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Innovation and Rapid Prototyping to Extend Silent Watch Capability for Expeditionary and Special Operations Vehicles

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Outline

- Innovation and Rapid Prototyping Event Overview
- Innovation Process and Event Phases
- Innovation Event Outcomes

Event Purpose

- Bring together expeditionary warfighters, program managers, and engineering expertise to rapidly innovate solutions to operational gaps
- Event focus is to solve a Power and Energy challenge faced by the Expeditionary warfighting community
- Utilized detailed needs finding assessment to identify event scope:
  - Lack of vehicle provided energy storage to meet mission silent watch requirements
    - USMC: C2, Comms, Artillery
    - SOCOM: C4I suite

Application of Innovation Principles at NSWC Crane

Warfighter-Driven Challenge → Tacit Knowledge & Needs Identification → Ideation → Concept Development → Prototype

- Little prep time
- Goal to build something tangible

- Dedicated time/space
- Diverse, multi-disciplined team
- Gov't only personnel thru ideation phase

- Team understands Warfighter's Env.
- Warfighter Comm. & Engineers work hand-in-hand; real-time tradeoffs

- Tangible output
- Opportunity to test in scenario based environment

Leadership Commitment and Support

Culture of Organization Attitude:: Passion:: Team Players

Reachback to Government Industrial Base

Recorder is resourced to team to capture and document the event (IP, lessons learned, best practices)

Event Plan

- Multi-phased approach for accelerated, expeditionary warfighter-driven innovation
- Phase 0: Needs finding → Problem Definition
- Phase 1: Ideation → Concept Design
- Phase 2: Development → working prototype
- Phase 3: System Integration → operational demonstration

Event Plan, cont

- Phase 0: Needs finding and analysis
  - Date: Mar – May 2016
  - Outcomes:
    - Extensive customer engagement strategy
      - Face-to-face interviews and assessment questionnaire
      - USMC: PdM EPS, PMMI, PM-MC3, SIAT, E2O
      - SOF: SOCOM PEO-SRSE, PEO-M, TALOS, PEO-SW, JSOC S&T
    - NSWC Crane P&E team conducted response assessment based on:
      - Commonality between USMC and SOF
      - Feasibility
      - Strategic Alignment
    - Led to event problem scope of:
      - Enhanced vehicle provided energy storage/power to meet mission system silent watch requirements

Event Plan, cont.

- Phase 1: SOFWERX Event in Tampa, FL
  - Date: August 3-4, 2016[1]
  - Desired outcomes:
    - Collaboration across Expeditionary community
    - User defined operation gap / challenge (requirement)
    - Ideation/brainstorming to identify concept design to meet user defined gap(s)
    - Obtain familiarity with vehicle details and layout to ensure form/fit/function of concept design
    - Identification of material needed to develop prototype solution
  - Participants: USMC, SOCOM, NSWC Crane, NSWC Carderock, Operators.

1. Event was conducted in parallel with PEO C4 and PM FOSOV Mobility C4 DirtyWerx Event to leverage operators, vehicles, equipment, etc., and to ensure the P&E design would meet any changing C4 needs.

Event Plan, cont.

- Phase 2: Prototype Development
  - Date: Aug 5 – Oct 25, 2016
  - Desired outcomes:
    - Obtain materials
    - Develop lab prototype/EDM
    - Initial testing/functionality
  - Participants: NSWC Crane, NSWC Carderock, industry partners (as needed), dialogue/feedback from customers/operators (as needed)

Event Plan, cont.

- Phase 3: Prototype integration and demonstrations
  - Date: 26-27 Oct 2016[1]
  - Desired Outcomes:
    - Integrate prototype solution on the platform
    - Conduct concept demonstration and testing
    - Obtain operational feedback for follow-on development/refinement
    - Develop plan to transition prototype solution into a program
  - Participants: NSWC Crane, PM-FOSOV, SOF operators

1. Pre-event integration and baseline system performance testing completed 24-25 Oct.

Event Outcomes

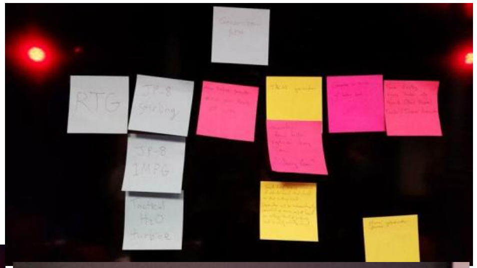
Phase 1: Needs Identification

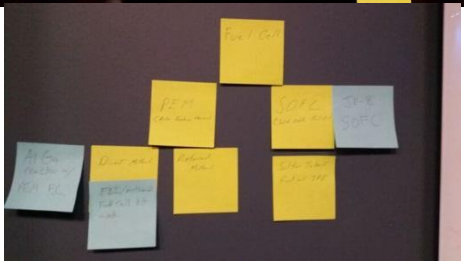
- Received platform/system briefs from PM's on perceived challenges and requirements
  - FOSOV briefed entire portfolio
    - LT-ATV, NSCV, GMV, MRAP
  - USMC focused on NOTM HMWWV platform, but issue applies broadly across OPFOR

- Conducted interviews with Operators
  - Paired SOF operator with USMC PM representative – 3 groups
  - Rotated three engineering teams to conduct interviews and define problem
- Outcomes:
  - Primary goal is to extend operational range of the vehicle
  - Extended silent watch is desired, but not at expense of vehicle start reliability
  - Vehicle signatures (thermal, audible) more important for SOF operations
  - Operators already carry multiple BA-5590, BA-5930 or BB-2590 communications batteries for each operation

Phase 1: Ideation

- Team brainstormed possible solutions
- Solutions grouped by type
  - New batteries
  - More batteries
  - Generators
  - Fuel cells
  - Alternative energy
- Technical team proposed concepts for operator feedback

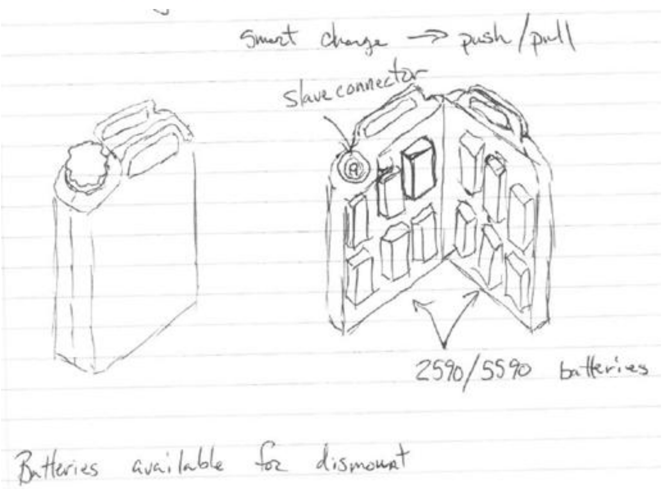







Phase 1: Concept Design

- **Provide a combination of energy storage solutions to allow for extended stationary/silent watch operation**
  - **Develop a battery box using standard communications batteries to resemble a standard fuel/water Jerry Can to add expandable energy storage**
    - **Jerry Can shape allows operators to disguise additional capability and mounting method/fixtures exist**
    - **Capable of accepting BA-5590, BA-5390 and BB-2590 batteries**
    - **Recharge BB-2590's when engine is operating**
  - **Replace the standard 6T VRLA battery with a Li-ion 6T (L6T) battery**
    - **Form / fit direct replacement but does have some different functional aspects**
    - **Development effort for additional functional aspects is being led by the Marine Corp / NSWC Crane team**



"Jerry Batt" Concept

Li-ion L6T Battery

Phase 2: Prototype Design and Development

"Jerry Batt" Auxiliary Power System

- Develop an auxiliary energy storage system in a Jerry Can footprint – "Jerry Batt"
- Three major sub-systems
  - Selection of Communication Equipment (CE) batteries (BB-2590)
  - Development of power electronics
  - Development of physical structure
- Selection of CE batteries
  - Multiple vendors and generations of Li-ion CE batteries exist
  - All contain robust BMS to protect the cell from electrical abuse
  - Selected UBBL13-01 based upon energy density and existing compatibility with power electronics
    - Additional equivalent vendors also available
  - Performed limited evaluation to verify UBBL13-01 performance (24V)

Discharge Rate	S/N 000072		S/N 000073		Rated	
	Ah Out	Wh Out	Ah Out	Wh Out	Ah Out	Wh Out
0.5A	9.7	283	9.9	290	9.8	288
3.5A	9.6	269	9.7	270	~9.6	~270

Jerry Can

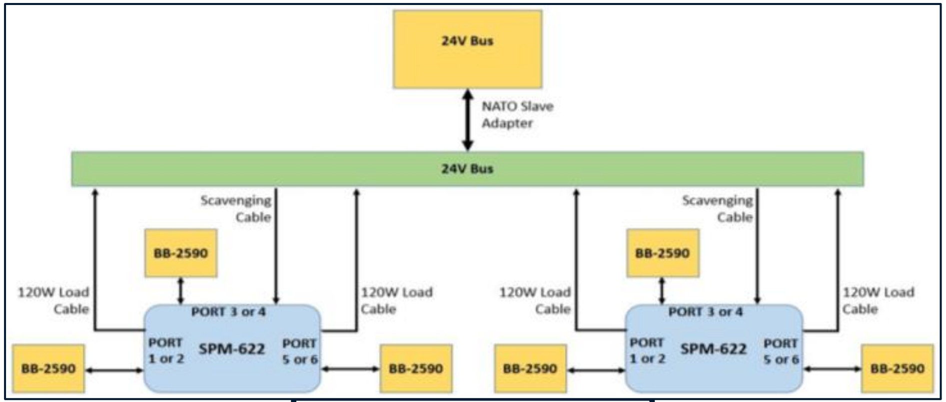

Jerry Batt


UBBL13-01

Development of Power Electronics

- **Power electronics requirements:**
  - **Bi-directional conversion between the 24V CE Battery (24V-30V) and vehicle 24V nominal bus (20V-28.8V) at high efficiency**
  - **Maintain CE battery safety, manage state of charge and SMBus communication**
  - **All CE batteries to be replaced anytime by operators**
- **Protonex Squad Power Manager (SPM-622) provided a COTS solution**
  - **Interfaces with all BB-2590 batteries, provides additional level of safety controls**
  - **Capable of sourcing up to 120W input or output per channel**
  - **Hot swappable, electronically isolated cabling and connectors**
- **Protonex utilized standard scavenging cabling with modified operational parameters to follow and operated based upon vehicle 24V bus voltage**

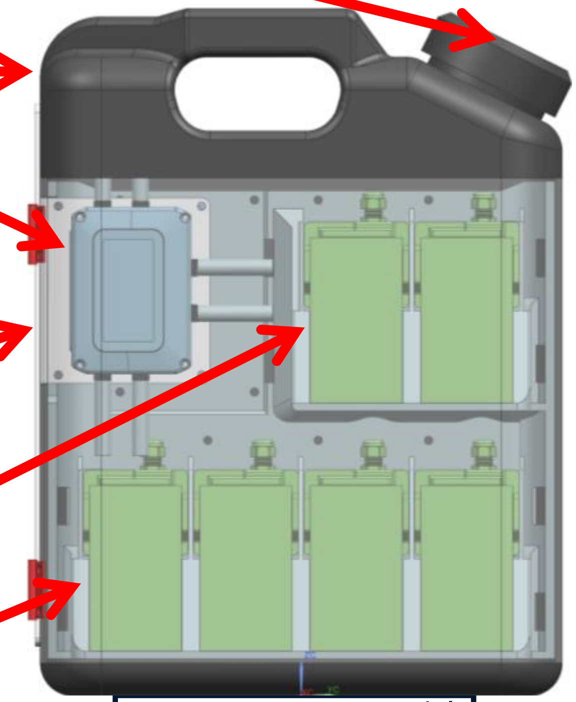
Protonex SPM-622



Power Electronics Layout

Jerry Batt Physical Structure

- NATO power connector standard on the GMV 1.0
- Standard A-A-59592A 20L Jerry Can
- COTS power management system to power electronics is BB-2590 battery interface
- Cooling plate for passive cooling
- Six standard communication batteries BB-2590's
- 3D Printed ABS structure to secure BB-2590's within the Jerry Can



Jerry Batt System Model

Jerry Batt System Picture

Jerry Batt Prototype System

Jerry Batt Testing At BIC

Li-ion 6T Detailed Solution

- **Three major tasks:**
  - **Select L6T battery**
  - **Develop L6T State-of-Charge (SOC) indicator for operator**
  - **Modify GMV 1.0 battery box to except 24V L6T batteries (Phase 3)**
- **Multiple vendors have developed L6T batteries to meet the MIL-PRF-32565 specification**
  - **Known manufactures are Bren-Tronics Inc, Eagle Pitcher Corp, Navitas Systems LLC and Saft.**
  - **All L6T batteries are 24V, designed to replace two 12V 6T AGM batteries**
  - **Bren-Tronics BT-70939AP selected**
    - **Only vendor that claimed Type 3 minimum capacity performance**
    - **Rated at 2.6kWh, 105Ah (Safety Not Evaluated)**
    - **Batteries provided by Bren-Tronics through Bailment agreement**

Bren-Tronics L6T

Li-ion 6T Battery Evaluation

- **Electrical evaluation performed to verify rated performance**
  - **Bren-Tronics rated capacity is at 29.4V charge voltage**
  - **The GMV 1.0 electrical system is designed to operate at 28.8V nominal**
  - **Two samples evaluated at 28.8V charge at different constant current rates**

Discharge Rate	S/N P721 (24V)		S/N P724 (24V)		6T AGM Rated (12V)	
	Ah Out	Whr Out	Ah Out	Whr Out	Ah Out	Whr Out
10A	103	2615	99	2506	120	1500
20A	102	2576	100	2519		
40A	101	2548	100	2519		
80A	101	2520	100	2509	80	1000

  - **The GMV 1.0 electrical system can operate a lower voltage based upon hardware performance**
  - **Two samples evaluated at 20A constant current and different charge voltage**

Recharge Voltage	S/N P721		S/N P724	
	Ah Out	Whr Out	Ah Out	Whr Out
28.8V	102	2576	100	2519
28.5V	95	2386	98	2456
28.0V	89	2219	91	2276
27.5V	82	2022	84	2070

  - **Testing performed at the Battery Innovation Center (BIC)**

L6T SOC Indicator System

- Developed through a joint MARCORSYSCOM and NSWC Crane effort
- All L6T batteries are required to measure and report SOC via CAN bus
  - L6T battery discharge curve different than 6T AGM rendering Voltmeter inaccurate
  - BMS also measures and reports battery temperature, voltage, current, and condition
- SOC indicator developed to poll each L6T battery SOC and report the lowest performing battery to the operator
  - Development boards used for processor and CAN bus communication
  - OLED screen reports SOC and battery reported errors
  - Red LED and audible alarm sounds once SOC is below threshold (30%)
  - Alarm can be acknowledged and silenced

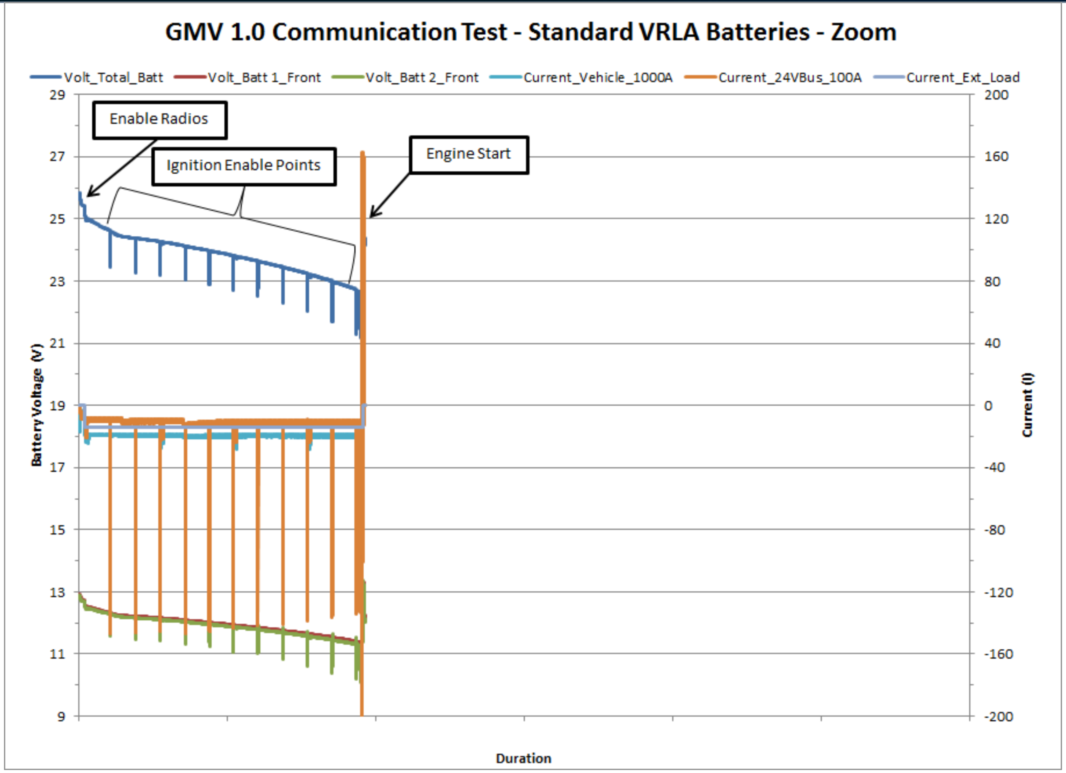
SOC Indicator Prototype

Phase 3 Outcomes

Demonstration Test Plan

- **FOSOV provided GMV 1.0 and multiple pieces of C4I gear for demonstration**
  - **C4I equipment included standard man portable radios, GPS, navigation tablet, and power distribution system totaling ~6.0A load**
  - **14.0A constant current load added to match missing gear**
- **Communication test developed**
  - **10 second radio transmission once per hour per radio**
  - **Check battery voltage every 15 min by turning on ignition (no engine start)**
  - **Repeat until battery voltage or SOC threshold is reached**
- **Rapid Innovation Prototype Laboratory (RIPL) at NSWC Crane used for all integration and demonstration**

Comm Simulation – 6T AGM VRLA



- Communication test performed on standard 6T AGM VRLA batteries
  - Batteries were fully charge prior to use, including comms equipment batteries
  - Battery voltage was half way into "Yellow" with batteries fully charged
  - 140A load for 8.5 seconds each time the vehicle accessories were enabled
  - Results comparable to the system threshold requirements
  - Engine successfully started with battery voltage at 22.5V total
  - Average load for the test was 19.5A, Consumed 71.3Ah at 1727Wh

L6T and Jerry Batt Integration

- GMV 1.0 cabling modified to connect two 6T batteries in parallel
- 24V to 12V DC to DC converter added to source 12V power to auxiliary systems
- Jerry Batt connected to NATO slave connector near 6T battery Box
- L6T SOC Indicator box mounted to L6T CAN Bus connectors and visible to driver

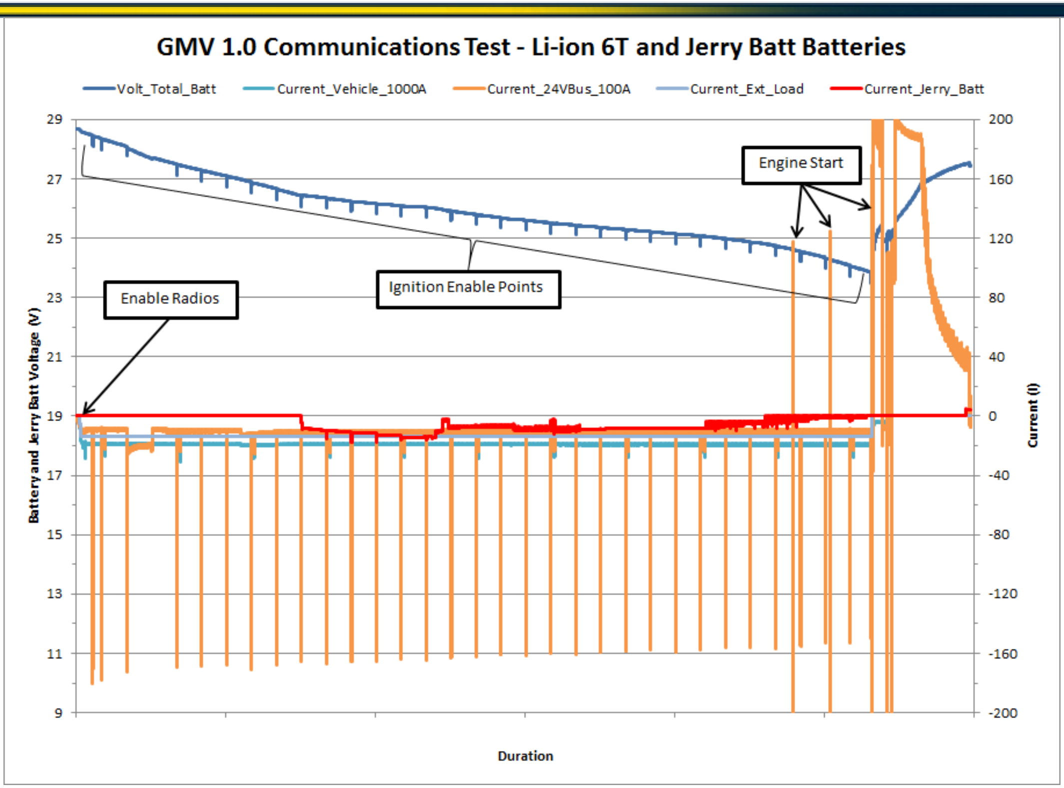
Standard 6T AGM

SOC Indicator

Jerry Batt System

L6T Modified System

Comm Simulation – L6T and Jerry Batt



- Communication test performed on two L6T batteries and Jerry Batt System
  - Batteries were fully charge prior to use, including comms equipment batteries
  - Combined system provided an 187% improvement over 6T AGM batteries (to 20% SOC)
  - Engine successfully started at 30%, 25% and 20% with battery voltage at 24V
  - Average load for the test was 19.2A
  - L6T batteries provided 148.1Ah at 3856.4Wh total, 74.8% of total available energy
  - Jerry Batt provided 54.5Ah at 1400.2Wh, 86% of total available energy

Results

- **Standard 6T AGM battery baseline developed using communication hardware**
- **Complete L6T and Jerry Batt system provided an 187% improvement**
  - **Two L6T batteries provided 73% of improvement**
  - **Jerry Batt system provided 27% of improvement**
- **Jerry Batt system provided the equivalent of 2.1 Jerry Cans of fuel consumed during normal GMV 1.0 idle operations**
- **L6T batteries and Jerry Batt could be recharged by the GMV 1.0**

Full System Charging

Protonex SPM-622

Issues and Lessons Learned

- Checking battery voltage draws a 140A, 8.5sec load to warm glow plugs, power engine ECU and operate fuel pump
  - Consumes .33Ah of energy each time
- Jerry Batt system was not able to supply full 480W (~19A) output and averaged 8A for the majority of testing
  - Protonex SPM-622 had 10A maximum current (not optimized for this application)
  - Future redesign would improve control logic to provide constant power output
- BB-2590 Communication batteries require 6-8 hours to recharge
- Additional 12V source is not required due to 24V-12V dual output generator
  - Additional filter may be required to provide clean power
- Leadership support and cooperative agreements with industry enabled rapid proof of concept prototype development
- Collaboration with operators, program managers, scientist and engineers allowed for a rapid solution to the warfighter driven challenge

Questions

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