

Analysis of Different Single-Stage Amplifiers

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Received 15 Sept. 2017, Published 05 Nov. 2017

Abstract: An amplifier is an electronic device that amplifies the weak signal or increases the strength of a weak signal. It can either be a separate piece of equipment or an electrical circuit contained within another device. Today, every device or circuit, be it analog or digital requires signal amplification at one level or the other during their functioning. Considering the most basic amplifiers i.e. single-stage amplifiers which are the basic building block of all the amplifiers, be it a multi-stage amplifier or a differential amplifier. All the three single-stage amplifier topologies i.e., common source (CS), common gate (CG), common drain (CD) have been analyzed.

Keywords: Amplifiers, single-stage amplifiers, common source, common gate, common drain.

1. INTRODUCTION

An amplifier is an electronic device which is used to increase or improve the strength of a weak signal without altering the basic characteristics of the signal [1]. The block diagram of an amplifier circuit with an input and an output is shown in figure 1. Here, at input end of the amplifier a weak signal is fed and a strong or amplified signal is received at output end. During this whole process of amplification, amplifier circuit utilizes the electric power from power supply for amplifying the signal. Amplifiers can be classified on several basis but considering here the classification based on the number of stages it can be classified into two broad categories: single-stage amplifiers and differential amplifiers. Single-stage amplifiers can further classified into three basic topologies namely common source (CS), common gate (CG), common drain (CD), discussed in this paper further. Moreover, any amplifier be it a multi-stage amplifier or differential amplifier can be implemented using any one of these basic single-stage topologies for operation[2].

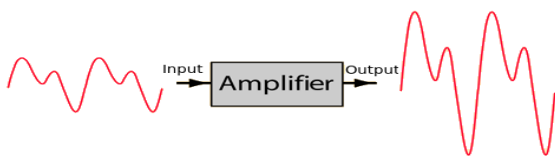


Figure 1. Block Diagram of an amplifier

2. COMMON SOURCE AMPLIFIER

Common source configuration is the most widely used configuration among all the three basic configurations [9]. The term common source used here means that the source terminal of the amplifier is grounded i.e., all the parameters are measured or analysed with respect to source terminal. A common source amplifier shown in figure 2. is implemented using an nMOS transistor M1 whose source is grounded and the drain is connected to power supply through a resistor R_S and the output is taken from drain terminal with respect to source terminal. The input signal V_{in} to be amplified is fed at the gate terminal and an amplified output signal is obtained from the output terminal V_{out} after amplification. Doing large signal analysis of the circuit we obtain the output of the system as:

$$V_{out} = V_{DD} - I_D R_D \quad (1)$$

Since the transistor M1 is operating in saturation mode the drain current I_D is given as:

$$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T)^2 \quad (2)$$

$$\text{Or, } I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{in} - V_T)^2 \quad (3)$$

Therefore, using equation (1) and (3) the output voltage is obtained as:

$$V_{Out} = V_{DD} - R_D \frac{\mu_n C_{ox} W}{2 L} (V_{In} - V_T)^2 \quad (4)$$

As we know, the gain is:

$$A_v = \frac{\delta V_{out}}{\delta V_{In}} \quad (5)$$

From equation (4) and (5) we get:

$$A_v = - R_D \mu_n C_{ox} \frac{W}{L} (V_{In} - V_T) \quad (6)$$

Or,

$$A_v = - R_D g_m \quad (7)$$

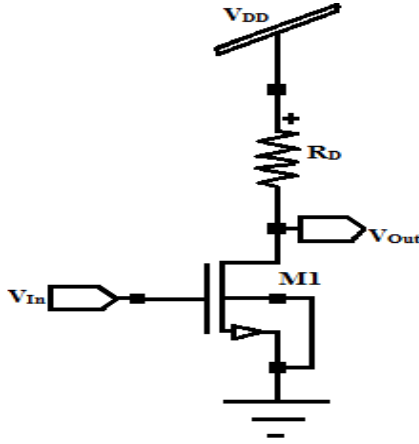


Figure 2. Common Source Amplifier

Where,

$$g_m = \mu_n C_{ox} \frac{W}{L} (V_{In} - V_T)$$

and

g_m = transconductance

μ_n = mobility

C_{ox} = oxide capacitance

W = channel width

L = channel length

V_T = threshold voltage

To calculate the gain of the above circuit we will be using small-signal analysis. Applying KCL on the small signal model of the common source amplifier shown in figure3, we get:

$$V_{Out} = - g_m V_{In} r_o \parallel R_D$$

Or,

$$V_{Out} = - g_m R_0 V_{In}$$

Where,

$$R_0 = R_D \parallel r_o$$

On differentiating above equation with respect to V_{In} , we get gain of the amplifier as:

$$A_v = \frac{V_{Out}}{V_{In}} = - g_m R_0$$

Or,

$$V_{Out} = V_{DD} - R_D \frac{\mu_n C_{ox} W}{2 L} (V_{In} - V_T)^2 \quad (8)$$

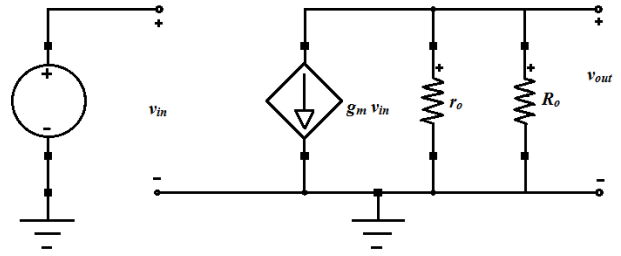


Figure 3. Small Signal Model of Common Source Amplifier.

3. COMMON GATE AMPLIFIER

As the name suggests, in common gate configuration the gate terminal is common or grounded i.e., is taken as reference node. As can be seen from the figure 4, the input signal to be amplified is given at the source terminal and the gate is grounded. The drain terminal is connected to the power source through a resistor and the amplified output is can be measured from drain terminal with respect to gate terminal.

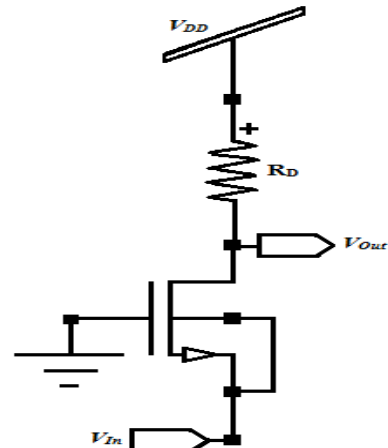


Figure 4. Common Gate Amplifier

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Using large signal analysis of the above circuit, we can write

$$V_{Out} = V_{DD} - I_D R_D \quad (9)$$

Since the transistor is operating in saturation region using equation 3, we have

$$V_{Out} = V_{DD} - \frac{\mu_n C_{ox} W}{2} (V_{GS} - V_T)^2 R_D \quad (10)$$

Substituting the value of V_{GS} , we get:

$$V_{Out} = \frac{\mu_n C_{ox} W}{2} (V_{In} - V_T)^2 R_D \quad (11)$$

To find the gain of above we use small-signal analysis method. The figure 6 below shows the small-signal model of common gate amplifier.

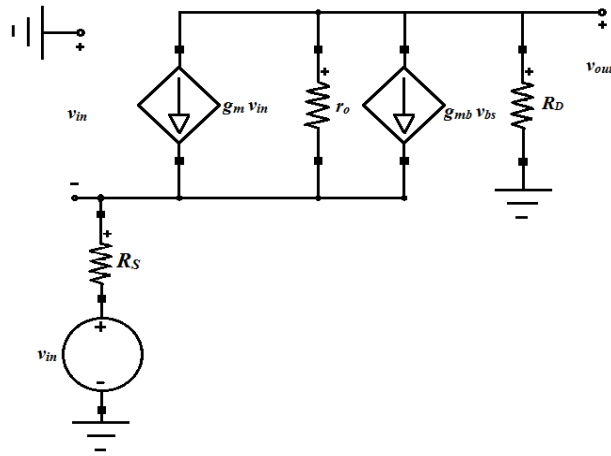


Figure 5. Small Signal Model of Common Gate Amplifier

The current through resistor R_S is

$$I_{R_S} = \frac{-V_{Out}}{R_D} \quad (12)$$

The current through r_o will be

$$I_{r_o} = \frac{-V_{Out}}{R_D} - g_{m1} V_1 - g_{mb} V_1 \quad (13)$$

So the output voltage can be given as:

$$V_{Out} = r_o \left(\frac{-V_{Out}}{R_D} - g_{m1} V_1 - g_{mb} V_1 \right) - \frac{V_{Out}}{R_D} R_S + V_{In} \quad (14)$$

Or,

$$V_{Out} = r_o \left[\frac{-V_{Out}}{R_D} - (g_m + g_{mb}) \left(V_{Out} \frac{R_S}{R_D} - V_{In} \right) \right] - \frac{V_{Out}}{R_D} R_S + V_{In} \quad (15)$$

On differentiating the above equation with respect to input V_{In} , we get a gain

$$A_{vCG} = \frac{V_{Out}}{V_{In}} = \frac{(g_m + g_{mb}) r_o + 1}{(R_D + R_S + r_o + (g_m + g_{mb}) r_o R_S)} R_D \quad (16)$$

4. COMMON DRAIN AMPLIFIER

Common Drain Amplifier is also known as Source Follower Amplifier. The source follower circuit is shown in figure 7 below. As can be seen, drain is the common or reference terminal and the input is provided at gate for amplification and a resistance is connected at the source terminal across which the output is measured.

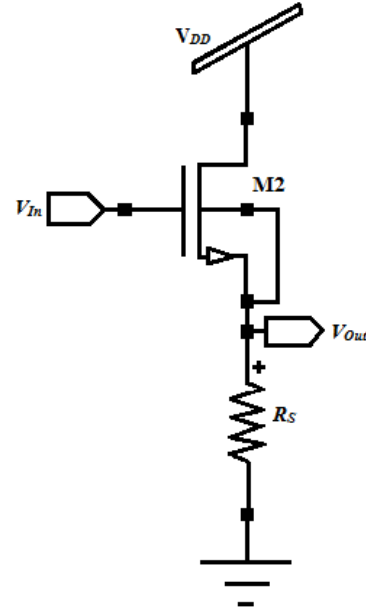


Figure 6. Common Drain Amplifier

The transistor M2 is operating in saturation region, using large signal analysis in above circuit we get the output voltage V_{Out} as:

$$V_{Out} = I_D R_S = \frac{\mu_n C_{ox} W}{2} (V_{GS} - V_T)^2 R_S \quad (17)$$

Substituting the values, we can write:

$$V_{Out} = \frac{\mu_n C_{ox} W}{2} (V_{In} - V_{Out} - V_T)^2 R_S \quad (18)$$

To calculate the gain of common drain amplifier we will be doing its small signal analysis using the small signal model shown in figure 8. Applying KCL we get

$$V_{Out} = [g_m V_1 + g_{mb} V_{BS}] R_S \tag{19}$$

$$V_{Out} = [g_m (V_{In} - V_{Out}) + g_{mb} V_{Out}] R_S \tag{20}$$

$$A_v = \frac{V_{Out}}{V_{In}} = \left[\frac{g_m R_S}{1 + (g_m + g_{mb}) R_S} \right] \tag{21}$$

Since

$$g_{mb} = \eta g_m \tag{22}$$

Therefore, for

$$g_m R_S \gg 1 \tag{23}$$

$$A_v \approx \frac{1}{1 + \eta}$$

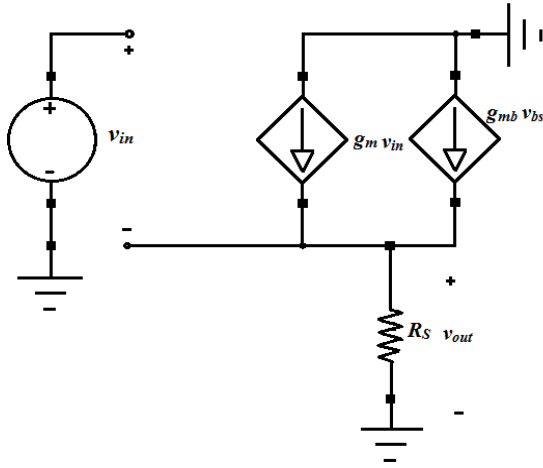


Figure 5. Small Signal Model of Common Gate Amplifier

5. CONCLUSION

This paper gives the basic idea of single stage amplifier topologies i.e. Common Source (CS), Common Gate (CG), Common Drain (CD) and their gain is using small signal model. In today’s world all the electronics equipments utilize amplifiers in one way or the other for instance in Voltage controlled oscillators [3-8], in wireless communication[9], etc.

Table-1 below compares various parameters of all the three configurations.

Table-1: Comparison of various parameters of all the three configurations.

Parameters	Common Gate	Common Drain	Common Source
Voltage gain	High	Low	Medium
Current gain	Low	High	Medium
Power gain	Low	Medium	High
Input/output phase relationship(in degree)	0	0	180
Input Resistance	Low	High	Medium
Output Resistance	High	Low	Medium

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