Design of a compact UWB Wilkinson Power Divider using ring structured and tapered line matching transformer

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Abstract. There is an increasing interest in the design of ultra-wideband (UWB) microwave components for UWB applications. One of the important components in the ultra-wideband application is power divider. In this paper, an ultra-wideband Wilkinson power divider (WPD) using ring structure and tapered line matching transformer is proposed. The aims of this research are to design an UWB WPD for feeding antenna UWB in use of detecting breast cancer. The method used in this research is simulation using finite integration based on CST STUDIO SUITE 2015 3D EM simulator software. This study shows the improvement of output responses due to the introduction of a tapered line and added isolation resistors. The bandwidth and input reflection coefficient are also improved by the ring structure. The proposed UWB WPD can be used for 1:2-way equal power division application in ultra-wideband range, such as UWB antenna which is operating in frequency 3-13 GHz. The simulation result shows that the return loss is better than -10 dB and the insertion loss is about 3.2 dB until 4.15 dB for the operating frequencies and impedance value of 50 ohms.

1. Introduction

Power divider is a passive component used in splitting or combining signals which plays an important role in the microwave applications [1]. Those applications such as microwave imaging, short-range indoor data transmission and positioning, healthcare like body area network, and through-the-wall radars [2]. The earliest and most widely used is Wilkinson power divider which can enable to reach the high isolation and matching between output ports. Nowadays, research works for design of ultra-wideband power divider and other UWB components are carried out extensively because of the advantages of UWB systems. UWB is radio technology which can be used in very low energy levels and operate from 3.1-10.6 GHz [3]. The advantages of the UWB systems are high data-rate and faster transmission capabilities, has low power spectral densities, that is about 41.3 dBm/MHz which is ensuring low interference with narrow-band and other wireless devices [4]. UWB also has advantage of high resolution, extremely low power consumption and low power emission [5].

Numerous works have been carried out to meet the requirements of UWB power divider such as wideband, high isolation, and compact size [6-11]. These works such as Wilkinson power divider [7], chain power divider [8], binary power divider [9], tapered lines power divider [10], defected ground structure [11], etc. Zou et al. has been investigated the performance of interconnected multi-way dividers and the effects the interconnecting lines have on the performance of the multi-way dividers [9]. The input return loss has the symmetric result about the centre frequency and found by the calculation.
the design, an UWB power divider with wide frequency range from 3-13 GHz has been design [10]. The advantage of this design using tapered lines is a better performance and it requires shorter lengths and lower number of elements than the equivalent multi-section Wilkinson power divider has. Design in Michele et al. provides a frequency range spanning from 3.1 GHz to 10.6 GHz with a Chebyshev response using DGS structure [11]. The DGS technique is used to realize the high impedance lines. Even though the return loss is quite good in operating frequency range, but the losses in the high frequency still so high. In this paper, we proposed an UWB Wilkinson power divider designed using tapered line and interconnecting transmission line. The designing and simulation process carried out using EM simulator and microstrip technology.

2. Circuit design
The first step is to design a 2-output port power splitter/divider which should meet all of the specifications. The desired specifications of the UWB Wilkinson power divider are shown in Table 1.

| Parameter       | Value          |
|-----------------|----------------|
| Bandwidth       | 3 GHz-13 GHz   |
| Insertion Loss  | -3 dB ≤ IL ≤ -4 dB |
| Isolation       | ≤ 15 dB        |
| Phase Unbalance | ± 0.2°         |

The design of UWB WPD use Rogers RO4530B as the material of substrate with the dielectric constant of 3.66 and thickness of 1.524 mm. This material used because it has low material losses and good power handling. This material has electric tan δ value of 0.0037 and thermal conductivity is about 0.62 Wm/K.

The impedance is influenced by width of the transmission line that can be calculated using equation (3) [6].

\[ Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{eff}}\left(\frac{W}{H}\right)^2 + 3.393 + 2\ln\left(\frac{W}{H} + 1.444\right)} \] (1)

If quarter-wavelength transmission lines with a characteristic impedance are added after the first stage, the input impedance at the input port of the first stage can be calculated by (2). The input port with this equation is perfectly matched at the centre frequency [9].

\[ Z(f_0) = \frac{(Z_bZ_a^{-1})^2}{2}Z_0^2\left(\frac{Z_bZ_a^{-1}}{2}\right)^2Z_0^{-1} \] (2)

Table 2 shows the parameters which is used in the design of an UWB power divider with ring structure and tapered line. Figure 1 shows the proposed design of an UWB power divider with the final dimension is 55 mm x 23.20 mm.
Table 2. Parameters used for UWB design.

| Parameters | Description                                | Value (mm) |
|------------|--------------------------------------------|------------|
| $T_c$      | Conductor Thickness                        | 0.035      |
| $T_s$      | Substrate’s Thickness                      | 1.524      |
| $L_1$      | Length of the horizontal section of ring structure | 2.82      |
| $L_{w1}$   | Feeder length                              | 3          |
| $R$        | Radius                                     | 1          |
| $L_2$      | Length of tapered line                     | 11         |
| $W_{z0}$   | Width of 50Ω line                          | 3.17       |
| $W_2$      | Width of the ring transmission line        | 0.7        |
| $W_3$      | Width of tapered line                      | 3          |
| $L_{50}$   | Width of tapered line                      | 19         |
| $L_a$      | Length of 50Ω line                         | 7.2        |
|            | Length of 50Ω line which is connected to output ports |         |

Figure 1. Proposed design of UWB Wilkinson Power Divider.

3. Results and discussion
From the simulation results, the values of return losses are smaller than -10 dB in the range of work frequencies, which are from 3 GHz to 13 GHz. Insertion losses that represent the amount of power sent to the output port are in the range of -3.2 dB to -4.15 dB. Return loss and insertion loss charts from the simulation results are shown in Figure 2.

Figure 2. Return loss and insertion loss results of the proposed design.
Isolation between the output ports and return loss for each output ports are other parameters observed in the power divider. In this study, the design of the UWB power divider shows that the return loss output value has a value which is less than -10 dB at the operating frequencies with a maximum return loss of -33.5 dB. Figure 3 shows the results of return loss and insertion loss for each output port in the UWB power divider designed in this research. The return loss shows the performance of the designed UWB power divider.

\[ \text{Figure 3. Return loss results for each output port.} \]

The return loss from figure 3 has the value less than -10 dB from frequency less than 3 GHz until more than 13 GHz. So, the bandwidth is really wide. The maximum return loss value from 3GHz-13 GHz is -33 dB. Besides, the insertion loss value shows the loss is between -3 dB and -4.1 dB. It means that the losses are not too high.

\[ \text{Figure 4. The results of the WPD UWB design isolation that has been made.} \]

Figure 4 shows the isolation between the two output ports. From the graph, it can be seen that the isolation value is less than -15 dB in the range of operating frequencies of the device. Isolation can be repaired by adding an isolation resistor on the two ditched transmission lines. But this will have an effect on increasing the insertion loss value because of losses on resistive loads. A part of the total power sent will be dissipated to heat in each isolation resistor. Therefore, another way to improve isolation is to change the resistance values of each of the isolating resistors.

One of the important things in designing a component is the compatibility with the characteristic impedance of the transmission line, i.e. the impedance must be 50 \( \Omega \). Figure 5 shows the impedance value of the UWB power divider device designed to be in accordance with the impedance of the transmission line. The result shows that the input impedance is 50.035 \( \Omega \) and output impedance is 49.98 \( \Omega \) which has approached the characteristic impedance value of the transmission line. The impedance value in input or output sides reached with changing the width value of the transmission line.
4. Conclusion
An UWB power divider using ring structure and tapered of transmission line has been realized. The developed UWB power divider has simulated return losses lower than -10 dB and isolation lower than -15 dB across the UWB frequency range, even higher, namely 3 - 13 GHz. The insertion loss varies from 3.2 dB up to 4.15 dB. The UWB power divider designed is suitable for amplifier, planar antenna feed network, and UWB radar antenna feed network.

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