A low cost temperature probe for well logging

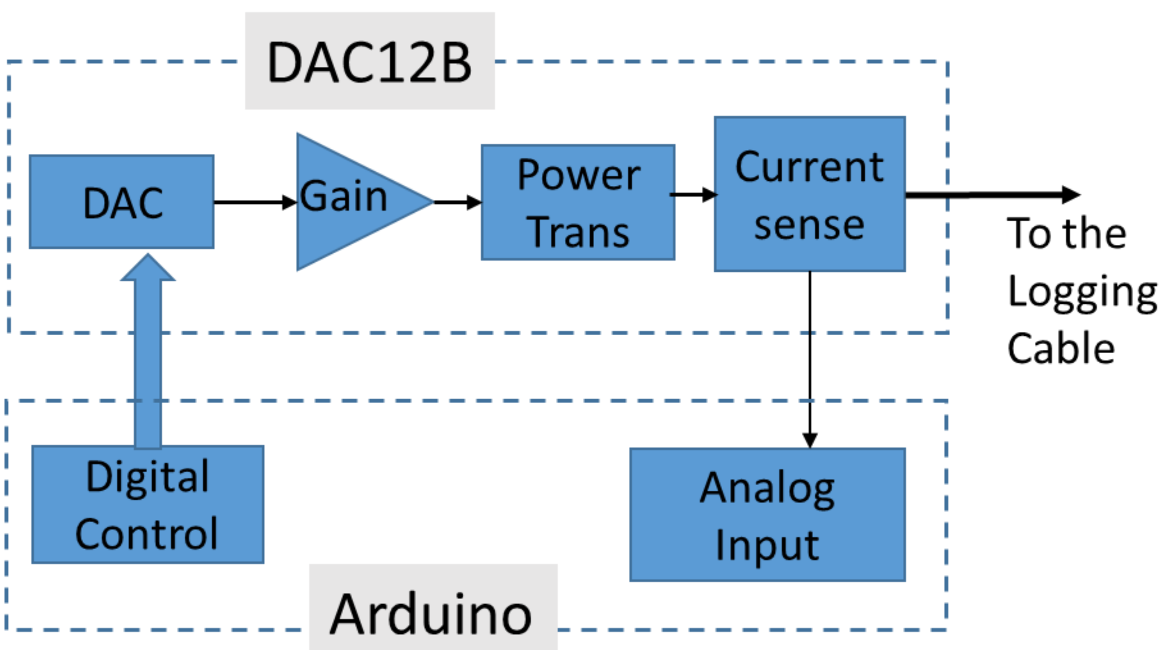
By Randy A Normann, Feb 12 2018

The AD590 is a "constant current" temperature sensor. The temperature reading is 1µA/K. The cost varies from $7.50 to $105.00 each with accuracy of +/-5°C to +/-0.5°C over a temperature range from -55°C to 125/150°C. The constant current device can be operated over 10 to 30 Kft logging cable. No other downhole electronics are required. The AD590 from Analog Devices is the simplest electronic temperature device known to the author.

The AD590 is a low cost means for building a temperature probe for logging low temperature geothermal wells. However, the 1µA/K signal is very sensitive to small leakage currents inside the logging cable. The primary cause of leakage current is well fluid reaching the logging cable's center conductor. The center conductor is most vulnerable where the logging cable is connected to the tool inside the cable head. A small leakage of a few micro-amps shifts the temperature reading the same number of degrees Celsius. Even the smallest trace of conductive geothermal fluids reaching the cable head connection will cause measureable error in the temperature measurement. As such, the owner of one such tool stopped using their AD590 temperature probe because they could not determine if the cable head was leaking current or if the well temperature was increasing. The loss of that tool was unfortunate. The solution is simple.

A solution is to use the DAC12B programmable power shield and an Arduino. Armed with a programmable precision power supply, the Arduino can detect the leakage current error and in some cases correct the temperature measurement accordingly.

So, let's look at how the AD590 works as inside the logging tool.



Simply provide 7 to 20V to the AD590 from the surface via the logging cable while logging. The sensor's temperature reading is 1µA/K. For example 25°C = 298K: as 298µA measured from the AD590. For the max temperature of 150°C the current is 420uA. Simply record the current running down the cable. Each micro-amp is a degree Kalvin (easily converted to Celsius by subtracting 273µA).

In the above figure, the DAC12B is providing a voltage based on programming instructions from the Arduino. The DAC12B has a simple SPI interface to the Arduino. This is a simple digital interface requiring only 3 wires for serial communication. The AD590 needs at least 7v to operate. The default output range on the DAC12B is 0 to 10V with 12bit resolution or ~2.5mV per step. (With simple modifications, the DAC12B can be altered for a wider range up to 0 to 30V.)

For illustration, assume the DAC12B voltage is set to 10V while logging. The DAC12B has a current monitor circuit on board. So the Arduino can monitor the current measurement from the DAC12B to determine the downhole temperature. It is really that easy.

So, let's say we have a leakage current at the cable head of 10µA or as 10V/1MOhm = 10µA. This would be a +10°C error in our measurement which is unacceptable.

Using the programmable DAC12B power supply, this error can be detected. The cable head leakage current is directly proportional to the cable voltage while the sensor current is not effected. The sensor is a constant current determined by the sensor's temperature NOT the sensor's voltage. (In truth there is always some small error << 1C with changing sensor voltage. Some allowance is needed in running this test.)

To detect an unwanted leakage current, simply hold the temperature probe at a static location in the well and change the cable voltage by some programmed Delta V (DV) as from 10V to 9V or DV = -1V. If no change in the temperature reading is detected, the tool and cable head are working as desired. If a change in current (DI) is detected, the error can be estimated knowing the DV and the logging cables resistance. To estimate the value of the error supply current, we calculate the resistance of the cable head leakage, Rleak.

Rleak = (DV - Rcable*DI)/DI;
Where DV=change in Voltage; DI=change in current; Rcable=cable resistance

A lab test using an AD590 tool was conducted with the following results. The ambient AD590 measured temp of 30.348°C when a 1M Ohm resistor simulating a leakage current at the cable head was added. This shifted the reading to 41.057°C. However, the user would not know that error existed unless the Arduino was programmed to provide a DV. So, the surface voltage to the cable was changed from 10V to 9V and the temperature reading dropped to 39.953°C. That's about a +1°C difference. Using programmed DV and measured DI and the known cable resistance of 1Kohm the Arduino calculated a new well temperature of 30.345°C. That's only an error of 0.003°C. A value within the sensors specification.

The test was repeated with a 100K ohm for 10 times the leakage current of the 1M ohm value. The ambient is now reading 30.649°C as the shop is heating in the summer sun. The 100K ohm leakage path increase the well temperature reading to 126.398°C. Dropping the voltage 1 volt reduced the temperature to 116.459°C, approximately a 10°C change. Correcting for the change in temperature with dropping voltage, the new well temperature is 30.928°C. That's an error of ~0.3°C. We should consider removing the tool from the well and fixing the cable head.

Conclusion

The AD590 is an easy way to build a temperature logging tool. The AD590 provides 1µA/K of constant current independent of the supply voltage. However, a micro-amp is a very small current. Any leakage current in the logging cable will be seen as an error in the tools temperature measurement. As such a programmable power supply for powering the cable running down to the tool must be used to validate the temperature measurement. It was shown, by changing the supply voltage by 1 volt any error current can be estimated. For small error currents, a correction of the measured temperature can be performed. If the error current is too high, the tool can be removed and repaired.

The combination of the Arduino and DAC12B (programmable power supply shield) can be used to detect and correct for leakage current.   The tool can be stopped periodically for a static temperature measurement. During this stop, the operator signals to the Arduino to test for leakage current before continuing the well log.