Compact 2-Way Power Divider for IoT Application

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Abstract. The utilization of power dividers covers a vast range of applications such as the Internet of Things (IoT). For this purpose, the need for having a robust and ergonomic electronic device is crucial. Bulky size could barely integrate onto the human body due to its weight that could be very difficult to implement. Hence, this paper presents the design of a compact power divider for IoT applications. It was designed on a substrate Rogers 4350B, ε_r=3.48, tan δ= 0.0037 and h=0.17mm. The design was meant to be operated at 2.4GHz frequency with the output of equally 3dB power division on the output port. Wilkinson design was implemented to perform the design of power divider which will be simulated using Computer Simulation Technology (CST) microwave studio simulation tools. Parameter sweep was done to its width of transmission line at 0.21mm and 0.31mm to optimize the performance of the design. The simulated result was then compared against measured results in which S-parameter was evaluated in terms of input return loss, isolation and power division. Simulated and measured results showed that 0.21mm width of the transmission line performs better as compared to 0.31mm width of the transmission line.

1. Introduction

The power divider is one of many important microwave passive devices which intended to provide power division[1]. Power dividers are used mostly in the field of radio technology. They operate to divide the amount of the electromagnetic power in a transmission line to a port enabling the signal to be used in another circuit[2]. Each port produces the same power division which is 3dB. Power divider can also perform measurement or monitoring, feedback, combining feeds to and from the antenna, antenna beam forming, providing taps for cable distributed systems such as TV cable, separating transmitted and received signals on telephone lines. This power divider is used in many applications such that the microwave application[3][4] for distribution of low power signal for two or multiple antennas, intermodulation distortion measurement which used power divider to combine two power signals and produces one signal outputs [5], and also in the RF technologies [6][7]. Internet of Things (IoT) is a system computer device related to mechanical and digital machines, objects, animals or people. IoT has the ability to transfer data over a network without requiring human to human. The examples of IoT applications are heart monitor implant, farm animal and alerting the driver whenever tyre temperature is low using sensors [8]. The utilization of commercial electronic power divider is bulky and not suitable for embedding onto the human body due to its size and weight. This is why compact power divider is needed to be designed and fabricated with a compact size for application in the field of IoT.
for use in animals or people in IoT applications. Some of the flexible substrates such as polyimide, kapton, textile and ink-jet paper are suitable to use in animals or people for IoT applications, however, the cost may be higher, or the structure is not robust to the surrounding weather or environment. Therefore, there is a demand to design a compact and lightweight power divider for use in IoT application so that it is suitable to attach to animal skin or human. The design of power divider based on Wilkinson design has been widely used due to many advantages including zero losses [9][10] with various purposes which include miniaturization and/or arbitrary power division [11], flexible organic substrate [9] and flexible microstrip power divider [12][13]. A robust substrate is said to be ergonomic enough which can be applied for various IoT applications including wearable power divider as in [14]. The authors design a balanced 3-way power divider as a feeding circuit for wearable antennas by using FR4 substrate. The simulation and measured prototyped showed good agreement in evaluated S-parameters. The authors in [15] have been introducing the equivalent power dividers for the purpose of Radio frequency (RF) components commonly used in wearable and flexible application whilst TO and TS topology were being the main concern in designing the power divider. Modified design formula was introduced to optimize the performance in terms of its applicability, size, bandwidth and electromagnetic compatibility. The outcome from the design was set to be the foundation on wearable and flexible power dividers in RF electronics[15]. Since lightweight substrates being one of the main concerns in designing wearable power dividers which has the possibility to be utilized in IoT application, Rogers 4350B was chosen in this structural design of this paper due to not only its lightweight feature but also the durability of the material. 2-way power divider was designed on Rogers 4350B that features 3 ports, 1 input port and 2 equivalent 3dB output ports which are based on the structural design of Wilkinson power divider as in Figure 1.

2. Methodology

2.1. Design of 2-way power divider

The basic Wilkinson power divider design is shown in Figure1 which featured with two parallel uncoupled quarter wavelength transmission line. The characteristic impedance of each uncoupled lines is \( \sqrt{2}Z_0 \) in order to match with the input port whilst \( 2Z_0 \) of the shunt resistor is connected to both of the output ports to provide the best isolation. 2.4GHz operating frequency spectrum was chosen in this power divider design which falls under the Wifi frequencies range. This was deliberately chosen due to the intended utilization of structural design for IoT applications. Apart from frequency setting, some of the design specifications which need to consider were the power division, return loss and the isolation which need to meet minimum reading at the end of the simulation and measurement process. Another key parameter that was paramount in designing the power divider itself was the waveguide port parameter setup. The determination of ports role was important to avoid any reversal between input and output ports. This design made use of copper conductor as the ground plane of the power divider whilst RO4350B was the substrate on top. Cooper is undeniably one of the best conductors which allow conductivity of current over the copper line. The dimension of the design was tabulated as in Table 1.
Table 1: Dimension of 2-way Wilkinson power divider

| Parameter                        | Dimension (mm) |
|----------------------------------|----------------|
| Dielectric constant ($\varepsilon_r$) | 3.48           |
| Dissipation factor, $\tan \delta$ | 0.0037         |
| Thickness, $h$                   | 0.17mm         |
| Transmission line thickness     | 0.17mm         |
| Feed line transmission length, $L_1$ | 4.1mm         |
| Width of transmission line, $W_1$ | 0.38mm         |
| Feed line transmission length, $L_2$ | 25.6mm      |
| Width of transmission line, $W_2$ | 0.21mm         |
| Feed line transmission length, $L_3$ | 7.63mm      |
| Width of transmission line, $W_3$ | 0.38mm         |

The circuit of the Wilkinson 2-way power divider design was made by using CST software as in Figure 2.

Figure 2: Circuit design of Wilkinson power divider in simulation software tool

The design featured with transmission lines which form the input and output port. Formula (5) was used to calculate the transmission line length ($L_1$), ($L_2$), ($L_3$) as tabulated in Table 1 and width of transmission line length ($W_1$), ($W_2$), and ($W_3$) was calculated using the formula in (1), (2). Result from the equation together with the impedance value of $Z_0=50\Omega$, distance thickness, $d=0.17\text{mm}$s was then substituted in equation (4) to acquire the final transmission line width.

\[
A = \frac{Z_0}{60} \sqrt{\frac{\varepsilon_r+1}{2}} + \frac{\varepsilon_r-1}{\varepsilon_r+1} \left(0.23 + \frac{0.11}{\varepsilon_r}\right) 
\]  

\[
B = \frac{377\pi}{1220\sqrt{\varepsilon_r}} 
\]  

\[
\frac{W}{d} = \frac{8B e^A}{\varepsilon_2 A^2} 
\]
For $W/d < 2$

$$\frac{W}{d} = \left[ \frac{2}{\pi} B - 1 - \ln(2B - 1) + \frac{\varepsilon - 1}{2\varepsilon} \left[ \ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon} \right] \right]$$  \hspace{1cm} (4)

For $W/d > 2$

$$\lambda_g = \frac{c}{f\sqrt{\varepsilon_e}}$$  \hspace{1cm} (5)

Where $C = 3 \times 10^8$ constant of light and the value of effective dielectric, $\varepsilon_e$ obtained from equation (5).

$$\varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \frac{1}{\sqrt{1 + 2d/W}}$$  \hspace{1cm} (6)

Parameter $\varepsilon_r$ in expression (1) and (6) represent the dielectric constant of substrate and $d$ in (2) and (6) represents the thickness of the substrate. Figure 2 displays CST layout of the 2-way Wilkinson power divider featuring 1 input port where (L1) represents the length in the input whilst (L2) represents the length of the quarter wavelength and (L3) was the output transmission line length. (W1) shows the transmission line width in the input port whilst (W2), and (W3) was the width of quarter wavelength and the output port width respectively. In this design, a quarter wavelength, (W2) was optimized in CST simulation software to retrieve the best performance out of the design at 0.21mm and 0.31mm.

3. Result and Discussion

The hardware prototype of a 2-way power divider is as shown in Figure 3. Three female SMA connectors were soldered accordingly at the ground plane to all of the ports. The fabricated Wilkinson dividers were measured by using Agilent PNA Network Analyzer E8362B to acquire S-parameters measured results.

Figure 3. Hardware prototype of 2-way power divider
3.1. Simulation results after parameter optimization

Figure 4. Return loss, S11 simulated result.

Figure 4 shows return loss, S11 measured result for both 0.21mm and 0.31mm width of transmission quarter wavelength (W2). It was found that 0.21mm gave better result compared to 0.31mm with more than -18dB of magnitude at 2GHz peak frequency which still in the range of evaluated operating frequencies with a minimum of 1GHz up to 3 GHz. Thus, gives the indication that the optimization of quarter wavelength gives effect. Figure 5 displays simulated results of isolation, S23 which can be understood that 0.21mm gave the best isolation compared with 0.31mm of (W2). The result recorded that both readings achieve the minimum requirement of S23 which need to be lesser than -10dB with 0.21mm reach up to more than -29dB whilst 0.31mm maximum magnitude at -18dB. It was also observed that 0.31mm initial magnitude did not meet the minimum requirement of the design. Hence, the best performance of S23 was recorded for 0.21mm width of (W2).

Figure 5. Isolation, S23 simulated result.
Figure 6. Power division, S12 simulated result

Figure 6 shows the simulated graph result for power division with both optimizations reading. The graph pattern displays positivity, hence the optimization which had been done does not affect minimum power divider requirement

3.2. Comparison of the simulated and measured result after parameter optimization

Figure 7. Comparison of the simulated and measured results of return loss, S11, S22, and S33 parameters.
The comparison of simulated and measured results as displayed in Figure 7, Figure 8 and Figure 9 was calculated and compared in term of its bandwidth percentage as in Table 2. Bandwidth percentage was calculated using the formula in (7)

\[ \%BW = \left( \frac{f_H - f_L}{f_H + f_L} \right) \times 100 \]  

(7)
Table 2. Summary of the bandwidth of simulated and measured results with respect to S-parameters

| Parameter | Frequency range | Simulated | Measured |
|-----------|-----------------|-----------|----------|
| $S_{11}$  |                | 1         | 1        |
|           | $f_l$           |           |          |
|           | $f_H$           | 3         | 2.8      |
|           | $\%BW$         | 50%       | 47.3%    |
| $S_{22}$  |                | Na        | 1        |
|           | $f_l$           | Na        | 1        |
|           | $f_H$           | Na        | 3        |
|           | $\%BW$         | Na        | 50%      |
| $S_{23}$  |                | 1         | 1        |
|           | $f_l$           | 1         | 1        |
|           | $f_H$           | 3         | 3        |
|           | $\%BW$         | 50%       | 50%      |
| $S_{33}$  |                | 1         | 1        |
|           | $f_l$           | 1         | 1        |
|           | $f_H$           | 3         | 3        |
|           | $\%BW$         | 50%       | 50%      |

4. Conclusion
A compact 2-way power divider had been designed in this paper featuring lightweight Rogers4350B as the substrate for IoT application. Measured and simulated results show that the design meets at least the minimum requirement of the specification that was made prior. The optimization on (W2) does give effect to the overall performance of the power divider. The evaluated S-parameters that were meant to meet the specification which was the return loss $S_{11}$, power division $S_{21}$, and isolation $S_{23}$ achieve the objectives of the design.

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