Benefits of Prognostics for Power Electronics Systems

Douglas Goodman

Dgoodman@RidgetopGroup.com

June 2014

Agenda

- Ridgetop Overview
- Prognostics and Reliability
- Solution Examples
  - Power Systems and Actuators
  - Rotary Systems (Gear Boxes)
  - Battery Management Systems
  - Intermittency Detection in cables and interconnections
- Questions

Ridgetop Group, Inc.

- Incorporated in 2000, and headquartered in Tucson, AZ. Ridgetop Europe established in 2010 in Belgium.
- Advanced Diagnostic and Prognostic solutions:
  - Sentinel Suite™ Family of Diagnostic and Prognostic Analysis Solutions
  - State of Health (SoH) and Remaining Useful Life (RUL) on complex electromechanical systems.
  - Improved Test Program Coverage Tools
  - Design and Integration Services
- Strong market position with commercial and government customers in USA, Canada, Europe, and Asia

Ridgetop Group Facilities in Tucson, AZ

Ridgetop Europe Facilities in Brugge, Belgium

Ridgetop Accreditations

CERTIFICATE OF REGISTRATION

Management Certification
MCNA
of North America

This is to certify that the
Quality Management system of:
Ridgetop Group, Inc.
3580 West Ina Road
Tucson, AZ 85741
US
has been assessed and found complying with the requirements of

ISO 9001:2008 & AS9100C

Approval is hereby granted by Management Certification of North America under its ANAB accreditation and in accordance with the AAQG Program and AS9104 Rev A, provided the certification rules and conditions are observed at all times.

Certification Scope:

Provision of engineering, research & development, electronic prognostics, integrated circuit design.

Certificate Number: 1107004 **Audit Date:** 22-Dec-2011

Issue Date: 27-Jan-2012 **Expiration Date:** 26-Jan-2015

On Behalf of:
Management Certification NA

ANAB

This certificate is non-transferable and remains the property of Management Certification of North America, The Woodlands, Texas, to which it must be returned upon request.

ISO9001:2008 Quality Management System

AS9100C Quality Management System

NATIONAL INSTRUMENTS™ Alliance Partner

ACCREDITATION OF TRUST

Microelectronics Trusted Source
CATEGORY 1A

By these presents the undersigned expresses the confidence of the Department of Defense, Defense Microelectronics Activity (DMEA) in the ability of the organization known as

Ridgetop Group, Inc.

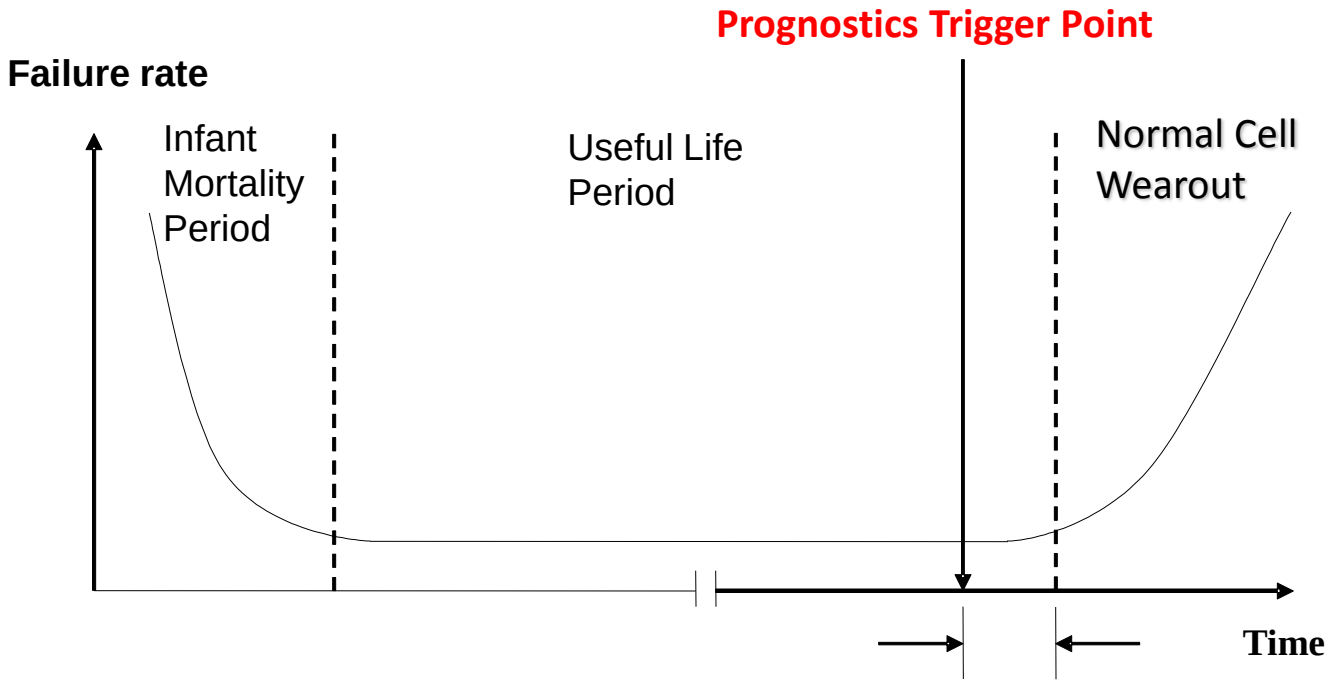
to deliver trusted foundry microelectronic goods and services to end users within the United States Government that correspond to Trusted Category 1A which meets Mission Assurance Category 1 as defined by Instruction 8500.2 of the Department of Defense Directives, effective this date.

878	1QD98	12 OCT 2010	12 OCT 2012	
Site Accreditation Number	CAGE Code	Effective Date	Renewal Date	Ted Okon Director, Defense Microelectronics Activity

Microelectronics Trusted Supplier (Defense Microelectronics Agency)

Prognostics Background

Reliability "Bathtub Curve"



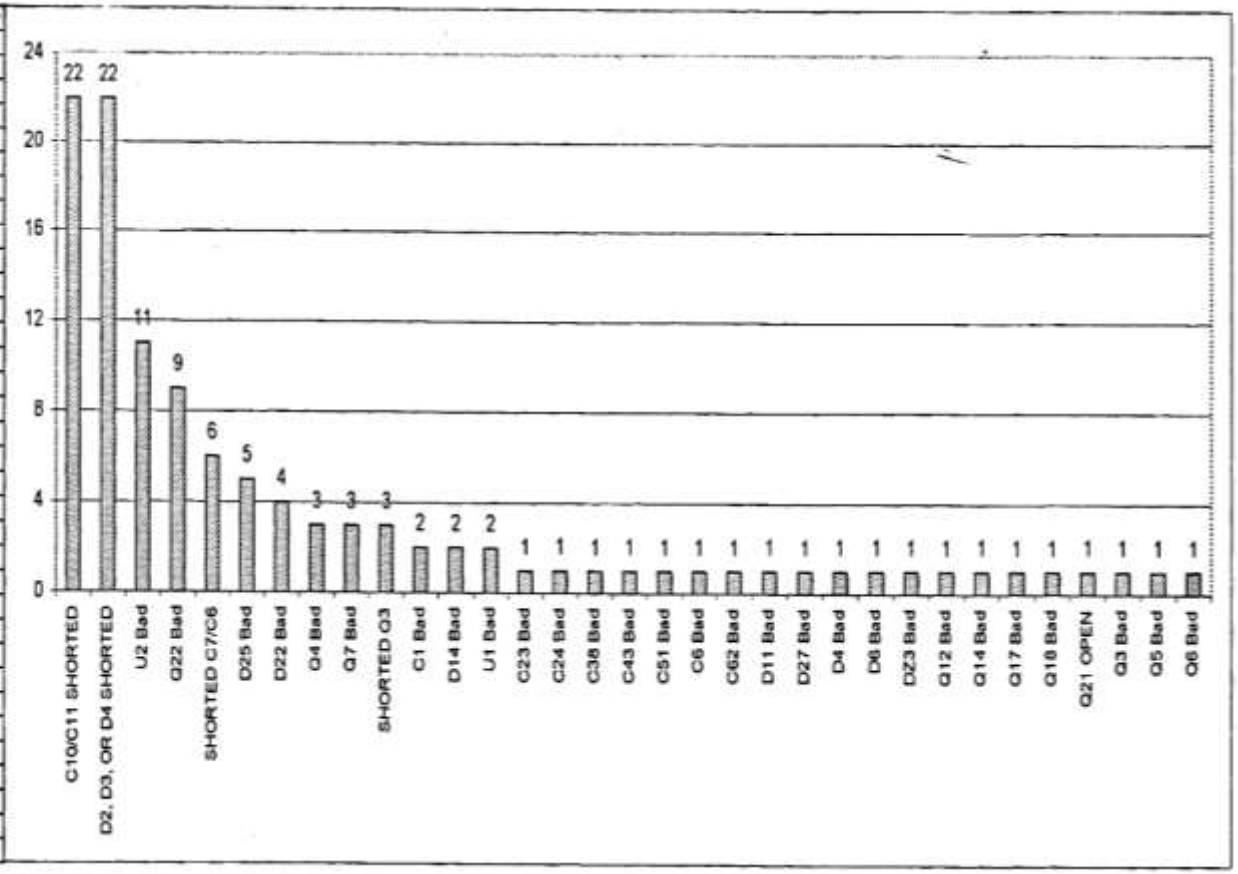
Threshold Trigger Points are selectable

Advanced Warning of Failure (RUL)

Pareto Analysis

Root Cause Analysis used for Failure Modes and Effects Analysis (FMEA)

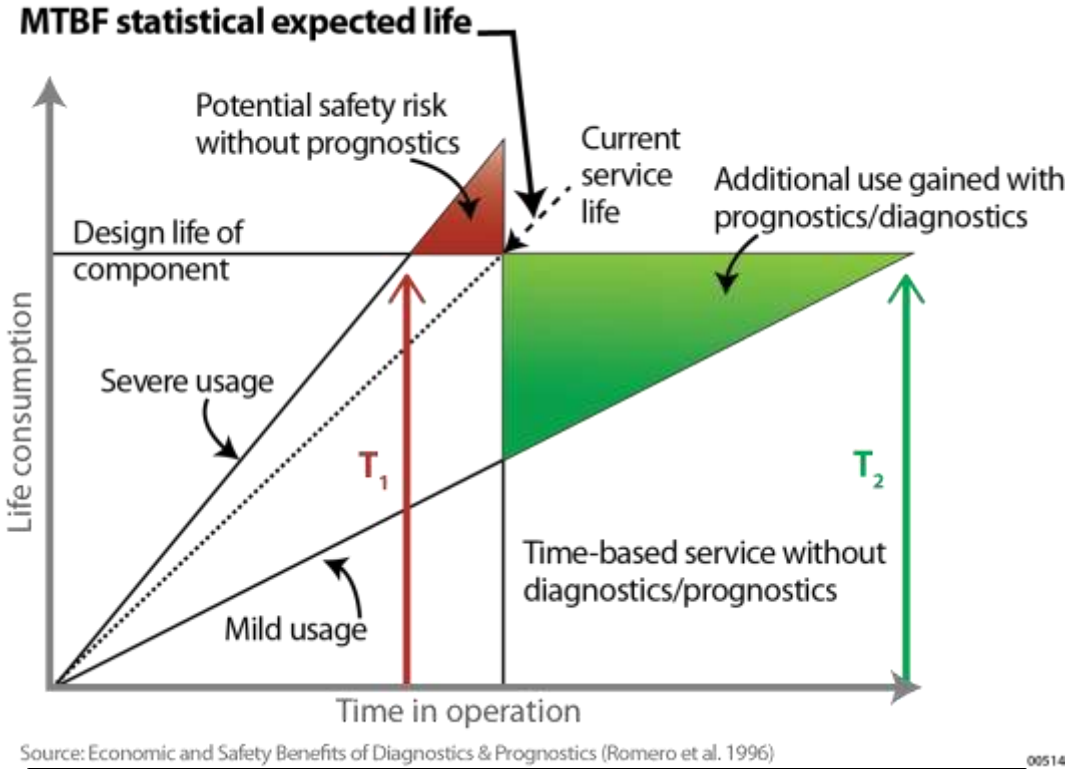
1st Level Root Cause	Quantity
C10/C11 SHORTED	22
D2, D3, OR D4 SHORTED	22
U2 Bad	11
Q22 Bad	9
SHORTED C7/C6	6
D25 Bad	5
D22 Bad	4
Q4 Bad	3
Q7 Bad	3
SHORTED Q3	3
C1 Bad	2
D14 Bad	2
U1 Bad	2
C23 Bad	1
C24 Bad	1
C38 Bad	1
C43 Bad	1
C51 Bad	1
C6 Bad	1
C62 Bad	1
D11 Bad	1
D27 Bad	1
D4 Bad	1
D6 Bad	1
DZ3 Bad	1
Q12 Bad	1
Q14 Bad	1
Q17 Bad	1
Q18 Bad	1
Q21 OPEN	1
Q3 Bad	1
Q5 Bad	1
Q6 Bad	1
Total Returns	114



Degradation Rates Dependent on Environmental Conditions

Usage Environment

- Usage monitoring would provide a safety benefit if actual usage is more severe than predicted **(red region, T_1)**.
- Service life can be extended beyond normal replacement time if the actual usage severity is known **(green region, T_2)**.



PHM enables replacement only upon evidence of need

Prognostics and Reliability

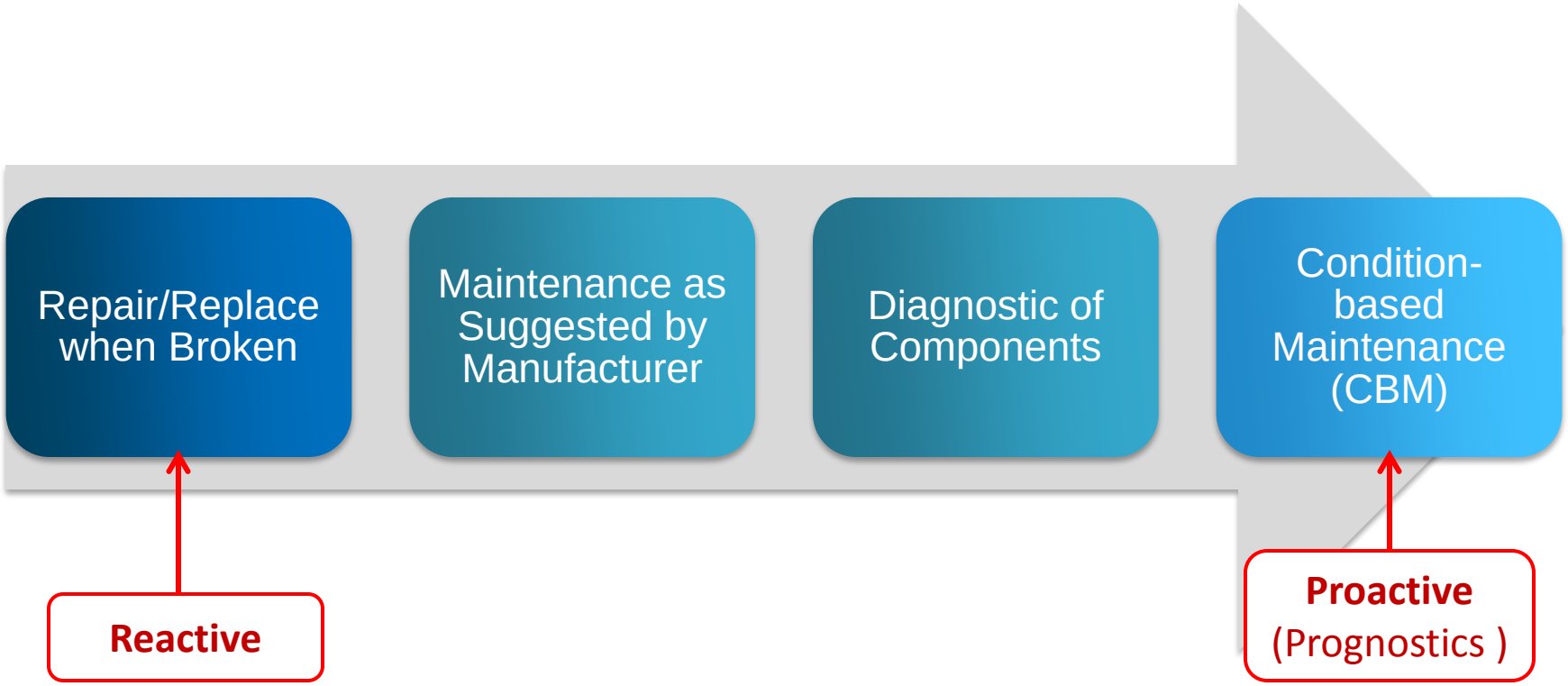
What is it?

- **Diagnostics** – is the process of determining the state of a component to perform its function(s).
- **Prognostics** – is predictive diagnostics which includes determining the remaining life or time span of proper operation of component.
- **Health Management** – is the capability to make appropriate decision about maintenance actions based on diagnostics/prognostics information, available resources and operational demand.

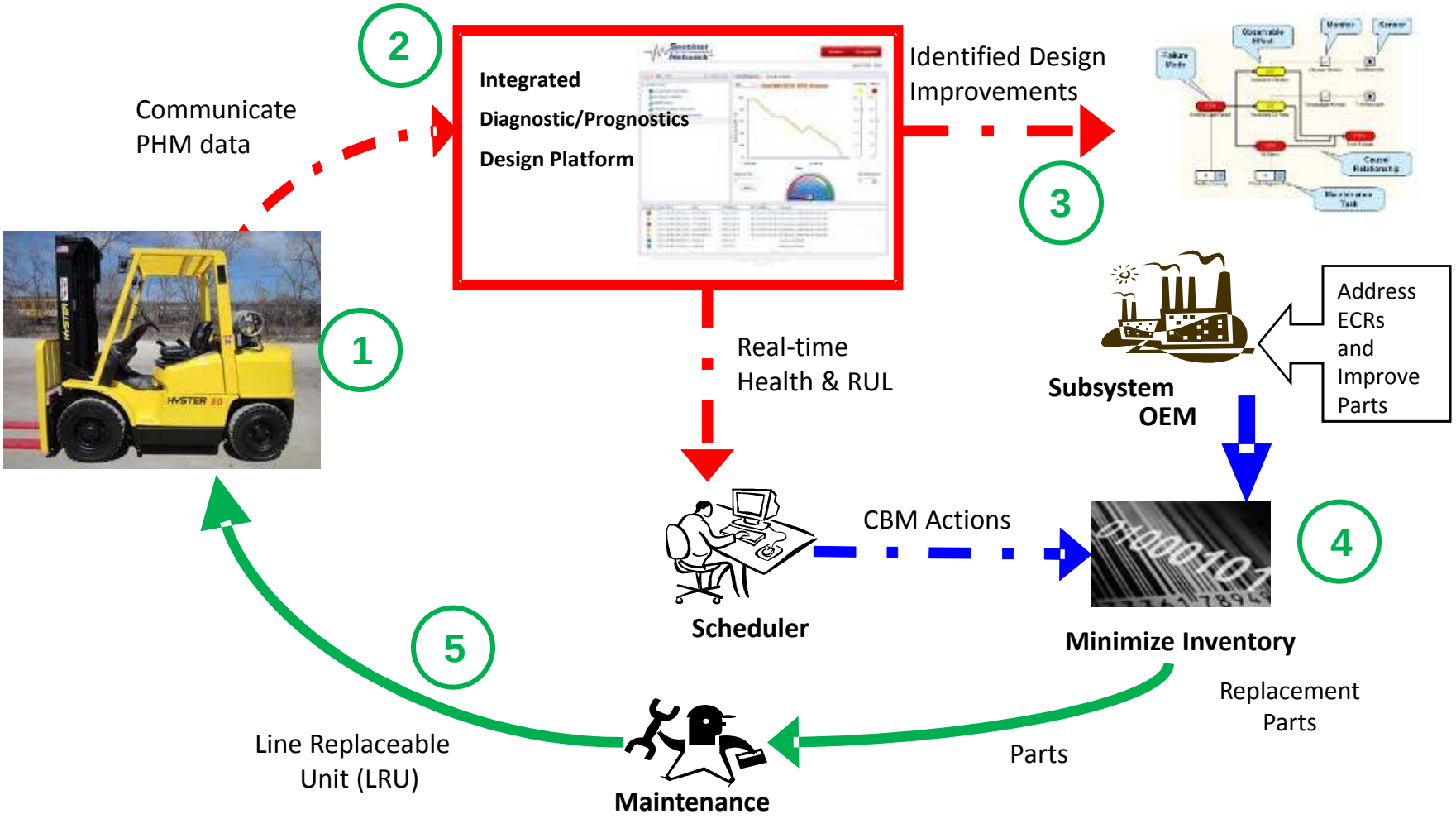
PHM turns ‘Bad Actors’ or ‘Intermittents’ into scheduled maintenance without affecting the success of the Mission

Prognostics Supports Proactive Maintenance

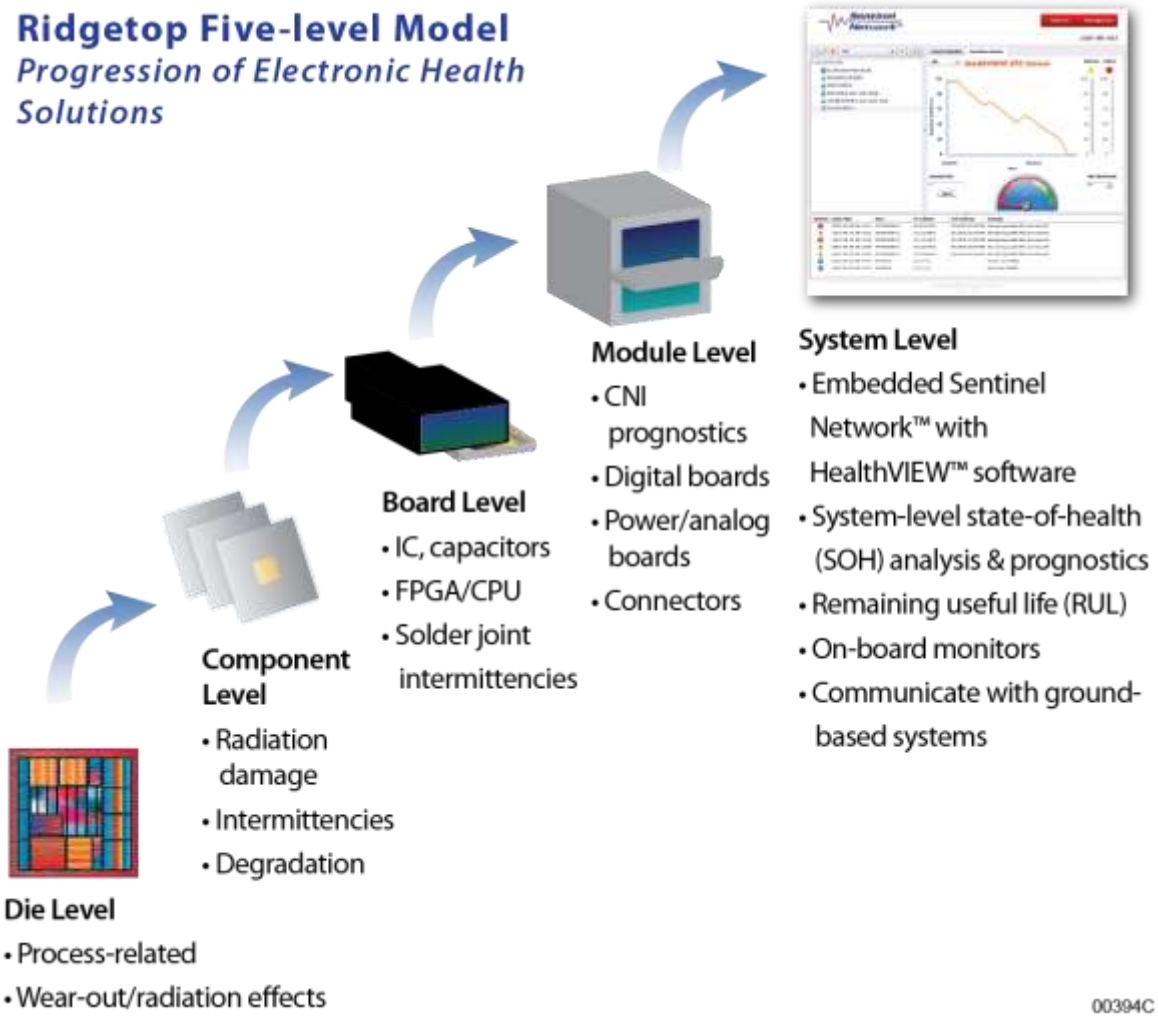
Going from REACTIVE to PROACTIVE



Prognostics Ecosystem

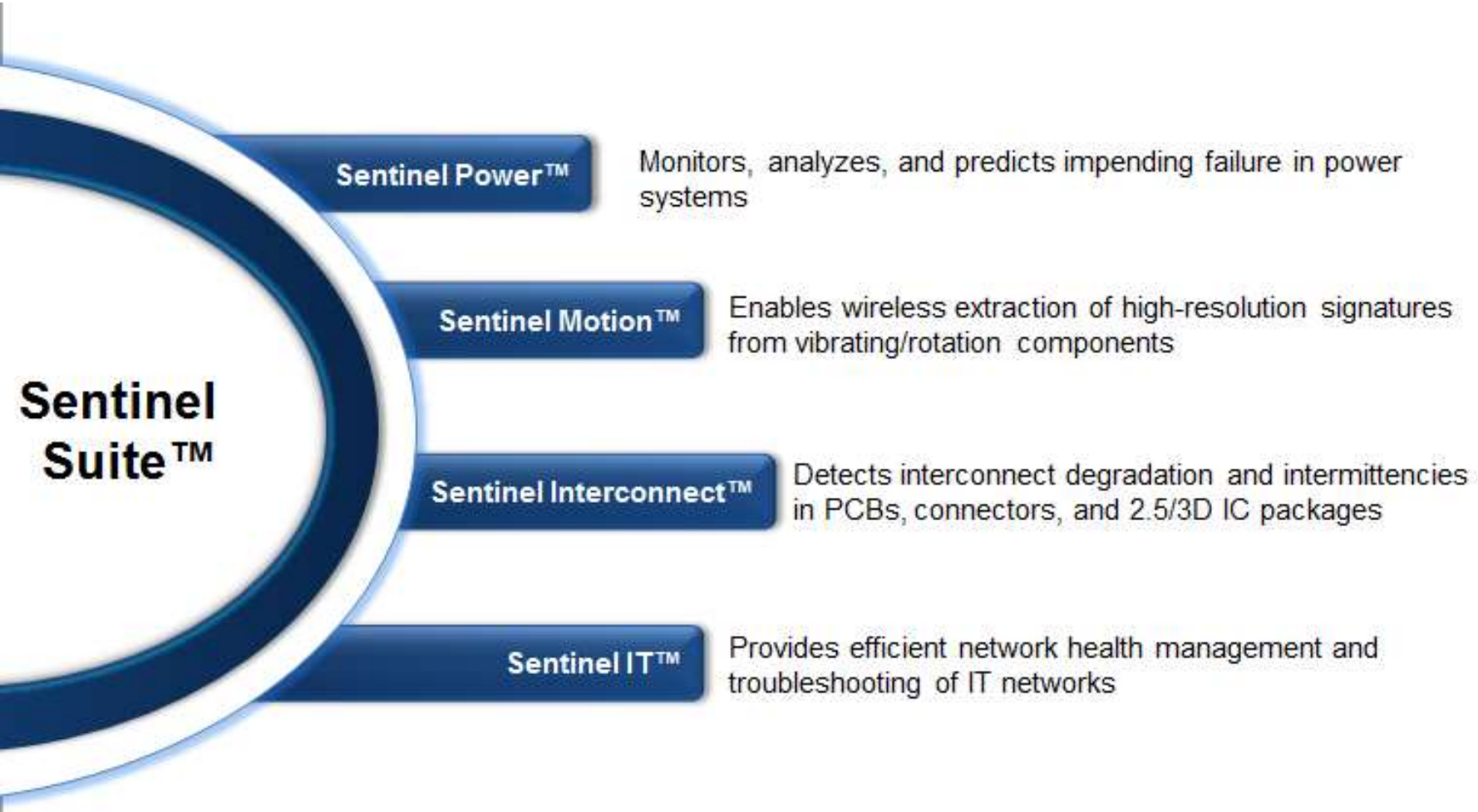


Faults Occur at Multiple Levels in Systems



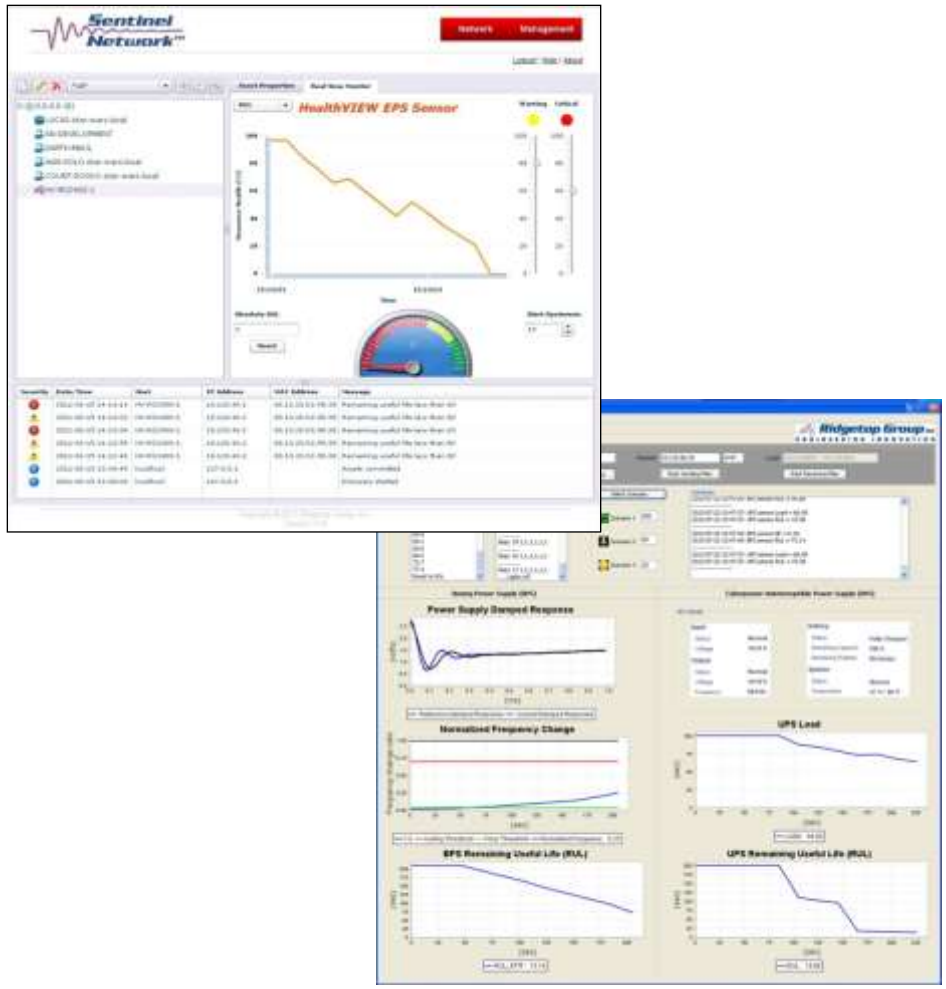
Ridgetop's Sentinel Suite Platform

A family of complete solutions for electronics prognostics and health management.



Sentinel Suite Complete Solution

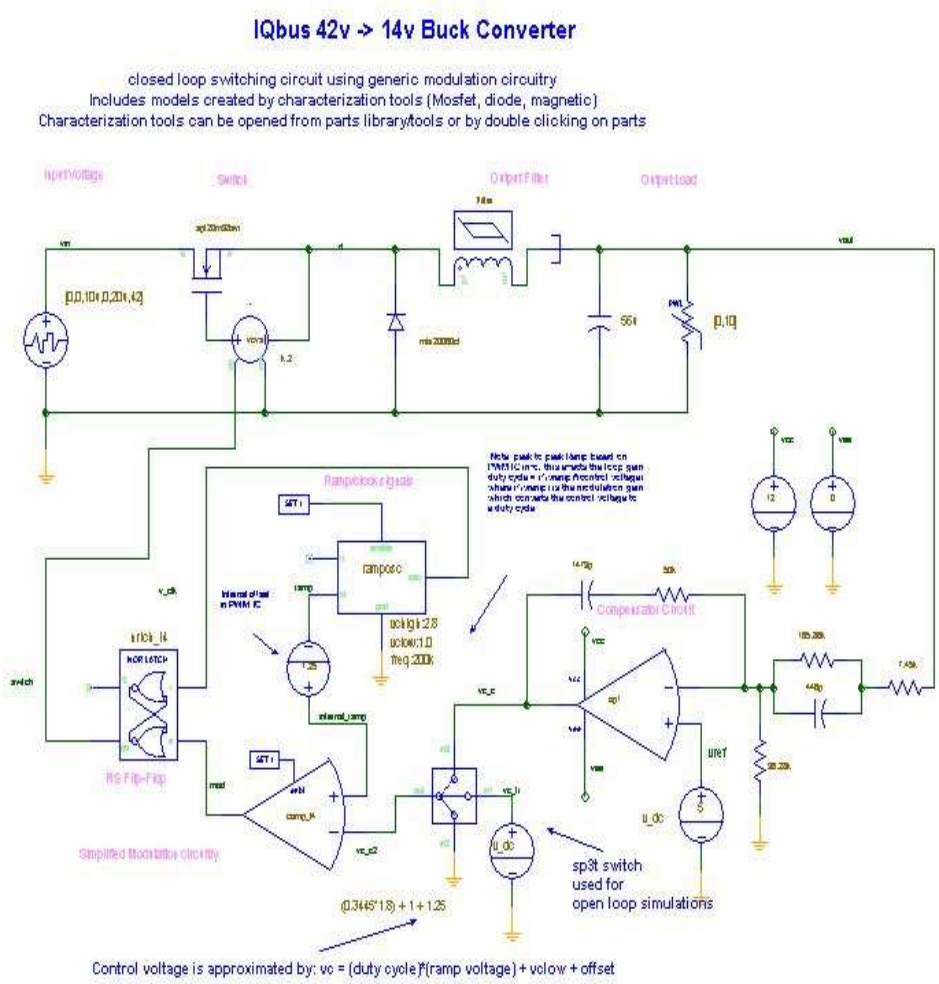
- Continuous sensor monitoring with analysis using proven algorithms
- Provides system-level State of Health (SoH) indication with accurate Remaining Useful Life (RUL) estimates
- Results can be integrated with existing CBM systems



Power Systems and Actuators

Building a Prognostic-Enabled System

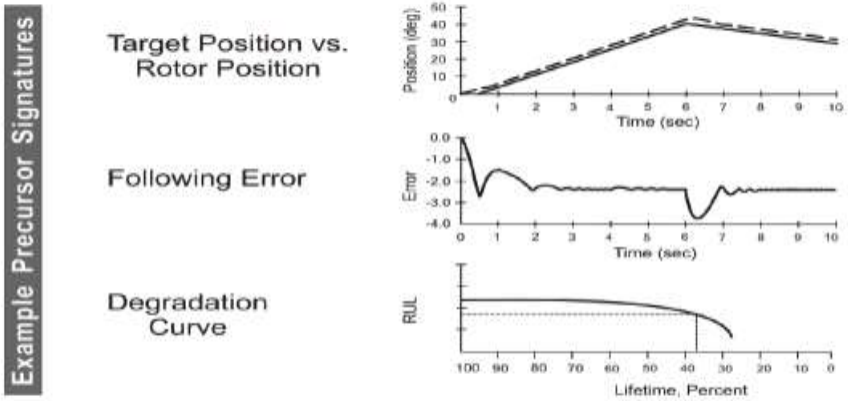
Switch Mode Power Converter (Buck Topology)



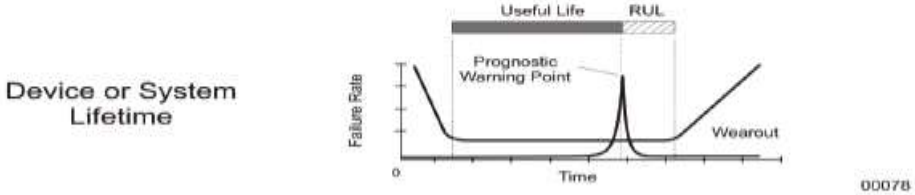
Basic Prognostic-Enabling Steps

Step 1: Characterize Device or System Failures

Step 2: Extract Precursor Signatures to Failure



Step 3: Calculate Remaining Useful Lifetime (RUL)



Designing a Prognostic Solution

Pareto Analysis

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C6 Bad	1
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D11 Bad	1
D27 Bad	1
D4 Bad	1
D6 Bad	1
DZ3 Bad	1
Q12 Bad	1
Q14 Bad	1
Q17 Bad	1
[illegible]	1
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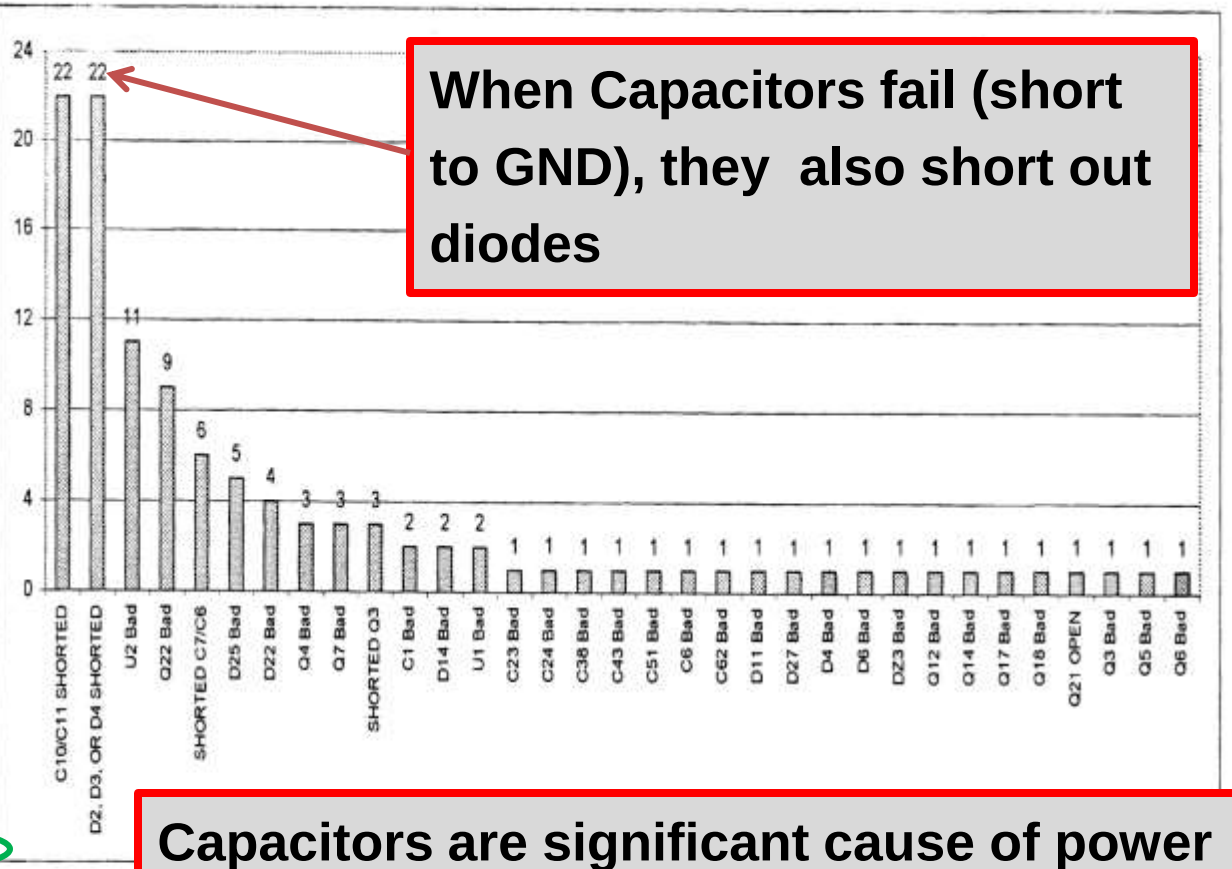
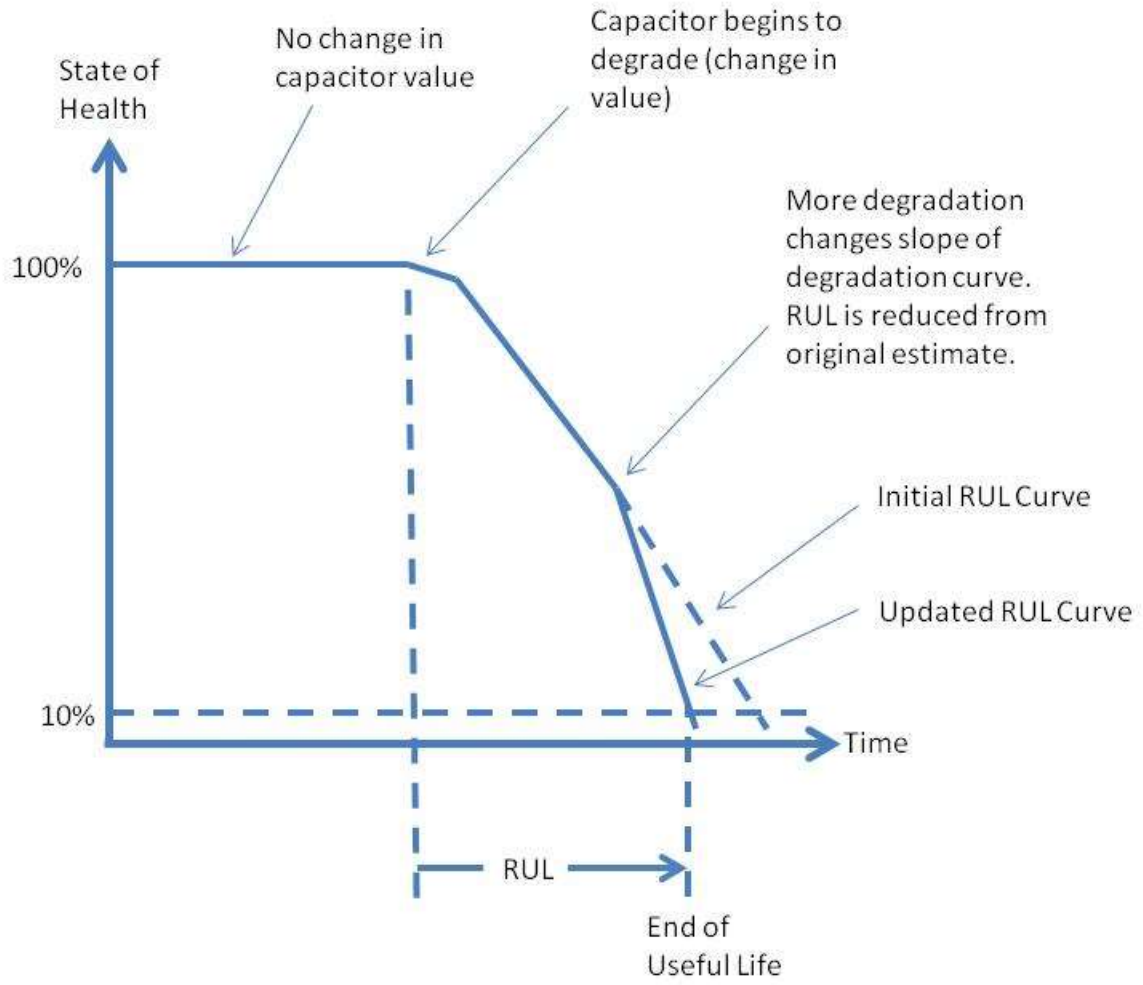


When Capacitors fail (short to GND), they also short out diodes

Customer returns

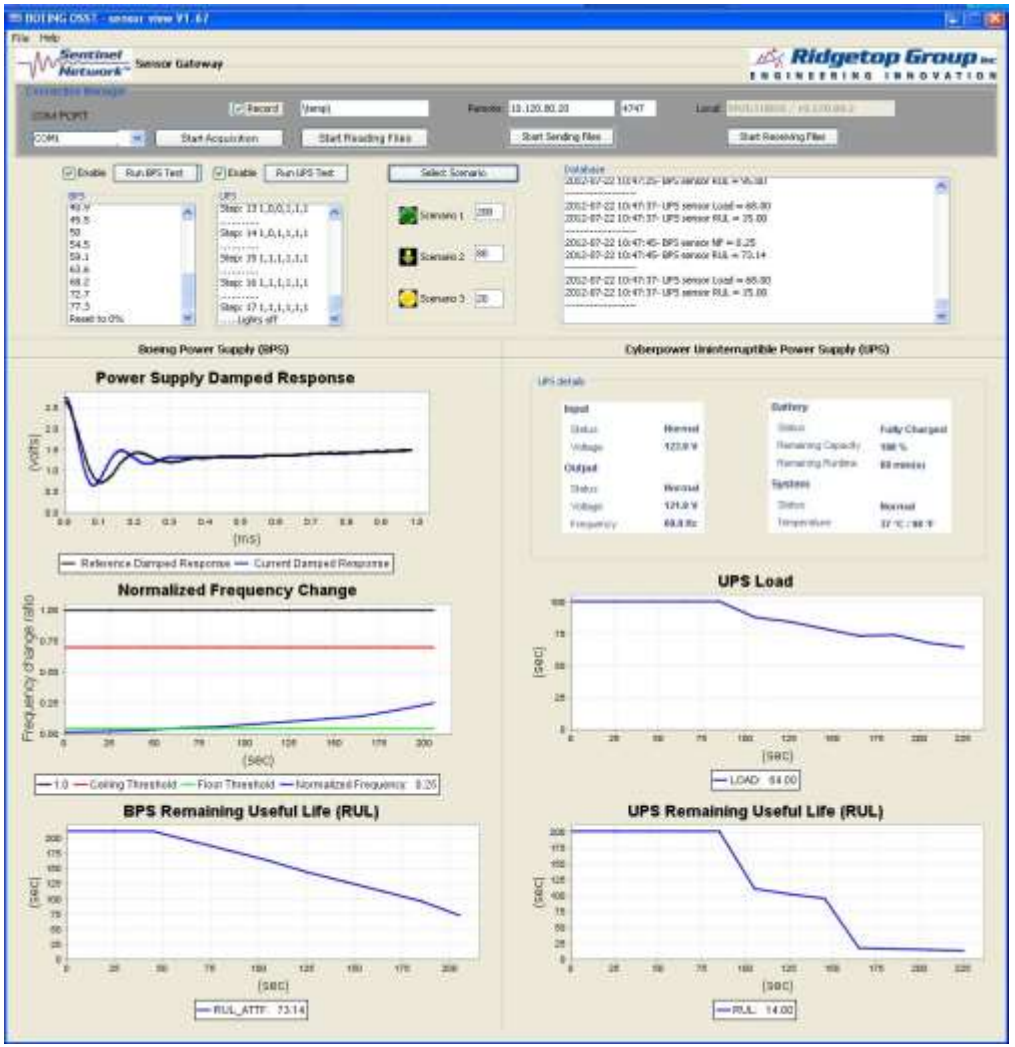
Capacitors are significant cause of power supply failures as reported here.

Objective: State of Health and RUL



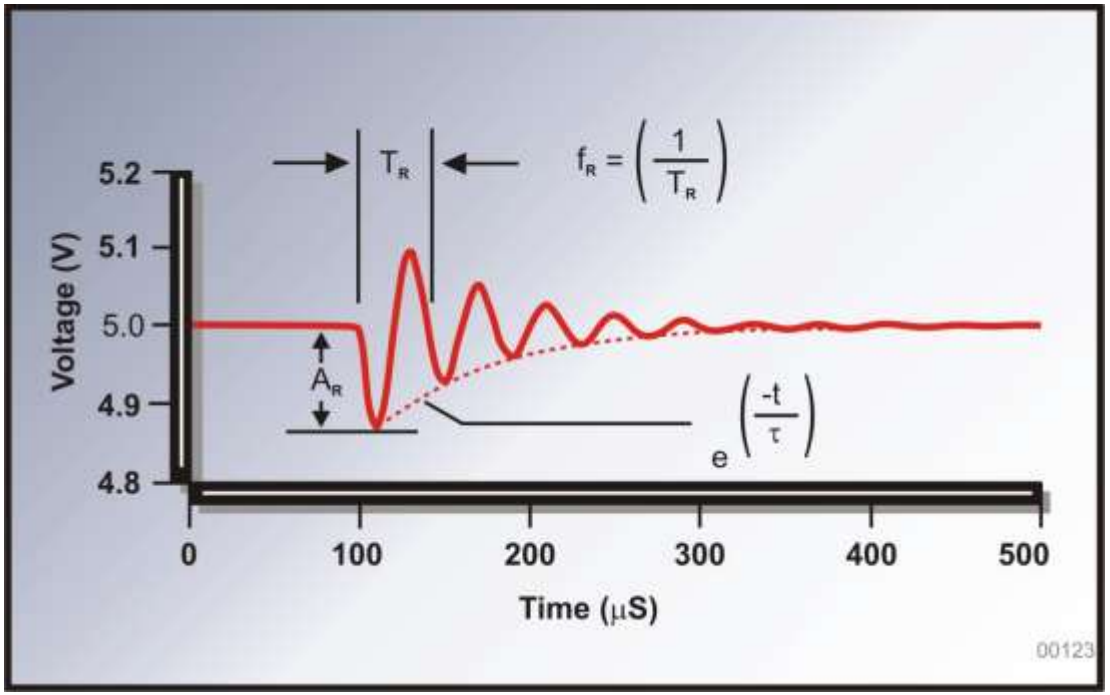
Helicopter Power System Application

- CBM+ applied to power systems in harsh environment
- Apache Helicopter where vibration, heat, shock all can reduce lifetime of deployed systems
- Extracts and processes eigenvalues as a metric of health



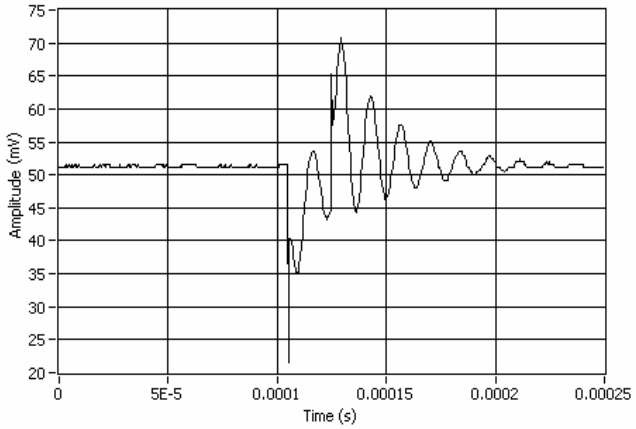
Power System Eigenvalue Extraction

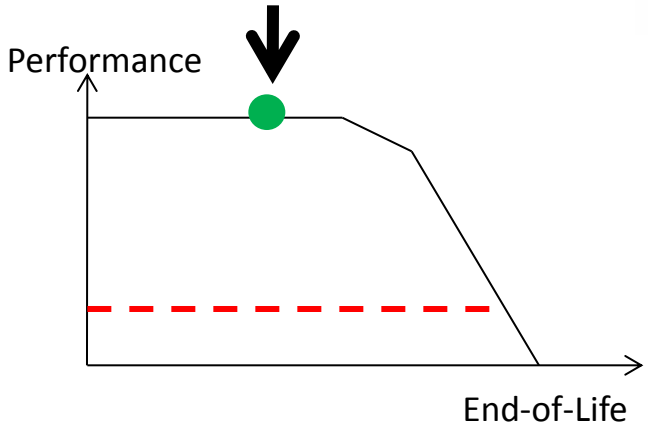
- Non-invasive diagnostic and health monitor for power system applications
- Stand alone early warning approach
- Detects wear out signatures prior to any noticeable reduction in performance
- Rapid testing on-line or off-line
- Patented method



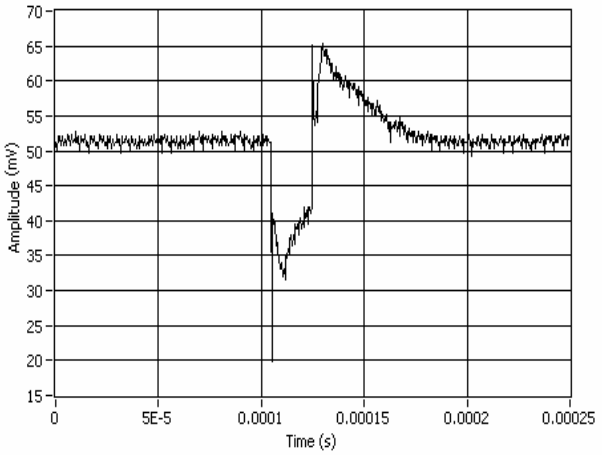
RingDown™ Power System Prognostics

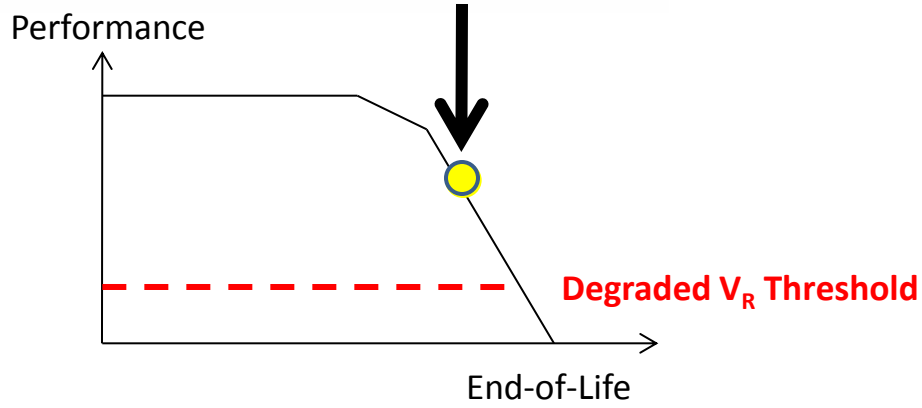
Good Power System





Degraded Power System

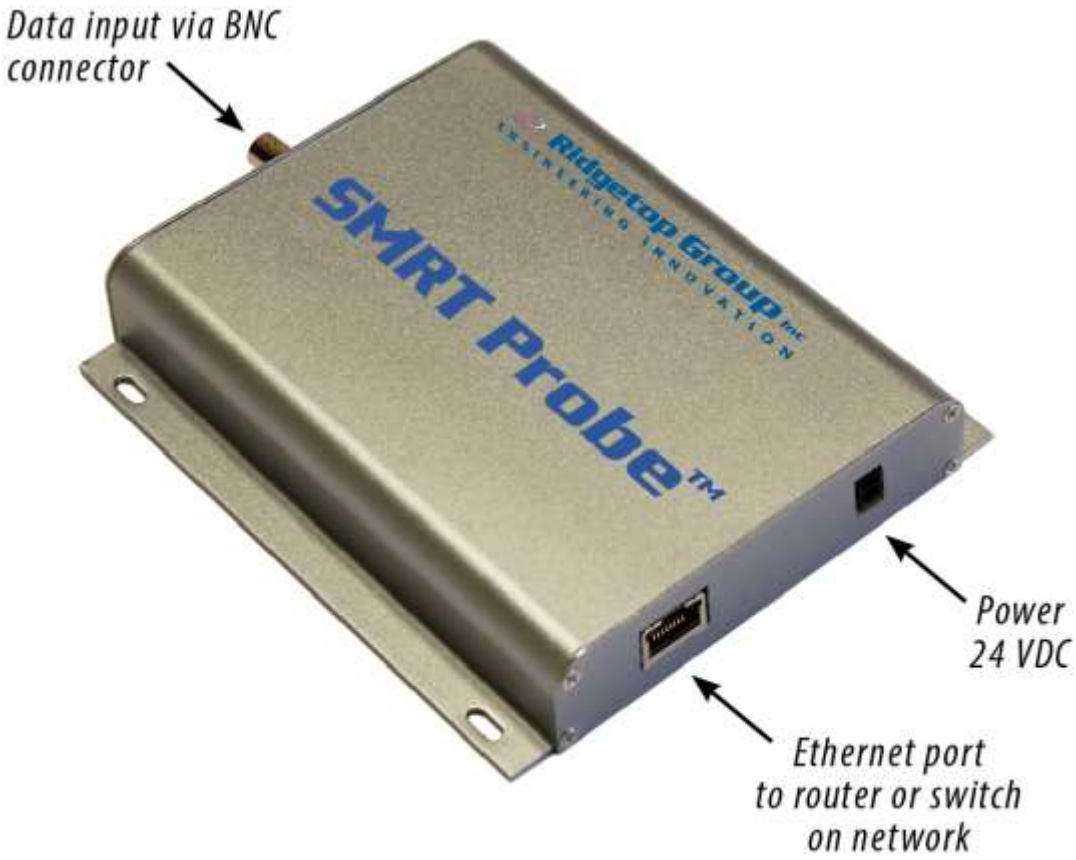




Both supplies provide regulated voltage, but one is degraded and will soon fail.

SMRT Probe™ Power System Signal Acquisition

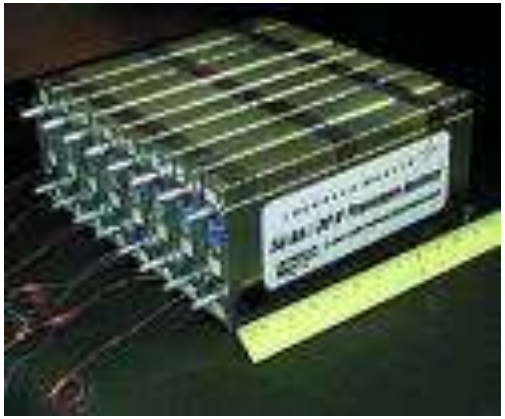
- Shows change in system response as power devices degrade with age or stress
- Prognostic indicator is independent of noise effects
- Effective extraction of degradation signatures on highly damped and “stiff” systems
- Applicable to a wide range of power systems



Battery Management Systems

Battery and Fuel Cell Management Systems

- Various Chemistries
  - Lithium Ion
  - NiCad
  - Lead Acid
  - etc
- PEM Fuel Cells
- Control Chips for balance of plant
- Individual Cell Monitors for adjustment of charge balance



Battery Technologies

- **From US Navy Sources:**

  "Predicting NiCad cell life expectancy, especially in series-connected multi-cell battery arrays, is a major issue within embedded military applications. Current cost to replace sonar system batteries is upwards of $450,000 each time. Moreover, poor battery reliability has significant intangible impacts to MH-60R fleet readiness "

- **Technical Issue:**

  The weakest cell in the series is vulnerable to reverse bias conditions during deep discharge. Conversely, the strongest cell in the string is vulnerable to over-charging in the charge cycle. This significantly reduces cell lifetimes and reliability.

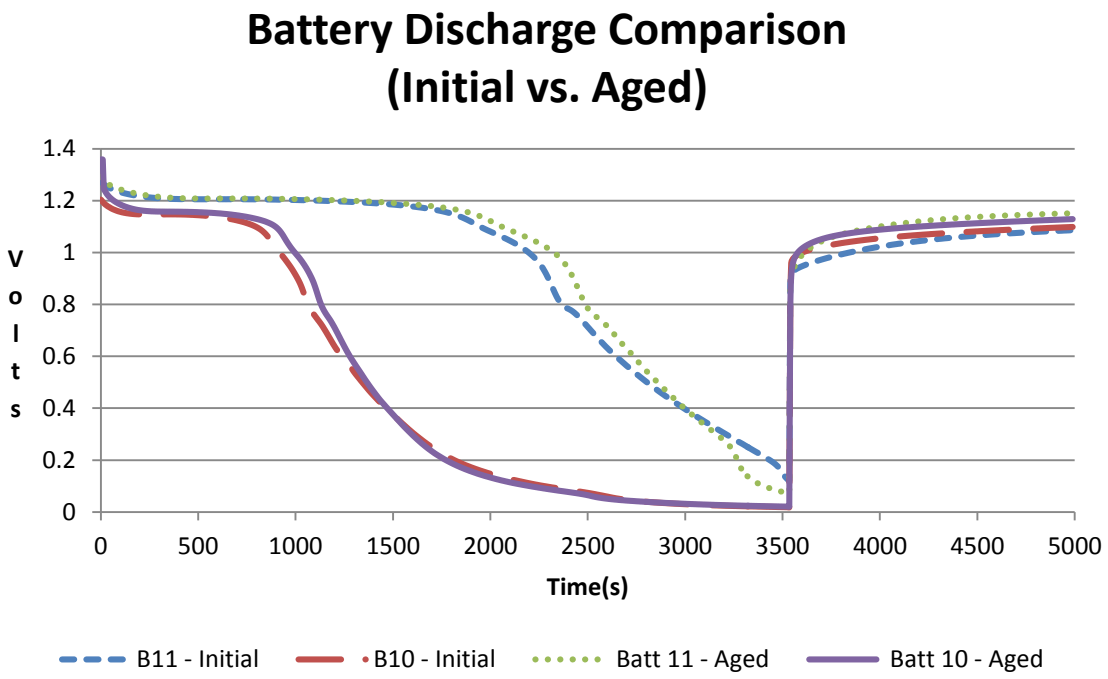
- **Ridgetop's solutions:**

  Innovative designs that allow individual cells to be monitored for charge and discharge, and optimize each cell so as to maximize battery life and reliability, as well as reduce overall system cost.

Battery Management Systems (BMS)

- Prognostic-enabling of BMS:
  - Monitor charge and discharge profiles for individual cells
  - Read SoC (State of Charge) of individual cells or a stack of cells
  - Examine the RUL(Remaining Useful Life) of individual cells
  - Dynamically balance the stack of cells to extend lifetime

Battery Discharge Curves

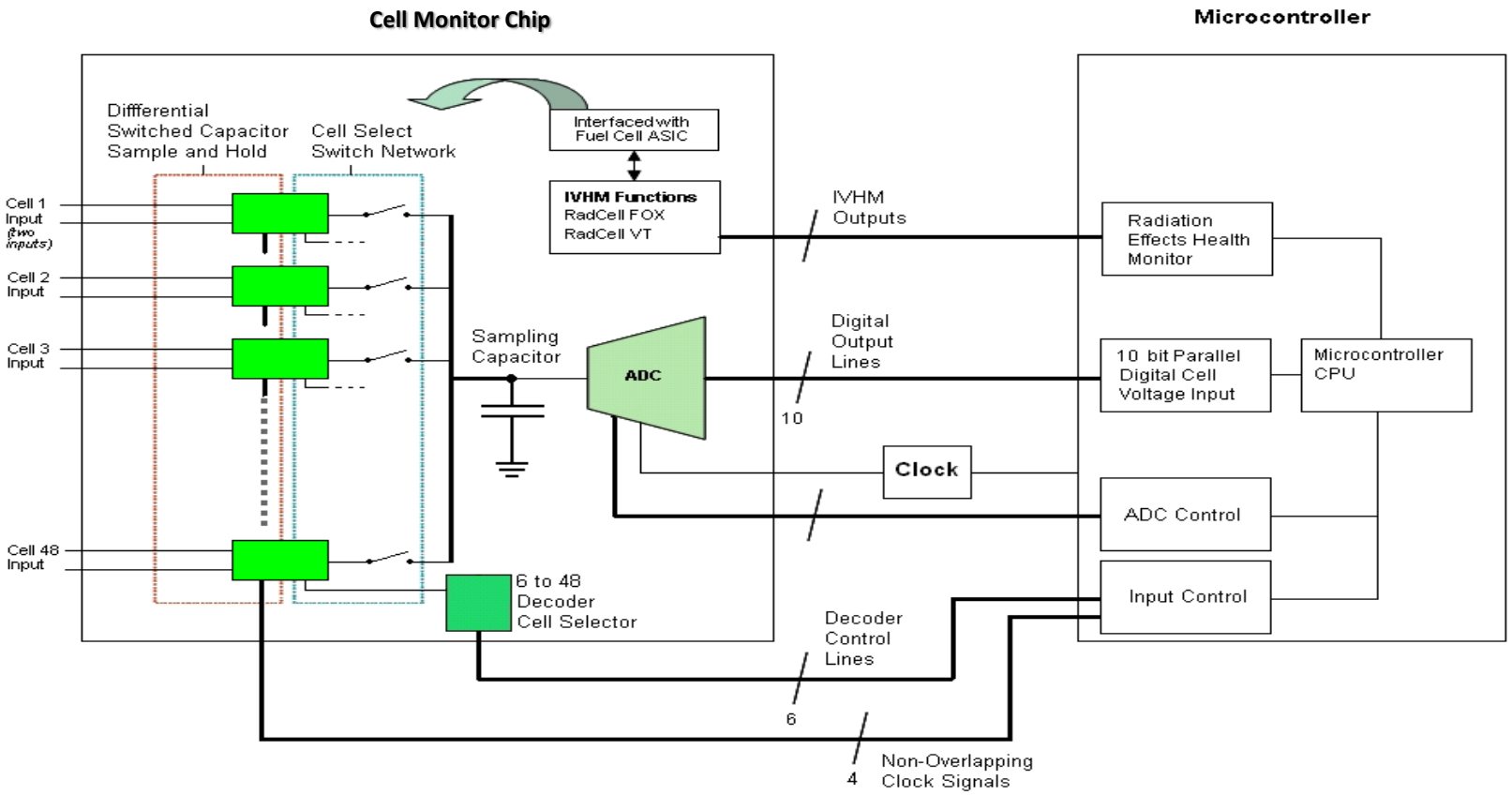


- Prognostic systems use this data for accurate State of Charge (SoC) and Remaining Useful Life (RUL) estimates.

Design Solution

- A special Lithium Ion Battery or Fuel Cell Stack Monitor Application Specific Integrated Circuit designed to measure individual, 0-2 VDC, cell voltages in up to a 48 cell stack. The analog cell voltages are sampled and converted to digital words with 9 bit resolution.
- Features include:
  - Single chip replaces 48 discrete cell measurement circuits
  - Rejection of common mode voltage up to 100VDC
  - Radiation hardened design
  - Integrated Prognostic cells measure cumulative radiation effects and provide early warning of impending failure
  - Supports Health Monitoring applications and more precise, closed loop designs of battery management systems (BMS)

Ridgetop Measurement and Control IC



Rotary Gearbox Prognostics

Gearbox Prognostics

Helicopters suspended as gearbox fault blamed for Super Puma ditching

STV 13 May 2012 12:02 BST

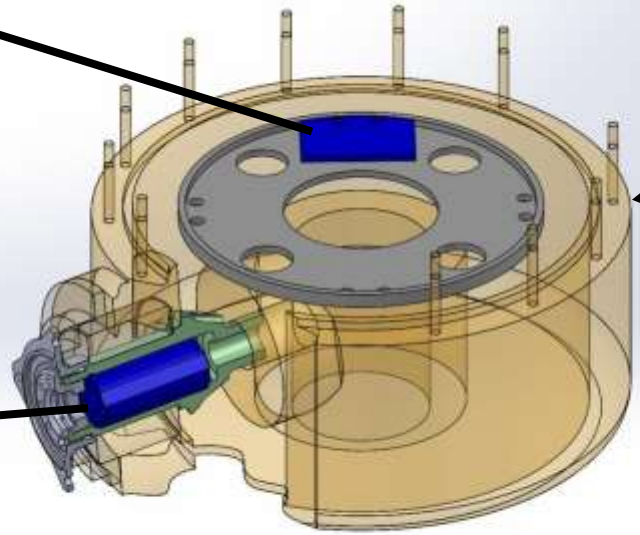
The owners of a helicopter which ditched in the North Sea last week grounded more aircraft today after an early investigation revealed a fault in its gearbox.

The move comes after an initial Air Accidents Investigation Branch examination of the EC225, which went down while carrying 12 passengers and two crew, showed it suffered a crack to a gearbox shaft.

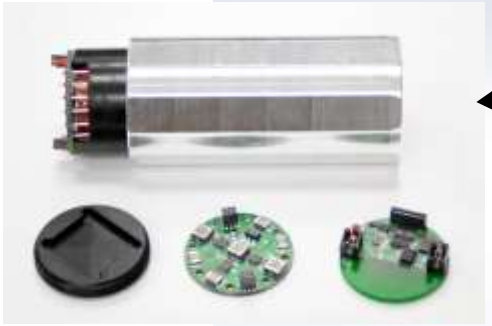
Source:http://news.stv.tv/north/99554-helicopters-suspended-as-gearbox-fault-blamed-for-superpuma-ditching/

Bell OH-58 Gearbox with RotoSense™ Unit Locations

Sun gear wireless sensor

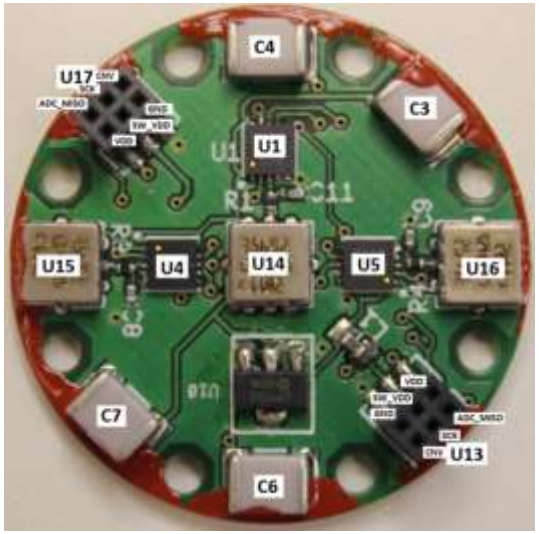


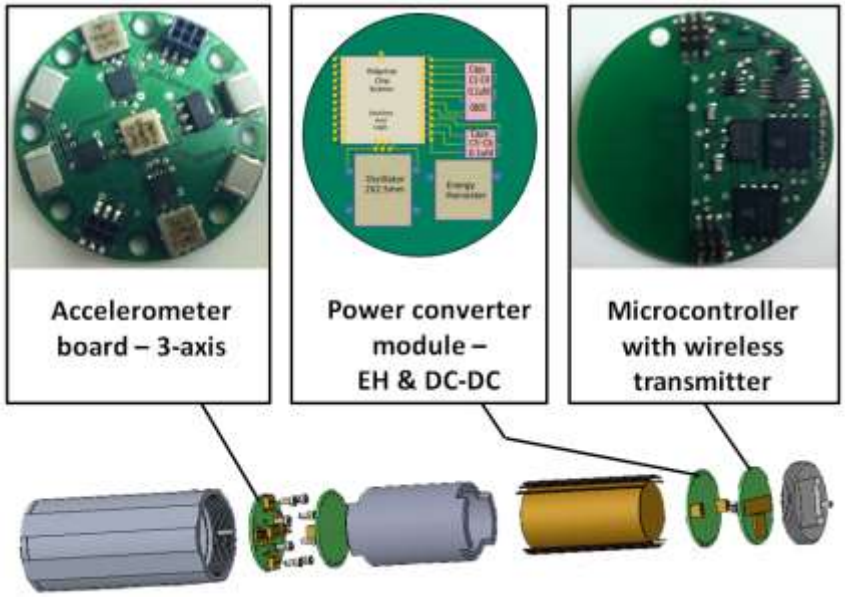
OH-58 Gearbox



Pinion gear wireless sensor

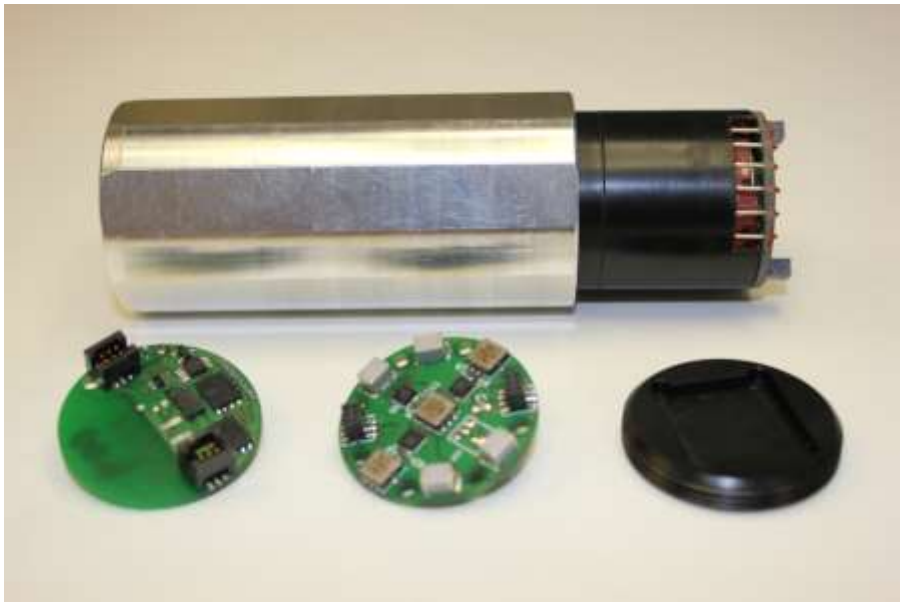
Current RotoSense System





Small size allows the whole system to be mounted in the shaft of the transmission

Current RotoSense System



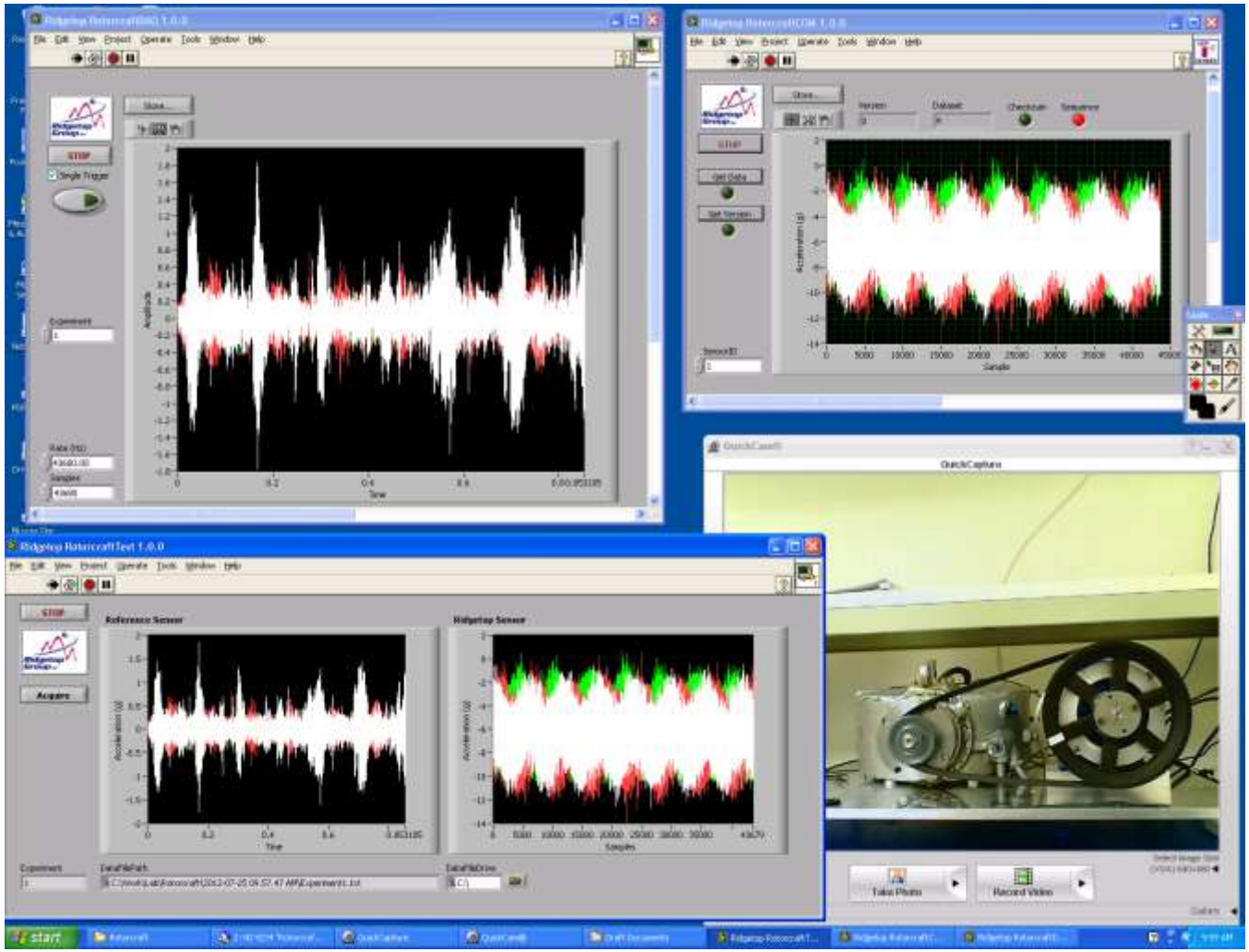
Complete module

(other enclosures are available)

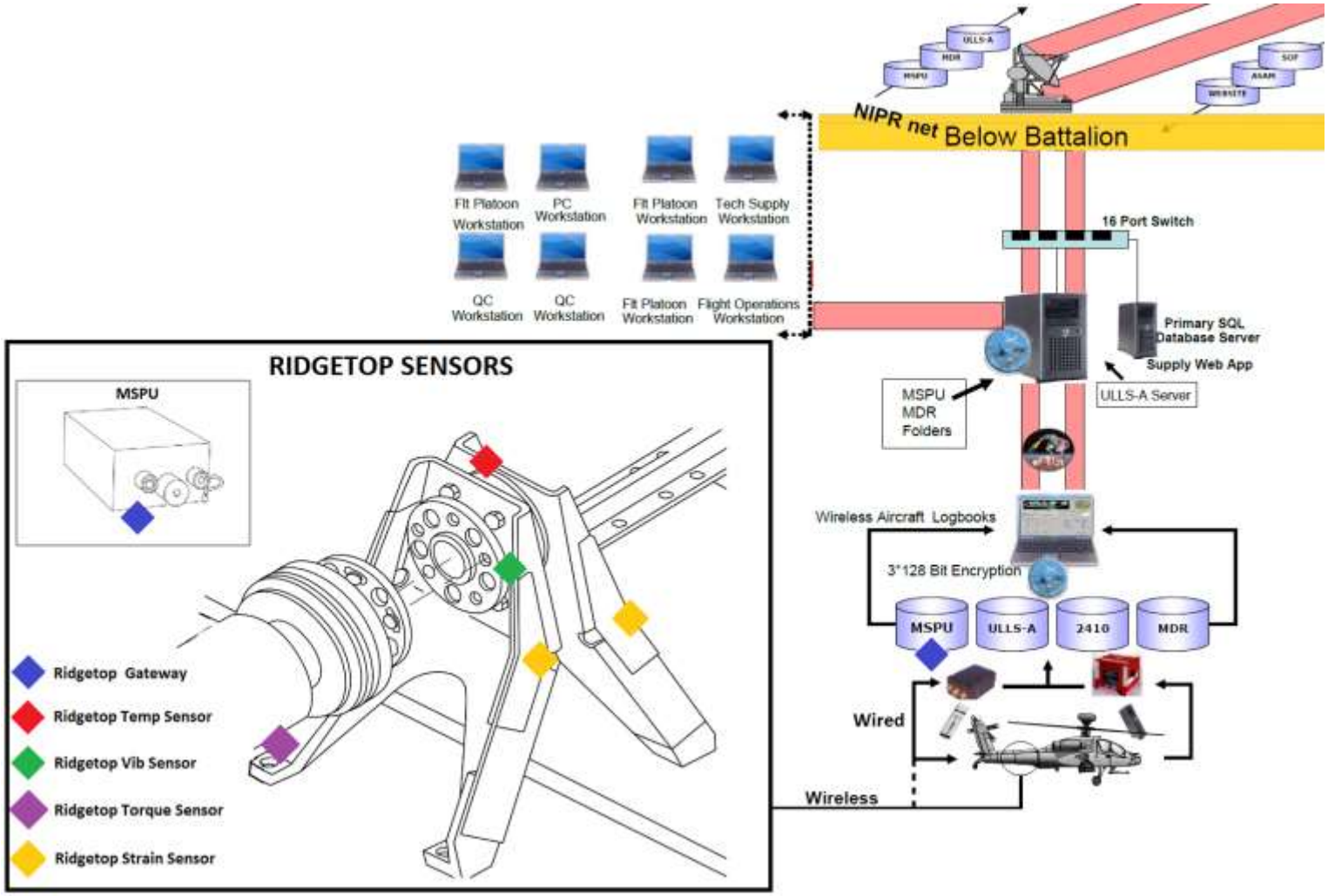
Module mounted in the shaft of the transmission

Wireless Interface

- Wireless rotation sensor inside Bell OH-58 gearbox spinning at 5,500 RPM
- Data is being logged and compared in real time between the local testbed and remotely located wireless gateway with exacting results

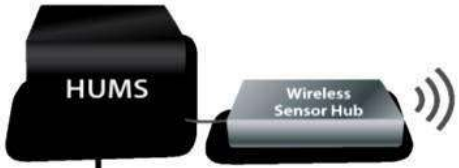


Sentinel Motion Extended Monitoring System



On Board and Off Board Issues

- Wireless Sensor nodes are placed in critical areas to collect both rotation and vibration data
- Onboard Health and Usage Management System (HUMS) integrates the SoH and RUL for immediate notification
- All data can be downloaded for CBM interactions with ground station equipment
- Criticality of faults (Classification)



Sentinel Motion with Wi-PHM – Wind Turbines

- RotoSense sensor is installed in the gearbox of wind turbines
- The sensor will gather data on the performance of the equipment
- The data will be transmitted wirelessly to a gateway in order to be processed and analyzed

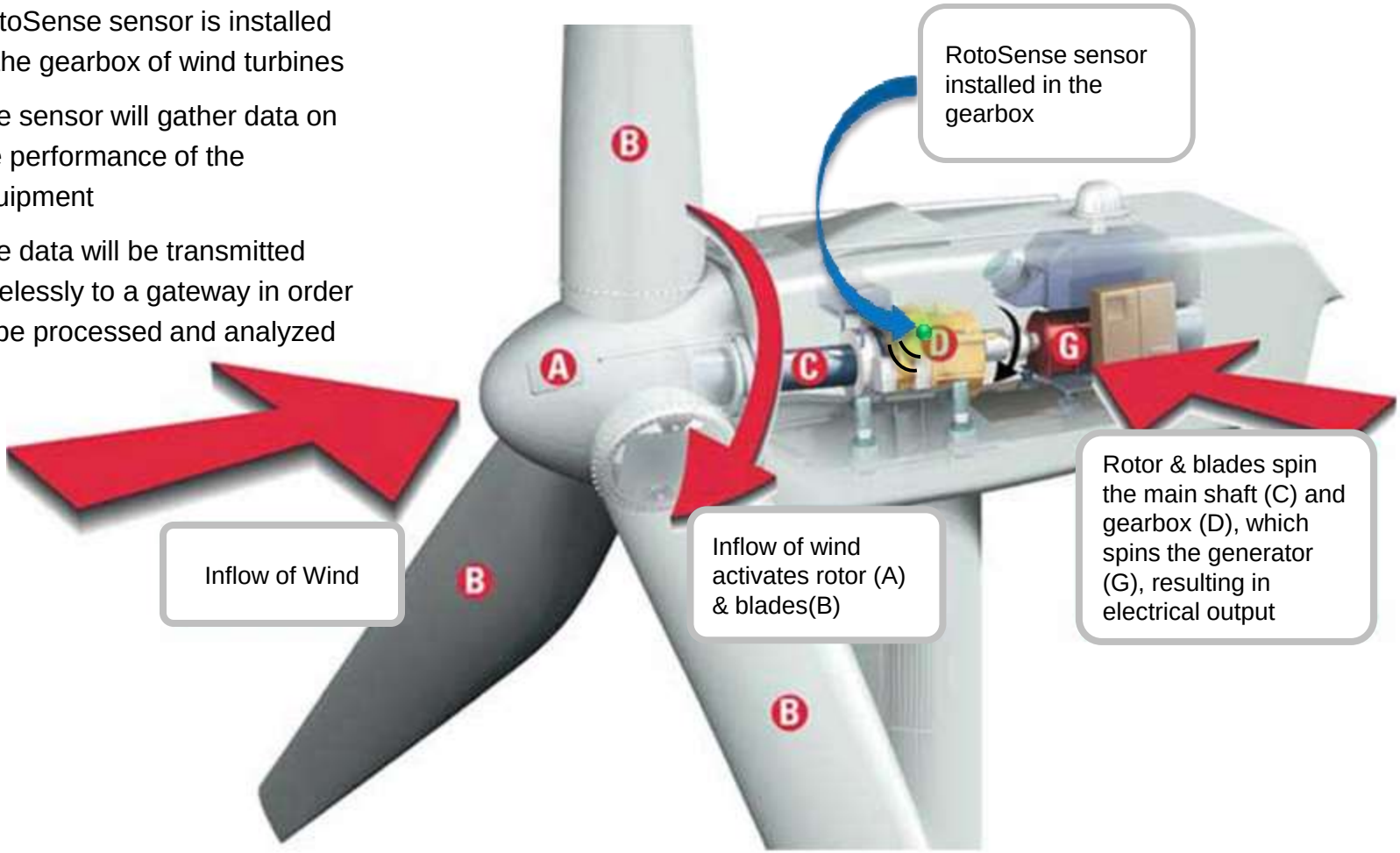


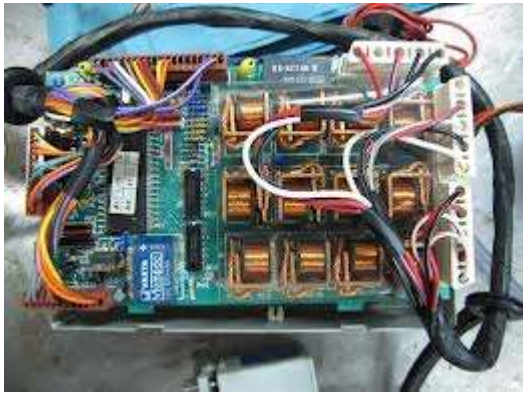
Image source: http://www.techienation.com/2008/08/14/understanding-wind-power-wind-generators-turbines/

Sentinel Motion Wind Power Application

Intermittency Detection

Intermittencies

- Over 50% of reported problems at the module level cannot be duplicated.
- Costly warranty repair cycle begins as intermittencies contribute to faults, then incorrect actions are taken for customer.
- Source of problem: Cables, solder joints and temperature-related performance variation in ICs, batteries and printed circuit boards



Intermittencies

- With present technology, reported electronic system problems in the field cannot be duplicated at the service point or in the lab
- “Three/Four-letter” words (CND, NTF, RTOK)
  - Could Not Duplicate (CND)
  - No Trouble Found (NTF)
  - Retest OK (RTOK)
- 50 to 80% of these CND/NTF/RTOK problem categories are reported by service personnel.
- Major culprits – Solder joint intermittencies and NBTI effects in deep submicron ICs

Solder Balls, Cracks and Fractures

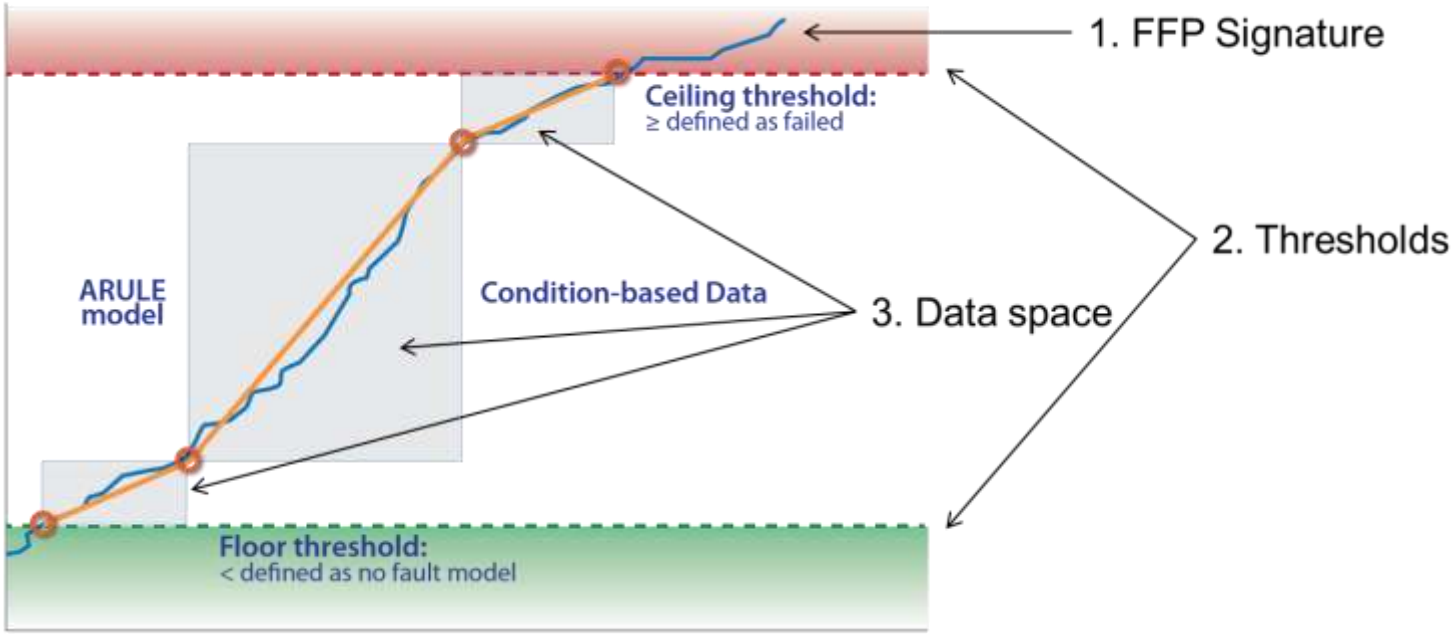
SJ BIST Detection Solution

SJ BIST is part of the Sentinel Interconnect product line

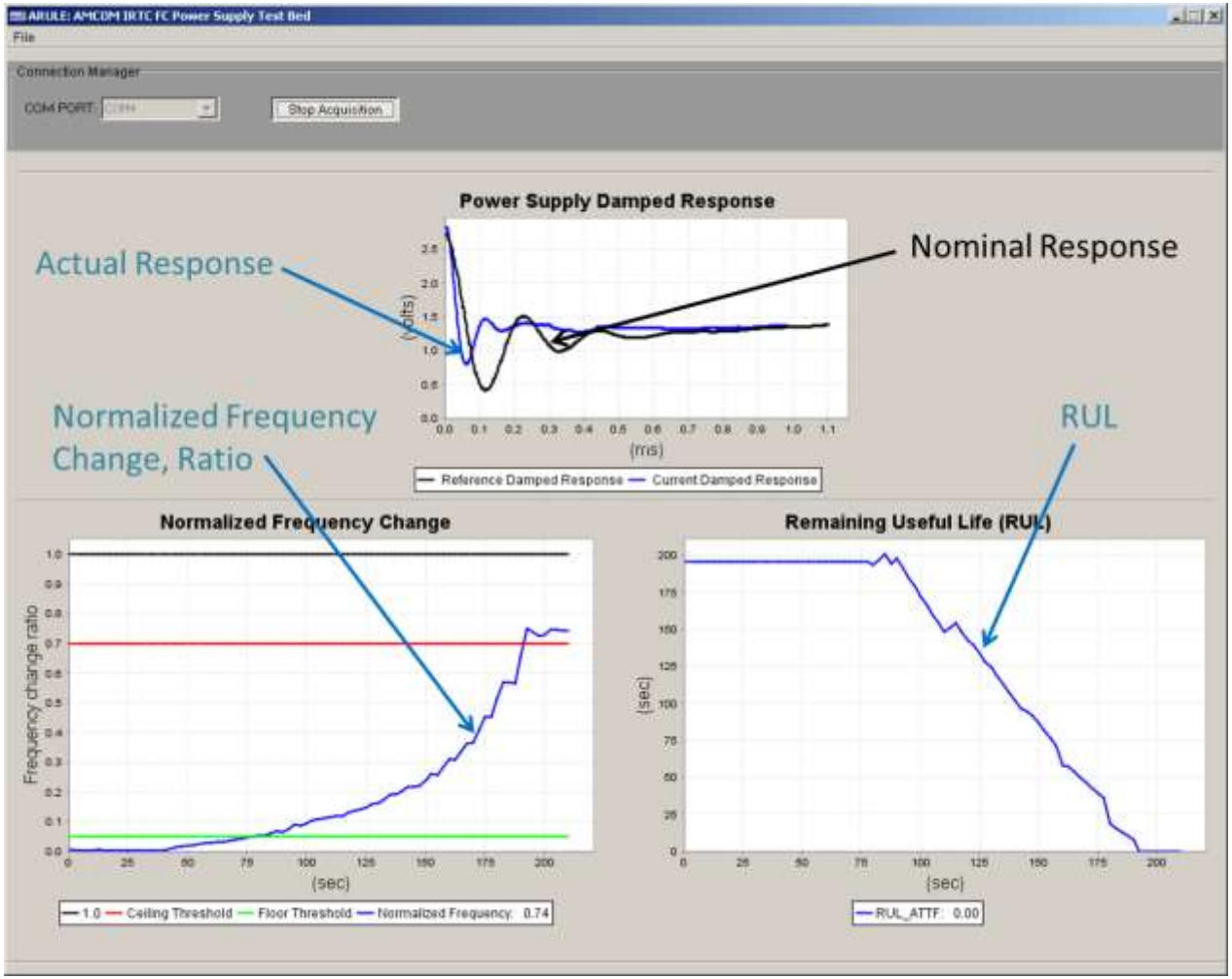
Prognostic Algorithms

Prognostic Algorithm (ARULE™)

- Ridgetop developed software that takes advantage of the fact that failure modes produce predictable degradation signatures.
- Each input data sample is used to adapt an Fault to Failure Progression (FFP) signature definition to the data.
- The adapted FFP signature definition is then used to produce accurate RUL and SoH estimates that can be used to generate diagnostic and prognostic information: messages, plots, thermometers, and so on.



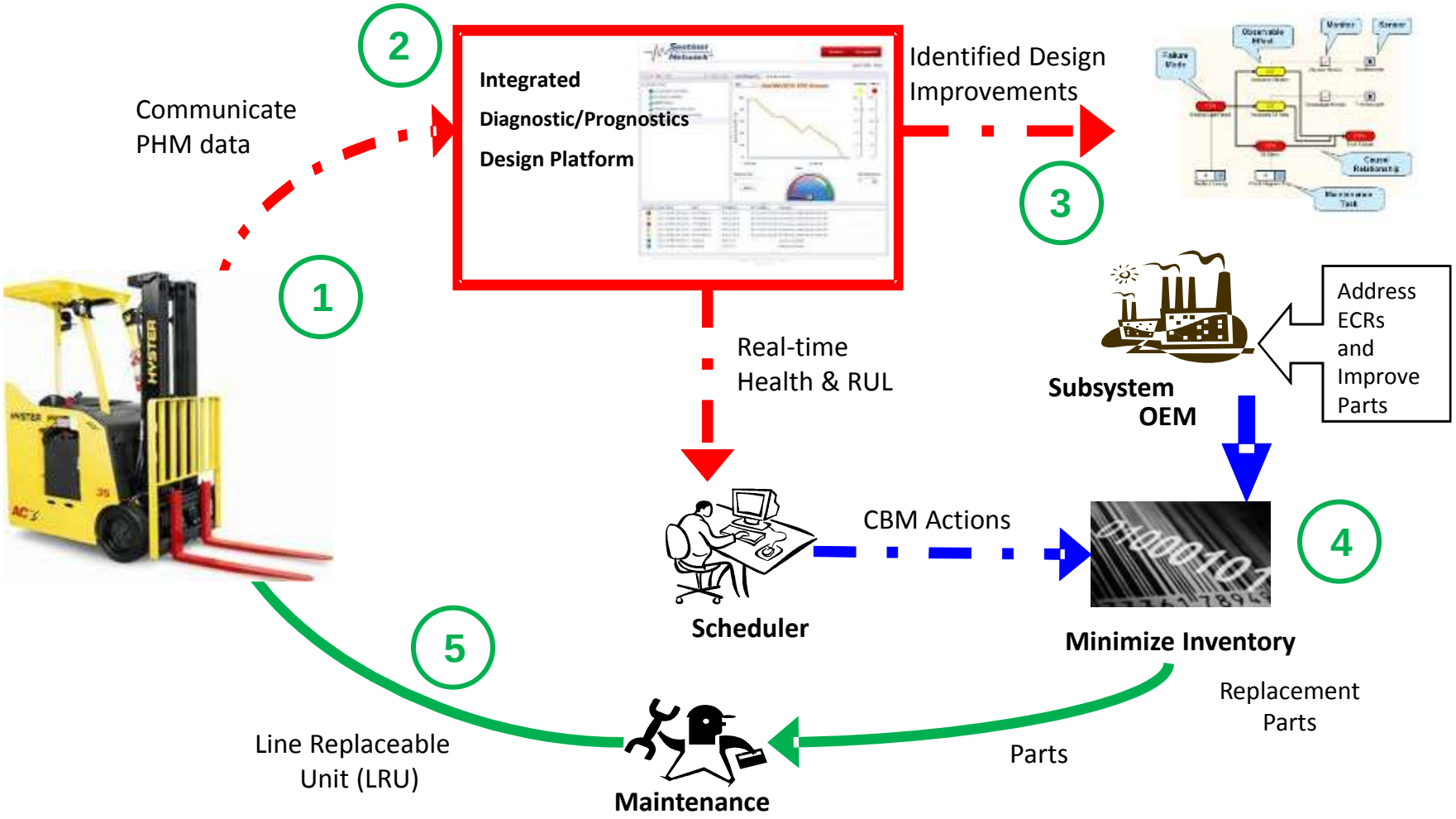
RingDown and ARULE*



* US PATENT 7,619,908; PATENT PENDING

Integrated Solutions

Prognostics Ecosystem



Summary

- Prognostics helps augment conventional reliability based design methods.
- Ridgetop has delivered innovative Sentinel Suite-based product solutions to many aerospace, industrial, and oil/gas equipment firms.
- Recent examples of prognostic-enabled systems

  Power Systems

  Power EHA actuator systems

  Printed circuit boards

  Mechanical Systems

Contact Information

Ridgetop Group Inc.

Doug Goodman
CEO
DGoodman@RidgetopGroup.com

3580 West Ina Road
Tucson, AZ 85741

Questions?

- Slides are available upon request. Use the GotoMeeting chat now or send an email to information@ridgetopgroup.com
- E-mail follow-up questions & comments to doug.goodman@ridgetopgroup.com
- Please fill out our brief feedback survey at https://www.surveymonkey.com/s/ZNC2H6Y

Thanks for your time and attention!