DESIGN AND DEVELOPMENT OF A COMPACT 1: 4 UNEQUAL WILKINSON POWER DIVIDER USING COAXIAL CABLES FOR VHF RADAR APPLICATIONS

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This article presents a novel implementation of compact Unequal Wilkinson Power Divider (UWPD) designed for the power split ratio (PSR) of 1: 4 using series and parallel combinations of the coaxial cables. This arrangement results in a very compact power divider for Very High Frequency (VHF) applications, has good matching at all the ports, very good amplitude balance, desired relative phase difference and isolation between the output ports. With proper choice of the cables, the proposed method of implementation is capable of handling high power with low insertion loss. Besides, by merely trimming the length of the coaxial cable the fine frequency tuning and phase equalization can be easily accomplished, this is not easy with its microstrip line configuration once its printed circuit board (PCB) fabrication process is carried out. Furthermore, the reduction upto 78.84 % has been achieved in the length of quarterwave line in the proposed 1: 4 UWPD as compared to that of its respective conventional design footprint, with potential for further miniaturization due to the use of the flexible coaxial cables. For the fabricated compact power divider the simulated and measured results are found in good agreement.

KEY WORDS*:* *Coaxial Cable, Miniaturization, VHF, Wilkinson Power Divider.*

1. INTRODUCTION

In rapidly growing technology including Internet Of Things (IoT), RFID, radar and wireless telecommunication systems, the components like the Unequal Wilkinson Power Dividers (UWPD) can be found in amplitude weighting control of antenna arrays in order to realize a required aperture distribution leading to the desired radiation pattern [1], to feed circularly polarized high-gain antennas that yield better connectivity with both fixed and mobile devices [2], in the design of various balanced power amplifiers, mixers, and multiport antenna feed networks [2]. For radar communication operating in Very High Frequency (VHF) band of 30 MHz to 300 MHz, the required length of the transmission line is in meters. Certainly, at VHF and lower frequencies, this type of power dividers / couplers would be unduly long, complex to fabricate and hence limits its applications. In modern telecommunication, due to system miniaturization and large scale integration, size reduction is definitely desirable for each system component. Moreover, in power dividers / couplers with increase in the power splitting ratio (PSR) [3], the required values of characteristic impedance of transmission line also increases. In the popular microstrip line configurations, the characteristic impedance beyond 150 Ω presents difficulty in realization due to its very small width, typically less than 0.5 mm.

The topology of the UWPD is illustrated in Fig. 1, where Port 1 is the input port while Port 2 and Port 3 are the output ports; Z_1, Z_2, Z_3, and Z_4 are the characteristic impedances of the transmission lines each of $\lambda_g / 4$ in lengths, where, λ_g is the guide wavelength. The PSR is (1: K^2) [3] between Ports 2 and 3 as given in (1) where, P_2 and P_3 are output power respectively at Port 2 and Port 3, the values of Z_1, Z_2, Z_3, Z_4, and R can be evaluated using (2 - 6) [3].

$$K^2 = \frac{P_3}{P_2} \dots\dots\dots\dots\dots\dots (1)$$

$$Z_1 = Z_0 \left(\frac{1+K^2}{K^3}\right)^{0.5} \dots\dots\dots\dots\dots\dots (2)$$

$$Z_2 = Z_1 K^2 \dots\dots\dots\dots\dots\dots (3)$$

$$Z_3 = \frac{Z_0}{\sqrt{K}} \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$Z_4 = Z_0\sqrt{K} \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

$$R = Z_0\left(K + \frac{1}{K}\right) \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Reference work on couplers for meter waves is largely unavailable in public domain [4-5]. In [4] the quadrature hybrid coupler (QHC) was realized at VHF (175 MHz) which consisted of two broadside-coupled brass strips of different widths, entirely surrounded by air in aluminum casing. By the same authors, some modified designs have been presented in [5-7] to achieve the size reduction of the coupler. A VHF QHC has been designed in [4-7] using two overlapping brass strips placed on the top and bottom surface of a Teflon substrate and it is not easy in terms of fabrication, and also bulky due to the use of heavy Teflon sheet. The N-way WPD operating at VHF using lumped element has been reported in [8]. But lumped element devices have narrow bandwidth as compared to distributed element devices. Also, commercially available lumped elements have limited choice of the available values. The work which is presented in this article is connected with the prior work of the same authors reported in [9] based on the coaxial cable implementation of equal power split WPD. In this present work, as a proof-of-concept of the coaxial cable implementation for unequal power split, a 1: 4 UWPD has been designed and developed. This proposed method of implementation is feasible for any value PSR with the appropriate combination of the cables, also advantageous for higher power handling capability as compared to microstrip lines. The measured results have been found to be in good agreement with the simulated results obtained using Advanced Design System (ADS) software tool.

Moreover, due to the use of the flexible coaxial cables it is certainly possible to achieve miniaturization in the fabricated prototype. Further, the performance of the proposed 1: 4 UWPD has been compared with earlier reported work especially operating in VHF band. The simulated results are experimentally validated with good agreement and discussed in the following sections.

2. DESIGN AND DEVELOPMENT

Coaxial cables RG188 (characteristic impedance Z_{C1} = 50 Ω) and RG187 (characteristic impedance Z_{C2} = 75 Ω) with Teflon (PTFE (Polytetrafluoroethylene)) dielectric material (dielectric constant ε_r = 2.1) have been used in the design of 1: 4 UWPD here. The diameters of the inner conductor of RG188 and RG187 cables are 0.54 mm and 0.31 mm, respectively, with outer conductor diameter of 2 mm for both the cables.

As shown in Fig 1, to achieve unequal PSR in 1: 4 UWPD the calculated values of Z_1, Z_2, Z_3, Z_4, and R are 39.5 Ω, 158.1 Ω, 35.5 Ω, 70.71 Ω, and 125 Ω respectively. For 1: 4 UWPD, Z_1 = 39.5 Ω and Z_3 = 35.5 Ω have been realized using a parallel combination of two RG 187 cables gave measured characteristic impedance of 34.6 Ω instead of theoretical value of 37.5 Ω when measured using the same technique reported in [9-10]. The Table 1 gives the equivalent characteristic impedance Z_t for various series / parallel combinations of the coaxial cables. As shown in the Table 1 for a series combination of three RG187 cables the measured value of characteristic impedance Z_t = 186 Ω and that of for a series combination of two RG187 cables is Z_t = 142.4 Ω. With a series combination of two RG187 with a RG188 gave measured characteristic impedance of 167.48 Ω which gives the optimum nearest value of the required characteristic impedance of Z_2 = 158.1 Ω. This variation in the characteristic impedance is mainly because of the change in effective dielectric constant due to change in equivalent capacitance and inductance when the two or more coaxial cables are realized in series / parallel combinations. Also, the requirement of Z_4 = 70.71 Ω which is close to the Z_{C2} of the available coaxial cable RG187. Based on the experimentally measured values of characteristic impedances as explained in foregoing discussion, the schematic diagram of the proposed 1:4 UWPD has been made in ADS software tool as depicted in Fig. 2. The final layout has been given in Fig. 3, with every cable of length of $\lambda_g / 4$ equal to 26 cm where $\lambda_g / 4$ equal to 26 cm where, λ_g is the guide wavelength at design frequency of 200 MHz. The isolation resistor of 130 Ω is connected between the two output ports.

3. DEVICE IMPLEMENTATION

A 1: 4 UWPD has been fabricated using readily available (50 Ω and 75 Ω) coaxial cables as discussed in earlier section and shown in Fig. 4. Input and output ports have been formed by using SMA type connectors. The length reduction in the $\lambda_g / 4$ line of the proposed 1: 4 UWPD upto 78.84 % has been achieved as compared to its conventional design footprint with additional advantage of higher power handling capability as compared to conventional microstrip line configuration.

4. RESULTS AND DISCUSSION

Measured results of the fabricated 1: 4 UWPD have been compared with its simulated results and shown in Figs. 5-7. It can be seen from Fig. 5, the fabricated 1:4 UWPD is tuned at (f_o) 198.7 MHz which is very close to the desired operating frequency of 200 MHz. The coupling loss at the Port 2 ($|S_{21}|$) and Port 3 ($|S_{31}|$) respectively are -1.19 dB and -7.77 dB, with resulting PSR of 1: 4.5 as observed in the Fig. 6. Good isolation between the two output ports ($|S_{32}|$) of -34.24 dB has been obtained as shown in the Fig. 6. The Fig. 7 implies outputs at the Port 2 and Port 3 are relatively equal in terms of the phase angles as desired. The frequency band between f_1 and f_2 has been considered to evaluate the salient bandwidths using (7) and given in Table 2.

$$\% \text{ Bandwidth} = \frac{f_2 - f_1}{f_o} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Further, the performance of the proposed 1: 4 UWPD has been compared with earlier reported work especially operating in VHF band as described in Table 3. It should be remembered that the additional losses in proposed devices are due to the cable bunch used as transmission lines and includes the cable coupling losses, connector loss for input / output connections, and also losses due to limitation in the choice of the characteristic impedances of the standard coaxial cables.

5. CONCLUSIONS

In this work, novel implementation of 1: 4 UWPD by means of the coaxial cables have been carried out for VHF radar applications. This technique of combining the coaxial cables in series and parallel method is simple to realize, affords easy fine tuning of center frequency, phase trimming and is useful for designing various VHF power dividers / couplers of any desired arbitrary power splitting ratios. Also, the high characteristic impedance of 167.4 Ω has been achieved for the proposed 1: 4 UWPD, which was very difficult to realize using conventional microstrip line due to very small width with less than 0.5 mm, with additional benefit of higher power handling capability. The simulated and measured results for the proposed power divider confirms good input and output matching, low insertion loss, good isolation and coupling as desired. It has been demonstrated from the fabricated prototype of 1: 4 UWPD that the overall quarterwave line length reduction is of 78.84 % can be achieved in the proposed method of implementation using the flexible coaxial cables as compared to its conventional design footprint. Such a compact power divider is useful in antenna feed networks in phased array of antennas or for power combining from amplifiers with desired power ratio, particularly at VHF and lower frequency applications in radar and other RF / Wireless telecommunication systems.

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Table 1. Characteristic Impedance of the Series or Parallel Combination of the Coaxial Cable

Characteristic Impedance (Ω) of one cable	**No. of Cables**	**Connection (Series or Parallel)**	**Equivalent Characteristic Impedance of the cable bunch**	
			Theoretical Value (Ω)	**Measured Value (Ω)**
50	2	Series	100	99
	3	Series	150	133.3
	4	Series	200	164.7
	5	Series	250	210
75	2	Series	150	142.4
	3	Series	225	186
50	1	Series	200	167.48
75	2			
75	2	Parallel	37.5	34.6

Table 2: Salient Bandwidths of the presented 1: 4 UWPD

Parameters	**Resultant Bandwidth (BW)**	
2:1 VSWR Bandwidth (BW)	168.7 – 225 MHz	28.3 %
15 dB Return Loss BW	183.7 – 211.5 MHz	13.9 %
15 dB Isolation BW	175 – 215 MHz	20.1 %
± 1^0 Phase imbalance BW	188.7 – 202.5 MHz	6.91 %
± 0.2 dB Amplitude imbalance BW	166.2 – 212.5 MHz	23.3 %

Table 3: Performance comparison of the presented UWPD with the earlier reported WPD especially operating in VHF Band

Ref.	**Power Split in WPD**	**Operating Frequency**	**Technique Used**	**Miniaturization achieved**
[8]	Equal	221 MHz	Lumped Elements	50 %
[9]	Equal	260 MHz	Coaxial Cables	55 %
This Work	1: 4 Unequal	200 MHz	Coaxial Cables	78.84 %

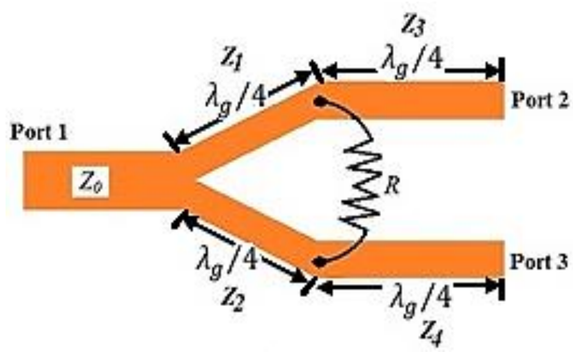

FIG. 1: Basic topology of the UWPD

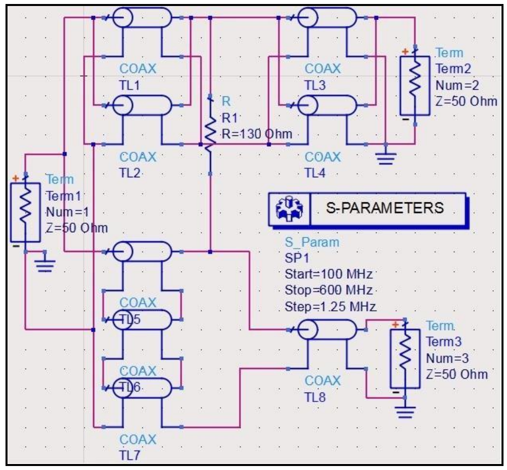

FIG. 2: ADS schematic of the proposed 1: 4 UWPD using the coaxial cables

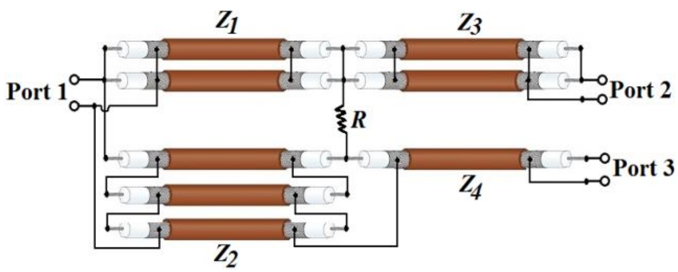

FIG. 3: Design layout of the proposed 1: 4 UWPD using the coaxial cables

FIG. 4: Photograph of the proposed miniaturized 1: 4 UWPD the coaxial cables (where 1, 2, and 3 indicates the port numbers)

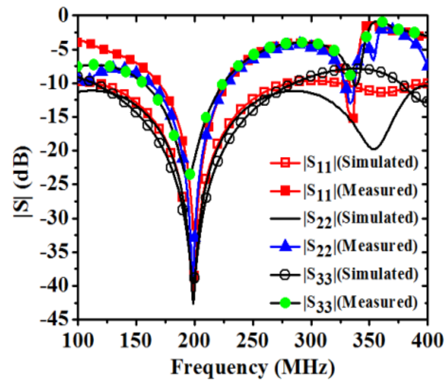

FIG. 5: Plot of Return Loss at all the Ports of the proposed 1: 4 UWPD

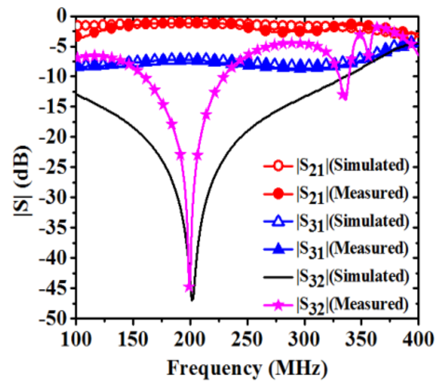

FIG. 6: Plot of Coupling ($|S_{21}|$, ($|S_{31}|$) and Isolation ($|S_{32}|$) of the proposed 1: 4 UWPD

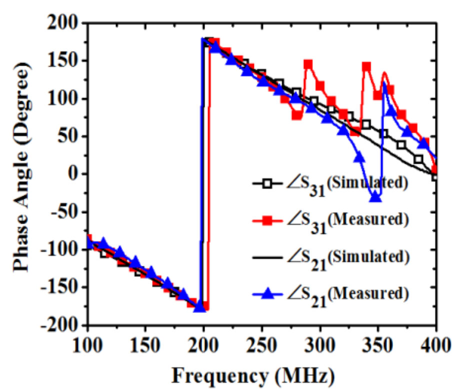

FIG. 7: Plot of Phase Angles of the proposed 1: 4 UWPD