Design of UWB Uniplanar 180° Hybrid Employing Ground Slots and Microstrip-Slot Transitions

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Abstract—**The paper describes the design of a uniplanar 180° hybrid with an ultra wideband (UWB) performance. The device uses a single substrate and all its four ports are of microstripline type. Its construction is accomplished by first designing separately the out-of-phase and in-phase dividers. To merge the two devices into the hybrid, the input port of the in-phase power divider is split into two lines to overpass a ground slot in the out-of-phase divider. The proposed design strategy results in the 180° hybrid exhibiting a well-balanced power division between the output ports and good quality return losses of the out-of-phase (difference) and in-phase (summation) ports across the band from 3 to 11GHz. The isolation between the difference and signal ports is excellent and the differential phase shift is also close to the ideal case of 180° and 0° across this band.**

Keywords-UWB hybrid, out of phase, divider;

I. INTRODUCTION

The 180° hybrid, also called magic-T, is a four-port network that offers out of phase (180° phase shift) and in-phase (0° phase shift) signal division between its two output ports [1]. The input port enabling the in-phase signal division is named the Σ-port (sigma-port) while the one providing the out-of-phase signal division is called the Δ-port (delta port). The property of the ideal 180° hybrid is that all four ports are perfectly matched and the Σ and Δ ports, as well as the two output ports, are isolated. These properties of the 180° hybrid make it very attractive for applications in microwave communication, measurement sub-systems and radar. In these applications the 180° hybrid is often required to be integrated with other microwave circuitry. In this case, a planar (microstrip or stripline) realization of this device is essential. One of the well-known planar realizations of the 180° hybrid is a 1.5λ ring coupler also called a rat-race hybrid. This device offers approximately 20% bandwidth. This bandwidth can be increased by replacing a 3λ/4 transmission line section of rate-race hybrid by a λ/4 coupled-line [2]. Known as the 180° reverse-phase hybrid-ring coupler, this device offers an operational bandwidth in the order of 40% (or one octave). More recent work described in [3] indicates that by incorporating crossovers, the ring hybrid developed in a coplanar waveguide technology not only can deliver more than one octave bandwidth but also can be miniaturized to 0.67 guided-wavelength. However, the use of crossovers makes this device non-planar. The solutions offered in [2], [3] provide a 180° hybrid with an increased operational bandwidth. However, none of them enables operation over an ultra wide frequency band. In 2002 US-FCC released an ultra wide frequency band from 3.1 to 10.6GHz for various applications [4]. The release of this frequency band has sparked a renewed interest in various broadband passive and active components, and antennas operating over UWB. It is because UWB technology shows promise to offer new capabilities with respect to wireless communications [5] and microwave imaging [6].

Out of many configurations of 180° hybrid/magic-T described in the microwave literature, the ones worthwhile of revisiting with respect to UWB applications are those described by de Ronde in [7], and Aikawa and Ogawa in [8]. The magic-T proposed by de Ronde in [7] is formed by the combination of planar in-phase and out of phase microstrip/slotline dividers. In the presented design, a slot to microstrip transition enables an UWB out-of-phase (180°) signal division due to an inherent property of this series type junction. The in-phase signal division realized by the shunt microstrip junction that offers a UWB operation with a reasonable return losses at the input port. However, the assembly of the two junctions into the magic-T offers only an octave band performance. The solution presented in [8] by Aikawa and Ogawa seems to be advantageous in terms of preserving UWB operation of two individual in-phase and out-of phase power dividers when combined into the magic-T. The proposed solution utilizes slot-to-microstrip or slot-to-microstrip transitions accompanied by either coupled microstrip lines or coupled slotlines. By using a transition between a single slotline and a coupled microstrip line (or alternatively between a microstrip line and coupled slot lines), a fine quality return loss of Δ port is accomplished. In turn, the Σ port uses a slot to microstrip transition (or a microstrip to slotline transition) which leads to 180° hybrid featuring a spectacular UWB performance over a 2 - 10GHz frequency range. However, this device is difficult to produce because of very fine manufacturing tolerances imposed by the edge-coupled lines. In order to provide a 180° phase shift these coupled lines have to be in a very close proximity. In [9], an alternative configuration of a planar 180° hybrid was presented. The out-of-phase signal division was accomplished using broadside, instead of edge-coupled microstrip lines.

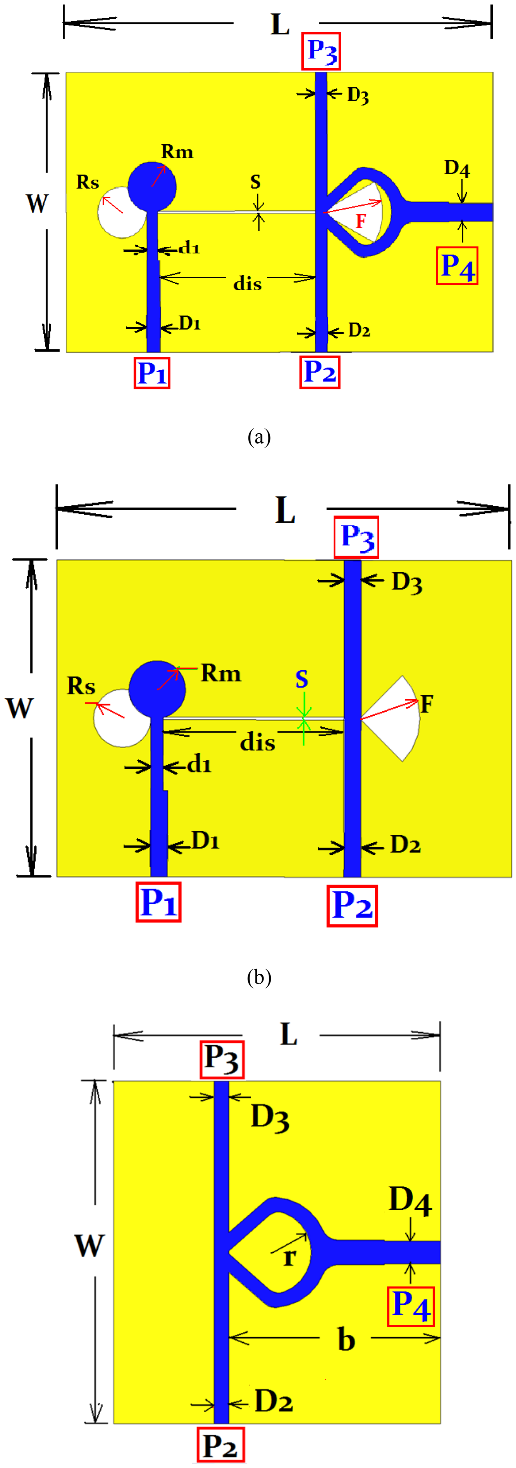
Because of this choice, a better quality 180° phase shift was realized than in [8].

However, the shortfall of the hybrid presented in [9] is that it uses a multi-layer microstrip-slot technique making it incompatible with uniplanar microstrip circuits. This shortfall is overcome in the present paper, which describes a fully uniplanar design of 180º hybrid. The design exploits the UWB out-of-phase divider described in [10] and shows how it can be unified with the in-phase microstrip divider into a fine quality UWB 180º hybrid.

II. DESIGN

The configuration of the proposed UWB 180° hybrid is illustrated in Fig.1a. The device uses a single substrate with ground slots. All its four ports, including Δ (port 1), Σ (port 4) and two output ports (port 2 and 3), are of microstrip type and are in the same plane. Therefore this device is uniplanar and offers an easy integration with conventional microstrip type circuits developed on the same substrate. This is the main advantage of this configuration compared with its counterparts described in [8], [9].

Fig. 1 b shows details of the out-phase divider while Fig.1 c reveals particulars of the in-phase divider which form the hybrid. The configuration of the out-of-phase divider shown in Fig.1 b is similar to the one reported in [10]. However, it includes new features. Its input port (port 1) is formed by a stepped-impedance microstripline. Also its output ports (port 2 and 3) are not of 50Ω characteristic impedance, as assumed in [10]. The use of microstrip output ports with characteristic impedances slightly higher than 50Ω serves the purpose of achieving a better quality impedance match for the input port of the out-of-phase divider of Fig. 1b, as well as of the input port of the in-phase divider of Fig.1c. By choosing the characteristic impedances of the output microstrip ports higher than 50 Ω, the load impedance of the two parallel lines is getting closer to the characteristic impedance of the input port, chosen as 50 Ω or less. The virtual open-circuit in the slotline-to-microstrip transition in the middle part of microstripline connecting the output ports, shown in Fig. 1b, is in the form of a radial sector slot instead of the circular slot used in [10]. The use of such shape of the virtual open circuit helps to unify the out- and in-phase dividers into the hybrid and overcomes the problem faced in the circuit described in [7]. As shown in Fig. 1c and Fig.1a, the input port (port 4) of the in-phase divider is split close to the T- junction to overpass the (ground slot) virtual open already present in the out-of-phase divider. While overpassing the virtual open the two lines have to meet at the centre of T-junction (the middle part of microstripline connecting ports 2 and 3). This is dictated by the fact that if they do not meet in the middle section of microstripline between ports 2 and 3 they form two open-circuited stubs for ports 2 and 3 when port 4 is excited. Such open-circuited stubs have an adverse effect on the return loss of port 4 especially at the upper part of UWB.



(a)

(b)

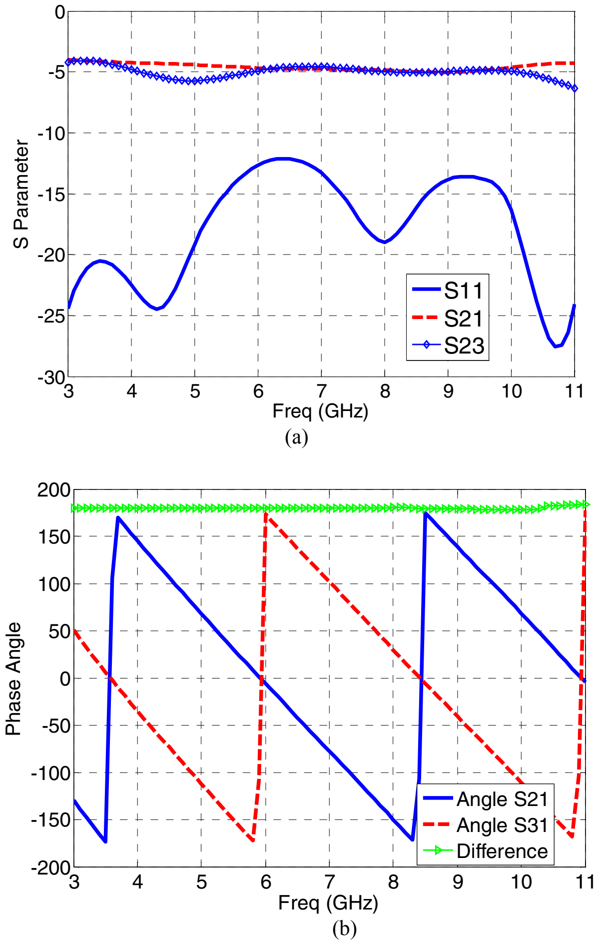
(c)

Fig.1 Configuration of (a) 180° hybrid, (b) out-of-phase (180°) power divider, and (c) in-phase power divider.

III. RESULTS

Following the above considerations, the design of the proposed uniplanar 180° hybrid is accomplished with Ansoft HFSS. In the design, Rogers RO4003C with thickness 0.508mm, dielectric constant 3.38 and tangent loss 0.0023 is used as a substrate. The final dimensions of the hybrid are obtained using a manual iterative process, first of the two individual dividers and then of the entire hybrid. They are: W=22mm, L=28mm, Rs=Rm=2mm, D1=1.1mm, d1=0.9mm, D2=D3=0.95mm, D4=1.45mm, S=0.2mm, F=4mm, r=2.5mm, b=13.6mm.

In the next step, the results for the out-of-phase and in-phase divider operating in isolation are presented. Fig. 2 shows the simulated results for the out-of-phase power divider obtained using Ansoft HFSS.



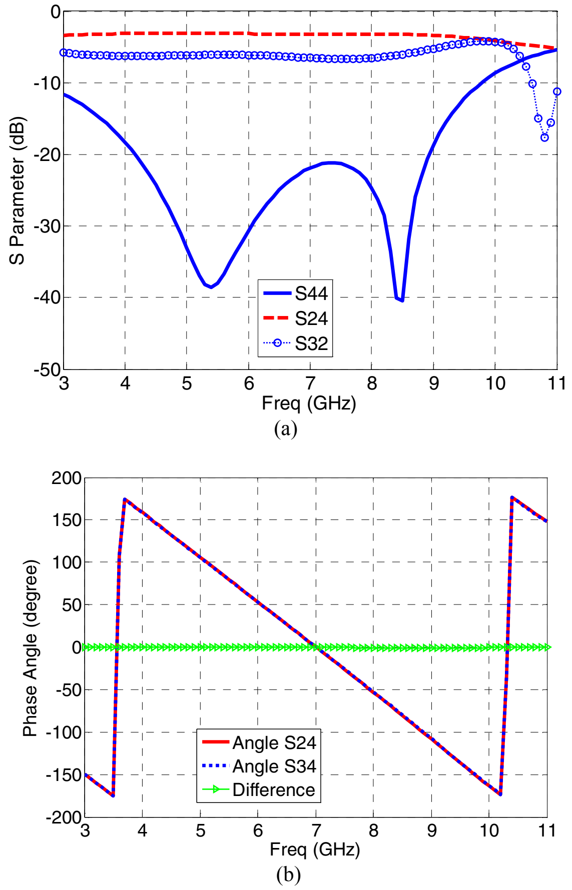
(a)

(b)

Fig.2 Performance of the 180° power divider: (a) amplitude and (b) phase characteristics.

These results reveal that the power is equally divided between the two output ports with an insertion loss of 4.75dB±0.25dB across the band 3 to 11GHz. The return loss of the input port (port 1) is better than 12dB for the whole band. Isolation between the output ports is in the range of (6dB). The poor isolation is the result of the unitary properties of the scattering matrix of a lossless three port [1]. The difference in phase between the two output ports is $180^\circ \pm 0.8^\circ$ over the band of 3.0-10.5GHz.

Fig. 3 shows the simulated results for the in-phase power divider obtained using Ansoft HFSS. These results reveal that the power is equally divided between the two output ports with an insertion loss of 3dB±1dB across the band 3-10.4 GHz. The return loss for the input port is higher than 10dB for the 3-9.8GHz band. Because of good quality return loss, the unitary properties of the scattering matrix make the isolation between the output ports to be sacrificed. It is in the range of 6.5dB over the band 3-9.3GHz. The difference in phase between the two output ports is $\pm 0.5^\circ$ over the band 3-11GHz.

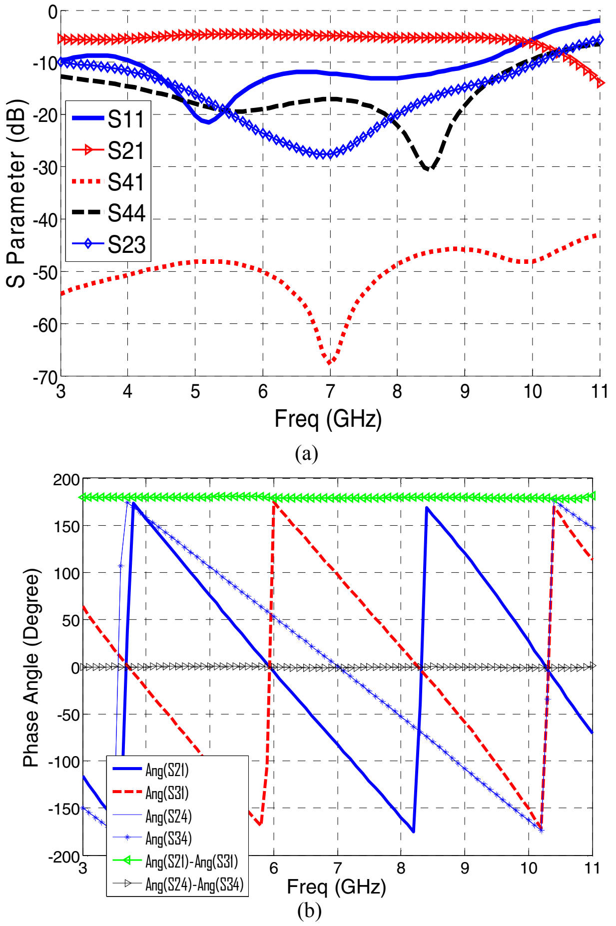


(a)

(b)

Fig.3 Performance of the in-phase power divider: (a), (b) amplitude and (c) phase characteristics.

Fig. 4 presents the simulated results for the 180° hybrid, as obtained with Ansoft HFSS, when the out- and in-phase dividers of Fig. 1 b and c are unified in one structure as shown in Fig. 1a. These results reveal that the in-phase and out-phase signal division presented earlier for the individual dividers in Fig. 2 and 3 is slightly affected by the unification process. However, the out-of and in-phase operation is still quite good across 3-9.7GHz. In addition, the hybrid features excellent isolation between its Δ (port 1) and Σ (port 4) ports.



(a)

(b)

Fig.4 Simulated performance of the 180° hybrid: (a) amplitude and (b) phase characteristics.

Having obtained satisfactory simulation results, the hybrid is manufactured and tested. Fig. 2 shows a photograph of the manufactured 180° hybrid.

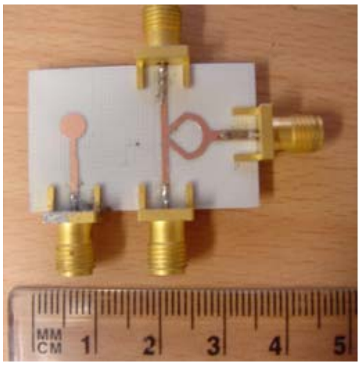


Fig.2 Photograph of the manufactured 180° hybrid. .

All the measured results of the developed hybrid were similar to the simulated ones. 10dB return loss performance for the Δ (port 1) and Σ (port 4) ports was approximately over the 3-10GHz band. The isolation of not less than 40dB between these ports was achieved over a larger bandwidth from 3 to 11GHz. The insertion loss between the Σ port and the two output ports (2 or 3) was very close to 3dB across 3 to 9 GHz. The insertion loss between the Δ port and the two output ports was about 5dB from 3 to 9GHz. Phase characteristics were close to ideal and similar to the simulated ones shown in Fig.4.

IV. CONCLUSION

In this paper, the design of a new UWB 180º hybrid has been presented. The device is uniplanar with all of its four ports formed by microstriplines. In order to achieve its UWB performance, the device employs microstrip-slot transitions and some extra features to overcome challenges in the unification process of the in- and out-phase dividers forming the hybrid. In the proposed approach, the Σ port of the in-phase divider is split into two microstriplines at the T-junction to avoid overlapping the ground slot in the out-of-phase divider. The design of the dividers and the hybrid has been accomplished using Ansoft HFSS. The designed device shows well balanced signal division accompanied by small insertion losses for its out- and in-phase modes of operation over the band of 3-11GHz. The phase deviations from 0º phase shift or 180º phase shift are only ±0.5º over a slightly reduced portion of UWB. Due to its symmetric structure, the hybrid exhibits an excellent isolation (>40dB) between its Δ and Σ ports. Because it is uniplanar, it can be integrated with many conventional microwave circuits on the same substrate board.

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