Design and implementation of a bandpass Wilkinson power divider with wide bandwidth and harmonics suppression

Hojatollah SOLEYMANI, Sobhan ROSHANI
Department of Electrical Engineering, Kermanshah Branch, Islamic Azad University, Kermanshah, Iran

Abstract: In this paper a Wilkinson power divider (WPD) is presented with ultra wide band of operation and harmonics suppression. This WPD is designed using coupling lines and meandered open stubs at main branches. The center frequency of the presented WPD is 4 GHz, which is fabricated and measured on RT/Duroid substrate with dielectric constant of 2.2. The proposed WPD provides good filtering band with high attenuation level. The 15 dB return loss operational bandwidth (BW) of the WPD is obtained between 3.2 GHz up to 5.3 GHz which shows 50% operational bandwidth.

Key words: Bandpass filter, Harmonic suppression, wide operation band, Wilkinson power divider

1. Introduction

Power dividers (PDs) are important elements in microwave devices which can divide or combine the input signal. WPDs are type of PDs which not only provide good isolation between output ports, but also can reduce the return losses of each port [1–5]. Microstrip transmission lines are used to fabricate the WPD devices in microwave applications. The microstrip lines are composed of a conducting line on a dielectric substrate which is separated from a ground plane [6].

Recently, wideband and multiband operations has become very important in modern communication system. In the following, several techniques in the field of wideband and harmonic suppression are discussed.

Coupled transmission lines are used instead of conventional transmission line to reduce the circuit size and obtain wide band operation in [7, 8]. A relative wide band operation is obtained in [7], however, the overall size of the WPD is rather large. A compact WPD with high selectivity and filtering response is presented in [9]. Five resonators are applied to provide the desired transmission zeros but the WPD suffers from about 1 dB of insertion loss in the pass band. In [10] a divider using hook-shaped resonator is presented at 2.4 GHz with second and third harmonic suppression. High out of band attenuation is obtained in this WPD but the operating pass band is not wide enough. A wideband WPD using distributed stepped impedance resonators (SIRs), operating at 2.3 GHz, is presented in [11]. The aim of presented WPD in [11] is to obtain wide band operation and harmonic suppression. Also, a fractional bandwidth (FBW) of 31% is achieved in this work. Another WPD with wide band operation and harmonic suppression is designed in [12]. The microstrip coupled lines are used in this divider to achieve wide operating bandwidth. Also, series extra resistor and capacitor

*Correspondence: s.roshani@aut.ac.ir
is presented in this work to enhance the isolation of the WPD, however this extra elements increase the cost and complexity of the divider. A filtering WPD with $\pi$ shaped structures is presented in [13]. In this work, the $\pi$ shaped resonators are used to realize the harmonic suppression. The achieved isolation and return losses are good but the operating bandwidth is totally poor. Another filtering WPD with high in band isolation is designed in [14]. The folded resonator is presented in this work to reduce the size and harmonics effects in the WPD. The in-band isolation about 30 dB is obtained in this work. However, the return loss is not acceptable in the pass-band and the fractional bandwidth is 3.5% which is very narrow. A WPD with bandpass response is fabricated in [15]. Two low pass filters (LPFs) and one band pass filter (BPF) is embedded in the structure of this work. The harmonic suppression level in this work is very high but the obtained FBW is 11% which is not wide enough. The BPF embedding technique is also applied in [16] to realize the bandpass response and good isolation between output ports. However, the insertion loss of about 1 dB is obtained in this work, which means that the main frequency signal will be attenuated.

Using open ended stubs [17–22] and compact resonant cell [23] in the main structure of the WPD are the other techniques for harmonic suppression and size reduction. However, both wide band and harmonic suppression merits are not realized in the cited works, simultaneously.

In this paper a WPD with the coupled lines and open ended stubs techniques are designed and implemented to realize harmonic suppression and ultra wideband operation, simultaneously.

2. Design procedure of the presented divider

The basic schematic of the applied topology is illustrated in Figure 1. The aim of the presented WPD is to achieve both harmonic suppression and wide band frequency simultaneously. In this paper, the coupled lines and harmonic suppression techniques are selected to widen the bandwidth and suppress the unwanted harmonics, simultaneously.

A conventional quarter wave length transmission lines could be replaced by coupled transmission lines. By applying these main coupled transmission lines, the basic structure of the WPD will be changed as Figure 2. The values of the coupled transmission lines could be described using equations (1-3) [1].

$$C = \frac{Z_{0o} - Z_{0e}}{Z_{0o} + Z_{0e}},$$

where, in the above equations, $C$ is the coupling coefficient. Also, $Z_{0e}$ and $Z_{0o}$ are the even- and odd-
characteristic impedance of the coupled lines, respectively, which could be obtained as follows [1]:

\[ Z_{0e} = Z_0 \sqrt{\frac{1 + C}{1 - C}} \]

\[ Z_{0o} = Z_0 \sqrt{\frac{1 - C}{1 + C}}, \]

where, \( Z_0 \) is the transmission lines characteristic impedance. The coupling lines can provide the wide band operation of the amplifiers. In addition, the open ended stubs could produce transmission zeros in the frequency response, therefore they could be used for harmonic suppression realizing. Subsequently, two open stubs are added near the output ports of the WPD as shown in Figure 3, which forms the primitive WPD.

The \( ABCD \) matrices of the coupled line (\( ABCD_{CL} \)) and output open stubs (\( ABCD_{OS1} \)) are defined in...
equations (4) [24] and (5) as below.

\[
ABCD_{CL} = \begin{bmatrix}
\frac{Z_{0e}+Z_{0o}}{Z_{0e}-Z_{0o}} \cos \theta & j \left(\frac{(Z_{0e}-Z_{0o})^2+(Z_{0e}+Z_{0o})^2\cos^2 \theta}{2(Z_{0e}-Z_{0o}) \sin \theta}\right) \\
\frac{j}{Z_{0e}-Z_{0o}} \frac{Z_{0e}+Z_{0o}}{Z_{0e}-Z_{0o}} \cos \theta & 1
\end{bmatrix}
\]

(4)

\[
ABCD_{OS1} = \begin{bmatrix}
1 & 0 \\
\frac{j \tan \theta_{OS1}}{Z_{OS1}} & 1
\end{bmatrix}
\]

(5)

Moreover, the \(ABCD\) matrix of the conventional \(\lambda/4\) line in WPD is equal to

\[
ABCD_{QWL} = ABCD_{CL} \times ABCD_{OS1}.
\]

(6)

In the case of structure in Figure 3, the circuit parameters can be calculated as follows.

The electromagnetic (EM) simulation results of the primitive WPD frequency response are depicted in Figure 4. All of the simulations in this paper are performed in Momentum section of advanced design software (ADS). The ADS software uses electromagnetic simulation (EM simulation) for simulating layout structures in Momentum section. EM simulation is a tool which solve the Maxwell’s equation that satisfies the given boundary and initial conditions. According to the frequency response of the primitive WPD, the values of insertion loss and isolation are better than 0.04 dB and 18 dB, respectively. In additions, the 15 dB bandwidth of 0.6 GHz from 3.5 GHZ up to 4.1 GHZ has obtained for the primitive WPD.

![Figure 4. The simulated frequency response of the primitive WPD.](image-url)

In order to size reduction realization for the presented WPD, the primitive WPD should be miniaturized as illustrated in Figure 5. The main couple transmission lines and open ended stubs are meandered to obtain overall size reduction of the divider. Also, the simulated frequency response of the primitive WPD after size
reduction is illustrated in Figure 6. As can be seen in Figures 5 and 6, not only the size reduction has been obtained for the primitive WPD, but also the parameters of the WPD have been slightly improved.

![Figure 5. Structure of the primitive WPD after size reduction.](image)

![Figure 6. The simulated frequency response of the primitive WPD after size reduction.](image)

### 2.1. The proposed power divider

As mentioned the primitive WPD after size reduction has relative good response but it should be improved. For example, good suppression band has been obtained for the divider but the suppression level is not yet acceptable. Therefore, extra transmission zeros should be added in the frequency response. Subsequently, two extra open ended stubs are added in the structure of the divider. After adding these extra open stubs, the final structure of the proposed WPD has been obtained which is shown in Figure 7. The two extra open ended stubs
are added near input port. They are also meandered to reduce the overall size of the divider. In the case of the final structure shown in Figure 7, the circuit parameters can be calculated as follows.

\[ ABCD_{QWL} = ABCD_{OS2} \times ABCD_{CL} \times ABCD_{OS1}. \]  

where, the ABCD matrix of the input open stubs \( ABCD_{OS2} \) can be obtained similar to equation (5).

![Diagram of the proposed WPD structure](image)

**Figure 7.** Structure of the proposed WPD.

The EM simulation results of the proposed WPD frequency response are depicted in Figure 8. As shown in this Figure; the suppression level of the frequency response is improved. Also the insertion losses are enhanced after adding two extra open ended stubs. Applied dimensions in the proposed WPD which are shown in Figure 7 are listed in Table 1.

<table>
<thead>
<tr>
<th>Dimensions (mm)</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>11</td>
<td>7</td>
<td>1.8</td>
<td>2.3</td>
<td>1.6</td>
<td>8</td>
<td>2.2</td>
<td>3.2</td>
<td>0.1</td>
<td>0.2</td>
<td>10.6</td>
<td>0.2</td>
</tr>
</tbody>
</table>

**Table 1.** The applied dimensions in the proposed WPD.

3. Results of the proposed WPD

RT/Duroid 5880 substrate with 31 mil thickness and \( \varepsilon_r = 2.2 \) is used for fabrication of the proposed WPD. Also, HP network analyzer 8720B, 130 MHz to 20 GHz, is used to measure the fabricated power divider. Figure 9 shows the photograph of the implemented WPD.
Figure 8. The simulated frequency response of the proposed WPD.

Figure 9. The photograph of the implemented WPD.

Figure 10. The measured and simulated $S_{21}$ and $S_{11}$ parameters of the proposed WPD.

Final size of the implemented divider is $15.8 \text{ mm} \times 18.8 \text{ mm}$ or $0.29\lambda_g \times 0.34\lambda_g$. The measured and EM simulation results of the proposed WPD frequency response are shown in Figures 10 and 11.
A 15 dB bandwidth of 50% with center frequency of 4.25 GHz corresponding to a 2.1 GHz operational bandwidth from 3.2 GHz up to 5.3 GHz is obtained as shown in Figure 10. The return loss is better than 15 dB in the entire operating bandwidth. Measured insertion loss and isolation are better than 0.8 dB and 16 dB in the entire frequency bandwidth. Also, the maximum output and input return losses are about 32 dB in the operating bandwidth. The presented WPD provides filtering band between 6 GHz up to 10 GHz with attenuation of better than 20 dB. This suppression band provides good harmonic suppression operation for the proposed WPD. In addition, a filtering band with attenuation level of better than 16 dB has been obtained for the lower frequencies up to 2.3 GHz. Parameters of the proposed WPD and the recently presented dividers are compared in Table 2.

Table 2. Parameters of the proposed WPD compared with the recently presented dividers.

<table>
<thead>
<tr>
<th>Refs.</th>
<th>Center Frequency</th>
<th>Insertion Loss</th>
<th>Wide Band</th>
<th>BW</th>
<th>Harmonic Suppression</th>
</tr>
</thead>
<tbody>
<tr>
<td>[9]</td>
<td>0.92 GHz</td>
<td>0.99 dB</td>
<td>-</td>
<td>20 dB BW- 6.5%</td>
<td>✓</td>
</tr>
<tr>
<td>[10]</td>
<td>2.4 GHz</td>
<td>0.45 dB</td>
<td>-</td>
<td>-</td>
<td>✓</td>
</tr>
<tr>
<td>[11]</td>
<td>2.3 GHz</td>
<td>1.3 dB</td>
<td>✓</td>
<td>&lt;10dB BW- 31%</td>
<td>✓</td>
</tr>
<tr>
<td>[12]</td>
<td>1 GHz</td>
<td>0.9 dB</td>
<td>✓</td>
<td>20 dB BW- 43%</td>
<td>✓</td>
</tr>
<tr>
<td>[13]</td>
<td>1 GHz</td>
<td>0.1 dB</td>
<td>-</td>
<td>-</td>
<td>✓</td>
</tr>
<tr>
<td>[14]</td>
<td>1.2 GHz</td>
<td>1.4 dB</td>
<td>-</td>
<td>16 dB BW- 3.5%</td>
<td>✓</td>
</tr>
<tr>
<td>[15]</td>
<td>0.9 GHz</td>
<td>0.68 dB</td>
<td>✓</td>
<td>13 dB BW- 11%</td>
<td>✓</td>
</tr>
<tr>
<td>[17]</td>
<td>2.05 GHz</td>
<td>1.6 dB</td>
<td>✓</td>
<td>10 dB BW- 62%</td>
<td>✓</td>
</tr>
<tr>
<td>[25]</td>
<td>2 GHz</td>
<td>0.9 dB</td>
<td>-</td>
<td>15 dB BW- 11%</td>
<td>-</td>
</tr>
<tr>
<td>This Work</td>
<td>4 GHz</td>
<td>0.8 dB</td>
<td>✓</td>
<td>15 dB BW- 50%</td>
<td>✓</td>
</tr>
</tbody>
</table>

As seen in Table 2, only a few reported works have wideband operation. However, the BW definitions are different among the reported works, because of different values of input return loss consideration in the bandwidth. For example, the highest BW in the Table belongs to WPD in [17]. But, the BW definition in [17] is the operating band in which the input return loss is considered better than 10 dB which is not desirable. Also, insertion loss is another important parameter in power divider design, which, insertion loss greater than 1 dB is not desirable. Therefore, in the proposed work according to high BW with better than 15 dB input return loss and low value of insertion loss in the operating band, excellent parameters have been achieved, compared with
the other researches. Also the proposed work shows good harmonic suppression for entire operating bandwidth.

4. Conclusion
A harmonic suppressed power divider with ultra wide operating band is presented in this paper. For verification, the designed divider is fabricated, and the simulation results are verified with the measurement data, which shows good agreement. The main merits of the proposed divider are harmonic suppression and ultra wide band operation, simultaneously. Also the other parameters of the divider are desirable which makes this divider applicable in the modern communication systems.

References


