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Piece-Wise Linear Approach for Optimum Point Adjustment of Single Stage, Single Transistor Amplifier

[1]Kapil Kumar, [2]Adarsh Srivastava, [3]Manish Kumar, [4]Shamim Akhter

[1,2,3,4]Department of Electronics & Communication Engineering
Jaypee Institute of Information Technology University, Noida, India

[1]kapil10305171mtech@gmail.com, [2]adarshsrivastava23@gmail.com

Abstract

Amplifiers have a vital role in the applications of engineering and as well as a component of amusement devices for human kinds. Gain and output voltage swing depends upon the designing parameters of that amplifier. In these parameters, selection of operating point is a challenging task. Operating point is extracted from the DC characteristics of the amplifier. Also, the dc characteristic depends upon the amplifier's gain, transconductance and drain resistance; which are mutually interdependent and have a perplexing relationship with the gate to source biasing voltage. The key factor is how to choose the value for drain resistance and biasing voltage to get the desired gain. In this paper a piece-wise linear approach has been developed to extract an optimum biasing voltage and value of drain resistance to achieve desired gain. It is elaborated using an example of single stage CS amplifier. Mathematical expressions have been developed to obtain the optimum biasing voltage and drain resistance.

Keywords- *Single stage single transistor amplifier; Biasing Voltage; Drain resistance; Optimum point; Output swing;*

I. Introduction

In this paper a single stage CS amplifier [1] [4] has been taken for illustration, our goal is to find out an optimum point of operation using DC characteristics of amplifier, where desired gain with maximum swing [3] can be achieved in the output. The CS Amplifier shown in the figure 1 has input as a combination of biasing voltage and externally applied signal. To find out the optimum point i.e. the value of V_{GSm}, the saturation/ active region is assumed as linear path i.e. called here piece-wise linear approach.

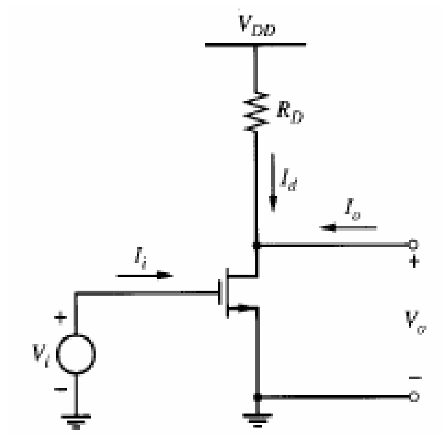

Figure 1: Single stage CS amplifier [1]

II. Optimum Point Computation

In figure 2, it has shown that for different values of drain resistance R_D i.e R_1, R_2, R_3, the slope and extension of saturation region over the input biasing voltage axis [1] [7], changes. So it is require to set a value of the resistance first, and then to select an optimum point. Apparently, for a maximum swing over a linear path, the input should be applied at a medium point to avoid clipping at the edges; so the mean values of gate to source voltage will be find out from linear path between P and S, for any value of drain resistance. V_{GSm} and V_{DSm} are the average values between the V_{GS1} & V_{GS2} and V_{DS1} & V_{DS2} respectively.

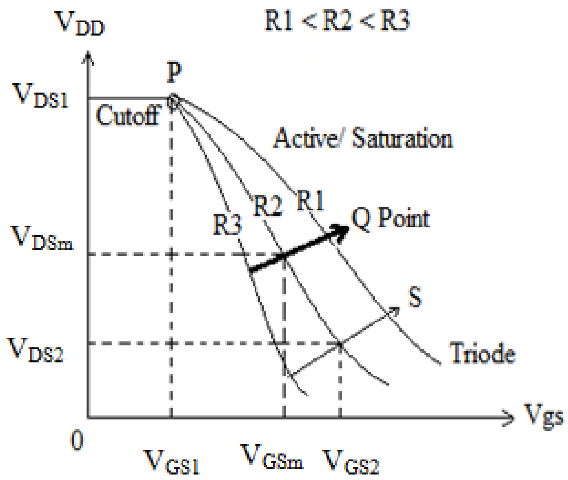

Figure 2: DC characteristics of CS amplifier with different drain resistances.

Steps will be as follow to compute the optimum point-

Step 1- To find out the slope of the assumed linear path PS.

Step 2- To find out the expression for the V_{DS1} and V_{DS2}.

Step 3- To find out the expression for the V_{GS1} and V_{GS2} and to find the algebraic mean of these two i.e. *Vm*.

Step 4- To find out the expression for drain resistance R_D.

Step 1-

A_V = Voltage gain (taking in amplitude)
g_m = Transconductance
V_{TH} = Threshold voltage
μ_n = electron mobility
C_{ox} = Oxide capacitance

For the gain and transconductance relation [1] -

$$A_V = -g_m R_D$$

$$R_D = -\frac{A_V}{g_m}$$

$$R_D = -\frac{A_V}{K_n(V_{GS} - V_{TH})} \quad (1)$$

where $K_n = \mu_n C_{ox} \frac{W}{L}$

$$V_{DS} = V_{DD} - \frac{1}{2}\mu_n C_{OX} \frac{W}{L}(V_{GS} - V_{TH})^2 R_D$$

$$\text{slope } \frac{dV_{DS}}{dV_{GS}} = S$$

$$0 - \frac{1}{2}\mu_n C_{OX} \frac{W}{L} 2(V_{GS} - V_{TH}) R_D = S$$

$$-g_m R_D = S \Rightarrow A_V \quad (2)$$

Where, *S* is any constant. equ (2) signifies that the slope of the DC characteristic curve is equal to the voltage gain of the single stage amplifier.

Step 2-

$$V_{DS} \geq V_{GS} - V_{TH}$$

This stands for N-MOS to be in saturation [3].
At critical point S-

$$V_{DS2} = V_{GS2} - V_{TH}$$

$$R_D = -\frac{A_V}{K_n V_{DS2}}$$

$$V_{DS2} = -\frac{A_V}{K_n R_D} \quad (3)$$

It can also be find out as –

$$A_V = -K_n(V_{GS2} - V_{TH})R_D$$

$$A_V = -K_n V_{DS2} R_D$$

$$V_{DS2} = -\frac{A_V}{K_n R_D} \quad (4a)$$

$$V_{DS1} = V_{DD} \quad (4b)$$

Step 3-

Now taking the slope of the linear path-

$$m = \frac{Y_2 - Y_1}{X_2 - X_1}$$

Where-
m = slope of the path
$Y_2 = V_{DS2}$
$Y_1 = V_{DS1} = V_O = V_{DD}$
$X_2 = V_{GS2} = ?$
$X_1 = V_{GS1} = V_{TH}$

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$$A_V = \frac{\frac{-A_V}{K_n R_D} - V_{DD}}{V_{GS2} - V_{TH}}$$

$$A_V V_{GS2} - A_V V_{TH} = -\frac{A_V}{K_n R_D} - V_{DD}$$

$$A_V V_{GS2} = \frac{-A_V}{K_n R_D} - V_{DD} + A_V V_{TH}$$

$$V_{GS2} = V_{TH} - \frac{1}{K_n R_D} - \frac{V_{DD}}{A_V} \quad (5)$$

$$V_m = (V_{GS1} + V_{GS2})/2$$

$$V_m = \frac{V_{TH} + \left(V_{TH} - \frac{1}{K_n R_D} - \frac{V_{DD}}{A_V}\right)}{2}$$

$$V_m = V_{TH} - \frac{1}{2K_n R_D} - \frac{V_{DD}}{2A_V} \quad (6a)$$

This should be noted that this value of V_m is extracted from the algebraic mean of the two values of V_{GS1} and V_{GS2} and to make it more simple by using equ [1] the following result can be analyzed-

$$V_m = V_{TH} - \frac{1}{2K_n\left(\frac{-A_V}{K_n(V_{GS} - V_{TH})}\right)} - \frac{V_{DD}}{2A_V}$$

$$\text{Putting } V_{GS} = V_m$$

$$V_m = \frac{V_{DD} + V_{TH} - 2A_V V_{TH}}{1 - 2A_V} \quad (6b)$$

As V_m is algebraic mean of V_{GS1} and V_{GS2} so it is nearly equal to V_{GSm} by the assumed piece-wise linear approach. So V_m or may be called as V_{GSm} , is chosen as optimum point.

Step 4-

By putting the value of V_m in equation (1) in place of V_{GS}, drain resistance R_D can be find out as-

$$R_D = -\frac{A_V}{K_n(V_m - V_{TH})} \quad (7)$$

By using equation (6a) or more simplified equation (6b); V_m can be used for optimum point selection for biasing of gate to source voltage [5] [6] and for this gate to source voltage by using equation (7); R_D can be calculated for a specific value of voltage gain.

III. Designing of Single stage amplifier

To design single stage, single transistor CS amplifier, Level 1 parameters is used in the Spice simulations [2] and following assumptions and parameters have been taken-

- At the gate of MOS there is no external resistance is applied [6] [8].
- There is no external capacitance applied at the load terminal;

$V_{DD} = 3$ volt; $L_d = 0.8$µm; $W = 10$µm; $L = 2$ µm;
Designed results for V_{GSm} and R_D for gain *-1*:-

Table 1: Verification results for various drain resistance and gate to source bias voltage simulations.

V_{GSm}*(volt)*	R_D*(kΩ)*	**Center point of output voltage swing *(volt)***
1.1	13.3333	2.950
1.2	6.6667	2.900
1.3	4.4444	2.851
1.4	3.3333	2.801
1.5	2.6667	2.751
1.6	2.2222	2.702
1.7	1.9048	2.652
1.8	1.6667	2.603
1.9	1.4815	2.554
2.0	**1.3333**	**2.505**
2.1	1.2121	2.455
2.2	1.1111	2.407
2.3	1.0256	2.358
2.4	0.9524	2.309
2.5	0.8889	2.260
2.6	0.8333	2.211
2.7	0.7843	2.163
2.8	0.7407	2.115
2.9	0.7018	2.066
3.0	0.6667	2.018

By using equation (6b) and above defined parameters the optimum point will be 2 Volt. For this value of *Vm* , value of $R_D = 1.3333$ kΩ from equation (7) for gain *-1*. This can be verified by observing the verification table 1, that the operating point approximately in the middle of the DC characteristic curve and maximum swing in the output can be achieved.

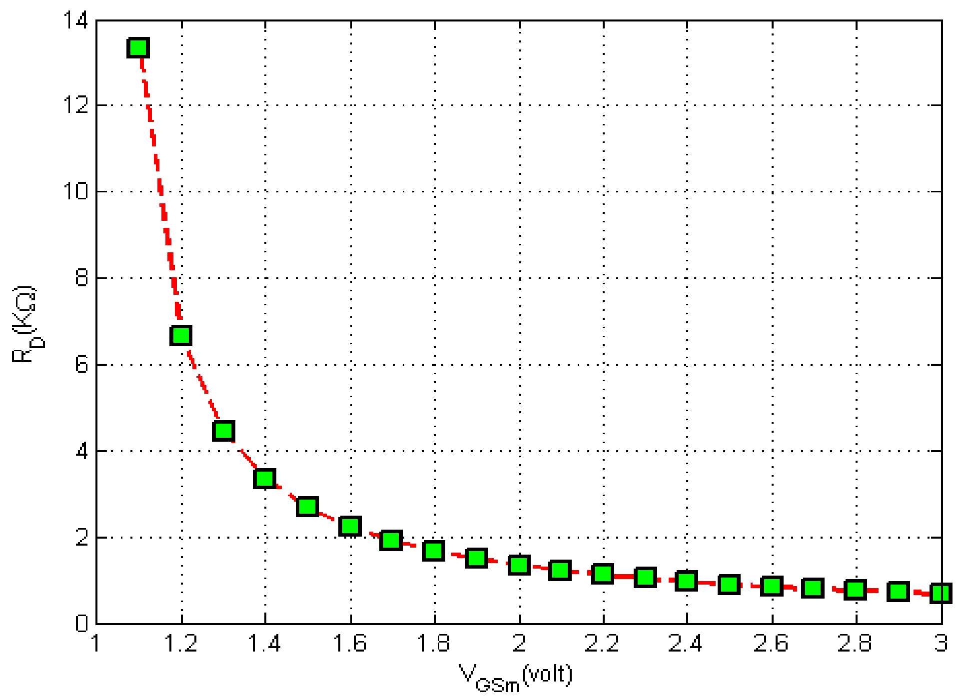

Figure 3: Drain resistance verses gate to source voltage.

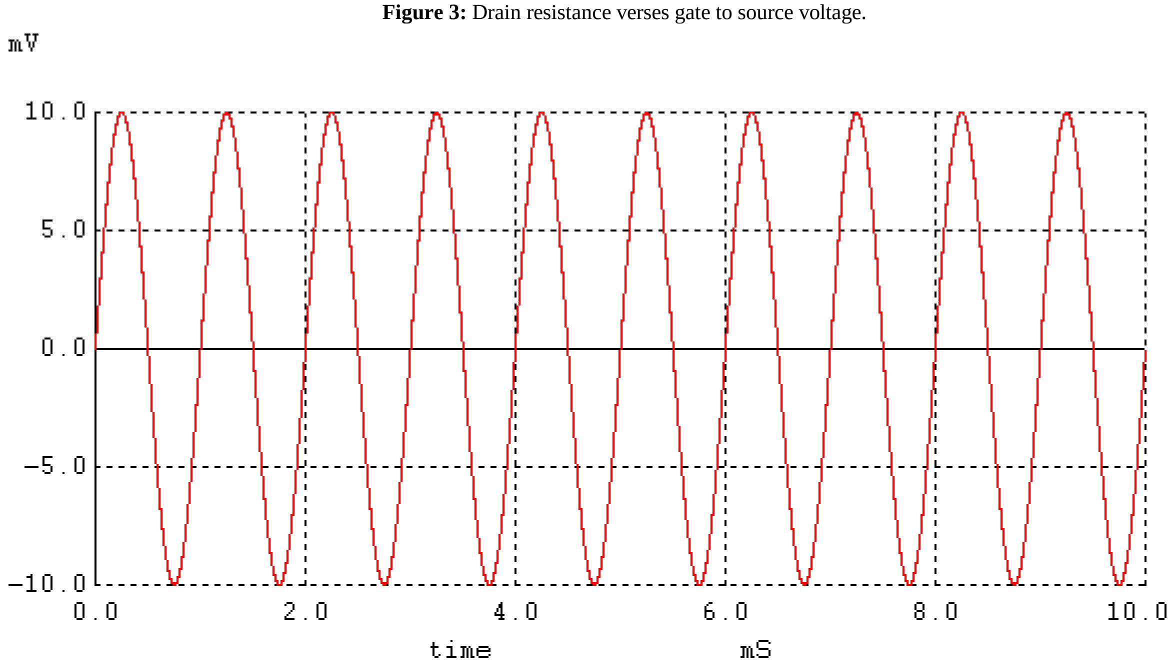

Figure 4: Input AC signal with 20.0 mV peak to peak

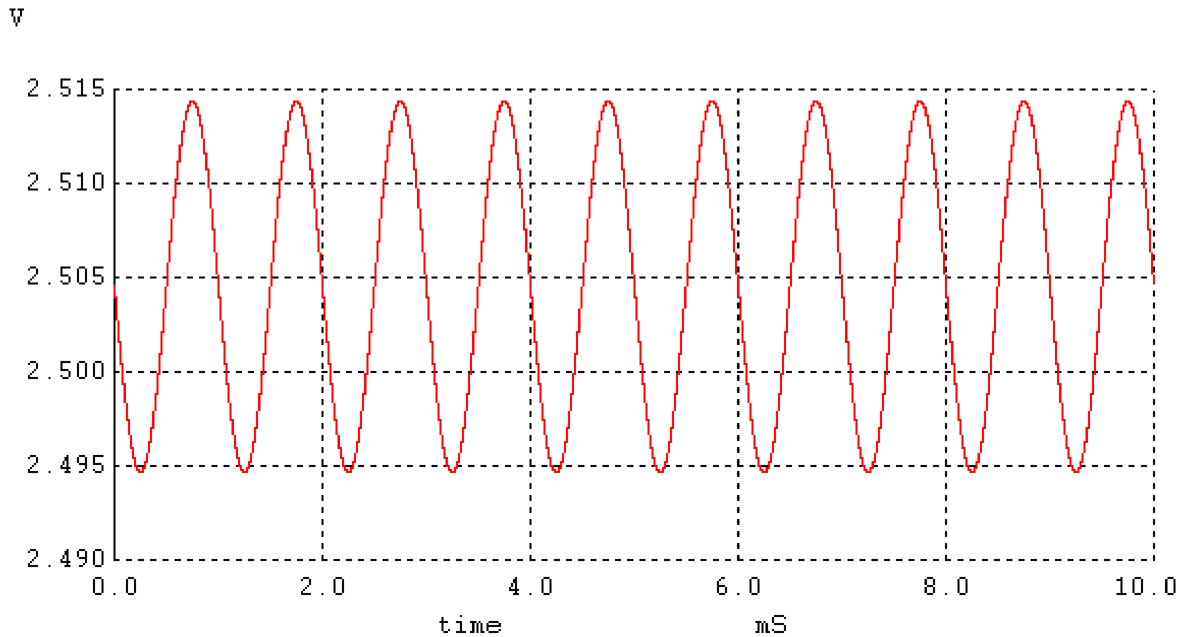

Figure 5: Drain to Source output signal swing showing 20.05 mV peak to peak*

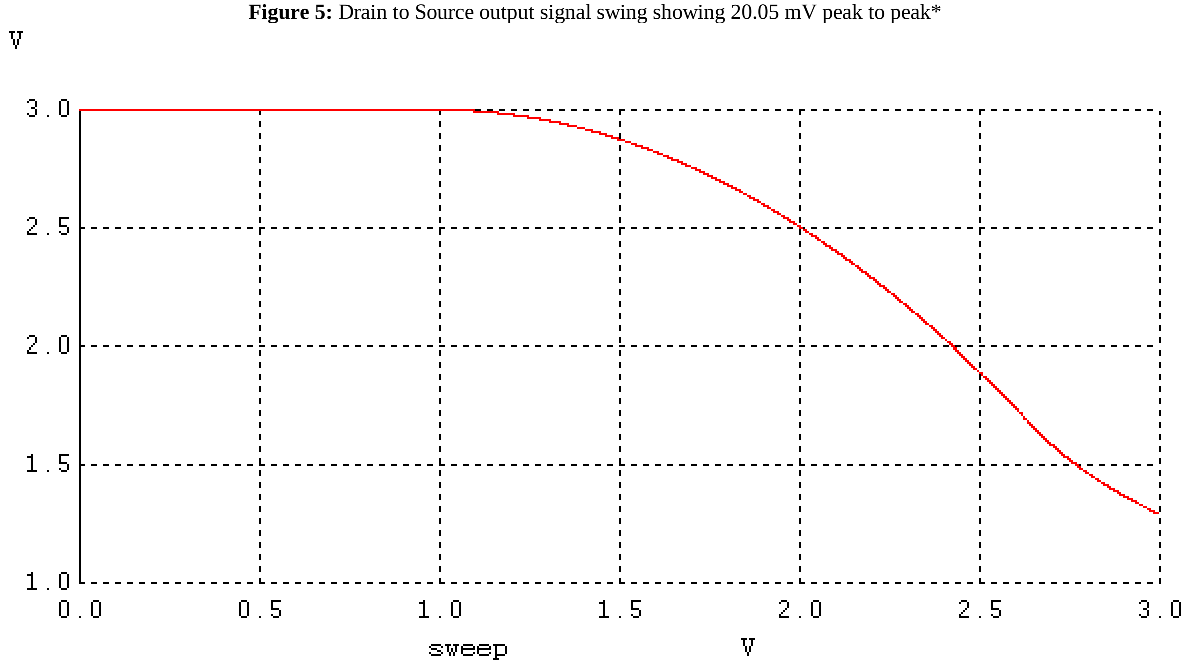

Figure 6: DC analysis of designed CS amplifier with gain *-1*

*This should be 20 mV. The value 20.05 mV is due to the approximations in the drain resistance.

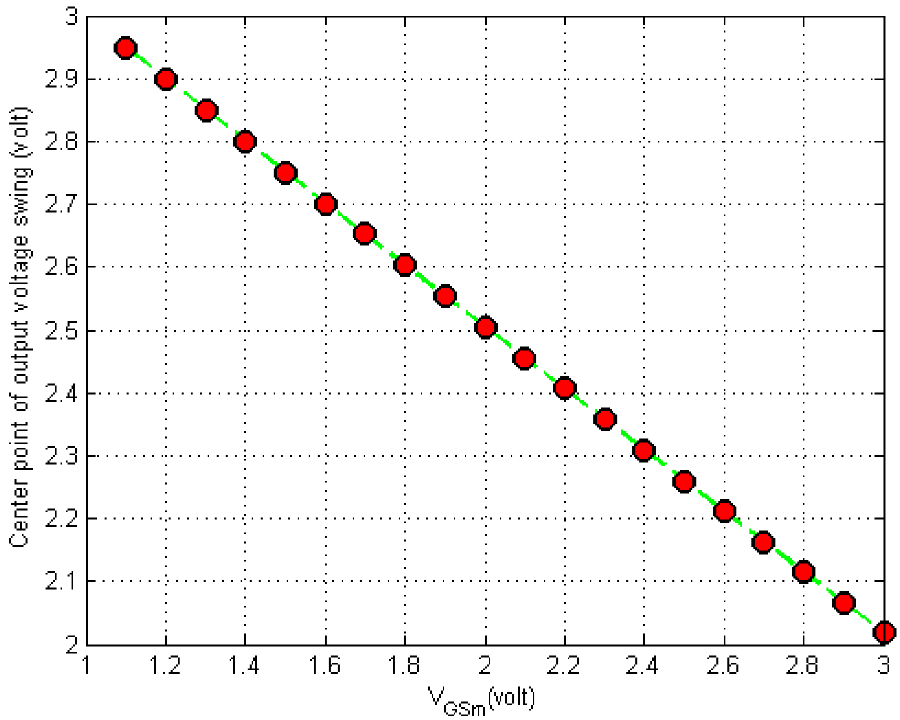

Figure 7: Center point of output voltage swing verses various computed operating points against different drain resistances

IV. Result

Using the derived expressions for drain resistance and optimum biasing point, a CS single stage amplifier has been designed, for which outcome voltage gain was near to the expected. Slightly error was detected due to the computational approximation in the value of drain resistance.

V. Conclusion

This is an important analysis for pedagogical purposes as for the understanding of students. Piece-wise linear approaches are very useful for basic understanding purposes in the field of modeling. This approach can be used in different designing and modeling of multistage amplifiers. Further, for more accurate analysis linear approximations can be extended to actual nonlinear analysis as a future work.

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