A Novel UWB Out-of-Phase Four-Way Power Divider

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Abstract **─** A novel ultra-wideband (UWB) out-of-phase four-way power divider is presented. To achieve a division over a large frequency range, T-junctions formed by slotlines and microstrip lines are utilized. Based on the transmission-line equivalent-circuit method, we derive the design equations of the proposed power divider. Furthermore, all measured results are in good agreement with the predicted design equations and simulations. In addition, based on the power divider, a completely novel feed network is proposed to improve the narrow band property of microstrip antenna array.

Index Terms **─** Four-way, microstrip, power divider, slotline, ultra-wideband (UWB).

I. INTRODUCTION

An ultra-wideband (UWB) radar system has the merits of high range resolution, powerful penetration, low probability of intercept and robust jamming immunity, for they transmit signals across a much wider frequency than conventional radar systems. The most common technique for generating a UWB signal is to transmit pulses with very short durations (less than 1 nanosecond). These very short pulses need a wider transmitter bandwidth as conventional radar systems. Thus, a wideband feed network is essential in a wideband antenna system.

Power dividers are fundamental components used in antenna array feed networks. However, for a microstrip antenna array, bandwidth is a key limiting factor. That's probably because of quantities of quarter wavelength transformations in the feed network and the mutual coupling of antenna elements. Thus, an efficient wide band power divider serves significant contribution to wideband antenna arrays [1].

In [2], a 10-section 10-chip Wilkinson power splitter was proposed with very good return loss, isolation and insertion loss when avoiding different phase velocities in even and odd mode.

In [3], the authors have shown a compact two-way UWB power divider formed by a slotline and two microstrip lines accompanied by a wideband microstrip-slotline transition. It is a three-port network with one input port and two output ports with 180° phase difference.

Based on the above design, in this letter, the configuration of a UWB uniplanar four-way power divider is presented accompanied by simple design rules. Opposite to traditional wideband Wilkinson dividers and multilayer dividers [4], by utilizing the wideband property of microstrip-slotline mutual coupling, this design does not use neither resistive elements nor multilayer substrate. Thus, it is preferred when constructing a feed network of a wideband microstrip antenna array.

In the presented design, the input port exhibits a return loss better than -10 dB across UWB range as demonstrated via simulations and measurements. Because of the inherent properties of a lossless five-port circuit [5], which are governed by unitary properties of its scattering matrix, it cannot offer a perfect match at all its five ports as its counterpart with resistors. Furthermore, isolation between its output ports is compromised by the quality of match of its input and output ports. The better the match at the input and output ports, the worse is the isolation between the output ports.

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II. ANALYSIS AND DESIGN

The configuration of the proposed power divider is shown in Fig. 1. The divider utilizes a T-junction formed by a microstrip line and two arms of slotline, and other two T-junctions formed by a slotline and two arms of microstrip line. All ports of the divider are in the form of microstrip line and at the top layer of the printed circuit board, whereas the ground plane is at the bottom layer. There is a narrow rectangle slot in the ground crossing with microstrip lines. Each end of the slot is ended with a radial stub. The slot is responsible for guiding the wave from the input port to four output ports. The signals are coupled and divided from the microstrip line to two opposite directions in the slotline, and then signals of each side couple from the slotline to two arms of the microstrip line which are in equal magnitude but of 180 ° difference in phase.

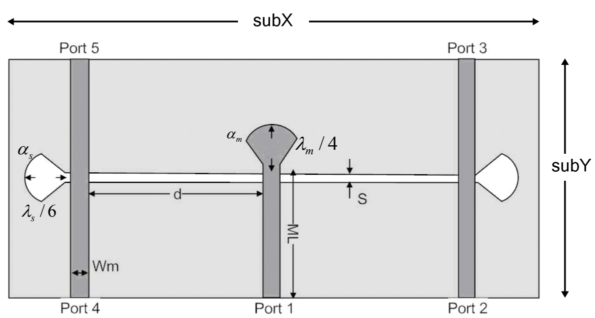


Fig. 1. Configuration of the proposed power divider.

The characteristic impedance of all the input and output ports Z_{m0} is designed as 50 Ω. The slotline length is *2d*, but *d* is an unconstrained parameter, here it is chosen as 0.88 λ_s (λ_s is the guided wavelength in slotline at the center frequency of 6.8 GHz). Due to the limitation of fabrication precision, we choose a 0.4 mm slotline which has a characteristic impedance of 112 Ω.

In order to efficiently (without reflections) couple the signals from the microstrip line to slotline, the end of the microstrip line is a radial line stub. It is utilized instead of a circular disk in [3] mainly because the radial line stub has an additional variety of flare angle α_m. The flare angle α_m is an important parameter for impedance and bandwidth tuning, whereas the radius of the radial open stub is set to be approximately a quarter guided wavelength of the microstrip line. The stub (input impedance Z_{ms}) exhibits a virtual short-circuit and inductance [6].

In order to efficiently couple a signal from the slotline to two microstrip lines, the end of the slotline is a radial stub. For the same reason, the flare angle α_s of the radial stub can be tuned for better result of impedance and bandwidth. The radius of the radial open stub is set as $\lambda_s/6$ for quarter-wavelength transformation to broaden the bandwidth [7]. The stub (input impedance Z_{ss}) exhibits a virtual open-circuit and capacitance.

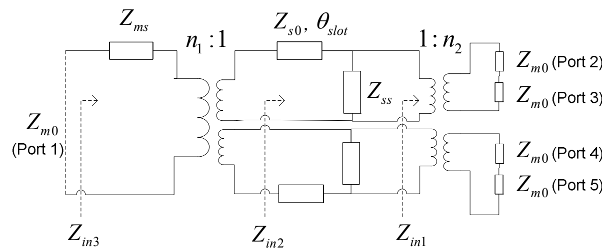


Fig. 2. The equivalent circuit of the proposed power divider.

The fundamental behavior can be explained by examining the corresponding equivalent circuits of the power divider shown in Fig. 2, Z_{in1}, Z_{in2} and Z_{in3} are input impedances at different locations. Z_{s0} is the characteristic impedance of slotline, whereas θ_{slot} is the electrical length of slotline length *d*. The microstrip-slotline transition is modeled by an ideal transformer with turn ratio n_1 and n_2. The approximate value of *n* has been calculated from [8] and *n* depends on the properties of microstrip and slotline. For the input and output microstrip ports have the same characteristic impedance, it can be calculated that $n_1 = n_2 = n = 0.9449$.

In the equivalent circuit, the coupling from microstrip line to slotline is equivalent as parallel connection, whereas the coupling from slotline to microstrip line is equivalent as series connection [9]. Though corresponding formulas are available, for simplicity and accuracy, the input impedance of microstrip stub Z_{ms} and input impedance of slotline stub Z_{ss} are simulated by an electromagnetic simulator (HFSS V12).

Thus, the equations are established as follows. When $Z_{in3}=Z_{m0}$, a best transmission from input port to output ports is achieved.

$$Z_{in1} = \frac{2}{n^2} \cdot Z_{m0}, \tag{1}$$

$$Z_{in2} = Z_{s0} \cdot \frac{\dfrac{Z_{ss} \cdot Z_{in1}}{Z_{ss} + Z_{in1}} + jZ_{s0} \tan\theta_{slot}}{Z_{s0} + j\dfrac{Z_{ss} \cdot Z_{in1}}{Z_{ss} + Z_{in1}} \cdot \tan\theta_{slot}}, \tag{2}$$

$$Z_{in3} = \frac{n^2}{2} \cdot Z_{in2} + Z_{ms}. \tag{3}$$

Based on the above equations, the detailed dimensions of the proposed power divider are shown in Table 1.

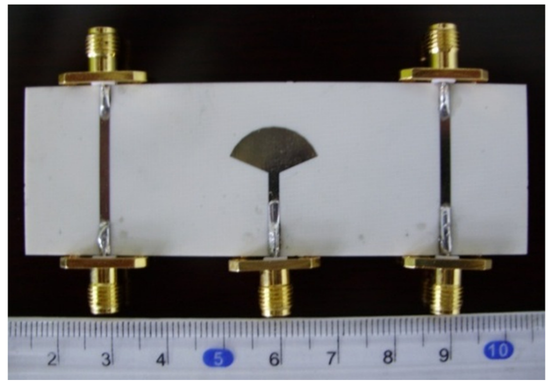
Table 1. Detailed dimensions of the proposed power divider

Substrate: RO4003C ε_r=3.38 tanδ=0.002 h=0.8mm				
subX	*subY*	$\lambda_s/6$	$\lambda_m/4$	W_m
90mm	30mm	7mm	8.3mm	1.8mm
α_s	α_m	*d*	*ML*	*S*
124deg	134deg	30mm	15mm	0.4mm

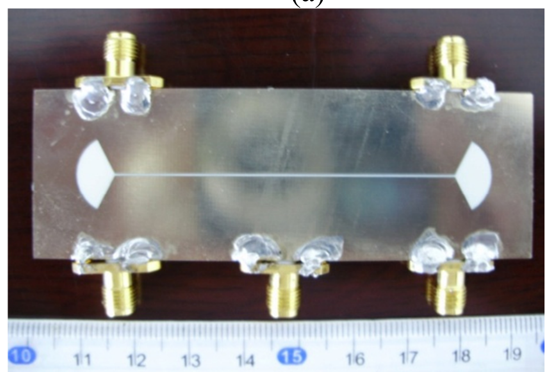
III. RESULTS AND DISCUSSION

The validity of the presented design method was tested by a prototype, as is shown in Fig. 3. It has an overall dimension of 90 mm×30 mm. The manufactured power divider was tested via simulations and measurements. The simulations were performed using HFSS V12, whereas the measurements were done using a vector network analyzer. The simulated and measured performances of the power divider are shown in Figs. 4-8. The measured return loss for the input port of the device is better than 10dB except for the high frequency band, because firstly the soldered SMA connectors lead to additional loss, secondly, the fabrication variation also results in some discrepancy between the simulated and measured results. The developed device exhibits an average insertion loss at the four output ports equal to 2dB across the 3.1-10.6 GHz band. Isolations between the output ports are more than 5dB (direct connected port 2, 3 and port 4, 5) and 11dB (indirect connected others ports).

Concerning the phase performance of the developed device, as is analyzed, the measured results indicate that the output signals from two direct connected ports have an 180° phase shift across the 3.1-10.6 GHz band.



(a)



(b)

Fig. 3. Photograph of the proposed power divider: the top view (a) and the bottom view (b).

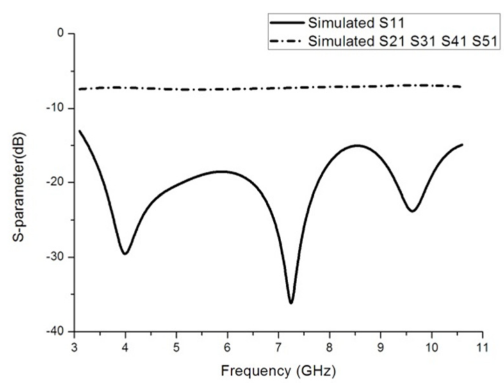


Fig. 4. Simulated return loss and insertion loss of the power divider.

We wish the presented analysis serves as an useful purpose for the band expansion of feed network of antenna array. In Fig. 9, we propose a completely novel in phase wideband feed network for 4×4 antenna array. It is composed of five power dividers as mentioned above. Every output port of the central power divider is linked by the input port of a new power divider. Considering the

180° phase difference of the output ports, ultra λm /2 length of microstrip is added to keep the output ports in phase. As every single power divider has the UWB property and simple structure, we believe the proposed feed network will have a good wideband property.

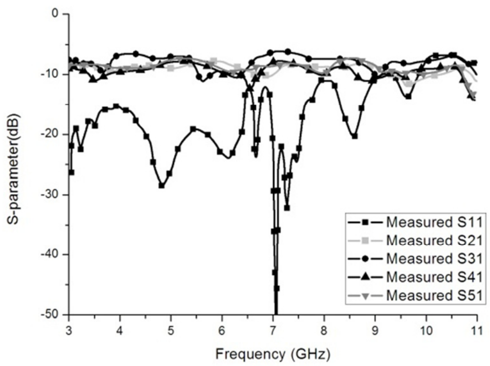


Fig. 5. Measured return loss and insertion loss of the power divider.

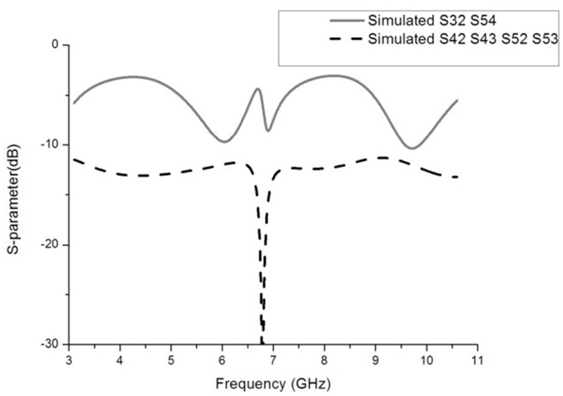


Fig. 6. Simulated isolation of the power divider.

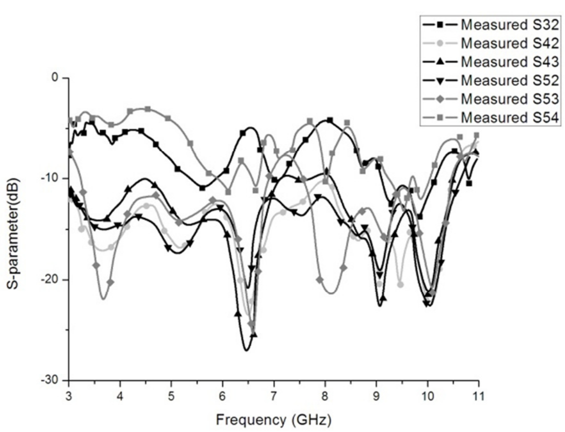


Fig. 7. Measured isolation of the power divider.

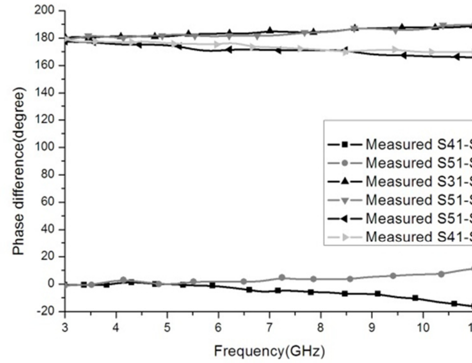


Fig. 8. Measured phase difference between the output ports.

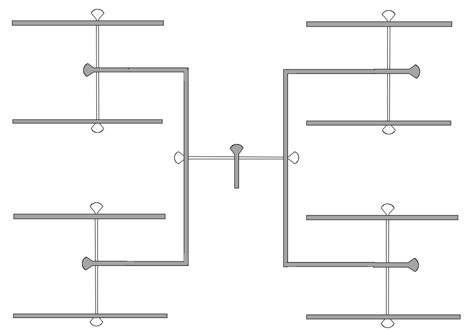


Fig. 9. A novel in-phase wideband feed network.

IV. CONCLUSION

A novel out-of-phase four-way power divider with UWB performance has been presented. The proposed device utilizes microstrip-slotline coupled structures. The simulated and measured results of the manufactured device have shown an UWB performance concerning the return loss, insertion loss and isolation. The design equations of the proposed UWB power divider have also been derived based on the transmission-line equivalent-circuit method. In addition, based on the power divider, a completely novel feed network is proposed to improve the narrow band property of microstrip antenna array.

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