Reconfigurable Feeding Network with Dual-band Filter for WiMAX Application

N. Edward¹, Z. Zakaria², N. A. Shairi³
Centre for Telecommunication Research & Innovation (CeTRI), Faculty of Electronic and Computer Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

ABSTRACT
Design and simulation for reconfigurable Wilkinson Power Divider (WPD) related to WiMAX application is proposed in this paper. This proposed design relates to dual band WiMAX frequencies at 2.5 GHz and 3.5 GHz. The main purpose of this design is to design a switchable feeding network that can cover the WiMAX standards by reconfiguring the microstrip line length using PIN diode switches. Besides, the power divider also can be design and develop as power combiner due to the passive component structure and hence reciprocal. In this proposed Wilkinson power divider, different band of frequencies for WiMAX application are obtained by using PIN diode. By turning ‘ON’ and ‘OFF’ the PIN diode, different frequencies are achieved between 2.5 and 3.5 GHz. This proposed design used Rogers RO4350 (er = 3.48, h = 0.508mm) as a substrate material and copper (thickness = 0.002 mm) related to patch of design. This simulation results showed that the S11 is less than -15dB; and S12 and S13 are better than -5dB. Based on these simulation results, the proposed WPD design using dual-band filter was well applied where it has better return loss (S11) with less than -15 dB for both WiMAX frequencies.

Keywords:
Dual-band filter
PIN diode
Reconfigurable
Wilkinson power divider
WiMAX

1. INTRODUCTION
Nowadays, reconfigurable mobile terminals have become the trend. Therefore, in order to fulfil these targets, a lot of reconfigurable antennas have been demonstrated in practice and examined [1]-[3]. Advanced feeding network is essential to support the systems such as smart antennas and phase-array antennas to be fully achieved [4]-[6]. The Wilkinson power divider (WPD) is one of the essential components in various microwave circuits and it has been commonly used for combination and power division in antenna feeding networks [6]-[9]. The conventional Wilkinson divider utilizes two quarter-wavelength transmission lines and only operates at a certain frequency [10].

In [11], a power divider which integrates coupler and filter is designed for radar systems. However, it is not tunable and the design is more complex. In order to make the power divider tunable, there are several actions can be done, such as using varactors [12]-[15]. But by using varactors, the design of WPD would become more complex. In [14], the tunable power divider is designed by electrifying the upper and lower surface electrode of the liquid crystal (LC) and changing the voltage value [16]. However, this design would complicate the fabrication process. Furthermore, by using PIN diodes, the tunable power divider capabilities can be obtained [17], [18].

Copyright © 2017 Institute of Advanced Engineering and Science. All rights reserved.

Corresponding Author:
Zahriladha Zakaria,
Centre for Telecommunication Research & Innovation (CeTRI), Faculty of Electronic & Computer Engineering, Universiti Teknikal Malaysia Melaka (UTeM), Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
Email: zahriladzhakaria@edu.com.my

Journal homepage: http://iaesjournal.com/online/index.php/IJECE
This project presents a miniaturized reconfigurable and switchable feeding network with dual-band filter for WiMAX standards, which is 2.5 GHz and 3.5 GHz. The feeding network comprises of two conventional WPD which can be individually reconfigured in length by using PIN diode switches. By adjusting the bias voltages of these PIN diodes, the operating frequency of the propose design can be altered between two different frequency bands: 2.3 GHz - 2.75 GHz and 3.25 GHz-3.9 GHz.

2. RESEARCH METHOD
2.1. Wilkinson Power Divider and Design Equation
The Wilkinson power divider, proposed by Ernest Wilkinson in 1960 gives isolation between ports in the output, is adept to match in all ports, and can be lossless when port at the output matches [19]. Figure 1 presents the equal transmission line circuit for WPD, where the force delivered to both ports at the output is equivalent [10].

![Figure 1. The circuit model of transmission line for WPD [10]](image)

Wilkinson Power Divider is a three port network consisting one input port and two output ports as shown in Figure 1. Mostly, depend on the application using it, power is divided equally or unequally at two different working of frequencies. At 2.5 GHz, 3.5 GHz and $Z_0 = 50 \, \Omega$ is used to design the power divider in which it needs resistor of isolation to be $2 \, Z_0 = 100 \, \Omega$ and the impedance of quarter-wave section split transmission line become $\sqrt{2}Z_0 = 70.7 \, \Omega$. The perfect S-matrix of the Wilkinson power divider with load that is matched is shown in (1).

$$S = \frac{-1}{\sqrt{2}} \begin{bmatrix} 0 & 1 & 1 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \end{bmatrix}$$

(1)

Scattering matrix indicates that as the signal entered to the port two, it will be the same which separated into ports two and three. Port which is matched sets $S_{11}$, $S_{22}$ and $S_{33}$ equals zero. As the signal is entered the port one, the power divider would be lossless. The magnitude (total squares each component) of column one of the scattering matrix is equivalent to one [10].

2.2. Design of Ideal WPD
Based on the Figure 2, it shows the schematic diagram and the equivalent lumped component circuit of WPD. The first step is to design the WPD by using Advanced Design System (ADS) software based on the schematic circuit below. We choose $Z_0 = 50 \, \Omega$.

![Figure 2. Schematic diagram and equivalent lumped component.](image)
After that, the ideal WPD is tested with dual-band filter to compare the performance of the ideal WPD with the proposed power divider. Figure 4 shows the design of the ideal WPD with dual-band filter. The dual-band filter is the combination of band-pass filter and band-stop filter.

2.3. The Proposed Design of WPD

Parametric study is done to narrow the frequency band of the WPD to make it only work at one frequency after testing it with the dual band filter. In ADS, the parameter of the power divider is tuned such as the width and the length to see the effect on the output. After that, both designs are combined to make it into one design by using pin diode to reconfigure the length of the transmission line in power divider. Figure 5 shows the circuit configuration after combined of the two power divider designs and D1-D8 are the pin diodes.

Figure 5. (a) WPD at 2.5 GHz, (b) WPD at 3.5 GHz and (c) The circuit configuration after combined the two WPDs.
From Figure 5 (c), when D3, D4, D5 and D6 are turned off, the power divider operates at frequency of 2.5 GHz and when D1, D2, D7, and D8 are turned off, the power divider operates at frequency of 3.5 GHz. After done with simulation of the proposed WPD’s circuit, then we need to generate the circuit layout and performed electromagnetic (EM) simulation which is more accurate than circuit simulation. Figure 6 shows the generated circuit layout of the proposed feeding network in EM simulation and the position of the pin diodes, D1-D8, in the circuit layout.

![Circuit Layout](image)

Figure 6. The circuit layout of the proposed WPD.

After that, the symbol of the layout is generated after simulation in EM. The symbol is dragged to a new schematic window and the view of the simulation can be either EM model, layout or schematic. In this simulation, the view for simulation of the circuit layout is chosen as layout. The symbol is tested with the dual band filter to analyze the performance of the proposed feeding network. Figure 7 and 8 shows the configuration of the symbol tested for WPDs operating at frequencies of 2.5 GHz and 3.5 GHz respectively.

![Circuit Layout with Dual Band Filter](image)

Figure 7. The circuit layout with dual band filter at 2.5 GHz.

![Circuit Layout with Dual Band Filter](image)

Figure 8. The circuit layout with dual band filter at 3.5 GHz.

3. RESULTS AND ANALYSIS

3.1. The Proposed Design of WPD

It has been analyzed that the transmission line at port 1 effect the most to make it narrow band. That’s mean this power divider does not have the same impedance with the conventional Wilkinson power divider. That is because the transmission line at the ports of the conventional Wilkinson power divider are $Z_0$ which is 50 $\Omega$, but after tuning the width and length of the transmission line, it will not have the same impedance. Therefore, for the conventional power divider, all transmission lines will be in the same width and length of the transmission line. But, for this design to have narrow frequency band, the transmission line
at the ports does not have the same size, which means that, port 1 have different values of impedance than port 2 and 3. After tuning the transmission line at the ports, port 1 have different dimension than port 2 and 3. But, for port 2 and port 3, it has the equal dimension of transmission line even after tuning. That is because it is to achieve the same output at port 2 and port 3. After that, both designs are combined to make it into one design by using pin diode to reconfigure the length of the power divider. From the analysis that have been made, it is found that the transmission line of the ports plays important role in getting narrow band.

The proposed power divider in Figure 5 (c) is simulated to obtain the S11, S12, S13 and S23 at 2.5 GHz and 3.5 GHz. When pin diode D3, D4, D5 and D6 are turned off, the power divider will operate at 2.5 GHz as shown in Figure 5 (a). When pin diode D1, D2, D7 and D8 are turned off, the power divider will operate at 3.5 GHz as shown in Figure 5 (b). The following Figure 9 and 10 shows the result for S11, S12, S13 and S23 at 2.5 GHz and 3.5 GHz respectively. The pin diode in the design is assumed as switch on and off to switch the frequency either 2.5 GHz or 3.5 GHz.

Figure 9. S11, S12, S13 and S23 results for WPD at 2.5 GHz.

Figure 10. S11, S12, S13 and S23 results for WPD at 3.5 GHz.

The return loss of proposed WPD at 2.5 GHz is about -16.353 dB, S23 is -7.871 dB, S12 and S13 is -3.9025 ± 0.0085 dB. Meanwhile, the return loss of WPD at 3.5 GHz is about -18.584 dB, S23 is -15.945 dB, S12 and S13 is -3.765 dB. In the EM simulation, it is found that the center frequency of the return loss is shifted to the left compared to circuit simulation. Therefore, in order to obtain the center frequency of the return loss at 2.5 GHz in EM simulation, we must obtain the center frequency higher than 2.5 GHz in circuit simulation. Then, the center frequency will be at 2.5 GHz for the return loss in EM simulation, same goes with center frequency at 3.5 GHz. Figure 11 and 12 shows the EM simulation’s result, S11, S12, S13, and S23 at 2.5 GHz and 3.5 GHz respectively. Compared to results in Figure 9 and 10, it shows that the center frequency did shift when in EM simulation.
The return loss for the proposed WPD at 2.5 GHz is -21.13 dB and at 3.5 GHz is -21.489 dB. The value for S12 and S13 for 2.5 GHz is -3.849 dB and for 3.5 GHz is -3.781 dB and -3.754 dB respectively. S23 that we get for the proposed power divider that operated at frequency 2.5 GHz is -7.215 dB and at 3.5 GHz is -7.298 dB. After that, the symbol of the layout is generated after simulation in EM and tested with the dual band filter. The following figures, Figure 13 and 14 show the results, S11, S12 and S13 for the proposed WPD which is tested with dual-band filter operates at frequency of 2.5 GHz and 3.5 GHz.
Based on the results that we get in Figure 13, when the proposed WPD operating at 2.5 GHz is tested with dual-band filter, only at 2.5 GHz frequency band of the dual band filter is turned on and it turned off the other frequency band. Meanwhile, when the proposed WPD operating at 3.5 GHz is tested with dual-band filter, only at 3.5 GHz frequency band of the dual band filter is turned on and turned off the other frequency band.

3.2. Design of Ideal WPD

Figure 15 and 16 shows the return loss, S11 and insertion loss, S12, S13 for both frequencies at 2.5 GHz and 3.5 GHz for an ideal transmission line respectively. It can be seen that both frequencies have return loss about -100 dB.

Figure 14. The results S11, S12, and S13 of the circuit layout tested with dual band filter at 3.5 GHz.

Figure 15. S11, S12, and S13 results for ideal WPD at 2.5 GHz.

Figure 16. S11, S12, and S13 results for ideal WPD at 3.5 GHz.
When the dual band filter is attached to the proposed WPD’s ports, only one frequency band will be turned on and the other band will be turned off. The dual band filter is operated at 2.5 GHz and 3.5 GHz. If the dual band filter is attached to the proposed WPD of 2.5 GHz, only the frequency band of the filter at 2.5 GHz will be turned on. But, by using the conventional design of WPD, it cannot turn off one of the band. Figure 17 and 18 shows the S11, S12 and S13 results for ideal WPD with dual band filter at 2.5 GHz and 3.5 GHz respectively. It proved that the ideal WPD that is connected to the dual band filter can’t turn off any one of the frequency band.

![Figure 17](image1.png)

**Figure 17.** S11, S12, and S13 results for ideal WPD with dual band filter at 2.5 GHz.

![Figure 18](image2.png)

**Figure 18.** S11, S12, and S13 results for ideal WPD with dual band filter at 3.5 GHz.

Table 1 shows the comparison of this work with previous work on the reconfigurable feeding network. In [17], the design is based on the conventional WPD and used pin diode as the tuning element. The conventional WPD has a wideband frequency. So, it cannot work with dual-band filter and can only reconfigure the operating frequency of the power divider.

| [17]                      | This work                  |
|---------------------------|----------------------------|
| **Type of power divider** | Conventional Wilkinson     |
|                           | power divider              |
| **Tunable element**       | Pin diode                  |
| **Type of frequency band**| Wideband                   |
| **Tunable properties**    | Operating frequency of     |
|                           | power divider              |
| **Work with dual-band filter** | No                       |
|                           | Operating frequency of     |
|                           | power divider and frequency|
|                           | band of dual-band filter   |
4. CONCLUSION

The design of the Reconfigurable Feeding Network with dual band filter for WiMAX Applications have been successfully designed, simulated, and investigated. Two of Wilkinson power dividers are designed and combined by reconfiguring the length of the transmission line using PIN diode. The conventional WPD has wideband frequency, but for this WPD design, it requires narrowband frequency either at frequency of 2.5 GHz or 3.5 GHz. The simulation results of the switchable feeding network showed good agreement for both frequencies with the return loss below -20 dB and S12/S13 better than -10 dB that have been achieved.

ACKNOWLEDGEMENTS

We are grateful to UTeM Zamalah Scheme, Center for Research and Innovation Management (CRIM) and Universiti Teknikal Malaysia Melaka (UTeM) for their encouragement and help in supporting financially to complete this research work.

REFERENCES

[1] A. Ghasemi, N. Ghalvbehchian, A. Mallahzadeh, S. Sheikholvazien. A reconfigurable printed monopole antenna for MIMO application. 2012 6th European Conference on Antennas and Propagation (EUCAP). Prague. 2012. pp. 1-4.
[2] J. H. Lim, G. T. Back, Y. I. Ko, C. W. Song, T. Y. Yun. A Reconfigurable PIFA Using a Switchable PIN-Diode and a Fine-Tuning Varactor for USPCS/WCDMA/m-WiMAX/WLAN. IEEE Transactions on Antennas and Propagation. 2010; 58(7): 2404-2411.
[3] A. Khaleghi, M. Kamvab. Reconfigurable Single Port Antenna With Circular Polarization Diversity. IEEE Transactions on Antennas and Propagation. 2009; 57(2): 555-559.
[4] S. H. Wi, Y. P. Zhang, H. Kim, I. Y. Oh, J. G. Yook. Integration of Antenna and Feeding Network for Compact UWB Transceiver Package. IEEE Transactions on Components, Packaging and Manufacturing Technology. 2011; 1(1): 111-118.
[5] S. Hebib, H. Aubert. Triband antenna feeding circuit for circular polarization diversity. 2011 41st European Microwave Conference, Manchester. 2011. pp. 890-893.
[6] J. L. Robert, P. Minard, A. Louzir. Feeding Concept for a Multisector Antenna System. 2008 38th European Microwave Conference, Amsterdam, 2008. pp. 1102-1105.
[7] A. H. Abdelrahman, F. Elhefnawi, A. Z. Elsherbeni, M. Hendi, S. Elramy. Compact circularly-polarized microstrip array antenna. 2010 Loughborough Antennas & Propagation Conference. Loughborough. 2010. pp. 113-116.
[8] C. H. Weng, H. W. Liu, C. H. Ku, C. F. Yang. Dual circular polarisation microstrip array antenna for WLAN/WiMAX applications. Electronics Letters. 2010; 46(9): 609-611.
[9] A. B. Santiko, N. D. Susanti, Taufiqurrachman. Compact Structure and Low Losses for Wilkinson Power Divider at 9400MHz Frequency for X-Band Antenna System. TELKOMNIKA. 2017; 15(1): 143-149.
[10] D. Pozar, Microwave Engineering, 3rd ed. Hoboken, New Jersey: John Wiley & Sons Inc. pp. 308-361, 2005.
[11] Y. Y. Maulana, Y. P. Saputera, A. B. Santiko, A. Setiawan. Compact Power Divider Integrated with Coupler and Microstrip Cavity Filter for X-band Surveillance Radar System. TELKOMNIKA. 2017; 15(1): 227-237.
[12] C. F. Chen, C. Y. Lin, B. H. Tseng, S. F. Chang. Compact microstrip electronically tunable power divider with Chebyshev bandpass response. 2014 Asia-Pacific Microwave Conference, Sendai, Japan. 2014. pp. 1291-1293.
[13] X. Y. Zhang, L. Gao, J. X. Xu. Tunable power divider based on coupled resonator with high-selectivity filtering response. 2015 IEEE MTT-S International Microwave Workshop Series on Advanced Materials and Processes for RF and THz Applications (IMWS-AMP). Suzhou. 2015. pp. 1-3.
[14] X. Shen, Y. Liu, S. Zhou, Y. Wu. A novel compact tunable coupled-line power divider using varactors. 2015 Asia-Pacific Microwave Conference (APMC). Nanjing. 2015. pp. 1-3.
[15] L. Guo, H. Zhu, A. M. Abbosh. Wideband Tunable In-Phase Power Divider Using Three-Line Coupled Structure. IEEE Microwave and Wireless Components Letters. 2016; 26(6): 404-406.
[16] Z. Guo, D. Jiang, H. Chen. A compact tunable filtering-power divider based on liquid crystal. 2015 IEEE International Conference on Communication Problem-Solving (ICCP). Guilin. 2015. pp. 416-418.
[17] W. Zhou, T. Arslan, K. Benkrid, A. O. El-Rayis, N. Haridas. Reconfigurable feeding network for GSM/GPS/3G/WiFi and global LTE applications. 2013 IEEE International Symposium on Circuits and Systems (ISCAS2013). Beijing. 2013. pp. 958-961.
[18] W. Zhou, T. Arslan, B. Flynn. A reconfigurable feed network for a dual circularly polarised antenna array. 2013 IEEE 24th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC). London. 2013. pp. 430-434.
[19] E. J. Wilkinson. An N-Way Hybrid Power Divider. IRE Transactions on Microwave Theory and Techniques. 1960; 8(1): 116-118.