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Forth Order Current Mode Band Pass Filter with Coupled Tuned by Current Using CCCDTAs

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Abstract: To obtain forth order current mode band pass filter with high accuracy, low sensitivity and coupled tuned by current, the basic circuit modes using CCCDTA, V-I converter, earthed analog impedance and floating-earthed analog inductance, were given. On the basis of band-pass filter with coupled tuning, two terminal resistors, two earthed analog impedances, and one floating-earthed analog inductance in the filter were substituted by the basic circuit modes. Forth-order current-mode band-pass filter with coupled tuned by current using CCCDTA s was realized. Under the conditions of critical coupling, the center frequency of the filter is 1.337100MHz, and the 3dB bandwidth is 0.346399MHz. The circuit uses three CCCDTA s, five grounded capacitors, and it is easy to be integrated. The parameters of the circuit can be tuned electronically by tuning bias currents. The results of computer simulation for weak coupling, strong coupling and critical coupling were given, which shows the analysis method is valid and effective.

Key words: forth-order band-pass filter; circuit mode; electronic tuning; analog inductance; CCCDTA

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1. Introduction

Since double tuning band-pass filter enjoys broad frequency bandwidth, good selectivity, and low sensitivity, it is widely used in practical engineering [1-3]. However, the filter coupled by inductance or capacitance isn't easy to be integrated and it has been restricted in high frequency system. Now, double tuning forth order current mode band pass filter involved is seldom investigated.

Recently, study on current controlled current differencing transconductance amplifier (CCCDTA) has been attracted more attention [4-8]. The basic circuit modes using CCCDTA, V-I converter, earthed analog impedance and floating-earthed analog inductance, were given. On the basis of band-pass filter with coupled tuning, two terminal resistors, two earthed analog impedances, and one floating-earthed analog inductance in the filter were substituted by the basic circuit modes. Forth-order current-mode band-pass filter with coupled tuned by current using CCCDTA s was realized. Under the conditions of critical coupling, the center frequency of the filter is 1.337100MHz, and the 3dB bandwidth is 0.346399MHz. The results of computer simulation for weak coupling, strong coupling and critical coupling were given, which shows the analysis method is valid and effective.

2. CCCDTA and its basic circuit modes

2.1 CCCDTA 元件

The circuit representation and its equivalent circuit of the CCCDTA are shown Fig.1. The terminal relation of the CCCDTA can be characterized by the following set of equations [5]:

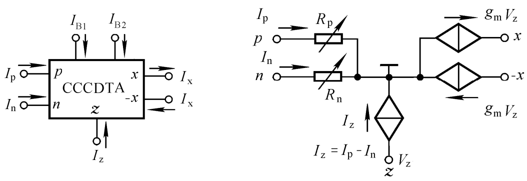


Fig.1 (a) The symbol of CCCDTA, (b) The equivalent circuit of CCCDTA

$$V_p = R_p I_p,\quad V_n = R_n I_n,\quad I_z = I_p - I_n,\quad I_x = g_m V_z, \tag{1}$$

where

$$R_p = R_n = \frac{V_T}{2I_{B1}}, \tag{2}$$

and

$$g_m = \frac{I_{B2}}{2V_T}, \tag{3}$$

where V_T is the thermal voltage, g_m is the transconductance gain of the CCCDTA, and R_p and R_n is parasitic resistances at the *p* and *n* input terminals, respectively.

2.2 basic circuit modes using CCCDTA

Fig.2 (a) shows the CCCDTA-based V-I converter. Routine analysis shows

$$I_o = I_z = \frac{V_i}{R_n} = \frac{2I_{B1}}{V_T} \cdot V_i\,. \tag{4}$$

Tuning bias current of CCCDTA, the

transconductance gain of the V-I converter is controlled linearly. Hence V_i is tuned to I_o. If V_i inputs into p port, the circuit is a inverting V-I converter.

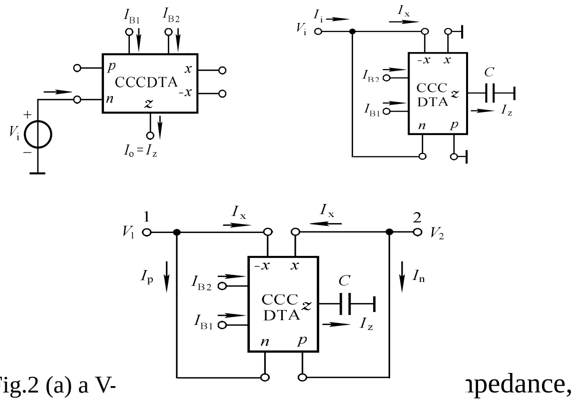


Fig.2 (a) a V- ... ıpedance, and (c) a floating-earthed analog inductance

Fig.2 (b) shows the CCCDTA-based earthed analog impedance. By inspection of Fig.2 (b), and using Eqns. (1), Eqn. (2), and Eqn. (3), we get the input impedance on input port of the circuit is

$$Z_i = sL_{eq} // R_n , \quad (5)$$

where

$$L_{eq} = \frac{R_n}{g_m} C = \frac{V_T^2 C}{I_{B1} I_{B2}} . \quad (6)$$

From Eqn. (5) and (6), it is clearly seen that the input port of the circuit can be equivalent to the parallel combination of an earthed inductor of value L_{eq} with a resistor of value R_n. R_n can be turned electronically by adjusting the bias current I_{B1}, and L_{eq} can also be tuned electronically by adjusting the bias current I_{B2} without influencing R_n.

Fig.2(c) shows the CCCDTA-based floating-earthed analog inductance. By inspection of Fig.2 (c), and using Eqns. (1), Eqn. (2), and Eqn. (3), we get the input impedance between node 1 and node 2 of the circuit is

$$Z_{12} = \frac{V_2 - V_1}{I_x} = sL_{eq} . \quad (7)$$

From Eqn. (7), it is clearly seen that the port between node 1 and node 2 of the circuit can be equivalent to floating-earthed analog inductance, which is similar to Eqn.6, and can be tuned electronically by adjusting the bias current I_{B1} and I_{B2}.

3. Electrically tunable forth order band pass filter

3.1 Circuit prototype of forth-order filter

Double tuning band-pass filter coupled by inductance is shown in Fig.3 [9]. Let $Y=sC+1/R+1/sL$, the transfer function in terms of Y and Z_c is

$$\frac{I_o}{I_i} = \frac{1}{R} \cdot \frac{1}{2Y + Z_c Y^2} = \frac{1}{YZ_c} \cdot \frac{1}{Y + 2/Z_c} . \quad (8)$$

For $Z_c=j\omega L_c$, substituting the expressions for Z_c and Y into Eqn. (8), the transfer function becomes

$$\frac{I_o}{I_i} = \frac{1/RL_cC^2}{(s^2 + s\omega_o/Q + \omega_o^2)(s^2 + s\omega_o/Q + \omega_o^2 + 2/L_cC)} , \quad (9)$$

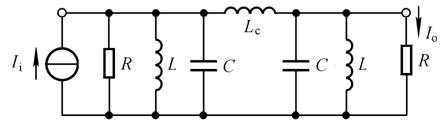
where $\omega_o = \frac{1}{\sqrt{LC}}$, $Q = R\sqrt{\frac{C}{L}}$. From Eqn. (9), the imaginary parts of the upper-half-plane poles are

$$j\omega_o \sqrt{1 - \frac{1}{4Q^2}} \approx j\omega_o , \quad (10)$$

$$j\omega_o \sqrt{1 + \frac{2}{\omega_o^2 L_c C} - \frac{1}{4Q^2}} \approx j\omega_o \sqrt{1 + \frac{2}{\omega_o^2 L_c C}} . \quad (11)$$

The real part of the poles is -（$\omega_o/2Q$）. To achieve the flattest possible magnitude characteristic, the distance between the upper-half-plane poles should be twice the distance from the real part of the poles [9]. That is,

$$\omega_o [\sqrt{1 + \frac{2}{\omega_o^2 L_c C}} - 1] \approx 2\frac{\omega_o}{2Q} . \quad (12)$$



For Q>>1/2, $\omega_o = 1/\sqrt{LC}$, Eqn.(3) simplifies to

$$L_c = QL \quad (13)$$

Eqn. (3) is just the conditions of critical coupling. The center frequency is approximately the arithmetic average of the imaginary parts of the two upper-half-plane poles [9]; that is,

$$\omega_m \approx \frac{\omega_o}{2}[1 + \sqrt{1 + \frac{2}{\omega_o^2 L_c C}}] \approx \frac{\omega_o}{2}[1 + \sqrt{1 + 2/Q}] . \quad (14)$$

-3dB bandwidth is

$$BW = \sqrt{2}\frac{\omega_o}{Q} \quad (15)$$

3.2 Electrically tunable forth order band pass filter using CCCDTAs

Two shunt inductors in Fig. 2 and one series capacitor are substituted by the earthed analog impedance in Fig.2(b) and the floating-earthed analog inductance in Fig.2(c), respectively. So, forth-order current-mode band-pass filter using CCCDTAs is shown in Fig. 4. The load resistor of the circuit is equal to the parallel connection of R_p of CCCDTA2 with R_n of CCCDTA3, and the source resistor of the circuit is equal to the parallel connection of R_n of CCCDTA1 with R_n of CCCDTA2. Hence, this circuit has simpler circuit description than the circuit using CCCII [10]。 For $I_{B11}=I_{B21}=I_{B31}=I_{B1}$, $I_{B12}=I_{B32}=I_{B2}$, $I_{B22}=I_{B3}$,using Eqn.(2) and (6), obtain the Q and ω_o of the filter , respectively,

$$\omega_o = \frac{1}{\sqrt{LC}} = \frac{\sqrt{I_{B1}I_{B2}}}{V_T C}, \quad (16)$$

$$Q = \frac{R_n}{2}\sqrt{\frac{C}{L}} = \frac{1}{4}\sqrt{\frac{I_{B2}}{I_{B1}}}. \quad (17)$$

From Eqn. (16) and (17), it is clearly seen that the Q and ω_o of the filter can be set by tuning I_{B1} and I_{B2}. Substituting Eqn. (6) and (17) into Eqn. (13), we write the conditions of critical coupling as follows:

$$I_{B3} = 4\sqrt{I_{B1}I_{B2}}\ . \quad (18)$$

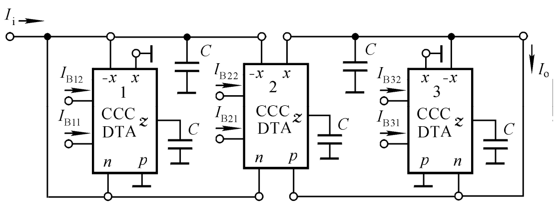


Fig.4 forth-order current-mode band-pass filter using CCCDTAs

Eqn.（14）is the critical coupling conditions represented by the bias currents of CCCDTA. If $I_{B3} < 4\sqrt{I_{B1}I_{B2}}$, this is weak coupling conditions; if $I_{B3} > 4\sqrt{I_{B1}I_{B2}}$, this is strong coupling conditions. Substituting Eqn. (16) and (17) into Eqn. (14), we write the center frequency of the filter as follows:

$$\omega_m \approx \frac{\sqrt{I_{B1}I_{B2}}}{2V_T C}[1+\sqrt{1+8\sqrt{\frac{I_{B1}}{I_{B2}}}}]. \quad (19)$$

Combining Eqn. (15), (16) and (17), -3dB bandwidth can be expressed as

$$BW == \frac{4\sqrt{2}I_{B1}}{V_T C}. \quad (20)$$

Eqn. (20) shows that BW can be tuned by adjusting I_{B1}, whereas Eqn. (19) indicates that ω_m can be adjusted by adjusting I_{B2}, and finally critical coupling conditions can be realized by adjusting I_{B3}. This means that the parameters of circuit can be tuned electronically and independently.

4. Simulation results

To validate the theoretical analysis, the CCCDTAs in Fig.4 are by the schematic implementation shown in the literature [5]. The filter characteristics are determined through the EWB5.0 simulation on transistor 2N2702(PNP) and 2N2712(NPN). To simplify results, we create the sub-circuit for CCCDTA by EWB5.0, the earthed analog impedance, and the floating-earthed analog inductance. Finally, the Fig.4 circuit is simulated with ±1.5V power supplies, C=1nF, I_{B1}=0.01mA, I_{B2}=4 mA, and I_{B3}=1.5 mA ,1.15 mA ,0.8 mA, 0.45 mA, 0.1 mA.

From Eqn. (16)-(17), we obtain

$$f_o = 1.224890\text{MHz}, Q = 1.$$

From Eqn. (18), when I_{B3}>0.8 mA , strong coupling take place; when I_{B3}<0.8 mA, weak coupling take place; when I_{B3}=0.8 mA, critical coupling take place. From Eqn. (19), (20), we get the center frequency and the -3dB bandwidth of the filter as follows:

$$f_m = 1.337100\text{MHz}, BW = 0.346399MHz\ .$$

The simulation results are shown in Fig.5, which are consistent with double tuning band-pass filter coupled by inductance. Using the pointer in EWB5.0, the f_m and BW of the circuit are obtained:

$$f_m = 1.3771\text{MHz}, BW = 0.3755237\text{MHz}\ .$$

Therefore, simulation results are consistent with theoretic analysis.

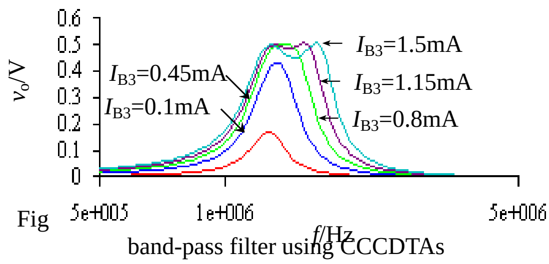


Fig band-pass filter using CCCDTAs

Note that, EWB5.0 cannot be immediately used to simulate current. Considering V-I converter in Fig.2 (a), connecting two V-I converters in parallel is equivalent to input source of Fig.4. Thus, obtain $V_i=(R_n/2)\ I_i$, and using OL in output termination, obtain $V_o=(R_n/2)\ I_o$. The voltage ratio between output and input is the current ratio, simulation current mode circuit, thus, was done.

5. Conclusion

A forth-order current-mode band-pass filter using CCCDTAs is proposed. This structure enjoys the following features:

1) A V-I converter, an earthed analog impedance, and a floating-earthed analog inductance using CCCDTA were given and were used

2) The circuit uses active components, grounded capacitors, and it is easy to be integrated;

3) The parameter of the filter can be tuned electronically;

4) Lower passive sensitivities.

The simulated result confirms the theoretical analysis. It is expected to be useful for applications in communication, instrumentation and measurement systems, especially at a high frequency range.

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