16/ENG04/065
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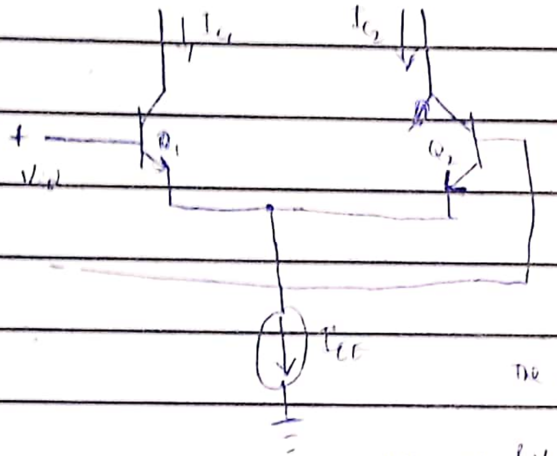
EEE 524

Analog Multipliers

These are probably the most important analog signal processing blocks. It is a circuit that produces an output which is proportional to the product of its input.

The Emitter-Coupled Pair as a simple multiplier:



As shown it produces output currents related to the differential input voltage by:

$$I_{c_1} = \frac{I_{EE}}{1 + \exp(-V_{id}/V_T)}$$

$$I_{c_2} = \frac{I_{EE}}{1 + \exp(V_{id}/V_T)}$$

The differential output current $\Delta I_C = I_{c_1} - I_{c_2} = I_{EE} \tanh(V_{id}/2V_T)$

assuming $(V_{id}/2V_T) << 1$: $\Delta I_C = I_{EE}(V_{id}/2V_T)$

As with the addition of more circuitry, I_{EE} which is the bias current for the emitter-coupled pair becomes proportional to a second input signal. Therefore, $I_{EE} \cong K_0(V_{i2} - V_{BE(on)})$

The differential output current of the emitter-coupled pair ~~also~~ also becomes

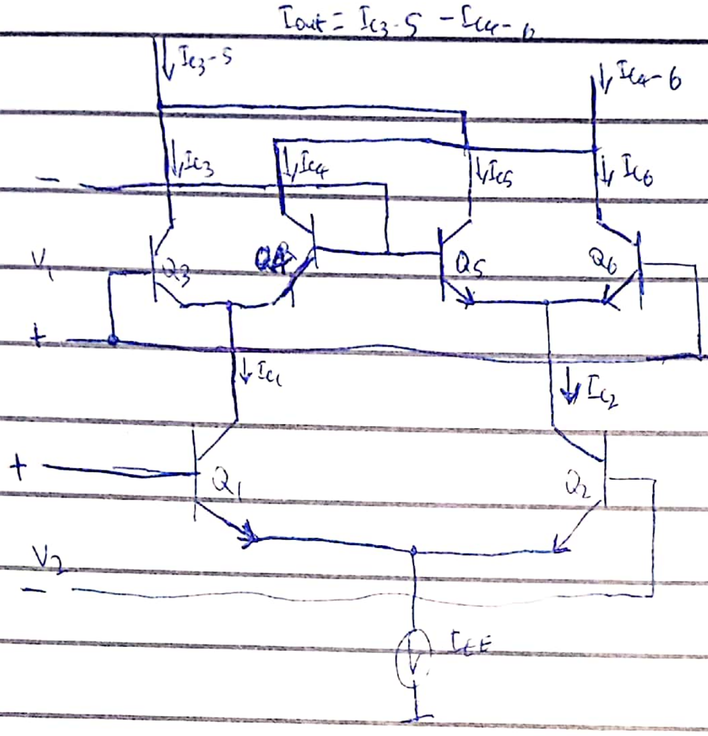
$$\Delta I_C \cong \frac{K_0 V_{id}(V_{i2} - V_{BE(on)})}{2V_T}$$

The produced circuit functions as a multiplier under the assumption that V_{id} is small and $V_{i2} > V_{BE(on)}$.
The ~~latter~~ latter assumption means the multiplier only functions in 2 Quadrants of the $V_{id} - V_{i2}$ plane and this type of circuit is called a two-Quadrant multiplier.

The Gilbert multiplier cell: This is a modification of the emitter-coupled cell and it allows four-Quadrant multiplication. It is the series connection of ~~an emitter coupled pair with two~~ two cross coupled emitter-coupled pair with an emitter coupled pair.

The collector current of Q_3 & Q_4 are ~~give~~ given by Q_5 & Q_6

$$I_{c3} = \frac{I_{c_1}}{1 + \exp(-V_1/V_T)} \; \& \; I_{c4} = \frac{I_{c_1}}{1 + \exp(V_1/V_T)} \qquad I_{c5} = \frac{I_{c_2}}{1 + \exp(V_1/V_T)} \; ; \; I_{c6} = \frac{I_{c_2}}{1 + e^{-V_1/V_T}}$$



The currents ~~of~~ I_{c1} & I_{c2} are related to V_2

$$I_{c1} = \frac{I_{EE}}{1 + e^{-V_2/V_T}} \quad \& \quad I_{c2} = \frac{I_{EE}}{1 + e^{V_2/V_T}}$$

After substituting I_{c1} & I_{c2} into I_{c3}, I_{c4}, I_{c5} & I_{c6}. The differential output current is then given by

$$\Delta I = I_{c3-5} - I_{c4-6} = I_{c3} + I_{c5} - (I_{c4} + I_{c6}) = I_{EE} \tanh(V_1/2V_T) \tanh(V_2/2V_T)$$

The Gillbert cell only acts as a multiplayer when $V_1 < V_T$ & $V_2 < V_T$. That is, it performs analog multiplication for small-amplitude signals.

Amplitudes of input signals are often much larger than V_T. So, a nonlinearity can be introduced to predistort the input signals to compensate for the hyperbolic tangent transfer characteristic of the basic cell. The required nonlinearity is called an <u>inverse hyperbolic tangent</u>

$$I_1 = I_{01} + K_1 V_1 \quad \& \quad I_2 = I_{01} - K_1 V_1$$

where I_{01} is the dc that flows in each ~~outpt~~ output lead if $V_1 = 0$

K = transconductance of the voltage-to-current converter.

$$\Delta I = I_{EE} \left(\frac{K_1 V_1}{I_{01}} \right) \left(\frac{K_2 V_2}{I_{02}} \right)$$

$$V_{out} = I_{EE} K_3 \frac{K_1}{I_{01}} \frac{K_2}{I_{02}} V_1 V_2 = 0.1 V_1 V_2$$

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Gilbert cell as a balanced modulator

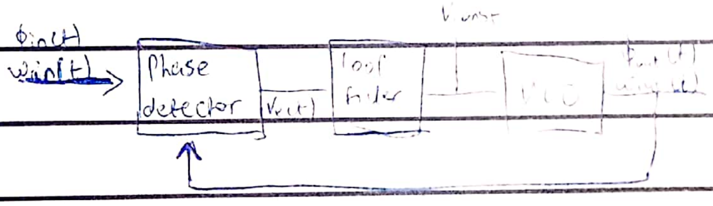
Looking at the Gilbert cell; if one of the inputs of a signal is large compared to V_T, it effectively multiplies the applied small ~~voltage~~ signal by a square wave making the cell a modulator.

Gilbert cell as a phase detector

If the two inputs are large compared to V_T and are both unmodulated signals of similar frequency, the circuit behaves as a phase detector and produces an output whose dc component is proportional to the phase difference between the 2 inputs.

Phase Locked Loop Circuits

A phase locked loop is a feedback system that includes a phase detector, VCO & low pass filter within its loop. It is used to force the VCO to replicate & track the frequency & phase at the input when in lock. It allows one oscillator to track with another.



Phase & frequency are interrelated by:

$$\omega(t) = \frac{d\phi}{dt}$$

$$\phi(t) = \phi(0) + \int_0^{t} \omega(t')\,dt'$$

Phase detector: This compares the phase at each input & generates an error signal, $V_e(t)$, proportional to the phase difference between the two inputs. K_D is the gain of the phase detector (V/rad).

$$V_e(t) = K_D\left(\phi_{out}(t) - \phi_{in}(t)\right)$$

Since 2 inputs are at the same frequency when the loop is locked, we have one output at twice the input frequency & an output proportional to the cosine of the phase difference. The doubled frequency ~~comp~~ component is then removed by the low pass filter. Any phase difference can then show up as the control voltage to the VCO.

VCO: Excess phase ~~of the~~ VCO is the system output

$$\phi_{out} = K_O \int_{-\infty}^{t} V_{cont}\,dt'$$