HAIT Journal of Science and Engineering A, Volume 3, Issue 1, pp. xxx-xxx

High input impedance band pass, all pass, and notch filters using two CCII's

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Received 6 September 2005, revised 21 December 2005, accepted 23 December 2005

Abstract

A new configuration for realizing high input impedance voltage-mode biquadratic filters with two inputs and one output is presented. The proposed configuration uses two second generation current conveyors (CCII's) of different polarity, two resistors, and two capacitors. The present configuration is capable of realizing band pass (BP), all pass (AP), and notch filter functions. The circuit demonstrates low active and passive sensitivity performance. The experimental results are found in good agreement with the theoretical predictions.

Keywords: Active filters, band pass filter, all pass filter, notch filter, current conveyor.

1 Introduction

The CCII is a device next to operational amplifier, which has three terminals x, y, z with the following properties [1]:

$$\begin{aligned} i_y &= 0, \\ v_x &= v_y, \\ i_z &= \pm i_x. \end{aligned}$$

Thus the y terminal has high input impedance, fed by voltage signal, draws no current and same signal transfers to the x terminal. When a load is connected across the x terminal, there is a flow of current through the x terminal which is conveyed to the z terminal according to its third property. The z terminal has high output impedance. Its initial applications include realisation of amplifier, adder, subtracter, logarithmic amplifier, as pointed by its inventor [1]. As compared to operational amplifier, it has unity gain while operational amplifier has a gain of about 200K or more which limits its operating frequency range. At present there is a growing interest in designing active filters using second generation current conveyor (CCIIs), and its availability in integrated circuit form as AD844, attracts considerable and continuous attention of researchers compared to other elements. The concept of CCII has been found very useful in filtering application due to its potential advantages over other active elements, such as high signal band width, greater linearity, larger dynamic range, simple circuitry, lower power consumption, use of grounded capacitors, lesser number of passive components, etc. [2-4].

Voltage signal processing circuits still play an important role in active filter circuit realizations [5,6]. Voltage-mode active filters with high input impedance are of great interest because several cells of this kind can be directly connected in cascade to implement higher order filters [9,10]. Recently, a growing interest has arisen in the designing of voltage-mode universal biquadratic filters with multiple inputs and single output. In this direction, Toumazou and Lidgey [11] proposed a high input impedance universal biquadratic filter using seven CCIIs, one operational amplifier buffer, eight grounded resistors, and two grounded capacitors. Liu and Tsao [12] proposed a new configuration for the design of low pass, high pass, band pass, and notch filter functions with single CCII connected to five passive one-port RC elements. Higashimura [13] described two networks for realizing transfer function synthesis using four plus type CCIIs, five resistors, and two grounded capacitors which are suitable for integration and offer high input impedance. Higashimura [14] reported also a novel general circuit configuration for realization of voltage mode universal biquad filters with high input impedance using single negative type CCII and four or six passive components. Later, Liu [15] designed a new configuration for high input impedance band pass, low pass, and high pass filter using two current feed back amplifiers, two resistors, and two grounded capacitors. This circuit offers various advantages, such as orthogonal control of ω_0 and Q, minimum component realization, and low component spread suitable for high Q application and low output impedance. The work by Higashimura and Fukui [16] reported high input impedance universal second order filter circuit employing seven CCII+, eight grounded resistors, and two grounded capacitors with component matching conditions. Horng et al. [17] described a new configuration for realizing high input impedance voltage mode low pass, band pass, and high pass filters simultaneously using four CCII+ and grounded passive components, which is suitable for integration. Cicekoglu et al. [18] reported a new CCII-based topology with two different filter realization possibilities at a time by using three CCII+, four grounded resistors, and three grounded capacitors without component matching conditions like low pass, band pass, and high pass functions. The circuit exhibits high input impedance and orthogonal control of ω_0 and Q. In another work, Cicekoglu [19] proposed a new multifunction filter implementation, which can simultaneously realize low pass, high pass, and band pass functions employing four CCII of different polarity and grounded passive components. The circuit exhibits high input impedance, no matching condition, and orthogonal control of ω_0 and Q. In the same year, Cicekoglu [20] presented ten different realization possibilities of multifunction filters with high input impedance, using three plus type CCIIs and only grounded passive components with similar advantages as the earlier circuit [19]. This realization produces only few filter functions and uses excessive passive components.

Recently, Horng [21] has described high input impedance voltage-mode universal biquadratic filter using three plus type CCIIs, two resistors, two floating capacitors, and an additional inverting amplifier for all-pass realization without matching conditions. The latest work by Horng [22] reported two configurations of high input impedance voltage-mode universal biquadratic filters with three inputs and one output using three plus type CCIIs and five to six passive components. It requires matching conditions for notch and all-pass responses, as well as an additional inverting amplifier for all-pass responses in both configurations.

From the above study it is clear that there exist no high input impedance universal filter using CCII, which uses minimum passive components and capable of realizing all pass (AP), band pass (BP), and notch filter functions. The major intention of this paper is to present a new configuration for realizing high input impedance universal biquadratic filters with two inputs and one output using two CCIIs, two resistors, and two capacitors. The new configuration offers the following additional advantages over earlier and recently published configurations:

(i) minimal required number of passive components,
(ii) no requirement of additional inverting amplifier,
(iii) simple component matching conditions,
(iv) presence of cascadability to implement higher order filters.

Although the proposed all-pass filter circuit has very advantageous features mentioned above, its quality factor value (Q) is not more than 0.5. This fact limits the proposed all-pass filter's application area to the delay equalization of second order filters. Fortunately, all-pass filters with Q values between 0.3 and 0.558 can provide very flat delay equalization [5]. For $Q = 0.558$, maximally flat delay equalization is obtained [5] and the proposed circuit's Q can be very close to that value. Consequently, due to advantageous features we mentioned above, the proposed circuit will be very useful for the delay equalization of the second order filters. Also the notch filter circuit can be applied as a band reject filter. The Q value of the band pass filter can be improved by cascading, making practically useful these filter circuits obtained from a single structure.

2 Circuit description

The proposed high input impedance voltage-mode universal biquadratic filter configuration is shown in Fig. 1. Using the terminal characteristics, as shown above, the voltage transfer function of the proposed circuit can be obtained as

$$V_0 = \frac{-V_1 s C_1 R_2 + V_2 \left[1 + s^2 C_1 C_2 R_1 R_2 + s\left(C_1 R_1 + C_2 R_2\right)\right]}{1 + s^2 C_1 C_2 R_1 R_2 + s\left(C_1 R_1 + C_2 R_2\right)}. \tag{1}$$

From (1), the following various filters can be realised.

(i) Band pass: If $V_2 = 0$, $V_1 = V_i$, the input voltage signal is V_i, and a second order band pass filter can be obtained. The voltage transfer function is given by

$$\frac{V_0}{V_i} = \frac{-s C_1 R_2}{1 + s^2 C_1 C_2 R_1 R_2 + s\left(C_1 R_1 + C_2 R_2\right)}. \tag{2}$$

(ii) Notch: If $V_1 = V_2 = V_i$, $R_2 = 2R_1 = 2R$, and $C_1 = 2C_2 = 2C$, the input voltage signal is V_i, and a second order notch filter can be obtained. The voltage transfer function is given by

$$\frac{V_0}{V_i} = \frac{1 + 4s^2 C^2 R^2}{1 + 4s^2 C^2 R^2 + 4sCR}. \tag{3}$$

(iii) All-pass: If $V_1 = V_2 = V_i$, $R_2 = 4R_1 = 4R$, and $C_1 = 4C_2 = 4C$, the input voltage signal is V_i, and a second order all-pass filter can be obtained. The voltage transfer function is given by

$$\frac{V_0}{V_i} = \frac{1 + 16s^2C^2R^2 - 8sCR}{1 + 16s^2C^2R^2 + 8sCR}. \tag{4}$$

Thus the circuit is capable of realizing band pass, notch, and all-pass functions. The inputs V_1, V_2 are connected to the high input impedance terminal (y port) of the two CCIIs, respectively. Thus the configuration enjoys the advantage of high input impedance. By cascading two or more such band pass filters, one can get high a Q band pass filter.

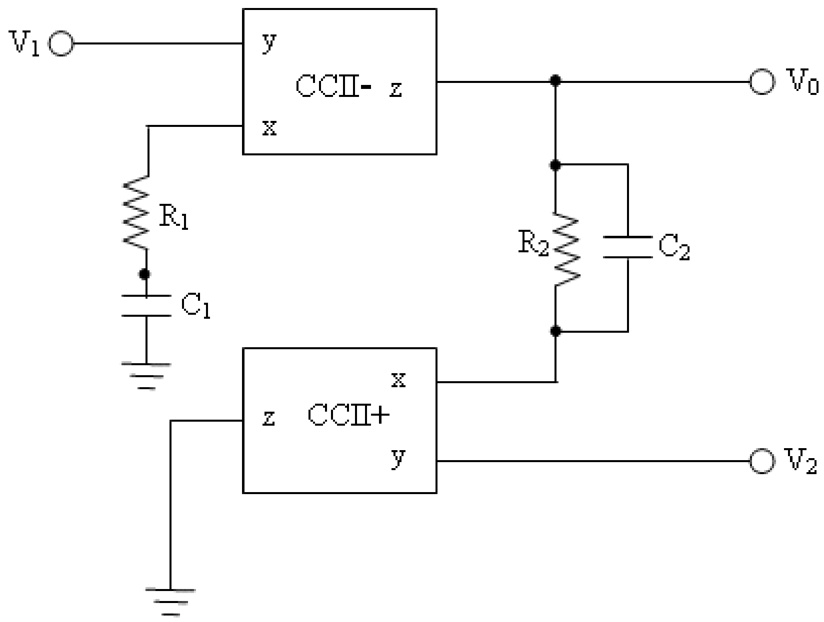

Figure 1: The proposed biquadratic filter configuration.

3 Effect of non-idealities of CCII

We can take into account non-idealities of the current conveyor (CCII), assuming $i_z = \pm\alpha\ i_x$ and $v_x = \beta\ v_y$ where $\alpha = 1- \in_1$ and $\in_1$ denotes the current tracking error, also $\beta = 1- \in_2$ and $\in_2$ denotes the voltage tracking error. For a non-ideal CCII, the voltage transfer function of the proposed circuit shown in Fig. 1 is given by

$$V_0 = \frac{-\alpha_1\beta_1 V_1 sC_1R_2 + \beta_2 V_2 \left(1 + s^2C_1C_2R_1R_2 + s(C_1R_1 + C_2R_2\right)}{1 + s^2C_1C_2R_1R_2 + s(C_1R_1 + C_2R_2)}. \quad (5)$$

Various filter functions can be realized from the equation (5) after satisfying the conditions as given below:

(i) Band pass: If $V_2 = 0$ (grounded), $V_1 = V_i$, the input signal is V_i, and a second order band pass filter can be obtained. The voltage transfer function is given by

$$\frac{V_0}{V_i} = \frac{-\alpha_1\beta_1 sC_1R_2}{1 + s^2C_1C_2R_1R_2 + s(C_1R_1 + C_2R_2)}. \quad (6)$$

(ii) Notch: If $V_1 = V_2 = V_i$ and $C_2 = C_3$, the input signal is V_i, and a second order notch filter can be obtained. The voltage transfer function is given by

$$\frac{V_0}{V_i} = \beta_2 \left(\frac{1 + s^2C_1C_2R_1R_2 + s(C_1R_1 + C_2R_2 - \frac{\alpha_1\beta_1}{\beta_2}C_1R_2)}{1 + s^2C_1C_2R_1R_2 + s(C_1R_1 + C_2R_2)} \right). \quad (7)$$

For a notch filter to exist,

$$C_1R_1 + C_2R_2 - \frac{\alpha_1\beta_1}{\beta_2}C_1R_2 = 0. \quad (8)$$

This condition is easily satisfied by proper selection of C_1, C_2, R_1, and R_2.

For simple design

$$C_1 = \frac{2\beta_2}{\alpha_1\beta_1}C_2 = \frac{2\beta_2}{\alpha_1\beta_1}C,$$

$$R_2 = \frac{2\beta_2}{\alpha_1\beta_1}R_1 = \frac{2\beta_2}{\alpha_1\beta_1}R,$$

the voltage transfer function becomes

$$\frac{V_0}{V_i} = \beta_1 \left(\frac{1 + \frac{4\beta_2^2}{\alpha_1^2\beta_1^2}s^2C^2R^2}{1 + \frac{4\beta_2^2}{\alpha_1^2\beta_1^2}s^2C^2R^2 + \frac{4\beta_2}{\alpha_1\beta_1}sCR} \right) \quad (9)$$

which represents a notch filter function.

(iii) All pass: If $V_1 = V_2 = V_i$ and $C_2 = C_3$, the input signal is V_i, and a second order all-pass filter can be obtained. The voltage transfer function is given by

$$\frac{V_0}{V_i} = \beta_2 \left(\frac{1 + s^2 C_1 C_2 R_1 R_2 + s(C_1 R_1 + C_2 R_2 - \frac{\alpha_1 \beta_1}{\beta_2} C_1 R_2)}{1 + s^2 C_1 C_2 R_1 R_2 + s(C_1 R_1 + C_2 R_2)} \right). \tag{10}$$

For an all-pass filter to exist,

$$C_1 R_1 + C_2 R_2 - \frac{\alpha_1 \beta_1}{\beta_2} C_1 R_2 = -(C_1 R_1 + C_2 R_2). \tag{11}$$

This condition is easily satisfied by proper selection of C_1, C_2, R_1, and R_2.

For simple design

$$C_1 = \frac{4\beta_2}{\alpha_1 \beta_1} C_2 = \frac{4\beta_2}{\alpha_1 \beta_1} C,$$

$$R_2 = \frac{4\beta_2}{\alpha_1 \beta_1} R_1 = \frac{4\beta_2}{\alpha_1 \beta_1} R,$$

the voltage transfer function becomes

$$\frac{V_0}{V_i} = \beta_1 \left(\frac{1 + 16 \frac{\beta_2^2}{\alpha_1^2 \beta_1^2} s^2 C^2 R^2 - 8 \frac{\beta_2}{\alpha_1 \beta_1} sCR}{1 + 16 \frac{\beta_2^2}{\alpha_1^2 \beta_1^2} s^2 C^2 R^2 + 8 \frac{\beta_2}{\alpha_1 \beta_1} sCR} \right) \tag{12}$$

which represents an all-pass filter function.

It is interesting to note that this circuit with non-ideal active element still realizes BP, AP, and notch filter functions with modified design conditions.

The resonance frequency ω_0, band width $\frac{\omega_0}{Q}$ and quality factor Q are given by

$$\omega_0 = \frac{1}{\sqrt{C_1 C_2 R_1 R_2}}, \tag{13}$$

$$\frac{\omega_0}{Q} = \frac{C_1 R_1 + C_2 R_2}{C_1 C_2 R_1 R_2}, \tag{14}$$

$$Q = \frac{\sqrt{C_1 C_2 R_1 R_2}}{(C_1 R_1 + C_2 R_2)}. \tag{15}$$

These parameters are not affected by a non-ideal CCII.

4 Sensitivity

The sensitivities of ω_0 and Q with respect to active and passive components are

$$S^{\omega_0}_{C_1C_2R_1R_2} = -1/2,$$

$$S^{Q}_{C_1R_1} = \frac{1}{2} - \frac{C_1R_1}{C_1R_1 + C_3R_3},$$

$$S^{Q}_{C_2R_2} = \frac{1}{2} - \frac{C_2R_2}{C_1R_1 + C_2R_2},$$

and

$$S^{\omega_0}_{\alpha_1\alpha_2\beta_1\beta_2} = \quad S^{Q}_{\alpha_1\alpha_2\beta_1\beta_2} = 0.$$

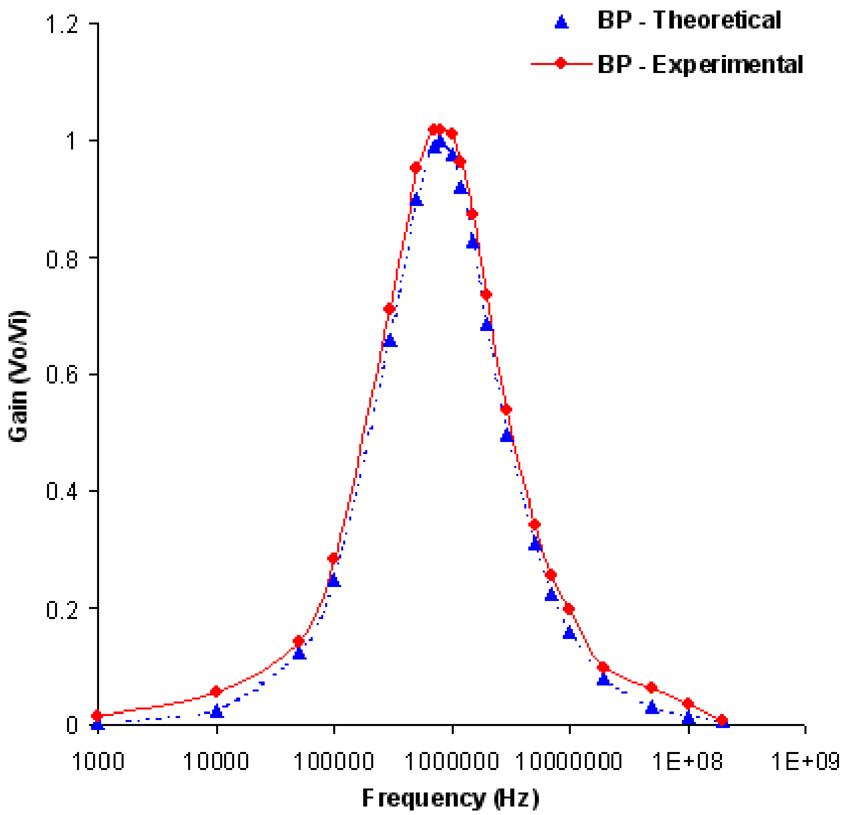

Figure 2: Frequency *vs* gain (V_0/V_i) plot of the band pass filter.

From the above calculation, the sensitivities of ω_0 and Q with respect to passive components are not more than unity, so the circuit enjoys low sensitivity performance.

5 Experimental results

The proposed circuit shown in Fig. 1 was tested experimentally for the following passive components values:

(i) $C_1 = C_2 = C = 200$ pf, $R_1 = R_2 = R = 1$ KΩ (for band pass filter).

(ii) $C_1 = 2C_2 = 2C = 200$ pf and $R_2 = 2R_1 = 2R = 2$ KΩ (for notch filter).

(iii) $C_1 = 4C_2 = 4C = 400$ pf and $R_2 = 4R_1 = 4R = 4$ KΩ (for all pass filter).

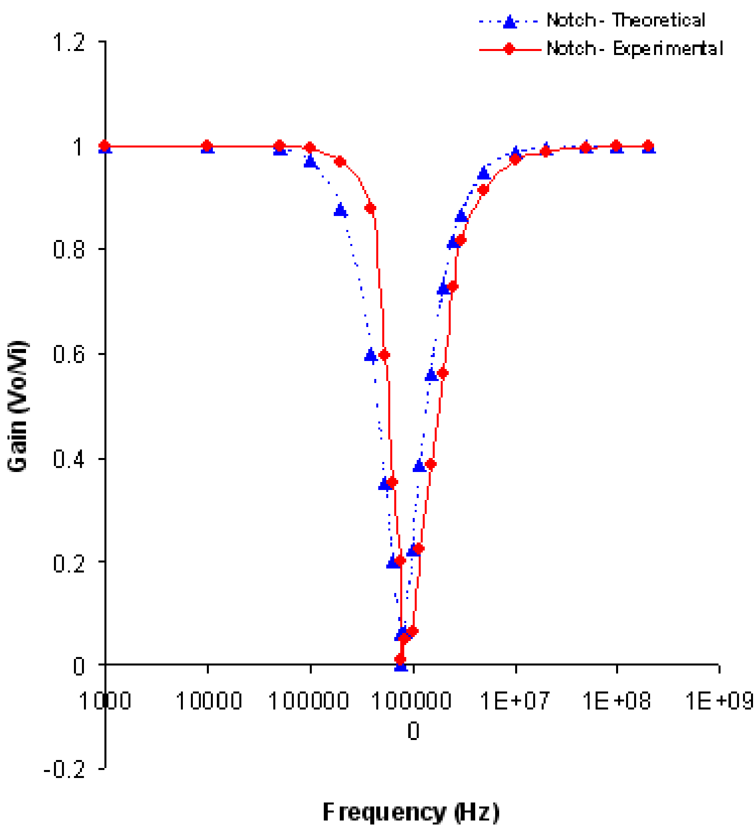

Figure 3: Frequency vs gain (V_0/V_i) plot of the notch filter.

All the experimental results for the band pass and notch filters were taken for the center frequency $(f_0) = 0.795$ MHz, and for the all pass phase crossover frequency 398 KHz.

The active element used in the experiment was a commercially available current feedback amplifier, AD844 of Analog Device which works as a CCII+, and using two CCII+, the CCII- was realized. The voltage supply to operate the IC-AD844 was taken as ±12 V.

The experimental results are found in good agreement with theoretical analysis, as can be seen from the graphs (Figs. 2, 3 and 4).

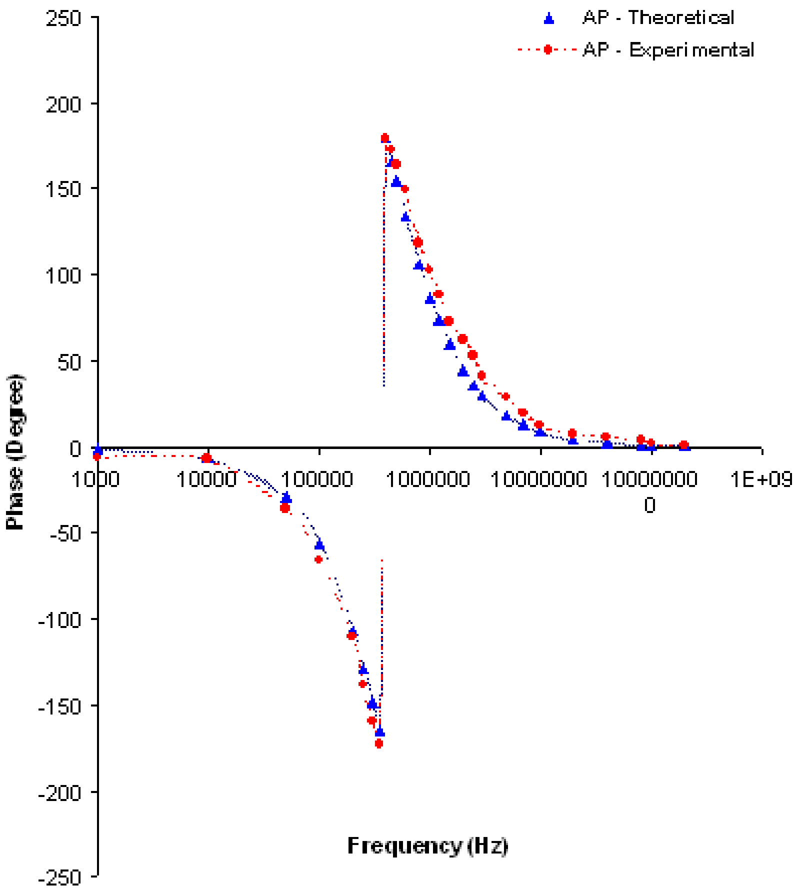

Figure 4: Frequency *vs* phase response of the all-pass filter.

6 Conclusions

A new configuration for realizing high input impedance band pass, all-pass, and notch filter functions with two inputs and one output using two CCIIs, two resistors, and two capacitors, is presented in this paper. The new configuration offers the following additional advantages over earlier and recently published configurations:

(i) minimal number of passive components,
(ii) no requirement of additional inverting amplifier,
(iii) simple component matching conditions,
(iv) cascadability to implement higher order filters.

The experimental results show that in comparison to operational amplifier based filter realizations, the current conveyor can easily realise filters in the high frequency range.

References

[1] A. Sedra and K.C. Smith, IEEE Trans. on Circuit Theory **17**, 132 (1970).

[2] K. Pal, Electronics Letters **16**, 639 (1980).

[3] C. Toumazou, F.J. Lidgey, and D.G. Haigh, *Analogue IC Design: The Current Mode Approach* (Peter Peregrinus Ltd., London, 1990).

[4] B. Wilson, IEE Proceedings **137**, 63 (1990).

[5] R. Schaumann and M.E. Van Valkenburg, *Design of Analog Filters* (Oxford University Press, N.Y., 2001).

[6] H. Schmid, Analog Integrated Circuits and Signal Processing **35**, 79 (2003).

[7] M. Bhusan and R.W. Newcomb, Electronics Letters **3**, 148 (1967).

[8] K. Pal and R. Singh, Electronic Letters **18**, 47 (1982).

[9] S.F.H. Naqshbendi and R.S. Sharma, International Journal of Electronics **55**, 499 (1983).

[10] A. Fabre, F. Dayoub, L. Duruisseau, and M. Kamoun, IEEE Trans. on Circuit and Systems-I **41**, 918 (1994).

[11] C. Toumazou and F.J. Lidgey, Electronic Letters **22**, 662 (1986).

[12] S.I. Liu, IEEE Trans. on Circuits and Systems-I **38**, 456 (1991).

[13] M. Higashimura, Electronics Letters **27**, 1345 (1991).

[14] M. Higashimura, Microelectronics Journal **23**, 359 (1992).

[15] S.I. Liu, Electronics Letters **31**, 1042 (1995).

[16] M. Higashimura and Y. Fukui, Electronics Letters **32**, 810 (1996).

[17] J.W. Horng, J.R. Lay, J.R., C.W. Chang, and M.H. Lee, Electronic Letters **33**, 472 (1997).

[18] O. Cicekoglu, and S.E. Ak, Proc. 10-th Int. Conf. on Microelectronics, ICM'98, Monastir, Tunisia, Dec.12-14 1998, p. 204 (1998).

[19] O. Cicekoglu, Microelectronics Journal **30**, 105 (1999).

[20] O. Cicekoglu, Microelectronics Journal **30**, 15 (1999).

[21] J.W. Horng, IEEE Trans. on Circuit and Systems-II **48**, 956 (2001).

[22] J.W. Horng, International Journal of Electronics **91**, 465 (2004).