

## EE 501 Lab9 Widlar Biasing Circuit and Bandgap Reference Circuit

Due Nov. 19, 2015

### Objective:

1. Understand the Widlar current source circuit.
2. Built a Self-biasing current source circuit.
3. Understand the bandgap reference circuit principle.
4. Investigate how to build bandgap reference circuit.

### Pre-lab:

1. Investigate how the specifications of your amplifier (designed in Lab5) vary with temperature and supply voltage.
2. Plot  $g_m$  (input pair), GBW, phase margin and UGF vs. temperature ( $-25^{\circ}C$  to  $85^{\circ}C$ ).
3. Plot total current vs. temperature ( $-25^{\circ}C$  to  $85^{\circ}C$ ).
4. Plot all specs above vs. supply voltage ( $V_{dd}-V_{ss}$ : from 2V to 6V)
5. Tabulate the variance (in percent) of all specifications mentioned above over temperature and supply voltage.
6. Try to explain why.

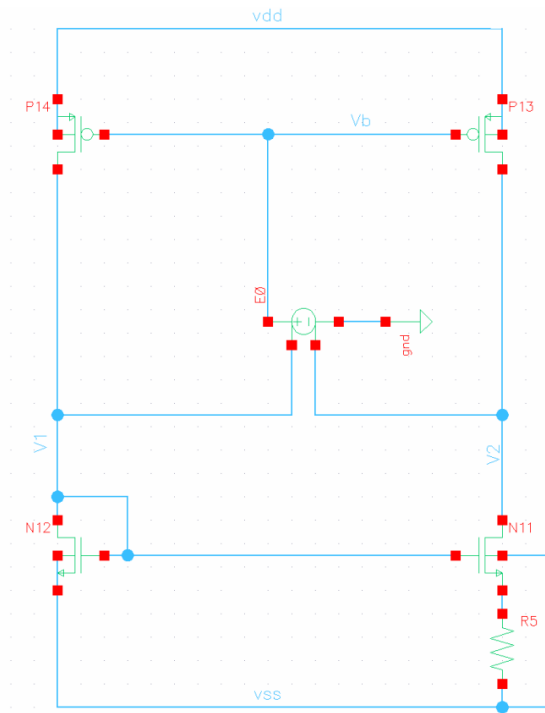
### Task A:

#### Procedures

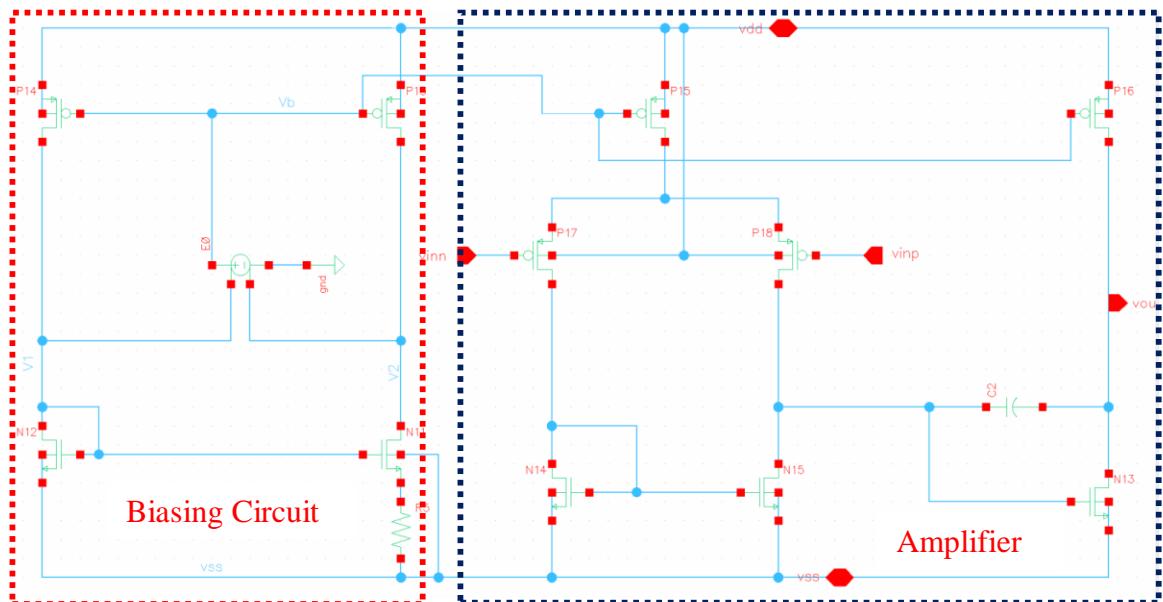
From pre-lab section, you should notice that all the specs vary with temperature. Therefore, in order to make our amplifier PVT robust, we need to generate a biasing circuit to keep input  $g_m$  constant with temperature.

In EE501 lecture, we introduced the Widlar current source and design strategy. Here we design a Self-biased current source based on Widlar current source which could generate constant  $g_m$  for us.

1. Design a self-biased Widlar current source circuit using design strategy mentioned in EE501 lecture ([References.pptx page 33](#)). And you can choose the desired biasing current as 10uA. The circuit is given by following. VCVS is used as a feedback opamp, as shown in References page 43 which improved sensitivity.

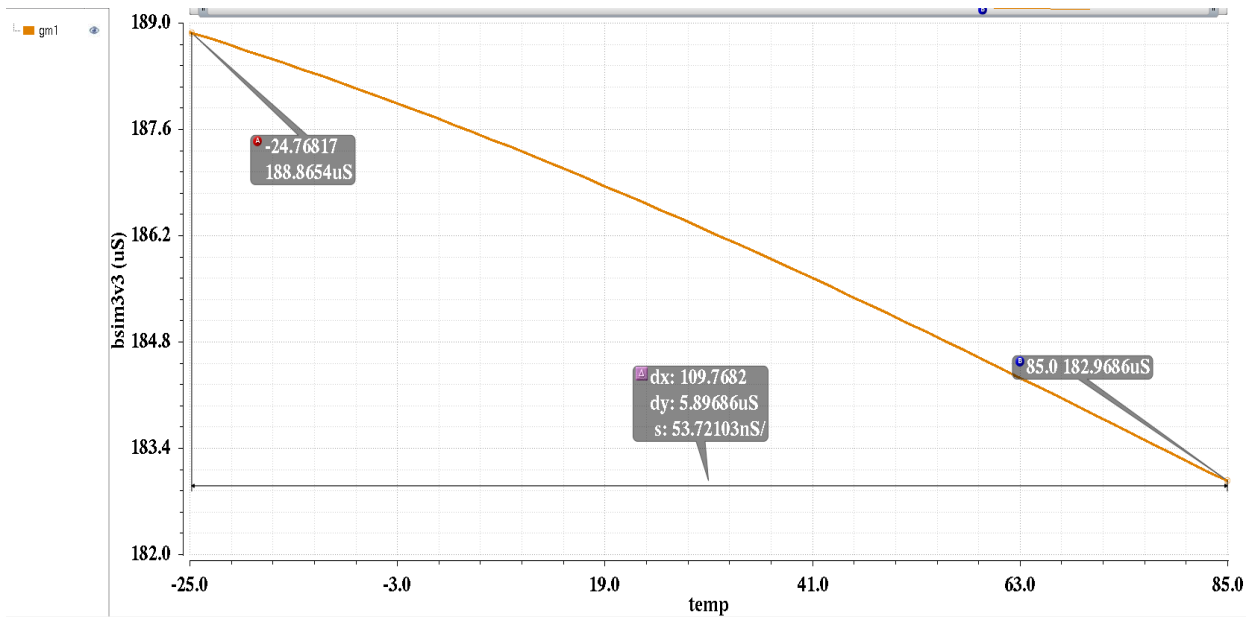


- Using this biasing circuit to bias your amplifier you designed in Lab5. Redo pre-lab step2, 3, and 4.

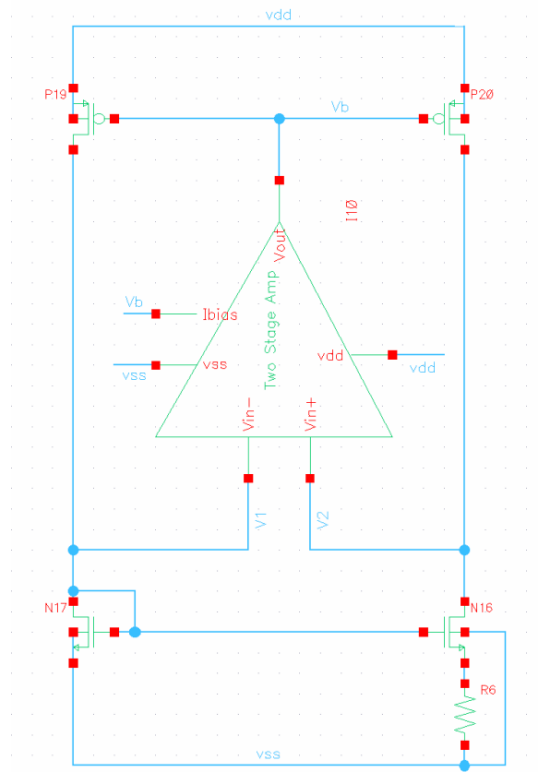


By sizing your biasing circuit properly, achieve gm, GBW, PM and UGF constancy within 5% variation through temperature and supply voltage.

One example for gm constancy is given by following.

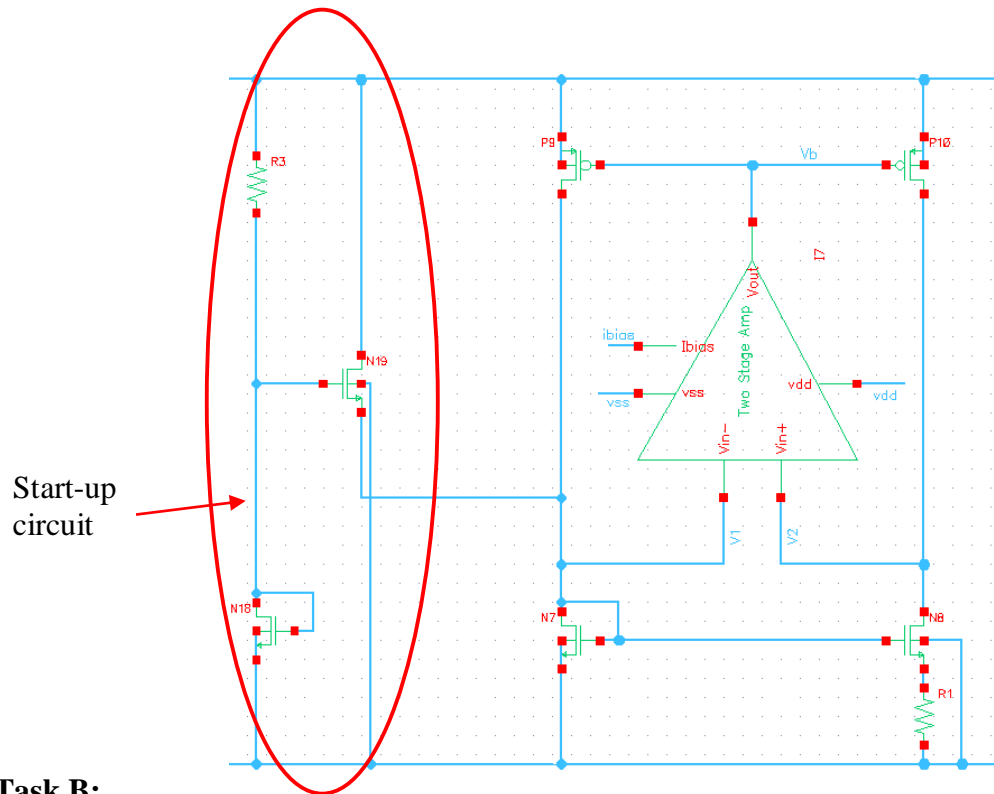


- Replace the VCVS with the amplifier you designed in Lab5, then repeat step2. (By replacing the VCVS, your amplifier also should be biased from this circuit, and the compensation capacitance may change, you could choose 200fF in this one).



$C_c$  in this amplifier is 200fF

- Add start-up circuit as shown as following. (You may choose different type start-up circuits as shown in lecture)



### Task B:

In previous section, you may notice that although we could achieve gm, GBW and UGF constant within 5% over temperature, the current variation is much larger. How could we get a constant current or voltage reference through temperature? In the lecture, we introduced bandgap reference which could achieve constant Vref and Iref.

1. Build a bandgap circuit following Fig. 2. (VCVS is used as a feedback opamp by assuming an opamp has been properly designed for generating supply independent reference. In a real design, the stability of the feedback loop should be assured.)
2. Choose the value of R0 and N. The resistor's value is always in the range of kilo ohms.
3. Estimate R1 with equation  $\frac{R_1 \ln(N)}{R_0} \approx 24$ .
4. Tune R1 to achieve zero temperature coefficient (TC) at the required temperature (such as 27 °C).
5. Then sweep VDD from 2 to 6 V and observe the independence with VDD.
6. Add the start-up circuit as shown in Fig. 5.
7. Replace the VSVS with designed opamp then repeat step 4.

### Report:

1. Show the simulation results in pre-lab section.

2. Briefly describe sizing steps for Self-biasing current source.
3. Show the complete schematic and simulation results of Task A.
4. Briefly explain sizing steps for Bandgap reference.
5. Show the complete schematic and simulation results of Task B.
6. Briefly state what you have learned.
7. Additional comments, problems and doubts.

## Appendix:

The bandgap reference voltage generator is designed to provide a stable reference voltage across the device operating temperature and voltage. The design uses a known BGR circuit, but replaces the PN junction diodes with MOSFET connection diodes.

The proposed bandgap voltage reference consists three circuit blocks: an opamp (VCVS), a bandgap core, and a startup circuit.

The bandgap reference circuit is used to generate a temperature independent voltage and is shown below. A key element in a bandgap circuit core is the diode. Unfortunately, AMI 0.5um technology does not have diode models in its library. In this work a PMOS diode connected elements have been used. The drain, gate, and source of the PMOS tied together to form the Anode and the body of the PMOS forms the Cathode. Figure 1 shows the PMOS diode used in proposed design.

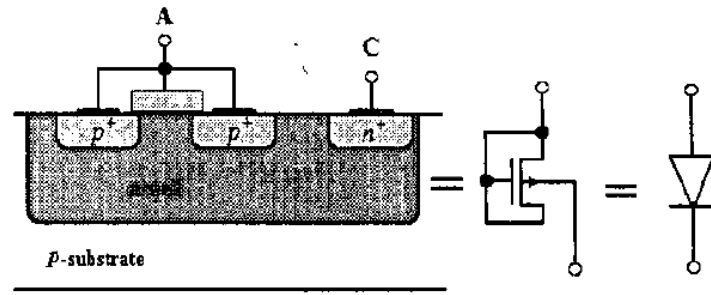


Figure 1 Generate a diode from a PMOS transistor.

The PMOS diode has the characteristic below:

1. Exponential relationship of current to voltage across holds.
2. PMOS diode exhibits a negative temperature coefficient similar to regular diodes.
3. The number of parallel components N affects the cut-in voltage (knee voltage).

The bandgap core provides the negative and positive temperature coefficients through the diode elements ( $\frac{\partial V_{be}}{\partial T}$ ,  $\frac{\partial V_T}{\partial T}$ ). For a diode,  $I = I_s(e^{\frac{V_{be}}{V_T}} - 1)$ , where  $\frac{\partial V_{be}}{\partial T} \approx -2\text{mV/C}$  at room temperature, and  $V_T = \frac{kT}{q}$ ,  $\frac{\partial V_T}{\partial T} \approx 0.085\text{V/C}$ .



$$\frac{\partial V_{\text{ref}}}{\partial T} = \frac{\partial V_{\text{be1}}}{\partial T} \frac{1}{R_1} + \frac{\partial V_T}{\partial T} \frac{\ln(N)}{R_0}$$

To obtain temperature independent reference voltage,  $R_0$ ,  $R_1$ , and  $N$  should meet the following relationship

$$\frac{R_1 \ln(N)}{R_0} \approx \frac{2}{0.085} \approx 24$$

A sample  $V_{\text{ref}}$  vs. Temperature plot is given as below. The  $V_{\text{ref}}$  is around 1.177 V at room temperature. ( $V_{\text{DD}}=5\text{V}$ ,  $V_{\text{SS}}=\text{gnd}$ )

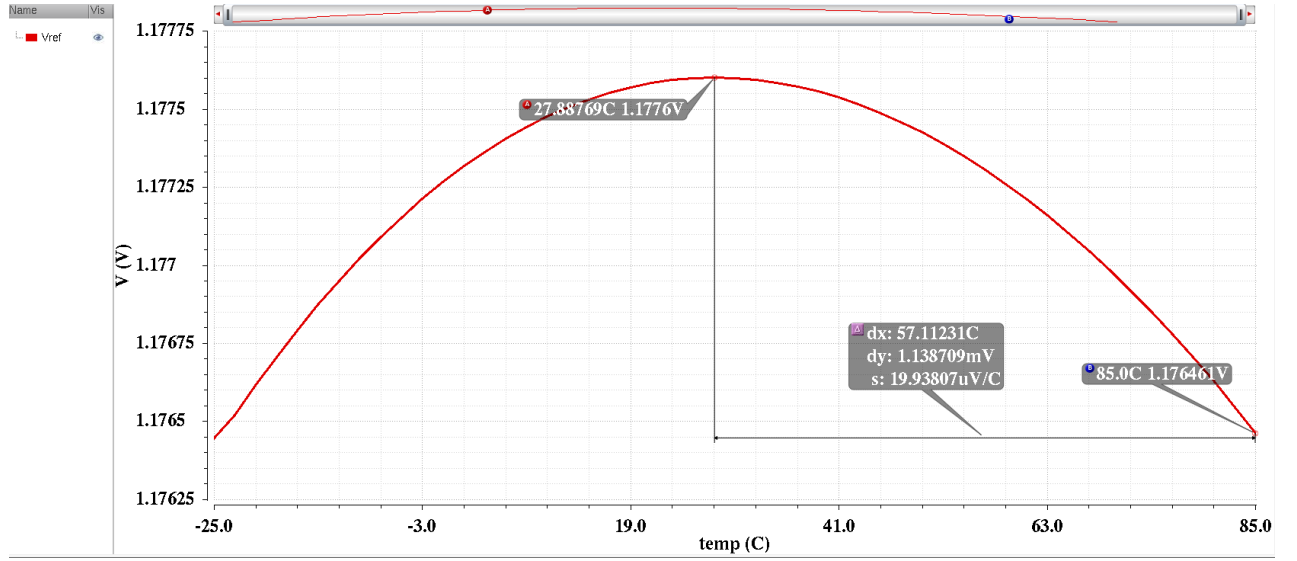


Figure 3  $V_{\text{ref}}$  vs. Temperature

The temperature coefficient (TC) was calculated using equation

$$\begin{aligned} \text{TC} &= \frac{1}{V_{\text{ref}}} \left( \frac{\partial V_{\text{ref}}}{\partial T} \right) = \frac{1}{V_{\text{ref}}} \left( \frac{V_{\text{ref}_{\text{max}}} - V_{\text{ref}_{\text{min}}}}{T_{\text{max}} - T_{\text{min}}} \right) \times 10^6 \\ &= \frac{1}{1.177} \left( \frac{1.138 \times 10^{-3}}{85 - (-25)} \right) \times 10^6 \approx 8.79 \text{ ppm/}^\circ\text{C} \end{aligned}$$

Then sweep  $V_{\text{DD}}$  from 2 to 6 V and observe the independence with  $V_{\text{DD}}$ .



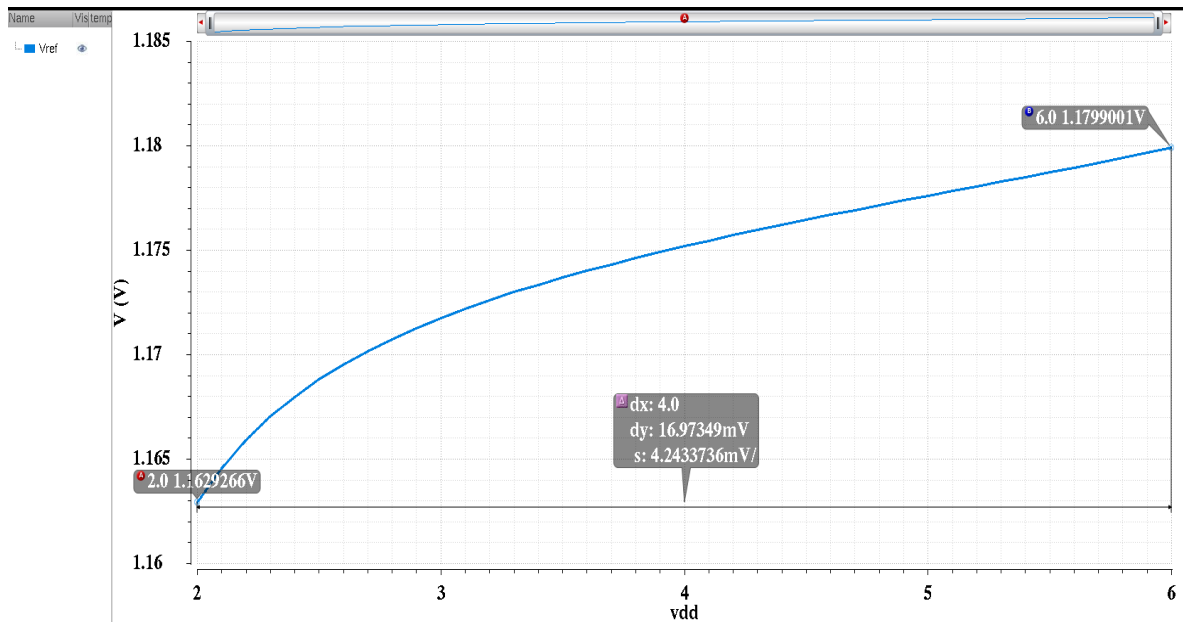


Figure 4  $V_{ref}$  vs.  $V_{DD}$

In simulation, your circuit may be able to start up. However, it doesn't guarantee that your circuit can start up after fabrication. So you should consider startup as a potential problem during the preliminary design phase. Build startup circuit as below or you can use other startup structure.

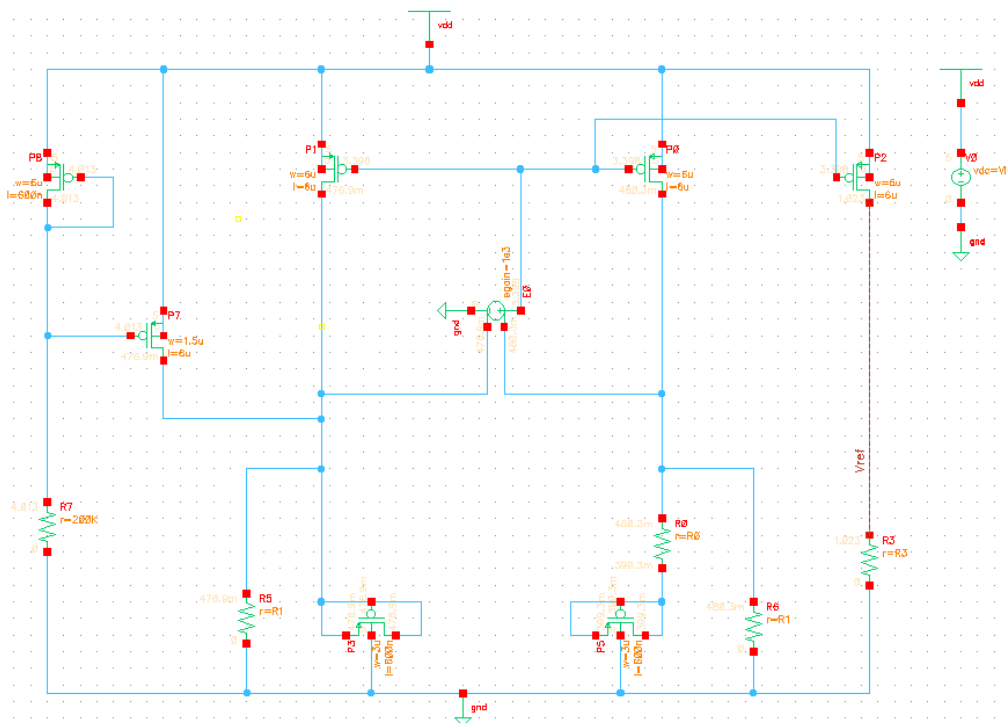


Figure 5 Bandgap reference circuit with startup circuit