Design of Wide Band-Rejection Filter using All-Stop Parallel Coupled Line Canonical Form along with Transmission Line

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Abstract. Microstrip parallel coupled lines in two-port canonical forms are used extensively in the design of bandpass and bandstop filters. Two parallel coupled lines form a four-port network and it can be converted into a two-port network by terminating two of the four ports either with open or short circuits or by connecting the two ends. There are ten two-port canonical forms for a four-port parallel coupled line structure. Out of these ten forms, three forms are all-stop in nature. These all-stop parallel coupled line circuits are never used in the design of filters due to high insertion loss over the entire periodicity. Parallel coupled lines are periodic with half-wavelength. Hence, the theme of this paper is to propose the usefulness of the all-stop parallel coupled lines in the design filters by connecting this all-stop parallel coupled line structure with a transmission line in parallel. Analysis has been carried out on this basic structure of all-stop parallel coupled line along with the transmission line to characterize over a period. After the analysis, it has been proposed that this composite structure can be used in the design of bandstop filters.

Keywords: Band-pass filters, band-reject filter, parallel coupled lines, scattering parameters, transmission line theory.

1. Introduction

Since the introduction of parallel coupled lines (PCLs) in the design of bandpass filters[1], vast research have been carried out on these circuits for different types of applications apart from filters[2-3]. These parallel coupled lines are used in the design of bandpass and band-reject filters due to the advantage of easy design and fabrication on microstrip technology. The only disadvantage of these structures is the dimensions and tolerances if it is required to have very stringent conditions.

The parallel coupled line is a four-port network and it is used as a two-port network in the design of bandpass filters. Depending on how the PCL is converted into a two-port network, there are ten canonical forms and mainly one of these canonical forms is used very extensively in the design of bandpass filters [4]. In the other canonical forms, there are short circuits that are to be realized on microstrip technology, it is little difficult to realize them. Hence the other canonical forms are rarely used in the literature. However due to the advancement in the printed circuit board technology, it is possible to realize a shorting pin with a radius as small as 0.1mm, and hence other canonical forms are gaining applications in recent times [5-8].

In the design of filters using the canonical forms, bandpass structure is used and few of the canonical forms are all-stop and all-pass in nature. As the name suggests the all-stop, this structure has been used very rarely in the design of bandpass filters. Hence, with the objective of using this all-stop parallel coupled line structure, a combination of all-stop parallel coupled line structure with the transmission line has been incorporated and analysis has been carried out on the new simple structure to design band-reject filters.

2. Problem Statement

The PCL as a four-port network is shown in Figure 1.

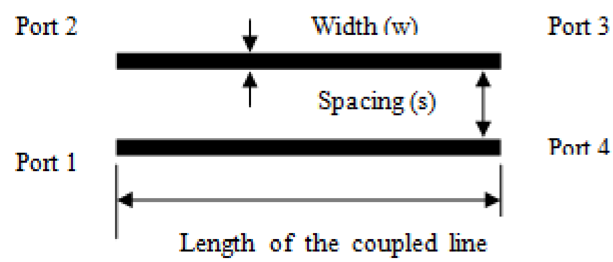

Fig.1 Geometry of the PCL structure.

Usually, this four-port network is used in the design of filters as a two-port network by using only two of the ports. The remaining two ports are either open or short or other combinations of short circuits and open circuits. In the two-port equivalent form, there are ten canonical forms.

Out of the ten canonical forms of a two-port PCL circuit, one bandpass structure of the PCL is used extensively in the design of filters [4]. Few of the canonical form structures mainly the all-stop and the all-pass structures have never been used in the design filters. There are three two-port canonical forms for a PCL in all-stop nature. The simplest of these three canonical forms are formed by open circuiting the adjacent two ports (Port 3 and Port 4) and using the remaining two ports as input (Port 1) and output port (Port 2) with respect to Figure1.

The other two canonical forms contain a short circuit either at a port (port 3 and port 4) or at both the ports 3 and 4. Even though it is possible to realize a shorting pin on the microstrip technology, it is still little difficult to realize a very thin radius shorting pin on microstrip technology. The other disadvantage with the other all-stop parallel coupled line structure is the asymmetry in the structure itself. Due to these reasons, the main emphasis in this paper has been given to all-stop parallel coupled line with the adjacent ports as open circuits. The analysis has been carried out for other

DOI: http://dx.doi.org/10.32452/IJAMT.2018.165169

structures as well. But their characteristics are not presented here due to the unsuitability of filter design.

3. Theoretical analysis (Methodology)

In order to analyze the nature of the composite structure of all-stop parallel coupled line with a transmission line, transmission line theory along with circuit theory has been used. The impedance parameters of the four port PCLs are well defined using the even-odd mode analysis. This four-port PCL can be converted into two port all-stop parallel coupled lines by making the two adjacent ports open circuit. Since the all-stop parallel coupled lines are connected in parallel to the transmission line, the admittance parameters of these two structures have been added in order to obtain the overall admittance parameters and then these admittance parameters have been converted into scattering parameters.

Different cases have been considered for this structure along with the parametric study on each case. In order to completely characterize this composite structure, three different cases have been considered. In the first case, only all-stop parallel coupled lines structure has been analyzed. In the second case, the simple transmission line has been loaded with all-stop parallel coupled lines structure. In the third case, all-stop parallel coupled lines structure has been connected with all-pass parallel coupled lines structure for two different lengths. These structures are represented in Figure 2.

In these layouts, the transmission line has been placed as a circular arc so as to minimize the coupling between the transmission line and PCL structure. In the same figure, all-pass parallel coupled line (half length) and all-pass parallel coupled line (full length) have been presented to have the effect of coupling between the lines.

4. Numerical Simulations and Results

Matlab [9] is used for numerical simulations. Simulations are carried out for a normalized characteristic impedance of unity and other impedances have been considered relative to this normalized characteristic impedance value of unity. The wavelength at the operating frequency is taken as unity and lengths of the coupled line section and transmission line have been taken as 0.25 units (one-quarter wavelength). With these values, the electrical length at the operating frequency is equal to π/2 radians. Since half wavelength electrical length is equal to a periodicity of π radians and the smallest length used in the composite structure is quarter wavelength, the overall structure is periodic with a periodicity of 4π radians. These normalized values can be easily converted to any frequency of operation by scaling the dimensions (lengths) of the structure depending on phase constant.

4.1. Case 1: Analysis of All-Stop PCLs

A single all-stop parallel coupled lines structure has three variables. These are the characteristic impedance z_c, even mode impedance z_e, and odd mode impedance z_o. Usually, the characteristic impedance of the coupled line is taken as the average of the even mode and odd mode impedances. Since this structure has multiple variables, a parametric study has been performed to observe the scattering parameters (insertion loss and return loss) of this all-stop parallel coupled lines structure. This study has been carried out for a different characteristic impedance of PCL for different values of even and odd mode impedances. Figure 3 represents the variation of insertion loss and return loss as a function of electrical length. The characteristic impedance of the PCL structure (z_c) are taken as 2 and 3 for two different values of odd mode impedances of $z_o = 1$ and $z_o = 1.75$. For the PCLs of characteristic impedance $z_c = 2$, the even mode impedances are $z_e = 3$ and $z_e = 2.25$. Similarly, the values of even-odd mode impedances for the characteristic impedance of $z_c = 3$ have been obtained as $z_e = 5$ and $z_e = 4.25$.

By a careful observation of Figure 3, the following conclusions are made for all-stop parallel coupled lines structure.

1. All-stop scattering parameters are functions of even-odd mode impedances of the PCL.
2. The insertion loss of this PCL is decreasing with increasing the characteristic impedance of the PCL for a given even or odd impedance. Usually, the characteristic impedance of the PCL is taken as the average of the even-odd mode impedances.

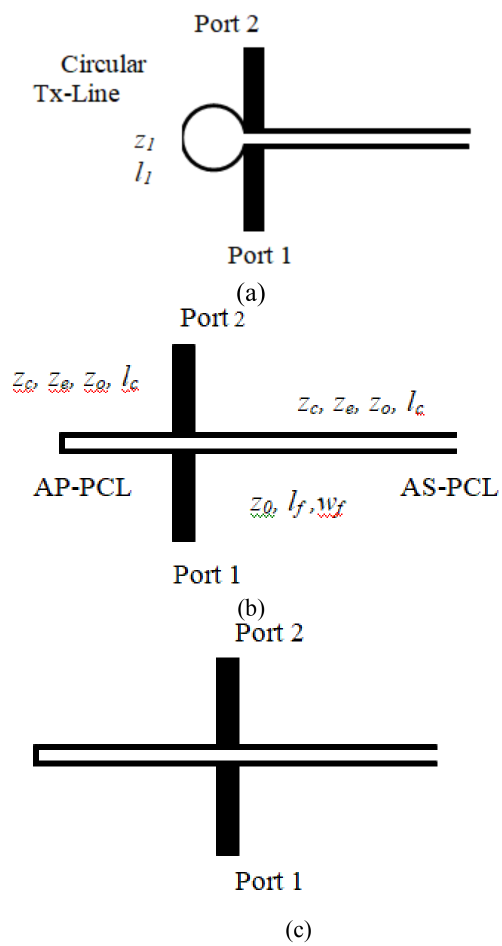

Fig.2 All-pass parallel coupled line with (a) a circular transmission line, (b). all-stop parallel coupled line (half-length), and (c) all-stop parallel coupled line (full length).

DOI: http://dx.doi.org/10.32452/IJAMT.2018.165169

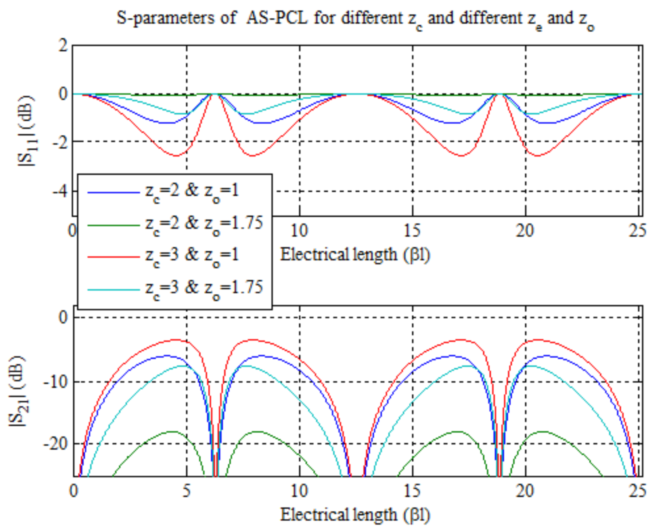

Fig.3 S-parameters of all-stop PCLs with characteristic impedances of 2 and 3 for different even and odd impedances.

3. Moreover, the insertion loss of this all-stop PCL structure is decreasing if the difference between even-odd mode impedance is increasing for a given characteristic impedance. If the difference between even-odd impedance is small, then this has less use in the design of bandstop filters.

4.2. Case 2: Simple transmission line loaded with all-stop parallel coupled line.

A simple transmission line has two variables in terms of its length and characteristic impedance (characteristic impedance varies with the width of the trace on microstrip technology). Even though there are two degrees of freedom (length and width), the length of the transmission line is fixed to the length of the coupled line. Then a parametric study has been carried out on all-stop parallel coupled line and transmission line by only varying the characteristic impedance of the transmission line. The impedance values ($z_1 = 1$) considered in the analysis for the Tx-line are 0.5, 1.0, 2.0, and 3.0 (all are normalized impedances). Here in the analysis, lengths of the PCL and the added transmission line are equal to one-quarter wavelength. Here again, different even-odd mode impedances with the all-stop parallel coupled line characteristic impedance of $z_c = 2.5$ (only one value) has been used. Figure 4 and Figure 5 represent the frequency characteristics of the composite structure. From these two figures, it can be observed that the asymmetrical filter design is possible using this structure.

The following conclusions can be made from the all-stop PCL along with transmission line:

1. Since all transmission lines are periodic, within a single period for this composite structure (according to the chosen dimensions, the periodicity in electrical angle is 8π radians), the bandstop frequencies are occurring at the one-fourth of the period and three-fourths of the period.
2. The bandwidth of these stop bands can be controlled by the characteristic impedance of the transmission line and the even-odd mode impedance of the PCL.
3. For a given characteristic impedance of the Tx-line and the characteristic impedance of PCL, the bandwidth of the stop band becomes narrower if the difference between even-odd mode is small.
4. For a given PCL characteristic impedance, by increasing the Tx-line characteristic impedance bandstop band is increasing. However, a smaller value of Tx-line is producing the ripple in the passband near the cut-off frequency.

A comparison with the conventional transmission line stub has been made with this all-stop parallel coupled line structure so as to provide the greater advantage of this all-stop parallel coupled lines structure with the conventional stub. From Figure 6 to Figure 8, the passband is flat for the all-stop parallel coupled lines in comparison with the conventional stub.

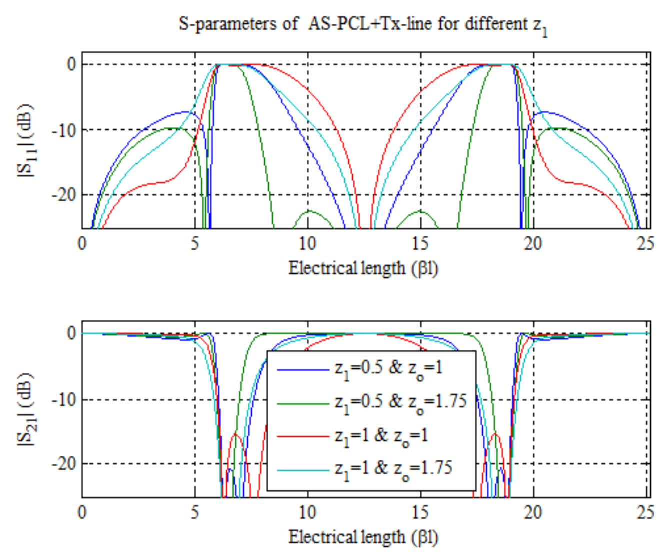

Fig.4 S-parameters of all-stop parallel coupled lines +Tx-line. $z_c = 2.5$.

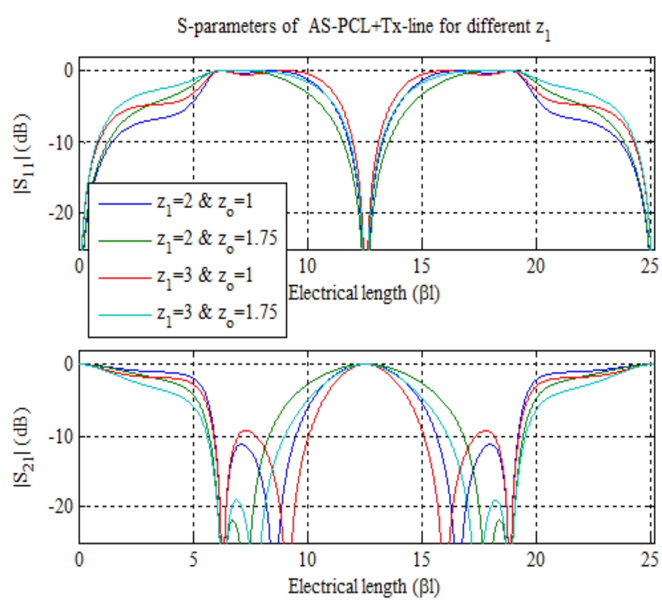

Fig.5 S-parameters of all-stop parallel coupled lines +Tx-line. $z_c = 2.5$.

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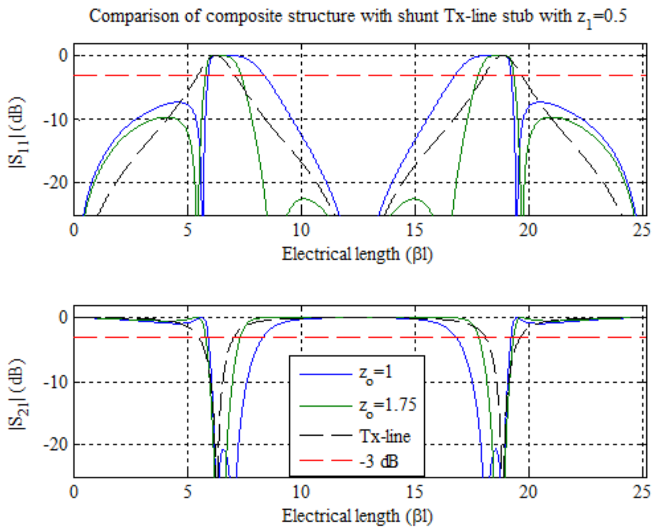

Fig.6 S-parameters comparison with Tx-line stub. Tx-line stub impedance is 0.5.

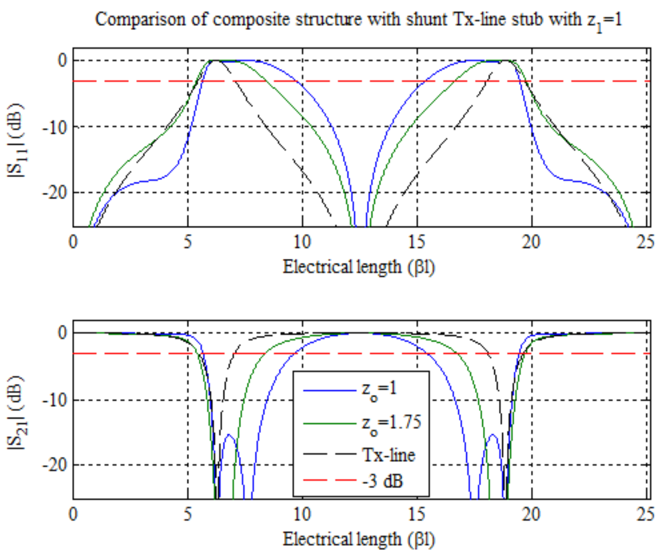

Fig.7 S-parameters comparison with Tx-line stub. Tx-line stub impedance is 2.5.

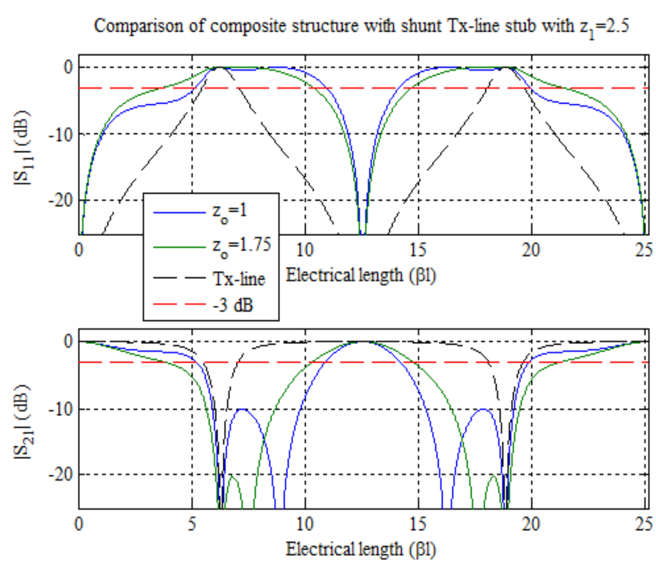

Fig.8 S-parameters comparison with Tx-line stub. Tx-line stub impedance is 2.5.

4.3. *Case 3: All-stop PCL loaded with all-pass PCL*

In another case, all-stop parallel coupled lines structure has been added to the all-pass PCL structure with two different lengths. These two structures have the same properties in terms of impedances. Figure 9 and Figure 10 represent the frequency characteristics of these two different cases for different even and odd impedances.

From these figures, it is observed that the scattering parameters for this case are similar to the transmission line connected with the all-stop PCL structure. However, the main difference is the symmetry. All-stop PCL along with all-pass PCLs structure is providing a more symmetrical response in comparison with the transmission line.

5. Full-wave electromagnetic simulations

Full-wave simulations are carried out for the three cases mentioned above on Roger's 5880 substrate with a relative dielectric constant of 2.2 and the height of the substrate is 0.508mm. The length of the coupled line section is taken as 20mm. The spacing between the coupled lines is taken as 0.23mm.

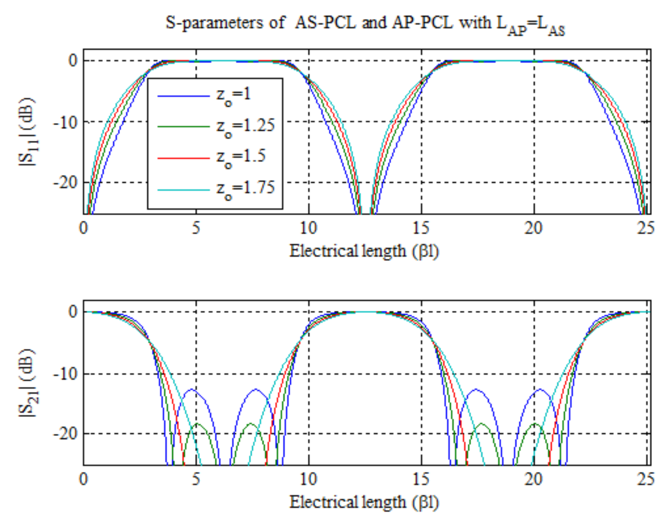

Fig.9 S-parameters of all-stop parallel coupled lines and all-pass PCL with full lengths.

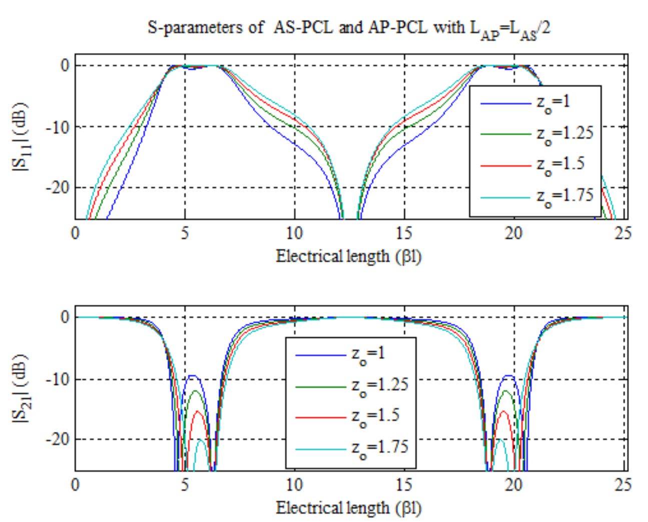

Fig.10 S-parameters of All-stop parallel coupled lines and AP-PCLs (with half length).

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The width of the trace is 0.23mm. These values give the coupled line characteristic impedance of 124.5Ω. The even-mode impedance of this structure is 162Ω and odd-mode impedance of 87Ω.

The transmission line impedance (case-2) is varied by varying the width of the trace. Width is taken as 0.23mm, 0.4mm, 0.7mm and 1.4mm. These widths are corresponding to the characteristic impedance of 123.5Ω, 101.1Ω, 78.5Ω, and 52.8 Ω on the considered substrate.

As mentioned in the numerical simulations that the all-stop PCL along with all-pass PCL (HL) is providing more wideband rejection in comparison to the simple transmission line. From the same figure, it also observed that the all-stop PCL with all-pass PCL (FL) is giving a very wideband rejection. This is in agreement with the numerical simulations.

After this, the transmission line impedance has been varied for 0.23mm, 0.4mm, 0.7mm and 1.4mm. Figure 12 represents the frequency response of the composite structure for these widths. From this figure, it is observed that smaller the characteristic impedance, narrower the band rejection. And hence by decreasing the transmission line impedance, the bandwidth can be controlled and the width of the rejection band is decreasing with decreasing the transmission line impedance which is in good agreement with numerical simulations.

Limitations: The main limitation of this composite structure is the control of the center frequency. It is limited by the lengths of the coupled line section and the added transmission line.

6. Conclusions

This paper presents the applications of all-stop PCL which has never used in the literature. Even though there appears to be a limited novelty, the applicability of all pass structure along with the transmission line has been presented in this paper for the first time. Numerical simulations have been verified by the full-wave electromagnetic simulations.

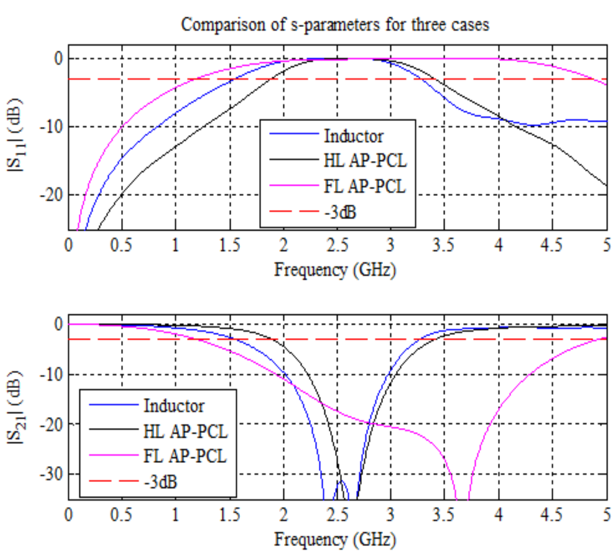

Fig.11 Full wave simulations of all-stop PCL +Tx line, all-stop PCL (HL) +all-pass PCL, and all-stop PCL(FL)+all-pass PCL.

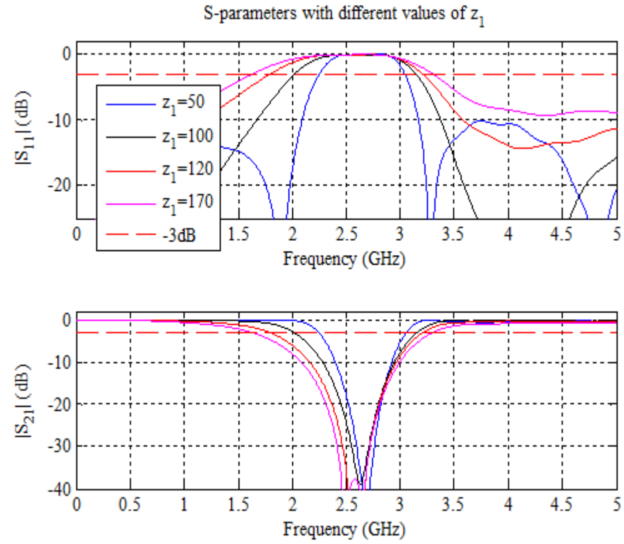

Fig.12 Full-wave simulations of AS-PCL for different -Tx line impedances.

It has been proposed in this paper a simple design of wideband rejection filter by all-stop PLC with all-pass PCL of full lengths.

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Biography of the author

Salman Raju Talluri: Salman Raju Talluri has completed his M.Tech from IITK in 2009 and obtained his Ph.D. titled "Analysis of non-linear transmission lines for opposite phase and group velocities" in 2017 from Jaypee University of Information Technology, Solan, Himachal Pradesh, India. His areas of interest include non-linear transmission lines, microwave engineering, and antenna arrays. He is currently working as an assistant professor in Jaypee University of Information Technology, Solan. He was with the Astra microwave products limited, Hyderabad for one year from 2006 to 2007.

DOI: http://dx.doi.org/10.32452/IJAMT.2018.165169