UNIVERSAL TUNABLE CURRENT–MODE BIQUAD EMPLOYING DISTRIBUTED FEEDBACK STRUCTURE WITH MO–CCCII

Roman Šotner — Josef Slezák — Tomáš Dostál — Jiří Petržela *

One possible application of the multiple-output electronically-tunable active building block as a universal filter with distributed feedback structure is presented. The suggested structure is less conventional than the well-known state-variable Kerwin-Huelsman-Newcomb but allows the same filter configurations with the similar properties. The major current-mode design approach disadvantage, *ie*, the necessity of multiple current outputs, is demonstrated. To date even a rather big line of the commercially available devices do not solve this problem. Some features of the active block used for modelling and transistor-level simulation are briefly discussed. The obvious chance for electronic tuning of the proposed filter is verified.

K e y w o r d s: current-mode, universal biquad, multi-output current conveyors, electronic adjusting

1 INTRODUCTION

In the case of current-mode (CM) circuits there is always a requirement to make a copy of the output current [1] into different directions (towards feedback, for summing function, *etc*). Generally, CM realizations are significantly simpler if compared with dual voltage-mode (VM) counterparts. This is mainly due to the elemental realization of the summing operation by a single node. On the other hand, the biggest obstacle is an implementation of the multiple-current outputs with both polarities next to the active block or in the so-called current distributor [2]. Recently, many integrated circuits suitable for CM applications up to the video frequencies are accessible, few of them with electronic tuning. Unfortunately, the lack of the multiple current outputs makes them less universal. Let us briefly discuss some examples. First, a voltage-controlled current multiplier (or second generation negative current conveyor CCII-) EL2082 is mentioned in [3–6], the well known and widely used trans-resistance amplifier AD 844 is utilized in [7]. It seems that the most potential is behind the trans-conductance amplifiers (OTA) [3, 8]. OTA followed by a current-feedback amplifier is covered by LT 1228 [9] and a diamond transistor with a voltage buffer can be recognized inside OPA 860 [10]. Referring to the best knowledge of the authors, the only active device with two current outputs (balanced) is OTA marked as MAX 435 [11]. This block is not recommended for new designs since its manufacturing process has been stopped.

Although this paper (especially proposed active building block) looks similar to [12], there are many fundamental improvements. The authors in [12] state that their circuit can be adjusted electronically but, in fact, notable the frequency and quality factor are adjusted by changing the resistors. Moreover, the filter is verified only in the low frequency range. Thus, a practical benefit of this "novel filter is disputable to say the least. Such conglutinate of the external transistors will have substantial parasitic effects. The circuitry proposed in this article has less passive elements (only two resistors and two capacitors). Of course, there is a possibility to make a multiple output performance by using several single-output devices with parallel high-impedance inputs but at the cost of raising the complexity of the network [13]. Such a solution takes a lot of place, it is necessary to work out a more complicated electronic adjusting (which is often simultaneous) and the final price is much bigger.

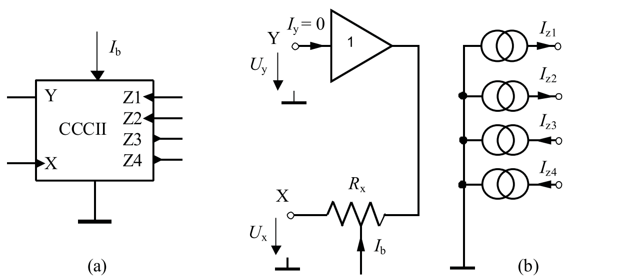

Fig. 1. Schematic symbol and the simplest behavioural model of MO-CCCII

In practice, it is quite simple to create a chips internal structure with multiple outputs by adding a proper number of current mirrors. In spite of this, the manufacturers are focused on developing a standard voltage-feedback (VFA) and current-feedback (CFA) amplifiers with a high transit frequency. Today, a device with a transit frequency beyond 1 GHz is not a rarity.

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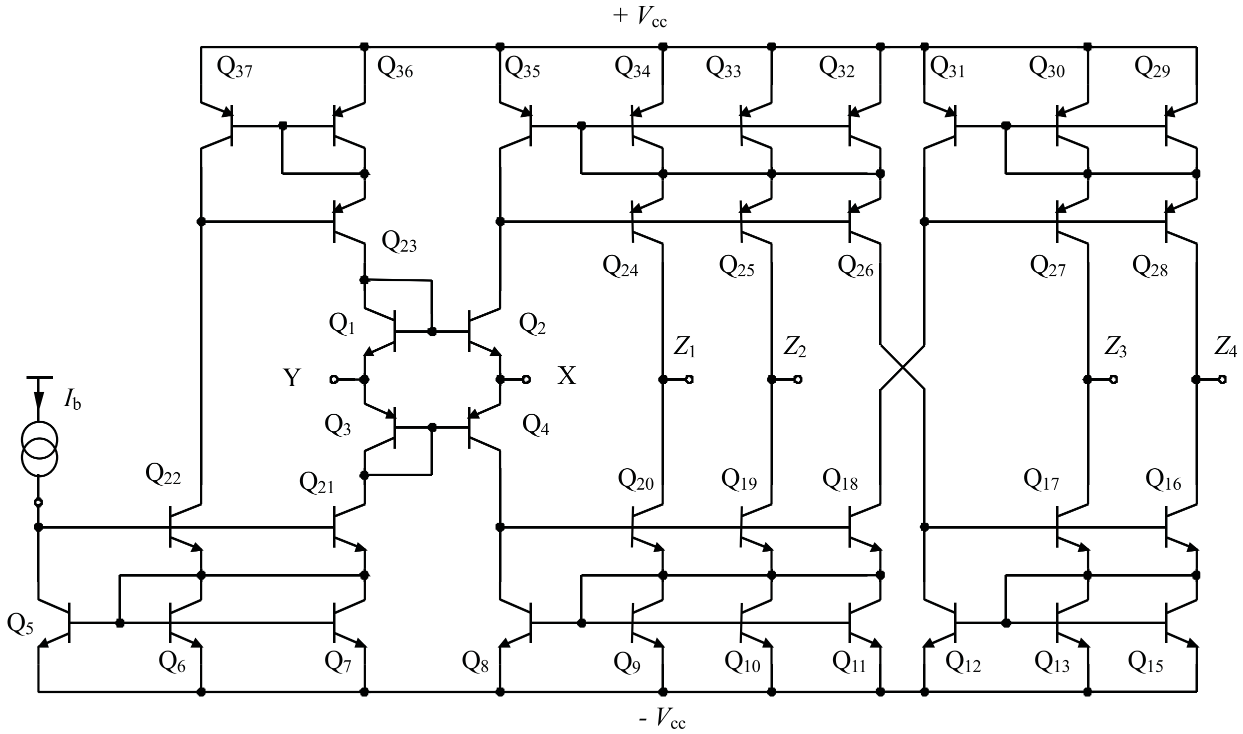

Fig. 2. Internal structure of MO-CCCII

Table 1. The internal parameters of the used bipolar transistors

MODEL PNP6 PNP							
+IS	$= 2.015 \times 10^{-16}$	BF	$= 1.418 \times 10^{2}$	NF	$= 1.000$	VAF	$= 2.058 \times 10^{1}$
+IKF	$= 1.085 \times 10^{-1}$	ISE	$= 2.233 \times 10^{-15}$	NE	$= 1.505$	BR	$= 3.252 \times 10^{1}$
+NR	$= 1.050$	VAR	$= 1.093$	IKR	$= 5.000 \times 10^{-5}$	ISC	$= 6.621 \times 10^{-16}$
+NC	$= 1.150$	RB	$= 3.346 \times 10^{1}$	IRB	$= 0.000$	RBM	$= 2.40$
+RE	$= 5.537$	RC	$= 2.156 \times 10^{1}$	CJE	$= 1.202 \times 10^{-13}$	VJE	$= 7.320 \times 10^{-1}$
+MJE	$= 4.930 \times 10^{-1}$	TF	$= 1.303 \times 10^{-11}$	XTF	$= 3.500 \times 10^{1}$	VTF	$= 3.259$
+ITF	$= 2.639 \times 10^{-1}$	PTF	$= 0.000$	CJC	$= 1.595 \times 10^{-13}$	VJC	$= 7.743 \times 10^{-1}$
+MJC	$= 5.000 \times 10^{-1}$	XCJC	$= 8.504 \times 10^{-2}$	TR	$= 1.500 \times 10^{-10}$	CJB	$= 7.620 \times 10^{-13}$
+VJS	$= 9.058 \times 10^{-1}$	MJS	$= 4.931 \times 10^{-1}$	XTB	$= 1.732$	EG	$= 1.184$
+XTI	$= 2.000$	KF	$= 10.890 \times 10^{-16}$	ASF	$= 1.000$	FC	$= 8.500 \times 10^{-1}$
MODEL PNP6 NPN							
+IS	$= 70.400 \times 10^{-18}$	BF	$= 1.570 \times 10^{2}$	NF	$= 1.000$	VAF	$= 7.000 \times 10^{1}$
+IKF	$= 39.750 \times 10^{-3}$	ISE	$= 32.190 \times 10^{-15}$	NE	$= 2.000$	BR	$= 0.7614$
+NR	$= 1.000$	VAR	$= 1.452$	IKR	$= 81.720 \times 10^{-3}$	ISC	$= 7.618 \times 10^{-21}$
+NC	$= 1.847$	RE	$= 5.537$	RB	$= 3.346 \times 10^{1}$	IRB	$= 0.000$
+RBM	$= 2.400$	RC	$= 2.156 \times 10^{1}$	CJE	$= 120.20 \times 10^{-15}$	VJE	$= 0.7591$
+MJE	$= 0.5406$	CJC	$= 133.80 \times 10^{-14}$	VJC	$= 0.6666$	MJC	$= 0.4509$
+XCJC	$= 8.450 \times 10^{-2}$	TR	$= 4.000 \times 10^{-11}$	CJS	$= 3.180 \times 10^{-14}$	FC	$= 0.827$
+TF	$= 12.130 \times 10^{-12}$	XTF	$= 2.049$	VTF	$= 1.813$	ITF	$= 42.930 \times 10^{-3}$
+TR	$= 40.000 \times 10^{-12}$	CJS	$= 3.180 \times 10^{-14}$	EG	$= 1.184$	XTB	$= 1.022$
+XTI	$= 1.780$	KF	$= 17.500 \times 10^{-15}$	AF	$= 1.000$	FC	$= 8.273 \times 10^{-1}$

2 MULTI–OUTPUT CCCII

A lot of publications employing multiple-output current conveyors (MO-CC) in various modifications already exist [14–16]. The authors usually focus on electronic tuning and on-chip implementation of the two current outputs. The principle of current conveyors (CC) itself is known for several decades and can be found in [3–5]. In practice, the nonzero input resistance of the current input node can be a problem. In the case of commercially

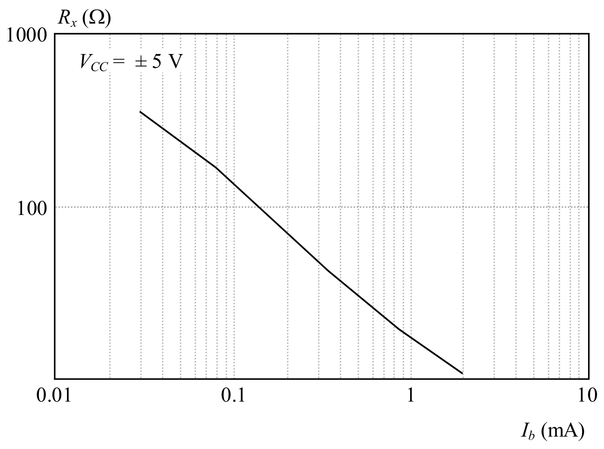

Fig. 3. The curve for $R_x = f(I_b)$ dependence

available devices these value can reach tens of Ω and for a CMOS integrated circuits hundreds of Ω up to a few kΩ [16, 17]. The concrete value strongly depends on the biasing current. This drawback can be eventually turned into an advantage. It means that in specific situations some general property of the integrated circuit can be changed. For example, the time constant of the CC based voltage or current integrator can be instantly controlled. Among circuit designers the favourite OPA860 takes advantage of the mentioned event. We encourage the engineers to utilize the second generation MO-CCCII given in Fig. 1.

Traditionally, for CCII+ [3, 5] the orientations of all currents are towards the active block. In our case we use opposite directions as demonstrated in Fig. 1. The structure using Wilson current mirrors in bipolar technology [18] is given in Fig. 2. Two positive as well as two negative outputs are available. This quantity is sufficient for an overwhelming majority of applications. If not, additional mirrors can be connected analogically [13]. The models of individual transistors [10] are described in Tab. 1. The obtained dependence of $R_x = f(I_b)$ is in Fig. 3.

3 PROPOSED UNIVERSAL FILTER

The signal flow graphs for particular configurations of the universal biquad filter are illustrated in Fig. 4. These configurations (transfer functions) can be established by using a single switch. The final circuitry with two CCCII-based integrators and two MO-CCCII distributors is given in Fig. 5. Note that this is the way how any transfer function can be realized, see Tab. 2 for further details. A filter with a desired transfer function never includes all four outputs of the active block. Thus, some current mirrors can be saved. For the higher-order circuits with this distributed network structures the demands for the number of distributor outputs raise.

Table 2. Concrete transfer function setup via switch position

SW_1	SW_2	SW_3	TRANSFER TYPE
on	off	off	high-pass (HP)
off	on	off	band-pass (BP)
off	off	on	low-pass (LP)
on	off	on	band-reject (BR)
on	on	on	all-pass (AP)

The individual transfer functions are following

$$K_{LP}(s) = \frac{\frac{1}{R_1^* R_2^* C_1 C_2}}{s^2 + \frac{1}{R_2^* C_2} s + \frac{1}{R_1^* R_2^* C_1 C_2}},$$
$$K_{BP}(s) = \frac{-\frac{1}{R_2^* C_2} s}{s^2 + \frac{1}{R_2^* C_2} s + \frac{1}{R_1^* R_2^* C_1 C_2}},$$
$$K_{HP}(s) = \frac{s^2}{s^2 + \frac{1}{R_2^* C_2} s + \frac{1}{R_1^* R_2^* C_1 C_2}}, \tag{1}$$
$$K_{BR}(s) = \frac{s^2 + \frac{1}{R_1^* R_2^* C_1 C_2}}{s^2 + \frac{1}{R_2^* C_2} s + \frac{1}{R_1^* R_2^* C_1 C_2}},$$
$$K_{AP}(s) = \frac{s^2 - \frac{1}{R_2^* C_2} s + \frac{1}{R_1^* R_2^* C_1 C_2}}{s^2 + \frac{1}{R_2^* C_2} s + \frac{1}{R_1^* R_2^* C_1 C_2}},$$

where $R_1^* = R_1 + R_{x1}$ and $R_{x1} = f(I_{b1})$. For the characteristic frequency and quality factor it holds

$$\omega_C = \sqrt{\frac{1}{R_1^* R_2^* C_1 C_2}}, \tag{2}$$

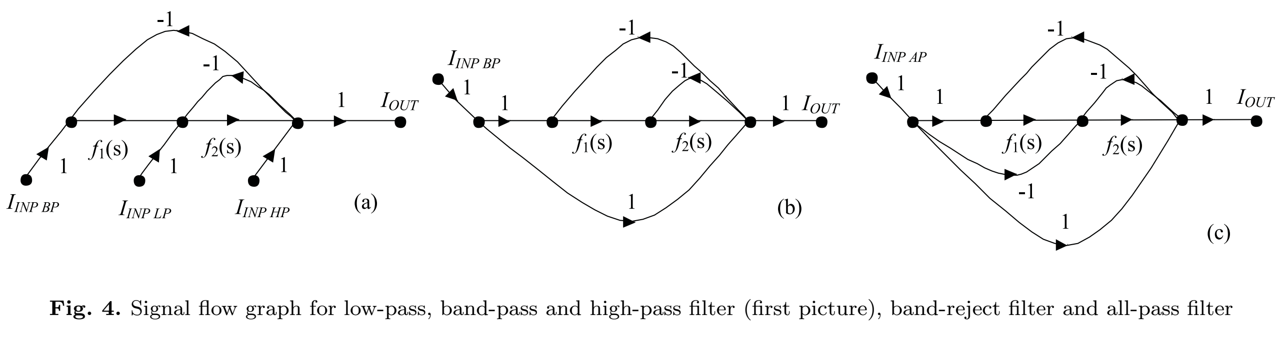

Fig. 4. Signal flow graph for low-pass, band-pass and high-pass filter (first picture), band-reject filter and all-pass filter

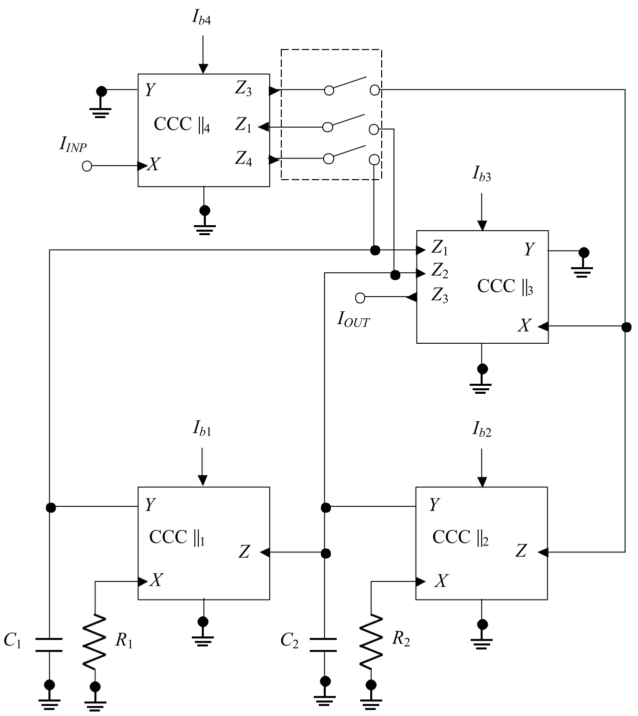

Fig. 5. Universal biquad

$$Q = R_2^* C_2 \sqrt{\frac{1}{R_1^* R_2^* C_1 C_2}} \,. \tag{3}$$

All relative sensitivities of f_C on the changes of the circuit elements are -0.5 and the sensitivities of Q are not greater than 1.

4 EXPERIMENTAL RESULTS

As it is evident in the pictures below, the filter is designed for $f_C = 2$ MHz with quality factor $Q = 1$. The values of resistors are chosen as $R_1 = R_2 = R = 50\,\Omega$ and capacitors $C_1 = C_2 = C = 220$ pF. Using (6) and (7) one can easily calculate $R_1^* = R_2^* = R^* = 362\,\Omega$ ($R_{x1} = R_{x2} = R_x = 312\,\Omega$). The mentioned R_x gives $I_{b1} = I_{b2} = I_b$ about $55\,\mu$A. The distributors control currents of]0$CCCII_3$ and CCCII$_4$ are $100\,\mu$A and the supply voltage is ± 5 V. The 3 dB gain drop for the highpass filter arises on the high frequency of 70 MHz. This value is well in the video range and represents the upper bound of the filter applicability. The verification of the achieved frequency characteristics (module only) is provided in Fig. 8. The entire frequency response of the all-pass filter is given in Fig. 7.

From the viewpoint of the cutoff frequency of the low-pass filter change (acquired frequency distance is 2.7 MHz until about 12.2 MHz), electronic adjusting by means of the control currents $I_{b1} = I_{b2}$ is demonstrated in Fig. 8 with the parameters given in Tab. 3.

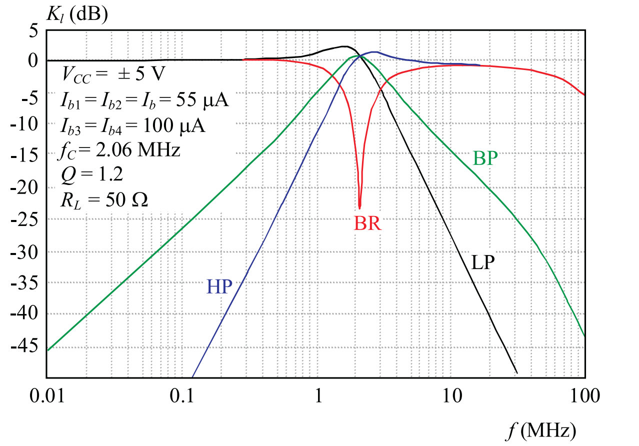

Fig. 6. Magnitude responses for low-pass, band-pass, high-pass and band-reject filters

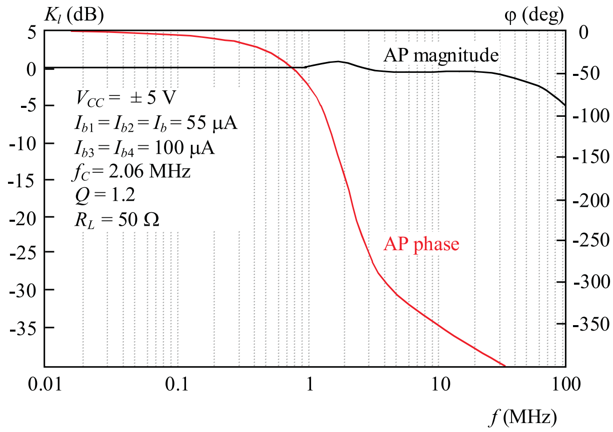

Fig. 7. Overall frequency response of all-pass filter

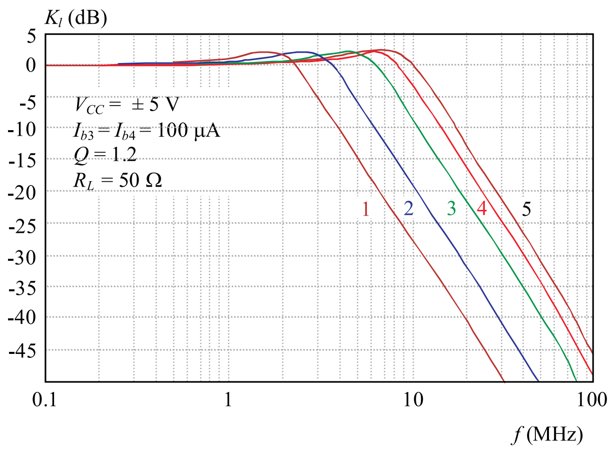

Fig. 8. Low-pass filter with electronic adjusting

Table 3. The values of the parameters in Fig. 8

index	$I_{b1}, I_{b2} (\mu\text{A})$	f_{-3dB}(MHz)
1	55	2.76
2	100	4.36
3	250	7.63
4	500	10.20
5	1000	12.25

5 CONCLUSION

This paper gives an idea concerning the filter with the multiple-output active blocks utilized for current distribution purpose. Evidently, the adequate solution with commercially available blocks (with single output) will be much more complicated. The employed MO-CCCII is great at good frequency response and in the possibility to turn the seeming disadvantage of $R_x = f(I_b)$ into the profitable control purpose. In the concrete filter network some CCCII current outputs can be omitted so that a bunch of transistors can be saved.

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