CMOS Voltage Reference Based on Threshold Voltage Summation

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Abstract: - The objective of this work is to design a CMOS voltage reference based on threshold voltage summation. An original circuit architecture was used. The circuit uses a threshold voltage extractor, a start-up and an operational amplifier.

Key-Words: - Voltage reference; CMOS; Threshold Voltage; Threshold Voltage Extractor; Trimmers

1 Introduction
The necessity of stable and reliable voltage references is well known in integrated circuit design. In A/D and D/A converters, voltage regulators and other circuits where the temperature influence is a limiting factor, the voltage references play a fundamental role. Bandgap circuits have been extensively used in this kind of application. In CMOS integrated circuits the vertical transistor can be used to make a bandgap reference or an all CMOS technique can be used to make the voltage reference, as it will be presented in this paper.

2 Proposed Circuit
The developed circuit is shown in Fig. 1. It is possible to see three basic blocks: the threshold voltage extractor, the start-up circuit and the operational amplifier.

The Vth extractor generates the bias current through the transistor M1Vth. In this transistor, the Vgs voltage is the Vgs voltages summation of the transistors M1B and M2B minus the Vgs voltage of the transistor M1A. This way, through the correct currents choice in these three transistors, a voltage equal Vth is obtained in the Gate/Source terminals of the transistor M1Vth. So, the bias current of the Vth extractor is a function of the Vth voltage. As the bias voltage is generated inside this circuit and it is not a direct function of VDD, exist the possibility of the circuit doesn’t start. Therefore, it is necessary to use a Start-Up circuit to guarantee this circuit will not start in a 0V condition. The operational amplifier role is to drive the output current.

Fig.1 Voltage source schematic.
The bias current of the Vth extractor is mirrored to transistor MG206. So, in the gate of the transistor MG211 is generated a voltage equal 2Vth, resulting in a current proportional to Vth, as shown in equation (1). The same occurs in transistor MG111.

\[ I_{2Vth} = \frac{K_F}{2} \left( \frac{W}{L}_{MG211} - (2 \cdot Vth_e - Vth_e) \right) = \frac{K_F}{2} \left( \frac{W}{L}_{MG211} \cdot Vth_e \right) \]  

(1)

The currents flowing in transistors MG211 and MG111, proportional to Vth, are mirrored to transistors MG25 and MR25 and added in node V25. The transistor MG25 is in the linear operation condition and its drain current is found using equation (2). The voltage VgsMR25 and the current IMR25 can be found multiplying the current I2Vth by the coefficients of the current mirrors. So, through the substitution of these values in equation 2, it’s possible to find equation (3). Equations (4) and (5) describe the coefficients used in equation (3). Equation (6) models the mobility variation with temperature. It is possible to observe that, as the temperature increases, the mobility decrease, thus, V25 increase.

\[ I_{MR25} = \mu_N \cdot C_{av} \left( \frac{W}{L}_{MR25} \right) \cdot (Vgs_{MR25} - Vth_N) \cdot V25 \]  

(2)

\[ V25 = \frac{(\gamma - 1)}{C_{av} \left( \frac{W}{L}_{MR25} \right) \cdot \sqrt{\frac{2 \cdot 2 - \lambda}{\sqrt{\frac{W}{L}_{MD54} \cdot \frac{W}{L}_{MD30}}}}} \cdot \mu_N \cdot R27 \]  

(3)

\[ \gamma = 1 + \sqrt{\frac{\frac{W}{L}_{MD50}}{\frac{W}{L}_{MD111}} \cdot \frac{\frac{W}{L}_{MD32}}{\frac{W}{L}_{MD211}}} \]  

(4)

\[ \lambda = \frac{\frac{W}{L}_{MG25}}{\frac{W}{L}_{MD211}} \cdot \frac{\frac{W}{L}_{MG111}}{\frac{W}{L}_{MD32}} \cdot C_{av} \left( \frac{W}{L}_{MG211} \right) \cdot \frac{1}{2} \left( \frac{W}{L}_{MG211} \right) \]  

(5)

\[ \mu(T) = \mu(T_0) \cdot \left( \frac{T}{T_0} \right)^{-\mu} \]  

(6)

So, in V25, a voltage with positive temperature gradient is obtained (equation 3) and it’s possible to adjust the curve inclination using the current mirrors of the circuit.

Equation 7 models the output voltage Vref. Equation 8 models the Vthn variation with temperature. As showed, the voltage Vthn decrease as temperature increase. So, as the voltage Vthn has a negative temperature gradient and the voltage V25 has a positive temperature gradient, it’s possible to adjust the parameters of the transistors to make Vref stable with temperature.

\[ V_{ref} = V_{thn} + V_{25} \cdot \left\{ \frac{1}{1 - \left( \frac{W}{L}_{MR25} \right)} \right\} \]  

(7)

\[ V_{thn} = V_{T_0} \cdot (T_0) - \alpha \cdot (T - T_0) \]  

(8)

3 Trimmers

Some structures were used in the circuit to work as trimmers. In Fig 3 is shown the schematic of these trimmers. Another similar structure was introduced between the current mirror composed by transistors MD211 and MG32. In the circuit of Fig 3 it is possible to increase or decrease the current passing through MD30 connecting MT1_D in MG30_D or in MD111_D, respectively. The same occurs with MT2_D, MT3_D, MT4_D and MT5_D. This way, it is possible to adjust the curve inclination in V25. MT1, MT2, MT3, MT4 and MT5 were designed to produce different inclinations in V25 and they can be used in parallel to produce even more combinations.

Fig.3 Trimmers schematic.

4 Layout

The circuit was designed and the layout was made using the 0.35µm AMS (Austria Micro-Systems) technology. High voltage transistors were employed, allowing the circuit to operate using VDD = 5V. A micrograph of the circuit is shown in Fig.4. The total area is 0.74mm². Inter-digitated transistors were used in some points of the circuit to save area.
5 Experimental Results

The circuit achieved 1mV of variation in a range of 27°C to 120°C. This variation is equivalent of 11 ppm/°C. The entire circuit consumption was 91 μA using 5V of VDD. In Fig. 5 are shown 4 results using 4 different combinations of the trimmers.

6 Conclusion

The layout was designed aiming a maximum density to avoid temperature gradients.

In the circuit of Fig. 4 it wasn’t used ESD (electrostatic discharge) protection in the bonding pads. The reason was to avoid any kind of influence from protection devices.

The high resistivity resistors were used because of two reasons: its low area consumption, and its non-linearity. About the second reason, it was verified in simulations that this characteristic improves the output stability in temperature.

The measurements showed that the proposed circuit presented a performance comparable to the bandgap references [3].

References:

