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THEORETICAL AND EXPERIMENTAL INVESTIGATION OF PARASITIC EFFECTS IN DOUBLE-Y BALUNS

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Abstract. Effects limiting the bandwidth of CPW_{FGP}−CPS double−Y balun are investigated both theoretically, using 3D electromagnetic simulators and experimentally. Analysis shows two kinds of parasitic effects: a) parasitic effects that depend on electrical length of input transmission lines for even and balanced modes and b) parasitic effects that depend on the length of open and short circuited stubs forming the double−Y balun, and they are observed in both regular odd mode and balanced mode. Developed theory enables prediction of parasitic resonances in $CPW_{FGP} - CPS$ baluns and shifting them out of an operating frequency bandwidth by changing physical dimensions of the balun. Theoretical results have been experimentally verified.

Key words: Double-Y Balun, coplanar waveguide, parasitic effects

1. Introduction

Among the double-Y baluns [4], $CPW_{FGP} - CPS$ [6] and $CPW_{FGP}-$ parallel microstrip baluns [7] demonstrate an extremely wide frequency range. The low edge of the frequency bandwidth is practically DC. However, some very sharp peaks have been noticed even at low frequencies, limiting the bandwidth of these baluns and degrading overall characteristics of the balun.

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The aim of this work is to investigate the parasitic effects in $CPW_{FGP} - CPS$ balun, both theoretically and experimentally. Among the double$-Y$ baluns $CPW_{FGP} - CPS$ balun is the most promising structure for applications, due to its uniplanar configuration and potentially wide bandwidth.

In this paper an electromagnetic simulation, based on the method of moments, is applied to $CPW_{FGP} - CPS$ balun. In order to simplify and speed up numerous calculations of transfer characteristics of the balun in a wide frequency range, the balun is firstly analyzed without substrate using $WIPL$ software [5]. In this way, the electrical lengths of different modes propagating along the analyzed structure become equal. This fact considerably simplifies identification of the resonances of different modes and enables prediction of the frequencies at which the resonances appear.

Parasitic effects observed in $CPW_{FGP} - CPS$ balun are divided into two main groups: ones whose resonances depend on the electrical length of the input transmission lines, and those whose resonances are determined by the length of open and short circuited stubs forming the double$-Y$ balun.

The results of theoretical analysis are verified on an experimental model which consists of two back-to-back $CPW_{FGP} - CPS$ baluns realized on the alumina substrate. Experimental model is also analyzed using $IE3D$ software package [2] that takes into account both circuit and housing. Although input coaxial connectors are not included in the simulation, good agreement with the experimental results is observed. This proves that EM simulators based on the method of moments can successfully be used instead of making many experiments, even in the case when the resonances of parasitic modes are investigated in very complex structures.

2. EM Analysis of a Balun without Substrate

2.1 Analysis of parasitic modes on the input transmission lines [3]

In this analysis length of open and short circuited stubs (L_s) is chosen to be very short in order to shift resonances which depend on the stubs towards higher frequencies. Two parasitic effects are observed: parasitic antenna mode (PAM) and parasitic balanced mode (PBM).

The geometry of analyzed $CPW_{FGP} - CPS$ balun consists of wires and plates, as shown in Fig. 1. The currents along wires and over plates are approximated by polynomial expansion whose basis functions automatically satisfy the continuity equation at the element junctions and free ends. Calculated $S_{21}-$characteristics of the baluns with different lengths of input transmission lines ($2L$) show that resonances of PAM depend on the length of input CPW_{FGP} and CPS lines that form a dipole antenna. Its resonances appear at the frequencies for which the length of dipole is equal to an odd multiple of $\lambda/2$, i.e.

$$2L = (2n+1)\frac{\lambda}{2}, \quad n = 0, 1, 2, \ldots \tag{1}$$

In the case that length of input CPW_{FGP} and CPS lines are not equal, the resonances appear at frequencies for which the length of dipole is equal to multiple of $\lambda/2$.

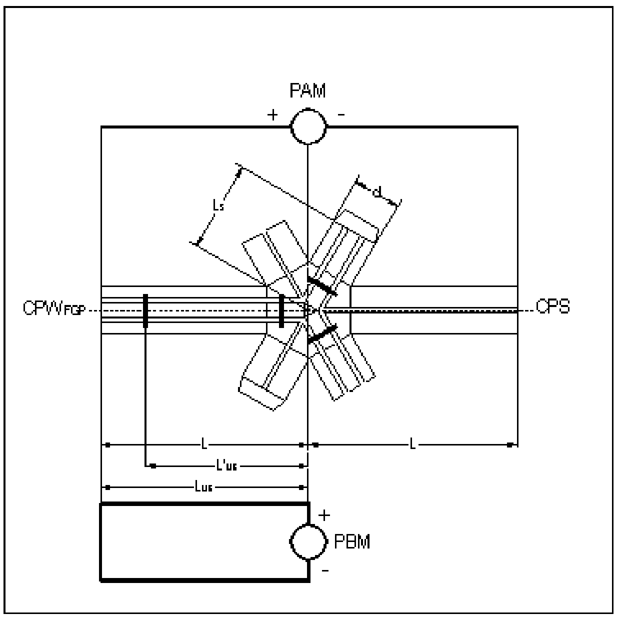


Fig. 1. The geometry of analyzed $CPW_{FGP} - CPS$ balun.

Besides shallow PAM resonances, very sharp resonances caused by parasitic balanced mode (PBM) are observed. These resonances depend on the length of input CPW_{FGP} line and they appear at frequencies for which the length of PBM contour (L_{ub}) is equal to multiple of $\lambda/2$, i.e.

$$L_{ub} = n\frac{\lambda}{2}, \quad n = 1, 2, \ldots \tag{2}$$

Analysis of the balun with reduced cross section of the transmission lines ($d = 0.5$ mm) shows that peaks caused by the resonances of PBM become sharper (without influence on PAM). Also, balun with smaller cross section has lower losses.

This kind of parasitic effects are not typical only for double$-Y$ baluns, but also for other transitions that consists of collinear CPW_{FGP} and CPS lines.

2.2 Parasitic effects caused by topology of double-Y balun

In order to investigate parasitic effect caused by open and short circuited stubs forming double-Y balun, the length of input transmission lines (2L) was shortened in order to shift PAM and PBM resonances to higher frequencies.

$S_{21}-$characteristics of two baluns with $L_{s1} = 3.866$ mm and $L_{s2} = 5.866$ mm ($2L = 4.88$ mm, $d = 1.0$ mm) are given in Fig. 2. Two very sharp peaks at frequencies $f_1 = 6.2$ GHz and $f_3 = 18.8$ GHz can be seen in transfer characteristics of balun with $L_{s2} = 5.866$ mm, while the balun with shorter L_s has corresponding peak at $f_1 = 9.2$ GHz. Frequencies of these peaks are very close to the values calculated on the basis of an equivalent circuit which predict the peaks at the frequency for which L_s becomes equal to an odd multiple of $\lambda/8$ [1].

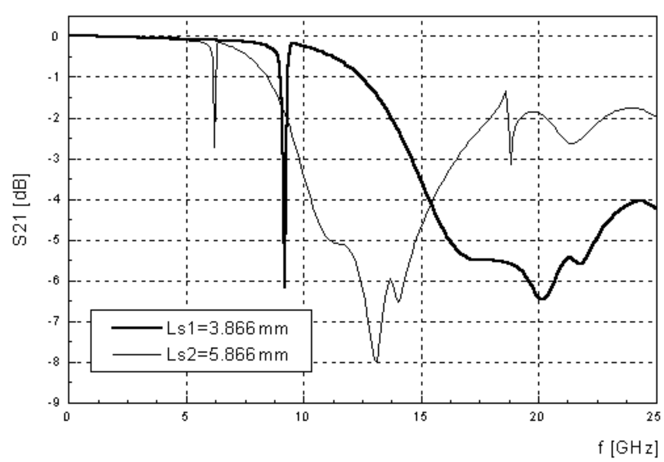


Fig. 2. $S_{21}-$characteristics for baluns with different length L_S.

Between sharp peaks, at the frequency for which L_s becomes $\lambda/4$ there is a deep minimum in $S_{21}-$characteristics that appears in fairly wide frequency range. Losses are considerably high, while maximum $VSWR$ is between 2-3. In Fig. 3., S_{21} is shown for the balun ($L_s = 5.866$ mm) excited by the regular and parasitic balanced mode (PBM) separately. It can be seen that air bridges placed regularly at the double$-Y$ junction, do not suppress PBM sufficiently at the frequencies above the first peak ($L_s = \lambda/8$). Losses curves are very similar for both, regular and PBM, although PBM has a considerably lower losses due to greater reflection.

Also, normalized real and imaginary parts of input impedance of the balun excited by regular and PBM show that both modes have an anti-resonance at the frequency for which the length of open and short circuited stubs become equal to $\lambda/4$. Real part of input impedance at that frequency is around 2-3 for regular, and 13-14 for PBM, and it is equal to $VSWR$.

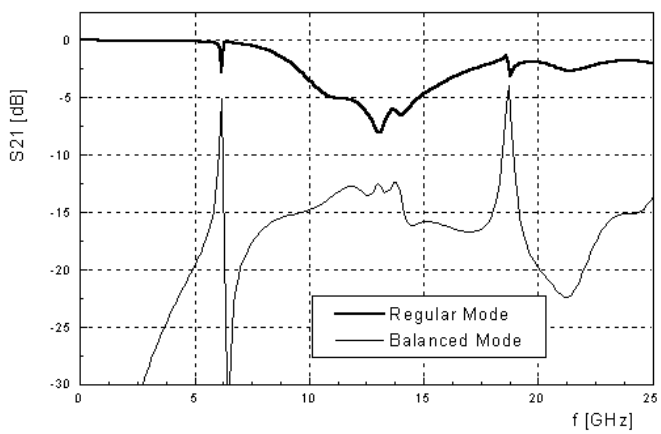


Fig. 3. Magnitude of S_{21} for the balun excited by regular and parasitic balanced modes.

If additional air bridges are put in the middle of CPW_{FGP} open and short circuited stubs it is possible to reduce the losses in double$-Y$ balun above the first dip. In this way, the transmission of PBM is considerably suppressed along the CPW_{FGP} stubs.

2.3 Parasitic effects in two back-to-back double-Y baluns

Parasitic effects are also investigated for the structure consisting of two back-to-back baluns with even and odd symmetry in order to compare theoretical and experimental results.

The structure with even symmetry and with additional air bridges placed on CPW_{FGP} stubs ($L_S = 5.866$ mm) is analyzed (Fig. 4.a)). Magnitude of S_{21} is given in Fig. 4.b) for two different distances between centers of the baluns: $L_1 = 14$ mm and $L_2 = 20$ mm. In $S_{21}-$characteristics shallow resonance with shape similar to PAM appears at 3.8 GHz and 3.2 GHz respectively. The shape of these resonances is considerably different from the low frequency resonance, observed in the measured S-parameters. It should be pointed out that the basic difference between analyzed structure and investigated experimental model is in the housing, which is not taken into account in this simulation.

In the first approximation, housing can be simulated by a metallic frame connected to the outer conductors of input CPW_{FGP} lines. The geometry of analyzed structure in odd configuration is shown in Fig. 5.a). The magnitude of $S_{21}-$parameters for two baluns in even and odd configuration with added metallic frame, are given in Fig. 5.b). It is seen that structure with odd symmetry does not transmit the regular mode at low frequency, due to connection between frame (housing) and central conductor of CPW_{FGP} line. Also, both structures have very deep minimum at 3.5 GHz, whilst the dip for structure with the even symmetry is a much sharper.

3. Experimental Results

3.1 Resonances of parasitic balanced mode

In order to verify the theory of resonances of parasitic modes in $CPW_{FGP} - CPS$ baluns, detailed measurements are performed. The measured circuit consists of two back-to-back baluns in the even configuration. In order to investigate the effects of PBM at input transmission lines, the test circuit is measured firstly with the air bridge placed at the end of $CPW - CPW_{FGP}$ taper and than with the air bridges removed. The magnitude of $S_{21}-$parameters for both cases are given in Fig. 6. It is seen that two additional resonances at $f_{1m} = 7.7$ GHz and $f'_{1m} = 15.3$ GHz appear when the air bridges are removed. This result is in agreement with eqn. (2) that predicts PBM resonances at frequency for which PBM contour becomes equal to the multiple of $\lambda/2$. Concerning PBM with the air bridges added, it is not easy to distinguish it from the superimposed other resonance at about $f_{2m} = 9.9$ GHz.

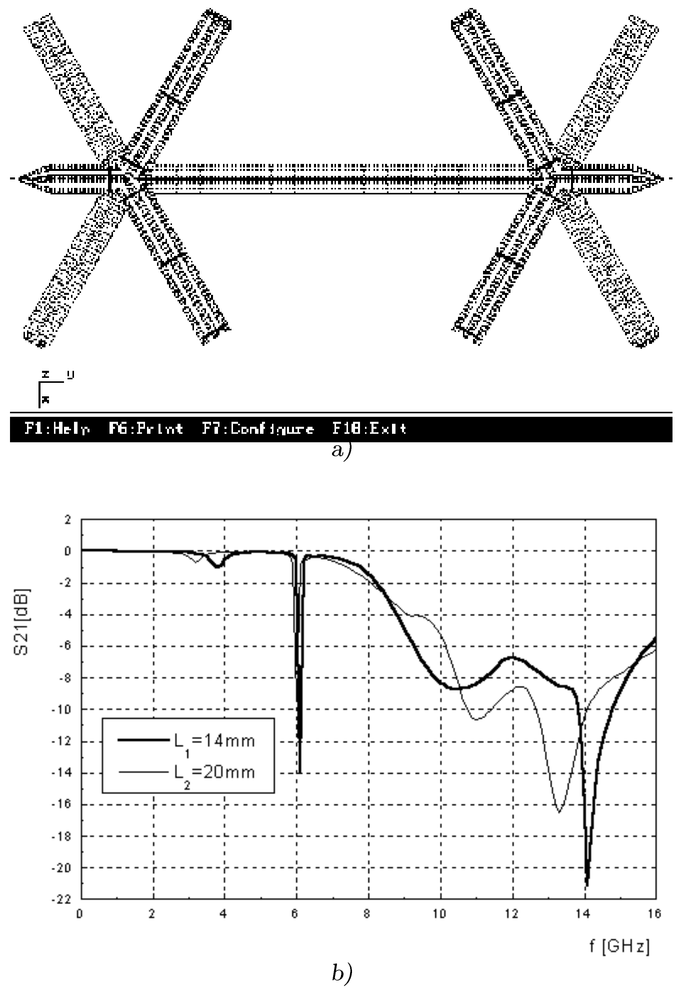
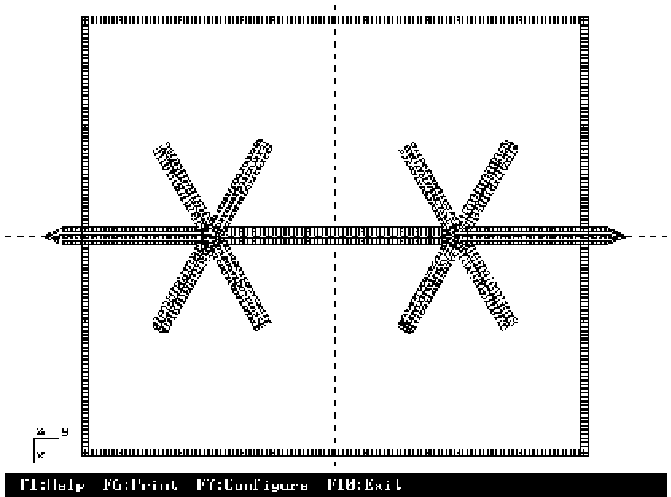


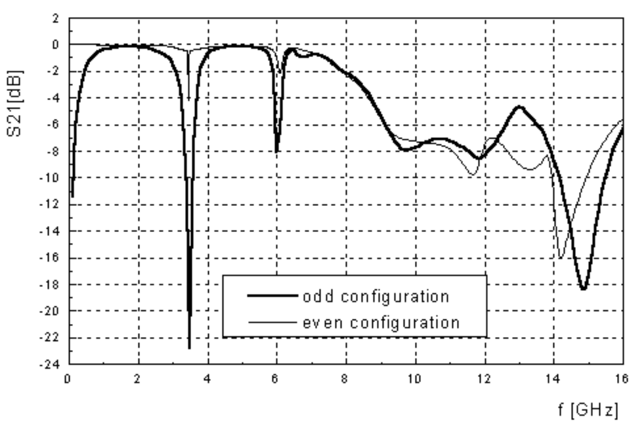
Fig. 4. a) Two back-to-back baluns with even symmetry, b) Magnitude of S_{21} for the structure with different distances between baluns.

3.2 Parasitic effects caused by topology of double-Y balun

Parasitic effects due to balun topology are investigated by adding air bridges along open and short circuited CPW_{FGP} stubs. Regularly, a doub-



a)



b)

Fig. 5. a) Analyzed structure with odd symmetry,
b) Magnitude of S_{21} for the structures with even and odd symmetry.

le$-Y$ balun has three air bridges at the junction, but, as the previous analysis shows, they do not suppress PBM sufficiently at higher frequencies, when the length of the stubs become equal to $\lambda/4$. Fig. 7. shows magnitude of $S_{21}-$parameters for the circuit with and without air bridges placed along CPW_{FGP} stubs.

It is seen that there is no resonance at 13.2 GHz at $S_{21}-$characteristics and that losses are lower above 10 GHz, when air bridges are placed along the stubs. The balun analyzed without substrate has both anti-resonances

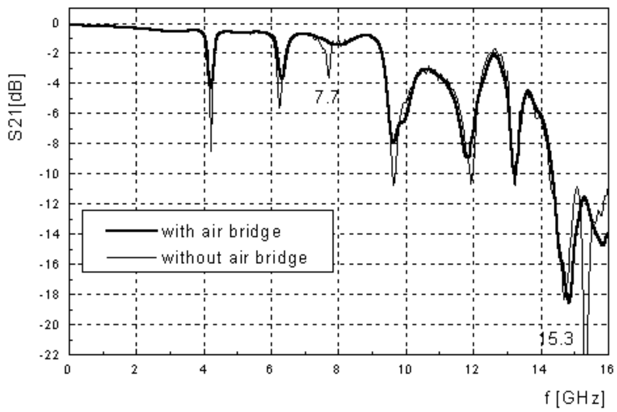


Fig. 6. Magnitude of S_{21} for the structure with and without air bridges at input CPW_{FGP} lines.

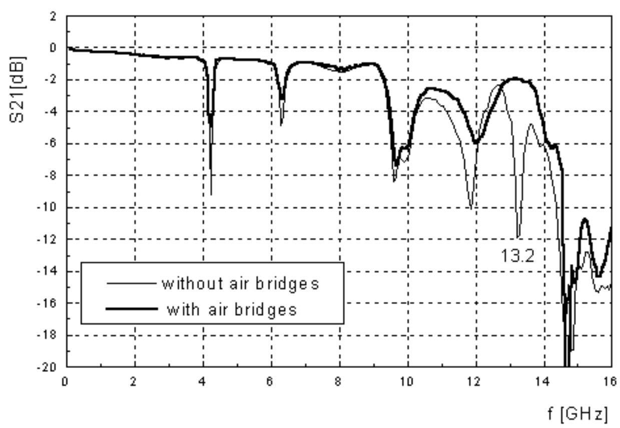


Fig. 7. Magnitude of S_{21} for structures with and without air bridges along CPW_{FGP} stubs

of regular and PBM at the same frequency. Due to different effective permittivities of the regular mode and PBM these anti-resonances should be about $f_r = 11.85$ GHz and $f_{PBM} = 13.2$ GHz respectively as can be seen in measured characteristics of baluns without air bridges.

3.3 Resonances of parasitic even mode

To identify resonances of parasitic even mode (PEM) in the complex circuit used in this experiment is extremely difficult. According to previous analysis it is known that input transmission lines are responsible for the

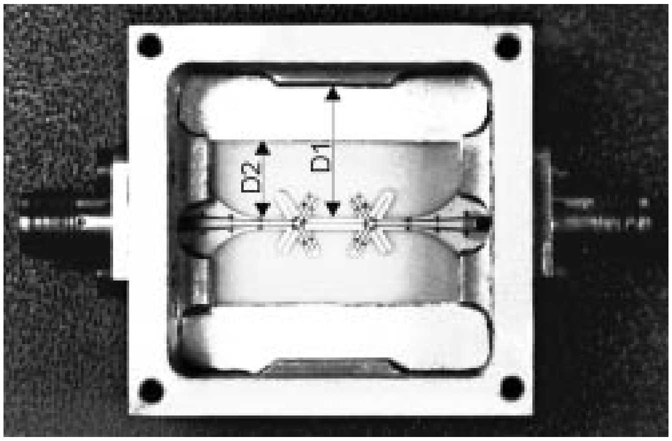
PEM resonances. Also, LINPAR [7] calculations of the characteristics of different modes propagating along CPW_{FGP} and CPS lines show that characteristics of PEM can be changed if the distance (D) between lines and surrounding metallic walls changes, while the characteristics of other modes stay unchanged.

Experiment is performed for three different distances (D): D_1 = 12.2 mm, D_2 = 6.5 mm and D_3 = 4.4 mm. Distance (D) is changed by changing the width of grounded metallic strips added in parallel to input transmission lines. Fig. 8. shows: a) test circuit and b) measured S_{21} parameters for three different distances (D). Peaks of PEM are shifted towards lower frequencies when distance (D) becomes smaller, while the other peaks stay at the same frequency or shifted to higher frequencies due to coupling between stubs and surrounding metallic walls. In this way, it is possible to identify PEM resonances.

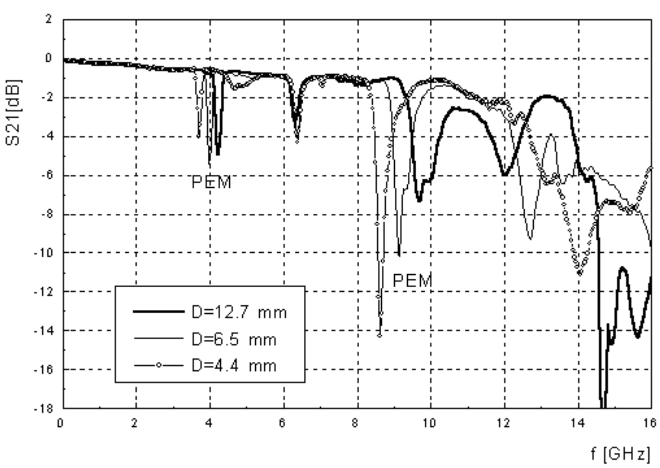
Table 1

D[mm]	12.2	6.5	4.4
$\varepsilon_{even}(CPW_{FGP})$	1.937	2.201	2.445
$\varepsilon_{even}(CPS)$	1.918	2.18	2.421
$\varepsilon_{even}(taper)$	1.671	1.942	2.228
f_{r1} [GHz]	5.066	4.729	4.455
f_{r1m} [GHz]	4.22	3.98	3.7
f_{r1}/f_{r1m}	1.2	1.188	1.204
f_{r2} [GHz]	10.132	9.458	8.91
f_{r2m} [GHz]	9.7	9.3	8.62
f_{r2}/f_{r2m}	1.044	1.016	1.033
f_{r2m}/f_{r1m}	2.3	2.34	2.33

Table 1. summarizes effective permittivities and resonances of PEM predicted by $LINPAR$ and eqn. (1) (f_{r1}, f_{r2}) and resonances observed during the experiment for different (D) (f_{r1m}, f_{r2m}). Thanks to the fact that CPW_{FGP} and CPS are low dispersive lines it is possible to predict the parasitic resonances in this circuit with pretty good accuracy, using only quasi-static calculation of the line parameters ($LINPAR$). Calculated first resonance is higher then measured one for about 20%, due to the fact that eqn. (1) does not take into account influence of the baluns themselves, but only the electrical lengths of the input transmission lines. Agreement between calculated second resonance and measured one is very good, which is due to the fact that measured ratio f_{2m}/f_{1m} is not 2 as it is expected, but about 2.3.



a)



b)

*Fig. 8. a) View of the test circuit,
b) Measured S_{21} for different distances (D) between CPW_{FGP} line and grounded metallic strips.*

4. Conclusion

Parasitic effects that limit the bandwidth in $CPW_{FGP}-CPS$ balun are investigated both theoretically and experimentally. Two kinds of parasitic resonances are observed: a) resonances that appear at input transmission lines caused by PEM and parasitic balanced mode (PBM) and b) resonances of the regular mode and PBM that appear due to specific topology of the double$-Y$ balun.

The first type of parasitic resonances are not typical only for double$-Y$ baluns, but for all structures consisting of collinear CPW_{FGP} and CPS lines. They are caused by PBM, excited at the input CPW_{FGP} line and PEM that appears at inputs of CPW_{FGP} and CPS lines.

The second kind of parasitic effects is typical for the double$-Y$ baluns and it is due to the different characteristic impedances of CPW_{FGP} and CPS lines or different electrical length of open and short circuited stubs.

Both effects are experimentally verified on a complex model that consists of two back-to-back baluns. The resonances of parasitic modes calculated from derived equations and using relative mode permitivities are in good agreement with measured ones.

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