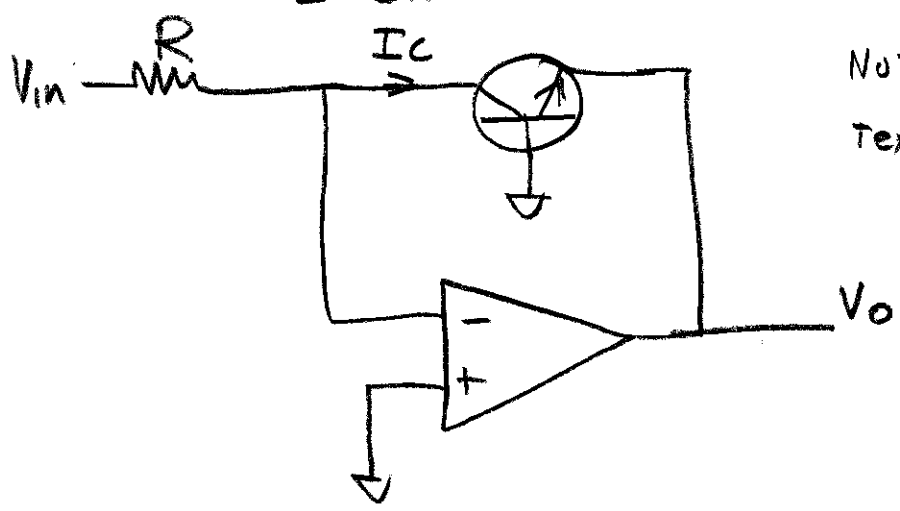


# LOGARITHMIC CIRCUIT



Note: NPN circuit  
text is for PNP

FROM EBERS-MOLL EQUATIONS:

$$I_C = C_{21} (e^{V_{EB}/(KT/q)} - 1) + C_{22} (e^{V_{CB}/(KT/q)} - 1)$$

T IS TEMPERATURE IN DEGREE KELVIN

q IS ELECTRON CHARGE =  $1.6 \times 10^{-19}$  COULOMBS

k IS BOLTSMANN'S CONSTANT =  $1.38 \times 10^{-23}$  JOULES/OK

THUS  $KT/q$  IS IN UNITS OF JOULES/COULOMB OR VOLTS

NOTE:  $V_{EB} = -V_o$ .

$V_{CB} = 0$  SO ONLY FIRST TERM OF  $I_C$  EQN IS USED

THUS:  $I_C = C_{21} (e^{-V_o/(KT/q)} - 1)$  WHICH CAN BE

WRITTEN AS:  $I_C + C_{21} = C_{21} (e^{-V_o/(KT/q)})$

SINCE  $C_{21}$  IS TYPICALLY IN THE FEMTO-AMPERE RANGE ( $10^{-15}$ ) AND  $I_C$  IS TYPICALLY BETWEEN 1uA AND 10mA, WE CAN WRITE:

$$I_C = C_{21} (e^{-V_o/(KT/q)})$$

NOTE ALSO THAT  $I_C = V_{in}/R$  . SO;

$$C_{21} e^{-V_0/KT/q} = \frac{V_{in}}{R}$$

DIVIDING BY  $C_{21}$  AND TAKING LN:

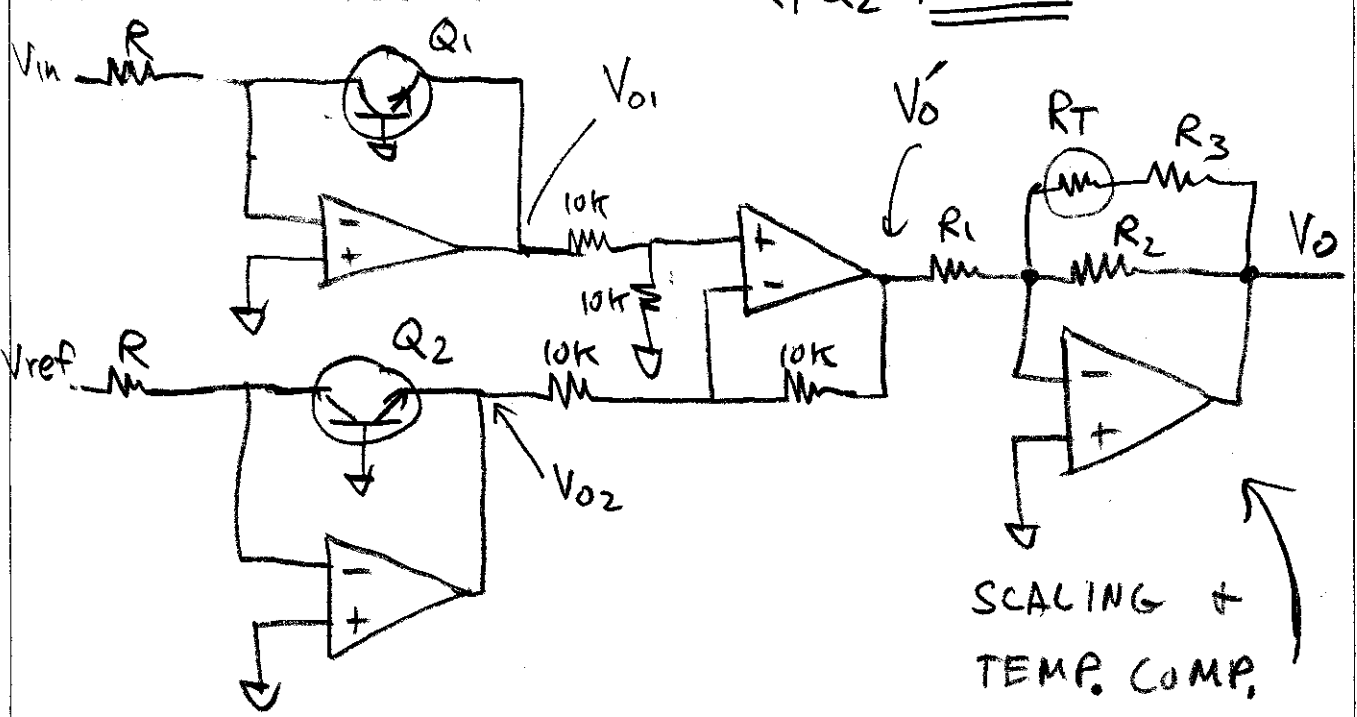
$$\frac{-V_0}{KT/q} = \ln\left(\frac{V_{in}}{C_{21}R}\right) = \ln\frac{V_{in}}{R} - \ln C_{21}$$

THUS:

$$V_0 = -\frac{KT}{q} \left[ \ln\frac{V_{in}}{R} - \ln C_{21} \right]$$

IMPROVED CIRCUIT

$Q_1, Q_2$  matched



$$V_{01} = -\frac{KT}{q} \left[ \ln\left(\frac{V_{in}}{R}\right) - \ln C_{21} \right]$$

$$V_{02} = -\frac{KT}{q} \left[ \ln\left(\frac{V_{ref}}{R}\right) - \ln C_{21} \right]$$

$$V_0' = -\frac{kT}{q} \left[ \ln\left(\frac{V_{in}}{R}\right) - \ln C_{21} - \ln\left(\frac{V_{ref}}{R}\right) + \ln C_{21} \right]$$

$$V_0' = -\frac{kT}{q} \left[ \ln\left(\frac{V_{in}}{R}\right) - \ln\left(\frac{V_{ref}}{R}\right) \right]$$

$$V_0' = -\frac{kT}{q} \left[ \ln\left(\frac{V_{in}}{V_{ref}}\right) \right]$$

NOTE:

1.  $C_{21}$  TERM CANCELS IF  $Q_1, Q_2$  MATCHED
2. NOTE SENSITIVITY TO TEMPERATURE

FINAL IMPROVEMENT:

1. ADD SCALING TO PRODUCE DESIRED LOG FUNCTION.
2. USE  $R_T$  (THERMISTOR — RESISTANCE DECREASES WITH INCREASE IN TEMP.) SUCH THAT SCALING GAIN DECREASES AT THE RIGHT RATE WITH TEMPERATURE INCREASE TO GREATLY REDUCE SENSITIVITY TO TEMPERATURE.