

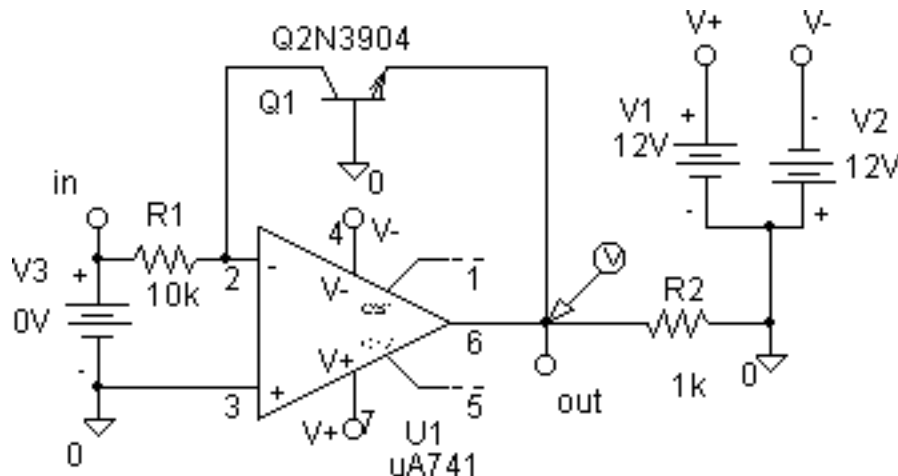
Logarithmic Amplifier Illustration

Applications involving signals with a very large dynamic range may offer difficulties in concurrently managing both large amplitude and small amplitude signals. For such circumstances the dynamic range can be compressed by logarithmic conversion (and subsequently expanded by exponentiation). The use of an intermediate logarithmic conversion to replace a multiplication by an addition also can be useful.

Logarithmic amplifiers, while not exceptionally complex conceptually, require considerable care actually to construct. Commercial devices, while not inexpensive, are available. This note describes essential concepts of logarithmic and exponential conversion..

Elementary Log Amplifier Circuit

The basis of the log amplifier is the very precise logarithmic relationship between the emitter current and base-emitter voltage of a bipolar transistor; this is quite precise over several orders of magnitude of emitter current. This relationship may be used to obtain a logarithmic voltage transfer function, as illustrated by the simplified circuit illustration below.



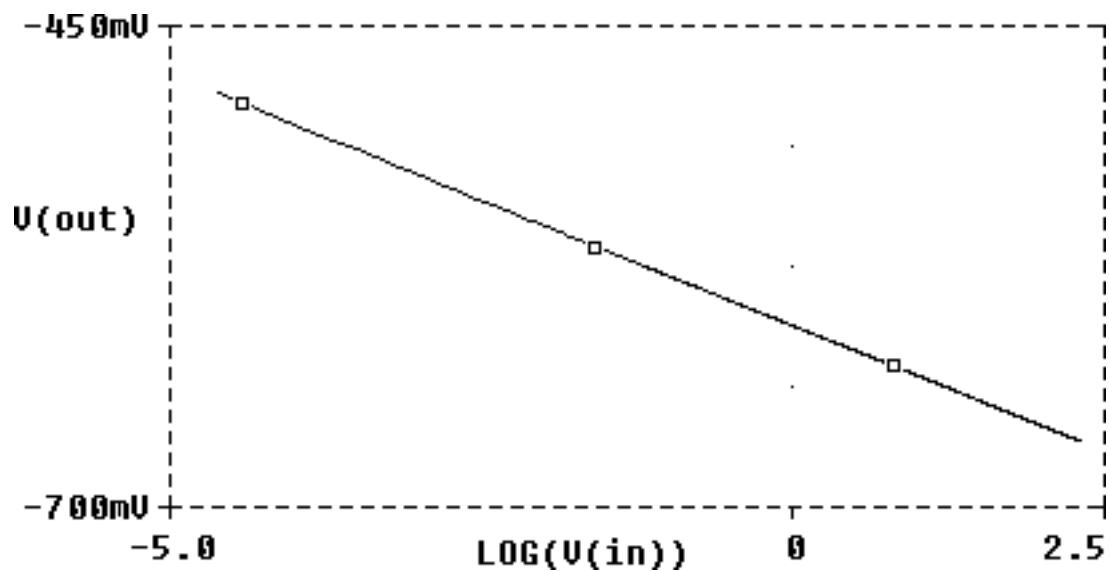
The transistor Q1 is the feedback element for the inverting amplifier. A current $V3/R1$, proportional to the (positive) input voltage $V3$, flows through the NPN feedback transistor (of course assuming the opamp is not saturated). Because the inverting input of the (high gain) amplifier is a virtual ground Q1 operates essentially as a diode-connected transistor. The transistor collector current $V3/R1$ produces (theoretically) an amplifier output voltage drop of

$$V_{out} = - \frac{kT}{q_e} \ln \left(\frac{V_{in}}{R1} / I_s \right)$$

where I_s is the transistor junction saturation current.

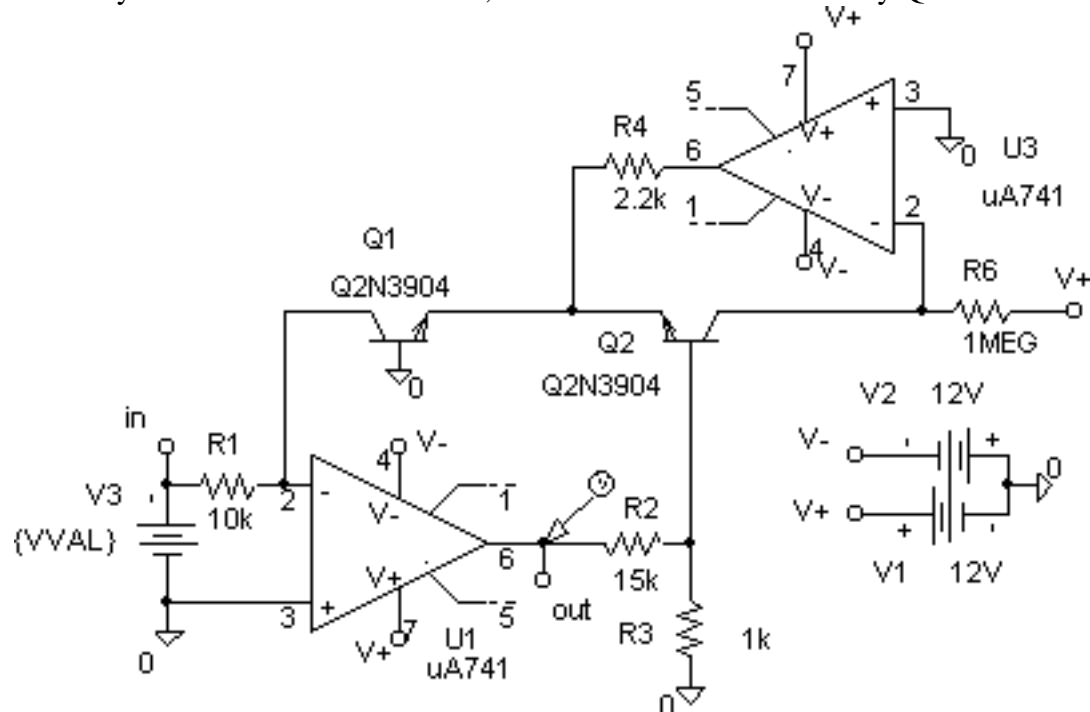
A PSpice analysis provides the Probe plot shown below; this is for a DC sweep of the input voltage. Note the change of axis variable to the natural logarithm of the input voltage. The opamp output voltage varies linearly over approximately three decades of input voltage change.

It should be noted that this circuit as it stands is not practical. Of particular significance are the temperature dependence of the underlying diode relation, and the uncertainty of the effective value of I_s .



Compensated Log Amplifier

A more realistic log amplifier circuit is drawn below. It is a modest pedagogical simplification of a circuit described in National Semiconductor Application Note AN 30. Q1 and the associated amplifier U1 form essentially the circuit described above, as is also the circuit formed by Q2 and U3.



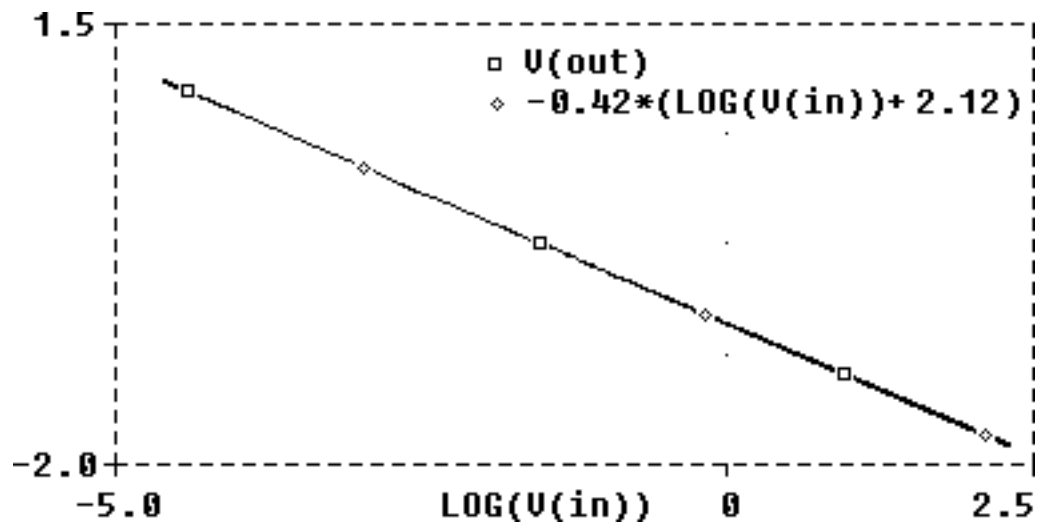
$$V_{out} = \frac{R2 + R3}{R3} (V_{BE2} - V_{BE1})$$

$$(V_{BE2} - V_{BE1}) = -\frac{kT}{q_e} \ln \frac{I_{C1}}{I_{C2}} \text{ where } \begin{cases} I_{C1} = \frac{V_{in}}{R1} \\ I_{C2} = \frac{V_+}{R6} \end{cases}$$

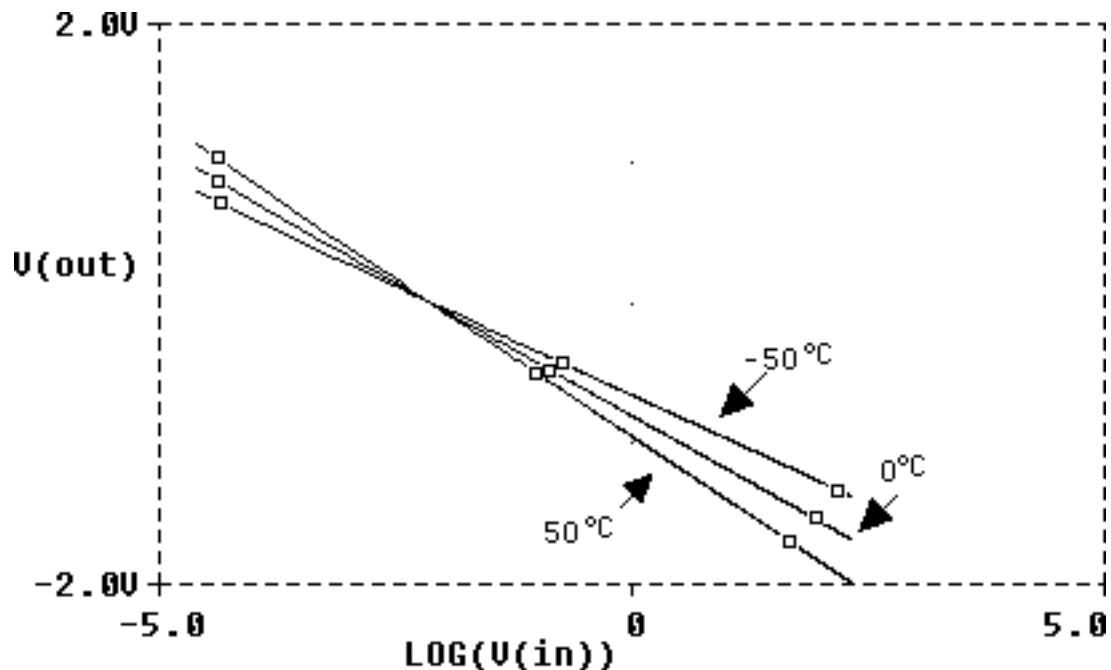
$$V_{out} = -\frac{kT}{q_e} \frac{R2 + R3}{R3} \ln \left(\frac{V_{in}}{V_+} \frac{R6}{R1} \right)$$

However the output voltage is proportional to the difference of the Q1-Q2 base voltages, as indicated by the first equation to the left. The voltage difference is proportional to the Q1-Q2 current ratio as shown in the second equation. Here we suppose Q1 and Q2 are closely matched devices, so that the uncertain saturation currents cancel. The Q2 current is fixed, so that the output voltage is proportional to the

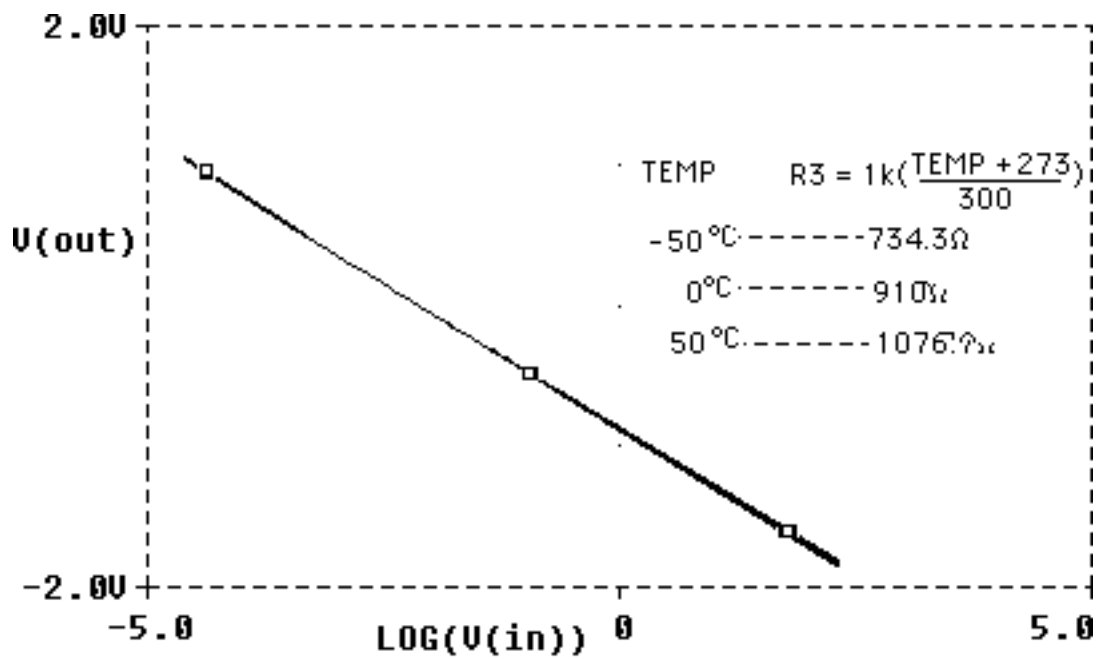
logarithm of V_{in} . Note the dependence of temperature in the coefficient, something we comment on further a bit later. A PSpice computation for a fixed temperature of 27°C is plotted below. Overlaid is the theoretical result calculated using the element values of the illustrative circuit.



The temperature dependency is illustrated in the following computed plot



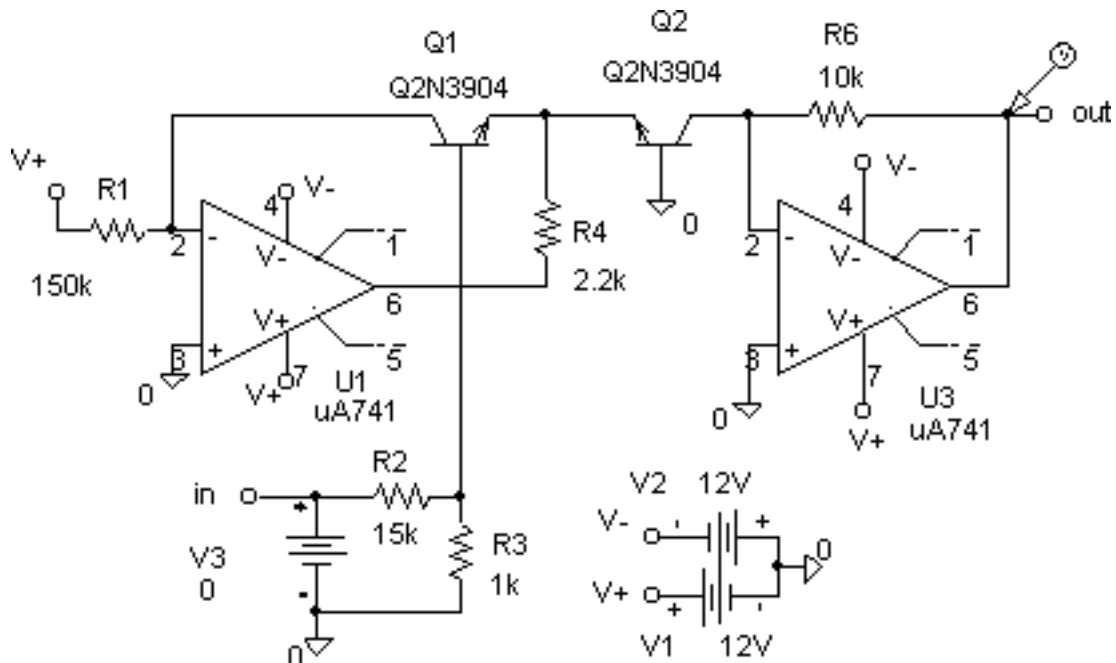
The temperature dependency can be compensated however by making the resistance of R3 appropriately temperature dependent. While the evaluation version of PSpice does not readily enable modeling such a resistor it is possible to compute the amplifier log characteristic separately for different temperatures and suitably modified resistance values, and superimpose the results as is done below. Note the significant improvement in temperature independence.



Inverse Log Amplifier

The converse operation to logarithmic compression is exponential expansion, and is illustrated by the following circuit (a simplification of a circuit also taken from the AN 30 reference cited above).

The feedback amplifier containing the diode-connected transistor Q1 (see diagram below) is similar to the arrangement in the logarithmic circuit, but in this case is used to provide a fixed reference current through Q1. The input voltage to be 'expanded' is applied to the base of Q1 through a resistive voltage divider.



The complementary transistor Q2 is connected so that

$$\begin{aligned}\frac{R3}{R2 + R3} V_{in} &= V_{B1} - V_{B2} \\ &= V_T \ln \frac{I_1}{I_S} - V_T \ln \frac{I_2}{I_S} \\ &= V_T \ln \frac{I_1}{I_2} \\ &= V_T \ln \left(\frac{V_+}{R1} \frac{1}{I_2} \right)\end{aligned}$$

where I_1 and I_2 are the respective emitter currents, and I_S is the saturation current for the assumed) matched transistor junctions. A second amplifier U3 is used to convert the Q2 current to a voltage:

$$V_{out} = I_2 R6 = R6 \frac{V_+}{R1} e^{-\frac{R3}{R2+R3} \frac{V_{in}}{V_T}}$$

Incidentally note that since the emitter current of Q1 is essentially fixed then so is the emitter junction voltage of Q1. Hence as the base voltage of Q1 is increased so is the common emitter voltage of Q1-Q2, i.e., the emitter junction forward-bias voltage of Q2 decreases. For a large enough input voltage the Q2 transistor no longer functions effectively as assumed, and the exponential relationship fails.

A PSpice computation for the circuit parameters indicated is illustrated below. The theoretical expectation for the output also is plotted.

