ECE 145C / 218C, notes set xx: g_m-Z_t Amplifiers

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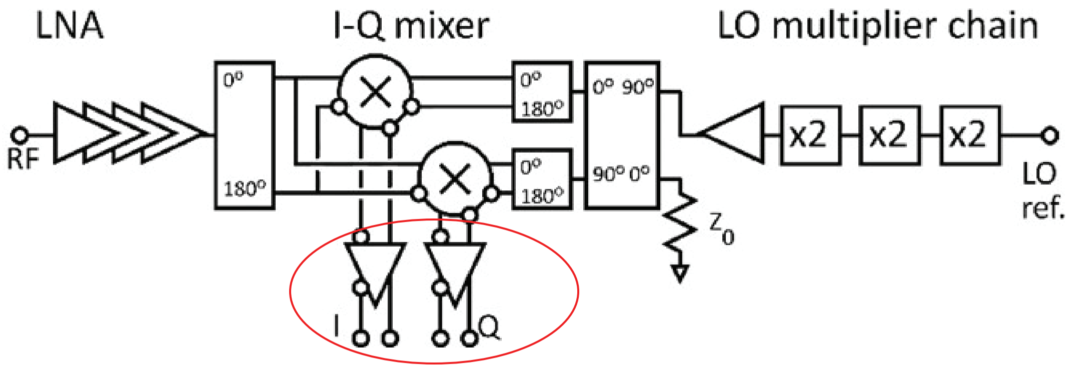
We must often design broadband gain blocks

Baseband amplifiers for high-data-rate wireless



Also for

....optical fiber recievers

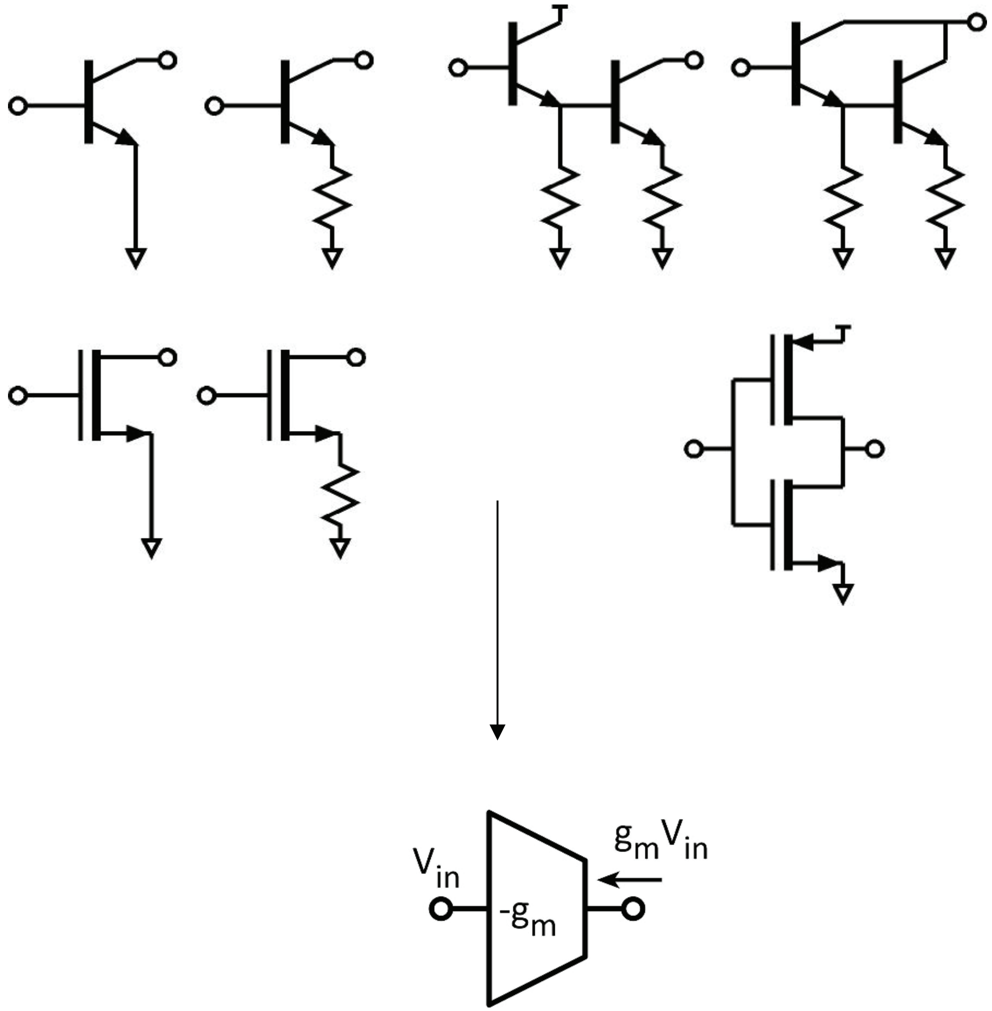
....and "wireline" (electrical wire) interfaces

Symbol rates can exceed 100 Gbaud

...resistive feedback amplifiers and g_m-Z_t amplifiers are useful for these

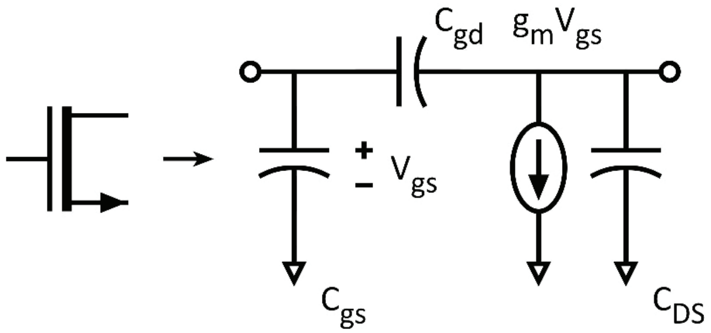
Transconductance Blocks

Basic transconductance blocks



Simple Transconductance Block Model

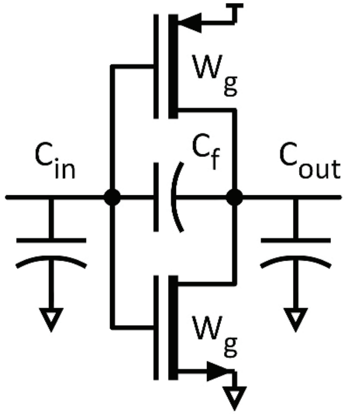
Simple FET model, neglecting R_g, R_{DS}, R_s...



Capacitances are proportional to W_g

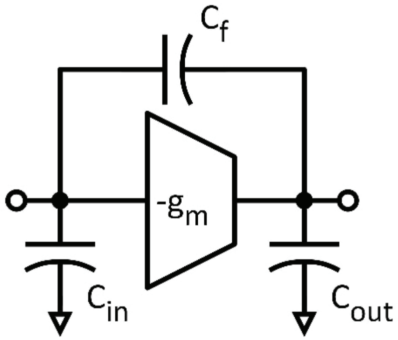
g_m is proportional to W_g

$\Rightarrow$ Capacitances are proportional to g_m



$$C_{in} = \tau_{in} g_m$$
$$C_{out} = \tau_{out} g_m$$
$$C_f = \tau_f g_m$$

$$\frac{1}{2\pi f_\tau} = \tau_{in} + \tau_f$$



Transimpedance Block

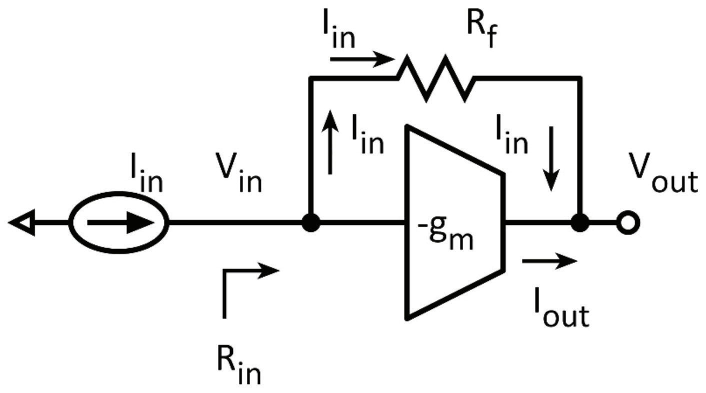
Transimpedance block:

$$I_{out} = -I_{in} \rightarrow V_{in} = I_{in} / g_m$$

$$V_{in} - V_{out} = I_{in} R_f$$

$$\rightarrow V_{out} = Z_T I_{in} \text{ where } Z_T = -(R_f - g_m^{-1})$$

$$\rightarrow R_{in} = 1/g_m$$

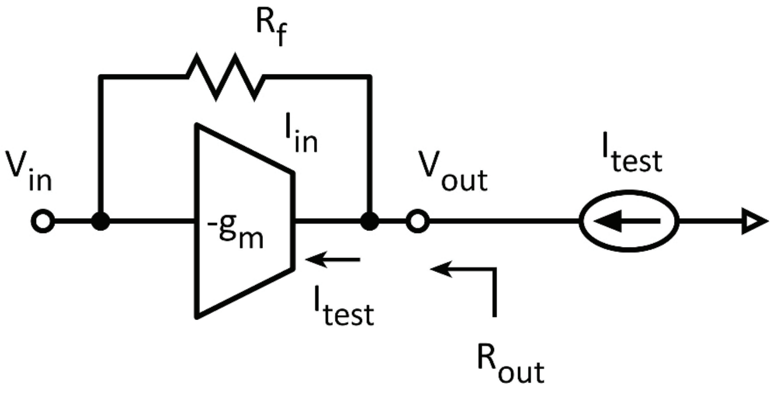


Output resistance:

$$I_{out} = I_{test} \rightarrow V_{in} = I_{test} / g_m$$

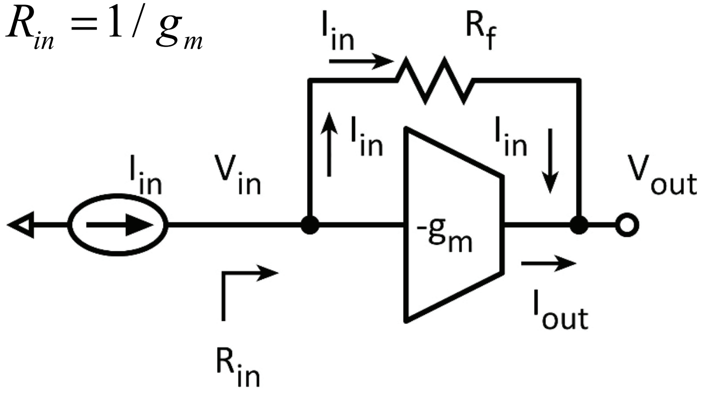
$$V_{in} - V_{out} = 0 \text{ Volts (no current in } R_f)$$

$$\rightarrow V_{out} = R_{out} I_{test} \text{ where } R_{out} = 1/g_m$$

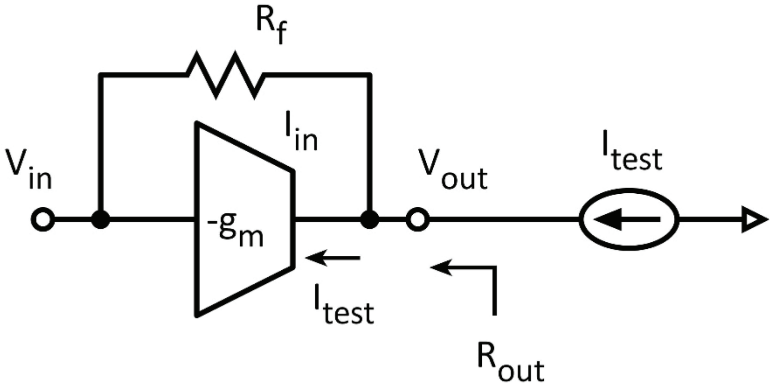


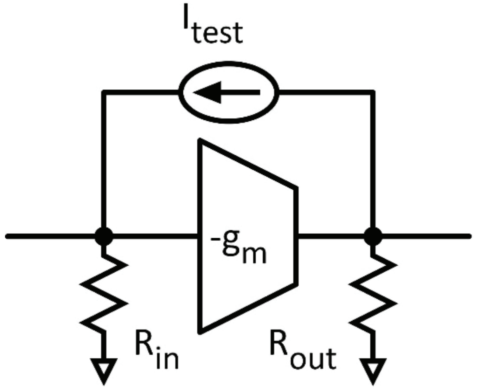
Transimpedance Block: MOTC Port Resistances

$$R_{in} = 1/g_m$$

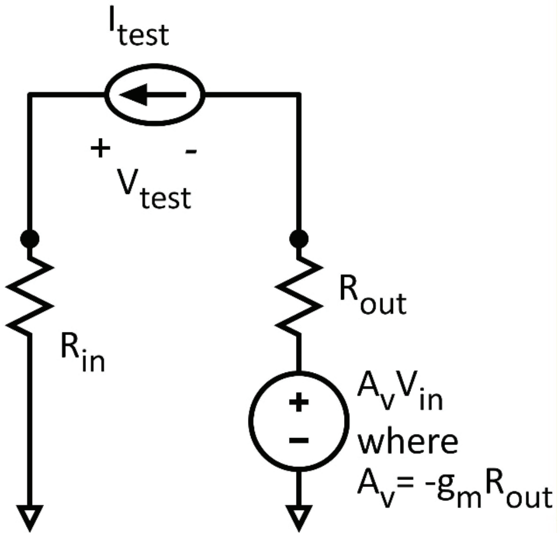


$$R_{out} = 1/g_m$$





$$V_{test} / I_{test} = R_{xx}^0 = R_{in}(1 + g_m R_{out}) + R_{out}$$

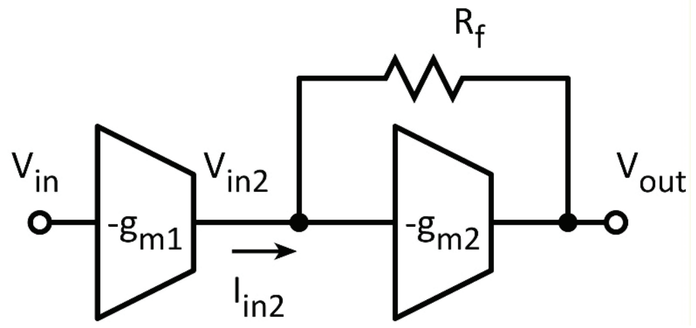


Transconductance-Transimpedance Amplifier

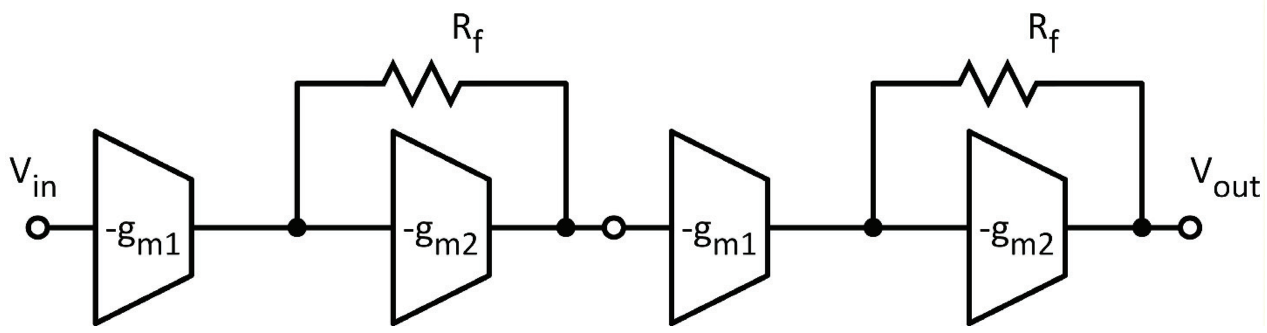
$V_{out} = -(R_f - g_{m2}^{-1}) I_{in2}$

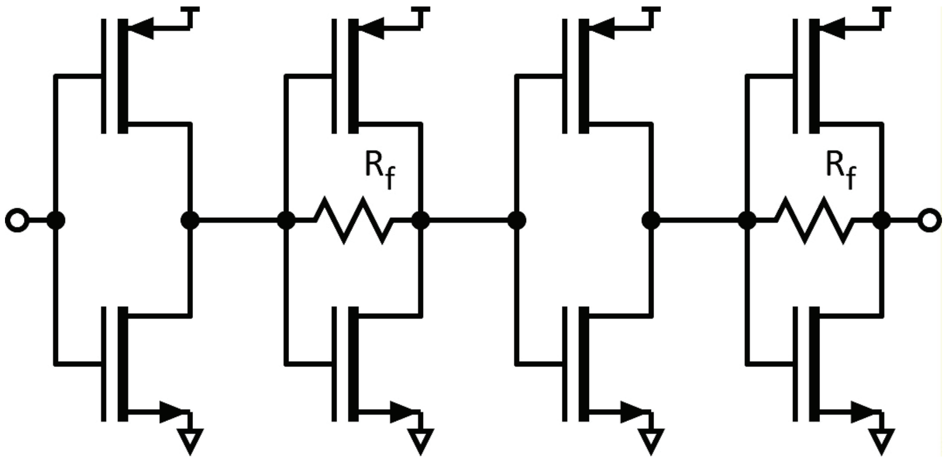
but $I_{in2} = -g_{m1} V_{in}$

$\rightarrow V_{out} = g_{m1} Z_T V_{in}$ where $Z_T = (R_f - g_{m2}^{-1})$



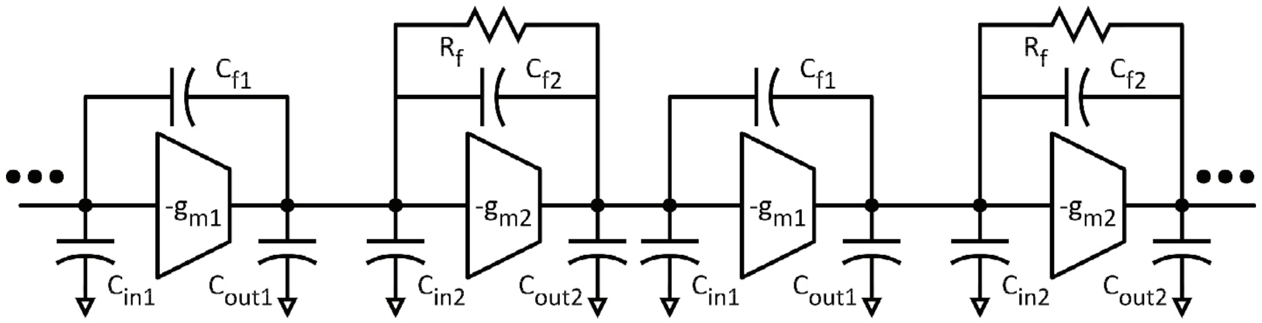
Examples:



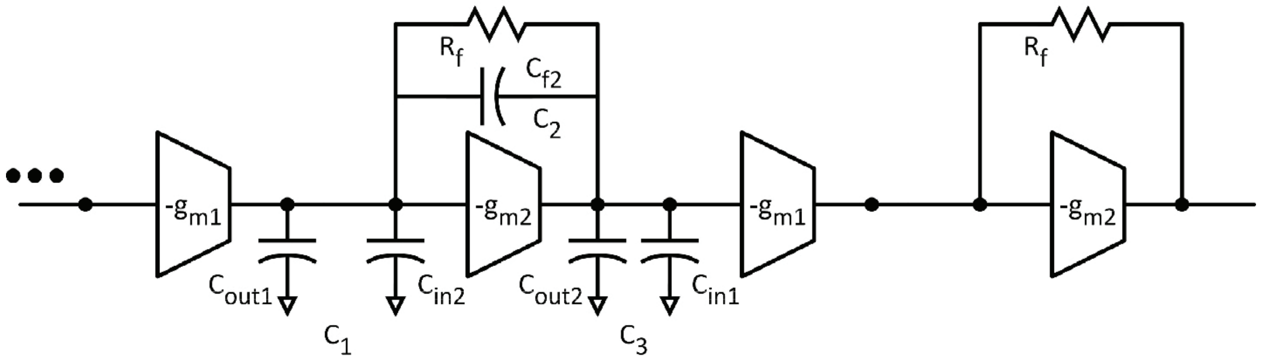


g_m-Z_t frequency response analysis (1)

In a multi-stage g_m-Z_t amplifier, analysis cannot isolate into individual blocks $\rightarrow$ difficult.



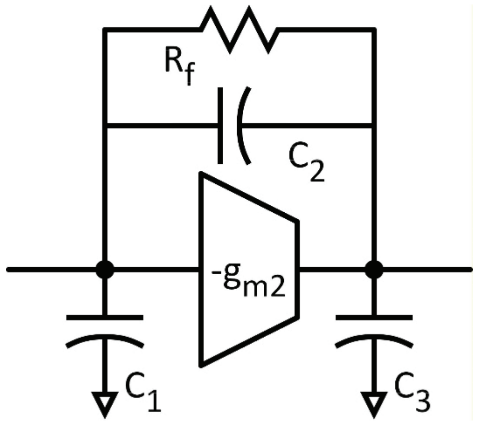
Let us approximate by neglecting C_f in the g_m (not Z_t) blocks:



This then becomes solvable to give a per-stage transfer function

g_m-Z_t frequency response analysis (2)

$$a_1 = R_{11}^0 C_1 + R_{22}^0 C_2 + R_{33}^0 C_3 = g_{m2}^{-1} C_1 + R_f C_2 + g_{m2}^{-1} C_3$$



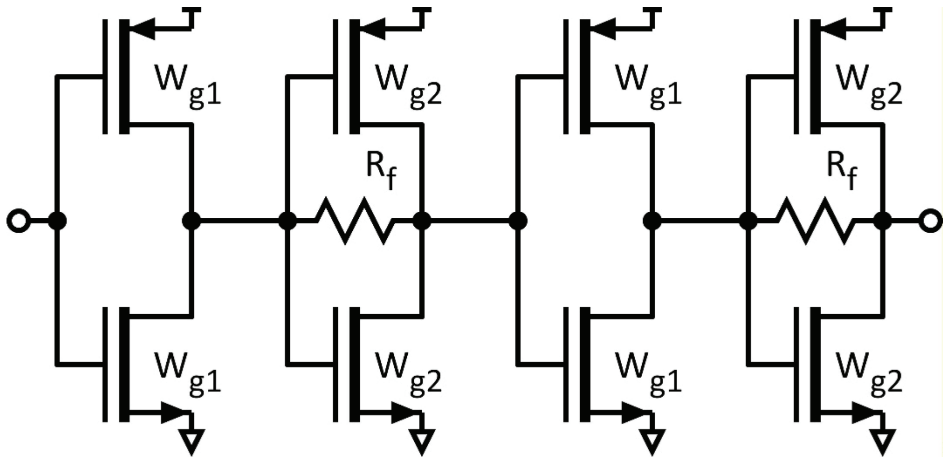
$$R_{22}^1 = R_f \;;\; R_{33}^1 = R_f \;;\; R_{33}^2 = g_{m2}^{-1}$$

$$\begin{aligned} a_2 &= R_{11}^0 C_1 R_{22}^1 C_2 + R_{11}^0 C_1 R_{33}^1 C_3 + R_{22}^0 C_2 R_{33}^2 C_3 \\ &= g_{m2}^{-1} C_1 R_f C_2 + g_{m2}^{-1} C_1 R_f C_3 + R_f C_2 g_{m2}^{-1} C_3 \\ &= g_{m2}^{-1} R_f \left(C_1 C_2 + C_1 C_3 + C_2 C_3 \right) \end{aligned}$$

where $C_1 = C_{out1} + C_{in2}$, $C_2 = C_{f2}$, and $C_3 = C_{out2} + C_{in1}$

and $C_{in1} = \tau_{in} W_{g1}$, $C_{out1} = \tau_{out} W_{g1}$, $C_{in2} = \tau_{in} W_{g2}$, $C_{out2} = \tau_{out} W_{g2}$, $C_{f2} = \tau_f W_{g2}$,

Giving $\omega_n = a_2^{-1/2}$ and $\zeta = a_1 a_2^{-1/2} / 2$



We can now find the amplifier bandwidth and damping factor as a function of the selected transistor sizes

Nested loop g_m-Z_t amplifier

We synthesize an overall resistive feedback amplifier satisfying

$g_{m4} = (1 - A_{v,overall}) / Z_o$

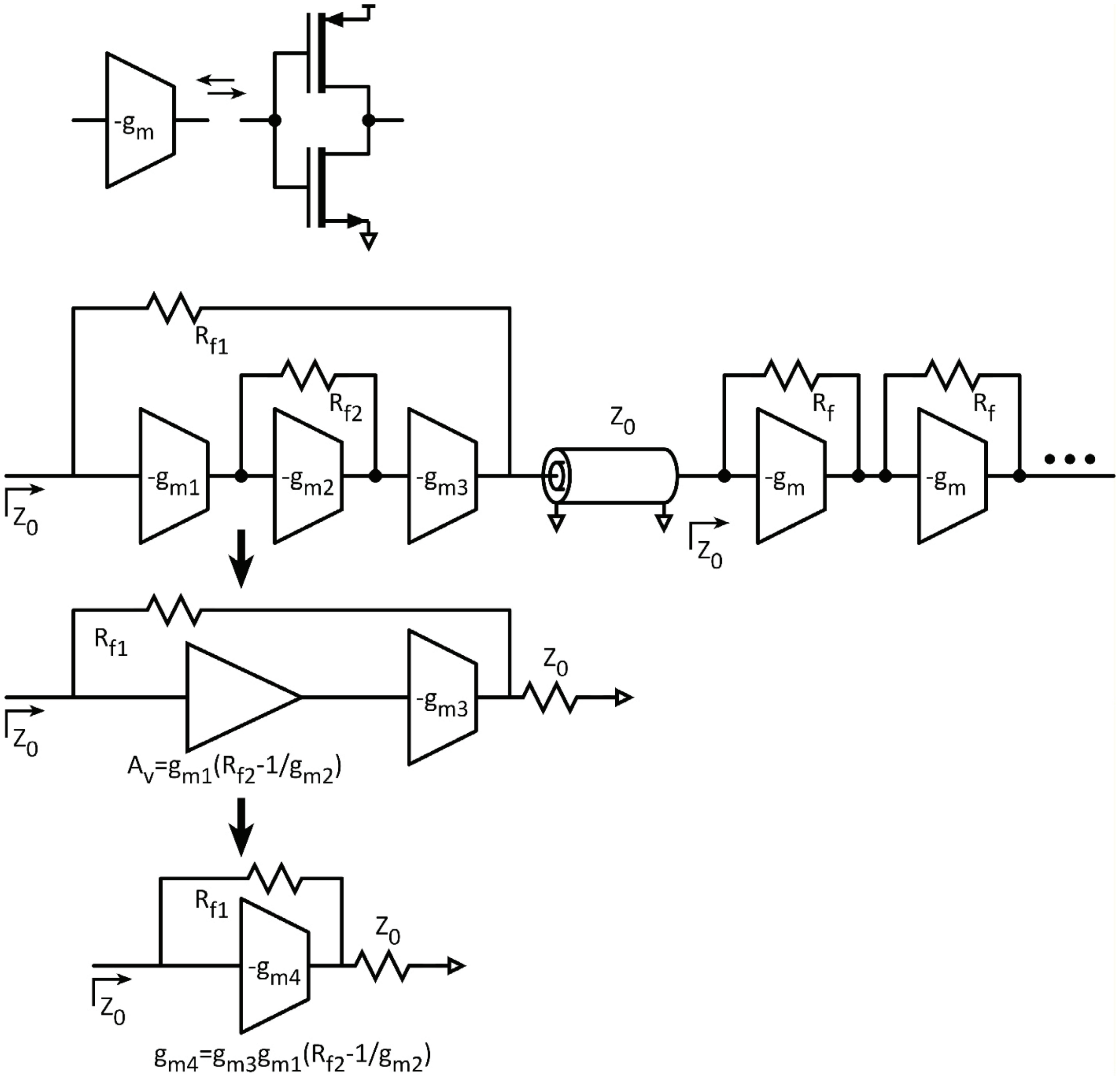
$R_{f1} = Z_0 (1 - A_{v,overall})$

So as to give (negative) gain $A_{v,overall}$ and $Z_{in} = Z_{out} = Z_o$

The overall transconductance g_{m4} is synthesized from a g_m-Z_t amplifier (g_{m1}, g_{m2}) and a transconductance block (g_{m3}).

The nested design permits a large per-state gain, hence a large R_{f1}, minimizing its noise contribution.

Careful loop stability analysis is advised

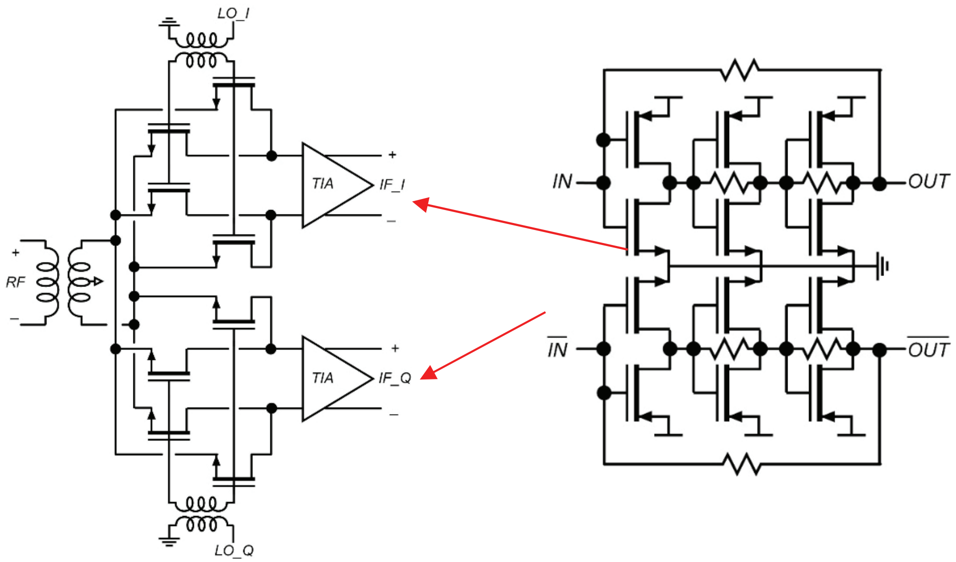


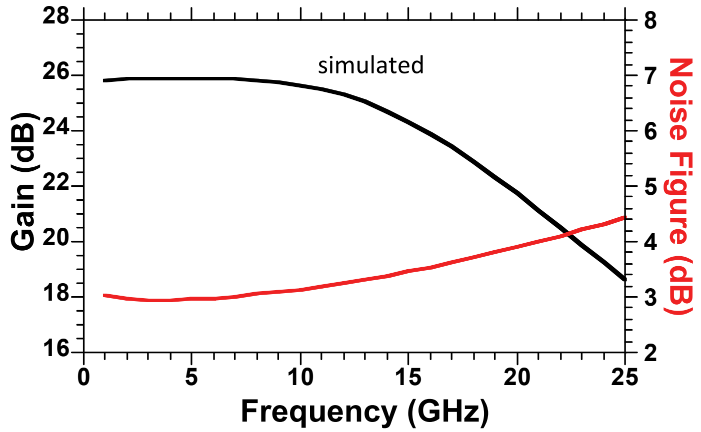
Nested loop g_m-Z_t amplifier

Example design in 45 nm SOI CMOS.

~15 GHz bandwidth, 26 dB gain

Relatively low noise for a broadband design.





A. Simsek, S. -K. Kim and M. J. W. Rodwell, "A 140 GHz MIMO Transceiver in 45 nm SOI CMOS," *2018 IEEE BiCMOS and Compound Semiconductor Integrated Circuits and Technology Symposium (BCICTS)*, San Diego, CA, USA, 2018