Single-to-differential converter

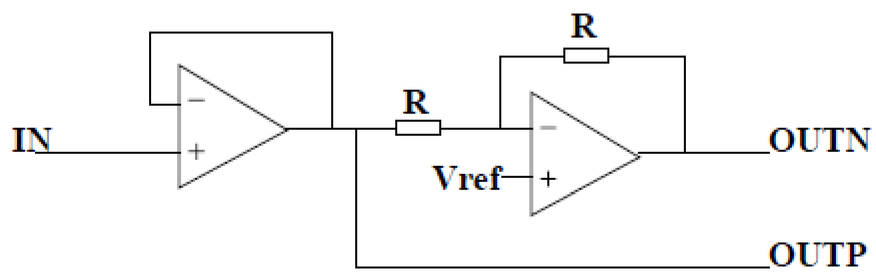
1. Continuous time S-2-D
   – Classical solution
   – With fully differential amplifier
   – High linearity solution
2. Discrete time S-2-D
   – Crossing the inputs
   – Short circuiting the inputs

Single-to-differential converter

1. Continuous time S-2-D
   – Classical solution

Classical solution

Well-known solution is presented below:



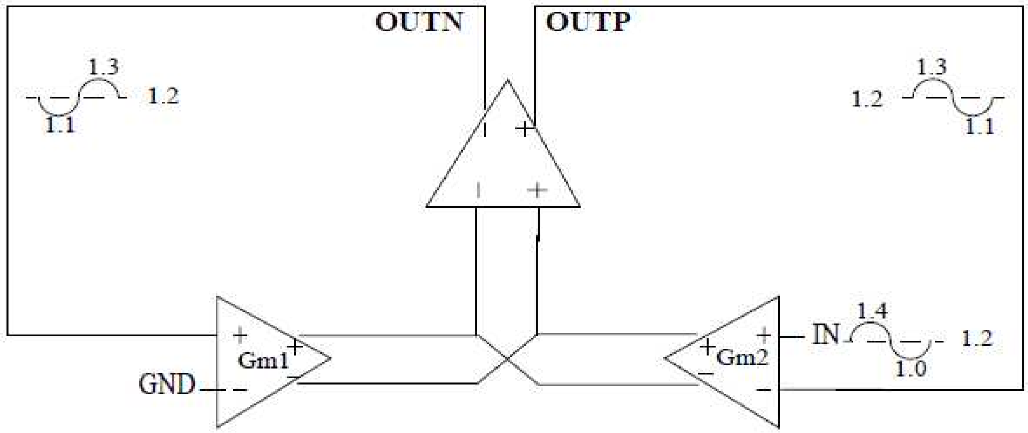
Classical single-to-differential converter

Main drawbacks:
Low Total Harmonic Distorsion performance since this is a single-ended structure.

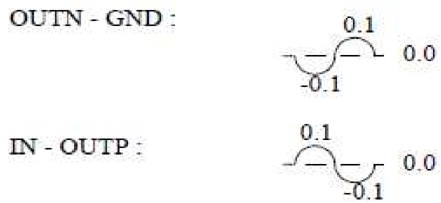
Single-to-differential converter

1. Continuous time S-2-D
   - Classical solution
   - With fully differential amplifier

With fully differential amplifier



single-to-differential converter using a fully differential amplifier



signals applied to Gm stages

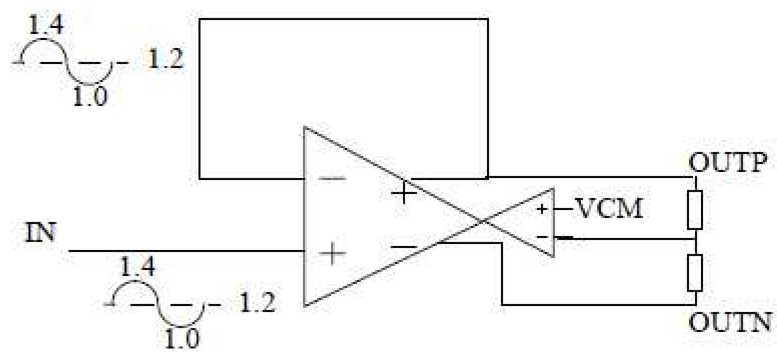
Main drawbacks:
Half of the signal is directly applied to each Gm stages.This could be a problem if the input dynamic range is too high because it leads to saturation of the Gm stages.

Single-to-differential converter

1. Continuous time S-2-D
   - Classical solution
   - With fully differential amplifier
   - High linearity solution

High linearity solution

OUTP is directly created by the differential amplifier.
OUTN is generated via the common mode amplifier.



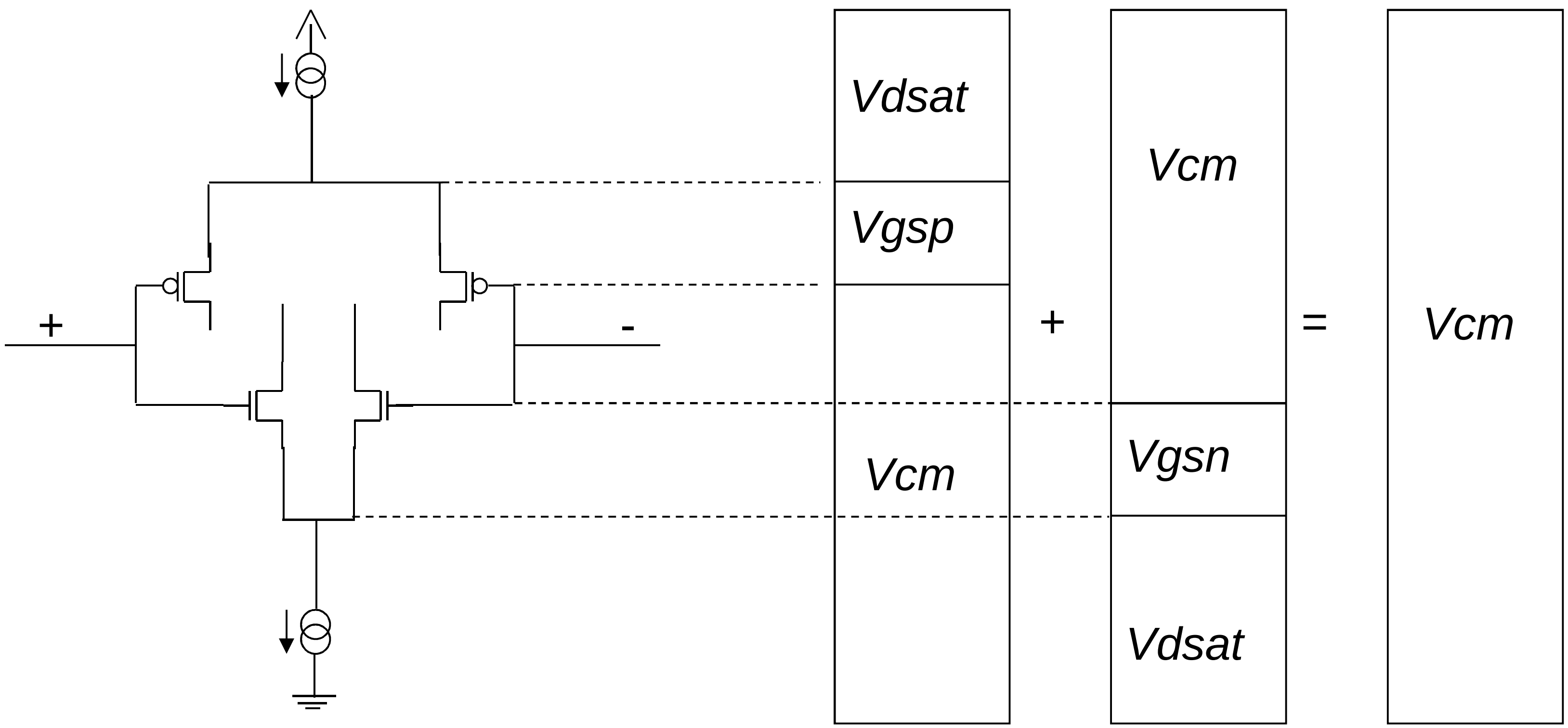
single-to-differential converter

Its differential structure allows to achieve a high linearity.
There is a high input dynamic range since the same signal is applied on the two parts of the input Gm.

High linearity solution

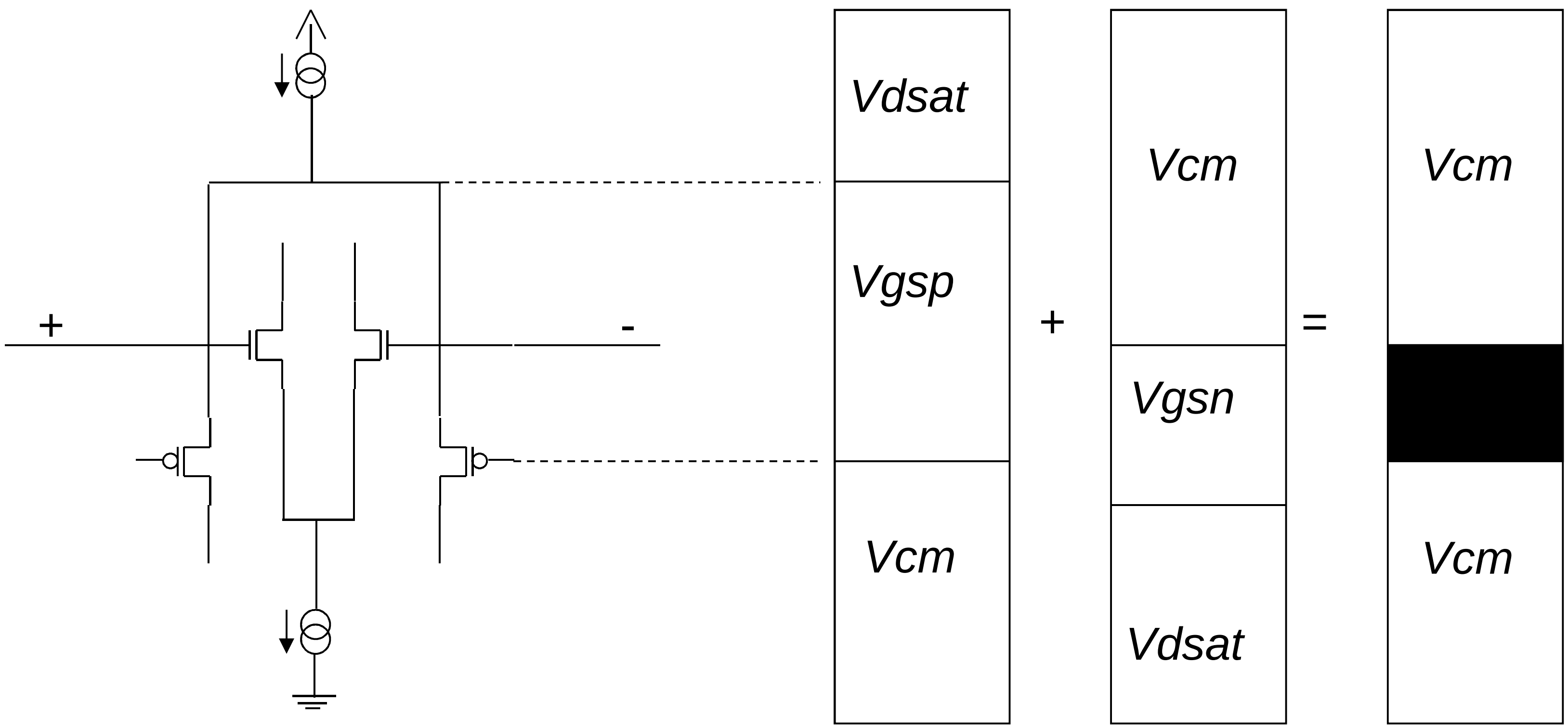
In case of rail-to-rail input swing, ***complementary differential pairs*** can be used to enhance the linearity. Some techniques are also available to make the sum of the current in each pair constant. These techniques aim to have a ***constant GM*** despite using two differential pairs.

Rail-to-rail input stage



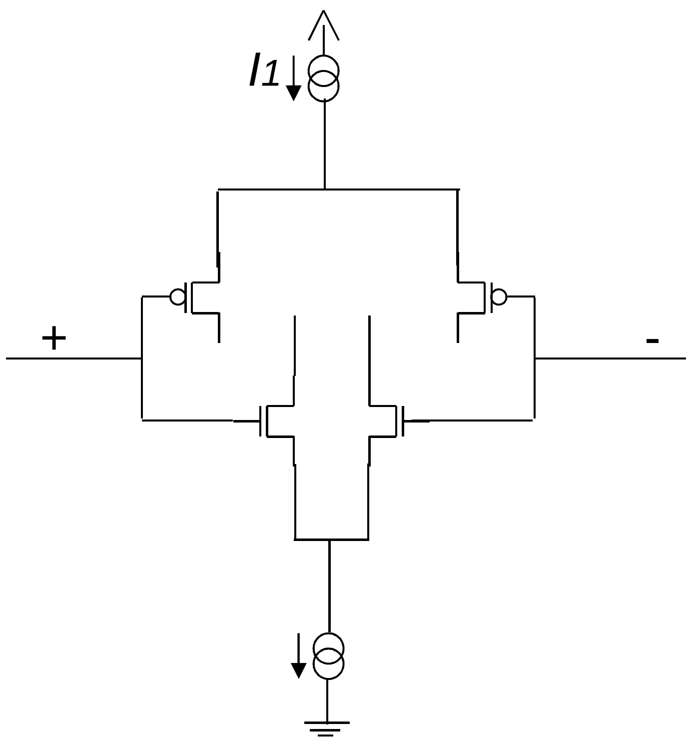
Vdd > 2Vgs+2Vdsat

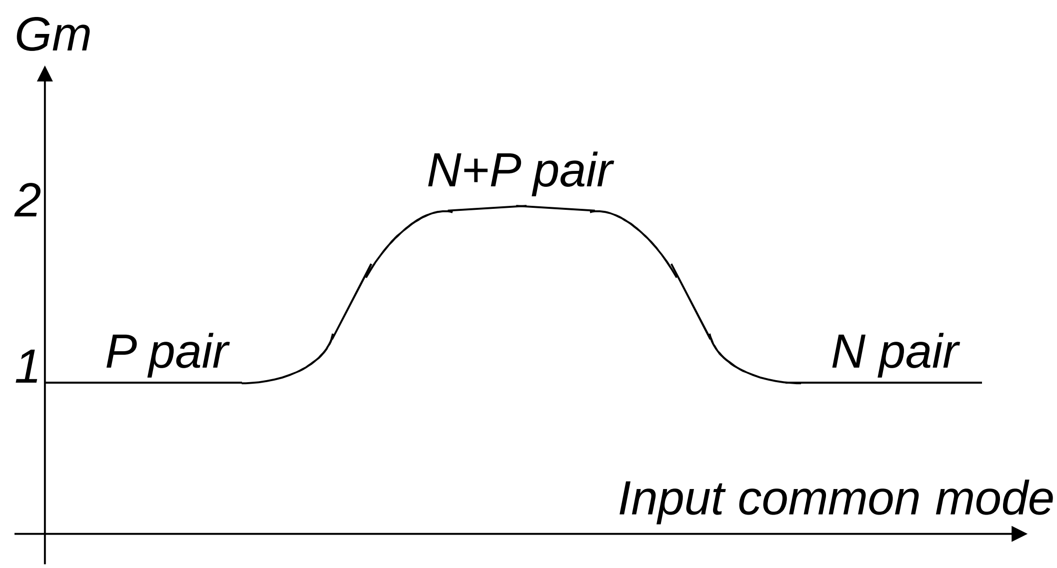
Rail-to-rail input stage



Vdd < 2Vgs+2Vdsat

Gm variation





Gm varies by a factor of two which leads to a bandwidth variation of 2.
As a consequence, this dependency on the input common mode introduces some non linearities on the S2D converter.

Gm variation

Weak inversion

$$Gm = \frac{qI}{nkT}$$

$$I_1 + I_2 = I_{ref}$$

$$Gm_1 + Gm_2 = G_{ref}$$

By making the sum of the current constant, we obtain a **constant Gm**.

Strong inversion

$$Gm = \sqrt{2.K.\gamma.I}$$

$$I_1 + I_2 = I_{ref}$$

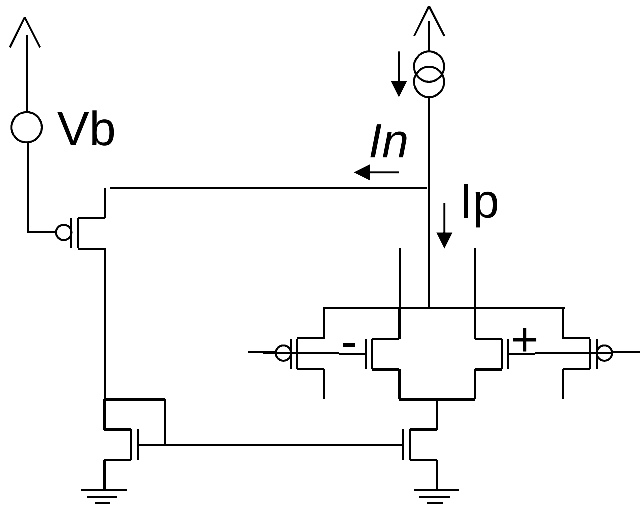
$$Gm_1 + Gm_2 = \sqrt{2.K.\gamma.}\left(\sqrt{I_1} + \sqrt{I_2}\right)$$

$$\text{If } (\mathrm{I}_1 = 2\mathrm{I} \text{ and } \mathrm{I}_2 = 0) \text{ then } \mathrm{Gm}_{\mathrm{equi}} = \sqrt{2.K.\gamma.}\sqrt{2I}$$

$$\text{If } (\mathrm{I}_1 = \mathrm{I} \text{ and } \mathrm{I}_2 = \mathrm{I}) \text{ then } \mathrm{Gm}_{\mathrm{equi}} = \sqrt{2.K.\gamma.}2\sqrt{I}$$

When both differential pairs are conducting the same current I, the global transconductance is ***40% higher*** *than a transconductance done by a single pair consuming a current 2I.*

Constant GM cell

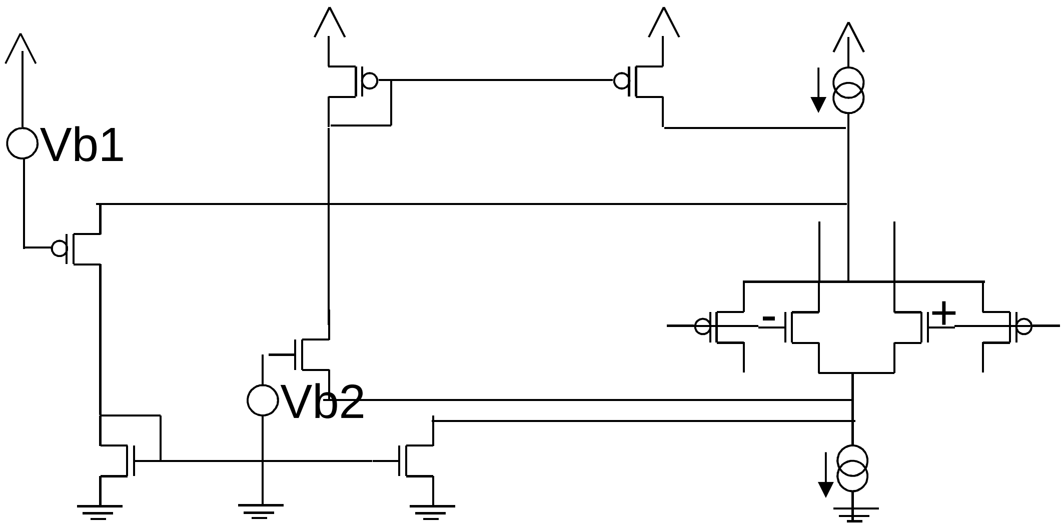


MOS in weak inversion or Bipolar => Gm variation 5%

MOS in strong inversion => Gm variation 41% $\left(\sqrt{2} \approx 1.414\right)$

(Johan H. Huijsing, Delft University of Technology, The Netherlands)

Constant GM cell



MOS in weak inversion or Bipolar => Gm variation 1%

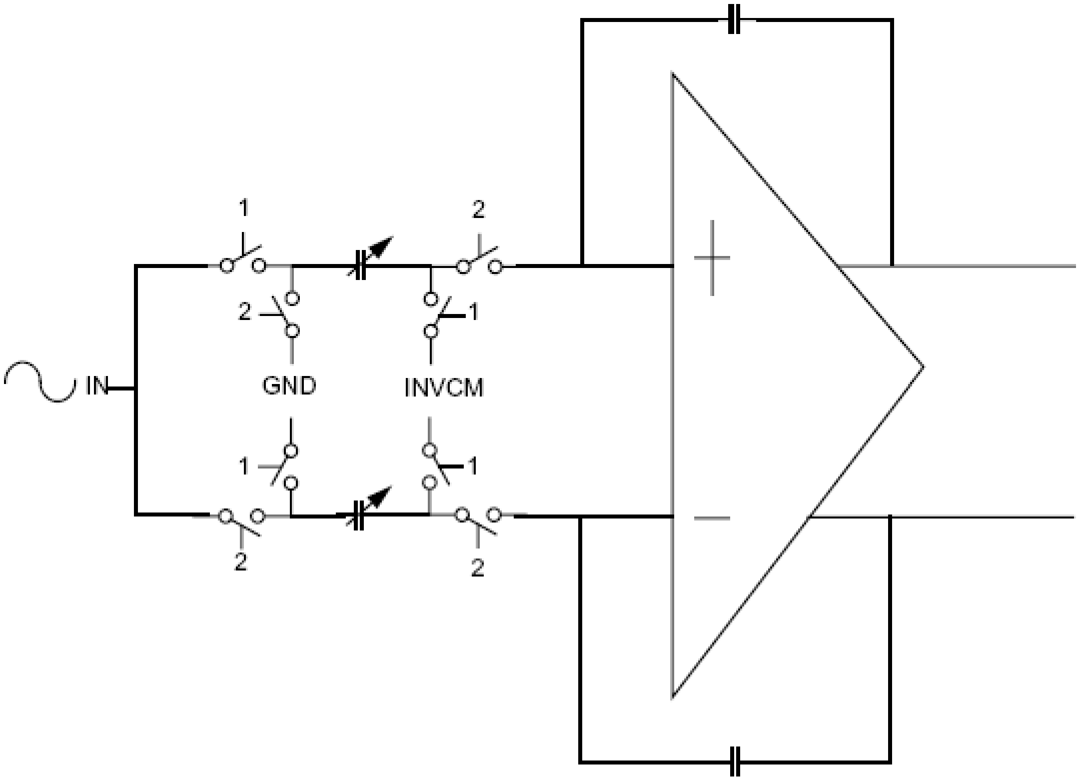
MOS in strong inversion => Gm variation 15%

(Johan H. Huijsing, Delft University of Technology, The Netherlands)

Single-to-differential converter

1. Continuous time S-2-D
   - Classical solution
   - With fully differential amplifier
   - High linearity solution
2. Discrete time S-2-D
   - Crossing the inputs

Crossing the inputs



Crossing the inputs

Transfer function:

$$H(z) = 1 + z^{-1/2}$$

Thus:

$$H(p) = 1 + e^{-j\omega T/2} = e^{-j\omega T/4}(e^{j\omega T/4} + e^{-j\omega T/4})$$

And:

$$H(\omega) = |2\cos(\omega T/4)|$$

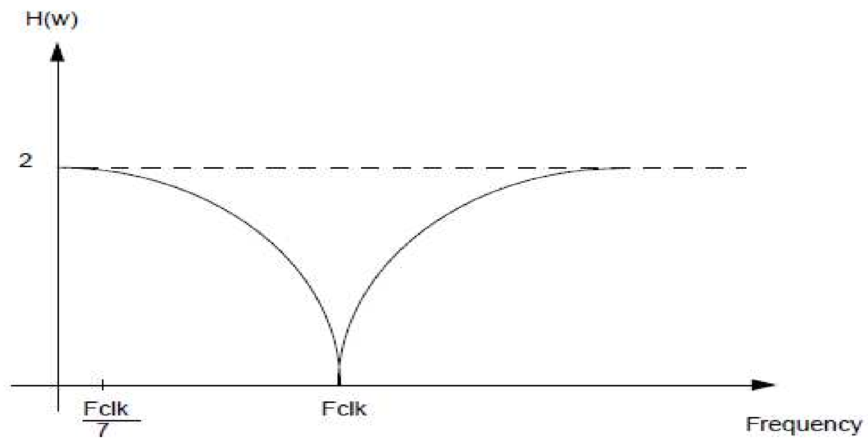
where W=2.pi.f and T=1/fclk

So:

$$H(\omega) = \left|2\cos\left(\frac{\pi}{2}\frac{f}{fclk}\right)\right|$$

For f=0, H(z)=2 which corresponds to a single-to-differential transfer function.

For f=fclk, H(z)=0 which introduces a notch.

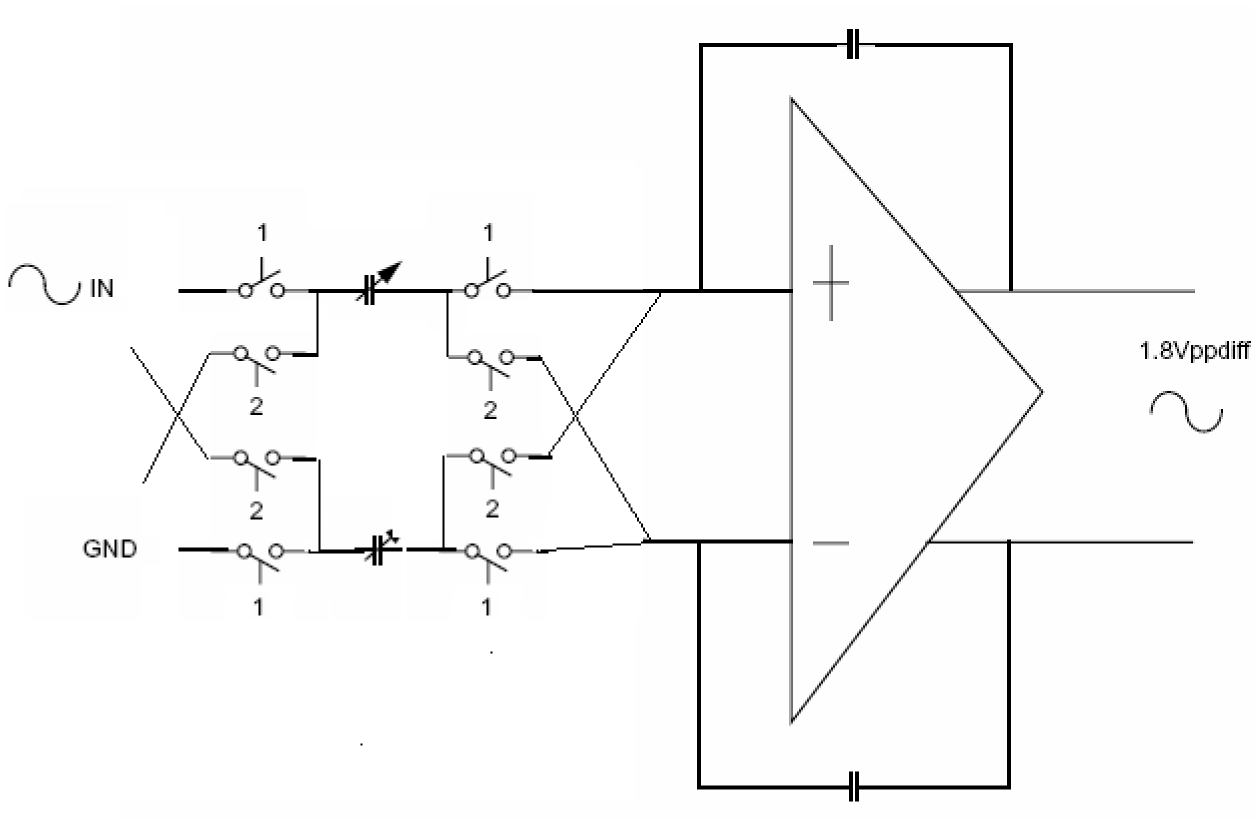


Crossing the inputs

This techniques produces a gain of 2 by using a ***double sampling*** on the input signal. However, this comes at a price for the front end buffer in case of an ***adaptive sampling time***. In this mode, sampling capacitor is connected to the buffer a certain amount of time (usually many clock periods) before being applied to the amplifier input during phase 2. Hence, this lets sufficient time for the buffer to charge the sampling capacitor.

In case of double sampling, this technique can ***no longer be used***.

Crossing the inputs



Fully floating switched capacitor integrator

Crossing the inputs

Differential operation leads to:

$$
\begin{aligned}
Y(n) &= (X^+(n) - X^-(n-1)) - (X^-(n) - X^+(n-1)) \\
&= (X^+(n) - X^-(n)) + (X^+(n-1) - X^-(n-1)) \\
&= X(n) + X(n-1)
\end{aligned}
$$

In z-transform domain:

$$
\begin{aligned}
Y(z) &= X(z) + z^{-1}.X(z) \\
&= (1 + z^{-1})X(z)
\end{aligned}
$$

$$
H(z) = \frac{Y(z)}{X(z)} = (1 + z^{-1})
$$

Thus:

$$
H(p) = 1 + e^{-j\omega T} = e^{-j\omega T/2}(e^{j\omega T/2} + e^{-j\omega T/2})
$$

Crossing the inputs

So :

$$H(\omega) = \left| 2\cos(\omega T / 2) \right|$$

Where w=2.pi.f and T=1/Fck

Thus:

$$H(\omega) = \left| 2\cos(\frac{\pi . f}{fck}) \right|$$

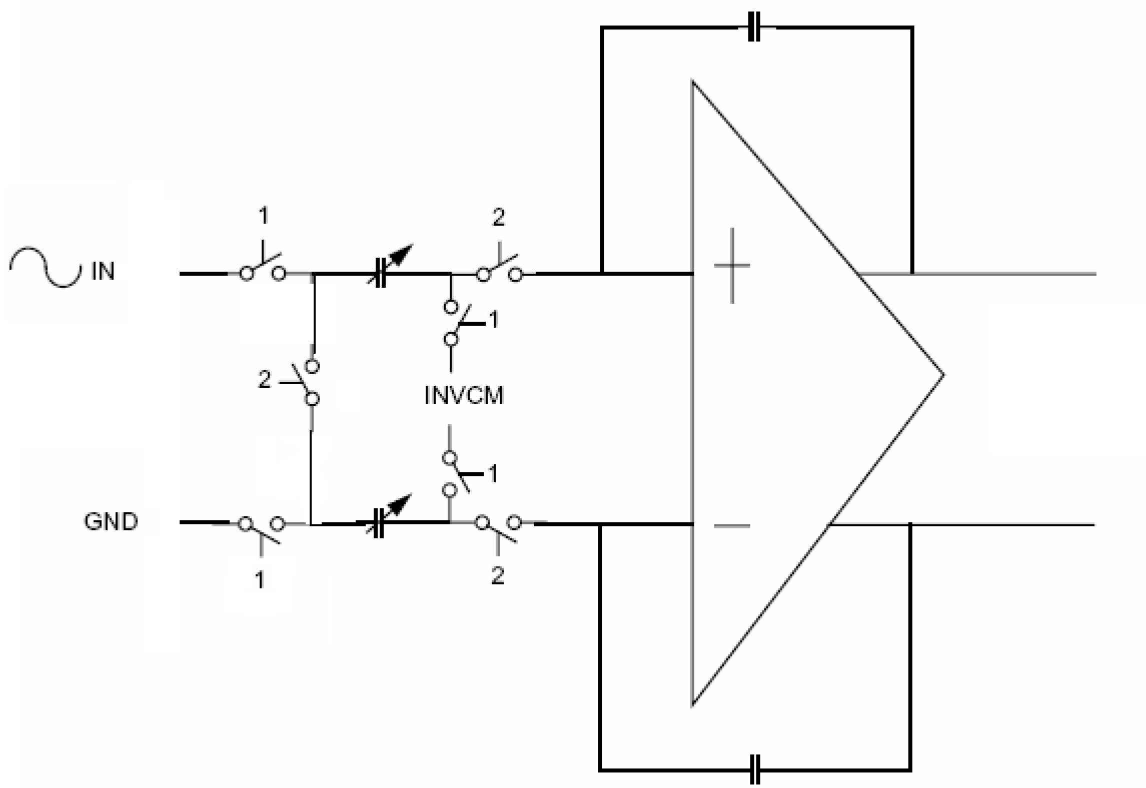
Which corresponds to a notch filter located at fck/2.

Notice that this schematic often presented in IEEE papers suffers from a ***major problem*** since the ***input common mode voltage*** of the amplifier is not well defined.

Single-to-differential converter

1. Continuous time S-2-D
   - Classical solution
   - With fully differential amplifier
   - High linearity solution
2. Discrete time S-2-D
   - Crossing the inputs
   - Short circuiting the inputs

Short circuiting the inputs



Short circuiting the inputs

This techniques produces a unitary gain by using a ***flash sampling*** on the input signal. As a consequence, specification on the front end buffer can be relaxed. On the other hand, ***common mode*** becomes ***harder to stabilize*** since sampling capacitors are no longer connected to a low impedance node during phase 2 (they behave as floating capacitors).