

## Lecture 4: Mixers (*Multiplication Devices*)

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EE423: Communication Electronics

### 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.

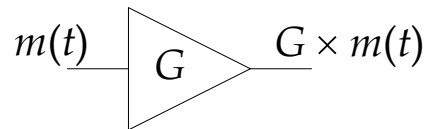


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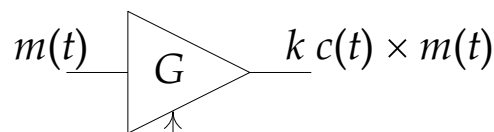
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## Variable Gain Amplifier



Fixed Gain



Variable Gain

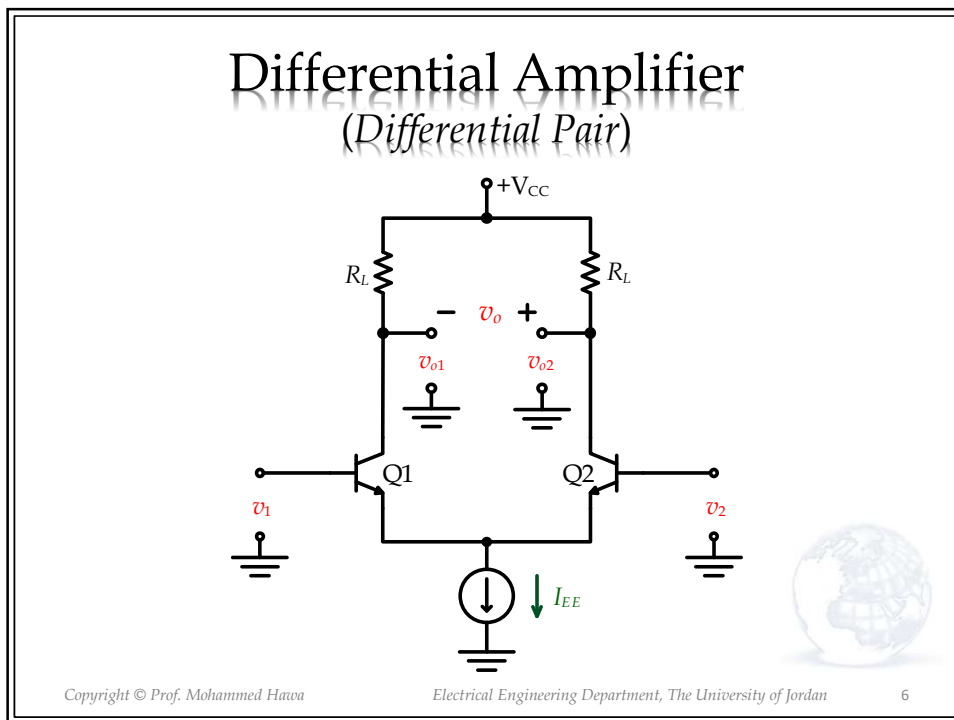
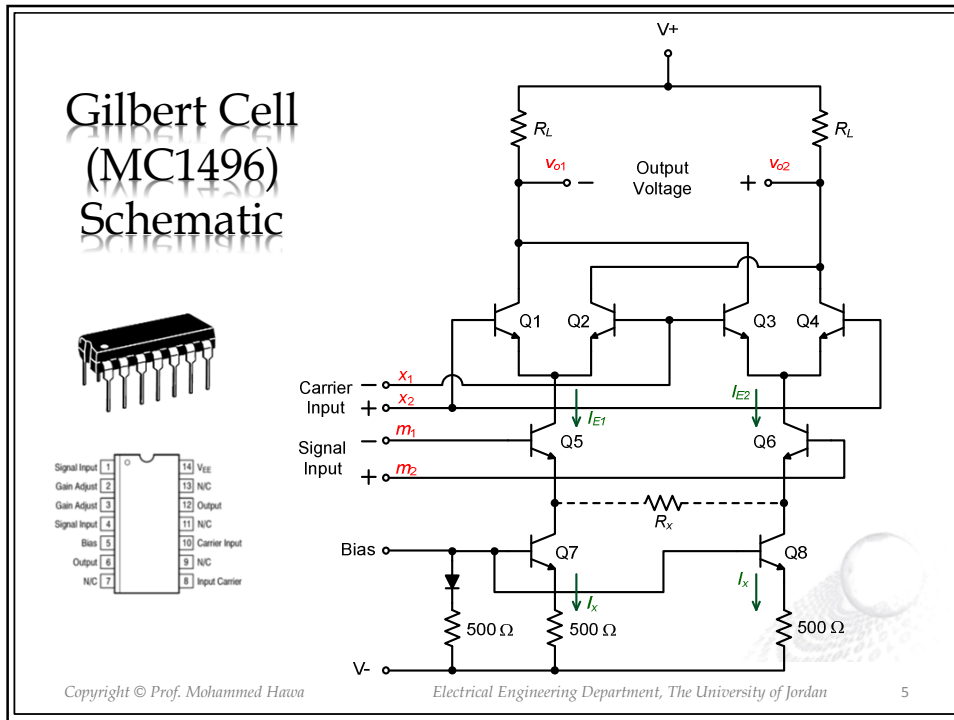
$$G = k c(t)$$



## 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).





# 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  $V_T = \frac{kT}{q} \approx 26\text{mV} @ 25^\circ\text{C}$

$k$ : Boltzmann constant

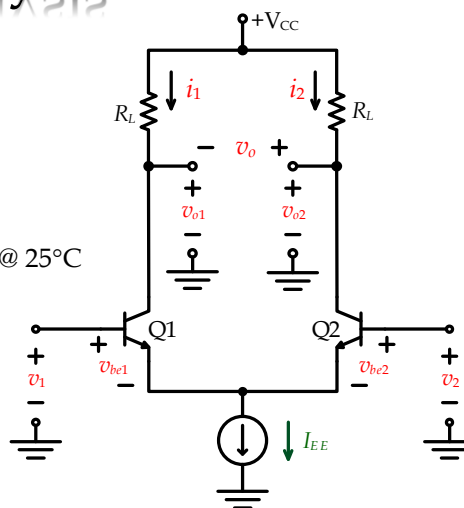
$$1.380649 \times 10^{-23} \text{ J}\cdot\text{K}^{-1}$$

$T$ : Temperature (in K)

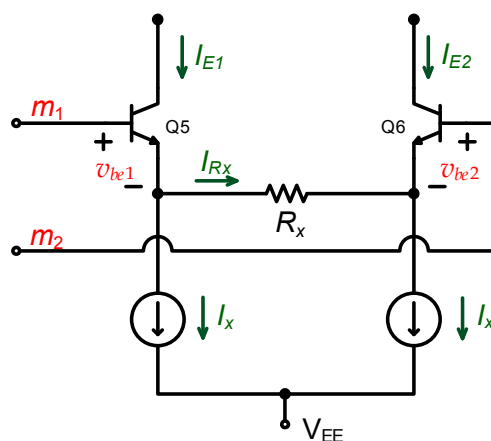
$q$ : Electron electrical charge

$$1.602176634 \times 10^{-19} \text{ C}$$

K (Kelvin) =  $^\circ\text{C}$  (Celsius) + 273.15



# Gilbert Cell Analysis

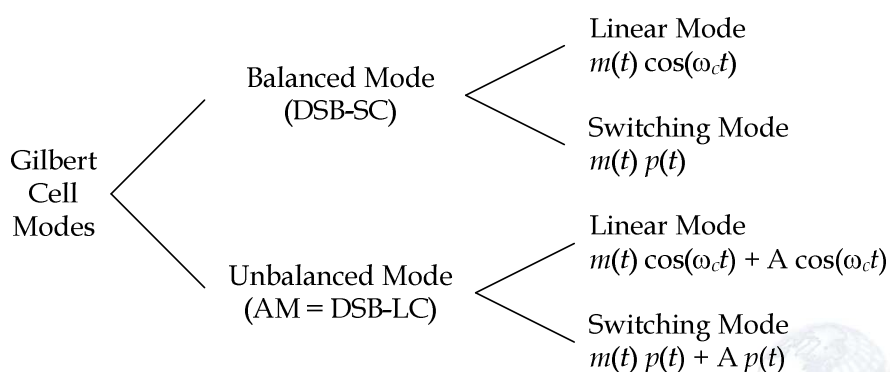


$$v_o(t) = v_{o2} - v_{o1} = \frac{-R_L}{R_x V_T}(x_2 - x_1)(m_2 - m_1)$$

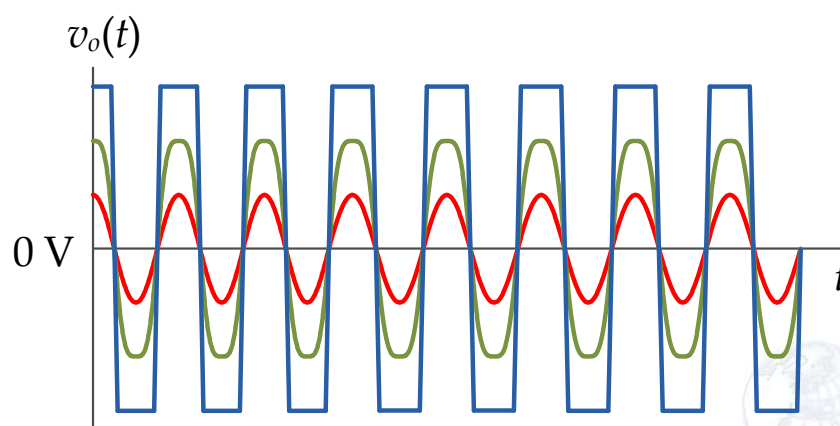
## Flexibility of Gilbert Cell

- 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.

## Gilbert Cell Four Modes



## Higher Input Voltage

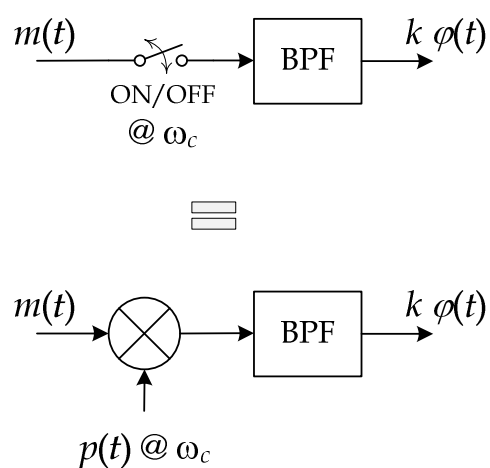


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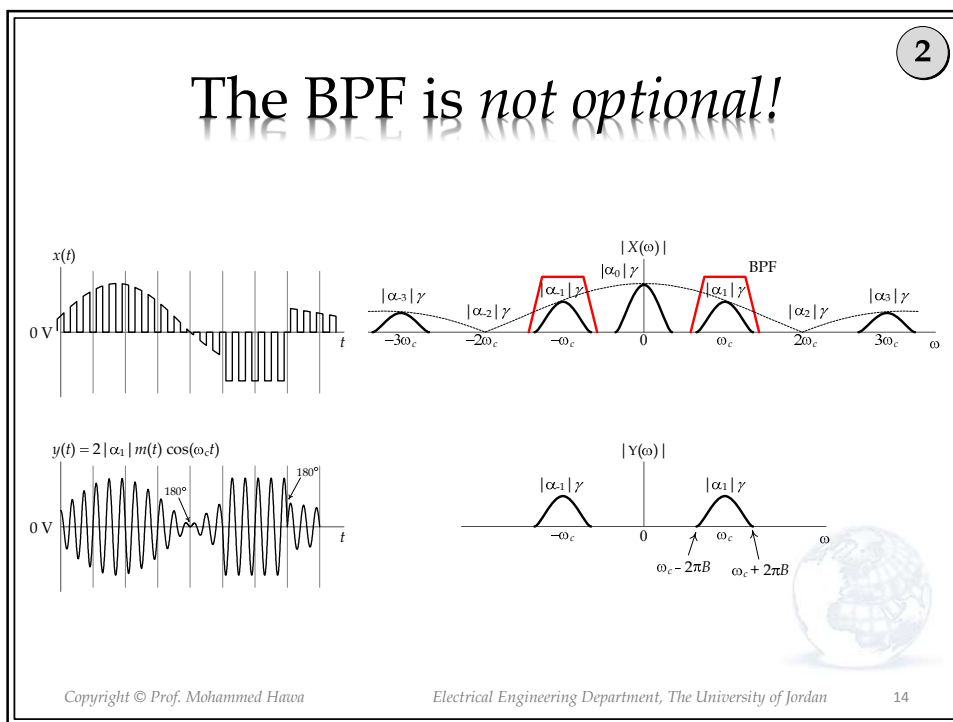
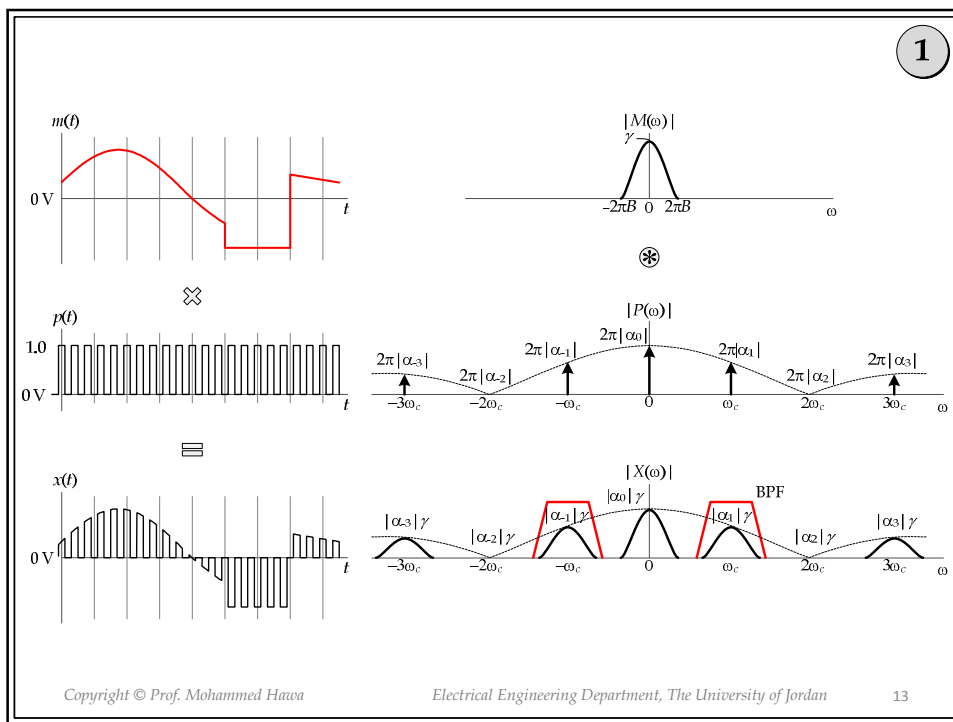
## Switching Modulator



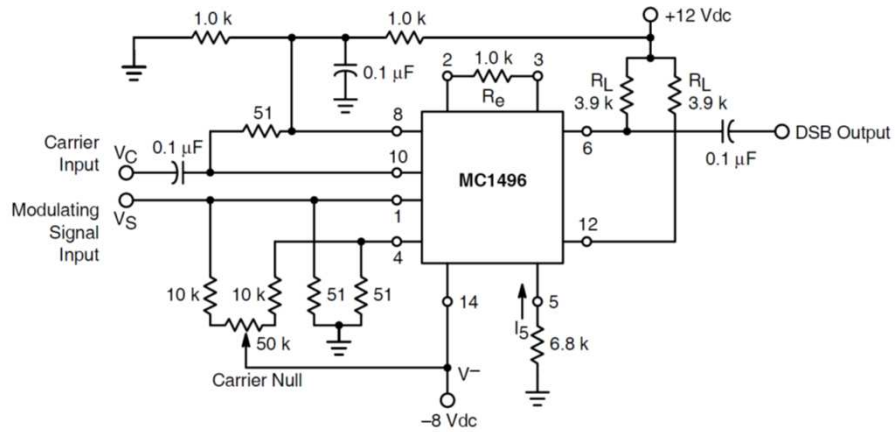
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## Balanced Modulator/Demodulator

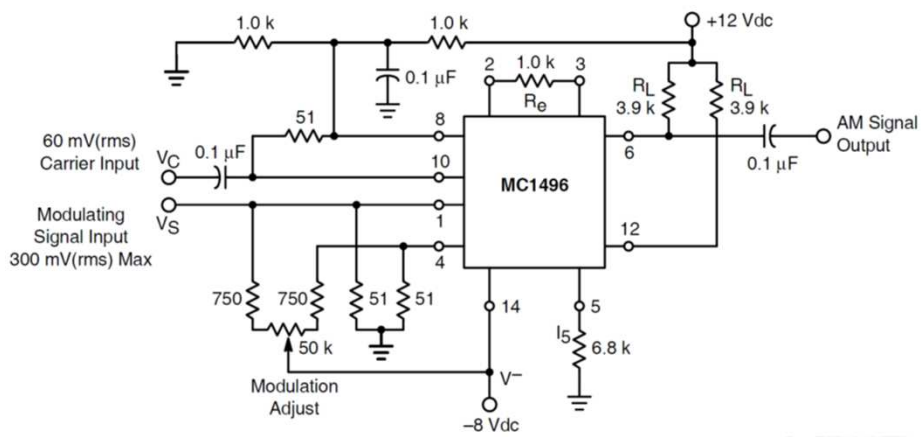


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## AM Modulator Circuit



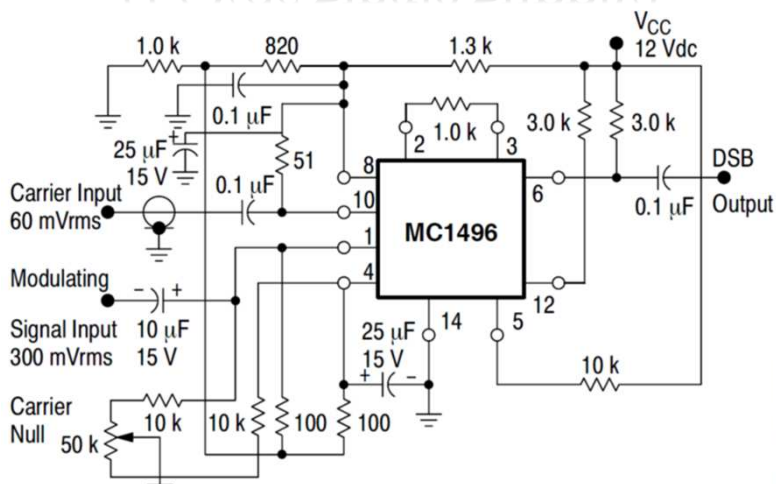
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## Balanced Modulator (12 Vdc Single Supply)

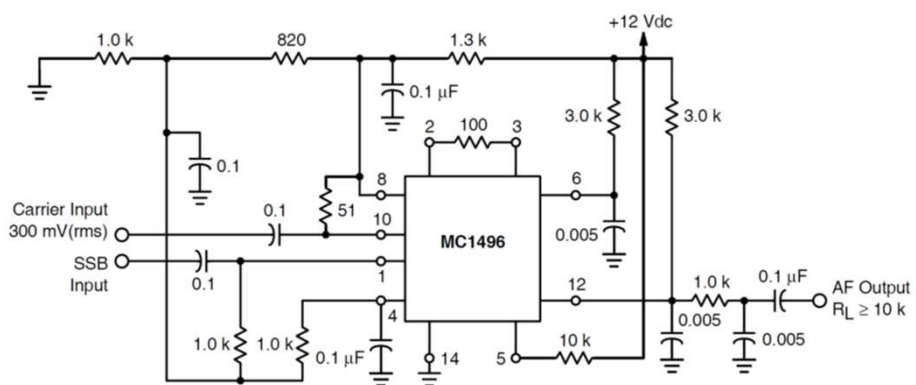


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## Product Detector (12 Vdc Single Supply)

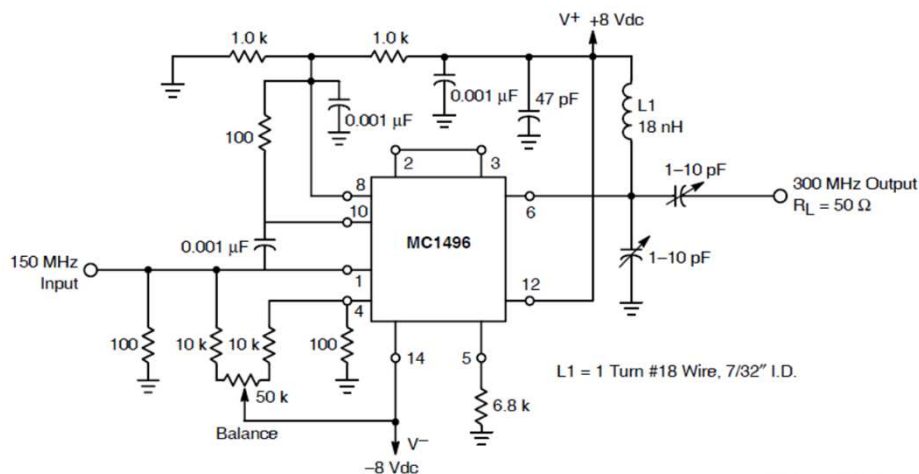


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## Frequency Doubler



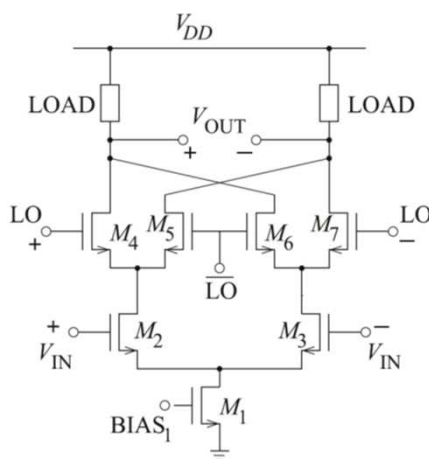
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## Practical Considerations

- 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).

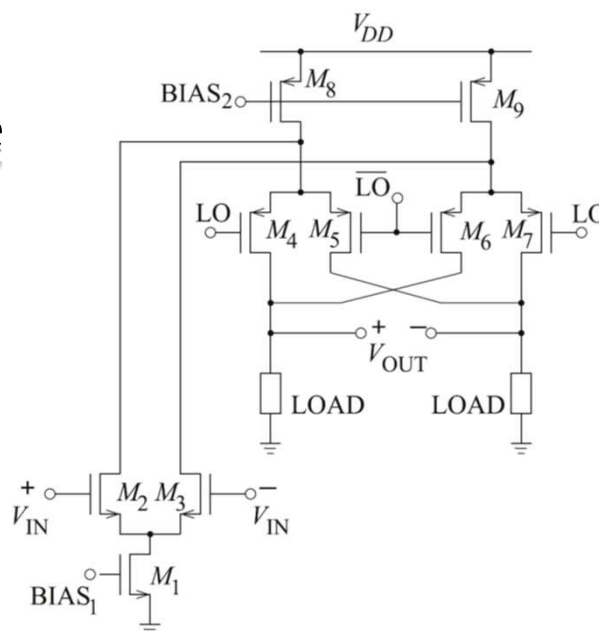


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## Folded Cascode Design



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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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