LECTURE 040 – COMMON SOURCE AND EMITTER OUTPUT STAGES

(READING: GHLM – 384-398, AH – 218-221)

Objective

The objective of this presentation is:

Show how to design stages that

1.) Provide sufficient output power in the form of voltage or current.

2.) Avoid signal distortion.

3.) Be efficient

4.) Provide protection from abnormal conditions (short circuit, over temperature, etc.)

Outline

- Common source stage
- Common emitter stage
- Summary

COMMON SOURCE OUTPUT STAGE

Current source load inverter

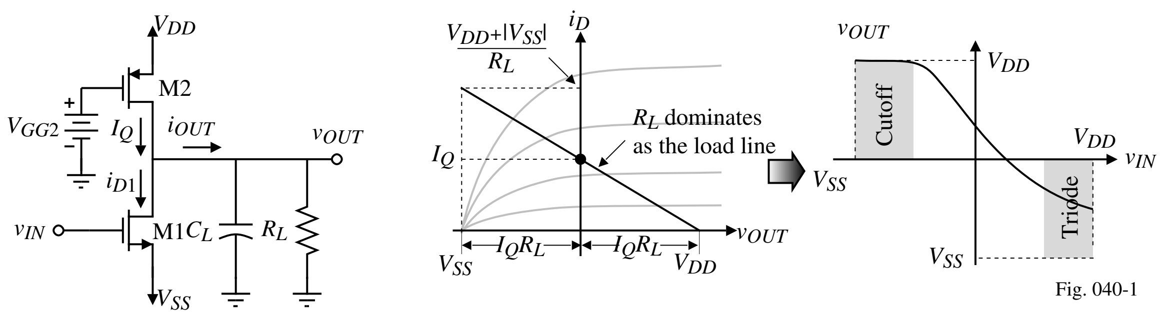

Fig. 040-1

A Class A circuit has current flow in the MOSFETs during the entire period of a sinusoidal signal.

Characteristics of Class A amplifiers:

- Unsymmetrical sinking and sourcing
- Linear
- Poor efficiency

$$\text{Efficiency} = \frac{P_{RL}}{P_{Supply}} = \frac{\dfrac{v_{OUT}(\text{peak})^2}{2R_L}}{(V_{DD}-V_{SS})I_Q} = \frac{\dfrac{v_{OUT}(\text{peak})^2}{2R_L}}{(V_{DD}-V_{SS})\left(\dfrac{(V_{DD}-V_{SS})}{2R_L}\right)} = \left(\frac{v_{OUT}(\text{peak})}{V_{DD}-V_{SS}}\right)^2$$

Maximum efficiency occurs when $v_{OUT}(\text{peak}) = V_{DD} = |V_{SS}|$ which gives 25%.

Specifying the Performance of a Common Source Amplifier

Output resistance:

$$r_{out} = \frac{1}{g_{ds1} + g_{ds2}} = \frac{1}{(\lambda_1+\lambda_2)I_D}$$

Current:

- Maximum sinking current is,

$$I^{-}_{OUT} = \frac{K'_1 W_1}{2L_1}(V_{DD} - V_{SS} - V_{T1})^2 - I_Q$$

- Maximum sourcing current is,

$$I^{+}_{OUT} = \frac{K'_2 W_2}{2L_2}(V_{DD} - V_{GG2} - |V_{T2}|)^2 \le I_Q$$

Requirements:

- Want $r_{out} << R_L$
- $|I_{OUT}| > C_L \cdot SR$
- $|I_{OUT}| > \dfrac{v_{OUT}(\text{peak})}{R_L}$

The maximum current will be determined by **both** the current required to provide the necessary slew rate (C_L) and the current required to provide a voltage across the load resistor (R_L).

Small-Signal Performance of the Class A Amplifier

Although we have considered the small-signal performance of the Class A amplifier as the current source load inverter, let us include the influence of the load.

The modified small-signal model:

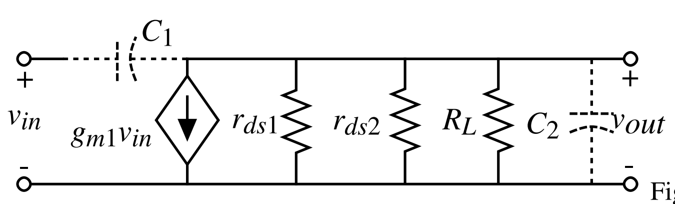

Fig. 040-02

The small-signal voltage gain is:

$$\frac{v_{out}}{v_{in}} = \frac{-g_{m1}}{g_{ds1}+g_{ds2}+G_L}$$

The small-signal frequency response includes:

A zero at

$$z = \frac{g_{m1}}{C_{gd1}}$$

and a pole at

$$p = \frac{-(g_{ds1}+g_{ds2}+G_L)}{C_{gd1}+C_{gd2}+C_{bd1}+C_{bd2}+C_L}$$

Example 5.5-1 - Design of a Simple Class-A Output Stage

Use the values of K_N'=110μA/V^2, K_P'=50μA/V^2, V_{TN}=0.7V and V_{TP}=-0.7V and design the W/L ratios of M1 and M2 so that a voltage swing of ±2 volts and a slew rate of ≅1 volt/μs is achieved if R_L = 20 kΩ and C_L = 1000 pF. Assume that $V_{DD} = |V_{SS}| = 3$ volts and V_{GG2} = 0 volts. Let the channel lengths be 2 μm and assume that C_{gd1} = 100fF.

Solution

Let us first consider the effects of R_L and C_L.

$$i_{OUT}(\text{peak}) = \frac{\pm 2\text{V}}{20\text{k}\Omega} = \pm 100\mu\text{A} \quad \text{and} \quad C_L \cdot SR = 10^{-9} \cdot 10^{6} = 1000\mu\text{A}$$

Since the slew rate current >> the current for R_L, we can safely assume that all of the current supplied by the inverter is available to charge C_L.

Using a value of ±1 mA,

$$\frac{W_1}{L_1} = \frac{2(I_{OUT}^{-}+I_Q)}{K_N'(V_{DD}+|V_{SS}| - V_{TN})^2} = \frac{4000}{110\cdot(5.3)^2} \approx \frac{3\mu\text{m}}{2\mu\text{m}}$$

and

$$\frac{W_2}{L_2} = \frac{2I_{OUT}^{+}}{K_P'(V_{DD}-V_{GG2}-|V_{TP}|)^2} = \frac{2000}{50\cdot(2.3)^2} \approx \frac{15\mu\text{m}}{2\mu\text{m}}$$

The small-signal performance of this amplifier is, A_v = -8.21 V/V (includes R_L = 20kΩ)

Broadband Harmonic Distortion

The linearity of an amplifier can be characterized by its influence on a pure sinusoidal input signal.

Assume the input is, $V_{in}(\omega) = V_p \sin(\omega t)$

The output of an amplifier with distortion will be

$$V_{out}(\omega) = a_1 V_p \sin(\omega t) + a_2 V_p \sin(2\omega t) + \cdots + a_n V_p \sin(n\omega t)$$

Harmonic distortion (HD) for the ith harmonic can be defined as the ratio of the magnitude of the ith harmonic to the magnitude of the fundamental.

For example, second-harmonic distortion would be given as

$$HD_2 = \frac{a_2}{a_1}$$

Total harmonic distortion (THD) is defined as the square root of the ratio of the sum of all of the second and higher harmonics to the magnitude of the first or fundamental harmonic.

Thus, THD can be expressed as

$$THD = \frac{[a_2^2 + a_3^2 + \cdots + a_n^2]^{1/2}}{a_1}$$

The distortion of the class A amplifier is good for small signals and becomes poor at maximum output swings because of the nonlinearity of the voltage transfer curve for large-signal swing.

COMMON EMITTER OUTPUT STAGE

Common Emitter Class A Output Stage

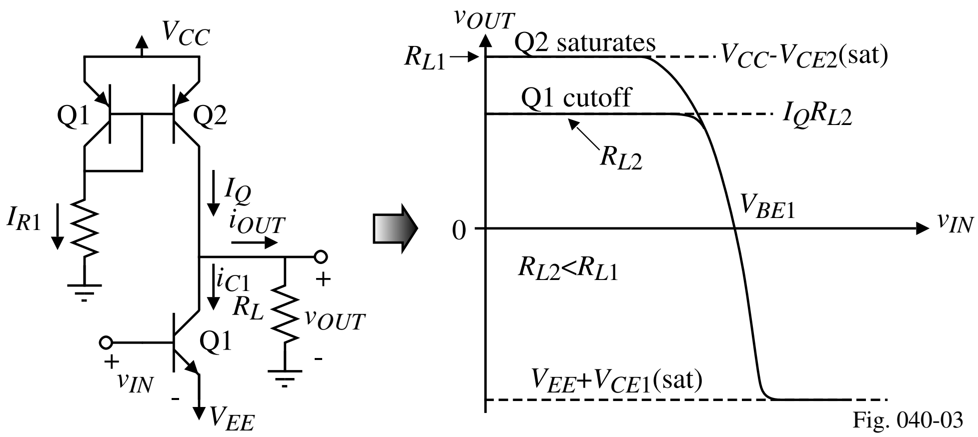

Fig. 040-03

Large signal characteristic:

$$i_{OUT} = I_Q - i_{C1}, \quad v_{OUT} = i_{OUT} R_L, \quad \text{and } i_{C1} = I_{s1}\exp\left(\frac{v_{IN}}{V_t}\right)$$

$$\therefore \quad v_{OUT} = -R_L\left[I_{s1}\exp\left(\frac{v_{IN}}{V_t}\right) - I_Q\right]$$

Harmonic Distortion in the Common Emitter Output Stage

Assume the input signal is

$$v_{IN} = V_{BE1} + v_{in}$$

Substituting this in the expression on the last slide gives,

$$v_{OUT} = -R_L\left[I_{s1}\exp\left(\frac{v_{IN}}{V_t}\right) - I_Q\right] = -R_L\left[I_{s1}\exp\left(\frac{V_{BE1}}{V_t}\right)\exp\left(\frac{v_{in}}{V_t}\right) - I_Q\right] = -I_Q R_L\left[\exp\left(\frac{v_{in}}{V_t}\right) - 1\right]$$

Using the expansion of $\exp(x) \approx 1 + x + x^2/2 + x^3/6 + \cdots$ gives

$$v_{OUT} = -I_Q R_L\left[\left(\frac{v_{in}}{V_t}\right) + \frac{1}{2}\left(\frac{v_{in}}{V_t}\right)^2 + \frac{1}{6}\left(\frac{v_{in}}{V_t}\right)^3 + \cdots\right] = a_1 v_{in} + a_2 v_{in}^2 + a_3 v_{in}^3 + \cdots$$

where

$$a_1 = -\frac{I_Q R_L}{V_t}, \qquad a_2 = -\frac{I_Q R_L}{2V_t^2} \quad \text{and} \quad a_3 = -\frac{I_Q R_L}{6V_t^3}$$

Suppose $v_{in}(t) = V_p \sin\omega t$, then

$$v_{OUT}(t) = a_1 V_p \sin\omega t + a_2 V_p^2 \sin^2\omega t + a_3 V_p^3 \sin^3\omega t + \cdots$$

$$= a_1 V_p \sin\omega t + \frac{a_2 V_p^2}{2}(1-\cos 2\omega t) + \frac{a_3 V_p^3}{4}(3\sin\omega t - \sin 3\omega t) + \cdots$$

$$\therefore \quad HD_2 = \frac{a_2 V_p^2}{2}\frac{1}{a_1 V_p} = \frac{a_2 V_p}{2a_1} = \frac{V_p}{4\,V_t} \quad \text{and} \quad HD_3 = \frac{a_3 V_p^3}{4}\frac{1}{a_1 V_p} = \frac{a_3 V_p^2}{4a_1} = \frac{1}{24}\left(\frac{V_p}{V_t}\right)^2$$

For $V_p = 0.5V_t$, HD_2 = 12.5% and $HD_3 \approx$ 1%

Small Signal Performance of the Common Emitter Output Stage

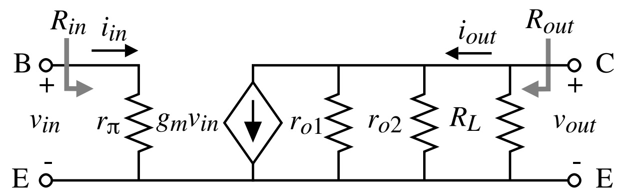

Fig. 040-04

Let $r_{o1}||r_{o2} = r_o$, then

$$R_{in} = r_{\pi 1} = \frac{\beta_o}{g_{m1}},\ R_{out} = \frac{r_o R_L}{r_o + R_L} \approx R_L,\ \frac{v_{out}}{v_{in}} = \frac{-g_{m1} r_o \cdot R_L}{r_o + R_L} \approx -g_{m1}R_L \text{ and } \frac{i_{out}}{i_{in}} = \frac{\beta_o \cdot r_o}{r_o + R_L}$$

If V_{out}(peak) = 0.6V, R_L = 1kΩ and I_Q = 1.86mA, then

$$A_v \approx -g_{m1}R_L = -\frac{I_C}{V_t}R_L = -\frac{1.86}{26}1000 = -70.6\text{V/V} \quad \Rightarrow \quad Vp = \frac{0.6}{|A_v|} = \frac{0.6}{70.6} = 8.5\text{mV (peak)}$$

$$\therefore \quad HD_2 = \frac{1}{4}\frac{8.5}{26} = 0.082 \quad \text{and } HD_3 = \frac{1}{24}\left(\frac{8.5}{26}\right)^2 = 0.0045$$

Where does the distortion come from?

The ac gain at the negative peak output voltage is $-\frac{1.86+0.6}{26}1000 = -94.6$V/V

The ac gain at the positive peak output voltage is $-\frac{1.86-0.6}{26}1000 = -48.5$V/V

Note the emitter follower is much more linear because of the inherent negative feedback.

SUMMARY

Requirements of Output Stages

- The objectives are to provide output power in form of voltage and/or current.
- In addition, the output amplifier should be linear and be efficient.
- Low output resistance is required to provide power efficiently to a small load resistance.
- High source/sink currents are required to provide sufficient output voltage rate due to large load capacitances.
- Types of output stages considered:

    Common emitter and common source
- Maximum efficiency is 25%
- Second-harmonic distortion can be significant