

# 1.1 TEMPERATURE COMPENSATED LOGARITHMIC AMPLIFIER

A number of instrumentation applications can benefit from Logarithmic amplifiers (LOG-AMPs) but this family of amplifiers always has temperature and loop stability problems for a wide range of input and operating temperature, here we are using a new linear PTC to resolve the temperature drift in the best mathematically accurate way and also a very robust design to make it stable in all operating conditions.

There are varieties of LOG-AMPs available from different chip manufacturers but the price is usually high and they are not as flexible as you like to.

First let's take a look at the linear PTC Thermistor (PTFT) introduced by VISHAY-DALE, this type of thermistor shows a linear behaviour over temperature in a wide range of  $-55^{\circ}\text{C}$  to  $125^{\circ}\text{C}$  with the maximum of  $\pm 300$  ppm inaccuracy of the thermal coefficient. So we have a variable resistor, which its value is a linear function of temperature, look at the following formulas:

$$R = R_{25} * [TC * (T - 25) + 1] \quad (\text{Formula-1})$$

In the above formula  $R_{25}$  is the resistance of the Thermistor at  $25^{\circ}\text{C}$  and  $TC$  is the slope of the line or temperature coefficient, as you see we have the temperature in degree Centigrade but our desire is in Kelvin so we have a change of variable to the following:

$$R = R_{25} * [TC * (T - 273 - 25) + 1] \quad (\text{Formula-2}) \quad \text{Or:} \quad R = R_{25} * TC * T + R_{25} * (-298 * TC + 1) \quad (\text{Formula-3})$$

In Formula-3 to make the second term zero we need to have:

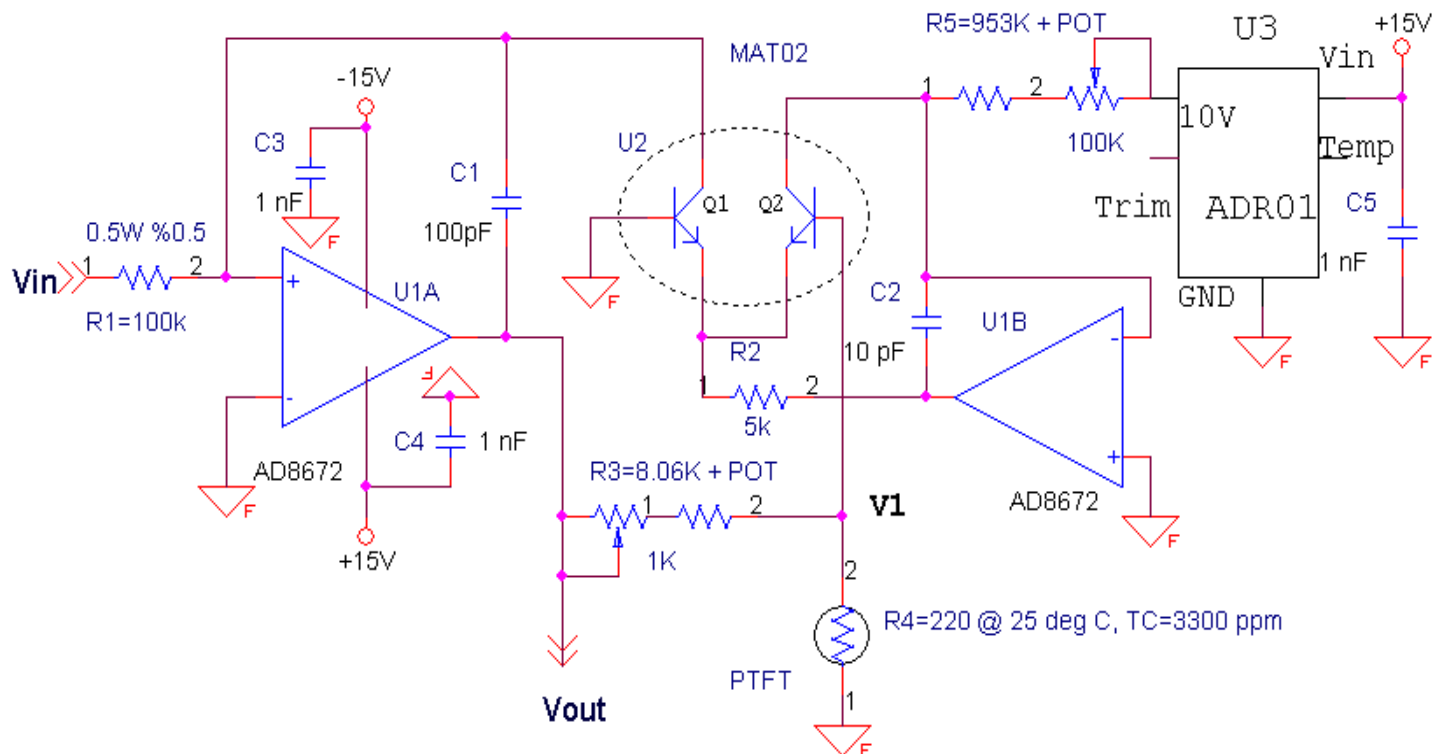
$$TC = \frac{1}{298} = 0.003355 \approx 3300 \text{ ppm} \quad (\text{Formula-4})$$

Suppose we need  $220 \Omega$  in room temperature so we have a Thermistor with the following formula:

$$R = 220 * 0.0033 * T = 0.726 * T \quad (\text{Formula-5})$$

We choose the biggest size (1206) to have a better heat transfer with the environment and also in the actual design we put the thermistor as close as possible to the matched pair of transistors (MAT02).

Now look at the circuit diagram in the following:



U1A injects the current proportional to the input voltage to the collector of the Transistor Q1, therefore the base current will be a fraction of the input voltage, obviously the base current is much lower and we have lower effects of voltage drop caused by bulk resistance on the base-emitter junction. In the other hand we use a precise 10 V reference voltage to bias Q2 using the same current injection circuitry, but with a constant current (around 10µA).

The voltage at the point V1 will be the difference of  $V_{BE1} - V_{BE2}$ , this reduction helps to discriminate the temperature change effects on voltage of the Base-Emitter junction.

Here are the calculations:

$$V1 = V_{BE2} - V_{BE1} = V_T \ln\left(\frac{I_{B2}}{I_{SS}}\right) - V_T \ln\left(\frac{I_{B1}}{I_{SS}}\right) = V_T \ln\left(\frac{I_{B2}}{I_{B1}}\right) \quad (\text{Formula 6})$$

And:

$$V1 = \frac{K * T}{q} \ln\left(\frac{I_{C2}}{I_{C1}}\right) = \frac{K * T}{q} \ln\left(\frac{R5}{\frac{V_{in}}{R1}}\right) = \frac{K * T}{q} \ln\left(\frac{10 * R1}{R5 * V_{in}}\right) \quad (\text{Formula 7})$$

Or:

$$V1 = -\frac{K * T}{q} \ln(V_{in}) + \frac{K * T}{q} \ln\left(\frac{10 * R1}{R5}\right) \quad (\text{Formula 8})$$

And we can see that there is a resistor network voltage division circuitry between  $V_{OUT}$  and V1, so:

$$V_{OUT} = \frac{R3 + R4}{R4} V1 = \frac{R3 + 0.726T}{0.726T} * V1 \quad (\text{Formula 9})$$

And with a realistic assumption of  $R3 \gg 0.726 * T$  we have:

$$V_{OUT} = -\frac{K * (R3)}{0.726 * q} \ln(V_{in}) + \frac{K * (R3)}{0.726 * q} \ln\left(\frac{10 * R1}{R5}\right) = 0.0001188 * R3 * \left[-\ln(V_{in}) + \ln\left(\frac{10 * R1}{R5}\right)\right]$$

Following values make a nice formula:

$$R3=8417 \Omega, R1=100K, R5=1M$$

$$V_{OUT} = -\ln(V_{in}) \quad (\text{Formula 10})$$

Now we need to calibrate the LOG-AMP, first apply an accurate source of 1V DC to the input and by adjusting the 100K POT make the output zero. Then apply 2.718 V and by adjusting 1K POT adjust the output at -1V. (You may apply higher voltages for better accuracy in calibration)

Now you can enjoy using a wide range input log amplifier which basically can handle input voltages up to hundred of volts!! Make sure you have protection diode in the inverting pin of the input amplifier and enough power rating on R1. By the way your LOG-AMP just works with positive input values!

Mazi Hosseini M.A.Sci., P.Eng