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SUMMARY OF ANALOG MULTIPLIERS

In an analog signal processing, the term analog multipliers refer to a circuit that takes two analog inputs and produces an output proportional to their product.

In this note, we take a close look on several types of analog multipliers that depend on **exponential transfer function of bipolar transistors.** A few are listed below;

- ✓ The emitter coupled pair as a simple multiplier
- ✓ Two quadrant restriction
- ✓ Gilbert multiplier cell
- ✓ Gilbert cell-DC analysis
- ✓ Gilbert cell applications
- ✓ Gilbert cell as multiplier
- ✓ Pre-warping circuit-inverse hyperbolic tangent
- ✓ Complete analog multipliers
- ✓ Gilbert cell as a balanced modulator
- ✓ Spectra for balanced modulator
- ✓ Gilbert cell as a phase detector

- **Emitter-coupled pair** by itself can be seen /used as a primitive multiplier
  Since we assume, $(V_{id} / 2V_T) << 1, \Rightarrow \Delta Ic = I_{EE}(V_{id} / 2V_T)$.
- In the **two quadrant restriction**, the multiplier circuit functions in the latter quadrant of the V_{id} and V_{i2} plan.
- **Gilbert multiplier cell** is a modification of the emitter-coupled cell and the two-quadrant multiplier since modern communication applications employ four-quadrant operations.
- **Gilbert cell-DC analysis / Gilbert cell applications**
  The gilbert cell application depends on three (3) main conditions;
  - **a)** If V_1 **or** $V_2 < V_T$ **then :** $\tanh(V_{1,2} / 2V_T) \cong V_{1,2} / 2V_T$
  - **b)** 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, then it acts as a modulator.
  - **c)** If both inputs are large compared to V_T, then all six transistors in the circuit behave as non-saturating switches.
- **Gilbert cell as multiplier**
  The circuit performs an analog multiplication for small amplitude input signals, but when the input amplitude signal becomes larger, a non-linear approach is employed.
- **Pre-warping circuit-inverse hyperbolic tangent**
  Because of the non-linearity approach in converting large input signal, warping effect occurs on the signal. So a pre-warping circuit is employed in solving the problem (i.e bringing an inverse hyperbolic tangent to compensate for the hyperbolic tangent transfer characteristic)
- **Complete analog multipliers**

This is made up of 6 transistors (3 pairs) which forms the multiplier core, the differential voltage-to-current converters form the single-ended outputs.

- **Gilbert cell as a balanced modulator**
  The gilbert cell can be employed as a balanced-modulator in communications systems by applying a sufficiently large signal directly to cross-coupled pair.
- **Spectra for balanced modulator**
  Balanced modulation occurs were there are no output components at the carrier-frequency or it's harmonics.
- **Gilbert cell as a phase detector**
  The circuit acts as a phase detector when two identical unmodulated-frequency signals are applied at the input. So it gives the output as the phase difference of the two inputs.

SUMMARY OF PHASE LOCKED LOOP (PLL) CIRCUITS

In summary; a phase locked loop is a feedback system that is composed of a **VCO, phase detector, and low pass filter** within its loop. Its purpose is to force the VCO to replicate and track the frequency and phase at the input when in lock.

- **Phase detector:** compares the phase at each input and generates an error signal, $v_e(t)$, proportional to the phase difference between the two inputs. Since an analog circuit acts as a phase detector when two identical unmodulated-frequency signals are applied at the input, we can then say;

  $v_e(t) = A(t)B(t)$.

  If,

  $A(t) = A\cos(\omega_0 t + \varphi_A)$

  $B(t) = B\cos(\omega_0 t + \varphi_B)$

  Then, $A(t)B(t) = (AB/2)[\cos(2\omega_0 t + \varphi_A + \varphi_B) + \cos(\varphi_A - \varphi_B)]$

- **The VCO:** oscillates at an angular frequency. A high loop gain is beneficial for reducing phase errors.

- **Low pass filter:** This circuit attends to two main sources of noise.
  1. Reference noise – This is a low pass transfer function. Usually small since we frequently use a crystal oscillator.
  2. VCO noise – This is a high pass closed loop transfer function. Often high.

  We also take a look at some important parameters/circuits in the PLL circuit.
  a) PLL dynamic range
  b) Lock range
  c) Capture range
  d) Approach (to the type of transfer function employed)
  e) Phase frequency detector
  f) Charge pump filter
  g) Closed loop frequency response
  h) PLL phase noise
  i) Reference spurs