Super Capacitor Power System for Sounding Rocket Payloads

P.P.Antony, S. Saju, R.G.Hari kumar Warrier, B.Manoj Kumar

Vikram Sarabhai Space Centre, Indian Space Research Organisation
Thiruvananthapuram, India 695022

ABSTRACT

Sounding rockets are a means of accessing middle atmosphere region for doing in-situ measurements of wind velocity, density measurements of electron, ion & photon, neutral wind velocity etc. RH200 chaff payload sounding rocket is intended to measure the middle atmosphere wind velocity about an altitude of 60-75 km using copper chaff cloud. The payload contains a sequencing timer, batteries & its associated pyro devices. The sounding rocket batteries are made up of high-energy silver-zinc(Ag-zn) cells capable to deliver high discharge pulse currents for pyro devices as well as the timer working voltage for a flight duration of about 120 seconds. These batteries require definite preparation time since it involves electrolyte filling, soaking and formation cycles, charging/discharging activation and its wet life is only six months. Sounding rocket launch schedules are highly volatile in nature and this paper gives a solution to above problem by using super capacitors instead of silver-zinc batteries. Super capacitor configurations, various test methods, qualification cycle and launch safety aspects adopted to induct these devices for aerospace use are described. Maxwell make ultra-capacitors were successfully flight tested in ISRO RH200 two-stage sounding rocket launched from Thumba equatorial rocket launching station (TERLS) and the test results are also included in this paper.

***Key words:** super capacitor, Pyro devices, telemetry, squib, countdown, launch, sounding rocket, sustainer, chaff ejection*

1. INTRODUCTION

Super capacitors are electrochemical devices which performs mid-way between batteries and conventional capacitors. As compared to batteries these devices can store only limited amount of charge but its power density is very high hence it can deliver high amplitude current pulses of multiple times.

High charge retention, ultra low internal resistance, high capacitance values are the other important features of super capacitors. Since the individual device voltage is only 2.5V, super capacitors are to be connected in series to get the required supply voltage. Super capacitor cell balancing during charging and charge retention schemes to be taken into consideration while dealing with super capacitors. Generally super capacitors are connected in parallel to batteries to improve their power delivery capacity for handling transient peak pulse loads.

RH200 sounding rocket is a two stage vehicle uses solid propellant with an overall length of 1180 mm and a lift mass of 120kg. First (Booster) stage is ignited from ground and Second (Sustainer) stage as well as chaff ejection pyro initiators are commanded by the onboard sequencing timer.

The avionics system power requirements of sounding rocket payloads are generally very small (less than 250 joules) however high energy batteries are used presently for meeting the high discharge current pulse loads of pyro devices. Most of the charged battery capacity wasted in battery itself even after completing the flight duration. Super capacitor power source design gives more focus on total energy delivery with adequate margin hence the size and weight of power source can be reduced.

As the super capacitor research progresses and in future dynamically variable capacitors also may be available to maintain a constant voltage output which further reduces the size and volume of capacitors.

2. PAYLOAD AVIONICS CONFIGURATION

Payload avionics have two functions; one system consists of super capacitor interface unit, sequencing timer & pyro devices in functional chain for the rocketry and the other system is to monitor their flight performance using Pulse code modulation (PCM) telemetry and S-band transmitter operating on Ag-Zn battery as shown in Figure 1. .

The electrical system have features like power changeover control relays, battery charging and monitoring circuits, relay pole voltage monitoring circuit etc. A 10 channel PCM encoder with analog to digital converter at a data rate of 200 kbps, 0.5W S-band transmitter forms the onboard telemetry chain. Super capacitor voltage and current values are transmitted during flight.

Super capacitors are configured in two bank sections where the first bank with five capacitors connected in series for the working of onboard timer working supply and the chaff ejection release pyro and the second bank section with two capacitors connected in series for the sustainer ignition pyro initiation. AD8202 instrumentation buffer amplifier and non-invasive hall-effect current sensor is used for voltage and current monitoring circuits respectively. For electrostatic discharge protection bleeder resistors are provided at battery sources and pyro initiator circuits.

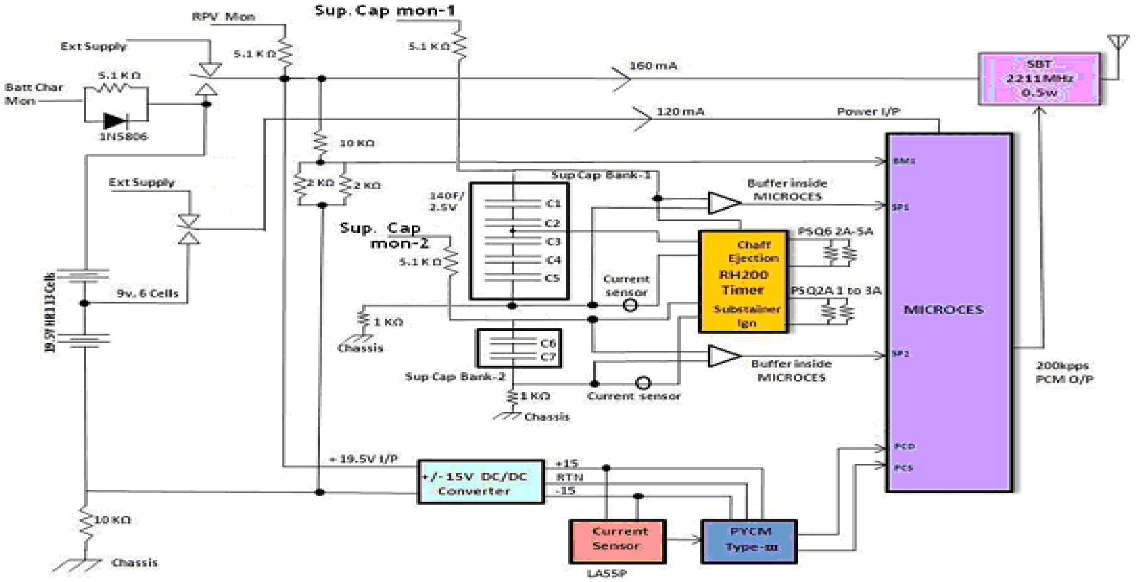

Fig.1. Payload avionics configuration

3. SUPER CAPACITOR ESTIMATION TECHNIQUES

Super capacitors are charged from ground power supplies and its discharge starts from rocket take-off. The energy storage capacitor power source should have sufficient capacitance value to maintain the voltage in the prescribed range for a specified amount of time. The parameters to determine the capacitor value are maximum to minimum operating range of working voltage, current drawn and discharge duration. In this case the capacitance estimation is given below.

Working voltage range (V_w) = 10V to 7.5V

Estimated current (I_L) = 250mA

Discharge duration (t_d) = 120 Seconds

Energy delivery (ΔE) = $V_w * I_L * t_d$ (1)

Eq. (1) gives a maximum energy delivery of 300 Watt-seconds or joules. From this equation the capacitor value can be estimated by eq(2).

$$\Delta E = \frac{1}{2} C(V_i^2 - V_f^2) \quad (2)$$

Where C - Capacitor value, V_i – Initial discharge voltage, V_f – Final discharge voltage.

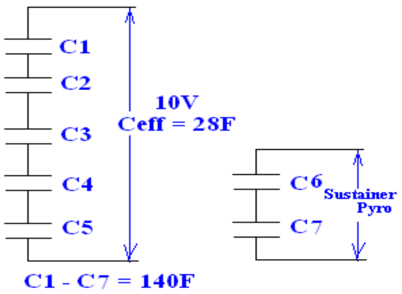

Figure 2. Super capacitor stack configuration

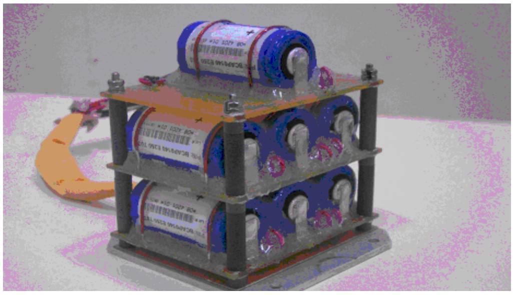

Figure 3. Photograph of super capacitor unit

From eq(2) the capacitor value estimated as 13.71 Farads. Absolute maximum rating of super capacitors is 2.5V and to ensure necessary de-rating it is charged up to 2V only. Hence 5 capacitors are to be connected in series to get a working voltage of 10V. Individual capacitor value should be 68.55 Farads (13.71 * 5). 140F super capacitor from Maxwell is selected which is above the estimated value. The energy requirement for pyro suib firing is very low when compared to timer working and only the required voltage and current to be ensured for an action time of less than 10 milli-seconds. Super capacitor stack configuration is shown in figure 2. where the two capacitors connected in series (4V/5A) for giving the sustainer rocket ignition. Super capacitor interface unit photograph is shown in figure.3.

4. QUALIFICATION CYCLE

Super capacitors have to be qualified and further undergo a qualification cycle as given figure 4 before using it in sounding rockets or any other aerospace systems.

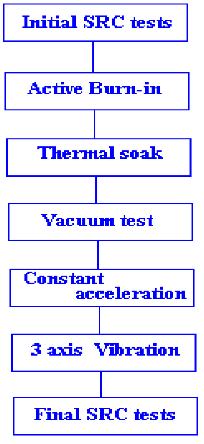

Figure 4. Qualification cycle

A. Initial Standard room condition (SRC) tests

During SRC tests capacitor parameters like capacitance value, equivalent series resistance (ESR), and leakage current are to be measured. After SRC tests unit under test should undergo environmental tests as per the flow chart given in figure 4 these parameters are verified during all the tests and values should be within the specified tolerances limit otherwise the unit would be rejected. Test setup photograph is shown in Figure 5. The test setup has power supplies and high sampling data acquisition system for assessing capacitor parameters.

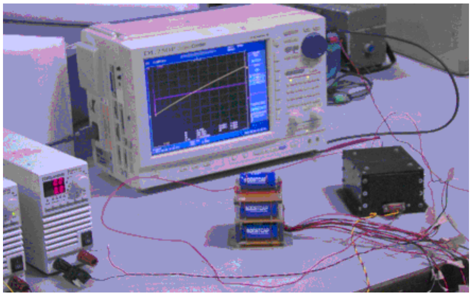

Figure 5. Photograph of capacitor parameter estimation test setup

B. Super capacitor parameter estimation

(i) Capacitance

Applying a constant charging current and measure the voltage across the capacitor where capacitance as given in eq (3). Time taken from 0V to 2V at constant current is a direct measure of capacitance value.

$$C = I_C * t_c/(V_f - V_i) \quad (3)$$

Where C-capacitance, I_C - Charging current, t_c – Charging time, V_f - Final voltage, V_i - Initial voltage.

ii) Equivalent series resistance (ESR)

ESR is the measure of voltage drop observed across super capacitor terminals when a constant load current is delivered as given in eq (4).

$$ESR = (V_i - V_f)/I_d \quad (4)$$

Where V_f - Final voltage, V_i - Initial voltage and I_d – Discharge load current.

(iii) Leakage current

The leakage current is a measurement of current drawn from the charging source after holding the device at rated voltage for 72 hours continuous at room temperature. The measured leakage current will be influenced by the temperature during the measurement, the voltage at which the device is measured and the age of the product. Ideally capacitors take infinite time to get fully charged but the longer the super capacitors held on charge the lower the leakage current of the device. This is due to the extremely large surface area of the electrode the time constant of the last 0.5% of the electrode area is extremely long due to the pore size and geometry.

C. Environmental testing for qualification

During environmental testing various test conditions are excised on super capacitor unit to ensure the reliability as well as the design margins. The test conditions are derived from the environmental test levels for sounding rockets. Flight acceptance level is lower than that of qualification level.

5. ROCKET ASSEMBLY & TESTING

The qualified unit is assembled in the rocket payload and an integrated testing have been carried out before the actual flight. During this testing super capacitor discharge voltage, load current, pulse loads of pyro devices have to be verified through telemetry link. Rocket assembly, testing and launch operations were carried out as per the flow chart given in figure 6.

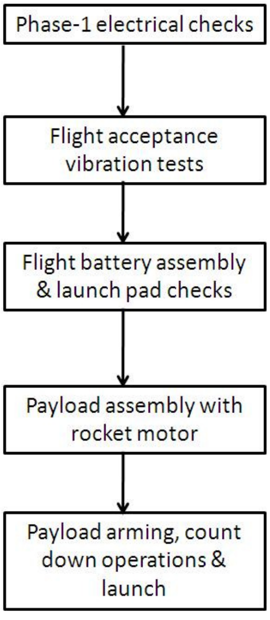

Figure 6. Electrical integration Flowchart for RH200 launches

Payload Avionics power system interfaces, signal conditioner gain setting, PCM slot allocation of measurements, RF radiated checks of transmitters, sequencer timer checks and pyro line testing with test squibs are carried out during phase-1 electrical testing. Then the subassemblies are mechanically integrated and flight acceptance vibration testing is carried out. Flight battery assembly, payload electrical umbilical interface checks, ground station telemetry interface checks will be carried out before the payload integration with rocket motor.

Safety interlocks are provided in the pyro line circuit and squibs were also kept safe till last minute launch operations. During pyro arming squibs were electrically connected to battery circuit and the squib initiation take place when commanded. Since the squibs are untested explosive devices redundant circuits are provided. Avionics systems are powered from external power supplies through umbilical and it will be changed over to internal battery just before the rocket lift-off.

6. RH200 SBT-07 SUPER CAPACITOR EXPERIMENTAL FLIGHT RESULTS

SBT-07 instrumented flight performed as expected and very encouraging results are obtained. Capacitor discharge plot shows a voltage fall of about 1V only during the timer working. Squib currents are recorded in the band of recommend firing current. Figure 9 shows the current verses voltage plot of super capacitor discharge during flight. Flight went up to an altitude of 60km for chaff release and wind velocity measurement.

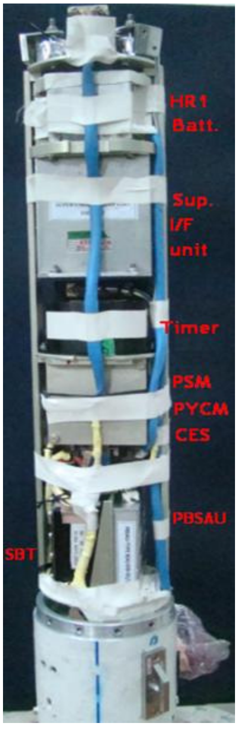

Figure 7. Payload avionics elements

Figure 8. RH200 SBT-05 ready for lift-off

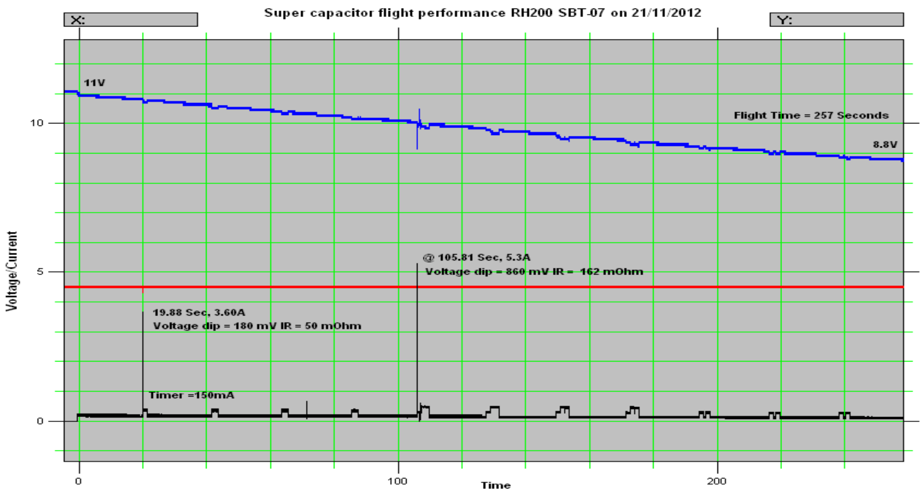

Figure 9. Super capacitor voltage and current plot of RH200 SBT-07

7. CONCLUSION

Presently work is in progress to make more sounding rocket launches with the latest range of super capacitors. This is very reliable cost-effective solution for sounding rockets. At the same time various efforts are in progress to induct this technology in avionics power system management circuits of launch vehicle's critical elements. Indigenous super capacitor development efforts are also planned.

8. REFERENCES

[1] Sven G. Bilén and Jesse K. McTernan : " Electrodynamic tethers for energy harvesting and propulsion on space platforms" AIAA 2010-8844 30 AIAA SPACE 2010 Conference & Exposition August - 2 September 2010, Anaheim, California.

[2] Tatsuo Shimizu and Craig I. Underwood "Power subsystem design for micro-satellites using super-capacitor storage" AIAA 2009-4500 7th International Energy Conversion Engineering Conference 2 - 5 August 2009, Denver, Colorado.

[3] Duran-Gomez J.L., Enjeti. P.N., von Jouanne .A, "An approach to achieve ride-through of an adjustable-speed drive with flyback converter modules powered by super capacitors" IEEE trasactions on industry applications Vol.38, Issue 2, pp.514-522, 2002.

[4] M.G. James, P.P. Antony, D.R. Gurunath, R.G. Harikumar Warrier : "Super capacitor for RH200 instrumented flight – test plan document ", MVIT-SEIG-BEID-682-12, Issue-1 dated Aug-2012.

[5] Henry Mechado : "Evaluation of Maxwell technology power cache ultra-capacitor" SAIC – JSC/NASA

[6] Michael J. Marcel and John Baker: "Integration of ultra capacitors into the energy management system of a near space vehicle" 5^{th} International energy conversion engineering conference and exhibit(IECEC),25-27,june 2007, St.Louis, Missouri.