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Voltage-Mode Universal Biquadratic Filter Using Tunable OTA in 180nm Technology

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Abstract: Conventional Operational Amplifiers (Op-Amps) limit their applications at high frequencies. Since output is a voltage, Op-Amps limit to frequencies up to few Megahertz. At those high frequencies, Operational Transconductance Amplifiers (OTAs) are being promising to replace Op-Amps as building blocks. OTAs are useful in realisation of active Gm-C filters. A Balanced OTA which is the simplest configuration of an Operational Transconductance Amplifier is chosen as a basic building block for the present work. The resulting OTA has improvement as compared to the basic balanced OTA in terms of better gain, CMRR and slew rate. Further, the improved circuit of balanced OTA is used to implement tunable OTA. The Tunable OTA designed in the present work has gain 55.48dB, Common Mode Rejection Ratio (CMRR) of 133.775dB, Slew rate of 45.67V/ μ s. A Bi-Quad Filter is implemented using Tunable OTA as an application example. A Low pass, High pass, Band pass, Band Reject and All pass filters are demonstrated by controlling the input control voltages. The circuits are implemented in gpdk180 in Cadence software.

Keywords - Operational Transconductance Amplifiers (OTAs), Common Mode Rejection Ratio (CMRR), gain, Balanced OTA, Tunable OTA

I. INTRODUCTION

Tunable OTA is a versatile building block for continuous time analog signal processing. Tuning of transconductance (gm) is an important requirement in many applications such as gm-C active filters, tunable grounded resistors, automatic gain control circuits, etc. Transconductance tuning is required not only to compensate for fabrication tolerances but also to achieve programmability of relevant parameters. Tuning in operational transconductance amplifier (OTA) is achieved by either varying transconductance as function of control voltage or bias current. With recent scaling in CMOS technologies use of voltage as control parameter for tuning is becoming increasingly difficult and thus for low voltage OTA applications, tuning is often achieved using bias current as it shows better linear range at low voltages.[1]

Tunability provides flexibility to change the range of filters and also the gain in automatic gain controllers. The OTA is known as tunable OTA when the MOSFET using in it operating in saturation or triode regions. If we change the control voltage or the bias current, then the transconductance will be varied. Because of linearity restrictions, the circuits which use voltage as control parameter to change the OTA transconductance will have limited range of operation at low voltage. OTA transconductance can also be made vary by changing the bias current. [6][7]

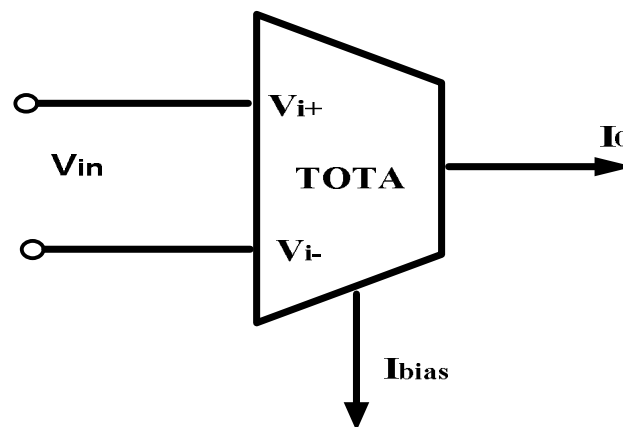


Figure 1.1: Tunable model of OTA

The tunable OTA is modelled as three input and one output terminals device as shown in Figure 1.1. Where V_+ and V_- is the input voltages applied at non-inverting terminal and inverting terminal respectively. I_{bias} is the bias current. The transconductance should be linearly dependent on the bias current for linear filter application. The circuit is biased by a constant current source. The use of constant current source is to prevent the transistors from leaving strong inversion region and hence improves the linearity.

A. Second Order Bi-Quad Filter

Operational amplifiers can be used to realize a linear system with an arbitrary biquadratic transfer function. A biquad transfer function can be realized straightforwardly with a pair of integrators in series, each introducing a factor $1/s$, with their outputs added to the input signal in a summer.

The parameters f_0 , Q and the band pass gain at the centre frequency are given in terms of the circuit parameters.[2]

The general second order (bi-quadratic)filter transfer function is given by,

$$T(S) = \frac{a_2 S^2 + a_1 S + a_0}{S^2 + \frac{\omega_0}{Q} S + \omega_0^2} \quad (1.1)$$

Figure 1.2 gives a structure of second-order biquad filters based on the OTA integrators. Each structure contains a global negative feedback. The low-pass, bandpass, high-pass, and band-stop functions can be flexibly realized using this structure by selecting the proper input from V_A , V_B , and V_C . For instance, a second order low-pass function can be obtained by taking V_A as the input and grounding V_B and V_C in Figure1.2. Its transfer function becomes:

$$H(S)_{low-pass} = \frac{g_{m1} g_{m2}}{S^2 C_1 C_2 + S C_1 g_{m2} + g_{m1} g_{m2}} \quad (1.2)$$

which has a second-order low pass property.

For realising bandpass, highpass and bandstop function, their transfer function are given below.

When V_B is given as input and V_A and V_C are grounded, then

$$H(S)_{band-pass} = \frac{s C_1 g_{m2}}{S^2 C_1 C_2 + S C_1 g_{m2} + g_{m1} g_{m2}} \quad (1.3)$$

When input is given at V_C , and V_A and V_B are grounded, then

$$H(S)_{high-pass} = \frac{s^2 C_1 C_2}{S^2 C_1 C_2 + S C_1 g_{m2} + g_{m1} g_{m2}} \quad (1.4)$$

When input is given at both V_C and V_A , V_B is grounded, then

$$H(S)_{band-stop} = \frac{s^2 C_1 C_2 + g_{m1} g_{m2}}{S^2 C_1 C_2 + S C_1 g_{m2} + g_{m1} g_{m2}} \quad (1.5)$$

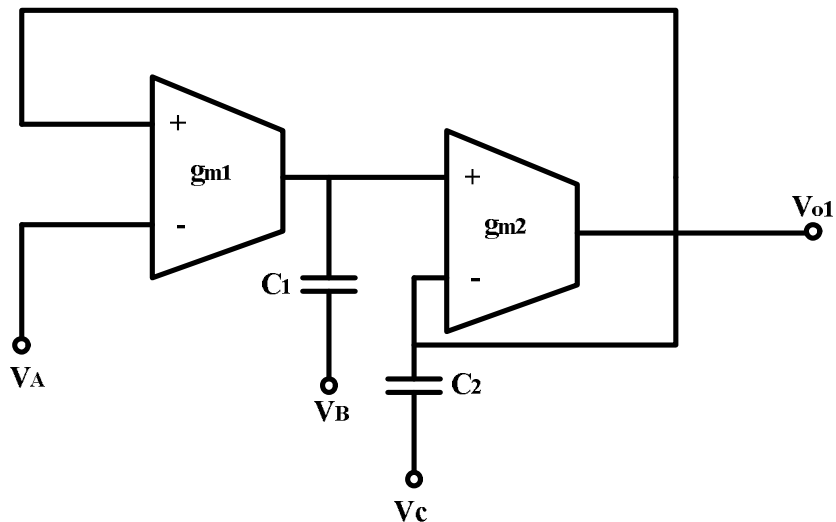


Figure 1.2 : Bi-Quad Filter using OTA

$$V_{o1} = \frac{s^2 C_1 C_2 V_C + s C_1 g_{m2} V_B + g_{m1} g_{m2} V_A}{S^2 C_1 C_2 + S C_1 g_{m2} + g_{m1} g_{m2}} \quad (1.6)$$

II. CIRCUITS AND OPERATION

A. Balanced OTA circuit

The circuit is called a symmetric or three current-mirror OTA uses self-biased loads. It has a larger trans-conductance, slew rate, and GBW. These specifications are made larger by increasing current mirror factor. The trans-conductance can be set by the tail current source, current mirror ratio, or size of the input transistors. The trans-conductance is usually the most important parameter, and it is fortunate that it can be determined by several parameters. Automatic tuning circuits sometimes vary the bias current in order to adjust the trans-conductance to the desired value. The phase margin is a measure of stability for the amplifier. This circuit is constructed from all the basic elements. The input stage is a differential pair. The sub-circuits composed of M1,3 and M2,4 are self-biased inverters. Transistors M3,5 M4,6 M7,8 and are simple current mirrors.[1][3]

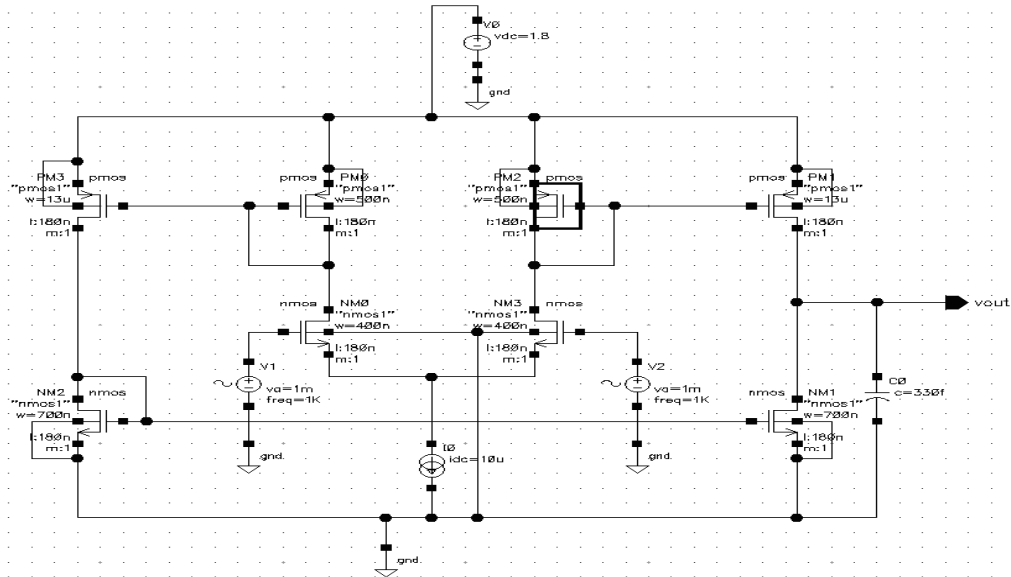


Figure 2.1: Design of balanced OTA in cadence tool

When designing the symmetrical OTA, transistors $M1 = M2$, $M3 = M4$, $M5 = M6$, and $M7 = M8$. This reduces the number of designable parameters to four transistor sizes and the tail current.[1]

Table 2.1: Transistor sizing of Balanced OTA

Transistors	W/L ($\mu\text{m}/\mu\text{m}$)
M1, M2	0.40/0.18
M3, M4	0.40/0.18
M5, M6	6/0.18
M7, M8	0.70/0.18

Table 2.2: Input specification for balanced OTA

Technology	Cadence gpdk180
Supply voltage	1.8 V
Input voltage in+	AC amplitude =500 mV Magnitude = 1 mV
Input voltage in-	AC amplitude = 1 mV Magnitude = 1 mV
Frequency	1 KHz
DC current	10 μA
Load Capacitance	330 fF

B. Tunable OTA circuit

Tunable OTA comprises of two stages of BOTA and a resistor connected in between the two stages. The first stage converts the differential input signal voltage into a signal current I_0 to flow into a resistor (Active-R). The voltage across the resistor is V_R is given by:

$$V_R = I_0 R = g_{m1} * V_{in} * R \tag{2.1}$$

The schematic of Tunable OTA is shown in Figure 4 and the voltage drop across resistor is given by:

$$V_R = I_0 R \tag{2.2}$$

$$V_R = g_{m1} * V_{in} \frac{1}{4\beta(V_{DD} - V_T)} \tag{2.3}$$

The total current I_{out} is given by,

$$I_{out} = g_{m2} * V_R \tag{2.4}$$

$$I_{out} = g_{m2} * g_{m1} * V_{in} \frac{1}{4\beta(V_{DD} - V_T)} \tag{2.5}$$

$$g_{m1} = \sqrt{2I_{b1}\beta_1} \text{ and } g_{m2} = \sqrt{2I_{b2}\beta_2} \tag{2.6}$$

$$\beta_T = \sqrt{\beta_1\beta_2} \cdot \frac{1}{2\beta(V_{DD} - V_T)} \tag{2.7}$$

Where β is the transconductance parameter of Active-R transistors.[5]

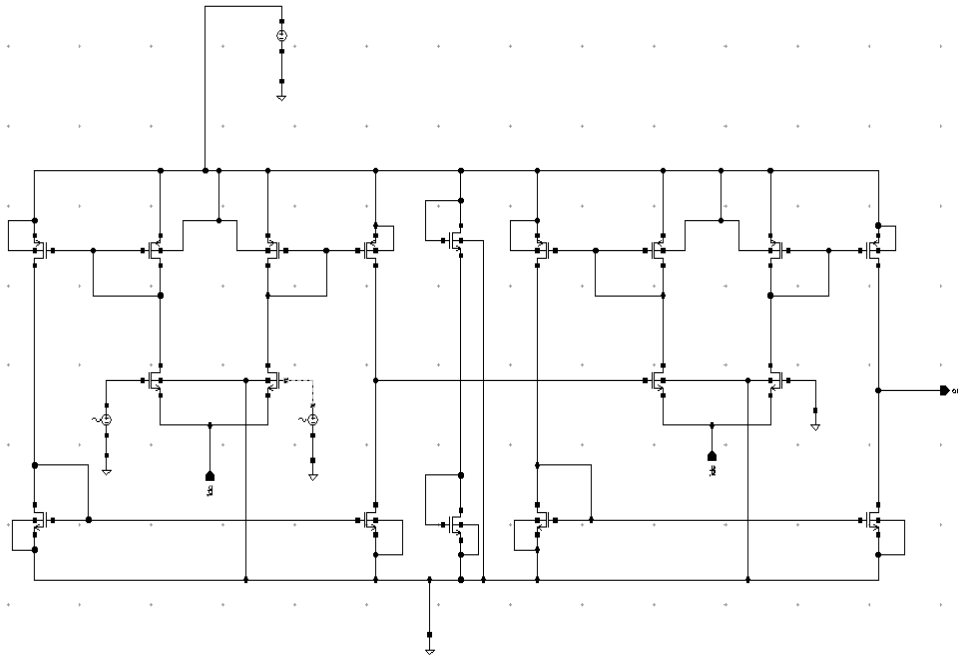


Figure 2.2: Design of Tunable OTA in Cadence

Table 2.3: Transistor sizing of Tunable OTA

Transistors	W/L($\mu\text{m}/\mu\text{m}$)
M ₁ , M ₂ , M ₁₁ , M ₁₂	7.2/0.18
M ₃ , M ₄ , M ₁₃ , M ₁₄	10.8/0.18
M ₅ , M ₆ , M ₁₅ , M ₁₆	9.8/0.18
M ₇ , M ₈ , M ₁₇ , M ₁₈	9.6/0.18
M ₉ , M ₁₀	1.8/0.18

C. Bi-Quad Filter using TOTA

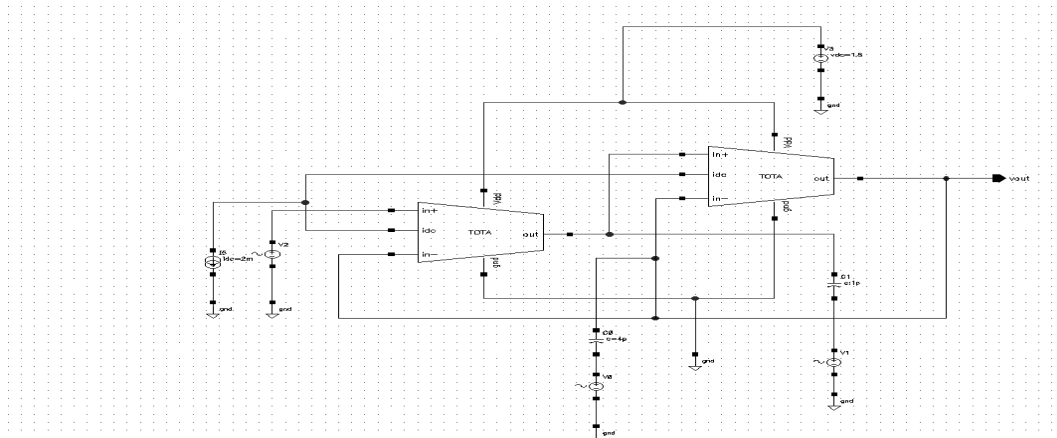


Figure 2.3: All pass filter using TOTA

III. SIMULATION RESULTS

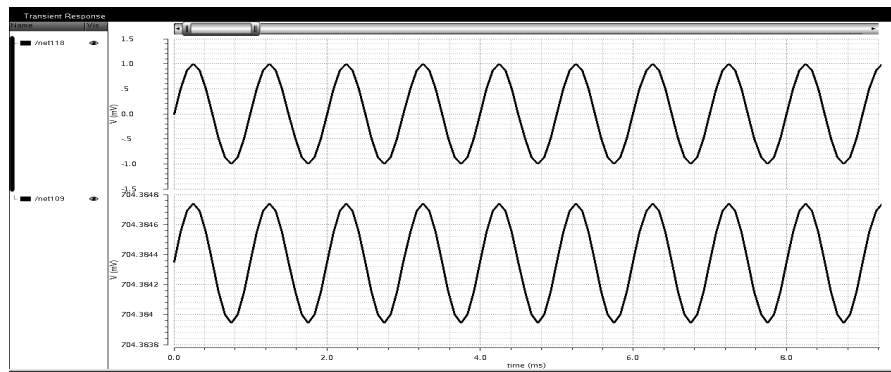


Figure3.1. Amplified output of OTA at Cadence tool

A. AC Analysis
 Gain=32.9 dB
 UGB=344.40 MHz

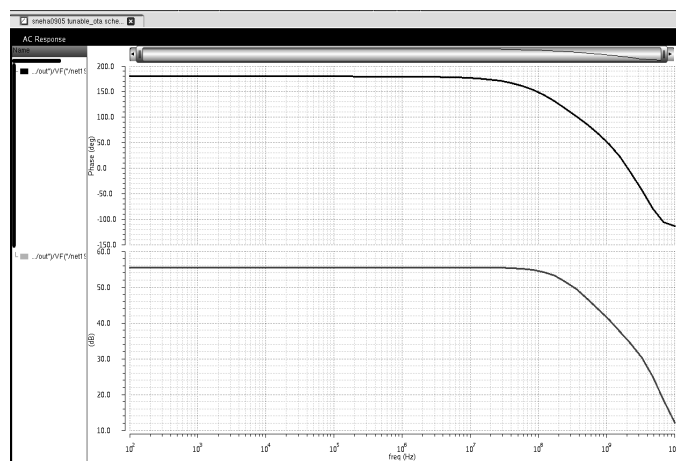


Figure 3.2: Gain of Tunable OTA

The gain of the tunable OTA is coming 55.48 dB with phase margin 209.32MHz.

The power dissipated at the output is coming 8.615mW. Slew rate is $45.67 \frac{V}{\mu s}$. The worst case delay propagation through critical path is 16.17nS.

B. CMRR

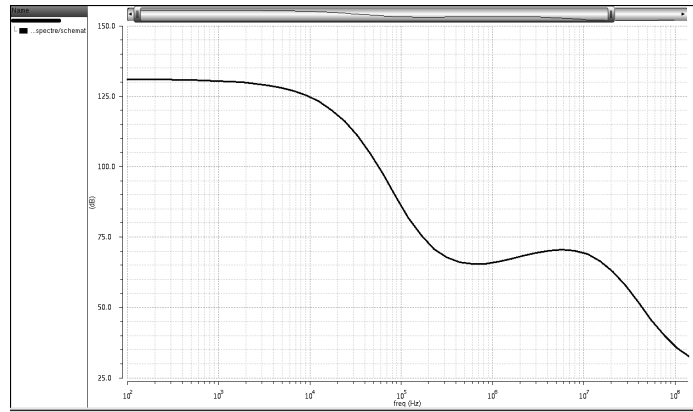


Figure 3.3: CMRR of Tunable OTA

CMRR of this circuit can be calculated as

$$CMRR = 20 \log_{10} \frac{55.48}{11.36 \times 10^{-6}} = 133.775 \text{ dB} \quad (3.1)$$

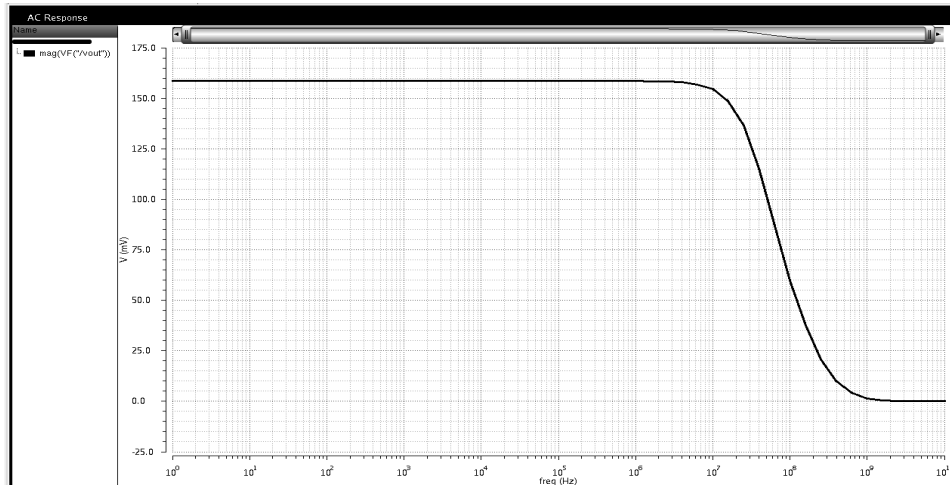


Figure 3.4: Low pass Response of TOTA

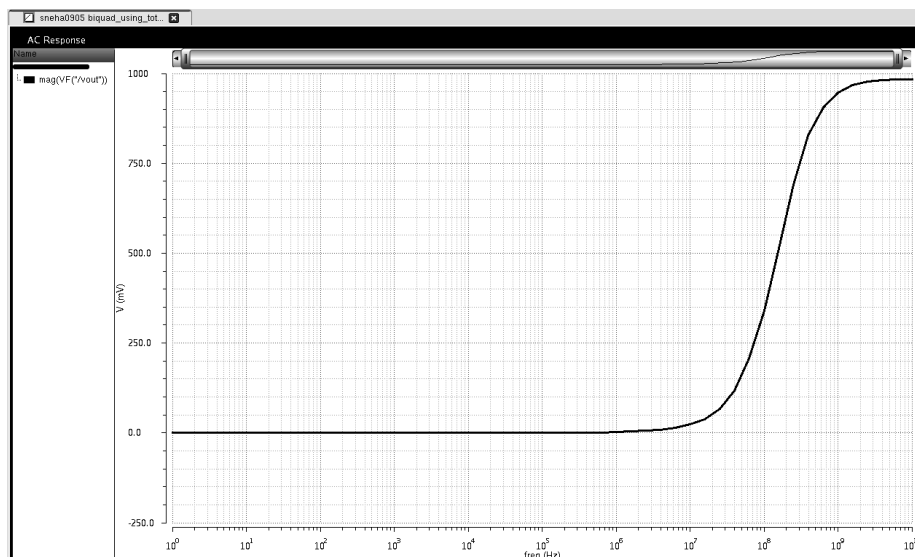


Figure 3.5: High pass Response for TOTA

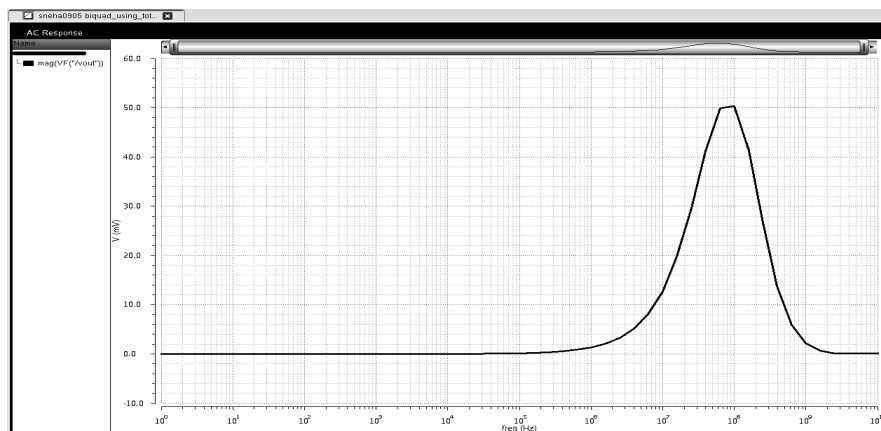


Figure 3.6: Band pass Response of TOTA

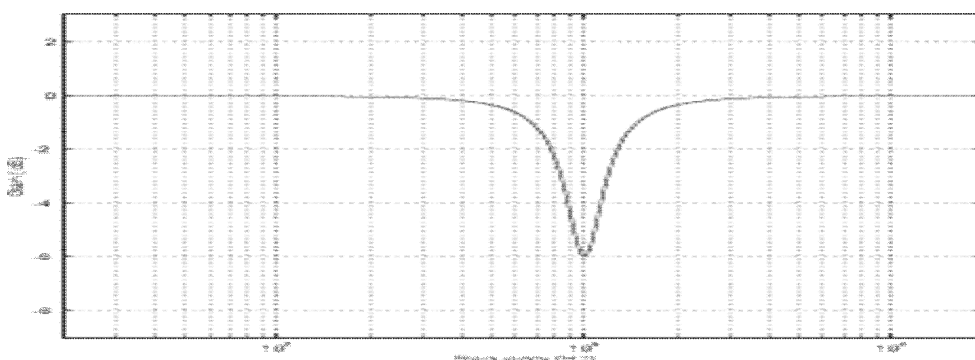


Figure 3.7: Band Reject Response of TOTA

IV. CONCLUSION

All designs are done in Cadence gpdk180. The balanced OTA has gain of 32.9 dB, Slew rate is 48.61 V/ μ S, CMRR is 123.91 dB, 120 μ W power dissipation. The advanced tunable OTA has gain of 55.48 dB, Slew Rate is 45.67 V/ μ S, CMRR is 133.775 dB and 8.615 mW power dissipation. In addition, the performance of both balanced and Tunable OTA is verified in the Simulation. A Bi-Quad Filter is implemented using Tunable OTA as an application example. A Low pass, High pass, Band pass, Band Reject and All pass filters are demonstrated by controlling the input control voltages.

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