Department of Electronic Systems

TFE 4188 - Advanced Integrated Circuits

Assignment M1 - Group 5

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1 Introduction

For this milestone, the goal is to create a circuit design that implements the functionality of converting a temperature to a current. The design utilizes the Skywater Open Source PDK and its SKY130 process node.

This report serves as preliminary documentation of the current progress of the project.

2 Key Parameters

The following table presents the key parameters for the design.

Table 1: Key parameters

Name	Description	Min	Typ	Max	Unit
Width	Maximum width	-	-	160	μm
Height	Maximum height	-	-	100	μm
VDD	Input supply	1.62	1.80	1.98	V
Temperature	Temperature range to measure	-40	-	125	$°C$
Current	Input current	-	120	200	μA

3 Specification

The following table presents the specifications for the design.

Table 2: Specifications

Name	Description	Min	Typ	Max	Unit	Notes
Accuracy	One-point accuracy	-5	0	+5	$°C$	-
Resolution	Temperature resolution	-	-	-	$°C$	TBD
Stability	-	-	-	-	-	TBD
Power consumption	-	-	-	-	W	TBD
Noise	Noise of the OTA	-	-	-	$V/\sqrt{Hz}$	TBD
Offset	Offset of the OTA	-	-	-	V	TBD
CMRR	CMRR of the OTA	-	-	-	dB	TBD
Gain	Gain of the OTA	-	-	-	-	TBD

4 Verification Plan

4.1 Accuracy

The accuracy of the current-to-temperature design will be verified by simulating the design in the entire temperature range. Afterward, the data will be extracted and compared to the ideal current function.

4.2 Current Consumption

The current consumption of the design will be simulated by measuring the current from the supply for the entire temperature range using a DC analysis testbench.

5 Functional Description

The project group is designing an IC temperature sensor using the SkyWater130 CMOS technology.

The intention is to use a circuit that generates a PTAT current. It is based on a modified Kuijk band gap reference mechanism i.e. using the V_{BE} voltage of a BJT (used as a diode):

$$V_{BE} = \frac{kT}{q} \cdot ln(\frac{I_D}{I_S})$$

6 Architecture

6.1 OTA Subcircuit

The following figure presents the OTA subcircuit:

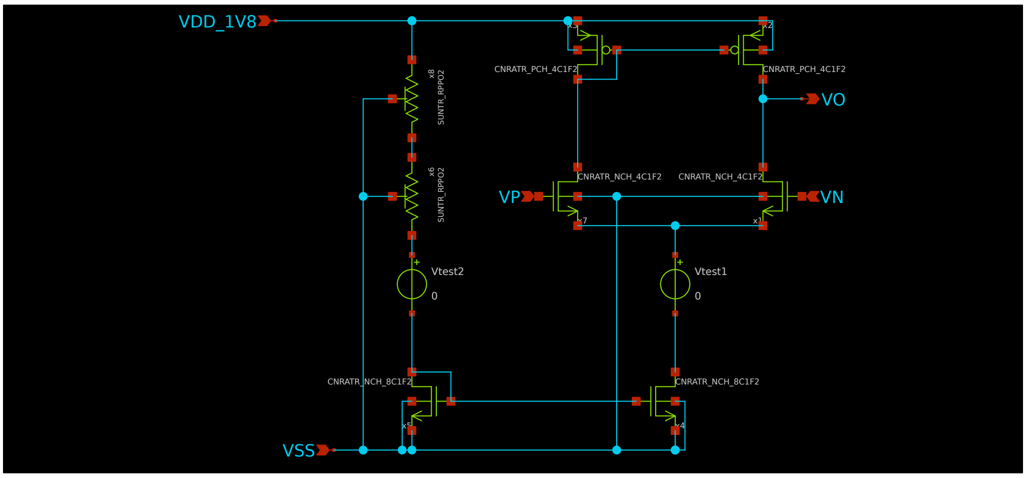

Figure 1: OTA design

The amplifier in negative feedback forces a 0 differential voltage. Hence, scaling the diode sizes properly, one can get a resulting voltage drop over the resistance of $V_{B1} - V_{B2}$, thus generating the PTAT current:

$$I_{PTAT} = \frac{kT}{q} \cdot ln(n) \cdot \frac{1}{R}$$

To bias the simple five-transistor OTA, a 60 μA current is desired. For that current, the 8C1F2 has a given gate-source voltage of $V_{GS} = 0.75V$ for $\frac{g_m}{i_d} = 15$. Since the supply voltage is $V_{DD} = 1.8$, the required resistor value can be calculated using:

$$R = \frac{V_{DD} - V_{GS}}{I} = \frac{1.8V - 0.75V}{60\mu A} = 17.5k\Omega$$

The implemented design uses two 8.8 k Ω in series.
The tail transistor is twice the size of the input transistors so it can carry twice the current.

6.2 Top Design

The following figure presents the top-level design:

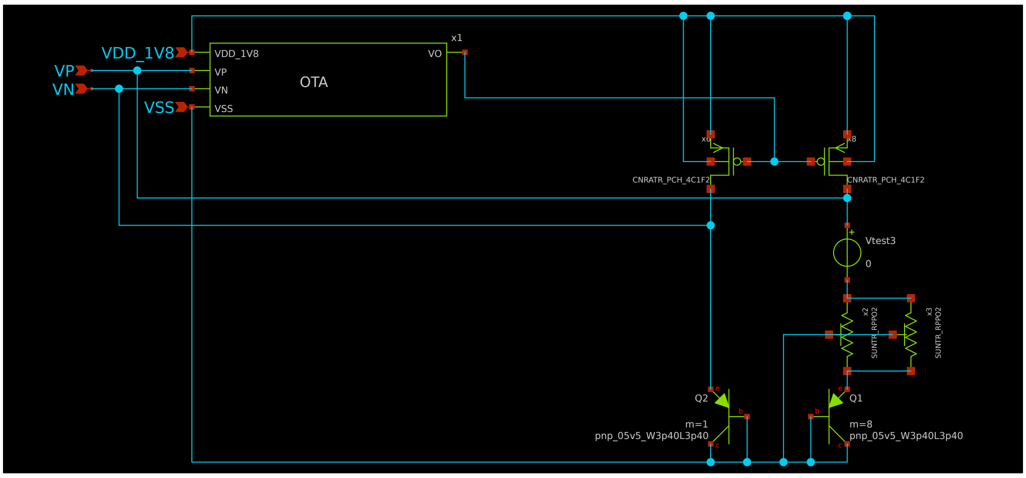

Figure 2: Top level design

The pnp BJTs work similar to diodes when operating in the triode region.
The diode current

$$I = I_S \cdot e^{\frac{qV_{BE}}{kT}}$$

where the reverse saturation current is proportional to the emitter area

$$I_S \propto A_E$$

implies that

$$V_{BE} = \frac{kT}{q} ln(\frac{I}{I_S})$$

From this, one can calculate the voltage drop over the resistors:

$$V_R = V_{EB_1} - V_{EB_2} = \frac{kT}{q} \cdot ln(\frac{I_1}{I_{S_1}}) - \frac{kT}{q} \cdot ln(\frac{I_2}{I_{S_2}}) = \frac{kT}{q} \cdot ln(n)$$

where n is the ratio of the pnp emitter areas.
Using an equivalent resistance of $4.4k\Omega$ and a pnp emitter area ratio of $n = 8$, one can calculate the predicted ideal slope of the temperature to current function:

$$I_{out} = \frac{\frac{kT}{q} \cdot ln(n)}{4.4k\Omega} \propto T$$

$$\frac{I_{out}}{T} = \frac{k}{q} \cdot ln(8) \cdot \frac{1}{4.4k\Omega} \approx 40.8nA/K$$

7 SPICE Simulations

All simulations presented in this section were performed in the typical corner.

7.1 Simulation of Current against Temperature

The following figures present the simulation results of the proposed design. The simulations were performed by configuring a temperature sweep from -40 °C to 125 °C using the following SPICE commands:

```
optran 1 1 1 10n 20u 0
DC temp -40 125 1
```

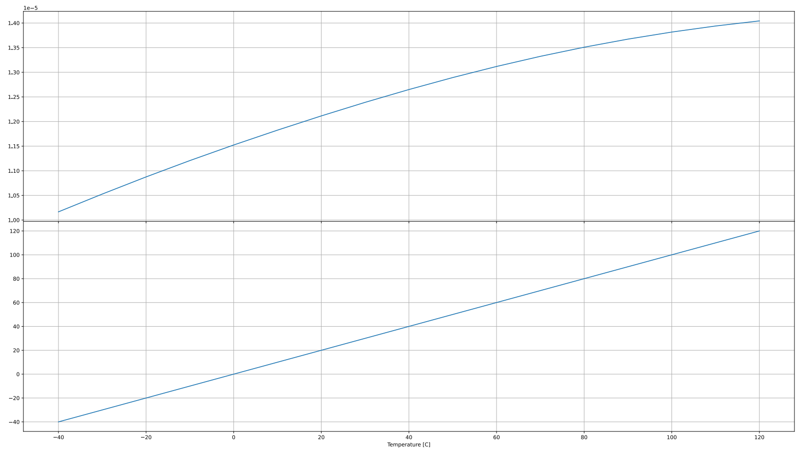

Figure 3: Simulation of current and temperature from -40 °C to 125 °C in cicsim

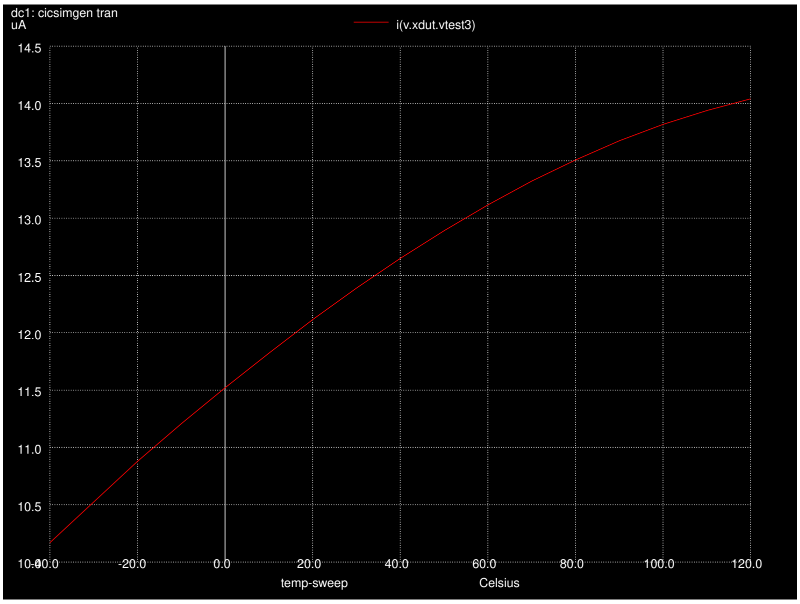

Figure 4: Simulation of current and temperature from -40 °C to 125 °C in NGSPICE

7.2 Calculation of Current Error

By extracting the data and running it in a simple Python script, one can compute the error of the measured current compared to the ideal current, as shown in the following figure:

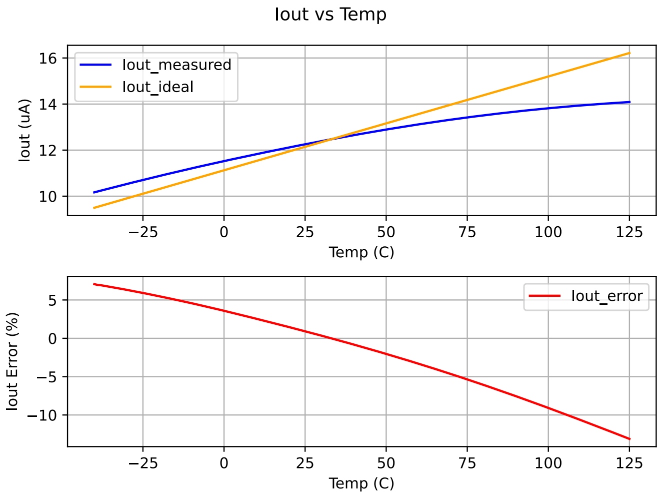

Figure 5: Plots of measured current and ideal current from -40 °C to 125 °C

One can observe that the measured current curve is non-linear and deviates from the ideal current by up to 14 %. The group hypothesizes that this is caused by the temperature dependence of the resistors and intends to address this in the next revision.

7.3 Simulation of Current Consumption

The following figure shows the simulated current consumption of the circuit:

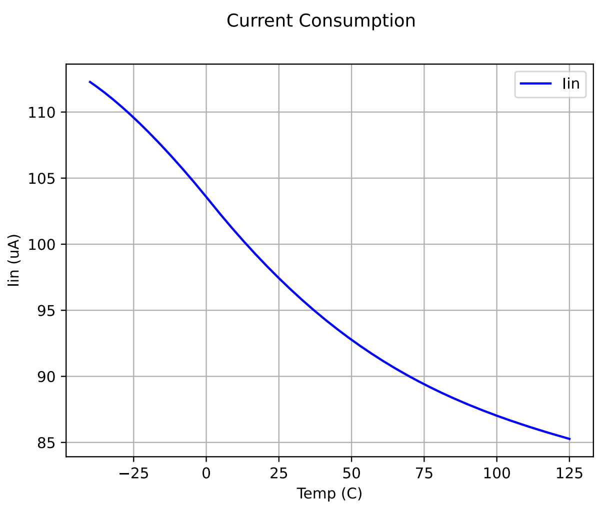

Figure 6: Simulated current consumption from -40 °C to 125 °C

The current consumption decreases due to the mirror ratio in the OTA worsening, which is something requiring further investigation. A possible hypothesis is the tail current going into the ohmic region.