LOGARITHMIC AMPLIFIER

In the case of a diode

$I = I_o\left(e^{\frac{V}{\eta V_T}} - 1\right)$. It is the diode current equation.

I_o = Reverse saturation current.

η = constant, 1 for Ge and 2 for Si.

V_T = Volt eq of temperature $\frac{KT}{e}$.

V = Applied forward bias Voltage

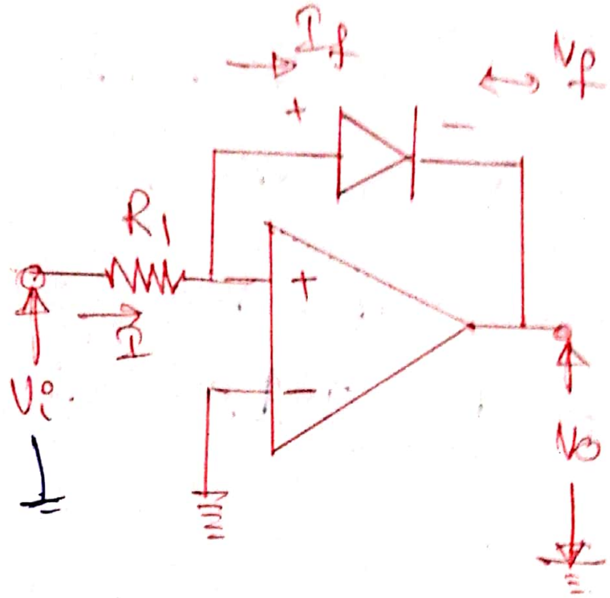
If V is large. $e^{\frac{V}{\eta V_T}} >> 1$

So $I = I_o \cdot e^{\frac{V}{\eta V_T}}$.

$\ln I = \ln I_o + \frac{V}{\eta V_T}$

$$\boxed{\therefore \quad V = \eta V_T \left[\ln I - \ln I_o\right]}$$

If temperature T is constant, η, V_T and I_o will be constants. If the diode is connected in feedback path of the op-amp, the o/p voltage will be a logarithmic function of the i/p voltage.



The non-inverting terminal is grounded. So, the inverting terminal will be at the virtual ground point.
Therefore all the input current I flows through the diode.

$$I = I_f$$

$$I = \frac{V_i}{R_1} = I_f.$$

I_f and V_f are related by the diode equation, $V_f = V_o$.

$$V_f = \eta V_T (\ln I - \ln I_o)$$

$$V_f = \eta V_T\left[\ln \frac{V_i}{R_1} - \ln I_o\right]$$

$$V_o = -V_f.$$

Hence $V_o \propto \ln(V_i)$.

because of feedback current $I = I_f$.

If changes exponentially with V.

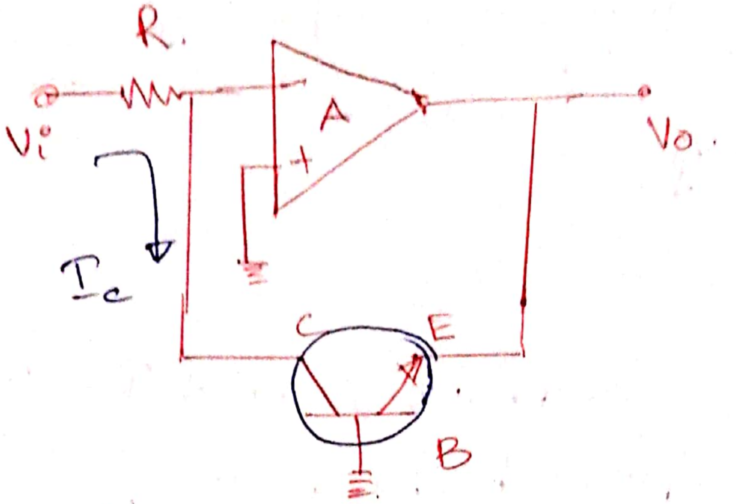
If T change, then Io will change and V_T will change.. So the logarithmic variation of Vo with Vi is valid at constant T.

these are used in logarithmic voltmeter to measure voltage from 0V to 1000V on a log scale (with a single scale).

However in the case of diode, the log relation voltage and current in not valid over a very wide range due to finite resistance in the diode.

So in practice, instead of a diode a transistor is used.

If a transistor is operated with V_c, I_c and V_{BE}, they can be related in the form



$$V_{BE} = K \cdot \ln I_c.$$

where k is constant, $K \propto T$

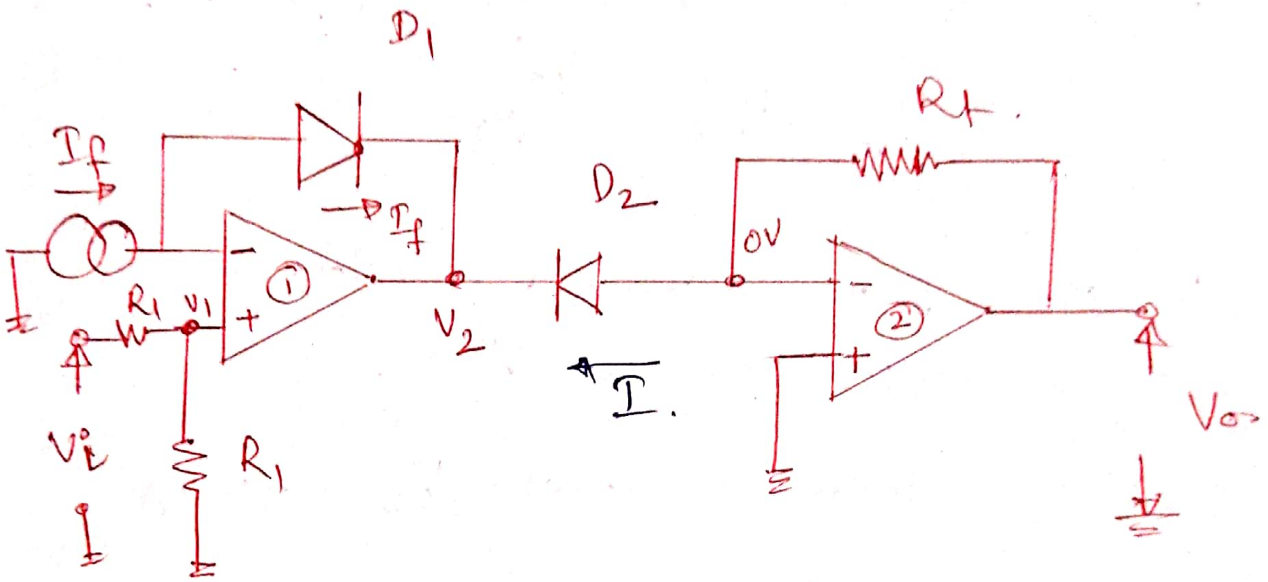
collector is at virtual ground point (Inverting terminal is at 0V). Base is grounded. Therefore $V_{CB} \simeq 0$.

$$V_i = I_c R.$$

$$V_o = V_{BE}$$

$$\boxed{\text{So} \quad V_o = k \ln\left[\frac{V_i}{R}\right]}$$

AntiLOGARITHMIC AMPLIFIER



Voltage V_1 at the non-inverting terminal of op-amp (1) is

$$V_1 = \frac{V_i R_2}{R_1 + R_2}$$

op-amp(1) is being used as differential amplifier $V_A \mp V_1$ because the I_f source is connected to the inverting terminal. If R is connected $V_A = V_1$. Voltage V_2 at the output of op-amp (1) is the difference of the voltages at the inverting and non-inverting terminals.

when the Diode D_1 in forward biased, feed back path in a short - circuit terminals.

therefore gain = 1 $V_2 = V_1 - V_A$.

V_A is not a virtual ground point.

$$So\ I_f = I_o \cdot e^{\frac{V_o}{\eta V_T}}$$

Diode is forward baised, so it is in closed - loop configuration.

Since diode is short $V_2 = V_1 - V_A$

The Voltage across the diode D_1 is the output of op-amp 1.

It is V_2.

Expression for V_2 is $\eta V_T \left[\ln(I_f) - \ln(I_o)\right]$

The cathode of D_1 need not be grounded.

I_f is the current that flows due to potential difference $(V_A - V_2)$

$$V_2 = \frac{V_i R_2}{R_1 + R_2} - \eta V_T \left[\ln I_f - \ln I_o\right]$$

$$V_2 = V_1 - V_A.$$

$$I = I_0\left(e^{-\frac{V_2}{\eta V_T}} - 1\right)$$

$$V_2 = -\eta V_T\left[\ln I - \ln I_0\right]$$

Voltage across the diode D_2 is.

$$V_2 = -\eta V_T\left[\ln I - \ln I_0\right]$$

D_2 is Reverse biased.

Voltage across diode D_2 is negative because the anode is at 0V and cathode is at -ve potential.

Therefor eq ② is in term of I_f and I.

From eq ②

$$V_2 = \frac{V_i R_2}{R_1+R_2} - \eta V_T\left[\ln I_f - I_0\right]$$

$$-\eta V_T\left[\ln I - \ln I_0\right] = \frac{V_i R_2}{R_1+R_2} - \eta V_T\left[\ln I_f - I_0\right]$$

$$V_i\left(\frac{R_2}{R_1+R_2}\right) = \eta V_T\left[\ln I_f - \ln I_0\right] - \eta V_T\left[\ln I - \ln I_0\right]$$

$$= \eta V_T\left[\ln \frac{I_f}{I}\right]$$

$I_f \neq I$ because the voltage across D_1 is $(V_2 - V_n)$. Voltage across D_2 is $-V_2$. current I through a diode follows exponential relation. R of a diode changes according to the current flowing through it.

output voltage V_o at op-amp (2) is

$$V_o = I R_f$$

R_f = feedback resistor.

$$I = \frac{V_o}{R_f}.$$

$$V_i * \frac{R_2}{R_1+R_2} = \eta \cdot V_T \ln \frac{I_f R_f}{V_o}$$

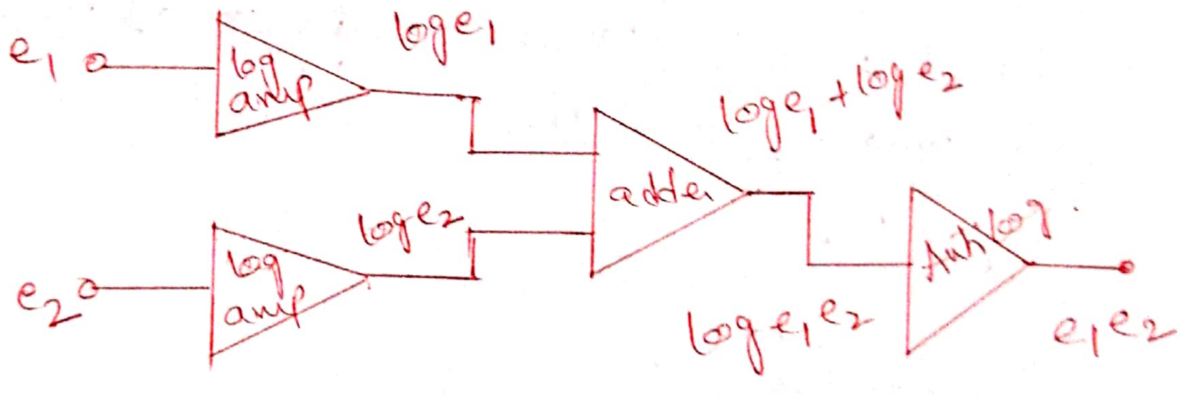
or $$-V_i \frac{R_2}{R_1+R_2} = \eta V_T \ln \frac{V_o}{I_f R_f}.$$

$$\boxed{V_o = I_f R_f \ln^{-1}\left[-V_i \cdot \frac{R_2}{(R_1+R_2)\eta V_T}\right]}$$

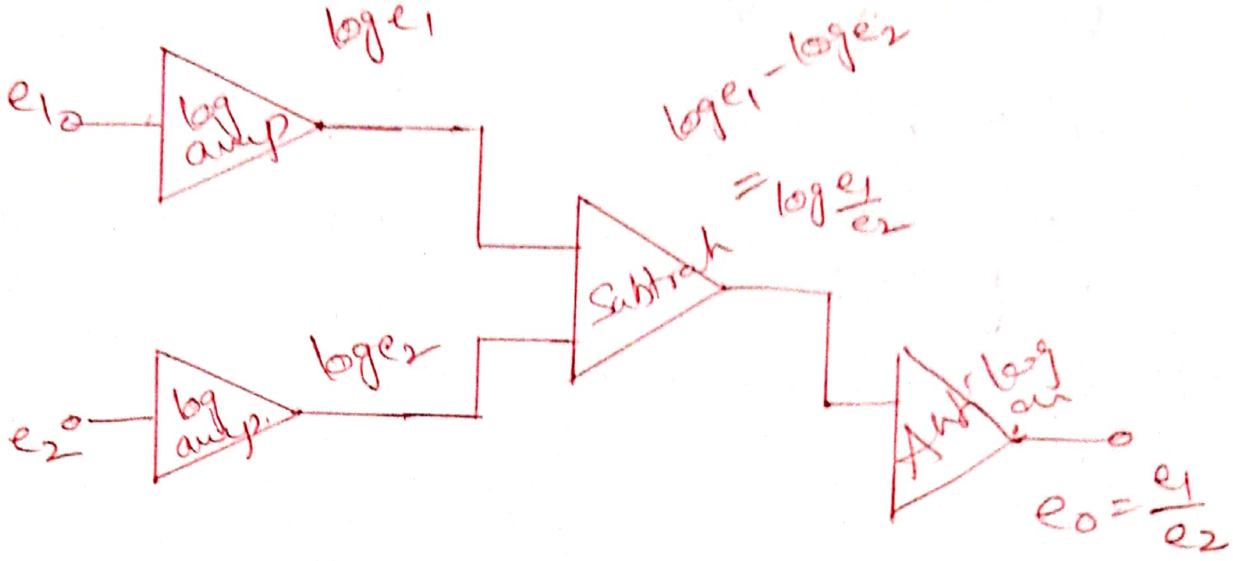
D_2 is forward biased. The anode of D_2 is at 0V.
Therefore, the cathode is at -ve potential.

Log and antilog amplifiers are used in analog computers and instrumental systems.

Log multipliers



Log multiplier circuit.



log Divider circuit.

Log multiplier.

The o/p e_o is the product of the input e_1 and e_2 can be DC Voltages or AC signals.

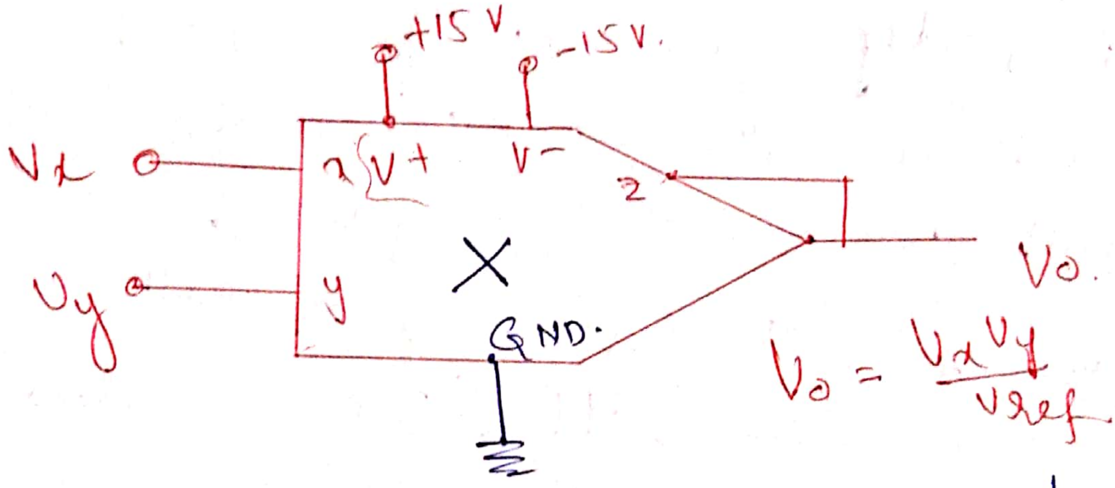
~~log Divider~~

~~The o/p e_o is the~~

There are a number of applications of analog multiplier such as

* Frequency doubling
* Freq shifting
* phase angle detection
* Real power computation
* Multiplying two signals, dividing and squaring of signal

A basic multiplier schematic symbol is shown in fig.



The o/p is the product of the two i/ps. divided by a reference voltage. Vref.

$$V_o = \frac{V_x V_y}{V_{ref}}.$$

Normally V_{ref} is ~~set~~ to 10V. So.

$$V_o = \frac{V_x V_y}{10}.$$

As long as

$$V_x < V_{ref}$$
$$V_y < V_{ref}$$

The output of the multiplier will not saturate.

If both I/ps are positive, the IC is said to be one quadrant multiplier.

→ A two quadrant multiplier will function properly if one I/p is held positive and the other is allowed to swing both positive and negative.

→ If both I/p may be either positive or negative, the IC is called a four quadrant multiplier.

There can be several ways to make a ckt which will multiply according to eq $V_o = \frac{V_x V_y}{V_{ref}}$.

One commonly used technique is log- antilog method.

This log-antilog method relies on the mathematical relationship that the sum of the logarithm of two numbers equals the logarithm of the product of those numbers.

$$\log V_x + \ln V_y = \ln (V_x V_y)$$

The block dia of a log-antilog multiplier Ic.

Log-amps Require the I/p and Referen voltages to be the same polarity.

This restricts log-antilog multiplier to one quadrant operation.

A technique that provide four quadrant multiplication is transconduct multiplier.

Some of the multiplier Ic chips available are AD533 and AD534.

Application of multiplier Ic

Frequency Doubling.

The multiplication of two sine wave of the same frequency, but of possibly different amplitudes and phases allows to double a freq and to directly measure real power.

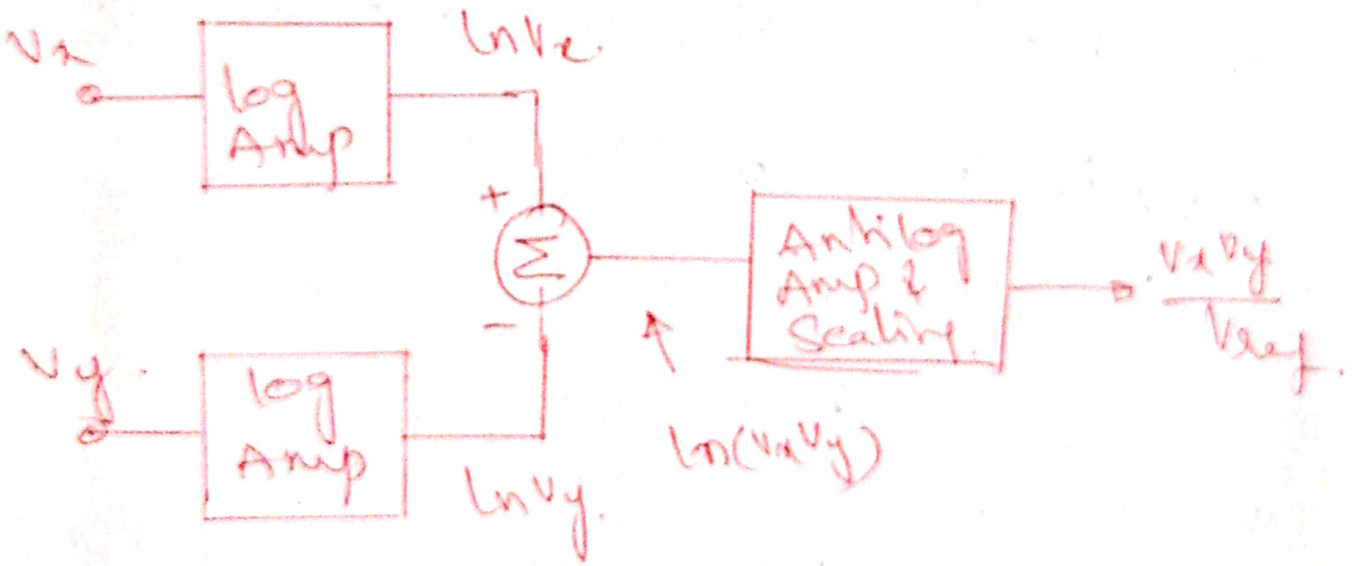
Let $V_x = V_x \sin \omega t$.

$V_y = V_y \sin(\omega t + \theta)$

where θ is the phase difference between the two signals.

Applying these two signals to the i/ps of a four quadrant multiplier will yield an o/p of

$$V_o = \frac{V_x \sin\omega t \cdot V_y \sin(\omega t + \theta)}{V_{ref}}$$



$$V_o = \frac{V_x V_y}{V_{ref}} \sin\omega t \left(\sin\omega t \cos\theta + \sin\theta \cos\omega t\right)$$

$$= \frac{V_x V_y}{V_{ref}} \left(\sin^2\omega t \cos\theta + \sin\theta \sin\omega t \cos\omega t\right)$$

$$\sin^2 a = 1 - \cos^2 a.$$

and

$$\cancel{\cos^2 a = 2\cos^2 A \ eq}$$

$$\cos 2A = 2\cos^2 A - 1$$

$$\cos^2 \alpha = \frac{1}{2} + \frac{1}{2}\cos 2\alpha.$$

$$\sin^2 \alpha = 1 - \frac{1}{2} - \frac{1}{2}\cos 2\alpha.$$

$$= \frac{1}{2} - \frac{1}{2}\cos 2a.$$

$$\therefore V_o = \frac{V_x V_y}{V_{ref}}\left[\cos\theta\left(\frac{1}{2} - \frac{1}{2}\cos 2\omega t\right) + \sin\theta \sin\omega t \cos\omega t\right]$$

But $\sin a \cos a = \frac{1}{2}\sin 2a$

$$\therefore V_o = \frac{V_x V_y}{2V_{ref}}\left(\cos\theta - \cos\theta\cos 2\omega t + \sin\theta \sin 2\omega t\right)$$

$$V_o = \frac{V_x V_y}{2V_{ref}}\cos\theta + \frac{V_x V_y}{2V_{ref}}\left(\sin\theta\sin 2\omega t - \cos\theta\cos 2\omega t\right)$$

The first term is a DC and is fixed (16)
by the magnitude of the signals
and their phase differen
The second term Varies with time,
but at twice the freq of the
i/p (2ω).