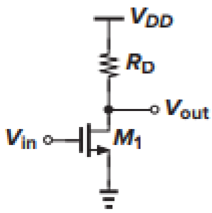
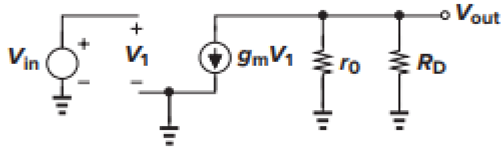
Common Source

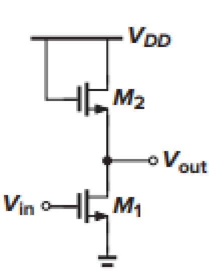




Maximize Gain

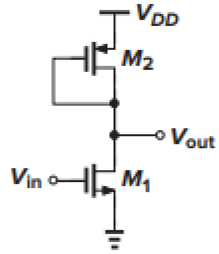
$$A_v = -\sqrt{2\mu_n C_{ox}\frac{W}{L} I_D}\,\frac{V_{RD}}{I_D}$$

Diode Connected Load



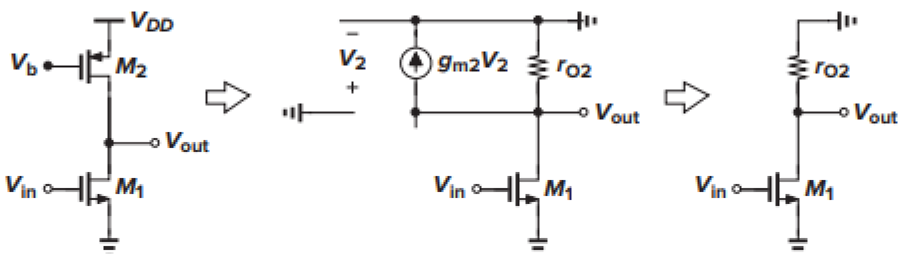
$$A_v = -g_{m1}\frac{1}{g_{m2}+g_{mb2}} = -\frac{g_{m1}}{g_{m2}}\frac{1}{1+\eta}$$

$$A_v = -\sqrt{\frac{(W/L)_1}{(W/L)_2}}\,\frac{1}{1+\eta}$$



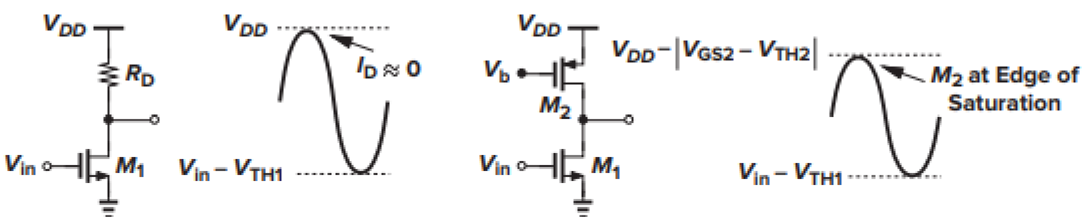
$$A_v = -\sqrt{\frac{\mu_n (W/L)_1}{\mu_p (W/L)_2}}$$

CS with current-source load



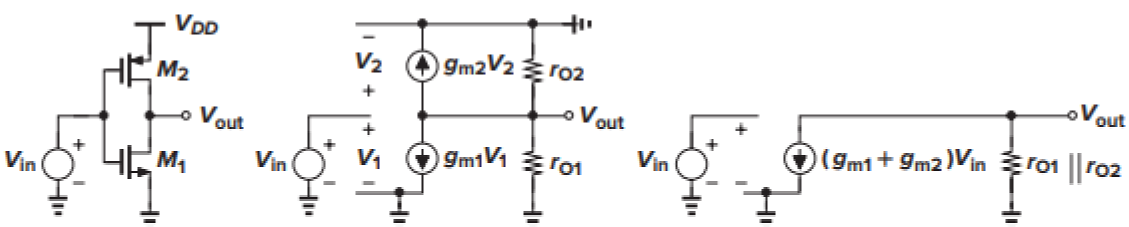
$$A_v = -g_{m1}(r_{O1}\|r_{O2})$$

Voltage Swing

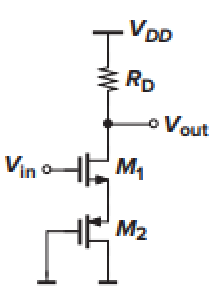


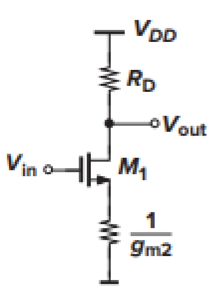
CS with Active Load

$$A_v = -(g_{m1}+g_{m2})(r_{O1}\|r_{O2})$$



CS with Source Degeneration





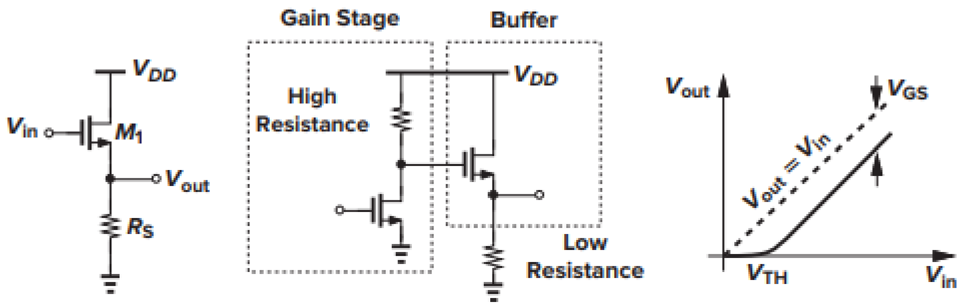
$$G_m = \frac{g_m}{1+g_m R_S}$$

$$A_v = -G_m R_D = \frac{-g_m R_D}{1+g_m R_S}$$

$$A_v = -\frac{R_D}{\frac{1}{g_m}+R_S}$$

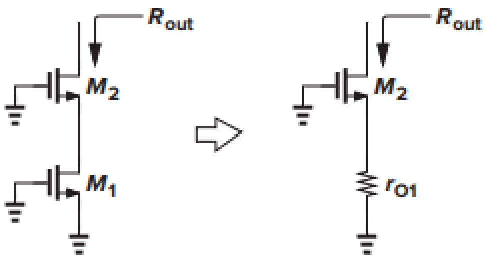
$$A_v = -\frac{R_D}{\frac{1}{g_{m1}}+\frac{1}{g_{m2}}}$$

Source Follower



$$A_v = \frac{g_m R_S}{1 + (g_m + g_{mb}) R_S}$$

Cascode



$$R_{out} = [1 + (g_{m2} + g_{mb2}) r_{O2}] r_{O1} + r_{O2}$$

Assuming $g_m r_O \gg 1$, we have $R_{out} \approx (g_{m2} + g_{mb2}) r_{O2} r_{O1}$.

A. Negative-TC Voltage (CTAT)

For a bipolar device, the forward voltage of a *pn*-junction diode exhibits a negative TC.

$$I_C = I_s \exp(V_{BE}/V_T) \text{ where } V_T = \frac{kT}{q}$$

$$I_S = bT^{4+m} \exp(-\frac{Eg}{kT})$$

$$V_{BE} = V_T \, ln\left(\frac{I_C}{I_S}\right)$$

$$\frac{\partial V_{BE}}{\partial T} = \frac{\partial V_T}{\partial T} \, ln \frac{I_C}{I_S} - \frac{V_T}{I_S} \frac{\partial I_S}{\partial T}$$

$$\frac{V_T}{I_S} \frac{\partial I_S}{\partial T} = (4 + m) \frac{V_T}{T} + \frac{E_g}{kT^2} V_T$$

$$\frac{\partial V_{BE}}{\partial T} = \frac{V_T}{T} \, ln \frac{I_C}{I_S} - (4 + m) \frac{V_T}{T} + \frac{E_g}{kT^2} V_T$$

$$= \frac{V_{BE} - (4 + m) V_T - E_g/q}{T}$$

Thus, at $T = 300K$ and $V_{BE} \approx 750\text{mV}$, the change in TC voltage with respect to temperature is $\partial V_{BE}/\partial T \approx -1.5\text{mV}$.

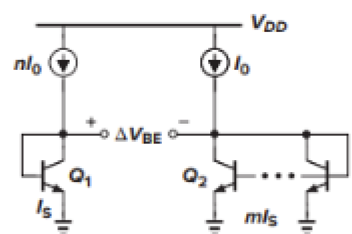


Fig. 1. PTAT Circuit

$$\Delta V_{BE} = V_{BE1} - V_{BE2}$$

$$= V_T \, ln(\frac{nI_0}{I_S}) - V_T \, ln(\frac{I_0}{mI_S})$$

$$= V_T \, ln(nm)$$

$$= \frac{kT}{q} \, ln(nm)$$

$$\frac{\partial}{\partial T} \Delta V_{BE} = \frac{\partial}{\partial T} \frac{kT}{q} \, ln(nm)$$

$$= \frac{k}{q} \, ln(nm)$$

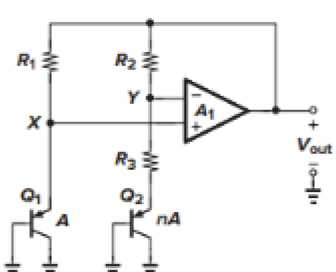
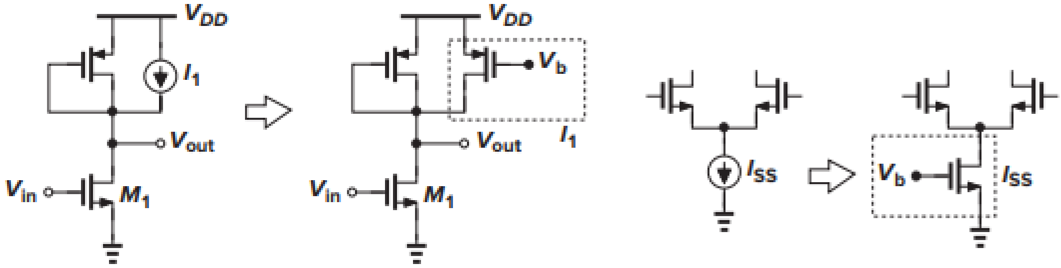


Fig. 2. Practical Bandgap Implementation

$$V_{REF} = \alpha_1 V_{BE} + \alpha_2 V_T ln(nm)$$

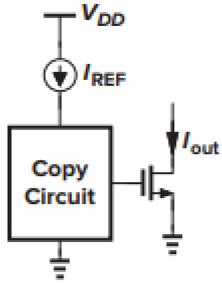
For simplicity, α_1 is chosen to be 1. Then V_{REF} is

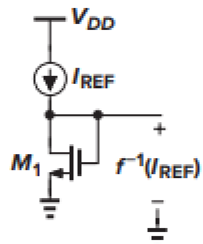
$$V_{REF} = V_{BE} + \alpha_2 V_T ln(m)$$

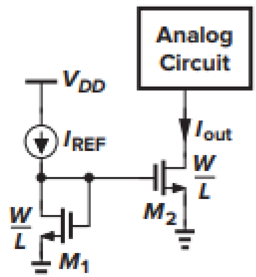


(a) (b)

Figure 5.1 Applications of current sources.







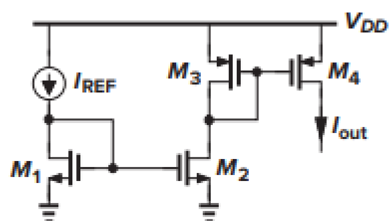
$$I_{REF} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1 (V_{GS} - V_{TH})^2$$

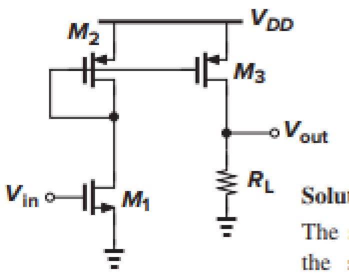
$$I_{out} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_2 (V_{GS} - V_{TH})^2$$

$$I_{out} = \frac{(W/L)_2}{(W/L)_1} I_{REF}$$

It is important to appreciate the cause-and-effect relationships stipulated by $V_{GS} = f^{-1}(I_{REF})$ and $f[f^{-1}(I_{REF})] = I_{REF}$. The former suggests that we must *generate* a V_{GS} *from* I_{REF}; i.e., I_{REF} is the cause and V_{GS} is the effect. A MOSFET can perform this function only if it is configured as a diode while carrying a current of I_{REF} [M_1 in Fig. 5.5(b)]. Similarly, the latter equation indicates that a transistor must sense $f^{-1}(I_{REF})$ $(= V_{GS})$ and generate $f[f^{-1}(I_{REF})]$. In this case, the cause is V_{GS} and the effect is the output current, $f[f^{-1}(I_{REF})]$ [as provided by M_2 in Fig. 5.5(b)].

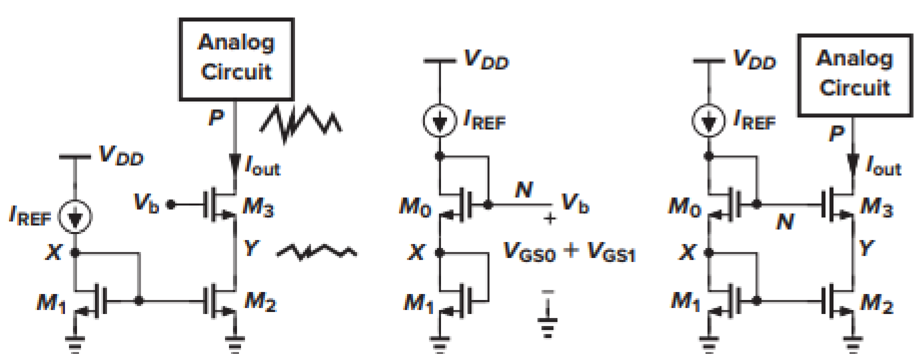
$$|I_{D4}| = \alpha\beta I_{REF}, \alpha = \frac{(W/L)_2}{(W/L)1}, \beta = \frac{(W/L)_4}{(W/L)3}$$





Solution

The small-signal drain current of M_1 is equal to $g_{m1}V_{in}$. Since $I_{D2} = I_{D1}$ and $I_{D3} = I_{D2}(W/L)_3/(W/L)_2$, the small-signal drain current of M_3 is equal to $g_{m1}V_{in}(W/L)_3/(W/L)_2$, yielding a voltage gain of $g_{m1}R_L(W/L)_3/(W/L)_2$.



(a) (b) (c)

Figure 5.12 (a) Cascode current source, (b) modification of mirror circuit to generate the cascode bias voltage, and (c) cascode current mirror.

$$V_N = V_{GS0} + V_{GS1}$$

$$= \sqrt{\frac{2I_{REF}}{\mu_n C_{ox}}}\left[\sqrt{\left(\frac{L}{W}\right)_0} + \sqrt{\left(\frac{L}{W}\right)_1}\right] + V_{TH0} + V_{TH1}$$

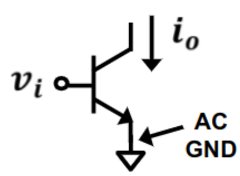
$$V_Y = V_X \approx \sqrt{2I_{REF}/[\mu_n C_{ox}(W/L)_1]} +$$

Table 7.4 Characteristics of MOSFET Amplifiers

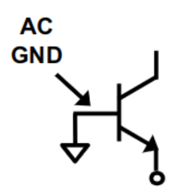
Amplifier type	Characteristics[a]				
	R_{in}	A_{vo}	R_o	A_v	G_v
Common source (Fig. 7.35)	∞	$-g_m R_D$	R_D	$-g_m(R_D \| R_L)$	$-g_m(R_D \| R_L)$
Common source with R_s (Fig. 7.37)	∞	$-\dfrac{g_m R_D}{1+g_m R_s}$	R_D	$\dfrac{-g_m(R_D \| R_L)}{1+g_m R_s}$ $-\dfrac{R_D \| R_L}{1/g_m + R_s}$	$-\dfrac{g_m(R_D \| R_L)}{1+g_m R_s}$ $-\dfrac{R_D \| R_L}{1/g_m + R_s}$
Common gate (Fig. 7.39)	$\dfrac{1}{g_m}$	$g_m R_D$	R_D	$g_m(R_D \| R_L)$	$\dfrac{R_D \| R_L}{R_{sig} + 1/g_m}$
Source follower (Fig. 7.42)	∞	1	$\dfrac{1}{g_m}$	$\dfrac{R_L}{R_L + 1/g_m}$	$\dfrac{R_L}{R_L + 1/g_m}$

[a] For the interpretation of R_{in}, A_{vo}, and R_o, refer to Fig. 7.34(b).

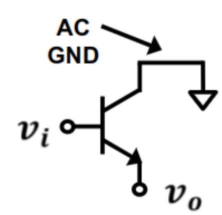
Common Emitter



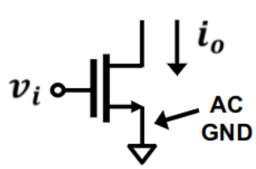
Common Base



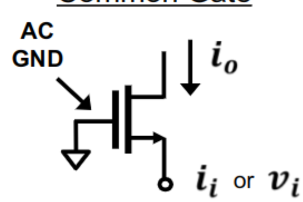
Common Collector or "Emitter Follower"



Common Source



Common Gate



Common Drain or "Source Follower"