COPLANAR WAVEGUIDE – SLOTLINE HYBRID RING COUPLER

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ABSTRACT

A uniplanar reverse-phase coplanar waveguide-slotline hybrid ring coupler is presented in the contribution. It consists of a combination of coplanar waveguide (CPW) and a slotline without ground plane on the bottom side of the dielectric substrate. Realized coupler has frequency band about 98% of the centre frequency for deviation of 1 dB from its 3 dB nominal coupling value *C*.

1. INTRODUCTION

Microwave directional couplers are used frequently in structures, where we need divide and/or sum microwave power – in dividers, attenuators, phase shifters, combiners and other microwave structures. We require, that these structures didn't have big return loss. The ring or 180° hybrid is one of many types of hybrid directional couplers. Its classic planar structure is based on using of microstrips. Of course, for variety of practical applications we have more structural types based on other types of planar transmission lines. We can use coplanar waveguide (CPW), conductor-backed coplanar waveguide (CB-CPW), coplanar strips (CPS), a combination of a coplanar waveguide and a slotline and many others. This paper is aimed at coplanar waveguide-slotline hybrid ring coupler.

2. COMBINED CPW-SLOTLINE RING HYBRID

In general, the 180° ring hybrid is a four-port linear circuit (Fig. 1). When input signal is supplied into port 1 (3), the output signals on ports 2, 3 (1, 4) are in-phase each other. Simultaneously, the port 4 (2) is isolated. When input signal is supplied into port 2 (4), the output signals on ports 1, 4 (2, 3) are in opposite phase each other. In this case, the port 3 (1) is isolated.

The scattering matrix for a 180° ring hybrid with ports marking according Fig. 1 has the following form.

$$[S]=\begin{bmatrix} S_{11} & S_{12} & S_{13} & 0 \\ S_{12} & S_{11} & 0 & S_{13} \\ S_{13} & 0 & S_{33} & S_{34} \\ 0 & S_{13} & S_{34} & S_{33} \end{bmatrix} \quad \text{eventualy} \quad \frac{-j}{\sqrt{2}}\begin{bmatrix} 0 & 1 & 1 & 0 \\ 1 & 0 & 0 & -1 \\ 1 & 0 & 0 & 1 \\ 0 & -1 & 1 & 0 \end{bmatrix} \quad ,$$

where the second scattering matrix is in the case of ideal (lossless and totally matched) reciprocal ring hybrid with 3 dB coupling between particular ports. Usualy phase invertor the three quarters wave segment is realized. In this coupler is substituted quarter wave slotline segment completed with the 180° reverse-phase CPW back to back balun.

Basic technical parameters of an ideal ring hybrid are defined by following equations [1]:

1. Insertion Loss *IL* [dB]

$$IL = 20\log\frac{1}{|S_{13}|} = 20\log\frac{Z_{02}}{Z_0} \quad , \tag{1}$$

2. Coupling *C* [dB]

$$C = 20\log\frac{1}{|S_{12}|} = 20\log\frac{1}{|S_{34}|} = 20\log\frac{Z_{01}}{Z_0} \quad , \tag{2}$$

where Z_{01}, Z_{02} are the characteristic impedances of the CPWs or slotline segments of the ring, and Z_0 is the characteristic impedance of the CPW feed lines (usually 50 Ω).

For the 3 dB hybrid, the values of coupling and insertion loss are equal each other $C = IL = 3$ dB and $Z_{01} = Z_{02} = Z_0\sqrt{2} = 70{,}71\,\Omega$.

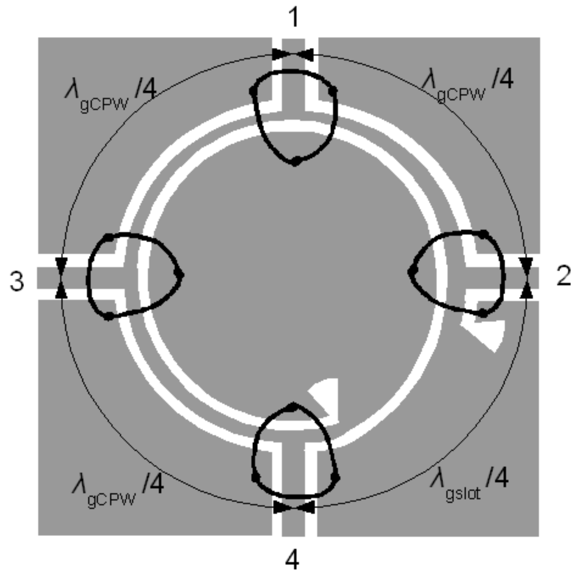

Figure 1: Construction of the CPW-slotline hybrid

Characteristic impedance of conventional coplanar waveguide is defined as:

$$Z_{0CPW} = \frac{30\pi}{\sqrt{\varepsilon_{eff}}}\frac{K(k_0')}{K(k_0)} \quad , \tag{3}$$

$$\varepsilon_{eff} = 1 + \frac{\varepsilon_r - 1}{2}\frac{K(k_1)}{K(k_1')}\frac{K(k_0')}{K(k_0)} \quad , \tag{4}$$

$$k_0 = \frac{S}{S+2G} \qquad k_1 = \frac{\sinh(\pi S/4h_1)}{\sinh\{[\pi(S+2G)]/4h_1\}} \qquad k_i' = \sqrt{1-k_i^2} \quad , \tag{5}$$

where $K(k)$ and $K(k')$ were complete elliptic integrals of the first kind with arguments k and k',respectively. G denotes the gap size of particular CPWs and S is the centre CPW strips width, h_1 is high of the substrate.

Characteristic impedance of slotline is defined as:

$$Z_{0CPW} = \frac{60\pi}{\sqrt{\varepsilon_{eff}}} \frac{K(k_0')}{K(k_0)} \quad , \tag{6}$$

$$\varepsilon_{eff} = 1 + \frac{\varepsilon_r - 1}{2} \frac{K(k_0)}{K(k_0')} \frac{K(k_\varepsilon')}{K(k_\varepsilon)} \quad , \tag{7}$$

$$k_\varepsilon^2 = 2\frac{\mathrm{tgh}\dfrac{\pi s}{2h}}{1+\mathrm{tgh}\dfrac{\pi s}{2h}} \qquad k_0^2 = 2\frac{\mathrm{tgh}\dfrac{\pi s}{2h_0}}{1+\mathrm{tgh}\dfrac{\pi s}{2h_0}} \qquad h_0 \approx h\left[1+\frac{0{,}0133}{\varepsilon_r+2}\left(\frac{\lambda_0}{h}\right)^2\right] \quad , \tag{8}$$

where λ_0 is wavelangth, s denotes the gap size of stripline, h_0 is effectiv high of the substrate.

Equations (6) – (8) were approximated by an analytical formulas [1].

The combined CPW-slotline ring hybrid was designed and realized on a 1 mm thick Arlon AD 1000 substrate with ε_r = 10,2 and for its parameters measurement the microwave scalar network analyzer Anritsu 54147A was used..

The cross dimensions of particular parts of CPWs and slotline were calculated by using an internet TX-Line Transmission Line Calculator from AWR Corporation [5].

Measured frequency characteristic are shown in Fig. 2, the technological as well as the main electrical data are summarized in Tab. 1. The measured nominal value of coupling at the central frequency of 3 GHz is 3,1 dB, the measured nominal value of insertion loss is 3,3 dB. In the whole investigated frequency range from 1 to 6 GHz the isolation of the ring hybrid is greater than 14 dB. For frequency range to 10 GHz we can use balun with angle 30° and length 5 mm. The 180° phase shifter back to back balun is frequency independ.

For a good connection assurance between various parts of ground planes in the CPW hybrid we use several bond wires connection (Fig. 1). This is also the simplest method to suppress an excitation of parasitic coupled slotline modes and possible parasitic resonances in the structure.

Bandwidth comparison CPW-slotline ring hybrid with microstrip hybrid, coplanar waveguide and conductor backed coplanar waveguide is presented in Tab.2. We can see, that bandwidth is largest for the combined CPW-slotline hybrid. Criterions used for the bandwidth estimation in our investigation were: the maximal coupling value C and/or insertion loss IL deviation of 1 dB from their 3 dB nominal sizes.

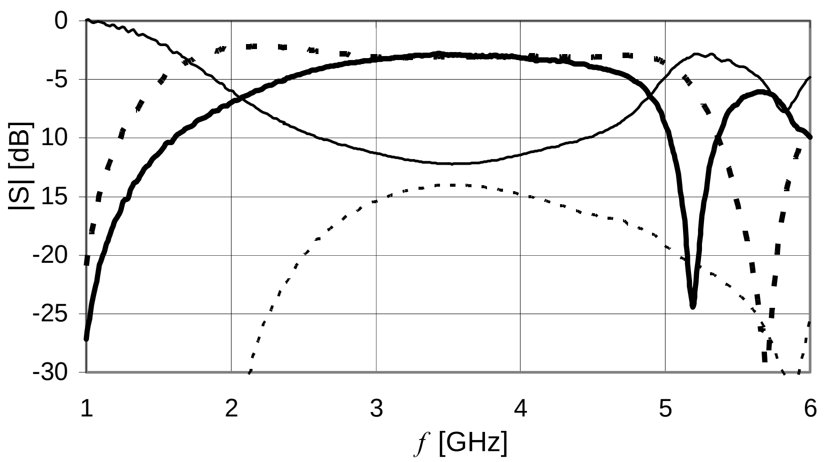

Figure 2: Frequency characteristics of combined CPW-slotline ring hybrid
(- - - *I*, ═ *IL*, = = = *C*, — *RL*)

Feed CPWs 50 Ω	G_0 = 0,5 mm S_0 = 1,26 mm
Ring sector CPWs 70,7 Ω	G_{CPW} = 0,5 mm S_{CPW} = 0,29 mm
Slotline section 70,7Ω **Balun**	G_{slot} = 0,28 mm υ = 30°, r = 5 mm
Parameter	**Bandwidth** [% of f_0]
C ± 1 dB	98
IL ± 1 dB	60

Tab. 1. Parameters of the combined CPW-slotline ring hybrid

where G denotes the gap size of particular CPWs and S is the centre CPW strips width, G_{slot} is gap size of slotline section, r is radius of balun, υ is angle of balun.

Parameter	Bandwidth [% of f_0]			
	Microstrip	CPW	CB-CPW	CPW-slotline
C ± 1 dB	73	72	78	98
IL ± 1 dB	34	36	35	60

Tab. 2. Ring hybrid bandwidth comparison

3. CONCLUSION

Uniplanar reverse-phase coplanar waveguide-slotline hybrid ring coupler has great bandwidth – about 98% of central frequency for deviation of 1 dB from its 3 dB nominal coupling value *C* and 60% of central frequency for deviation of 1 dB from its 3 dB nominal insertion loss value *IL*. It was checked by measurement. These values are comparable with another art of planar hybrid, so called De Ronde's hybrid coupler [3].

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