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Phase locked loop (PLL)

A PLL is a feedback system which contains a VCO, LPF and a phase comparator, connected in such a way that the oscillator maintains a constant phase angle relative to the reference signal.

It's purpose is to force the VCO to replicate and track the prequency and phase at the input when in lock. The PLL is a control system allowing one oscillator to track another. It is possible to have a phase offset between input and output, but when locked, the prequencies must exactly track, i.e

$$\phi_{out}(t) = \phi_{in}(t) + const$$
$$\omega_{out}(t) = \omega_{in}(t)$$

The three main elements of the PLL include

① Phase detector
② Loop filter
③ VCO.

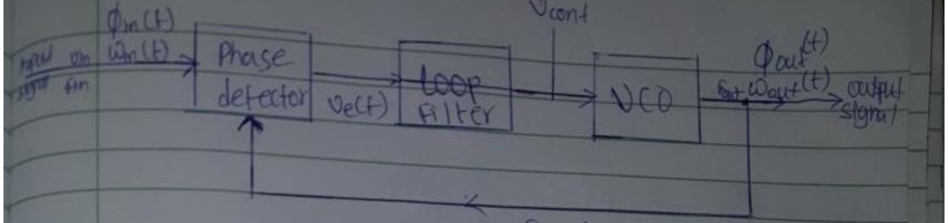

Fig 1: PLL Block Diagram

Phase and frequency are interrelated by:

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

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

- Phase Detector: It compares the phase at each input and generates an error signal, $V_e(t)$. which is proportional to the phase difference between the two inputs. i.e

$$V_e(t) = K_p [\phi_{out}(t) - \phi_{in}(t)]$$

where K_p => gain of the phase detector (V/rad)

Circuits which canbe used as phase detector Include
- analog multiplier or mixer
-

- VCO: (Voige Controlled oscillator): It generates an output frequency that is directly proportional to the input voltage. The VCO oscillates at an angular frequency ω_{out} The frequency is set to a nominal ω_0 when the control voltage is zero. The frequency is assumed to be linearly proportional to the control voltage with a gain coefficient K_0 or K_{vco} (rads/V)

$$\omega_{out} = \omega_0 + K_0 V_{cont}$$

- LPF (Low Pass filter): It is used to get rid of the high frequency components in the output of the phase detector. It also removes the high frequency noise.

Operating Principle of PLL

From the PLL Block diagram (fig 1)

The input signal V_{in} with an input frequency f_{in} is passed through a phase detector which compares the input frequency f_{in} with the feedback frequency f_{out}. The phase detector provides an output error voltage V_e (= f_{in} + f_{out}) which is a DC voltage. The DC voltage is then passed to an LPF. The LPF removes the high frequency noise and produces a steady DC level, The DC level is then passed on to a VCO. The output frequency of the VCO (f_{out}) is directly proportional to the input signal. Both the input prequency and output frequency are compared and adjusted through feedback loops until the output prequency equal the input frequency.

The PLL works in three (3) stages which are:

1 free running
2 Capture
3 Phase lock.

- free running stage! This refers to the stage when there is no input voltage applied.
- Capture stage: At this stage the VCO starts to change and begins to produce an output prequency as soon as the input prequency is applied.
- Phase locked stage: This refers to the stage at which frequency comparison stops as soon as the output frequency is adjusted to become equal to the input prequency

frequency:

Importan terms in PLL

a Lock Range : This is the range of input signal frequencies over which the loop remains locked once it has captured the input signal. This can be limited either by the phase detector or the VCO frequency range

b Capture range: This is the range of input frequencies around the VCO center frequency onto which the loop will lock when starting from an unlocked condition. Sometimes a frequency detector is added to the phase detector to assist in initial acquisition of lock.

Applications of PLL

1 Clock generation
2 frequency synthesizer
3 Clock recovery in a serial data link.

Analog multipliers

Analog multipliers are circuits thats take two analog inputs and produce an output proportional to their product.

Below are several analog multipliers which depend on the exponential transfer function of bipolar transistors

Analog multiplier using an Emitter couple transistor pair.

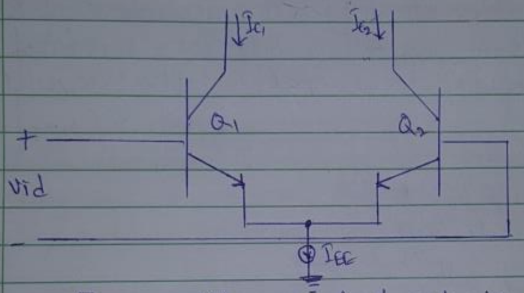

fig ① Emitter coupled Pair

The emitter-coupled pair in fig 1 produces output current that are related to the differential input voltage by:

$$I_{C_1} = \frac{I_{EE}}{1+\exp(-V_{id}/V_T)}$$

$$I_{C_2} = \frac{I_{EE}}{1+\exp(V_{id}/V_T)}$$

$$\Delta I_C = I_{C_1} - I_{C_2} = I_{EE} \tanh(V_{id}/2V_T)$$

where

V_T => thermal voltage

I_{EE} => bias current for the emitter.

Fig 2 below shows that the emitter coupled pair can be used as a simple multiplier using this configuration.

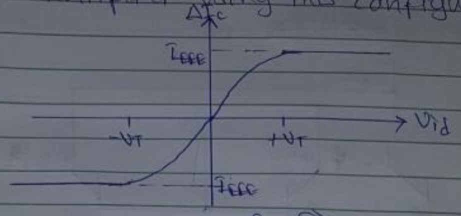

Fig ②

~~When the differential input voltage $v_{id} << V_T$: then~~

~~$\Delta I_C = I_{EE}(v_{id}/2V_T)$~~

If $(v_{id}/2V_T) << 1$ then:

$$\Delta I_C = I_{EE}(v_{id}/2V_T)$$

Adding more circuitry to fig 1, makes I_{EE} proportional to a second input signal. Thus we have

$$I_{EE} \simeq k_0(v_{i2} - V_{BE(on)})$$

Then the differential output current of the emitter coupled pair becomes:

$$\Delta I_C \simeq \frac{k_0 v_{id}(v_{i2} - V_{BE(on)})}{2V_T}$$

Thus a circuit that functions as a multiplier under the assumption that v_{id} is small and that v_{i2} is greater than $V_{BE(on)}$ has bee produced.

This means that the multiplier functions in only two quadrants of $v_{id} - v_{i2}$ plane, and this type of circuit is called a two-quadrant multiplier. The two quadrant multiplier has a many communication applications but most practical multipliers allow four quadrant operation.

The Gilbert multiplier cell is a modification of the emitter-coupled cell which allows four quadrant multiplication.

Gilbert ~~multiplier~~ cell.

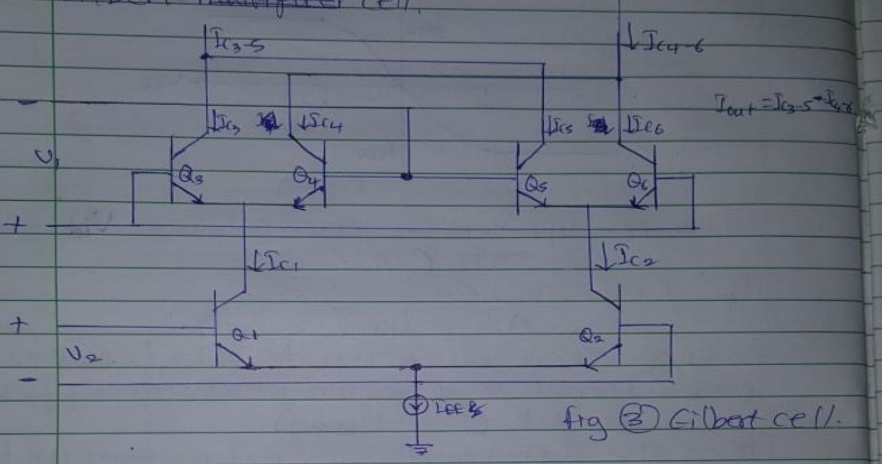

fig ③ Gilbert cell.

The Gilbert ~~multiple~~ cell is the basis for most integrated circuit balance multiplier systems. The series connection of an emitter-coupled pair with two cross-coupled, emitter-coupled pairs produces a particularly useful transfer characteristic.

$$I_{C3} = \frac{I_{C1}}{1+\exp(-V_1/V_T)}$$

$$I_{C4} = \frac{I_{C1}}{1+\exp(V_1/V_T)}$$

$$I_{C5} = \frac{I_{C2}}{1+\exp(V_1/V_T)}$$

$$I_{C6} = \frac{I_{C2}}{1+\exp(-V_1/V_T)}$$

The two currents I_{C1} and I_{C2} are related to V_2

$$I_{c1} = \frac{I_{EE}}{1+\exp(-V_2/V_T)} \quad , \quad I_{c2} = \frac{I_{EE}}{1+\exp(V_2/V_T)}$$

Substituting I_{c1} and I_{c2} in expressions for I_{c3}, I_{c4}, I_{c5} and I_{c6} we get:

$$I_{c3} = \frac{I_{EE}}{[1+\exp(-V_1/V_T)][1+\exp(-V_2/V_T)]}$$

$$I_{c4} = \frac{I_{EE}}{[1+\exp(V_1/V_T)][1+\exp(-V_2/V_T)]}$$

$$I_{c5} = \frac{I_{EE}}{[1+\exp(V_1/V_T)][1+\exp(V_2/V_T)]}$$

$$I_{c6} = \frac{I_{EE}}{[1+\exp(-V_1/V_T)][1+\exp(V_2/V_T)]}$$

The differential output current is then given by:

$$\Delta I = I_{c3-5} - I_{c4-6} = I_{c3} + I_{c5} - (I_{c4} + I_{c6}) = (I_{c3} - I_{c6}) - (I_{c4} - I_{c5})$$

$$\Delta I = I_{EE} \tanh(V_1/2V_T) \tanh(V_2/2V_T)$$

∴ the dc transfer characteristic, is the product of the hyperbolic tangent of the two input voltages.

Applications of Gilbert cell.

The three main applications of the Gilbert cell depend on the range of V_1 and V_2:

1 If $V_1 < V_T$ and $V_2 < V_T$ then:

$$\tanh(V_{1,2}/2V_T) \simeq V_{1,2}/2V_T$$

It works as a multiplier

2. If one of the inputs of a signal that is large compared to V_T, this effectively multiplies the applied small signal by a square wave, and acts as a modulator.

3 If both inputs are large compared to V_T, and all six transistors in the circuit behave as

non-saturating switches. This is useful for the detection of phase differences between two amplitude-limited signals, as is required in phase-locked loops and is sometimes called the phase detector mode.

Gilbert cell as a multiplier.

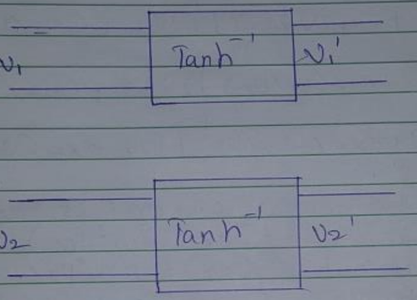

Fig 4: Input signals

If $V_1 < V_T$ and $V_2 < V_T$ then:

$$\tanh(x) = x + x^3/3 + \cdots \cong x$$

Thus for small-amplitude signals, the circuit performs an analog multiplication. But the amplitudes of the input signals are often much larger than V_T.

An alternate approach is to introduce a non-linearity that predistorts the input signals to compensate for the hyperbolic tangent transfer characteristic of the basic cell. The required non-linearity is an inverse hyperbolic tangent characteristic

Gilbert cell as a modulator

In communication systems, the need frequently arises for the multiplication of a continously varying signal by a square wave. This is easily accomplished with the multiplier circuit by applying a sufficiently large signal directly to the cross coupled pair.

Gilbert cell as a phase detector

If unmodulated signals of identical frequencies are applied to the inputs of the Gilbert cell the circuit behaves as a phase detector and produces an output whose dc component is proportional to the phase difference between the two inputs.