

Fundamentals of Analog & Mixed Signal VLSI Design

Exercise 1 (18.09.2024)

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Problem 1 Stacked transistors

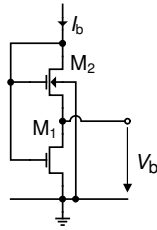


Figure 1: Stacked transistors.

1.1 Voltage V_b as a function of transistor's β_1 and β_2

Calculate the voltage V_b in circuit shown in Fig. 1 as a function of the betas (β_1 and β_2) of transistors and of the thermodynamic voltage (in weak inversion) or the pinch-off voltage (in strong inversion), assuming:

- Both transistors are biased in weak inversion.
- Both transistors are biased in strong inversion.

1.2 Channel voltage

If the transistors have the same width W , then

$$\frac{\beta_1}{\beta_2} = \frac{L_2}{L_1}, \quad (1)$$

and the circuit can be considered as a single transistor with length $L = L_1 + L_2$. The channel voltage can then be extracted at a fraction ξ along the channel by the common source and drain diffusion of M_2 and M_1 respectively

$$\xi = \frac{L_1}{L_1 + L_2} = \frac{\beta_2}{\beta_1 + \beta_2}, \quad (2)$$

Knowing that the current I_b is due to diffusion of minority carrier, it is given by,

$$I_b = -\mu \cdot \frac{W}{L} \cdot Q_i \cdot \frac{dV}{d\xi} \quad (3)$$

with $\xi = x/L$. Show that V_b is actually equal to the channel voltage along the channel $V(x)$.

Problem 2 The Vittoz current reference [1]

Fig. 2 shows the Vittoz current reference generating a current I_b which for M_1 and M_3 biased in weak inversion is proportional to absolute temperature (PTAT) [1]. The bias current I_b is available as a source current from M_6 or a sink current from M_5 . Transistors M_2 and M_4 are assumed to be identical whereas M_3 is made K -times larger than M_1 (i.e. $\beta_3 = K \cdot \beta_1$). All transistors are biased in saturation.

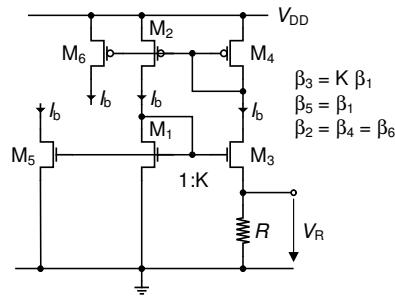


Figure 2: The Vittoz current reference.

2.1 Weak inversion

Calculate the value of the current I_b as a function of the transistor ratio K assuming that both M_1 and M_3 are in weak inversion. Do the transistor M_2 and M_4 need to be in weak inversion as well?

2.2 Strong inversion

Calculate the value of the current I_b as a function of the transistor ratio K assuming that both M_1 and M_3 are in strong inversion. Do the transistor M_2 and M_4 need to be in strong inversion as well?

Problem 3 The Oguey current reference [2]

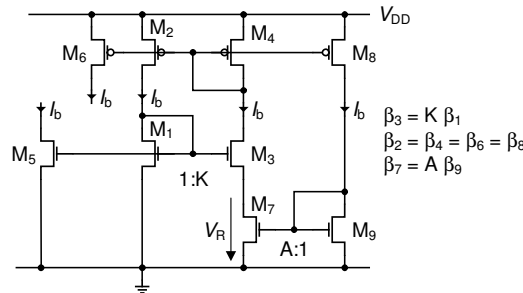


Figure 3: The Oguey current reference.

The resistor in the Vittoz current reference of Fig. 2 can actually be replaced by a transistor M_7 which is biased in the linear region by making it A -times larger than M_9 [2]. All other transistors are assumed to be biased in saturation. M_1 and M_3 are biased in weak inversion, whereas M_7 and M_9 are biased in strong inversion. Find the expression of the bias current I_b in terms of ratios K and A and the specific current I_{spec9} of M_9 and I_{spec7} of M_7 .

References

- [1] E. Vittoz and J. Fellrath, "CMOS analog integrated circuits based on weak inversion operations," *Solid-State Circuits, IEEE Journal of*, vol. 12, no. 3, pp. 224–231, June 1977.
- [2] H. J. Oguey and D. Aebischer, "CMOS current reference without resistance," *Solid-State Circuits, IEEE Journal of*, vol. 32, no. 7, pp. 1132–1135, July 1997.