An Improved Bilateral Floating Resistor Circuit with Positive and Negative Resistances

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Abstract: ***In this paper, we propose an improved bilateral floating resistor circuit with positive and negative resistances for low supply voltage. In this programmable resistor circuit, current addition/subtraction is carried out at the gate terminal where voltage is applied Furthermore, in this circuit control voltages are given to high impedance terminal of the MOSFET which helps in reducing effect of loading on to control voltage terminals. In addition, this circuit uses only two transistors between supply rails. The proposed circuit can realize the large range of positive and negative resistances. Simulations are carried out in 180nm technology and realized resistance values are from -100kΩ to 100kΩ. The circuit performance is tested by using it in inverting amplifier configuration of op-amp.***

Keywords: Floating resistor, low supply voltage, op-amp, negative resistance

1. Introduction

In CMOS technology, a implementation of resistor is formed on silicon wafer in the same way as a transistor or a capacitor. However it is difficult to achieve precise value, which are implemented by using polysilicon or diffusion area and resistance values are not variable. Therefore, there are so many bilateral floating resistors have been proposed. In this floating resistor circuit, the resistance values can be varied by changing the controlled voltages.

In this paper, we proposed an improved bilateral floating resistor circuit having both positive and negative resistance [1]-[2]. Characteristics of the proposed circuit are independent of threshold voltage.The proposed circuit uses only two transistors between the supply voltages, which enable to operate at low supply voltages. In this programmable resistor circuit, current addition /subtraction is carried out at the gate terminal where voltage is applied. Furthermore, in this circuit control voltages are given to high impedance terminal of the MOSFET which helps in reducing effect of loading on to control voltage terminals[3]. Simulations are carried out in 180nm technology.. The circuit performance is tested by using it in inverting amplifier configuration of op-amp[4]-[6].

2. Circuit Principle

We propose a design method of floating resistor which can be explained through a simple block diagram showing Fig.1. The current and voltages are applied to the two terminals of resistor which are two end points of block diagram. Current subtraction is carried out at the gate terminal of MOSFET by wiring, wherein the same transistor is used for input/output voltage, because the current through the gate terminal of the MOSFET is zero. Non linear cancellation block gives the a linear V-I relation for the circuit.

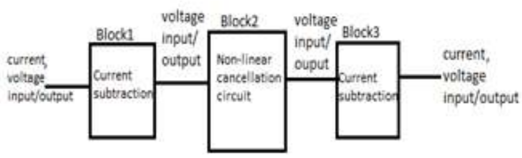

Figure 1: Block diagram representing the circuit design

3. Circuit Diagram and Operations

Figure 3 shows the circuit diagram of floating resistor featuring positive-negative resistance. The nodes Vx and Vy are two terminals of the resistor. All the transistors are being operated in the saturation region and it is assumed that, for all the transistors, bulks are connected to sources.

The current equation for the MOS-FET in saturation region is given by the equation

$$I_D = \frac{1}{2} k_n' \frac{W}{L} (V_{GS} - V_t)^2 \ (1)$$

$$k_n' = \mu_n \ c_{ox} \ (2)$$

Where W/L, c_{ox}, μ_n, V_T and V_{GS} are aspect ratio the gate oxide capacitance per unit area, the electron mobility, the threshold voltage and gate-source voltage respectively.

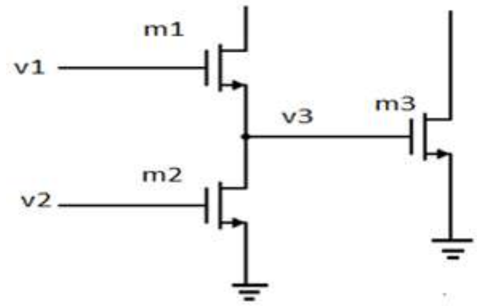

Figure 2: Basic element of the proposed circuit

From basic element of proposed circuit, The drain currents of transistors m1 and m2 are given by equations

$$I_{D1} = \frac{1}{2} k_n' \frac{W}{L} (V_{GS1} - V_t)^2 \ (3)$$

$$I_{D2} = \frac{1}{2} k_n' \frac{W}{L} (V_{GS2} - V_t)^2 \ (4)$$

From figure 2 drain currents of m1 and m2 are same.

$$I_{D1} = I_{D2}$$

From equations (3) and (4)

$$(V_{GS\,1} - V_t)^2 = (V_{GS\,2} - V_t)^2$$

$$V_{GS\,1} = V_{GS\,2}$$

$$V_1 - V_3 = V_2$$

$$V_3 = V_1 - V_2 \ (5)$$

The drain current of transistor m3 given by equation

$$I_{D3} = \frac{1}{2} k'_n \frac{W}{L} (V_{GS\,3} - V_t)^2$$

$$I_{D3} = \frac{1}{2} k'_n \frac{W}{L} (V_3 - V_t)^2$$

Substitute equation (5) in above equation, we get

$$I_{D3} = \frac{1}{2} k'_n \frac{W}{L} (V_1 - V_2 - V_t)^2 \ (6)$$

The drain currents of transistors m3, m6, m9 and m12 are given by equations

$$I_{D3} = \frac{1}{2} k'_n \frac{W}{L} (V_X - V_{C2} - V_t)^2 \ (7)$$

$$I_{D6} = \frac{1}{2} k'_n \frac{W}{L} (V_X - V_{C1} - V_t)^2 \ (8)$$

$$I_{D9} = \frac{1}{2} k'_n \frac{W}{L} (V_Y - V_{C1} - V_t)^2 \ (9)$$

$$I_{D12} = \frac{1}{2} k'_n \frac{W}{L} (V_Y - V_{C2} - V_t)^2 \ (10)$$

The equivalent resistance of the circuit can be expressed by the equation

$$R = \frac{V_X - V_Y}{I_{IN}} = \frac{V_X - V_Y}{I_{OUT}} \ (11)$$

The necessary condition for any resistor circuit is that, the Input current is equal to the output current, namely,

$$I_{IN} = I_{OUT} = I_6 + I_{12} - I_3 - I_9 \ (12)$$

Substitute drain currents equations(7-10) in equation (12)

$$I_{IN} = I_{OUT} = K'_N (V_{C2} - V_{C1})\ (V_Y - V_X) \ (13)$$

Substitute equation (13) in (11) and results in equivalent resistance equal to

$$R = \frac{1}{K'_N (V_{C2} - V_{C1})} \ (14)$$

From equation (14), if Vc1 is larger than Vc2, R has negative resistance. On other hand, when Vc1 is smaller than Vc2, R has positive resistance. The resistance R can be realized precisely, because the equivalent resistance R is independent of the threshold voltageV_t.

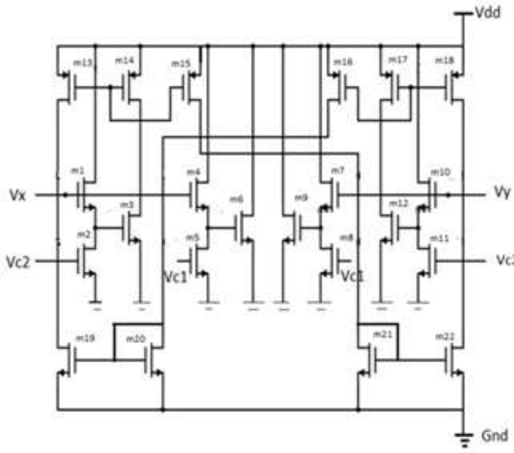

Figure 3: Circuit diagram of proposed bilateral floating resistor

4. Simulation Results

Mentor graphic tool is used for the circuit simulation and the simulation of circuit is carried out by varying the voltage Vc2 from 0.9 to 1.1v while keeping the voltage Vc1 at 1V. The obtained resistance values are from -100k to 100k. Fig.4 shows V-I characteristics of the proposed circuit for positive resistance having value of 97kΩ. Fig.5 shows V-I characteristics of the proposed circuit for negative resistance having the value of -104kΩ.

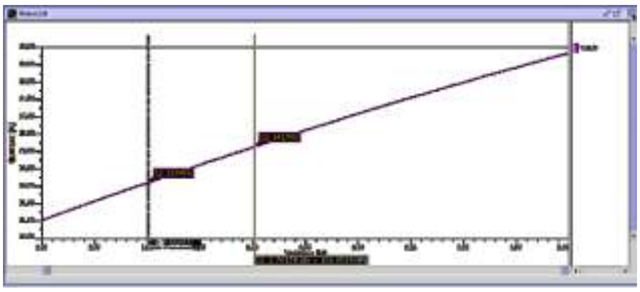

Figure 4: V-I characteristics of the proposed circuit for positive resistance.

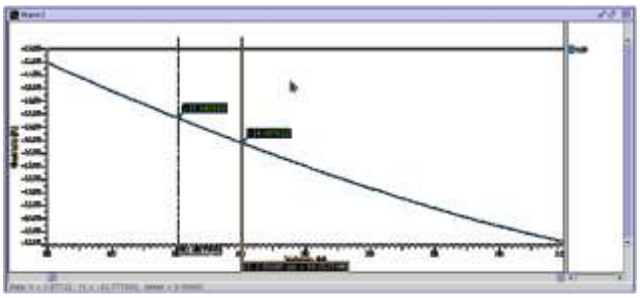

Figure 5: V-I characteristics of the proposed circuit for negative resistance

5. Application

In this circuit the signal is applied to the non-inverting input of the amplifier. However the feedback is taken from the outside via resistor. . The input to the op-amp draws no current means that the current flowing in the resistors R1 and R2 is the same. Gain of this circuit depends on the values of these two resistors. The R1 resistor is replaced by the proposed resistor. If we use R1 as a positive resirtor, gain of the amplifier has negative value. If we use R1 as a negative resirtor, gain of the amplifier has positive value.

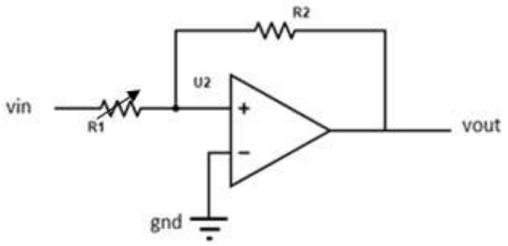

Figure 6: A simple non-inverting amplifier

6. Simulation Results

Figures show the transient input-output responses of the circuit where R1 is replaced by proposed circuit. Figure 7 shows the transient input-output responses of the circuit where R1 is replaced by positive programmable floating resistor. Figure 8 show the transient input-output responses of the circuit where R1 is replaced by negative programmable floating resistor.

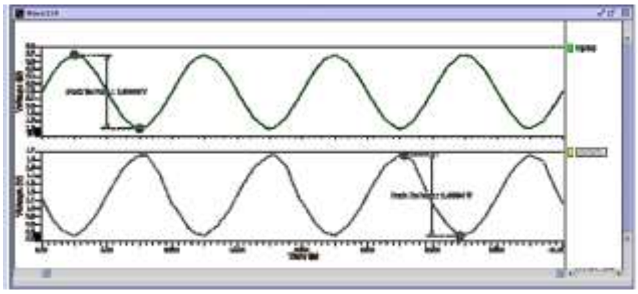

Figure 8: Transient response for fig.6 where R1 is replaced by proposed positive resistance.

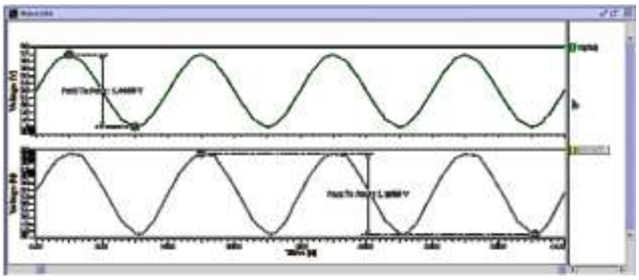

Figure 9: Transient response for fig.6 where R1 is replaced by proposed negative resistance.

7. Conclusion

We proposed an improved bilateral floating resistor circuit having both positive and negative resistance. Characteristics of the proposed circuit are independent of threshold voltage. Hence resistance value has no affects of variation in threshold voltage. The proposed circuit uses only two transistors between the supply voltages, which enable to operate at low supply voltages. In this programmable resistor circuit, current addition /subtraction are carried out at the gate terminal where voltage is applied. Control voltages are given to high impedance terminal of the MOSFET which helps in reducing effect of loading on to control voltage terminals Simulations are carried out in 180nm technology and conforms concept of the circuit and its application.

References

[1] T Oura, T Yoneyyama, S Tantry, H Asai “A CMOS floating resistance circuit having both positive and negative resistance values”, 2001
[2] S Tantry, T Oura, T Yoneyama' and H Asail “A low voltage floating resistor having positive and negative resistance values”, 2002
[3] K.Nagaraj, "New CMOS floating voltage-controlled resistor", 1986
[4] Behzad Razavi “Design of analog CMOS integrated circuits”,2002
[5] Adel s. smith and Kenneth c. Smith “Microelectronic circuits”
[6] S.Takagi, 2.Czamul and N.Fujii, "A Synthesis of Highly Linear MOS Circuits and Their Application to Filter Realization", IEICE Fundamentals, Feb. 1994