Research into Progression of a Safe Active Mitigation System for Fragment Impact Threats

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Presentation Coverage

- Background.
- Impact Threat:
  - Dealing with impact threats,
  - Requirements, Safety, etc.,
- Original design concept.
- Early work on active system.
- Developments of new sensor :
  - Discrimination of Non-threatening strike.
- Firing sub-system evaluation.
- Proposed new system design:
  - System safety.
- Conclusions.

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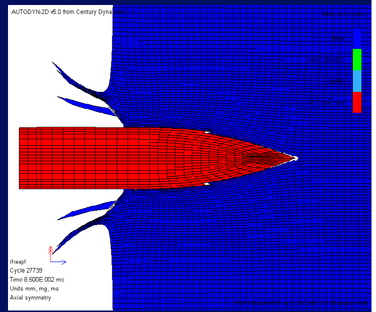
Background

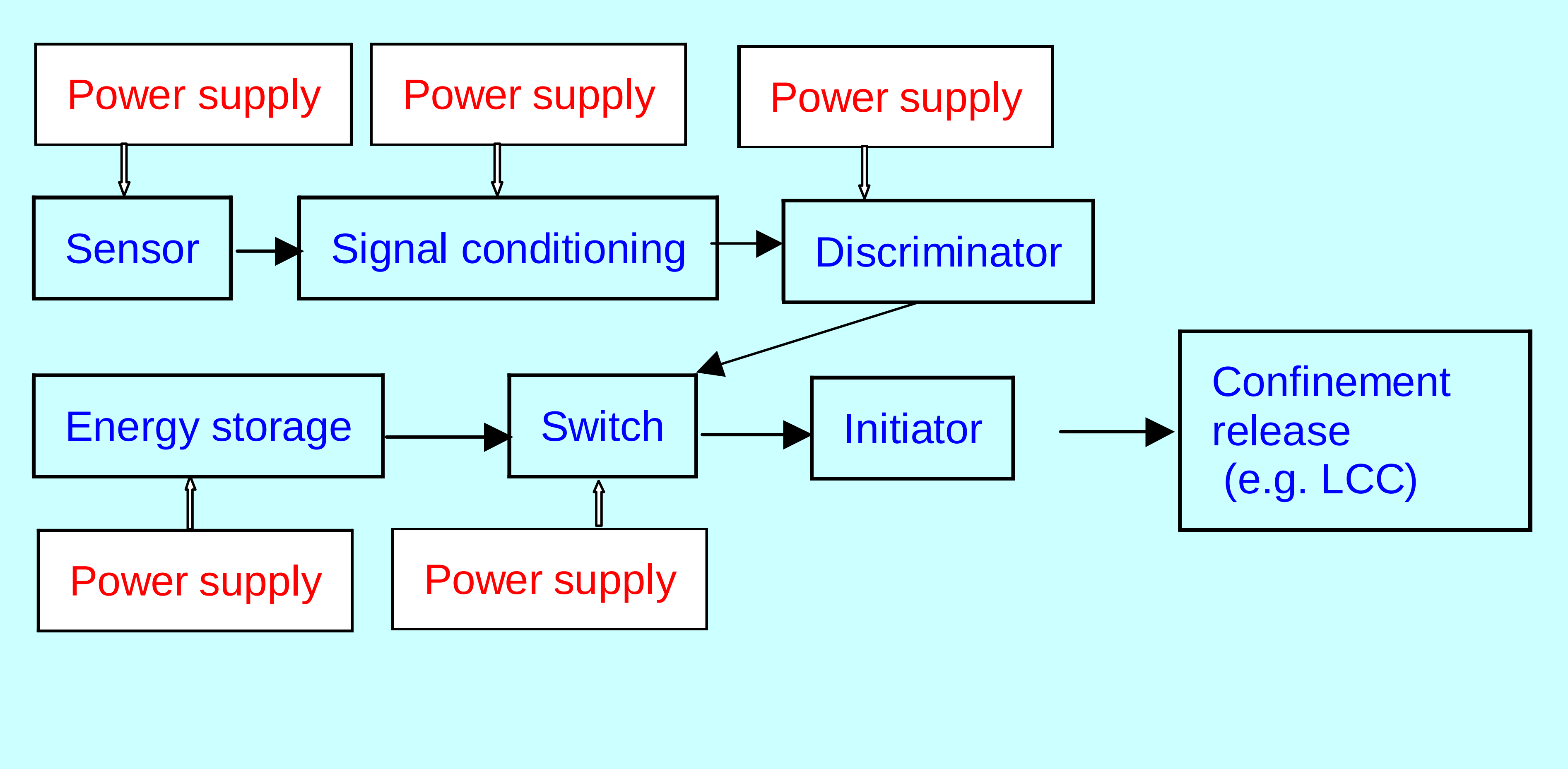
- Impact Threats:
  - IM Bullet and Fragment threats – wide velocity range (800-2500 m/s)
  - Fragments - less penetrative than bullets but greater energy.
  - Outcomes may be SDT, XDT, DDT, deflagration, burning, no reaction.
- Dealing with impact threats:
  - Passive protection: (No Energetics employed)
    - Cases/barriers to reduce penetration velocities or break-up projectile.
    - Design modifications e.g. use of shock-reduction liners.
    - Can be easier to achieve on warheads than motors.
  - Active protection: (Energetics or reactive materials used)
    - Our concentration here on confinement-release types.
    - Noted some doubts on their safety.
    - None seen to be fast enough to cope !

Research on original active concept

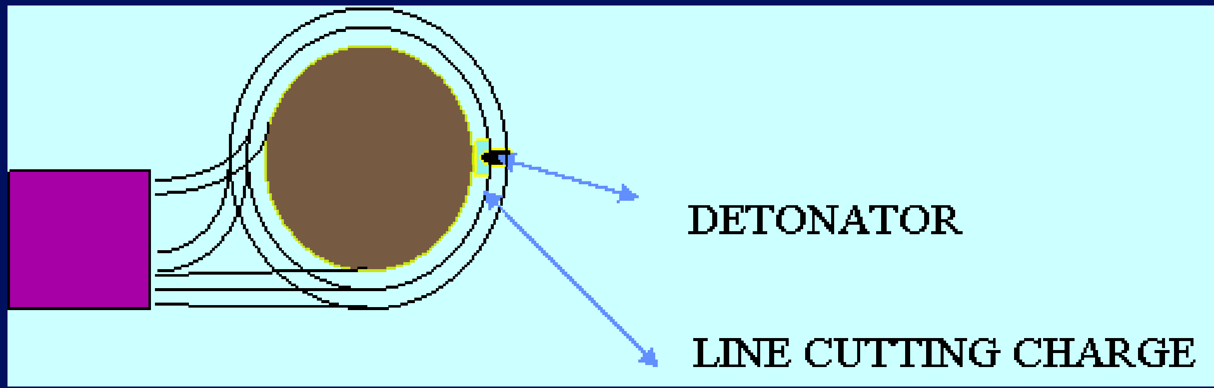


- Aimed to vent motor case to prevent DDT or BVR.
- As EM response development times are fast - (S/XDT (100µs), DDT (100ms)) then could we:
  - Arm and fire a venting device safely? We thought Yes!
- Impact sensor & velocity measure based on fibre-optic cable:
  - Trials from original concept onward to practical system.
- Confinement relief developed:
  - Taken on from ex RARDE LOVUM Programme, well tested,
  - Line Cutting Charge - Ag sheathed, filled HNS;
  - Showed we could get ‘soft effect’ on EM.

CONCEPT – INITIAL ARCHITECTURE



Trials on Initial system



- System trialled
  - Power supply
  - Twin FO cables
  - Discriminator
  - Detonator
  - LCC
  - Mechanical safe-arm
- System worked well, within the available time frame, & was improved

  BUT

  – Not multi-strike capable,
  – Could not discriminate non-threatening strikes,
  – Was too bulky and massive for a number of applications,
  – Continuous power was required for sense & pre-charge to fire.

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Aims of New Research Initiative

New & more stringent goals set for new initiative:

- Improve detector & discriminator components to give:
  - Multi-shot capability (and “soldier –proof”)
  - Ability to identify non-threatening impacts.
- Act ONLY on detection of a threatening strike, to then:
  - Initiate a mitigation system reliably,
    - Within an acceptably short time,
    - Without on-board electrical power.
- Continue to address aspects on safety.
- Obtain reduced mass/volume & simpler devices

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Sensor – Research into PVdF use

- PVdF (polyvinylidene di-fluoride) seemed attractive.
- Electrically polarisable, flexible, light, rugged, cheap.
- Piezoelectric and pyroelectric properties.
  - Used in many stress, strain and thermal sensors.
- Early trials found that high speed perforation causes different mode –'volume depolarisation'.
  - Produces electrical pulse in microsecond timescale.
- Our tests showed might produce an adequately large signal.
- Might distinguish between high & low speed perforation.

So, commenced new shot trials programmes on PVdF

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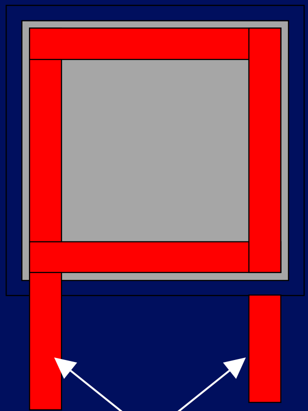
Sensor Evaluation - Experimental set-up

SENSOR



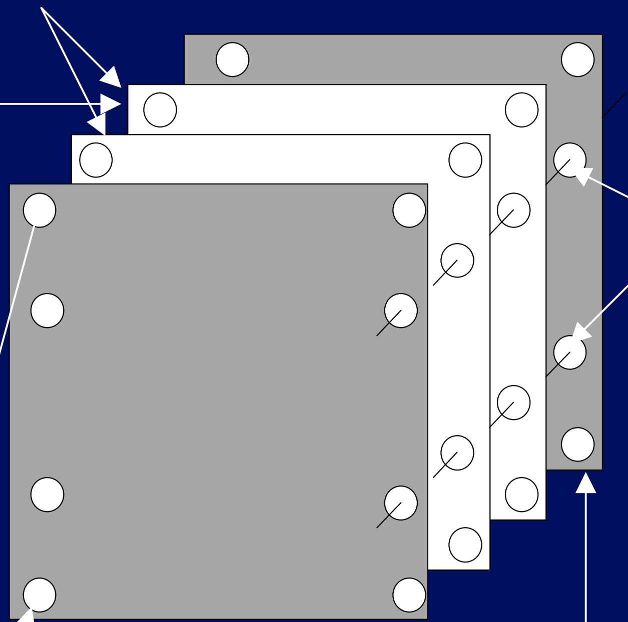
Inserted between paper insulated target plates.

Cu tape as electrical connection to ‘scope via coax.cable

100mm square, 110µm PVdF sheets

TARGET ARRAY

Paper insulation



Clamp

Target support holes

100mm square 1.6mm Al. target plates

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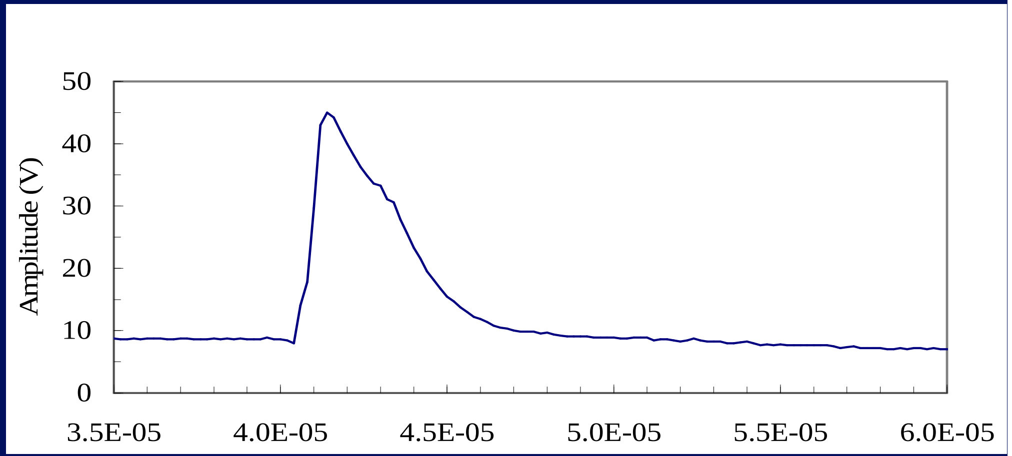
PVdF Sensor - Output

Results of extensive testing - for a range of fragments, at varying speeds (up to 500 m/s & 500 – 2400 m/s)



- Signal characteristics
  - Amplitude correlates with area of PVdF destroyed.
  - Rise time ~ perforation duration & area of penetrator.
  - Magnitude increasingly strong over range 500-2400m/s.
  - Different character resulting from strikes below 400m/s.
- Concluded that sensor
  - Responds well/reliably to high velocity perforation.
  - Discriminates low velocity perforation.
- Noted 2 Sensors could determine strike velocity (if required).

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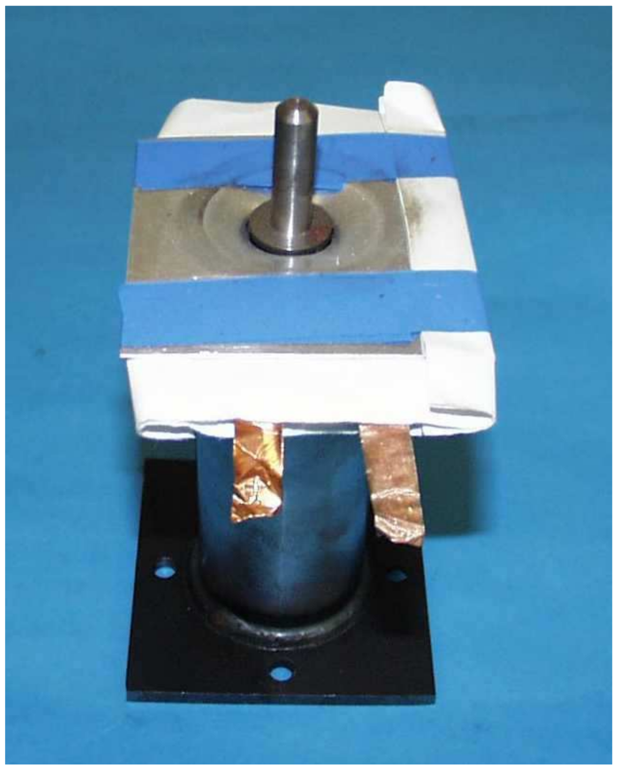
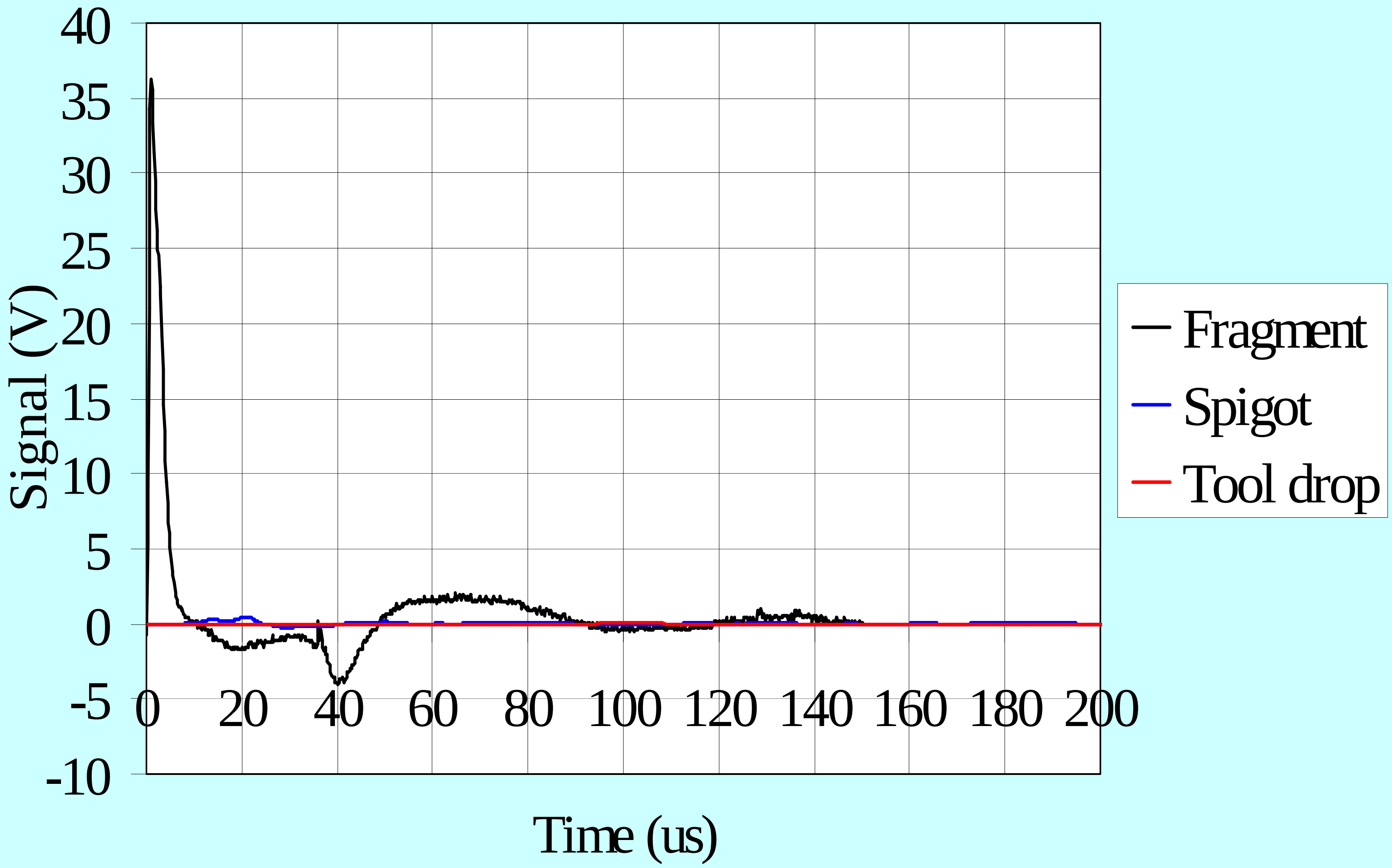
Sensor Evaluation – low speed impacts

- Perforation (spigot) & non-perforation (tool drop) test vehicles.



Sensor – discrimination results



Sensor Discrimination Evaluation - Conclusions

- Waveform peak from fast bullet/fragment impact:
  - some 100 times greater than peak from spigot intrusion,
  - some 1000 times greater than output from tool drop impact.
- Volume depolarisation mode different to piezo-electric mode
- Discrimination can be achieved by:
  - Tailoring input pulse requirement of a firing control switch to a typical output of a sensor from perforation threats at >500m/s
  - Imposing a signal amplitude requirement- say of >5V
  - Imposing a time for perforation (rise time) of a few microseconds. (<5)
- Thus, a separate discriminator is superfluous for our range- where only need to operate LCC for faster threats.

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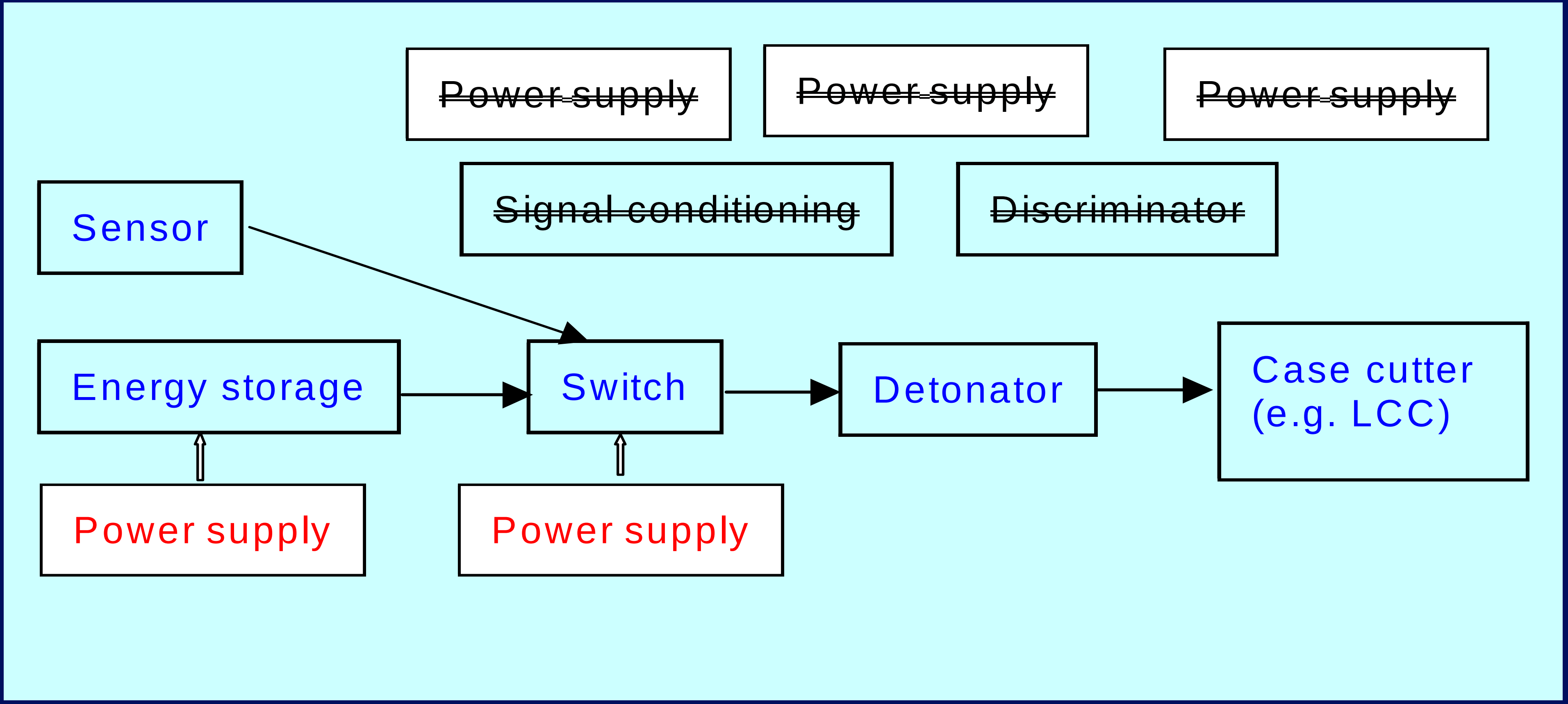
CONCEPT – REVISED LAYOUT



Thus, Reduction in discrimination & power components

Firing sub-system evaluation – Final selection

- We ruled out the following detonator/initiators:
  - EBW & EFI - they have excessive energy requirements.
  - Hot wire devices - as too slow.
  - Conducting composition devices - too sensitive.
- <u>Semiconductor Bridge Devices (SCB) seemed attractive.</u>
  - SCB response times <5μs at 50V and 5mJ input.
  - Passed human body discharge simulation (ESD) tests.
  - Also passed No-Fire and insulation resistance tests.
  - Has an All-Fire current of 8.3A,
    - easily achievable from our high velocity perforations.

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Sensor matching to SCB – Trials results

- We had confirmed that a high velocity metal projectile could:
  - Generate 70V & about 50mJ perforating a single PVdF film,
  - Directly be used to initiate an SCB.
- We showed that could NOT initiate SCBs through low velocity fragments (<500m/s), spigot and tool-drop stimuli threats.
- We also tested new targets with several layers of PVdF to ensure a significant overmatch of power requirements.
  - This obviated the use of a separate power source.
- We had achieved objectives & required TRL at this stage of research & could look for applications.

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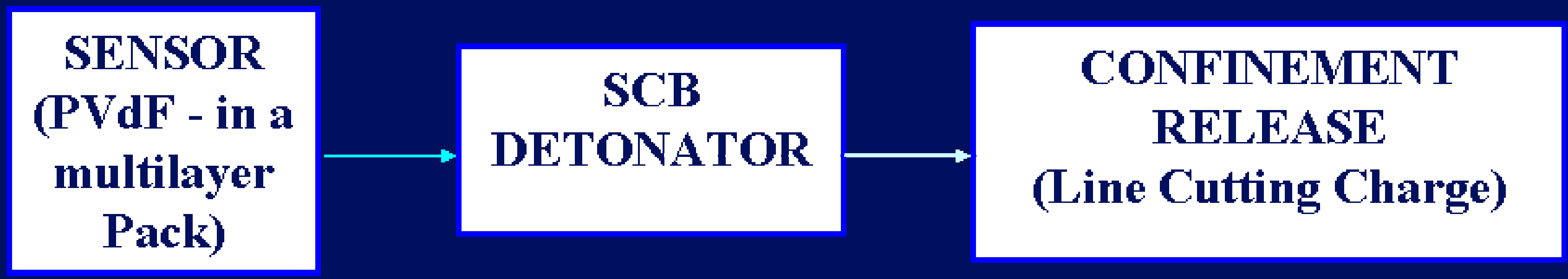
PROPOSED FINAL CONCEPT



Safety aspects appear challenging; but only at first sight

- Only projectiles fast enough to be hazardous will generate a firing signal for the ECB detonator - False alarms/low velocity strikes not cause output.

- Has ability to still respond correctly after earlier low velocity impacts.

- Could also use a double PVdF sensor:
  1st sensor identifies a valid threat projectile in velocity via voltage generated at right characteristics,
  2nd sensor then used to provide correct energy to activate detonator.

i.e. Effectively acts as a normal '2-environments' safety device.

Conclusions of the research effort

- We have demonstrated & tested in a sub-system design, a new, innovative but safe, active mitigation sensor based on PVdF.
- Shown the volume depolarisation of PVdF generates a suitable firing pulse for an SCB detonator when subject to impacts at >500m/s.
- Sensor also discriminates against non-threat impacts, based on output signal (as piezoelectric response is of different form).
- No energy storage, conditioning or switching needed.
- Initiator based on PVdF sensor and SCB detonator meets safety standards – at least equivalent to that in many RM igniters.
- Adequate safety ensured to meet the greater risk arising from fragment attack responses – thus is ALARP.

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Reduce Vulnerability – Achieve an IM

- Achievement of IM compliance requires a systems design approach
  - However, designs must consider the trade offs needed
  - "Where, even with a systems approach, it is not possible to achieve full IM compliance, reduction in risk to ALARP becomes the overall objective .."
- Most often a need to consider Active and Passive mitigation
  - "Mitigation ... can offer a potentially simple and cost effective solution to many systems .."
- *If there is a choice between having Active mitigation or leaving a system with a severe response – what will you do?*

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