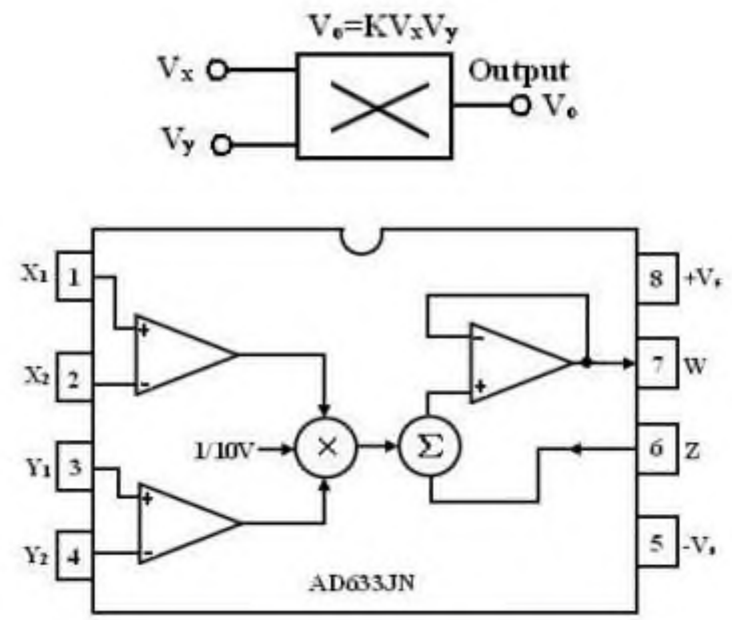
Analog Multiplier ICs

Analog multiplier is a circuit whose output voltage at any instant is proportional to the product of instantaneous value of two individual input voltages.Important applications of these multipliers are multiplication, division, squaring and square – rooting of signals, modulation and demodulation.These analog multipliers are available as integrated circuits consisting of op-amps and other circuit elements. The Schematic of a typical analog multiplier, namely, AD633 is shown in figure.



Multiplier IC and its symbol

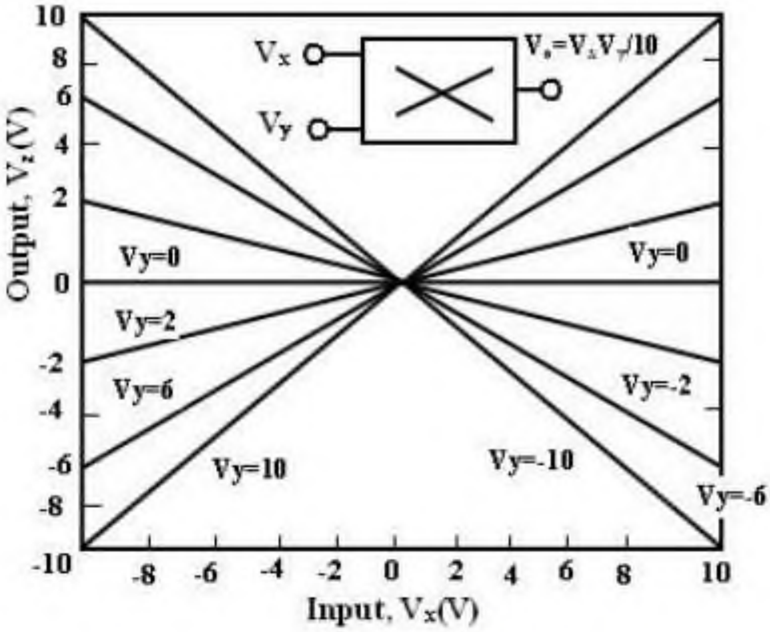
- The AD633 multiplier is a four – quadrant analog multiplier.
- It possesses high input impedance; this characteristic makes the loading effect on the signal source negligible.
- It can operate with supply voltages ranging from ±18V.
- IC does not require external components.
- The typical range of the two input signals is ±10V.

Schematic representation of a multiplier:

The schematic representation of an analog multiplier is shown in figure. The output V_0 is the product of the two inputs V_x and V_y is divided by a reference voltage V_{ref}. Normally, the reference voltage V_{ref} is internally set to 10V. Therefore, $V0 = V_xV_y/10$. In other words, the basic input – output relationship can be defined by $KV_x V_y$ when K = 1/10, a constant. Thus for peak input voltages of 10V, the peak magnitude of output voltage is 1/10 *10 *10 =10V. Thus, it can be noted that, as long as $V_x < 10V$ and $V_y < 10V$, the multiplier output will not saturate.

Multiplier quadrants:

The transfer characteristics of a typical four-quadrant multiplier are shown in figure. Both the inputs can be positive or negative to obtain the corresponding output as shown in the transfer characteristics.



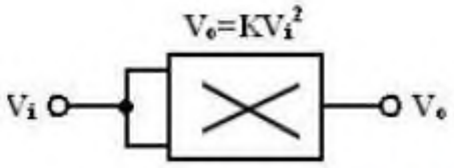
Transfer characteristics of a typical four-quadrant multiplier

Applications of Multiplier ICs:

The multiplier ICs are used for the following purposes:

1. Voltage Squarer
2. Frequency doublers
3. Voltage divider
4. Square rooter
5. Phase angle detector
6. Rectifier

Voltage Squarer:



voltage squarer circuit

Figure shows the multiplier IC connected as a squaring circuit. The inputs can be positive or negative, represented by any corresponding voltage level between 0 and 10V. The input voltage V_i to be squared is simply connected to both the input terminals, and hence we have, $V_x = V_y = V_i$ and the output is V0 = KVi2. The circuit thus performs the squaring operation. This application can be extended for frequency doubling applications.

Frequency doublers:

Figure shows the squaring circuit connected for frequency doubling operation. A sine-wave signal Vi has a peak amplitude of Av and frequency of f Hz. Then, the output voltage of the doublers circuit is given by

$$v_0 = \frac{A_v \sin 2\pi ft \cdot A_v \sin 2\pi ft}{10} = \frac{A_v^2}{10}\sin^2 2\pi ft = \frac{A_v^2}{20}(1 - \cos 4\pi ft)$$

Assuming a peak amplitude Av of 5V and frequency f of 10KHz, V0 =1.25–1.25cos2 π(20000) t. The first term represents the dc term of 1.25V peak amplitude. The input and output waveforms are shown in figure. The output waveforms ripple with twice the input frequency in the rectified output of the input signal. This forms the principle of application of analog multiplier as rectifier of ac signals.

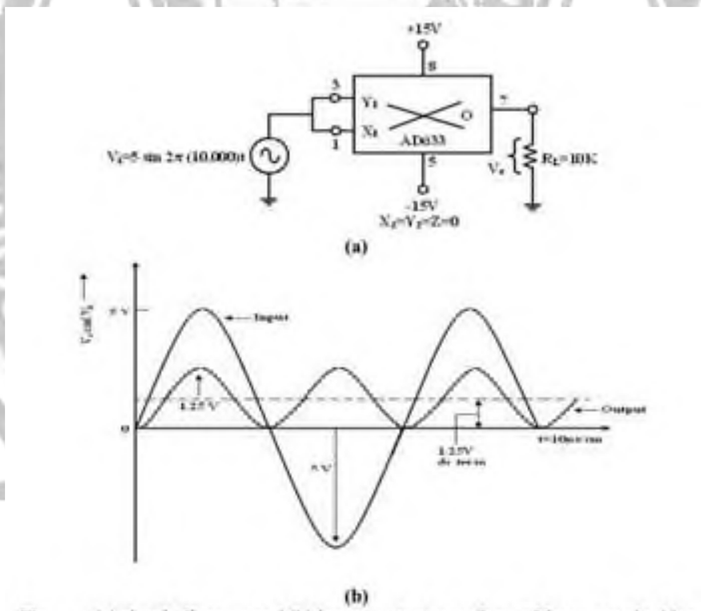


Fig. (a) circuit diagram and (b) input –output waveform of frequency doubler

The dc component of output V_0 can be removed by connecting a 1μF coupling capacitor between the output terminal and a load resistor, across which the output can be observed.

Voltage Divider:

In voltage divider circuit the division is achieved by connecting the multiplier in the feedback loop of an op-amp.The voltages V_{den} and V_{num} represent the two input voltages, Vdm forms one input of the multiplier, and output of op-amp VoA forms the second input.The output V_{OA} forms the second input. The output VOM of the multiplier is connected back of op- amp in the feedback loop. Then the characteristic operation of the multiplier gives

$$V_{om} = KV_{OA}\, Vdm \qquad (1)$$

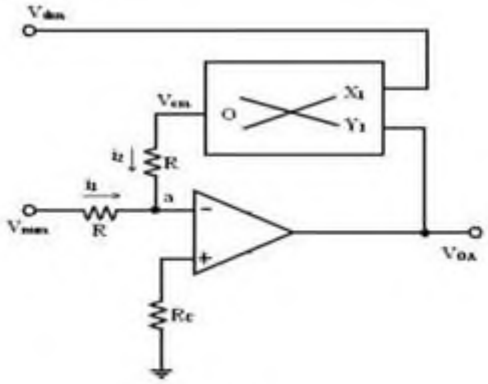


Fig divider circuit

As shown in figure, no input signal current can flow into the inverting input terminal of op-amp, which is at virtual ground. Therefore, at the junction a, $i_1 + i_2 = 0$, the current i1 = V_{num} / R, where R is the input resistance and the current $i_2 = V_{om}$ /R. With virtual ground existing at a,

$$i_1 + i_2 = V_{num} / R + V_{om} / R = 0$$

$$KV_{OA}\, V_{den} = -\, V_{num}$$

or

$$voA = -\, v_{num}/Kv_{den}$$

where V_{num} and V_{den} are the numerator and denominator voltages respectively. Therefore, the voltage division operation is achieved. V_{num} can be a positive or negative voltage and V_{den} can have only positive values to ensure negative feedback. When V_{dm} is changed, the gain $10/V_{dm}$ changes, and this feature is used in automatic gain control (AGC) circuits.

Square Rooter:

The divider voltage can be used to find the square root of a signal by connecting both inputs of the multiplier to the output of the op-amp. *Substituting* equal in magnitude but opposite in polarity (with respect to ground) to Vi. But we know that Vom is one- term (Scale factor) of V0 * V0 or

$$-V_i = V_{om} = V^2/1\ 0$$

Solving for V_0 and eliminating √-1 yields. V0 = √10|Vi |

Eqn. states that V_0 equals the square root of 10 times the absolute magnitude of V_i.The input voltage Vi must be negative, or else, the op-amp saturates.The range of Vi is between -1 and -10V. Voltages less than -1V will cause inaccuracies in the result.The diode prevents negative saturation for positive polarity Vi signals. For positive values of Vi the diode connections are reversed.

Phase Angle detector:

The multiplier configured for phase angle detection measurement is shown in figure. When two sine-waves of the same frequency are applied to the inputs of the multiplier, the output V0 has a dc component and an AC component.

The trigonometric identity shows that

Sin A sin B =1/2 (cos (A-B) – cos (A+B)).

When the two frequencies are equal, but with different phase angles, e.g. A=2πft +θ for signal Vx and B= 2πft for signal V_y, then using the identity

[sin (2 ft+)][sin2 ft)]=1/2[cos -cos(4 ft +)]

=1/2(dc- the double frequency term)

Therefore, when the two input signals V_x and V_y are applied to the multiplier, V_0 (dc) is given by

$$v_v(dc) = \frac{v_{xp} v_{yp}}{20} \cos\theta$$

where V_{xp} and V_{yp} are the peak voltage amplitudes of the signals V_x and V_y. Thus, the output V_0(dc) depends on the factor cos θ. A dc voltmeter can be calibrated as a phase angle meter when the product of V_{xp} and V_{yp} is made equal to 20. Then, a (0-1) V range dc voltmeter can directly read cos θ, with the meter calibrated directly in degrees from a cosine table. The input and output waveforms are shown in figure.

Then the above eqn becomes V_0 (dc) = cos θ, if we make the product V_{xp} V_{yp} = 20 or in other words, V_{xp} – V_{yp} = 4.47V.

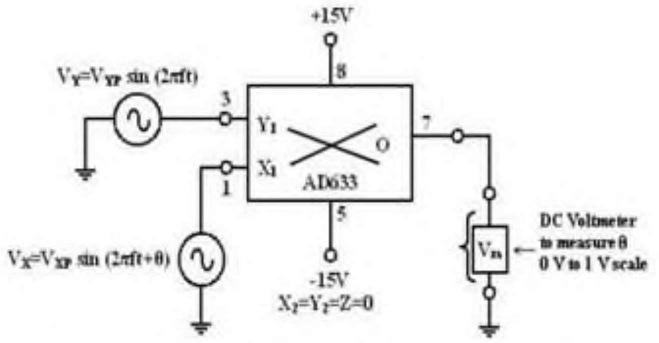
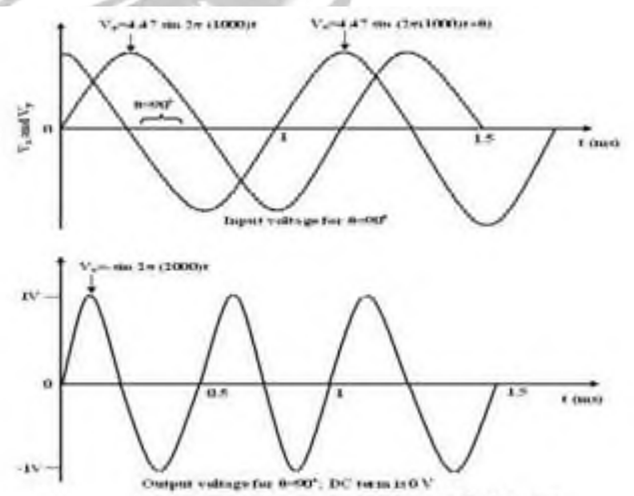


Fig . Phase angle measurement circuit diagram



input- output waveforms of phase angle detector

Analog Multipliers:

A multiple produces an output V0 which is proportional to the product of two inputs $V_x$and V_y.

$$V_0 = KV_xV_y$$

where K is the scaling factor = (1/10) V^{-1}.

There are various methods available for performing analog multiplication. Four of such techniques, namely,

1. Logarithmic summing technique
2. Pulse height/width modulation Technique
3. Variable trans conductance Technique
4. Multiplication using Gilbert cell and
5. Multiplication using variable trans conductance technique.

An actual multiplier has its output voltage V_0 defined by

$$V_0 = \frac{(V_x + \phi_x)(V_y + \phi_y)}{10(1+\varepsilon)} + \phi_0$$

where φx and φy are the offsets associated with signals Vx and Vy, ε is the error signal associated with K and φ0 is the offset voltage of the multiplier output.

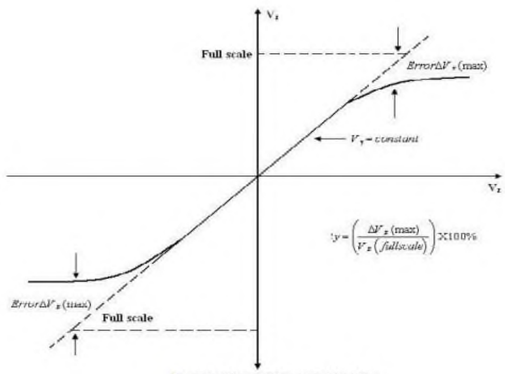
Terminologies associated voltage of the multiplier characteristics:

- Accuracy:

This specifies the derivation of the actual output from the ideal output, for any combination of X and Y inputs falling within the permissible operating range of the multiplier.

- Linearity:

This defines the accuracy of the multiplier. The Linearity Error can be defined as the maximum absolute derivation of the error surface. This linearity error imposes a lower limit on the multiplier accuracy.

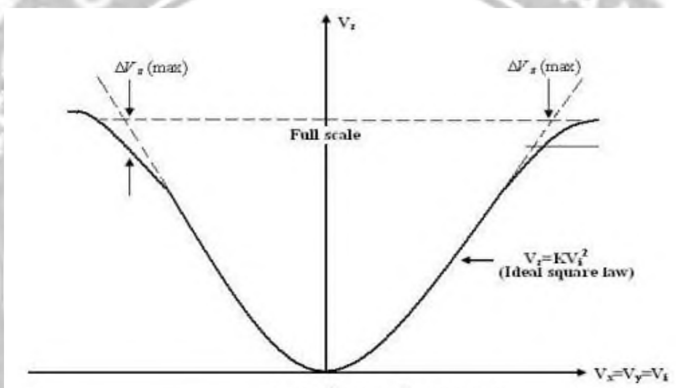


Linearity of the multiplier

The figure shows the response of the output as a function of one input voltage V_x when the other V_y is assumed constant. It represents the maximum percentage derivation from the ideal straight line output. An error surface is formed by plotting the output for different combinations of X and Y inputs.

- Square law accuracy:

The Square – law curve is obtained with the X and Y inputs connected together and applied with the same input signal. The maximum derivation of the output voltage from an ideal square –law curve expresses the squaring mode accuracy.



squaring mode accuracy

- Bandwidth:

The Bandwidth indicates the operating capability of an analog multiplier at higher frequency values. Small signal 3 dB bandwidth defines the frequency f0 at which the output reduces by 3dB from its low frequency value for a constant input voltage. This is identified individually for the X and Y input channels normally.

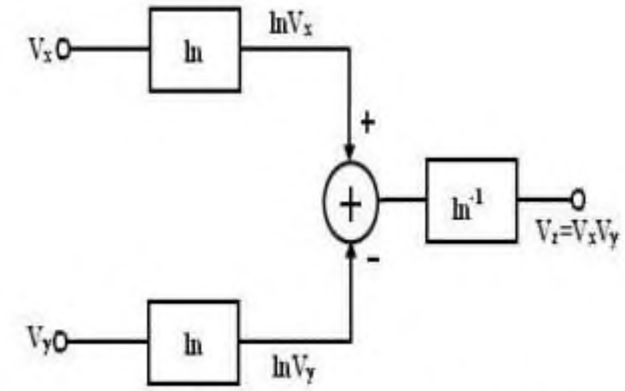
The transconductance bandwidth represents the frequency at which the transconductance of the multiplier drops by 3dB of its low frequency value. This characteristic defines the application frequency ranges when used for phase detection or AM detection.

- Quadrant:

The quadrant defines the applicability of the circuit for bipolar signals at its inputs. First – quadrant device accepts only positive input signals, the two quadrant device accepts one bipolar signal and one unipolar signal and the four quadrant device accepts two bipolar signals.

Logarithmic summing Technique:

This technique uses the relationship $\ln V_x + \ln V_y = \ln(V_x V_y)$



logarithmic summing method

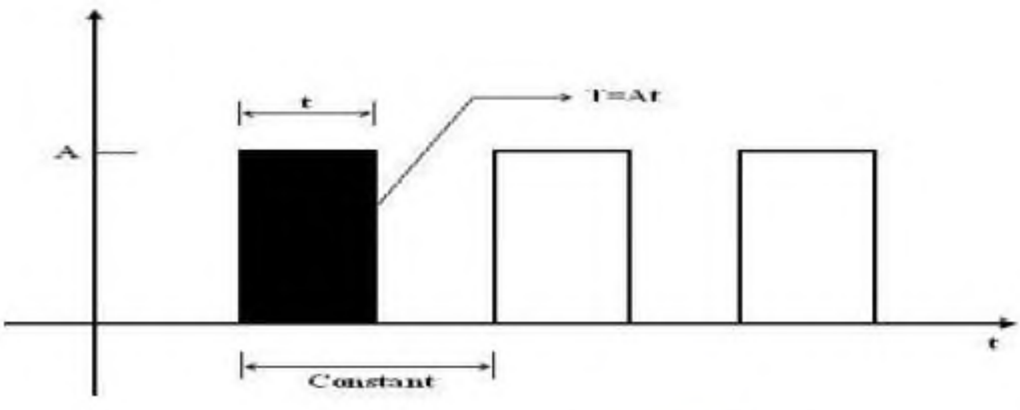
As shown in figure the input voltages V_x and V_y are converted to their logarithmic equivalent, which are then added together by a summer. An antilogarithmic converter produces the output voltage of the summer. The output is given by,

$$V_z = \ln^{-1}(\ln(V_x V_y)) = V_x V_y .$$

The relationship between I_0 and V_{BE} of the transistor is given by $I_C = I0e^{(VBE / VT)}$. It is found that the transistor follows the relationship very accurately in the range of 10nA to 100mA. Logarithmic multiplier has low accuracy and high temperature instability. This method is applicable only to positive values of V_x and V_y.

Limitation: this type of multiplier is restricted to one quadrant operation only.

Pulse Height/ Width Modulation Technique:



Pulse Height/ Width Modulation Technique

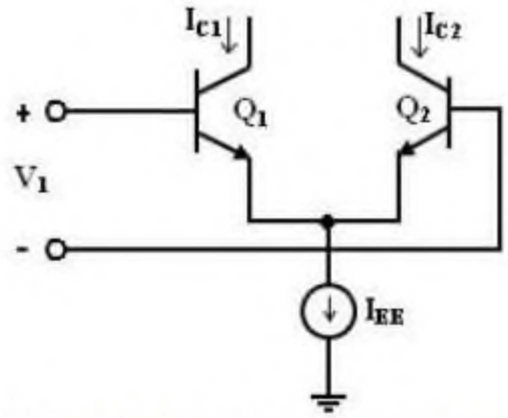
In this method, the pulse width of a pulse train is made proportional to one input voltage and the pulse amplitude is made proportional to the second input voltage. Therefore, $V_x=K_x A$, $V_y = K_y t$, and $V_z = K_z T$ where K_x, K_y, K_z are scaling factors. In figure A is the amplitude of the pulse, t is the pulse width and T is the area of=the pulse=. Therefore,

$$V_z = K_z T = \frac{V_x V_y}{k_x k_y}$$

The modulated pulse train is passed through an integrated circuit. Therefore, the input of the integrator is proportional to the area of pulse, which in turn is proportional to the product of two input voltages.

Analog multiplier using an Emitter coupled Transistor pair:

The output currents I_{C1} an d I_{C2} are related to the differential input voltage V_1 by



multiplier circuit using an emitter coupled pair

$$I_{C1} = \frac{I_{EE}}{1+e^{-V_1/V_T}}$$

$$I_{C2} = \frac{I_{EE}}{1+e^{V_1/V_T}}$$

where V_T is thermal voltage and the base currents have been neglected. Combining above eqn., difference between=the two output currents as

$$\Delta I_C = I_{C1} - I_{C2}$$

$$= I_{EE}\left(\frac{1}{1+e^{-V_1/V_T}} - \frac{1}{1+e^{-V_1/V_T}}\right)$$

$$= I_{EE}\tanh\left(\frac{V_1}{2V_T}\right)$$

The dc transfer characteristics of the emitter – coupled pair is shown in figure. It shows that the emitter coupled pair can be used as a simple multiplier using this configuration. When the differential input voltage $V_1 << V_T$, we can appropriate as given by

$$I_{EE}\tanh\left(\frac{V_1}{2V_T}\right) = I_{EE}\left(\frac{V_1}{2V_T}\right)$$

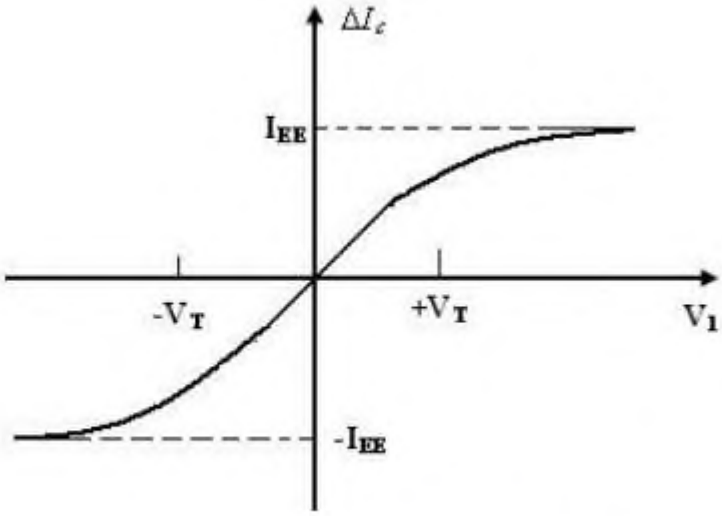
Then the equa becomes

$$\Delta I_C = I_{EE} \left(\frac{V_1}{2V_T}\right)$$

The current I_{EE} is the bias current for the emitter – coupled pair. If the current I_{EE} is made proportional to a second input signal V_2, then

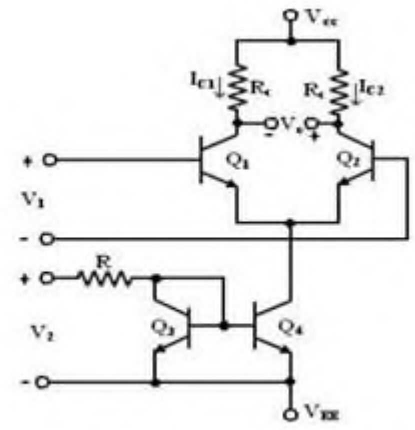
$$I_{EE} = K_0 (V_2 - V_{BE(on)})$$

Substituting above eqn. , we get $\Delta I_C = K_0 V_1 (V_2 - V_{BE(on)})/2V_T$



DC Transfer characteristics of emitter coupled pair

This arrangement is shown in figure. It is a simple modulator circuit constructed using a differential amplifier. It can be used as a multiplier, provided V_1 is small and much less than 50mV and V_2 is greater than V_{BE} (on). But, the multiplier circuit shown in figure has several limitations. The first limitation is that V_2 is offset by V_{BE} (on).



A simple modulator using a differential amplifier

The second is that V_2 must always be positive which results in only a two-quadrant multiplier operation. The third limitation is that, the tanh (X) is approximately as X, where X = V_1 /2VT. The first two limitations are overcome in the Gilbert cell.