Design Problem

Bandgap

Specifications

Specification	Description	Value
$\lvert\Delta V_{REF}\rvert$	Difference between 1.35V and V_{REF} at T = 27°C	≤ 1mV
$TC(N=8)$	Temperature coefficient from -50°C to 150°C	≤ 15 ppm/°C
P_{diss}	Power dissipation including bias circuitry	≤ 50µW
PSR	Ratio of v_{out} to v_{dd} at 1 kHz	≤ -60dB
PM	Phase margin of any combined ±feedback loops	≥ 50°
$TC(N=7)$	Best trimmed output when N = 7	≤ 15 ppm/°C
$\lvert\Delta V_{REF}(N=7)\rvert$	Difference between V_{REF} when N=7 and V_{REF} when N=8 , T = 27°C	≤ 1mV
$TC(N=9)$	Best trimmed output when N = 9	≤ 15 ppm/°C
$\lvert\Delta V_{REF}(N=9)\rvert$	Difference between V_{REF} when N=9 and V_{REF} when N=8, T = 27°C	≤ 1mV
V_{min}	Minimum value of V_{DD} when $TC(N=8)$ is ≤ 15ppm/°C	1.5V
V_{DD}	Positive power supply voltage	5V
V_{SS}	Negative power supply voltage	0V

Simulation Help

Simulating Worst Case Conditions:

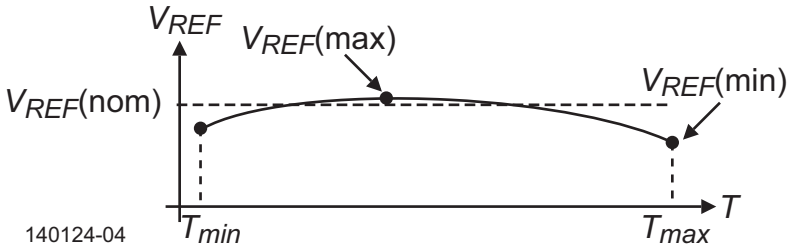
The PTAT voltage is generated using the ratio of BJTs. In this problem the nominal ratio will be 8.

In order to simulate worst case conditions, this ratio will be changed to 9 and to 7. You are to design a trimming network that when the bandgap circuit has been designed for best TC with *N*=8, that you can bring the TC back into this range using only your trimming network.

Each trim bit is controlled by a DC voltage source with a value of 0V or 5V which you will use to implement the bit or not.

Measuring TC:

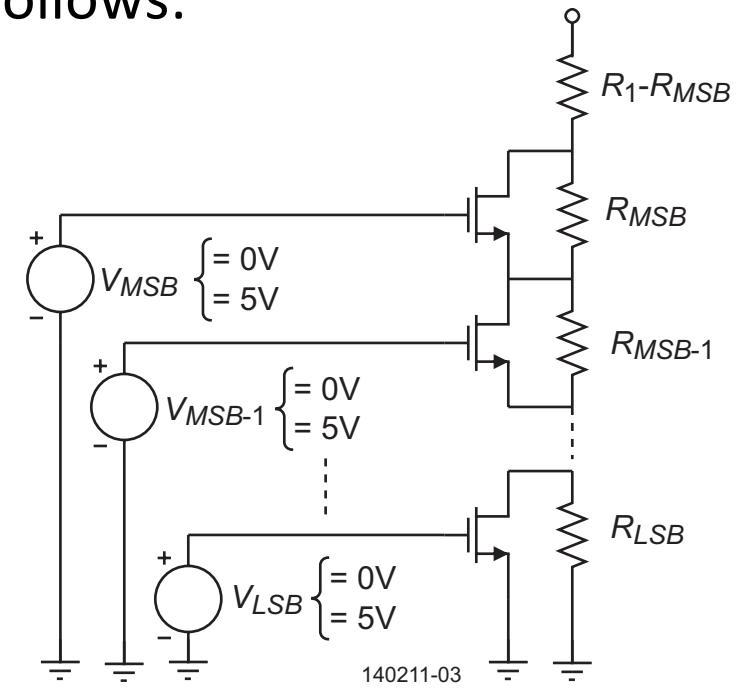
For this problem, TC is measured as illustrated.



$$TC = \frac{V_{REF}(\max) - V_{REF}(\min)}{V_{REF}(nom)[T_{\max} - T_{\min}]} \times 10^6 \text{ ppm/°C}$$

Trimming Design

For this problem, the trimming will be implemented for simulation as follows:



To find the initial tolerance, measure the output at 27°C when N=7 and N=9. This should identify your initial tolerance.

Design the W/L values so that the MOSFET $R_{ON} << R_{Trim}$ – however if they are too big, they will leak drain current at higher temperatures. You will manually set the bits as desired by setting the voltage sources to 0V or to 5V.

Scoring Algorithm – Verified by SPICE

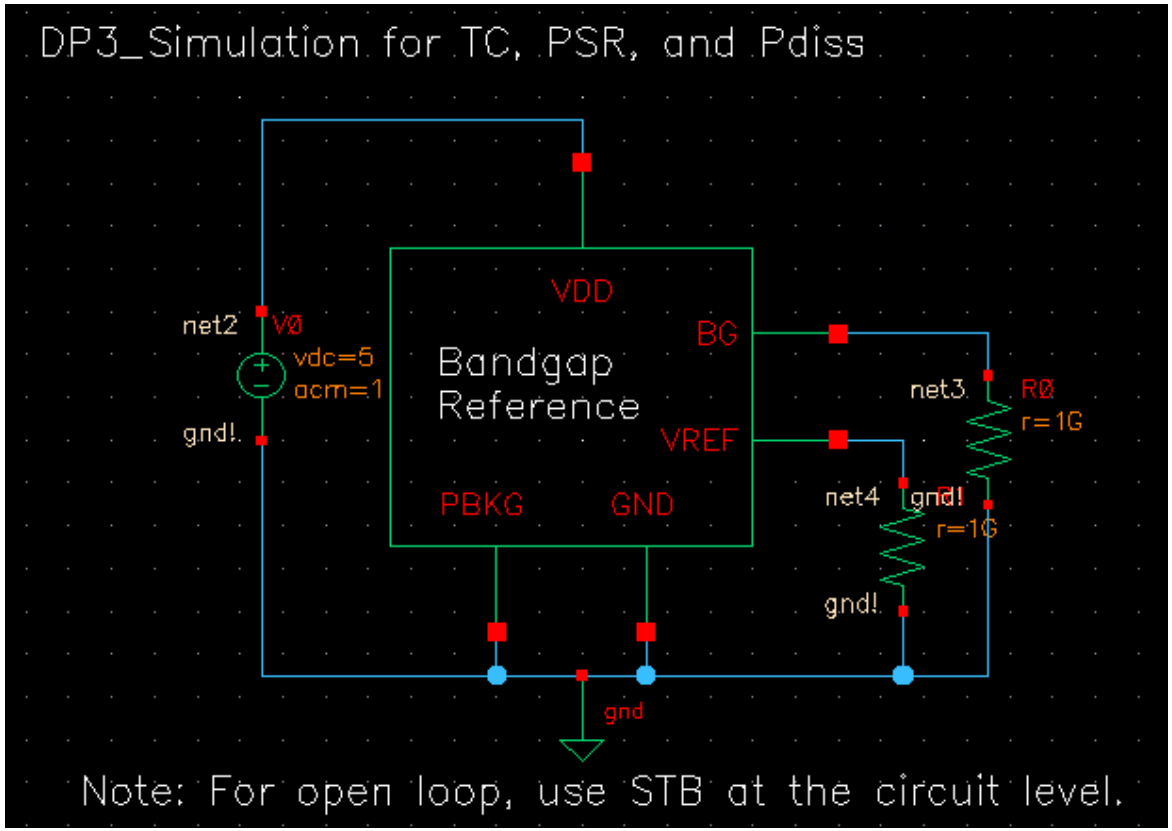
$$\text{SCORE} = \min\left[5{,}5\times\left(\frac{1\text{mV}}{|\Delta V_{REF}|}\right)\right] + \min\left[5{,}5\times\left(\frac{15ppm/°C}{TC(N=8)}\right)\right] + \min\left[5{,}5\times\left(\frac{50\mu W}{P_{diss}}\right)\right]$$
$$+\min\left[5{,}5\times\left(\frac{|PSR|}{60dB}\right)\right] + \min\left[5{,}5\times\left(\frac{PM}{50°}\right)\right] + \min\left[5{,}5\times\left(\frac{15ppm/°C}{TC(N=7)}\right)\right]$$
$$+\min\left[5{,}5\times\left(\frac{1\text{mV}}{|\Delta V_{REF}(N=7)|}\right)\right] + \min\left[5{,}5\times\left(\frac{15ppm/°C}{TC(N=9)}\right)\right] + \min\left[5{,}5\times\left(\frac{1\text{mV}}{|\Delta V_{REF}(N=9)|}\right)\right]$$
$$+\min\left[5{,}5\times\left(\frac{1.5}{V_{MIN}}\right)\right] - 10\times(\text{No. of VDC} \neq 5 \text{ or } 0\text{V}) - 10\times(\text{No. of IDC})$$

Maximum score is 50 points.

- You should use only components from the 0.35µm XFAB library (no ideal components)
- If you use a dc voltage source of value not equal to 5V or 0V, enter the number of sources used in the score sheet
- If you use any dc current source, enter the number of sources used in the score sheet

Test Bench

After you create your circuit, you should define a symbol and place it in the test bench below to conduct the simulations.



Comments

- Students should extract or find the parameters (V_T, K_P', and λ) for the transistor simple models that can be used for design purposes before simulation
- Do hand analysis of the design and make any modifications necessary
- Replace the bandgap symbol with a symbol for your bandgap design and use the predefined simulation states to determine the performance of your design
- Evaluate your score using the Excel score sheet and include a schematic with W and L values if your score is greater than 45/50.