# SMD resistors as bridgewire elements of pyrotechnical initiators

## Introduction

Pyrotechnic ejection and actuation are used extensively in rockets due to the exceptional power density they provide.
Examples of pyrotechnic<->electronic interfaces are:

- Initiation of combustion of motors both on the ground and in flight.
- Triggering of pyro-mechanical actuators such as pin pullers and pyro-pyroactuated valves
- The firing of BP charges to pressurise sections of the airframe and eject recovery equipment

Each of these tasks has its own set of requirements Presented here is an analysis of the use of small surface mount resistors for use in pyrotechnic initiators.

## Elements of a pyrotechnical initiator.

At it's core, all initiators consist of a device to convert electrical energy into heat and some sensitive pyrotechnic coating to convert this heat into combustion.
The heat generating device is nearly always a fine resistance wire between two terminals, also known as a "bridgewire". However this may be substituted with a spark gap as with the HV ignition system or the pyrogen coating may be conductive. Bridgewire materials common in amateur rocketry are: Steel wool, Nichrome wire and Magnesium wool (flash bulbs).

The pyrogen coating is usually a lacquer bonded Chlorate or Perchlorate oxidised, with a significant amount of sensitising catalyst added.

### Characteristics of bridgwires.

The two characteristics of bridgewires used in amateur rocketry are:

- All fire current, the minimum current required to guarantee the initiation of the pyrogen coating,
- Post fire resistance, or the resistance of the bridgewire after the pyrogen coating has combusted,

*All-fire current*-The requirement for High All fire currents for ground based initiation is one of safety, personnel are closest to the rocket when it is on the launch pad and having an initiator that requires several amps of current to fire reduces the risk of accidental ignition. High current sources however, are usually quite heavy, bulky, and not found in small amateur rockets. This brings about the requirement for low all-fire current devices, typically requiring < 1A to initiate the pyrogen, that can be fired from current sources as small as a good 9V battery. A good analysis of the current vs time profile of a variety of commercially available initiators is available on the web (Electrical Current Requirements of Model Rocket Igniters, Briody, Robert 2000). Interestingly Briody observed that the peak current of an AG1 flashbulb, a device usually considered to have a low all-fire current, was nearly 10 amps. It should be noted though that the device only drew this current for less than 50uS and as such, assuming a resistance of 1Ohm a 50uF capacitor across the supply terminals could supply this current. Briody goes on to test the effect of some of the lower all-fire current devices on the terminal voltage of some 9V batteries. His results show alarming dips in supply voltages which, assuming a micro controller fed from a 5V regulator with a 3V dropout, could easily cause a reset and single event failure of flight electronics. However Briody's test apparatus did not include any capacitance across the supply rails, and as such does not accurately represent the electrical configuration of a real flight system.

*Post fire resistance*-Initiators with high post fire resistances are usually designed such that the bridegwire breaks due to either the current passing through it or the heat generated by the pyrogen coating. This is an important consideration for ground based, multiple initiator applications such as clustered motors or fault tolerant ignition, because it means that when an initiator has fired (or not fired and simply burned out) all of the current supplied by the electronic circuit flows through the additional initiators, improving the probability that they will function correctly.

Most in-flight electronics can be expected to fire multiple initiators during a flight. Given that high current sources may not be available to these circuits, it is important that these in-flight initiators have a high post-fire resistance (preferably open circuit) in order to minimise stress on the power source and reduce the chance of a micro controller brown out that could result in subsequent events failing. A typical example of this is the firing and deployment of a drouge parachute at or near apogee causing a reset with the result that the main parachute is never released.

| | **All-fire current >1A** | **All-fire Current <1A** |
|---|---|---|
| **Post-fire resistance >10Ohms** | Ground based ignition, multiple initiators | In-flight initiation with multiple channels |
| **Post-fire resistance <10Ohms** | Ground based ignition, single initiator | In-flight initiation with a single channel |

**Table1,Current-Resistance matrix.**

## Bridgewire options

*Nichrome wire*-NiCr wire is the mainstay of bridgewire techniqes it is used in nearly all commercial applications and most amateur igniters and squibs. It is very cheap (less than US$1 a foot) and can be obtained in a variety of gauges. It does however have two key disadvantages: a). It is difficult to solder, requiring special fluxes, this can reduce the reliability of connections. b) It has a fairly low resistance and is difficult to obtain in very fine diameters though retail outlets. To date, the best source of fine Nichrome has been from hobby stores where it is sold as a cutting wire for battery powered foam cutters.. There has been much work done on nichrome bridgewires for amateur use see Richard Nakka's site and Johnny Dyer's pages for some good examples of the craft.

Nichrome bridgewire igniters typically require 2-10A to reliably fire. at this current the wire melts and fuses leaving an open circuit post fire resistance.

Nichrome igniters are appropriate for ground based ignition only.

*Conductive pyrogen*-Although less common than bridgewire designs, conductive pyrogen initiators are available in the market place. Copperhead igniters are perhaps the most prolific example of this. In this type of initiator the pyrogen and resistance elements are one and the same, this is achieved by adding electrically conductive material to the pyrogen mix. A common additive is lamp black, however graphite powder or fine metal powders may be substituted. The key advantage of conductive pyrogen initiators is ease of manufacture. Typically two bare wires are dipped in the pyrogen which is then allowed to harden, Solvent based (NC Lacquer) binders work well in these mixes. The amount of conductive agent required is easily determined by trial and error to achieve a resistance between 4 Ohms and 20 Ohms. Nb it is important when using NC Lacquer to allow the initiator to achieve its final resistance by letting it dry fully, either by leaving it at room temperature for 12 hours or by heating it to 100deg C for 10 minutes.

*Metal film resistors*-The use of low wattage resistors as bridgewires has been investigated previously by (Dahlquist,1998) stipulates a 20000%-40000 power overload to reliably pyrolise the resin coating of a 1/4W carbon resistor. This 50W-100W value generating a power flux of $1000\mathrm{W/cm}^2$

*SMD Resistors*-Recent experiments with 805series surface mount resistors have shown that they form functional bridgwires. Further investigation revealed that this resisitor consists of a ceramic substrate with a thin layer of nichrome plated on one side and "caps" of nickle plated on each end.

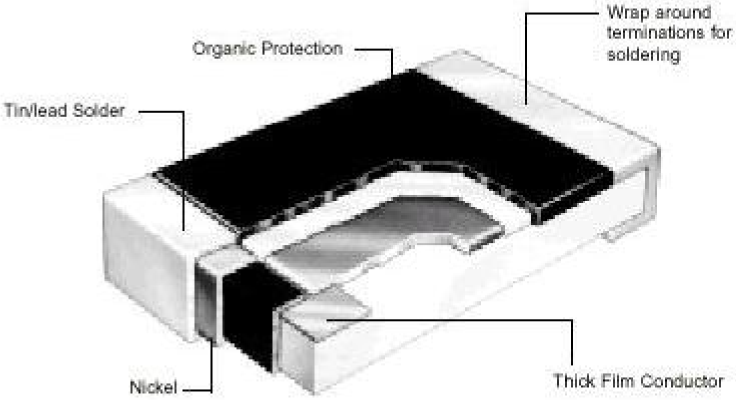


Fig1, Ceramic chip resistor construction

As with metal film, through-hole, resistors, it is necessary to generate sufficient heat to pyrolise the organic coating of the resistive element, in order to transfer heat to the material to be ignited. One of the advantages of SMD resistors is then that the surface area of the coating to be pyrolised is much smaller than that of a through-hole type, (0.018cm^2 vs 0.05cm^2). Assuming the coatings were the same then this change alone would reduce the power requirement from 50W to 18W. However the coating on the 0805 series SMD resist is substantially more volatile and values as low as 3.4W (190W/cm^2) have been observed.

## Methodology.

In order to establish the suitability to task of SMD resistors, four experiments were conducted followed by a set of field trials:

*Experiment1:*
Initially empirical tests were undertaken to determine the suitability of 0805 SMD resistors as bridgewires. Two strands of 0.1" pitch computer ribbon cable were separated, tinned and soldered to the ends of a 10ohm resistor. This was then dipped in a small container of FFFFG BP and wired in series with a peak reading multimeter. A 9V power supply was connected and the peak current recorded.

*Experiment2:*
Due to some non linearity of I vs V observed in the initial tests, an experiment was conducted to determine the surface temperature of the SMD resistor vs power dissipation.

*Experiment3:*
To further test the validity of the all-fire value of these devices 10 samples were prepared as per the aforementioned method. 5 of these were coated with a simple pyrogen consisting of 60% fine Ammonium Perchlorate and 40% Nitrocellulose Lacquer so that the effects of ionised gas on current consumption might be observed. A testing apparatus, Similar to Briody was constructed and all 10 units were fired.

*Experiment4:*
A final run of tests were performed using improved instrumentation and finer control over Pdiss, 10Ohm SMD resistors were coated with a simple AP based pyrogen. This time, current was sampled at 1Khz using a laptop with an in built version of the low cost A-D converter, a low impedance power supply was used and an optical sensor detected and accurately timed the onset of ignition.

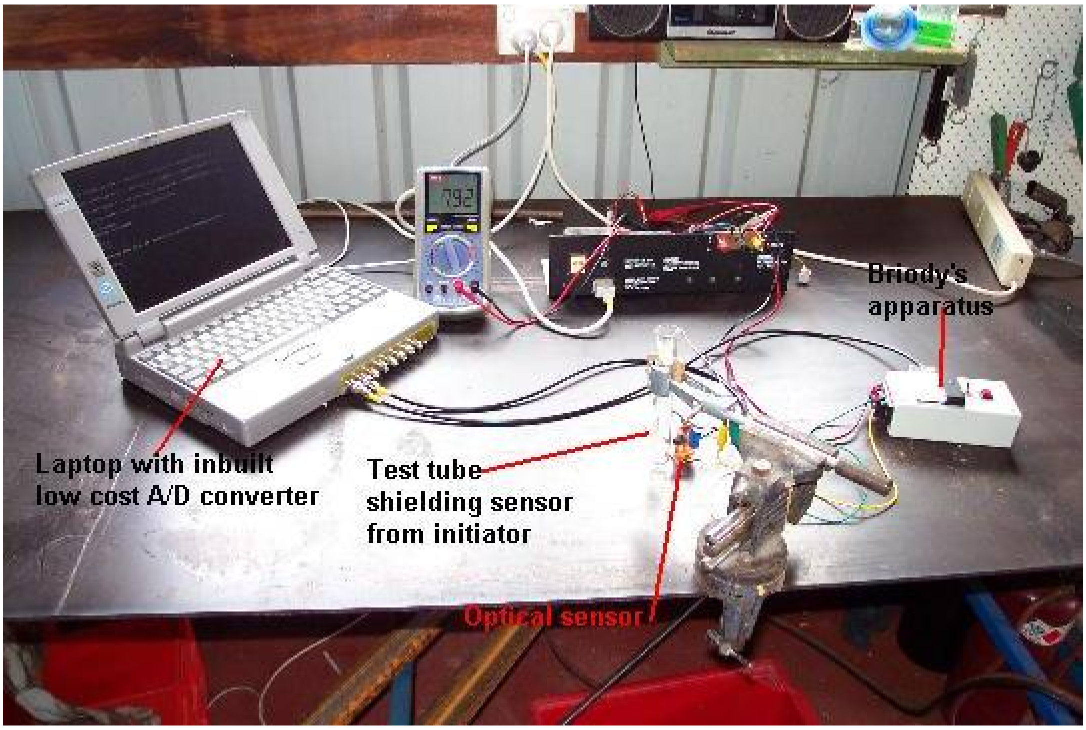


**Fig2,** Apparatus used for final tests

*Field Trials:*
Finally field trials were conducted by the Experimental Rocketry Group in which 30 initiators were used for a variety of ignition and recovery operations during an actual launching campaign.

## Results.

*Experiment #1:*
*Ignition of FFFFG BP vs current*

| Test | Resistance | Peak Current | Result |
|---|---|---|---|
| 1 | 100 Ohm | 0.09A | No Ignition, resistor remained intact |
| 2 | 47 Ohm | 0.2A | No Ignition, resistor remained intact |
| 3 | 20 Ohm | 0.43A | Ignition after 5 seconds, open circuit after firing |
| 4 | 10 Ohm | 0.63A | Ignition in <0.5 seconds, open circuit after firing |
| 5 | 10 Ohm | 0.6A | Ignition in <0.5 seconds, open circuit after firing |
| 6 | 10 Ohm | 0.64A | Ignition in <0.5 seconds, open circuit after firing |

**Table2**

*Experiment #2:*
*Temperature vs Power*

| Test | Peak Current | Voltage | Power | Temperature |
|---|---|---|---|---|
| 1 | 0 | 0 | 0W | 25 deg C |
| 2[1] | 110mA | 1V | 0.11W | 42 deg C |
| 3 | 390mA | 3V | 1.17W | 161 deg C |
| 4 | 400mA | 4V | 1.6W | 190 deg C |
| 5[2] | 450mA | 5V | 2.5W | N/A |

[1], rated maximum dissipation for the device

[2], device went open circuit before a temperature reading could be taken

**Table3**

*Experiment #3:*
*Current vs time (Briody's Aparatus)*

| | |
|---|---|
| | **Test #:** 1<br>**Bridgewire:** 10Ohm 0805 SMD resistor<br>**Power supply:** 9V Alkaline battery<br>**Vertical scale:** 500mA/div<br>**Horizontal scale:** 100mS/div<br>**Fire current:** 770mA<br>**Description:** Uniform heating for maximum energy transfer to propellant. Burnout occurred after approx |

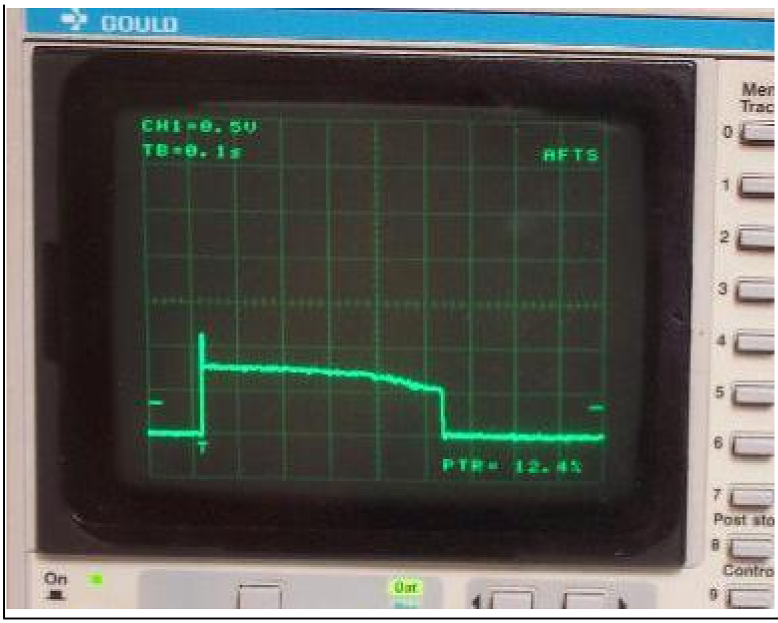
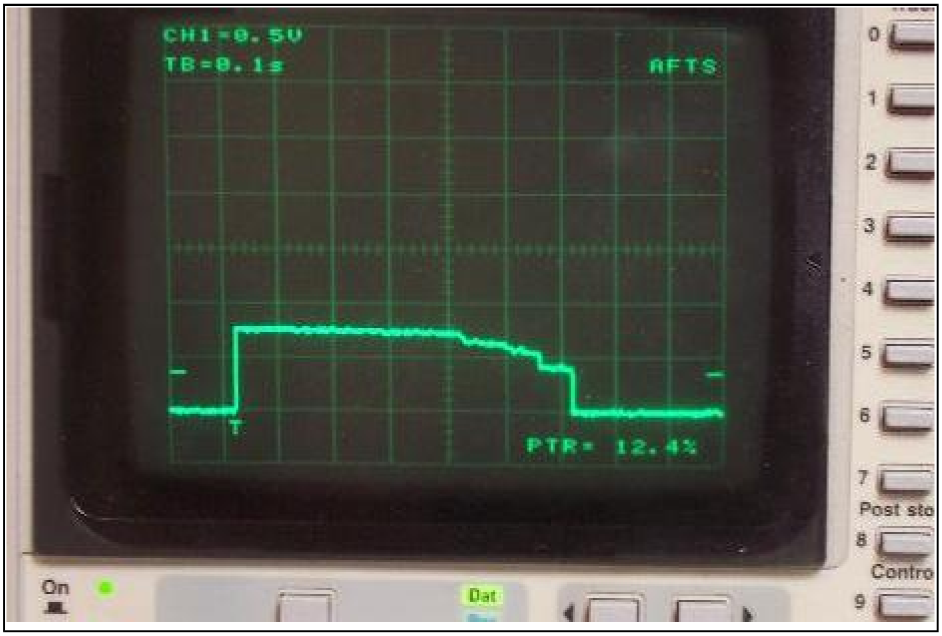
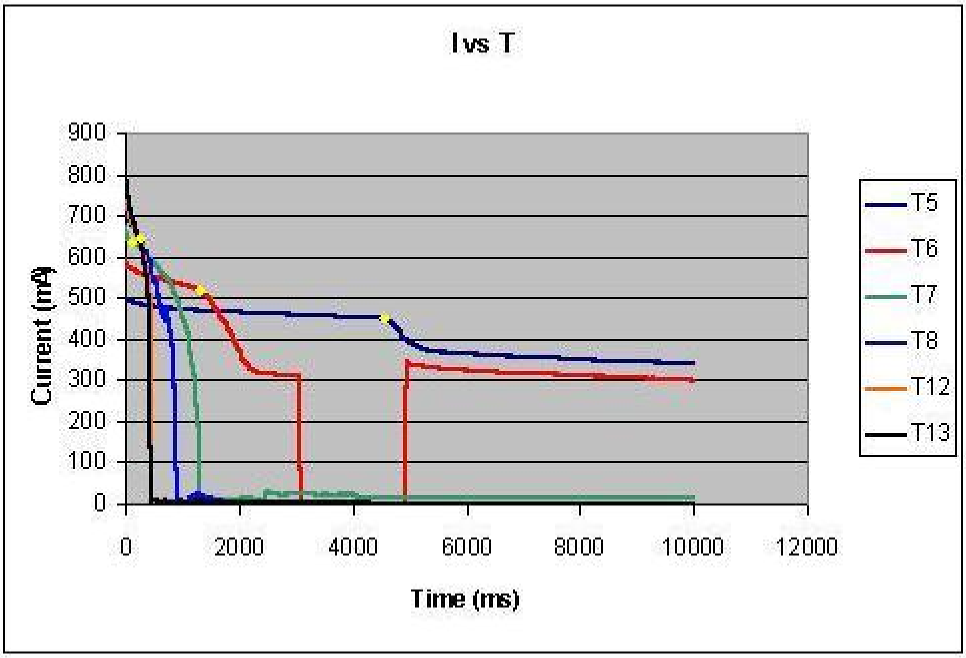
| | |
|---|---|
|  | 0.5 seconds at which point the resistor became open circuit. |
| | **Test #:** 2<br>**Bridgewire:** 10Ohm 0805 SMD resistor<br>**Power supply:** 14V, Low impedance<br>**Vertical scale:** 2A/div<br>**Horizontal scale:** 20mS/div<br>**Fire current:** 1.5A<br>**Description:**In this test, the resistor fused in about 5ms, there was insuffcient energy released to carburise the organic coating of the chip and an initiator failure resulted. |
|  | **Test #:** 3<br>**Bridgewire:** 30Ohm 0805 SMD resistor<br>**Power supply:** 14V, Low impedance<br>**Vertical scale:** 500mA/div<br>**Horizontal scale:** 100mS/div<br>**Fire current:** 750mA<br>**Description:** It is important to maintain approximately 700mA through these resistors. |

Table4

### *Experiment #4:*
### *Ignition of AP vs Currrent (Improved aparatus)*

| Test | Voltage | Ignition time | Current at Ignition | Pdiss at ignition |
|---|---|---|---|---|
| 1 | 2V | no ignition | | |
| 2 | 3V | no ignition | | |
| 3 | 4V | no ignition | | |
| 4 | 5V | no ignition | | |
| 5 | 6V | 4530mS | 448mA | 2.67W |
| 6 | 7V | 1270mS | 616mA | 4.3W |
| 7 | 8V | 320mS | 616mA | 4.9W |
| 8 | 9V | 350mS | 613mA | 5.5W |
| 12 | 9.5V | 330mS | 605mA | 5.75W |
| 13 | 9.75 | 260mS | 641mA | 6.2W |
| 9 | 10V | no ignition | | |
| 10 | 11V | no ignition | | |
| 11 | 12V | no ignition | | |

**Table5**



Current vs time for tests 5,6,7,8,12,13 (where ignition was observed)
Marker indicates ignition time
Nb. The dropout in T6 was caused by a digital misplacement.

**`Fig3, Ceramic chip resistor construction`**

*Field trials:*

| **Launch** | **Initiator role** | **Result** |
|---|---|---|
| **1:** 29mm Commercial AP Motor | Ignition (pyrogen coated) | Successful ignition |
| **2:** 29mm Commercial AP Motor | Ignition (pyrogen coated) | Successful ignition |
| **3:** Candy Motor | Deployment charge (no coating on resistor) | Successful deployment |
| **4:** 40mm N2O Hybrid motor with Candy ignition slug | Ignition (pyrogen coated) | Successful ignition |
| **5:** 29mm Comical AP Motor | Ignition (pyrogen coated) | Successful ignition |
| **6:** Candy Motor | Deployment charge (no coating on resistor) | Successful deployment |
| **7:** 29mm Comical AP Motor | Ignition (pyrogen coated) | Successful ignition |
| **8:** 40mm N2O Hybrid motor with Candy ignition slug | Ignition (pyrogen coated) | Successful ignition |
| **9:** 29mm Comical AP Motor | Ignition (pyrogen coated) | Successful ignition |

## Discussion

*Experiment #1:*
These tests showed that reliable ignition of FFFFG gunpowder, a common ejection charge composition, with a known ignition temperature of 250deg C (online http://www.sciencenet.org.uk/Origins/gunpowder.html) was possible when the resistors were forced to dissipate more than 4W of power.

Post fire inspection of the resistors that could be recovered showed the NiCr film had fused and melted. Combined with the observed all-fire current of 0.6A, indicated that these devices might make acceptable, in-flight, initiators.

*Experiment #2:*
The manufacturer of the SMD resistors quotes a temperature coefficient of 50degC/W The observed value of 61.4 degC/W is very close.

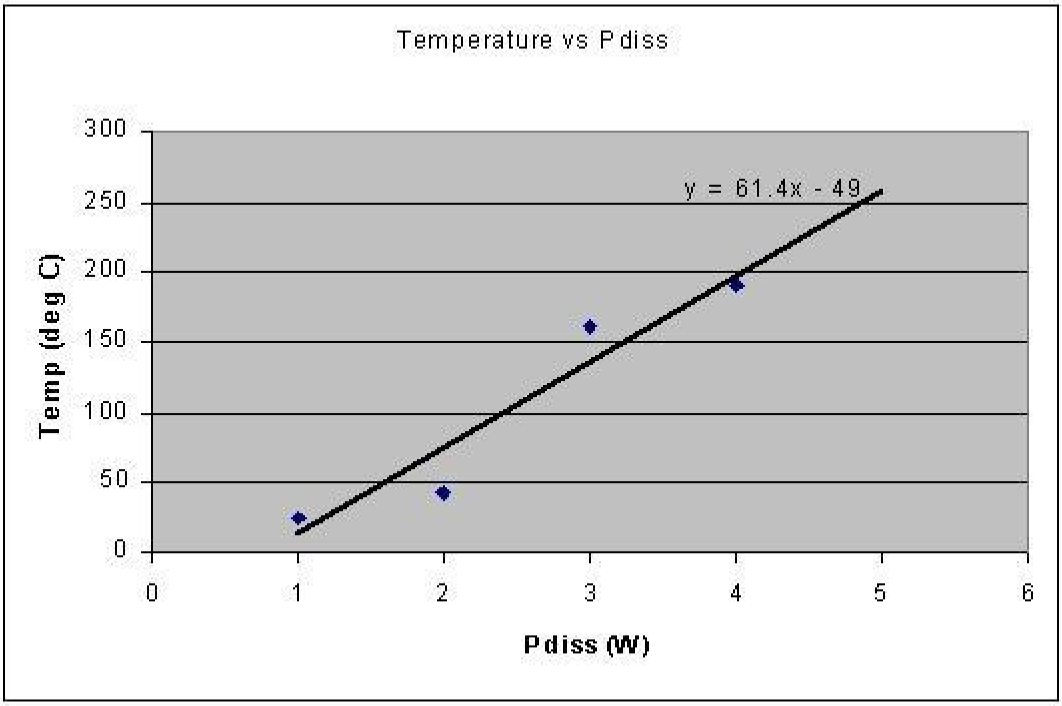


**Fig4, Temp vs $P_{dis}$chart**

$$T \approx 61.4 P_{dis}$$

Eqn 1.

*Experiment #3:*
This series of tests gave the first evidence that over driving the resistors could cause failure. Test 2 clearly shows that the NiChrome resistive element fused before raising the temperature of the resistor to the ignition point of the pyrogen coating (approx 350 deg C). It is interesting to note that Dahlquist makes no mention of this phenomenon. The reason that non SMD resistors do not exhibit this behaviour is probably due to the resistive element being coated on all surfaces by a thermally conductive coating.
In the case of the SMD resistors, 50% of the surface of the resistive element is insulated by the ceramic base of the device. This allows high temperatures to build quickly on that surface, fusing the resistive element before the entire device can reach an elevated temperature.
This is important because, when combined with the temperature coefficient observed in Experiment #2, it establishes the minimum sensitivity required for a pyrogen to work with these devices.

*Experiment #4:*
The enhanced accuracy of the apparatus used here allowed the usable power range (with conventional pyrogens) to be fairly well defined as 4-6.5W.

If we take the 6.5W figure and apply a temperature coefficient of 61 degC/W then the least sensitive pyrogen that could be used with SMD resistor bridgewires would have an ignition temperature of 396degC. Fortunately there are many pyrogens more sensitive than this.

*Field trials:*
The narrow range of allowable Pdiss for these devices makes the 100% success rate in the field seem unusual. In all field testing and ground testing of flight electronics (totalling >50

tests), no failure of SMD resistor based initiators has been observed. The reason for this appears to be that the flight systems used are all powered by 9V batteries. These devices have a fairly high internal resistance, typically 5 Ohms, combined with the observed resistance of a 10 Ohm SMD resistor at 300+ degree's (15Ohms) limits the maximum current that can be supplied to approx 0.5A. In other words the internal resistance of the 9V battery and the ohmic resistor act as a constant current source. T6,T7,T8,T12,T13 in experiment #4 demonstrate part of this behaviour, displaying very uniform current over a range of voltages.

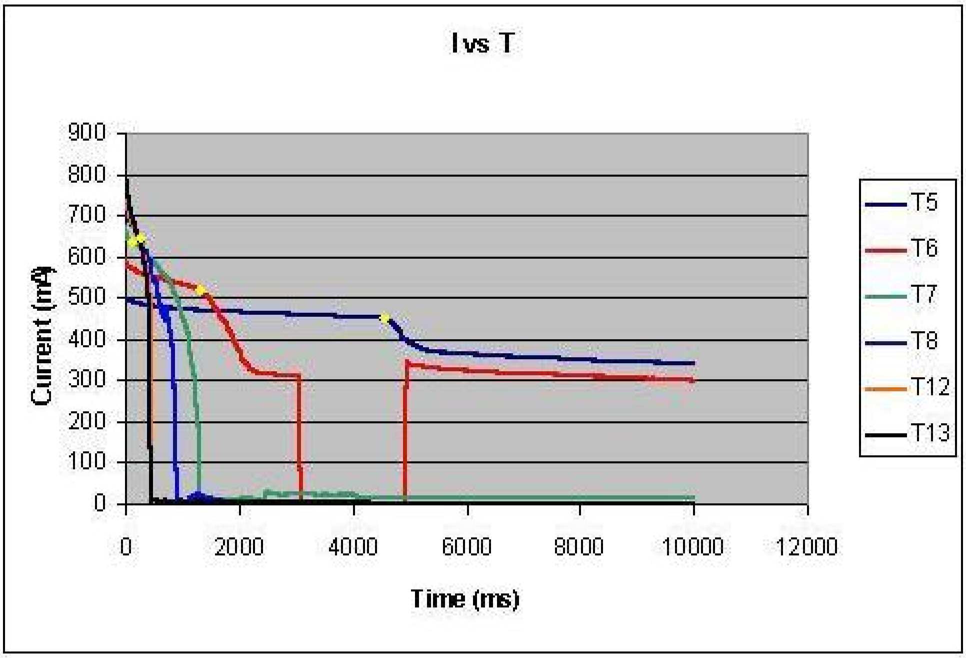


Fig5, Current v's time chart

Referring back to Experiments #4, and #2, change in resistance vs temperature can be tabulated.

| T(degC) | R (Ohms) | Delta R (%) |
|---|---|---|
| 264.02 | 11.36364 | 13.6% |
| 300.86 | 12.98701 | 29.9% |
| 337.7 | 14.68189 | 46.8% |
| 353.05 | 15.70248 | 57.0% |
| 380.68 | 15.21061 | 52.1% |

Table6

Regression analysis gives

$$\Delta R = 0.0037 \times T$$

Eqn2 Ohmic coefficient

The large change in effective resistance at elevated temperatures means (up to 57%)that the derived Ohmic coefficient must be included when calculating resistance values.

## Calculating appropriate value of R for a give voltage and pyrogen

Ohms laws

1).
$$E = I \times R$$

2).
$$P = I^2 \times R$$

3).
$$P = \frac{E^2}{R}$$

4).Substituting 3 into Eqn1

$$\frac{E^2}{R_{Effective}} = \frac{T_{ign}}{61.4}$$

5). Solving for $R_{effective}$

$$R_{Effective} = \frac{E^2}{0.016287 \times T_{ign}}$$

6). Eqn2 solved for $R_{effective}$

$$R_{Effective} = R \times 0.0037 \times T_{ign}$$

7). 5 and 6 Solved for R

$$R = \frac{E^2}{6.0262 \times 10^{-5} T_{ign}}$$

## Conclusion

805 series SMD resistors make effective, low all fire current, high post fire resistance, bridgewires for pyrotechnic initiators. Some care needs to be taken to calculate the correct value of R to use, however significant numbers of field trials indicate that an engineering "sweet spot" exists when these devices are used with the 9V batteries typically used to

power amateur flight electronics.

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