BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

EEE 466 (January 2024)

Analog Integrated Circuits & Devices Laboratory

Final Project Report

G1 (Project Group 3)

Design of Bandgap Reference Voltage Generator

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1 Abstract

A bandgap reference is a crucial component in electronic circuits, designed to provide a stable DC bias voltage regardless of temperature, power supply variations, or changes in load. Constructed using Cadence's gpdk045 library, our bandgap reference voltage generator incorporates several key elements. These include a current mirror-based Proportional to Absolute Temperature (PTAT) voltage generator, a Complementary to Absolute Temperature (CTAT) voltage generator, and an active RC filter aimed at noise reduction.

2 Introduction

Creating a Voltage Reference Generator is essential in analog and mixed-signal circuitry like data converters and voltage regulators. To achieve an optimal voltage reference, we aim for the following:

1. Ensuring the output voltage remains unaffected by temperature variations.
2. Guaranteeing the output voltage remains consistent regardless of changes in the power supply.
3. Providing the capability to scale the output voltage easily.
4. Ensuring operation across a broad range of supply voltages.

Within this project, we've developed a bandgap reference voltage generator with specified parameters such as output voltage, supply current, output voltage noise, temperature coefficient, line regulation, and load regulation.

Target specifications:

V_{REF}	0.9	V
Supply Current (max)	0.1	mA
Output voltage noise	0.2 (0.1Hz to 10Hz)	mVP-P
Output current capability	1	mA
Temperature Coefficient (-40°C ~125°C) (max)	50	ppm/°C
Input Voltage Range	2-5	V
Line Regulation	1	mV/V
Load Regulation	1	mV/mA

3 Design

Operation:

The cascode mirror (M5-M8) keeps the currents in Q1, Q2, and Q3 identical.

Thus,

$$V_{BE1} = I_2R + V_{BE2}$$

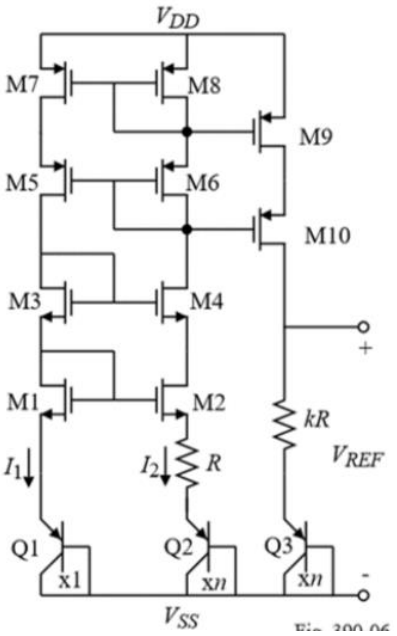
or

$$I_2 = \frac{V_t}{R}\ \ln(n)$$

Therefore,

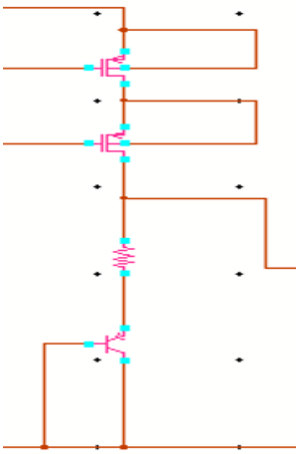
$$V_{REF} = V_{BE3} + I_2(kR) = V_{BE3} + kV_t \cdot \ln(n)$$

Use k and n to design the desired value of K (n is an integer greater than 1).



In our design, the overall circuit can be broken into the following parts-

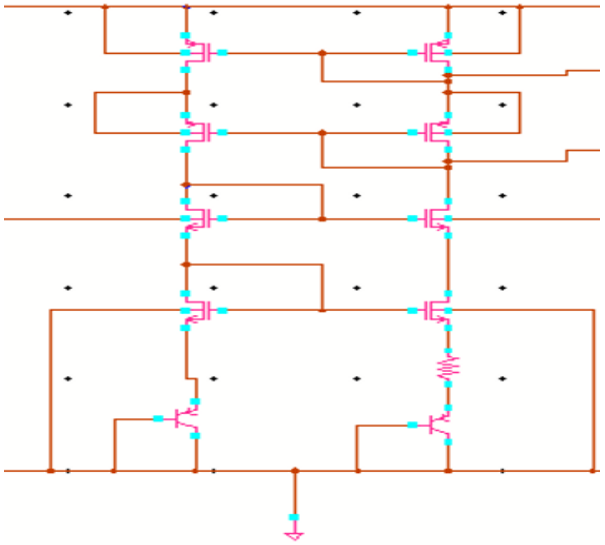
1. CTAT Circuit Design



V_{BE} of a diode connected BJT decreases with temperature. We can use a diode or a BJT to generate CTAT (Complementary to Absolute Temperature) voltage.

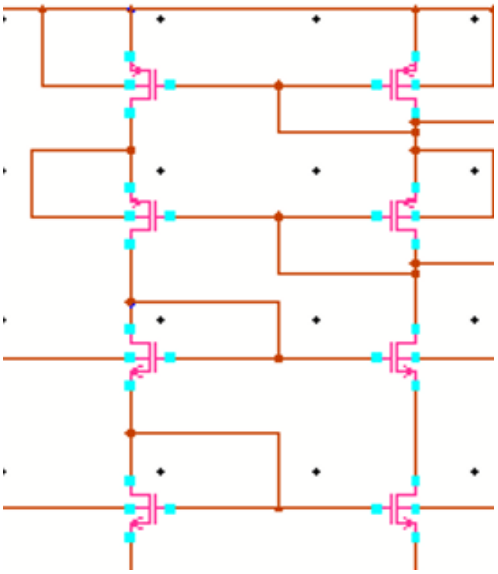
When a diode or diode connected BJT is biased using a constant current source, the diode voltage shows CTAT nature. Thermal voltage (V_T) and saturation current both are temperature dependent but I_s dominates making the overall voltage CTAT.

2. PTAT Circuit Design



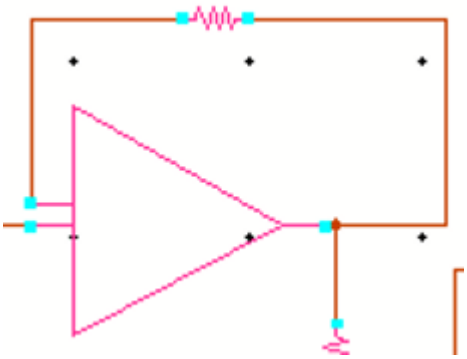
In this figure, due to the difference in BJT area, the two branches individually generate CTAT voltages with different slopes. The difference of these two voltages is PTAT (Proportional to Absolute Temperature) in nature.

3. Cascode Current Mirror



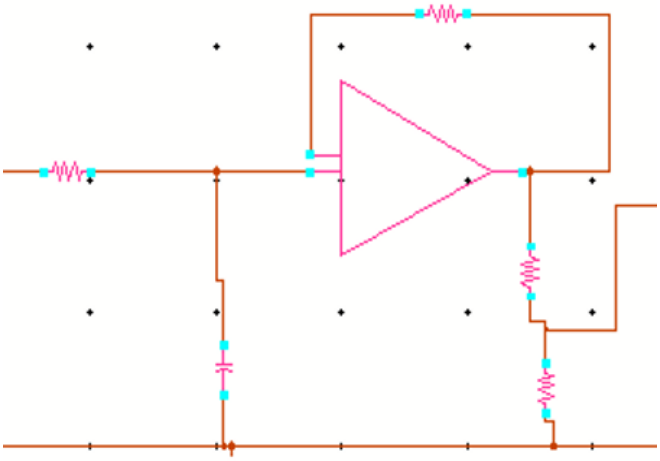
A cascode current mirror provides better supply rejection compared to a single stage current mirror

4. Buffer stage



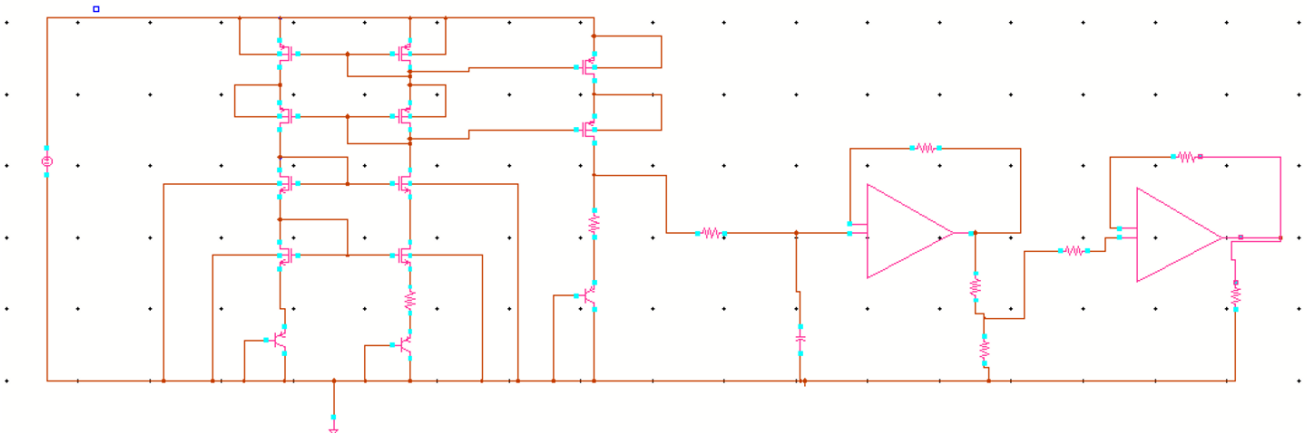
Buffer stage provides isolation between the bandgap reference generator and external loads. This ensures that various loading conditions do not have any effect on the reference generator circuit.

5. Active Low Pass Filter



An active low pass filter is used for meeting the noise specification.

4 Simulation Model

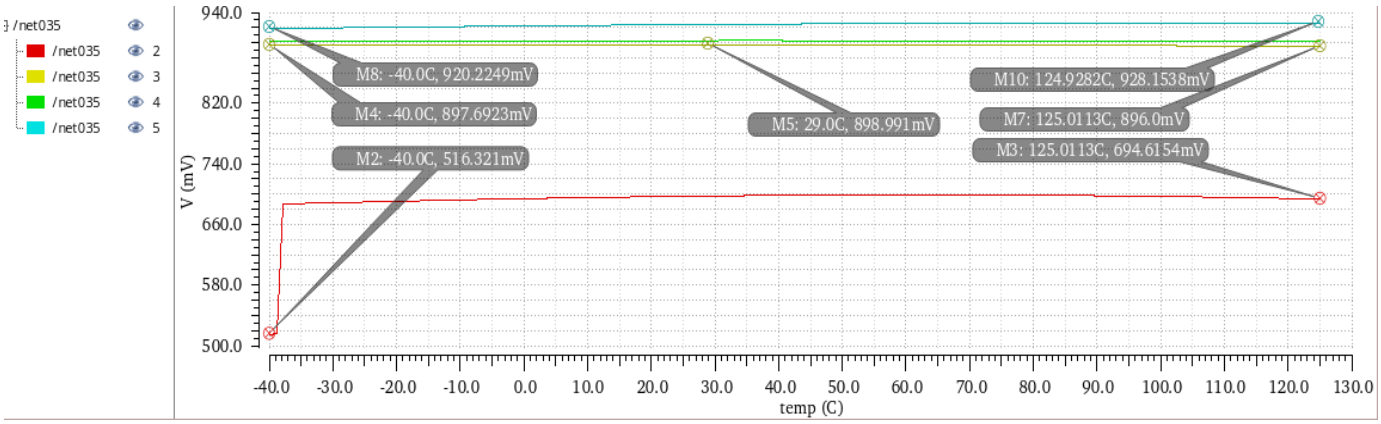


5 Implementation

Initially, we constructed distinct CTAT and PTAT circuits. Their integration facilitated temperature independence. Next, employing a cascode current mirror circuit ensured independence from supply voltage fluctuations. Subsequently, we implemented a filter to diminish low-frequency output noise.

1. Results

Plot of final Vref and d/dT (Vref) (With Respect to Temperature):

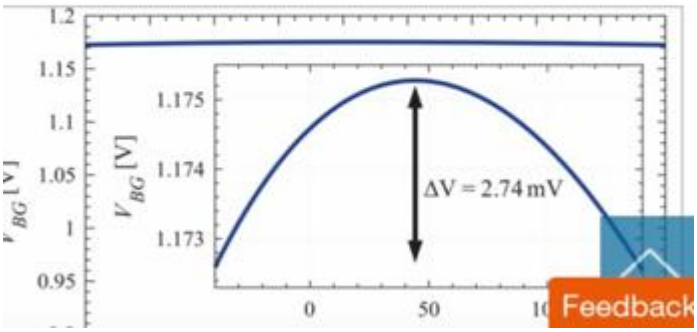


The formula of temperature coefficient in ppm/ C can be given as follows:

$$\frac{V_{BG,max} - V_{BG,min}}{V_{BG,mean} \cdot (T_{max} - T_{min})} \cdot 10^6,$$

For the following figure,

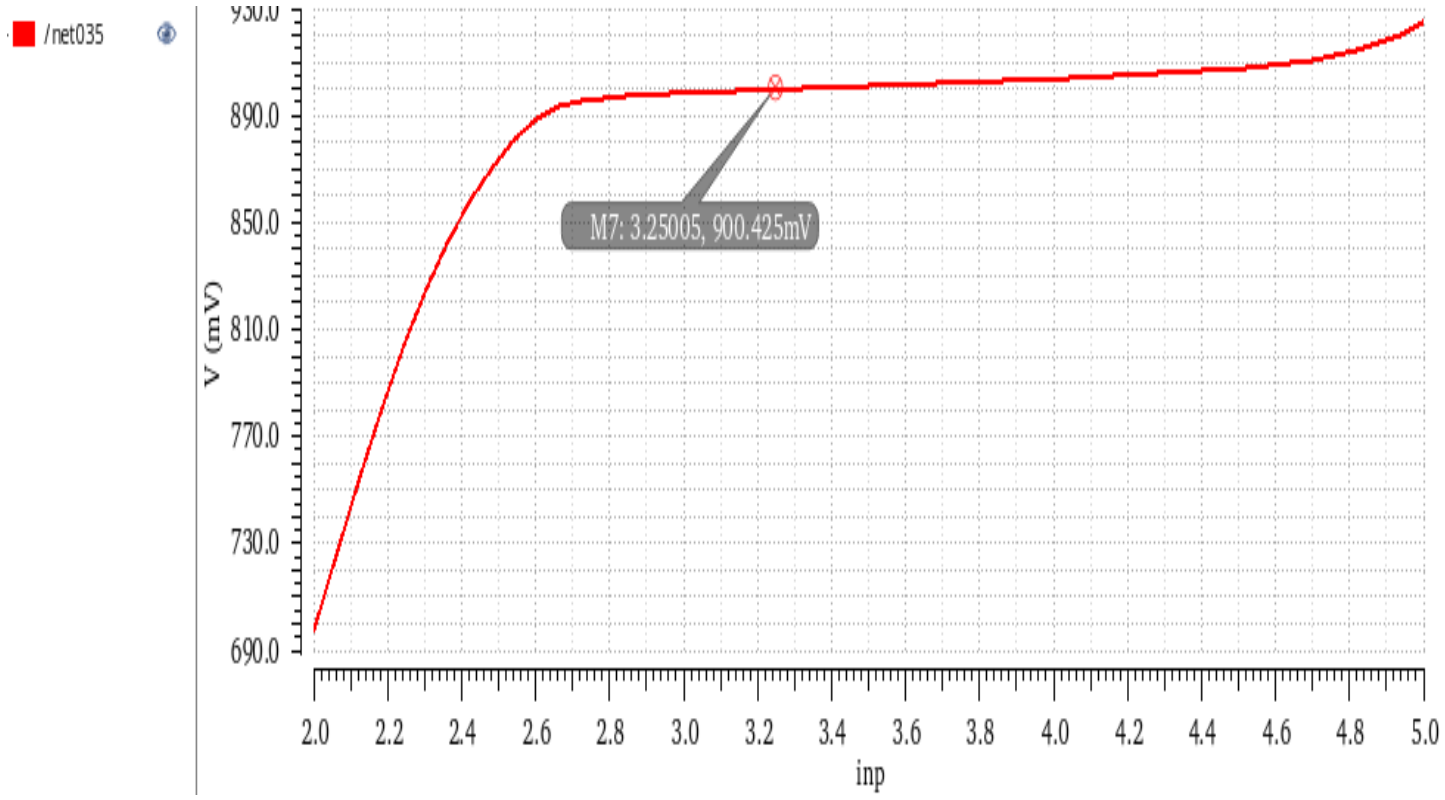
the voltage temperature coefficient is approximately 13 ppm/°C.



Using the formula, we can show that,

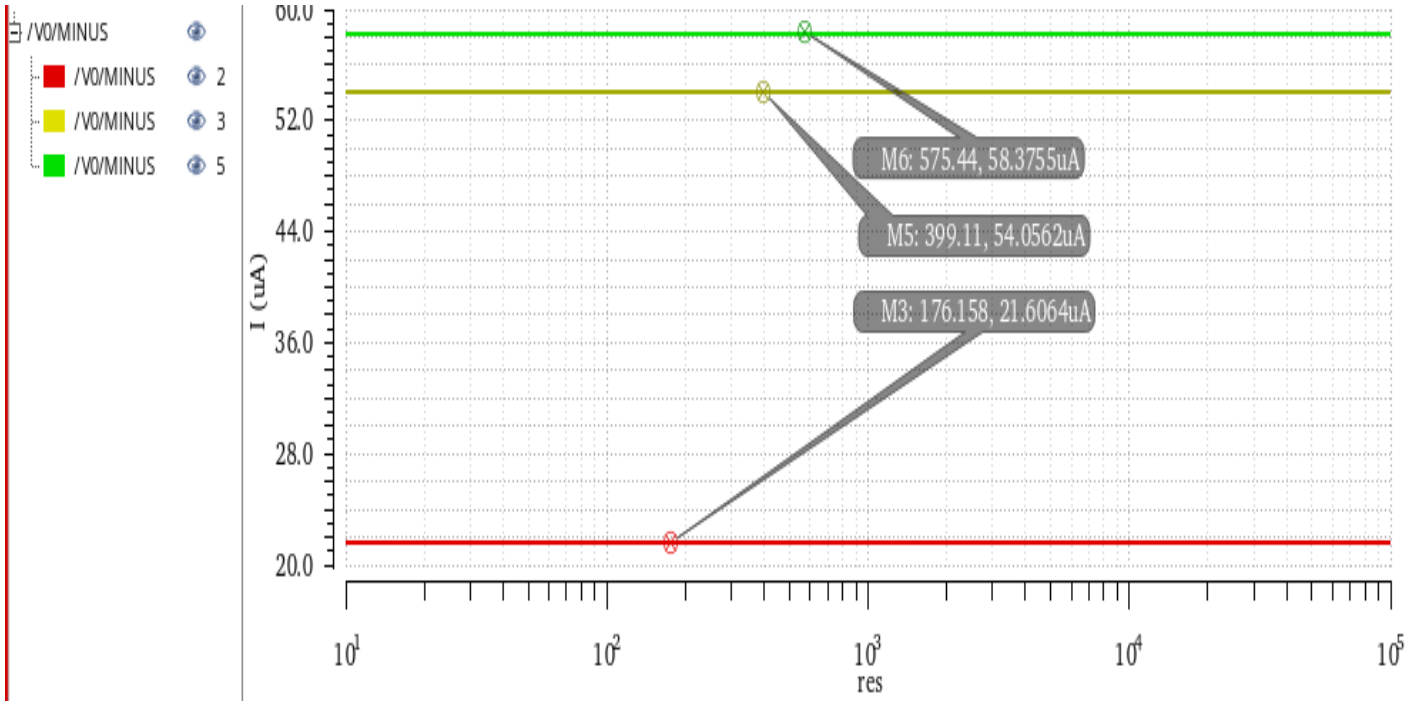
The temperature coefficient of our design is around 20.197 ppm/ C for the circuit that we designed. (Vmax=898.991 mV, Vmin=896 mV)

Plot of final Vref (With Respect to voltage):



This circuits requires minimum 2.6V supply to operate properly. In 3-4V supply range, which is also our primary area of interest, this circuit can provide almost constant Vref.

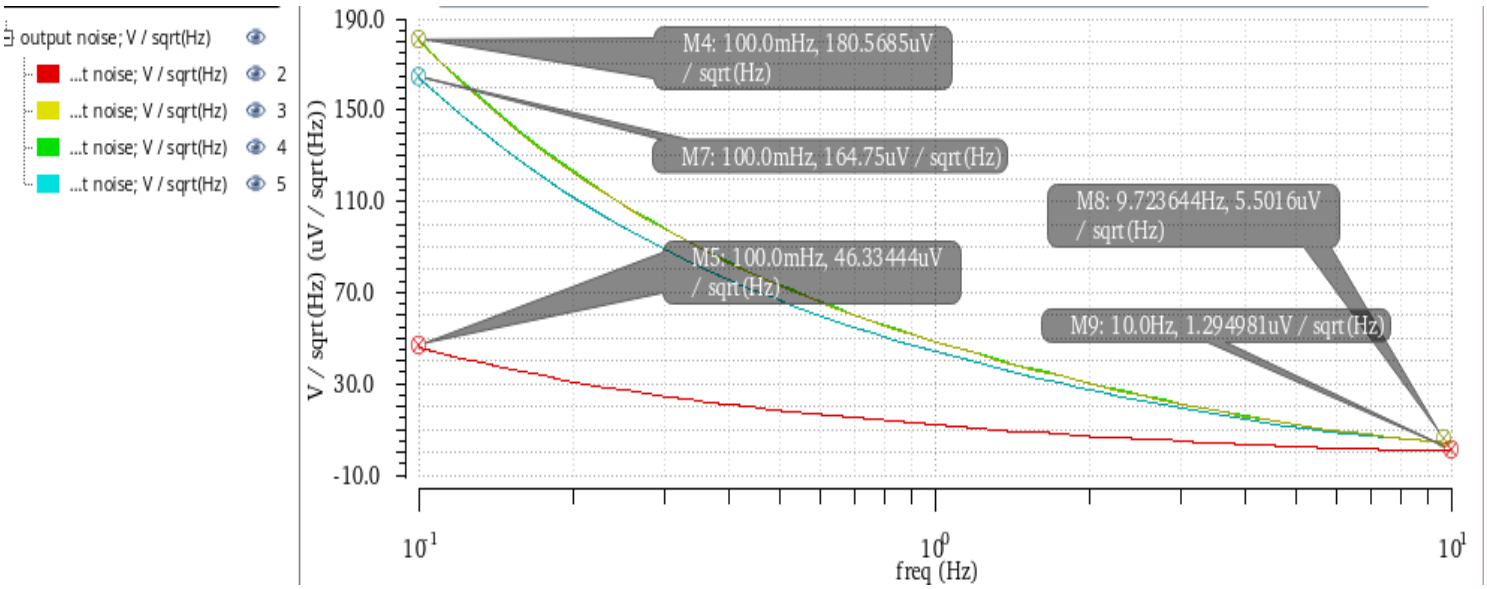
Plot of Supply Current:



Here, a dc sweep is performed in the x axis for varying R and in the y axis for varying Vin. All values are less than 100uA.

Plot of Noise Spectral Density:

Peak to peak noise = 6.6*$Noise_{rms}$



$Noise_{rms}$ = max(noise spectral density)*sqrt(bandwidth)

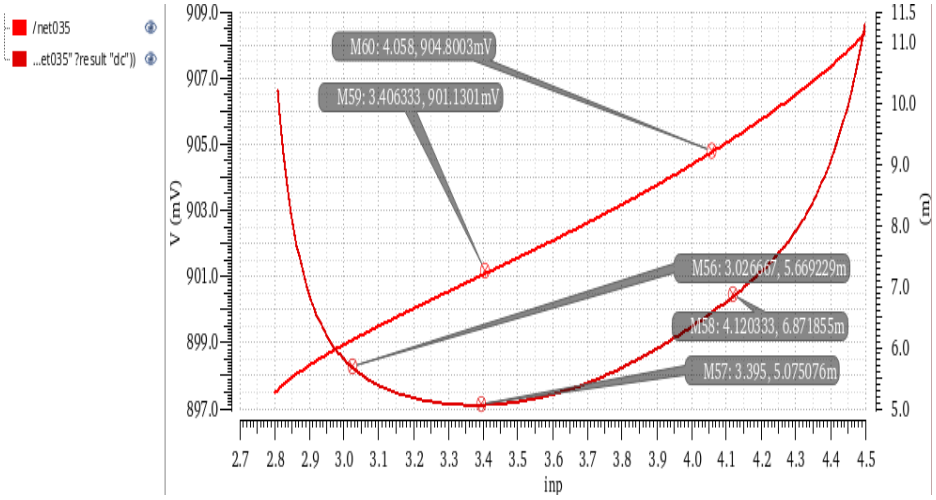
The bandwidth of this circuit after adding a passive RC filter with very low cutoff frequency is nearly 0.0855 Hz. Thus, overall peak to peak noise is nearly 26.892 uV.

Plot for Line Regulation:

Line Regulation is the ability of a power supply to maintain a constant output voltage (Vo) despite changes to the input voltage (Vi)

Straight line : output voltage

Curve line : d(vout)/d(vin) vs input voltage



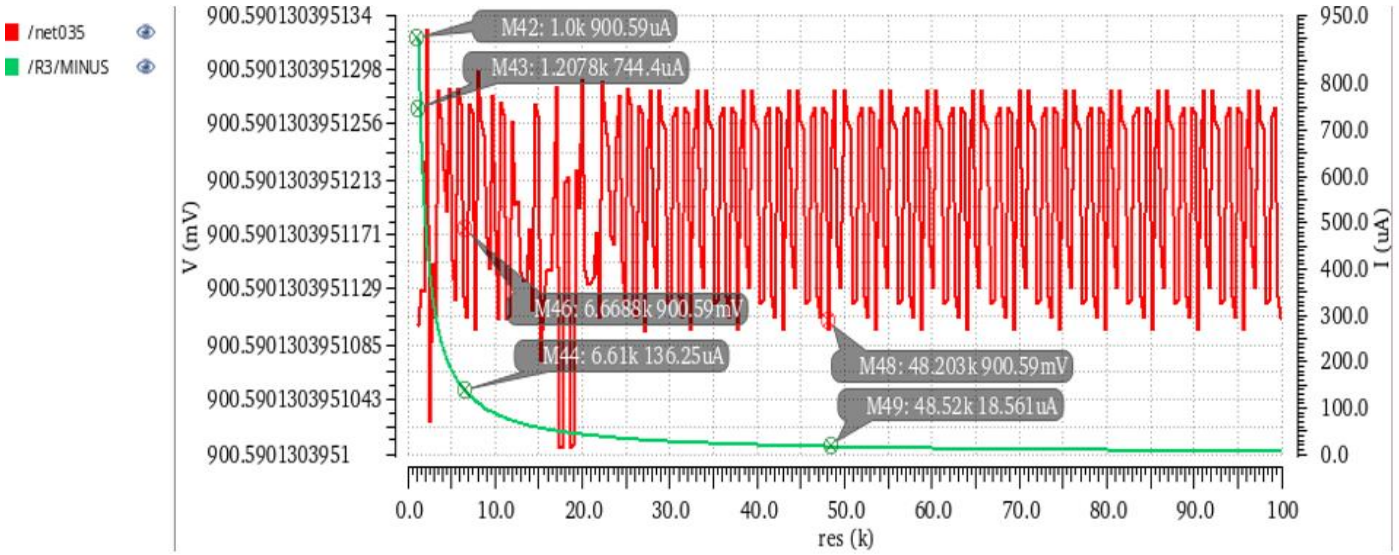
Within 3-4V supply voltage range, the minimum value of line regulation of this circuit is –

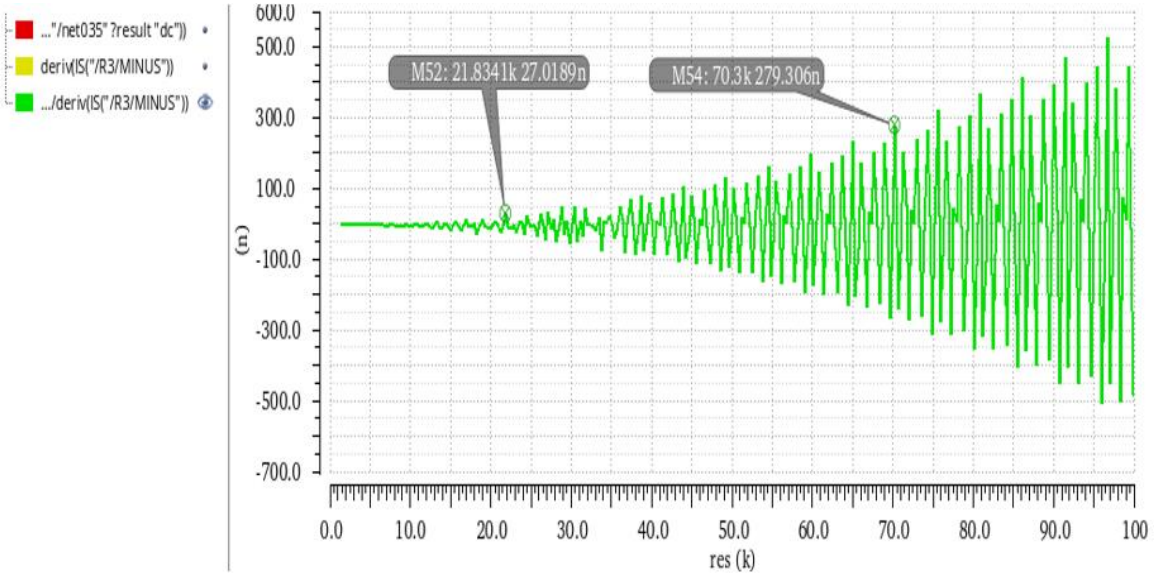
$$\frac{\Delta Vout}{\Delta Vin} = 5.07 mV/V$$

Plot for Load Regulation:

Load regulation is a characteristic that expresses how much the output voltage changes before and after the output current changes. In regards to the electrical characteristics, it expresses how many mV change when the output current is changed from a certain number of of mA to another certain number of mA.

The plot of Vout vs R & dv/di are shown here:

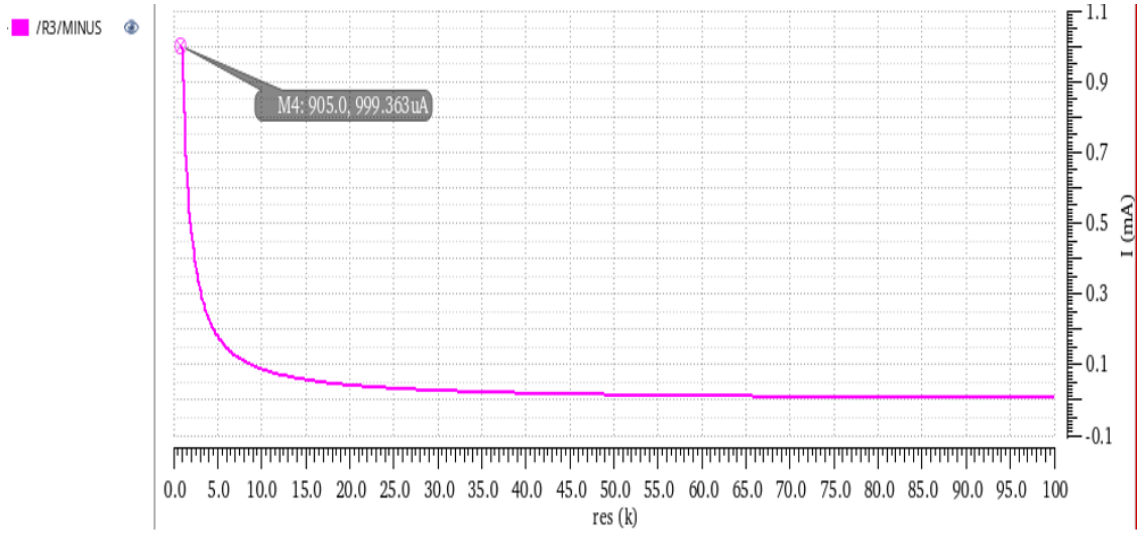




The max value is 279.306n mV/mA.

Plot of Output Current Capability:

For 4 V input,



We get the maximum output current of 1mA at 905 Ohm load.

Final Specs:

Vref	900.425	mV
Supply Current (max)	58.375	uA
Output Voltage Noise	26.892 (0.1 Hz to 10 Hz)	uV P-P
Output Current Capability	999.363	uA
Temperature Coefficient	20.197	ppm/ C
Input Voltage Range	2.6-4.7	V
Line Regulation	5.07	mV/V
Load Regulation	2.79×10^{-7}	mV/mA

6 Future Work (PO(l))

Our designed circuit can be improved by using an operational amplifier in PTAT circuit. Moreover, BJT is much bigger in size and fabrication of BJT is problematic. Hence, all MOSFET structures can be used in future.

7 References

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