EE230-02 RFIC II
Fall 2018

Lecture 11: Passive Mixer

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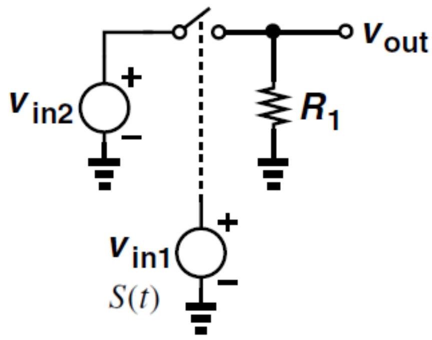
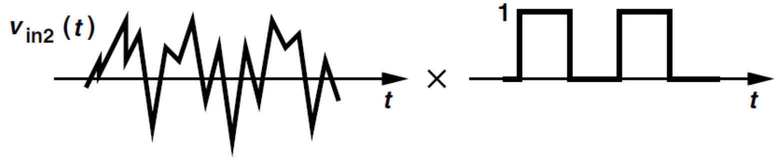
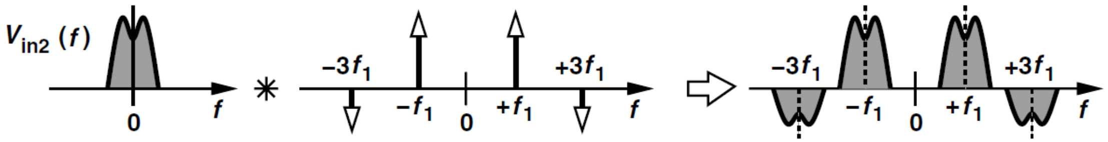
ENG-259

RF Mixer



$$v_{out}(t) = v_{in2}(t) \cdot S(t)$$





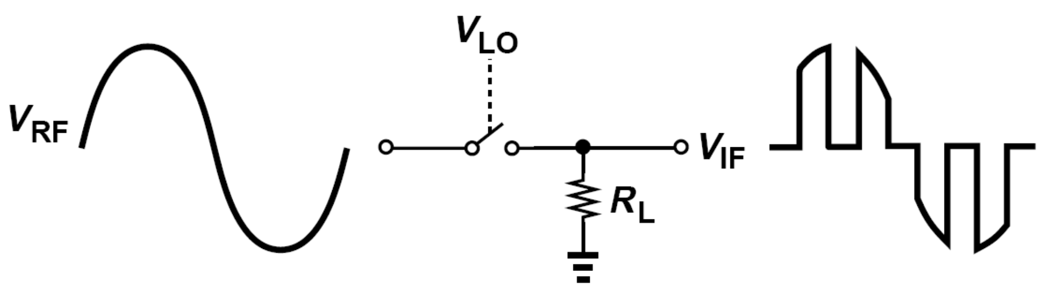
$$T_1 = 2\pi/\omega_1$$

$$V_{out}(f) = V_{in2}(f) * \sum_{n=-\infty}^{+\infty} \frac{\sin(n\pi/2)}{n\pi} \delta\left(f - \frac{n}{T_1}\right) = \sum_{n=-\infty}^{+\infty} \frac{\sin(n\pi/2)}{n\pi} V_{in2}\left(f - \frac{n}{T_1}\right)$$

What is the amplitude when n=1? ➡ $\frac{1}{\pi}$

Conversion Gain of Passive Mixer

- The conversion gain is **1/*π*** for abrupt LO switching.
- We call this topology a **"return-to-zero" (RZ) mixer** because the output falls to zero when the switch turns off.

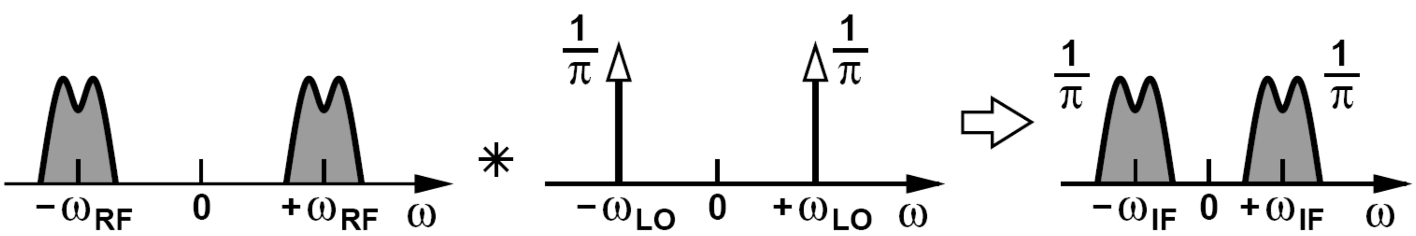


(a)

log(1 / 3.14) * 20 =

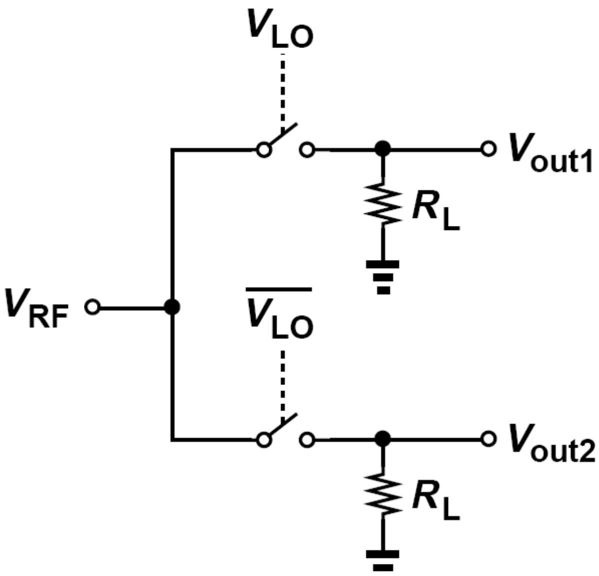
-9.93859296146

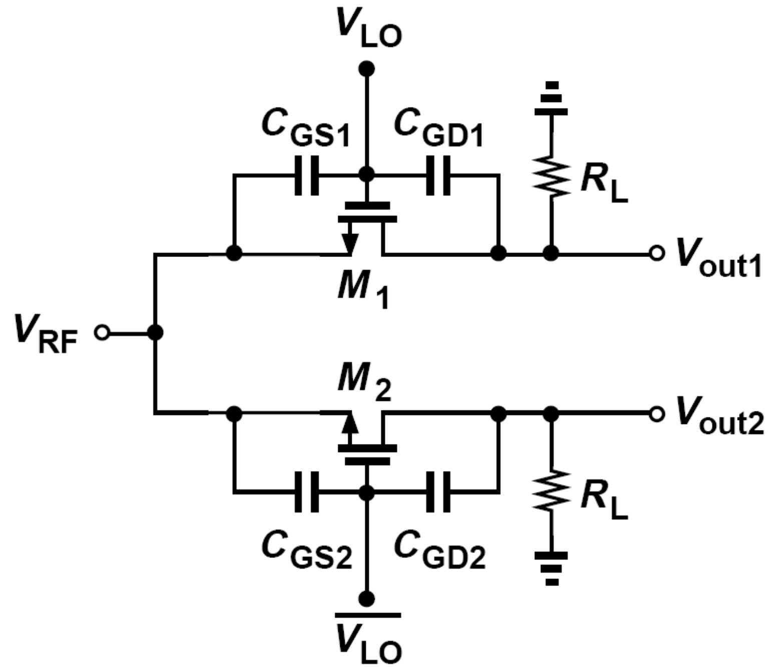
Conversion Gain -10dB



Single-Balanced Mixer

- Single-ended RF input
- Differential LO





- ➢ A more efficient approach where two switches are driven by differential LO
- ➢ Commutate the RF input to the two outputs
- ➢ LO-RF feedthrough at ω_{LO} vanishes if the circuit is symmetric

Conversion Gain of Single-Balanced Topology

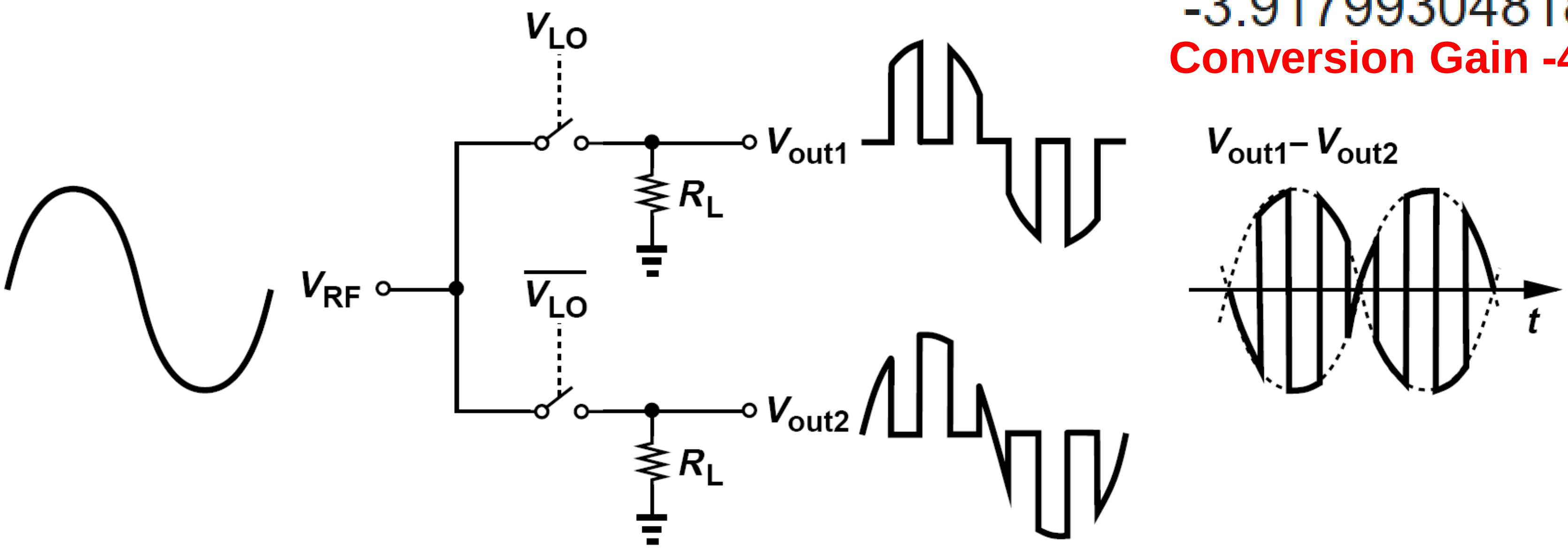
Determine the conversion gain of the single-balanced topology.

Solution:

log(2 / 3.14) * 20 =

-3.91799304818

Conversion Gain -4dB

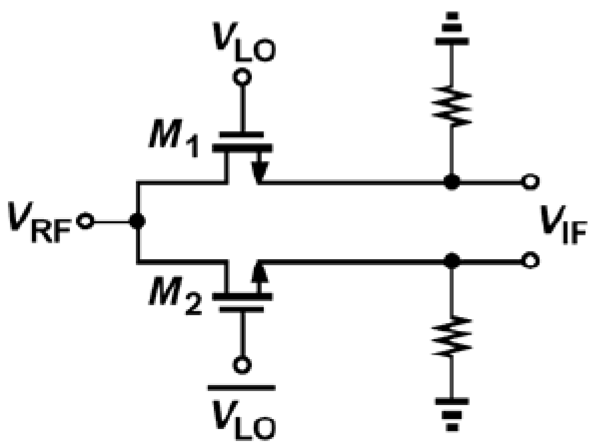


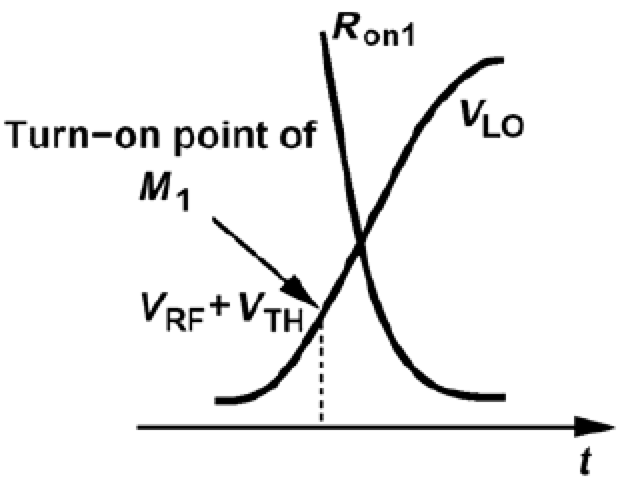
- **The second output is similar to the first but shifted by 180º.**
- **Differential output contains twice the amplitude of each single-ended output.**
- **Conversion gain is therefore equal to 2/π (≈ -4 dB).**
- **Superior to the single-ended topology**

Passive Mixer Noise and Linearity

- Flicker Noise: Passive mixers generate little flicker noise in the baseband output if the transistors do not enter saturation at any point during the cycle and carry no dc current.

- Linearity: Passive mixers with rail-to-rail LO swings can achieve a high linearity, e.g., IP3 ~ 10-15 dBm.





Flicker Noise Model in BSIM4

BSIM4 provides two flicker noise models.

- fnoiMod = 0, Simple flicker noise model for hand calculations
- fnoiMod = 1, Unified physical flicker noise model

These two modes come from BSIM3v3,
but the unified model has many improvements.

fnoiMod=0

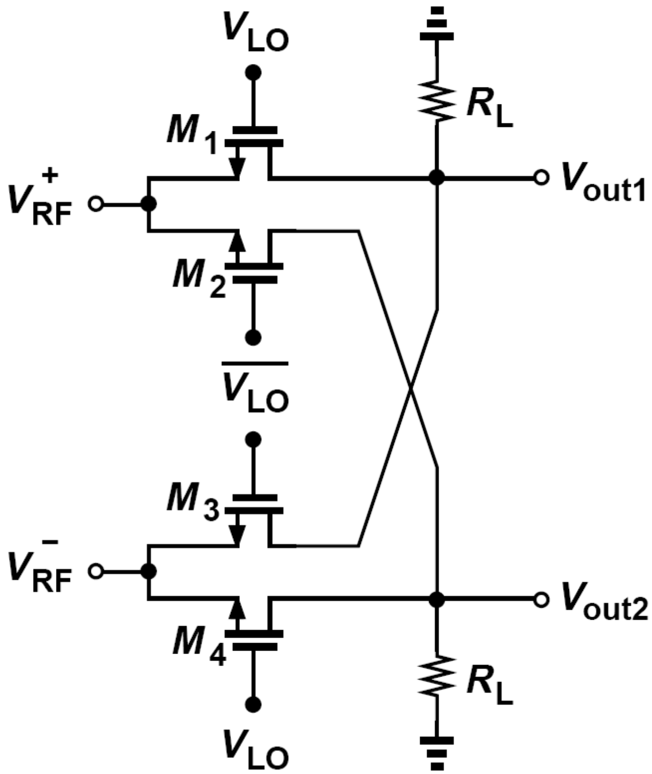
$$S_{id}(f) = \frac{KF \cdot I_{ds}^{AF}}{C_{oxe} L_{eff}^{2} f^{EF}}$$

fnoiMod=1

$$S_{id,inv}(f) = \frac{k_B T q^2 \mu_{eff} I_{ds}}{C_{oxe}(L_{eff} - 2 \cdot LINTNOI)^2 A_{bulk} f^{ef} \cdot 10^{10}} \left(NOIA \cdot \log\left(\frac{N_0 + N^*}{N_l + N^*}\right) + NOIB \cdot (N_0 - N_l) + \frac{NOIC}{2}\left(N_0^2 - N_l^2\right) \right)$$

$$+ \frac{k_B T I_{ds}^2 \Delta L_{clm}}{W_{eff} \cdot (L_{eff} - 2 \cdot LINTNOI)^2 f^{ef} \cdot 10^{10}} \cdot \frac{NOIA + NOIB \cdot N_l + NOIC \cdot N_l^2}{(N_l + N^*)^2}$$

Double-Balanced Mixers



At Vout1, VLO and VLO-bar cancel their feed-through.

When VLO is high:
Vout1 – Vout2 = (VRF+) – (VRF-)

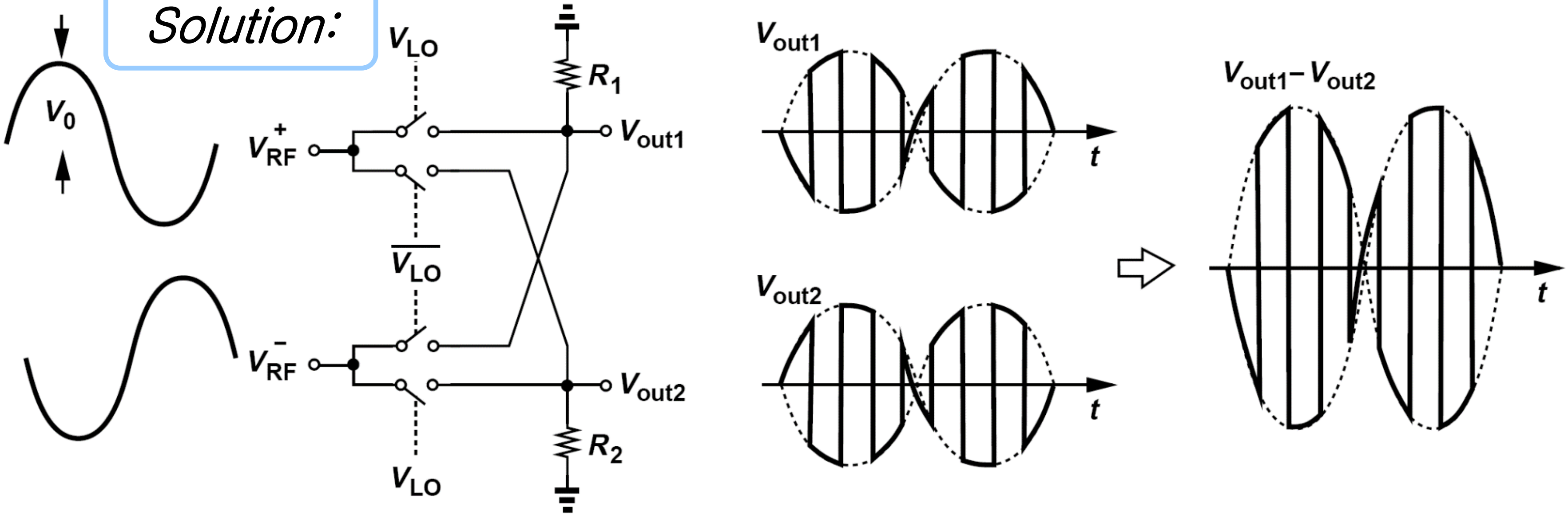
When VLO is low:
Vout1 – Vout2 = (VRF-) – (VRF+)

- Connect two single-balanced mixers
- Output LO feedthroughs cancel but their output signals do not.
- Both balanced LO waveforms and balanced RF inputs.

Conversion Gain of Double-Balanced Topology

Determine the voltage conversion gain of a double-balanced topology. (Decompose the differential output to return-to-zero waveforms.)

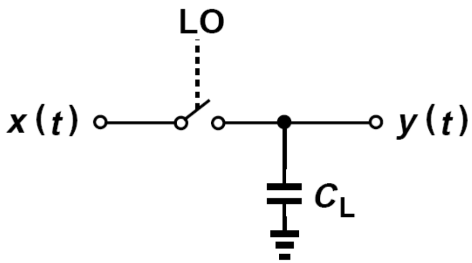
Solution:

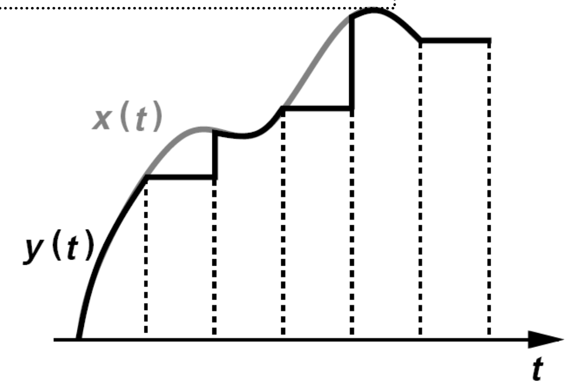


- V_{out1} is equal to V_{RF}^{+} for one half of the LO cycle and equal to V_{RF}^{-} for the other half.
- V_{out1} - V_{out2} can be decomposed into two return-to-zero waveforms with amplitude $2V_0$.
- Each of these waveforms generates an IF amplitude of $(1/\pi)2V_0$ and 180º out of phase.
- Therefore, V_{out1} - V_{out2} contains an IF amplitude of $(1/\pi)(4V_0)$.
- Noting that the peak differential input is equal to $2V_0$, Conversion gain is $2/\pi$

Sampling Mixer

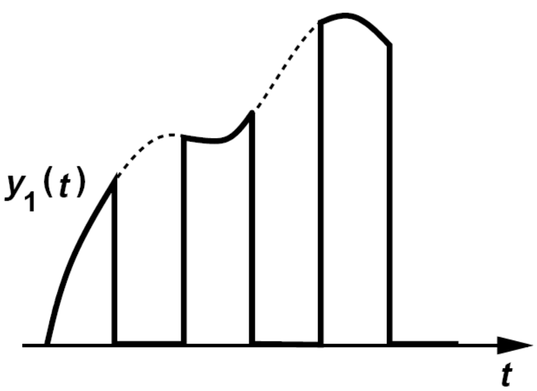
- Replace the resistor with a capacitor
- Operates as a sample-and-hold circuit
- A higher gain because the output is held—rather than reset

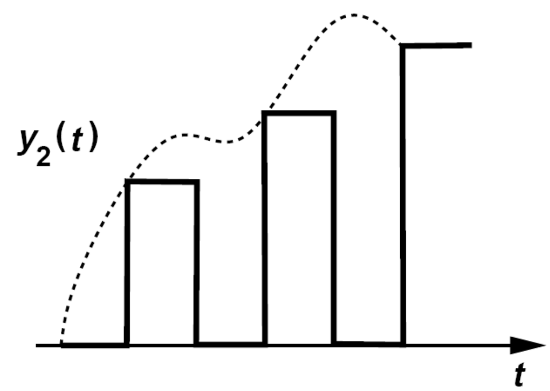




(a)

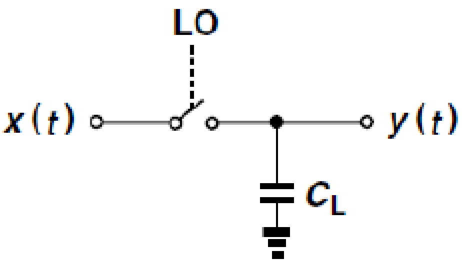
The output waveform of figure on the right (top) can be decomposed into two as figure at bottom.

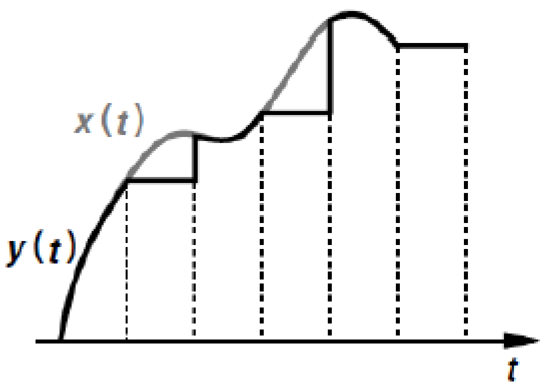




Conversion Gain of Sampling Mixer

- "Non-Return-to-Zero" (Sampling) Mixers: Case I: Voltage-Driven





Conversion Gain Calculation:

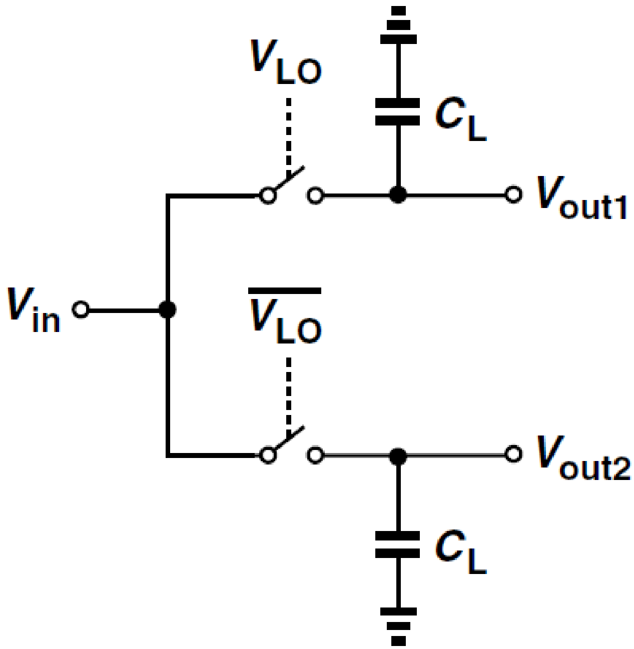
$$|Y_1(f) + Y_2(f)|_{IF} = \sqrt{\frac{1}{\pi^2} + \frac{1}{4}}[|X(f - f_{LO})| + |X(f + f_{LO})|]$$
$$= 0.593[|X(f - f_{LO})| + |X(f + f_{LO})|].$$

log(0.593) * 20 =

-4.53890613271

Conversion Gain -4.5dB

Single-Balanced Sampling Mixer



Conversion Gain ~ 1.5 dB

log(1.18600) * 20 =

1.48169378056

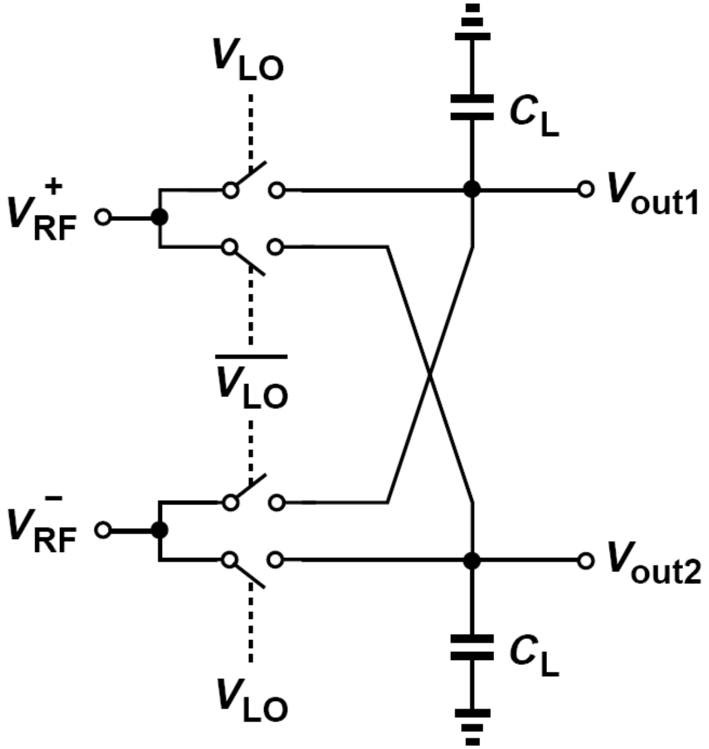
- **Voltage conversion gain of 1.5dB**
- **2X the gain of a simple Sampling Mixer**
- **Single-Balanced Sampling Mixer has 5.5 dB higher gain than RZ Mixer**
- **Therefore, the RZ Mixer rarely used**

Conversion Gain of Double-Balanced Sampling Mixer

Determine the voltage conversion gain of a double-balanced sampling mixer.

Solution:

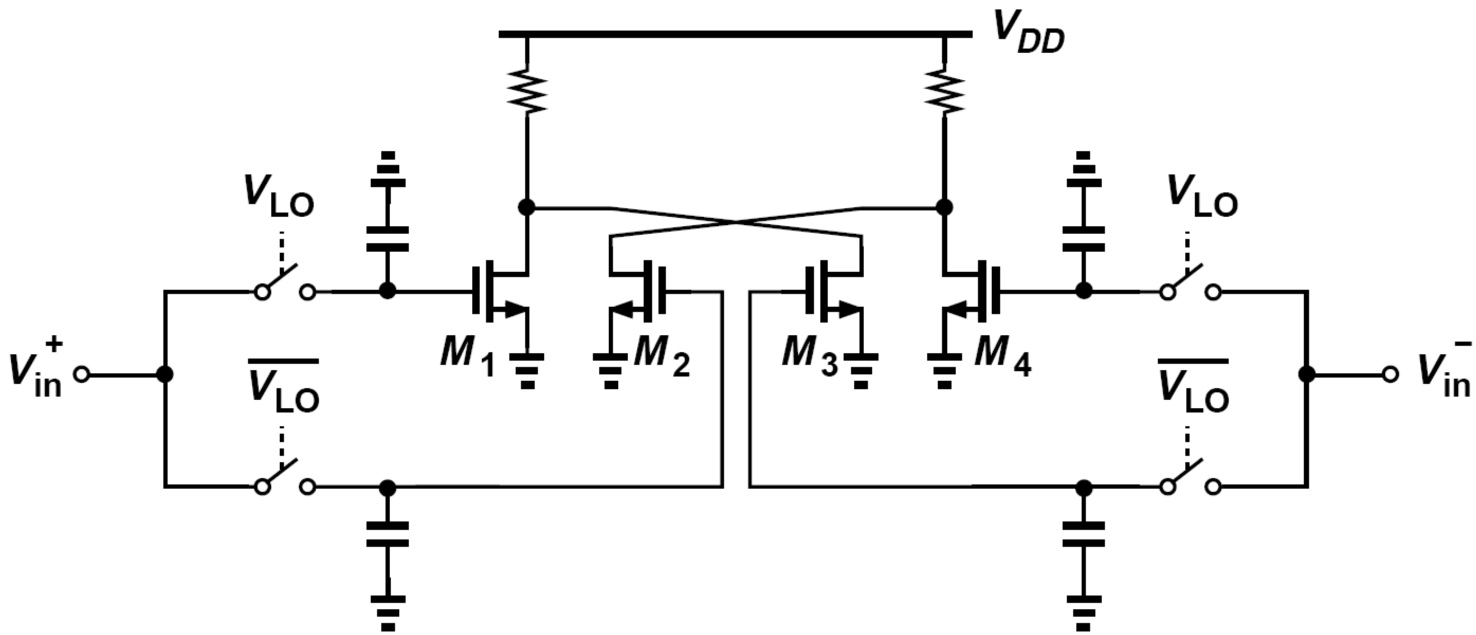
- **The capacitors play no role here because each output is equal to one of the inputs at any given point in time.**
- **The conversion gain is therefore equal to 2/π**



Conversion Gain -4dB

Combining Currents of Two Single-Balanced Mixers

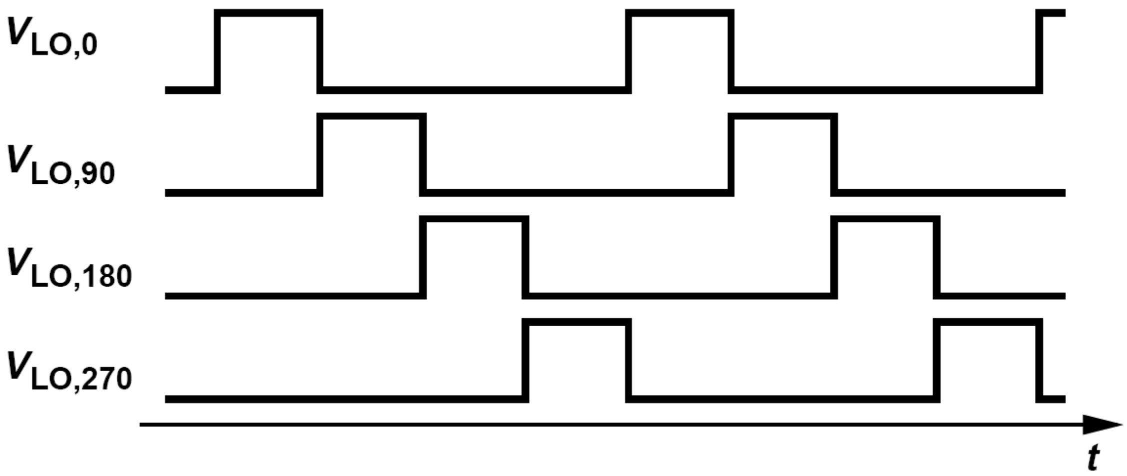
Conversion Gain 1.48dB



- **Use of two single-balanced mixers**
- **Sum the Outputs in the current domain**
- **Mixer conversion gain is then1.48 dB**

Noise and Nonlinearity Contribution, Duty Cycle

- Passive mixers need not employ a 50% LO duty cycle. In fact, the mixers utilizing a 25% duty cycle provide a higher gain.



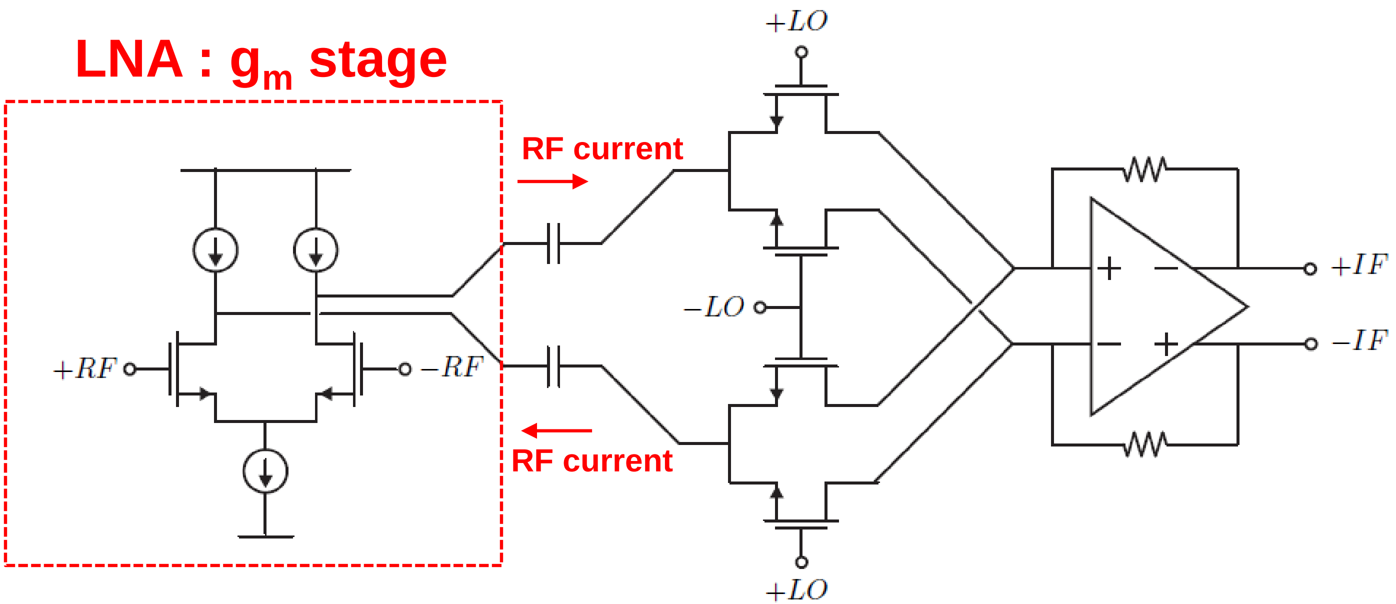
Voltage-driven the RF current entering each switch generates an IF current given by

$$I_{IF}(t) = \frac{2}{\pi}\frac{\sin \pi d}{2d} I_{RF0} \cos \omega_{IF} t$$

As expected, d = 0.5 yields a gain of $2/\pi$.
More importantly, for d = 0.25, the gain reaches $2\sqrt{2}/\pi$, 3 dB higher.

Conversion Gain -0.9 dB

Passive MOS Commutator



- The input stage is a G_m stage similar to a Gilbert cell mixer. The Gilbert Quad, though, has no DC current and switches on/off similar to a passive mixer.
- The output signal drives the virtual ground of a differential op-amp. The current signal is converted into a voltage output by the op-amp.

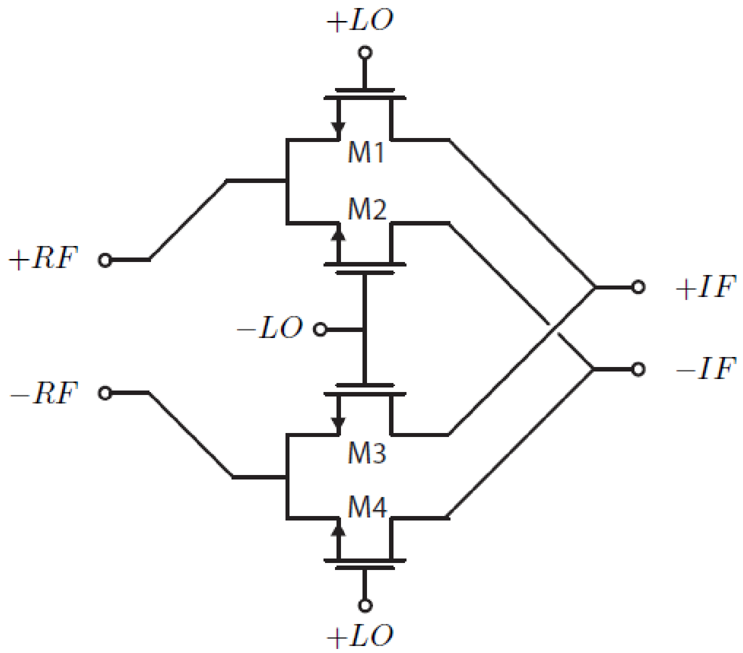
Advantages of Passive MOS Commutator

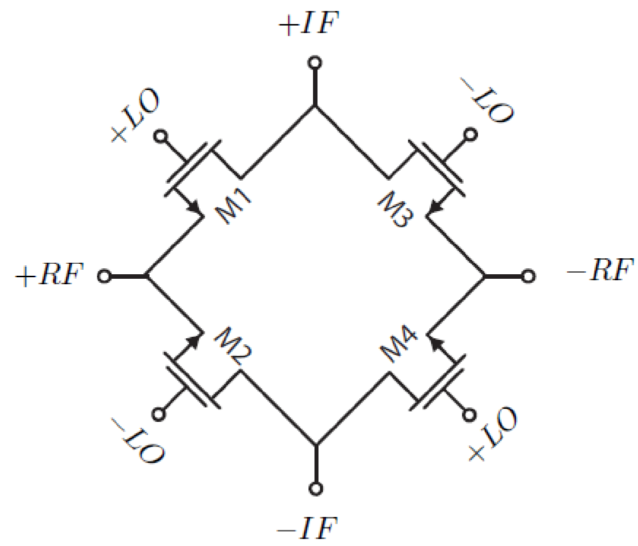
- No DC current in quad implies that there is no flicker noise generated by the switching quad. This is the key advantage.
- The linearity is very good since the output signal is a current. The voltage swing does not limit the linearity of the mixer. This is to be contrasted to a Gilbert cell mixer where the voltage swing is limited due to the headroom of the switching mixer and the transconductance stage.
- The op-amp output stage can be converted into an IF filter (discussed later)

Disadvantages of Passive MOS Commutator

- Need large LO drive compared to the active Gilbert cell mixer.
- Need an op-amp. This requires extra power consumption and introduces additional noise.
- Need a common mode feedback circuit at the input of the op-amp.

Ring or Quad





- Note that the Gilbert quad is really a folded ring. Thus the passive and active mixers are very similar. The main difference is how the quad devices are biased. In the Gilbert cell they are biased nominally in saturation and have DC current. In the passive mixers, they are biased near the threshold.