Modeling of Strip-Loaded Coplanar Waveguide (July 2021)

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***Abstract*—This paper presents slow wave structure based on a cascade of four unit cells of micro-strip loaded coplanar waveguide (CPW). Each cell functions as a low pass filter and the filter can be considered as a slow wave structure from a dispersion point of view. The structure is originally designed at 3GHz and its dimensions were altered to be at 5GHz, by scaling and by changing the stub lengths the frequency was fine tuned.**

***Index Terms*—coplanar waveguide (CPW), cross junction, high-pass filter, low-pass filter, shielded CPW (S-CPW), slotline, split-ring resonator (SRR).**

I. Introduction

COPLANER waveguide (CPW) is very important microwave component that supports two modes coplanar mode and parasitic slotline mode the coplanar mode has even symmetry while the parasitic slotline has odd symmetry we used to think in a way to suppress the parasitic slotline mode but this way adds up parasitic capacitance and make fabrication more expensive. That's why we thought of benefiting from the parasitic mode instead of suppressing it as it adds extra degree of freedom to the design and that's why the CPW cross-junction equivalent circuit model is introduced. This section presents the 3-dB CPW slotlines Wilkinson power divider application. The power divider consists of CPW input port, two slotlines and isolation network.

The divider is based on the theory of operation of Wilkinson power divider that splits an input signal into two equal phase output signals or combines two equal-phase signals into one in the opposite direction. Figure 1(b) shows the equivalent circuit model of the divider where the divider's input port is connected to the even mode junction by a transmission line and the odd mode is terminated with a short- circuited stub. At the junction ports (n2, n5, n3) and (n4, n5, n1) the 1:1 transformers are separated, the even modes are terminated with open-ended TLs of zero lengths while the odd modes are connected through matched transmission lines to the divider output ports. The junction port (n3, n4, n5) is connected to the isolation network. In the circuit model the even mode is connected to a resistor R/2 parallel to an open-circuited stub but the odd mode is connected to a 2R resistor parallel to a short-circuited stub.

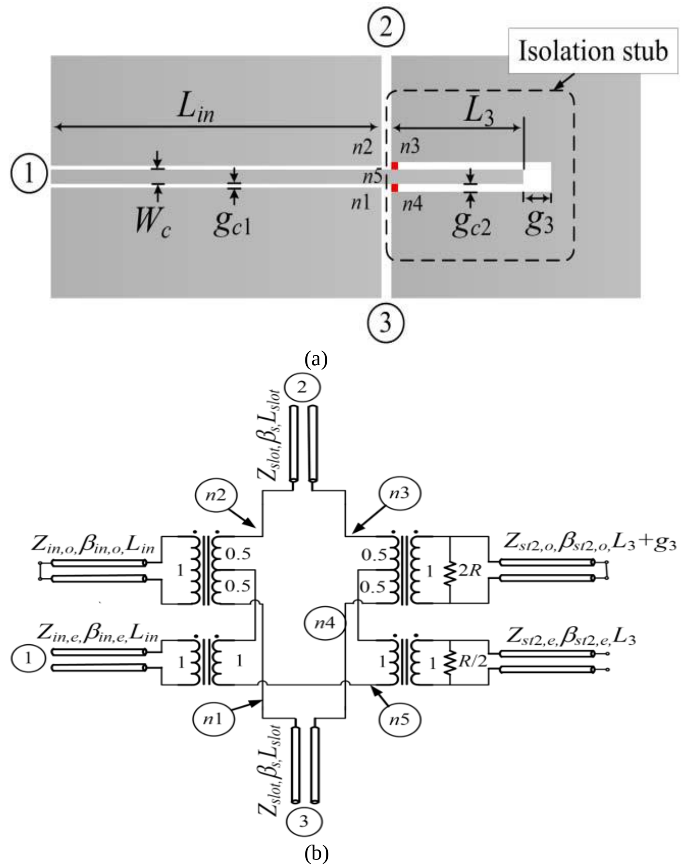


Fig. 1.(a) Layout of the power divider. (b) Equivalent circuit model of the power divider.

The two techniques are symmetric and can be exposed to perfect E/H planes and both gives the same reduced circuit models which ensures the validity of the model for the symmetrical CPW structures.

This application provides various circuit models to the proposed Wilkinson power divider to measure the reflection coefficient at the input port, to show the circuit model in the even mode excitation and the circuit model during the odd mode excitation. Figure. 3(a) shows the circuit model to calculate S11 parameter, the structure is fed through the input port of the CPW, the two slotline ports are matched so we can measure the reflection coefficient at the input port, the two CPWs TLs carry the even mode only due to even symmetry and excitation, the matched slotlines are parallel acting as a

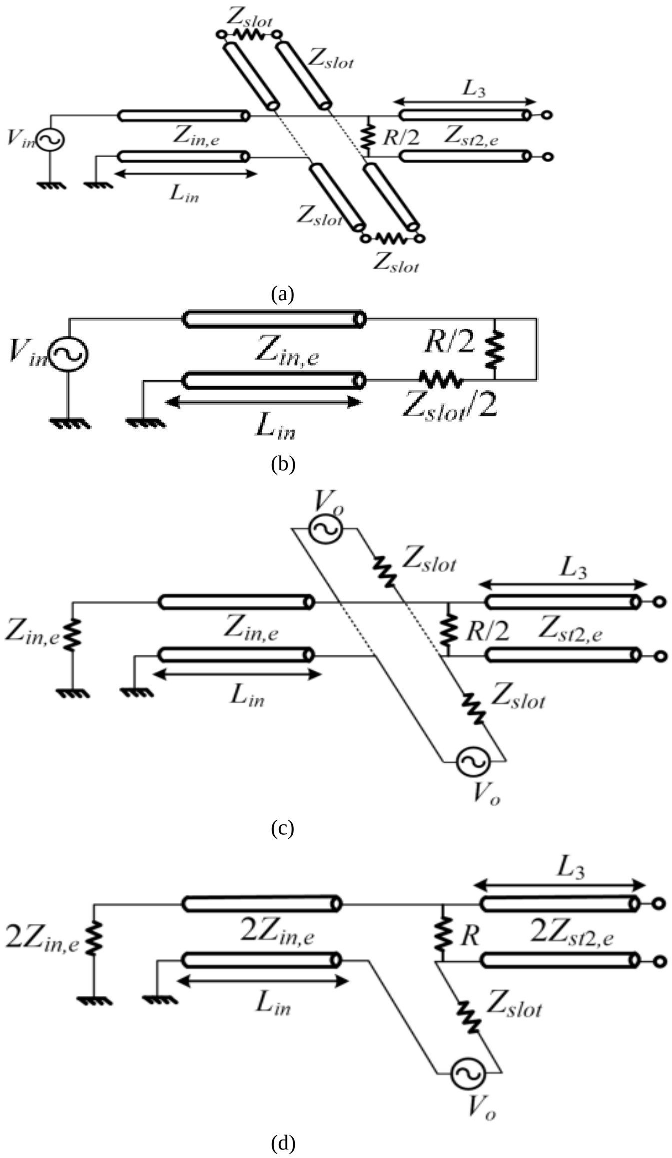


Figure. 3(a)Circuit model. (b) Reduced circuit model. (c) Circuit model for even mode excitation.(d) Reduced circuit model after applying the open-circuit boundary at symmetry plan.

resistor and the matching is achieved if the length of the isolation stub even mode (L_3) is adjusted to $\lambda_{st2,e}/4$ (2) (the R/2 resistor will be short circuited) and the Z_{slot} is equal to double the characteristic impedance of the input CPW even mode and double the source impedance Z_s (1).

$$L_3 = \lambda_{st2,e}/4 \qquad (1)$$

$$Z_{slot} = 2Z_{in,e} = 2Z_s \qquad (2)$$

For even mode excitation figure. 3(c) shows the two CPWs (input and isolation CPW) operate in the even mode and the two slotline ports are equally excited by V_0. Figure. 3(d) shows the reduced circuit model the open-ended stub shortens the resistor R. and the impedance of the input port both lead to. zero even reflection coefficient. Figure. 3(d) shows the model after applying open-circuit boundary at symmetry plane.

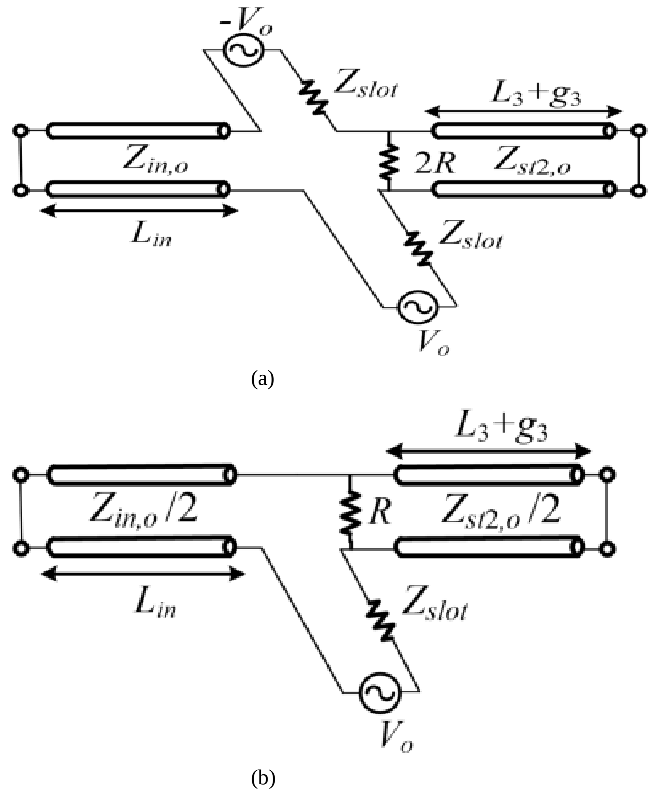


Figure. 4(a)Reduced circuit model after applying short-circuit boundary at the symmetry plane.(b) Circuit model for odd mode excitation.

Figure. 4(a) and figure. 4(b) show the odd mode operation of the divider and the reduced circuit model after applying the short-circuit boundary condition. The proposed design input and isolation CPWs operate at the odd mode while microstrip Wilkinson power divider doesn't support odd mode operation.

$$L_{in} = \lambda_{in,o}/2 \qquad (3)$$

$$L_3 + g_3 = \lambda_{st2,o}/4 \qquad (4)$$

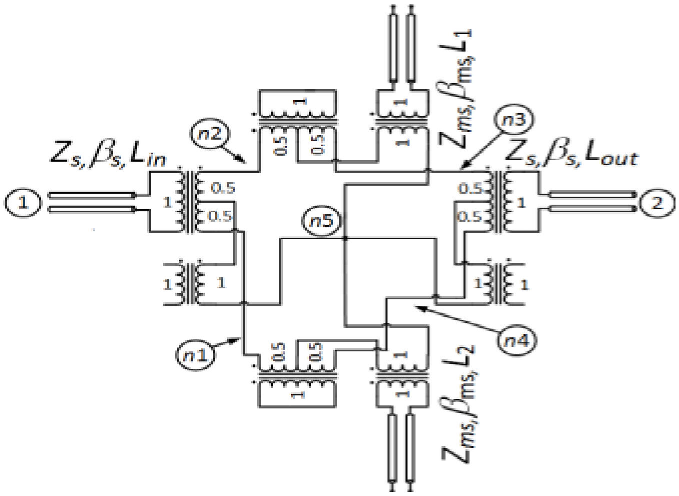
$$R = Z_{slot} = 2Z_s \qquad (5)$$

II. Cross-Junction & SRR-Loaded CPW

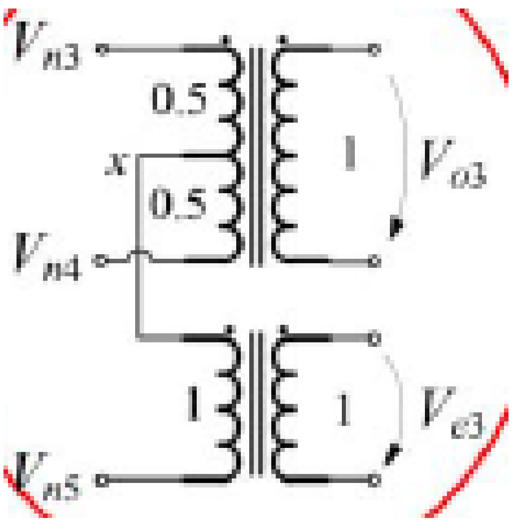
A. Theory of Cross-Junction

A problem arises when solving a multimode CPW cross junction as each CPW has two modes, even and odd. Applying Kirchhoff laws gives a 8×8 matrix that is considered large, hard to simplify or solve and no easy design equations can be derived, if the matrix was to be solved as it is, a lot of time will be consumed in tuning and optimization. In some cases for an eight port structure the old models gives a far more significant number of transformers.

The proposed solution is a new physically based equivalent circuit model of the CPW cross junction is built on physics rather than equations, so it provides insights to the circuit operation. The new model uses only eight transformers with

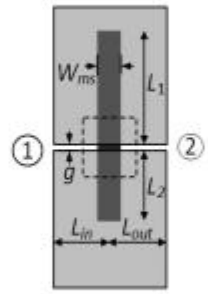


(a)

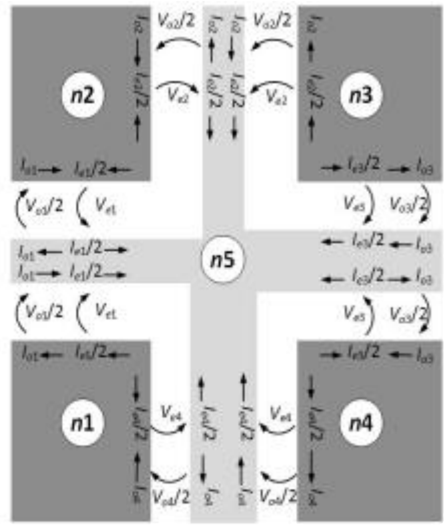


(b)

Fig. 5(a). equivalent circuit model of CPW cross junction.
(b)Transformer model with voltages



(a)



(b)

Fig. 6. (a) Strip-loaded slotline. (b) Slotted-microstrip cross junction.

eight electrical ports and four physical ports to represent the cross junction as an equivalent circuit as shown in figure 5(a).

The new model allows the development of new structures and can adapt to already existing ones as for example: it allows for a relatively easy design method of CPW to slot-line transition, the new model also led to a new realization of a 3-dB CPW to slot-line Wilkinson power divider isolating the two output ports using the odd mode and 2 resistors in place of the one isolating resistor placed between the two output ports in the micro-strip implementation of the Wilkinson power divider.

There are no air bridges in the equivalent circuit model, therefore both even and odd modes are present in each CPW, when writing the equations relating even and odd voltages to node voltages and currents at a single physical port, it is clear that these same equations represent a pair of transformers that have the same phase, one of the transformers has a turns ratio of one, as shown in figure 5(b), therefore it represents the even mode, the second transformer is a center tapped one with a turns ratio of half, therefore, it represents the odd mode, the pervious description and conditions on the transformers satisfies the set of equations given by equivalent circuit model.

$$V_{o3} = V_{n3} - V_{n4}$$
$$V_{e3} = \frac{1}{2}(V_{n3} + V_{n4}) - V_{n5}$$
$$I_{o3} = \frac{1}{2}(I_{n3} - I_{n4})$$
$$I_{e3} = -I_{n5} = I_{n3} + I_{n4}$$

For the equivalent circuit model to completely represent the cross junction, an equivalent model is used for each CPW, and they are connected together. Each center tapped transformer is connected to the following center tapped one forming the 4 outer nodes, the 4 terminals of the one turns ratio transformers are connected together forming the central common node.

For validation of the proposed model, different structures with already Known characteristics and solutions were tested, the resulting S-parameters were identical to previous solutions.

B. *Theory of SRR-Loaded CPW*

This section describes the proposed equivalent circuit model of spilt ring resonator coplanar waveguide (SRR-CPW), the idea begins with strip-loaded slotline which is a slotline loaded by a floating conductor strip on the opposite side of substrate as shown in Fig.5(a). and by comparing this structure to multimode slotted-microstrip cross junction shown in Fig.5(b) which reveals that the strip-loaded slotline is a special case of slotted-microstrip cross junction.

And Fig.6(a) shows the transformer model of strip-loaded slotline with the applied boundary conditions which leads to the even mode at cross junction port 1 to be connected open

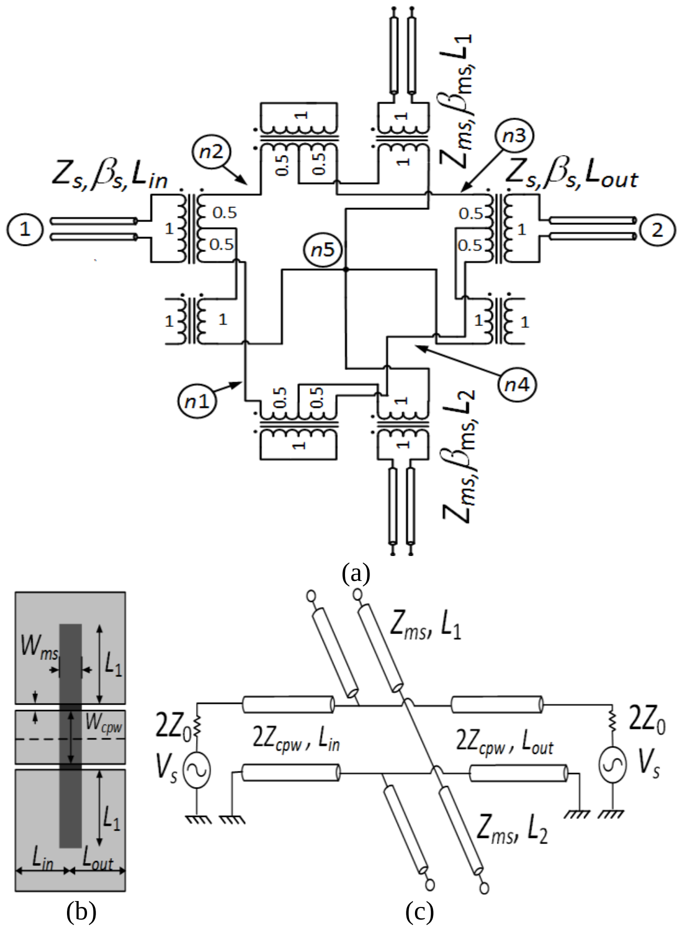


Fig. 8. (a) Current distribution on the slotline. (b)Strip-loaded CPW Physical layout. (c) Strip-loaded CPW Reduced circuit model.

circuit of zero length and odd mode at the same port to be connected to a transmission line with its own characteristic impedance. Port 3 is like port 1, this assumes uniform host line for simplicity. Port 2 and 4 are the complement of port 1 and 3, so its odd mode is terminated by short circuit with zero length, and its even mode is connected to a conventional microstrip open stub with its own characteristic impedance.

Then the asymmetrical strip-loaded slotline structure which have been discussed before having been modified to be a symmetric strip-loaded CPW. And the symmetry of the structure preserves the even-mode excitation, and hence, the presence of perfect-H symmetry plan that bisects the structure which shown in Fig.6(b).

After that, the last but not least modification of the structure is making a ring of two strip-loaded slotlines junction. The CPW center conductor and the strip beneath it form a transmission line that connect the two junctions. These modifications depict the symmetric SRR-loaded CPW which is shown in Fig.7(a) and its physical parameters of the rings are radii and the conductor width. The proposed equivalent circuit model is shown in fig.7(b), which presents half the structure only as there is a perfect-H symmetry plane, and as shown in Fig.7(b) the equivalent circuit model can be considered as combination of two equivalent circuit model of strip-loaded slotline.

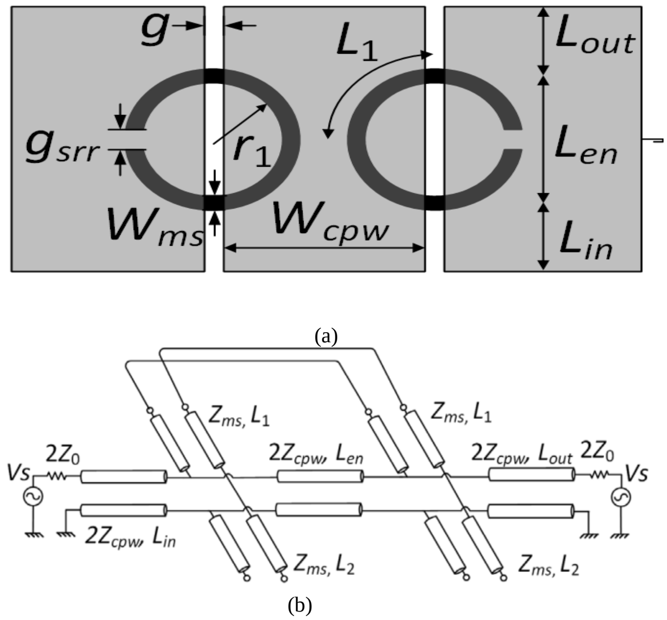


Fig. 9. (a) SRR-loaded CPW. (b) Half-circuit model of SRR-loaded CPW.

From transmission line point of view, we see that the proposed model of SRR-CPW consists of SRR section beneath slotline gab and open-end effects, and also we take in consideration the effect of EM coupling between the host line and SRR and the substrate thickness which are included in electrical length properties of the lines.

Research paper also provide the developed circuit model which determine by applying the even-odd symmetry the equivalent input impedances which we conclude before that at resonance frequency the even input impedance is the same of input odd impedance.

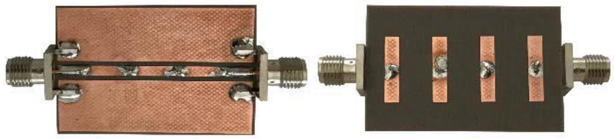
$$Z_{in}^{o} = \frac{2jZ_{ms}Z_{cpw}\tan(\beta_{cpw}L_o)\left(\tan(\beta_{ms}L_1) - \cot(\beta_{ms}L_2)\right)}{2Z_{cpw}\tan(\beta_{cpw}L_o) + Z_{ms}\left(\tan(\beta_{ms}L_1) - \cot(\beta_{ms}L_2)\right)}$$

$$Z_{in}^{e} = \frac{-2jZ_{ms}Z_{cpw}\cot(\beta_{cpw}L_o)\left(\cot(\beta_{ms}L_1) - \cot(\beta_{ms}L_2)\right)}{2Z_{cpw}\cot(\beta_{cpw}L_o) + Z_{ms}\left(\tan(\beta_{ms}L_1) - \cot(\beta_{ms}L_2)\right)}$$

III. SLOW WAVE STRUCTURE

A. Theory

One of the applications that benefit from the proposed model of spilt ring resonator CPW is a slow wave structure low pass filter which is a slotline by two stubs in series with each other and in shunt to the host line, is suitable for conventional CPW filter implementation. So to realize compact stepped impedance low-pass filters, the series inductors are implemented by electrically short sections of high impedance host lines, but the shunt capacitors are realized using the microstrip stubs instead of low impedance host sections. The previous filter realizes a slow wave structure from a dispersion point of view. And due to CPW structure which assumes periodicity, the structure will be capacitively loaded periodic section of transmission line. So



(a) (b)

Fig. 10. Fabricated slow wave TL. (a) Top layer. (b) Bottom Layer.

by increasing the value of shunt capacitor raises the slow wave factor but decreases the Bloch impedance. And the impedance of the host CPW needs to be to realize a Bloch impedance of 50Ω as mentioned at research paper.

The mentioned dimensions and lengths at research paper as the following: The substrate is a 0.787-mm-thick Arlon DiClad 880. The host CPW strip width is 2 mm, and the gap is 1 mm, which provides a CPW impedance of 107Ω.

The stub width is 3 mm, which provides microstrip impedance of 43Ω and an open-end capacitor of 45 fF. The length of the stub is 5 mm, and the pitch is 10 mm. And the following figures shows the transmission line structures from research paper.

B. *Simulation Results*

The slow wave structure is realized using a substrate RO4003 (Єr = 3.55) with thickness of 0.762mm. The dimensions used are physical length of 40mm, center strip of 2mm width, a gap of 1mm and a length of 5mm for each of the eight stubs, The results of the paper were then duplicated to operate at the same frequency as in figure(11).

To duplicate the results at 5GHz frequency, the entire had to be scaled down by a factor of 0.36 without changing the substrate material or thickness and then all the stub lengths were decreased to 4.5mm for fine tuning, these results are shown in figure(12).

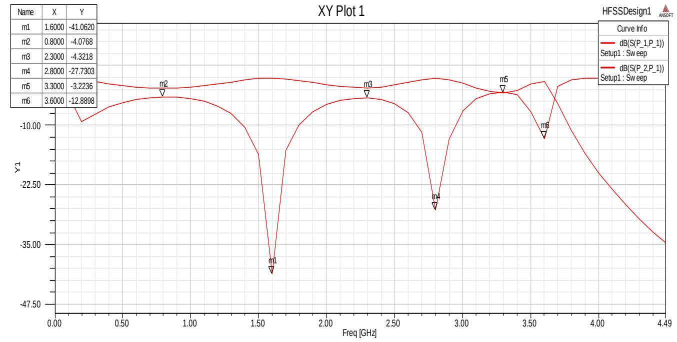


Fig. 11. Duplicate results of slow wave structure at the same frequency.

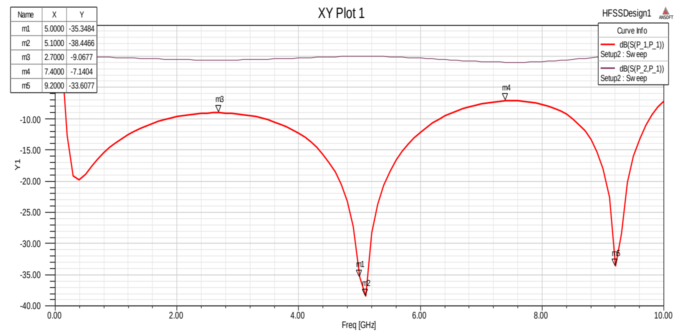


Fig. 12. Duplicate results of the slow wave structure at 5GHz.

IV. CONCLUSION

The paper presented the theory of the cross junction CPW, its new equivalent circuit model, and how this model was achieved. One of the applications of the said model was discussed, which is the 3-dB CPW slot-line Wilkinson power divider. The paper also presented the theory of both the SRR loaded CPW and the slow wave structure based on strip loaded CPW. Finally the slow wave structure was simulated and results were presented.

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