APPLICATIONS INFORMATION THE DAWN ELECTRONICS PROPORTIONALLY CONTROLLED HEATERS

THEORY OF OPERATION

All standard Dawn Electronics, Inc. Proportionally controlled heaters (Fig. 1) are basically the same. They consist of a temperature sensing bridge, an amplifier and a power stage, all of which are mounted on a Beryllia substrate to form the heater. The temperature sensing bridge is made up of two equal resistors (R), the thermistor (RT) and a temperature set resistor consisting of the series combination of RS and RA. The bridge, amplifier and power stage form a feedback control loop that forces the power stage to heat until the thermistor resistance RT is equal to RS + RA. Resistor RS is external and is selected by the user. Resistor RA is internal to the heater package and limits the maximum control temperature.

TEMPERATURE SET ACCURACY

Temperature set accuracy is the precision with which the programmed temperature of a Dawn proportionally controlled heater can be set to an absolute value. The temperature set accuracy of the heaters is primarily dependent on the resistance tolerance of the thermistor. The thermistor used in the Dawn heater is specified to be 100,000Ω ± 10% at 25°C with a Negative Temperature Coefficient (NTC) of 4.8%/°C. This can result in a ± 2.1°C error in thermistor temperature when the thermistor is 100,000Ω. In addition, the thermistor manufacturer adds an additional Manufacturing Tolerance (MT) to the thermistor resistance as the temperature deviates from 25°C. The fixed resistors in the bridge have a tolerence of 1% and contribute less than ± 0.5°C to the initial temperature set accuracy of the heater. Table 1 shows the initial set temperature vs temperature set resistor for all of the standard Dawn heaters. This Table takes into consideration all of the tolerences dicussed above. For example: It is desired to set the temperature of a DN-515 heater to 80 °C. from Table 1, a 6.8KΩ resistor is selected to set the temperature to 80 °C. However, there is a ± 3.5°C tolerance which could result in a set temperature between 76.5 and 83.5 °C.

TEMPERATURE STABILITY

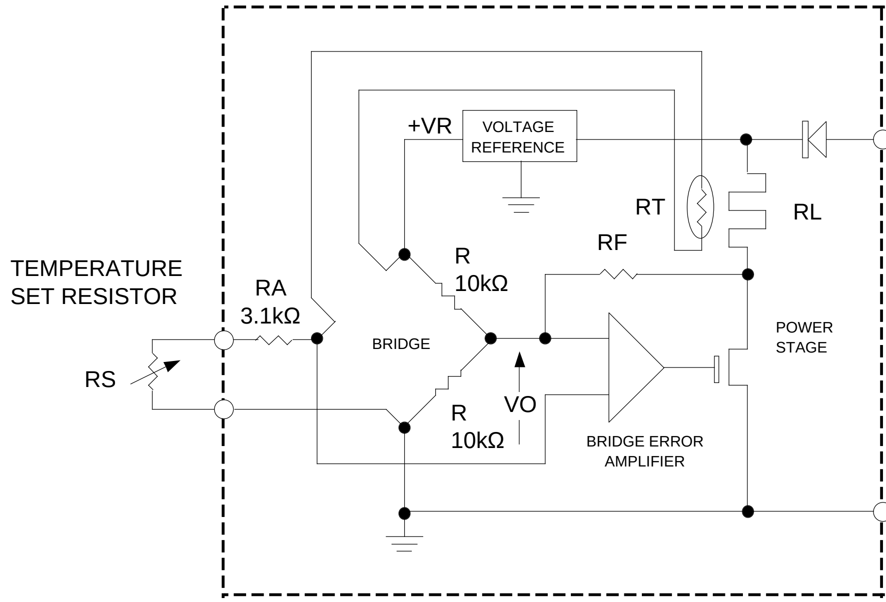
Temperature stability is the precision with which the base of the proportionally controlled heater maintains constant temperature over thermal load, supply voltage and ambient temperature variations. Note, that it is the temperature of the thermistor that is actually controlled. Therefore, the temperature stability of the base of the heater is dependent on the thermal gradient between the thermistor and the base of the substrate.

There will be a decrease in temperature of the thermistor from zero to maximum heater power. This is because the power supplied by the heater is proportional to a finite bridge output voltage. The magnitude of this temperature difference, from no load to full load, is determined by the feedback resistor (RF) and is approximately -0.05 °C per Watt increase of output power for all of the Dawn heaters. For example, the temperature of the thermistor will change -1 °C from no thermal load to a load of 20 Watts. DN-515 base heater temperature stability vs heater power is shown in Figure 2.

Temperature variation with time is associated almost entirely with aging of the thermistor. There is not extensive data on this. However, best indications are that the thermistor will vary less than ± 0.5% in resistance (± 0.1 °C) per year. Any controller using a thermistor as the temperature sensing device will have similar aging characteristics.

TEMPERATURE SET HYSTERESIS

There is no hysteresis associated with the Dawn proportionally controlled heaters. Hysteresis in temperature control systems is normally associated with "on-off" type controllers where the heater turns on at a higher temperature than it turns off. Proportionally controlled heaters constantly apply the exact amount of power to a load to maintain precise temperature control.



SYMPLIFIED SCHEMATIC
OF DAWN D.C.HEATERS

Figure 1

HEATER BASE TEMPERATURE VARIATION
VS
HEATER POWER

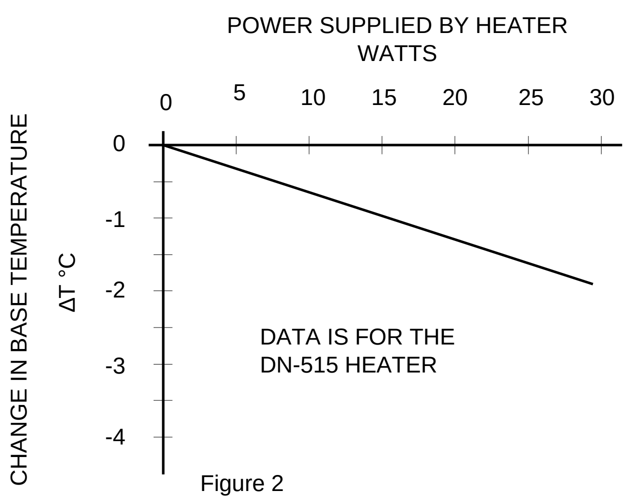


Figure 2

SET TEMPERATURE (T)
VS
TEMPERATURE SET RESISTOR (RS)

RS KΩ	T °C	TOL. ±°C	RS KΩ	T °C	TOL. ±°C	RS KΩ	T °C	TOL. ±°C	RS KΩ	T °C	TOL. ±°C
360.1	0	3.0	79.6	29	2.5	20.2	58	3.0	4.60	87	3.5
340.6	1	3.0	75.8	30	2.5	19.3	59	3.0	4.40	88	3.5
322.3	2	3.0	72.2	31	2.5	18.4	60	3.0	4.10	89	3.5
305.0	3	3.0	68.8	32	2.5	17.5	61	3.5	3.90	90	3.5
288.7	4	3.0	65.5	33	2.5	16.7	62	3.5	3.60	91	3.5
273.4	5	3.0	62.5	34	2.5	15.9	63	3.5	3.40	92	3.5
259.0	6	3.0	59.5	35	2.5	15.2	64	3.5	3.20	93	3.5
245.4	7	3.0	56.8	36	2.5	14.5	65	3.5	3.00	94	3.5
232.5	8	3.0	54.1	37	2.5	13.8	66	3.5	2.80	95	3.5
220.4	9	3.0	51.6	38	2.5	13.2	67	3.5	2.60	96	3.5
209.0	10	3.0	49.2	39	2.5	12.5	68	3.5	2.40	97	3.5
198.3	11	2.5	46.9	40	2.5	11.9	69	3.5	2.20	98	3.5
188.1	12	2.5	44.8	41	3.0	11.4	70	3.5	2.00	99	3.5
178.5	13	2.5	42.7	42	3.0	10.8	71	3.5	1.80	100	3.5
169.4	14	2.5	40.7	43	3.0	10.3	72	3.5	1.68	101	3.5
160.8	15	2.5	38.9	44	3.0	9.8	73	3.5	1.52	102	3.5
152.7	16	2.5	37.1	45	3.0	9.3	74	3.5	1.37	103	3.5
145.1	17	2.5	35.4	46	3.0	8.9	75	3.5	1.23	104	3.5
137.8	18	2.5	33.8	47	3.0	8.4	76	3.5	1.09	105	3.5
131.0	19	2.5	32.3	48	3.0	8.0	77	3.5	0.95	106	3.5
124.5	20	2.5	29.4	49	3.0	7.6	78	3.5	0.82	107	3.5
118.3	21	2.5	29.4	50	3.0	7.2	79	3.5	0.70	108	3.5
112.5	22	2.5	28.1	51	3.0	6.8	80	3.5	0.58	109	3.5
107.0	23	2.5	26.8	52	3.0	6.5	81	3.5	0.46	110	3.5
101.8	24	2.5	25.5	53	3.0	6.1	82	3.5	0.35	111	3.5
96.9	25	2.5	24.4	54	3.0	5.8	83	3.5	0.25	112	3.5
92.2	26	2.5	23.2	55	3.0	5.5	84	3.5	0.14	113	3.5
87.8	27	2.5	22.2	56	3.0	5.2	85	3.5	0.04	114	3.5
83.6	28	2.5	21.2	57	3.0	4.9	86	3.5			

Table 1

CONSTRUCTION OF THE PROPORTIONALLY CONTROLLED HEATERS

The Dawn Electronics proportionally controlled heaters are designed to heat an object attached to their base and regulate the temperature to a constant value determined by a single external resistor. As illustrated in Figure 3, all of these devices contain the heater element, the temperature sensing thermistor and the associated electronics needed to perform the temperature control function. It is the temperature sensing thermistor located on the heating surface of the device that is controlled at constant temperature. However, it is the temperature of the heater surface in contact with the object being heated that is specified. In order to maintain the temperature of the object being heated as close to the temperature of the thermistor as possible, it is important that the mating surfaces be flat and clean. In addition, thermal compound, such as Dow Corning 340, be applied between the surfaces. Typical heater base temperature change vs. thermal load are shown in the data sheet for the heaters.

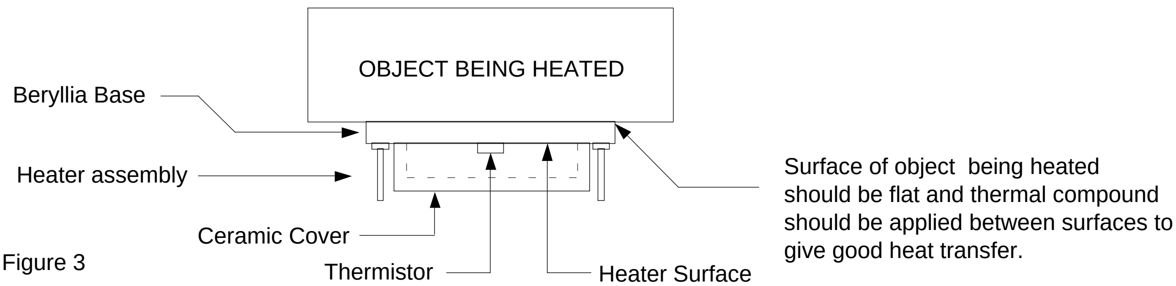


Figure 3

HEATER POWER REQUIRED TO KEEP AN OBJECT AT A CONSTANT TEMPERATURE

Equation 1.1 illustrates the amount of heating power that is required to maintain an object at a constant temperature Ts. The magnitude of the power is dependent on the difference in temperature of the object and the surrounding environment. In addition, the amount of power required to maintain a constant temperature is dependent on the properties of the object being heated such as surface area and the power generated within the object. Figure 4 illustrates how heater power varies with temperature difference and thermal resistance. This curve is for PD = 0.

1.1 $$P = \frac{1}{K}(\Delta T) - P_D$$

Where:

K is the thermal resistance of the object being heated in °C/Watt

ΔT is the difference in temperature of the object and the ambient temperature in °C

P_D is the power generated by the object being heated

P is the power required to keep the object at a fixed set temperature in Watts

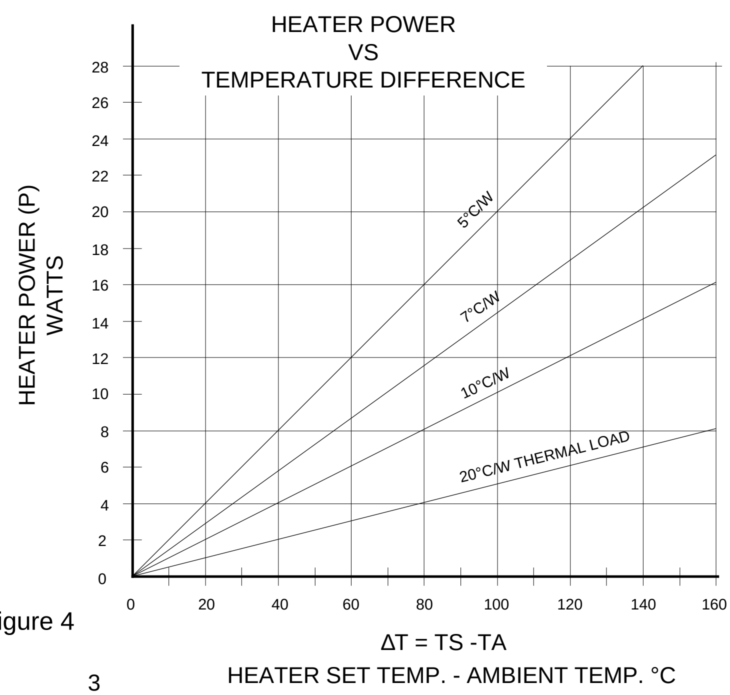


Figure 4

Figure 5 shows the amount of power required to maintain constant temperature of an object mounted to the base of the DN-515.

Example: Find the heater power required to maintain the temperature of an object at a constant temperature of 90°C when the ambient temperature is +10°C and the object being heated has a thermal resistance of 10°C per Watt.

Solution: Draw a vertical line through the 80°C mark on the temperature differential axis. The intersection of this line and the 10°C per Watt thermal load line determines the amount of power required to maintain the object at 90°C. The power required is 8 Watts which is 0.286 Amperes of current from a 28 Volt D.C. power supply.

If one Watt of heat is generated in the object being heated then the DN-515 would only have to generate 9 Watts of power to maintain the object at 90°C. It should be noted that the self heating of the object causes a10°C temperature rise by itself. Thus the DN-515 will stop regulating temperature when the ambient temperature reaches 80°C.

HEATER POWER
VS
TEMPERATURE DIFFERENTIAL
FOR THE DN-515

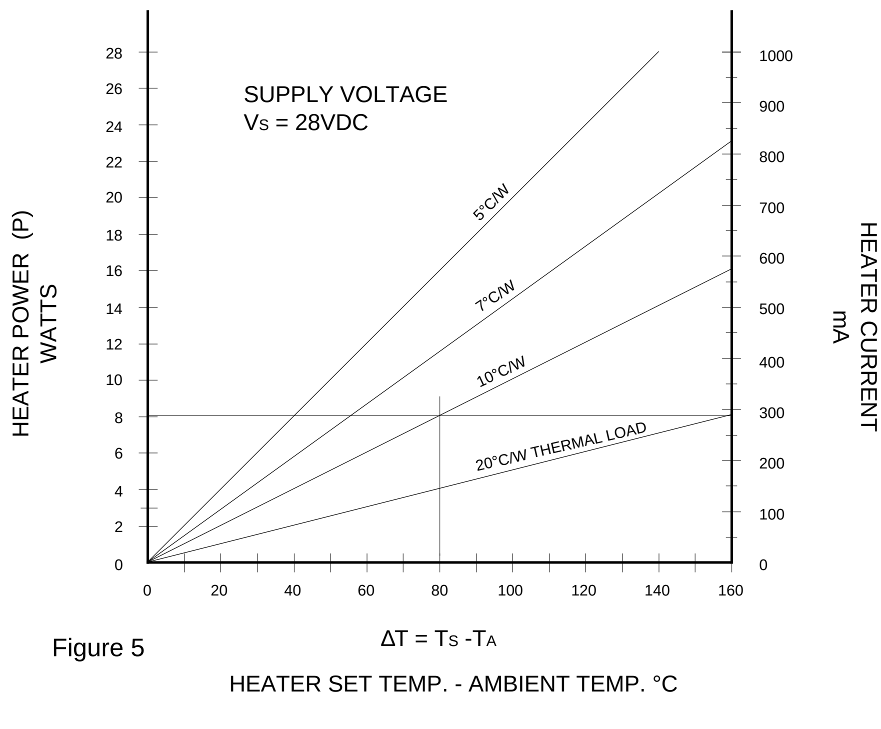


Figure 5

ALTERNATE METHOD FOR MOUNTING THE DAWN PROPORTIONALLY CONTROLLED HEATERS

The method for mounting the DN-515 and DN-520 heaters illustrated in the data sheets for these devices can result in in cracking of the substrate if care is not taken when bolting down the mounting screws. An alternate approach for mounting these devices is illustrated below. A mounting bracket is placed across the top of the heaters and screwed into the object being heated. This method of mounting distributes the clamping force across the cover of the heater thus eliminating the stress on the mounting ears on the bottom substrate. It is still very imporant that the surface to which the heater is mounted is flat and clean. Any camber in the mounting surface or particles located between the heater and the mounting surface can cause poor heat transfer or may cause breakage of the substrate.

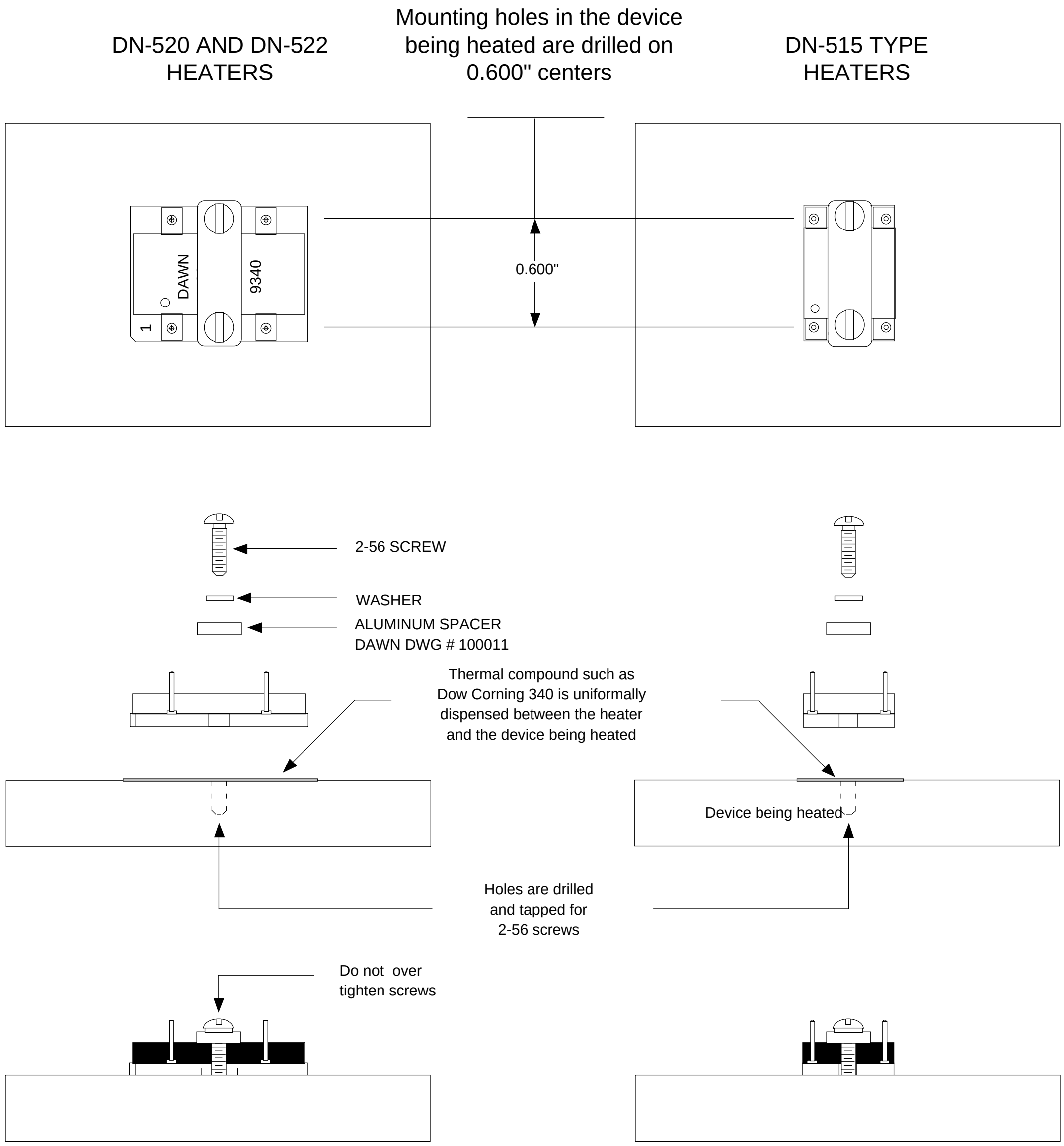


Figure 6

THE DN-505 AS A LOW TEMPERATURE BLACK BODY RADIATOR

The back surface of the DN-505 or any other Dawn heater can be used as a low temperature block body radiator for IR measurements. Painting the back of the ceramic substrate black is satisfactory or attaching an anodized aluminum plate with thermally conductive epoxy to the surface of the heater would also work . This approach is illustrated in Figure 7. The cover of the DN-505 could be epoxied to an insulator for support. This will not affect the temperature stability of the device since the cover is alumina and has a much higher thermal resistance than the Beryllia base.

If the power supply voltage is held constant, the temperature of the radiating surface should be stable to 0.3°C. Variation of surface temperature for the DN-505 vs power supply voltage is shown in Figure 8. Air currents across the radiator surface should be kept to a minimum for optimum performance.

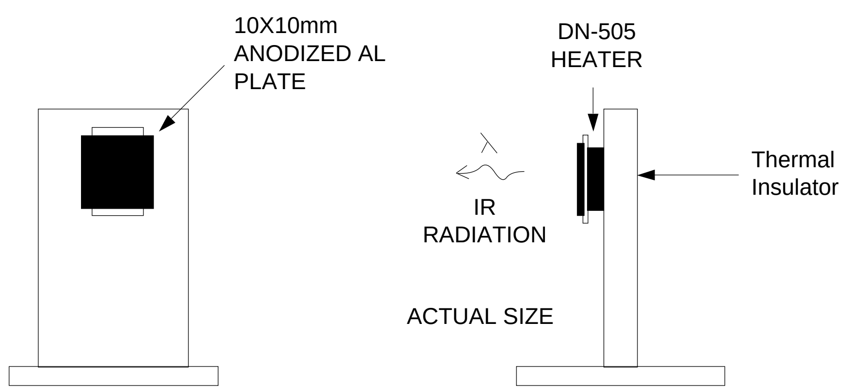


Figure 7

BLACK BODY RADIATOR USING THE DN-505

DN-505
SET TEMPERATURE CHANGE
VS
POWER SUPPLY VOLTAGE

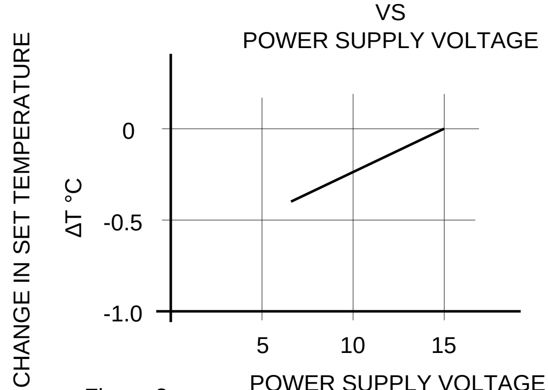


Figure 8

TEMPERATURE CONTROL USING THE DC HEATERS AND AN EXTERNAL TEMPERATURE SENSOR

The temperature of the DN-515 proportionally controlled heater is normally controlled by a thermistor located inside the device and an external temperature program resistor that is connected between Pins 3 and 4. This is illustrated in Figure 3. The temperature of the thermistor is controlled to better than one degree C over operating extremes. However, the temperature of the actual object being heated may be less than the set temperature of the thermistor due to the thermal resistance path between the DN515 heater and the object. The block diagram in Figure 9 and the schematic diagram in Figure 10 show a method of using an external temperature sensor to precisely control the temperature at the spot where the sensor is attached. This circuit overides the internal thermistor temperature sensing circuitry thus forcing the DN-515 to supply enough power to force the temperature of the external sensor to its preset value.

BLOCK DIAGRAM OF TEMPERATURE CONTROL LOOP USING AN
EXTERNAL TEMPERATURE SENSOR WITH THE DN 515 HEATER

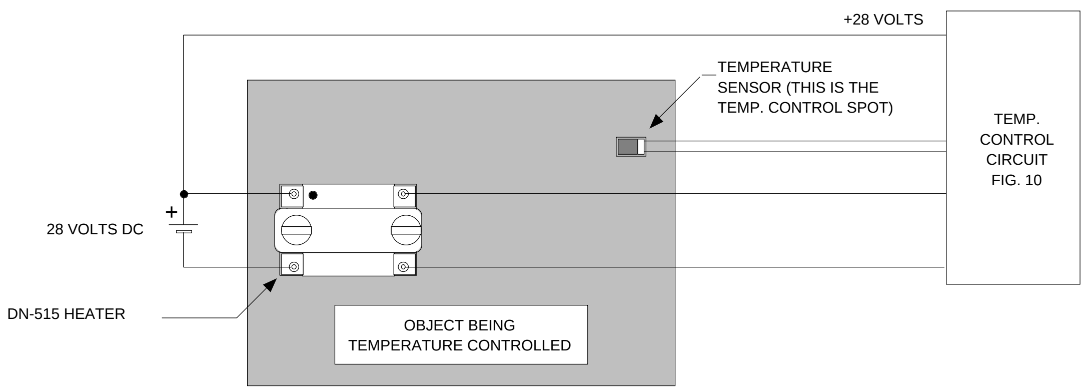


Figure 9

The circuit internal to the DN-515 has finite control loop gain (proportional control) thus the thermistor decreases in temperature as the thermal load increases. This coefficient of temperature change with power is approximately -0.035 °C per watt of heater power increase. This fact makes it possible to overide the internal control circuit of the DN-515 heater with an external temperature sensor and a circuit that contains proportional and integral control. The integrator gives the resultant control loop infinite D.C. gain thus overiding the DN-515 internal control loop. In practice, the open loop gain at D.C. is limited by the gain of the integrator amplifier and the shut resistance of the integrator capacitor.

The circuit in Figure 10 uses a Platinum RTD as the temperature sensor. This RTD along with two matched 10KΩ resistors and a temperature set resistor RS form a bridge circuit. The control loop forces the RTD to be equal to RS which balances the bridge. R4 limits the current flowing through the RTD to approximately 1mA to minimize self heating of the RDT. The resistance change with temperature of most RDTs is 0.385% per °C. Therefore the output of the bridge circuit is 3.85mV/°C for a 1,000 ohm RTD. The differential output of the bridge is applied to a combination amplifier, integrator stage. The high frequency gain of the stage is the ratio of R2 to R1 while the integrator time constant is the product of R1 and C. The amplifier gain and the integration time constant are interdependent in this circuit. A slightly more complex circuit that has interdependent gain and integration time constant control is illustrated in Figure 11.

TEMPERATURE CONTROL OF THE DN-515 USING AN EXTERNAL PLATINUM RTD

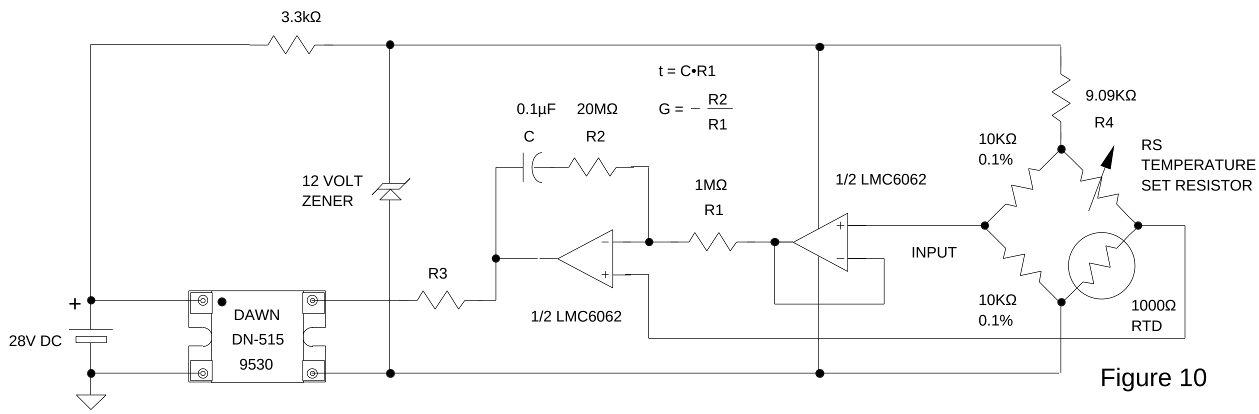


Figure 10

Notes:

1. The integrator time constant should be as close to the thermal time constant between the source of heat and the temperature sensor. The integrator time constant (t = C•R1) is best determined by experiment. A time constant that is too short may cause low frequency oscillations while one that is too long will cause slow settling times. Time constants of one to 10 seconds are common for applications employing the DN-515 heater

2. The gain of the amplifier for the circuit in Figure 10 should be set at about 50 for a 100Ω RDT and 5 for 1000Ω RTD. Once again it is best to experiment for optimum results.

3. The object being heated should be a good thermal conductor such as aluminum or copper. Make sure that the heater and the temperature sensor are in good thermal contact with this object otherwise temperature control may never be achieved.

4. Select R3 so that the set temperature of the DN-515 is 5 to 10 degrees higher than the temperature set by the external RTD. This prevents the temperature from over shooting during the turn-on cycle.

TEMPERATURE CONTROL OF THE DN-515 USING AN EXTERNAL PLATINUM RTD WITH INDEPENDENT GAIN AND TIME CONSTANT CONTROLS

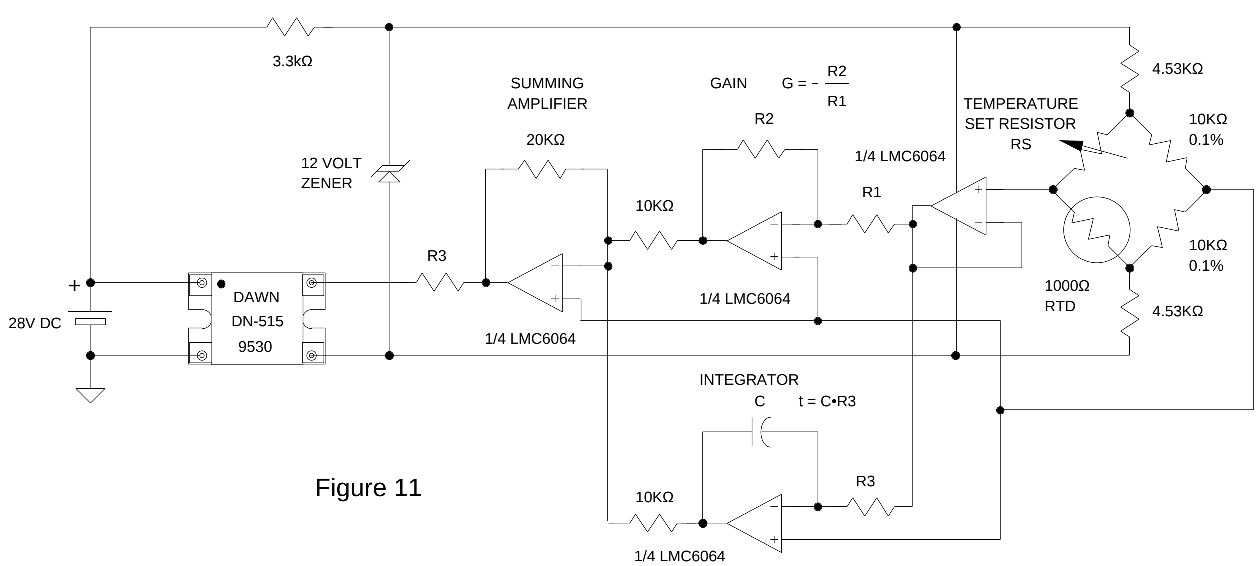


Figure 11

TEMPERATURE REGULATION WITH THERMAL LOAD VARIATIONS

The electrical current that flows in all of the Dawn heater products when the power supply voltage is first applied is the startup current. This also causes maximum power to be generated by the heater. When the temperature of the heater (thermistor) reaches the programmed set temperature, the current to the heater will be reduced to the level required to maintain the heater and the device attached to it at the set temperature.

Temperature variation of the base of the heater products with thermal load change is measured using a setup such as illustrated in Figure 7. A small hole is drilled in the base of an aluminum block and a thermistor of other temperaature sensor is mounted to the back side of the heater. Leads are brought out to a digital thermometer to measure the surface temperature of the heater. Air flow across the surface of the aluminum block is varied to change the thermal load. Base temperature variation with load is shown for the DN-515 in Figure 8. The base temperature change for thermal load change for the Dawn heaters is generally less than the temperature variation vs thermal load change shown on the data sheet for this device.

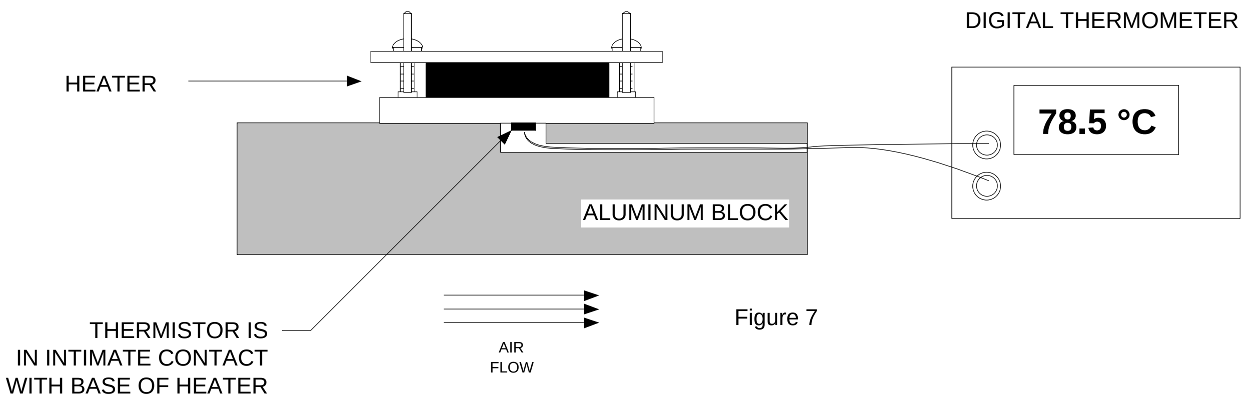


Figure 7

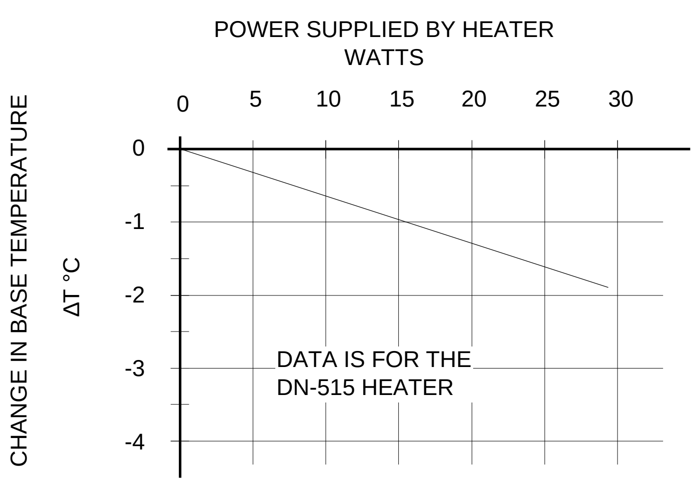


Figure 8

DAWN
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