EE539: Analog Integrated Circuit Design;

Nagendra Krishnapura (nagendra@iitm.ac.in)

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1 NONLINEARITY

For a linear circuit,

$$V_{out} = A.V_{in}$$

where A is the gain of the citcuit.
But for a nonlinear circuit,output is a nonlinear function of input,i.e.,

$$V_{out} = f(V_{in})$$

Let the bias point as $V_{out,0}$,$V_{in,0}$
If we expand this using Taylor's series around operating point,then

$$f(V_{in}) = V_{out,0} + \frac{dV_{out}}{dV_{in}}|_{V_{in.0}}(V_{in} - Vin, 0) + \frac{1}{2}\frac{d^2V_{out}}{dV_{in}^2}|_{V_{in,0}}(V_{in} - V_{in,0})^2 + ...$$

Let the bias point as $V_{out,0} = 0$,$V_{in,0} = 0$,then

$$\Rightarrow = \frac{dV_{out}}{dV_{in}}|_{V_{in.0=0}}V_{in} + \frac{1}{2}\frac{d^2V_{out}}{dV_{in}^2}|_{V_{in,0=0}}V_{in}^2 + ...$$

The first term in the above equation gives the small signal gain of the amplifier,the remaining terms are generated due to nolinearity.
Let a nonlinear system,with input as $x = V_o cos(wt)$ equation,

$$y = f(x) = a_1 x + a_2 x^2 + a_3 x^3 + ...$$

$$\Rightarrow y = a_1 V_o cos(wt) + a_2 \frac{V_o^2}{2} + a_2 \frac{V_o^2}{2} cos(2wt) + ...$$

The first term is the fundametal frquency component.
The second term is the offset .
And the remaing terms are higher order hamonics,which are having integer multiples of fundamental frequency. Harmonics strength increases faster than that of the fundamental component.

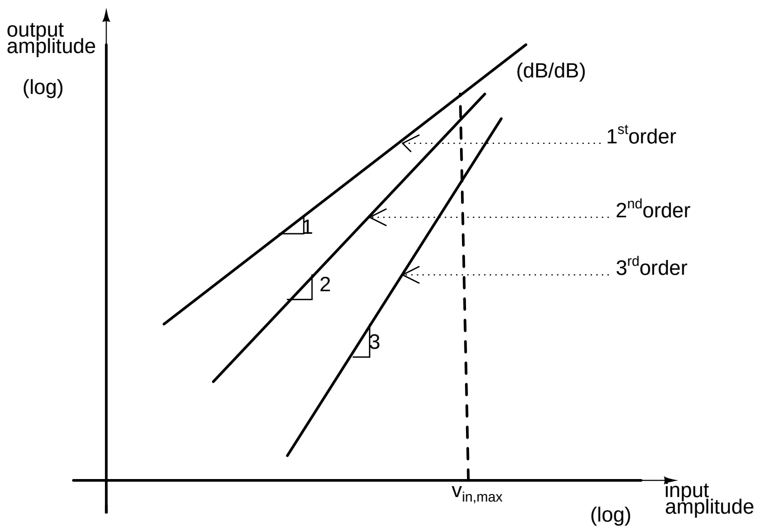

Figure 1: Harmonic distortion

Nonlinearity places a limit on the maximum input signal.

HARMONIC DISTORTION=$\frac{HD_N}{fundamental}$

2 CS AMPLIFIER

$$V_{out} = V_{DD} - I_D R_L = V_{DD} - \frac{\mu C_{ox} W}{2L}(V_{bias} + v - V_t)^2 R_L$$

$$V_{out} = V_{DD} - \frac{\mu C_{ox} W}{2L}(V_{bias} - V_t)^2 R_L + \frac{\mu C_{ox} W}{L} R_L.v + \frac{\mu C_{ox} W}{2L} v^2 R_L$$

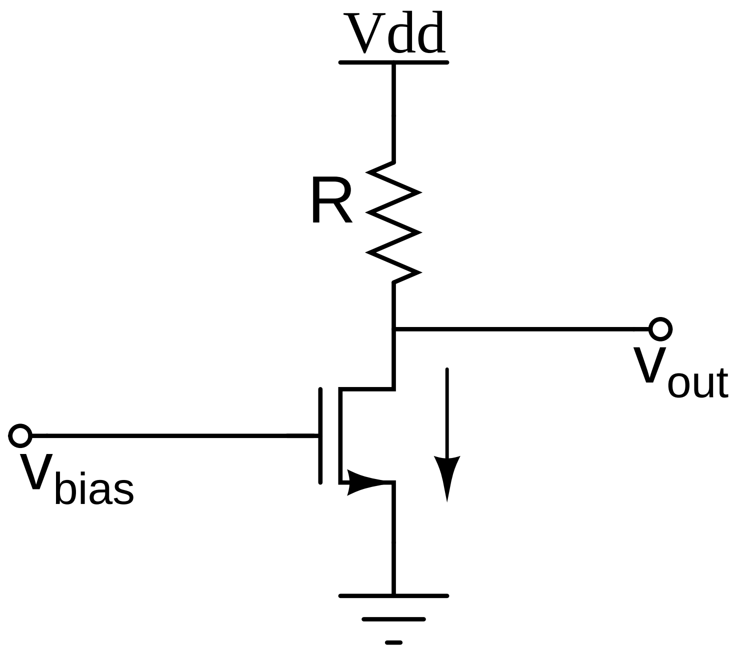

Figure 2: CS amplifier

The first term in the above equation is the dc output voltage.
The second term is $g_m R_L v$.
and the third term is is generated due to nonlinearity.
The value of v for which nonlinear term negligible is,

$$\frac{\mu C_{ox} W}{L} R_L.v \gg \frac{\mu C_{ox} W}{2L} v^2 R_L$$
$$\Rightarrow v \ll 2(V_{bias} - v_t)$$

If there is large over drive voltage then the maximum input signal amplitude is also large.
Let $v = V_p cos(wt)$

$$v_{out} = \frac{\mu C_{ox} W}{L}(V_{bias} - V_t) R_L V_p cos(wt) + \frac{\mu C_{ox} W}{L}(\frac{V_o^2}{2} + \frac{V_o^2}{2} cos(2wt)) + ...$$

Here offset also varies with the input signal level.
Harmonics are charcterized by "Harmonic distortion".

Harmonic distortion= $\frac{HD_2}{fund}$

$$= \frac{V_p}{4(V_{bias} - V_t)}$$

As input strength increases the ”Harmonic distortion”also increases in the above equation.
As increasing the overdrive voltage ”Harmonic distortion” decreases in the above equation.
But as increasing the overdrive voltage ”gain” decreases.
”NOISE LIMITS THE SMALLEST SIGNAL WE CAN APPLY TO AN AMPLIFIER ” The output power

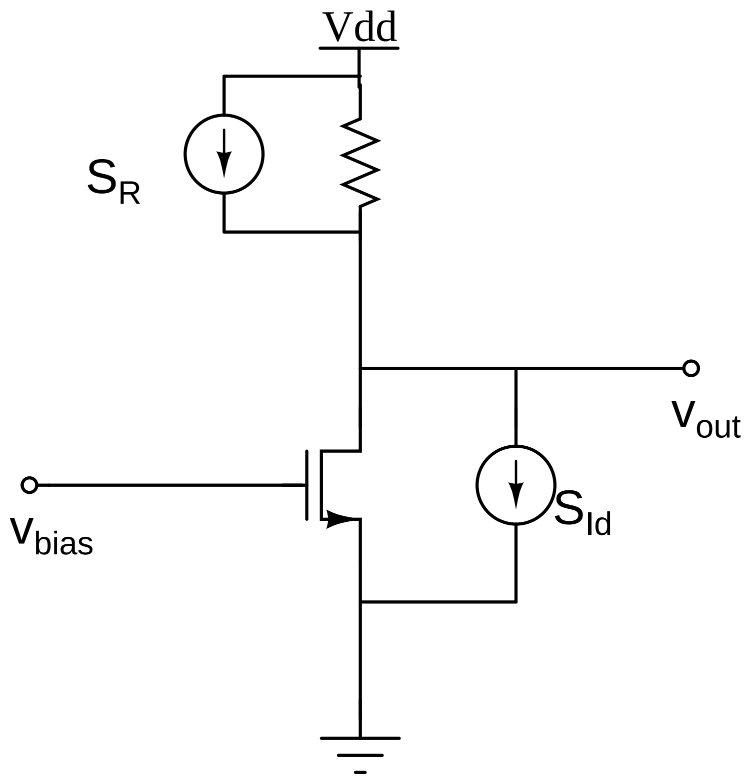

Figure 3: Noise sources in cs amplifier

spectral density is

$$S_{V_o} = (S_{I_d} + S_R)R^2$$

$$S_{V_o} = (\frac{8KTg_m}{3} + \frac{4KT}{R})R^2$$

$$S_{V_o} = 4KTR(1 + \frac{2g_m}{3})$$

In the above equation the second term dominates since $g_m R \gg 1$
Let bandwidth,B.The rms output noise power is

$$V_n^2 = 4KTR(1 + \frac{2g_m}{3}).B$$

Output signal power is,$g_m R \frac{V_p}{\sqrt{2}}$

SNR@output=

$$\frac{(g_m R \frac{V_p}{\sqrt{2}})^2}{4KTR(1 + \frac{2g_m}{3}).B}$$