IMPROVED CPW TO SLOTLINE TRANSITIONS

K.HETTAK, J.Ph.COUPEZ, T. LE GOUGUEC, S.TOUTAIN,
P.LEGAUD*AND E.PENARD*

LEST URA CNRS N°1329 ENST de Bretagne B.P 832 29285 BREST Cédex
* CNET LAB/OCM/MLS-Lannion

Abstract

The paper presents a new approach for designing an ultra broadband coplanar to slotline transition. The procedure is carried out in three steps: design, modeling and fabrication of two new broadband uniplanar CPW to slotline transitions, in the 1 GHz to 50 GHz frequency range. The advantages of these transitions are discussed. Both transitions are modeled using one approach which consists of building a model, based on physical considerations, that is compatible with usual CAD software (discontinuities effects are not taken into account except short/open circuits-end effects). This allows the design and optimization of very broadband transitions in uniplanar technology. The overall agreement between the measured and modeled insertion-loss and return-loss of two back-to-back transitions is good. A maximum relative bandwidth of 7.7:1 is achieved with 10 dB return loss, and the corresponding insertion loss is less than or equal to 2 dB.

I.Introduction

CPW to slotline transitions are used in different types of antenna structures [1], balanced mixers [2] and other microwave circuits such as uniplanar magic tee [3]. Many researchers have dealt with the problem of developing broadband transitions from CPW to slotline [4]-[5]. Some intuitive approaches of this problem have been reported with bandwidths of about 5:1 [6] and 5.2:1 [7], the latter operating in the 1.6 to 8.0 GHz frequency range.

A problem quite similar to the subject considered here has been treated in [8]. In this paper, a coplanar-slotline double junction balun is presented for frequencies up to 40 GHz. But, contrary to the expected results, double junction baluns [9] do not demonstrate all-pass network characteristics. The main reason for the frequency bandwidth limitation is that the slotline open circuit is realized by means of a circular slotline, which corresponds to a good open circuit only over a 2-3 octaves frequency range. In addition an increase of insertion loss, which is partially due to the radiation of the circular slotline, can be observed [9]. Theoretically, all stubs and transmission lines must have the same characteristic impedance to maintain a good match over a broad frequency range [10]. However, this condition is not valid due to the dispersion characteristics of the slotline and the CPW. Finally, an accurate equivalent circuit for open circuit has not been reported yet, and a systematic approach which consists of developing a broadband transition from coplanar to slotline is still lacking. The present paper intends to give a response to this problem. Our approach is based on the shifting of the lower and upper band-edge frequency of the bandpass response of the equivalent model, which is generally adopted for the transition (the lower band-edge decreasing and the upper band-edge increasing). To illustrate this idea, we propose a new configuration of broadband CPW to slotline transition, which corresponds to a combination of multi $\lambda_g/4$ shorted slotline and $\lambda_g/4$ open CPW stubs.

II. Alternative solutions for designing a broadband CPW to slotline transition

The majority of baluns are based on the well-known concept of the Marchand balun [11]. A number of them, developed for MIC applications, use a combination of CPWs and slotlines etched on one side of the substrate. A typical MIC balun known as CPW to slotline transition is presented in figure 1. It combines a $\lambda_g/4$ open CPW stub and a $\lambda_g/4$ shorted slotline stub, connected on the main line in series and in parallel, respectively .

For this structure, the expression of the transmission coefficient is given by:

$$S_{21} = \frac{2}{(2-X_1)-jX_2}$$

with :

$$X_1 = \left(z_{scpw} \cdot y_{sslot} \cdot \cot an^2 \left(\frac{\pi f}{2 f_o} \right) \right)$$

$$X_2 = \left(z_{scpw} + y_{sslot} \right) \cdot \cdot \cot an \left(\frac{\pi f}{2 f_o} \right)$$

where

z_{scpw} : normalized equivalent characteristic impedance of the CPW stub

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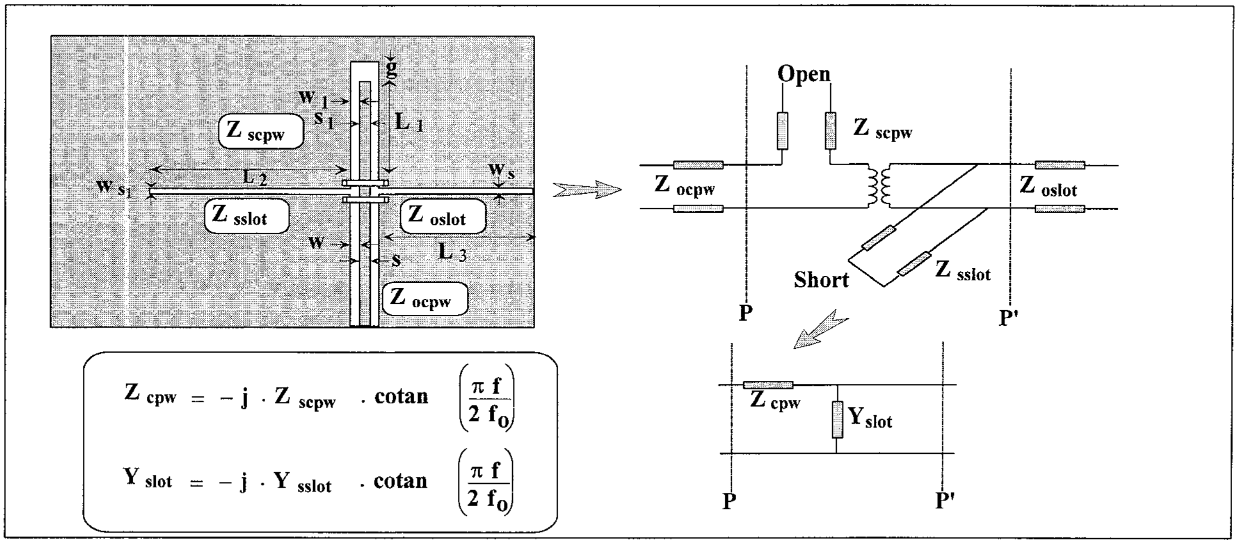


Fig.1 Typical CPW/slotline transition and its equivalent circuit

Parameters	Value	Units
s	30	µm
w	25	µm
s_1	130	µm
w_1	25	µm
w_{s1}	110	µm
w_s	25	µm
g	100	µm
Z_{ocpw}	60	Ω
Z_{oslot}	60	Ω
Z_{scpw}	40	Ω
Z_{sslot}	90	Ω
L_1	2.1	mm
L_2	2.4	mm
L_3	2.5	mm

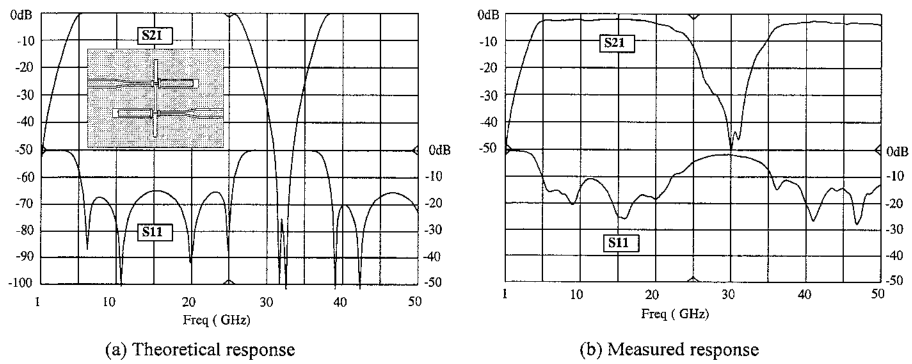


Fig.2. Simulated (a) and experimental (b) results of classical back-to-back transitions (single stub configuration) (Al_2O_3 substrate : h = 0.254 mm, $\varepsilon_r = 9.9$)

y_{sslot} : normalized equivalent characteristic admittance of the slotline stub

f_0 : center operating frequency

f : frequency

This structure has a bandpass response. This can be easily explained if we consider the variations of the S21 module with frequency:

- At very low frequencies ($f << f_0$) and for f near $2f_0$, $|S_{21}|$ tends towards 0
- For $f = f_0$, $|S_{21}|$ is equal to 1

By inspection of (1), an optimal operating bandwidth may be obtained, if this expression is quasi-independant of f over the largest frequency range. This condition is verified when the terms X_1 and X_2 are negligible i.e., when Z_{scpw} and Y_{sslot} tend towards 0. Furthermore, it should be noted that the periodicity of the response is $2f_0$ when the center operating frequency for the transition is fixed to f_0. To satisfy this condition, a first idea is to choose the highest value for Z_{sslot} and the lowest value for Z_{scpw} , allowed by the technological process.

As illustrated by figure 2, the transition bandwidth increases, with respect to the solution $Z_{sslot} = Z_{scpw} = 50\Omega$. In addition, it can be observed that the theoretical simulations compare well to the experimental results. The bandwidth is 3.9:1 with a 10 dB return loss and a corresponding insertion loss less than or equal to 2.5 dB

Another possibility, presented in figure 3, is to choose a double $\lambda_g/4$ CPW stubs configuration with a low Z_{scpw} value and a double $\lambda_g/4$ slotline stubs configuration with a high Z_{sslot} value. It allows to reduce the contribution of the terms, which depend on the frequency in (1). Indeed, with respect to a single $\lambda_g/4$ transition, we have two parallel impedances in series on the main line (equivalent to the two open CPW stubs) and two series admittances in parallel (equivalent to the two shorted slotline stubs): see figure 3. Thus, the parameters Z_{scpw} and Y_{sslot} in X_1 and X_2 are replaced by $Z_{scpw}/2$ and $Y_{sslot}/2$ in (1), respectively. This leads to a significant reduction of the frequency dependence.

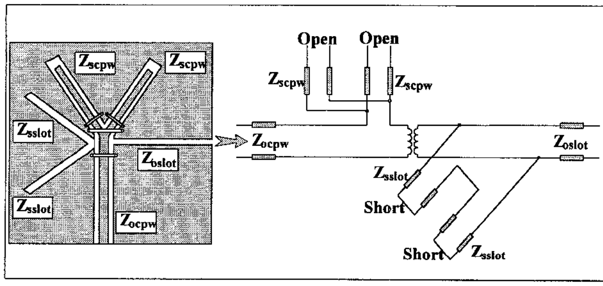


Fig.3 Multi-stubs configuration of the CPW/slotline transition and its equivalent circuit

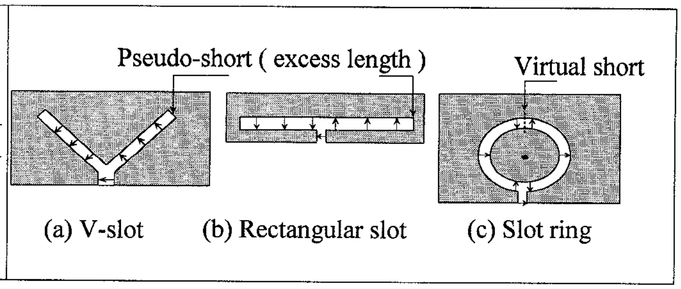
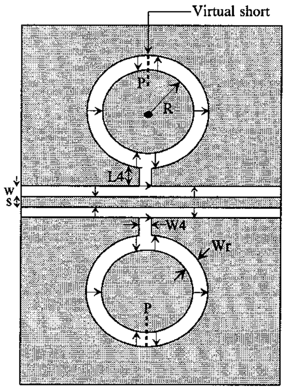
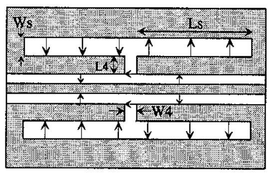


Fig.4 Electric field distribution of three types of slotline resonators



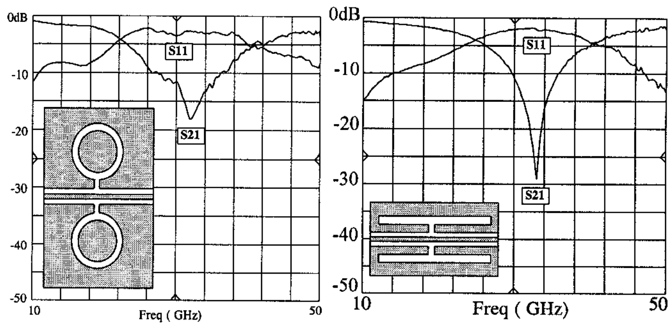
(a) Double slot ring millimeter-wave resonator

Parameters	Value	Units
S	50	μm
W	25	μm
W4	50	μm
Wr	25	μm
L4	25	μm
R	0.38	mm
Ws	25	μm
Ls	1.1	mm



(b) Double rectangular slot millimeter wave resonator nonradiating

Fig.5 Top view of double slot-resonators with electrical field distribution (arrows)



(a) (b)

Fig.6 Experimental results for the double slot ring (a) and rectangular slot (b) resonators (Al_2O_3 substrate : h = 0.254 mm, ε_r = 9.9)

However, it is also advisable to study the optimal geometric configuration of the slotline stubs for the following reasons:
a/ to limit the end effects (pseudo-short end) which are significant especially for large width values W_{s1} [12].
b/ to avoid radiation effect.
Under these conditions, the three following configurations seem appropriate.
While, the first configuration (figure 4a) is very easy to implement, it partially radiates and needs some end correction. To minimize radiation, the second configuration (figure 4b) seems to be the most appropriate. For the third configuration (figure 4c), it is not necessary to know and describe the equivalent circuit of the short end, but unfortunatly, it radiates a little. It is noteworthy that the end effects are essentially a second-order effect in contrast to radiation which plays an important role in the loss process.

For the configuration b (figure 4b), the experimental results show that the first resonance of the rectangular slot resonator appears when the length of the slot is approximately equal to $\lambda_g/2$. The two half-parts of the resonator are excited with a 180° phase difference via a short slotline feeder (figure 5b). Consequently, radiation problems are avoided due to this out of phase excitation. Regarding the slot ring resonator, its advantages are discussed in detail in [13]. The main advantage of this last configuration is the location of a virtual short in the P-plane (figure 5a) in comparison with the rectangular slot resonator where the pseudo-short ends are equivalent to excess lengths. For these two configurations experimental results are compared (figures 6a & 6b); it can be observed that rectangular resonator presents better performance.

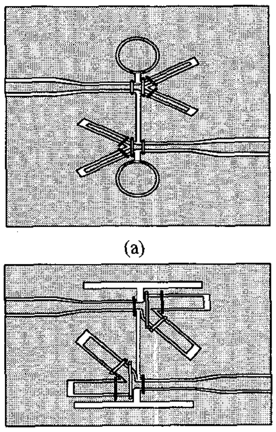
III. Simulation and experimental results of the two novel transitions

Based on the approach mentioned in the previous section, two experimental circuits (figure 7) were designed at f_o = 15 GHz and fabricated on Alumina substrates (ε_r = 9.9 , h=0.254 mm). The equivalent circuit, using HP-MDS, is shown in figure 8. The discontinuities effects are not taken into account except Ls and Cc, respectively the short end inductances for the rectangular slotline (figure 7b) and the open circuit capacitances for the CPW stubs (figures 7a & 7b).For all tested circuits , the experimental results are in very good agreement with the simulation. As expected, we observe a significant increase of the operating bandwidth, especially for the novel CPW to slotline transition built from the uniform double $\lambda_g/4$ CPW and $\lambda_g/2$ rectangular slotline non radiating resonator.

For the first transition (figure 7a), the maximum relative bandwidth ratio is larger than 7:1 with a 10 dB return loss. The corresponding insertion loss is less than or equal to 2.5dB. Regarding the second transition (figure 7b), the maximum relative bandwidth ratio is larger than 7.7:1 with a 10 dB return loss. The corresponding insertion loss is less than or equal to 2 dB. It should be noted that the transmission loss variation with frequency is mainly due to the input and output CPW's and the slotline length between the two transitions.

Conclusion

In this paper, it is shown that it is possible to widen significantly the bandwidth of CPW to slotline transitions. The largest bandwidth is obtained for the two novel proposed transitions corresponding to a multistubs configuration, where two types of slotline resonators are used. Experimental and simulated results are in good agreement and show excellent performance over a bandwidth ratio larger than 7.7:1.



Parameters	Value	Units
s	30	μm
w	25	μm
s_l	130	μm
w_1	25	μm
$w_{sl} = w_r$	110	μm
w_s	25	μm
g	100	μm
Z_{ocpw}	60	Ω
Z_{oslot}	60	Ω
Z_{scpw}	40	Ω
Z_{sslot}	90	Ω
L_1	2.1	mm
$L_2 = L_s$	2.4	mm
L_3	2.5	mm
R	0.38	mm

Fig.7 The new types of back-to-back CPW to slotline transitions :
(a) uniform double $\lambda_g/4$ CPW and $\lambda_g/2$ circumference slotline ring resonator
(b) uniform double $\lambda_g/4$ CPW and $\lambda_g/2$ rectangular slotline nonradiating resonator

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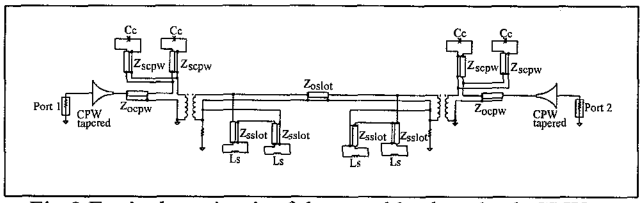
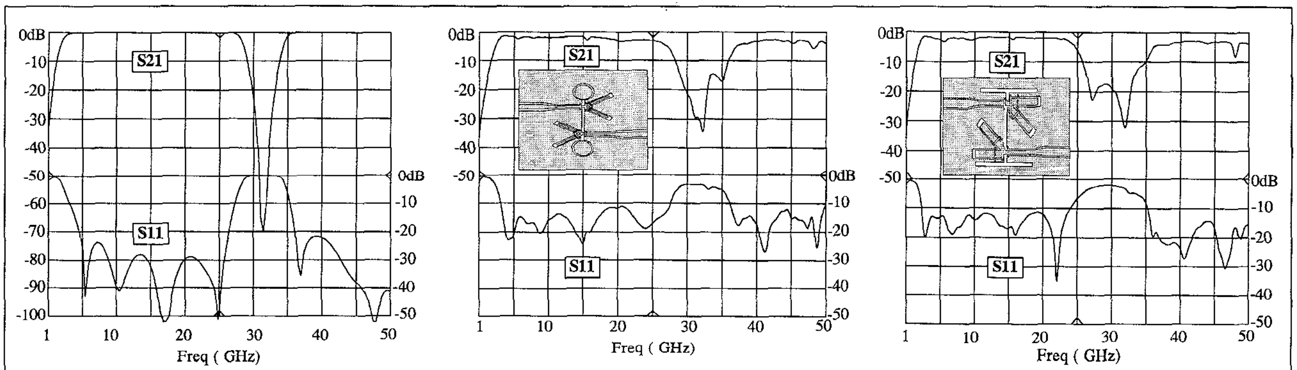


Fig.8 Equivalent circuit of the novel back-to-back CPW to slotline transitions



(a)Theoretical response (b)Measured responses

Fig.9 Frequency responses of the new types of back-to-back transitions