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Miniaturized Power Divider with Triple-Band Filtering Response Using Coupled Line

GROUP NO. – B15

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Abstract—***This report explains the design and analysis of a miniaturized efficient triple-band filtering power divider (FPD). The device operates at three frequency ranges: 1.23GHz, 2.41GHz, and 3.55GHz. This device uses coupled-line resonators for signal splitting and filtering across three distinct frequency bands. The design demonstrates high performance with minimal signal loss, good isolation, and accurate filtering obtained both by simulations and measurements. Its small size and simple design, the FPD is highly suitable for applications like Wi-Fi and 5G, aligning well with theoretical predictions and experimental results.***

Keywords—Resonant frequency, Power dividers, Passband, Band-pass filters, Filtering, Resonators, Impedance, Coupled line, isolation, filtering power divider, miniaturized, triple-band

I. INTRODUCTION

The publication [1]"Miniaturized Power Divider with Triple-Band Filtering Response Using Coupled Line" focuses on the design and implementation of a triple-band power divider that is compact and efficient. This work builds on the [2] Wilkinson power divider (WPD) concept by replacing conventional quarter-wave transmission lines with coupled-line resonators, enabling simultaneous power division and filtering.

Figure 1 illustrates the proposed power divider's schematic and fabricated prototype, highlighting its compact layout on an FR4 substrate.

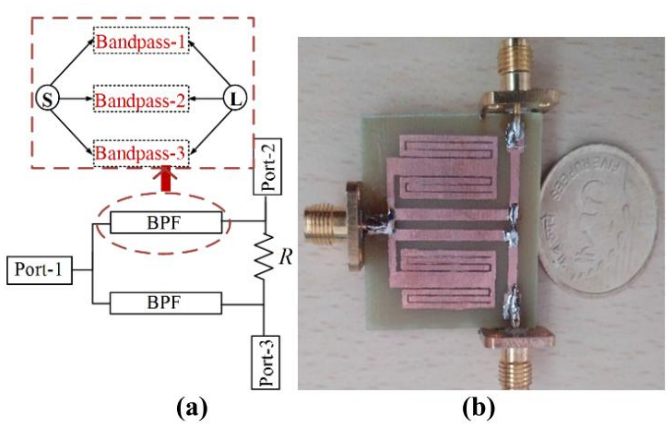


FIGURE 1. [1] Proposed filtering power divider: (a) Schematic topology, (b) fabricated prototype.

The layout of the proposed FPD, shown in Figure 2, features three coupled-line resonators: Resonator-1, Resonator-2, and Resonator-3 to achieve the triple-band response at frequencies of 1.23 GHz, 2.41 GHz, and 3.55 GHz. The resonant frequencies can be fine-tuned by modifying the size and spacing of the resonators. The proposed FPD incorporates isolation resistor positioned between the output ports to ensure minimal signal interference and stabilize the device's performance. The power divider was fabricated using an FR4 substrate and tested for performance.

The results showed fractional bandwidths of 20% (1.1 GHz to 1.35 GHz), 37% (2.0 GHz to 2.9 GHz), and 15% (3.25 GHz to 3.8 GHz) for the three frequency bands. By placing two resistors between two pairs of symmetrical resonators centred on the central input feed line, the isolation between the ports is also increased[1]. High isolation between the output ports and a compact size makes it suitable for applications like L-band, WLAN, and sub-6 GHz 5G systems.

This emphasizes the importance of compact and efficient multiband components in wireless communication systems.

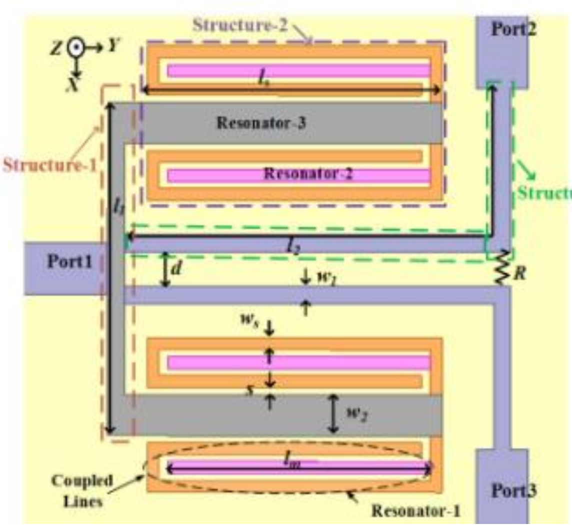


FIGURE 2. [1] The structural layout of the designed triple band Filtering power divider [All dimensions are in mm: l_1 = 19.5, l_2 = 31.0, l_s = 17.2, l_m = 15.3, w_1 = 1.0, s = 0.4', w_s = 0.7, w_2 = 2.4, d = 2.0].

II. Research Question

The primary research question of this study addresses: “How can a miniaturized power divider be designed to filter signals for three frequency ranges while maintaining high isolation and efficiency?”. This study aims to address the growing demand for multiband functionality in wireless systems and focuses on the use of coupled-line resonators to achieve this functionality. The design parameters of the FPD, such as the length and gap of the coupled lines are optimized, to achieve the desired operational frequencies and bandwidths with minimal interference between output ports.

[2] Wilkinson power dividers (WPDs), are effective, but they have certain limitations in multiband applications. WPDs depend on quarter-wave transmission lines, which are bulky and unsuitable for size-constrained systems. Additionally, these designs often require separate filtering components, increasing the overall size and complexity of the circuit. WPDs also face challenges in achieving high isolation and consistent performance across multiple frequency bands, which limits their applicability in advanced wireless systems.

To overcome these limitations, [1] this study incorporates coupled-line resonators into the power divider design to enable triple-band operation. By combining filtering and power division functionalities into a compact structure, the proposed design eliminates the need for separate filtering components and reduces the size of the device. This study presents an effective solution to address the limitations of WPDs, demonstrating strong isolation, low insertion loss, and precise filtering for multiband systems.

III. Simulation Output In HFSS

In our project, the proposed triple-band filtering power divider was simulated in HFSS. The model developed in HFSS, is shown in Figure 3. It incorporates material properties and boundary conditions matching those of the fabricated prototype. The model included three coupled-line resonators connected to achieve the frequencies of 1.23 GHz, 2.41 GHz, and 3.55 GHz.

The model was analysed to evaluate key parameters such as insertion loss, return loss, isolation, and E-field distributions.

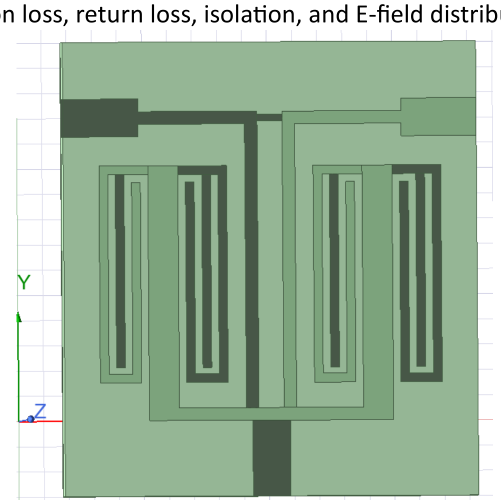


FIGURE 3. HFSS designed structure.

The simulated S-parameter results are shown in Figure 4. The key observations include:

- **Resonant Frequencies -** 1.2275 GHz, 2.1812 GHz, and 3.4937 GHz, closely matching theoretical values.
- **Insertion Loss, |S21| -** Below 3 dB across all three passbands, ensuring efficient signal transmission, with specific values of 0.7 dB (1st band), 0.6 dB (2nd band), and 0.5 dB (3rd band).
- **Return Loss, |S11| -** Greater than 19.5 dB, indicating excellent impedance matching and minimal signal reflection.
- **Isolation, |S23| -** Greater than 18 dB for all bands, indicating strong separation between output ports.
- **Fractional Bandwidths -** 22.1%, 35%, 13% for the three frequency bands 1.0875GHz to 1.3587GHz, 1.91GHz to 2.6625GHz, 3.2662GHz to 3.72GHz respectively.

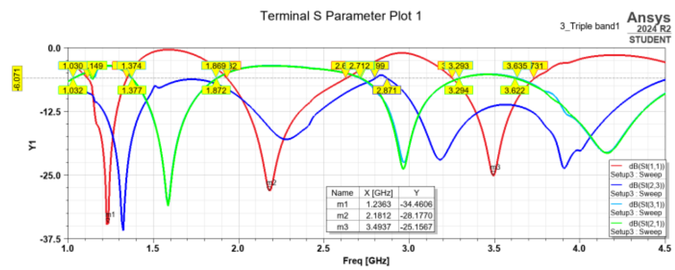
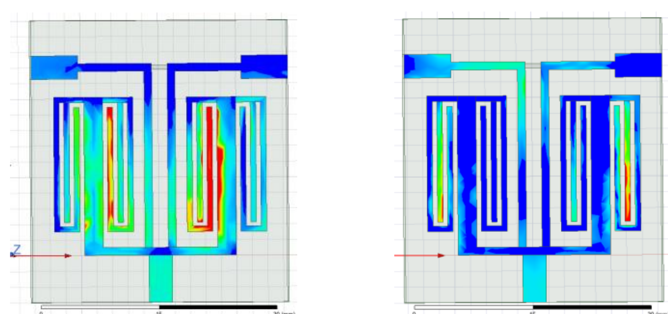


FIGURE 4. Simulated S-parameter of tri-band

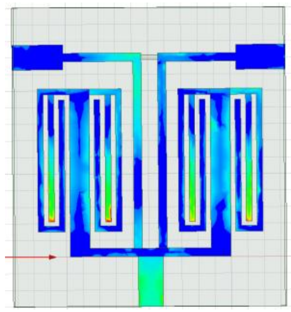
The electric field distributions at resonant frequencies showed concentrated fields in the resonator regions validating theoretical expectations. Figure 5 shows the E-field patterns for the three frequencies – 1.23 GHz, 2.41 GHz, 3.55 GHz.

At 1.23 GHz, the E-field distribution is highly concentrated around Resonator-1, showing that it primarily controls the first passband. At 2.41 GHz, Resonator-2 dominates the E-field distribution, with significant energy concentrated along its structure. At 3.55 GHz, the E-field is concentrated around Resonator-3.

These results confirm the reliability and effectiveness of the power divider in maintaining performance across the specified bands.



(a) (b)



(c)

FIGURE 5. **E-field distribution of tri-band FPD: (a) 1.23 GHz, (b) 2.41 GHz, and (c) 3.55 GHz.**

IV. Comparison And Interpretation

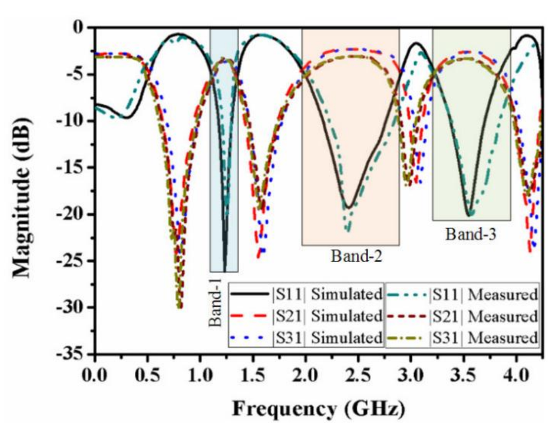
Figure 6 shows the S-parameter results of the triple-band FPD, comparing the simulated data with the results provided in the publication. The simulation results were closely matched with the results in the publication.

Specific comparisons include:

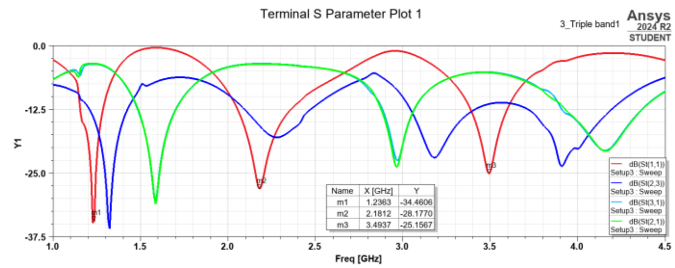
- **Resonance Frequencies:** The publication reported [1] resonance frequencies at 1.23 GHz, 2.41 GHz, and 3.55 GHz. Simulations closely matched these. The resulted resonance frequencies after simulation are at 1.2275 GHz, 2.1812 GHz, 3.4937 GHz, confirming the device could effectively work at desired bands. The slight variations between simulated and measured frequencies are due to practical factors like slight variations in material properties.
- **Bandwidths:** The paper reported [1] fractional bandwidths of 20%, 37%, and 15% for the three frequency bands, while simulated fractional bandwidth are 22%, 35%, and 13%, respectively.

The small differences are likely due to the ideal conditions in simulations compared to real-world experiments.

- **Isolation:** The simulated isolation levels exceeded 18dB and the paper reported isolation exceeds in 18dB.
- **Insertion Loss and Return Loss:** Both experimental and simulated results showed insertion loss below 3 dB and return loss above 19.5dB, confirming the reliability of the design practically.



(a)



(b)

FIGURE 6. **S-parameter of tri-band FPD: (a) [1] publication results (b) HFSS simulation results.**

The results align well with the theoretical principles discussed in the study.

The resonant frequencies depend on the inductance and capacitance of the coupled-line resonators, which are determined by the physical dimensions of the structure. Adjusting the resonator dimensions helps to tune these frequencies. Increasing the length of the resonators resulted in lower frequencies due to increased inductance. Modifying the spacing between resonators tuned the coupling strength and operational pass bands.

$$fr = \frac{1}{2\pi\sqrt{LC}}$$

By replacing traditional quarter-wave lines with coupled-line resonators, the device significantly reduces its size. This design has high performance with fewer components, making it both practical and cost-effective for modern applications.

V. Conclusion

The proposed triple-band filtering power divider successfully meets the demands of modern wireless communication systems. Power dividers, commonly referred to as power combiners, find their application in various circuits such as mixers, balanced amplifiers, and antenna feed circuits [2]. By combining compact design, high isolation, and minimal signal loss, it is useful for multiband applications like Wi-Fi, L-band, and sub-6 GHz 5G technologies. The project successfully reproduced the key outcomes of the publication, demonstrating the practical and effective proposed triple-band filtering power divider for multiband wireless applications.

Reference

[1] D. K. Choudhary, N. Mishra, P. K. Singh and A. Sharma, "Miniaturized Power Divider With Triple-Band Filtering Response Using Coupled Line," in IEEE Access, vol. 11, pp. 27602-27608, 2023, doi:10.1109/ACCESS.2023.3257985.

[2] M. C. Farah and F. S. Belkhodja, "Design of Wilkinson Power Divider for Mobile and WLAN Applications," in *All Sciences Proceedings*, vol. 1, 1st International Conference on Pioneer and Innovative Studies, pp. 53-56, Konya, Turkey, Jun. 2023