A Modified Bisected-T Matching Network for Microwave Filter Design

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Abstract

In this paper, a proposed method to implement the image parameter filters is presented. It is based on cascading π-networks and using a proposed bisected-T m-derived matching section to the source and load impedances instead of the use of the cascaded T-networks and the classical bisected-π matching sections. The proposed method achieves the advantage of reducing the total number of the inductors in the circuit which is a great benefit for circuit implementation in the recent monolithic microwave integrated circuit (MMIC) technology. The method also finds application in broadband microwave distributed amplifiers design.

Index Terms − Microwave circuits, microwave filters, image parameter filters.

الخلاصة

في هذا البحث قدمت طريقة جديدة لتمثيل المرشحات نوع (image parameter). انها تعتمد على تكرير مقاطع مرشحات نوع (π) واستخدام مقطع موالمة لممانعة المصدر او الحمل وهي مقطع نصف T مبتكرة بدلا من الطريقة التقليدية التي تعتمد على تكرار مقاطع نوع (T) ودوائر موالمة نصف π المعروفة. الطريقة الجديدة تحقق فائدة تقليل المحاثات في النظام وبتالي تحقيق فائدة جيدة في التمثيل باستخدام تكنولوجيا الدوائر المايكروية المتكاملة. هذه الطريقة لها ايضا تطبيقات في تصميم المضخمات المايكروية التوزيعية عريضة الحزمة .

I. Introduction

The image parameter method of filter design involves the specification of passband and stopband characteristics for a cascade of simpler two-port filter sections [1]. The method is very efficient and suitable for simple filter designs, but has the disadvantage that arbitrary frequency response cannot be incorporated into the design because the image impedances of the filters are frequency depended specially near the cutoff frequency. Thus, although the procedure is relatively simple the design must be iterated and optimized many times to achieve the desired result. The image parameter design method up to now is based on the T-filter structure [2] and [3]. Fig.1 shows

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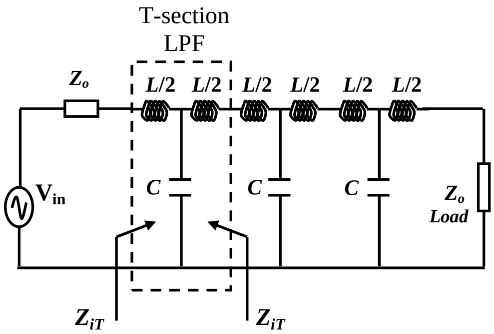
a low-pass filter based on cascading several T-filters.



The T-sections should be identical and have the same image impedance in order to have no reflection in the occared transferred signal so that the maximum power transfer takes place over the prescribed bandwidth. The image impedance Z_i for a reciprocal symmetric two-port network is defined as the impedance looking into one port when the other port is also terminated in Z_i . For T-filter sections the image impedance is given by [4]

$$Z_{iT} = \sqrt{\frac{L}{C}}\sqrt{1-(\frac{\omega}{\omega_c})^2} \quad (1)$$

where ($\omega_c = 2 / \sqrt{LC}$) is the cutoff frequency of the filter, and ($\sqrt{L/C} = Z_o$) is the characteristic impedance of the filters. There is another important condition in the design that is, the load and source impedance (Z_o) must be transformed into the image impedance of the filters. Otherwise, the gain response will not be flat as a function of frequency. The Bisected-π m-derived matching network shown in Fig.2 with m=0.6 serves this purpose well [5]. The impedance looking into the input port of this circuit is equal to the image impedance of the filter sections while the impedance looking into the output port is equal to the load and source impedance Z_o .

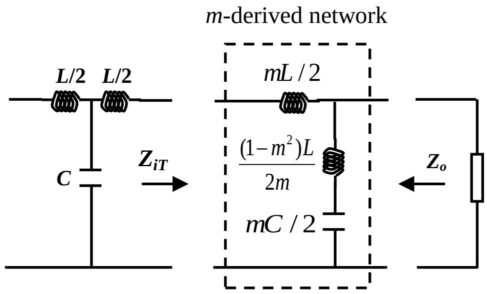


Fig.2 Bisected-π m-derived matching section between the T-LPF and Z_o

High-pass constant-T section and its matching circuit are shown in Fig.3. It is clear that the positions of the inductors and capacitors are reversed from those in the low-pass prototype and thus, the HPF circuit in the T-form has half the number of inductors and twice the number of capacitors as compared to the T-LPF. On the other hand, ($\omega_c = 1 / 2\sqrt{LC}$) is the design equation of the HPF.

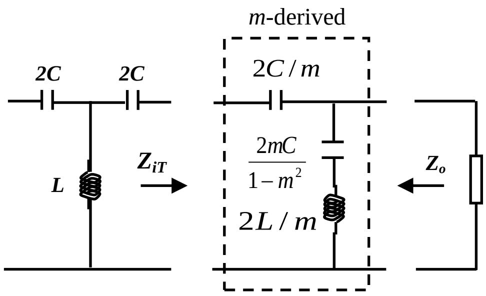


Fig.3 Bisected-π m-derived matching section between the T-HPF and Z_o

The use of m-derived sections increases the circuit size by adding new inductors to the circuit, thereby increasing the design and optimization complexity. The goal of this paper is to develop a design method based on less number of inductors.

Ii. Filter Design By Cascading Π-Network

Microwave systems nowadays are implemented using monolithic microwave integrated circuit technology [6]. One of the main challenges in realizing the integrated filters is creating the high-quality inductors necessary [7]. Since the value of the inductor depends on its layout [8], therefore it is a big gain if the total number or the values of the inductors in a circuit are reduced. Cascading constant π-networks can also be used in the design of the image parameter filters. The structure of the low-pass filter is demonstrated in Fig.4 . As shown, the filter has one inductor in the π structure while it had two inductors when it was in the T structure.

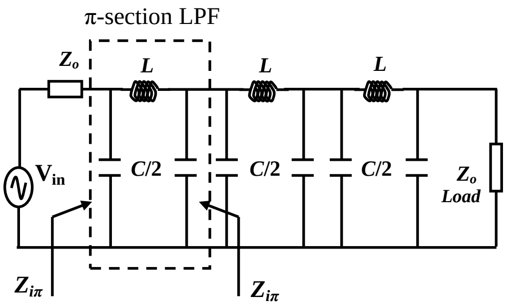


Fig.4 Image parameter LPF with π-networks

The image impedance of the π-network is determined as [4]

$$Z_{i\pi} = \sqrt{\frac{L}{C}} \;/\; \sqrt{1-(\frac{\omega}{\omega_c})^2} \quad (2)$$

The cutoff frequency and the characteristic impedance are given by ($\omega_c = 2/\sqrt{LC}$) and ($Z_o = \sqrt{L/C}$) respectively.

We have seen that the π-filter section also suffers from the disadvantage of a nonconstant image impedance, and because of the term ($\sqrt{1-(\omega/\omega_c)^2}$) in the $Z_{i\pi}$ equation, the load/source impedance ($Z_o = \sqrt{L/C}$) can not be matched well. The m-derived filter section is a modification of a T-network and will be designed to overcome this problem.

Iii. Bisected-T *M*-Derived Section

The m-derived circuit shown in Fig.5 is half of a T-network that can be used at the input and output of the filter circuit to provide a nearly constant impedance match to and from Z_o , and to enhance the passband response.

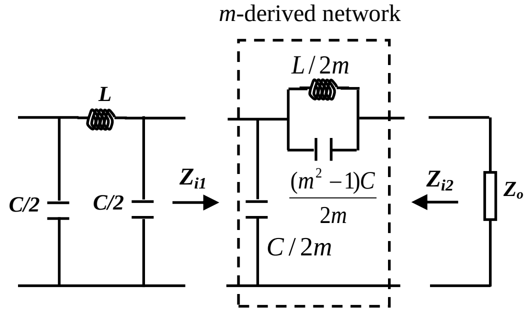


Fig.5 Proposed m-derived matching section for π-LPF

This bisected-T section is not symmetric network so that the image impedances Z_{i1} and Z_{i2} are unequal and can be found by using the ABCD parameters as following:

Fig.6 is a representation of the proposed m-derived network.

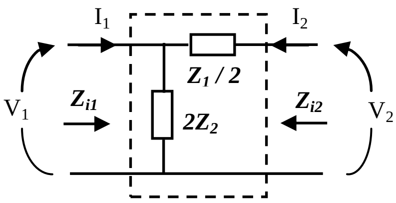


Fig.6 Bisected-T network

The port voltages and currents are related as [3]

$V_1 = AV_2 + BI_2$ (3a)

$I_1 = CV_2 + DI_2$ (3b)

The ABCD parameters of the network are

$$A = \frac{V_1}{V_2}\downarrow_{I_2=0} = 1 \qquad (4a)$$

$$B = \frac{V_1}{I_2}\downarrow_{V_2=0} = \frac{Z_1}{2} \qquad (4b)$$

$$C = \frac{I_1}{V_2}\downarrow_{I_2=0} = \frac{1}{2Z_2} \qquad (4c)$$

$$D = \frac{I_1}{I_2}\downarrow_{V_2=0} = 1 + \frac{Z_1}{4Z_2} \qquad (4d)$$

The image impedances Z_{i1} and Z_{i2} are given by [3]

$$Z_{i1} = \sqrt{\frac{AB}{CD}} \qquad (5a)$$

$$Z_{i2} = \sqrt{\frac{BD}{AC}} \qquad (5b)$$

Substituting the corresponding values of Z_1 and Z_2 to find the ABCD parameters and then to find the image impedances gives

$$Z_{i1} = \sqrt{\frac{L}{C}} \ / \ \sqrt{1-(\frac{\omega}{\omega_c})^2} \qquad (6a)$$

$$Z_{i2} = \sqrt{\frac{L}{C}} \ \frac{\sqrt{1-(\frac{\omega}{\omega_c})^2}}{[\ 1-(1-\frac{1}{m^2})(\frac{\omega}{\omega_c})^2\ ]} \qquad (6b)$$

Equations (6a) and (6b) mean that the image impedance at the input of the proposed matching network is identical to that of the π-section. But at the output, the image impedance will depend on (m), so we can choose m to minimize the variation of the impedance over the frequencies within the passband of the filter, and this extra degree of freedom can be used to design an optimum matching section. Fig.7 shows the variation of the image impedance with frequency for several values of m; the value m=1.7 nearly gives the best results.

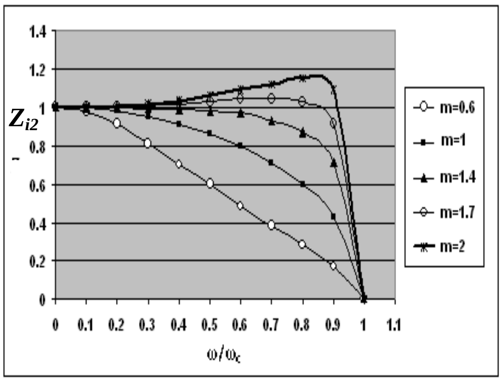


Fig.7 Z_{i2} as a function of frequency

For the HPF, the design structure in the π-form with its proposed m-derived matching section is shown in Fig.8. The design equation is changed to: $\omega_c = 1\ /\ 2\sqrt{LC}$. As evident from the figure, number of the inductors is doubled as compared to the HPF in the T-structure of Fig.3. Thus, although the proposed design of the HPF gives good results in the response, it increases the circuit size, so it is not advisable to use the proposed method with the high-pass filters.

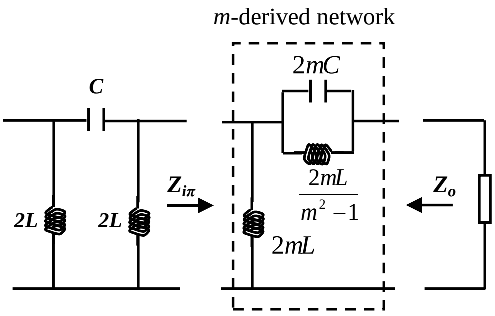


Fig.8 Proposed m-derived matching section for π-HPF

Iv. Simulation Example

The design of a three stages image parameter low-pass filter with 10GHz cutoff frequency and 50Ω characteristic impedance was simulated in Microwave Office program two times; first by using the classical T topology with bisected-π m-derived matching section of *m*=0.6, and next by using the proposed topology with bisected-T matching section of *m*=1.7 . Fig.9 illustrates the S-parameters of the classical filter while the performance of the proposed filter is shown in Fig.10 . These results clearly show that the new design method offers good agreement in the forward gain (S_{21}) with the conventional design with some improvement near the cutoff frequency. The input and output return losses (S_{11} and S_{22}) of the proposed design are generally below those of the conventional design. This explains that the new *m*-derived matching section not only occupy less circuit size but also improves the matching problem.

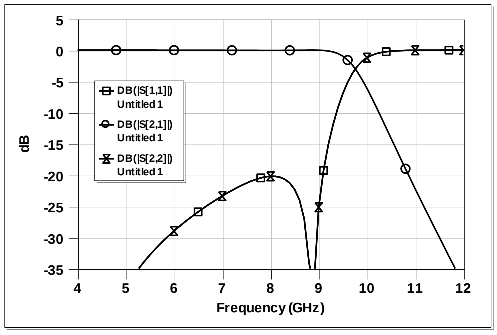


Fig.9 Performance of the constant-T sections filter

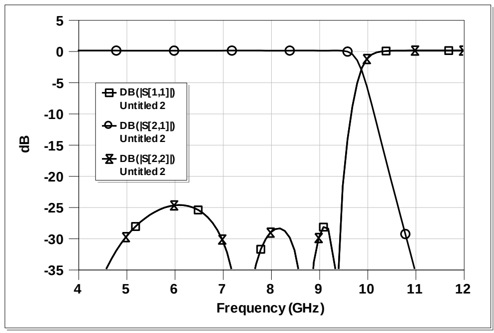


Fig.10 Performance of the constant-π sections filter

V. Conclusion

This paper demonstrated how to improve the performance of the image parameter filters in less layout space. Key to the design was the use of the π-filtering network plus a proposed *m*-derived matching network. This method is suitable and useful for the design of LPFs. Schematic structures of a LPF employing the conventional and suggested topologies designed and simulated. The results indicate the validity of the proposed design methodology.

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