A NOVEL WILKINSON POWER DIVIDER FOR IOT APPLICATIONS

Abstract

The utilization of a power divider is essential for distributing power among multiple devices. This study introduces an innovative approach by employing the Wilkinson power divider with a lossless junction. In the context of IoT devices, a major concern revolves around their substantial power consumption, posing limitations on battery life and overall efficiency. To mitigate this challenge, the paper suggests the use of modulators in lieu of traditional transceivers, presenting a solution to enhance IoT devices. The passive characteristics of modulators, combined with the efficient signal division facilitated by the Wilkinson power divider, contribute to a reduction in power consumption. This, in turn, extends battery life, elevates efficiency, and bolsters the overall performance of IoT devices. This method incorporates a simple switch in its implementation, ensuring simplicity and a design characterized by low complexity.

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I. INTRODUCTION

The Internet of Things (IoT) refers to a network of physical objects, or "things," equipped with sensors, software, and other technologies to communicate and exchange data with other systems over the internet. In today's world, wireless channels play a crucial role in most communications. The radiofrequency (RF) spectrum is essential for wireless communication infrastructure, and the IEEE 802.11 standard defines various RF bands used for Wi-Fi connections, ranging from 900 MHz to 60 GHz.

Wireless telecommunications networks use radio communication for various purposes, such as radio and TV transmission, mobile phones, two-way radios, wireless networking, and satellite communication. Radio waves, which fall within the frequency range of 30Hz to 300 GHz, are crucial for wireless communications. A transmitter connected to an antenna generates radio waves, which are then received by another antenna connected to a radio receiver.

Power dividers are electronic devices that split an input signal into two or more signals with lower power. These dividers are often used with antennas to radiate radio waves efficiently. In wireless networks, devices communicate through wireless data links between network nodes. Examples of wireless networks include cell phone networks, satellite communication networks, wireless sensor networks, WLANs, and terrestrial microwave networks.

Wireless technology has revolutionized communication, enabling seamless connectivity and data exchange between devices and systems. IoT and wireless networks continue to drive innovation and transform various industries, making them more efficient and interconnected.

II. POWER DIVIDER

Power division becomes necessary in RF and microwave systems when the available power needs to be distributed among multiple applications. To accomplish this, a convenient device called a power divider is used. This device takes a single input signal and produces two or more output signals with equal or unequal power distribution [1].

A power divider operates on a simple principle: In equal power distribution, the power level of each output signal is 1/N of the power level of the input signal, where N represents the number of outputs in the divider. For example, if there are two output signals, each will receive half the power of the input signal. Similarly, if there are four output signals, each will receive one-fourth of the input power. Otherwise, the power will be distributed in random ratios among the outputs [2].

In the most common type of power divider, the output signals are maintained in phase. This means that the peaks and troughs of the signals occur simultaneously, resulting in constructive interference. As a result, the output signals are synchronized and can be used efficiently in various applications where coherent signal distribution is essential.

A power divider is a useful device in RF and microwave systems when power needs to be shared among multiple applications [3]. By equally or unequally dividing the input power among two or more output signals, it enables effective signal distribution and synchronization, making it an essential component in modern communication systems and applications. There are special power dividers that provide controlled phase shifts between outputs [4].

The power divider finds extensive application in microwave and millimeter-wave circuits, serving as a fundamental component in various systems [5]. It is commonly used as a feeder network for phased-array antennas, power amplifiers, and other circuit elements. Additionally, it plays a crucial role in transmission line fault testing, balanced amplifiers, RF transmitters, and receivers, as well as phase shifters.

The power divider's versatility is evident in its usage for signal separation in telephone lines, inter-modulation distortion tests, and antenna beamforming networks. Furthermore, it serves as a power combiner when applied in reverse, combining two lower power signals into a single output signal.

In the initial designs of power dividers, specifically T-junctions, a significant drawback was the lack of isolation between the output ports [6]. The T-junction power divider has three ports, with the input signal being fed through Port 1. The main objective is to evenly distribute the power across Ports 2 and 3 without any signal reflections, as illustrated in Figure 1. However, due to the insufficient isolation between the output ports, there could be issues with power distribution. The power output through Ports 2 and 3 might not be consistent because of the mutual interference or coupling between these ports. This lack of isolation can result in some of the power intended for one output port leaking into the other, leading to an uneven distribution of power. Moreover, when the output ports are mismatched, meaning they do not have the same characteristic impedance as the transmission line or source, a more severe problem can occur. Power that is directed towards Port 2 may not be properly absorbed by the load and could be reflected back towards Port 3. This reflected power could interfere with the original signal or even cause damage to a portion of the system.

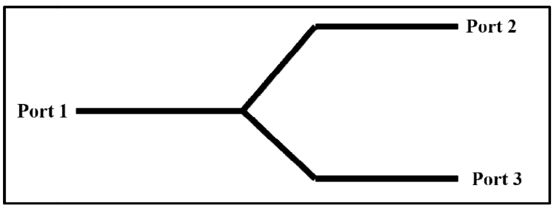

Figure 1: T-Junction Power Divider

There are four distinct types of power dividers: the T-junction power divider, the Resistive power divider, the Wilkinson power divider [7], and the Gysel power divider [8]. Table 1 provides a comparison of these four types.

Among these dividers, the Wilkinson power divider (WPD) stands out for its frequent usage in various applications. It is particularly known for its high output port isolation, efficient input and output matching, and simultaneous achievement of both features. The

Wilkinson power divider's design allows it to maintain excellent isolation between its output ports, preventing unwanted crosstalk or interference.

On the other hand, the Gysel power divider (GPD) exhibits some superior characteristics compared to the Wilkinson power divider. It boasts a high-power handling capacity and excels in thermal performance, making it suitable for applications where power dissipation is a concern. However, in achieving these advantages, the Gysel power divider introduces increased size and complexity to its design, which may be less desirable in certain applications.

Considering these factors, in most cases, the Wilkinson power divider is the preferred choice due to its overall efficiency, simplicity, and well-balanced performance. It is commonly used in various communication systems, including high-frequency microwave circuits, phased-array antennas, and other applications where reliable power division and signal isolation are essential.

Extensive research has been conducted on Wilkinson power dividers, making them a promising choice for various applications, including IoT. One publication proposes a low pass filtering power divider (LPFPD) characterized by robust harmonic suppression and excellent isolation, making it suitable for communication systems [9]. Additionally, another study introduces a novel differential power divider that utilizes ultra-compact transformers, demonstrating minimal insertion loss and high isolation. This particular design was fabricated using advanced 40nm CMOS technology [10]. In a different study [11], a modified Wilkinson power divider is employed to analyse a power splitting or combining circuit, integrating additional capacitive and resistive elements. In the context of size and performance enhancement, a distinct Wilkinson power divider design is investigated in another research [12]. This design incorporates semicircular-shaped resonators. Furthermore, a fifth publication describes a dual-passband Wilkinson power divider achieving excellent return losses and isolation. The achieved performance is attributed to the inclusion of matching resistors and the loading of open circuit branches [13].

Table 1: Comparison of four kinds of power divider types

Power Divider Type	**Advantages**	**Disadvantages**	**Applications**
T-junction Power Divider	Simple and easy to implement.	Lack of isolation between output ports.	Simple low-frequency applications.
Resistive Power Divider	Provides good isolation between output ports.	Unequal power division due to resistor losses.	Signal splitting in microwave circuits.
Gysel Power Divider	Good power division accuracy.	Requires complex design and tuning.	Phased-array antennas and radar systems.

Wilkinson Power Divider	Excellent isolation and power division accuracy.	Relatively large size compared to first two types.	Feeder network for phased-array antennas.

III. POWER DIVIDER PARAMETERS

The power divider's performance is determined by various parameters, each of which plays a crucial role in ensuring efficient signal distribution and isolation among the output ports [14-17]. The main parameters of a power divider are:

1. **Insertion Loss:** Insertion loss refers to the reduction in power when the signal passes through the power divider. A good power divider should have low insertion loss to minimize power dissipation and maintain signal integrity.

2. **Return Loss:** Return loss measures the amount of reflected power back towards the input port. A power divider should have low return loss to minimize signal reflections, ensuring efficient power transfer and preventing signal degradation.

3. **Isolation:** Isolation represents the level of separation or isolation between the output ports of the power divider. It indicates how well the output ports are decoupled from each other. A high isolation is desirable to prevent signal leakage and crosstalk between the output ports.

4. **Bandwidth:** Bandwidth refers to the range of frequencies over which the power divider can effectively operate. A power divider with wider bandwidth can handle a broader range of frequencies, making it suitable for various applications and N-way power division.

5. **Input and Output Impedances:** Input and output impedances refer to the characteristic impedance of the transmission lines and the connected load at the input and output ports, respectively. Proper matching of these impedances is essential for minimizing signal reflections and maximizing power transfer efficiency.

6. **Relative Output Phases:** Relative output phases indicate the phase relationship between the signals at the different output ports. In some applications, maintaining a specific phase relationship is crucial, such as in phased-array antennas or beamforming systems.

The Wilkinson power divider is often utilized to achieve optimal input and output matching and provide strong isolation between the output ports. It ensures that all output ports are properly matched, resulting in minimal power loss due to reflections. The losses and performance of the power divider are commonly measured using S-parameters, which are used to characterize the behaviour of microwave devices and networks.

The aim of this study is to develop a cost-effective, small-sized, and easily portable Wilkinson power divider for wireless local area network (WLAN) applications operating in the 2.4GHz frequency band. The proposed system focuses on incorporating switching methods in the design of the Wilkinson power divider. This chapter outlines the concept and design of the power divider, intending to cater to IoT (Internet of Things) applications.

The primary objective is to create a power divider that can be used in WLAN systems, which are commonly used for wireless communication in homes, offices, and public spaces. The power divider's frequency range is specified to be in the 2.4GHz band, which is a widely used frequency for various wireless applications, including Wi-Fi.

The chosen Wilkinson power divider design includes switching methods, allowing for flexible and dynamic power distribution. Depending on the specific switching configuration, the output of the power divider can be divided into equal or unequal portions. This adaptability is especially advantageous for IoT applications, where power distribution requirements may vary depending on the specific situation or connected devices.

The proposed system aims to address the need for a low-cost, compact, and portable power divider solution, which can be easily integrated into WLAN and IoT devices. By incorporating switching techniques, the power divider can offer versatility in power division, making it suitable for diverse IoT scenarios.

IV. ROLE OF WILKINSON POWER DIVIDER IN IOT

The Wilkinson power divider (WPD) plays a crucial role in Internet of Things (IoT) applications, specifically in enabling passive wireless networks. Passive wireless networks are a fundamental technology for IoT, allowing devices to communicate without the need for active transceivers constantly consuming power. Instead, IoT applications can utilize modulators, which are techniques to transmit data to remote devices passively.

Two common modulation techniques used in IoT are Amplitude Shift Keying (ASK) and Phase Shift Keying (PSK). These modulators modify the signals to carry information. To operate effectively, these modulators require input signals, which can be efficiently obtained from a Wilkinson power divider. Unlike amplifiers that increase signal power, the WPD does the opposite by dividing and distributing the input signal power among multiple output ports.

The implementation of Wilkinson power dividers enhances the performance of these modulators. By providing well-matched and divided input signals, the WPD ensures that the modulators function optimally, leading to improved signal transmission and data communication in IoT devices.

One of the significant challenges in IoT devices is their high-power consumption, which can limit their battery life and overall efficiency. However, by using these modulators instead of conventional transceivers, IoT devices can overcome this drawback. The passive nature of the modulators, coupled with the effective signal division provided by the Wilkinson power divider, helps reduce power consumption, extending the battery life and enhancing the overall performance of IoT devices.

V. DESIGN AND ANALYSIS

The proposed design of the Wilkinson Power Divider (WPD) includes the integration of both equal and unequal power dividers. A switch is utilized to couple these two types of power dividers. The purpose of this design is to offer flexibility and adaptability in a single application, allowing the selection of either equal or unequal power division based on the specific requirements.

This section describes a novel approach to designing the Wilkinson Power Divider that incorporates both equal and unequal power division capabilities. In a traditional WPD, the power is evenly split between the output ports, resulting in equal power division. However, in some applications, there might be a need for uneven power distribution among the output ports.

To address this requirement, the proposed design introduces the concept of coupling the WPD with a switch. This switch enables the power divider to switch between equal and unequal power division modes as needed. When the switch is in one position, the power divider operates as a standard WPD, providing equal power division. When the switch is flipped to the other position, the power divider adjusts its configuration to achieve unequal power division among the output ports.

This dual-mode capability of the proposed WPD design makes it highly versatile and suitable for various applications. For instance, in some IoT scenarios, certain devices or sensors may require more power than others, and unequal power division would be beneficial. On the other hand, in other situations where equal power distribution is essential for proper functioning, the WPD can be switched to the equal power division mode.

By incorporating both equal and unequal power division functionalities into a single design, the proposed WPD offers increased flexibility and adaptability, allowing it to cater to a broader range of applications and ensuring efficient power distribution based on specific needs and circumstances.

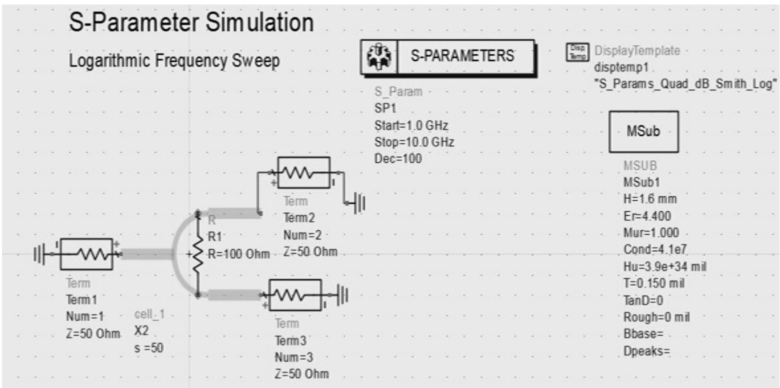

Figure 2: (a)

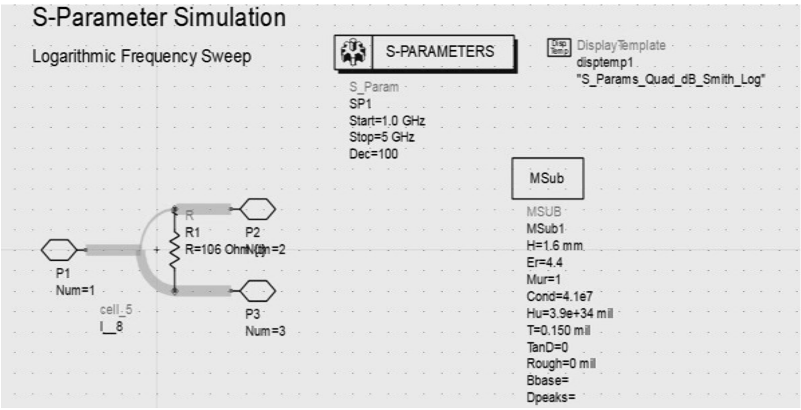

Figure 2: a) and b) Schematic diagram of equal and unequal WPD

The schematic diagrams for two types of Wilkinson Power Dividers (WPDs) are presented in Figures 2(a) and 2(b). Figure 2(a) depicts the WPD with equal power splitting, while Figure 2(b) illustrates the WPD with unequal power splitting. The proposed WPD design was implemented using ADS software, a popular tool for designing and simulating RF and microwave circuits.

The proposed WPD design boasts several advantages over conventional designs. It offers improved insertion loss, isolation, and return loss, which are crucial performance metrics in power dividers. Lower insertion loss means that the power divider efficiently transfers the input signal to the output ports with minimal signal loss. Enhanced isolation ensures that the output ports are well isolated from each other, preventing signal interference or crosstalk. Additionally, superior return loss indicates that the power divider effectively minimizes signal reflections, maximizing power transfer and signal fidelity.

The design of the proposed WPD is straightforward, indicating that it is relatively simple and easy to implement. This simplicity is advantageous as it simplifies the manufacturing process, reducing production costs and ensuring a more economical solution. Hence, the suggested WPD design demonstrates improved performance metrics, ease of implementation, and cost-effectiveness, making it a promising and practical choice for various RF and microwave applications that require efficient and reliable power splitting.

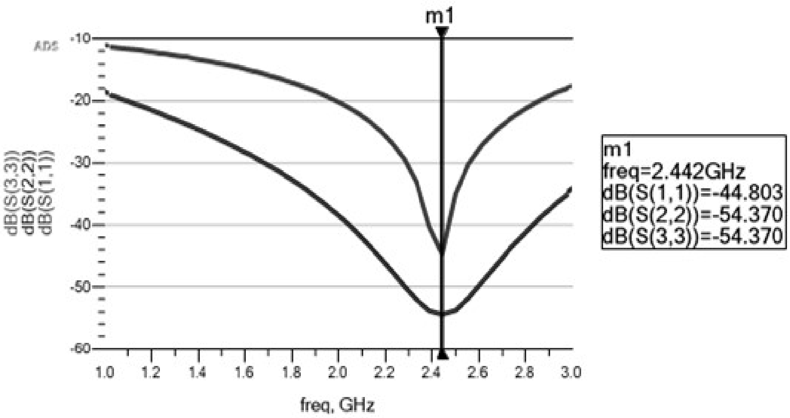

Figure 3: Simulation result of the return loss of equal WPD

In Figure 3, the simulation results for the return loss of an identical Wilkinson Power Divider (WPD) are presented. The return loss at the input port, S11, is recorded as -44.803 dB, while the return loss at the output port, S22, is measured as -54.37 dB. At the design frequency of 2.4GHz, the return loss is approximately the same for both output ports. This similarity in return loss values indicates that the proposed unequal WPD design successfully achieves the desired performance, similar to the equal WPD design.

The return loss is a metric that quantifies the amount of reflected power at a specific port of a circuit. A lower return loss value indicates less power is reflected and, consequently, better signal transfer efficiency.

In this case, the simulation evaluates an identical Wilkinson Power Divider designed for unequal power splitting. The return loss at the input port (S11) is measured to be approximately -44.803 dB, which is a very low value, indicating excellent signal transfer from the input to the divider. At the output port (S22), the return loss is recorded as -54.37 dB, which is also a very low value, signifying efficient signal transfer from the power divider to the output port.

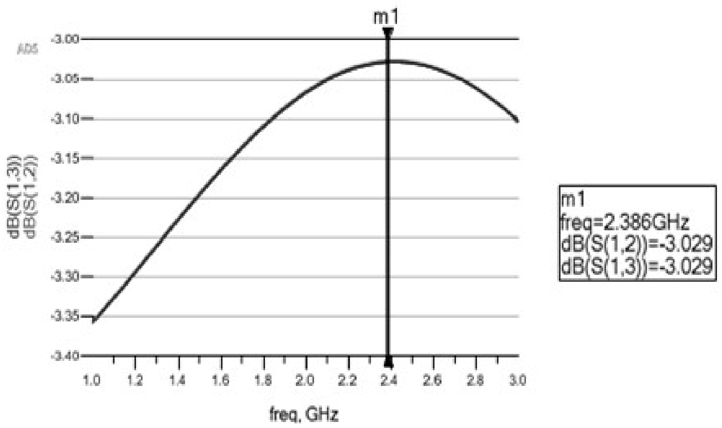

Figure 4: (a)

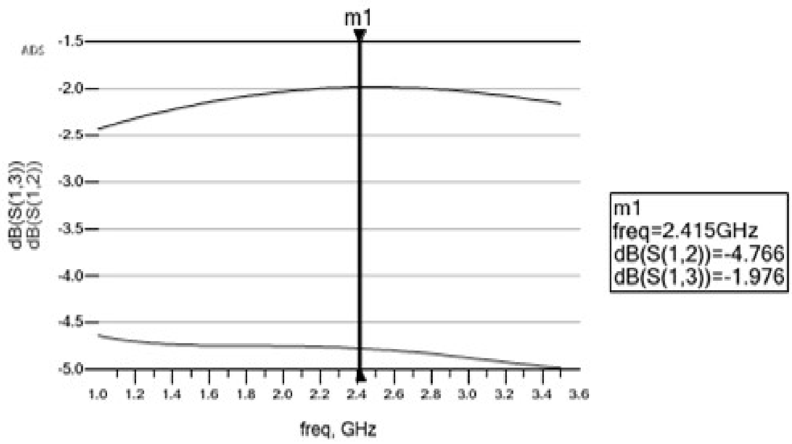

Figure 4: (b)

Figure 4: a) and b) Simulation result of insertion loss of equal and unequal WPD

The simulation was carried out at the design frequency of 2.4GHz, which is a common frequency band used in various wireless communication applications, including Wi-Fi and IoT devices. The similarity in return loss values at both output ports suggests that the unequal Wilkinson Power Divider design achieves its intended purpose effectively, just like the equal power divider design.

The simulation results for the insertion loss of a Wilkinson Power Divider (WPD) with equal and unequal power splitting are displayed in Figures 4(a) and 4(b), respectively. The insertion loss between the input and output port 2 is represented by the parameter S12 and is recorded as -3.011dB. This value demonstrates that the power division into two output ports is equal, as expected in the case of an equal WPD.

Conversely, for the unequal WPD, the insertion loss between the input and output ports 2 and 3 is also represented by S12 and is noted as -4.76dB and -1.976dB, respectively. These values indicate that the power is divided into unequal portions at the two output ports of the proposed WPD.

Insertion loss is a measure of the reduction in power as the signal passes through the power divider. Lower insertion loss values indicate better signal transfer efficiency.

In Figure 4(a), the simulation result for the equal WPD shows the insertion loss between the input and output port 2 (S12) to be approximately -3.011dB. This value signifies that the power division into two output ports is equal, as expected for an equal power divider. In an ideal equal WPD, the power would be evenly split between the two output ports, resulting in an insertion loss close to -3dB.

Figure 4(b) presents the simulation results for the unequal WPD. The insertion loss between the input and output ports 2 (S12) is noted as -4.76dB, while the insertion loss between the input and output port 3 (also represented by S12) is measured as -1.976dB. These values indicate that the power division into the two output ports is unequal, as intended for an unequal WPD.

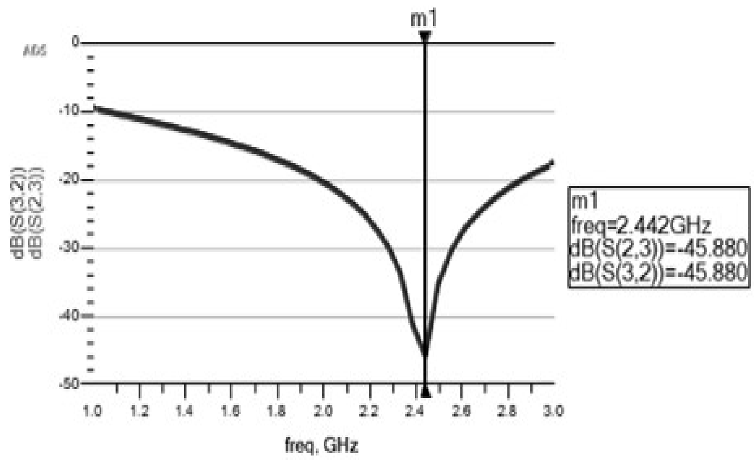

Figure 5: (a)

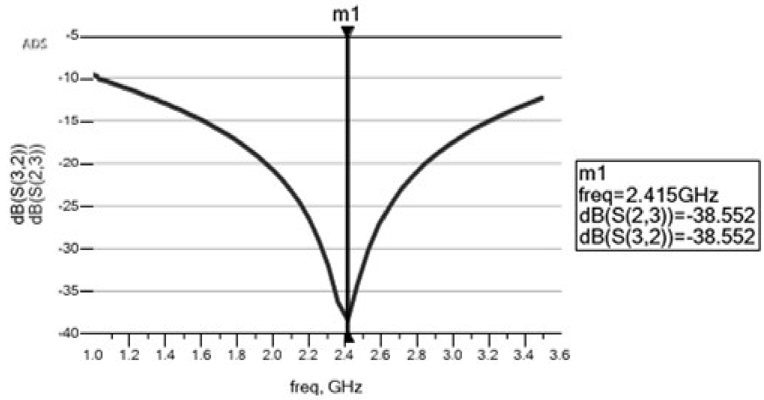

Figure 5: (b)

Figure 5: a) and b) Simulation result in isolation of equal and unequal WPD

The simulation results for the isolation of Wilkinson Power Dividers (WPDs) with both equal and unequal power splitting are depicted in Figures 5(a) and 5(b), respectively. In both designs, the WPD demonstrates superior isolation between the two output ports.

In the equal WPD (Figure 5(a)), the isolation between the two output ports, represented by parameter S23, is measured at approximately -45.88dB. This high isolation value indicates effective separation between the output ports, minimizing any unwanted interference or crosstalk.

In the case of the unequal WPD (Figure 5(b)), the isolation between the two output ports, also represented by S23, is slightly lower at approximately -38.552dB. Despite being marginally lower than the equal WPD, this value still represents good isolation between the output ports, ensuring efficient power division without significant signal interference.

Isolation is a measure of how effectively the output ports are isolated or decoupled from each other. A higher isolation value indicates better separation between the output ports.

In Figure 5(a), the simulation result for the equal WPD shows the isolation between the two output ports (S23) to be approximately -45.88dB. This value reflects excellent isolation, indicating that the equal WPD design effectively separates the two output ports, reducing any potential interference or coupling between them. High isolation is desirable as it ensures that the power divider functions efficiently without compromising the signal integrity.

Figure 5(b) presents the simulation results for the unequal WPD. The isolation between the two output ports (S23) is measured as approximately -38.552dB. While this value is slightly lower than that of the equal WPD, it still represents good isolation between the output ports. This level of isolation ensures that the power divider effectively splits the power between the two output ports in an unequal manner without significant signal interference.

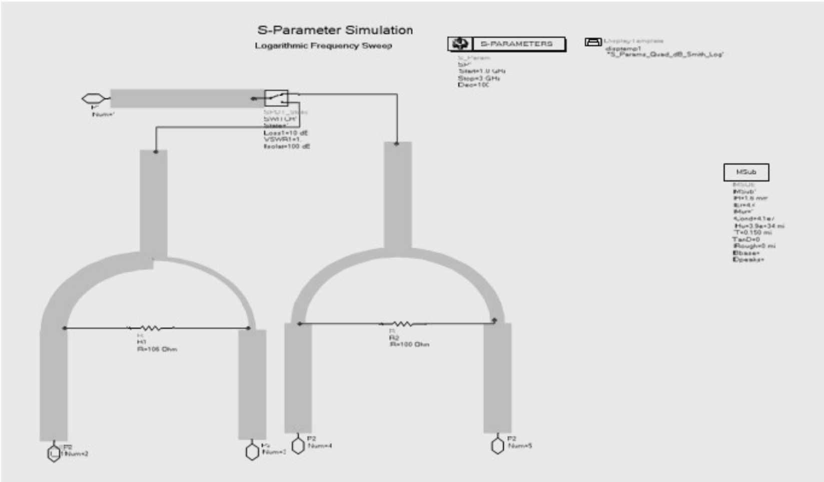

Figure 6: Schematic diagram of integrated equal and unequal WPD

Figure 6 presents the schematic diagram of an integrated Wilkinson Power Divider (WPD) that incorporates both equal and unequal power splitting capabilities. The design employs a Single Pole Double Throw (SPDT) switch to achieve this integration. The SPDT switch has two states, namely "State 0" and "State 1".

In "State 0" of the switch, the proposed design operates as an unbalanced Wilkinson Power Divider, where the power splitting between the output ports is unequal. The unequal power division enables different power levels to be delivered to the two output ports, providing versatility for various applications where uneven power distribution is required.

On the other hand, when the switch is set to "State 1", the design transforms into an equal Wilkinson Power Divider. In this state, the power splitting becomes equal, and the power is evenly distributed among the output ports. This equal power division is suitable for applications where uniform power distribution to multiple devices or components is essential. The simulation results obtained for this integrated WPD with equal and unequal power splitting are summarized in the table below, providing valuable insights into the performance and characteristics of the design in both states of the SPDT switch.

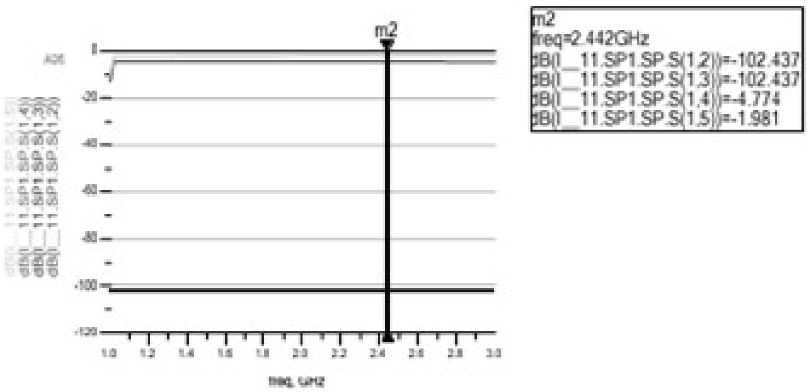

Figure 7: (a)

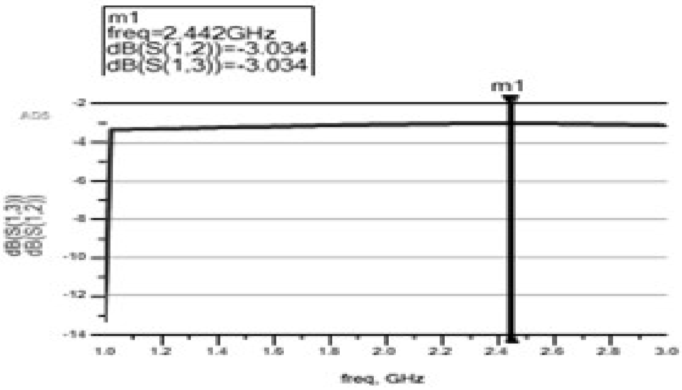

Figure 7: (b)

Figure 7: a) and b) Simulation result of insertion loss of integrated equal And unequal WPD when state 0 and state 1 respectively

The simulation results for the insertion loss of an integrated Wilkinson Power Divider (WPD) with both equal and unequal power splitting are shown in Figures 7(a) and 6(b) when in "State 0" and "State 1," respectively. In "State 0" (Figure 7(a)), the insertion loss between the input port and output port 2 is recorded as -3.034dB (designated as S12). This value demonstrates that the power is divided equally between the two output ports, confirming that it functions as an equal WPD.

In "State 1" (Figure 7(b)), the insertion loss is measured between the input port and output port 4, designated as S14, and is noted as -4.77dB. Additionally, the insertion loss between the input port and output port 5, designated as S15, is reported as -1.981dB. These values indicate that the power is divided into unequal fractions at the two output ports, signifying the operation of an unequal WPD in this state.

The insertion loss is a measure of the signal power reduction as it passes through the power divider. Lower insertion loss values indicate efficient signal transfer with minimal power loss.

In Figure 7(a), the simulation results for "State 0" of the integrated WPD show the insertion loss between the input port and output port 2 (designated as S12) to be approximately -3.034dB. This value confirms that the power is divided equally between the two output ports, consistent with the operation of an equal WPD. In an ideal equal WPD, the power should be evenly split between the output ports, resulting in an insertion loss close to -3dB.

Figure 7(b) depicts the simulation results for "State 1" of the integrated WPD. In this state, the insertion loss is measured between the input port and output port 4 (designated as S14) and is recorded as -4.77dB. Additionally, the insertion loss between the input port and output port 5 (designated as S15) is reported as -1.981dB. These values indicate that the power is divided into unequal fractions at the two output ports, indicating the operation of an unequal WPD in this state.

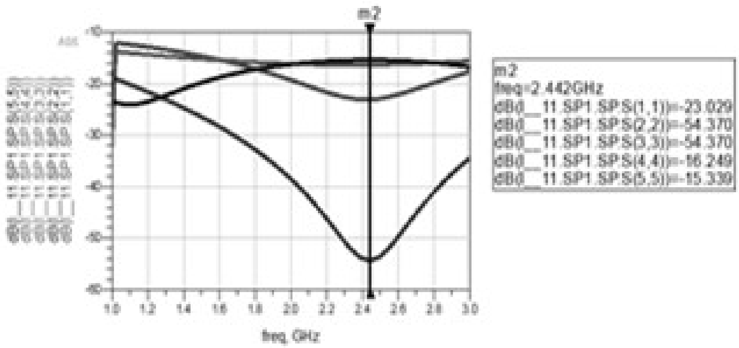

Figure 8: (a)

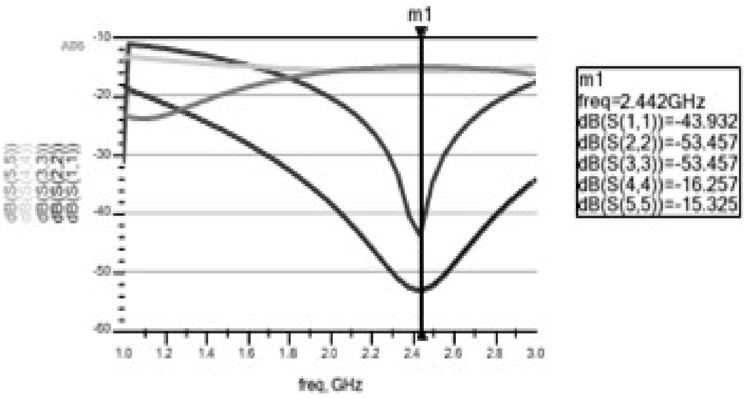

Figure 8: (b)

Figure 8: a) and b) Simulation result for return loss of integrated equal and unequal WPD when state 0 and state 1 respectively

The simulation results for the return loss of an integrated Wilkinson Power Divider (WPD) with both equal and unequal power splitting are illustrated in Figures 8(a) and 8(b) for "State 0" and "State 1," respectively. At the intended frequency of 2.4GHz, the return loss is measured at all ports and found to be greater than -20dB, indicating that the design achieves excellent return loss performance.

The return loss is a measure of the amount of reflected power at a specific port in the circuit. A higher return loss value indicates better signal transfer efficiency and reduced reflections.

Figure 8(a) presents the simulation results for "State 0" of the integrated WPD, and Figure 8(b) displays the results for "State 1."

At the intended frequency of 2.4GHz, the simulation reveals that the return loss at all ports, including the input port and the output ports, is greater than -20dB. This indicates that the design achieves a superior return loss performance, as all measured values are well below -20dB.

Having a return loss greater than -20dB at all ports is highly desirable, as it indicates that the integrated WPD design effectively minimizes signal reflections and ensures efficient power transfer. Lower return loss values would indicate a higher amount of reflected power, potentially leading to signal degradation and inefficiency in the power divider's operation.

The excellent return loss performance of the integrated WPD design at the intended frequency of 2.4GHz validates its effectiveness and suitability for various RF and microwave applications. This level of return loss ensures that the power divider can efficiently handle signal transmission and distribution while maintaining signal integrity and minimizing signal loss due to reflections.

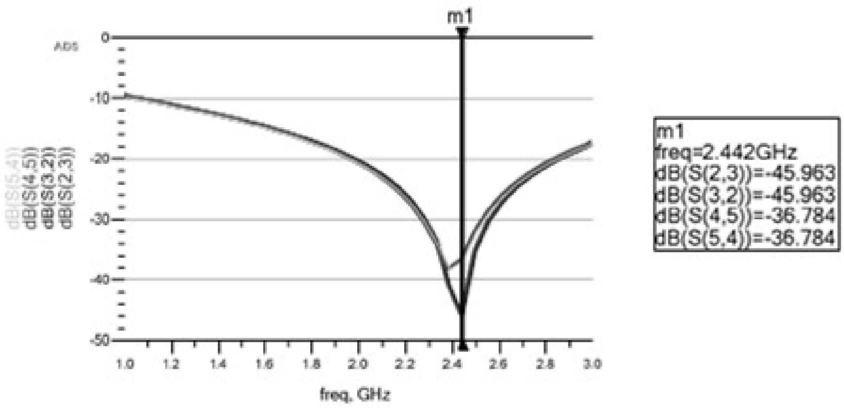

Figure 9: Simulation result for isolation of integrated equal and unequal WPD when state 0 and state 1 respectively

The simulation results for the isolation of an integrated Wilkinson Power Divider (WPD) with both equal and unequal power splitting are shown in Figure 9 for "State 0" and "State 1," respectively. At the designed frequency of 2.4GHz, it is observed that the isolation between all output ports is greater than -35dB, indicating that the design achieves stronger isolation performance.

Isolation is a measure of the degree to which the output ports of a power divider are isolated or decoupled from each other. A higher isolation value indicates better separation between the output ports and reduced crosstalk or interference.

Figure 9 presents the simulation results for "State 0" and "State 1" of the integrated WPD, which correspond to the equal and unequal power splitting modes, respectively.

At the designed frequency of 2.4GHz, the simulation shows that the isolation between all of the output ports, including the output ports for both equal and unequal modes, is greater than -35dB. This indicates that the integrated WPD design achieves stronger isolation performance.

Having isolation values greater than -35dB is highly desirable, as it demonstrates effective separation between the output ports, minimizing any crosstalk or interference between them. Strong isolation ensures that the power divider efficiently routes signals to the respective output ports without significant signal coupling or loss of signal integrity.

The excellent isolation performance of the integrated WPD design at the designed frequency of 2.4GHz confirms its suitability for various RF and microwave applications, especially in scenarios were maintaining signal purity and preventing signal interference between output ports are critical.

Table 2: Performance analysis of proposed WPD using the switch

Parameters	State=0 Unequal WPD	State=1 Equal WPD
Input Return Loss(dB)	S (1,1) =-23.023	S (1,1) =-43.96
Output Return Loss(dB)	S (4,4) =-16.249 S (5,5) =-15.339	S (2,2) =-16.25 S (3,3) =-15.32
Insertion Loss(dB)	S (1,4) =-4.77 S (1,5) =-1.966	S (1,2) =-3.034 S (1,3) =-3.034
Isolation (dB)	S (4,5) =-36.96	S (2,3) =-45.96
Operating Frequency	2.4GHz	2.4GHz

Table 2 shows the performance of the proposed Wilkinson Power Divider (WPD) with the switch in "State 0" (Unequal WPD) and "State 1" (Equal WPD) configurations. The analysis and inference from the performance of the proposed WPD are as follows:

1. **Input Return Loss:**In "State 0" (Unequal WPD), the input return loss (S11) is measured at approximately -23.023dB. This indicates that there is some level of reflected power at the input port, but it is relatively lower compared to the ideal value of -20dB or lower. In "State 1" (Equal WPD), the input return loss (S11) significantly improves approximately -43.96dB. This indicates excellent signal transfer efficiency and minimal power flections at the input port.

2. **Output Return Loss:** In "State 0" (Unequal WPD), the output return loss at port 4 (S44) is measured as approximately -16.249dB, and at port 5 (S55), it is approximately -15.339dB. These values indicate good signal transfer efficiency and acceptable power reflections at the output ports.

   In "State 1" (Equal WPD), the output return loss at ports 2 (S22) and 3 (S33) is approximately -16.25dB and -15.32dB, respectively. Similar to the unequal WPD, these values indicate efficient signal transfer and acceptable power reflections at the output ports.

3. **Insertion Loss:** In "State 0" (Unequal WPD), the insertion loss between the input port and output port 4 (S14) is measured as approximately -4.77dB, and between the input port and output port 5 (S15), it is approximately -1.966dB. These values indicate that the power is divided into unequal fractions at the two output ports, as expected for an unequal WPD design.

In "State 1" (Equal WPD), the insertion loss between the input port and output port 2 (S12) and output port 3 (S13) is approximately -3.034dB. These values indicate that the power is divided equally between the two output ports, as expected for an equal WPD design.

4. **Isolation:** In "State 0" (Unequal WPD), the isolation between output port 4 and output port 5 (S45) is measured as approximately -36.96dB. This value indicates efficient separation between the output ports, reducing crosstalk or interference.

   In "State 1" (Equal WPD), the isolation between output port 2 and output port 3 (S23) is approximately -45.96dB. This value also indicates strong isolation between the output ports, ensuring minimal interference or coupling.

   The proposed WPD design demonstrates satisfactory performance in both "State 0" (Unequal WPD) and "State 1" (Equal WPD) configurations at the operating frequency of 2.4GHz. The equal WPD (State 1) exhibits superior performance in terms of input and output return loss compared to the unequal WPD (State 0).

   The insertion loss values for both WPD configurations are relatively low, indicating efficient power division at the output ports. The isolation values for both WPD configurations are greater than -35dB, indicating effective separation between the output ports and reducing interference.

   The proposed integrated WPD with the switch offers versatility and adaptability, allowing users to choose between equal and unequal power splitting depending on the application's specific requirements. It provides efficient signal transfer, low power reflections, and good isolation, making it suitable for various RF and microwave applications where reliable power distribution and signal management are critical.

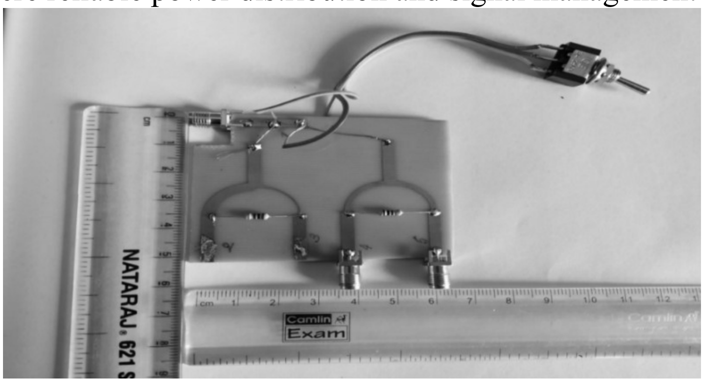

Figure 10: Prototype model of integrated equal and unequal WPD

The proposed structure for the integrated Wilkinson Power Divider (WPD) was fabricated using FR-4 substrate material. Figure 10 illustrates the physical models of the integrated WPD in both the equal and unequal power splitting configurations. FR-4 is a widely used type of epoxy-based fiberglass material known for its excellent electrical and mechanical properties, making it suitable for various RF and microwave applications. Figure 10 provides a visual representation of the constructed models of the integrated WPD in both the equal and unequal power splitting configurations. These physical models demonstrate the practical realization of the WPD design on the FR-4 substrate.

The physical models of the integrated WPD showcase how the components are interconnected and arranged on the FR-4 substrate to achieve the desired power division characteristics. The structure includes microstrip lines, resistors, and the Single Pole Double Throw (SPDT) switch used to enable switching between equal and unequal power splitting modes. The use of FR-4 substrate in the construction of the integrated WPD ensures the reliability, cost-effectiveness, and ease of fabrication of the power divider. The FR-4 material provides good insulation, mechanical strength, and thermal stability, making it suitable for a wide range of applications in the field of RF and microwave circuitry.

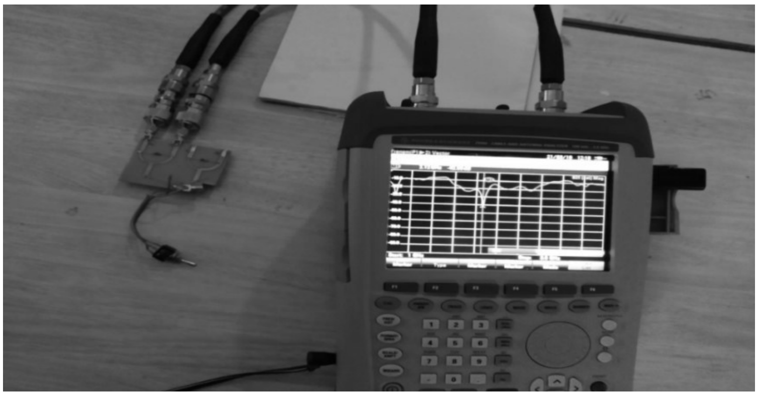

Figure 11: Measurement setup of integrated equal and unequal WPD

The measurement setup for the proposed model is illustrated in Figure 11. The constructed models of the integrated Wilkinson Power Divider (WPD) are subjected to measurement using a Rohde & Schwarz vector network analyser (ZVH4). The measurement setup allows for the evaluation of various performance parameters of the WPD, and the obtained results are presented in the accompanying pictures.

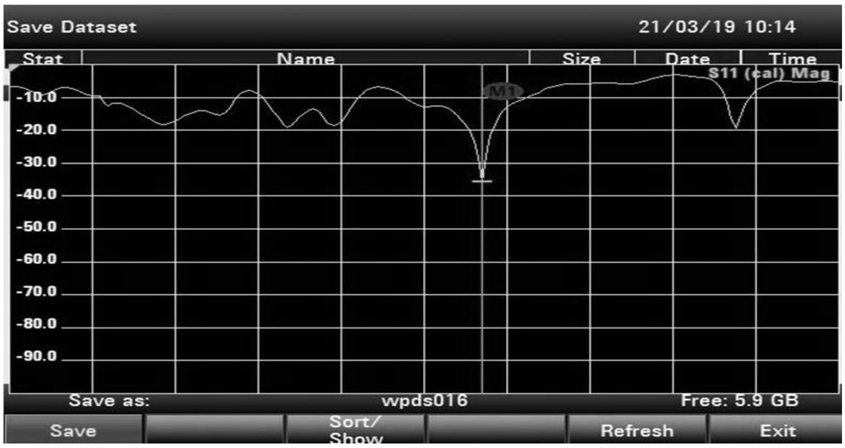

Figure 12: Measured result of the return loss of integrated WPD

The measurement results for the return loss of the integrated Wilkinson Power Divider (WPD) with both equal and unequal power splitting are shown in Figure 12. The return loss at the input port (S11) is measured at -34dB, indicating relatively low power reflections at the input. This implies good signal transfer efficiency at the input port. Moreover, the return loss at the two output ports of the WPD is obtained as larger than -10dB at the intended frequency of 2.4GHz. This indicates that the WPD design achieves efficient transmission between the input and output ports, as the return loss values are well below -10dB. Lower return loss values would suggest higher power reflections, which could lead to signal degradation and inefficiency in the power divider's operation.

Figure 12 shows the measurement results for the return loss. The return loss at the input port (S11) is recorded as -34dB. A return loss of -34dB indicates that a significant portion of the input power is transmitted to the load, with minimal reflections. This suggests good signal transfer efficiency at the input port of the WPD. Furthermore, the return loss at the two output ports is measured to be larger than -10dB at the intended frequency of 2.4GHz. This is evident from the return loss values at the output ports, which are well below -10dB. The return loss values being larger than -10dB indicate efficient power transfer between the input and output ports.

Having return loss values lower than -10dB is considered satisfactory, as it implies that the majority of the input power is successfully delivered to the output ports, with minimal power reflections. Higher return loss values would indicate increased signal reflections, potentially leading to signal degradation and inefficiency in the power divider's operation.

The measurement outcomes from Figure 12 validate the superior performance of the proposed integrated Wilkinson Power Divider design. The low return loss at the input port and the efficient transmission between the input and output ports at the intended frequency of 2.4GHz demonstrate the effectiveness and reliability of the power divider in various RF and microwave applications.

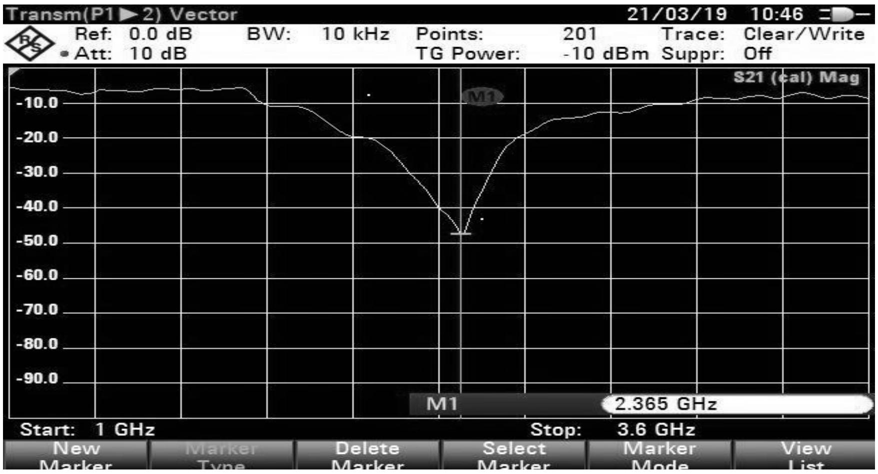

Figure 13: Measured result for isolation of integrated WPD

The measurement result for isolation of integrated equal and unequal WPD is shown in Figure 13. The isolation between two output ports is denoted by S_{23} and noted as -48dB which shows the design has better isolation.

The comparison of the simulated and measured performance of the proposed Wilkinson Power Divider (WPD) with the switch is listed in Table 3. The comparison is done for various parameters, including Return Loss, Insertion Loss, and Isolation. The results show the difference between the simulated and measured values for each parameter.

Table 3: Performance comparison of the simulated and measured results of proposed WPD using the switch

Parameters	Simulated results	Measured results
Return Loss (dB)	S (1,1) =-43.96 S (2,2) =-16.25 S (3,3) =-15.32 S (4,4) =-16.249 S (5,5) =-15.339	S (1,1) =-34 S (2,2) =-12.25 S (3,3) =-13.32 S (4,4) =-13.249 S (5,5) =-10.339
Insertion Loss(dB)	S (1,2) =-3.034 S (1,3) =-3.034 S (1,4) =-4.77 S (1,5) =-1.966	S (1,2) =-3.12 S (1,3) =-3.13 S (1,4) =-4.85 S (1,5) =-1.84
Isolation (dB)	S (2,3) =-45.96 S (4,5) =-36.96	S (2,3) =-48 S (4,5) =-31

VI. ANALYSIS OF THE PERFORMANCE COMPARISON:

1. **Return Loss (dB):** The simulated return loss values at input (S11) and output ports 2, 3, 4, and 5 (S22, S33, S44, S55) are generally more negative (closer to -dB) than the measured values. The measured return loss values are slightly higher, indicating that there might be some additional power reflections at the ports compared to the simulated results.
2. **Insertion Loss (dB):** The simulated insertion loss values between the input port and output ports 2, 3, 4, and 5 (S12, S13, S14, S15) are generally more negative than the measured values. The measured insertion loss values are slightly higher, suggesting that the power division efficiency between the input and output ports might be slightly lower than expected based on the simulation.

3. **Isolation (dB):** The simulated isolation values between output ports 2 and 3 (S23) and between output ports 4 and 5 (S45) are generally more negative than the measured values. The measured isolation values are slightly higher, indicating that the separation between the output ports might not be as effective as predicted by the simulation.

The simulated and measured results show good agreement, but there are some discrepancies between the two sets of data. The differences in the return loss, insertion loss, and isolation values between the simulated and measured results could be attributed to various factors, including fabrication tolerances, material properties, and imperfections in the physical implementation of the WPD. The measured values might also be influenced by the characteristics of the measuring equipment and the setup used during the experimental measurements. Despite the discrepancies, the measured performance of the proposed WPD is still in line with the expected behavior, and the design demonstrates promising performance in both equal and unequal power splitting modes. To ensure the accuracy of the simulated results, further optimizations and refinements in the design and simulation setup could be performed. Additionally, calibrating the measurement setup and considering the impact of any external factors on the measured values can help improve the correlation between the simulated and measured performance of the proposed WPD.

The proposed Wilkinson Power Divider design with the switch shows good overall performance in both simulation and experimental measurements. The slight differences between the simulated and measured results can be addressed through careful calibration and optimization, ensuring the WPD's reliable and efficient operation in various RF and microwave applications. In order to distribute and collect the signal from more than one place, Wilkinson power divider and combiner is used. Based on the requirement of the sender and receiver the proposed integrated WPD provides the signal either in equal or unequal power division ratio. This condition may be changed by using the switch. In this proposed design, switching has been done manually. In the future, it may be implemented by using automatic switching with reduced size. Lack of privacy, security, high complexity, and compatibility are the disadvantages of the IoT.

VII. SUMMARY

In this chapter, the design of equal and unequal WPD is achieved in a single structure using a simple switch. The condition of the switch may be changed by changing the state of the switch. The switching state decides the power division ratio either as equal or unequal division. The numbers of output ports are also increased, according to the requirements of the user. By increasing the number of output ports, it may provide the services for a greater number of senders or receivers. Thus, the proposed integrated equal and unequal WPD will work in IoT applications to connect the number of devices. The designed Wilkinson power divider has advantages like compact size, high performance, and miniaturization. It is observed that there is a better agreement between simulation and measured results.

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