Feasibility of Microstrip Wilkinson Power Dividers on FR4 Substrates for L-Band (1-2 GHz) Applications

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The feasibility of using FR4 is investigated via the testing of Wilkinson power dividers operating in portions of the L-band (1-2 GHz).

1. Introduction

Microstrip structures are very popular choices both for circuits and antennas. Wilkinson power dividers in microstrip form are indispensable components for printed antenna array feeding networks. In principle, low loss specialized microwave substrates are used for best results. However, since substrate cost is the dominant factor for microstrip passive circuits [1], there is a need to use cheaper materials such as FR4 without compromising the performance.

In this paper, the feasibility of using FR4 is investigated via the testing of Wilkinson power dividers operating in portions of the L-band (1-2 GHz). The 1-2 GHz band serves significant wireless applications such as cellular mobile [2] and mobile satellite data [3].

The principles of the Wilkinson power divider operation, microstrip implementation and fabrication details are given in section 2. Results are given in section 3 using a divider built on Duroid as a performance benchmark.

A discussion on FR4 tolerances and potential consequences on amplitude and phase errors is also included in Section 4.

2. Principles of Wilkinson Power Divider Design

Wilkinson [4] proposed a power divider design that provides isolation between the output ports unlike the resistive divider or the T-junction. The design principles are included here for completeness, following Pozar [5]. The signal from the input port is split into two coupled lines quarter wavelength long that lead to the two output ports. The layout of Figure 1 assumes microstrip form i.e. a signal line printed on the top side of a fully metalized substrate, the bottom side serving as the ground plane.

There is no power lost in the divider. All the ports can be matched. The presence of resistor dissipates only the reflected power.

The most important performance metric is the 3 dB power split. Adopting the port convention of Figure 1 the power split is expressed via the S21 and S31 scattering parameters. The isolation between ports is measured by S23 and S32. The matching of each port is measured by S11, S22, S33. All scattering parameters can be readily measured via a vector network analyzer.

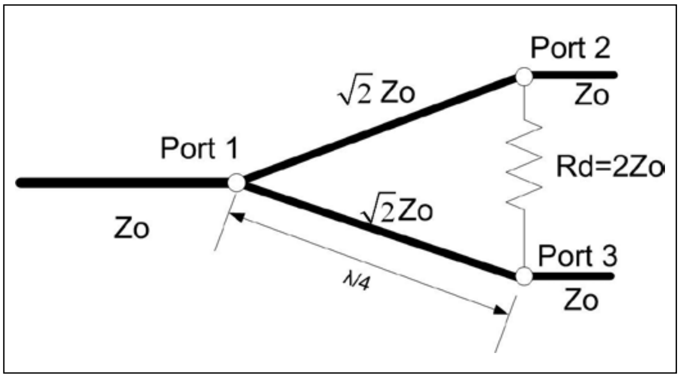

Figure 1 • Conceptual layout of a microstrip Wilkinson Power Divider.

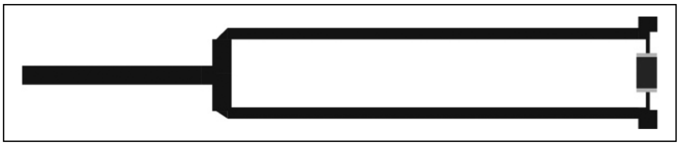

Figure 2 • Layout of a microstrip Wilkinson Power Divider (top layer) with a chip resistor.

Figure 2 shows the actual layout of the divider. Recall that the impedance for a given substrate dielectric constant and height is governed by the width of the line [6] (see Equation 1 below) whereas the length is equivalent to a delay expressed in wavelengths or degrees at the target design frequency. The resistance of Figure 1 is in reality a chip resistor of 100Ω.

It should be noted that there are many design variations extensions that achieve broadbanding or multiple band operation, see for example [7,8]. The focus of this note is on the substrate choice rather than optimal design.

3. Experimental Results

Substrates are characterized mostly by their dielectric constant and loss tangent. Usually for microwave applications low loss highly stable dielectric constant such as Duroid are used. On the other hand, PCB circuits are usually fabricated on FR4 which is cheap but on the expense of greater loss. Considering that substrates with varying thickness exhibit different loss and variations from the nominal dielectric constant, FR4 thin substrates with thickness h=0.5mm and h=1mm were tested. As benchmark substrate a Duroid microwave substrate with thickness 1.11 mm and dielectric constant ε_r=2.2 is used.

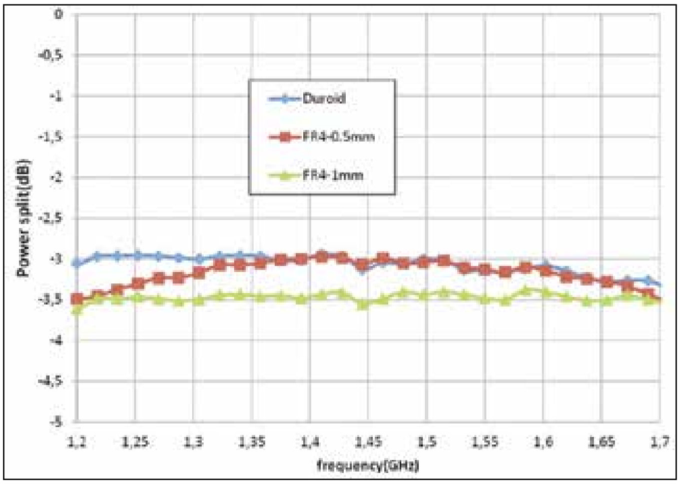

Figure 3 • Measured power split for Wilkinson dividers for FR4 substrates compared with Duroid.

Two dividers were built on FR4 and one on Duroid. Input matching was better than -10 dB for all three versions. The 3 dB power split is shown in Figure 3.

It can be seen (Figure 3) that the power split of the FR4-1mm substrate introduces about 0.5 dB loss whereas the FR4-05mm substrate, maintains a good split but for half the bandwidth of the Duroid one.

The measured return loss, for the frequency band of Figure 3, was better than 10 dB, i.e. VSWR<2 for all the dividers.

4. Tolerance Analysis and Error Effects

The substrate used was FR4 with a nominal dielectric constant of ε_r=4.2. FR4 is a mix of epoxy resin and glass. The glass additions can cause variations of the constant up to 4.6 especially for thicker substrates. The 4.2 value is more appropriate for thin substrates. The impedance of a microstrip line is given by [6].

$$Z_o = \frac{42.4}{\sqrt{\varepsilon_r+1}} \ln\left\{1+\frac{4h}{W}\left[\frac{14+\frac{8}{\varepsilon_r}}{11}\frac{4h}{W}+\sqrt{\left(\frac{14+\frac{8}{\varepsilon_r}}{11}\right)^2\left(\frac{4h}{W}\right)^2+\frac{\pi^2}{2}\left(1+\frac{1}{\varepsilon_r}\right)}\right]\right\} \tag{1}$$

The tolerance in the dielectric constant could lead to a maximum impedance error of about 2 Ω .

The dielectric constant variations change the guided wavelength. Since the divider is using quarter wavelength sections (Figure 1), the tolerances can cause phase errors up to 4.4 degrees/ quarter wavelength.

These substrate tolerances can cause errors in the power splitters. The most direct consequence of that in an antenna array fed by such splitters is an increase in the minor sidelobes level.

5. Conclusions

It was found that the Wilkinson divider on the 0.5 mm thickness FR4 has comparable behavior to the specialized substrate divider and could be considered as a cheap and viable alternative for applications in the 1-2 GHz band.

About the Author:

Christos Kalialakis was born in Watrellos, France. He was awarded a Ph.D. in Electronic and Electrical Engineering from the University of Birmingham, UK in 1999. He received the B.Sc. in Physics and the Master in Telecommunications in 1993 and 1995, both from the Aristotle University of Thessaloniki, Greece (A.U.Th). He has industry experience working in the UK as an antenna designer and then in Greece as an RF Hardware Engineer working on RFIC testing and measurement. Since the end of 2002, he has been employed by EETT (National Regulatory Authority of Greece), first as an Expert on Wireless Communications and since 2004 as Deputy Head of the Thessaloniki Regional Office. He is also a lecturer adjunct at the Radiocommunications Laboratory, A.U.Th. Dr. Kalialakis is an IEEE Senior Member and a regular reviewer for several journals.

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