EMZ 310

Practical report 1 & 2

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Summary

Micro strip transmission line design depends on the electric parameters of the dielectric material used, namely the relative dielectric constant (εr) and tangent losses (tanδ). In the case of less expensive dielectric materials, such as FR4, these values can vary significantly. This practical study investigates methods of using simulation programs, in this case Sonnet_lite, to determine these parameters for a specific batch of dielectric material. It also investigates how such programs can be used to simplify the design process for impedance matching networks for micro strip transmission lines and improve the accuracy of such designs. In conclusion; this allows the use of less expensive substrates to realize circuits where great accuracy is required, reducing cost and improving competitiveness.

Table of contents

Introduction 4

Problem Statement 4

Problem Formulation 4

Background 4

Transmission Coefficient 4

Quarter Wave Resonant Circuit 5

Stub Impedance Matching 5

Design and Implementation 6

Approach 6

Detailed Design and Implementation 6

Experiment 1 6

Experiment 2 7

Results and Discussion of Results 8

Experiment 1 8

Experiment 2 11

Conclusion 15

References 16

Appendix A : Smith chart for calculations 17

Introduction

Problem Statement

1. Micro strip circuit designs depend on the electric parameters for the dielectric material used. The most commonly used dielectric material, FR4, is usually estimated to have the electric parameters relative dielectric constant (ε_r) is 4.4 and tangent losses ($\tan\delta$) is 0.001. In reality this value varies significantly from one batch to another. The problem is to accurately determine the electric parameters of for a particular batch of FR4. (Odendaal, 2011:13)

2. Once accurate values for the electric parameters have been determined a micro strip circuit could be designed to implement board level transmission lines. When the load driven by the transmission line is not matched to the line a matching network will be required, to prevent signal deterioration and to give maximum power transfer. This is often achieved by using an open or closed circuit stub. The problem is to accurately design such a circuit. One also needs to design the micro strip transmission line to have a specific characteristic impendence.

Problem Formulation

1. Accurately determine the electric parameters of dielectric material FR4 of a particular batch.

2. Design a micro strip transmission line to have the standard characteristic impedance of 50Ω, and accurately design a matching network by use of an open circuit stub.

Background

Transmission Coefficient

The transmission coefficient is a measure of how much of the incoming wave at port 1 is transmitted to the output port 2. It is usually given in on a logarithmic decibel scale and can be easily converted to a linear scale using the following relation:

$S_{log} = 20\log S_{lin}$ [dB]

Example: If S_{12} = -30.5 dB then only 0.03 (3%) of the incoming wave is transmitted to the output port 2. (Odendaal, 2011:13)

Quarter Wave Resonant Circuit

As shown in Fig.1 the parallel stub is an open circuit. At 1 = $\lambda_g/4$ the circuit becomes an effective short circuit that causes a mismatch. This blocks most of the signal from passing from port 1 to port 2. The wavelength depends on the relative dielectric constant (ε_r) by the following relationship

$$\lambda_g = \frac{\lambda_o}{\sqrt{\varepsilon_{eff}}}$$

When

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \frac{1}{\sqrt{1 + 12\frac{h}{W}}}$$

This is true for a micro strip transmission line. (Odendaal, 2011:13)

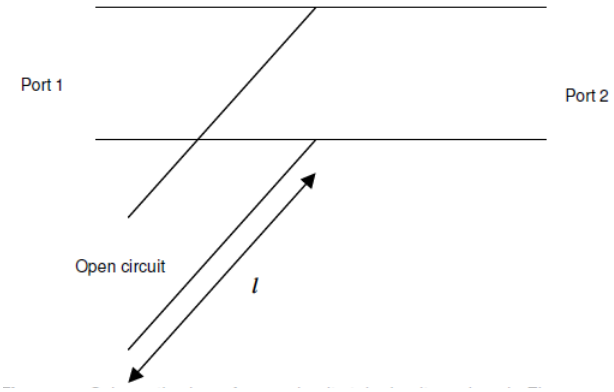


Fig.1

Stub Impedance Matching

A transmission line and termination point is matched when the impedance of the termination load and the characteristic impedance of the line is the same. Due to the nature of real circuits this is usually not the case. To match the line one solution is to add additional impedance in parallel to the load impedance to reduce ohmic losses we move along the transmission line towards the generator until a point is reached where the resistive component of the load impedance and the characteristic impedance is matched. At this point we only have to add a purely reactive component. This component can be realized by a capacitor, inductor, open circuit stub or closed circuit stub. (Ulaby, Michielsen & Ravaioli, 2010:114)

Design and Implementation

Approach

1. An actual circuit, based on theoretical design, was manufactured and tested. The results obtained where then compared to results obtained from a simulation of the same design in Sonnet_Lite to determine the actual values of the electric parameters of FR4, namely relative dielectric constant (ε_r) and tangent losses (tanδ).

2. A theoretical design of an impedance matching circuit was designed and implemented in a simulation in Sonnet_Lite. Minor adjustments where made to the design to achieve the desired results.

Note: all simulation was done in Sonnet_Lite

Detailed Design and Implementation

Experiment 1

To determine the real electric parameters of a specific batch of FR4 two circuits where designed: a quarter wave resonant circuit to determine εr and a simple straight transmission line to determine tangent losses (tanδ).

The quarter wave resonant circuit was designed to have a resonant point at 1.8 GHz and would thus block most of the transmitted signal at this frequency. This circuit was designed to have the dimensions shown in fig.2. The circuit was then tested the transmission coefficient observed. The results where compared to the results from a simulation. A comparison of the frequency at which the resonant point was found was made. The εr value in the simulation was adjusted by trail and error until the simulation results where as close as possible to the actual results. This value was then taken as the actual εr.

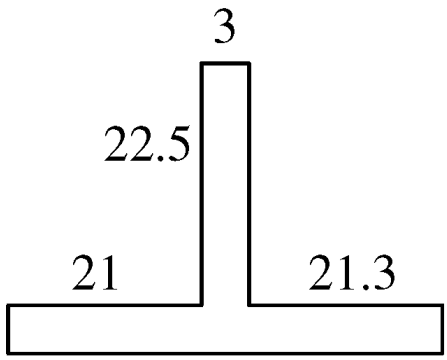


Fig. 2

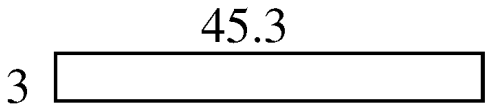


Fig. 3

This strait transmission circuit was designed to have the dimensions shown in fig.3. The εr value obtained was then applied to the strait transmission line

simulation. The actual results obtained are compared to the simulation results. A comparison of the transmission coefficient at 1.8GHZ was made. The tanδ in the simulation was adjusted by trail and error until the simulated losses experienced at 1.8 GHz matched the actual valve as close as possible. (Odendaal, 2011:13)

Experiment 2

A matching network was designed based on theoretical calculations to match a 50 Ω transmission line to a termination impedance of 25 + j8.33 Ω at an operation frequency of 1GHz. The complete calculation below where made with the aid of a smith chart attached in appendix A. (Odendaal, 2011:13)

$Z = 50\Omega$
$ZL = 25 + j8.33$

Normalize the impedance to 50 Ω

z_L = (25 + j8.33)/50
= 0.5 + j0.16666

To design a parallel open circuit stub it is easier to work with the normalized admittance (verified using smith chart).

y_L = 1/z
=1/ (1.8+j0.6)

The position to insert the stub is found using the smith chart by moving towards the generator along the SWR circle until the position where the normalized resistance is equal to one.

l = 0.347λ -0.284λ =0.063λ
To find to wavelength the formula $\lambda = c/ (\text{sqrt } (\varepsilon_r)*f)$

λ = (2.998*10^8)/ (sqrt (3.3)*1*10^9)
=0.165m

l = 0.063*0.165
=10.40 mm

Z_l =1 - j0.825 (From smith chart)

The required reactance of the stub impedance is then j0.825 the length is read off the smith chart

s = 0.109λ
=0.109*0.165
=17.985 mm

Before the actual dimensions of the micro strip transmission line can be determined we need to determine the width of the transmission line that gives it a characteristic impedance of 50 Ω. This was done by simulating the transmission line, measuring the VSWR and input impedance of a simple straight transmission line with an input and output termination of 50 Ω. If the desired characteristic impedance of 50 ohms had been achieved the input impedance at the start of the line would be 5 Ω 0 and the voltage standing wave ratio would be one. The width of the line is adjusted by trail and error until the best possible match was achieved.

The theoretical design was then implemented in a simulation and the small adjustments made until the desired results had been achieved, that is a voltage standing wave ratio of 1 at 1 GHz. The bandwidth where the VSWR is smaller than 1.5 was then be graphically determined.

Results and Discussion of Results

Experiment 1

The network analyzer produced the graph of transmission coefficient (measured in decibels) as a function of frequency, as shown in fig.4 (Odendaal, 2011:13), for the actual quarter wave resonant circuit compared to the simulated result for the expected value of FR4 in fig. 5. Table 1 below summarizes the steps taken to adjust the simulated ε_r value to match the actual resonant point. The actual ε_r value is determined to be 4.23. Fig.6 shows the simulated graph with this actual ε_r as a function of frequency. Fig.7 shows the simulated graph after of tanδ as been determined as shown on page 10. This is a very good match of the graph shown in fig.4.

Electric permittivity (ε_r)	Frequency at which resonant point is found
4.40	1.814
4.45	1.804
4.35	1.822
4.30	1.832
4.28	1.836
4.25	1.842
4.24	1.844
4.23	1.846

Table 1

Measured data

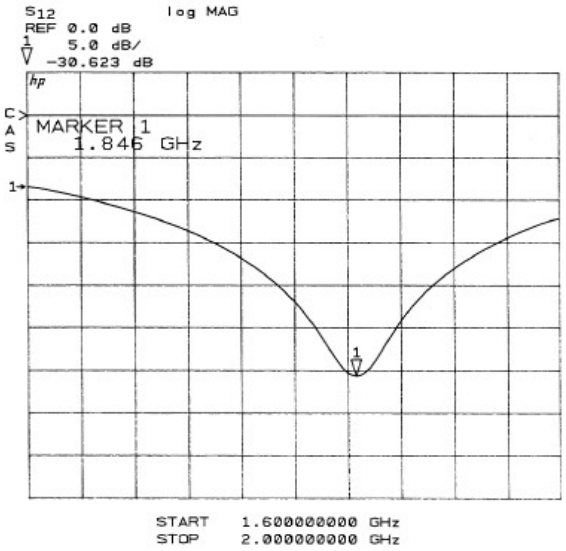


Fig. 4

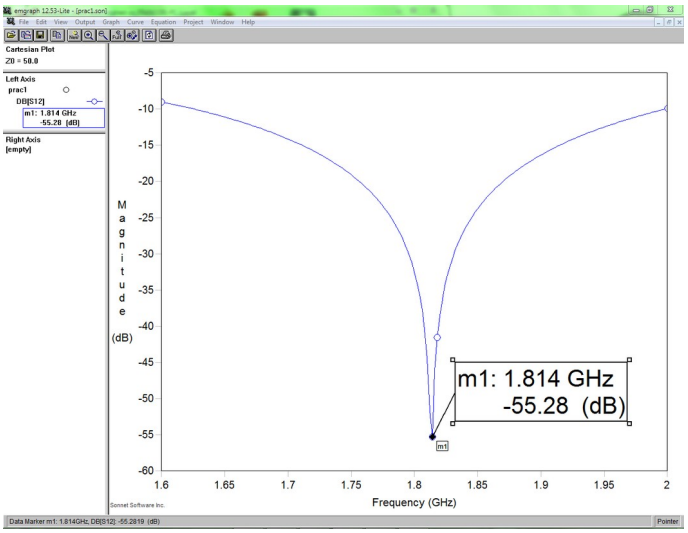


Fig. 5

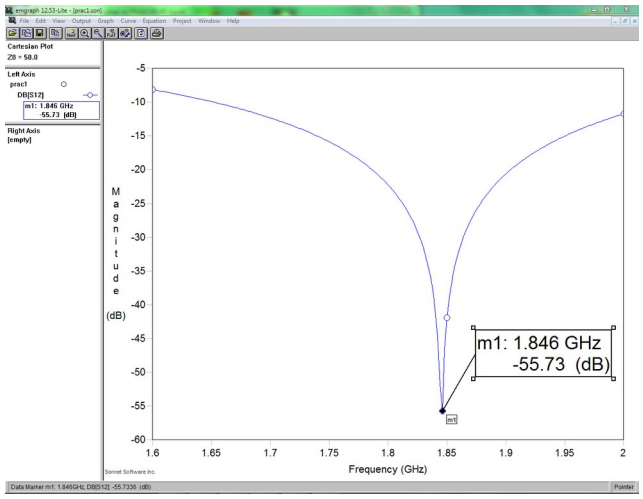


Fig. 6

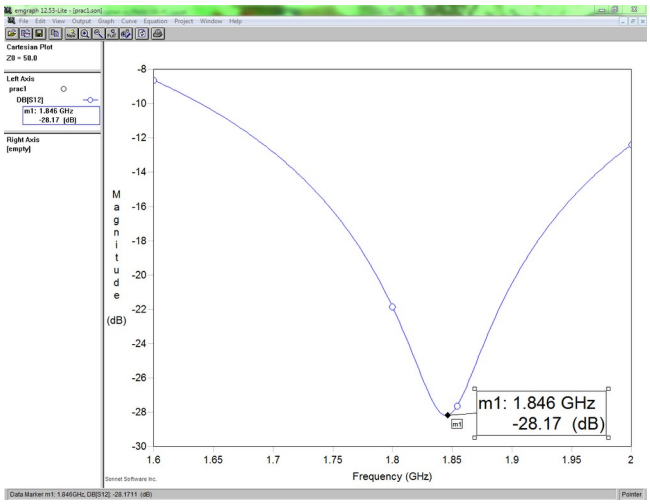


Fig. 7

The network analyzer produced the graph of transmission coefficient (measured in decibels) as a function of frequency, shown in fig.8 (Odendaal, 2011:13) for the actual simple straight circuit compared to the simulated result based on the ε_r determined previously and the expected tanδ shown in fig. 9 The table below summarizes the adjustments made to the simulation to match it to the actual tanδ measured at 1.8 GHz. The actual tanδ value is determined as 0.304. Fig.10 shows the resultant graph of transmission coefficient as a function of frequency.

Loss tangent (tanδ)	Loss in dB
0.001	-0.02766
0.01	-0.13818
0.02	-0.2566
0.03	-0.377
0.032	-0.4011
0.031	-0.389
0.0305	-0.383
0.0304	-0.3818
Table 2	

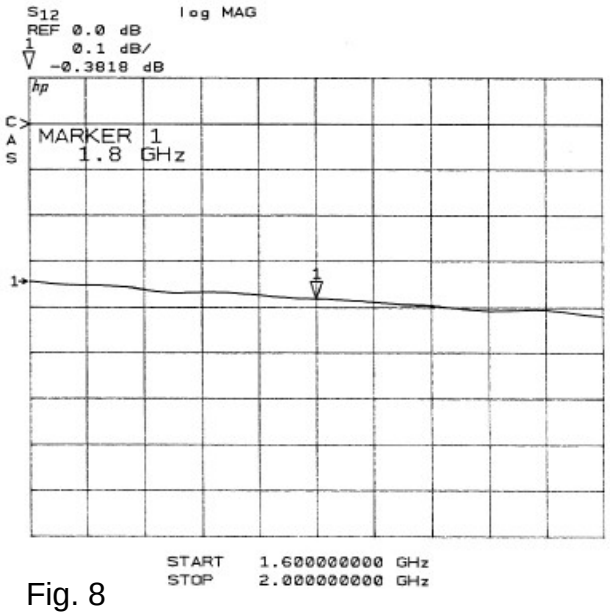


Fig. 8

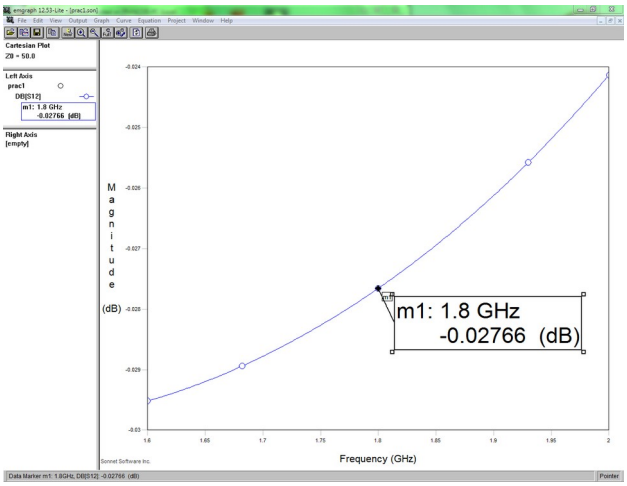


Fig. 9

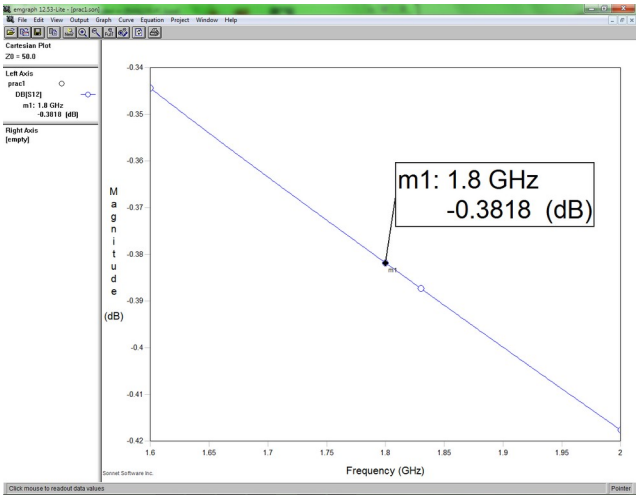


Fig. 10

Experiment 2

To find the width needed for the micro strip line to have a characteristic impedance of 50 ohms the following widths where simulated, the input impedance at the start of the line measures and the VSWR determined at 1 GHz. The first three simulations where performed to get a better feel for how the characteristic impedance behaves when the width of the line is changed. I clearly illustrates that making the width smaller increases the characteristic impedance and thus the input impedance, and vice versa. For the next few simulations only a quick simulation to determine Z_{in} was done until the value got close to the desired one. This was done to speed up the simulation time. The best width was taken to be 3.7mm. The simulated result is show fig.11 a graph of the VSWR as a function of frequency.

Width (mm)	Z_{in} port 1	VSVR at 1 GHz
6	36.34	1.207
3	57.39	1.0103
1	99	1.90
2.9	58	1.121
3.1	56	---
3.3	54	---
3.5	52	---
3.7	50.44	1.002
3.8	49.5	1.008
Table 3		

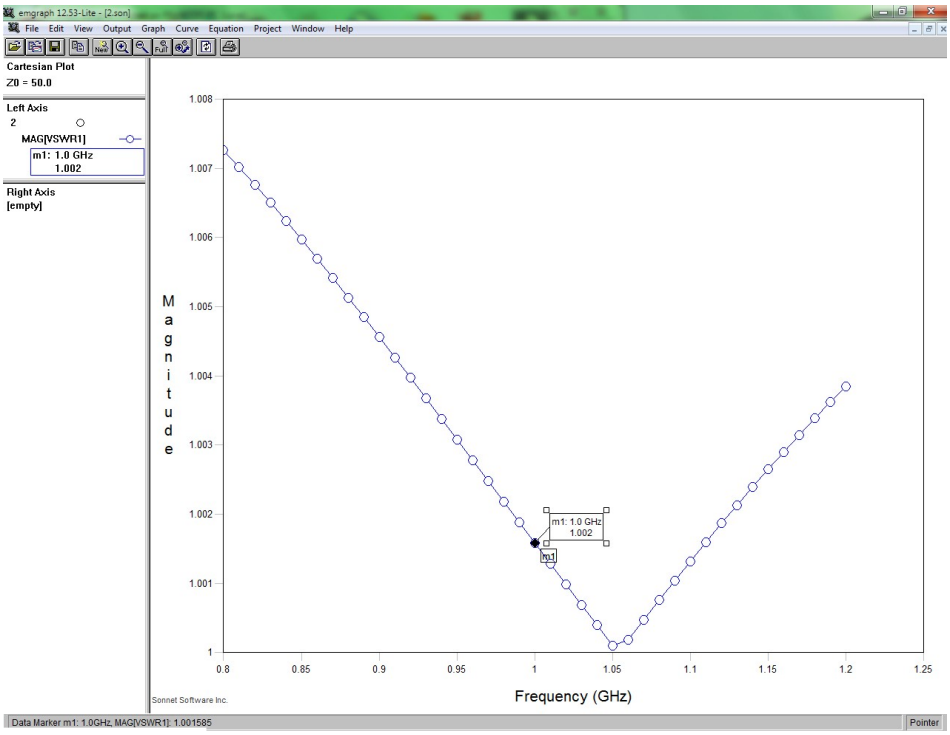


Fig.11

Based on the above result the following dimensions for the final circuit was simulated circuit was found based on the assumption that the theoretical values (l,s) are measured from the end of the line to the centre of the perpendicular line:

a = l - w/2
= 10.40 – 3.7/2
= 8.55
= 8.6

b = s – w/2
= 17,985 – 3.7/2
= 16.135
=16.5

Where a is the distance from the edge of the board to the edge of the stub, and b is the length of the stub from the edge of the main line as shown in fig.12.

Fig 13 shows the graph of the VSWR as a function of frequency for the circuit as designed theoretically while fig 14 shows the graph after the adjustment where made and the final design values of a is 9.6mm and b is 17mm was settled on. Table 4 shows the steps taken. Fig.15 shows the input impedance of at the start of the line Z_{in} for a number of frequencies on a smith chart.

The bandwidth of the design requirement can be determined graphically by finding the frequencies where VSWR is 1.5 on the simulated graph as shown in fig.16. This bandwidth is found to be from 0.67 GHz till 1.505 GHz and is thus 0.835 GHz wide.

a (mm)	b (mm)	VSWR
8.4	16.5	1.176
8.8	16.5	1.169
9.2	16.5	1.156
10	16.5	1.314
9.4	16.5	1.15
9.6	16.5	1.45
9.6	17	1.09
9.6	17.1	1.114
9.6	16.9	1.095
9.6	16.8	1.129
Table 4		

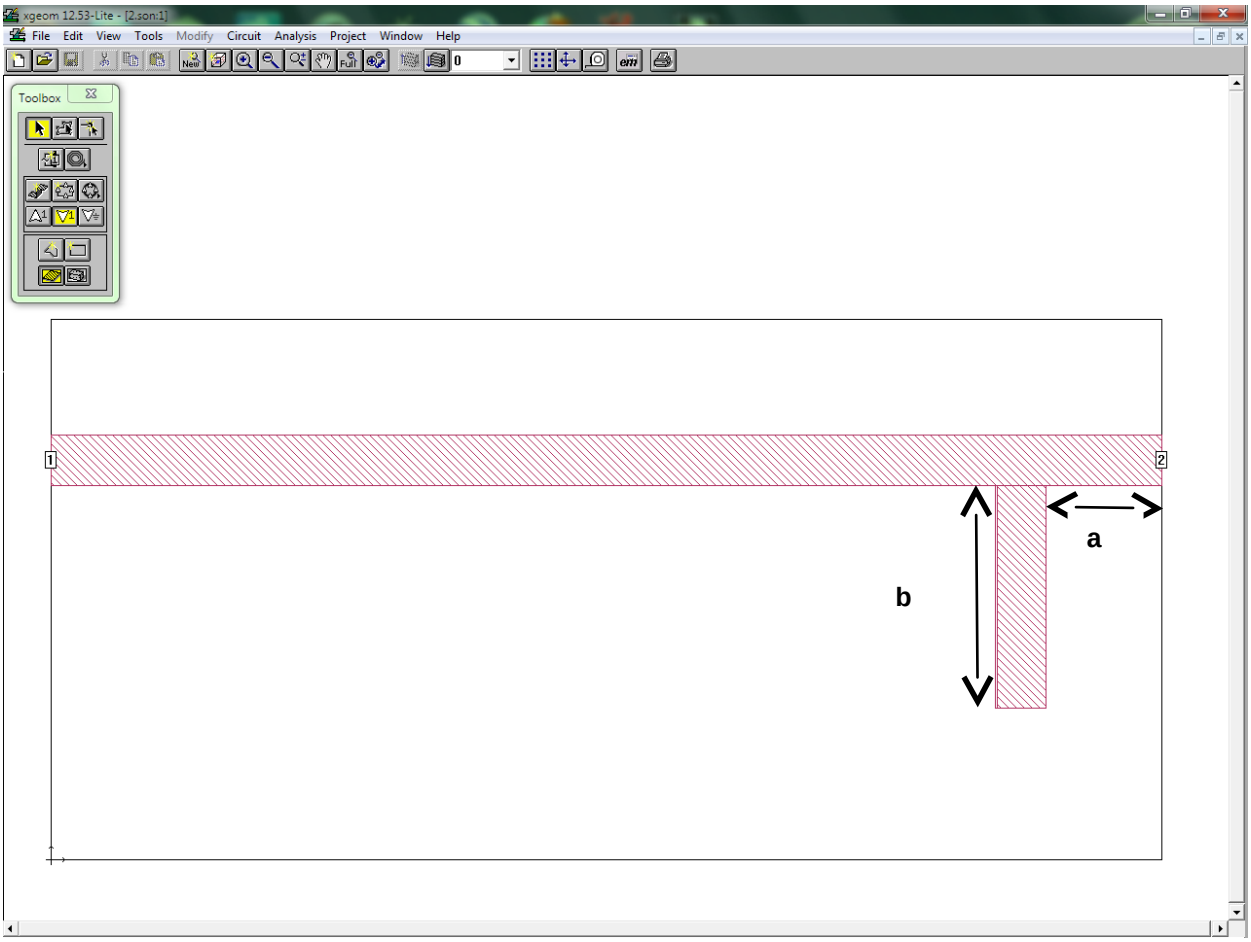


Fig. 12

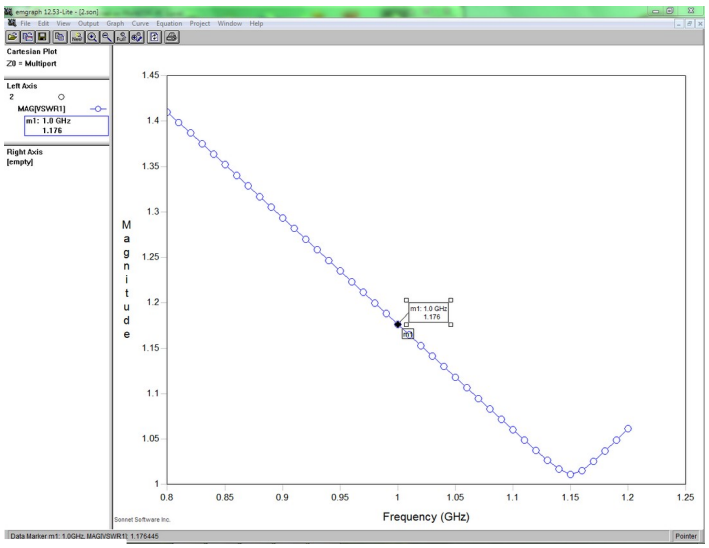


Fig. 13

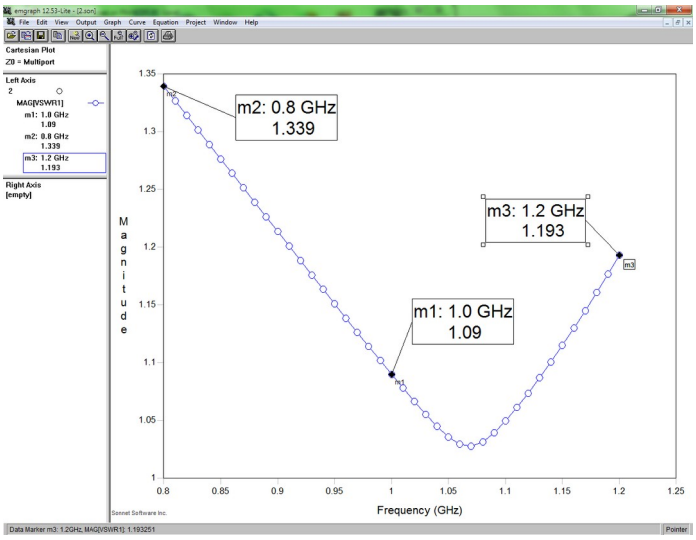


Fig. 14

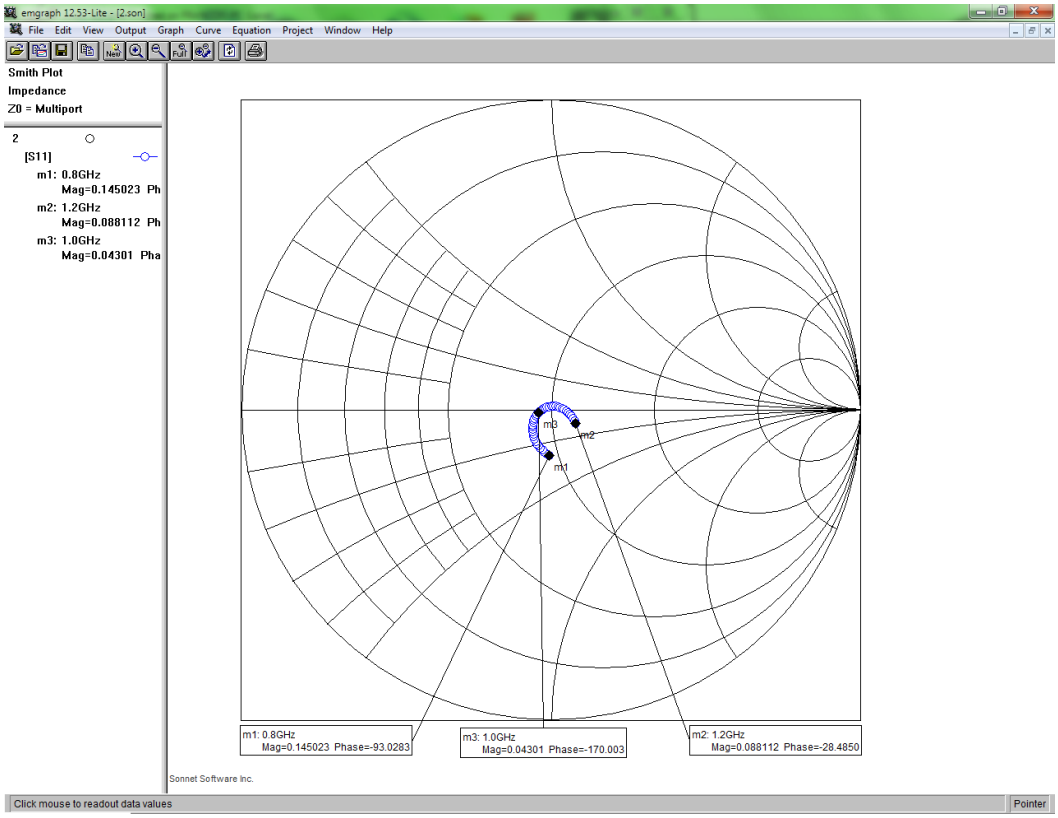

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Impedance
Z0 = Multiport
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m1: 0.8GHz
Mag=0.145023 Ph
m2: 1.2GHz
Mag=0.088112 Ph
m3: 1.0GHz
Mag=0.04301 Pha
m1: 0.8GHz
Mag=0.145023 Phase=-93.0283
m3: 1.0GHz
Mag=0.04301 Phase=-170.003
m2: 1.2GHz
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Fig. 15

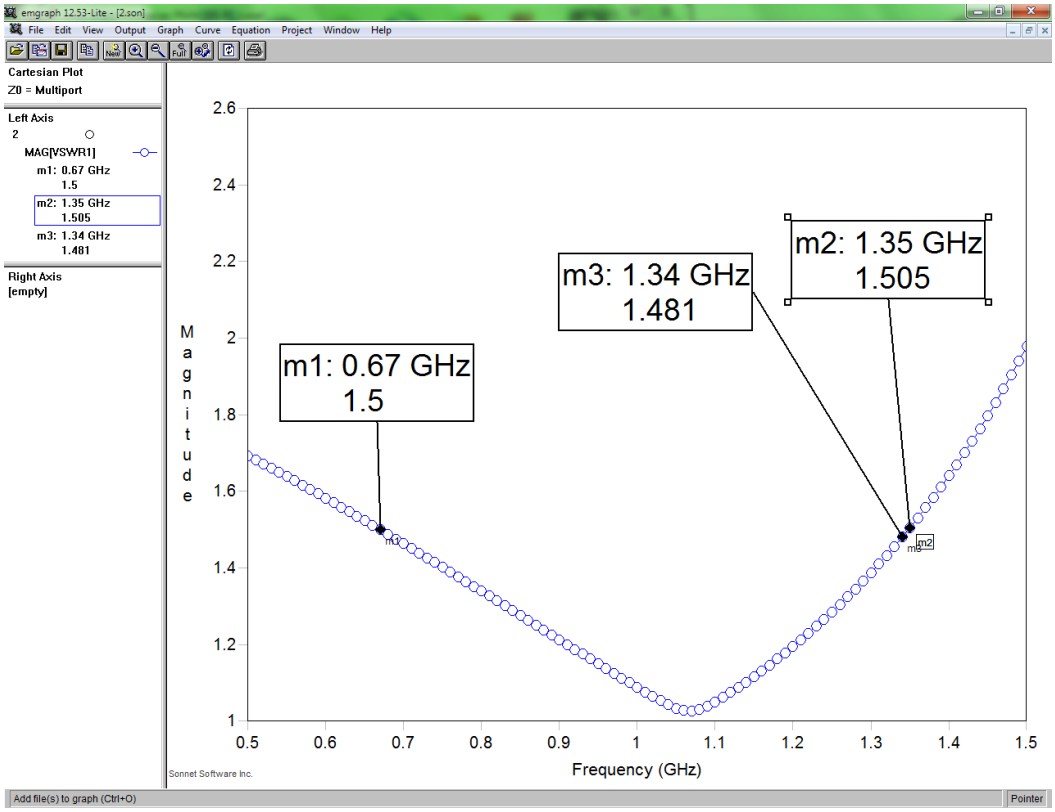

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File Edit View Output Graph Curve Equation Project Window Help
Cartesian Plot
Z0 = Multiport
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1.5
m2: 1.35 GHz
1.505
m3: 1.34 GHz
1.481
Right Axis
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m1: 0.67 GHz
1.5
m3: 1.34 GHz
1.481
m2: 1.35 GHz
1.505
Magnitude
Frequency (GHz)
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.5
0.6
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1
1.1
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1.4
1.5
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Fig. 16

Conclusion

By using simulation software the electric characteristics of a specific batch of FR4 can be accurately determined. This allows the use of inexpensive FR4 for designs that require a great amount of accuracy, rather than a more expensive substrate that has guaranteed characteristics. This allows manufacturers to reduce the cost of products and allows them to be more competitive. By using simulation programs one can also verify impedance matching circuit designs, and possibly improve them. This allows one to achieve more accurate designs which are often essential at higher operating frequencies. Simulation programs also for simplified determination of certain design parameters such as the dimensions required to achieve specified characteristic impedance.

References

1. Odendaal,J.W. 2011. *Study Manual, Electromagnetism 310.* University of Pretoria
2. Ulaby, F.T., Micielsen, E. & Ravaioli, U. 2010. *Fundamentals of Applied Electromagnetics: 2 – 11 Impedance matching.* Pearson International

Appendix A: Smith chart for calculations