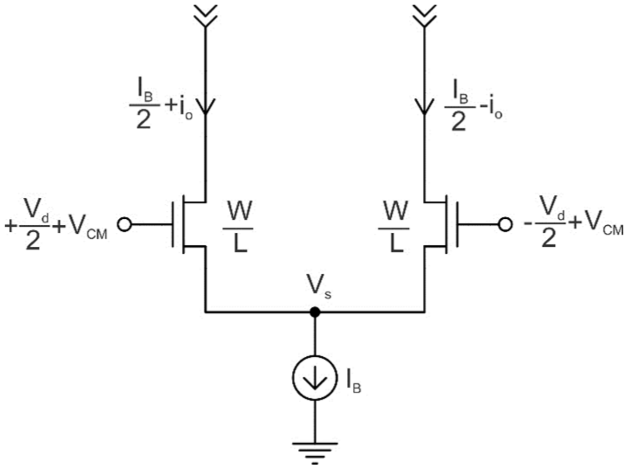
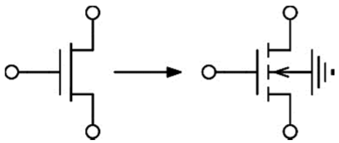
Amplificador Diferencial

Os amplificadores diferenciais são blocos básicos na construção de Amplificadores Operacionais (OpAmp), Amplificadores Operacionais de Transcondutância (OTA), comparadores de tensão, moduladores, osciladores, etc...

Par diferencial tipo N – Inversão Forte

Saturação





Equações do circuito

$$\beta = k_p \frac{W}{L}$$

$$\frac{I_B}{2} + i_0 = \frac{\beta}{2\alpha}\left(\frac{v_d}{2} + V_{CM} - v_s - V_T\right)^2$$

$$\frac{I_B}{2} - i_0 = \frac{\beta}{2\alpha}\left(-\frac{v_d}{2} + V_{CM} - v_s - V_T\right)^2$$

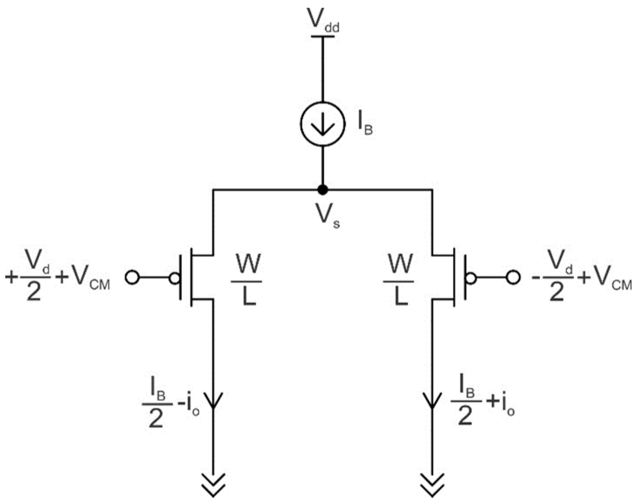
$$\boxed{i_0 = \frac{v_d\sqrt{4I_B\beta\alpha - \beta^2 v_d^2}}{4\alpha}}$$

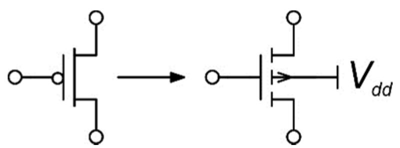
$$gm = \frac{di_0}{dv_d}$$

$$\boxed{gm = \frac{\beta\left(2\alpha I_B - \beta v_d^2\right)}{2\alpha\sqrt{\beta\left(4\alpha I_B - \beta v_d^2\right)}}}$$

Par diferencial tipo P – Inversão Forte

Saturação





Equações do circuito

$$\beta = k_p \frac{W}{L}$$

$$\frac{I_B}{2} - i_0 = \frac{\beta}{2\alpha}\left(v_s - \frac{v_d}{2} - V_{CM} - |V_T| \right)^2$$

$$\frac{I_B}{2} + i_0 = \frac{\beta}{2\alpha}\left(v_s + \frac{v_d}{2} - V_{CM} - |V_T| \right)^2$$

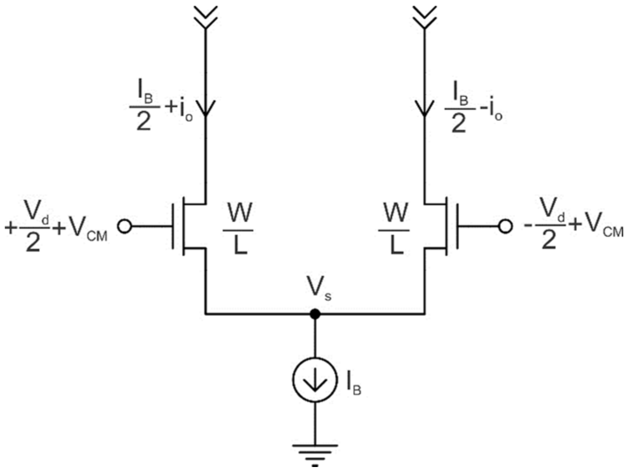
$$\boxed{i_0 = \frac{v_d\sqrt{4I_B\beta\alpha - \beta^2 v_d^2}}{4\alpha}}$$

$$gm = \frac{di_0}{dv_d}$$

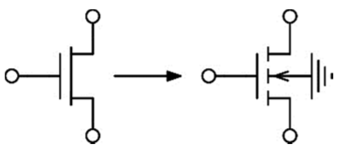
$$\boxed{gm = \frac{\beta\left(2\alpha I_B - \beta v_d^2\right)}{2\alpha\sqrt{\beta\left(4\alpha I_B - \beta v_d^2\right)}}}$$

Par diferencial tipo N – Inversão Fraca

Saturação



$$\begin{cases} 0 \le V_{GS} \le V_T \\ I_{DS} = I_{D0} e^{\frac{V_{GS}-V_T}{n\phi_T}} \\ I_{D0} = \phi_T^2 k_p \frac{W}{L_{EF}}(n-1) \\ n = 1 + \frac{\gamma}{2\sqrt{2\phi_F + V_{SB}}} \\ \phi_T = \frac{k_B T}{q} \\ k_p = \mu_n C_{ox} \end{cases}$$



Equações do circuito

$$\frac{I_B}{2} + i_0 = I_{D0} e^{\frac{\frac{v_d}{2}+V_{CM}-v_s-V_T}{n\phi_T}}$$

$$\frac{I_B}{2} - i_0 = I_{D0} e^{\frac{-\frac{v_d}{2}+V_{CM}-v_s-V_T}{n\phi_T}}$$

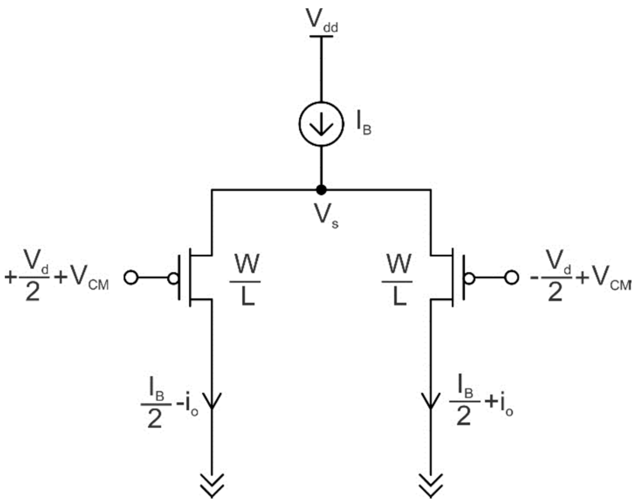
$$\boxed{i_0 = \frac{I_B}{2}\left(\frac{e^{\frac{v_d}{n\phi_T}}-1}{e^{\frac{v_d}{n\phi_T}}+1}\right) = \frac{I_B}{2}\tanh\left(\frac{v_d}{2n\phi_T}\right)}$$

$$gm = \frac{di_0}{dv_d}$$

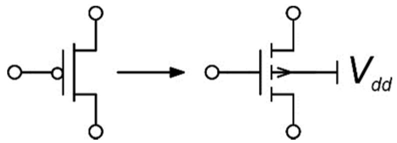
$$\boxed{gm = \frac{I_B}{n\phi_T}\frac{e^{\frac{v_d}{n\phi_T}}}{\left(1+e^{\frac{v_d}{n\phi_T}}\right)^2}}$$

Par diferencial tipo P – Inversão Fraca

Saturação



$$\begin{cases} 0 \le V_{SG} \le \left|V_T\right| \\ I_{SD} = I_{D0} e^{\frac{V_{SG}-\left|V_T\right|}{n\phi_T}} \\ I_{D0} = \phi_T^2 k_p \dfrac{W}{L_{EF}}(n-1) \\ n = 1 + \dfrac{\gamma}{2\sqrt{2\phi_F + V_{BS}}} \\ \phi_T = \dfrac{k_B T}{q} \\ k_p = \mu_p C_{ox} \end{cases}$$



Equações do circuito

$$\frac{I_B}{2} - i_0 = I_{D0} e^{\frac{v_s - \frac{v_d}{2} - V_{CM} - \left|V_T\right|}{n\phi_T}}$$

$$\frac{I_B}{2} + i_0 = I_{D0} e^{\frac{v_s + \frac{v_d}{2} - V_{CM} - \left|V_T\right|}{n\phi_T}}$$

$$\boxed{i_0 = \frac{I_B}{2}\left(\frac{e^{\frac{v_d}{n\phi_T}} - 1}{e^{\frac{v_d}{n\phi_T}} + 1}\right) = \frac{I_B}{2}\tanh\left(\frac{v_d}{2n\phi_T}\right)}$$

$$gm = \frac{di_0}{dv_d}$$

$$\boxed{gm = \frac{I_B}{n\phi_T}\frac{e^{\frac{v_d}{n\phi_T}}}{\left(1 + e^{\frac{v_d}{n\phi_T}}\right)^2}}$$

Equações Normalizadas na Inversão Forte

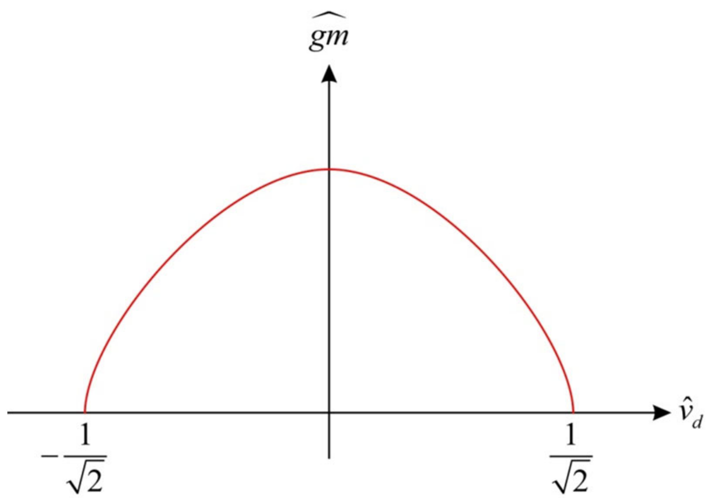
$$i_0 = \frac{v_d\sqrt{4I_B\beta\alpha - \beta^2 v_d^2}}{4\alpha}$$

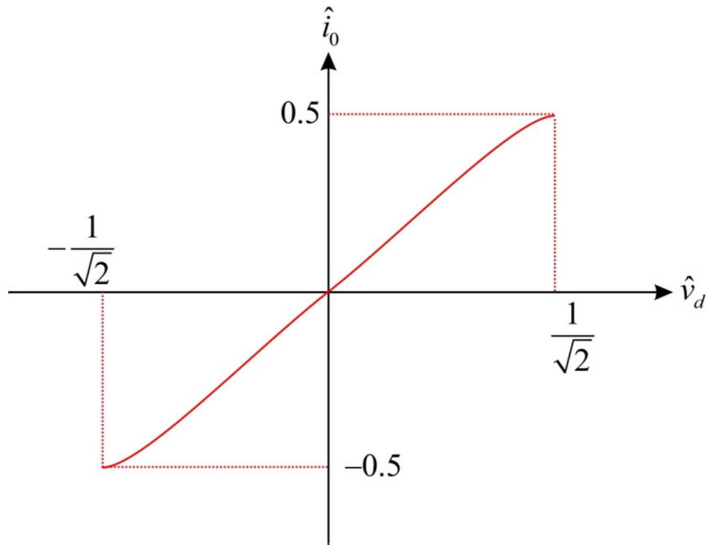
$$gm = \frac{\beta\left(2\alpha I_B - \beta v_d^2\right)}{2\alpha\sqrt{\beta\left(4\alpha I_B - \beta v_d^2\right)}}$$

$$\hat{v}_d = \frac{v_d}{2}\sqrt{\frac{\beta}{\alpha I_B}} \qquad \hat{i}_0 = \frac{i_0}{I_B} \qquad \widehat{gm} = \frac{2\sqrt{\alpha}}{\sqrt{\beta I_B}}\, gm$$

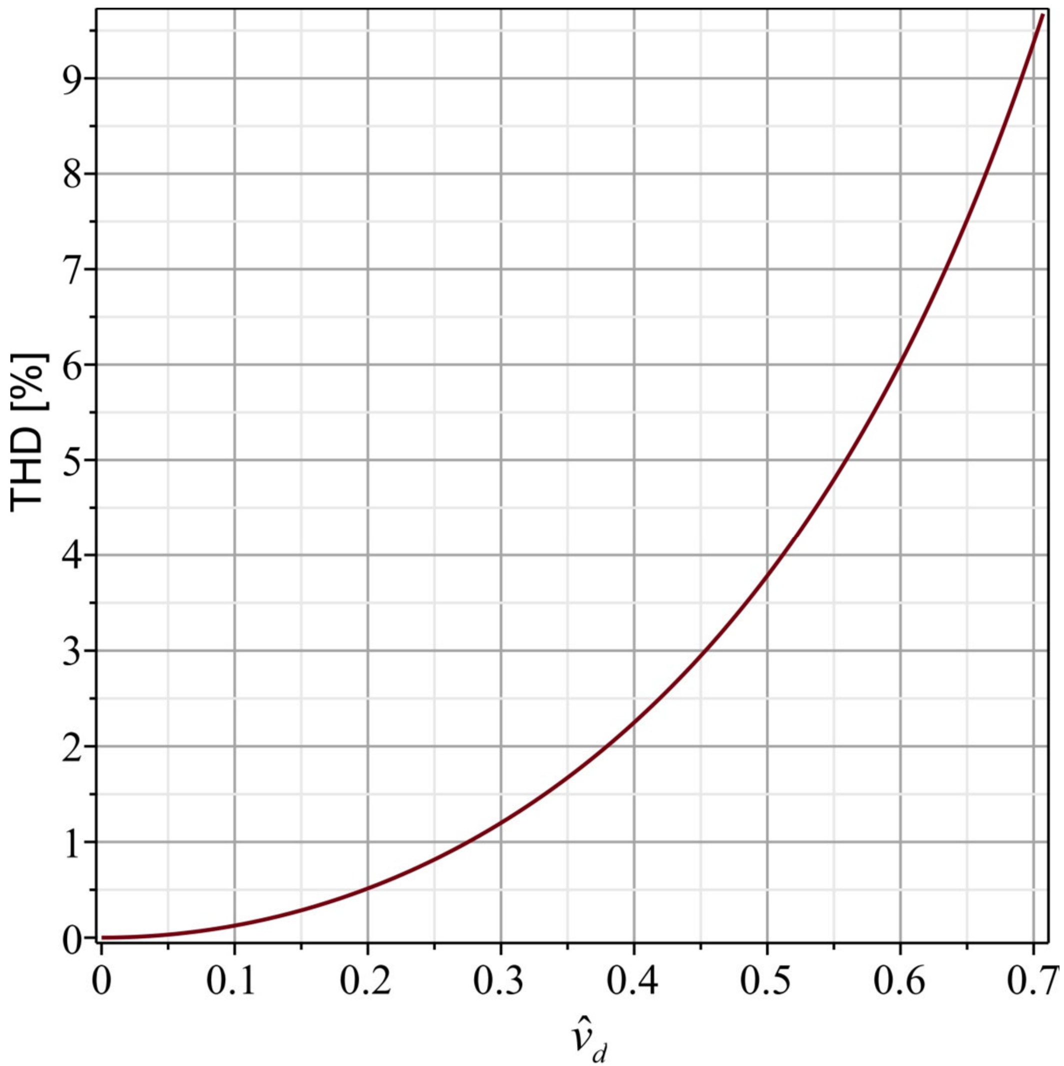
$$\hat{i}_0 = \hat{v}_d\sqrt{1-\hat{v}_d^2} \longrightarrow \widehat{gm} = \frac{\left(1-2\hat{v}_d^2\right)}{\sqrt{1-\hat{v}_d^2}}$$

$$\left|\hat{v}_{d_{\max}}\right| = \frac{1}{\sqrt{2}} \longrightarrow \left|\hat{i}_{0_{\max}}\right| = \frac{1}{2} \longrightarrow \widehat{gm}_{\max} = 1 \longrightarrow \widehat{gm}_{\min} = 0$$





Curva de THD para a Tensão Diferencial Normalizada, THDmax=10%

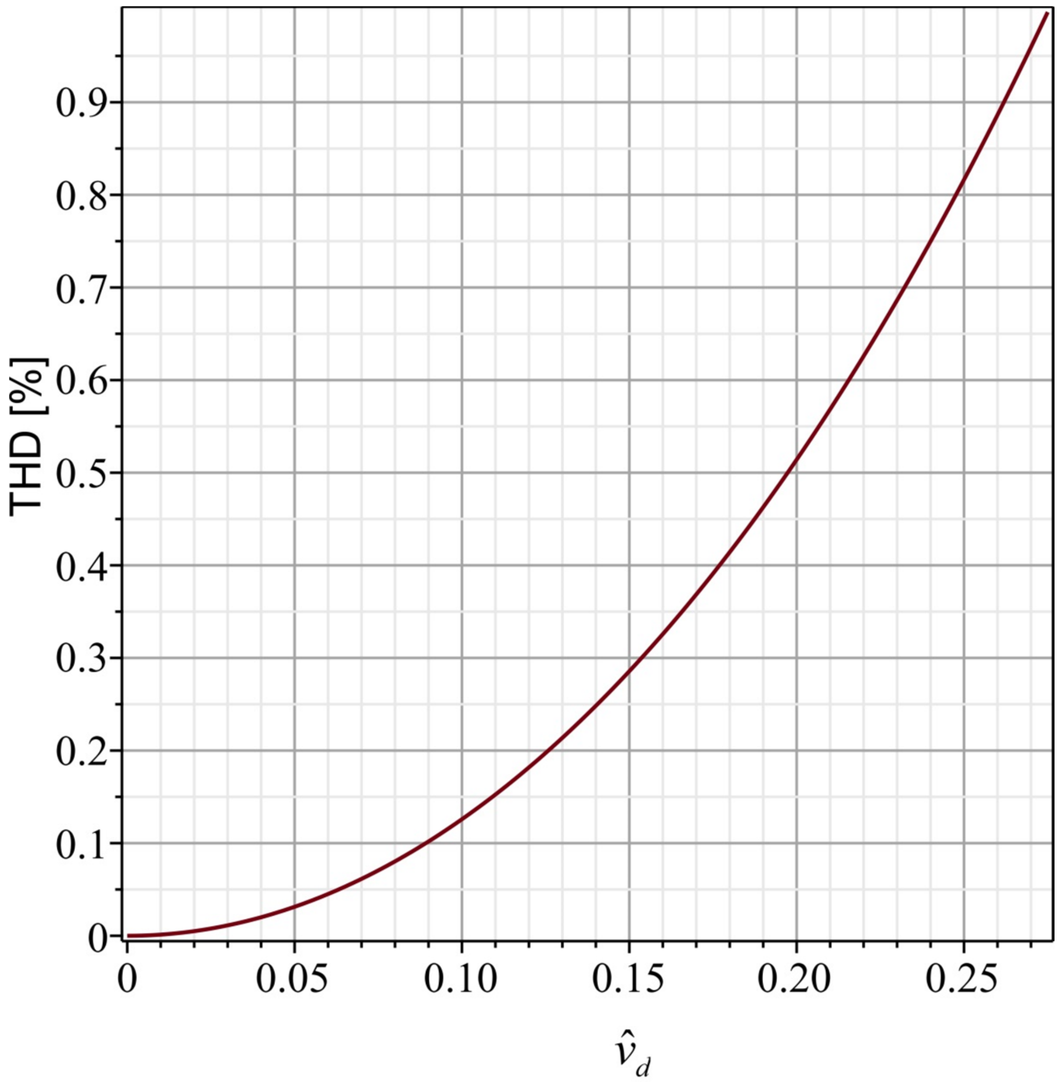


$$\hat{v}_d = \frac{v_d}{2}\sqrt{\frac{\beta}{\alpha I_B}}$$

$$\widehat{gm} = \frac{\left(1-2\hat{v}_d^2\right)}{\sqrt{1-\hat{v}_d^2}}$$

$$\widehat{gm} = \frac{2\sqrt{\alpha}}{\sqrt{\beta I_B}}\,gm$$

Curva de THD para a THD_{max}=1%



$$\hat{v}_d = \frac{v_d}{2}\sqrt{\frac{\beta}{\alpha I_B}}$$

$$\widehat{gm} = \frac{\left(1-2\hat{v}_d^2\right)}{\sqrt{1-\hat{v}_d^2}}$$

$$\widehat{gm} = \frac{2\sqrt{\alpha}}{\sqrt{\beta I_B}}\,gm$$

Equações Normalizadas na Inversão Fraca

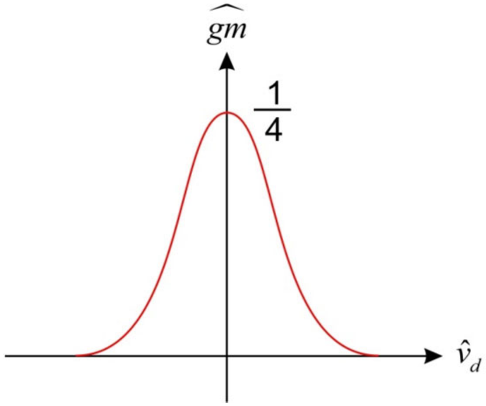
$$\hat{v}_d = \frac{v_d}{n\phi_T} \qquad \hat{i}_0 = \frac{2}{I_B} i_0 \qquad \widehat{gm} = \frac{n\phi_T}{I_B} gm$$

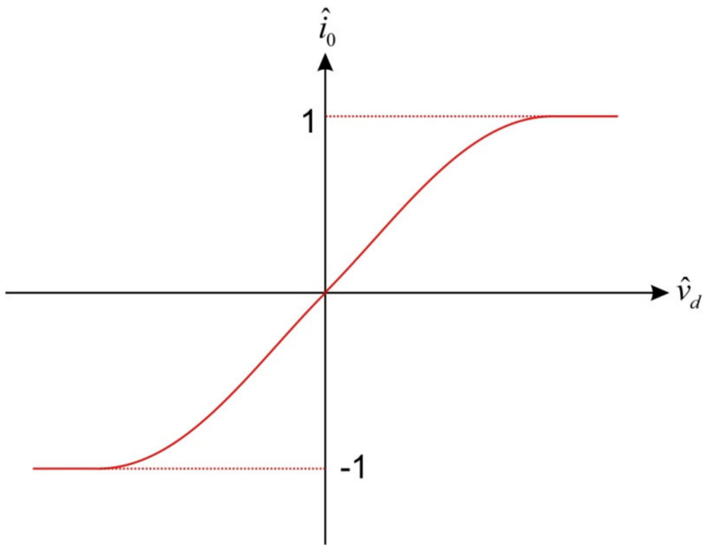
$$i_0 = \frac{I_B}{2}\left(\frac{e^{\frac{v_d}{n\phi_T}} - 1}{e^{\frac{v_d}{n\phi_T}} + 1}\right) = \frac{I_B}{2}\tanh\left(\frac{v_d}{2n\phi_T}\right)$$

$$\hat{i}_0 = \frac{e^{\hat{v}_d} - 1}{e^{\hat{v}_d} + 1} = \tanh\left(\frac{\hat{v}_d}{2}\right) \longrightarrow \widehat{gm} = \frac{e^{\hat{v}_d}}{\left(1 + e^{\hat{v}_d}\right)^2}$$

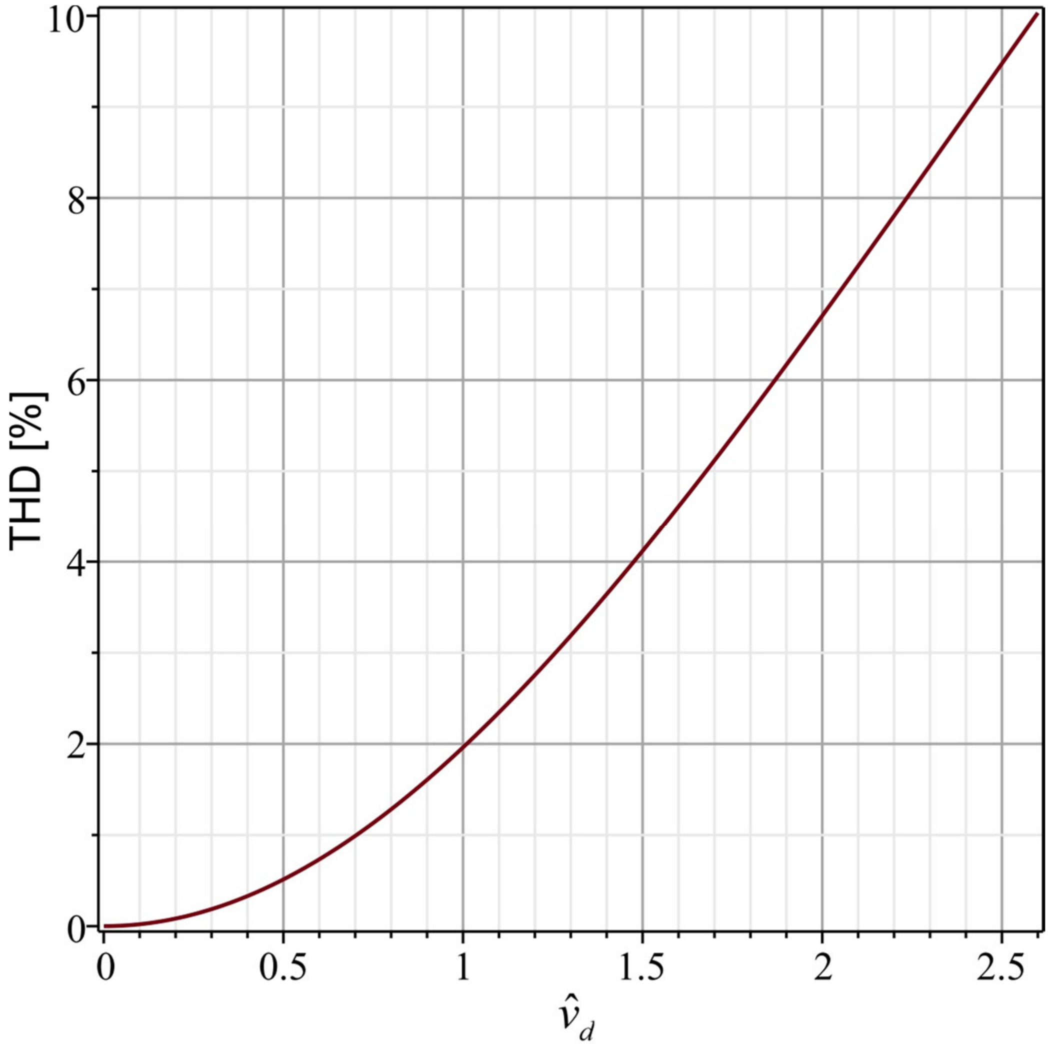
$$gm = \frac{I_B}{n\phi_T}\frac{e^{\frac{v_d}{n\phi_T}}}{\left(1 + e^{\frac{v_d}{n\phi_T}}\right)^2}$$

$$\left|\hat{i}_{0_{\max}}\right| = 1 \longrightarrow \widehat{gm}_{\max} = \frac{1}{4} \longrightarrow \widehat{gm}_{\min} = 0\Big|_{|\hat{v}_d| = \infty}$$





Curva de THD para a THD_{max}=10%

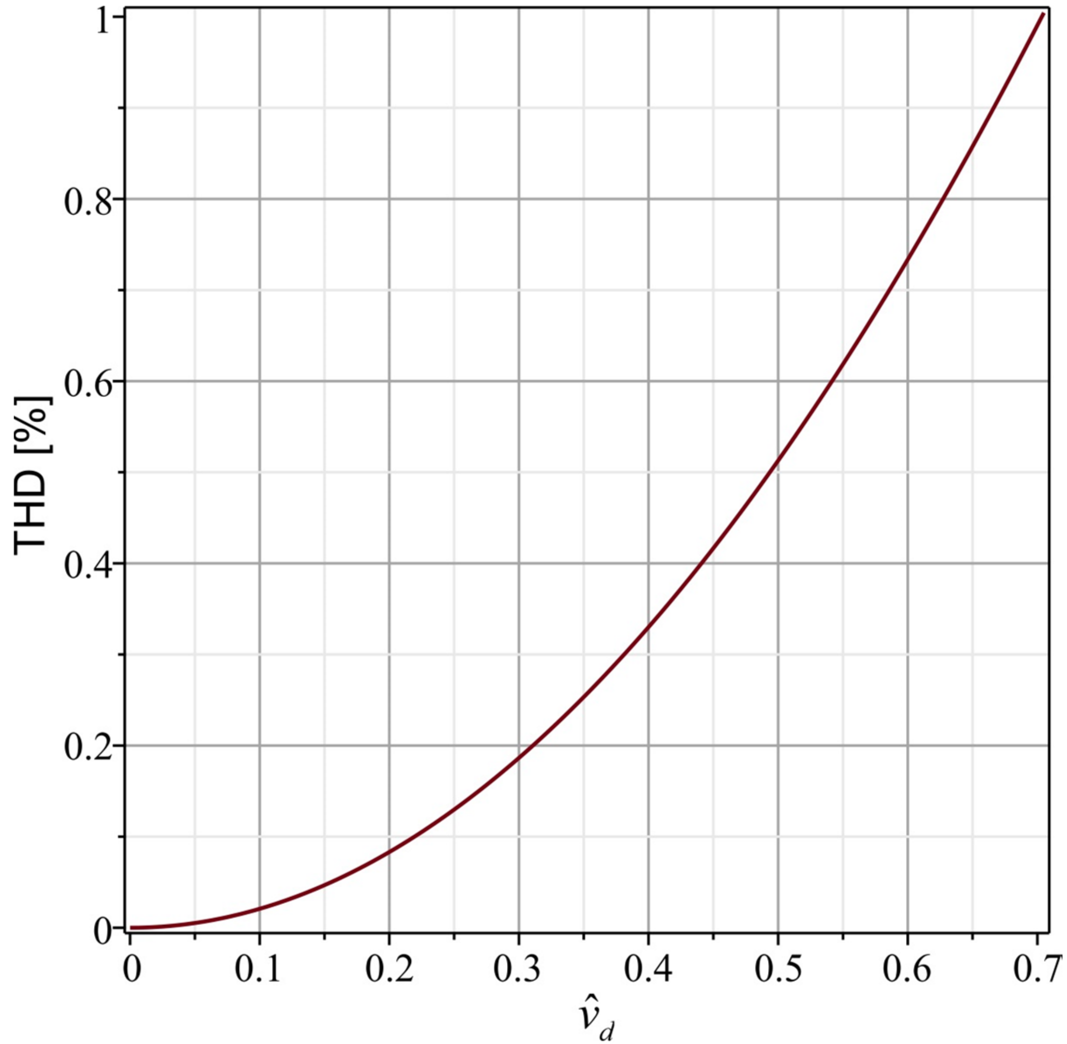


$$\hat{v}_d = \frac{v_d}{n\phi_T}$$

$$\widehat{gm} = \frac{e^{\hat{v}_d}}{\left(1+e^{\hat{v}_d}\right)^2}$$

$$\widehat{gm} = \frac{n\phi_T}{I_B}\, gm$$

Curva de THD para a THD_{max}=1%



$$\hat{v}_d = \frac{v_d}{n\phi_T}$$

$$\widehat{gm} = \frac{e^{\hat{v}_d}}{\left(1+e^{\hat{v}_d}\right)^2}$$

$$\widehat{gm} = \frac{n\phi_T}{I_B}gm$$

Final deste Tópico