology for applications requiring UL 94V-0 certification. These materials conform to the requirements of IPC-4103, slash sheet /10 for RO4003C, see note #1 for RO4350B slash sheet determination.

Features and Benefits:

RO4000 materials are reinforced hydrocarbon/ceramic laminates - not PTFE
- Designed for performance sensitive, high volume applications

Low dielectric tolerance and low loss
- Excellent electrical performance
- Allows applications with higher operating frequencies
- Ideal for broadband applications

Stable electrical properties vs. frequency
- Controlled impedance transmission lines
- Repeatable design of filters

Low thermal coefficient of dielectric constant
- Excellent dimensional stability

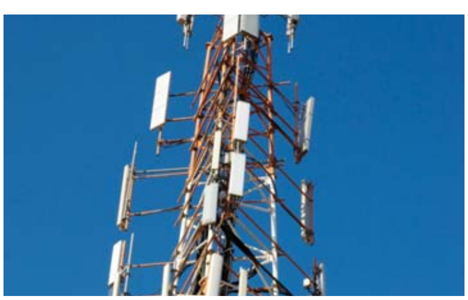
Low Z-axis expansion
- Reliable plated through holes

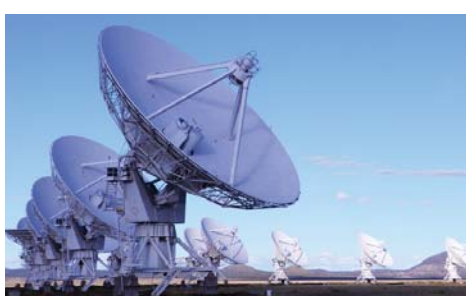
Low in-plane expansion coefficient
- Remains stable over an entire range of circuit processing temperatures

Volume manufacturing process
- RO4000 laminates can be fabricated using standard glass epoxy processes
- Competitively priced

CAF resistant

Some Typical Applications:
- Cellular Base Station Antennas and Power Amplifiers
- RF Identification Tags
- Automotive Radar and Sensors
- LNB's for Direct Broadcast Satellites





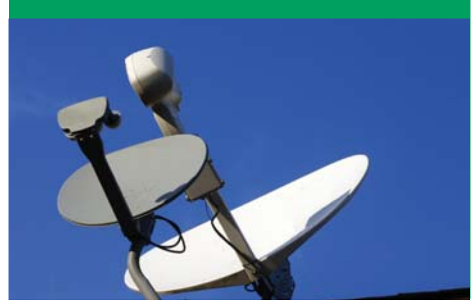


Chart 1: RO4000 Series Materials Dielectric Constant vs. Temperature

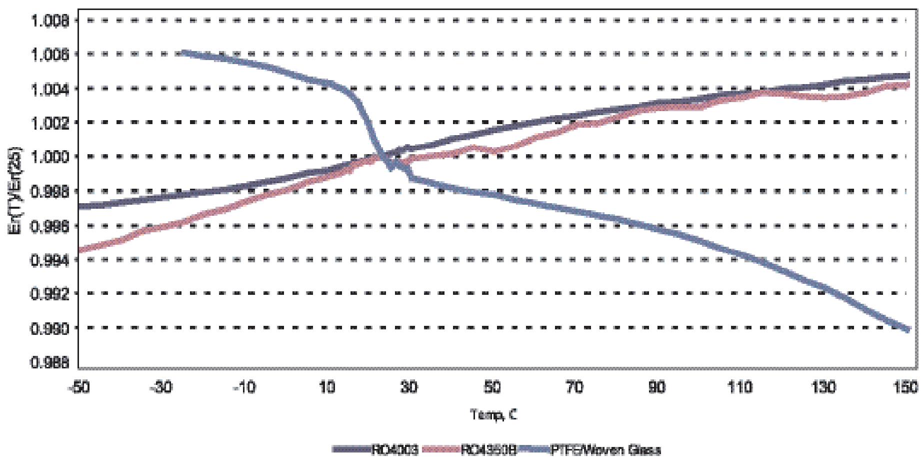


Chart 2: RO4000 Series Materials Dielectric Constant vs. Frequency

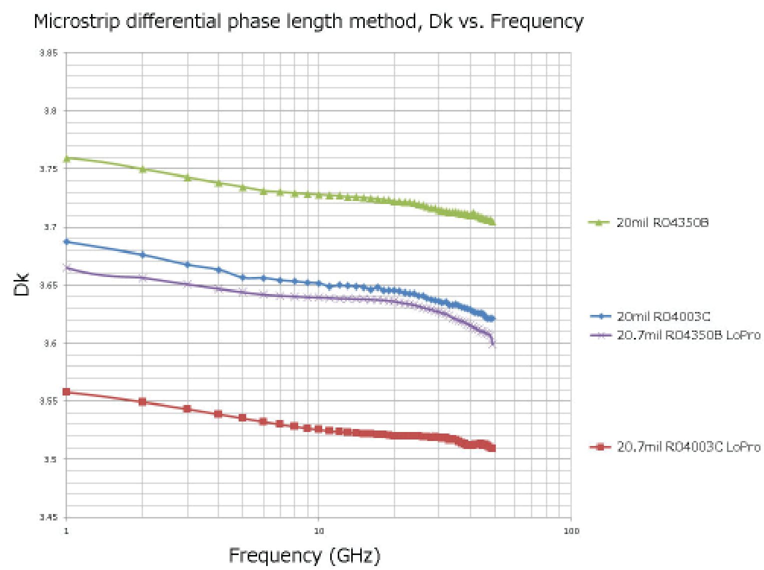
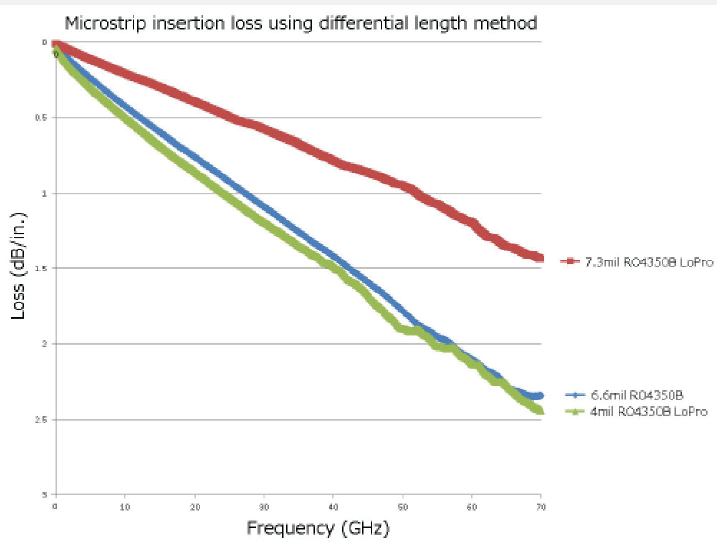


Chart 3: Microstrip Insertion Loss



Advanced Connectivity Solutions
100 S. Roosevelt Avenue, Chandler, AZ 85226
Tel: 480-961-1382 Fax: 480-961-4533 www.rogerscorp.com

Property	Typical Value		Direction	Units	Condition	Test Method
	RO4003C	RO4350B				
Dielectric Constant, ε_r Process	3.38 ± 0.05	(1) 3.48 ± 0.05	Z	--	10 GHz/23°C	IPC-TM-650 2.5.5.5 Clamped Stripline
(2) Dielectric Constant, ε_r Design	3.55	3.66	Z	--	8 to 40 GHz	Differential Phase Length Method
Dissipation Factor tan, δ	0.0027 0.0021	0.0037 0.0031	Z	--	10 GHz/23°C 2.5 GHz/23°C	IPC-TM-650 2.5.5.5
Thermal Coefficient of ε_r	+40	+50	Z	ppm/°C	-50°C to 150°C	IPC-TM-650 2.5.5.5
Volume Resistivity	1.7 X 10^{10}	1.2 X 10^{10}		MΩ•cm	COND A	IPC-TM-650 2.5.17.1
Surface Resistivity	4.2 X 10^{9}	5.7 X 10^{9}		MΩ	COND A	IPC-TM-650 2.5.17.1
Electrical Strength	31.2 (780)	31.2 (780)	Z	KV/mm (V/mil)	0.51mm (0.020")	IPC-TM-650 2.5.6.2
Tensile Modulus	19,650 (2,850) 19,450 (2,821)	16,767 (2,432) 14,153, (2,053)	X Y	MPa (ksi)	RT	ASTM D638
Tensile Strength	139 (20.2) 100 (14.5)	203 (29.5) 130 (18.9)	X Y	MPa (ksi)	RT	ASTM D638
Flexural Strength	276 (40)	255 (37)		MPa (kpsi)		IPC-TM-650 2.4.4
Dimensional Stability	<0.3	<0.5	X,Y	mm/m (mils/inch)	after etch +E2/150°C	IPC-TM-650 2.4.39A
Coefficient of Thermal Expansion	11 14 46	10 12 32	X Y Z	ppm/°C	-55 to 288°C	IPC-TM-650 2.4.41
Tg	>280	>280		°C TMA	A	IPC-TM-650 2.4.24.3
Td	425	390		°C TGA		ASTM D3850
Thermal Conductivity	0.71	0.69		W/m/°K	80°C	ASTM C518
Moisture Absorption	0.06	0.06		%	48 hrs immersion 0.060" sample Temperature 50°C	ASTM D570
Density	1.79	1.86		gm/cm^3	23°C	ASTM D792
Copper Peel Strength	1.05 (6.0)	0.88 (5.0)		N/mm (pli)	after solder float 1 oz. EDC Foil	IPC-TM-650 2.4.8
Flammability	N/A	(3)V-0				UL 94
Lead-Free Process Compatible	Yes	Yes				

NOTES:
(1) RO4350B 4 mil laminates have a process Dk of 3.33 ± 0.05 and are in conformance with IPC-4103A/240. All other RO4350B laminate thicknesses are /11 and /240 compliant.
(2) 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 or refer to Rogers' technical papers in the Rogers Technology Support Hub available at http://www.rogerscorp.com.
(3) RO4350B LoPro® laminates do not share the same UL designation as standard RO4350B laminates. A separate UL qualification may be necessary.

Typical values are a representation of an average value for the population of the property. For specification values contact Rogers Corporation.

RO4000 LoPro laminate uses a modified version of the RO4000 resin system to bond reverse treated foil. Values shown above are RO4000 laminates without the addition of the LoPro resin. For double-sided boards, the LoPro foil results in a thickness increase of approximately 0.0007" (18μm) and the Dk is approximately 2.4. The Dk decreases by about 0.1 as the core thickness decreases from 0.020" to 0.004.

Prolonged exposure in an oxidative environment may cause changes to the dielectric properties of hydrocarbon based materials. The rate of change increases at higher temperatures and is highly dependent on the circuit design. Although Rogers' high frequency materials have been used successfully in innumerable applications and reports of oxidation resulting in performance problems are extremely rare, Rogers recommends that the customer evaluate each material and design combination to determine fitness for use over the entire life of the end product.

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Standard Thickness	Standard Panel Size	Standard Copper Cladding
RO4003C: 0.008" (0.203mm), 0.012 (0.305mm), 0.016"(0.406mm), 0.020" (0.508mm) 0.032" (0.813mm), 0.060" (1.524mm) RO4350B: *0.004" (0.101mm), 0.0066" (0.168mm) 0.010" (0.254mm), 0.0133" (0.338mm), 0.0166" (0.422mm), 0.020"(0.508mm), 0.030" (0.762mm), 0.060"(1.524mm) Note: Material clad with LoPro foil add 0.0007" (0.018mm) to dielectric thickness	12" X 18" (305 X457 mm) 24" X 18" (610 X 457 mm) 24" X 36" (610 X 915 mm) 48" X 36" (1.224 m X 915 mm) *0. 004" (0.101mm) material is not available in panel sizes larger than 24"x18" (610 X 457mm)	½ oz. (17μm) electrodeposited copper foil (.5ED/.5ED) 1 oz. (35μm) electrodeposited copper foil (1ED/1ED) 2 oz. (70μm) electrodeposited copper foil (2ED/2ED) **PIM Sensitive Applications:** ½ oz (17μm) LoPro Reverse Treated EDC (.5TC/.5TC) 1 oz (35μm) LoPro Reverse Treated EDC (1TC/1TC)

The information in this data sheet is intended to assist you in designing with Rogers' circuit materials. It is not intended to and does not create any warranties express or implied, including any warranty of merchantability or fitness for a particular purpose or that the results shown on this data sheet will be achieved by a user for a particular purpose. The user should determine the suitability of Rogers' circuit materials for each application.

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