FACTA UNIVERSITATIS
Series: **Electronics and Energetics** Vol. 30, N° 2, June 2017, pp. 179 - 185
DOI: 10.2298/FUEE1702179D

A NEW LUMPED ELEMENT BRIDGED-T ABSORPTIVE BAND- STOP FILTER

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Abstract. *Following a brief review of previous work on bandstop filters, the inadequacy of a recent work to obtain a perfect notch or perfect absorption at the notch frequency ω_0 is demonstrated. A simple and elegant alternative solution, based on purely analytical arguments, is then presented. The resulting network is shown to achieve perfect matching as well as perfect absorption at the notch frequency and has several other advantages. A comparison has also been made with the conventional bridged-T band-stop filter.*

Key words: *bandstop filter, bridged-T network, circuit design.*

1. INTRODUCTION

Bandstop filters are circuits which reject, to within a specified tolerance, a band of frequencies around a centre frequency at which there is complete rejection. Such filters are known by various names, such as band rejection filters, notch filters, null networks etc. and are required in many situations in communication and instrumentation. Bandstop filters have fascinated a large number of researchers, including the present author, who has written papers on the analysis [1-7], design [8] and its limitations [9], and analysis and applications of dual input techniques to such filters [10-12]. All these contributions relate to analog circuits. Bandstop filters are also required in digital signal processing, and the author and his students have done extensive work on digital notch filters, using both FIR and IIR techniques [13-21]. Of these, [21] is a review of FIR notch filter design, which appeared in this journal.

At low frequencies, passive RC networks are mostly used, except in situations where a selectivity, defined as (notch frequency)/(3 dB stop bandwidth), is required to be more than half. In the latter cases, either active RC filters or LC networks are to be used. For high frequencies, LC networks are easily designed and implemented. At microwave frequencies, distributed networks are preferred over lumped networks, although the latter

Received November 3, 2016
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have the advantage of occupying less space, and as is well known, space is a premium in microwave integrated circuits. Examples of lumped element microwave bandstop filters can be found in [22-29], while bandstop filters with distributed elements can be found in [30,31].

2. SCOPE AND ORGANIZATION OF THE PAPER

This paper is concerned with the design of a band-stop filter which achieves a perfect notch and perfect absorption at some frequency ω_0. In this context, we first demonstrate, in Section 3, the inadequacy of a recent solution proposed by Chieh and Rowland [32], by network theoretic arguments. In the next Section, we present a new, simple and elegant alternative design, based on purely analytical arguments. The resulting network is shown to achieve perfect matching as well as perfect absorption at the notch frequency, and has several other advantages. A normalized design is discussed in Section 5, and the simulation results are presented. A comparison of the new design with the conventional bridged-T band-stop filter is made in Section 6. Finally, Section 7 gives the concluding comments.

3. CHIEH AND ROWLAND'S DESIGN

Chieh and Rowland [32] proposed the symmetrical network of Fig. 1 where

$$Z_1(j\omega)=1/(j\omega C), \tag{1a}$$

$$Z_2(j\omega)=R_1+j\omega L_1+1/(j\omega C_1) \tag{1b}$$

and

$$Z_3(j\omega)=R_2+j\omega L_2+1/(j\omega C_2). \tag{1c}$$

and both Z_2 and Z_3 resonate at the same frequency ω_o. For ready reference, we reproduce here the expressions for the z-parameters of the network and the scattering parameters, in slightly different forms:

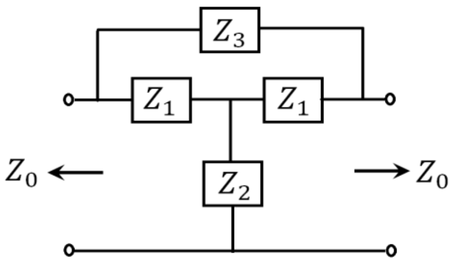

Fig. 1 The bridged-T network

$$z_{11}=z_{22}=Z_2+(Z_1^2+Z_1Z_3)/(2Z_1+Z_3), \tag{2}$$

$$z_{12}=z_{21}=Z_2+Z_1^2/(2Z_1+Z_3), \tag{3}$$

$$S_{12}=S_{21}=2z_{21}\,Z_o/[(z_{11}+Z_o)^2-z_{21}^2], \tag{4}$$

and

$$S_{11}=S_{22}=(z_{11}^2 - z_{21}^2]/[(z_{11}+ Z_o)^2-z_{21}^2]. \quad (5)$$

Note from (2) and (3) that

$$z_{11}=z_{21}+Z_1Z_3/(2Z_1+Z_3). \quad (6)$$

From (4) and (5), we observe that for a perfect notch as well as perfect absorption at the frequency ω_o, we require

$$z_{21}(j\omega_o)=0 \quad (7)$$

and

$$z_{11}(j\omega_o)= Z_o. \quad (8)$$

From (1), we have

$$Z_1(j\omega_o)=1/(j\omega_oC),\ Z_2(j\omega_o)=R_2,\ \text{and}\ \ Z_3(j\omega_o)=R_1. \quad (9)$$

Substituting these values in (3) gives, on simplification,

$$z_{21}(j\omega_o)= R_2+1/[\, j\omega_oC(2+ j\omega_oC\, R_1)], \quad (10)$$

which cannot be made zero. Also, under this condition,

$$z_{11}(j\omega_o)= R_2+(1+ j\omega_oC\, R_1)/[\, j\omega_oC(2+ j\omega_oC\, R_1)], \quad (11)$$

which cannot be equal to Z_o if the latter is purely resistive, which is usually the case. Equation (8) can be satisfied only if Z_o is a complex series *RC* impedance. Thus the network of Fig. 1 with the element values given by (1) can achieve neither perfect notch nor perfect absorption.

4. THE NEW DESIGN

The problem to be solved can be restated as follows: Given ω_o and R_o and the network topology of Fig.1, find Z_1, Z_2 and Z_3 such that

$$z_{21}(j\omega_o)=Z_2(j\omega_o)+[Z_1(j\omega_o)]^2/[2Z_1(j\omega_o)+Z_3(j\omega_o)]=0, \quad (12)$$

and

$$z_{11}(j\omega_o)=z_{21}(j\omega_o)+Z_1(j\omega_o)Z_3(j\omega_o)/[2Z_1(j\omega_o)+Z_3(j\omega_o)]=R_o. \quad (13)$$

where Z_o has been assumed to be resistive, equal to R_o. In view of (12), (13) reduces to

$$z_{11}(j\omega_o)=Z_1(j\omega_o)Z_3(j\omega_o)/[2Z_1(j\omega_o)+Z_3(j\omega_o)]=R_o. \quad (14)$$

From (14), Z_3 is expressed in terms of Z_1 as

$$Z_3(j\omega_o)=2R_oZ_1(j\omega_o)/[Z_1(j\omega_o)-R_o]. \quad (15)$$

Combining this with (12) and simplifying, we get

$$Z_2(j\omega_o)=[R_o-Z_1(j\omega_o)]/2. \quad (16)$$

We can now choose a Z_1. If we take $Z_1(j\omega_o)=1/(j\omega_oC)$, as in [1], then (15) gives, on simplification,

$$Z_3(j\omega_o)=[2R_o/(1+\omega_o^2C^2R_o^2)]+j\omega_o[2CR_o^2/(1+\omega_o^2C^2 R_o^2)] \quad (17)$$

which represents a series combination of an inductance L_3 and a resistance R_3, where

$$R_3=[2R_o/(1+\omega_o^2C^2R_o^2)] \text{ and } L_3=2CR_o^2/(1+\omega_o^2C^2 R_o^2). \quad (18)$$

Similarly, (16) gives

$$Z_2(j\omega_o)=(R_o/2)+j\omega_o/(2\omega_o^2C), \quad (19)$$

which also represents a series combination of an inductance L_2 and a resistance R_2, where

$$R_2=(R_o/2) \text{ and } L_2=1/(2\omega_o^2C). \quad (20)$$

In theory, C can be chosen to have any value, but as we shall see, it will be most convenient to choose C from the expression for R_3 given in (18), which gives

$$C=[(2R_o/R_3)-1]^{1/2}/(\omega_oR_o) \quad (21)$$

Note that if we choose

$$C=1/(\omega_oR_o), \quad (22)$$

then R_3 becomes equal to R_o. Also, under this condition, (17) and (18) give

$$L_3=R_o/\omega_o \text{ and } L_2=R_o/(2\omega_o). \quad (23)$$

This choice of C is advantageous because then Z_3 can be obtained by a series combination of Z_2 and Z_2 and there is no spread in the element values of the network. Also note that lossy inductors can be used with ease because their losses can be absorbed in their series resistances. Finally, the element valus of the network are consolidated as

$$C=1/(\omega_oR_o),\ L_3=2L_2=R_o/\omega_o \text{ and } R_3=2R_2= R_o. \quad (24)$$

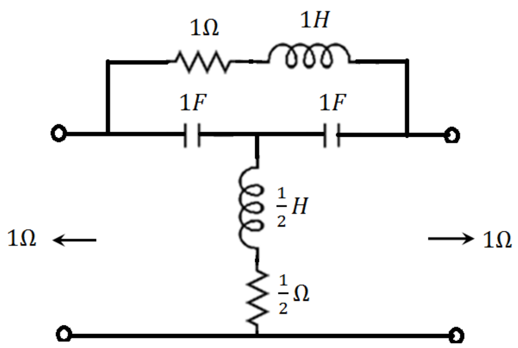

Fig. 2 The normalized design of the absorptive bandstop filter

5. A Normalized Design

It is always convenient to have a normalized design which can be denormalized by impedance and frequency scaling. Let R_o=1 ohm and ω_o=1 rad/sec. Then (24) gives the element values as

$$C=1\text{F},\ L_3=2L_2=1\text{H} \text{ and } R_3=2R_2=1 \text{ ohm}. \quad (25)$$

The resulting network is shown in Fig. 2. This network has been simulated with MATLAB and the obtained plots of $|S_{11}(j\omega)|$ and $|S_{21}(j\omega)|$ are shown in Fig. 3. These plots exactly match the theoretical predictions.

6. Comparison with the Conventional Bridged-T Bandstop Filter

It may be noted that compared to network proposed in [32], the conventional bridged-T bandstop filter [3] performs better because it achieves a perfect notch but not perfect absorption. In this network,

$$Z_1(j\omega_o)=1/(j\omega C),\ Z_2(j\omega_o)= r+j\omega L, \text{ and } Z_3(j\omega)=R. \tag{26}$$

The network then achieves a perfect notch at $\omega=[2/(LC)]^{1/2}$ under the condition $L=CRr$, but it cannot achieve $S_{11}(j\omega_o)=0$ unless Z_o is a parallel combination of a capacitor C and a resistor $R/2$, which is not the usual case. Also, if we choose $r=R$, then there is no spread in the component values. Further, as in the proposed alternative, a lossy inductor can be used here. In addition, in comparison with the networks of [32] and that proposed here, it uses the least number, viz. three of reactive elements, yielding a transfer function of order three.

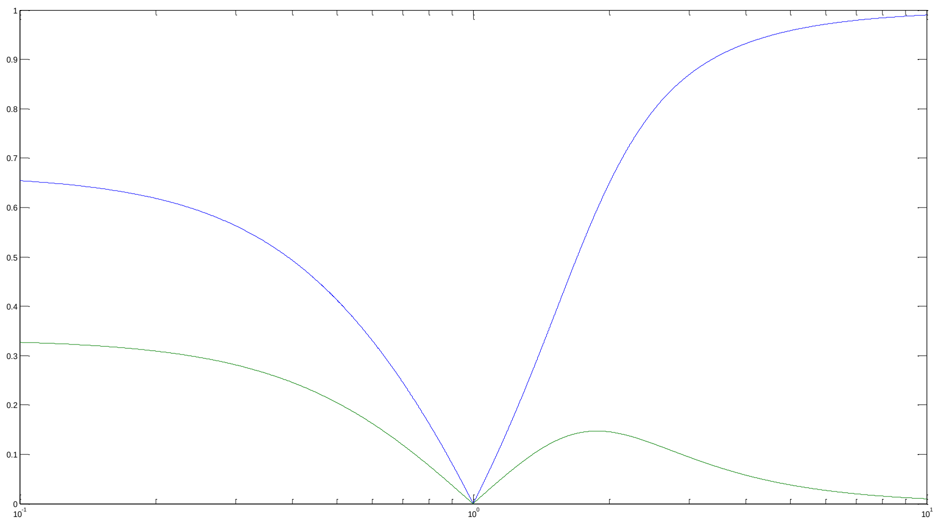

Fig. 3 Performance of the normalized design. The upper curve is a plot of $|S_{21}(j\omega)|$ and the lower curve represents $|S_{11}(j\omega)|$

7. Concluding Comments

It has been shown that the network proposed in [32] achieves neither a perfect notch nor perfect absorption. An alternative solution is proposed here purely by analytical, rather than physical or heuristic arguments, which achieves these two objectives simultaneously. The element values are obtained very simply, rather than by numerical and parametric methods as in [32]. Also, the new solution uses only two capacitors, instead of four, which reduces the order of the transfer function by two. By an appropriate choice of the elements, there is no spread in the element values. A normalized design has been presented and the resulting characteristics of $|S_{11}(j\omega)|$ and $|S_{21}(j\omega_o)|$ have been plotted. A comparison of the two circuits has also been made with the conventional bridged-T bandstop filter.

Acknowledgement: *The author thanks Professor Y. V. Joshi for his help in the preparation of the manuscript and performing the simulation.*

REFERENCES

[1] S. C. Dutta Roy, "Analyzing the parallel-T RC network – yet another method", *IETE J. Educ.,* vol. 44, pp. 111-116,

[2] S. C. Dutta. Roy, "A quick method of analyzing parallel ladder networks", *Int. J. Elect. Eng. Educ.,* vol. 13, pp. 70-75, Jan. 1976.

[3] S. C. Dutta Roy, "Miller's theorem revisited", *Circuits, Syst. Signal Proces., vol.* 19, pp. 487-499, Dec. 2000.

[4] S. C. Dutta Roy, "On second order digital bandpass and bandstop filters", *IETE J. Educ.*, vol. 49, pp. 59-63, May-Aug. 2008.

[5] S. C. Dutta Roy, "Interference rejection in a UWB syetem: an example of LC driving point synthesis", *IETE J. Educ.,* vol. 50, pp. 55-58, May-Aug. 2009.

[6] S. C. Dutta Roy, "On some three terminal lumped and distributed RC null networks", *IEEE Trans. Circuit Theory,* vol. CT-11, pp. 98-103, Mar. 1964.

[7] S. C. Dutta Roy and B. A. Shenoi, "Notch networks using distributed RC elements". *Proc. IEEE*, vol. 54, pp. 1220-1221, Sept. 1966.

[8] S. C. Dutta Roy. "On the design of parallel-T resistance capacitance networks for maximum selectivity", *J.ITE*, vol. 8, pp. 218-223, Sept. 1962.

[9] S. C. Dutta Roy, "Parallel—T RC network : limitations of design equations and shaping the transmission characteristic", *lndian J. Pure Appl. Phys.*, vol. 1, pp.175-181, May 1963.

[10] S. C. Dutta Roy, "Dual input null networks", *Proc. IEEE*, vol. 55, pp. 221-222, Feb. 1967.

[11] S. C. Dutta Roy and N. Choudhury, "An application of dual input networks", *Proc. IEEE,* vol. 56, pp. 647-646. May 1970.

[12] S. C. Dutta Roy and R. P. Sah. "Dual input distributed RC notch filter", *lnd. J. Pure Appl. Phys*., vol. 9, pp. 762-763, Sept. 1971.

[13] S. C. Dutta Roy, S. B. Jain and B. Kumar, "Design of digital notch filters", *IEE Proc. – Vision, Image Signal Process*., vol. 141, pp. 334-338, Oct. 1994.

[14] B. Kumar, S. B. Jain and S C. Dutta Roy, "On the design of FIR notch filters", *IETE J. Res.*, vol. 43, pp. 65-68, Jan.- Feb. 1997.

[15] S. B. Jain, B. Kumar and S. C. Dutta Roy, "Design of FIR notch filters by using Bernstein polynomials", *Int. J. Circuit Theory Applic.,* vol. 25, pp. 135-139, Mar.-Apr. 1997.

[16] S. C. Dutta Roy, S. B. Jain and B. Kumar, "Design of digital FIR notch filters from second order llR prototype", *IETE J. Res., vol.* 43, pp. 275-279, Jul.-Aug. 1997.

[17] S. B. Jain, B. Kumar and S. C. Dutta Roy, "Semi-analytic method for the design of digital FIR filters with specified notch frequency", *Signal Process*., vol. 59, pp. 235-241, 1997.

[18] Y. V. Joshi and S. C. Dutta Roy, "Design of llR digital notch filters", *Circuits, Syst. Signal Process.,* vol. 16, pp. 415-427, 1997.

[19] Y. V. Joshi and S. C. Dutta Roy. "Design of lift notch filters with different passband gains",*IEE Proceedings — Vision, Image Signal Process*., vol. 147, pp. 11-19, Feb. 1998.

[20] Y. V. Joshi and S. C. Dutta Roy. "Design of IIR multiple notch filters based on all-pass filters", *IEEE Trans.Circuits Syst.-II: Trans. Briefs*, vol, 46, pp. 134-138, Feb. 1999.

[21] S. C. Dutta Roy, B. Kumar and S. B. Jain, "FIR notch filter design – a review" (invited paper), *Facta Universitatis (NIS) – Series : Electron. Energ.*, vol. 14, pp. 295-327, Dec. 2001.

[22] A. S. Alkanhal, "Compact bandstop filters with extended upper passbands", *Active and Passive Components,* vol. 2008, DOI: http://dx.doi. Org/10.11552008/356049.

[23] O. P. Gupta and R. J. Wenzel, "Design tables for a class of optimum new bandstop filters", *IEEE Trans. Microw. Theo. Tech.*, vol. 18, pp. 402-404, July

[24] K. S. K. Yeo and P. Vijaykumar, "Quasi-elliptic microstrip bandstop filters using tap coupled open loop resonators", *Prog. Electromag. Res.*, vol. 35, pp. 1-11, 2013.

[25] Y. S. Mezaal, H. T. Eyyuboglu and J. K. Ali, "Wide bandpass and narrow bandstop microstrip filters based on Hilbert fractal geometry: design and simulation results", *PLOS One*, vol. 9, e115412, 2014.

[26] M. M. Bait-Sawailam, "Miniaturized bandstop filters using slotted complementary networks", *Int. J. Dig. Inform. and Wireless Commun.*,vol. 4, pp. 401-407, Mar. 2014.

[27] D. R. Jachowski, "Narrowband absorption bandstop filtres with multiple signal paths", US Patent no. 7323955B2, Pub: Jan. 29 2008.

[28] W. M. Pathelbab and M. B. Steer, "Design of bandstop filters utilising circuit prototypes", *IEE Micrpw, Ant. Propag.*, vol. 1, pp. 523-526, March 2007.

[29] D. R. Jachowski, "Tunable lumped element notch filter with constant bandwidth", In Proc. of the IEEE Int. Wireless Inf. Technol. Syst. Conf., pp. 1-4, 2010.

[30] T. C. Lee, J. Lee, E. J. Naglich and D. Peroulis, "Octave tunable lumped element notch filter with resonator Q-independent zero reflection coefficient", In Proc. of the IEEE MTT-S Int. Digest, pp. 1-4, 2014.

[31] J. Lee, T. Leeand W. J. Chappel, "Lumped element realization of absorptive bandstop filter with anomalously high spectral isolation", *IEEE Trans. Microw. Theo. Tech.*, vol. 60, pp. 2424-2430, Aug. 2012.

[32] J. S. Chieh and J. Rowland, "Quasi-lumped element bridged-T absorptive bandstop filter", *IEEE Microw. Wireless Compon. Lett.*, vol. 26, pp. 264-266, Apr. 2016.