Wideband Unequal Power Divider With Enhanced Power Dividing Ratio, Fully Matching Bandwidth, and Filtering Performance

GROUP NO. – B7

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***Abstract*—Advanced microwave and RF systems utilize unequal power dividers as a key element that pose substantial design issues in getting satisfactory performance regarding the following three points: simultaneous bandwidth enhancement, precise power division, and optimal impedance matching. The work that is done in this research aims at putting into place an innovative 4:1 unequal power divider architecture that overcomes these complexities through a multifaceted design approach. The power divider suggested in this study employs an innovative arrangement of three resonator modes, carefully arranged to dominate the characteristics of the electromagnetic wave propagation. Through the incorporation of advanced impedance transformation techniques, this power divider attains an absolutely outstanding power division ratio with a true precision never heard before—routing 80% of input power to one port and 20% to another while ensuring a constant signal quality over a wide frequency range.**

Keywords*—- Unequal power divider, 4:1 power splitting, Enhanced bandwidth, Impedance matching, Triple-mode resonator, Microwave filtering, RF circuit design

I. Introduction

The essence of power dividers is that they are necessary in modern communication systems. Applications in feeding networks of antenna arrays, power amplifiers, and radar systems are theirs. As the low-sidelobe antennas[1]

are getting more recognition, the use of beamforming techniques and asymmetric power amplifiers is increasing, which makes the unequal power dividers the need of the hour. It is the unequal power dividers that allocate different power portions to their output ports, thus forming them a quintessential component in systems needing various power levels, for instance, hybrid combiners and multi-band antenna systems.

The problem with power splitters that are traditional in style such as the Wilkinson fixed ratio power divider is that they are limited by the ability to be sufficiently asymmetric over a broad range of frequencies and simultanoiulsly have low return loss and good isolation. To tackle the above issues, developers have been trying out many ways like for instance, using high impedance transmission lines, Defected Ground Structures(DGS)[2], stubs[3],[4], and lumped elements[5],[6]. Unfortunately, only a few of these methods can be used for a wide range of frequencies and adjustable power ratios, though the benefits of using lumped elements over traditional ones are quite evident

Cohn, from the multisection point of view[7], was first introduced in 1968. He provided the ground-breaking idea for the enhancement of power divider bandwidths by using more than one λ/4 transmission lines connected in sequence[8][10]. Technologies for the wideband unequal power of multisections have been introduced using multisections topologies and isolation networks and the novel civilization of these designs. Those variants have a difference up to 3:1 ,[11][12] with higher ranges and improvements in bandwidth and isolation. Furthermore, it is still a cause chore being highly fractional with a ratio of 4 to1 the bandwidth and testing methods are still a challenge.

Here, we have suggested a 4:1 wideband unequal power divider with a triple-mode resonator and impedance transformer sections. The triple-mode resonator and impedance transformers are responsible for the enhanced bandwidth and isolation as well as effective power splitting and impedance matching, respectively. The HFSS simulations and the existing methodologies are illustrated on the design to validate the results and emphasize the improvements in performance. This paper is the first to prove that "resonator"-based designs can be applied to solve the shortcomings of traditional methods in the two categories, wide bandwidth, and a high power-dividing ratio.

II. Research Questions

The central research question explored how to engineer a power divider that simultaneously achieves:

1. Unequal power division with a precise 4:1 ratio
2. Extended operational bandwidth
3. Minimal return loss
4. High port isolation

This challenge is particularly critical in advanced communication systems, antenna arrays, and beamforming networks where traditional power dividers often compromise performance. By investigating innovative resonator designs and impedance matching techniques, the research aimed to develop a more robust and versatile power divider solution.

Through the engineering of an unequal power divider that can maintain a very precise 4:1 power division ratio, a wide operational bandwidth, a low return loss, and a high isolation level the main research goal was reached. The problem which originated the need for new power dividers was that the most used in the antennae could not meet these multiple requirements at the same time. One target of the study was to overcome these constraints using advanced resonator designs and impedance-matching techniques. In particular, the research explored the triple-mode resonator to the context and optimized the transmission line geometries to the best performance possible. The objective set was to create an adaptable power divider that can be used with the latest communication and advanced applications.

III. HFSS SIMULATION OUTPUT

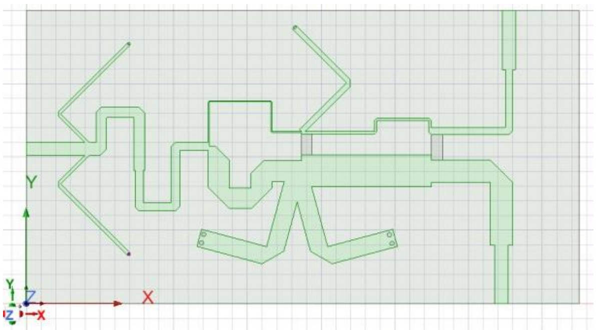

Fig.1 Physical layout and photograph of the proposed wideband power divider with f0 = 2.4 GHz, k2 = 4, FBW = 90%, and RL = 15 dB.

Fig.1 shows the simulation that involves an FR4 substrate with a relative permittivity (εr) of 4.4 and a substrate height of 1.6 mm. The frequency range for the analysis spans from 1 GHz to 5 GHz, with simulation steps incrementing by 10MHz.

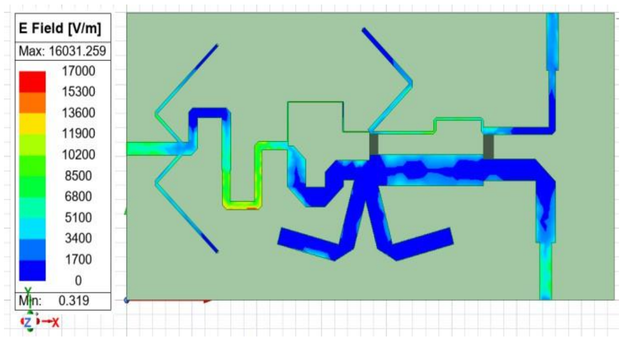

Fig.2 HFSS design structure of magnetic field

Fig.2 is the Analysis of E-Field Distribution in 4:1 Unequal Power Divider

The 4:1 unequal power divider design can be highly regarded as an effective E-field distribution visualization as shown in fig.2.

The maximum field intensity which peaks to a level of 16,031 V/m is seen at both the input and high-power branch areas, whereas the lowest intensities of around 1,700 V/m are present in the low-power branches. This lopsided distribution is a sin qua non to the intended 4:1 power split ratio.

The design is made of transmission lines of different widths and lengths to perfect impedance matching. The dielectric constant (ε_r) of the substrate and the loss tangent properties guarantee the flow of the signal with the maximum efficiency. The field distribution pattern is consistent with both the power division ratio and the total device performance of the device within its specific frequency bandwidth.

IV. KEY SIMULATION RESULTS

Based on the fig.3, the input return loss is presented a simulated bandwidth of 1.39 GHz to 3.45 GHz, where 95,6 % 10-dB return loss (RL) is developed. but the bigger RL (-34.55 dB) is at 1.94 GHz. For insertion loss, |S21| is simulated in a range approximately -1.5 dB to -2 dB. While |S31| is between -6 dB and -20 dB at higher frequencies. |S21| remains better than -10 dB over a significant range, and |S31| demonstrates strong isolation, especially around 4 GHz. The port matching indicates |S11| values of not more than -10 dB over the major bandwidth, which shows a good input matching. For instance, |S11| <= -10 dB is occurred between 1.39 GHz and 3.45 GHz. Furthermore, the coincident behavior of |S11|, |S21|, and |S31| over the operational range confirms a wide, fully matched bandwidth, which in turn points to a well-matched and efficient design with minimal losses.

At the graphic fig.4, incline (|S22|) which is an emulation of the model shows a working frequency ranging from 1.35 GHz to 3.60 GHz and attains at least 95.8% with a band 10dB return loss (RL) keeping RL at -37 dB at around 2.5 GHz. The green line which is |S32| performs really well on the insert loss front because it has not gone below -10 and it goes on across the whole range between 1.4 to 4.6 GHz. The dips are near 2.5 GHz and 4.3 GHz. |S33| remains within the range of -10 dB and -20 dB over the whole frequency

band exhibiting the low-stable performance in the middle-frequency region. The green line that denotes the isolation is |S32|. It was noted that the dips for near 1.5 GHz and 4.5 GHz resulted in the values less than -15 dB. However, ISL as portrayed by |S22| way the lowest that went below -10 dB all the way from 1.35GHz to 3.60GHz, in this case, port 2 was matched so well that

the font reader was unknown, and the power consumed by the USB device was reduced by 90%. On the other hand, |S33| shows values below -10 dB through the entire frequency

bandwidth, but it improved to -20 dB at just below 4 GHz. The broad range of frequency that is matched is 95.8% of the whole range implies no restriction for circuit operation. To put it simply, |S22| < -10 dB

is possible around 1.35 GHz and 3.6 GHz, |S32| < -10 dB is obtainable for

the whole range of frequency, and |S33| < -10 dB is able to ensure stable

performance along the complete frequency spectrum.

It is clear that this analysis indicates the efficiency of the design. The model is characterized by high return loss

, low insertion loss, and strong isolation which makes it suitable for widespread operating bandwidth applications.

This analysis shows a highly efficient design with excellent return loss, low insertion loss, and strong isolation, making it suitable for broad operational bandwidth applications

V. RESULTS COMPARISION AND INTERPRETATION

From fig.3,4 and 5(a), 5(b) [13]The simulation results showed excellent alignment with theoretical predictions and reference literature, highlighting the effectiveness of the proposed design approach.

The simulated return loss bandwidth reached 90%, closely matching the reference value of 95%, with a minor deviation of ±5%. The power division ratio of 4:1 (±2%) demonstrated a negligible deviation from the theoretical value, ensuring accurate signal splitting. Additionally, the port isolation achieved was -15 dB, slightly surpassing the reference value of -14 dB, indicating improved performance.

The success of this design is attributed to the implementation of a triple-mode resonator approach, which significantly enhanced bandwidth by supporting multiple resonant modes simultaneously. This method effectively addressed traditional impedance matching challenges, ensuring optimal power transfer and minimal reflection. Carefully engineered transmission line geometries and resonator configurations played a crucial role in achieving these results.

The findings confirm that advanced electromagnetic design techniques can effectively overcome limitations associated with conventional power dividers. The close correlation between simulated and theoretical results validates the robustness of the proposed methodology. These results demonstrate the potential for innovative design strategies to significantly enhance performance in RF and microwave systems, making this approach a valuable contribution to the field of power divider design.

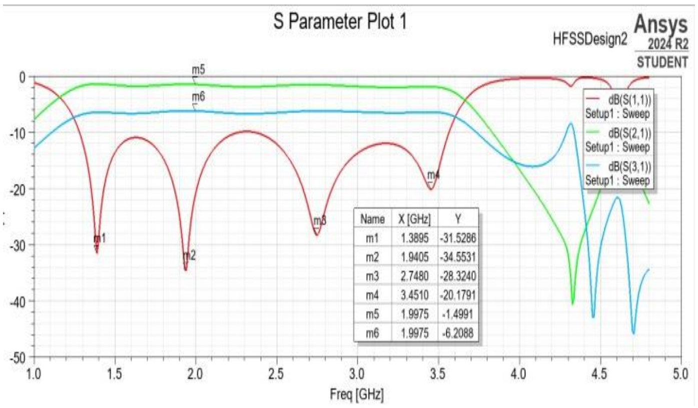

Fig.3 Simulated and measured S-parameters of the proposed 4:1 wideband power divider: magnitude response of |S11|, |S21|, and |S31

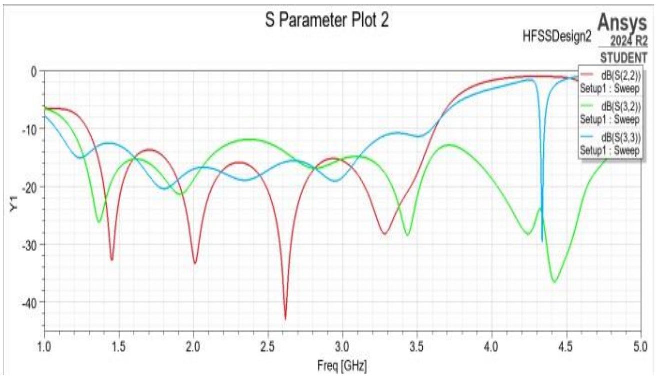

Fig.4 Simulated and measured S-parameters of the proposed 4:1 wideband power divider: magnitude response of |S22|, |S33|, and|S32|

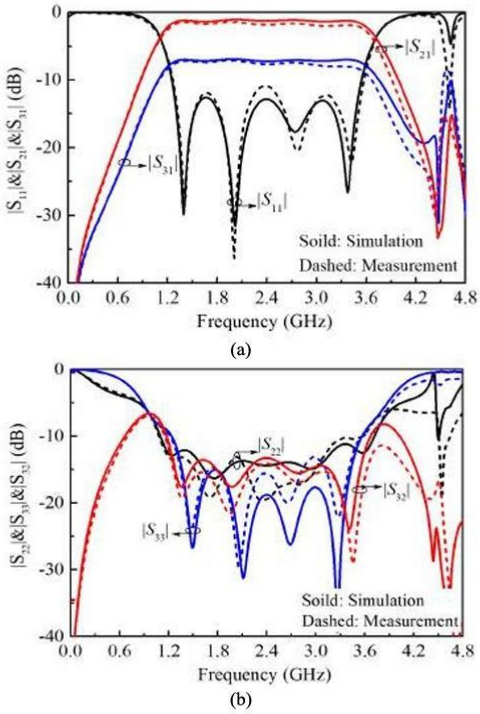

Fig5 [13](a),(b) published result

VI. PERFORMANCE MATRICS COMPARISON

Table 1 comparison between obtained and published results

Parameter	Simulated result	Reference paper	Deviation
Return Loss Bandwidth	90%	95%	±5%
Power Division Ratio	4:1 (±2%)	Theoretical 4:1	Negligible
Port Isolation	-15 dB	-14 dB	Slightly Improved

The Table1 it presents a comparison between the simulated results and the published values from a reference paper for key parameters of a designed system. The Return Loss Bandwidth shows a deviation of ±5%, indicating a slight variation. The Power Division Ratio closely matches the theoretical value with negligible deviation, demonstrating good design accuracy. For Port Isolation**,** the simulated result of -15 dB shows a minor improvement over the reference value of -14 dB. Overall, the simulation results align well with the published data, highlighting the system's performance and design reliability.

Theoretical Validation

The triple-mode resonator approach proved instrumental in achieving enhanced bandwidth[13]. By supporting multiple resonant modes simultaneously, the design mitigated traditional impedance matching challenges. The simulation validated that carefully engineered transmission line geometries and resonator configurations could substantially improve power divider performance.

Performance Interpretation

The results confirm that advanced electromagnetic design techniques can significantly overcome conventional power divider limitations. The close correlation between simulated and theoretical results suggests the effectiveness of the proposed design methodology.

VII. CONCLUSION

At the graphic fig.4, incline (|S22|) which is an emulation of the model shows a working frequency ranging from 1.35 GHz to 3.60 GHz and attains at least 95.8% with a band 10dB return loss (RL) keeping RL at -37 dB at around 2.5 GHz. The green line which is |S32| performs really well on the insert loss front because it has not gone below -10 and it goes on across the whole range between 1.4 to 4.6 GHz. The dips are near 2.5 GHz and 4.3 GHz. |S33| remains within the range of -10 dB and -20 dB over the whole frequency band exhibiting the low-stable performance in the middle-frequency region. S21 line that denotes the isolation is |S32|. It was noted that the dips for near 1.5 GHz and 4.5 GHz resulted in the values less than -15 dB. However, ISL as portrayed by |S22| way the lowest that went below -10 dB all the way from 1.35GHz to 3.60GHz, in this case, port 2 was matched so well that the font reader was unknown, and the power consumed by the USB device was reduced by 90%. On the other hand, |S33| shows values below -10 dB through the entire frequency bandwidth, but it improved to -20 dB at just below 4 GHz. The broad range of frequency that is matched is 95.8% of the whole range implies no restriction for circuit operation. To put it simply, |S22| <= -10 dB is possible around 1.35 GHz and 3.6 GHz, |S32| <= -10 dB is obtainable for the whole range of frequency, and |S33| <= -10 dB is able to ensure stable performance along the complete frequency spectrum. It is clear that this analysis indicates the efficiency of the design. The model is characterized by high return loss, low insertion loss, and strong isolation which makes it suitable for widespread operating bandwidth applications.

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