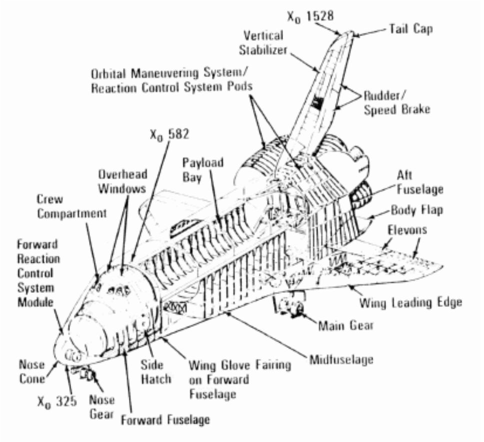
Failed cell detection circuit

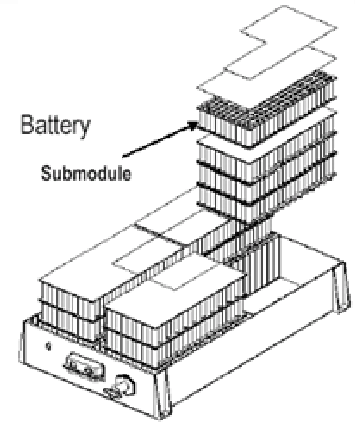
Frank Davies

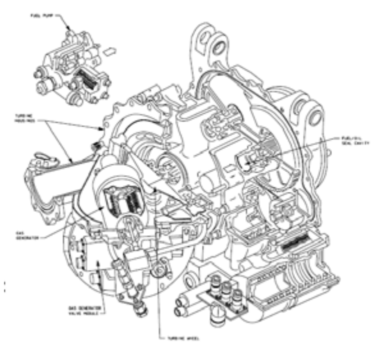
September 2, 2014

- This circuit was designed to provide a fine-grained pre-mission check on a critical system.
- The Space Shuttle had a hydraulic system that used a pump driven by a 135 hp hydrazine turbine.
  - Hydrazine fire was in the top-ten list of hazards (fire during landing in 1983)
  - Shuttle program funded program (EAPU/AHPS) to replace the hydrazine turbines with a battery/motor system.
  - Effort cancelled later.
- One of two candidate battery systems had 41 banks of 80 18650 size cells in parallel (41S-80P).
- We needed a simple pre-flight test system that could verify that all cells were functioning properly.
  - Test system must add minimal mass and connectors



Orbiter





In batteries built with many parallel strings of cells it is complicated to detect non-functional or damaged strings.

- One bad string in a large number of parallel strings makes a small percentage difference but significantly affects safety margins.
- Faulty strings can be detected by monitoring individual currents during load tests, but monitoring many parallel strings gets complicated.
- If each string has a resistive current shunt, many wires must run from the battery to the equipment used to test it. In a high voltage, high power battery, these wires present safety concerns because they are not isolated from the high voltage buss.
- Having isolated current sensors solves the safety concerns, but such sensors are bulky and do not solve the problem of a large number of sensor wires exiting the battery.

- Technology covered by NASA patent 8,570,047

Advantages:

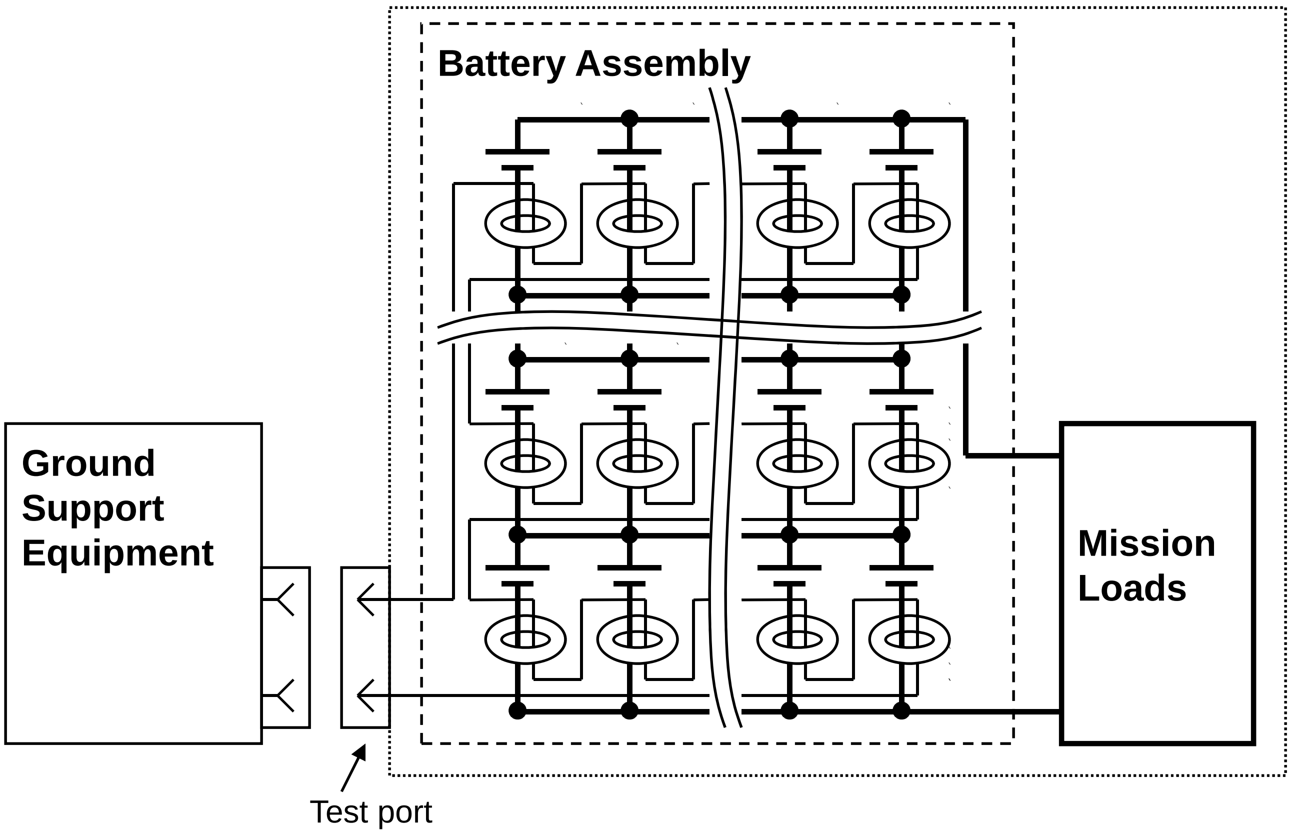
- Easy detection of single string fault among many strings.
- Minimal components added to battery (one toroid core per string plus winding wires)
- Core saturation minimizes effects on battery impedance when battery is supplying nominal load current.
- Electrical isolation intrinsic to design.
- No effect on battery DC and low frequency impedance.

Disadvantages:

- Small effect on battery impedance at high frequencies.
- Extra connector on battery is necessary.

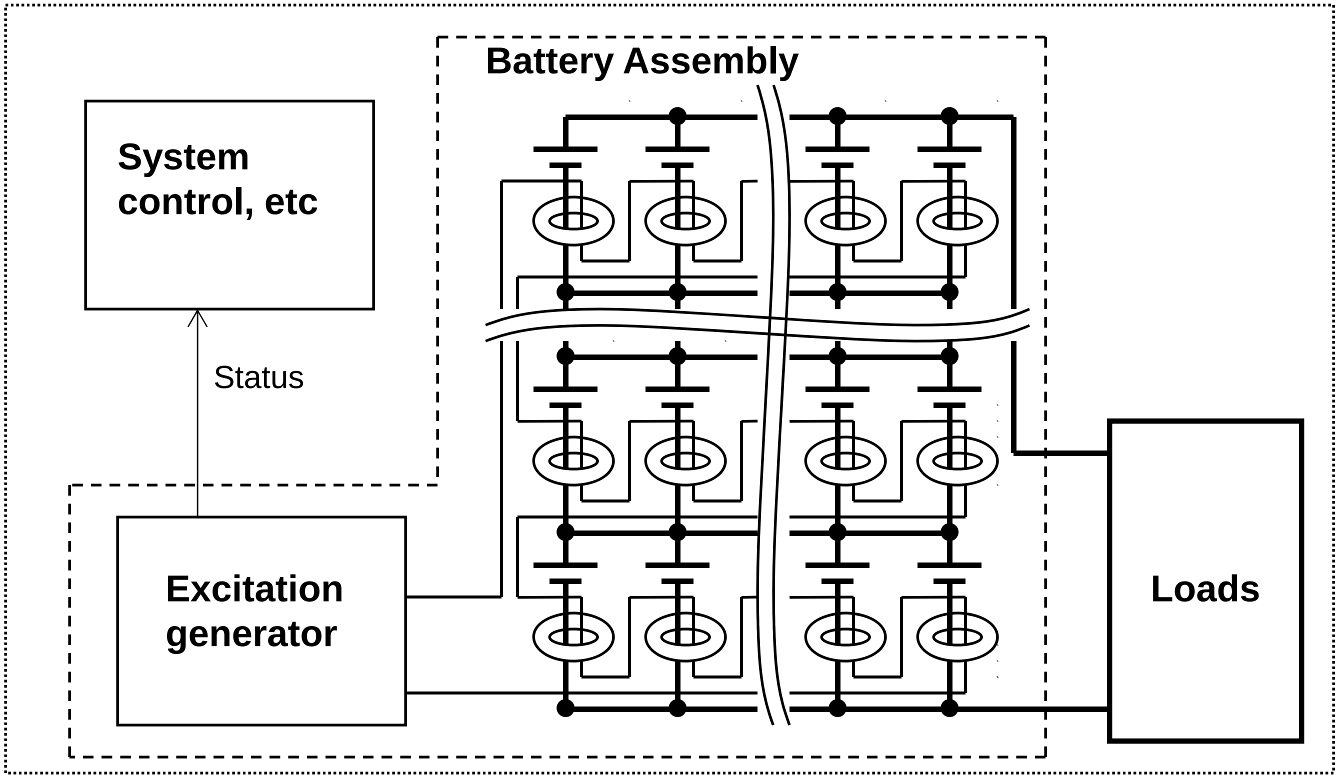
Pre-operational check

For operations and missions where battery mass and size are critical and opportunities for maintenance or reconfiguration during the mission are limited.

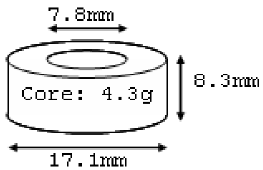


Continuous monitoring:

For operations without a distinct pre-operational test phase, where continuous monitoring is merited because maintenance or reconfiguration can be performed in response to a detected problem.

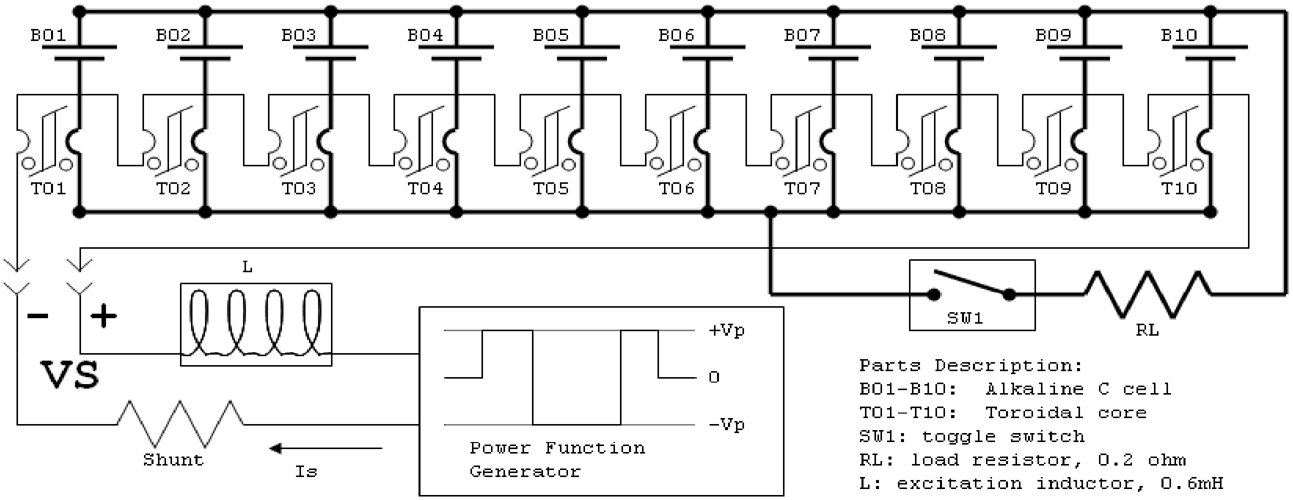


10 cell prototype



T01-T10: Toroidal Transformer core added in series with each cell (10 total).

Schematic of 10 cell test battery:

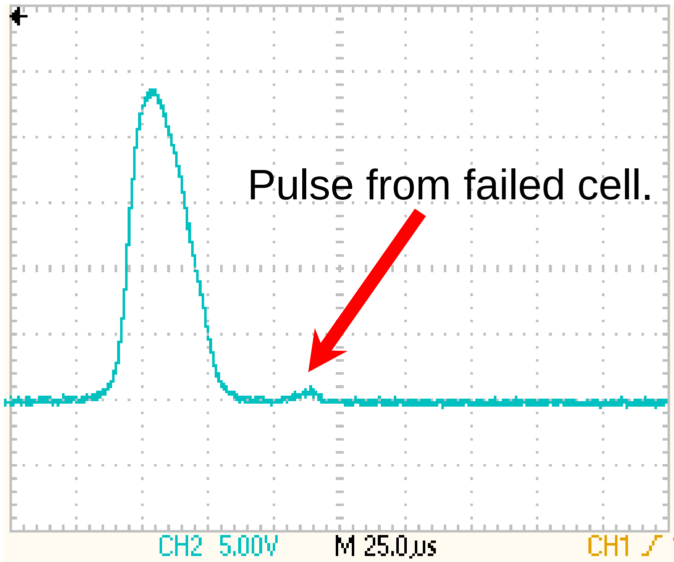


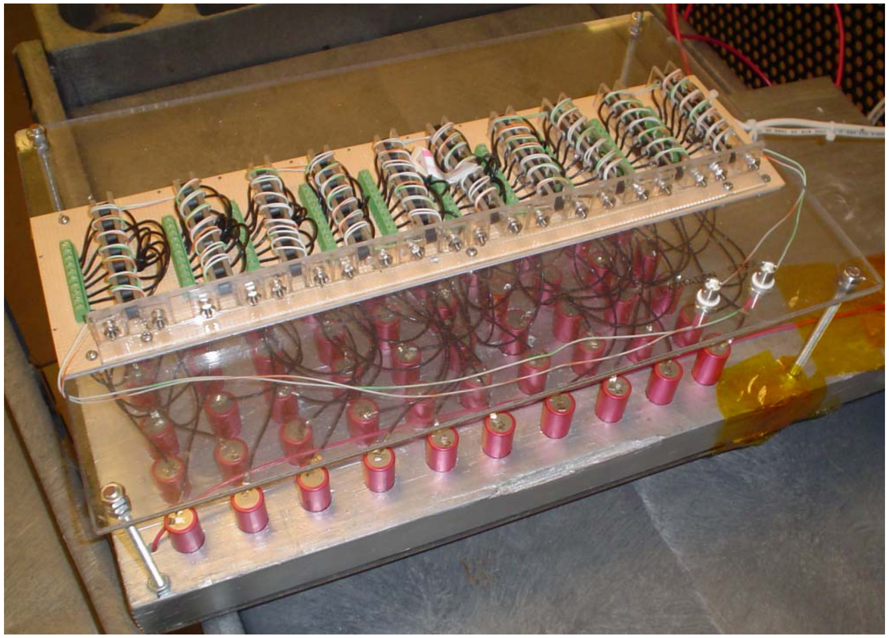
VS pulse with all cells good:

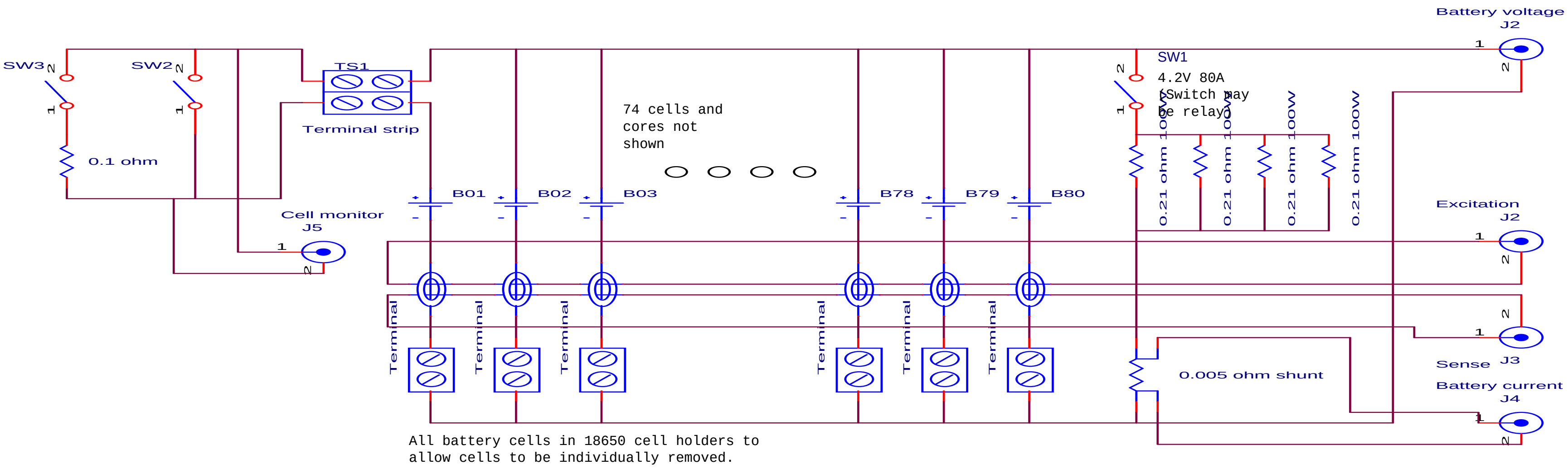
VS pulse w/ one cell failed open:

Pulse from failed cell.

75 cell prototype (180Ahrs)







Operating principle: Single string operation

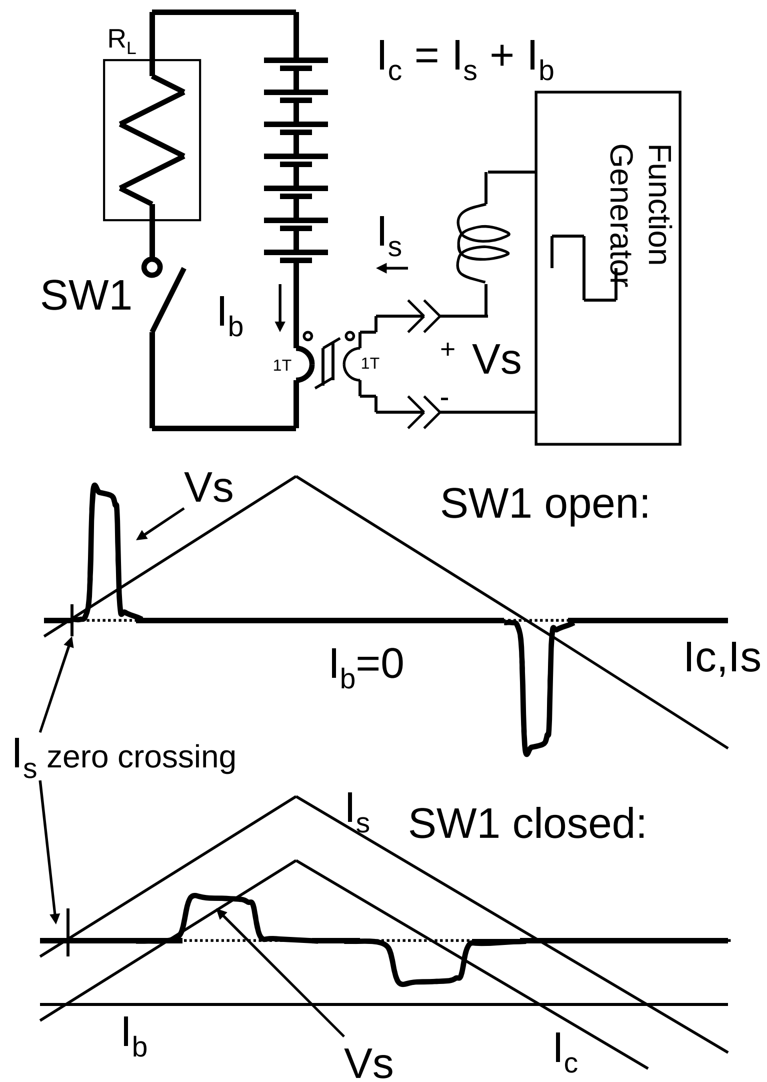
Basic principle: A toroidal core can act as a sensor that turns a current level into the timing of a pulse.

SW1 open:

1. No current through battery and resistor ($I_b = 0$).
2. Function generator and inductor make triangular current waveform.
3. Pulses on Vs right after zero crossings of sense current (I_s).

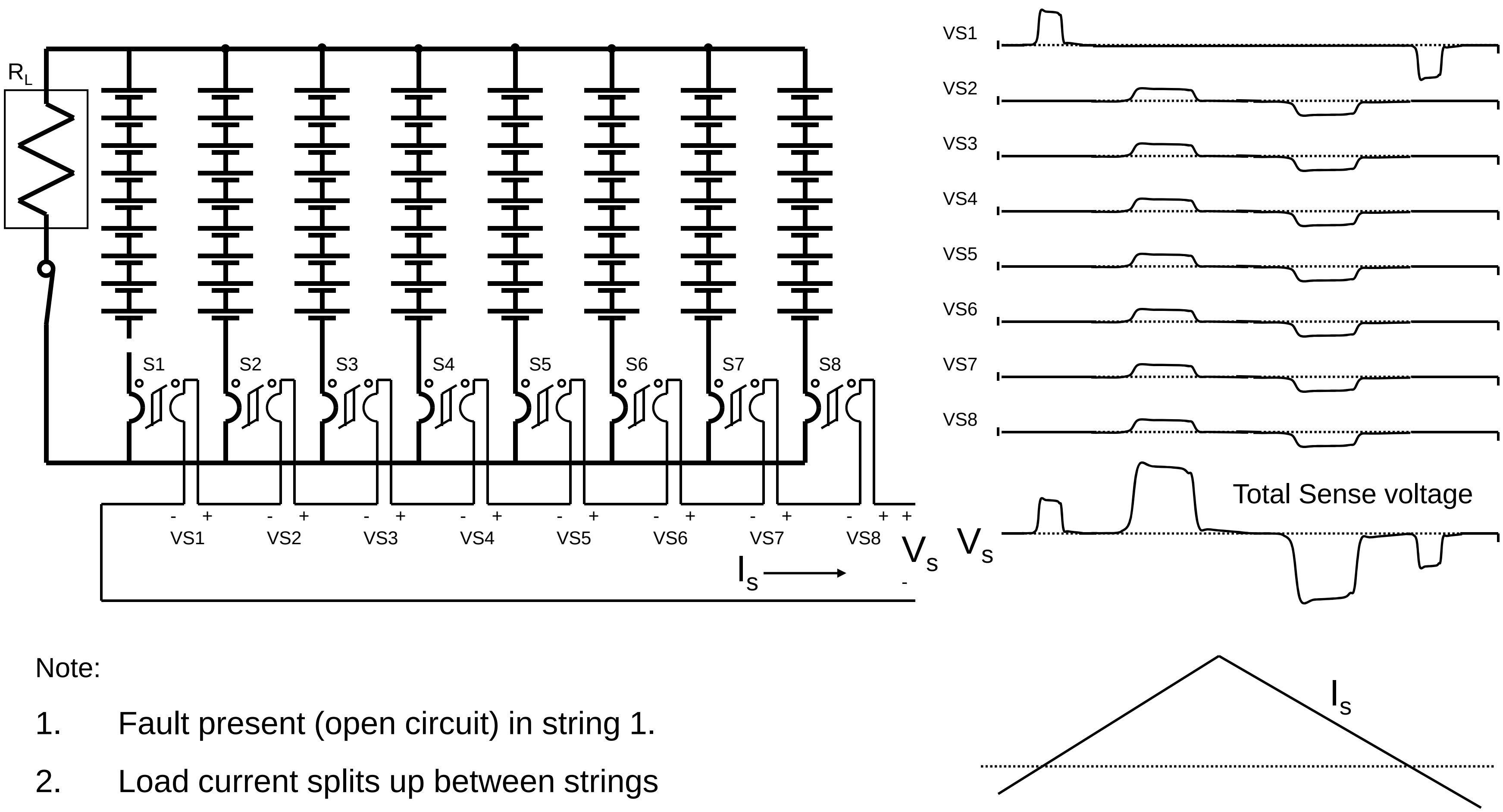
SW1 closed:

1. DC current through battery and load.
2. DC current adds to I_s to shift zero crossings of magnetizing current (I_c).
3. Pulse shape changed by interaction with battery and load impedance.
4. Timing of pulse (delay from I_s zero crossing) changed due to DC battery current.



Operating principle: multiple strings

Basic principle: A cell string with a problem produces a pulse at a different time than all the good pulses.



Note:

1. Fault present (open circuit) in string 1.
2. Load current splits up between strings