

Sub-1 V power supply CMOS Bandgap reference

Fuding Ge

Power supply limitation of conventional design

The operation principle of conventional bandgap reference is to sum the forward-biased junction voltage with a negative tempco (V_{be} in CMOS) with the amplified thermal voltage with a positive tempco. The minimum power supply voltage is high than 1 V due to:

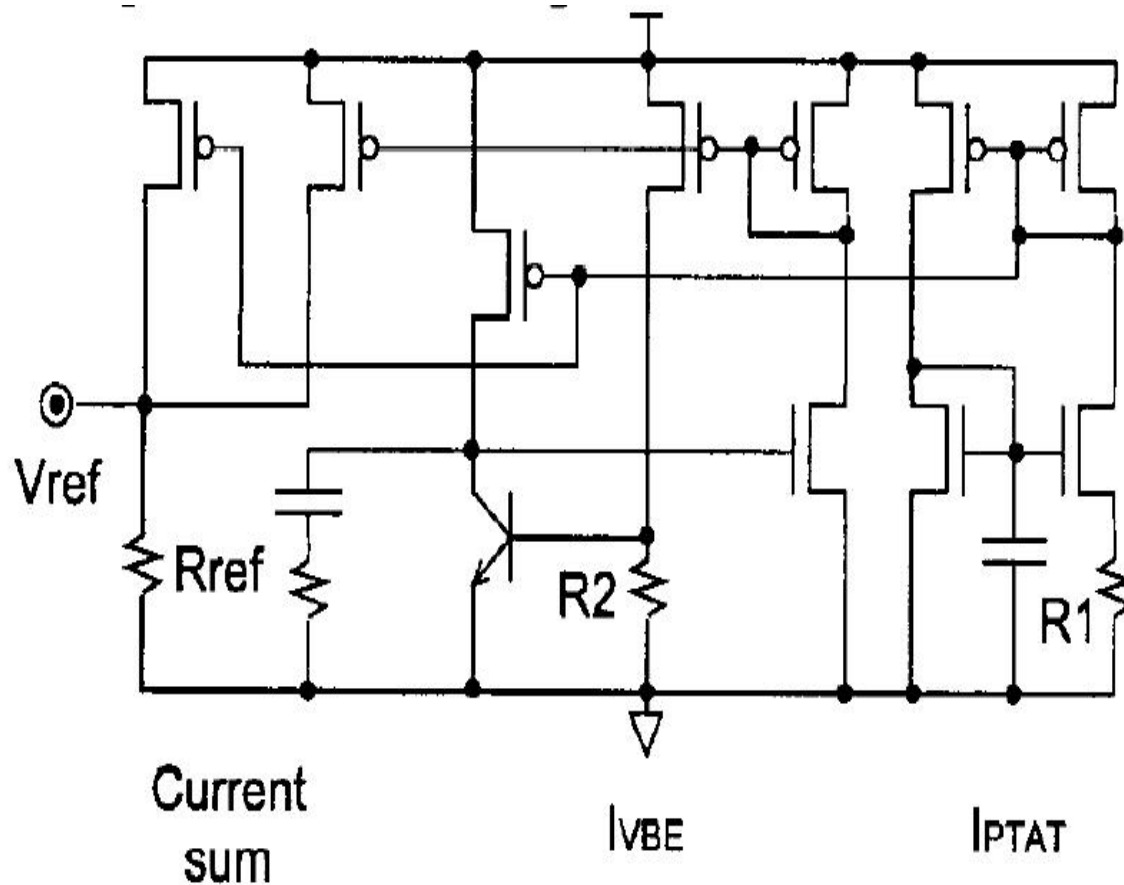
- The reference is about 1.25 V which is larger than 1V
- The PTAT current generation loop is limited by V_{BE} and the input common mode voltage of the amplifier

Low power supply design principle

Two principles for low power supply design:

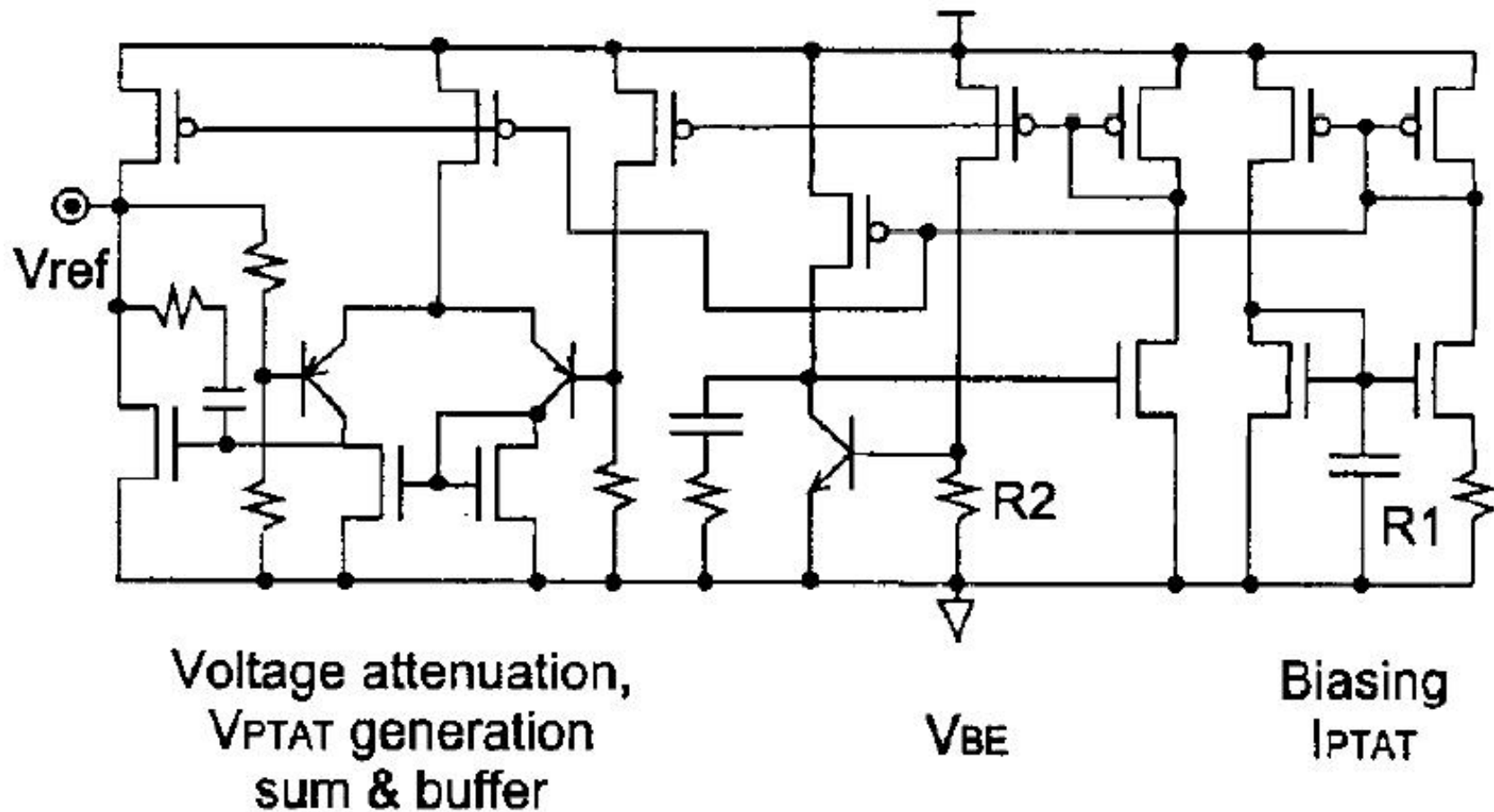
- summing two current with opposite tempco, then reference generated by controlled resistor.
- summing two attenuated voltage with opposite tempco (using resistive voltage divider).

Current-summing mode [1]

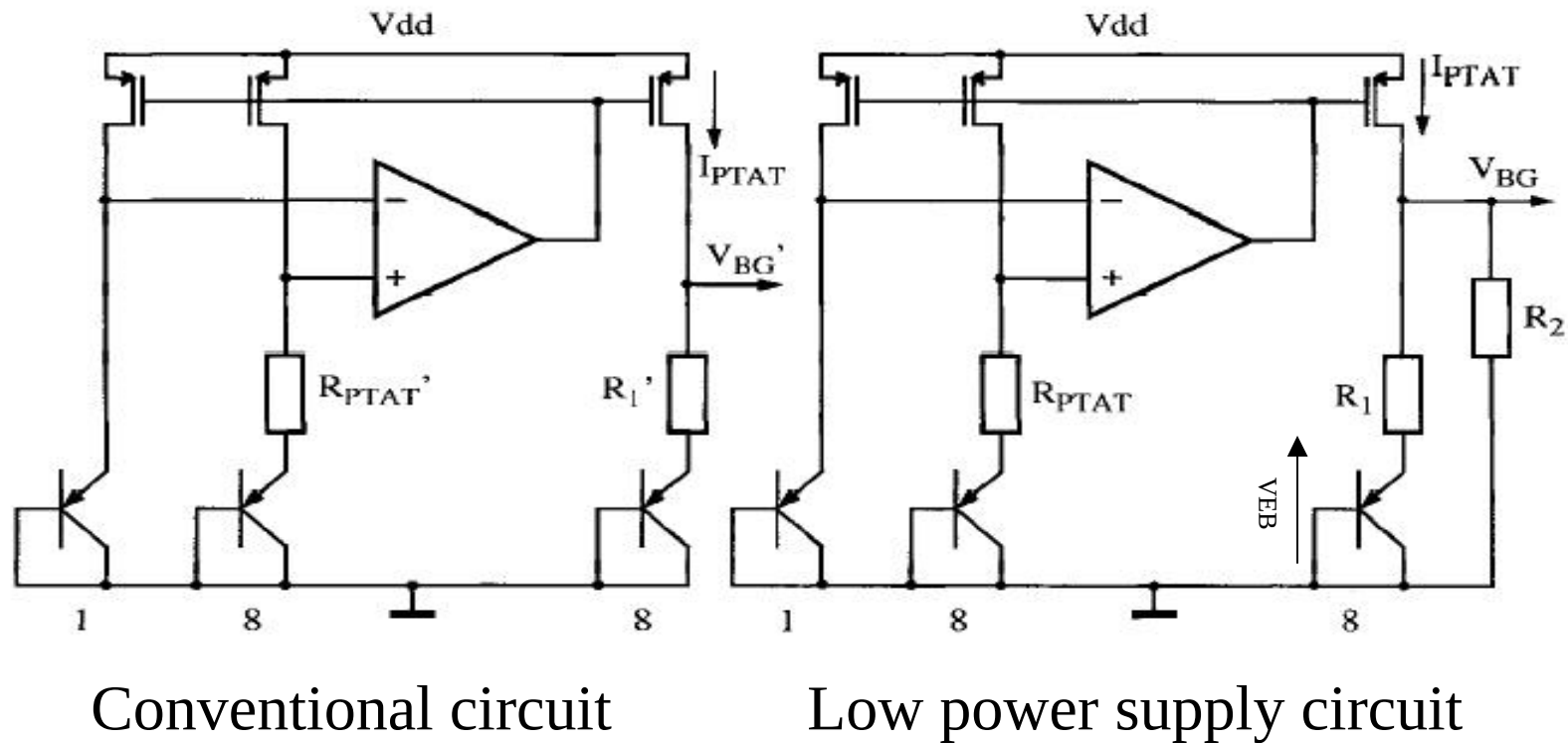


Fuding Ge: Low power supply
bandgap reference

Voltage-summing mode [1]



A simple circuit based on resistive divider network [2]



Voltage reference value

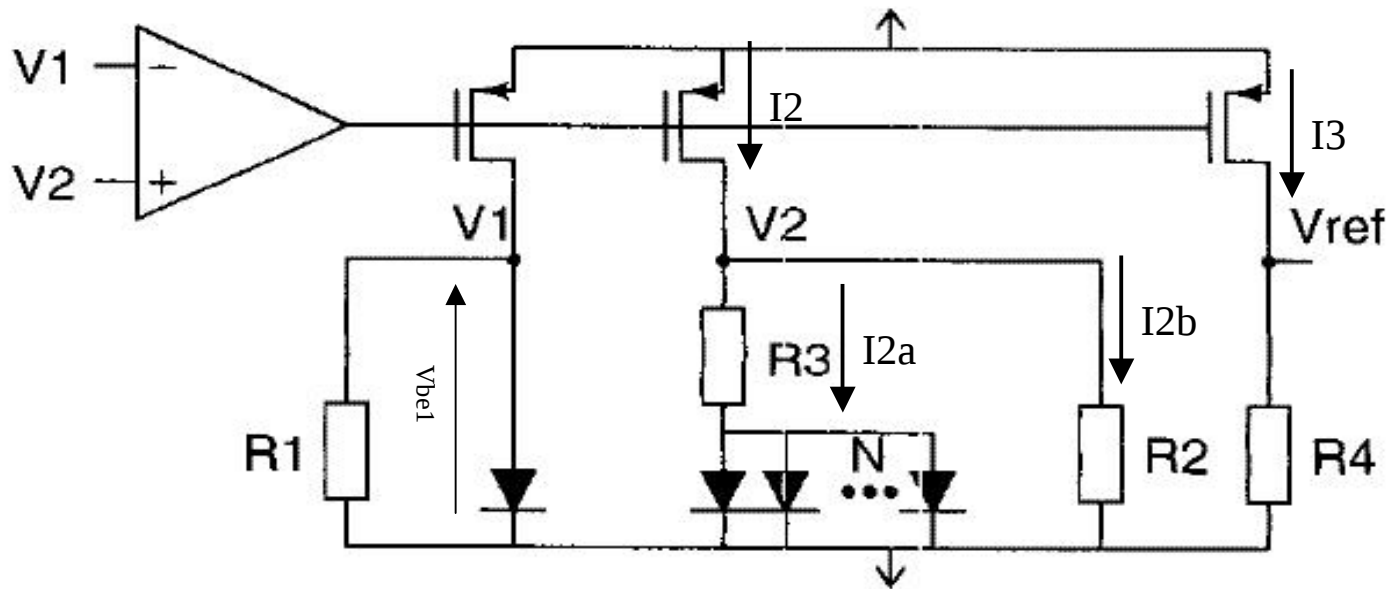
$$I_{PTAT} = \frac{V_T \ln n}{R_{PTAT}}$$

$$\frac{V_{BG} - V_{EB}}{R1} + \frac{V_{BG}}{R2} = I_{PTAT}$$

$$V_{BG} = \frac{R2}{R1 + R2} (V_{EB} + I_{PTAT} R1) = \frac{R2}{R1 + R2} \left(V_{EB} + \frac{V_T \ln n}{R_{PTAT}} R1 \right)$$

R1=92.5 KOhms, R2=142.5 KOhms, VBG=0.67 V

Bandgap reference based on resistive divider network [3]



The current of the controlled source is proportional to

$V_{be1} + \frac{R2}{R3} \Delta V_{be}$ which is exactly what is needed for a temperature independent reference

$$V_{ref} = I_3 R4 = (I2a + I2b) R4 = R4 \left(\frac{V_{be1}}{R2} + \frac{\Delta V_{be}}{R3} \right)$$

$$V_{ref} = \frac{R4}{R2} \cdot \left(V_{be1} + \frac{R2}{R3} \Delta V_{be} \right)$$

$V_{be1} + \frac{R2}{R3} \Delta V_{be}$ is the conventional bandgap reference ($\sim 1.25V$)

Thus the reference voltage can be freely changed from the conventional bandgap reference of 1.25

Reference voltage & resistor values

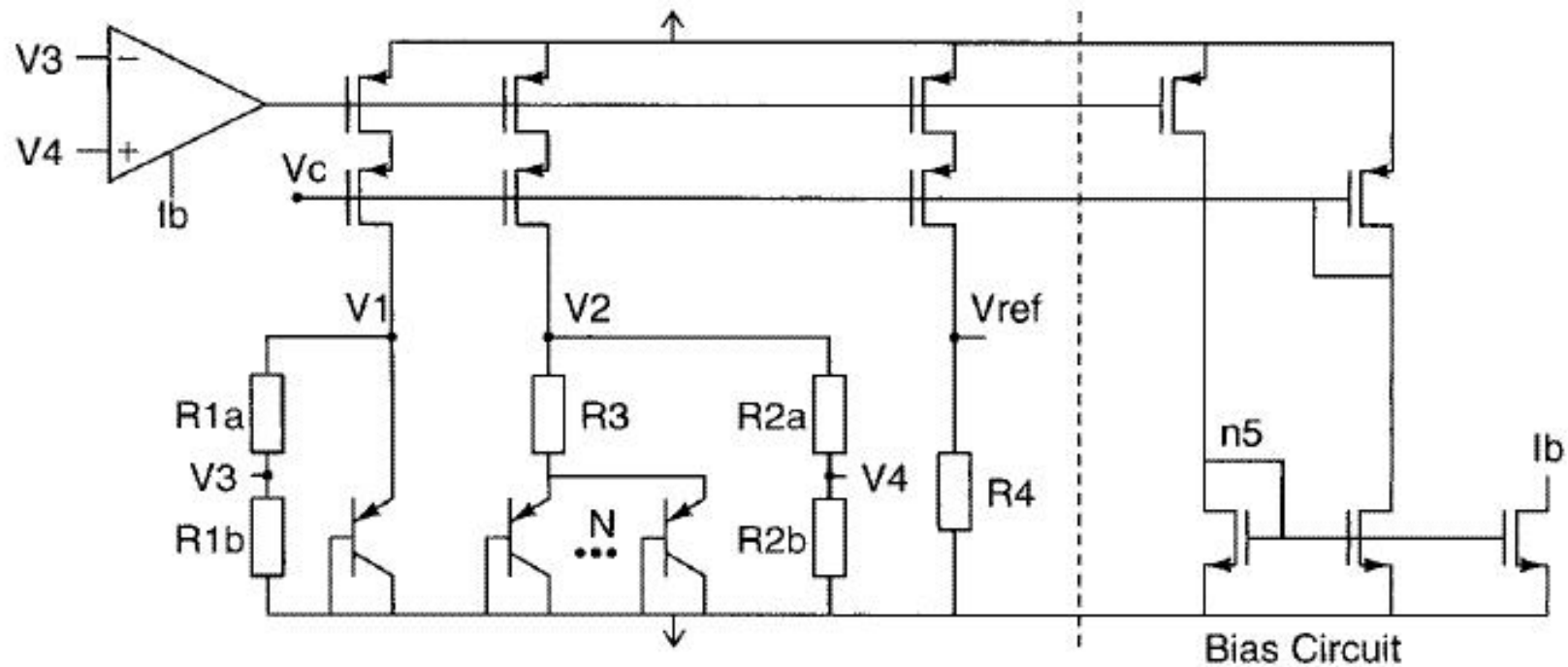
For the original design:

$R1=R2=2063\text{K}\Omega$

$R4=884\text{K}\Omega$,

$$V_{ref} = \frac{884}{2063} \cdot 1.25 \approx 0.53V$$

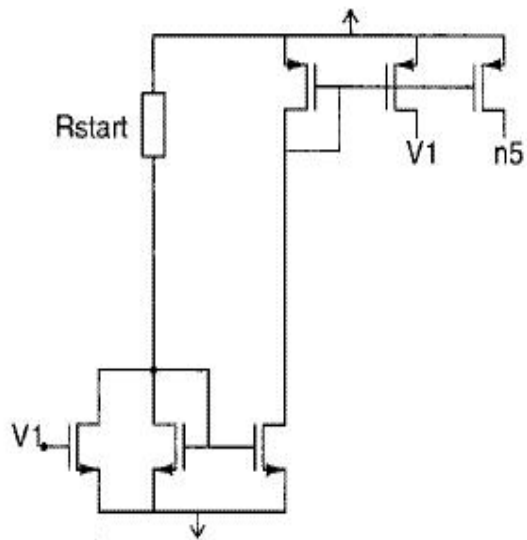
Improved version by Waltari [4]



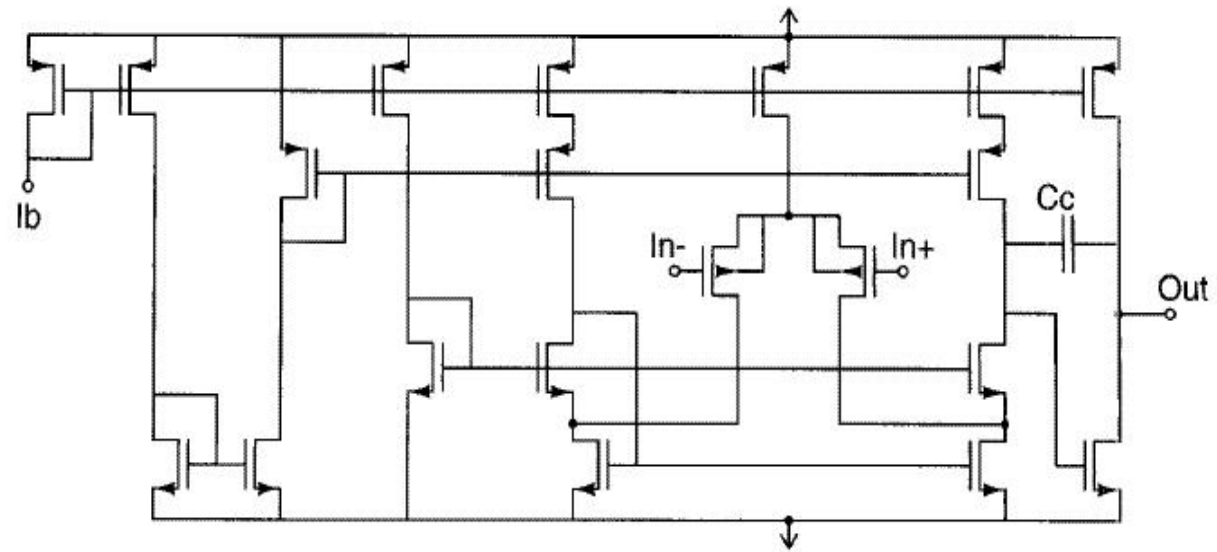
Improvements

Larger output impedance of the current source by cascoding device;
V1 and V2 is about 0.7V; V3 and V4 in the range of 0.15 to 0.2V.
Better input range for the opamp.

Opamp and start-up circuit [4]

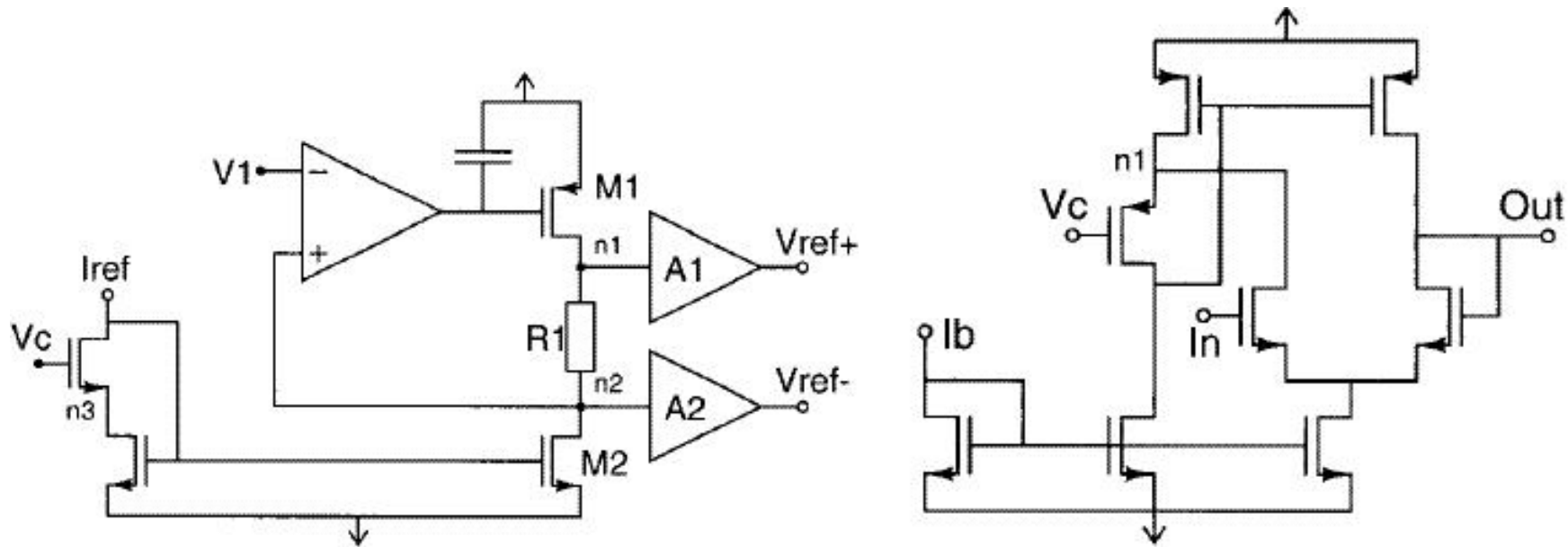


Start-up circuit



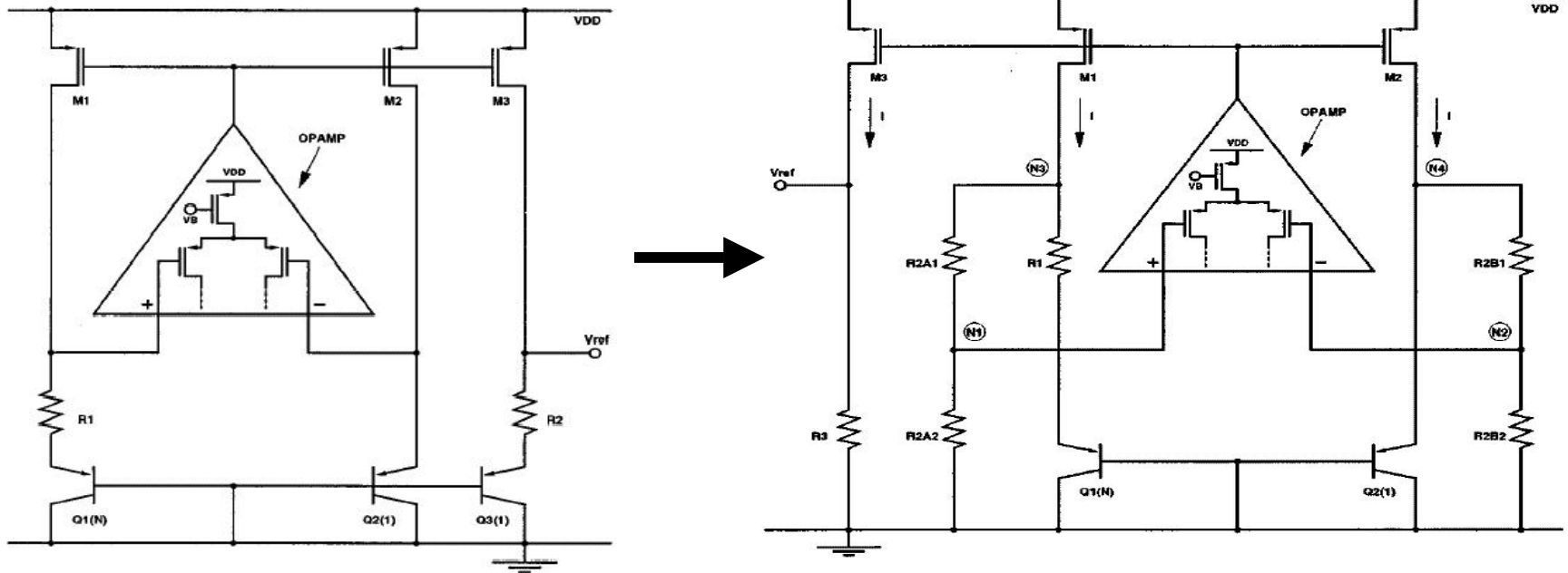
Note that the opamp is self-biased from the bandgap core. Good design!

Differential reference driver circuit

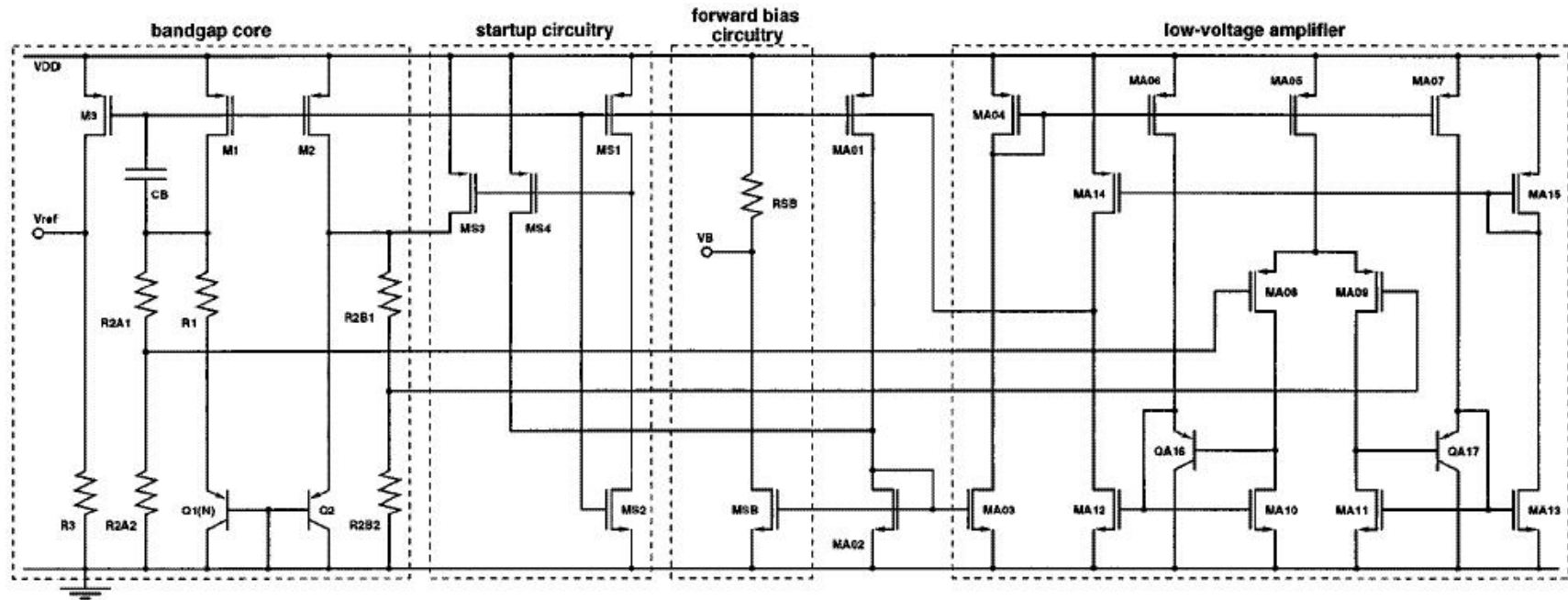


Circuits used to provide the voltage reference for ADC

Improved version by Leung [5]

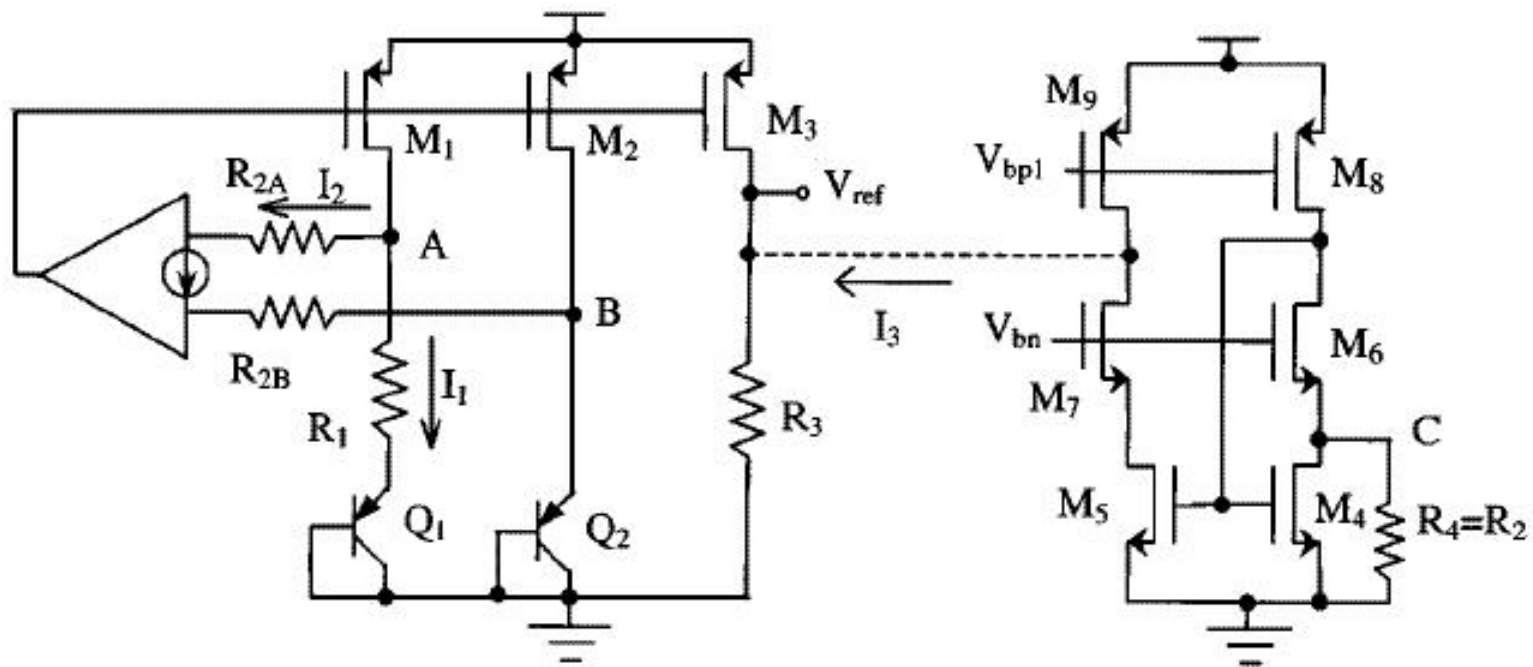


Complete schematic [5]

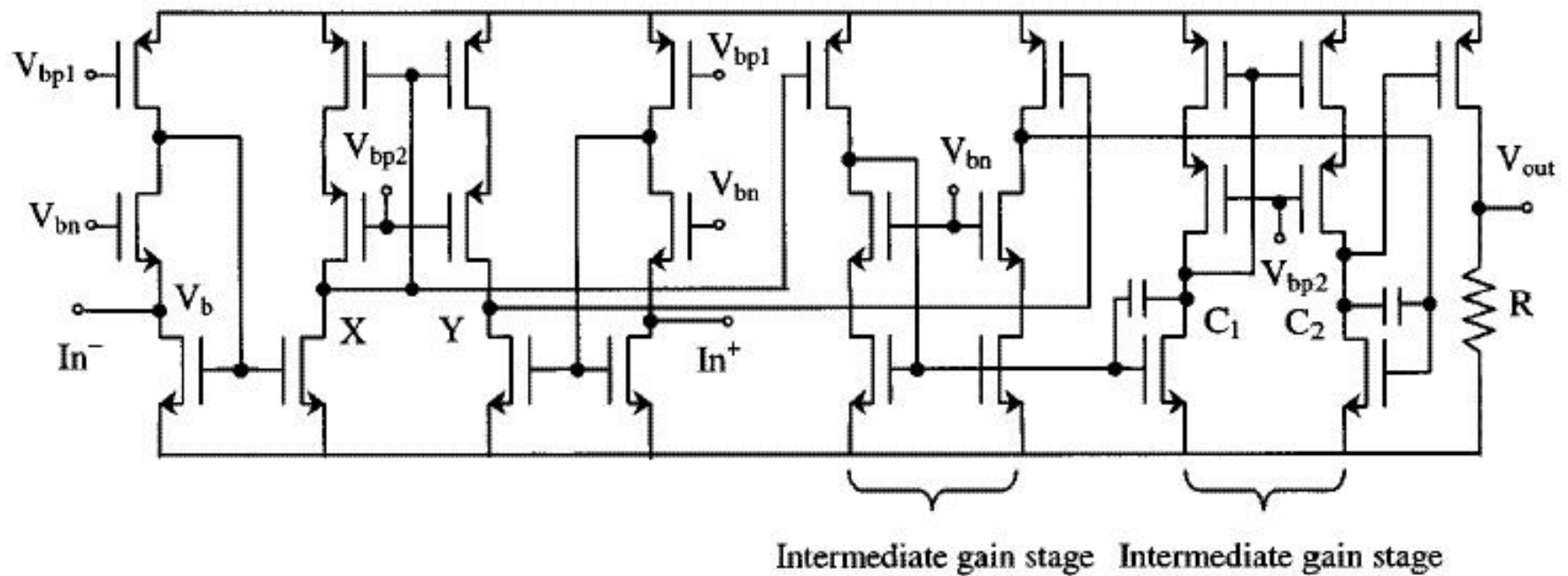


- Forward-bias the source-bulk junction to reduce the threshold voltage of the pMOS
- Low-V amplifier with DC level-shifting current mirror

Using transimpedance amplifier [6]



Transimpedance amplifier circuit



References

- [1]: Ripamonti, G.; Bertolaccini, M.; Peritore, R.; Schippers, S, “Low power-low voltage band gap references for flash- EEPROM integrated circuits: design alternatives and experiments”, Electronics, Circuits and Systems, 1999. Proceedings of ICECS '99. The 6th IEEE International Conference on , Volume: 2 , 1999 pp: 635 -638 vol.2
- [2] Neuteboom, H.; Kup, B.M.J.; Janssens, M. “A DSP-based hearing instrument IC”, Solid-State Circuits, IEEE Journal of , Volume: 32 Issue: 11 , Nov. 1997, pp: 1790 –1806
- [3] Hironori Banba et al, “A CMOS bandgap reference circuit with sub-1-V operation”, IEEE JSSC, 1999(5), Vol34, pp670-674
- [4] Mikko Waltari, Halonen, K, “Reference voltage driver for low-voltage CMOS A/D converters”, Electronics, Circuits and Systems, 2000. ICECS 2000. The 7th IEEE International Conference on , Volume: 1 , 2000 Page(s): 28 -31 vol.1
- [5] Ka Nang Leung, Mok, P.K.T, “A sub-1-V 15-ppm/°C CMOS bandgap voltage reference without requiring low threshold voltage device”, Solid-State Circuits, IEEE Journal of, pp 526 – 530, April 2002
- [6] Yueming Jiang, Lee, E.K.F, “Design of low-voltage bandgap reference using transimpedance amplifier’, Circuits and Systems II: Analog and Digital Signal Processing, IEEE Transactions on On page(s): 552 - 555 June 2000