RELIABILITY IMPROVEMENT PROJECT DECISION MAKING – WATER COOLING SYSTEM REDESIGN

BY

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Submitted to the System Design & Management Program in partial fulfillment of the requirements for the degree of Master of Science in Engineering & Management at the

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Abstract

Deciding on which reliability & performance improvement projects to launch or to reject has historically been an extremely challenging responsibility of Teradyne management. Incorrect decisions can lead to major customer dissatisfaction, which may subsequently lead to loss of market share. Teradyne Engineering and Marketing team have been trying to develop a tool that would assist in their reliability improvement project decision making.

The challenge is the dynamic aspects of the reliability improvement projects. Like most engineering projects, reliability improvement projects have variables such as internal workforce, productivity, skill sets, customer expectations and many others that are in constant motion. These variables make the assessment of reliability projects extremely difficult in a static framework. This research will incorporate these key variables into a dynamic framework to help assess individual reliability improvement projects.

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1	2/1/05	Paul Devine	Michael Norton	Origination
2	3/11/05	Paul Devine	Michael Norton	Scope Definition Added
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5	4/20/05	Paul Devine	Michael Norton	Technical Comparison
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8	5/5/05	Paul Devine	Michael Norton	Incorporate inputs
9	6/1/05	Paul Devine	Michael Norton	Final Review
10	6/8/05	Paul Devine	Michael Norton	Finalized

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1 Scope of this Document

This document contains a description of a tool that could aggregate financial, engineering, marketing, and customer service information to generate quantitative data to make informed decisions on large scale reliability projects for existing products at Teradyne.

The tool described in this document will be applied to a current reliability project proposal to determine project viability and applicability.

The reliability project proposal is currently in Phase II of the product development cycle process at Teradyne. The tool is expected to accommodate dynamic inputs and generate breakeven or sensitivity analysis for different market scenarios and conditions.

2 SUMMARY OF THE PROPOSAL

The proposal is to generate a tool that incorporates financial data, marketing forecasts, engineering resource requirement, product roadmap, customer satisfaction impact, and product warranty exposures to determine the viability of reliability improvement projects at Teradyne Inc.

The primary advantages of the proposed project assessment tool are:

- Tool is comprehensive: Financial, Marketing, Engineering and Customer data driven tool
- Teradyne does not currently have a tool that can offer break even analysis for reliability improvement projects
- Flexibility of the tool will allow the users to define parameters.
- Ease of use. The tool will be Microsoft Excel based.

3 Background on Teradyne

3.1 Teradyne Inc.

Found in 1949, Teradyne is one of the leaders in the Automatic Test Equipment (ATE) industry. The company is made up of 5 divisions; Assembly Test, Broadband Test, Connection Systems, Semiconductor Test, and Vehicle Diagnostic Solutions.

3.1.1 Assembly Test Division

ATD is a global leader in electronics and testing and inspection solutions serving the world's leading original equipment manufacturer and electronics manufacturing services suppliers. ATD provides reliable and convenient solutions used to accelerate product development cycles, measure production efficiency and control manufacturing quality in a wide range of advanced technology products and processes.

3.1.2 Broadband Network Test Division

The Broadband Network Test Division offers state-of-the-art testing capabilities that support service provider's goals to sell and deploy more broadband services sooner and improve the efficiency of qualification, provisioning, and customer care for DSL and CATV high speed data networks. Products include: Celerity, 4-Tel II, 4 Tel, and Netflare.

3.1.3 Connection Systems Division

The Connections Systems Division provides total system solutions to industry leading OEMs, with high-performance circuits, high-speed, high-density connectors, multi-gigabit backplane assemblies and complete system integration and test services. Products and services include: GbX, VHDM, VHDM-HSD, VHDM L-Series, and NeXLev.

3.1.4 Semiconductor Test Division

Semiconductor Test meets the test needs of semiconductor companies and subcontractors worldwide, with the largest semiconductor ATE market share. This division delivers test solutions for a broad range of semiconductor devices, including the latest microprocessor, graphic chipsets, networking, wireless, and consumer devices, IMAGE processors, and low-cost, high-performance microcontrollers. For more information, visit the semiconductor test website.

3.1.5 Vehicle Diagnostic Solutions Division

The Vehicle Diagnostic Solutions Division provides diagnostic test and information solutions to the automotive and allied sectors. As the world's leading diagnostic solutions provider for the automotive industry, this division's products and services test the functionality of electrical components on a vehicle and are used in manufacturing facilities and service dealerships worldwide. The division plays a key role in the design, configuration, test and diagnosis of complex electromechanical systems in aerospace, agriculture, defense and mass transportation markets.

In essence, each of these five divisions provides testing solutions that are cater to its market segments. In 2003, Teradyne had sales of $ 1.4 billion, and currently employs about 6100 people worldwide. Teradyne's leadership technology and innovation has been widely recognized within the ATE industry, however, many of its customers are demanding products with lower price and higher performance.

Recognizing that the Overall Equipment Efficiency (OEE) has become one of the most critical aspects of capital equipment purchasing decision making in the ATE industry, Teradyne has declared the improvement of product Mean Time Between Failure (MTBF) and Mean Time To Repair as one of corporate initiatives to retain current customer base and attract new customers. Unfortunately, limited resources and funding force the company to evaluate every large scale reliability improvement project proposal and determine whether to sponsor the project or to reject it. Furthermore, these proposals are often evaluated from scratch without a standard process. Due to the lack of established process, a significant number of these evaluations are conducted in a hurried manner.

One of the challenges to making decisions on reliability project proposals is that Teradyne does not have a mechanism/tool to objectively evaluate reliability improvement project proposals. In other words, the company is lacking a tool that could aggregate information and generate synthesized data to help make the right decisions

The challenge of creating such tool lies is the dynamic aspects of the reliability improvement projects. Like most engineering projects, reliability improvement projects have variables such as internal workforce, productivity, product roadmap, skill sets, customer expectations, and many others that are in constant motion. Thus it is important that a tool be both comprehensive and flexible enough to capture these variable factors

4 CORPORATE PERSPECTIVE

4.1 Review of Reliability Improvement Process at Teradyne

The reliability process is an extension to the Revolutionizing Product Development (RPD) process used by all Divisions in Teradyne. The chart at the end of this document shows the Phase Gates of RPD and how the reliability activities are tie to those gates.

4.1.1 Summary

The project team must design its product with reliability as a primary concern, and then, verify that reliability has been achieved. Reliable design is achieved by learning from previous projects, then architecting and designing the system with reliability in mind. The guiding principle for verification is to force all potential failures to occur as early as possible through stress testing, so that the root causes are fixed before any system is shipped to a customer. The data gathered from these tests serve as a vital set of data points for constructing the tool for this project.

4.1.2 Stress to Kill

Individual high-risk components—e.g., components used in large numbers per system, using new technology or a new supplier, or in an application unique to Teradyne—are stressed to irreversible failure before prototype testing begins. This gives rapid estimates of their failure rate under normal conditions and understanding of their failure mechanism(s).

4.1.3 Step Stress Testing

A dedicated reliability prototype runs 24hours/day 7days/week, under normal and limit conditions, then beyond limits to cause 'soft' failure (a failure that disappears when conditions return to normal) before any system is shipped to a customer. This exposes design issues—such as power, cooling and timing limits—and marginal components.

The team tracks all failures that occur to root cause and fixes them using a Failure Reporting and Corrective Action System (FRACAS). Any potential exception must immediately be reported to management (project, Division, or higher) for resolution. Once the product ships, there is a similar emphasis on reliability, with all delivered product undergoing stress testing and all field and factory failures tracked to root cause and fixed.

Each Division or each project has a reliability engineer responsible for ensuring that the projects create and carry out these plans.

4.1.4 Reliability Steps

Reliability is designed into a product and verified with the following sequential steps:

a) Learn from previous projects by eliminating failing components, improving process, etc.

b) Architect the system for reliability

c) Follow design rules that will force a reliable design

d) Identify and verify the reliability of the high-risk components in the new design before the prototype work starts, thus allowing the prototype phase to concentrate on the unpredicted failures

e) Dedicate a prototype to reliability testing, tracking and fixing all failures that occur, and thus moving up the reliability ramp before FCS

f) Track and follow up on all field failures after FCS

The team performs these steps and monitors reliability throughout the project, with status and latest reliability estimates reviewed at the end of each phase of the project.

4.2 Phase I - Concept Development

The Project Manager and Marketing Product Manager set the reliability target in terms of Mean Time Between Failures (MTBF) based on market requirement or strategy.

The core team describes its approach to reliability in the Project Execution Strategy Matrix (PESM) for the new project.

They use project assessments from previous projects as input to the design, e.g., a decision not to use components that proved unreliable on previous products. The architecture of the product must also support the MTBF target, e.g., in its use of redundancy, the number of boards and components in a system.

The Reliability Manager, working with the core team, will:

a) Identify the critical reliability components for the product, as known at this stage, and how they will handle them

b) Confirm the Design Rules that the project will use

c) Indicate how reliability will be required from each vendor, e.g., by inclusion of a qualification program in the contract

d) Set the initial MTBF budget for each board or subsystem

4.3 Phase II - Product Planning

The Core team and Reliability Manager complete the reliability planning for the rest of the product implementation, defining deliverables for each of the subsequent reviews of the project. The plans include a listing of resource requirements: equipment, personnel, prototype hardware, and subcontract costs for accelerated component and subsystem tests. The plans cover:

a) Reliability prediction

b) Setting of reliability budgets and collection of reliability data

c) How the project will avoid or mitigate reliability problems from previous projects

d) Early identification and resolution of critical items

e) Verification of reliability during the prototype phase

f) Performance verification (or system characterization)

g) The use of board teams that take responsibility for each board's reliability

h) Reliability Prediction

The MTBF of the complete product depends on the failure rate of each item that it contains within the system. Before any prototype is built, the reliability engineer tracks the predicted MTBF continuously based on the current, probably partial, 'Bill of Materials' and current failure rate predicted for each item (from standard tables, field data on similar components, etc.).

The prediction is only as accurate as the failure rates for the individual items, but it does direct the project's attention to the critical items that can affect the MTBF drastically, e.g., a potentially unreliable component used in large numbers.

Once the reliability prototype is available, the reliability engineer supplements the prediction with actual data from the hardware. Typically, the actual MTBF remains below the predicted until the unexpected and design errors are solved.

4.3.1 Subsystem Reliability Budget

The reliability engineer defines an MTBF budget for each subsystem to support the overall system goal, based on the anticipated system architecture and the reliability predictor. These budgets are given to the design engineers along with other design requirements, and reviewed at each major milestone.

4.3.2 Project assessment

The core team lists how it will avoid problems that affected previous products, e.g., by designing out unreliable components or by qualifying specific parts fully. They update the PESM to reflect their approach to reliability.

4.3.3 Critical Items

The reliability engineer identifies the top 5 to 10 critical risk components—based on the reliability predictor, experience from previous products and potentially risky use of new technology—and ensures that there are action plans for each. These components might be a relay or a custom analog ASIC part, a part that is used in large numbers per system, or a new kind of connector. The action plan includes 5-element tables for each item, and covers:

a) Stress to kill under controlled conditions, with appropriate design of experiment and failure analysis

b) Involvement of Supply Line Management group to work with the vendor on their qualification process and failure information

c) Regularly scheduled contact with the vendor

d) Tracking of failure rates and failure analysis of the part if previously used in other Teradyne designs

e) A contingency plan and the criteria that would launch it should the chosen component fail reliability qualification

f) The actions called for in the plans should be completed before the prototype stage of the project.

4.3.4 Prototype Verification

An essential requirement is to force the ramp of reliability to occur before First Customer Shipment. The Reliability Engineer sets up a dedicated prototype simulating customer usage 24-hours/day seven days/week to run for about three months for a platform or major derivative product before first customer ship. The system put into to a normal operating condition, of temperature voltage etc. The system will also be operated at the design limits, and finally beyond these limits until soft failures occur. This 'Step Stress Testing: SST' uncovers weak components and design practices that do not allow for manufacturing variability. It also sets the limits for the 'Environmental Stress Screen: ESS' process used by Manufacturing.

The board teams log *all* failures on *all* systems—on the reliability prototype, engineering development prototypes and foundry board and system tests—tracks them to root cause, and fixes them.

The failures at this stage are particularly significant since—statistically—early failure often means frequent failure. This activity also finds the gaps in diagnostic coverage and tracks down intermittent failures. It is important to point out that data these failure data is extremely valuable for the overall analysis of product reliability and the information should be applied to the reliability tool(s) as much as possible. Essentially, more historical data will help validate future reliability requirements as well as help build more credible reliability predictions.

4.3.5 Performance Verification (or System Characterization)

Performance Verification confirms that the product works reliably throughout its operating ranges—including supply voltages, temperature, clock skew and perhaps vibration—and that calibration and checkers have suitable guardbands against the spec. Design Engineering tests the product at and beyond these ranges, tracking to root cause and fixing the failures.

4.3.6 Board Teams

Board Teams are cross-functional teams that are responsible for the detailed planning and execution of the board (or appropriate sub-system) test plan. Each board team is the owner of one board/sub-system. From a reliability viewpoint, their job is to:

a) Capture *all* problems in a fault tracking system
b) Prioritize problems and trace them to root cause
c) Create containment and permanent corrective action plans for all prioritized problems
d) Verify all corrective actions
e) Monitor yield, cycle time, and MTBF data
f) Provide failure reports and status to the entire project group
g) These teams capture the results of their work as changes to design rules and in the project assessment.

All the above plans are presented at the Commitment Phase review and the activities completed through the rest of the implementation of the project, as described in the following sections.

4.3.7 Design

Design reviews occur throughout the Design stage that include considerations of reliability, e.g., target junction temperatures, component derating, timing margins, test coverage as described in the design rules. Just as when it fails to meet functionality criteria, a design will fail the review if it fails to meet the reliability criteria. A deliverable at each review is confirmation that all subsystem designs meet their reliability budgets and have passed all design reviews. Items checked at the reviews include:

a) Subsystem MTBFs, compared to budget

b) Test coverage/scan/BIST

c) Identifying and mitigating critical reliability risks

d) Component derating

e) Worst-case timing margins

f) Cooling and power margins

g) Minimizing thermal and mechanical stresses

h) Designing out known unreliable parts and vendors

i) Maximizing noise margins

j) Layout best practices: minimizing crosstalk, noise, and voltage drop

k) Adherence to DFM, DFT guidelines

In parallel, the Reliability Engineer implements the action plans for the critical risk components. All issues must be resolved by the time the first prototype is staged. The resolution may be either a demonstration that the part is reliable, or various corrective actions:

a) Design out the part

b) Change its conditions of use

c) Changes made by the vendor

d) A temporary screen to remove suspect components (at the vendor and/or Teradyne)

e) First Prototype Staged

If all critical components are resolved, prototype testing can concentrate on unexpected failure sources uncovered by its system level testing. Development engineers run prototypes to check their designs; the Reliability Engineer runs an early prototype dedicated to reliability verification to uncover early failures that otherwise would be found at the customer site. All use FRACAS (Failure Reporting Analysis Corrective Action System) for all failures they encounter.

The reliability prototype simulates continuous customer usage—running test programs, docking and undocking, etc.—and is run under SST conditions.

4.4 Phase III—Detailed Design and Development

The review covers all reliability items to ensure that the project is still on track to deliver a reliable product:

a) All issues resulting from the critical item list and reliability prototype, including closure plans for the open items

b) Performance verification

c) Reliability budgets and predictor values

4.5 Phase IV - Product Test, Product Verification, Product Validation

Before the Division can ship the first system, all reliability issues must be resolved at the review. Ideally all components on the critical list are fixed, the reliability predictor and prototype experience shows that the target reliability is achieved, and performance verification shows that the system will work under all specified environmental and margin conditions. For any proposed exceptions, the project must detail mitigation and closure plans (e.g., screens for components while the vendor implements the root cause fix, temporary waivers), state the impact on MTBF, and estimate any retrofit costs. Management thus has the data needed to decide whether to accept any or all of the limitations or hold shipment.

4.6 Phase V—Product Ramp/Product Release

The Operations group performs 'Environmental Stress Screening: ESS' on all products shipped: they stress each manufactured system beyond its environmental limits to create potential soft failures (the limits are determined by the SST activity on the reliability prototype). Reliability data is collected from this activity, from other testing in the factory, and from user sites. Engineering forms QITs for all high bars on the Failure Pareto charts, reporting to the Division on a regular basis for:

a) Root Cause

b) Root Cause fix

c) Component Screen (how do we ensure no more weak components are shipped from the vendor while waiting for the root cause fix)

d) System Screen (how do we identify weak components already assembled into systems and subsystems)

e) Field retrofit plan (what do we do about problems in systems already shipped)

Table 1- Glossary

Failures in Time	FIT	The failure rate for a component as number per billion hours.
Soft failure		A failure that occurs when an item is subjected to abnormal environmental conditions, and that disappears when the environment is corrected.
Accelerated Life Testing (Stress to kill)	ALT	Stressing a component to early failure by subjecting it to abnormal environmental conditions—of temperature, voltage, vibration, humidity, etc.—to estimate its failure rate under normal conditions, and to determine its failure mechanisms. Destructive testing.
Step Stress Testing	SST	Testing a prototype system or subsystem at various values of its environmental parameters to identify marginal components and determine how robust the design is. Non-destructive testing. SST establishes the margins at which the system can operate reliably—the design margins—and the margins at which soft failures may occur. These margins will be used for subsequent ESS (see below) during manufacturing.
Environmental Stress Screening	ESS	During manufacturing, the testing of a subsystem or system at and beyond its environmental limits to provoke potential soft failures.

Figure 1 – Example of Divisional Report on Field Failures

A capacitor within in the chip was failing after several months of operation.

Assumed root cause. Later proved to be incorrect

All new parts from the vendor are screened for potential failures.

Allows us to detect which parts already assembled on boards are likely to fail.

What we intend to do about replacing parts in existing systems.

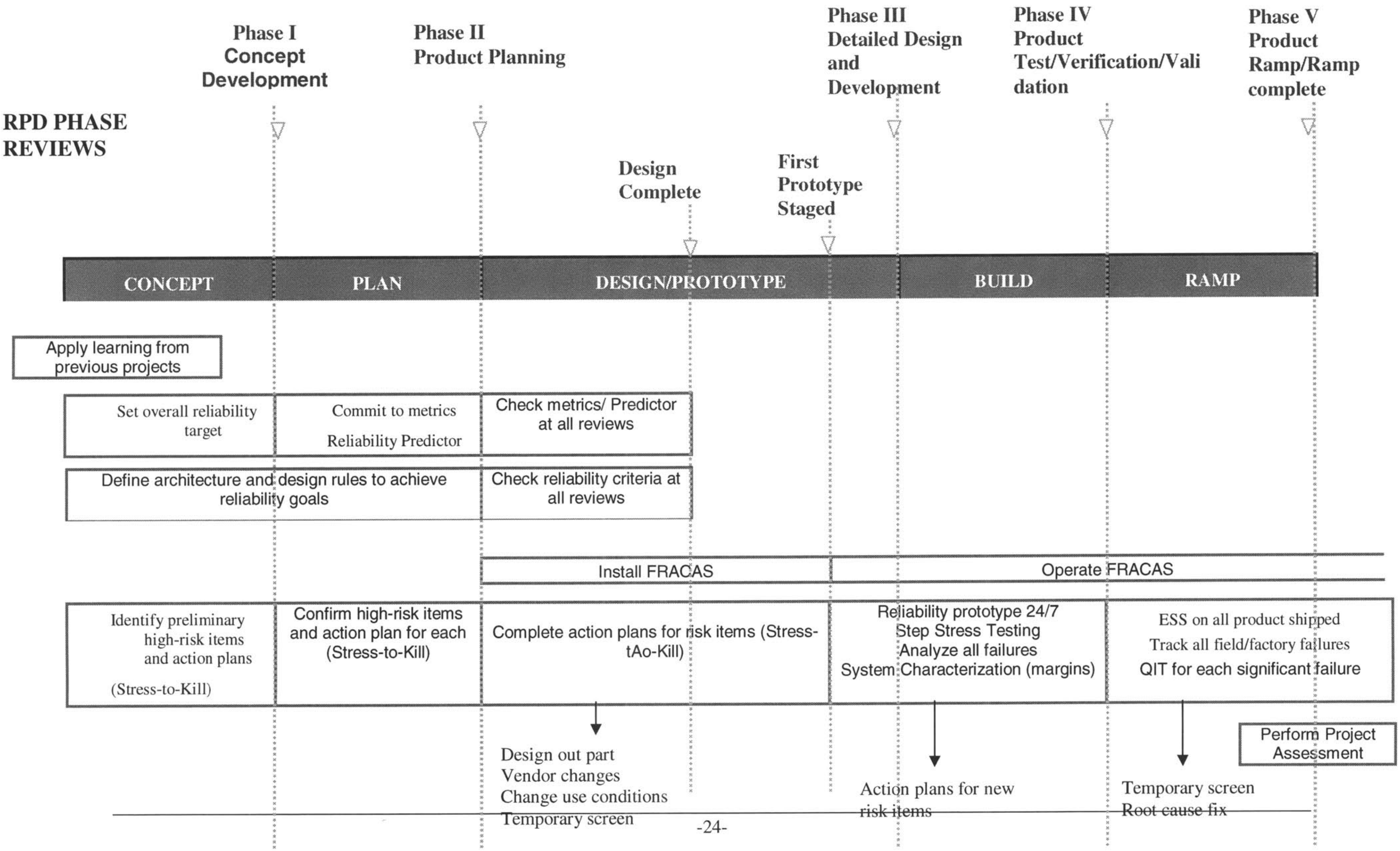
RPD PHASE REVIEWS

Root Cause	Root Cause Fix	New Component Screen	Field Screen	Field Retrofit Plan
MOMCAP breakdown.	Change bottom plate from Ti to TiW, for smoother oxide interface to increase breakdown voltage.	Screen for output resistance, Vs-to-ground impedance, and "normal" (11.2 v) voltage stress.	Measure Vs-to-ground resistance on board. Good is > 20 kohm. Use temperature measurement to help isolate to particular driver.	All boards in-house have been screened. Process in place to continue screening. Screen all boards at customer sites.

Notes and action items

1. Process change notice has been issued by ADI to change to TiW.
2. ADI will screen and ship all old-process wafers and packaged parts that they have in stock.
3. TiW qualification results due 1/99.
4. On PCBs, the screen has found 142 functional drivers with bad MOMCAPs. This is a rate of 3300 ppm. So far, nineteen systems at system-test and six systems in the field have been screened.
5. We have 62 boards in-house with the screened parts and will be tracking them. So far there have been 3 MOMCAP popouts: 2 at ICT and 1 at NPL. None were functional failures. This is a rate of 750 ppm.

Figure 2 – FRED Project Milestones



4.7 Warranty Impact

Most of the gross product margins have buried in it some amount of money that is reserved to ensure that the product manufacturer and the sellers have some capital available in the future to cover the costs of potential warranty claims made by their customers. Consequently, the higher the sales the higher the reserved warranty amount will be. Perhaps more importantly, the lower the reliability of the product, the greater the amount of revenue that must to be set aside to execute against warranty claims without eroding expected profits from product sales.

One way of looking at the contingency for the warranty claims figure is that this is the expected reduction in profit due to reliability escapes in the design and manufacturing process.

If the design calls for more nuts and bolts than needed, the cost of goods to manufacture the product will be higher. Cost-reduction efforts should be initiated to remove the unneeded fasteners to save some money on the cost of materials. After the unneeded screws have been removed, the cost of goods to manufacture the product will decrease and the profit will increase. The manufacturer then has the option of receiving a slight increase in profit or reducing the product cost with the opportunity of greater market share. Of course, having such options help ensure the company's future.

Companies with little or no reliability as part of the new product development product can have warranty expenses that reach 10 to 12 % of the annual sales dollar. Companies that have some reliability imparted during the development process can lower this figure to 6 to 8%. Only those companies that have implemented a cross-functional reliability process in their new product development process ever get this below 1%.

For companies with ten million dollars in annual sales and poor reliability, in essence, a million dollars is being handed over to the cost of doing business. To recoup the million dollars, how many salesmen would have to be hired to return this figure to the bottom line? How hard will the purchasing department have to negotiate to keep the cost of the products competitive? How many manufacturing people will have to be eliminated to maintain profitability? If this revenue was available for staffing more designers for product development, it would reduce time to market and increase the profit.

Every time you send a service person to your customer with replacement parts you are paying for poor reliability. All those extra parts in the stockroom that are there to support field service are really dollars set aside as a contingency for warranty claims, and poor reliability. All those materials parked in the stockroom are costing you money that can otherwise be actively making money, finding more customers, and hiring more employees.

Reliable products can help you prevent lost warranty dollars. To reverse this loss, the reliability of your products must be improved. And every improvement returns a portion of these lost warranty dollars. Not one, not two, but many reliability improvements will accumulate to return a significant portion of the lost sales dollar for better use.

4.8 Global Customer Service at Teradyne

4.8.1 GCS - Global Customer Services

GCS is a division of Teradyne for ATE system parts support, semiconductor test system maintenance engineering support and other customer support services. GCS has over 450 people in the division, supporting Teradyne's installed base from 32 support locations and 7 part repair facilities in 15 countries.

Teradyne GCS operates under the following vision:

Global – WHERE - Teradyne GCS serves a customer base with a worldwide perspective.

Customer – WHO – Teradyne GCS is focused on customer satisfaction throughout the lifecycle of the product.

Services – HOW – Teradyne GCS delivers value to customers. GCS provides the services which meet and, often exceed, the needs of our customers.

4.8.2 Organization of GCS

GCS has 2 major service units - Part Services (PS) and General Field Service (GFS). These units are supported by GCS's Customer Support Network (CSN), Information Services, Marketing, and Finance organizations.

4.8.3 GCS offering

GCS offers a spectrum of services to support Teradyne customers. GCS' approach is to match its services with the maintenance service goals of Teradyne customers, from total outsourcing of parts and labor services to a transactional parts and labor relationship. The blend of services selected can be further customized based on the customer's internal resources and desire to manage support for the test floor.

4.8.4 GCS Service Coverage Area

GCS provides service from 32 support locations around the world. Most service originates at one of Teradyne's support centers strategically located in the high-technology centers of Asia, Europe, and the US. The GCS group also has individual maintenance engineers and maintenance teams close to customers or on-site at individual customers. This is part of Teradyne GCS' overall approach - to focus on providing the level of support that meets the customer's requirements.

4.8.5 Customer Rating

Teradyne was rated #1 in Service after Sales and overall #1 among broad line ATE suppliers in the VLSI Research 1997 "10 BEST" Customer Satisfaction survey for suppliers of test and material handling equipment. Other broad line ATE suppliers who made the 10 BEST list (in order after Teradyne) were HP, Advantest, Schlumberger, LTX, and Ando. Teradyne was also rated #1 for Technical Leadership, Software Support, and Quality of Results.

Founded in 1976, VLSI Research, Inc. is considered the leading research authority for trends and issues concerning semiconductor capital equipment. Teradyne has been ranked in the "10 BEST" every year since the survey began in 1988. Cleary, Teradyne has been offering products that have been well received over the years. The idea is not to debate the success of Teradyne's products in the market place, but rather, discuss how to optimize the resources and improve the reliability of the products further differentiate Teradyne's products from its competition's; thus delivering higher customer satisfaction.

4.9 Parts Services

4.9.1 Types of Parts Services Offered

The GCS Parts organization provides advanced board replacement, board repair, calibration, and part sales for all Teradyne ATE systems - semiconductor and assembly. The organization has board repair centers in 7 locations around the world - Boston, Agoura Hills, San Jose, Boise, Cebu (Philippines), Costa Rica and Kumamoto (Japan). There are 11 parts stocking centers located in Seoul (Korea), Cebu, Hsinchu (Taiwan), Singapore, Amsterdam, Tokyo, Wuxi (China), Agoura Hills, San Jose, Boise, and Boston.

4.9.2 Part Inventory Management

The GCS inventory centers in Asia, Europe, Japan, and the United States are actively managed to ensure that the right part is available when the customer calls. A team of people plan the inventory levels around the world, managing the level of inventory in each of the regional stocking centers, and updating parts when Engineering Change Orders dictate that the entire inventory in the repair loop be revised. GCS manages over 30,000 part numbers and use standardized planning tools and statistical modeling techniques to create stocking strategies that consider data like historical usage, a region's current installed base, and new systems being shipped into an area.

4.9.3 Customer Order Process

Teradyne customers can call their local GCS Customer Service Center to order parts through standard advanced replacement or repair services. Customers should also call the local center to obtain quotes for repairs and for purchase of non-repairable spare parts. Non-repairable spare parts include items such as pogo pins, fuses, filters, etc. GCS also sells spare and replacement boards for all out-of-production test systems.

4.10 Spares

4.10.1 Types of Spares Parts Offered

GCS can provide a recommended kit of parts to meet a desired fault coverage level for the customer. We offer two spare part services:

Table 2: Spares Program Description

Service	*Description*
SparesLease	A customized program for on-site spare parts with Teradyne owning the inventory. SparesLease provides fast, dependable on-site replacement parts availabililty.
Purchased Spares	Spare parts kits custom-configured to desired coverage levels are available for purchase. For those desiring capital investment.

4.11 Field Services

4.11.1 Types of Field Services Offered

Teradyne Field Service organization provides engineers to support and maintain the installed base of semiconductor test systems. GCS engineers will back up a customer's maintenance staff with telephone troubleshooting support, come on-site for system installations or for system repair, and provide preventive maintenance to help reduce unscheduled downtime and increase system uptime. GCS labor service is available on a per-call basis or as part of on-going coverage under a service agreement. Maintenance engineering services offered include:

Table 3: Field Service Programs

Service	*Description*
On-Site System Repair	Teradyne service engineers come on-site to repair a system.
Telephone Assistance	Service engineers provide telephone back-up assistance in troubleshooting a system with customer maintenance engineers.
Installation Services	Teradyne performs initial system installation and can install future options or upgrades.
Training	Standard and custom training can be provided at a Teradyne service center or on-site.
Preventive Maintenance	Periodic maintenance service provides cleaning and pro-active troubleshooting.
Performance Verification / Calibration	We will verify system performance to the device-under-test.
System Moves	We can de-install, package, and re-install systems that are being moved within your site or between sites, and also plan and supervise the entire move process.

4.11.2 Types of service agreements offered

In April 2002 Teradyne announced new suite of High Performance Engineering and Operational Services Packages for our semiconductor test customers. These packages bring the right expertise directly to Teradyne customers 24 hours a day, 7 days a week through a variety of options - over the web, via the telephone, through Internet connectivity, and on-site. The High-Performance Packages prepare customers for increased levels of business by providing more flexible access to expertise, more rapid response, faster application and hardware solutions and improved uptime - all offered with superior price performance. Refer to our homepage for more information on these next generation support services:

4.12 Warranty Policy at Teradyne

The following Policy Statement is a copy of the Warranty Policy Outline from the Global Customer Service Group at Teradyne:

a) Teradyne warrants for one year that new integrated test systems manufactured by Teradyne will be free of defects in workmanship and materials and will substantially conform to product specifications. Teradyne does not warrant that the operation of Products will be uninterrupted or error free.

b) The warranty period begins on the date of installation. Installation of the Product occurs upon successful completion of Teradyne's installation procedures that demonstrate that the Product is able to do useful work. If Customer schedules or delays installation by more than 30 days after tender, the warranty period begins on the 31st day after tender.

c) During the warranty period, Teradyne, at no charge to Customer, will service, adjust, or replace any non-conforming part(s) returned under this warranty.

d) For integrated test systems installed by Teradyne, on-site repair, limited to servicing, adjusting, or replacing part(s), will be performed for a period of 1 year after commencement of the warranty at no additional cost to Customer.

e) Teradyne warrants for 90 days that applications interfaces will substantially conform to the product specifications. Teradyne's options and sub-systems will be covered by the remaining original warranty as the system to which they are attached or for 90 days after tender, whichever is longer.

f) This warranty applies only to normal use of the Product and shall be void if Teradyne determines that defects or non-conformities of the Product were caused by the Customer's negligence, misuse, or accident; or by unauthorized repair, alteration or installation of the Product. This warranty does not extend to consumable items such as filters or fuses, nor to mechanical parts of the Product failing from normal wear and tear. Customer's sole remedy and Teradyne's exclusive liability for claims against Teradyne shall be the repair or replacement of the defective or non-conforming Product and parts, or, if repair or replacement cannot be accomplished, Teradyne will refund to Customer amounts paid for the Product, depreciated over a 3 year period.

g) Teradyne's warranty with respect to software is set forth in Teradyne's Software License Agreement.

h) Some newly manufactured Teradyne products may contain remanufactured parts that are equivalent-to-new in performance.

i) The above warranties are exclusive and no other warranty, whether written or oral, is expressed or implied. Teradyne Specifically disclaims the implied warranties of merchantability, fitness for a particular purpose and non-infringement.

5 RELIABILITY IMPROVEMENT PROJECT – LIQUID COOLING MODULE REDESIGN

5.1 Background

This project was initially started as an effort to improve the overall reliability of the Tiger Test Head cooling system. Tiger is a highest performance test system offered by Teradyne that was design to compete and capture the market share in the high-end, mix-signal, SOC *(System-On-Chip)* market. Tiger liquid cooling assembly or LCA, which houses 176 liquid cooling modules, is designed to keep the instrument boards in the Teradyne Tiger Test Systems at certain temperature. The key temperature indicator is measured from a critical ASIC called Falcon on one of the main instruments in Tiger systems. However, due to the design of the liquid cooling modules, the cooling water was not adequately cooling certain portions of the instrument in the Tiger Test Head which led to higher than expected failure rates for several boards. The temperature profile image (Figure 7) illustrates the uneven and inadequate cooling generated by the current Liquid Cooling Module or LCM. The higher failure rate resulted in lower than desired MTBF for the Tiger product and the lower reliability has led to significant customer dissatisfaction.

Although reliability improvement is the main driver that launched the project assessment activities, factors such as the time it takes to repair a failed component and the realization that considerable cost could be taken out of the current design became as important, or more, in significance as reliability.

This project concept will yield a product that is easier to service, that is more cost effective, and is expected to have an increase in overall reliability.

Figure 3 - Project Execution Strategy Matrix: Liquid Cooling Module Redesign

PROJECT DEFINITION	PROJECT'S KEY OBJECTIVES IN PRIORITY SEQUENCE: REDESIGN OF TIGER'S LIQUID COOLING ASSEMBLY (LCA) TO INCREASE SUB-SYSTEM RELIABILITY BY AN ORDER OF MAGNITUDE FROM CURRENT FAILURE RATE OF 0.15 FAILURES/SYSTEMS/QUARTER. REDESIGN SUB-SYSTEMS: LIQUID COOLING MODULES (LCM), DISTRIBUTION MANIFOLD, DELAFIELD PLATE, AND TEST HEAD MECHANICAL STRUCTURE TO SUPPORT NEW LCA. PROJECT'S PRIORITIES: 1. LCA RELIABILITY TARGET: 0.015 F/S/Q 2. SCHEDULE TARGET: PHASE 4 IN JUNE.05 3. SERVICEABILITY TARGET: MTTR: 2 HRS. 4. COST TARGET: REDUCTION OF $6.5K PER TEST HEAD PROJECT'S CONSTRAINTS 5 MONTH DURATION TO COMPLETE PHASE 4 DESIGN VERIFICATION (PROVING LONG TERM RELIABILITY) * FAILURES/SYSTEM/QUARTER
Project Governance and Staffing	Project Team Structure: Program Management – S. Anthony Engineering Management – W. Rappole Product Management – Paul Devine

	PTF – Cross-functional membership incl. OPS
The structure of project tasks and activities	Projects will follow the RPD Phase Gate process The Program Mgr. will maintain the master schedule The Program Mgr and Engineering Mgr. will actively manage risks The project will rely on Reliability Analysis and testing to prove achievement of Reliability target.
Design/Prototype/ Test	Reviewed and executed design verification plans. Full Reliability and testing will be performed during Phase 4 DVT. Full Manufacturing and Serviceability process verification.
Senior Management Review and Control	Sr. Mgt approval of each project Phase (2, 3, and 4) Any deviation to the project objectives requires review from key stakeholders and Sr. Management before changes to objectives are implemented. Sr. Management ensures correct focus for meeting divisional and business unit priorities.
Real-Time Mid-Course Correction	Reviewed and executed design verification plans. Full Reliability and testing will be performed during Phase 4 DVT. Full Manufacturing and Serviceability process verification.

5.2 Summary of Reliability Project Proposal

The Liquid Cooling Assembly redesign project aims to create an entirely new, lower cost, more reliable LCA within the existing Tiger Test Head. It attaches to the existing mounting locations on the structure of the test head and uses the same instruments with the same the Heat Spreader Plates (cold plates). It takes the same flow of 15 gallons per minute with the same inlets and outlet tubs from the same Cooling Distribution Unit.

The effort includes:

a) The basic framework of the Cooling Distribution Unit and hoses up to the Test Head must remain basically the same, but all the parts between the ends of the Cooling Distribution Unit inlet and outlet hoses are candidates for redesign

b) Back-plate assembly (Delafield plate – Plate vendor)

c) Manifolds

d) LCMs

e) Reexamining the way the cooling water is presented to the heat spreader plates

f) The redesign could have a major impact on some of the other systems within the Test Head including the vacuum and the water sensing systems.

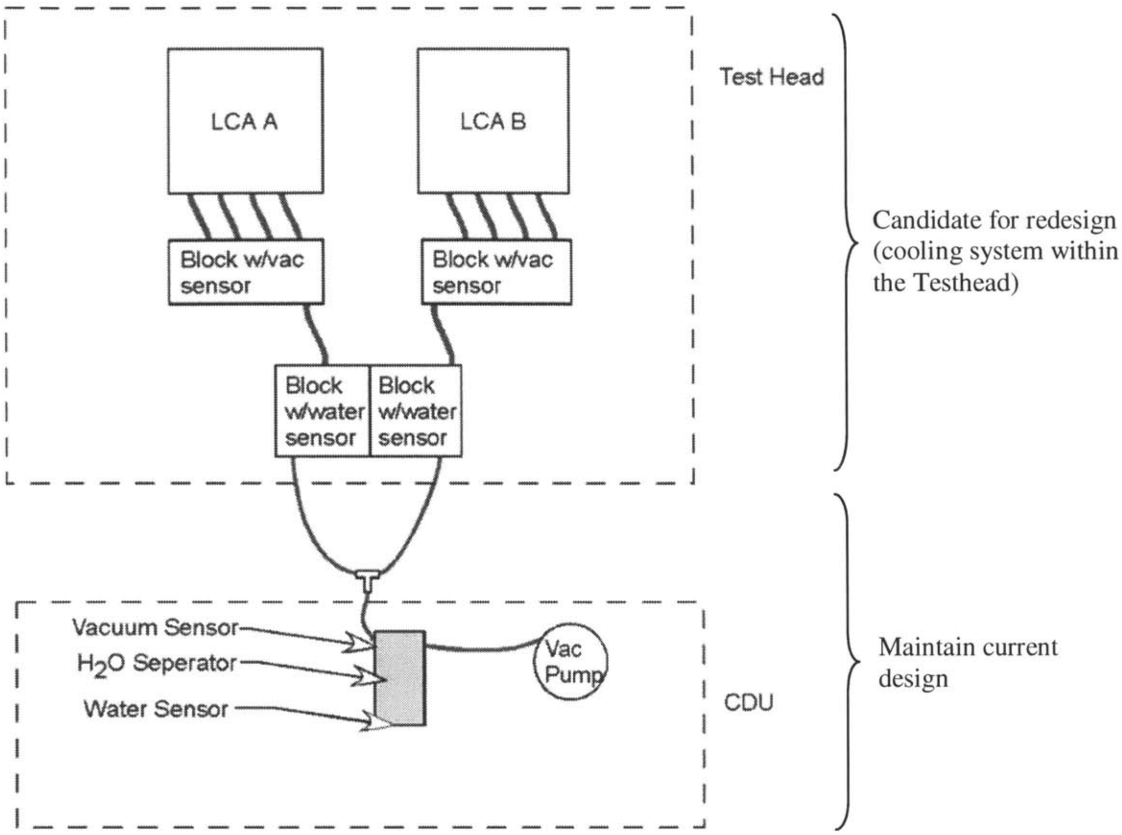


Figure 4 – Tiger Test Head Diagram

The secondary objective of this effort is to reduce the cost of the cooling solution for the Tiger Testhead. Many of the parts included in the current design account for a disproportionately high material cost of the Tiger. Any and all changes made by this project must be critically evaluated for cost.

5.2.1 Summary of Key Objectives:

a) Improve the reliability of the cooling system:

b) Reduce LCA usage from .070 failures/system/quarter to .015 failures/systems/quarter

c) Reduce Mean Time To Repair

d) Field Replacement Unit (FRU) replacement time is reduced significantly from 7 hours to 1 hour

e) New LCM module vs. entire LCA

f) Reduce overall Test Head cost by $8.5K

As a result of the multiple reliability issues attributed to the Tiger Cooling System, a Design Assessment and Concept meeting was held in 4Q of 2004.

The purpose of this meeting was to look at the cooling system in general, and to define what solutions there might be and how to implement them. The participants settled on the following courses of action

a) First, a set of short-term "tweaks" were defined that would potentially improve the overall reliability quickly, <4-6 months. These tweaks and their results are not discussed here.

b) Second, design a long term solution (< 9-15 months) that would get at the root cause of many of the failure modes seen in the current cooling system by doing a redesign of the entire system.

A number of high-level concepts for the redesigned LCA were considered at the Design Assessment meeting. Both the "Bladder" design and the "H2O Cold Plate" design were solutions that satisfy the requirement of high reliability improvement. At the design assessment meeting, the bladder design was selected due to the reduced impact on other product development efforts, time to market and retrofit liability.

The results of the Design Assessment meeting are summarized here:

Concept Desirability			
Short Term Tweak	Higher Confidence Tweak	Bladder	Water Cold Plates
23.0 %	14.5%	28.7%	33.7%

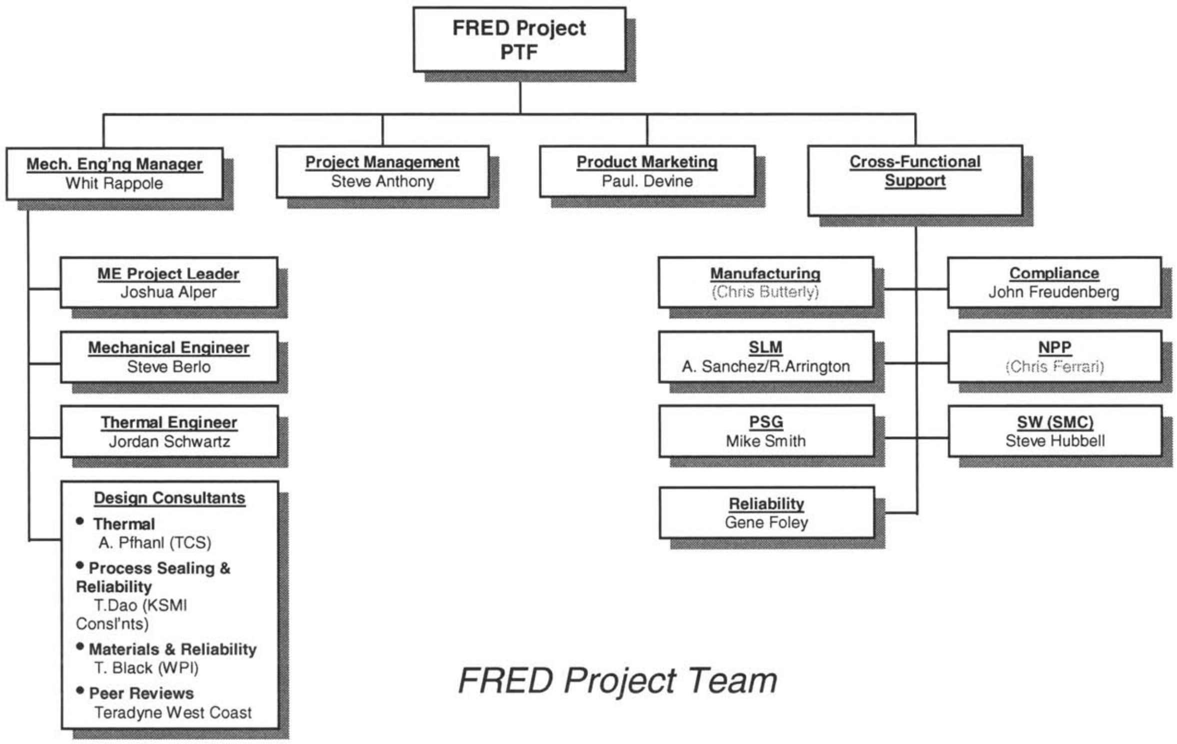
	ST Tweak	Bladder	H20 Cold Plate
Effort [man-months]	60	110	110
Schedule [mths to Ph IV]	6	12-15	12-21
Impact to Jag/Flex	low	moderate	High
Reliability Improve.	mod	high	high
Manuf Improvement	low	mod-high	mod-high
Invention	low	High	moderate
Reliability Risk	high	moderate	low
Retrofit liability	$2.5M	$2.5M	$12M

Figure 5 – Results of Cooling Design Assessment

5.3 Project Team

The FRED team consists of 8 main project members. The team includes a mechanical engineering lead, a project manager, a product manager, and various support members.

Figure 6 – FRED Project Team Organizational Chart



5.4 Liquid Cooling Module Redesign: Bladder Design

This project proposes the new "bladder" design. A new concept has been developed to implement this "bladder" design with the primary goal of improving the reliability of the Tiger cooling system. Its scope is limited to the redesign of the LCAs, which may include:

a) Re-examining the way the cooling water is presented to the heat spreader plates, via flow patterns within a single bladder

b) Reexamining the flow patterns within the bladders as they contact the HSPs, addressing the stagnation points and hot spots in the flow path that have been shown to lead to the release of gas from the cooling fluid and the collection of this gas in turn leaking to component overheating.

c) Addressing the film to frame seal integrity issues with the current design

d) Re-examining the way the cooling water is taken from the CDU outlet hose and delivered to the LCMs, addressing leakage past the o-rings in the current design

e) Reexamining the leak sensing and leak containment systems, addressing the frequency with which the system is shut down due to leakage.

The project is limited to the Test Head and will not be making changes in the Cooling Distribution Unit. The Cooling Distribution Unit and hoses up to the Test Head must remain basically the same, as well as the volume and temperature of the water flow. Major changes to the Test Head structure are also not acceptable, nor are any other changes that will unduly extend the upgrade time.

In addition, this solution needs to be a high reliability solution that can be implemented in systems in the field. It needs to be a solution that is installable in a reasonable amount of time so that it can be introduced into the field as a reactive PUP; given to customers at the time of LCA failure instead of replacing it with another old LCA as is currently the procedure.

5.5 Thermal and Fluid Flow Benefits of the Proposed Design

Figure 7 - Thermal Image of Current Liquid Cooling Module

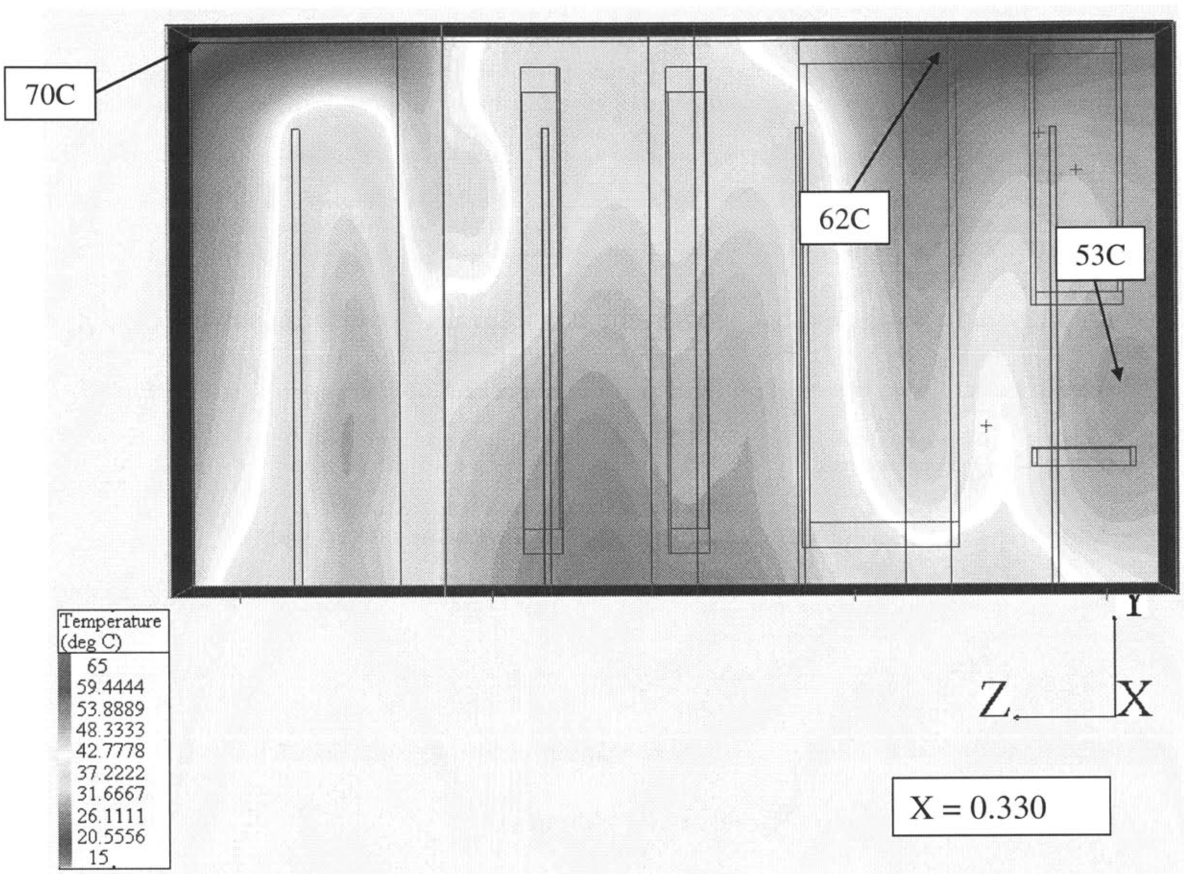
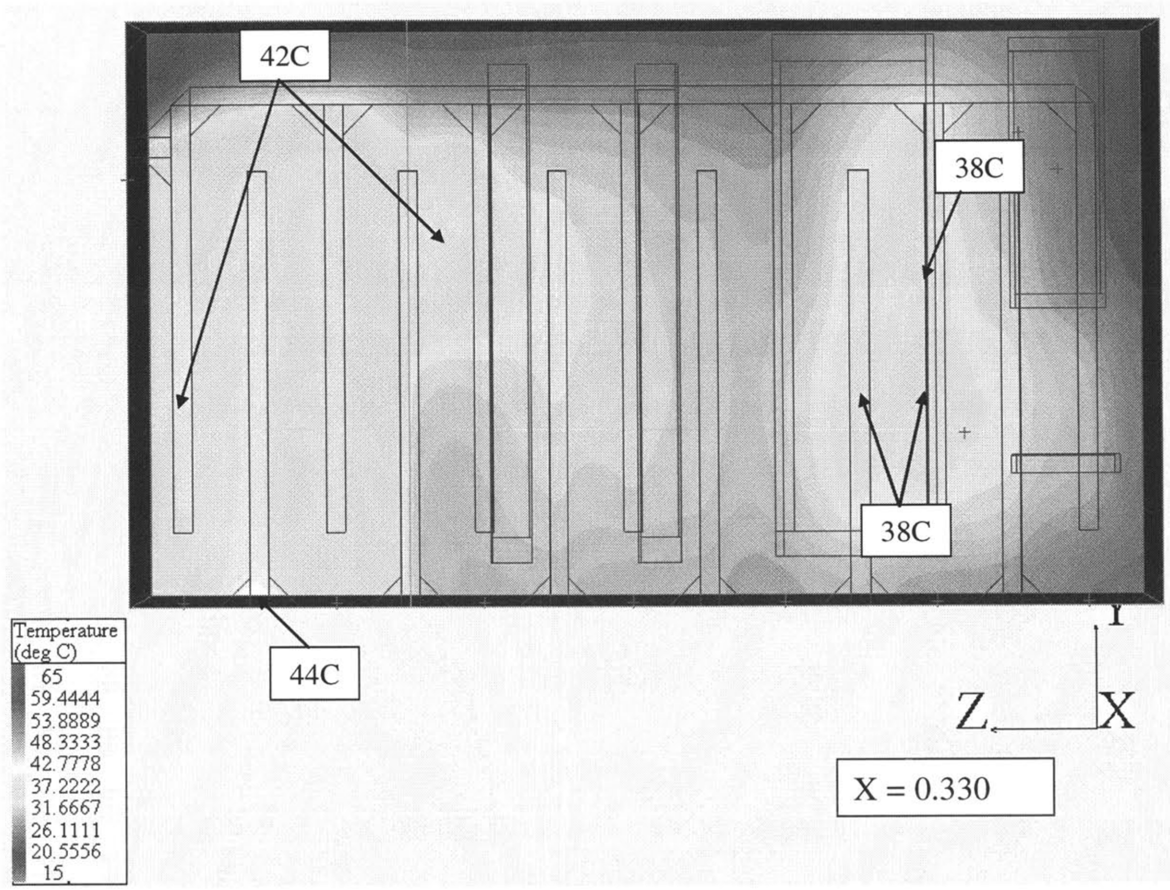


Figure 8 – Cooling Profile for Proposed Redesigned Liquid Cooling Module



a) The serpentine design provides a reduction in maximum temperatures in the heat spreader plates of 21-27 deg. C below the current LCM design

b) The serpentine design provides a reduction in maximum temperatures in the coolant of up to 38 deg. C below the current LCM design

c) The serpentine design significantly reduces the size of stagnant and low fluid velocity regions in the cooling bladder, resulting in more uniform flow and an apparent higher mode flow rate

d) Increasing film thickness from 0.005 in to 0.010 in results in only a 2-3 deg. C increase in temperature at local hot spots (.005 is current design film thickness)

e) The serpentine design provides a greater reduction in local temperatures than does increasing flow rate by 2X on the current design

5.6 Project Detail

The LCM redesign project creates an entirely new Liquid Cooling Module (plastic bags) targeting higher reliable within the existing Tiger Test Head. It is meant to be a drop in replacement of the existing "bags" in the Tiger cooling assembly. The proposed solution will use the technology and material selection executed as part of the original Fully Redesigned LCM or FRED. FRED design and focus on a replacement solution that will improve reliability and serve as an alternative to the existing product. It takes the same flow of 15 gallons/minute with the same inlets and outlet tubs from the same manifold. The new LCM addresses four project objectives defined for FRED:

Table 4 – Current LCA VS. Proposed LCA

	Current LCA	*LCA Redesign FRED (Proposed)*
Subsystem Reliability	**Current: 0.15 f/s/q** Non-standard Film-Frame Sealing Process Thinner Films 60°C Material Limit	**Target: 0.015 f/s/q** Standard RF Film-Film Sealing Process Thicker Films 93°C Material Limit
MTTR & FRU Cost	**8 hrs repair time** **$5,400 FRU** 180 lb FRU weight	**2 hrs repair time** **$400 FRU** 5 lb FRU weight (estimate)
Thermal Performance	**Max Falcon ~94°C** Large Stagnation Points Higher Temps in DUT Left/Right Orientation	**Max Falcon ~80 to 85°C** (estimate) No Stagnation Points No Sensitivity to DUT Orientation
Manufacturing Cost	**$25,070 material cost +** 15 day T-Use burn-in per LCA at Teradyne	**$18,400 material cost** (estimate)

Table 5 – Technical Benefits of different Tiger Cooling Redesign projects.

	Liquid Cooling Assembly (Current)	Full Redesign "FRED" (Proposed)
Liquid Cooling Modules	Per LCA Side: 88 Per Test Head: 176	Per TH Side: 22 Per Test Head: 44
Number of Water Connections (inlet/outlet)	Per LCM: 2 Per LCA Side: 176 Per Test Head: 352 (Total of 4 O-rings/LCM)	Per Module: 2 QDs Per Test Head: 88
Number of Vacuum Connections	Per LCM: 1 Per LCA Side: 88 Per Test Head: 176 (Total of 2 O-rings/LCM)	Per Module: 1 Per Test Head: 44
Number of O-Rings	Per LCM: 6 Per LCA Side: 528 Per Test Head: 1056	Per Module: 0 Per Test Head Side: 0 Per Test Head: 0
Number of Total Connections	Per LCM: 3 Per LCA: 264 Per Test Head: 528	Per Module: 3 Per Test Head Side: 66 Per Test Head: 132

6 Reliability Improvement Project – Decision Making Tool Development

6.1 Tool Concept

6.1.1 Break Even Analysis

As it was described earlier in the document, the proposal of this project is to generate a breakeven analysis tool that incorporates product forecasts, engineering resource requirements, and product warranty exposures, reliability statistics, and product failure rates to determine the viability of reliability improvement projects at Teradyne Inc.

6.1.2 Product Forecast

Although the reliability issues, particularly those related to the Liquid Cooling Modules, have been damaging customer satisfaction and product confidence in the market place, the Teradyne management is reluctant to sponsor the multimillion dollar reliability project proposal: FRED Full Redesigned Liquid Cooling Assembly. The reluctance stems from the anticipated decrease in sales volume of Tiger Systems in 2006. In the second half of 2005, Teradyne is planning to introduce a new product called "UltraFLEX" that is expected to replace the current system (Tiger) in the market place. Once UltraFLEX is introduced to the Automatic Test Equipment market, the marketing group at Teradyne anticipates a dramatic decrease in sales volume of Tiger systems. Realizing that the Tiger Systems in the market will be limited once the UltraFlex systems are introduced, the senior management at Teradyne would like to study and understand more comprehensive breakeven analysis of the reliability project that includes the product forecast information for next 5 to 10 years in order to make their decisions. The full forecast information is described in the assumptions table on page ##

6.1.3 Current Failure Rate

The current failure rate, as it is noted in the Table 4 is 0.15 failures/system/quarter. With approximately 150 systems in the field, this failure rate translates to more than 22 LCA failures per quarter. The failure rate is considered unreasonably high for a subsystem that is designed to cool instruments within the test head. In addition, the LCA failures often lead to instrument failures due to lack of proper cooling. As a result, costly replacement procedures are performed. In addition, the MTBF numbers, which define the reliability of the product, decrease dramatically.

6.1.4 Expected Failure Rate

The desired failure rate of the Liquid Cooling Module Design project is 0.015 failures/system/quarter. The desired failure rate is 10 times lower than the current failure rate of 0.15 failures/system/quarter. This failure rate would result in approximately 2 failures per quarter for the entire fleet of the product.

6.1.5 Current Customer Base

Approximately 150 Tiger systems have been purchased by 30 different customers. The systems are currently installed in 24 different cities/sites in 11 different countries. The locations of these systems are critical in organizing reliability improvement plans since field inspections and upgrades are often necessary. As noted in the Table 4 it takes approximately 8 hours to perform the LCA failure replacement procedure and it costs $54,000.

Table 6 – Customer Sites

Customer Sites	
ALLENTOWN, PA	OSAKA, JAPAN
AMBATTUR, CHENNAI, INDIA	PATHUMTHANI, THAILAND
AUSTIN, TX	PENANG, MALAYSIA
BAYAN LEPAS, MALAYSIA	SAN DIEGO, CA
CHUNGCHEONGNAM-DO, SOUTH KOREA	SANTA CLARA, CA
COLORADO SPRINGS, CO	SELANGOR, MALAYSIA
FOLSOM, CA	SEOUL, SOUTH KOREA
HAIFA, ISRAEL	SHANGHAI, PRC
HILLSBORO, OR	SINGAPORE
HSINCHU, TAIWAN	TAIPEI, TAIWAN
IRVINE, CA	THORNHILL, CANADA
KAOHSIUNG, TAIWAN	YOKNEAM, ISRAEL

Countries	
CANADA	PEOP.REP.CHINA
INDIA	SINGAPORE
ISREAL	TAIWAN
JAPAN	THAILAND
KOREA	UNITED STATES
MALAYSIA	

6.1.6 Key Customers

Of the 30 or so Tiger customers, approximately half of the customer base is considered as the "key customers." The key customers are repeat buyers with large Teradyne system install base and/or the customer has high potential for large install base in the future.

6.1.7 Material Cost

The material costs of components or assembly are generally provided by the finance group. The costs are based on six months average of the receipt price of the material. A 10% overhead or material handling charges are added to the final material cost.

The material cost of the LCA project is estimated to be between \$6,350~\$7,350 per assembly. The numbers are based on several quotes from 8 different suppliers.

6.1.8 Project Investment

The engineering group estimates that the total cost of the project would be \$2.2 million dollars and the project would take 4 quarters to complete.

Table 7 – Investment & Projected Project Costs

	2Q05	3Q05	4Q05	1Q06
Engineering Investment	\$440,000	\$591,000	\$608,000	\$538,000
Cumulative project cost	\$440,000	\$1,031,000	\$1,639,000	\$2,177,000

6.2 Summary of Assumptions

- Project duration 4 quarters (Q1 2005 –Q4 2005)
- Tiger will ship at a rate of 20/qtr thru 1Q 2005, 15/qtr thru 3Q 2006, and 10/qtr thru 4Q 2006
- Current LCA FRU cost is $15,000 + 7 hrs of labor at $100/hr
- Redesign LCA FRU cost is $250 + 1 hr of labor at $100/hr
- The resource investment required to execute the LCA redesign is estimated at 8 full time resources for 4 quarters (effort)
- Engineering expenses are estimated at $360K/qtr (includes people and material resources)
- The expectation is to ship another 115 Tigers after the LCA redesign is complete (2.5 years or 10 qtrs)
- First shipment with Redesigned LCA occurs in early 3Q05.

- Manufacturing Engineering Salary $65,000.00
- Fringe $17,550.00
- Hourly $40.00
- Assembler Hourly $15.73

- Total Liquid Cooling Assembly (LCA) Cost for Global Customer Service - New LCA

- Assembly Labor (Initial Manufacture) 6 hrs @ 15.73$/hr
- Assembly Labor (Burn-in Install) 6 hrs @ 15.73$/hr
- Engineer Labor (Burn-in Install) 3 hrs @ 40$/hr
- Assembly Labor (Burn-in Deinstall) 6 hrs @ 15.73$/hr
- Engineer Labor (Burn-in Deinstall) 3 hrs @ 40$/hr

- Total LCA cost for routine production
- Assembly Labor (Initial Manufacture) 6 hrs @ 15.73$/hr

- Assembly Labor (System Install) 6 hrs @ 15.73$/hr

- Total Liquid Cooling Assembly (LCA) cost for Global Customer Service LCA Repair
- Assembly Labor (Burn-in Install) 6 hrs @ 15.73$/hr
- Engineer Labor (Burn-in Install) 3 hrs @ 40$/hr
- Assembly Labor (Burn-in Deinstall) 6 hrs @ 15.73$/hr
- Engineer Labor (Burn-in Deinstall) 3 hrs @ 40$/hr

- Engineering Time @ SGP Engineering Labor Costs Travel/Food/Lodging
- September 8th - October 31st Onsite $26,880.00 $16,000.00
- Average 2 Engs for 42 days

- Materials Testing During this period $15,000.00

6.3 Tool Development

The algorithm behind the tool required a number of elements including;

a) Market Projections

b) Sustaining Engineering Costs

c) Development Engineering Costs

d) Warranty Impact

e) Key Customer Impact

f) Sensitivity/Scenario Analysis

The next four chapters provide brief descriptions of each of the elements that have been incorporated into the tool algorithm.

6.3.1 Market Projections

- Using the system forecast from the Platform Marketing group at Teradyne, a 10 year product sales projection table was created
- Cumulative Fleet size was calculated based on the current fleet size and the future shipment forecasts
- Systems with the traditional LCAs were estimated
- Systems with the new LCAs were estimated based on the project schedule
- Costs are calculated based on failure rate, warranty status, key customer requests for replacements.

Figure 9 – Underlying Assumptions

	1Q05	*2Q05*	*3Q05*	*4Q05*	*4Q13*	*1Q14*	*2Q14*	*3Q14*	*4Q14*
Ship Rate (per Qtr)-Midterm Goal as of 2-1-05	22	22	22	10	1	1	1	1	1
Fleet Size	80	102	125	147	235	236	237	238	239
Old LCA System Fleet size	80	102	125	147	160	160	161	162	163
Old LCA System (Division $)	39	55	70	84	32	32	32	32	32
New LCA System Fleet size (Mean)	0	0	0	0	71	72	73	74	75
New LCA System Fleet (Division $)	0	0	0	0	11	11	11	11	12
Total (Division $)	**39**	**55**	**70**	**84**	**43**	**43**	**43**	**43**	**43**

6.3.2 Development and Sustaining Engineering Costs

- A dedicated Engineer or Engineers will be required in the event that there are a catastrophic number of failures that would impact shipments of new Tiger Systems to customers.
- The engineer(s) would be responsible for root cause analysis and containment plans
- The engineer(s) would be responsible for working with LCA manufactures to understand nd stabilize the manufacturing process as necessary.
- The engineer(s) would be responsible for leading a cross functional team that would be made of members from the Supply Line Management group, manufacturing engineering, planning,

Table 8 – LCA Cost Assumptions for GCS

Total Liquid Cooling Assembly (LCA) Cost for Global Customer Service - New LCA							
Material		$	6,943.6	$	694	$	7,638
Assembly Labor (Initial Manufacture)	6 hrs @ 15.73$/hr	$	94.4	$	327	$	421
Assembly Labor (Burn-in Install)	6 hrs @ 15.73$/hr	$	94.4	$	327	$	421
Engineer Labor (Burn-in Install)	3 hrs @ 40$/hr	$	120.0	NA		$	120
Assembly Labor (Burn-in Deinstall)	6 hrs @ 15.73$/hr	$	94.4	$	327	$	421
Engineer Labor (Burn-in Deinstall)	3 hrs @ 40$/hr	$	120.0	NA		$	120
						$	**9,141**

Total LCA cost for routine production							
Material		$	5,764.9	$	576	$	6,341
Assembly Labor (Initial Manufacture)	6 hrs @ 15.73$/hr	$	94.4	$	327	$	421
Assembly Labor (System Install)	6 hrs @ 15.73$/hr	$	94.4	$	327	$	421
						$	**7,183**

Total Liquid Cooling Assembly (LCA) cost for Global Customer Service LCA Repair							
Material		$	440.0	$	44	$	484
Overhead		$	188.8	$	653	$	842
Assembly Labor (Burn-in Install)	6 hrs @ 15.73$/hr	$	94.4	$	327	$	421
Engineer Labor (Burn-in Install)	3 hrs @ 40$/hr	$	120.0	NA		$	120
Assembly Labor (Burn-in Deinstall)	6 hrs @ 15.73$/hr	$	94.4	$	327	$	421
Engineer Labor (Burn-in Deinstall)	3 hrs @ 40$/hr	$	120.0	NA		$	120
						$	**2,408**

Engineering Time @ SGP	*Engineering Labor Costs*		*Travel/Food/Lodging*			
8 Weeks On Site	$	26,880.0	$	16,000.0	$	42,880
Average 2 Engs for 42 days						
Misc					$	2,120
Materials Testing During this period	$	15,000.0			$	15,000
					$	**60,000**

- The sustaining engineering costs of $60,000 per quarter was accounted for in the calculation
- The calculation also took into account several "catastrophic" situations where 4 or more engineers are needed to contain the reliability and quality issues at the supplier site. The amount was estimated to be approximately $178,000 per event.

	1Q05	*2Q05*	*3Q05*	*4Q05*	*3Q13*	*4Q13*	*1Q14*	*2Q14*	*3Q14*
Engineering Cost of Sustaining Current LCA production to support Tiger Build (1 person = $30K/QTR) Catastrophic	2	2	4	2	4	2	2	2	4
	60	60	178	60	178	60	60	60	178
Engineering Cost of Sustaining Current LCA production to support Tiger Build (0.25 person = $30K/QTR) with FRED as the Back up									
	60	60	178	60	8	8	8	8	8

6.3.3 System Warranty

- The warranty status will be dynamic. The number of "in-warranty" will vary over time and the projected number of new systems sold over the next 10 years.
- The current "in-warranty" and "out-of-warranty" systems are provided by the Global Customer Service at Teradyne.
- The warranty status also accounted for those customers who may extend their warranty status by purchasing extended warranty offers. The estimation was based on historical sales data on extended warranty. Historically, less than 5% of customers purchased extended warranty from Teradyne.

Table 9 – Warranty Assumptions

	1Q05	2Q05	3Q05	4Q05
Systems out of warranty	48	56	64	74
Systems under warranty	32	46	61	73

→

1Q13	2Q13	3Q13	4Q13	1Q14	2Q14	3Q14	4Q14
282	283	284	285	286	287	288	289
9	9	9	9	9	9	9	9

6.3.4 Scenarios

- **Scenario A - Do Nothing.** This scenario assumes that Teradyne will not pursue any additional reliability improvement projects on the Liquid Cooling Modules. The failure rate of 0.15 failures/system/quarter will be expected for the life of the product.

Table 10 – Do Nothing Scenario

1Q05		2Q05		3Q05		4Q05	
$	125	$	139	$	272	$	172
$	125	$	265	$	537	$	709

⇨

1Q14		2Q14		3Q14		4Q14	
$	154	$	154	$	273	$	95
$	7,161	$	7,315	$	7,587	$	7,682

- **Scenario B - Partial Proactive Upgrade.** New Systems are fitted with new and improved LCMs. Only Key customers receive new LCMs on their out-of-warranty systems

Table 11 – Partial Proactive Upgrade Scenario

1Q05		2Q05		3Q05		4Q05	
$	565	$	730	$	880	$	710
$	565	$	1,296	$	2,176	$	2,885

⇨

1Q14		2Q14		3Q14		4Q14	
$	74	$	74	$	74	$	67
$	5,638	$	5,713	$	5,787	$	5,854

- **Scenario C – New Systems Only.** Only the new systems are fitted with new and improved LCMs. The systems old LCMs will continue to be serviced with old LCMs as they fail in the field.

Table 12 – New Systems Only Scenario

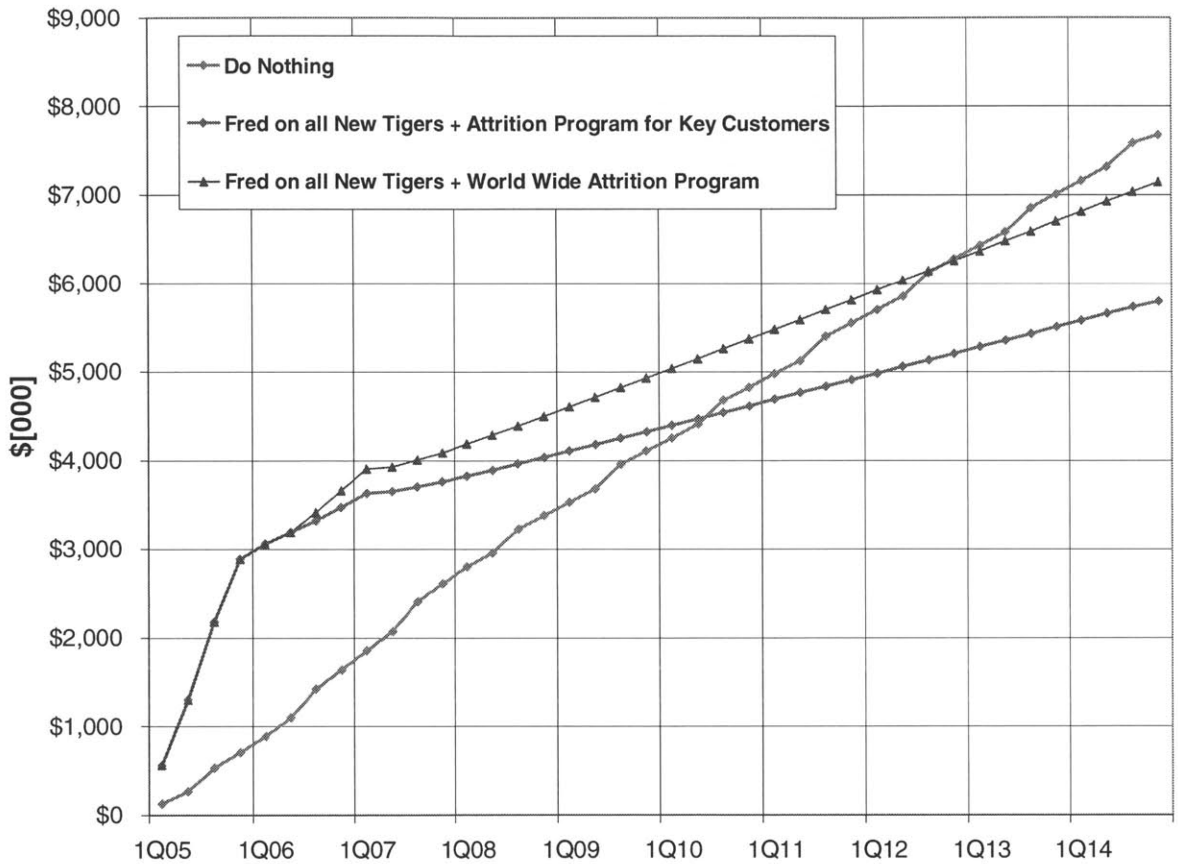
1Q05	2Q05	3Q05	4Q05
$ 565	$ 730	$ 880	$ 710
$ 565	$ 1,296	$ 2,176	$ 2,885

⇨

1Q14	2Q14	3Q14	4Q14
$ 75	$ 75	$ 75	$ 66
$ 5,578	$ 5,653	$ 5,728	$ 5,794

6.3.5 Results

The Phase II Review Meeting for the Liquid Cooling Module Redesign was held on April 25th, 2006. The breakeven analysis tool offered…..



Midterm Plan	Year	2005	2006	2007	2008	2009	2010	2011 and Beyond	
	# Sys	89	81	17	7	5	4	4	

Figure 10 – Breakeven Graph

Table 13 - Variables

Variables			Default
Flex+ Ramp Delayed by*	2	QTRS	0
% Key Customers w/repair subsidies	30%		30%
% Tigers owned by Key Customers	50%		50%
Tiger Biz Changes by (indicate+/-)	0%		0%
Current LCA Failure Rate	0.2	F/S/Q	0.15
FRED Failure Rate (Target)	0.015	F/S/Q	0.015

Table 14 - Financials

Financials		
"Do Nothing Cost" over 10 years	$	7,682
FRED on New Tigers + Attrition on Key	$	5,794
Projected Savings over 10 years	**$**	**1,888**
Break Even in		**3Q09**
"Do Nothing Cost" over 10 years	$	7,682
FRED on New Tigers + Attrition for All	$	7,142
Projected Savings over 10 years	**$**	**540**
Break Even in		**1Q12**

7 REFERENCE

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8 TABLES

9 TABLE OF FIGURES