THE TWINTOR IN BANDSTOP SWITCHED-CAPACITOR LADDER FILTER REALISATION

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INTRODUCTION

Switched-capacitor (SC) filter structures based on passive ladder simulations have attracted much attention because of their low sensitivity properties. However an instablity problem exists in the design of bandstop SC ladders by stray-insensitive LDI integrators [1]. A second order building block technique has been proposed in [2] to overcome this difficulty.

In this paper a new type of second order building-block called a twintor (TWinned INTegraOR) is introduced for bandstop SC ladder design. The circuit uses two signal channels to directly realise the basic bandstop operators without term cancellations [2], and also reduces the required opamp operation speed by a factor of two. Either single-input or differential-input integrators are allowed, giving flexibility for fabrication.

THE TWINTOR CIRCUIT

Following a matrix leapfrog method [3-4] a passive lowpass reference RLC ladder, Fig.1a, is described by the nodal admittance matrix equation

$$(sC + \frac{1}{s}\Gamma + G) V = J \tag{1}$$

where C, Γ and G are admittance matrices formed by the contributions of capacitors, inductors and resistors respectively. The voltage vector $V = [v_1, -v_2, v_3, -v_4, \ldots]$ to ensure all the entries of the matrices non-negative. It is well known that in the continuous time domain a symmetric bandstop function can be derived from a normalised lowpass one by transformation [5], Fig.1b

$$s \longrightarrow a^{-1} \left(\frac{s}{\omega_m} + \frac{\omega_m}{s} \right)^{-1}$$

$$\text{with} \quad a = \frac{\omega_m}{\omega^+ - \omega^-} \qquad \omega_m = \sqrt{\omega^+\omega^-} \tag{2}$$

Substitute (2) into (1) and perform the bilinear transformation $s=2(1-z^{-1})/T(1+z^{-1})$,

$$\left\{ a^{-1} \left(\frac{2}{\omega_m T} \frac{1-z^{-1}}{1+z^{-1}} + \frac{\omega_m T}{2} \frac{1+z^{-1}}{1-z^{-1}} \right)^{-1} C + a\left(\frac{2}{\omega_m T} \frac{1-z^{-1}}{1+z^{-1}} + \frac{\omega_m T}{2} \frac{1+z^{-1}}{1-z^{-1}} \right) \Gamma + G \right\} V = J \tag{3}$$

Multiply through (3) by the coefficient of Γ and rearrange to give

$$(A - 4\,\alpha z^{-1}\Psi\Phi\,\Gamma - \Phi 2G) = (-1+\Phi)\, J \tag{4}$$

where

$$\Phi = (\beta z^{-1} - 1)/(1-z^{-2})$$
$$\Psi = (z^{-1} - \beta)/(1-z^{-2})$$
$$A = \alpha^{-1} C + \alpha\,\Gamma - G$$

with

$$\mu = \omega_m T/2$$
$$\alpha = a\,(\mu^{-1} + \mu)$$
$$\beta = (\mu^{-1} - \mu)/(\mu^{-1} + \mu)$$

Topologically decompose Γ into,

$$\Gamma = A_L D_L A_L^T \tag{5}$$

where A_L is an incidence matrix of the inductors in the ladder, D_L is a diagonal matrix of reciprocal inductance values. With this (4) can be rewritten in the form

$$\begin{cases} AV = \Phi(A_L W + 2GV) + (-1+\Phi) J & \text{(6a)} \\ W = 4\alpha^{-1} z^{-1} \Psi D_L A_L^T V & \text{(6b)} \end{cases}$$

A signal flow graph can be drawn to represent (6), Fig.1c, which can be replaced by a SC circuit. The frequency dependant operators Ψ and Φ given by (4) are realised with a new TWINTOR second order strays-insensitive biquad scheme, Fig. 2a. In a twintor each opamp is operated only in every other period, T. The charge relations for the circuit of Fig.2a are

$$C_3[y^e(n) - y^e(n-2)] = -C_1 x^e(n) + C_2 x^o(n-1) \quad \text{when n even} \tag{7a}$$

$$C_3[y^o(n) - y^o(n-2)] = -C_1 x^o(n) + C_2 x^e(n-1) \quad \text{when n odd} \tag{7b}$$

Therefore the overall transfer function is given by

$$Y(z) = \frac{1}{C_3} \frac{C_2 z^{-1} - C_1}{1-z^{-2}} X(z) \tag{8}$$

Notice that the denominator $(1-z^{-2})$ is exactly realised without term cancellation.

It can be seen from Fig.2b that now the clock period is 2T compared to T in a conventional LDI integrator SC circuit. This means that the operation speed for the whole circuit, determined by sampling frequency, can be doubled without requiring an increase in opamp speed.

By selecting suitable capacitance values, Φ and Ψ can be easily implemented. When twintors are connected together to form a ladder structure, some simplifications are possible by separating signals into two channels, Fig.2c. The first equivalence in Fig.2c is obvious. For the second equivalence, notice that a sampling signal of an even (odd) channel opamp output in a odd (even) period is actually the signal held from the previous period, therefore a delay factor, z^{-1}, is realised. A number of switches are saved by this two channel technique.

An overall 6th order bi-channel bandstop SC ladder is shown in Fig.3 with the lowpass RLC ladder of Fig.1a as reference prototype. The specifications and the component values are listed in Table. 1. The simulated response of the SC bandstop ladder is shown in Fig.4. A negative input is required to realise the constant term in (6a), which may be avoided by the technique of [6].

CONCLUSIONS

A new strays-free SC circuit scheme has been proposed for bandstop SC ladder design. A major feature of the new circuit is that the clock period required is 2T so that the circuit can operate at a higher speed without extra demands on opamp performance.

ACKNOWLEGEMENTS

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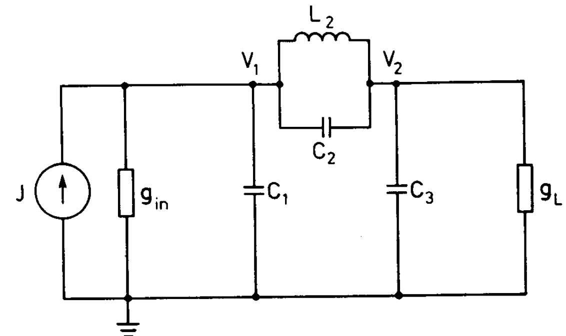

Fig.1 (a) A normalised lowpass ladder.

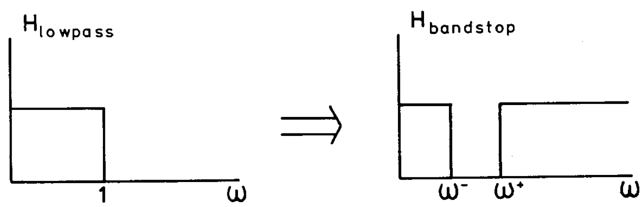

Fig.1 (b) Lowpass to bandstop transformation.

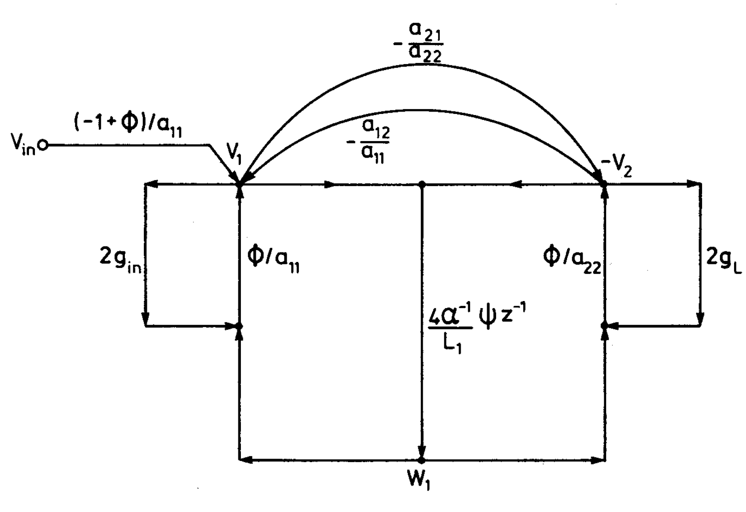

Fig.1(c) The signal flow graph of leapfrog type simulation.

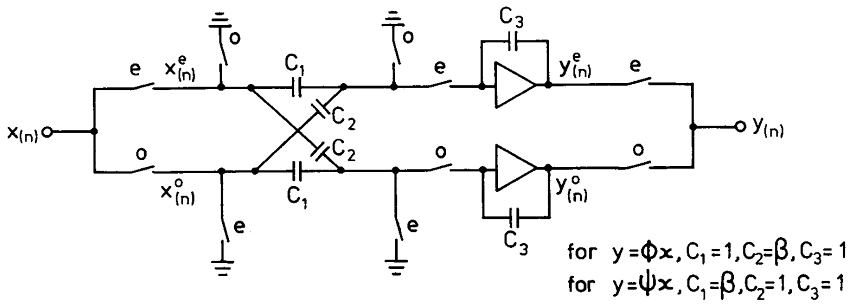

Fig. 2 (a) A twintor circuit

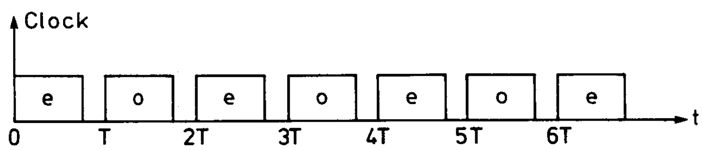

Fig. 2 (b) Twintor clock waveform

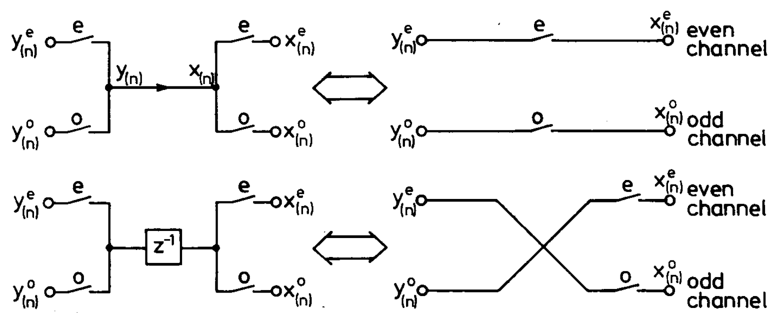

Fig. 2 (c) Two channel equivalent connection of twintors.

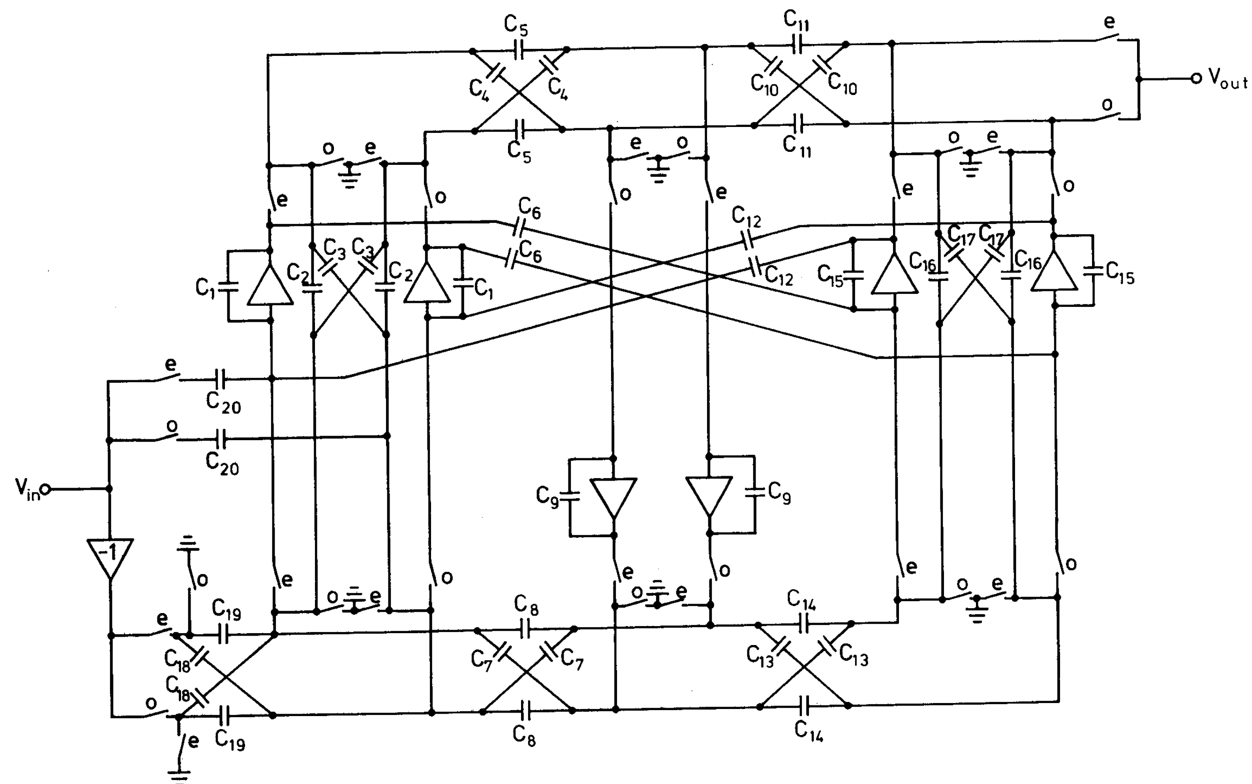

Fig. 3 A 6th order bandstop SC bi-channel filter realisation.

TABLE 1
DESIGN DATA FOR THE 6TH ORDER SC BANDSTOP FILTER

Specifications for the Bandstop SC Filter

lower passband edge		4.5 kHz	upper passband edge		5.5 kHz
lower stopband edge		3.5 kHz	upper stopband edge		6.5 kHz
passband ripple	<	0.1 dB	stopband attenuation	>	26 dB
sampling frequency		100 kHz			

Normalized Data for the Lowpass SC Ladder Reference Filter

G1 = GL = 1	C1 0.91646	L2 0.96995	C2 0.17046	C3 0.91646

Component Values for the Bandstop SC Filter

C1 14.79097	C2 1.414525	C3 1.398662	C4 1.614900	C5 1.633215
C6 15.64070	C7 37.44417	C8 37.86882	C9 1.000000	C10 1.141830
C11 1.154780	C12 10.93656	C13 37.86304	C14 38.29245	C15 10.57509
C16 1.011341	C17 1.000000	C18 1.977572	C19 2.000000	C20 1.000000

number of capacitors	40	number of switches	30
number of op amps	6	total capacitance	439.51
capacitance spread	38.29		

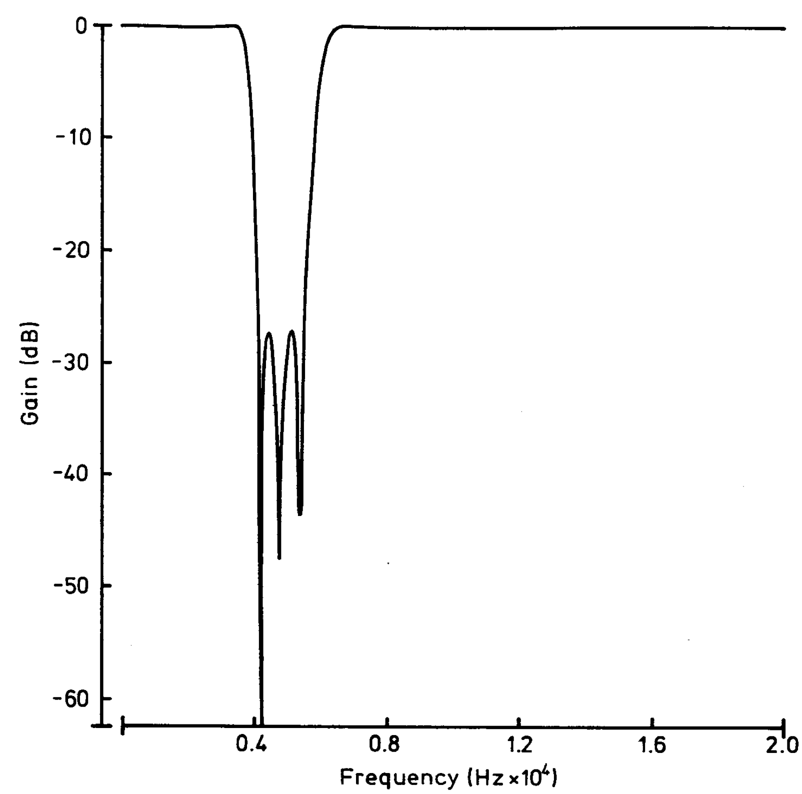

Fig. 4 Computed response of the SC bandstop filter.