A Resistive Degeneration Technique for Linearizing Open-Loop Amplifiers

Twinkel Manna
Department of Electrical Engineering
Indian Institute of Technology, Ropar
Punjab,India
2024eem1037@iitrpr.ac.in

***Abstract*—This brief represents linearization techniques for open loop amplifiers. It utilizes the exponential V−I transfer of MOS transistors in weak-inversion together with a weak form of resistive degeneration. By using a specific relationship between the input transconductance and the source degeneration resistance, the amplifier have significant reduction (∼ 50×) in its third-order distortion component. Based on this linearization principle, two amplifier topologies are proposed by implementing the degeneration in (a) pseudo-differential and (b) common-mode configuration.Also this paper highlights all those parameters that effects the linearized behavior.**

***Index Terms*—open loop amplifier – nonlinearity – resistive degeneration**

I. Introduction

Current trends in analog-to-digital converter (ADC) design, especially focusing on residue amplifier topologies, so it notes a push toward designs that are simpler and more power-efficient, although there is a trade-off between power efficiency and linearity. Open-loop amplifiers or integrators are recognizable for their power efficiency, but they tend to exhibit nonlinearity, making them less suitable for applications that require high linearity. The paper mentions analog linearization techniques as a means to enhance linearity, though these can add circuit complexity, leading to higher power and area costs. Digital calibration is another approach for addressing non-idealities in ADCs, but this method often results in significant digital power consumption.

II. OPEN LOOP AMPLIFIERS

Open Loop Amplifier is an amplifier which have no feedback path. It means the output cannot be controlled thier operation or cannot be stabilized. It have certain usefulness in this field towards ADCs, Comparators, Signal Detectors, certain oscillators and resedue amplifiers topologies.It have very high gain and this high gain is fixed and does not change if we varry input signal. In contrast to closed-loop amplifiers, an open-loop amplifiers amplify the input signal without feedback which results in a higher sensitivity to input changes and non-idealities. But there is significant nonlinear behavior for this amplifier, especially for large input signals. This makes them less suitable as an application applications where high linearity needed, such as precise analog signal processing. We need linearization techniques to improvised the behavior.

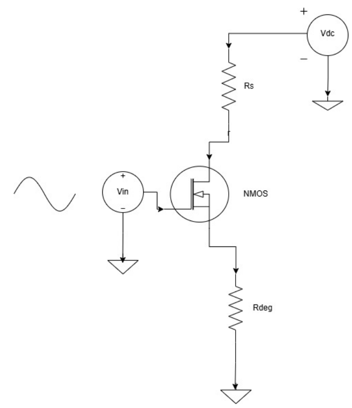

Fig. 1. Source degenerative circuit

III. RESISTIVE DEGENERATION

This technique is used in amplifiers to linearize and stabilize the behavior of this amplifier for certain uses. It involves resistor with the source in MOSFET as illustrated in fig (1) . It introduces negative feedback especially in the open loop amplifier. The degenration registor R_{deg} make a voltage drop across it and the voltage drop depends on the input signal. This voltage drop at the source terminal, along the degeneration resistor, substracts from the input voltage to form the effective control voltage across transistor. Due to the feedback effect, even when the input signal tries to drive more current through the transistor, there is increase in voltage drop across R_{deg} This limits the amount of current that can flow through the transistor. Effectively, the resistor pushes back against the current increase that occurs with a rising input signal. So it effects the transconductance and the effective transconductance for over all circuit can be written as :

$$g_{\text{m,eff}} = \frac{g_m}{1 + g_m \cdot R_{\text{deg}}} \tag{1}$$

IV. LINEARITY AND NON LINEARITY IN AMPLIFIERS

We have to define metrics first for quantifying the effects of nonlinearity. As we can observe in the large-signal analysis of single-stage and differential amplifiers, circuits usually shows

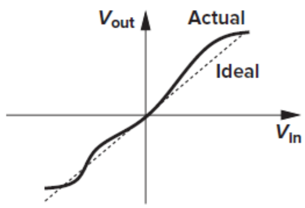

Fig. 2. Input/output characteristic of a nonlinear system [XI]

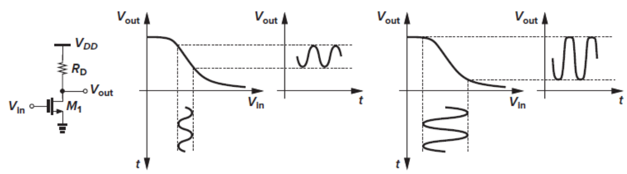

Fig. 3. Distortion in common-source stage [XI]

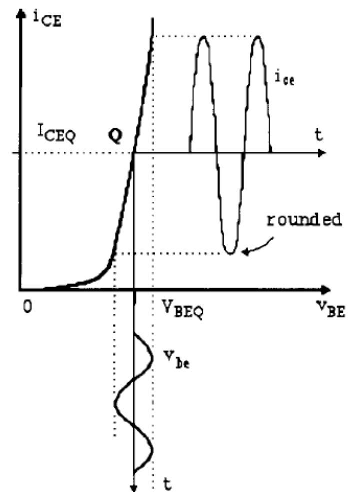

Fig. 5. Generation of nonlinear distortion caused by the nonlinear $I_C - V_{BE}$ characteristic.[XI]

a nonlinear input/output characteristic. Depicted in fig (2), such a characteristic deviates from

a straight line as the input swing increases. Two examples are shown in Fig(3) and (4). In a common-source stage or a differential pair, the variation of output becomes heavily nonlinear as the input level increases. In other words, for a small input change, the output is a reasonable replica of the input, but for large change in input, the output exhibits "saturated" levels. The nonlinear behavior of a circuit can also be expresses how much the slope varries, and hence the small-signal gain, with the change of input level as illustrated in Fig. (3).

V. HARMONIC DISTORTION

Suppose, an amplifier having a weak nonlinearity as in fig (5). Input signal and output signal are denoted by u(t) and y(t). At low frequencies, the output of this amplifier can be expressed interms of its input by power series:
$y = a_0 + a_1 u + a_2 u^2 + a_3 u^3 + ...$

Coefficient a_0 represents the dc component and coefficient a_1 represents the gain of the amplifier, whereas a_2, a_3,..... coefficients , represent its distortion. These distortion coeffcients can be obtained from the analytic expression of the function as given by:

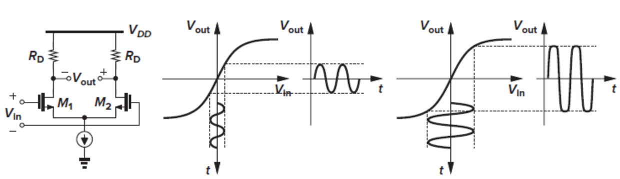

Fig. 4. Distortion in differential pair [XI]

$$a_n = \frac{1}{n!} \left. \frac{d^n y}{du^n} \right|_{u=0} \tag{2}$$

Cosine waveform of frequency and amplitude at the input of that amplifier gives output components at all multiples of ω. Under low-distortion conditions, only second- and third-order distortion components are considered. Where input $u = Ucos(\omega t)$
so output can be written as:
$y = \left(a_0 + \frac{a_2}{2}U^2\right) + \left(a_1 + \frac{3}{4}a_3 U^2\right) U \cos(\omega t) + \frac{a_2}{2}U^2 \cos(2\omega t) + \frac{a_3}{4}U^3 \cos(3\omega t) + \cdots$.
Odd-order distortion, a_3 modifies the signal component at the fundamental frequency. Terms $a_3 u^2$ can be neglected, however, with respect to a_1 , provided the U signal amplitude is sufficiently small. Harmonic distortion (HD) XI is defined as the ratio of the component of frequency to the one at the fundamental frequency.
$HD_2 = \frac{1}{2}\frac{a_2}{a_1}U$ and $HD_3 = \frac{1}{4}\frac{a_3}{a_1}U_2$
So, total harmonic distortion THD is given by:

$$THD = \sqrt{HD_2^2 + HD_3^2 + \cdots} \tag{3}$$

VI. V I CHARACTERISTICS

We often assumes as V_{GS} drops below V_{TH} that the device must turns off abruptly. In reality, for $V_{GS} \approx V_{Th}$, a "weak" inversion layer still exists and for that reason, some current flows from D to S terminal. Even for $V_{GS} < V_{Th}$, and I_D is finite, but it shows an exponential dependence on V_{GS} [1] ,Called subthreshold conduction. This effect can be formulated for V_{DS} greater than roughly 100 mV as

$$I_D = I_0 \exp\left(\frac{V_{GS}}{\xi V_T}\right) \tag{4}$$

where I_0 is proportional to W/L, $\xi > 1$ is a nonideality factor, and V_T = kT/q. We can also say the device operates in "weak

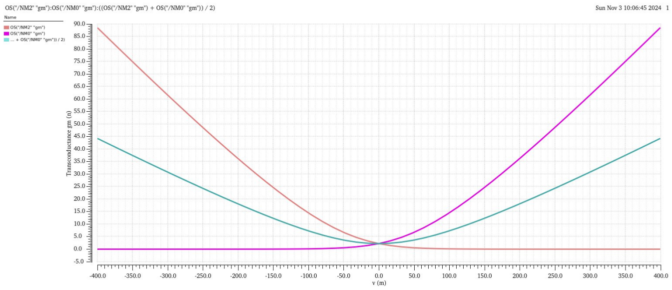

Fig. 6. Large resistance $R_{deg} >> 1/g_m$

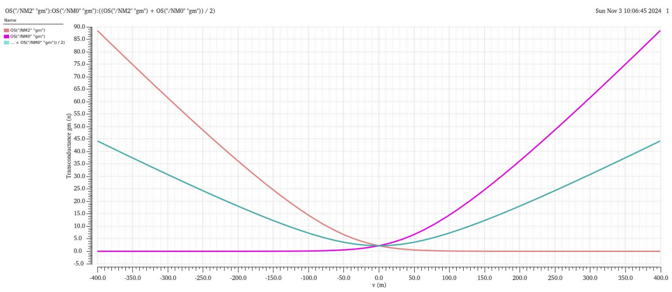

Fig. 7. Large resistance $R_{deg} >> 1/g_m$

inversion.” (Similarly, when VGS $>$ VTH, we say the device operates in “strong inversion.”)

VII. TRANSCONDUCTANCE

The transconductance gm can be derived as XI,

$$g_m = \frac{dI_{DS}}{dV_{in}} = \frac{I_B}{nU_T}\exp\left(\frac{V_{in}}{nU_T}\right) = \frac{I_{DS}}{nU_T}. \tag{5}$$

So, the transconductance gm varies exponentially with the input signal, illustrated in Fig.(6) where g_{mp} and g_{mn} are the transconductances of the positive and negative half-circuit . As V_{GS} increases, g_{mp} also increases exponentially whereas gmn decreases at a much slower rate. Hence, the overall transconductance gm,eff of the amplifier increases, resulting in an expanding nonlinear characteristic. Now we consider, a large degeneration resistor ($R_{\mathrm{deg}} >> \frac{1}{g_{\mathrm{m}}}$) is used. Due to a large internal loop-gain or degeneration factor $(1 + g_{\mathrm{m}}R_{\mathrm{deg}})$, the transistor’s exponential $\mathrm{V} - \mathrm{I}$ characteristic is strongly reduced as illustrated in fig (7), this limits the maximum transconductance. Thus, as the differential input increases, the transconductance g_{mn} reduces more than the corresponding increase in g_{mp}. This causes the overall transconductance $g_{m,eff}$ to decrease with the input signal, leading to a compressing nonlinearity.

The small signal voltage gain of resistive degenration circuit is given by :

$$A_v = -\frac{g_m R_D}{1 + g_m R_{deg}} \tag{6}$$

As R_{deg} increases effective transconductance of the amplifier decreases as shown in fig (8) where transconductance of positive half circuit and negative half circuit both have considered.

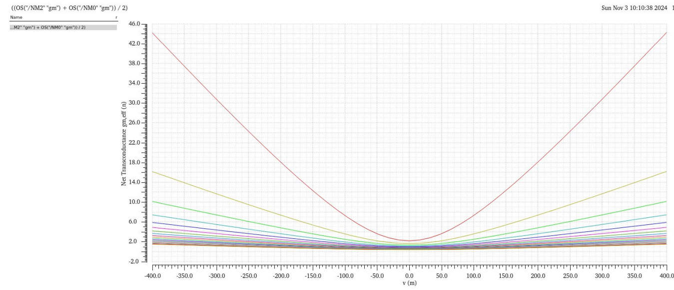

Fig. 8. Transition from an expanding to a compressing nonlinearity as the degeneration resistance R_{deg} increases

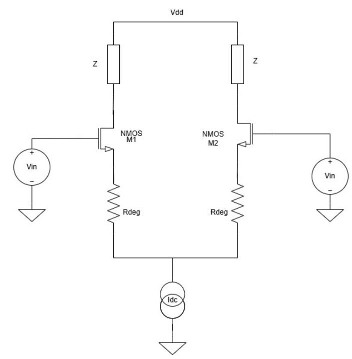

Fig. 9. PDD Topology

VIII. PDD AND CMD TOPOLOGY AND THIER COMPARISION

The PDD topology consists of two transistors M1 and M2 illustrated in fig.(10) in a differential-like configuration, with degeneration resistors connected to each transistor’s source.Although the topology appears differential,but we only have one active input. The input signal is applied to one transistor of PDD, and the other transistor is kept at a fixed DC bias voltage. So, it is called a ”pseudo-differential” effect. Here, each transistor has its own degeneration resistor, which improves linearity by providing local negative feedback.This topology exhibits variation of 0.6% as illustrated in fig.(11). In the CMD topology illustrated in fig.(9) , two transistors are present in a fully differential configuration, but with both transistors receiving differential inputs. CMD has true differential behavior, with one transistor having the positive input and the other having the negative input. A single resistor (or current source) is connected between the connected source node and ground as illustrated in fig(11). This resistor is known as the common-mode degeneration resistor. In both topologies, M1 and M2 must operate in ”weak inversion saturation” region(subthreshold region r=3) CMD exhibits less variation in g_m or better linearity because CMD amplifiers only active for the common mode signals.

IX. PVT

The optimum linearity condition depends strongly on temperature (T) also. To reduce the influence of temperature on linearity, the bias current I_B needs to be controlled with the

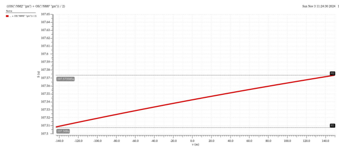

Fig. 10. Transconductance of PDD

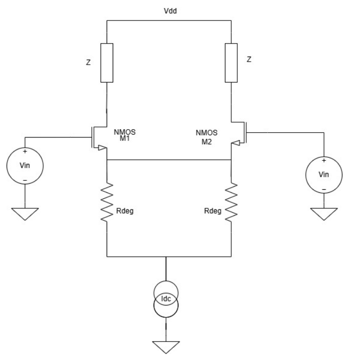

Fig. 11. CMD Topology

variation of temperature. This can be realized by using a PTAT biasing circuit fig (12) where Transistors M1,M2 operate in the weak-inversion saturation region and M3,M4 transistors act as a current mirror. The temperature is bieng controlled by controlling the PTAT current I_{PTAT}, which can be further adjusted by resistor R_B while the absolute current level is managed by a temperature independent current I_C.

X. MISMATCH

The above mentioned linearity techniques can only improve odd-order distortion components of the amplifier. However, any mismatch in transistors (design parameter W/L) or resistors of the differential amplifiers give rise to even-order harmonic distortion, which cannot be corrected by the proposed linearization technique.

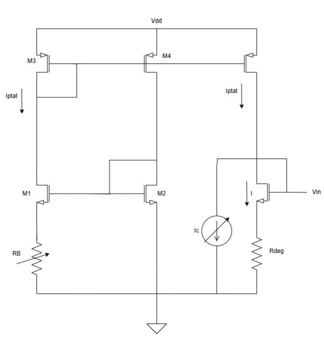

Fig. 12. PTAT Bissing

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