Design Feature

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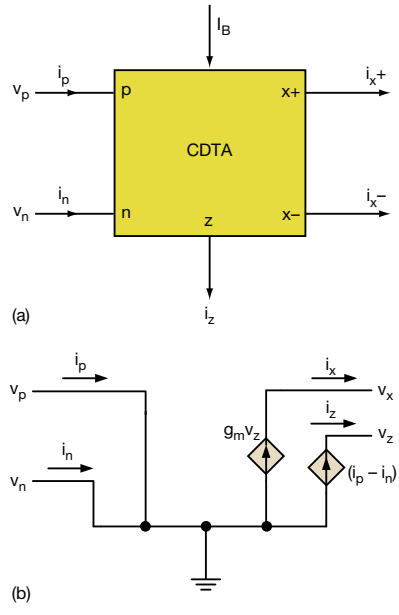
# SINGLE CDTA leads to MULTIPLE FILTERS

**By using a current differencing transconductance amplifier, a number of different high-frequency filter responses, such as lowpass, highpass, bandstop, and bandpass functions, can be achieved with one amplifier by means of electronic tuning.**

Electronically tuned filters can be implemented with a versatile circuit known as a current differencing transconductance amplifier (CDTA). In fact, it is possible to realize a filter design that is capable of providing all of the standard filter functions—including lowpass, highpass, bandpass, bandstop, and all pass functions—from the same CDTA without the need of component matching conditions, nor having to change circuit topology. The natural frequency of the filter can be tuned electronically by varying the bias current to the CDTA.

Filters of many different response types are widely used in high-frequency circuits. For that reason, having a circuit that can double as several different types of filters can be quite useful for a variety of applications (in commercial, industrial, and even military circuits). Based on an active component, a CDTA, the natural frequency ($\omega_0$) of this filter design is modified simply by changing the bias current to the amplifier.




**1. These diagrams show the symbolic representation of the CDTA (a) along with its equivalent circuit (b).**

Introduced more than a decade ago, CDTAs are active building blocks with two current inputs and two kinds of current outputs.[1] They have been used in various designs since their introduction, with many active biquad circuits implemented by means of CDTA.[2-8] In fact, the literature has reported on the use of a small number of active and passive components as part of a KHN filter,[2,3]—although its highpass responses were not at high output impedances, and the design approach did not support bandstop and allpass filter responses. A multiple-input, single-output filter was unveiled in the literature,[4-6] capable of realizing all of the biquad filter responses simultaneously, although it required a large number of active components. A multifunction filter with a minimum number of devices was proposed in the technical literature,[7] but it required some modifications to the topology to implement the different filter responses. Even though work previously performed with only one CDTA achieved all of the different filter responses, it required a large number of passive components.[8]

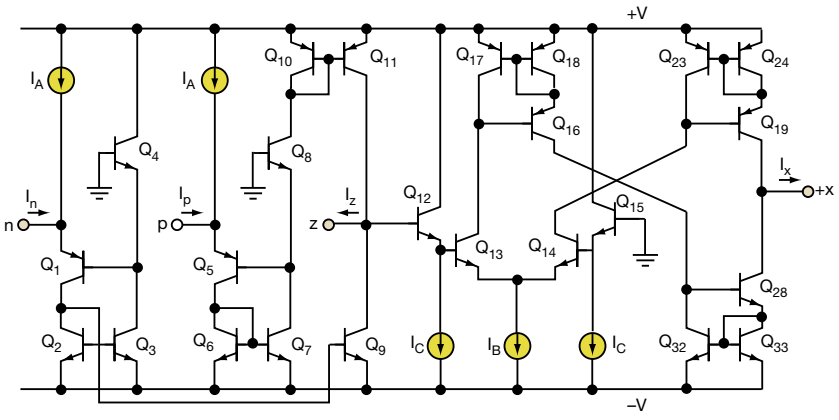
One goal of this current report is to provide those different filter responses, with reduced power consumption and manufacturing cost, using a multiple-input, single-output multifunction biquad. The filter construction employs a single CDTA as the active component, along with two resistors and two capacitors as the passive circuit elements. The proposed configuration can implement all the filter responses simultaneously (i.e., lowpass, highpass, bandpass, and bandstop responses). The nature frequency ($\omega_0$) can be electronically adjusted tunable transconductance. The circuit enjoys low active and passive sensitivities.

*Figure 1* shows the circuit representation and equivalent circuit of the CDTA. The terminal expression can be defined by the equalities in Eq. 1:

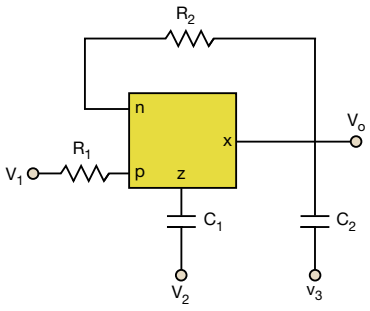
$$V_p = V_n = 0\,,\quad i_z = i_p - i_n\,,\quad i_{x+} = g_m v_z\,,\quad i_{x-} = -g_m v_z \qquad (1)$$

The input terminals are represented by p and n, while the




**2. This schematic diagram shows the bipolar circuit of the CDTA.**




**3. This is the simple schematic diagram for the CDTA-based three-input, single-output multifunction filter.**

output terminals are identified by z and x. Parameter $g_m$ represents the transconductance gain of the CDTA, while $v_Z = i_Z \times z_z$ with $z_z$ represents the external impedance connected to terminal z. The differential current, $i_p - i_n$, is applied to the input terminals and flows over to terminal z where an external impedance is connected to this node. The voltage drop at terminal z is transferred to a current at terminal x, $i_x$, by means of a transconductance parameter, $g_m$; the latter is electronically controlled by an external bias current, $I_B$.

*Figure 2* shows the possible bipolar realization of the CDTA detailed in this work. The circuit consists of a current-differencing circuit, $Q_1 - Q_{11}$ and a transconductance amplifier, $Q_{12} - Q_{33}$. In this case, the transconductance gain, $g_m$, is directly proportional to the external bias current, $I_B$, which can be written as Eq. 2:

$$g_m = \frac{I_B}{2V_T} \quad (2)$$

where the device voltage, $V_T = 26$ mV, at a reference temperature of +26°C represents the thermal voltage.

*Figure 3* shows the proposed CDTA-based three-input, single-output multifunction filter. The topology is very simple; all the second-order filter responses can be realized simultaneously without changing circuit components. Equation 3 offers the mathematical basis for the different filter responses based on the transconductance gain:

$$V_o = \frac{S^2 V_3 + S\frac{g_m}{C_2}V_2 + \frac{g_m}{C_1C_2R_1}V_1}{S^2 + S\frac{1}{C_2R_2} + \frac{g_m}{C_1C_2R_2}} \quad (3)$$

Referring to Eq. 3, a lowpass function is obtained when $V_1 = V_{in}$ and $V_2 = V_3 = 0$. The bandpass response is obtained when $V_2 = V_{in}$ and $V_1 = V_3 = 0$. The highpass function is possible when $V_3 = V_{in}$ and $V_1 = V_2 = 0$. The bandstop function is achieved when $V_1 = V_3 = V_{in}$ and $V_2 = 0$. The allpass filter function is obtained when $V_3 = V_1 = -V_2 = V_{in}$. The natural angular frequency and quality factor of the filter can be found from Eq. 4:

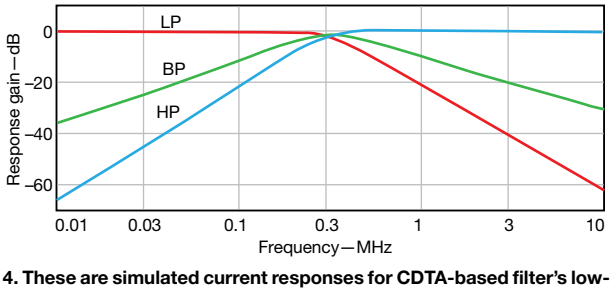
$$\omega_0 = \sqrt{\frac{g_m}{C_1C_2R_2}}, \quad \frac{\omega_0}{Q} = \frac{}{C_2R_2} \quad (4)$$

From Eq. 4, it is possible to find that the different filter responses can be electronically tuned by altering the amplifier's transconductance gain through bias current $I_B$. By taking into account the non-idealities of the CDTA in terms of frequency, the port relations in Eq. 1 can be rewritten as Eq. 5:

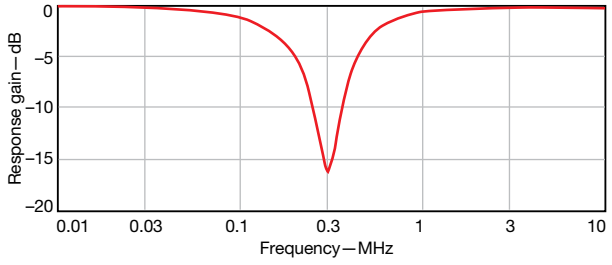
$$V_p = V_n = 0, \quad I_z = \alpha_p I_p - \alpha_n I_n, \quad I_{x+} = g_m V_z, I_{x-} = -g_m V_z \quad (5)$$

where:

$a_p = 1 - \varepsilon_p$ and
$\varepsilon_p(|\varepsilon| \times 1)$ denotes the current tracking error from p to z and
$a_n = 1 - \varepsilon_n$ and
$\varepsilon_n(|\varepsilon_n| \times 1)$ denotes the absolute value of the current tracking error for indices from n to z of the CDTA, respectively.
Reanalyzing the filter presented in *Fig. 3*, the denominator polynomials of the transfer functions can be described as shown in Eq. 6:




**4. These are simulated current responses for CDTA-based filter's lowpass, bandpass, and highpass responses for a 10-MHz bandwidth.**




**5. These are simulated current responses for the CDTA-based filter's bandstop responses.**

$$D(S) = S^2 + S\frac{1}{C_2R_2} + \frac{\alpha_n g_m}{C_1C_2R_2} \quad (6)$$

In this case, the modified parameters $\omega_0$ and $\omega_0/Q$ are rewritten as Eq. 7:

$$\omega_0 = \sqrt{\frac{\alpha_n g_m}{C_1C_2R_2}}, \quad \frac{\omega_0}{Q} = \frac{1}{C_2R_2} \quad (7)$$

The active and passive sensitivities are:

$$S_{g_m}^{\omega_0} = S_{\alpha_n}^{\omega_0} = \frac{1}{2}, S_{C_1}^{\omega_0} = S_{C_2}^{\omega_0} = S_{R_2}^{\omega_0} = -\frac{1}{2}, S_{R_1}^{\omega_0} = S_{\alpha_p}^{\omega_0} = 0 \quad (8)$$

$$S_{C_2}^{\omega_0/Q} = S_{R_2}^{\omega_0/Q} = -1, S_{C1}^{\omega_0/Q} = S_{R_1}^{\omega_0/Q} = S_{g_m}^{\omega_0/Q} = S_{\alpha_p}^{\omega_0/Q} = S_{\alpha_n}^{\omega_0/Q} = 0 \quad (9)$$

From the above sensitivity figures, it turns out that the circuit enjoys very low active and passive sensitivities.

For the theoretical analysis, the circuits were simulated by PSPICE. The CDTA employed the schematic bipolar implementation given in *Fig. 2* with the transistor model parameters of PR100N (PNP) and NP100N (NPN) of the bipolar arrays ALA400 from AT&T.[9] The supply voltages are ±V, and the bias currents re $I_A = I_C = 100$ μA.

To ease simulation, the capacitance was set so that $C_1 = C_2 = 1$ nF while $R_1$was set at 1 kΩ, $R_2 = 0.5$ kΩ, and the transconductance gain value was set at $g_m = 2$ mA/V($I_B = 100$ μA). *Figure 4* shows the simulated frequency responses of the low-pass, bandpass, and highpass filter configurations, while *Fig. 5* shows the bandstop filter response for the proposed filter.

This biquad filter can serve as different designs, tuning the responses by adjusting the external bias current to the filter's active component, a CDTA. The filter's performance was simulated with PSPICE from Cadence Design Systems (www.cadence.com) reinforcing performance expected from theory. The CDTA-based filter circuit offers low active and passive sensitivities, and no component matching is required. mw

ACKNOWLEDGMENT

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