On the New Design of CFA based Voltage Controlled Integrator/ Differentiator Suitable for Analog Signal Processing

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Abstract: - Some new active Voltage Controlled RC integrator and differentiator circuit realizations, with both single and differential input capabilities, using a few passive components and a current feedback amplifier (CFA) device, are proposed. A multiplier (ICL - 8013) element has been appropriately utilized in the feed forward / feedback connection to obtain electronic tuning of the time constant (τ_o) by the d.c. control voltage (V_c) of the multiplier. Experimental result on wave processing had been verified in the frequency range of 50 KHz ~ 300 KHz. The active τ_o sensitivities in the event of non-ideal CFA are shown to be extremely low.

Key-Words: - Current feedback amplifier, voltage controlled integrator/differentiator (VCI/VCD)

1. Introduction

Active - RC integrator and differentiator have been recognized as special function circuits, which find a variety of applications in signal / wave processing. These circuits essentially synthesizes a ratio type (y_1/y_2) function involving an active device like the voltage operational amplifier, operational transconductance amplifier, current conveyor [1-6]. Recently the CFA device is being widely used for analog function circuit design [7-9]. The major advantages of the CFA over the ubiquitous op-amp are the enhanced device bandwidth at higher slew-rate, and, accurate port tracking properties leading to insensitive design [10-12]. A number of CFA based integrator/differentiator structures with passive tuning have been reported in the recent past [13-15].

Some such new circuits are proposed with electronic tuning capability derived by incorporating a multiplier (ICL- 8013) element appropriately in the feed forward / feedback connection with the CFA. Both single and differential input configurations are reported.

Sensitivity analysis assuming finite port tracking errors ($\in \neq o$) in the CFA shows extremely low active τ_o - sensitivity. Experimental results on wave processing in the frequency range 50 KHz ~ 300 KHz have been verified by hardware implementation and with PSPICE macromodal simulation .

2. Single Input VCI / VCD

The single - input voltage controlled integrator/differentiator (VCI / VCD) structures using a CFA is shown in Fig.1. The port relations of the CFA are

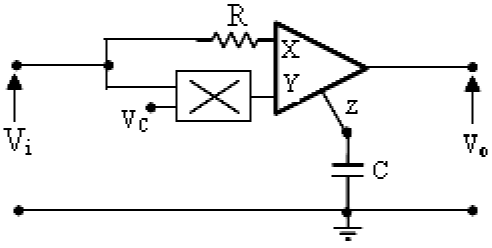
$$\left.\begin{array}{l} i_Z = \alpha\ i_X \quad v_X = \beta\ v_Y \quad v_o = \delta\ v_Z \\ \text{where } \alpha = 1 - \in_i \quad \beta = 1 - \in_V \quad \delta = 1 - \in_o \end{array}\right\} \quad (1)$$

and $i_y = 0$.

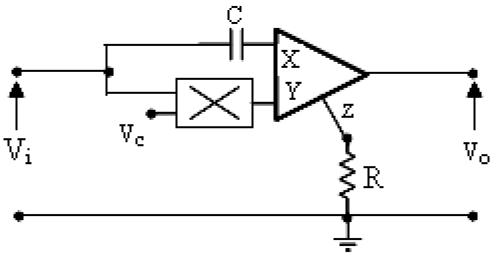
Usually the errors ($\in$) are quite small ($|\in| << 1$): for an ideal device they vanish ($\in = 0$) and port signals are tracking, i.e., $\alpha = \beta = \delta = 1$. Analysis assuming ideal CFA yields the voltage transfer for the VCI in Fig.1 (a) and VCD in Fig.1 (b) as

$$\left.\begin{aligned} \frac{V_o}{V_i}\bigg|_a &= G_a = \frac{1}{s\tau_o} & \tau_{oi} &= \frac{RC}{(1-kV_c)} \\ \frac{V_o}{V_i}\bigg|_b &= G_b = -s\tau_o & \tau_{od} &= \frac{RC}{(1-kV_c)} \end{aligned}\right\}(2)$$

Where k (= 0.1/volt) is the multiplier constant. Note that if V_c is varied in the range $1 \le V_c \le 10$ volt (d.c), the time constant may be adjusted electronically; as $kV_c \rightarrow 1$, enlargement of the nominal time constant for the integrator [16] and reduction of that for the differentiator may be obtained. The proposed circuits are quite simple requiring only the minimum active and passive components.



(a) Integrator



(b) Differentiator

Fig. 1 Single – input voltage (Vc) controlled configurations

3. Differential Input VCI / VCD

The proposed configuration are shown in Fig.2 (a) and (b) for which we get

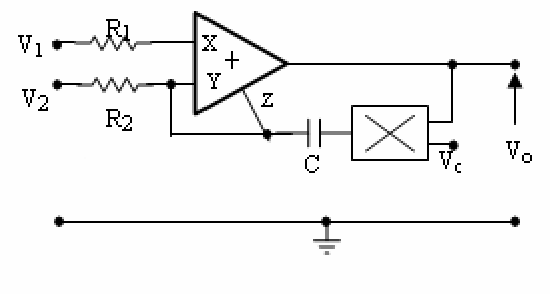
$$\left.\begin{aligned} V_{oa} &= \frac{a(V_2 - aV_1)}{sCR_1(1-kV_c)+a-1} \\ -V_{ob} &= \frac{\{V_2(sCR_1+1-a)-V_1 sCR_1\}}{(a-kV_c)} \end{aligned}\right\}(3)$$

Where a = R_1 / R_2

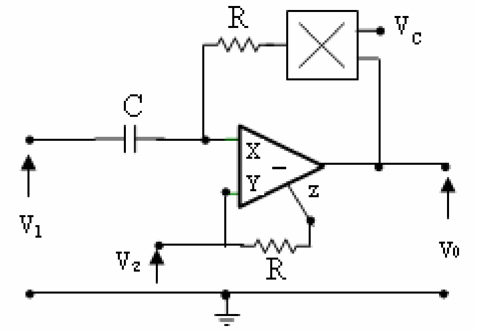
The realizability condition for both the structures for a true differential input feature is a = 1, i.e., $R_1 = R_2 = R$. Then one gets the differential mode transfer $V_{oa} / (V_2 - V_1) = H_a$ and $V_{ob} / (V_2 - V_1) = H_b$ as

$$\left.\begin{aligned} H_a &= 1/s\tau_{0i}; & \tau_{0i} &= RC(1-kV_C) \\ H_b &= -s\tau_{0d}; & \tau_{0d} &= RC/(1-kV_C) \end{aligned}\right\}(4)$$

Thus variation of V_c tunes τ_o electronically. Note that by RC: CR interchanges in Fig. 2(a), one gets a dual-input differentiator but with two capacitors, as it had been reported [17] using opamps. Here we propose the same using a single capacitor. In Fig.2 a pair of equal-value resistors are needed for feeding the two input signals for symmetrical handling of two signals for a truly differential mode operation. Hence in the event of IC adaptation of the proposed circuits, matched resistors and the capacitor may be so fabricated that the sensitivity errors can be reduced significantly.



(a) Integrator



(b) Differentiator

Fig. 2 Differential input voltage (V_c) controlled configurations.

4. The Multiplier-CFA Structure

The ICL-8013 is a four-quadrant analog multiplier whose output is proportional to the algebraic product of two input signals. The high accuracy (± 0.5 %), wide bandwidth (1 MHz) and increased versatility of ICL-8013 make it ideal for all applications in the field of voltage controlled amplifiers/tuners .The internal circuit of the ICL-8013 multiplier contains essentially two voltages to current converters for the two inputs; outputs of the converters are fed to a balanced variable gain amplifier followed by an opamp output stage. The details of the internal circuit connection and their functions are available in ref [18].

The internal architecture of CFA indicates that the device provides current feedback when connected in closed loop and hence should possess a low impedance (R_x) at the inverting input mode, a high impedance (Z_y) at the non-inverting node and also a high output impedance current source Z node (for $V_o=V_z$). From the AD-844 data sheet [19], $R_x = 50\ \Omega$, $Z_y = R_y//C_y$ where $R_y= 2\ M\Omega$, $C_y= 2$ pF and $Z_z= R_z//C_z$ where $R_z= 3\ M\ \Omega$ and $C_z= 5$ pF.

5. Effects of Non-Ideal CFA

The CFA device is considered to be nonideal with finite port tracking errors ($\in\ \neq 0$). Hence the modified transfer ratios for Fig.1 are

$$\left.\begin{aligned}\tilde{G}_a &= \frac{-(1-\varepsilon_i)(1-\varepsilon_o)\left\{1-(1-\varepsilon_v)kV_C\right\}}{sCR}\\ \tilde{G}_b &= \frac{(1-\varepsilon_i)(1-\varepsilon_o)\left\{1-(1-\varepsilon_v)kV_C\right\}}{sCR}\end{aligned}\right\} \quad (5)$$

Similar analysis had been carried out for the circuits in Fig.2 which shows that the transfer ratios and values of τo are modified. These modified values are listed is Table-1. It may be seen that for the circuit in Fig.2 (b), the modified transfer equation, after satisfying the realizability condition as in Table-1, is given by

$$\left.\frac{V_o}{(1-\varepsilon_v)V_2 - V_1} = \frac{CR_1}{\left\{1+\varepsilon_o-\varepsilon_v-kV_C\right\}}\right\} \quad (6)$$

The noninverting input signal thus is seen to be slightly reduced (since $|\in| <<1$) for the differential-mode in the event of a nonideal CFA.

Table 1. Modified Expressions of Transfer Equation, Relizability and τ_O for Fig.1 and Fig.2

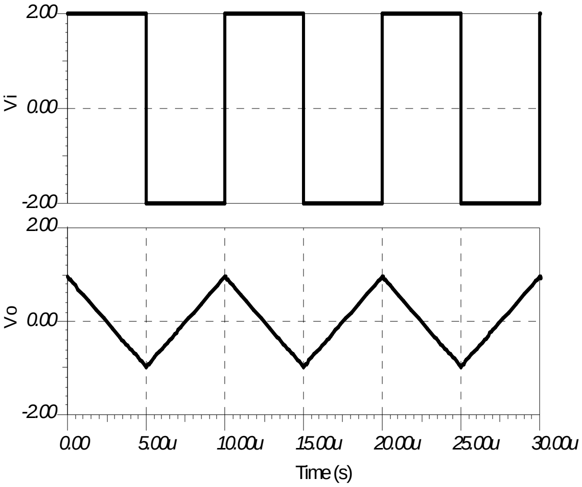
Fig.	Transfer Equations	Relizability	$\tilde{\tau}_O$
1(a)	$\tilde{G}_a = -1/s\ \tilde{\tau}_o$	none	RC /(1- $\in_t$) {1-(1-$\in_v$)kV_c}
1(b)	$\tilde{G}_b = -s\ \tilde{\tau}_o$	none	(1-$\in_t$) {1 - (1-$\in_v$) kV_c}RC $\in_t = \in_i + \in_o$
2(a)	$\tilde{H}_a = \frac{V_o}{aV_2 - V_1} = \frac{(1-\in_o)}{a-(1-\in_t)+s\ CR_1\{1-(1-\in_o)\ kV_c\}}$	a = 1 - $\in_t$	(1+$\in_0$ - kV_c) CR_1
2(b)	$-V_o\ (1+\in_t)\{a-(1-\in_t)\ k\ V_c\} = V_2\{(1-\in_v)\ sCR_1 + (1-\in_v)-(1+\in_i)\ a\} - V_1\ s\ C\ R_1$	a =1-($\in_i$ + $\in_v$)	CR_1/(1+$\in_o$ - $\in_v$ - kV_c)

6. Experimental Results

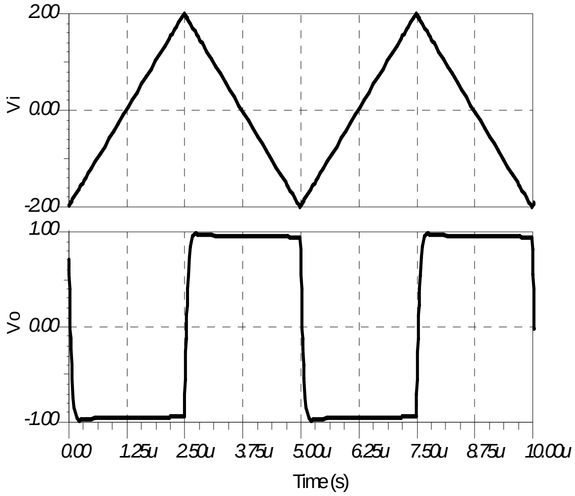
All the proposed configurations had been tested with hardware implementation and by PSPICE macromodal simulation [20]. The AD-844 CFA was used as the active device and the ICL-8013 multiplier had been used as the d.c. voltage (Vc) control element. In our experiments, regulated bias voltages were set at 0 ±12 V. d.c. for the CFA and multiplier devices and, Vc was varied in the range $1V \leq Vc \leq 10$ V. Both time domain tests for wave conversion, and sinusoid response for phase error (θe) measurement were carried out. Some typical results on wave conversion by the integration / differentiation functions are shown in Fig.3 and in Fig.4 for single –input and dual-input connections respectively. For these time–domain tests, the input signals were square wave for the integrators, and triangular wave for the differentiators. The electronic tuning range for the integrators is shown in Fig.5 where variation of time constant (τ_o) and the slope (M) of the output ramp relative to V_c are shown graphically. The parameter M had been measured by using an expression $M = V_{opp} / T_i$ where T_i is the period of integration. The output Voltage (Vo_{pp}) and M (Volts/ms) had been measured from the oscilloscope display which had subsequently been verified by the PSpice simulation. These results have been compared with the theoretically calculated values, and an error of less than ±5 % on this wave conversion was obtained over the entire tuning range of $1V \leq V_c \leq 10$ V d.c. The proposed circuits exhibited satisfactory sinusoid response at extended frequency ranges. The measured phase (θ) responses obtained with simulation are listed in Table-2.

Table 2.
Phase Response of Integrators/Differentiators

	Fig. 1		Fig. 2	
	(a)	(b)	(a)	(b)
Signal Frequency f (KHz)	750	200	400	400
Measured Phase θ (deg)	89.1	96.9	88.2	93.0
Phase Error θ_e (deg)	0.9	6.9	1.8	3.0

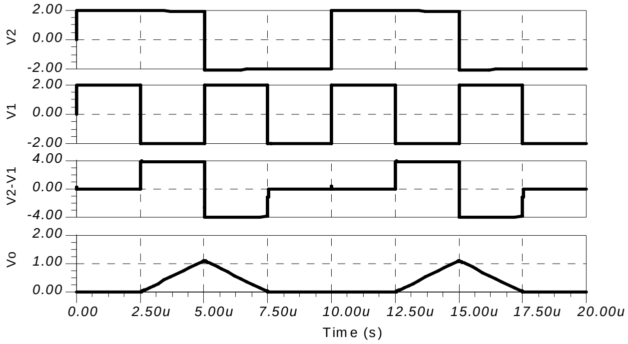


(a) Wave conversion at 100 KHz by the inverting VCI of Fig.1 (a) using R = 1 KΩ, C = 2.5 nF and V_c = 5 V. d.c.

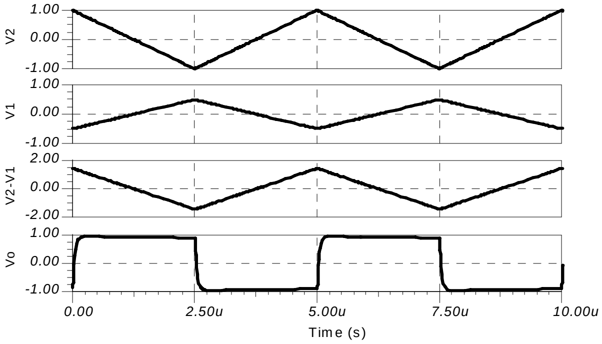


(b) Wave conversion at 200 KHz by the inverting VCD of Fig. 1(b) using R = 2 KΩ, C = 1 nF and V_c = 7 V. d.c.

Fig. 3 Test results of the single – input integrator/ differentiator

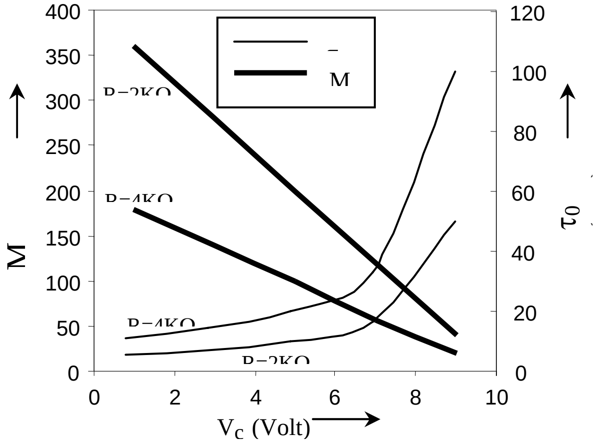


(a) Wave conversion with V_2 at 100 KHz and V_1 at 200 KHz for the VCI of Fig.2 (a) having R1 = R_2 = 2 KΩ, C = 5 nF and V_c = 1 V. d.c.

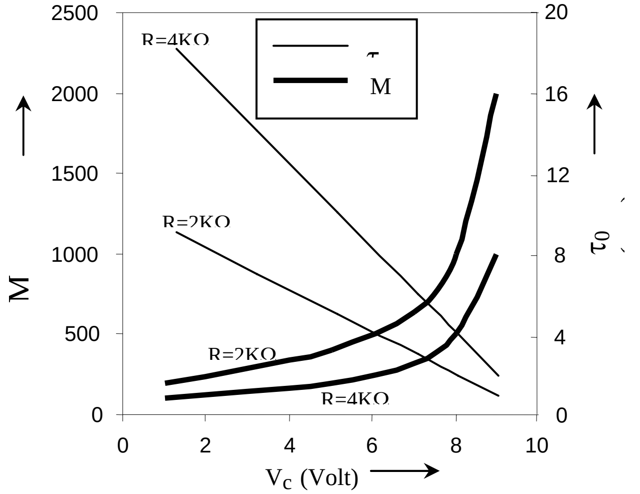


(b) Wave conversion with antiphase triangular input signals at 200 KHz for the VCD of Fig.2 (b) having R_1 =R_2 = 1 KΩ, C = 1.25 nF V_c = 4 V. d.c. and V_2 = 2 V (pp), V_1 = -1 V (pp).

Fig. 4 Test results of the dual – input integrator / differentiator



(a) Characteristics of inverting circuit in Fig. 1(a) measured with V_i = 4V (pp) square wave at 100 KHz and C = 2.5 nF.



(b) Characteristics of dual – input circuit in Fig. 2(a) measured with antiphase inputs V_2 = - V_1 = 2 V (pp) square wave at 100 KHz and C = 5 nF.

Fig. 5 Electronic tuning characteristics of the proposed VCIs

7. Conclusion

Some new CFA- RC voltage controlled integrator / differentiator (VCI / VCD) circuits having single or dual- input capability are proposed; the feature of electronic tuning of τ_o had been obtained through the d.c. control voltage (V_c) of a multiplier element incorporated suitably in the configuration. The realizability equations are derived for both ideal and nonideal CFA device. Experimental results on wave conversion and tuning characteristics are included. The proposed circuits exhibited satisfactory sinusoid response at extended frequency ranges with the expected attenuation of 20 dB/decade.

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