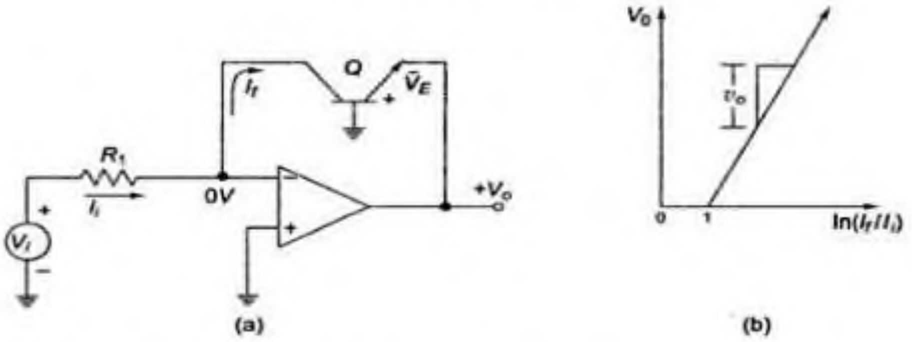
Log Amplifier:

$$V_o = V_i ln\left(I_f / I_i\right)$$



Fundamental log-amp Circuit and its characteristics

There are several applications of log and antilog amplifiers.
Antilog computation may require functions such as ln x, log x or sin hx.

Uses:

- Direct dB display on a digital Voltmeter and Spectrum analyzer.
- Log-amp can also be used to compress the dynamic range of a signal.

A grounded base transistor is placed in the feedback path. Since the collector is placed in the feedback path. Since the collector is held at virtual ground and the base is also grounded, the transistor‘s= voltage[-current−1] relationship becomes that of a diode and is given by,

$$I_E = I_s[e^{\frac{qV_{BE}}{kT}} - 1]$$

and since $I_c = I_E$ for a grounded base transistor $I_C = I_s\, e^{kT}$
Is-emitter saturation current $\approx 10^{-13}$A
k=Boltzmann‘s constant
T=absolute temperature (in°K)

$$V_o = -\frac{kT}{q} ln\left(\frac{V_i}{R_1 I_S}\right) = -\frac{kT}{q} ln\left(\frac{V_i}{V_R}\right)$$

where $V_{ref} = R_1 I_s$
The output voltage is thus proportional to the logarithm of input voltage.
Although the circuit gives natural log (ln), one can find log10, by proper scaling
Log10X=0.4343 ln X
The circuit has one problem.

The emitter saturation current Is varies from transistor to transistor and with temperature. Thus a stable reference voltage V ref cannot be obtained. This is eliminated by the circuit given below

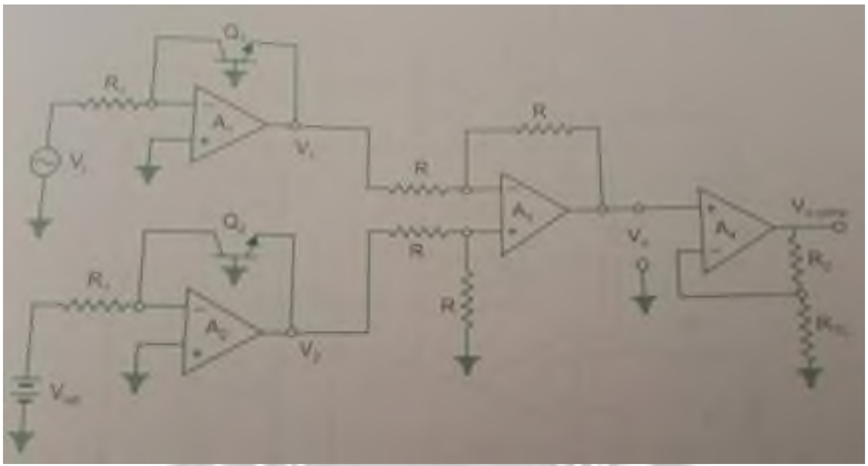


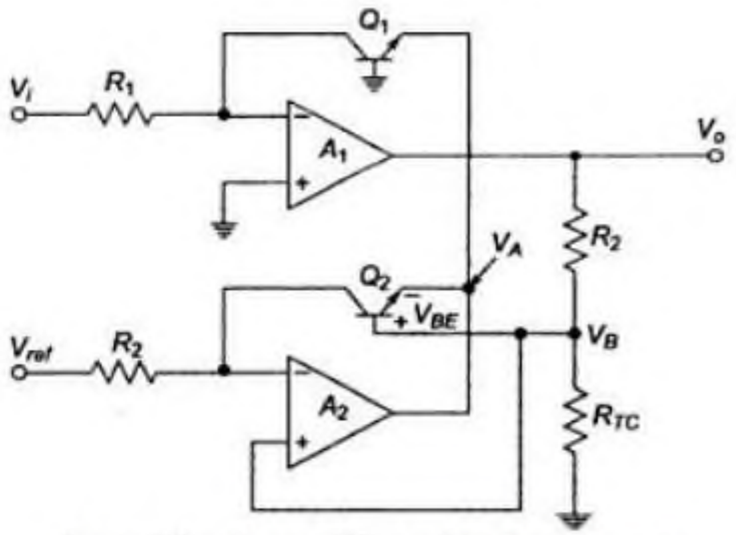
Fig: Log-amp with saturation current and temperature compensation

The input is applied to one log-amp, while a reference voltage is applied to one log-amp, while a reference voltage is applied to another log-amp. The two transistors are integrated close together in the same silicon wafer. This provides a close match of saturation currents and ensures good thermal tracking.

Assume $I_{S1}=I_{S2}=I_S$

Thus the reference level is now set with a single external voltage source. Its dependence on device and temperature has been removed. The voltage Vo is still dependent upon temperature and is directly proportional to T. This is compensated by the last op-amp stage A4 which provides a non-inverting gain of $(1+R_2/R_{TC})$. Temperature compensated output voltage V_L

$$V_L = \left(1 + \frac{R_2}{R_{TC}}\right)\frac{kT}{q} ln\left(\frac{V_i}{V_R}\right)$$

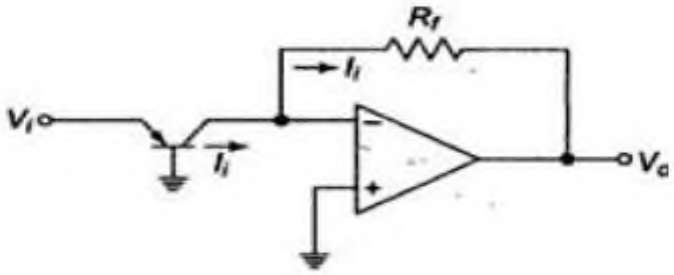


Logarithmic amplifier using two op amps

Where R_{TC} is a temperature-sensitive resistance with a positive coefficient of temperature (sensor) so that the slope of the equation becomes constant as the temperature changes.

Antilog Amplifier

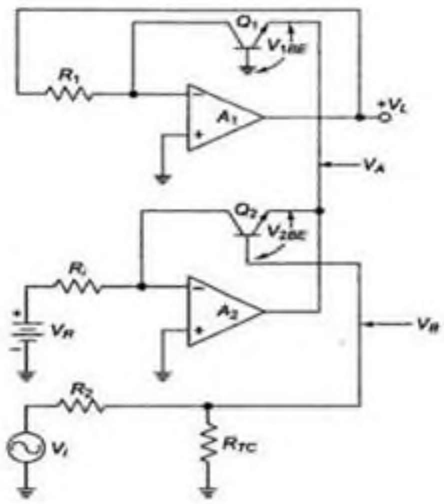
`A circuit to convert logarithmically encoded signal to real signals. Transistor in inverting input converts input voltage into logarithmically varying currents.



Antilog amplifier

$$I_i = I_c = I_s(e^{\frac{\eta V_{BE}}{kT}}) \text{ and } V_0 = R_f\, I_s(e^{\frac{\eta V_{BE}}{kT}})$$

The circuit is shown in figure below. The input Vi for the antilog-amp is fed into the temperature compensating voltage divider R_2 and R_{TC} and then to the base of Q_2. The output of A2 is fed back to R_1 at the inverting input of op amp A_1. The non-inverting inputs are grounded



Antilog amplifier

$V_{1BE} = \frac{kT}{q}\ln[\frac{V_L}{R_1 I_s}]$ and $V_{2BE} = \frac{kT}{q}\ln[\frac{V_B}{R_1 I_s}]$ and $V_A = -V_{1BE}$ and $V_B = R_{TC}/(R_2+R_{TC})\, V_i$

$V_{Q2E} = V_B + V_{2BE} = R_{TC}/(R_2+R_{TC})\, V_i - \frac{kT}{q}\ln[\frac{V_B}{R_1 I_s}]$

$V_{Q2E} = V_A$

Therefore, $$-\frac{kT}{q}ln\left(\frac{V_L}{R_1I_S}\right)=\frac{R_{TC}}{R_2+R_{TC}}V_i+\frac{kT}{q}ln\left(\frac{V_R}{R_1I_S}\right)$$

Rearranging, we get

$$\frac{R_{TC}}{R_2+R_{TC}}V_i=-\frac{kT}{q}ln\left(\frac{V_L}{R_1I_S}\right)-\frac{kT}{q}ln\left(\frac{V_R}{R_1I_S}\right)$$

$$=-\frac{kT}{q}ln\left(\frac{V_L}{V_R}\right)$$

We know that $\log_{10} x = 0.4343\, ln\, x$.

Therefore, $$-0.4343\left(\frac{q}{kT}\right)\left(\frac{R_{TC}}{R_2+R_{TC}}\right)V_i=0.4343\, ln\left(\frac{V_L}{V_R}\right)$$

$$-0.4343\left(\frac{q}{kT}\right)\left(\frac{R_{TC}}{R_2+R_{TC}}\right)V_i=\log_{10}\left(\frac{V_L}{V_R}\right)$$

$$-KV_i=\log\left(\frac{V_L}{V_R}\right)$$

$$K=0.4343\left(\frac{q}{kT}\right)\left(\frac{R_{TC}}{R_2+R_{TC}}\right)$$

$$V_L=V_R10^{-KV_i}$$

The output V_o of the antilog- amp is fed back to the inverting input of A_1 through the resistor R_1.Hence an increase of input by one volt causes the output to decrease by a decade.

Phase Shift Circuits

The phase shift circuits produce phase shifts that depend on the frequency and maintain a constant gain. These circuits are also called constant-delay filters or all-pass filters. That constant delay refers to the fact the time difference between input and output remains constant when frequency is changed over a range of operating frequencies.

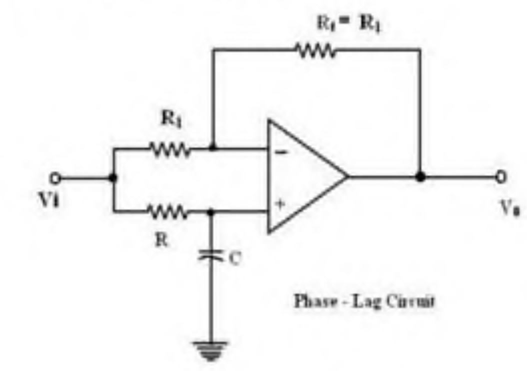
This is called all-pass because normally a constant gain is maintained for all the frequencies within the operating range. The two types of circuits, for lagging phase angles and leading phase angles.

Phase-lag circuit:

Phase log circuit is constructed using an op-amp, connected in both inverting and non inverting modes. To analyze the circuit operation, it is assumed that the input voltage v1 drives a simple inverting amplifier with inverting input applied at(-)terminal of op-amp and a non inverting amplifier with a low-pass filter.

It is also assumed that inverting gain is -1 and non-inverting gain after the low-pass circuit is

$1+\frac{R_f}{R_1}=1+1=2$ Since $R_f=R_1$.



Phase lag circuit

Analysis:

$$From\ branch\ C,\ V_B=\frac{1}{C}\int I_1\,dt$$

$using\ Laplace\ Transform$

$$V_B(s)=\frac{1}{sC}I_1(s)----(1)$$

$$From\ branch\ R\ \ I_1(s)=\frac{V_i(s)-V_B(s)}{R}----(2)$$

(2) (1) ,

$$V_B(s)=\frac{V_i(s)}{1+sRC}$$

$$From\ Branch\ R_1, I_2(s)=\frac{V_i(s)-V_B(s)}{R_1}=\frac{V_i(s)-V_A(s)}{R_1}$$

$$From\ Branch\ R_f, I_2(s)=\frac{V_A(s)-V_o(s)}{R_f}=\frac{V_B(s)-V_o(s)}{R_f}$$

$$Simplyfing\ we\ get,\frac{V_o(s)}{V_i(s)}=\frac{1-SCR}{1+SCR}$$

$$Sub\ S=j\omega$$

$$\frac{V_o(j\omega)}{V_i(j\omega)} = \frac{1 - j\omega CR}{1 + j\omega CR}$$

$$Magnitude = 1 \; hence \; |V_o| = |V_{in}|$$

$$Phase \; \theta = -\tan^{-1}(\omega RC) - \tan^{-1}(\omega RC)$$

$$\theta = -2\tan^{-1}(\omega RC)$$

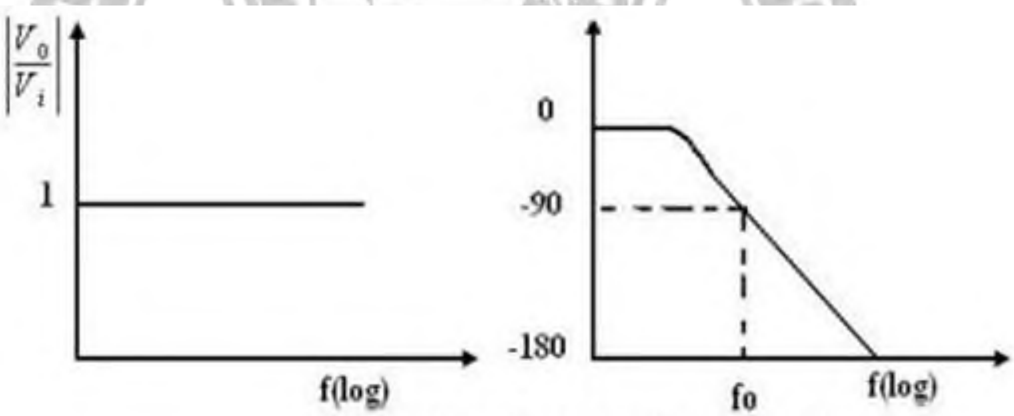
$Case \; (i) \; \omega = 0 \; then \; \theta = 0$

$Case \; (ii) \; \omega = \infty \; then \; \theta = -180°$

$$\theta = -2\tan^{-1}(2\pi fRC)$$

$$\theta = -2\tan^{-1}\left(\frac{f}{f_0}\right)$$

$$f_0 = \frac{1}{2\pi RC}$$



Bode plot of phase lag circuit

The relationship is complex as defined above equation and it shows that it has both magnitude and phase. Since the numerator and denominator are complex conjugates, their magnitudes are identical and the overall phase angle equals the angle of numerator less the angle of the denominator.

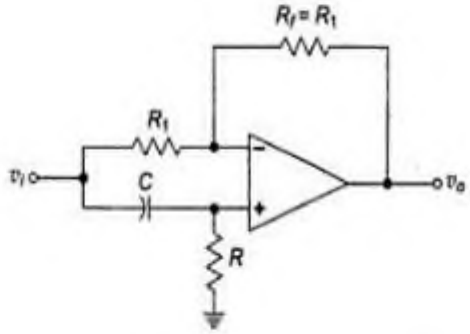
Phase-lead circuit:

The phase-lead circuit is in which the RC circuit forms a high pass network. The output voltage is expressed as.

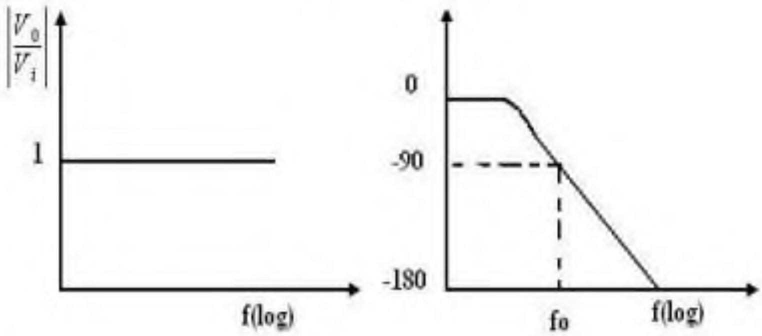
$$\theta = -2\ \tan^{-1} RC\omega$$

$$\frac{V_O(jw)}{V_i(jw)} = -\frac{(1 - jwRC)}{(1 + jwRC)}$$

$$\theta = 180° - 2\ \tan^{-1} RC\omega$$



Phase lead circuit



Bode plot of Phase lead circuit