
# Smart Sensors for Distributed Event-Triggered System Health Monitoring

**Ridgetop Group, Inc.**

**Doug Goodman, President & CEO**

**Kyle Ferrio, VP Advanced Research**

# Agenda

- Quick Introduction to Ridgetop Group
- Event-Driven Inspection
- Smart Sensors

# Ridgetop Group, Inc.


**Ridgetop Group Facilities in Tucson, AZ**

- Arizona-based firm, founded in 2000, with focus on electronics for critical applications
- Two divisions: Semiconductor & Precision Instruments (SPI) and Advanced Diagnostics & Prognostics (ADP)
- Technology leader in precision test structures for QA and prognostic applications
- Wide range of commercial and government customers

- Worldwide nanotechnology R&D partners in industry and academia
- Foundation and focus in physics-of-failure for electronic systems

**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 ACCREDITED

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

**ISO9001:2008 Quality Management System**


**AS9100C Quality Management System**

ACCREDITATION OF TRUST

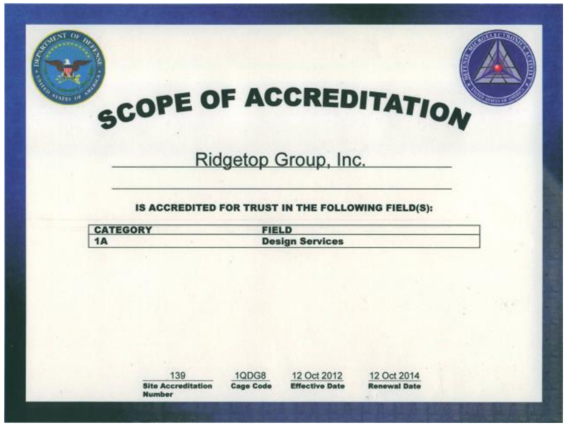
**Microelectronics Trusted Source**
**CATEGORY 1A**

**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.**

| 139 | 1QDG8 | 12 Oct 2012 | 12 Oct 2014 | |
|---|---|---|---|---|
| **Site Accreditation Number** | **Cage Code** | **Effective Date** | **Renewal Date** | **Ted Glum, Director, Defense Microelectronics Activity** |



SCOPE OF ACCREDITATION

Ridgetop Group, Inc.

**IS ACCREDITED FOR TRUST IN THE FOLLOWING FIELD(S):**

| CATEGORY | FIELD |
|---|---|
| 1A | Design Services |

| 139 | 1QDG8 | 12 Oct 2012 | 12 Oct 2014 |
|---|---|---|---|
| **Site Accreditation Number** | **Cage Code** | **Effective Date** | **Renewal Date** |

**Microelectronics Trusted Supplier (Defense Microelectronics Activity)**

# Partners and Customers

LOCKHEED MARTIN

AkerSolutions

DELL

GENERAL ATOMICS

ATK

BOEING

GOODRICH

Rolls-Royce

INGENIUM AEROSPACE

Raytheon

Honeywell

MOOG

ASTRONICS CORPORATION

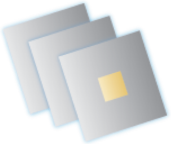
BAE SYSTEMS

# Faults Occur at Multiple Levels in Systems

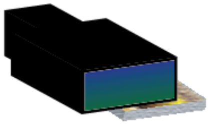
**Ridgetop Five-level Model**

***Progression of Electronic Health Solutions***

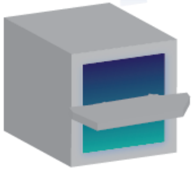
**Die Level**
- Process-related
- Wear-out/radiation effects



**Component Level**
- Radiation damage
- Intermittencies
- Degradation



**Board Level**
- IC, capacitors
- FPGA/CPU
- Solder joint intermittencies



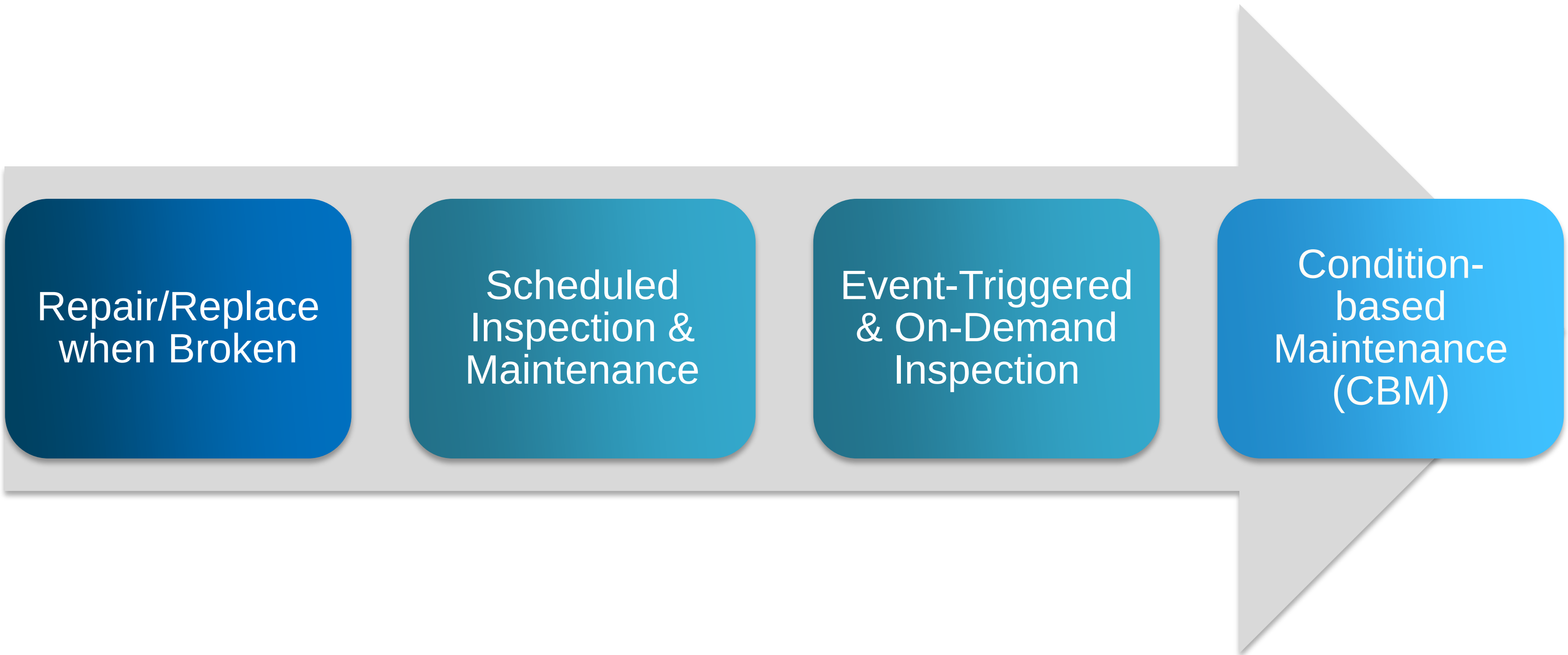
**Module Level**
- CNI prognostics
- Digital boards
- Power/analog boards
- Connectors


**System Level**
- Embedded Sentinel Network™ with HealthVIEW™ software
- System-level state-of-health (SOH) analysis & prognostics
- Remaining useful life (RUL)
- On-board monitors
- Communicate with ground-based systems

00394C

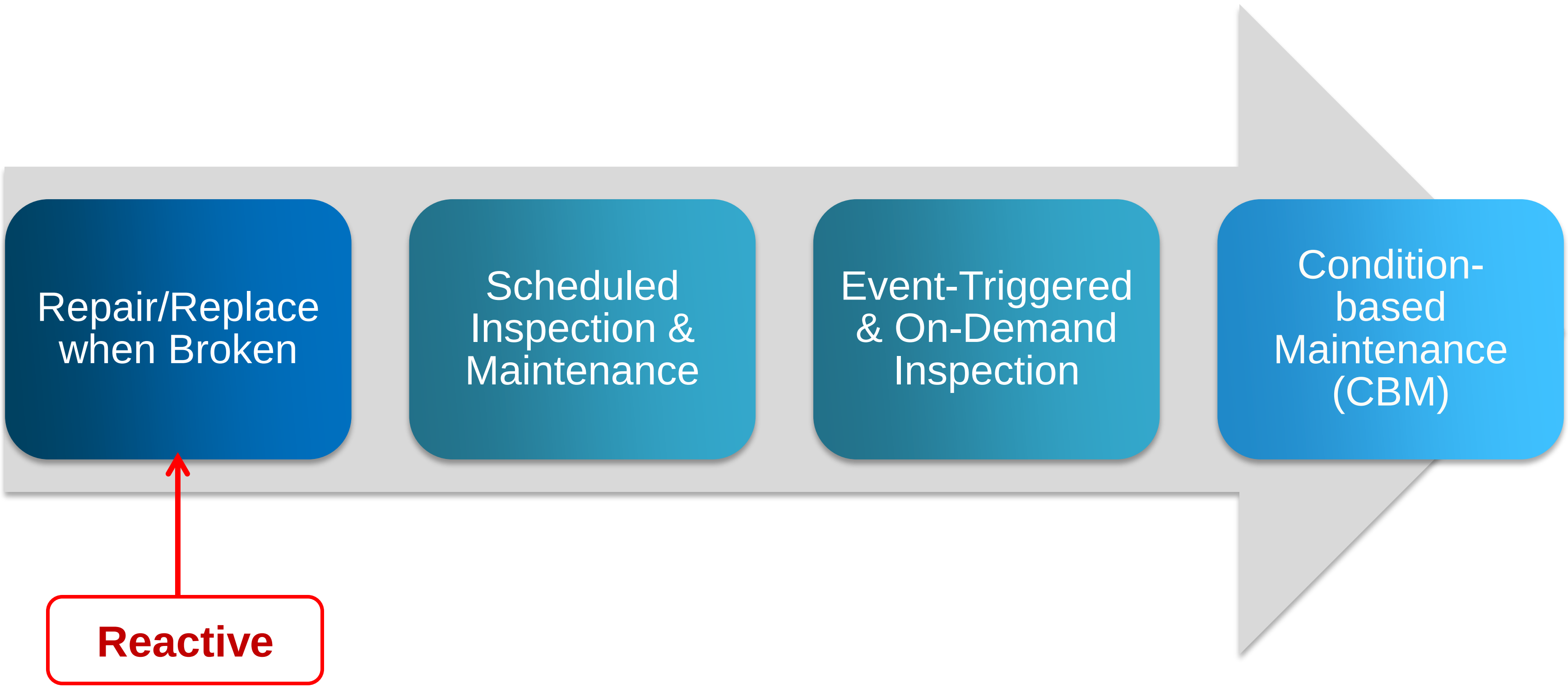
# Evolution of Maintenance Practices

## Going from REACTIVE to PROACTIVE



# Evolution of Maintenance Practices

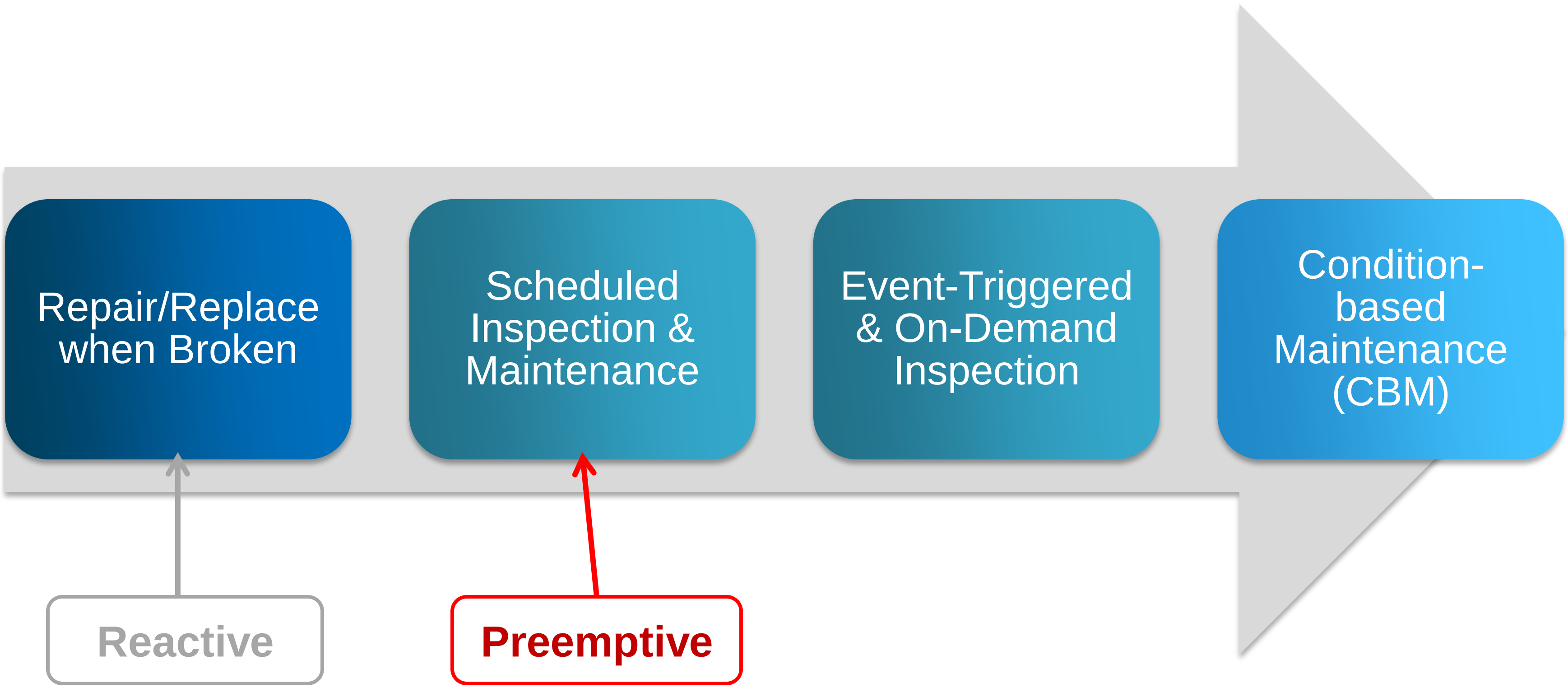
## Going from REACTIVE to PROACTIVE




**Reactive maintenance plans are unacceptable for critical systems.**

# Evolution of Maintenance Practices

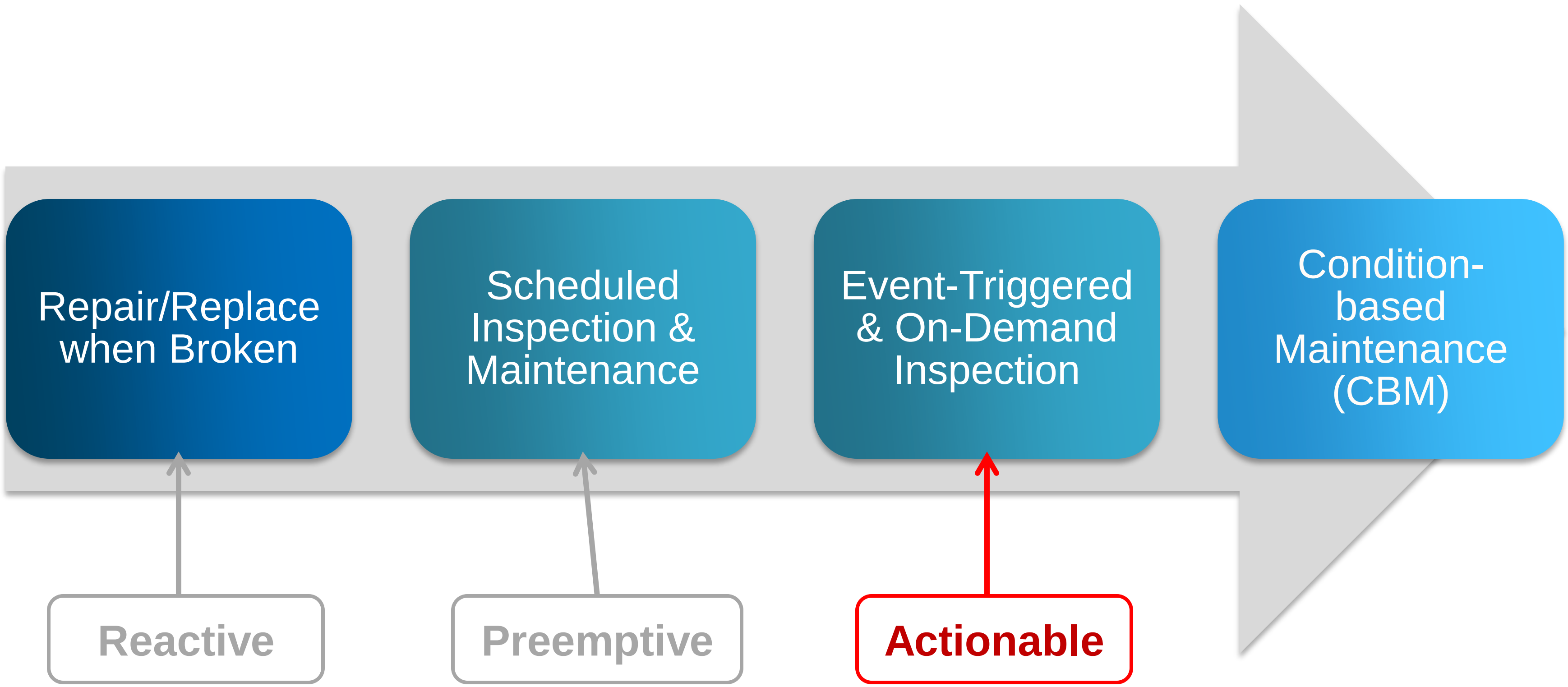
## Going from REACTIVE to PROACTIVE




**Preemptive maintenance may increase risk to crew and vehicle.**

# Evolution of Maintenance Practices

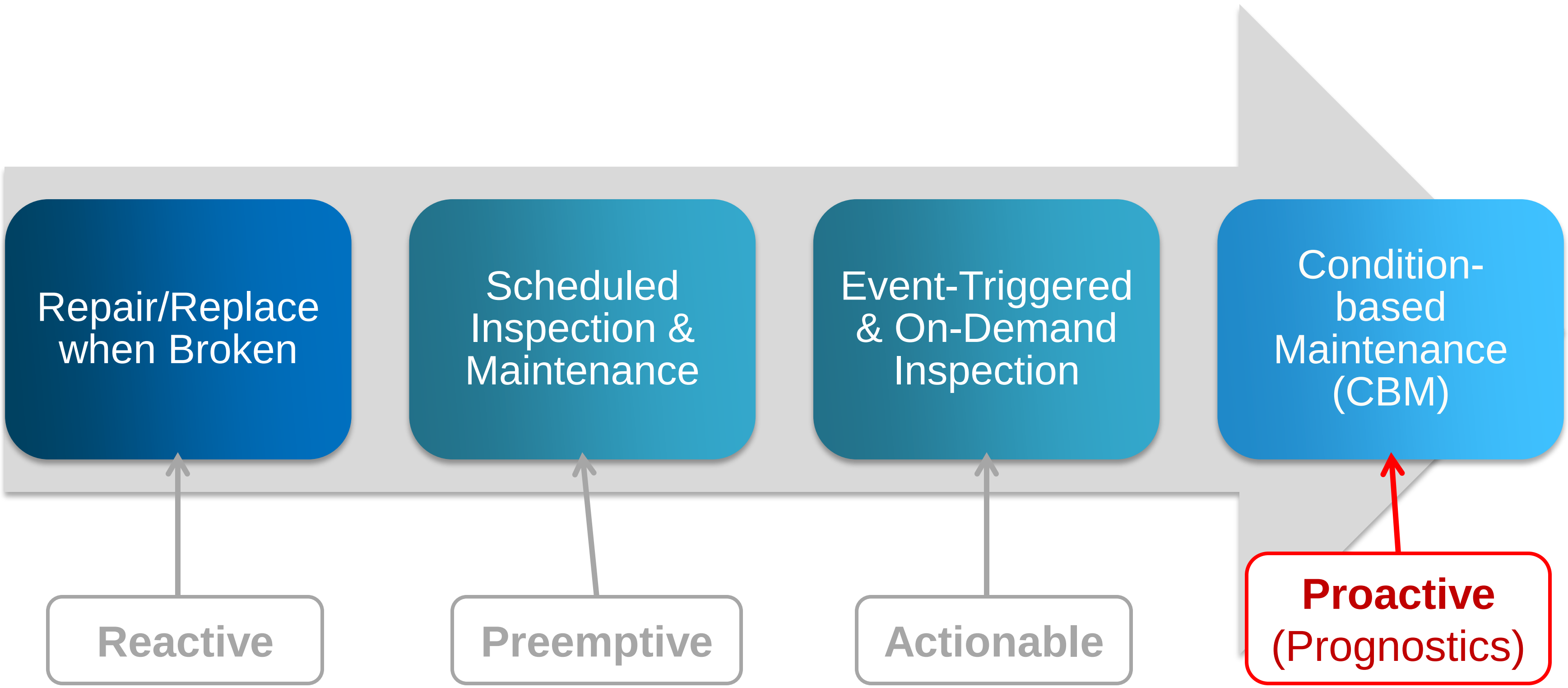
## Going from REACTIVE to PROACTIVE




**Event-triggered maintenance is based on *timely and actionable* information.**

# Evolution of Maintenance Practices

## Going from REACTIVE to PROACTIVE




**Smart sensors and algorithms provide the prognostic horizon for CBM.**

# The Challenge: Situational Awareness

- Cannot be in all places at all times
- Slow, dangerous work
- High risk to crew and vehicle
- Autonomous monitoring should be the norm

NASA STS-116
http://spaceflight.nasa.gov/gallery/images/shuttle/sts-116/html/s116e05983.html

# Sensors, Everywhere?

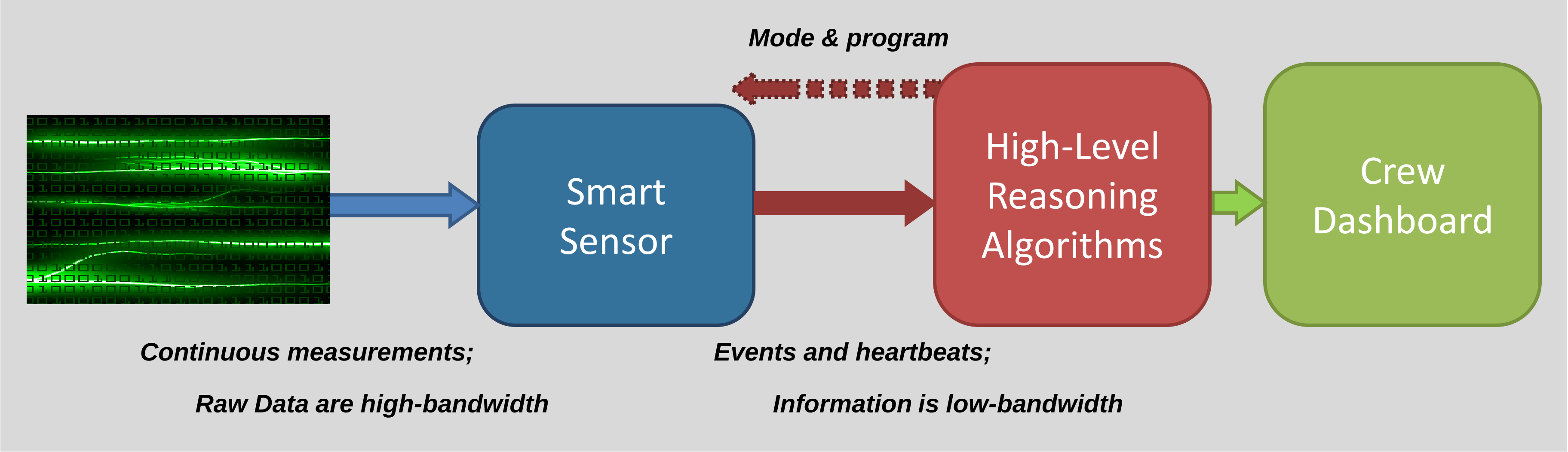
- Sensors improve situational awareness
  - But data is not the same as information!

- New challenges
  - Big Data
  - Proliferation of sensors implies growth of data
  - Extracting actionable information from big data is hard, even on earth
    - → Compute burden
    - → Power draw
    - → Cooling load

Google press release
http://www.google.com/about/datacenters/

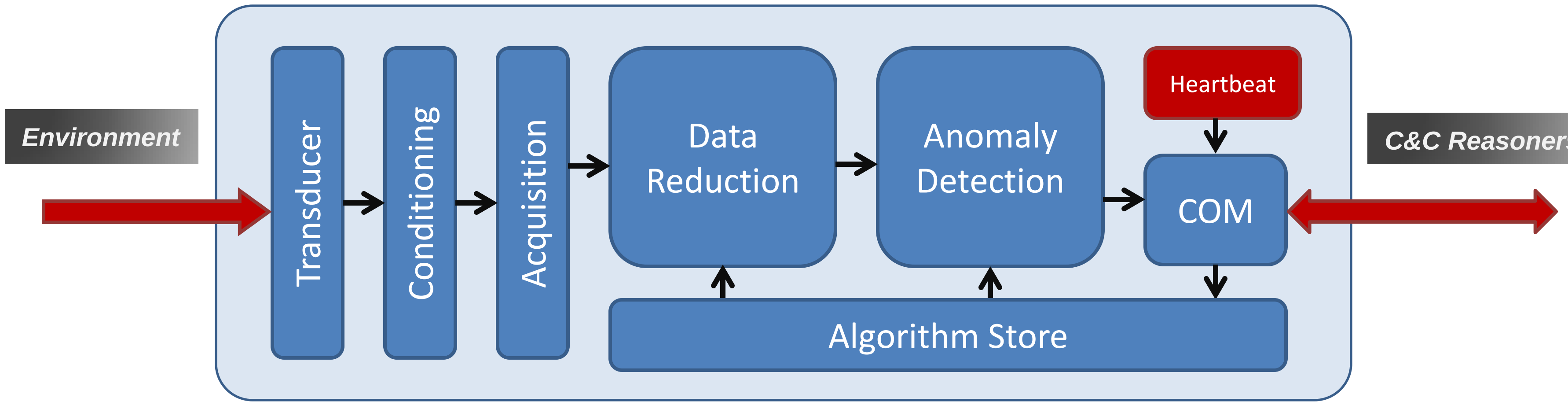
# Smart Sensors Ease Data Burden

- Big Data in Space can borrow from Big Data on Earth
  - Don't move (much of) the data to the algorithms
  - Move routine computation to the data
  - Monitor *locally* and persistently with low-power sensors
  - Reduce data to events *locally*, at the sensor
  - Communicate *events* over low-bandwidth, low-power channel
  - Stream *data* at full (or fractional) bandwidth only when commanded



# Smart Sensors Ease Data Burden

- Smart Sensors transform data into information by combining…
  - Physical instruments
  - Dynamic data acquisition scheduling
  - First-order data reduction → event detection
  - Low-bandwidth communication and control
  - Remotely reconfigurable algorithms
  - Integrate (except transducer) in a rad-hard ASIC




# RotoSense™

# NASA Spinoff 2012 – RotoSense™

Office of the Chief Technologist

Value for NASA, Benefits for the Nation

NASA Spinoff

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Spinoff 2012

## Wireless Sensors Pinpoint Rotorcraft Troubles

*Transportation*

**NASA Technology**

Helicopters present many advantages over fixed-wing aircraft: they can take off from and land in tight spots, they can move in any direction with relative ease, and they can hover in one area for extended periods of time. But that maneuverability comes with costs.

For example, one persistent issue in helicopter maintenance and operation is that their components are subject to high amounts of wear compared to fixed-wing aircraft. In particular, the rotor drive system that makes flight possible undergoes heavy vibration during routine performance, slowly degrading components in a way that can cause failures if left unmonitored. The level of attention required to ensure flight safety makes helicopters very expensive to maintain.

*Ridgetop's wireless MEMS accelerometer can gather quality data from spots inaccessible to the sensors typically employed today.*

As a part of NASA's Fundamental Aeronautics Program, the Subsonic Rotary Wing Project seeks to advance knowledge about and improve prediction capabilities for rotorcraft, with the aim of developing technology that will meet future civilian requirements like higher efficiency and lower noise flights. One of the program's goals is to improve technology to detect and assess the health of critical components in rotorcraft drive systems.

Full article here: http://spinoff.nasa.gov/Spinoff2012/t_6.html

# Problem Statement

**Helicopters suspended as gearbox fault blamed for Super Puma ditching**

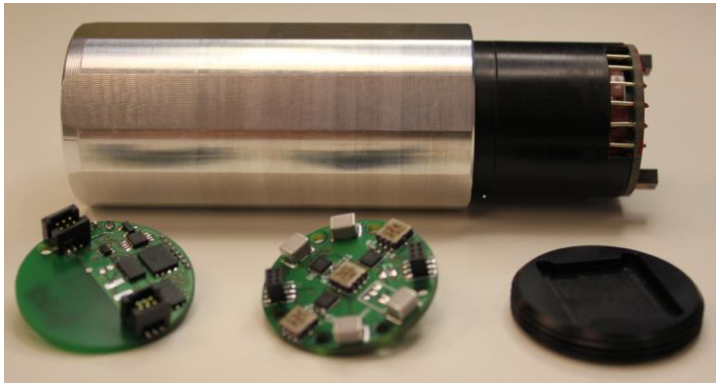
STV 13 May 2012 12:02 BST

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/

# Solution: RotoSense



- RotoSense is a wireless rotational vibration sensor
- IEEE standard 802.15.4 wireless implementation
- Sensing tool wear, chatter, or spindle balance in CNC applications
- Detecting prognostic vibrational signatures in rotating shafts or pinions to give early warning of gear tooth cracking or spalling in wind turbines and transmissions
- Applications include:
  - CNC
  - Down-hole oil & gas drilling
  - Wind turbines and transmissions

| Specification | Value |
|---|---|
| MEMS accelerometer peak impact | >200 g |
| Operating temperature | 93 °C |
| Sensor housing | 1.5” diameter x 3” length |
| Sensor data memory | 2 Mbits |
| Accelerometer sensitivity | <20 mV/g at 100 Hz |
| Wireless data rate | 75 kbaud nominal |
| Battery powered | 3.6 V high-temp battery, 4.5 Ah, 200 °C |
| Battery life | 4 months at a 50% duty cycle |
| Sensor and signal conditioning bandwidth | 20 kHz |
| ADC resolution | 16 bits |
| ADC sample rate | >250 kHz |

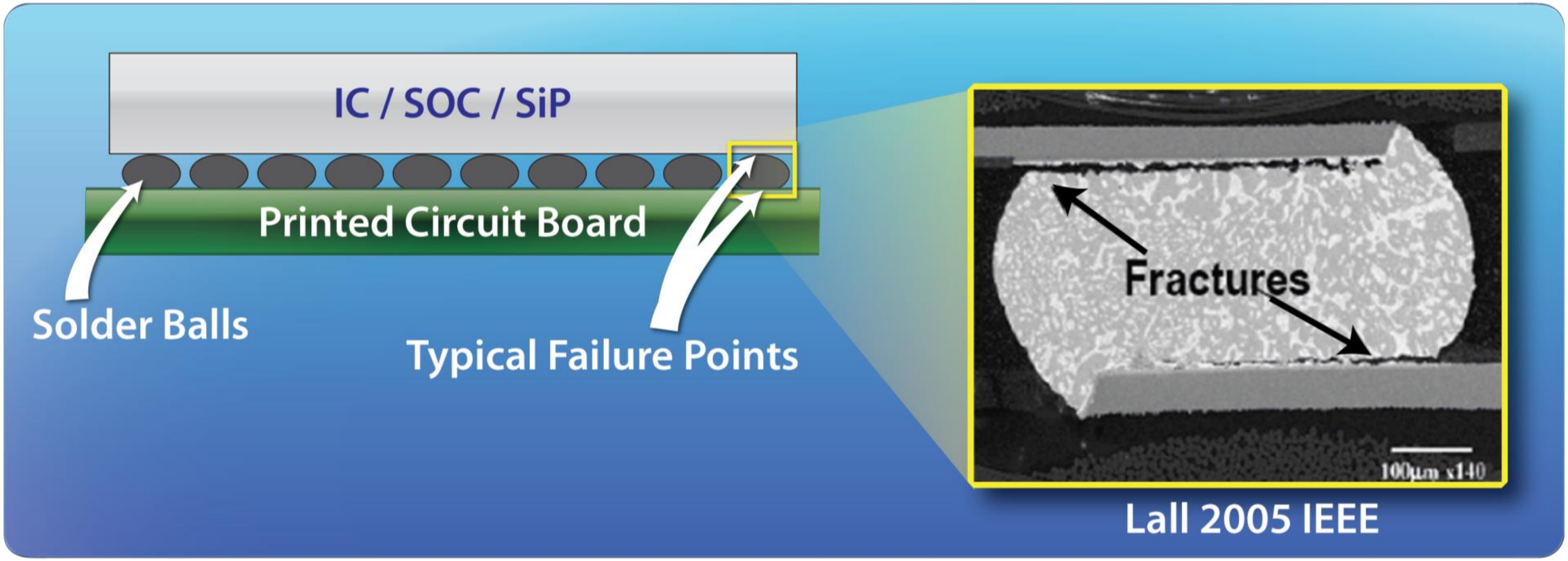
# Intermittencies

- **Electrical based intermittent/No Fault Found (NFF) issues are amongst the most difficult to identify and deal with in complex systems.**
- **Ridgetop's unique approach to addressing this will be critical to enabling reliable system performance for years to come**

# Intermittencies

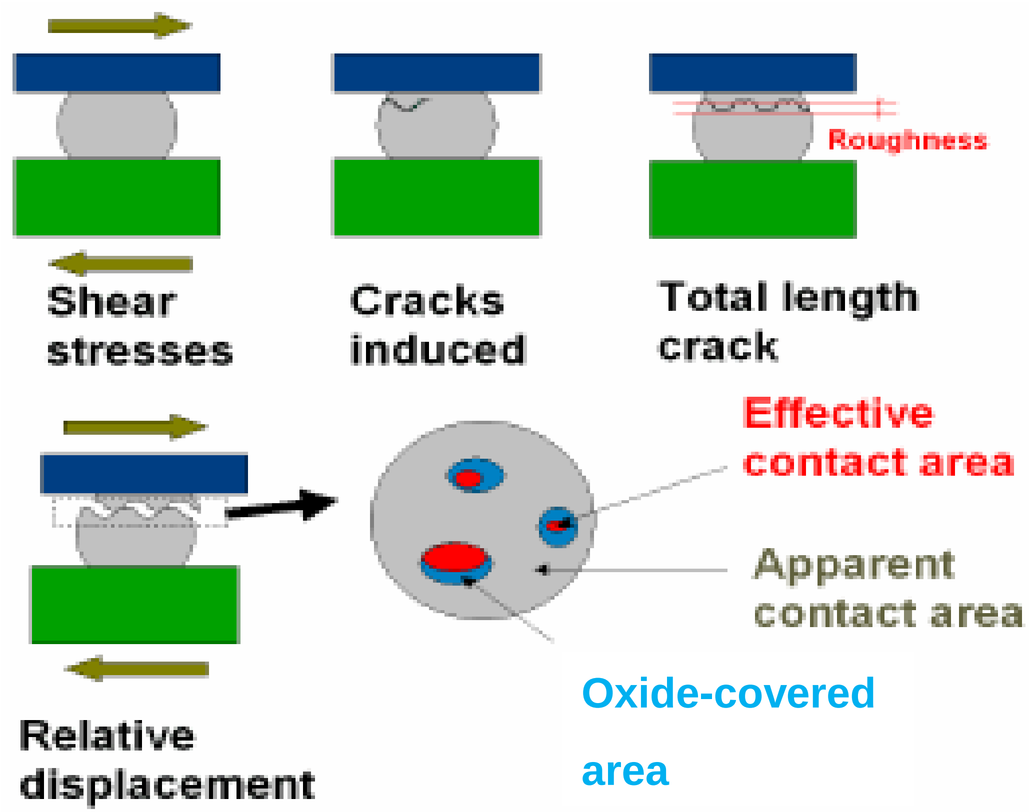
- With present technology, reported electronic system problems in the field cannot be duplicated at the service point or in the lab
- "Three/Four-letter" words (CND, NTF, RTOK)
  - Could Not Duplicate (CND)
  - No Trouble Found (NTF)
  - Retest OK (RTOK)
- 50 to 80% of these CND/NTF/RTOK problem categories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

# Solder Balls, Cracks and Fractures



# Mechanisms of Failure

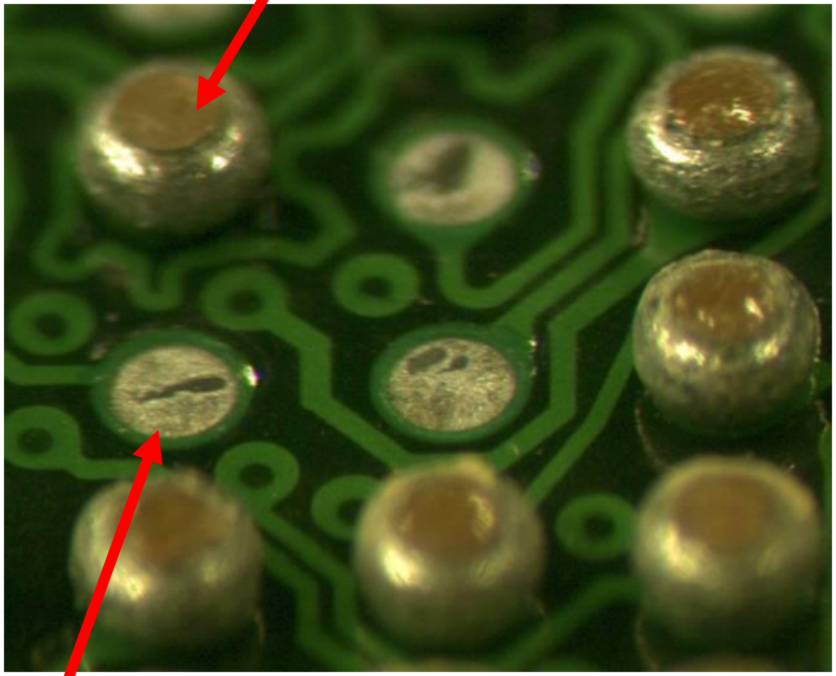
- Fatigue fractures (cracks) are caused by thermo-mechanical stress/strain
- During periods of high stress, fractured bumps tend to momentarily open and cause intermittent faults of high resistance for periods of ns to µs
- Over time, contamination and oxidation films occur on the fractured faces: the effective contact area becomes smaller and smaller
- Transient opens can be detected by event detectors

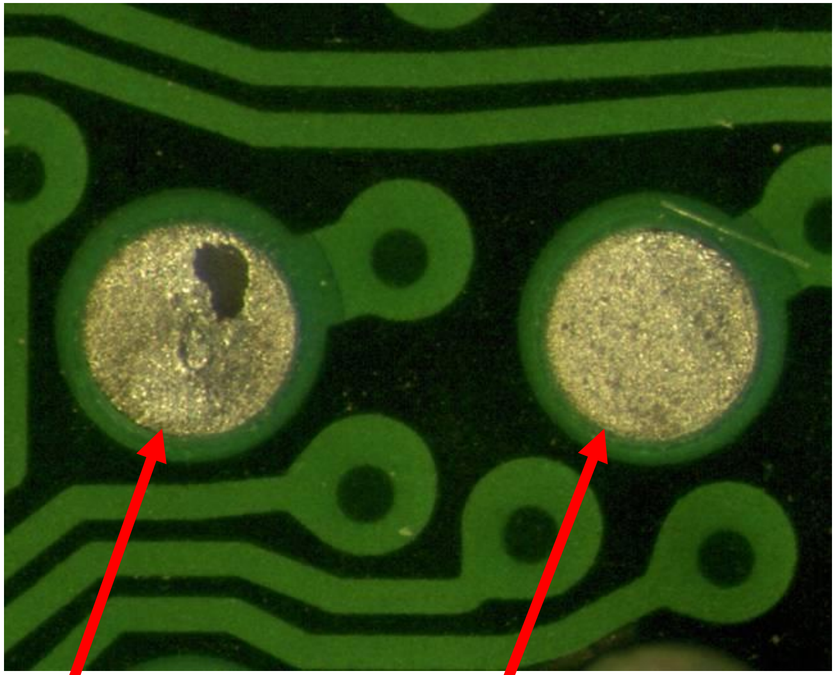


# Mechanics of Failure

## HALT results - Pulled FPGA – Damaged Solder Balls

**Undamaged**





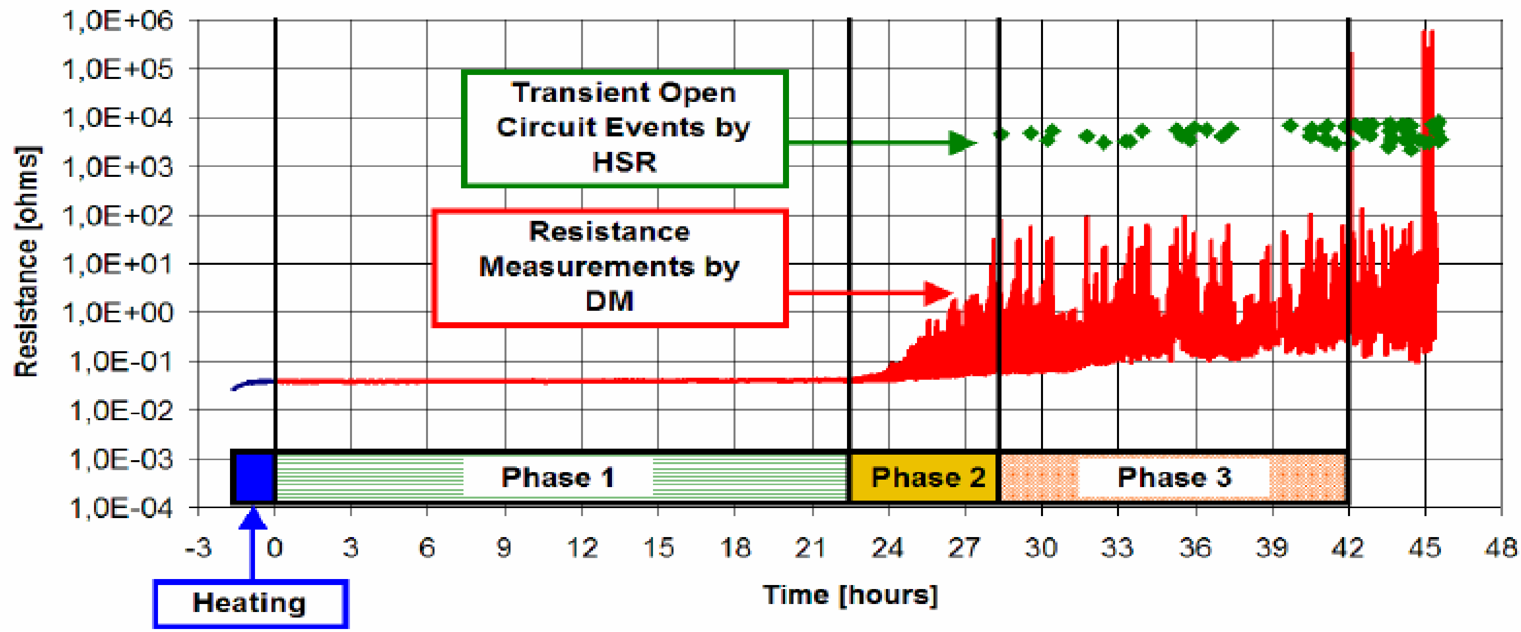
**Damaged**: Cracked

**Cracked**, not detectable

**Fractured,** detectable

# Intermittent Faults

- Faults are intermittent: confirmed by CAVE, Auburn Univ., German automobile manufacturer, BAE Systems and other firms
  - **Occur during periods of increasing strain**
  - **Multiple occurrences per cycle**
  - **Industry standard:  200 ohms +, 200 ns +**

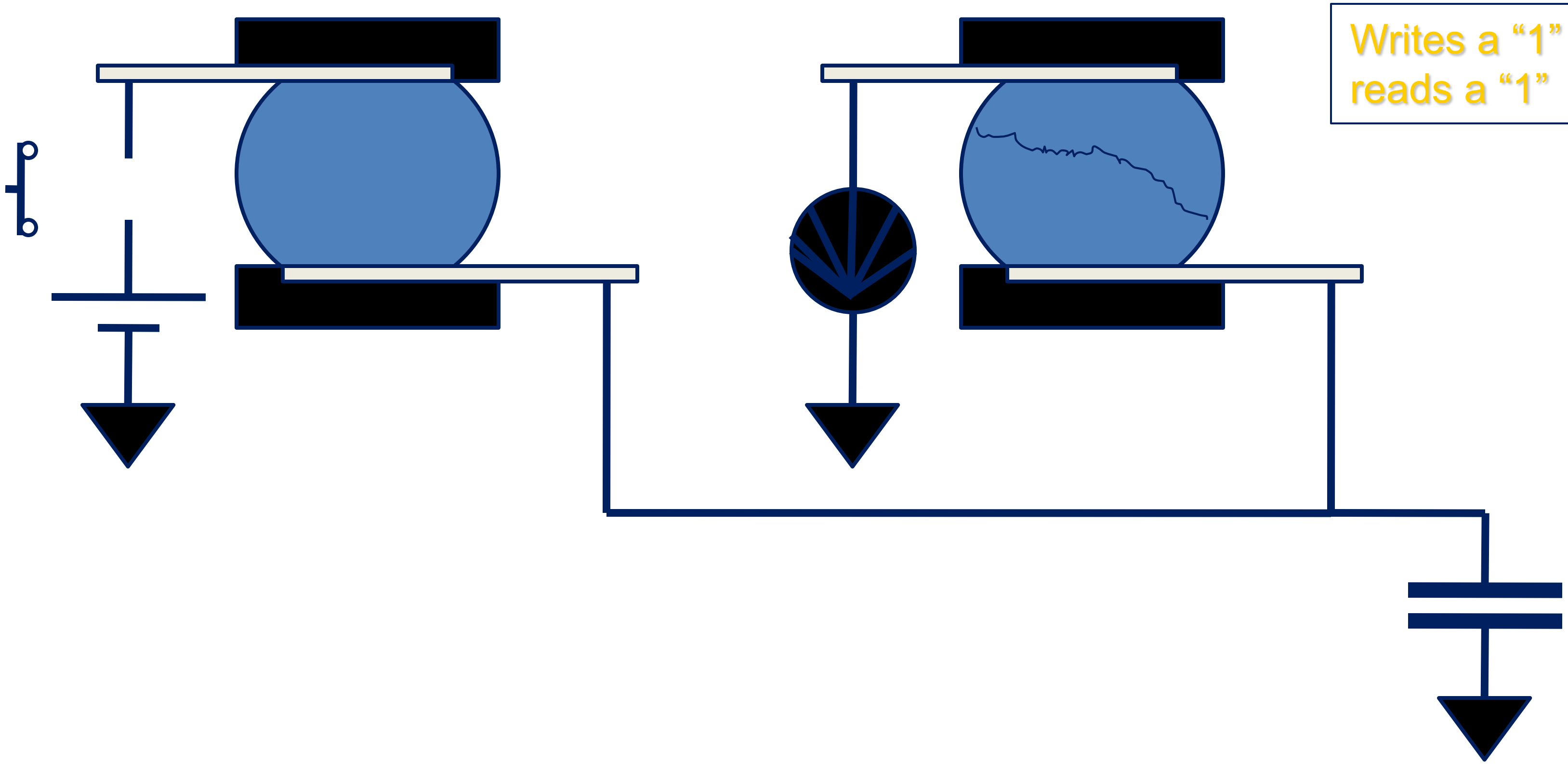


# SJ BIST™ Objectives & Features

- Objectives
  - Detection of impending interconnect failures
  - Unique in-situ testing in operating circuits
  - Technology-independent
- Feature and Benefits
  - Detects ball fractures prior to catastrophic failure of circuit
  - Provides actionable maintenance data
  - Independently tested and verified
  - Endorsed by leading automotive and aerospace customers

# SJ BIST Operation

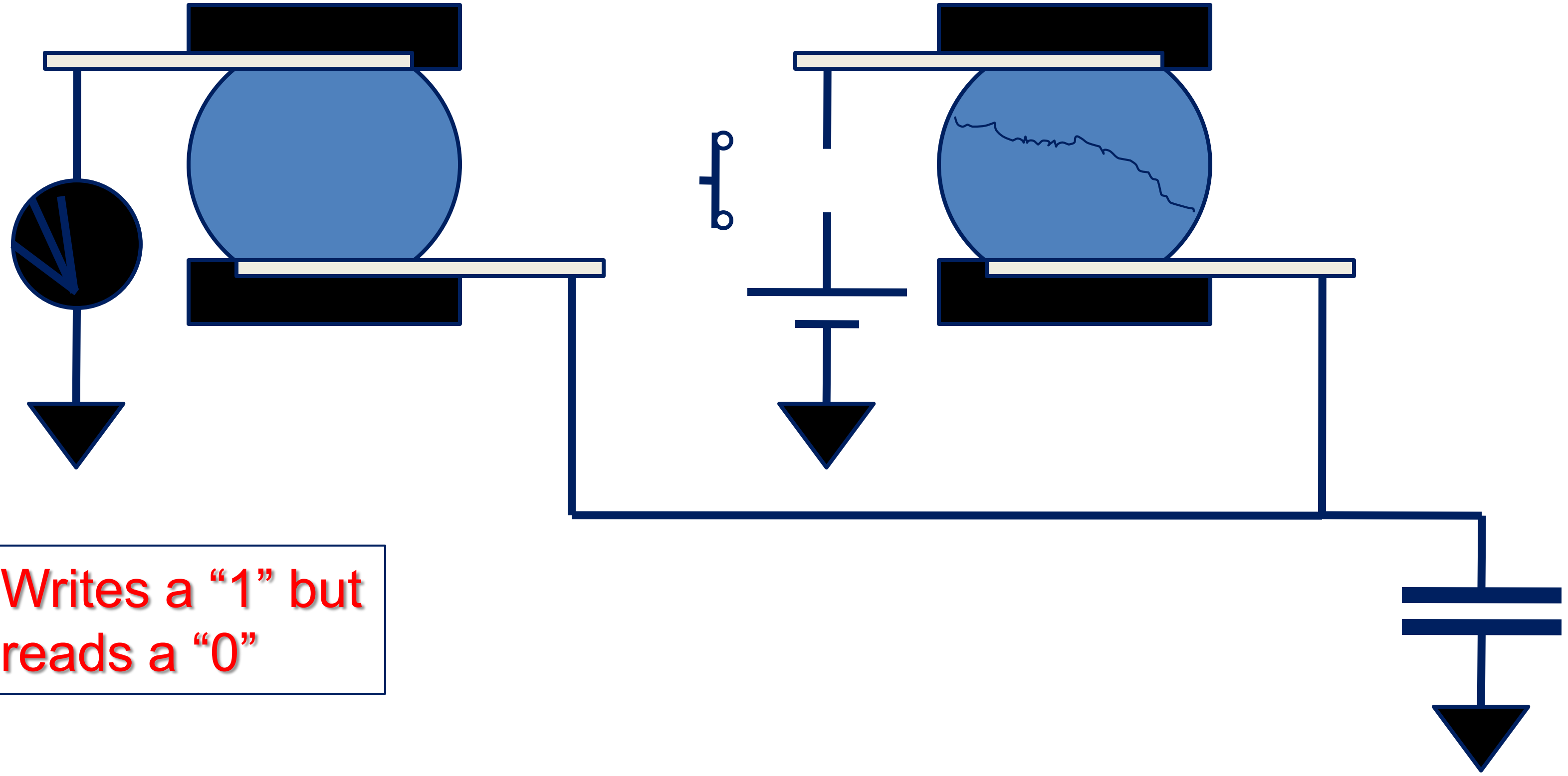
## Healthy Solder Joint



Writes a “1” and reads a “1”

# SJ BIST Operation

## Faulty Solder Joint

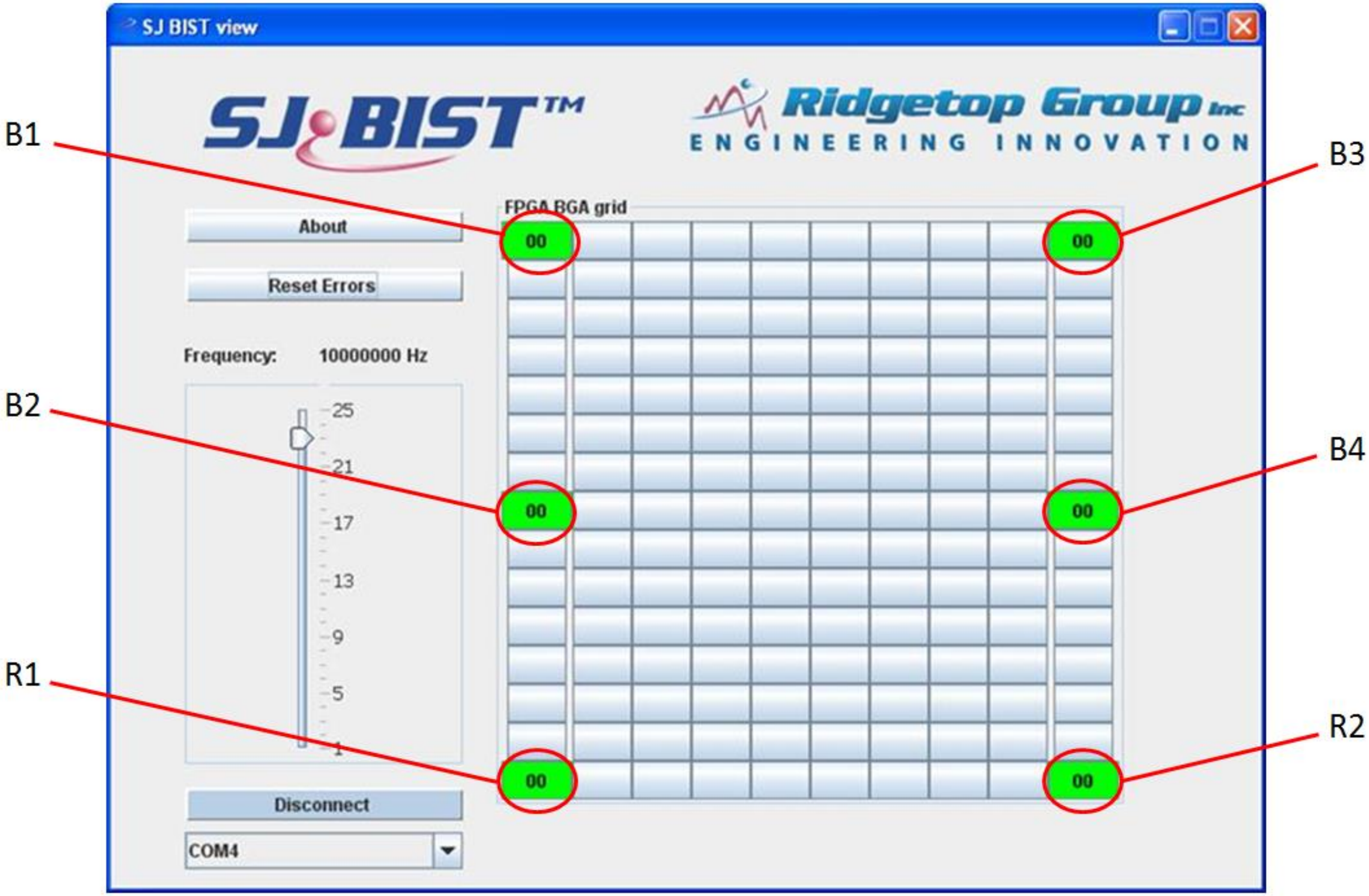


Writes a “1” but reads a “0”

# SJ BIST Summary

- Available as:
  - Verilog or VHDL core for FPGA
  - Microcontroller code
- Requires dedicated I/O + capacitor
- Runs concurrently
- Interconnect reliability verification
  - Process qualification
  - Lifetime observation

# SJ BISTView GUI



# Contact Information

## Ridgetop Group Inc.

**Doug Goodman**
President & CEO
DGoodman@RidgetopGroup.com

3580 West Ina Road
Tucson, AZ 85741

# SJ BIST Demo Kit Hardware

- The SJ BIST Demo Kit, built into an impact-resistant case, contains a control board that is connected to a 324-pin test integrated circuit (Xilinx XC6SLX16-2CSG324C FPGA) in a fine-pitch ball grid array package.
- SJ BIST is designed and programmed to monitor the health of the solder balls in 12 I/O ports that have been configured to form six groups of two pairs of pins.
- There are four push buttons used for manual fault injection, and two dials that adjust the resistance between the FPGA pins in order to demonstrate the sensitivity of SJ BIST to resistance changes.

# Demonstration Kit Hardware

# Hardware

- **Assigned I/O Pins**
  - In the test board, pairs of I/O pins are wired together to form test groups for monitoring by SJ BIST. The pins being monitored are configured as six groups of two pins each, for 12 pins total.
- **SJ BIST Fault Injection**
  - To simulate a failure, the SJ BIST Demo Kit has fault injection push buttons and dials that allow to inject various types of faults into six of the FPGA pin pairs.
  - Faults injected by pushing the SJ BIST Demo fault injection push buttons (B1, B2, B3, or B4) or by adjusting the dials (R1 or R2), are being monitored by SJ BIST cores and can lead to detection depending on the selected observation frequency.