مدارهای مخابراتی

ص ۳-۱)

$$i_D = \alpha V_D + \beta V_D^3 + \gamma V_D^5$$

$$g_D(t) = \frac{\partial i_D}{\partial v_D}\Big|_{v_D = V_1\cos\omega_0 t} = \alpha + 3\beta V_D^2 + 5\gamma V_D^4$$

$$g_D(t) = \alpha + 3\beta V_1^2 \cos^2\omega_0 t + 5\gamma V_1^4 \cos^4\omega_0 t$$

$$g_D(t) = \alpha + 3\beta V_1^2\left(\frac{1+\cos 2\omega_0 t}{2}\right) + 5\gamma V_1^4\left(\frac{1+\cos 2\omega_0 t}{2}\right)^2$$

$$\swarrow$$

$$\boxed{\left\{\frac{1}{4} + \cos 2\omega_0 t + \frac{1}{4}\left(\frac{1+\cos 4\omega_0 t}{2}\right)\right.}$$

$$g_D(t) = (\underbrace{\alpha + \frac{3\beta V_1^2}{2} + \frac{15}{8}\gamma V_1^4}_{A}) + (\underbrace{\frac{3}{2}\beta V_1^2 + 5\gamma V_1^4}_{B})\cos 2\omega_0 t$$

$$+ \underbrace{5/8}_{C}\,\gamma V_1^4 \cos 4\omega_0 t$$

$$v_D = V_{s_1}\cos\omega_{s_1} t + V_{s_2}\cos\omega_{s_2} t - v_{IF}(t)$$ از دید سیگنال کوچک

$$i_d(t) = g_D(t)\cdot v_d(t)$$

$$i_d(t) = (A + B\cos 2\omega_0 t + C\cos 4\omega_0 t)\times$$

$$(V_{s_1}\cos\omega_{s_1} t + V_{s_2}\cos\omega_{s_2} t - V_{IF}\cos(2\omega_0 + \omega_{s_1})t$$

$$i_d(t) = A(V_{s_1}\cos\omega_{s_1}t + V_{s_2}\cos\omega_{s_2}t) - AV_{IF}\cos(2\omega_0+\omega_{s_1})t$$

$$+ B(V_{s_1}\cos 2\omega_0 t.\cos\omega_{s_1}t + V_{s_2}\cos 2\omega_0 t\cos\omega_{s_2}t)$$

$$- B\,V_{IF}\cos 2\omega_0 t\cos(2\omega_0+\omega_{s_1})t$$

$$+ C\,V_{s_1}\cos 4\omega_0 t\cos\omega_{s_1}t + \overset{CV_{s2}}{\cos} 4\omega_0 t\cos\omega_{s_2}t)$$

$$- C\,V_{IF}\cos 4\omega_0 t\cos(2\omega_0+\omega_{s_1})t$$

$$i_{dIF}(t) = -AV_{IF}\cos(2\omega_0+\omega_{s_1})t$$

$$+ \frac{B}{2}V_{s_1}\cos(2\omega_0+\omega_{s_1})t$$

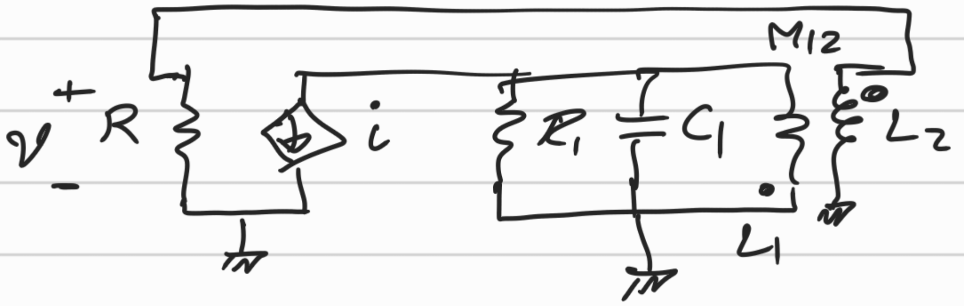
$$V_{IF}(t) = i_{dIF}(t)\,R_L$$

$$V_{IF} = \left(-AV_{IF} + \frac{B}{2}V_{s_1}\right)R_L$$

$$V_{IF} = \frac{B/2\,(V_{s_1})R_L}{1 + AR_L}$$

$$B/2\,V_{s2}\,R_L\cos(2\omega_0+\omega_{s2})$$ مؤلفه پارازیتی

$i = \alpha v + \beta v^2 + \gamma v^3$ (۳-۳

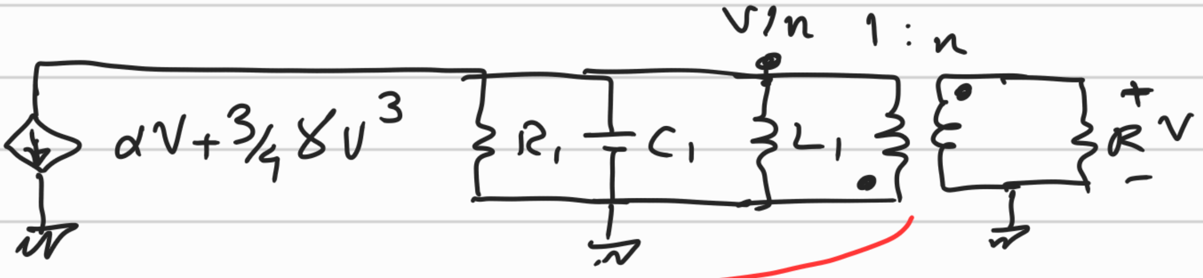


$v(t) = V\cos\omega_0 t$

$$i(t) = \alpha V\cos\omega_0 t + \beta (V\cos\omega_0 t)^2 + \gamma (V\cos\omega_0 t)^3$$

$$i(t) = \alpha V\cos\omega_0 t + \beta V^2 \left(\frac{1+\cos 2\omega_0 t}{2}\right) + \gamma V^3 \cos\omega_0 t \left(\frac{1+\cos 2\omega_0 t}{2}\right)$$

$$i(t) = \left(\alpha V + \frac{3}{4}\gamma V^3\right)\cos\omega_0 t + \frac{\beta}{2}V^2 \cos 2\omega_0 t + \frac{\gamma}{4}V^3 \cos 3\omega_0 t$$



با توجه بر سرهای قرارداد

$$kcl:\ -\left(\alpha V + 3/4\,\gamma V^3\right) + V/n\left(G_1 + j\omega C_1 + \frac{1}{j\omega L_1} + n^2 G\right) = 0$$

$$-\alpha + \frac{1}{n}\left(G_1 + j\left(\omega C_1 - \frac{1}{\omega L_1}\right) + n^2 G\right) = \frac{3}{4}\gamma V^2$$

فرکانس نوسان جایی که بخش موهومی صفر شود .

$$\omega_0 = \frac{1}{\sqrt{L_1 C_1}}$$

شرط نوسان :

$$-\alpha + \frac{1}{n}(G_1 + n^2 G) = 3/4\, \gamma V^2$$

$$V = \sqrt{\frac{4}{3\gamma}\left(\frac{1}{n}(G_1 + n^2 G) - \alpha\right)}$$

دامنه ولتاژ اسیلاتور محلی

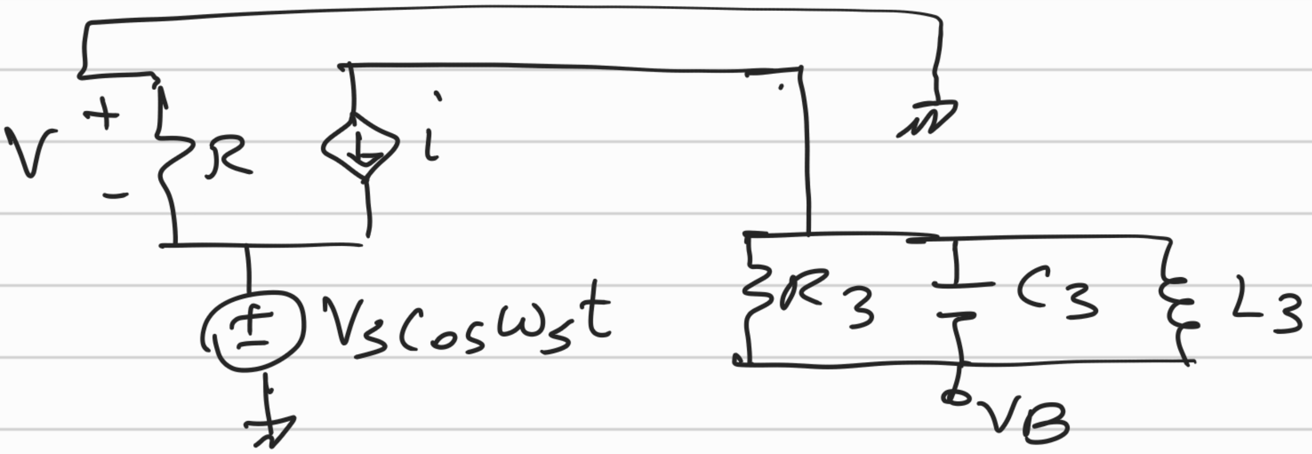
$$G_1 = 1/R_1 \;,\quad G = 1/R \;,\quad n = \frac{M_{12}}{L_1}$$

تحلیل میکسر

$$i(t) = \alpha V + \beta V^2 + \gamma V^3$$

$$g_d(t) = \frac{\partial i}{\partial v} = \alpha + 2\beta V + 3\gamma V^2$$

هدایت انتقالی عنصر غیرخطی



$V = -V_s \cos \omega_s t$ $\longrightarrow$ $i(t) = g_d(t)\, V_{signal}$

signal

small signal

↙

$$i(t)_{\text{small signal}} = \left(\alpha + 2\beta V \cos\omega_0 t + 3\gamma V^2 \cos^2\omega_0 t\right) \times \left(-V_s \cos\omega_s t\right)$$

↙

$$i(t)_{\text{small signal}} = -\alpha V_s \cos\omega_s t - \beta V V_s \cos(\omega_0+\omega_s)t - \beta V V_s \cos(\omega_0-\omega_s)t$$

$$-\frac{3\gamma}{2} V_s V^2 \cos\omega_s t - \frac{3}{4}\gamma V_s V^2 \cos(2\omega_0-\omega_s)t$$

$$-\frac{3}{4}\gamma V_s V^2 \cos(2\omega_0+\omega_s)t$$

$$i_{IF}(t) = -3/4\, \gamma V_s V^2 \cos(2\omega_0+\omega_s)t$$

چون L_3 ، C_3 در فرکانس $2\omega_0+\omega_s$ تنظیم شده‌اند

$$g_c = \frac{I_{IF}}{V_{RF}} = \frac{3/4\, \gamma V_s V^2}{V_s} = 3/4\, \gamma V^2$$

$$v_o(t) = V_B - g_c V_s \cos(2\omega_0+\omega_s)t$$

$$v_o(t) = V_B - 3/4\, \gamma V^2 V_s \cos(2\omega_0+\omega_s)t$$

۵_۳

$$I_E(t) = \frac{V_{Lo} + 12 - V_{BE}}{R_B} =$$

منبع جریان زوج
دیفرانسیل

$$= \cos(2.01\pi \times 10^{7} t) + 2.06\,mA$$

mA

$$i_2(t) = \frac{I_E(t)}{2}\left(1 - \tanh\left(\frac{x}{2}\cos\omega_0 t\right)\right)$$

$$x = \frac{V_S}{V_T}$$

$$i_2(t) = \frac{I_E}{2}(t)\left[1 - 2a_1(x)\cos\omega_s t - 2a_3(x)\cos 3\omega_s t \ldots\right]$$

$$i_{2IF}(t) = -\frac{1}{2} \times 2a_1(x)\,\frac{\cos(6.59 - 6.28)\times 10^{7} t}{2}$$

$$\omega_{IF} = \frac{1}{\sqrt{35\times 10^{-6} \times 2.89 \times 10^{-9}}}$$

$$\omega_{IF} = 3.14 \times 10^{6}\ rad/sec$$

$$\omega_{IF} = \omega_0 - \omega_s$$

$$\omega_0 = 6.59 \times 10^{7}\ rad/sec$$

$$\omega_s = 6.28 \times 10^{7}\ rad/sec$$

$$g_c = \frac{I_{IF}}{V_s} = \frac{1/2\, a_1(x)}{V_s}$$

$$V_0(t) = V_{CC} - R_L g_c V_s (1 + m f(t)) \cos(3.14 \times 10^{6} t\ )$$

$$v_o(t) = 12 - 2.2 \times \frac{1}{2} a_1(x) (1 + m f(t)) \cos(3.14 \times 10^6 t)$$

$$x = \frac{V_s}{V_T} = \frac{10m}{25m} = 0.4$$

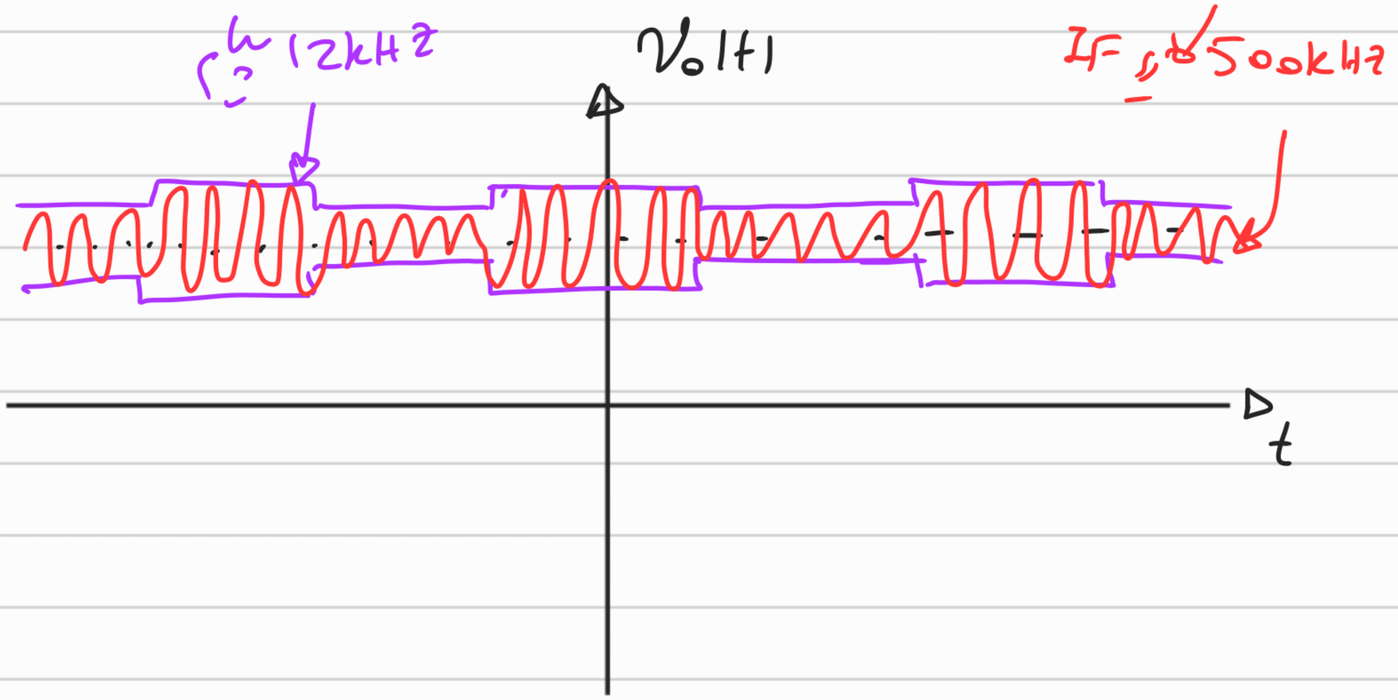
$$V_s = I_s \times 5k\Omega = 2\mu A \times 5k\Omega = 10\,mVolt$$

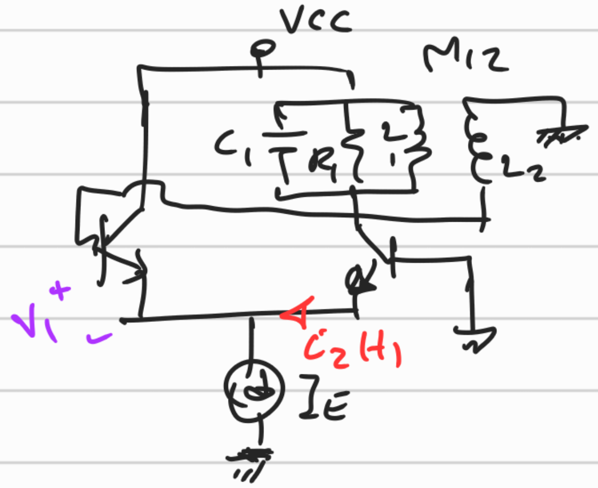
مدار تشدید بین ، و

$$\frac{a_1(x)}{x} \simeq \frac{1}{4}$$

اگر $x < 1$

$$a_1(x) = \frac{x}{4} = 0.1$$





۷-۳) تحلیل نوسان ساز

فرکانس نوسان

$$\omega_0 = \frac{1}{\sqrt{L_1 C_1}}$$

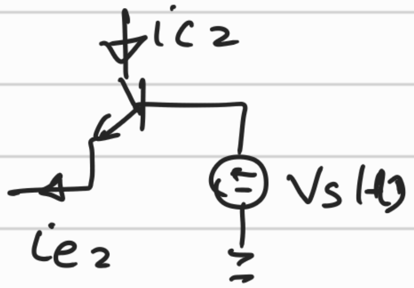
$$G_m = \frac{G_1}{n(1-n/\beta)} \qquad n = \frac{M_{12}}{L_1}$$

$$i_2(t) = \frac{I_E}{2}\left(1-\tanh\left(\frac{V_1}{2V_T}\right)\right)]$$

$$x = \frac{V_1}{V_T}$$

$$g_m(t) = \frac{\partial i_2(t)}{\partial v_1} = -\frac{I_E}{2}\left(\frac{1}{2V_T}\right)\left(1-(\tanh(x))^2\right)$$

$$\underset{signal}{i_2} = g_m(t) \cdot V_s(1+mf(t))\cos\omega_s t$$



$$\underset{signal}{i_2(t)} = \frac{I_E}{4V_T} \times \big(2a_1(x)\cos\omega_0 t + 2a_3(x)\cos 3\omega_0 t + 2a_5(x)\cos 5\omega_0 t\big)^2 V_s(1+mf(t))\cos\omega_s t$$

$$\underset{signal}{i_2(t)} = \frac{I_E}{4V_T} V_s(1+mf(t))\, 4 \times \Big(a_1^2(x)\underset{\textcircled{\text{۱}}}{\cos^2\omega_0 t} + a_3^2(x)\underset{\textcircled{\text{۲}}}{\cos^2 3\omega_0 t} + a_5^2(x)\underset{\textcircled{\text{۳}}}{\cos^2 5\omega_0 t}$$
$$+ 2a_1(x)a_3(x)\cos\underset{\textcircled{\text{۴}}}{\omega_0} t\cos 3\omega_0 t$$
$$+ 2a_1(x)a_5(x)\cos\underset{\textcircled{\text{۵}}}{\omega_0} t\cos 5\omega_0 t$$
$$+ 2a_3(x)a_5(x)\cos 3\underset{\textcircled{\text{۶}}}{\omega_0} t\cos 5\omega_0 t\Big)(1+mf(t))\cos\omega_s t$$

فرکانس های تولید شده :

① $2\omega_0 \pm \omega_s$

② $6\omega_0 \pm \omega_s$

③ $10\omega_0 \pm \omega_s$

④ $\begin{cases} 2\omega_0 \pm \omega_s \\ 4\omega_0 \pm \omega_s \end{cases}$

⑤ $\begin{cases} 6\omega_0 \pm \omega_s \\ 4\omega_0 \pm \omega_s \end{cases}$

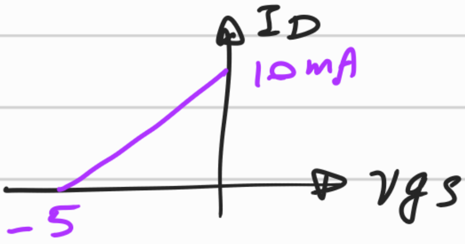
⑥ $\begin{cases} 8\omega_0 \pm \omega_s \\ 2\omega_0 \pm \omega_s \end{cases}$

پایین ترین مؤلفه $2\omega_0 - \omega_s$ است که در جملات ① ، ④ ، ⑥ ظاهر می شود .

$$i_{IF}(t) = \frac{I_E}{V_T} V_s(1+mf(t))\left\{\frac{a_1^2(x)}{2} + \frac{a_1(x)a_3(x)}{2} + \frac{a_3(x)a_5(x)}{2}\right\}\cos(2\omega_0-\omega_s)t$$

همانطور که ملاحظه می کنید در این مخلوط کننده در فرکانس های $\omega_0 \pm \omega_s$ خروجی نداریم لذا مخلوط کننده هارمونیکی نامیده می شود چون ω_s با هارمونیک های ω_0 مخلوط می شود .

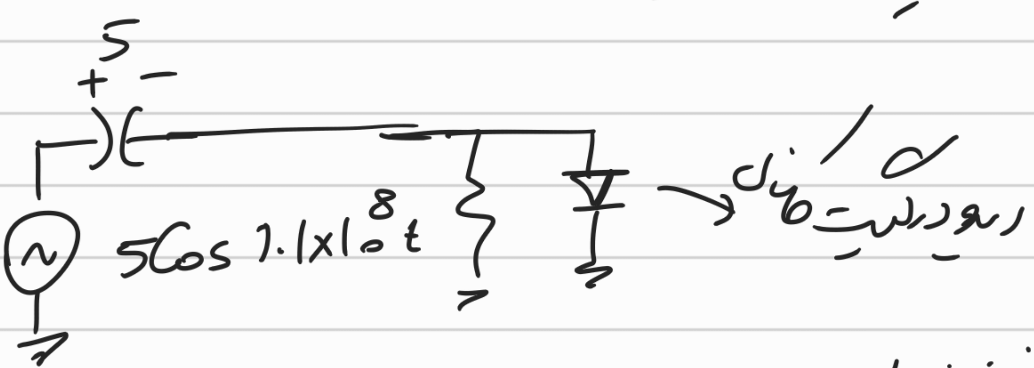
$$v_o(t) = V_{CC} - R_2\, i_{IF}(t)$$



۳-۸) ازش صفح

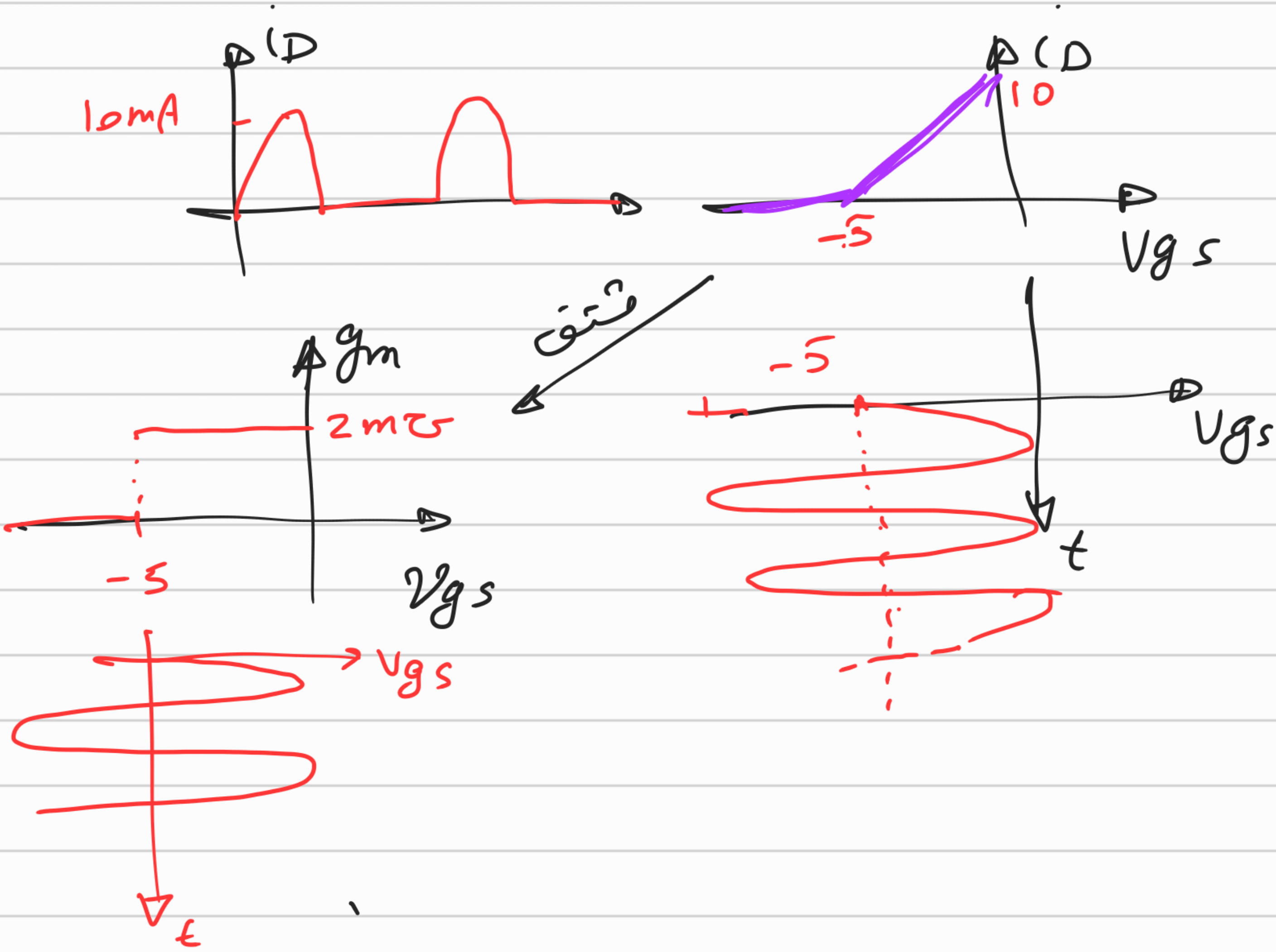
با توجه به وجود خازن 2pF

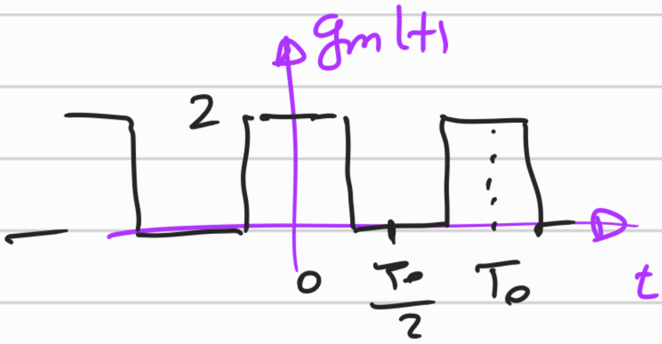
این خازن به اندازه پیک ولتاژ اسیلاتور محلی شارژ می شود (مثل مدار clamp)



پس از شارژ این خازن داریم :

$$V_{gs} = 5\cos 1.1\times10^{8}t - 5$$





$$g_m(t) = 2\,S(t)$$

← تابع پنجره متناوب

$$S(t) = \frac{1}{2} + \sum_{n=1}^{\infty} \frac{\sin n\pi/2}{n\pi/2} \cos n\omega_0 t$$

$$g_m(t) = 1 + \frac{4}{\pi}\cos\omega_0 t - \frac{4}{3\pi}\cos 3\omega_0 t + \cdots$$

$$i_d(t) = g_m(t)\,V_s(t) = \left(1 + \frac{4}{\pi}\cos\omega_0 t + \cdots\right) V_s \cos\omega_s t$$

$$i_{d\,IF}(t) = \frac{4}{\pi} \times \frac{V_s}{2} \cos(\omega_0 - \omega_s)t$$

$$g_c = \frac{I_{IF}}{V_s} = \frac{4}{\pi}$$

$$V_{out}(t) = 15 - 5k\Omega \times \frac{4}{\pi} \times 50mV\,(1 + \cos 10^4 t)\cos 10^8 t$$

$$\omega_{IF} = \frac{1}{\sqrt{1\mu H \times 100pF}} = \frac{1}{\sqrt{10^{-16}}} = 10^8\ rad/sec$$

$\omega_0 = 1.1 \times 10^8$ $\qquad$ $\omega_0 - \omega_s = 10^8\ rad/sec$

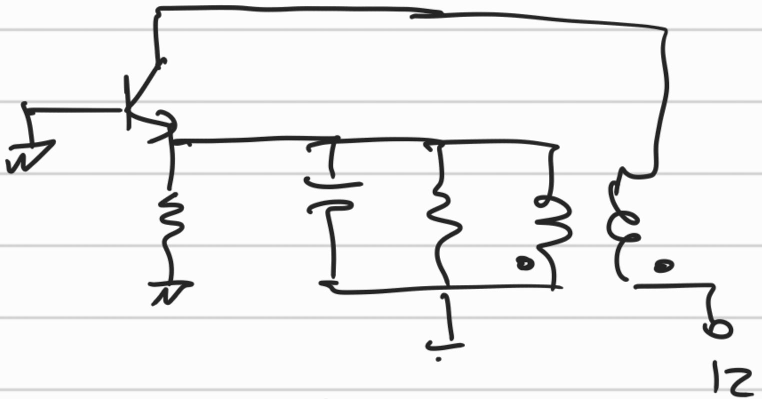
$\omega_s = 10^7$

در مدار ورودی گیت امپدانس خازن در فرکانس اسیلاتور محلی $\frac{1}{\omega C} \simeq 500\Omega$ و مقاومت متصل به گیت $1M\Omega$ است با توجه به کوچکتر بودن امپدانس خازن نسبت به مقاومت

ولتاژ اسیلاتور محلی و RF به خوبی به گیت کوپل می‌شوند. خازن نقش هم‌سطح‌ساز ولتاژ را دارد.

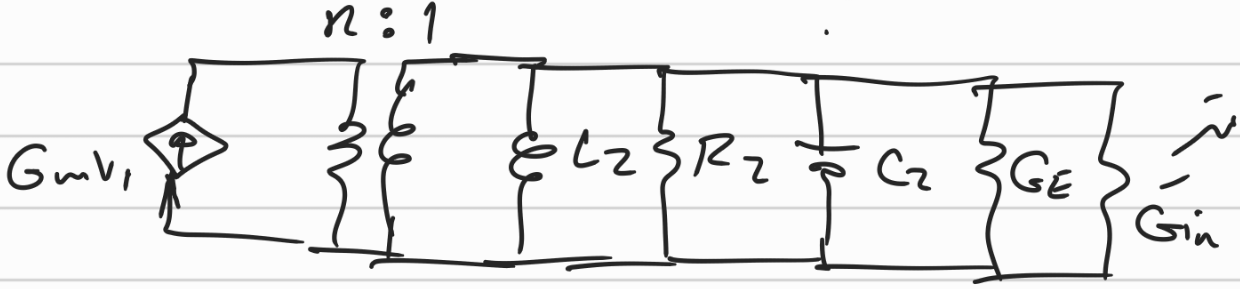
(۳-۹

تحلیل نوسان ساز



$$\omega_0 = \frac{1}{\sqrt{L_2C_2}} = 3.141 \times 10^7 \ rad/sec$$

$$f_0 \simeq 5MHz$$



دامنه نوسان درامیتر

$$n = \frac{M_{12}}{L_2} = 30 \qquad G_{in} = \frac{1}{\alpha} G_m$$

$$, I_E = \frac{3.75 - 0.7}{3k\Omega} = 1mA \rightarrow V_A = I_{EQ}(R_E + (1-\alpha)R_B)$$

جریان نقطه کار

$$\downarrow$$

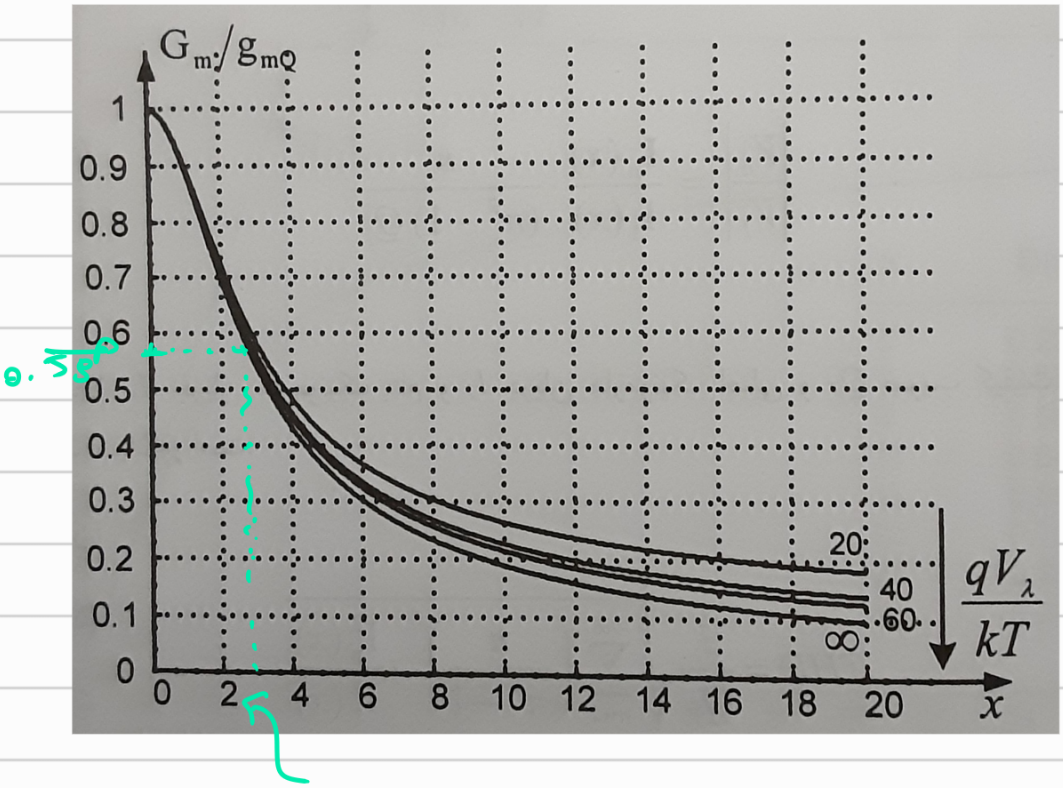
$$V_A = 1mA \times 3k\Omega = 3 \ Volt$$

$$g_{mQ} = \frac{I_C}{V_T} = \frac{1}{25} = 40m\mho$$

$$kcl: \ \frac{1}{n} G_m v_1 = \left(G_2 + G_E + \frac{G_m}{\alpha}\right) v_1 \ \text{که} \ G_m = \frac{G_2 + G_E}{\frac{1}{n} - \frac{1}{\alpha}}$$

. ادرشد

$$G_m = \frac{1/2.27 + 1/3}{1/30} = 23.21 \ m\mho$$



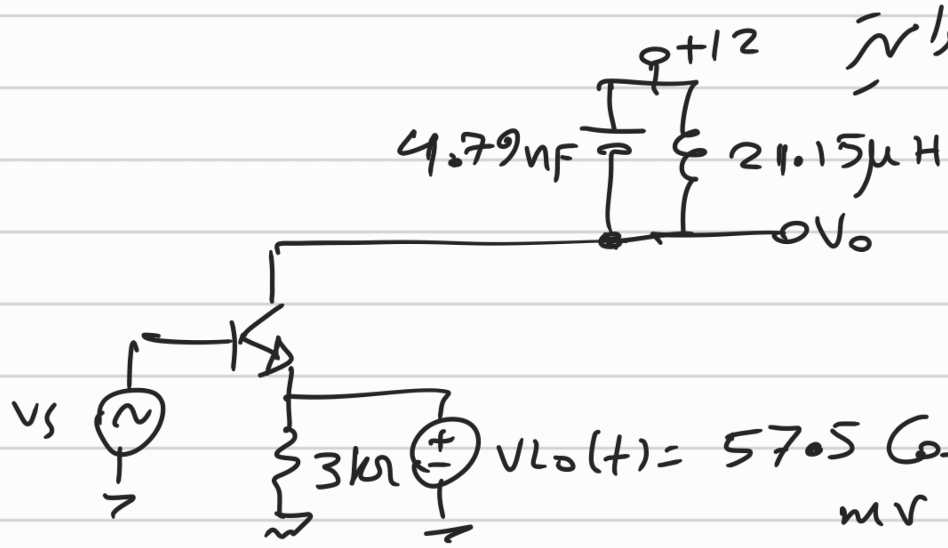
$$\frac{V_\lambda}{V_T} = \frac{3}{25mV} = 120$$

$$\frac{G_m}{g_m} = \frac{23.21}{40} = 0.58$$

$x \simeq 2.3 \longrightarrow V_1 = V_T \cdot x = 57.5\,mV$

دامنه ولتاژ اسیلاتور محلی لازم است

[illegible]

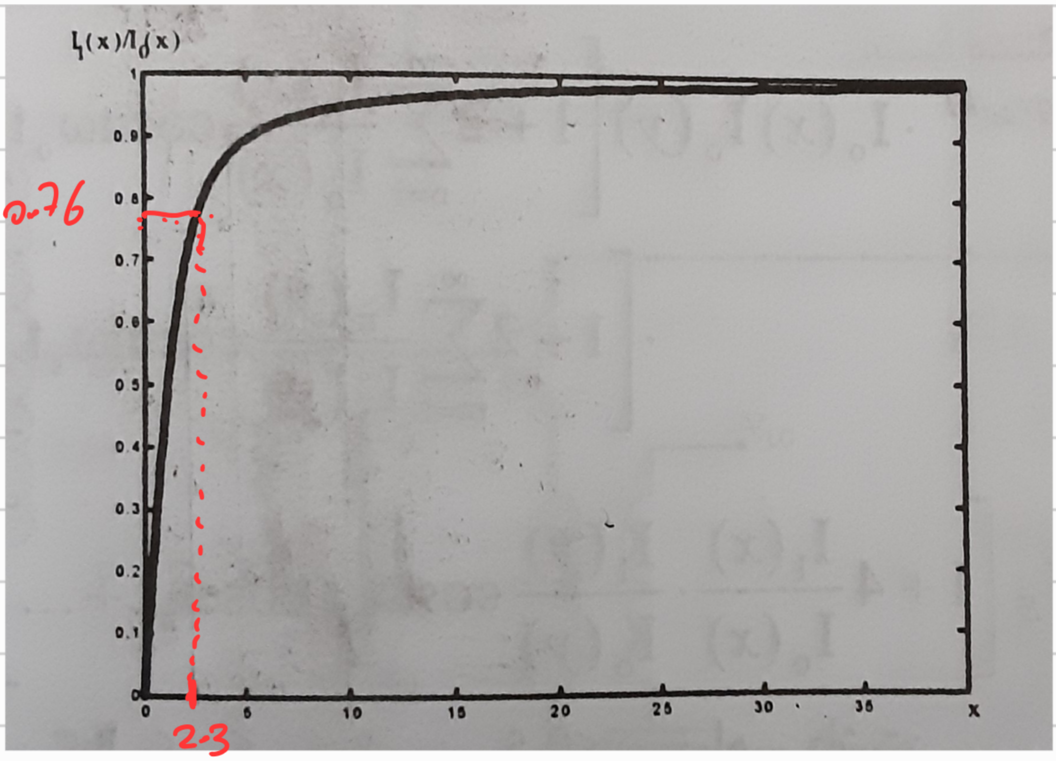


$V_{Lo}(t) = 57.5 \cos(3.14\times10^7 t)$ mV

چون سیگنال اسیلاتور محلی به امیتر و RF به بیس داده شده از تحلیل انجام شده در درس می‌توان استفاده کرد

$$g_c = g_m \frac{I_1(x)}{I_0(x)} = 40\times0.76 = 30.4_{m\mho}$$

$$x = \frac{V_1}{V_T} = 2.3$$



$$V_{out}(t) = 12 - \underset{\substack{\uparrow \\ g_c}}{30.4\,m℧}\; x$$

$L_3 = 21.15\,\mu H$

$Q_{L3} = 30$ $\Rightarrow \omega_{IF} = 3.14 \times 10^{6}$ rad/sec

$C_3 = 4.79\,nF$

$$Q_{L3} = \frac{R_L}{\omega_{IF} L_3} \Rightarrow R_L = Q_{L3} \cdot \omega_{IF} L_3$$

$$R_L = 30 \times 3.14 \times 10^{6} \times 21.15 \times 10^{-6}$$

$$R_L \simeq 2\,k\Omega$$

$$V_{out}(t) = 12 - 2 \times \underset{\substack{\uparrow \\ g_c}}{30.4} \times \underset{\substack{\uparrow \\ V_s}}{0.010}\,(1 + 0.8 f(t)) \cos \omega_{IF} t$$

$$V_{out} = 12 - 0.6\,(1 + 0.8\,f(t))\,\mathrm{Cos}\,\omega_{IF}\,t$$