LPRDS-CMS-2011

Lafayette Photovoltaic Research and Development System

Cell Management System

ECE492 – Spring 2011

Statement of Work

PRELIMINARY DRAFT

Lafayette College

Electrical and Computer Engineering Department

17 December 2010
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Scope

Lafayette College ECE Department is pleased to propose the design, fabrication, and deployment of a Cell Management System (CMS) and other subsystems to be integrated into the Lafayette Photovoltaic Research and Development System (LPRDS) by the end of the Spring term, 2011.

The main goals of LPRDS-CMS-2011 are to deliver the following:

- A fully integrated and operational system with 24x7 demo availability.
- Automated management of the aggregate EDS battery and its individual LiFePO4 cells.
- Functional integration with the existing SCADA (Supervisory Control and Data Acquisition) system supporting a range of demonstration, diagnostic and operational activities.
- Proven and dependable integration with the safety subsystem.

These items shall be installed in Acopian Engineering Center room 401 and shall reliably, safely, and maintainably operate as part of the existing LPRDS, performing a continuous demonstration of Photovoltaic energy conversion over a 5-year service life.

This document describes the detailed requirements for the project.
Applicable Documents

A detailed description of the DFE Photovoltaic system and previous LPRDS designs that the CMS-2011 must integrate with, including detailed electrical specifications, is contained in the previous year web sites.

http://academicmuseum.lafayette.edu/engineering/ece492-2009/

http://sites.lafayette.edu/ece492-sp10/

Management Requirements

The LPRDS-CMS-2011 shall be designed, developed, fabricated, tested, demonstrated, and documented by a student team during a challenging 14-week schedule.

Key milestones in the program are as follows.

Acceptance Testing

Acceptance testing comprises the Acceptance Test Plan (ATP) and the Acceptance Test Report (ATR). These are deliverables D004 and D005.

Acceptance Testing and its supporting deliverables represent 60% of the grade for ECE 492.

Everyone in the team gets the same project success portion in his or her grade as measured by the ATR and its supporting deliverables. Thus, the importance of the ATP/ATR is paramount. All other activities in the project should serve the one goal of successfully executing acceptance testing.

The student team at CDR presents the plan for Acceptance Testing.

Critical Design Review (CDR)

The student team must schedule and execute a Critical Design Review presentation.

At CDR, the engineering team will present the detailed design of the LPRDS-CMS-2011 along with an up-to-date project Plan of Record (PoR). The main live presentation of CDR shall be high level and relatively formal, with sidebar meetings scheduled immediately afterward to cover specific critical topics in more detail. Outside reviewers will be invited to witness and comment on CDR and sidebars.

The CDR is a multi-disciplined technical and management review to ensure that the PoR can proceed into fabrication, integration, and test. At CDR the team demonstrates that the detailed design is complete and that it will meet the stated performance requirements within cost, schedule, risk, and other system constraints. CDR is successful if the detailed design, fab, QA, and management plans form a satisfactory basis for proceeding into fabrication, integration and test.

Included in the CDR is a presentation of the system level Acceptance Test Plan (ATP), D004, that enumerates system level testing that will demonstrate compliance with all system level requirements.

The primary milestone at CDR is the approval of the ATP (D004). The project cannot continue past CDR if the ATP is not approved.
**Purchasing Deadline**

10 Mar 2010, 5 PM

Fabrication that relies on the Lafayette College machine shop or any outside vendor, including PC board fabrication, should be ordered by this deadline. Every subsystem BOM presented at CDR should be on order by this date.

**Quality Assurance**

The team will conduct ongoing Quality Assurance (QA) Audits to review the results of subsystem tests and to revise the PoR as required. The results of the QA Audits are documented in the QA Audit Report, D006.

**System Engineering**

*Integrating the independent subsystems into an overall working system is a critical and mandatory part of this project. It is easy to underestimate the amount of time required for this task. The team should conduct a vigorous system engineering effort from day 1 and leave ample time for system integration and acceptance testing at the end of the project.*

**Acceptance Testing Completed**

29 Apr 2010

Acceptance testing shall be successfully completed and the Acceptance Test Report (ATR), D005 and QA Audit Report, D006, delivered by this deadline. The ATR represents 60% of the course grade shared by all team members. Obviously, the system must be completely integrated and ATP execution begun some time earlier than this date. ECE professors shall be invited to witness any and all portions of the execution of the ATP.

**Formal Demonstration and Delivery**

6 May 2010

The team will present the completed system to all interested parties on or prior to this date. The presentation will be per GPR011, and shall include a verbal presentation of the technical design and management experience, along with a live physical demonstration.

*Project materials shall be disposed of per GPR012 no later than 6 May.*
*Unless otherwise stated, all deliverables are due no later than 6 May.*
Program Management Requirements

Budget for Direct Costs

Direct Labor and Materials costs, including shipping costs, for the entire LPRDS-CMS-2011 shall be limited to $3,000.

Any direct item to be purchased must be requested on a Lafayette ECE Department Purchase Request form. An ECE professor must approve all requests. The team shall keep a binder or spreadsheet with all approved purchase request forms. These should be tracked by the team against orders and received material. It is recommended that a single Task Group or individual be assigned for managing material procurement.

The ECE Department Secretary will not accept unapproved requests nor will the Secretary accept requests that are not on the standard form. Basis for approval will be the degree to which the expense fits with the project plan of record. Overnight shipping will not be approved.

Running totals of costs incurred should be updated daily or even in real time if necessary, especially near the purchasing deadline. Updated cost reports and budgets shall accompany requests for major purchases.

The received material may be stored in the empty cabinets and shelves in room 412 and/or 400. It is the responsibility of the team to receive, inventory, and preserve the stock of received material.

Labor Resources, Management, and Organization

A team of ECE Seniors and two ECE professors shall comprise the entire engineering labor pool. The team must establish processes for organizing, planning, and allocating work to individuals and teams. A process for intra-team communication must be developed.

Overhead Resources

The Lafayette College Engineering Division shops and labs shall be the primary technical resource for fabrication. External contract fabrication facilities may be utilized when necessary, subject to the budget for direct costs.

The team should be aware of the lead-time required by the machine shop and other resources, factoring this time into the project schedule.
Deliverables and Data Items

All LPRDS-CMS-2011 hardware and operational software shall be installed permanently in AEC Room 401. Final disposal of all project materials shall be per GPR012.

All data items, reports, and forms shall be in compliance with GPR001.

Documents must be delivered electronically both to the project web site and by individual email to all the course instructors by the due date.

<table>
<thead>
<tr>
<th>Deliverable</th>
<th>Description</th>
<th>Due Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>D001</td>
<td>CDR Presentation Materials</td>
<td>Delivered to web site and reviewers 24 hrs prior to CDR</td>
</tr>
<tr>
<td>D002</td>
<td>Users Manual</td>
<td>Draft at CDR, final 6 May (5 PM)</td>
</tr>
<tr>
<td>D003</td>
<td>Final Report and Maintenance Manual</td>
<td>Draft at CDR, final 6 May (5 PM)</td>
</tr>
<tr>
<td>D004</td>
<td>Acceptance Test Plan</td>
<td>Approved at CDR</td>
</tr>
<tr>
<td>D005</td>
<td>Acceptance Test Report</td>
<td>29 April</td>
</tr>
<tr>
<td>D006</td>
<td>QA Audit Report</td>
<td>29 April</td>
</tr>
<tr>
<td>D007</td>
<td>Project Web Site</td>
<td>Must be updated regularly.</td>
</tr>
<tr>
<td>D008</td>
<td>LPRDS-CMS-2011 Integrated System</td>
<td>Final disposition per GPR012 no later than 6 May (5 PM)</td>
</tr>
<tr>
<td>D009</td>
<td>Conference Paper</td>
<td>TBD</td>
</tr>
<tr>
<td>D010</td>
<td>Project Poster</td>
<td>6 May (5 PM)</td>
</tr>
</tbody>
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**D001: CDR Materials**

All materials presented or referenced at CDR shall be on the project web site and made available to the reviewers 24 hours prior to the commencement of CDR.

The CDR Materials must include the following items:

1. An updated system design, comprising the final, detailed, and complete hierarchical subsystem breakdown. This breakdown shall be reflected in all other documentation consistently. BOMs, test plans, ICDs, schedules, etc… shall all use the same breakdown.
2. Detailed specifications for each subsystem type, including interface definition and functional requirements.
3. Subsystem test plans or test benches for each subsystem type. These shall include step-by-step instructions for testing the function and interface of each subsystem with a report template for recording results that includes specification limits and clear pass/fail criteria.
4. An approved electrical safety plan per GPR005.
5. Reports or white papers documenting analysis that demonstrates compliance with any requirement that is not “obviously” met by the design. Specifically required at CDR are
   • An analysis of current, dissipation, temperature, and voltage ratings per GPR005.
   • A reliability analysis, per GPR006.
   • A maintainability analysis, per GPR007.
   • A manufacturability analysis of tolerances per GPR008.

   Any new requirements that result from these analyses automatically become part of the project requirements and shall be addressed in the design.

6. Operation of critical circuits shall be simulated and proven against test benches using SPICE, Modelsim, or other simulators. Simulation results shall be presented at CDR.

7. Interface control specifications captured in an interface control document and System Drawing that documents the exact way subsystem types are instantiated and interconnected. Pinouts of all connectors, conductor assignments in cabling shall be documented in the ICD.

8. “Build to Print” fabrication specifications for all subsystems requiring outside fabrication.

9. An enhanced requirements analysis (traceability matrix) showing that the detailed design and testing meets all requirements and constraints. The traceability matrix shall allocate every top level requirement to a functional requirement and/or interface specification in at least one subsystem, and every subsystem shall have each of its functions and interfaces tied to at least one top level requirement.

10. A revised cost analysis and detailed program budget that documents costs to date and demonstrates compliance with financial constraints.

11. A revised program schedule that documents progress to date and identifies system and software critical path drivers to meet schedule constraints.

12. An approved system level Acceptance Test Plan. All requirements met by analysis must have the analytic work completed in this draft.


**D002: Users Manual**

A users manual, per GPR001, shall be provided.

**D003: Final Report and Maintenance Manual**

A professional quality final report, including a maintenance manual, per GPR001, shall be provided. The Final Report must have an attractive cover page, an initial “executive summary” section, followed by detailed technical sections and appendices documenting all aspects of the project.

This document shall be delivered electronically, per GPR001. In addition, a single paper copy shall be printed, attractively bound, and physically delivered to the chairman of the ECE department.
D004: Acceptance Test Plan

The Acceptance Test Plan (ATP) is a document that describes how the system as a whole will be tested so as to prove compliance with all requirements and specifications. The ATP should include forms that can be filled out by testers during execution. These filled out forms will be used to create the ATR.

Compliance can be proved in any of the following three ways:

- **Analysis** – detailed logical analysis can demonstrate compliance by reasoning from known facts (a priori or empirically) in the form of a proof. Analysis can be used in conjunction with the results of subsystem QA testing, along with generally accepted technical principles to prove system level requirements are met. Analysis memos and relevant data are attached to the ATR.

- **Test** – an explicit test, experiment, or demonstration can be used to make compliance with a certain requirement obvious. The results of any measurements conducted as part of an ATP test is included in the ATR, along with the pass/fail criteria and result.

- **Inspection** – compliance is made evident by directly examining the system. Photographs or other evidence gathered in an inspection is included in the ATR.

The ATP should be arranged to minimize the work involved in testing. If possible, multiple requirements should be demonstrated by each test. The ATP should include a compliance matrix making it obvious that all requirements have been addressed by the plan.

D005: Acceptance Test Report

The Acceptance Test Report (ATR) is a document that documents the results of the execution of the Acceptance Test Plan (ATP). An ECE professor must witness the performance of the ATP and sign the ATR. The ATR should include measured data and analysis results that demonstrate compliance with all specifications. Each test should have the following items noted

- Date/Time
- Person Performing Test
- ECE Professor witnessing test.
- Test Results
- Relevant Specs and Requirements
- Pass Fail Criteria
- Pass Fail Determination

The testers and witnesses must physically sign the overall document. Since the test reports will likely include such handwritten content, they need to be scanned and
preserved in electronic form. The paper document must be handled per GPR001 and GPR012.

**D006: QA Audit Report**

This report comprises the results of subsystem testing per the subsystem test plans. It shall adhere to the documentation standards of GPR001. Since the test reports will likely include handwritten content, they shall be scanned and preserved in electronic form. The original paper must be disposed of per GPR012.

For each subsystem type, the QA Audit Report should include a record of the testing of each instance of the subsystem, including the date and time of the testing along with a handwritten signature of the test technician. The testing record shall include actual test results explicitly recorded compared against specification limits and pass/fail criteria with each result clearly marked as pass or fail.

**D007: Project Web Site**

A project web site is required per GPR001 and GPR012. The URL of the web site shall be

http://sites.lafayette.edu/ece492-sp11

The content of this site shall be professionally presented and organized. The site must serve the real time needs of the project, but also must be left as a useful resource for reference in the years to come.

**D008: LPRDS-CMS-2011 Integrated System**

This deliverable is essential. LPRDS-CMS-2011 must be fully integrated and working upon delivery.

All the integrated hardware, software, and firmware constituting the LPRDS-CMS-2011 system shall be installed in AEC room 401. Any additional parts, subsystems, paperwork, tooling, or other physical material associated with the system should be disposed of per GPR012. Soft copies of all deliverable data items shall be placed on the project web site per GPR012.

**D009: Conference Paper**

The LPRDS-CMS-2011 shall be documented in a suitable form and presented at an academic conference during the Spring 2011 term.

**D010: Project Poster**

The LPRDS-CMS-2011 shall be documented as an attractive and interesting summary poster and set of detailed posters. These posters shall be delivered in electronic form per GPR001. In addition, the summary poster shall be physically printed in large format and hung in the 4th floor AEC hallway.
Technical Requirements

Figure 1 shows LPRDS-ETS in the context of the Department Furnished Equipment (DFE) that constitutes the overall LPRDS.

![Diagram of LPRDS-ETS](image)

Figure 1. The LPRDS Installed in Context

Figure 2 is a high-level block diagram showing the major components of the LPRDS-ETS.
**R002: Energy Storage**

The LPRDS-CMS-2011 shall develop a new Energy Storage Subsystem (ESS) that will replace the existing ESS. The main function of the ESS is to act as an *Energy Accumulator* to store excess electrical energy available from the PV array and later deliver that stored energy to the Energy Delivery subsystem.

The existing ESS design does not allow any automated per-cell or aggregate battery management. There is no way to charge the cells individually taking into account their individual characteristics. *The LPRDS-CMS-2011 shall re-engineer the ESS to permit per-cell battery management.*

The new system shall charge every cell in the ESS to its maximum recommended capacity. Should some cells charge faster than others, a means shall be provided to bypass the cells that become full first, allowing complete charge to be delivered to cells that charge more slowly.

![Figure 2. LPRDS-ETS Top Level Block Diagram](image-url)
On discharge, every cell shall be monitored and over-discharge of any individual cell must be avoided.

The ESS shall be capable of standalone operation. It shall be possible to properly charge and discharge the ESS without needing an outside computer system for control or monitoring. Indicators shall be provided that give a basic display operational state (charge/discharge rate) and charge state (fuel gauge). Controls shall be provided, if needed, to permit standalone management.

In addition to local controls and indicators, a remote SCADA system shall be able to monitor in detail the voltage, current, and state of charge of the aggregate ESS battery and every individual cell in the ESS, as well as the overall ESS parameters.

The low-level data interface to SCADA shall be RS-485. It is not necessary to retain the EDS data formats or communication protocols established in ETS-2009.

Although a new charge-management system must be developed, the LPRDS-CMS-2011 shall re-use the existing LiFePO4 cells incorporated in the existing ESS system. Also, to the largest extent possible, the existing mechanical enclosure, cabling, controls, and safety interfaces for the old ESS should be re-used.

To the extent they do not conflict or are superseded, old ESS requirements given in the LPRDS 2009 and 2010 specifications will apply to the new ESS in the LPRDS-CMS-2011. Those specifications are quoted below for convenience:

**R002b: Legacy ESS Requirements**

1. The discharge power capacity of the ESS shall be able to meet the power requirements of the Energy Delivery subsystem when that system is delivering the maximum required power to a load.

2. The ESS shall be internally protected from excessive charge or discharge rates, excessive overcharge, and excessive discharge.

   A shutdown switch, compliant with NEC and the safety plan must be provided as part of the ESS. When the switch is open, DC energy from the energy accumulator shall not be conducted to the LPRDS-ETS. This switch must be easy to operate, mounted on the ESS in a visible location, and must have the ability to be key-locked in the disabled state.

   An indicator light shall be provided on the ESS that illuminates when the ESS disconnect switch is enabled and DC energy is present and can be connected to the rest of the LPRDS-ETS.

3. The ESS shall have a safety interface with the rest of the LPRDS-ETS designed in such a manner that a fault anywhere in the LPRDS-ETS system will cause the ESS to disconnect the DC energy from the accumulator and go into a fault state. A fault indicator light shall be provided on the ESS that illuminates when a fault has caused the shutdown of the ESS.
The ESS must be built with a normally open isolation relay or equivalent wired in such a way that when the safety interface is interrupted or not present, no voltages will be delivered.

All energy storage in the ESS must be in closed containers with safety interface, indicators, and controls as required herein. Containers must include an appropriately rated fuse or circuit breaker. The safety relays must be rated to interrupt the rated fuse current at the maximum expected voltage.

Multiple energy storage containers connected in series may be isolated by a total of two relays, provided that interconnects between the containers are protected by non-conductive conduit anchored solidly to the containers. All voltages outside the energy storage container must decay to below 30 V within ten seconds of when the relays are disconnected. For example, filter capacitors must have bleeder resistors across them.

The energy storage containers must have closable access ports allowing a electrical probe to make contact with each extreme of the HV system. These will be used to permit testing the isolation stipulated by the safety plan. Optionally, access to the same electrical nodes may be provided at another point.

Each energy storage container must have a prominent indicator, such as an LED that will illuminate whenever that container contains a voltage greater than (at a maximum) 30V. This must be clearly visible in bright room light. As an alternative, the battery container may contain an embedded analog meter clearly visible from the outside.

The energy storage container and mounting system must be sturdy. The materials used to construct the container should ideally be electrically insulating, mechanically robust, fireproof, and transparent to allow easy inspection. Not all of these properties are available in a single material, but the following are required:

- Mechanically robust, fireproof insulating material (e.g., Nomex) between live electrical parts and any conductive portions of the container.
- Adequate structural robustness for the weight of the accumulator.
- There must be no unintentional electrical conduction paths through any of the walls of the container. (Metal screws, rivets, etc.)
- The container must be prominently labeled with high voltage signs, at least 30 sq-in, with a red (or white on red) lightning bolt and the text High Voltage or Danger High Voltage.
- Systems capable of venting hydrogen gas (batteries) must have a ventilation system that is active whenever the system is charging, whether from on-board or off-board sources.

An interface to the SCADA system shall be provided, with format as required for supervisory functions.

At a minimum, the SCADA shall be able to monitor voltage and current on all interfaces of this subsystem, internal temperature in all critical locations of this subsystem, and operational or fault state.
**R006: Applications Programming Interface and System Development Kit**

The LPRDS has a fully documented software Applications Programming Interface (API) and a System Development Kit (SDK) that an applications programmer can use to write software applications that control and monitor all interfaces and functions supported by the SCADA. As much as possible, software support for LPRDS-2011-CMS must use this API to access SCADA functions. However, it is acceptable to extend the scope of the API to support both low level debugging applications and high-level automated applications of the CMS so long as overall software functionality of LPRDS is not compromised. SDK additions must meet legacy API requirements and include a complete toolchain, with compilers, linkers, libraries, include files, utilities, compilers, as well as developer level documentation.

The complete SDK, including API documentation and application source under configuration control shall be delivered to or linked by the project web site.

**R008: Demonstration Application**

The LPRDS-CMS-2011 shall provide a fully documented, user friendly, Demonstration Application. The Demonstration Application must allow a non-technical, minimally trained human user to successfully witness an automatic demonstration of the capabilities of the LPRDS-CMS-2011 and DFE system per GPR011.

The LPRDS-CMS-2011 must include a large display that is visible through the window of room AEC401 allowing passers-by to witness some aspects of the demo. The word “display” in this requirement refers to the aggregate appearance of controls, indicators, and other visually appealing paraphernalia. The use of a computer monitor or LCD panel may be part of that aggregate “display”, but that computer monitor is not, by itself, the system “display”.

The DFE of the existing LPRDS includes various visual components that may be used as part of the overall large display; however, these components, without modification, do not meet some overall system requirements (e.g. the self-power requirement.) The LPRDS “display” must be reworked in LPRDS-CMS-2011 as required.

The Demonstration Application should be designed to provide an interesting demonstration with few, if any, interactive options and a robust tolerance for possible mistakes made by the operating user. System damage should not be possible with this application.

This application software must be written in conformance with the LPRDS API (R006), built with tools provided in the SDK, and run on a suitable hardware platform included with and powered by the LPRDS-CMS-2011 system.
**R009: Modifications of the LPRDS**

Modifying the high voltage and PV portion of LPRDS, or modifying the RPI, or physical alteration of the building is not permitted except with permission of the ECE Department.

The mechanical packaging and cabling existing for the ESS and overall LPRDS rack (including safety switches, displays, and alarms) shall be re-used as much as possible.

Mechanical attachments for enclosures, conduits, and other equipment may be added to the LPRDS or Room 401 with the prior approval of the ECE Department.

**R010: Power Input Independence**

The installed LPRDS-CMS-2011 shall be able to operate without any power derived from building mains. The RPI, SCADA, and Demonstration Application must be able to operate entirely on power provided by the LPRDS without unduly draining the ESS overnight or during cloudy days. All voltages needed shall be generated by LPRDS-CMS-2011 circuitry per GPR005.

The above requirement for power input independence notwithstanding, in order to allow maintenance or demonstration of the LPRDS for long periods with no solar power without draining of the batteries, a “maintenance power mode” shall be provided. When the LPRDS is in this mode, the LPRDS system shall be fully functional with power derived entirely from the building mains. It shall be possible to switch in and out of “maintenance power mode” quickly and easily.

**R011 Safety Interface**

The existing RPI safety interface shall be fully retained. This interface shall be connected to all the major LPRDS-CMS-2011 subsystems and shall provide a mechanism by which the entire system can be quickly and reliably shut down to a safe, un-energized state should a fault be detected anywhere in the system. The safety interface shall be designed in a failsafe manner so that, should it be cut, broken, or removed at any location, shutdown will immediately occur. The safety interface must be completely independent of any other interface.
General Project Requirements

The following requirements fully apply to the LPRDS-CMS-2011 unless waived or superseded herein by specific requirements of this project. Compliance with these requirements must be established by analysis, demonstration, or inspection. Compliance results must be documented with the system, either in the ATR or in the QA Report.

Special Waivers and Restrictions

1. Analysis must show the system is compliant to GPR002; however, no formal environmental testing or empirical data is required.

2. Analysis can be used to show the system is compliant to GPR003; no formal EMI/EMC certification testing or empirical data is required.

3. Surface temperatures, supply current drains per GPR005 must be analytically predicted at CDR and physically measured and verified as compliant during ATP.

4. The integrated Photovoltaic system must comply with the National Electric Code (NEC), particularly article 690.

   In the life cycle sustainability analysis required by GPR009, the useful system life shall be estimated in the context of factors that could increase or decrease its longevity, both in the short run (<30 years) and the long run. It is required that the analysis of GPR009 determines in detail the total cost of purchasing and operating of a 2 kW PhotoVoltaic system such as the LPRDS, comparing and contrasting its performance, cost, and sustainability with other energy alternatives available today, including those reasonably known to be available for widespread deployment the near future. Particular attention should be paid to externalized life cycle costs. Such external costs should be considered separately as design options, and weighed against political and ethical constraints, and market propensities on both the supply and demand side.

5. The system life for the purpose of requirements analysis other than for GPR009 shall be 5 years.

6. An electrical safety plan shall be developed and adopted by CDR.

GPR001: Documentation

Complete and accurate documentation must be provided with all projects. These documents shall include documents for mechanical and electrical fabrication, test results, software development kits, maintenance manual, user manual, and specification compliance matrices, and technical papers. All documentation shall be accumulated in electronic form, centralized in a project website, and thoroughly indexed. The website represents the primary point of delivery for document data items.

Text documents shall be written in a professional style commensurate with quality standards established by Lafayette College ECE writing courses (e.g. ES225 and ECE211).

All original paper documents should be scanned and stored electronically. The original should be disposed of per GPR012.
Test reports for hardware and software must show the date/time of testing, name and signature of the tester, and name/signature of any witnesses.

For all electronic PCB designs the following fabrication documents are required: dated, and numbered schematics or mechanical drawings on Lafayette College drawing format, circuit net-lists, bills of materials, artwork, assembly drawings, and all other files and instructions necessary for CAM or manual manufacturing. The source files for fabricating PCBs and editing linked schematics shall be clearly identified and preserved.

Documentation must be provided both for original designs and for any subcontracted designs. For purchased vendor components within the design, all vendor manuals and documentation shall be retained with the system. Proper mechanical drawings are required for fabricated mechanical parts. Manufacturers data sheets and interface drawings are required for all purchased components.

For software and firmware designs: Source code, and executable binaries for all applications; Verilog, constraints and configuration bitstreams for FPGAs; and ROM image files in commonly accepted JED or HEX formats for all PLDs.

A “Users” manual is required. This should be a high level document that explains all operational procedures and techniques needed to operate the system is a safe and effective manner, including “getting started”, “FAQ”, detailed explanations of all functions and controls, and user level calibration and maintenance.

A technical “Maintenance” manual is required. This should be a low level document that explains the unique technical principles and details of system operation. The maintenance manual includes information on any advanced maintenance or calibration techniques that could be applied by an expert maintainer. A set of schematics, pinouts of all connectors, the signal assignments of all cables, and the semantics of all interfaces (hardware and software) must be documented within this manual.

All documentation must be provided and delivered in electronic form. Emailing a description of a document along with a URL into the project web site is an acceptable and desirable form of delivery. The use of standard and portable document formats (e.g. PDF, TXT), must be used so that the documentation can be viewed on any computer without the need for proprietary applications. The documentation must be arranged in an organized and professional manner on the project web site.

**GPR002: Environmental**

All projects must demonstrate reliable and normal functional operation in ambient lab temperatures of 15 °C to 30 °C, 10% to 80% RH, non-condensing. The overall system must tolerate a storage environment of 0 °C to +60 °C, 5% to 95% RH, non-condensing. Designs should use electronic components rated for commercial temperature range (0 – 70 °C) or better.

**GPR003: EMI/EMC**

Unintentional electromagnetic radiation radiated or conducted from designs must meet US CFR Title 47 Part 15 subpart B regulations for Class A digital equipment. Intentional radiators must meet subpart C regulations. Exemptions from 15.103 are not allowed.
**GPR004: Hazmats**

Hazardous materials should be avoided in designs. If use of a hazardous material is essential to the function of the design and there is no non-hazardous alternative, the use of the hazardous material must comply with the Lafayette College Chemical Hygiene Plan.

All materials used in electronic circuit fabrication must meet 2002/95/EC RoHS directives. NiCd or Lead-Acid batteries may not be used in new designs.

Any portion of the design or prototype that is discarded must be discarded according to the Lafayette College Chemical Hygiene plan. Also, projects should discard the collected electronic waste in an ecological-friendly manner as per the 2002/96/EC WEEE directive, either by ecological disposal or by reuse/refurbishment of the collected waste.

**GPR005: Safety and Good Practice**

All work shall comply with good industry practice that enhances reliability and maintainability. These practices include such items as

- Color coded wiring in accordance with applicable industry standard color codes (e.g. NFPA 79 or UL508 for power wiring, EIA/TIA 568 for network wiring, etc…)
- Clear labeling of all controls and indicators.
- An obvious and clearly labeled system-wide power shutdown switch.
- Silkscreen on PCBs that includes reference designators, noted power supply voltages and other critical signals. Silkscreen must show a Lafayette College logo, the words “Made in USA”, a RoHS logo, assembly number and revision, and designated locations for serial numbers to be attached or written. PCB bottom copper should have text indicating the board part number and rev.
- Fuses shall be socketed and at least 5 spares must be included with system delivery; breakers shall be resettable. All are readily accessible per maintainability requirements.
- Service loops on all cable harnesses.
- Access panels on enclosures.

Software/firmware developed must adhere to the principles and practice established in Lafayette College course CS205. Source code must be maintained under configuration control.

FPGA Logic shall be defined in HDL according to the rules and guidelines established in Lafayette College course ECE491.

**Embedded computer processors shall have reset buttons. These buttons must be readily acceptable for maintenance, but not so easy to hit that they degrade reliability.**

Current drain analysis must be provided for all power supplies. Each supply voltage must have a current rating with a 50% safety factor over the anticipated peak current.
All resistors or other parts dissipating more than 25 milliwatts shall be identified and analysis shall be provided that shows all such parts are properly rated for peak and average power dissipation and have a proper heat sink and fan, if necessary, that provides adequate cooling over the ambient temperature range.

Fans should be protected with grilles and filters. EMI analysis must consider the fan opening and specify EMI tight grillwork if necessary.

Components must be cooled such that the surface temperature is no greater than 40 degrees C above ambient.

Power dissipation rating of parts shall be 50% overrated over the required temperature range.

Working voltage of capacitors shall be 25% overrated above the peak voltage anticipated, including all expected glitches, spikes, and tolerance limits.

Project activities must adhere to the general Lafayette College safety policy, possibly augmented by any ECE Department or ECE Laboratory safety rules. Applicable rules are those in effect on the date of ATP.

Any project that develops AC RMS or DC potential differences greater than 30 Volts between any two points within the design (other than at the unmodified mains input side of a UL listed commercial power supply) must develop and implement an electrical safety plan before any circuits are powered. The safety plan must document the processes, design constraints, and equipment that will be used to ensure the safety of all participants. The ECE Director of Laboratories must approve the electrical safety plan. A project team member must be designated project safety officer. It shall be the project safety officer’s responsibility to insure that all activities adhere to the project safety plan.

All equipment developed must comply with applicable national standards. Specifically, all electric supply, communications lines, and equipment must be designed, constructed, operated, and maintained in accordance to The National Electrical Safety Code (NESC) – ANSI C-2. Installations of electric conductors and equipment that connect to a building main supply of electricity must be designed, constructed, operated and maintained in accordance to The National Electric Code (NEC) ANSI/NFPA 70.

Any interconnection with the Lafayette College power grid is subject to the approval of Plant Operations. Any interconnection with the Lafayette College campus computer network is subject to the approval of the Information Technology Services department.

Use and design of lasers shall be in accordance with American National Standards Institute (ANSI) Z136.1-2000, "American National Standard for Safe Use of Lasers". Only low power Class I, II and Class IIIa (<5 mW) lasers should be used. If project requirements necessitate higher power, the project must develop and implement a laser safety plan before any laser work begins. The safety plan must document the processes, design constraints, and equipment that will be used to ensure the safety of all participants.

All projects that involve RF power of any level must be designed to ensure that participants are not exposed to RF in excess of the recommended exposure limits adopted by the FCC (most recently in 1996, but note the proposed rule change in 2003). If project requirements necessitate radiated RF power in excess of 100 mW, the project must develop and implement an RF exposure safety plan before any high power RF work
begins. The safety plan must document the processes, design constraints, and equipment that will be used to ensure the safety of all participants.

**GPR006: Reliability**

The system wide Mean Time Between Failures (MTBF) must be greater than 1000 hours over the system lifetime.

Reliability requirements must be demonstrated in the ATP both by analysis and by inspection. The use of MIL-HDBK-217, Bellcore TR-332, or other equivalent techniques are encouraged for the analysis. Every part and subsystem in the full BOM must be explicitly considered in the MTBF analysis.

Parts with power dissipation over 25 milliwatts shall be identified and the reliability analysis shall include reliability derating of these components based on the expected dissipation.

In addition to the analysis, a reliability inspection shall be conducted during ATP where the system is shown to operate for 24 hours without any obvious failure.

Failures are defined as anything that causes system requirements to be missed. Failures include, but are not limited to computer software lock-ups, shutdowns caused by overheating, automatic operations stalled by exceptions or requests for human intervention, as well as random component failure.

**GPR007: Maintainability**

The system wide Mean Time To Repair (MTTR) must be less than 1 week over the system lifetime.

Maintainability requirements must be demonstrated in the ATP both by analysis and by inspection. The use of MIL-HDBK-472 (N1) and MIL-STD-470B, ISO/IEC 25000:2005, or other equivalent techniques are encouraged for the analysis.

In the maintainability analysis you should assume a stock of recommended spare parts. The list of these spare parts should be included in the ATP. The Users Manual should include a section giving simple troubleshooting procedures. The Maintenance Manual should have more elaborate diagnosis and troubleshooting resources.

In addition, a maintainability inspection shall be conducted during ATP where a novice using procedures included in the User Manual demonstrates the diagnosis and repair of a likely failure, and an expert using resources included in the Maintenance Manual demonstrates the diagnosis and repair of an UN-likely failure.

**GPR008: Manufacturability**

A production design is a project design that could reasonably be manufactured in large quantity (e.g. greater than 1000 units/yr). All production designs must be built from components and subassemblies that have a sustainable source of supply over the system lifetime. To demonstrate that this requirement is met, it must be shown that each item in the Bill of Materials (BOM) for the design is available from a minimum of two independent suppliers. In addition, industry trends shall be considered when selecting
implementation options. Designs should choose options most aligned with future industry
trends.

The tolerances of components shall be considered in the design. Any component with a
value that determines a critical voltage, time constant, frequency, or other parameter shall
have a tolerance such that system requirements are met with 99% yield in manufacturing.
An analysis shall be provided that identifies any tolerance critical components and proves
that the tolerances are adequate to meet system requirements at that yield.

**GPR011: Project Demonstration**

Completed projects must be demonstrated for review by ECE faculty.

It is highly encouraged that the entire design, or some major functional subsystem of the
design is suitable for continuous, unattended display as a self-contained, active
demonstration that would excite the interest of students, faculty, and other ECE
Department visitors. Such demonstrations must fit in a compact public area and operate
safely and without unreasonable disturbance of its neighbors. User interaction with the
demo is encouraged, but if activated by someone, the demonstration must deactivate
automatically after some short delay. The MTTR and MTBF of the demonstration must
meet or exceed the project-level Maintainability and Reliability requirements given
herein. Visitor interaction with the demonstration, and possible failures caused by such
interaction, shall be considered in the MTBF analysis.

**GPR012: Final Disposal of Projects**

Projects may be stored for future work, placed on display, or discarded. Time must be
included in project schedules for final disposal.

If a project is to be stored, all its materials must be collected together in a single location.
If possible, these materials should be enclosed in a sealed container, locked cabinet, or
secure room that contains only these materials from one project and no other. If certain
parts are impractical to store with the bulk of the project materials, these separate parts
must be clearly labeled so their association with the stored project is obvious.

Projects placed on display may have portions not on display. The undisplayed portions
shall be either stored or discarded as described herein.

Portions of projects or complete projects that are discarded must be discarded in
accordance with Hazmat procedures described herein.

Test equipment moved from labs shall be replaced in its original location.

Trash, loose wires, scattered components, and other detritus resulting from frenzied
development and testing shall be cleaned up.

Paper documents that have been scanned per GPR001 shall be placed in a paper recycling
bin.

The project web site must be updated with all final documents. The documents on the
final web site must match the delivered system. Obsolete documents on the web site shall
be removed.
## Acronym Glossary

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<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>AC</td>
<td>Alternating Current</td>
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<tr>
<td>AEC</td>
<td>Acopian Engineering Center</td>
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<tr>
<td>API</td>
<td>Applications Programming Interface</td>
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<tr>
<td>ATP</td>
<td>Acceptance Test Plan</td>
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<tr>
<td>ATR</td>
<td>Acceptance Test Report</td>
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<tr>
<td>BOM</td>
<td>Bill Of Materials</td>
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<tr>
<td>CAM</td>
<td>Computer Aided Manufacturing</td>
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<td>CFE</td>
<td>Customer Furnished Equipment</td>
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<tr>
<td>CFR</td>
<td>Code of Federal Regulations</td>
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<td>CDR</td>
<td>Critical Design Review</td>
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<tr>
<td>COC</td>
<td>Certificate Of Compliance</td>
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<td>DC</td>
<td>Direct Current</td>
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<tr>
<td>EC</td>
<td>European Community</td>
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<tr>
<td>ECE</td>
<td>Electrical and Computer Engineering</td>
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<tr>
<td>EMI</td>
<td>Electro Magnetic Interference</td>
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<tr>
<td>EMC</td>
<td>Electro Magnetic Compatibility</td>
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<td>ETC</td>
<td>Estimate To Complete</td>
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<td>FAQ</td>
<td>Frequently Asked Questions</td>
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<td>FCC</td>
<td>Federal Communications Commission</td>
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<td>FPGA</td>
<td>Field Programmable Gate Array</td>
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<tr>
<td>ICD</td>
<td>Interface Control Document</td>
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<tr>
<td>LPRDS</td>
<td>Lafayette Photovoltaic Research and Development System</td>
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<tr>
<td>LCA</td>
<td>Life Cycle Assessment</td>
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<tr>
<td>MTBF</td>
<td>Mean Time Between Failures</td>
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<td>MTTR</td>
<td>Mean Time To Repair</td>
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<tr>
<td>NEC</td>
<td>National Electric Code</td>
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<td>NESC</td>
<td>National Electrical Safety Code</td>
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<tr>
<td>PDR</td>
<td>Preliminary Design Review</td>
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<tr>
<td>PLD</td>
<td>Programmable Logic Device</td>
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<td>PM</td>
<td>Program Management</td>
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<td>POR</td>
<td>Plan Of Record</td>
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<td>QA</td>
<td>Quality Assurance</td>
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<td>RH</td>
<td>Relative Humidity</td>
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<td>RMS</td>
<td>Root Mean Square</td>
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<td>ROM</td>
<td>Read Only Memory</td>
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<tr>
<td>UI</td>
<td>User Interface</td>
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<td>UL</td>
<td>Underwriters Laboratories</td>
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<tr>
<td>WBS</td>
<td>Work Breakdown Structure</td>
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