Lecture 4: Mixers (*Multiplication Devices*)

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How to build a *Mixer*?

- Variable Gain Amplifier or Switch
  - The basic design.
- Gilbert Cell (e.g., MC 1496)
  - Popular (suitable for Integrated Circuits).
- Switching Modulator
  - Uses diodes or transistors as switches.
  - Diodes represented cheaper option before ICs, but transistors can be used as well.

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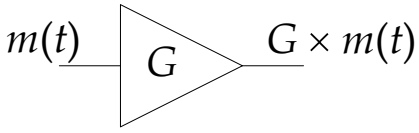
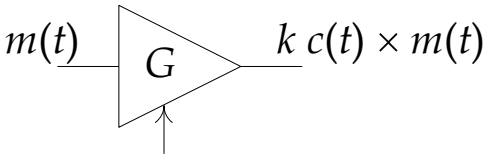
Variable Gain Amplifier



Fixed Gain



Variable Gain

$G = k\,c(t)$

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Gilbert Cell

- Gilbert cell is main mixer design in modern ICs.
- Built using 8 transistors in a configuration of 3 variable-gain differential amplifiers.
- Uses matched transistors (BJT, FET, etc). Matching transistors are easier to build within one IC.
- Uses differential signals, which is the preferred method for ICs, especially CMOS.
- Can be used in *linear mode* (i.e., analog multiplication device) or *switching mode* (i.e., switching modulator) (aka Gilbert mixer).

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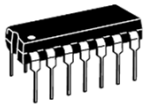
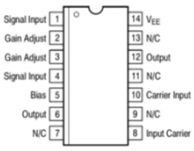
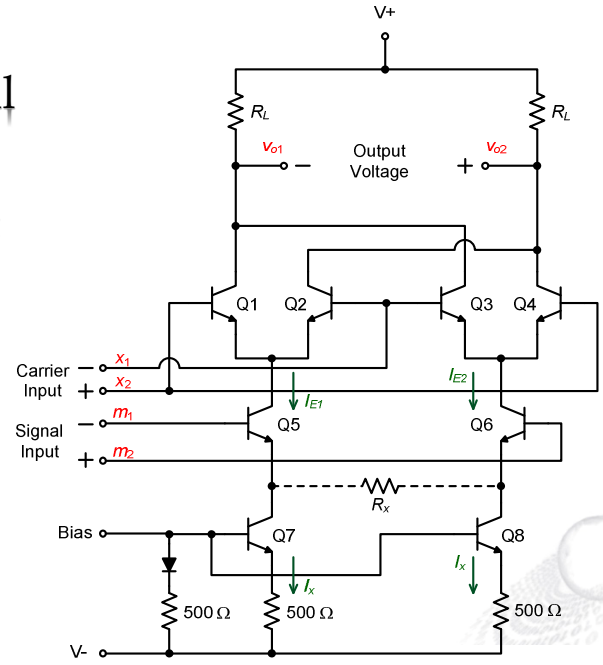
Gilbert Cell (MC1496) Schematic







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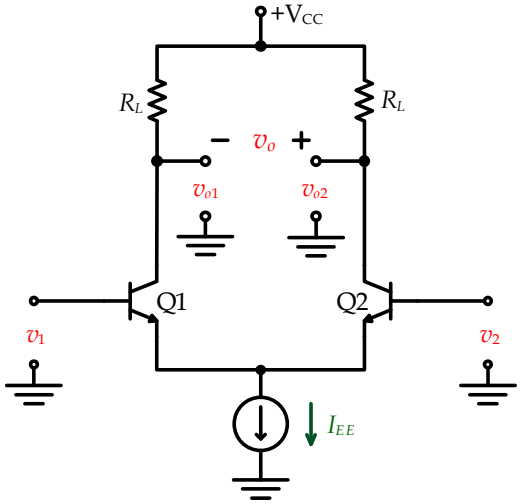
Differential Amplifier

(*Differential Pair*)



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Amplifier Analysis

$$v_o(t) = v_{o2} - v_{o1}$$

$$v_o(t) = \frac{-I_{EE} R_L}{2V_T}(v_2 - v_1)$$

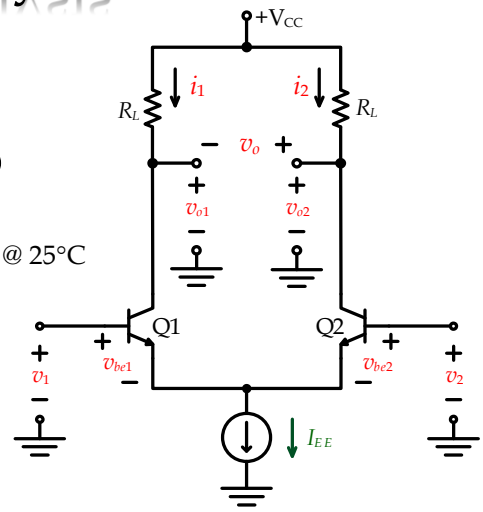
Thermal voltage $V_T = \frac{kT}{q} \approx 26\text{mV}$ @ 25°C

k: Boltzmann constant
1.380649×10^{-23} J·K^{-1}

T: Temperature (in K)

q: Electron electrical charge
1.602176634×10^{-19} C

K (Kelvin) = °C (Celsius) + 273.15



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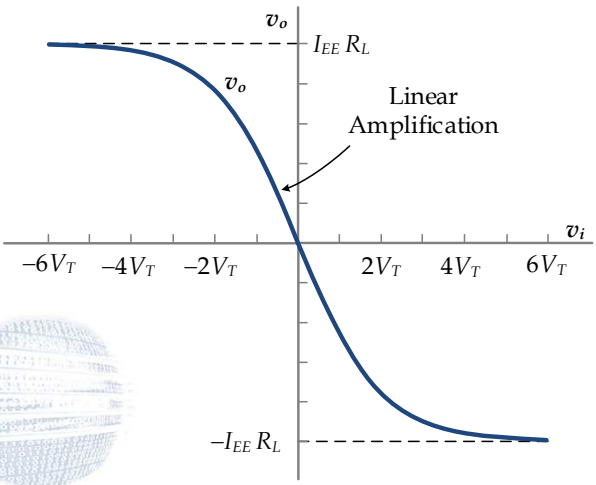
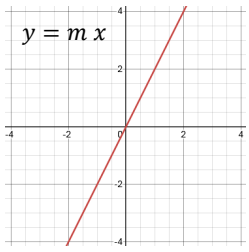
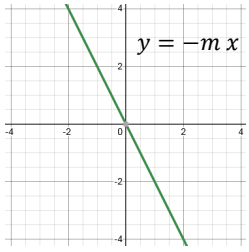
Linear Region







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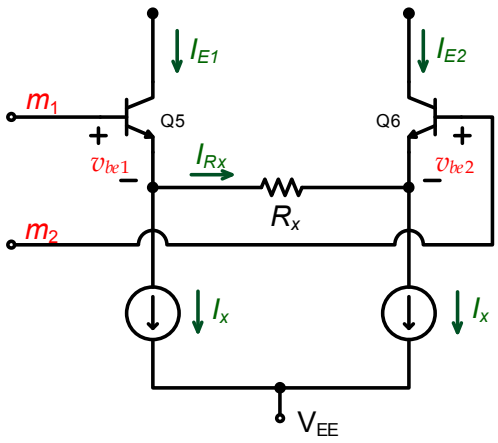
Gilbert Cell Analysis



$$v_o(t) = v_{o2} - v_{o1} = \frac{-R_L}{R_X V_T}(x_2 - x_1)(m_2 - m_1)$$

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Flexibility of Gilbert Cell

- Gilbert Cell can operate in one of four possible modes based on balancing and/or saturating the upper differential amplifiers.
- In the unbalanced mode, the gain of the top two differential amplifiers is unbalanced, which adds a residual carrier in the output signal (*see* potentiometer).
- If the upper differential amplifiers are pushed into saturation, their output is closer to square wave, than a sinusoidal signal.

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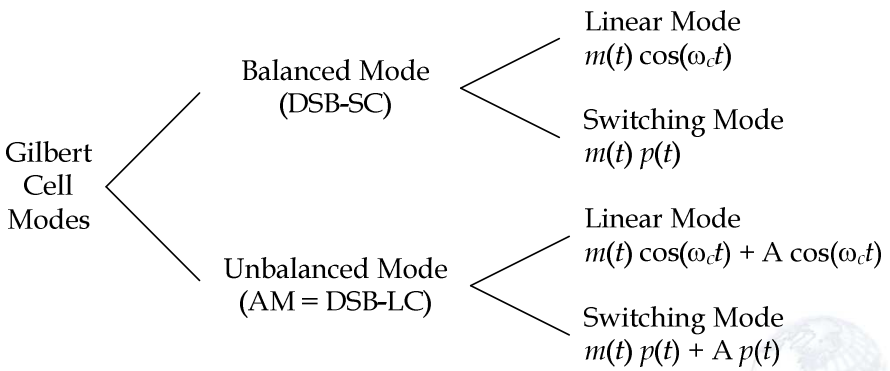
Gilbert Cell Four Modes



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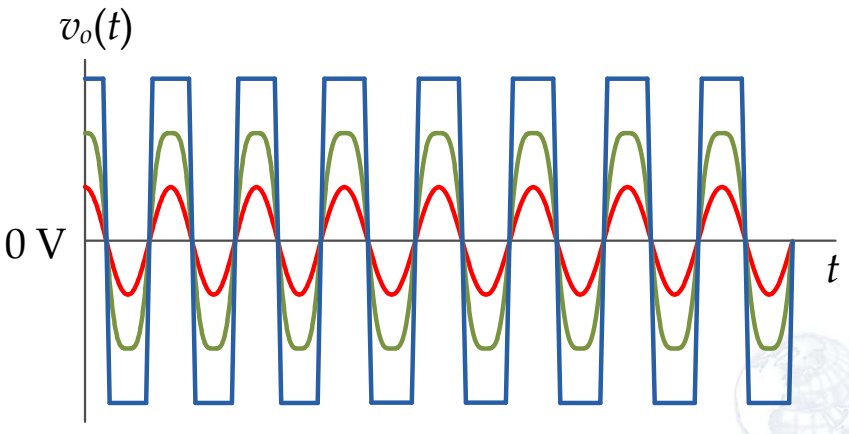
Higher Input Voltage



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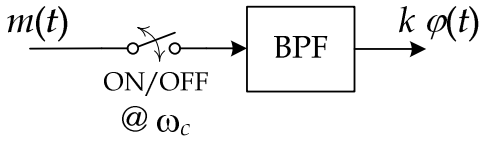
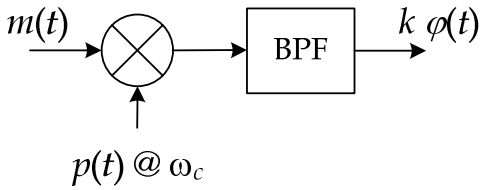
Switching Modulator





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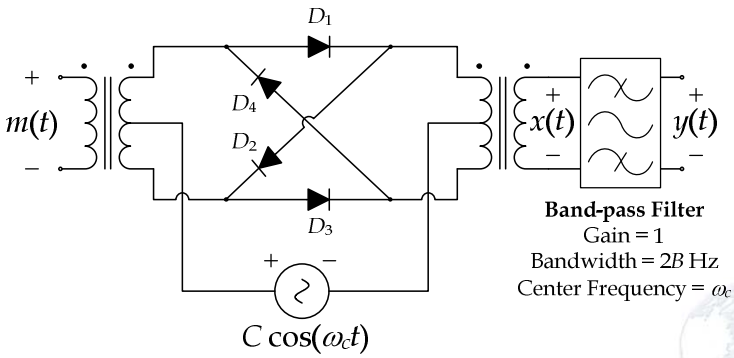
Switching Modulator (*Ring modulator*)



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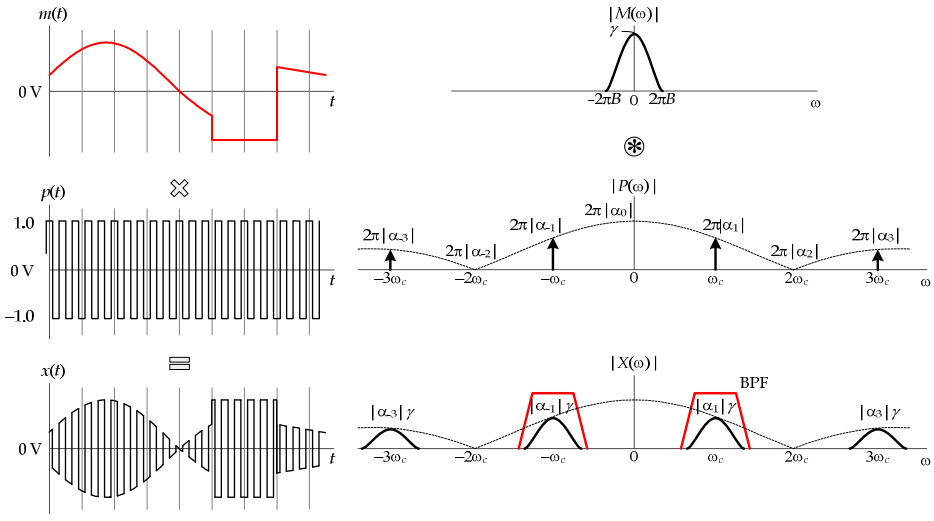

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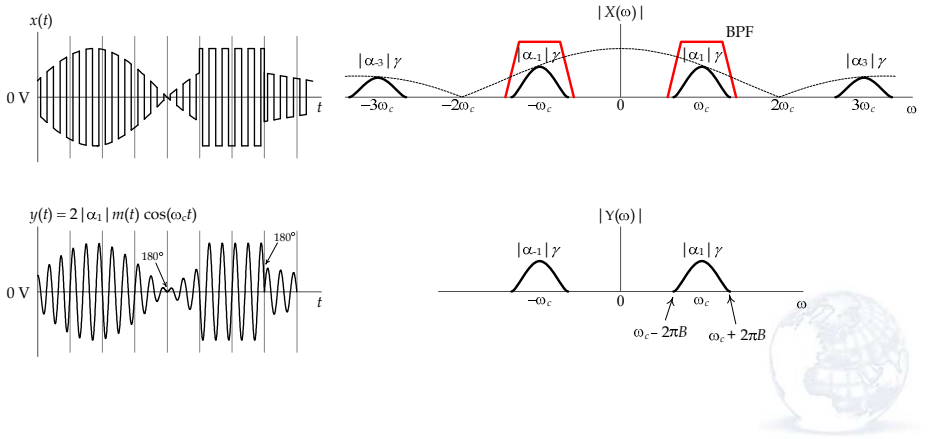
2

The BPF is *not optional!*



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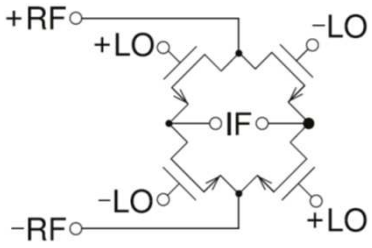
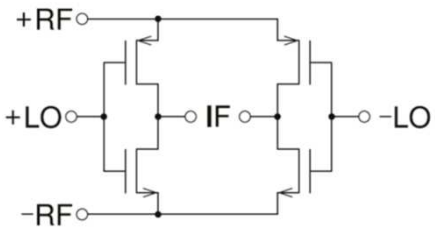
Transistor Ring Mixers



(a) MOS ring mixer



(b) CMOS H-bridge ring mixer

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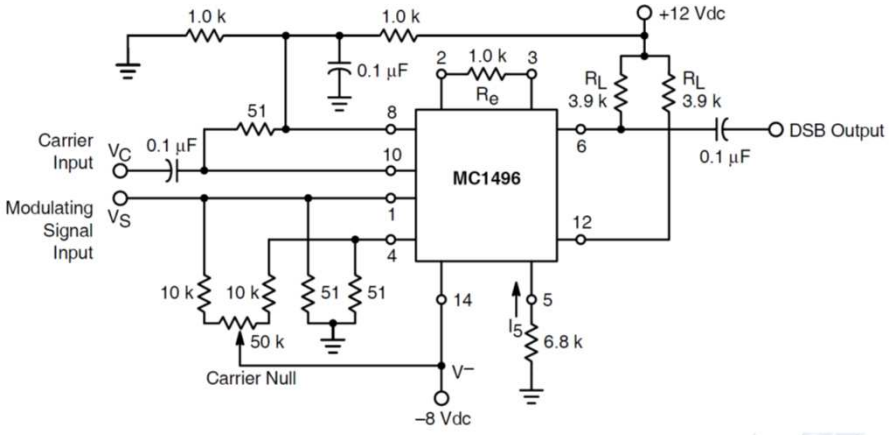
Balanced Modulator/Demodulator



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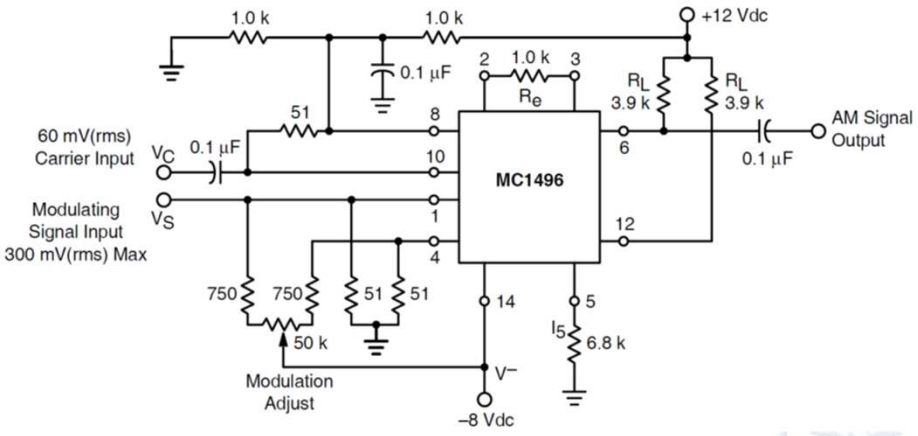
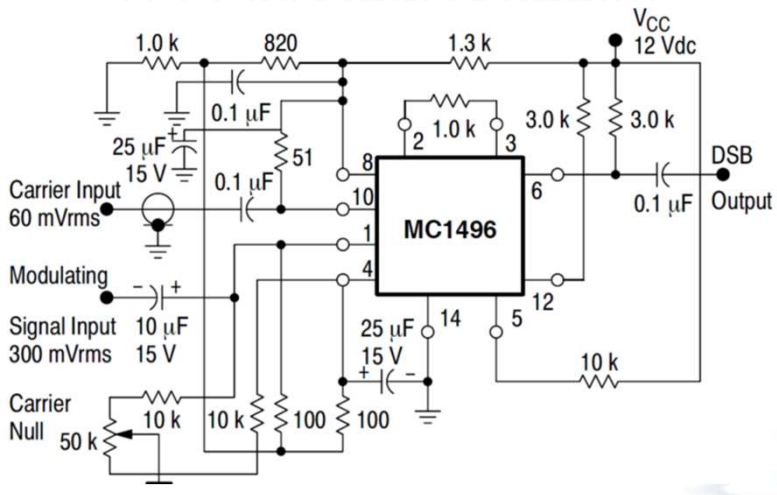
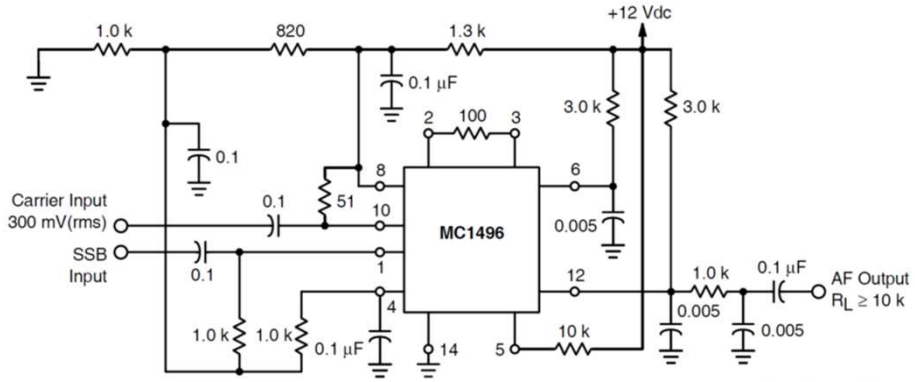
AM Modulator Circuit



Balanced Modulator (12 Vdc Single Supply)



Product Detector (12 Vdc Single Supply)



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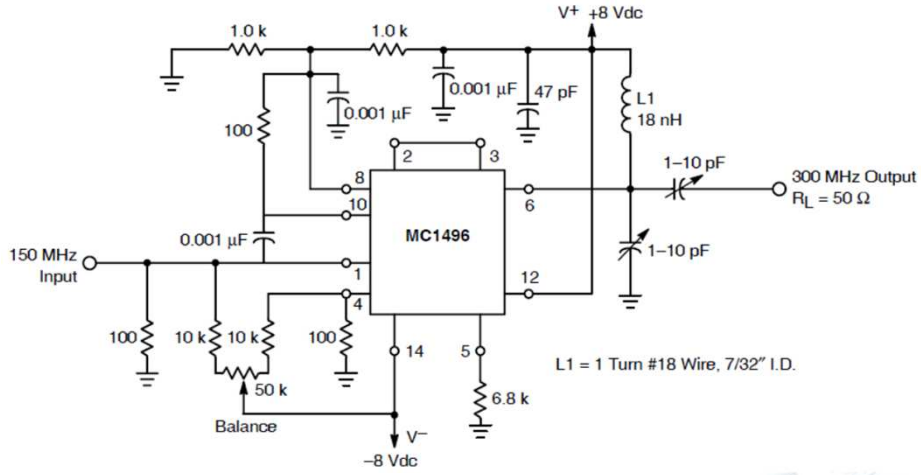
Frequency Doubler



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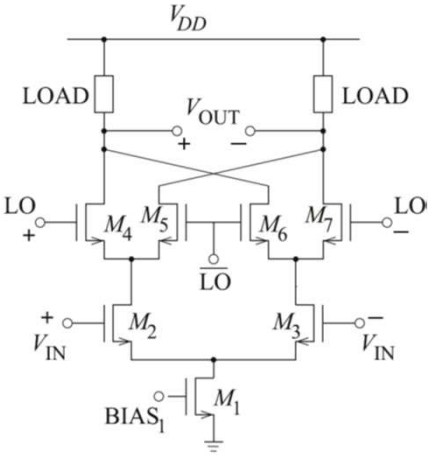
Practical Considerations

- One problem with Gilbert mixer is reduced voltage swing resulting from three drain-source voltage drops between the supply rails.
- Classic solution is to use a folded cascode design (cascode amplifier design with the mixer).



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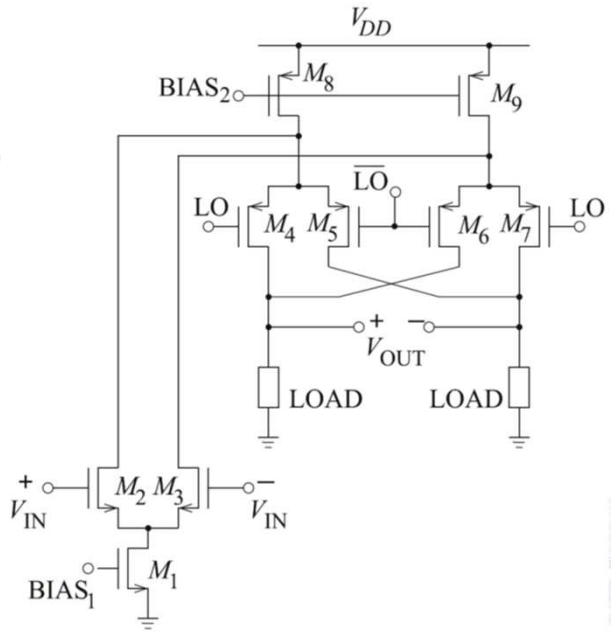
Folded Cascode Design



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Practical Considerations

- Gilbert cell in linear mode requires small voltage level RF input signal.
- This can be a problem because of the trend of reducing supply voltage of ICs.
- One solution is to replace each of the middle amplifying transistors by multiple transistors with progressively offset biasing that staggers the saturation transfer characteristic of a transistor circuit to realize a more linear characteristics.

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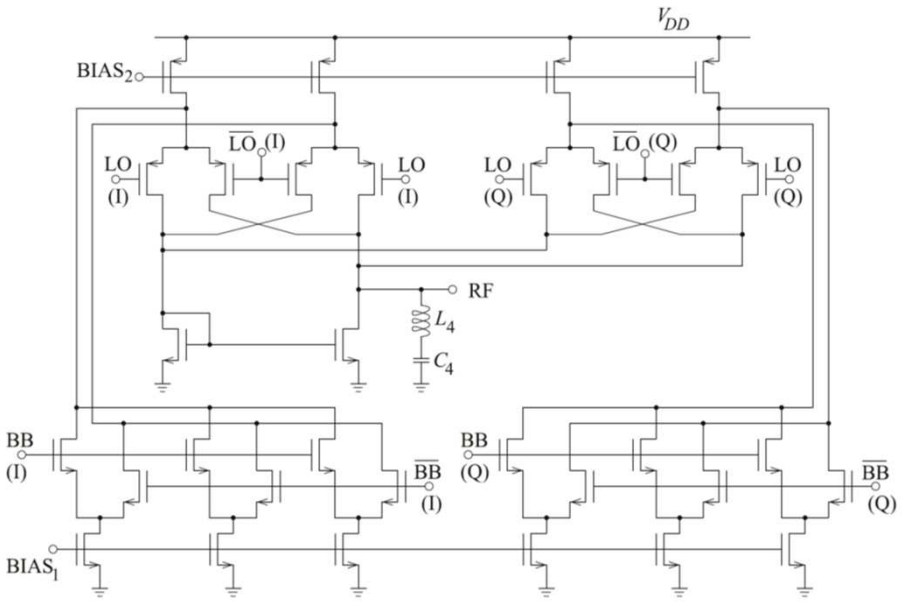

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