# ANSWERS
# -
# TSEK03
## RADIO FREQUENCY INTEGRATED CIRCUITS

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|---|---|
| Date: | 2013-03-14 |
| Time: | 14-18 |
| Location: | TER1 |
| Aids: | Calculator, Dictionary |
| Teachers: | Behzad Mesgarzadeh (5719) |
| | Amin Ojani (2716) |

12 points are required to pass.

12-16 : 3

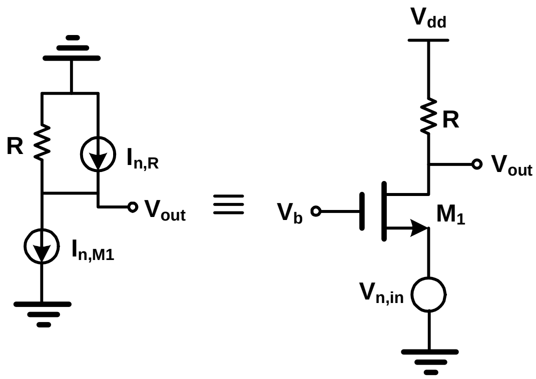
16-20 : 4

20-24 : 5

**Please start each new problem at the top of a page!**
**Only use one side of each paper!**

**1)**

There are two thermal noise sources as shown below.




Since:

$\overline{I_{n,R}^2} = 4kT/R$
$\overline{I_{n,M1}^2} = 4kT\gamma g_m$

The output noise in both circuits should be the same. Then:

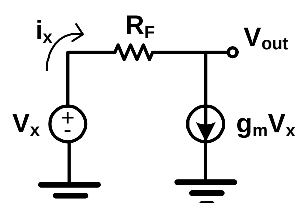
$$\overline{V_{n,out}^2} = (4kT\gamma g_m + 4kT/R) \cdot R^2 = \overline{V_{n,in}^2}(g_m R)^2$$

Then we can determine the input referred noise as:

$$\overline{V_{n,in}^2} = \frac{4kT}{g_m^2}(\gamma g_m + 1/R)$$

**2)**

Small-signal model:




(a) $i_x = g_m V_x \rightarrow R_{in} = \dfrac{V_x}{i_x} = \dfrac{1}{g_m}$

(b) Gain from the gate of the transistor to the output:

$$\frac{V_{out} - V_x}{R_F} + g_m V_x = 0 \rightarrow \frac{V_{out}}{V_x} = 1 - g_m R_F$$

After matching: $g_m = 1/R_S \rightarrow A = \frac{V_{out}}{V_{in}} = \frac{1/g_m}{R_S + 1/g_m}(1 - g_m R_F) = \frac{1}{2}(1 - \frac{R_F}{R_S})$

If $R_F = 25R_S$, then: $A = -12$

(c) The noise of $R_S$ is multiplied by the gain square to appear at the output. Thus:

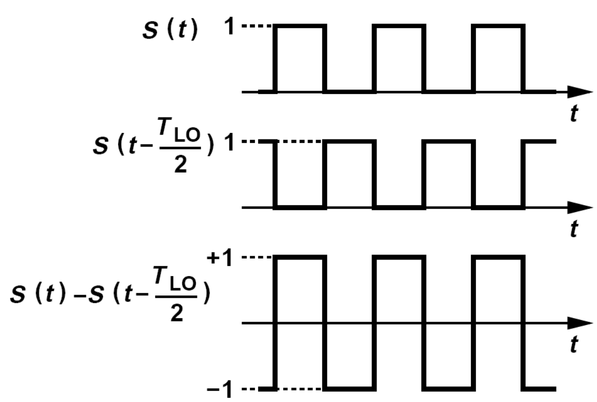
$$\overline{V^2_{n,out,R_S}} = 4kTR_S \cdot \frac{1}{4}(1 - \frac{R_F}{R_S})^2$$

If $R_F \gg R_S$:

$$\overline{V^2_{n,out,R_S}} \approx 4kTR_S \cdot \frac{1}{4}(-\frac{R_F}{R_S})^2 = kT\frac{R_F^2}{R_S}$$

**3)**

(a)




$$V_{out}(t) = I_{RF}R\,[S(t) - S(t - T_{LO}/2)]$$

If $V_{RF} = A_{RF}\cos(\omega_{RF}t)$, then by ignoring the higher order terms:

$$V_{IF} = V_{out} = \frac{4}{\pi}g_{m3}RA_{RF}cos(\omega_{RF}t)cos(\omega_{LO}t) = \frac{2}{\pi}g_{m3}RA_{RF}cos((\omega_{RF} - \omega_{LO})t)$$

Therefore the conversion gain is:

$$G_C = \frac{V_{IF}}{A_{RF}} = \frac{2}{\pi}g_{m3}R$$

(b) $\overline{V^2_{n,out,M_3}} = 4kT\gamma g_m R^2$

$\overline{V^2_{n,out,R_S}} = 4kTR_S(g_m R)^2$

$\overline{V^2_{n,out,R}} = 2 \times 4kTR$

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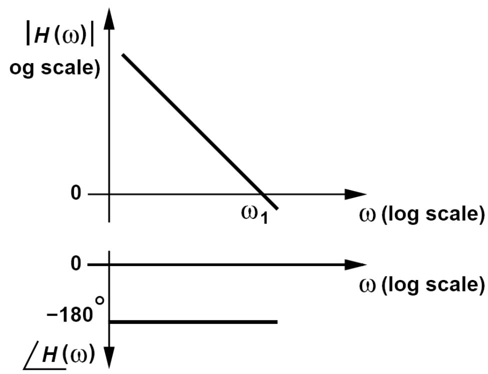
The noise figure can be written as:

$$NF = \frac{\overline{V^2_{n,out,M_3}} + \overline{V^2_{n,out,R_s}} + \overline{V^2_{n,out,R}}}{G_C^2 \overline{V^2_{n,out,R_S}}} = \frac{\pi^2}{4}\left(1 + \frac{\gamma}{g_m R_S} + \frac{2}{g_m^2 R_S R}\right)$$

**4)**

(a) $\frac{Y}{X}(s) = \frac{k^2}{k^2 + s^2}$

(b) The open-loop transfer function is $k^2/s^2$. Two poles at origin gives a -180$^o$ constant phase shift and a magnitude with -40 dB/dec slope.




(c) Differential equation: $\frac{d^2y}{dt^2} + k^2 y = kx$.
For $x = 0$, $y = A\cos(\omega_1 t + \phi)$ is the solution of the abovementioned equation. If we replace it in the differential equation we get:

$-A\omega_1^2 \cos(\omega_1 t + \phi) + k^2 A \cos(\omega_1 t + \phi) = 0 \rightarrow \omega_1 = k$ (oscillation frequency)

**5)**

(a) Refer to the course book Chapter 9.

(b) Refer to the course book Chapter 9.