LOG AND ANTILOG AMPLIFIER

Prepared By:
Amit Degada

Introduction

- Log and Antilog Amplifiers are non-linear circuits in which the output voltage is proportional to the logarithm (or exponent) of the input.

- It is well known that some processes such as multiplication and division, can be performed by addition and subtraction of logs.

- They have numerous applications in electronics, such as:
  - Multiplication and division,
  - Powers and roots
  - Compression and Decompression
  - True RMS detection
  - Process control

Two basic circuits

- There are two basic circuits for logarithmic amplifiers
  - transdiode and
  - diode connected transistor
- Most logarithmic amplifiers are based on the inherent logarithmic relationship between the collector current, I_c, *and* the base-emitter voltage, $\mathbf{v_{be}}$, in silicon bipolar transistors.

Two basic circuits

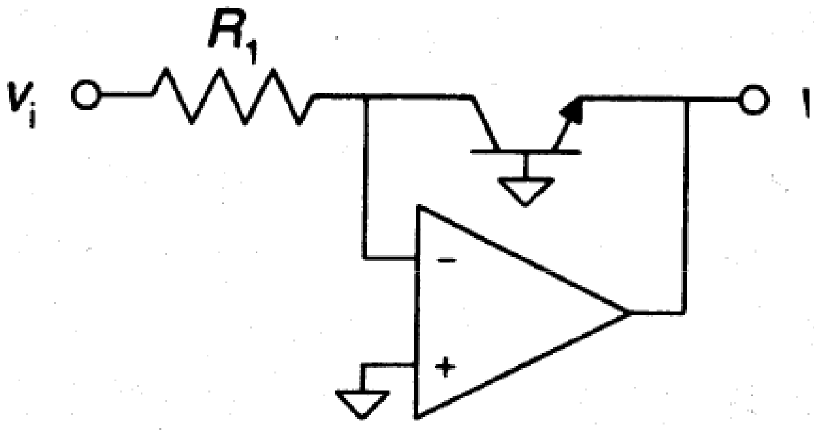


Fig: Transdiode Log Amplifier

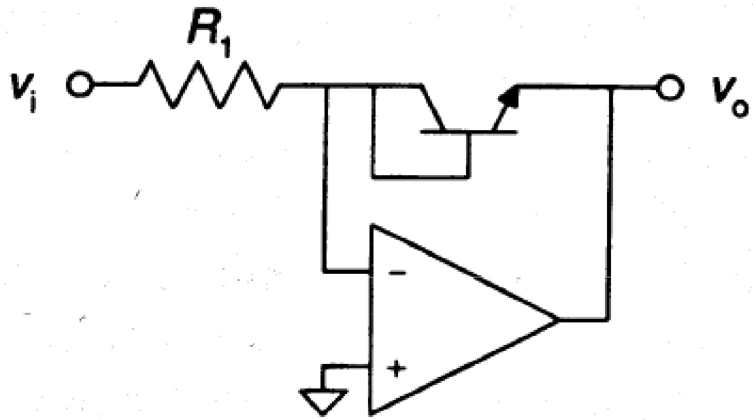


Fig: Diode coected Resistor Log Amplifier

Transdiode Log Amplifier

The input voltage is converted by *R1* into a current, which then flows through the transistor's collector modulating the base-emitter voltage according to the input voltage.

- The opamp forces the collector voltage to that at the noninverting input, 0 V
- From Ebers-Moll model the collector current is

$$I_c = I_s(e^{qVbe/kT} - 1) = I_s(e^{Vbe/V_T} - 1) \approx I_s \cdot e^{Vbe/V_T}$$

- where I_s is saturation current, q is the charge of the electron $1.6\mathrm{x}10^{-9}$ Coulombs, k is the Boltsman's constant $1.38\mathrm{x}10^{-23}$ Joules, T is absolute temperature, V_T is thermal voltage.
- For room temperature 300ºK

$$I_c = I_s(e^{38.6Vbe} - 1) \approx I_s \cdot e^{38.6Vbe}$$

- The output voltage is therefore

$$Vout = -Vbe = -V_T \ln\left(\frac{i_C}{I_S}\right) = -\frac{V_T}{2.3}\lg\left(\frac{v_i}{R_1 I_S}\right) = \left(-0.0259 \cdot \ln\frac{Vin}{Ri \cdot Is}\right)$$

Thermal and Frequency stability

- This equation yields the desired logarithmic relationship over a wide range of currents, but is temperature-sensitive because of $\boldsymbol{V_T}$ and $\boldsymbol{I_S}$ resulting in scale-factor and offset temperature-dependent errors.
- The system bandwidth is narrower for small signals because emitter resistance increases for small currents.
- The source impedance of voltage signals applied to the circuit must be small compared to R1. Omitting R1 yields a current-input log amp.
- Using a *p-n-p* transistor changes the polarity of input signals acceptable but limits the logarithmic range because of the degraded performance *of p-n-p* transistors compared to *n-p-n* transistors

IC Log Amps

- These basic circuits needs additional components to improove the overall performance, i.e:
  - to provide base-emitter junction protection,
  - to reduce temperature effects,
  - bulk resistance error and op amp offset errors,
  - to accept bipolar input voltages or currents,
  - and to ensure frequency stability.

Note:
(FYI: For your Information Only)

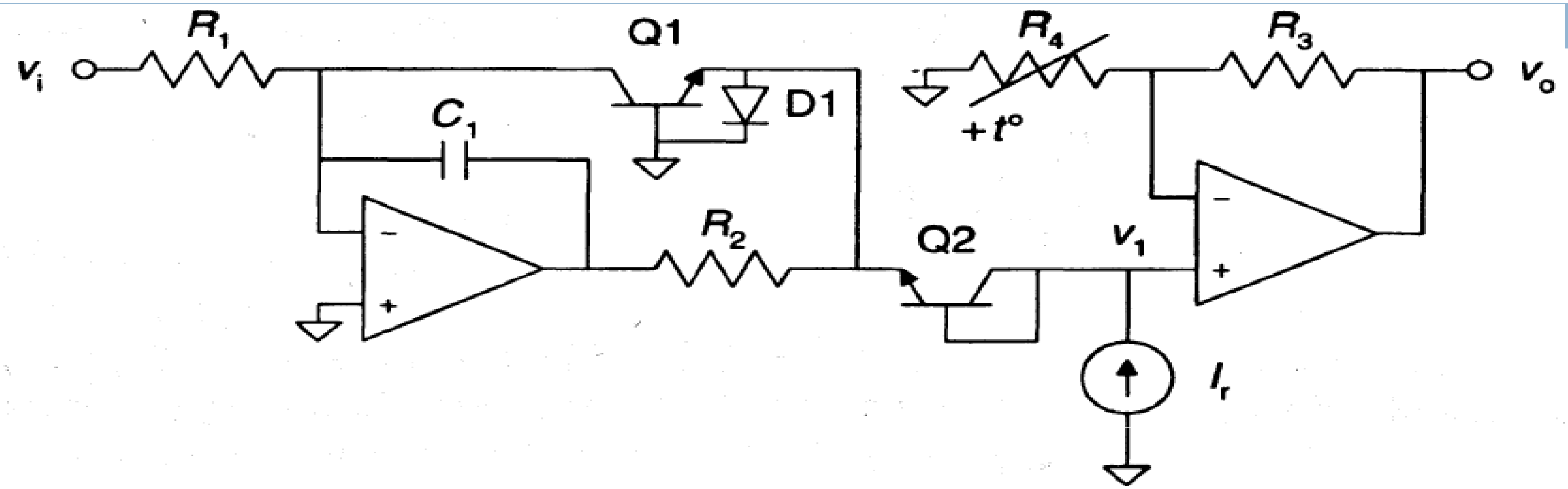
- Such circuit techniques are used in integrated log amps: AD640, AD641, ICL8048, LOG100, 4127.
- IC log amps may cost about ten times the components needed to build a discrete-component log amp.
- Nevertheless, achieving a 1% logarithmic conformity over almost six decades for input currents requires careful design.

Temprature Compensation

$$v_o = -V_T \ln\left(\frac{v_i}{R_1 I_S}\right)$$

- The equation for output voltage shows that the scale factor of the basic transdiode log amp depends on temperature because of V_T and
- that there is also a temperature-dependent offset because of I_S.
- Temperature compensation must correct both error sources.
- Figure (next slide) shows the use of a second, matched, transistor for offset compensation and a temperature-dependent gain for gain compensation.

Temprature Compensation



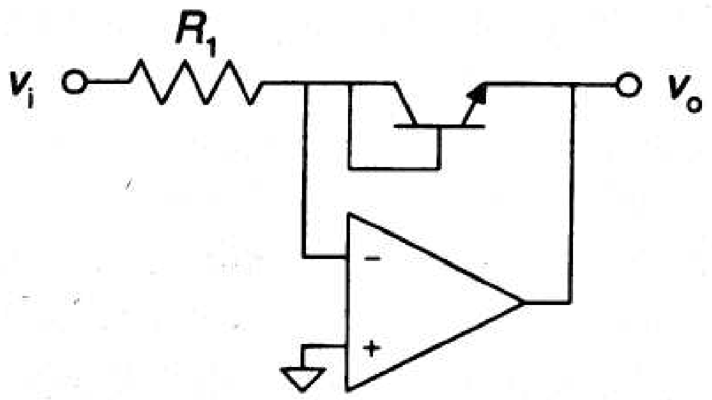
- Temperature compensation in a transdiode log amp:
- a second transistor (Q2) compensates the offset voltage and
- a temperature-sensitive resistor *(R4)* compensates the scale factor
- For transistors Q1 & Q2 we have

$$v_{BE1} = V_T \ln\left(\frac{v_i}{R_1 I_{S1}}\right) \qquad v_{BE2} = V_T \ln\left(\frac{I_r}{I_{S2}}\right)$$

- where ***Ir*** is a reference, temperature-independent, current.

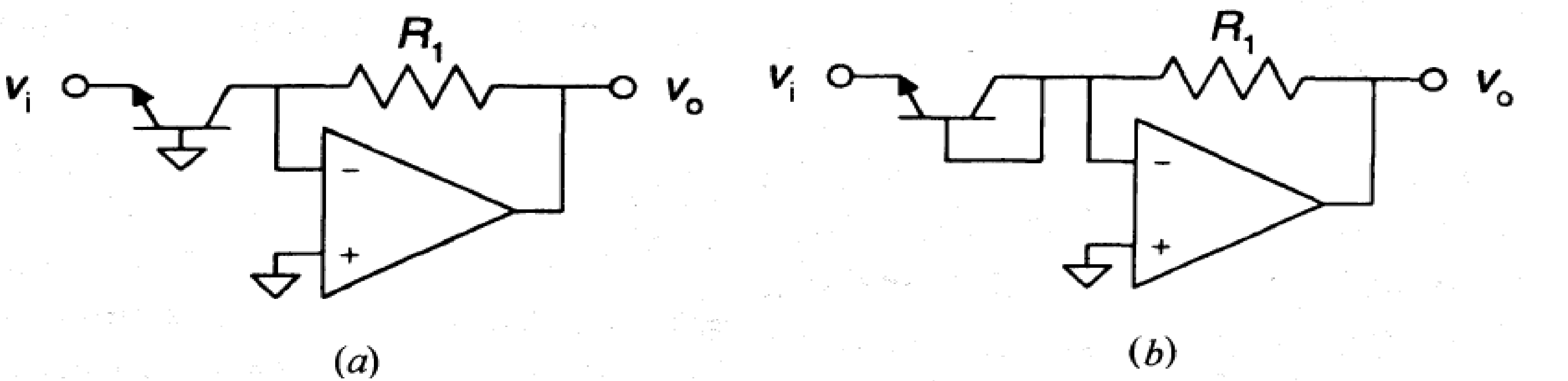
Diode-connected Log Amp

- In the second circuit a BJT connected as a diode to achieve the logarithmic characteristic.
- The analysis is the same as above for the transdiode connection, but the logarithmic range is limited to four or five decades because the base current adds to the collector current.
- On the pro side,
  - the circuit polarity can be easily changed by reversing the transistor,
  - the stability improves, and
  - the response is faster.



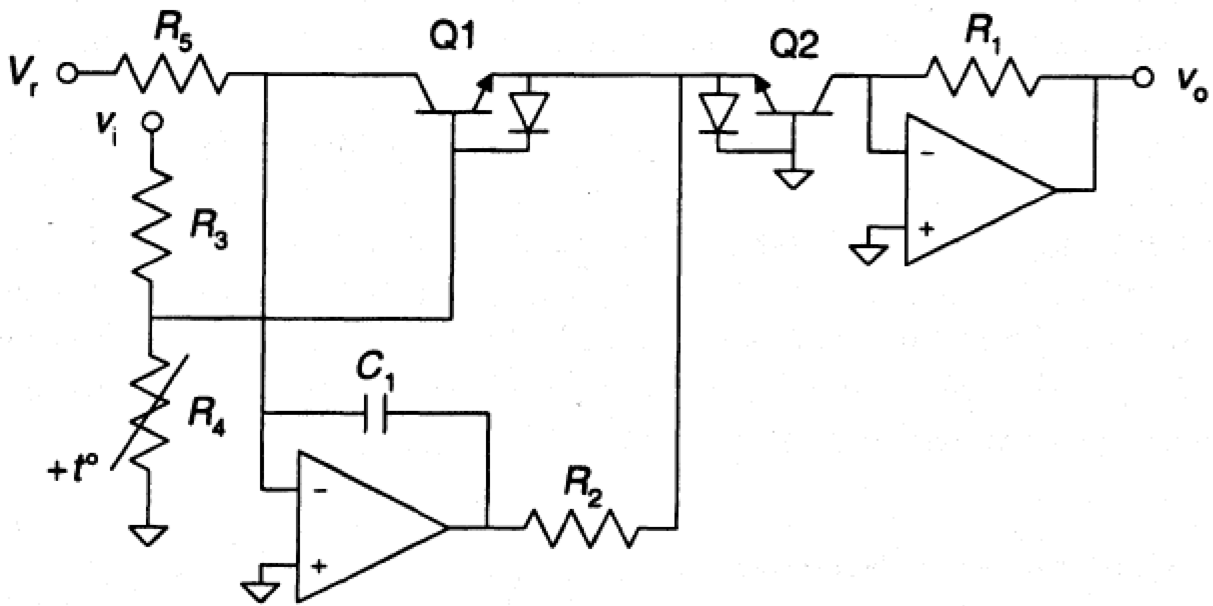
Exponential (Antilog) Amplifiers

- An exponential or antilogarithmic amplifier (antilog amp), performs the function inverse to that of log amps:
- its output voltage is proportional to a base (10, *e)* elevated to the ratio between two voltages.
- Antilog amps are used together with log amps to perform analog computation.
- Similar to Log Apms there are two basic circuits for logarithmic amplifiers
  - (a) transdiode and
  - (b) diode connected transistor



Antilog Amplifier

- Interchanging the position of resistor and transistor in a log amp yields a basic antilog amp.
- The base-collector voltage is kept at 0 V, so that collector current is given by
- $$i_c \approx I_s \cdot \exp\left(v_{BE} / V_T\right)$$
- and for negative input voltages we have: $v_o = i_C R_1 = I_S R_1 \exp(-v_i / V_T)$
- There is again a double temperature dependence because of $\boldsymbol{I_S}$ and $\boldsymbol{V_T}$.
- Temperature compensation can be achieved by the same technique shown for log amps.



Log-Antilog

- Log and antilog amp circuits include the same elements but arranged in different feedback configurations.
- Some integrated log amps have uncommitted elements allowing us to implement antilog amps.
- Some **IC** (like ICL8049) are a committed only antilog amp.
- Some so-called *multifunction converters* (AD538, LH0094, 4302) include op amps and transistors to simultaneously implement log and antilog functions, or functions derived thereof, such as
  - multiplication,
  - division,
  - raising to a power,
  - or taking a root

Basic Multiplier

- Multipliers are based on the fundamental logarithmic relationship that states that the product of two terms equals the sum of the logarithms of each term.
- This relationship is shown in the following formula:

$$\ln(a \times b) = \ln a + \ln b$$

- This formula shows that two signal voltages are effectively multiplied if the logarithms of the signal voltages are added.

Multiplication Stages

- The multiplication procedure take three steps:

1. 1. To get the logarithm of a signal voltage use a Log amplifier.

$$V_1^* = \ln(V_1) \quad \text{and} \quad V_2^* = \ln(V_2)$$

2. 2. By summing the outputs of two log amplifiers, you get the logarithm of the product of the two original input voltages.

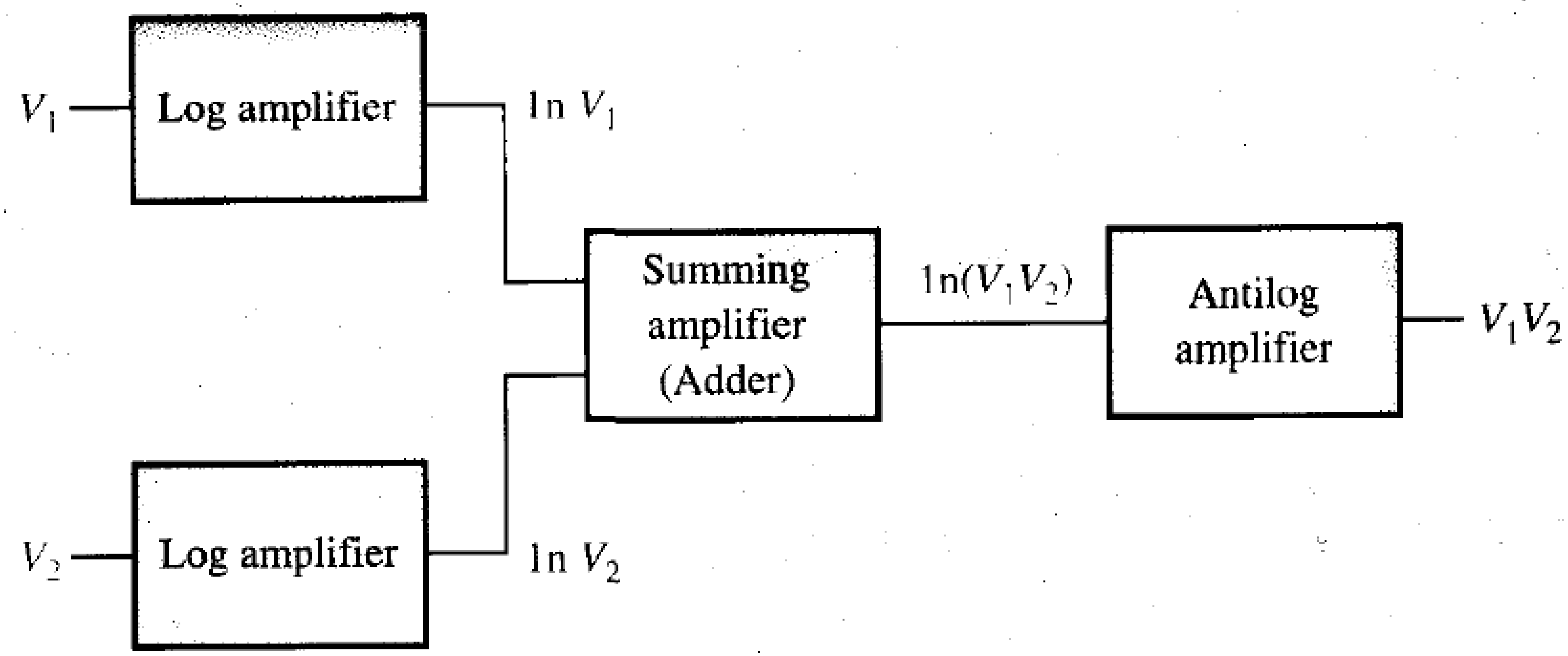
$$V_O^* = V_2^* + V_2^* = \ln(V_1) + \ln(V_2) = \ln(V_1 \cdot V_2)$$

3. 3. Then, by taking the antilogarithm, you get the product of the two input voltages as indicated in the following equations:

$$V_O = \exp(V_O^*) = \exp[\ln(V_1 \cdot V_2)] = V_1 \cdot V_2$$

block diagram of an analog multiplier

- The block diagram shows how the functions are connected to multiply two input voltages.
- Constant terms are omitted for simplicity.



Basic Multiplier Circuitry

- The outputs of the log amplifier are stated as follows:

$$V_{out(\log 1)} = -K_1 \cdot \ln\left(\frac{V_{in1}}{K_2}\right)$$

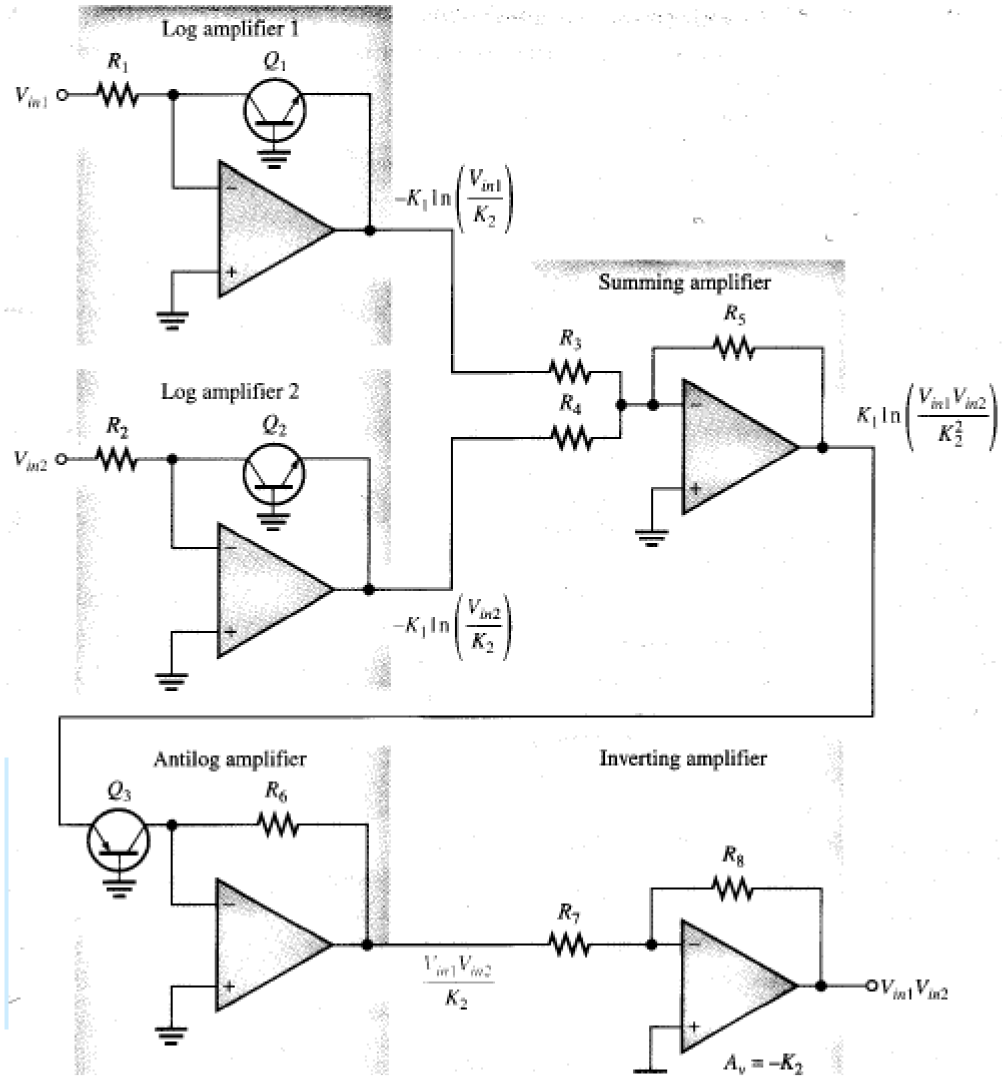
$$V_{out(\log 2)} = -K_1 \cdot \ln\left(\frac{V_{in2}}{K_2}\right)$$

where $K_1 = 0.025$ V, $K_2 = R \cdot I_{ebo}$ and $R = R1 = R2 = R6$.

The two output voltages from the log amplifiers are added and inverted by the unity-gain summing amplifier to produce the following result:

$$V_{out(sum)} = K_1 \cdot \ln\left[\ln\left(\frac{V_{in1}}{K_2}\right) + \ln\left(\frac{V_{in2}}{K_2}\right)\right] =$$

$$= K_1 \cdot \ln\left(\frac{V_{in1} \cdot V_{in2}}{K_2^2}\right)$$



Basic Multiplier Continue……

- This expression is then applied to the antilog amplifier; the expression for the multiplier output voltage is as follows:

$$V_{out(\exp)} = -K_2 \cdot \exp\left(\frac{V_{out(sum)}}{K_1}\right) = -K_2 \cdot \exp\left[\frac{1}{K_1} K_1 \cdot \ln\left(\frac{V_{in1} \cdot V_{in2}}{K_2^2}\right)\right] =$$

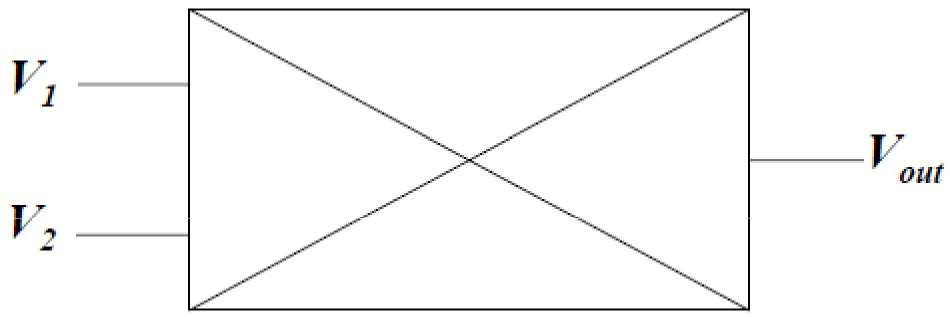
$$= -K_2\left(\frac{V_{in1} \cdot V_{in2}}{K_2^2}\right) = -\frac{V_{in1} \cdot V_{in2}}{K_2}$$

- The output of the antilog (exp) amplifier is a constant (*1/K2*) times the *product* of the input voltages.
- The final output is developed by an inverting amplifier with a voltage gain of —*K2*.

$$Vout = -K_2\left(-\frac{V_{in1} \cdot V_{in2}}{K_2}\right) = V_{in1} \cdot V_{in2}$$

Four-Quadrant Multipliers

- Four-Quadrant Multiplier is a device with two inputs and one output.



$$V_{out} = k \cdot V_1 \cdot V_2$$

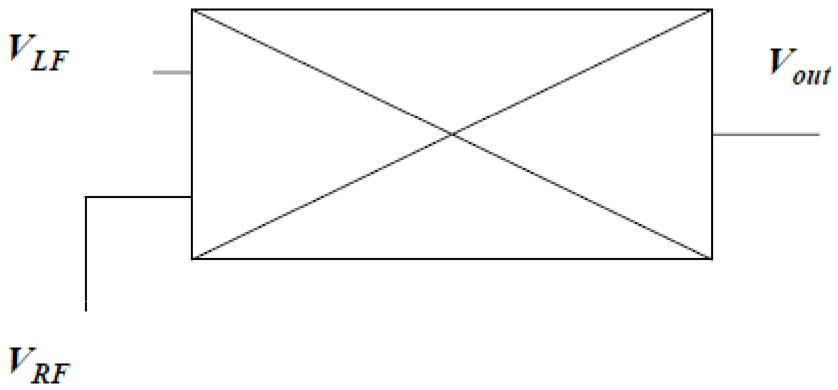
- Typically k = 0.1 to reduce the possibility of output overload.
- It is called four-quadrant since inputs and output can be positive or negative.
- An example device is Motorola MC1494, powered by ± 15 V power supply

Multiplier Applications

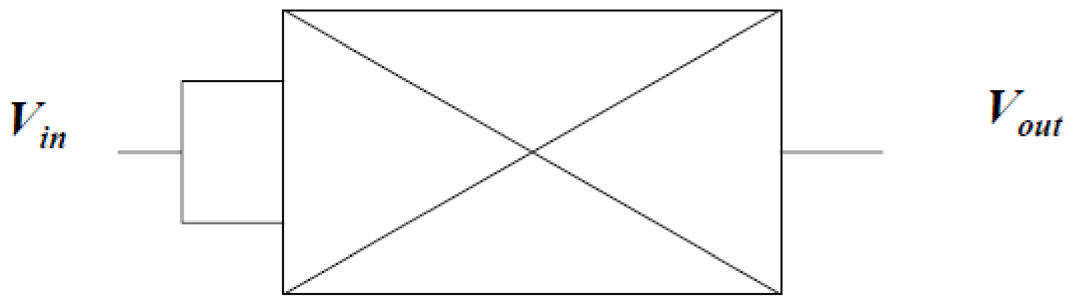
- Alongside the multiplication Multipliers have many uses such as:
  - Squaring
  - Dividing
  - Modulation / demodulation
  - Frequency and amplitude modulation
  - Automatic gain control

Amplitude Modulation & Squaring

- Amplitude Modulation



- Squaring circuit



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3. Website: www.electronics.dit.ie

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