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Research paper

UWB Power Divider using Tapered Transmission Line and Loaded Structure

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Abstract

An Ultra-wideband (UWB) power divider with tapered line and loaded structure is presented in this paper UWB applications. The power divider is designed and simulated with a loaded structure to enhance the bandwidth and for size miniaturization. From the simulation and measurement results, it shows that the power divider working frequency is from 2-14 GHz. The phase for port 2 and port 3 of the designed power divider is in phase can be useful to radiate the two port UWB devices.

Keywords: *Ultra-Wideband; Power Divider; Tapered Line; Loaded Structure.*

1. Introduction

Power divider circuits are the essential elements in communication, especially in antenna design. The most likely designed power divider is Wilkinson power divider [1,2] for equal phase and amplitude. The Wilkinson power divider is a network used to match the output ports, by considering the transmission line impedance in even-odd mode [1]. It can be used for different polarization or phase control purposes, but in this case, it was designed mainly to match the bandwidth for complete ultra-wideband [3].

Microwave power dividers are passive elements that widely used in microwave systems. It is used to distribute input signal power to two or more output ports. The development for ultra-wideband (UWB) wireless systems has presented a challenge to the design of wideband microwave circuits, including power divider. The most straightforward power divider design is a T-junction structure. A quarter-wave transformer is used for impedance matching of the output ports to the standard load impedance. Due to the poor isolation and narrow bandwidth for return loss better than 15 dB, it is seldom used in modern microwave circuits.

E. J. Wilkinson overcomes the poor isolation issue by adding a resistor across output ports [4]. It was a breakthrough in power divider design. The power divider, however, is only optimized at a single frequency due to the limitation of the quarter-wave transformer. Since the line length is precisely quarter wavelength at the center frequency, the operating bandwidth of the power divider is limited regarding return loss and isolation. Multiple quarter-wave transformers connected in cascade improve the bandwidth [5,6] at the cost of increasing the size of the circuit. However, ripples were observed in the transmission coefficient due to discontinuities at impedance steps. Many methods have been proposed to reduce the size, but they come with some degradation of the electrical performances. To overcome all these problems, exponentially tapered line was introduced [7].

In this paper, a power divider with a UWB frequency range is presented. The quarter-wave transformer in the conventional Wilkinson power divider is replaced by an exponentially tapered microstrip line. Moreover, a loaded structure. The remainder of the paper is as follows; a complete power divider configuration in Section 2. While the discussion based on obtained results are analyzed in Section 3. The final section summarizes the discussion in the form of a conclusion.

2. Power divider configuration

The design was carried out using a simple T-divider circuit as discussed in [8, 9], where a taper edged three-way transmission line power divider circuit was designed for a single frequency band. To achieve the results for complete ultra-wideband different modifications were performed in the design such as the addition of electromagnetic band gap (EBG) [10, 11], fractal shape transmission line, etc. Which in this case is useful for bandwidth matching. EBG is the addition of small radiators (without direct excitation) coupled electromagnetically to match the propagation of assigned frequencies [10].

As discussed earlier the design carried out for three-way transmission line was initiated with a simple T-divider circuit having two tapered edge transmission lines [9] to match the impedance. The complete design process was simulated using CST microwave studio with transmission line matrix (TLM) solver method. The dielectric substrate used in this case was FR-4 with the permittivity of $\mathcal{E}r = 4.2$, having transmission line incorporated at one side, while a complete ground structure comprised of copper at the other side. Since the power divider required to attach directly to an array so the distance between the two transmission lines should be the same as that of the distance between the array elements, which in this case was 3λ/4. The characteristic impedance of the antenna and T-divider is Zo = 50 Ω. To match the impedance of 50 Ω at all three feedlines of T-divider, a quarter wave transformer was then implemented to match 50 Ω and 100 Ω impedance at the main feed, this impedance Z1 for the transformer can be calculated using following equation [12]:

$$Z_1 = Z_o\sqrt{2} \tag{1}$$

Where Z1, in this case, is calculated as 70.7 Ω. Next step was to calculate the length and width of the 50 Ω transmission line and 70.7 Ω quarter wave transformer the equations used in this case are as follows [12]:

$$L_t = \frac{\lambda_0}{4\sqrt{\varepsilon_r}} \tag{2}$$

Where Lt is the length of transmission line, Ɛr is the dielectric permittivity and λo =c⁄fo, in which c = 3x108 m/s and fo=6.5 GHz respectively.

$$W/h = 8e^{A}/(e^{2A} - 2) \tag{3}$$

For W/h<2

$$W/h = 2/\prod[B - 1 - \ln(2B - 1) + (\varepsilon_r - 1)/2\varepsilon_r\{\ln(B - 1) + 0.39 - (0.61/\varepsilon_r)\}] \tag{4}$$

For W/h>2 (4.8)
Where W is the width of feed and h is the height of the substrate, which in this case is 1.5mm.

$$A = (Z_o/60)[(\varepsilon_r + 1)/2]^{1/2} + [(\varepsilon_r - 1)/(\varepsilon_r + 1)(0.23 + (0.11/\varepsilon_r))] \tag{5}$$

$$B = 377\prod/(2Z_o\sqrt{\varepsilon_r}) \tag{6}$$

Based on the equations mentioned above the length and width calculated using different values of characteristics impedance were then used to simulate UWB power divider circuit, and the CST optimized values were then summarized in Table 1. As the transmission line followed in [9] was designed for a single frequency band but in this project it was designed with some modification to operate it over the entire UWB band for which a loaded structure [10] was introduced between port 2 and 3 of the circuit and two square shape radiators near the main feed to achieve the required bandwidth.

Table 1: Design Parameters of UWB Power Divider

Impedance (ohm)	Length (mm)	Width (mm)
50	13.8	1.85
70.7	2.89	0.41
100	12.55	1.10

The loaded structure that has a periodic structure and having a frequency band gap in which no surface wave propagation is allowed. The designed power divider, including loaded structure along with the dimensions, is shown in Figure 1. From the figure it can be seen clearly that the port 1, 2 and 3 have equal impedance of 50 Ω as the length and width were similar, while in order to match feed 1 with port 2 and 3, a 100 Ω feed with the tapered edge was added and to match it with main feed of 50 Ω another 70.7 Ω impedance was introduced. To achieve the desired bandwidth a triangular slot [12] was added near the loaded structure of main port to taper the edges of 70.7 Ω feed.

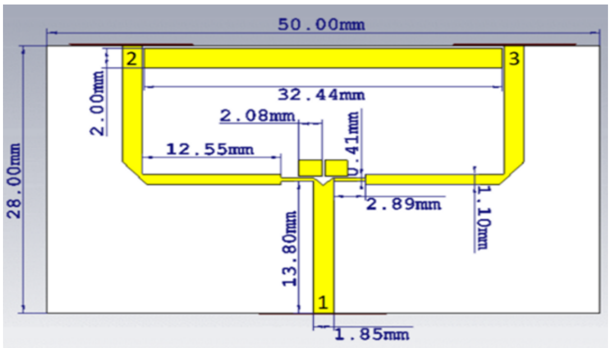

Fig. 1: UWB Power Divider Structure.

3. Results and discussions

After the successful simulation of the design using CST, the results obtained regarding scattering parameter (S11) and phase to match the impedance of port 2 and 3 with the main feed of 50 ohms are illustrated in Figure 2. The bandwidth achieved as a result of tapered shape T-divider simulation ranging from 2-14.5 GHz is illustrated in Figure 2 (a), which is once again 5 GHz greater than the one defined by FCC. Figure 2 (b) demonstrated the phase to match the transmission line port 2 and 3 in corresponds to the main feed and thus the results provided this information that the designed transmission lines at port 2 and 3 are in phase with the primary 50 Ω feed and can be useful to radiate the two port UWB antenna array.

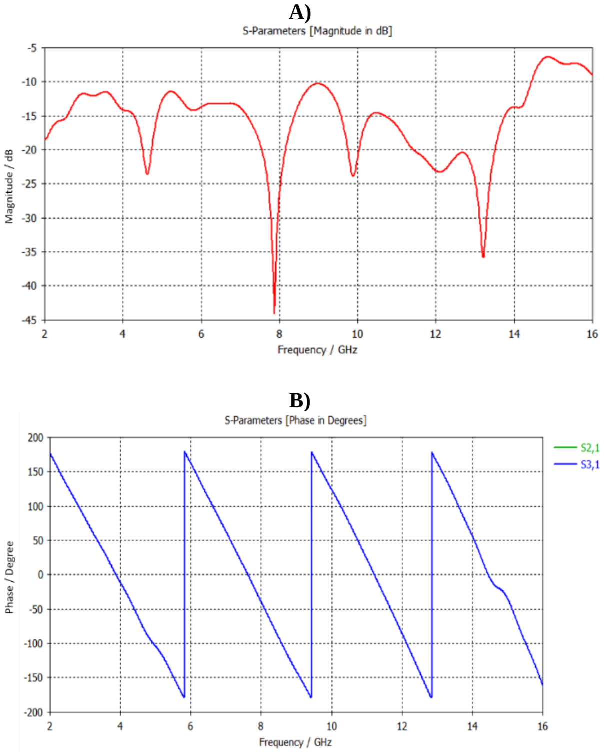

Fig. 2: Simulated Results of UWB Power Divider A) S-Parameter Result from 2-14.5 Ghz B) Phase at Port 2 and 3.

Later the current distribution over the surface of the transmission line was computed, and the obtained result is shown in Figure 3. It is clear from the figure that the current is distributing uniformly at port 2 and 3 and also some of the currents is passing through the loaded structure, which was not excited directly. However, these loaded structures were automatically coupled due to the excitation of the transmission line. Thus the designed power divider also has a compact size, and it will also contribute towards the compactness when in contact with an antenna array.

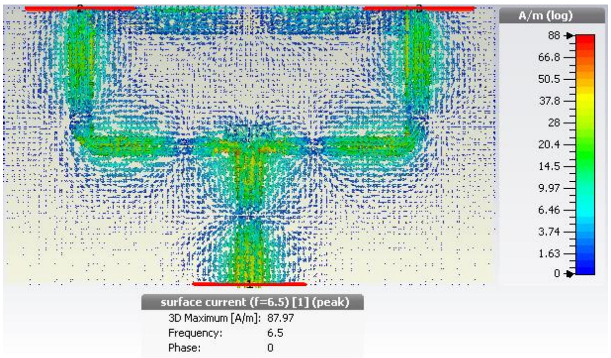

Fig. 3: Surface Current Distribution of UWB Power Divider.

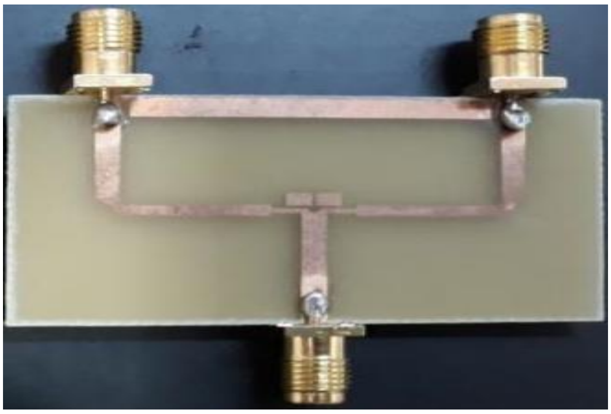

Fig. 4: Fabricated UWB Power Divider.

A)

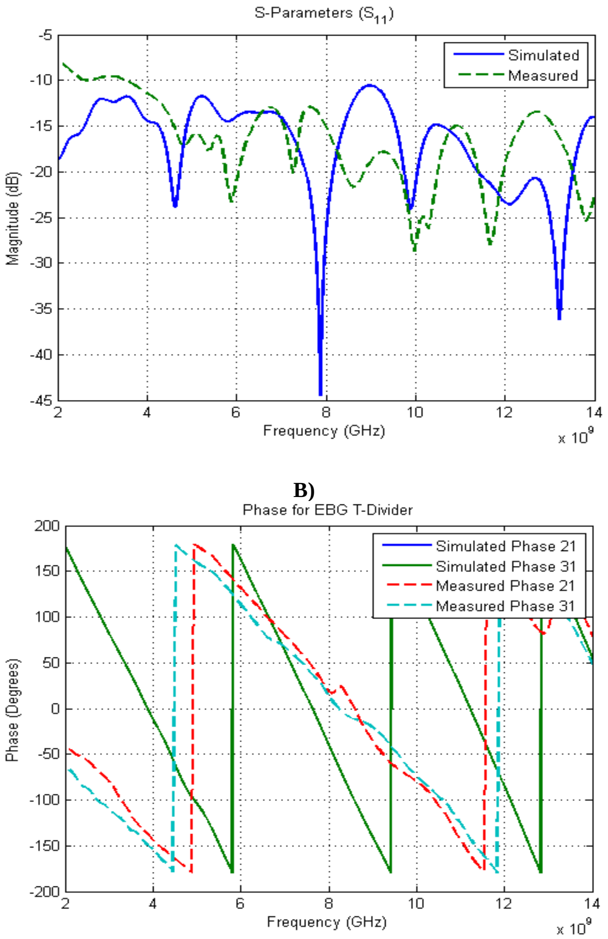

Fig. 5: Measurement and Simulation Results A) S-Parameter; B) Phase.

A 50 Ω terminal port is connected to port 2 and 3 of the circuit to match the terminals phase accordingly. The fabricated power divider as depicted in Figure 4 was measured for the return loss S11, and phase. The measured results in Figure 5(a), it shows that the return loss obtained is within the range of UWB and is below -10 dB cutoff similar to the simulated range. Also, the phase for port 2 and 3 are in phase as shown in Figure 5(b), the slight deviation in the result is due to the calibration error of the VNA available for measurement. Also, because the loaded structure gaps were fabricated manually using a steel blade.

4. Conclusion

A UWB power divider using FR-4 as a substrate has been investigated in this study for UWB applications. A compact UWB power divider has been successfully designing using a tapered line and loaded structure where the S11 obtained from the simulation and measurement are within the UWB frequency range. The phase for port 2 and 3 are in phase which means the power separate equally with the same phase for port 2 and port 3.

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