SUMMER/FALL 2009

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CENTER FOR ADVANCED LIFE CYCLE ENGINEERING (CALCE)
WWW.CALCE.UMD.EDU, TEL: 301-405-5323

INSIDE

Mission Statement

To develop scientifically based innovative methodologies that decrease life-cycle risks for the next generation of electronic products and systems, and to create and maintain an educational and technology transfer infrastructure for their rapid dissemination and utilization.

Message from the Director

Every day we entrust ourselves to trains, airplanes, and automobiles, which all depend heavily on properly functioning electronics. Many of us take it for granted that everything will go smoothly and that the systems we're depending on will operate safely and reliably. Although it is unpleasant to consider, the failure of these safety-critical systems could have a devastating impact on our lives. The recent catastrophic crash of two commuter trains in Washington, D.C., demonstrates the terrible toll of electronics failures.

Engineers tasked with designing and producing complex systems that are safe and reliable face difficult challenges. These challenges will only grow in complexity as pressure mounts to reduce costs, increase outsourcing and, at the same time, comply with stricter environmental regulations. CALCE is committed to helping the electronics industry successfully understand and meet these challenges.

An example of such a challenge for the electronics industry is the 2008 European Union End of Life Vehicle Annex II, which requires automotive manufacturers, many of whom are already struggling financially, to remove all lead from the solder in their circuit boards by December 31, 2010. Further, a bill recently introduced in the U.S. House of Representatives would restrict electronics materials currently banned by the EU from entering the U.S. market. In addition, the European RoHS Directive is expected to be updated to include medical devices as well as measurement and control instrumentation. CALCE has been tracking these developments and is vigorously involved in conducting research and providing educational resources to help its industry partners meet these new challenges.

Due to its strong commitment to education, CALCE has solidified its role as a knowledge and resource base for the development of reliable electronics. In order to keep its industry partners up to date on the latest developments, CALCE has recently made the following successful educational efforts:

- Tutorials on diagnostics, prognostics and system health management;
- Workshops on design-for-reliability and CALCE's reliability assessment software;
- A workshop on the testing of lead-free electronic assemblies;
- A four-day "hands-on" failure analysis short course;
- The Third International Symposium on Tin Whiskers in Demark;
- Various short courses on reliability in Korea, Japan, Taiwan, China, England, Sweden and Norway.

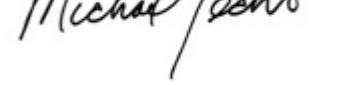
CALCE is also offering web seminars (webinars) beginning in November, whereby attending participants will be able to obtain continuing education credit. This is a new way for industry members to benefit from the CALCE's latest research and its expansive knowledge base.

To support its Electronic Products and Systems Consortium (EPSC) members, CALCE is engaged in over 30 projects. This includes developing models and test methods to assess the effectiveness of insulated coatings to prevent tin whisker shorts. CALCE has created test data to evaluate the impact of elevated electrical current on lead-free solder interconnect reliability and evaluated the corrosion resistances of new printed wiring board surface finishes. In addition, CALCE has actively developed models for mechanical torsion and vibration fatigue of lead-free soldered assemblies. CALCE recently established a test facility to assess the degradation of rechargeable lithium batteries. CALCE is also assessing a number of micro-electro-mechanical systems devices. CALCE will provide a review of EPSC research findings in October.

The CALCE Prognostics and Health Management (PHM) Consortium has been developing new Fusion Prognostics methods that "fuse" physics-of-failure and data-driven prognostics methods. In addition to its work with members of the consortium, the CALCE PHM team has been working on multiple large research contracts with NASA and the U.S. Army, and collaborated with many small businesses on SBIR projects. In the fall of 2009, the CALCE PHM team will offer a interdisciplinary PHM course where students will learn about the scientific foundations of PHM and have the opportunity to implement PHM in real-life applications through hands-on projects.

The CALCE Test Services and Failure Analysis Laboratory has been actively involved in assessing designs for sustainable and renewable energy systems. The lab recently performed many assessments, including simulations of proposed photovoltaic control system designs, using CALCE's Simulation Assisted Reliability Assessment (SARA®) software. SARA is a software tool that accounts for the varying life cycle profiles an electronic component is expected to encounter. The lab has also been investigating failures in printed circuit board assemblies attributed to problems with relay contact materials, flux residues, delamination in reworked assemblies, and component-side copper dissolution in BGA packages with non-nickel barrier pads. The Test Services group also offers on-site short courses in lead-free awareness, accelerated product qualification, and obsolescence management.

CALCE continues to stand at the forefront of electronics reliability and prognostics. We are dedicated to providing our consortia members and the electronics industry at-large with progressive educational resources, groundbreaking research, and high-quality failure analysis. We are committed to helping the industry meet the difficult challenges ahead. I invite you to visit CALCE on the Web (http://www.calce.umd.edu) to learn more.



Michael Pecht Ph.D., PE
Chair Professor
Director of CALCE

CALCE Electronic Products and Systems Consortium Fall Technical Review Meeting

The CALCE Electronic Products and Systems Consortium (EPSC) will hold its 2009 Fall Technical Review and Project Planning Meetings from October 13-14 at the Adele H. Stamp Student Union on the University of Maryland's College Park campus. The meetings will provide EPSC members with an opportunity to review FY09 research findings and discuss FY10 Research Projects.

This event is free for CALCE EPSC members. All current Consortium members are invited to attend. Invited guests pay a $1,500 registration fee to attend. Non-EPSC organizations interested in joining CALCE and attending the meetings should contact Dr. Michael Osterman (osterman@calce.umd.edu).

The following projects will be presented at the meeting:

- Solder Joint Reliability of Reprocessed Parts and Reworked/Repaired SMT Assemblies
- Vibration Fatigue Life of Pb-free Interconnects
- TMM Testing of SAC105 Solder
- Electrochemical Migration of Pb-free Printed Circuit Boards with Through-hole and Surface Mount Components
- Lead-Free Electronics Use and Repair Dynamic Simulation
- Physics-of-Failure (PoF) Qualification of Complex Electronic Systems
- Shock & Drop Qualification of MEMS Structures for Hand-held Products and Fundamental Understanding of MEMS Structures Subjected to High Shock Loads
- PoF Models for Vibration Fatigue Mechanisms in SAC Assemblies at Different Temperatures
- Electronic Component Failure Categorization under Gun-Launched High G Loading
- Fundamental Understanding of MEMS Structures Subjected to High Shock Loads
- Improved Flex Cracking Calculator and Failure Detection for Multilayer Ceramic Capacitors
- RF and Digital Signal Analysis for Interconnect Reliability Assessment
- Reliability of Embedded Planar Capacitors
- Characterization of Thermo-mechanical Behavior of FBGA DDP-applied Memory Module
- Rapid Assessment of Viscoelastic Properties of Polymeric Materials
- Reliability Assessment of Power Electronic Cooling System
- High Temperature Electronics Roadmap
- Part Total Ownership Cost Model Extensions
- Counterfeit Parts Control Plan for the Trusted Aerospace Electronics Supply Chain
- Degradation Analysis of Lithium Ion Batteries
- Role of High Current in Solder Interconnect Reliability under Temperature Cycling
- Evaluation of Prestacking versus Stack and Reflow Package on Package (PoP) Assembly Process
- Mechanical Torsion Reliability of Package on Package (PoP)
- Evaluation of Conformal Coat for Tin Whisker Mitigation
- Effectiveness of Tin Whisker Removal and Impact of Corrosion on Whisker Growth
- Tin Whisker Properties/Failure Mitigation Offered by Conformal Coats

The agenda for this event is available at www.calce.umd.edu under Upcoming Events.

CALCE Simulation Assisted Reliability Assessment Software Workshop

On October 12, 2009, CALCE will host the Simulation Assisted Reliability Assessment Software Workshop at the University of Maryland in College Park, MD. There is no cost for CALCE EPS Consortium members to attend.

CALCE has developed one-of-a-kind software that provides physics-of-failure-based simulation assisted reliability assessment at the PCB and component levels. Attendees will have the chance to learn about new features and use the software in a classroom environment. For more information, contact Dr. Michael Osterman (osterman@calce.umd.edu).

CALCE Research Assistant Wins Best Technical Presentation Award

CALCE Research Assistant, Lyudmyla Panashchenko, received the Best Research Assistant Presentation Award at the 2009 CALCE EPSC Spring Technical Review, held this past March. Ms. Panashchenko presented research findings from project C09-05: Effectiveness of Tin Whisker Removal and Impact of Corrosion on Whisker Growth. Ms. Panashchenko and the research team on project C09-05 investigated the effectiveness of brushes, tape, heating and ultrasonic cleaning on removing tin whiskers. Ms. Panashchenko works under the guidance of Dr. Michael Osterman and has been instrumental in investigating failure mitigation strategies for tin finished hardware, examining test methods for assessing whisker growth, and examining plating process to produce whiskers. In addition to her presentation at the EPSC Technical review, Ms. Panashchenko recently presented test findings at the 2009 Electronic Components and Technology Conference (ECTC) showing whisker formation on nickel underlayered tin that occurred after sequential temperature cycling and damp heat exposure. For more information, contact Dr. Michael Osterman (osterman@calce.umd.edu).

Lyudmyla Panashchenko receives Best Research Assistant Presentation Award from CALCE EPSC IAB Vice Chairman, Mike Davisson, Agilent

SN100C Thermal Fatigue Model for Interconnects Released to EPSC Members

The latest release of the CALCE Simulation Assisted Reliability Assessment (SARA®) software includes a thermal fatigue model for the SN100C, a tin-copper alloy with small additions of nickel and germanium. SN100C solder has made in-roads for use in electronic assembly, particularly as a wave solder material, due to its lower cost and significantly reduced copper dissolution. SN100C is also being used by some as a lead-free hot air solder leveled (HASL) finish for printed wiring boards.

The SN100C thermal fatigue interconnect model, available in the CALCE SARA software, was developed from test data of over ten individual test sets derived through a systematic test program and carried out over a two year period. The tests included 15, 75, and 120 minute dwell times and temperature conditions from as low as -50 C to as high as 125C. Each test included a sample size of 32 data points. The fatigue model has been further validated against experimental data reported by other research groups.

The CALCE SARA software already includes thermal fatigue interconnect models for SAC405/305, Sn3.5Ag, Sn62Pb2Ag and Sn63Pb. The addition of SN100C provides CALCE SARA coverage for the most prevalent lead-free solders. The CALCE SARA software offers the ability to model printed circuit boards, perform thermal and vibration analysis, and conduct a life expectancy assessment for test and field use conditions. For more information please contact, Dr. Michael Osterman (osterman@calce.umd.edu).

CALCE PHM Spring Technical Review

CALCE conducted a two-day technical review meeting for the PHM Consortium from March 19-20, 2009. The technical review meeting focused on various projects that the PHM Consortium has been working on for the past year, including data-driven and fusion prognostic projects. In addition, Prof. Pecht presented an updated PHM industry roadmap.

The following projects were presented at the review meeting: PHM cost modeling; precursor parameter identification for IGBTs; fusion prognostics; prognostics for aging systems; residual estimation for isolating faulty parameters; prognostic using vehicle usage data; prognostics using RF impedance monitoring; anomaly detection using a bayesian support vector machine; event prediction through Cox Poisson counting process model; prognostics for electronics under storage conditions; PoF based prognostics, prognostics of embedded planar capacitor laminates; and use of temperature rise as a precursor to interconnect failure. Consortium members were excited about the research and the potential benefits for their organizations.

The Fall 2009 Technical Review Meeting will be held on October 15 and 16, 2009 at the Adele H. Stamp Student Union on the University of Maryland's College Park campus. The agenda will be posted on the CALCE PHM website. If you are interested in joining the consortium, please contact Prof. Michael Pecht (pecht@calce.umd.edu).

CALCE Education Course on Data-Driven Techniques

On March 18, 2009, CALCE conducted a one-day short course on data-driven techniques. This course included tutorials on: prognostics and health management metrics; anomaly detection techniques; covariance estimation techniques; and algorithms, including principal component analysis, support vector machines, symbolic time series, multivariate state estimation techniques, self-organizing maps, and neural networks. This course was attended by participants from many leading organizations, including NASA, the U.S. Army, the U.S. Navy, Frontier Technology Inc., nCode International, Benchmark Electronics, National Defense (Canada), QinetiQ, Boeing, and General Dynamics-AIS. Due to the success of this tutorial, CALCE is now planning more short courses on data-driven techniques, physics-of-failure based PHM and Fusion Prognostics. If your organization is interested in short courses on PHM, please contact Sony Mathew (sonym@calce.umd.edu).

New Prognostics Research Faculty at CALCE

CALCE is proud to welcome Mr. Gerald (Jerry) Seidel as a Faculty Research Advisor. Mr. Seidel holds a BS and an MS in Aerospace Engineering from Penn State University, and has completed advanced studies in Engineering Mechanics and Mathematical Optimization at Case Western Reserve University. He retired from NASA Headquarters after 45 years of federal civil service. At NASA HQ, he worked for the Office of Aeronautics, where he managed aircraft structures research and coordinated partnership activities with the U.S. Military Services. Prior to joining NASA, he was the Principal Engineer for Advanced Structural Technologies with the U.S. Naval Air Systems Command (NAVAIR), and preceded that post with various engineering positions at the U.S. Naval Air Development Center (NADC).

At NADC, Seidel performed structural service life analysis and tracking on Navy aircraft, including flight recorder data collection and analysis of F-14 aircraft operating from an aircraft carrier. He was also involved with counting accelerometers on tactical aircraft and photographic landing loads surveys for design criteria specification. At NAVAIR, he investigated various vehicle health and life monitoring technologies, including vibration signature monitoring of helicopters and the development of Health and Usage Monitoring Systems (HUMS). He also sponsored work with fatigue life gauges, acoustic emissions, and a fiber-optic crack sensor. At NASA HQ, he represented the U.S. on international technical cooperation groups and represented NASA on inter-government committees, including the Joint Logistics Commanders Group, an Aging Aircraft study group, and an inter-agency committee investigating reliability and life issues associated with electrical wiring. For more information, contact Sony Mathew (sonym@calce.umd.edu).

Prof. Pecht Presents on PHM at International Conferences

Prof. Pecht presented at the Prognostics & Health Management, Condition-Based Maintenance and Health & Usage Monitoring Symposium, held in Shrivenham, UK, from April 21-22, 2009. Prof. Pecht discussed prognostics implementation in aerospace applications. He addressed the challenges facing the avionics industry, operational and environmental demands on avionics, and approaches to conducting prognostics for avionics.

Prof. Pecht presented the keynote speech at the EuroSimE 09 Conference, held at the Delft University of Technology, Delft, Netherland, from April 27-29. He spoke on the topic of "Prognostics and Health Monitoring for Improved Qualification," and presented a prognostics and health monitoring (PHM) based qualification methodology that provides early detection of faults, helps determine life cycle conditions, detects intermittent faults, improves product reliability and provides added benefits to product qualification. The fusion prognostics approach, which blends elements of the PoF and data-driven approach, was also presented at this conference.

In July, Prof. Pecht lectured on prognostics and health management methods and logistics at the 2009 Vehicle Maintenance & Repair Conference held in London, UK, from July 13-15. This conference was organized by Defence IQ, a division of IQPC (International Quality and Productivity Center). This inaugural conference addressed maintenance of ground vehicles, both in theatre and in depot; and the current programs, technologies, initiatives, and frameworks that are used to meet operational needs and improve the readiness of military vehicles.

Prof. Pecht delivered the keynote address at the 8th International Conference on Reliability, Maintainability and Safety (ICRMS 2009) held in Chengdu, China from July 20-24. His topic was "A Bird's Eye View on the Global Experience in PHM Development and Implementation." He spoke about the many applications where PHM is being implemented, the various methodologies, return-on-investment and the challenges in implementing PHM. During the conference, he also moderated a forum, "China PHM Forum 2009," which was held on July 21. To learn more, contact Prof. Michael Pecht (pecht@calce.umd.edu).

CALCE-ARL Project Kickoff: Autonomous Prognostic Monitoring Device and Algorithms

To predict the remaining useful life of critical devices, components, and sub-systems on a multitude of U.S. Army platforms, CALCE proposed the development of an autonomous prognostic monitoring device with the following attributes: a small form factor, minimal power consumption, wireless data transmission enabled, and the ability to integrate with existing diagnostics and sensors. Recently, CALCE was awarded two contracts by the U.S. Army Research Laboratory (ARL) to develop an autonomous monitoring device as well as algorithms that can process the collected data and identify primary patterns or relationships within the data to reveal how the system is changing. CALCE has teamed up with Texas-based ePrognostics LLC to develop the monitoring device for ARL.

On May 1, 2009, CALCE, ARL, and ePrognostics LLC held a kickoff meeting at the University of Maryland's College Park campus. The CALCE-ePrognostic sensor system is a novel monitoring device that can monitor multiple parameters used for prognostics including, but not limited to, temperature, humidity, vibration, shock, and external sensors. This device will be wireless and can be mounted in the host system easily and non-intrusively. The new system will also have the processing efficiency necessary to expedite operational and logistical decision making without severely impacting the physical and logistical footprint.

This project ties in with another CALCE-ARL project to develop algorithms that reveal fundamental relationships within the data. Relationships within the training data provide the foundational knowledge about the system, and relationships between the observed fielded data and training data reveal how the system is changing. Thus, there are critical relationships between the observation (sensory data), the knowledge (training data), and how decisions, conclusions, and estimations are made. The algorithms developed in that effort will be incorporated into the new sensor system. The sensor systems provide data that algorithms use to compile a composite characterization of the system. Any anomaly identified is further trended for statistical relevance. For more details, please contact Prof. Michael Pecht (pecht@calce.umd.edu).

Version 2.3 OF PHM ROI Tool Available

The CALCE Prognostics and Health Management (PHM) Return on Investment (ROI) tool is a stochastic discrete-event simulation that can follow the life history of a population of systems containing one or more LRUs (Line Replaceable Units) and determine the effective life cycle costs, availability, and avoidable failures for sockets (a socket is a unique instance of an installation location for a LRU). Version 2.3 of the PHM ROI tool is now available for PHM Consortium members. This new version includes the following functions:

- Availability Penalty model (modeled in two different ways: cumulative and non-cumulative model).
- Inventory On/Off switch – previous versions did not provide the option of considering (On) or ignoring (Off) the inventory model while running the simulation.
- User's Manual enhancements

Previous enhancements to this version include:

- Spares inventory (including initial spares, spare replenishment policy, and lead time on spares).
- ROI analysis of one PHM approach relative to another.
- Bug fixes to ROI Plot (plotting negative values and displaying probability of negative ROIs)
- Conversion from static to stochastic ROI calculation
- Investment cost plotting
- Detailed implementation cost calculations (including recurring, non-recurring, and infrastructural costs)
- Operational profile specification
- Cost of money

For more information, contact Dr. Peter Sandborn (sandborn@calce.umd.edu).

CALCE Offers Continuing Education Credit for Web Seminars

Beginning this November, CALCE will offer continuing education credits through the University of Maryland for advanced studies in electronics packaging and reliability. The credits will be offered through distance learning as part of the CALCE web seminar (webinar) series.

To receive a continuing education credit, individuals will be required to attend ten web seminars offered over an eighteen month period and complete a limited number of assignments based on the web seminar material. Employees from CALCE consortium member organizations may attend the webinars free of charge. Individuals who are not consortium members may sign up to attend the seminars for a fixed fee. Recent CALCE web seminar topics have included:

- Thermal fatigue models for lead-free solder interconnects;
- Strategies for obsolescence management;
- PWA failures under static and flexural loading;
- Electrochemical migration in lead-free assemblies; and
- The impact of lead-free rework on interconnect reliability.

A small registration fee will be charged for individuals seeking continuing education credits.

Details for CALCE web seminars and the continuing education credits can be found at: http://www.calce.umd.edu/seminars/seminars.htm. For more information, contact Dr. Michael Osterman (osterman@calce.umd.edu).

U.S. Military Urged to Buy North American PCBs

The North American circuit board and electronic circuits packaging industry is urging the U.S. military to support a robust and technically advanced domestic supply base of military board products by buying military circuit boards–even boards considered to be non-critical technology–from U.S. and Canadian companies. "Access to less complex PCBs for DOD use will provide manufacturers with sustained, predictable financial support, ensuring stability within a dependable, consistent and secure supply base for the DOD," says IPC member Mike Moisan of TTM Technologies Inc. in Santa Ana, Calif.

The U.S. Department of Defense's (DOD) support of U.S.- and Canadian-produced circuit boards is part of a six-part policy recommendation that the IPC is preparing for the U.S. Navy, which the DOD has designated as its printed circuit board executive agent. Acting as the DOD's circuit board agent, the Navy, with the aid of the IPC, is tasked with strengthening U.S. national defense readiness by developing a circuit board interconnect technology roadmap for the DOD. In addition, the Navy is formulating a policy to ensure that the DOD has access to circuit board manufacturing capabilities and the technical expertise necessary to meet future military requirements.

For more information on printed circuit boards, please contact Bhanu Sood by phone at +1 (301) 405-3498 or bpsood@calce.umd.edu.

Effects of Moisture Content on Dk and Df of PCB Material

Printed circuit board (PCB) laminate datasheets often provide the coefficient of thermal expansion (CTE), glass transition temperature (Tg), dielectric constant (Dk), and dissipation factor (Df) values to provide insight into the thermal and electrical properties of the PCB material. But, these properties vary with changes in the moisture content of the PCB laminate material.

A recent CALCE study has shown that moisture content in the PCB laminate has a significant impact on the thermal and electrical properties of PCBs. Test samples with varying moisture content were preconditioned and tested per IPC test methods indicated in PCB laminate datasheets. The results indicated that many of the preconditioning steps prescribed in the IPC test methods do not address the issue of the initial moisture content of test samples. This study provides recommendations on how to conduct these thermal and electrical measurements with proper preconditioning and equipment parameters. For more information, please contact Bhanu Sood at +1 (301) 405-3498 or bpsood@calce.umd.edu.

CALCE-Buehler Failure Analysis Course a Success

In April 2009, CALCE and Buehler jointly conducted another intensive four-day short course on failure analysis of electronics at the CALCE Test Services and Failure Analysis Laboratory (TSFA). The course was attended by reliability engineers, device engineers, and process engineers from various companies and government organizations. The course included detailed lectures on failure mechanisms, modes, and effects analysis; non-destructive and destructive analytical techniques; and hands-on work with both the latest Buehler sample preparation equipment and the state-of-the-art equipment at the CALCE TSFA Laboratory.

Based on the success of this and past courses, CALCE and Buehler are offering the course again from September 15 to 18, 2009. Course outline and registration information can be found by visiting http://www.calce.umd.edu/facourse/fall2009. For more information about the course, please contact Bhanu Sood at +1 (301) 405-3498 or bpsood@calce.umd.edu.

LED Reliability

Manufacturers have expressed interest in adopting light emitting diode (LED) lighting because of its energy saving potential and positive environmental effects. LED usage is likely to grow as environmental regulations regarding hazardous substances and incandescent lamp usage restrictions gain traction. For example, bills to abandon usage of incandescent lamps were proposed in the European Union, Australia, and California (starting in 2010), and Ontario, Canada (starting in 2012). LED lighting has seen limited usage as decoration, but, due to technological advancements and a downward price trend, will soon expand to the general lighting industry. However, the price gap between LED lighting and conventional lighting is still significant. As a result, LED lamps must offer performance and reliability benefits that justify the added expense.

A light emitting diode (LED) is a type of photon-emitting semiconductor that emits light due to the injection electroluminescence effect. LED chips are composed of a p-junction, a quantum well (active layer), and an n-junction, as shown in Figure 1.

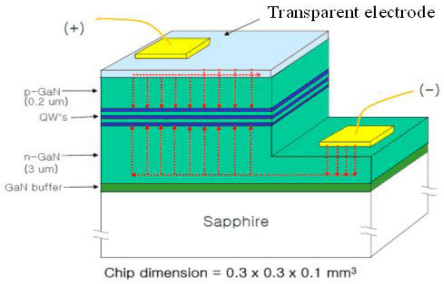


Figure 1

When a p-n junction is biased in the forward direction, electrons in the n-junction have sufficient energy to move across the boundary layer into the p-junction, and holes are injected from the p-junction across the active layer into the n-junction. The active region of an ideal LED emits one photon for every electron injected. Each charge quantum particle (electron) produces one light quantum particle (photon). Thus, an ideal active region of an LED has a quantum efficiency of unity. The internal quantum efficiency is defined as the number of photons emitted from an active region per second divided by the number of electrons injected into the LED per second. The extraction quantum is defined as the number of photons emitted into free space per second divided by the number of photons emitted from the active region per second. The extraction efficiency can be a severe limitation for high-performance LEDs. It is quite difficult to increase the extraction efficiency beyond 50% without resorting to highly sophisticated and costly device processes. The external quantum efficiency is defined as the internal quantum efficiency multiplied by the extraction quantum efficiency. This can also be expressed as the number of photons emitted into free space per second divided by the number of electrons injected into the LED per second. Upon electron-hole recombination, electric potential energy is converted into electromagnetic energy as visible light.

CALCE is starting a program on the development of prognostics based LED assessment that will allow the LED industry to achieve the following goals: (1) providing advanced warning of failures; (2) minimizing unscheduled maintenance, extending maintenance cycles, and maintaining effectiveness through timely repair actions; (3) reducing the life-cycle cost of equipment by decreasing inspection costs, downtime, and inventory; and (4) improving qualification and assisting in the designing and logistical support of fielded and future systems. For more details, please contact Prof. Michael Pecht (pecht@calce.umd.edu).

Free Cooling at Telecom Base Station

The telecommunications industry has become increasingly concerned with the energy costs of its operating infrastructure, which includes base stations and data centers. One way to save energy is to increase the controlled ambient temperatures of these facilities, thereby reducing energy consumption for cooling and overall energy cost. However, the impact of an increase in temperature on the performance and reliability of telecommunications equipment is a concern. CALCE has developed a multi-stage process for evaluating and mitigating the potential risks emanating from this proposed increase in operating temperature.

To support the communications infrastructure, base stations are installed all over the world and are supported by data centers. Base stations are physical installations containing electronic and communication equipment from which communications are transmitted and relayed. Data centers include the buildings, facilities, and rooms that contain enterprise servers, communication equipment, cooling equipment, and power equipment. Thus, these centers provide the computing backbone of the communications infrastructure. Base stations are generally remote and unmanned, whereas data centers are staffed by employees.

Approximately 1.5–3.0% of the energy produced in industrialized countries is consumed by data centers. The electricity consumed by data centers in Western Europe was about 56 TWh (costing about $12 billion) in 2007 and was projected to increase to 104 TWh per year by 2020. As a result, data centers account for nearly 14% of the information and communications technology industry greenhouse gas emissions. Base stations contribute 60% of total greenhouse gas emissions within a typical cellular telephone service provider.

At present, more than 50% of the energy consumed by data centers is devoted to the power and cooling infrastructure that supports the electronic equipment. One way to save energy in data centers is to increase the operating temperatures, thereby reducing the energy consumption needed for cooling. While this method saves energy and money, it will cause an increase in operating temperature and may adversely affect the performance and reliability of electronic equipment. CALCE offers a method to identify and evaluate the potential risks to telecommunication equipment associated with increased operating temperatures. This method considers three product deployment stages: concept, realization and deployment. At every stage, the evaluation includes performance and reliability assessment. Performance testing is used to verify that the product can meet or exceed the functional requirements. Additionally, reliability assessment is used to estimate product life and assess industry-standard reliability related metrics. For more information, please contact Prof. Michael Pecht (pecht@calce.umd.edu).

CALCE Develops Test Methods for Electrolytic Capacitors

The performance and lifespan of aluminum liquid electrolytic capacitors are affected by a variety of factors associated with their design, materials of construction, processing, and production quality. CALCE has been developing a series of new test methods that allow capacitors to be evaluated with regard to quality factors, which have a direct bearing on their reliability. One test method assesses the integrity of the mechanical seal to identify which capacitors are susceptible to early life failures as a result of electrolyte evaporation through inadequate seals. A second test was developed to measure the relative quantity of electrolyte within a production lot of capacitors. The third test method provides an accurate means to calculate the core temperature of a functioning capacitor based on readily available external temperature measurements. Among other things, this information can lead to more accurate lifespan predictions based on tests performed under actual operating conditions. For more information, please contact Dr. Michael H. Azarian at (301) 405-7555 or mazarian@calce.umd.edu.

Power Supply Reliability

The goal of CALCE's Power Supply Reliability project is to develop a Prognostics and Health Management (PHM) methodology for switch mode power supplies (SMPS) with a focus on insulated gate bipolar transistors (IGBT). SMPS are used in electronic equipment and systems as a source of regulated power. SMPS are present in all forms of electronics, but play a critical role in avionics, medical equipment, hybrid electric vehicles, and computers. In these applications, failure or breakdown of a power supply can result in huge casualties or economic loss. Therefore, the need to improve the reliability of power supplies by implementing diagnostic and prognostics capabilities is critical.

The outcomes of this project will be: 1) identification and documentation of IGBT failure modes and mechanisms in SMPS applications; 2) model constants for the PoF models identified for critical failure mechanisms; 3) data-driven models to estimate the remaining useful life of IGBTs in SMPS; and 4) guidelines to implement PHM in fielded power supplies.

The first outcome of this project will be the documentation of a set of life cycle profiles for the environmental and operational conditions of various power supplies. These profiles will include loads critical to assessing reliability, including temperature, power, current, and voltage levels. For each critical failure mechanism identified by the FMMEA, the electrical parameters that are likely to be affected by the mechanism will be tabulated. These failure mechanisms will be accelerated and the data collected from the tests will be used to determine precursors.

For each of these mechanisms, probabilistic physics-of-failure models will be developed that will relate the growth of the defects to interest and damage accumulation. Defect growth and damage accumulation in IGBTs will be inferred from electrical measurements of precursor parameters, such as C-V measurements of the gate oxide for IGBTs, which serve to indirectly measure the defect level, i.e., the gate oxide charge state. In this data analysis, we will evaluate multiple parameters together in order to separate the effects of environmental parameters on the precursor parameters. For example, if a threshold voltage increase is identified at a low temperature that may not indicate part degradation but may reflect the increase in threshold voltage due to temperature effects. A key outcome of this work will be a fundamental identification of the precursors to failure that can be used in diagnostic detection and root cause failure analysis, and an assessment of those faults that permits detection early enough for prognostic analysis.

Another key outcome of the work will be the development of data-driven techniques for assessing remaining life. This approach to diagnostics and prognostics will be documented in the form of flowcharts and procedures. The approach will be demonstrated on a commercially available SMPS by: measuring precursors and key electrical parameters of the power supply; assessing the remaining life under accelerated life profile conditions; continuing to monitor the precursors and the electrical parameters as life is consumed under accelerated life profile conditions until power supply failure; then conducting a full root cause failure analysis to validate the failure mode, mechanism, and time-to-failure assessed by the prognostic methods developed. Finally, the project will provide guidelines for implementing PHM in power supplies in terms of parameters that need to be monitored, sensor selection, and placement. For more information, please contact Dr. Diganta Das (digudas@calce.umd.edu)

Early Detection of Interconnect Degradation

A paper entitled "Early Detection of Interconnect Degradation by Continuous Monitoring of RF Impedance," authored by Daeil Kwon, Michael H. Azarian, and Michael Pecht, was published in the June 2009 issue of the IEEE journal, Transactions on Device and Materials Reliability (ISSN: 1530-4833). The paper reports the groundbreaking work of CALCE researchers who have developed a non-destructive means of sensing the earliest stages of crack growth in solder joints, including a demonstration of the use of RF impedance measurements as an early indicator of physical degradation of interconnects. As illustrated in Figure 2 below, a direct comparison between RF impedance, DC resistance, and an event detector showed that RF impedance responded to interconnect degradation much earlier than either of the more traditional techniques. Mechanical fatigue test results showed that RF impedance increased in response to the early stages of solder joint cracking while the DC resistance remained unchanged. Failure analysis revealed that the RF impedance increase resulted from a physical crack, which initiated at the surface of the solder joint and propagated only partway across it. These results demonstrate that RF impedance can serve as a non-destructive early indicator of interconnect degradation.

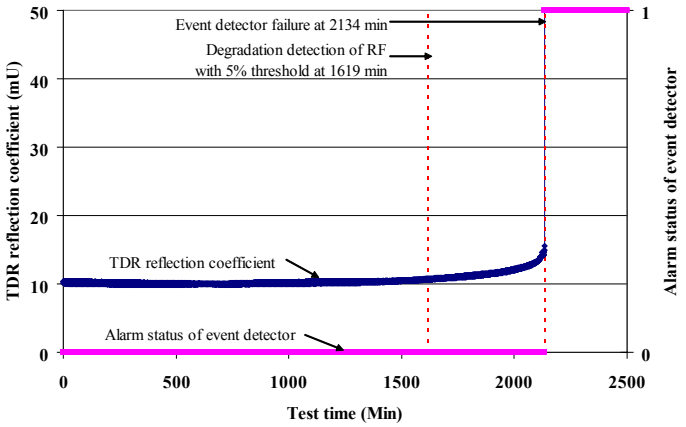
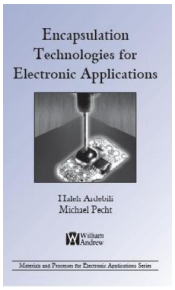


Figure 2. Comparison between RF impedance and an event detector during a fatigue test. The RF measurement, performed using time domain reflectometry, detected degradation at only 76% of total life, providing ample time for preventative action.

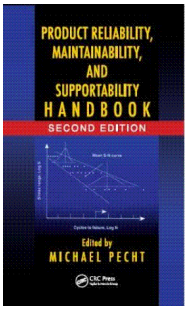
For high speed electronics operating at frequencies of several hundred MHz or more, signal propagation is sensitive to small amounts of interconnect damage such as partial cracks in a solder joint. The results of this paper imply that reliability assessment based on DC resistance measurements, using equipment such as data loggers or event detectors, may overestimate the lifetime of high speed electronic assemblies. RF impedance monitoring provides an improved means for assessing reliability in these products. Furthermore, RF impedance monitoring can be used as a prognostic tool. In-situ measurements can be compared to an appropriate threshold that allows for the identification of the time at which the interconnect begins to degrade. This event can be a failure precursor, which can trigger an alarm to provide condition-based maintenance, thereby increasing product availability, reducing unplanned down-time, and potentially creating substantial savings in operational, repair, logistical and liability costs. This technique can also improve real-time reliability prediction of electronic products when incorporated into sensing circuitry that is either located on a circuit board, in an assembly, or in external diagnostic hardware. For more information, please contact Dr. Michael H. Azarian at (301) 405-7555 or mazarian@calce.umd.edu.

New Book on Encapsulation Technology Published



Encapsulation Technologies for Electronic Applications, by Haleh Ardebili and Michael Pecht (William Andrew), focuses on the encapsulation of microelectronic devices, with additional attention to the encapsulation of connectors and transformers. Various encapsulation techniques are explained, including molding, potting, glob-topping, underfilling and printing encapsulation. This book also addresses defects and failures related to encapsulation, and provides up-to-date information on the trends and challenges of encapsulation and microelectronics packages, including the application of nanotechnology. For more details, contact Prof. Michael Pecht (pecht@calce.umd.edu).

Second Edition of Product Reliability Handbook Published



The second edition of the bestselling Product Reliability, Maintainability, and Supportability Handbook by Michael Pecht (CRC Press) helps professionals to identify shortcomings in the reliability practices of their organizations and empowers them to overcome these shortcomings. This book discusses product effectiveness and its related functions, presents the mathematical theory for reliability, and introduces statistical inference concepts as ways to analyze probabilistic models from observational data. In addition, the text addresses the latest developments in the field and introduces a new methodology (FMMEA) to identify potential failure mechanisms. For more details, contact Prof. Michael Pecht (pecht@calce.umd.edu).

CALCE PhD Student Wins Multiple Academic Awards

On May 1, 2009, CALCE student and Mechanical Engineering PhD candidate, Vidyu Challa was honored with three academic awards at the University of Maryland's Mechanical Engineering Student Awards for her exemplary academic achievement and her research. Challa, who works with CALCE as a student research assistant, conducts research on the effects of joule heating on the reliability of stamped metal land grid array sockets under the guidance of Prof. Pecht and Dr. Osterman.

Challa was awarded the Phi Delta Gamma fellowship for the 2008-2009 academic year. The $1,000 award is offered to a graduate student who "best exemplifies interdisciplinary scholarship achievement." Challa also received a Graduate Summer Research Fellowship for the summer of 2009. The Graduate Summer Research Fellowship, which includes a $5,000 stipend, is awarded to outstanding doctoral students based on the significance and feasibility of their proposed research. For the 2009-2010 academic year, Challa earned the Ann Wylie Dissertation Fellowship, a $ 10,000 stipend awarded to outstanding doctoral students based on the quality of their work, and the potential contribution of the dissertation to the student's field of research. For more information on Challa and her research, contact Dr. Michael Osterman (osterman@calce.umd.edu).

2009 Symposium on Avoiding, Detecting, and Preventing Counterfeit Electronic Parts

On December 2 and 3, 2009, CALCE will hold a two-day symposium on avoiding, detecting, and preventing counterfeit parts, in collaboration with SMTA, at the Samuel Riggs Alumni Center at the University of Maryland's College Park campus. This symposium will be valuable to supply chain managers, component engineers, brand protection specialists, marketing and procurement policy makers, contracts management, security specialists, and other interested engineers. Our goal is to provide relevant information that will be useful for solving problems today while planning for tomorrow's business and technology environment. Speakers at the workshop are exempted from the registration fee. If you are interested in presenting, submit an abstract of your proposed presentation to Dr. Diganta Das via email at diganta@umd.edu. For more information, please visit www.calce.umd.edu.

Selected Publications

CALCE publications are available online at: http://www.calce.umd.edu/articles/ Below is a list of recent additions:

1. L. Nie, M. Osterman, M. Pecht, F. Song, J. Lo and S.K. Lee, "Solder Ball Attachment Assessment of Reballed Plastic Ball Grid Array Packages," Equipment for Electronic Products Manufacturing (Chinese), Vol. 169, pp. 1-5, February 2009.
2. J. G. Elerath and M. Pecht, "A Highly Accurate Method for Assessing Reliability of Redundant Arrays of Inexpensive Disks (RAID)," IEEE Transactions on Computers, Vol. 58, No. 3, pp. 289-299, March 2009.
3. L. D. Lopez, V. Challa, and M. G. Pecht, "Assessing the Reliability of Elastomer Sockets in Temperature Environments," IEEE Transactions on Device and Materials Reliability, Vol. 9, Issue 1, pp. 80-86, March 2009.
4. T. Shibutani, M. Osterman, and M. Pecht, "Standards for Tin Whisker Test Methods on Lead-Free Components," IEEE Transactions on Components and Packaging Technologies, Vol. 32, No. 1, pp. 216-219, March 2009.
5. D. Kwon, M. H. Azarian, and M. Pecht, "Early Detection of Interconnect Degradation by Continuous Monitoring of RF Impedance," IEEE Trans. on Device and Materials Reliability, Vol. 9, No. 2, pp. 296-304, June 2009.
6. L. Nie, J. Cai, M. Pecht, and R. Ciocci, "Environmental Regulations in Lead-free and Halogen-free Electronics," Electronics & Packaging (Chinese), Vol. 9, No. 6, pp. 42-47, June 2009.
7. S. Woo, D. L. O'Neal, and M. Pecht, "Improving the Reliability of a Water Dispenser Lever in a Refrigerator Subjected to Repetitive Stresses," Engineering Failure Analysis, Vol. 16, No. 5, pp. 1597-1606, July 2009.
8. S. Woo, D. L. O'Neal, and M. Pecht, "Design of a Hinge Kit System in a Kimchi Refrigerator Receiving Repetitive Stresses," Engineering Failure Analysis, Vol. 16, No. 5, pp. 1655-1665, July 2009.
9. S. Woo, M. Pecht, and D. O'Neal, "Reliability Design and Case Study of a Refrigerator Compressor Subjected to Repetitive Loads," International Journal of Refrigeration, Vol. 32, No. 3, pp. 478-486, 2009.
10. S. Mathew, M. Osterman, M. Pecht, and F. Dunlevey, "Evaluation of Pure Tin Plated Copper Alloy Substrates for Tin Whiskers," Circuit World, Vol. 35, No. 1, pp. 3-8, 2009.
11. M. Pecht and J. Gu, "Physics-of-failure-based Prognostics for Electronic Products," Transactions of the Institute of Measurement and Control, Vol. 31, No. 3/4, pp. 309–322, 2009
12. L. Nie, M. Osterman, and M. Pecht, "Copper Pad Dissolution and Microstructure Analysis of Reworked Plastic Grid Array Packages in Lead-free and Mixed Assemblies," SMTA Journal, Vol. 22, No. 2, pp. 13-20, 2009.
13. M. Pecht, "Reliability, Maintainability, and Availability," in Handbook of Systems Engineering and Management. Ed. Andrew P. Sage and William B. Rouse. 2nd ed. Wiley-Interscience, New York, NY, pp. 361-95, 2009.

Frontiers of Prognostics & Health Management Conference 2010

From January 12-14, 2010, CALCE will host the 2010 Frontiers of Prognostics & Health Management Conference at the University of Macau, in Macau, P.R. China. PHM-2010 Macau is the second conference of its kind to promote the realization and application of PHM as a key enabler for the growth of a broad range of industries in the Asia Pacific region. The conference will bring together experts and leaders from industries, government organizations, and leading research centers who will share their aspirations for the application of PHM in their respective areas. This event will be an important platform for exchange and networking among leading players in the emerging PHM field, especially in the Asian Pacific region.

Researchers and participants from academic and government organizations are invited to submit papers on: Principles methods results; Data-driven methods for anomaly detection, diagnosis, and prognosis; Innovation applications; Industrial applications; Physics-of-failure; Sensors; Structural sensing; Health management; and System design and Engineering. For more details, contact Prof. Michael Pecht (pecht@calce.umd.edu).

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