MIDDLE EAST TECHNICAL UNIVERSITY

ELECTRICAL AND ELECTRONICS ENGINEERING DEPARTMENT

EE400 SUMMER PRACTICE REPORT

SP Company: ASELSAN MGEO

Microelectronics, Guidance and Electro-Optics Business Sector

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Table of Contents

About the Company

Brief Information about the Company

ASELSAN [1]is a company of Turkish Armed Forces Foundation, established in 1975 in order to meet the communication needs of the Turkish Armed Forces by national means. Currently (5,43% of the shares are owned by the Foundation whereas the remaining 15,3% runs in İstanbul Borsa stock market.
ASELSAN is the largest defense electronics company of Turkey whose capability/product portfolio comprises communication and information technologies, radar and electronic warfare, electro-optics, avionics, unmanned systems, land, naval and weapon systems, air defence and missile systems, command and control systems, transportation, security, traffic, automation and medical systems. Today ASELSAN has become an indigenous product exporting company, investing in international markets through various cooperation models with local partners and listed as one of the top 100 defense companies of the world (Defense News Top 100).
ASELSAN, together with the technology emphasis in its vision, has targeted to be a company that maintains its sustainable growth by creating value in the global market; preferred due to its competitiveness, trusted as a strategic partner, and caring for the environment and people. Together with the highly qualified engineering staff within more than 5000 employees, being the main driving factor of the company's success, ASELSAN allocates 6% of its annual income for self-financed research and development activities.

Milestones of the Company

- In January 1976, M. Hâcim KAMOY was assigned as the General Manager.
- In 1978, the first premises in Macunköy Facility were completed and the manufacturing operation started.
- In 1980, the first manpack and tank wireless radios were delivered to the Turkish Armed Forces.
- In 1981, the first hand-held radio and Bank Alarm Systems were designed.
- In 1983, the first export was realized.
- Between the years 1982-1985, new products such as Field Telephones, Computer Controlled Central Systems and Laser Distance Measurement Appliances were included in the inventory.
- In 1986, ASELSAN contributed to the power of Turkish Armed Forces with the Electronic Warfare and Data Terminal appliances it developed.
- In 1987, ASELSAN was included in a common project attended by 4 NATO countries for the manufacturing of Stinger Missile and started the required investment for the thick film hybrid circuit production.
- In 1988, ASELSAN produced the first avionic appliance for the F-16 program.

- In 1989, the first technology transfer to Pakistan was realized. Wireless radio production was started with ASELSAN license in NTRC facilities in Pakistan.

- On date 21.05.1990, the ASELSAN shares were offered to the public and as of date 01.08.1990, the shares were started to be traded in IMKB (İstanbul Stock Exchange).

- In 1990, ASELSAN was restructured in the 3 groups according to its fields of activity.

- In 1991, a Radar Technology Center was established in Aselsan with the SSIK 91-3 decision.

- In 1992, the Radar systems were included in the ASELSAN product range.

- In 1992, an Electro-Optical Technology Center was established in Aselsan with the SSIK 92-4 decision.

- In 1994, studies with regard to design, assembly and commissioning works for Highway Emergency Assistance Communication Systems and Toll Collection Systems and marketing of the same to foreign countries were started.

- In 1995, project activities in main subjects such as Microelectronic, Guidance and Electro-Optical Group with the ongoing works and Hybrid Microelectronic, Inertial Navigational System, Infrared Guiding, Laser Guiding, Thermal Imaging Sensors, Passive Imaging Concentrators, Laser Generators and Sensors were realized.

- In 1995, integration studies with regard to the applicability of electro-optical systems to different platforms and their more effective usage were realized and furthermore the production of ring laser gyroscope INS system was started.

- In 1996, the TASMUS agreement was executed.

- In 1997, ASELSAN 1919 Mobile Phone was launched to the market.

- In 1998, thermal cameras, thermal weapon sight and thermal vision devices with target coordination addressing devices were submitted to the use of Turkish Armed Forces.

- In 1999, agreements for Air Defense Early Warning and Command Control System, MILSIS Electronic Warfare and X-Band Satellite Communication System were executed.

- In the year 2000, Necip Kemal BERKMAN was assigned as the General Manager.

- In 2001, ASELSAN took over 72% of the shares of ASELSAN MİKES A.Ş.

- In 2001, the project for the serial production of KMS systems was executed.

- In 2002, the equity capital of the company increased two and a half times compared to the previous year and reached the level of approximately one fourth of the aggregate resources.

- In 2002, the Project for MWS-TU Missile Warning System and Leopard Volkan Fire Control System to be used in the Turkish Armed Forces Air Platforms was executed.

- In 2003, agreements covering a long period for big projects such as SPEWS-II F-16 Electronic Warfare Auto Defense System, Military Police Integrated Communication and Information System were executed.

- In 2004, HEWS-CMDS CHAFF/FLARE shooter system Project was executed

- In 2005, HEWS, Helicopter Laser Warning Receiver system (LIAS) Project and Turkish Land Forces Avionic System Modernization Project was executed.

- In 2006, Cengiz ERGENEMAN was assigned to the General Manager position, Fuat AKÇAYÖZ was assigned as the Group President of Microwave and System Technologies, Dr. Faik EKEN was assigned as the Communication Devices Group President and KAHRAMANGİL was assigned as the Micro Electronic, Guidance and Electro-Optical Group President.

- In 2006, ASELPOD Project was executed.

- In 2007, the construction of ASELSAN Integration Hall Building was completed and settlement activities were realized.

- In 2007, MILGEM war system supply project was executed.

- In 2008, ATAK agreement and Multi Band Digital Common Wireless Radio (ÇBSMT) Project were executed and ASELSAN delivered the first originally developed Air Defense Radar.

- In January 2008, Microwave and System Technologies Group Presidency was restructured as Defense System Technologies and Radar, Electronic Warfare and Communication Systems Group Presidency. Fuat AKÇAYÖZ was assigned to the position of Group President of Defense System Technologies and Ergun BORA was assigned to the position of Group President of Radar, Electronic Warfare and Communication Systems.

- In 2008, Coast Guard Command search and rescue Project, AKSAZ and FOCA Naval base under and surface surveillance and acquisition system (Yunus) Project, New Type Police Station Boat Project and JEMUS Kastamonu, Konya Wireless Radio system projects were executed.

- In 2009, four Research and Development Centrals were established, Leopard-1 Tank modernization was completed, MILGEM Warfare System 2nd Vessel Project, Ammunition Transfer system Project for Self-Propelled Howitzer (Fırtına- Storm) Ammunition vehicle and SAR / Reconnaissance System Supply Integration Project were executed.

- In 2009, STAMP and SOP system project for UAE, ADOP-2000 Fire Support System project, and the project for Land Located remote ED/ET capability gaining projects were executed.

- In the year 2010, 112 Emergency Call Center was established in Antalya and Isparta, the Digital Trunk wireless radio system tender of İzmir Metropolitan Municipality was won and Tasmus-G 2nd Army Project deliveries were realized.

- In the year 2010, within the requirement by UAE, the subcontracting agreement was executed with Raytheon Company for the Patriot Missile System Antenna Mast Group products, ATMACA Electronic Systems development project, Pakistan Ministry of Defense

Software Based Wireless Radio project, Naval Platform 3B Research Radar project, Self-propelled Air Defense Artillery and Fire Administration System Development project, 12 Air Defense Radar projects and 35 MM Towing Air Defense Artillery Modernization and Fragmentation Ammunition Development project were executed.

- In the year 2011, following the manufacturing and plant acceptance tests of the Shipborne LPI Radar system ALPER (ASELSAN Low Power ECCM Radar) originally developed developed by ASELSAN, it was integrated to the TCG Heybeliada corvette within the scope of MILGEM Project, the Harbor Acceptance Tests were completed successfully and the first duty was started after the completion of the delivery.

- In the year 2011, MILGEM 1 Ship TCG HEYBELİADA Naval Acceptance Tests were completed successfully and was delivered to the navy. "AY Class Diesel-Electric Submarines Upgrade Project" was executed between. SSM, ASELSAN, STM and RAYTHEON companies. "Lower and Medium Altitude Air Defense Missile System Project Design and Development Period Agreement" was executed between SSM and ASELSAN. On date 12 April 2011, President Abdullah Gül visited the Macunköy Facility.

- In May 2012 Necmettin BAYKUL was assigned as board of Directors. By the city hall, the name “Hacim KAMOY” founder of ASELSAN, has been given to the park nearby Macunköy facilities.

- By year 2012, Turkey’s first national Air Defense System “Pedestal Mounted Stinger System” which has been designed and produced by ASELSAN, and whose delivery took nearly 23 years, last 5 pieces has been delivered to Turkish Armed Forces.

- In the year 2013, ASELSAN has continued its climb for the aim of being one of the top 50 defense companies, and ranked 74th according to annual sales.

- In 2013, ASELSAN was the company who has participated most at the 11th International Defence Industry Fair (IDEF 2013).

- In year 2013, ASELSAN has won the “Leadership at Technology” award at the innovation week organized by Turkish Exporters’ Association. ASELSAN has also won “Year 2013 Innovativeness Creativity Product Award” among the large companies with the SERHAT Counter Mortar Radar product at the event of TESİD Innovativeness Creativity Awards.

Vision

Being a national technology company that maintains its sustainable growth by creating value in the global market; preferred due to its competitiveness, trusted as a strategic partner, and caring for the environment and people.

Mission

By focusing primarily on the needs of the Turkish Armed Forces; to provide high-value-added, innovative and reliable products and solutions to both local and foreign customers in the fields of electronic technologies and system integration; continuing activities in line with global targets as well as increasing brand awareness and contributing to the technological independence of Turkey.

Organizational Structure

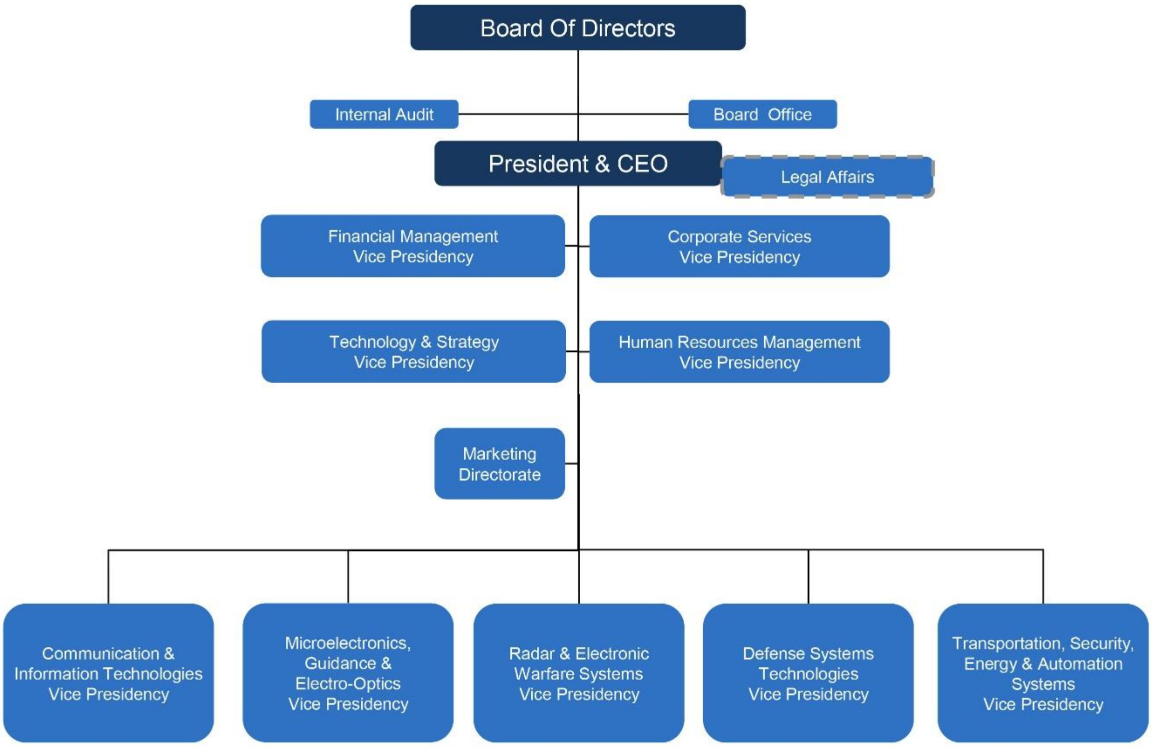

Figure 1. Organizational Structure of ASELSAN

Introduction

I had my summer practice at ASELSAN Akyurt Facility. There are several directorates working in different areas of microelectronics, electro-optics etc. My department, Flight Safety Engineering Department, is working under the Avionics Design Directorate. The main purpose is to investigate and analyze the reliability and safety of the avionic components designed in the other departments.

As the reliability engineering is a specific engineering discipline, I had no idea about reliability& safety concepts. So, in the first 2 weeks of my internship, I was told to do a research on the reliability engineering concepts and then give a presentation on the reliability prediction methods. After the presentation, a designed circuit board was given to me so that I could calculate its reliability parameters and analyze the results. After getting both theories and practical knowledge of reliability, I was asked to research on another new concept for me, Highly Accelerated Life Test (HALT). HALT Process is a stress testing methodology for enhancing product reliability and it is possible to observe the response of the product under extreme temperature& vibration conditions. I had a chance to test some products in HALT Chamber and analyze the results.

Works Conducted

Reliability Engineering

Reliability engineering is a sub-discipline of systems engineering that emphasizes dependability in the lifecycle management of a product. To be able to understand this discipline, some important concepts of reliability should be defined.

Reliability can be simply defined as the ability of an item to perform a required function without failure under stated conditions for a stated period of time. Or in a mathematical form, the probability that an item can perform a required function under given conditions for a given time interval *(t1,t2)*. It is denoted by $R(t)$ with *t* denoting the interval *(t1, t2)*. Derivation of the reliability function $R(t)$ can be shown like,

$$R(t) + Q(t) = 1 \tag{1}$$

$$R(t) = 1 - Q(t) \tag{2}$$

$$R(t) = 1 - \int_0^t f(s)\, ds \tag{3}$$

$$R(t) = \int_t^\infty f(s)\, ds \tag{4}$$

In reliability calculation of any component/system, what matters is the time. The moment that we are studying reliability is called as “mission time”. Reliability is a probabilistic value depending on the mission time and it must be between 0 and 1.

There are some important terms defining the reliability explained below.

- $\underline{\lambda(t): failure\ rate}$:

Failure rate is the frequency with which an engineered system or component fails, expressed in failures per unit of time. It is often denoted by the Greek letter λ (lambda) and is highly used in reliability engineering. Usually it is expressed by the unit fpmh (failure per million hours).

Failure rate is algebraically defined as:

$$\lambda(t) = \frac{R(t)-R(t+\Delta t)}{\Delta t \times R(t)} \tag{5}$$

Where $R(t)$ corresponds to the reliability probability function.

- $\underline{h(t): instantaneous\ failure\ rate(Hazard\ Rate)}$:

Hazard Rate is nothing but the limit value of failure rate $\lambda(t)$ as time difference goes to zero value.

$$h(t) = lim_{\Delta t \to 0} \frac{R(t) - R(t + \Delta t)}{\Delta t \times R(t)} = \frac{1}{R(t)} \times \frac{-dR(t)}{dt} \tag{6}$$

From the equation above, Reliability can be approximated to

$$R(t) = e^{-\lambda t} \quad \text{Assuming that } R(0) = 1 \ \&\ \lambda\ constant. \tag{7}$$

- $\underline{Mean\ Time\ to\ Failure\ (MTTF)}$:

This value is the mathematical representation of the expected value of time till the failure.

$$MTTF = \int_0^\infty R(t)\, dt \tag{8}$$

- $\underline{Mean\ Time\ Between\ Failure\ (MTTF)}$:

This term is defined for the repairable systems and defines the amount of time between two failures. It is mathematically defined as

$$MTBF = \frac{1}{\lambda} \tag{9}$$

This equation helps us to make more accurate and meaningful comments on the reliability. Because the failure rate of a system does not give a clear meaning itself, where MTBF gives a more physical reliability intuition about the system.

Reliability Analysis

Reliability analysis of a system is a wide process and includes some steps:

- Reliability Prediction
- Reliability Block Diagram Analysis
- Failure Modes, Effects and Criticality Analysis *(FMECA)*
- Fault Tree Analysis

During my summer practice, I usually worked on the reliability prediction methods and applications.

Reliability Prediction [2]

Reliability predictions are one of the most common forms of reliability analysis. Reliability predictions predict the failure rate of components and overall system reliability. These predictions are used to evaluate design feasibility, compare design alternatives, identify potential failure areas, trade-off system design factors, and track reliability improvement.

Reliability predictions are evaluated from bottom to up. This methodology means that reliability calculations are started from the component level. Bringing components' data together, an overall system's reliability can be predicted.

Reliability Prediction Models

Some mathematical& statistical models are developed to be able to standardize the reliability predictions all around the world. All models' basic prediction methods are similar except some little differences. These differences occur due to the different working areas. Most popular prediction models are given below.

MIL-HDBK-217

It is known as the original reliability prediction handbook published by the Department of Defense, based on work done by the Reliability Analysis Center and Rome Laboratory. [3]

It contains failure rate models for the various part types used in electronic systems, such as ICs, transistors, diodes, resistors, capacitors, relays, switches, connectors, etc.

Failure rate models are based on field data obtained for a wide variety of parts and systems. This data was analyzed and many simplifying assumptions were thrown in to create usable models.

MIL-HDBK-217 includes mathematical reliability models for nearly all types of electrical and electronic components. The variables in these models are parameters of the components such as number of pins, number of transistors, power dissipation, and environmental factors.

MIL-HDBK-217 contains two methods of performing predictions. [3]

- Parts Count - normally used early in the design and is based on anticipated quantities of parts to be used
- Parts Stress – normally used later in the design and is based on the stresses applied to each individual part

Bellcore/Telcordia

Bellcore was a telecommunications research and development company that provided joint R&D and standards setting for AT&T and its co-owners. Because of dissatisfaction with military handbook methods for their commercial products, Bellcore designed its own reliability prediction standard for commercial telecommunication products. In 1997, the company was acquired by Science Applications International Corporation (SAIC) and the company's name was changed to Telcordia.

Telcordia continues to revise and update the standard. The latest two updates are SR-332 Issue 2 (September 2006) and SR-332 Issue 3 (January 2011), both called "Reliability Prediction Procedure for Electronic Equipment." Includes main concepts of MIL-217 but also has the ability to take into account burn-in, field and laboratory testing data.

This method also consists of Parts Stress & Parts Count Methods.

There are some other reliability prediction models to be used in different industries:

Prediction Model	Applied Industry
MIL-HDBK-217	Military
Telcordia	Telecommunication
CNET 93	Telecommunication
HRD5	Telecommunication
PRISM	Military
SAE	Automotive

Table 1. Empirical prediction methods in common use

As mentioned in Table 1, there are several reliability prediction standards defined for different areas of industry. In ASELSAN MGEO, MIL-HDBK-217 is used to estimate the reliability of electronic components and systems. MIL-HDBK-217 model also includes different types of reliability prediction methods for different purposes. The most popular ones of these methods are given below.

Reliability Prediction Methods

- ➢ Similar Equipment Method
- ➢ Generic Parts Count Method
- ➢ Parts Stress Analysis
- ➢ Hybrid Microelectronic Devices
- ➢ Prediction for Items Prone to Wear-Out
- ➢ Prediction for One-Shot Devices

Similar Equipment Method

- It is the most basic reliability prediction method before the design process
- This method is based on the idea of the reliability prediction in terms of:
    - ➢ MTBF
    - ➢ Failure Rate
    - ➢ Similar Parameters
- Estimating the system reliability based on experience gained from operational items of similar function.
- Low accuracy rate due to using historical data instead of exact data.

Parts Count Reliability Prediction

This prediction method is applicable during bid proposal and early design phases when insufficient information is available to use the part stress analysis models shown in the main body of this Handbook. The information needed to apply the method is generic part types (including complexity for microcircuits) and quantities, part quality levels, and equipment environment. The equipment failure rate is obtained by looking up a generic failure rate in one of the following tables, multiplying it by a quality factor, and then summing it with failure rates obtained for other components in the equipment. The general mathematical expression for equipment failure rate is calculated with this method in the following way,

$$\lambda_{ITEM} = \sum_{i=1}^{n} N_i * (\lambda_{Gi} * \pi_{Qi}) \qquad (10)$$

λ_{ITEM}: total failure rate

N_i: quantity of ith generic part

λ_{Gi}: generic failure rate of ith generic part

π_{Qi}: quality factor of ith generic part

In this definition, an important assumption is made such that all failure rates(λ) are assumed to be to constant.

This method is very easy to apply and gives us more accurate results compared with the similar item method. But it still has certain disadvantages like:

- As failure rate products of each components are summed, It is actually assumed that all parts of the system must be functioning simultaneously. But many times, there are some redundancies, alternate modes of operation (to be explained in the following section) in the system which we ignore by putting them into the summation.
- As it can be seen from the definition formula of this method, there is no input indicating the stress levels applied to the system/product. A system's reliability value changes significantly with changing stress levels. But this method, we certainly ignore this effect. λ_{Gi} value is determined for the worst-case stress level conditions. Because of this situation, the obtained result is far away from the true reliability value.

To solve the 1st problem, the method of redundancy is preferred to get a more accurate reliability prediction.
Redundancy is the provision of alternative means or parallel paths in a system for accomplishing a given task such that all means must fail before causing a system failure.
System reliability and mean life can be increased by additional means by applying redundancy at various levels.
Reliability engineers often need to work with systems having elements connected in parallel and series, and to calculate their reliability. To this end, when a system consists of a combination of series and parallel segments, engineers often apply very convoluted block reliability formulas and use software calculation packages.

- **Reliability of Series Systems**

A series system is a configuration such that, if any one of the system components fails, the entire system fails. Conceptually, a series system is one that is as weak as its weakest link. A graphical description of a series system is shown in Figure 2.

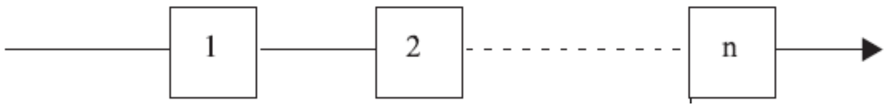

Figure 2. Representation of a Series System of "n" Components

Reliability predictions in series systems are calculated as

$$R_s = R_1 \times R_2 \times \dots R_n \qquad \text{(if the component reliabilities differ)} \quad (11)$$

$$R_s = R_i^n \qquad \text{(if all components are identical)} \quad (12)$$

To summarize, in this type of connected systems, system success is equivalent to the success of each component.

- **Reliability of Parallel Systems**

A parallel system is a configuration such that, as long as not all of the system components fail, the entire system works. Conceptually, in a parallel configuration the total system reliability is higher than the reliability of any single system component. A graphical description of a parallel system of "n" components is shown in Figure 3.

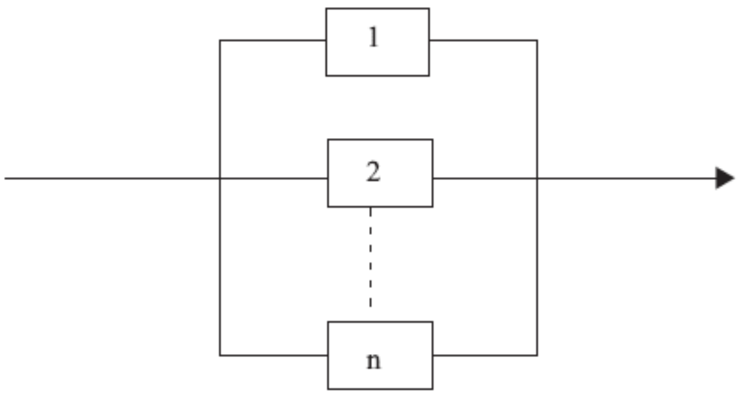

Figure 3.Representation of a Parallel System of "n" Components

Reliability predictions in parallel systems are calculated such as

$$R_s = 1 - \prod (1 - R_i) = 1 - [(1 - R_1)\times(1 - R_2)\times \ldots\times(1 - R_n)] \tag{13}$$

If all "n" components are identical, such as $R_1 = R_2 = \cdots = R_n = R$

$$R_s = 1 - \prod (1 - R_i) = 1 - [1 - R]^n \tag{14}$$

The logic behind the reliability calculation of parallel systems is simple. For a parallel system to fail, all parallel branches must fail at the same time. For this reason, reliability of such a system should be calculated by multiplication of the failing probabilities of all sub-components subtracted from 1.

By using the series and parallel reliability diagrams, we can solve one of the disadvantages of the generic parts count method explained above. It is no more necessary to consider all components in reliability estimation.

But for the second problem, it is not possible to find a solution with the generic parts count method. Because in this model, the failure rates are kept constant and not influenced by the stress level. To solve this issue, a better approach to calculate reliability is preferred named "Part Stress Reliability Prediction Method".

Part Stress Reliability Prediction Method

As mentioned as the reason of inaccuracy of Parts Count Prediction Method, failure rates of components vary significantly with the applied stress level. In this method, each stress level is considered as an input and by these inputs, new failure rates belonging to the components are determined due to the military standard MIL-217.

In a general meaning, the failure rate is determined by

- the strength of the components
- The stress level applied to components.

This technique is based on analyzing the effects of applied stresses (temperature, voltage, vibration, etc.) to failure rate so that it becomes possible to achieve more accurate reliability estimations. There are several part stress methods explained in different reliability models. But in ASELSAN MGEO, MIL-HDBK-217F standard is used and I have studied with this standard on my reliability estimations.

Each electronic component has its own reliability prediction model defined in MIL-HDBK-217F Model such as microcircuits, diodes, transistors, lasers, resistors, capacitors etc.
It is not possible to explain all components' prediction method in this model. But I will try to give an example to give an intuition on this method.
For this example, I chose to estimate the reliability of a capacitor as its calculation is simple to understand the concept of this method.

Example:
A 400 VDC rated capacitor type CQ09A1KE153K3 is being used in a fixed ground environment, 50°C component ambient temperature, and 200 V-DC applied with 50 V_{rms} @ 60 Hz. The capacitor is being produced in full accordance with the applicable specification.
Estimate the reliability of this capacitor in terms of failure rate.

CQ09A1KE153K3 is a specific code defined by product manufacturers. Although It looks like meaningless, it shows a lot of important information about the product.

In this case, "CQ" corresponds that this product is produced with respect to the MIL-C-19978 Specification. This information will help us to find the right coefficients to be used in the reliability calculations. The letter "E" in the code means that this capacitor's DC Rating value is equal to 400 Volts. "153" number is about the capacitance value. It is quite similar to the resistance color code. The capacitance value is found by the first 2 numbers multiplied by the ten to 3rd number-Picofarads. The capacitance value becomes,

$$C = 15\times10^{3} PicoFarads$$

In MIL-HDBK-217F Standard, failure rate is defined as

$$\lambda_p = \lambda_b\times\pi_T\times\pi_C\times\pi_V\times\pi_{SR}\times\pi_Q\times\pi_E \frac{failures}{10^6 hours} \tag{15}$$

where,

$$\lambda_b: base\ failure\ rate\ constant$$

$$\pi_T: temperature\ factor$$

$$\pi_C: capacitance\ factor$$

$$\pi_V: voltage\ stress\ factor$$

$$\pi_{SR}: series\ resistance\ factor$$

$$\pi_Q: quality\ factor$$

$$\pi_E: environment\ factor$$

Each of these terms shows its effect by multiplying with the base failure rate. With changing stress levels, an updated failure rate is created. By considering all these stress levels, more accurate reliability estimations can be made. All these factors and their effects to the failure rate will be investigated.

Temperature Factor:

$$\pi_T = exp\ (-\frac{Ea}{8.617 * 10^{-5}} \times (\frac{1}{T + 273} - \frac{1}{298})) \tag{16}$$

In MIL-HDBK217 standard, there are some predefined π_T values calculated by the temperature and Ea value obtained from a defined variable "Column" in MIL-217.

T(ºC)	Column 1	Column 2
20	.91	.79
50	1.6	1.9
100	3.2	15
150	5.6	56

Table 2. Ea values with changing temperature and column number.

By these predefined values, it becomes easier to find the true π_T value. This "Column" information is defined in the standard with respect to the manufacturing type of the component. In this case, our manufacturing code "CQ" can be observed below in Table 3 from MIL-217 HDBK to find its column information. Also, It should be noted that all these values in Table 3 are calculated from the base formula to calculate π_T(Eq. 16).

Capacitor Style	Spec. MIL-C-	Description	λ_b	π_T Table - Use Column:	π_C Table - Use Column:	π_V Table - Use Column:	π_{SR}
CP	25	Capacitor, Fixed, Paper-Dielectric, Direct Current (Hermetically Sealed in Metal Cases)	.00037	1	1	1	1
CA	12889	Capacitor, By-Pass, Radio - Interference Reduction, Paper Dielectric, AC and DC (Hermetically sealed in Metallic Cases)	.00037	1	1	1	1
CZ, CZR	11693	Capacitor, Feed through, Radio Interference Reduction AC and DC (Hermetically sealed in metal cases), Established and Nonestablished Reliability	.00037	1	1	1	1
CQ, CQR	19978	Capacitor, Fixed Plastic (or Paper-Plastic) Dielectric (Hermetically sealed in metal, ceramic or glass cases), Established and Nonestablished Reliability	.00051	1	1	1	1
CH	18312	Capacitor, Fixed, Metallized (Paper, Paper Plastic or Plastic Film) Dielectric, Direct Current (Hermetically Sealed in Metal Cases)	.00037	1	1	1	1

Table 3. Parameters belonging to different types of capacitor.

From the Table 3, It can be observed that “CQ” code for a capacitor corresponds to some important information about the component such as

- Its Description: Our capacitor is a fixed plastic dielectric one.
- Its λ_b Value: The base failure rate is determined with respect to each capacitor style. In this situation, our λ_b value is equal to 0.00051 which will be used in the Formula 15.
- Its π_T Value (Column number to be used): As it can be seen in Table 3, temperature factor depends on the environment temperature and column number. This column number is determined with respect to the raw material that the product is manufactured. Also, the variable -E_a- in the definition of π_T changes with product’s type.

This column issue is also important for other factors (capacitance, voltage stress, etc.) and they will be investigated in the following topics.

Capacitance Factor:

Capacitance factor is defined as the following formulas with for different columns,

$$\begin{aligned} \pi_C &= C^{.09}\ for\ Column\ 1 \\ \pi_C &= C^{.23}\ for\ Column\ 2 \end{aligned} \tag{17}$$

As the capacitance value is $15\times10^3\ pF$ and our column number is 1,

$$\pi_C = (15\times10^{-3})^{0.09} = 0.69 \tag{18}$$

Voltage Stress Factor:

In reliability estimations, voltage stress level is an important issue as the applied voltage level to the device changes its stability and reliability. Each device has its working voltage range and when the stress level exceeds this range, the failure risk increases. To regard this situation, a new ratio called "S" is defined in the following way,

$$S = \frac{Operating\ Voltage}{Rated\ Voltage} \tag{19}$$

By this value, π_V value is calculated with respect to the formulas given in Table 4. Number of column is determined from MIL HDBK-217 and shows the type of the device.

Number of Column	Definition of π_V
1	$\pi_V = \left(\frac{S}{0.6}\right)^5 + 1$
2	$\pi_V = \left(\frac{S}{0.6}\right)^{10} + 1$
3	$\pi_V = \left(\frac{S}{0.6}\right)^3 + 1$
4	$\pi_V = \left(\frac{S}{0.6}\right)^{17} + 1$
5	$\pi_V = \left(\frac{S}{0.5}\right)^3 + 1$

Table 4. Voltage Stress Level for different columns.

As our capacitor's column number for π_V calculation is 1, the formula in the first row will be used.

$$S = \frac{Operating\ Voltage}{Rated\ Voltage} = \frac{200 + \sqrt{2} \times 50}{400} = 0.68 \tag{20}$$

$$\pi_V = (\frac{S}{0.6})^5 + 1 = (\frac{0.68}{0.6})^5 + 1 \cong 2.9 \quad (21)$$

Series Resistance Factor:

Another important factor effecting the reliability of the capacitor is the series resistance factor. To regard this effect, a ratio named "CR" is defined as the following,

$$CR = \frac{Effective\ Resistance\ Between\ Capacitor\ and\ Power}{Voltage\ Applied\ to\ Capacitor} \quad (22)$$

For different CR values, π_{SR} values are given in MIL-HDBK 217 standard as in the following Table 5.

$CR = \frac{Eff.Res.Between\ Cap.and\ PowerSupply}{Voltage\ Applied\ to\ Capacior}$	π_{SR} **Value**
>0.8	.66
>0.6 to 0.8	1.0
>0.4 to 0.6	1.3
>0.2 to 0.4	2.0
>0.1 to 0.2	2.7
0 to 0.1	3.3

Table 5. Series Resistance Factor for capacitors with different CR values.

For the capacitor in the example, this CR ratio is between 0.6 and 0.8 making π_{SR} equal to 1.

Quality Factor:

Quality factor is all about the manufacturing process of the electronic product. Manufacturers establish devices' quality code so that we can achieve π_V value from the related table in MIL-HDBK 217 given in Table 6.

Quality	π_Q
D	.001
C	.01
S, B	.03
R	.1
P	.3
M	1.0
L	1.5
Non-established reliability capacitors	3.0
Commercial or Unknown Screening Level	10.

Table 6. Quality factors for capacitors with different quality levels.

As our example capacitor's quality level is not established in its datasheet, we assign it to "Non-established reliability capacitors" class and so that our π_V value is equal to 3.0.

Environment Factor:

Reliability of an electronic component also depends on its working environment. In different environments, environment factor is used to represent this effect. There are several environments defined in MIL-HDBK 217 standard. (E.g. A_{IC} corresponds to the "Airborne, Inhabited, Cargo" environment where G_F corresponds to the "Ground, Fixed" environment.) All environments and their corresponding π_E values can be observed from Table 7.

Environment	π_E
G_B	1.0
G_F	10
G_M	20
N_S	7.0
N_U	15
A_{IC}	12
A_{IF}	15
A_{UC}	25
A_{UF}	30
A_{RW}	40

Table 7. Environment factors for several environments.

For our example, fixed ground environment is stated. So, our environment factor value is equal to 10 according to the Table 7.

Bringing All Factors Together;

$$\lambda_b = 0.00051$$

$$\pi_T = 1.6$$

$$\pi_C = 0.69$$

$$\pi_V = 2.9$$

$$\pi_{SR} = 1$$

$$\pi_Q = 3.0$$

$$\pi_E = 10$$

Putting all variables together,

$$\lambda_p = \lambda_b \times \pi_T \times \pi_C \times \pi_V \times \pi_{SR} \times \pi_Q \times \pi_E \frac{failures}{10^6 hours} \tag{23}$$

$$\lambda_p = 0.049 \frac{Failures}{10^6 hours} \text{ for the capacitor in the example.} \tag{24}$$

Hybrid Microelectronic Devices

A hybrid microelectronic device is a combination of two or more integrated circuit types, or one integrated circuit type and discrete components. For these devices, different reliability prediction methodology is preferred than monolithic microelectronic devices, especially for IC Circuits.

I did not work on this kind of devices' reliability calculation. But to show its difference, an example failure rate formula of the hybrid devices is given like,

$$\lambda_p = \sum \{N_C * \lambda_C * K_G + (N_r * \lambda_r + \sum N_I * \lambda_I + K_G + \lambda_s) K_F * K_E\} * K_Q * K_D \frac{failures}{10^6 Hours} \tag{25}$$

Prediction for Items Prone to Wear-Out

To be able to talk about items prone to wear-out, It is essential to mention about bathtub curve that can be observed in Figure 4.

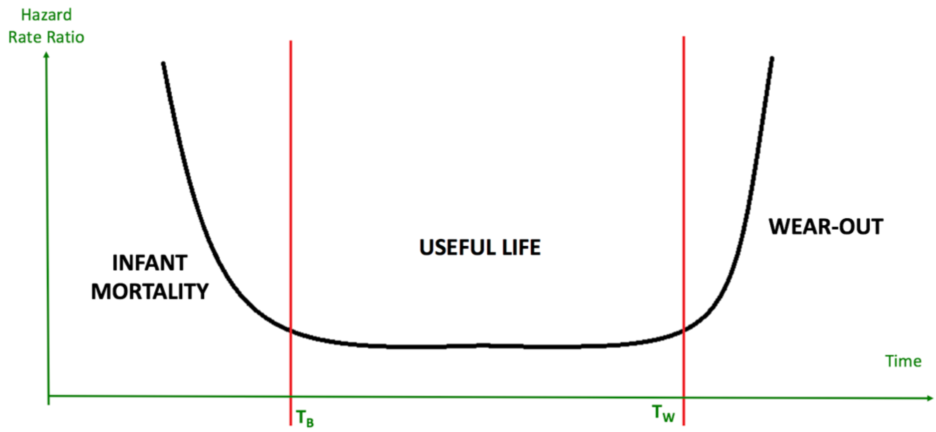

Figure 4. Bathtub Curve showing the Hazard Rate.

The bathtub curve is a widely used tool in reliability engineering. It describes a particular form of the hazard function cpmrising three parts shown in Figure 4:

- The first part is a decreasing failure rate, known as early failures representing “Infant Mortality”.
- The second part is a constant failure rate, known as random failures representing “Useful Life”.
- The third part is an increasing failure rate, known as wear-out failures representing “Wear-Out”.

Each electronic device wears out after some time. And beyond that time, reliability parameters do not remain same. Their tolerance to the applied stresses decreases and they become less reliable. For this purpose, more complex estimation methods are applied for devices beginning to wear-out. As I did not work with any kind of device wearing-out, these methods will not be examined in this report.

Reliability Prediction for One-Shot Devices

One shot device is an item that is required to perform its function once during normal operation use. Especially in the defense industry, there are several one-shot components. As these components cannot be tested, some predefined constants are used for reliability estimation of them. Some examples of one-shot devices and their predefined reliability values are given in Table 8.

One-Shot Device	Reliability
Rocket Motor, case-bonded type	0.9993
Flare, guided missile	0.9994
Igniter, fusehead	0.9983

Table 8. Reliability values for some one-shot devices.

Reliability Calculations

After gaining some knowledge and experience in reliability calculation of electronic systems, I was given to calculate the reliability of a pre-designed electronic board in ASELSAN MGEO Facility. All components used in the board were given with their quantity, type and brand. I first reached all components' datasheet and find necessary parameters so that I could calculate the true reliability values with respect to MIL-HDBK 217 standard. All these values can be found in Appendix A.

All these values are used to calculate each component's individual failure rate. After this, due to their connections (parallel/series) these failure rates are summed and the total failure rate of the system is concluded.

	FAILURE RATE SUMMATIONS			
	Quantity	Type	Sum of Failure Rates	
	15	Capacitor	0,2370018656	
	14	Resistor	1,17505	
	8	Diode	1,31345	
	1	Connector	0,655500	
	3	Transistor	3,338496	
	1	Driver Receiver (MicroCircuit)	0,1222	
	1	Operational Amplifier (MicroCircuit)	0,1272	
	1	Gate (MicroCircuit)	0,0918	
TOTAL FAILURE RATE	44	Sample Board	7,060693894	FPMH
(MTBF) Mean Time Between Failures		Sample Board	141629,1394	OPERATING HOURS

Table 9. Total Failure Rate and MTBF Values Corresponding to the Overall System.

Failure rate result means that our system will fail about 7 times in every million hours. With this value, an approximate mean time between failures from Eq. 9 can be calculated.

HALT (Highly Accelerated Life Test)

Reliability prediction methods are applied to the systems so that some enhancements to improve reliability can be made. But before this step, for this purpose, Highly Accelerated Life Test Process is applied to the designed systems so that weaknesses of the system can be determined and improved. The HALT [4] helps the design process in the following ways:

- reduces warranty claims
- releases product to market earlier
- extends warranty periods of the product

HALT is a series of tests performed on a product as part of the design process to aid in improving product robustness. The principal idea of HALT is to find design weaknesses as quickly as possible and then fix them.

After improving one weakness, the next design weakness is found and improved and so on until no design weaknesses remain that could result in field failures. During HALT, a product is stressed beyond the product specifications to quickly accelerate and identify design weaknesses. It must be noticed that HALT is not a pass/fail test. It is a test to define all possible weaknesses to be able to repair them before releasing the product to the market.

The Theory Behind the HALT Process

When a product is designed, it should be verified that all design specifications are provided. These specifications are mostly focused on the response of the product to different stresses. Every product has an operating range for any stress and this range is determined by the lower and upper operating limits. Design operating range is the stress level range that the end product is designed to function properly.
Ideally, it is expected that the product will operate beyond the specification limits named as design margins. These two margins (lower& upper) provide a safety range in case of an extreme situation for the system. Specification range and design margins can be observed on the above of Figure 5.
HALT Process will improve the product's reliability by increasing the design safety margins. In HALT process, the product is stressed beyond its specifications. At some point the product will not operate anymore referred to as a failure. There are 2 possible failures possible, soft (recoverable) and hard (non-recoverable) failures. If the product returns to operate normally when the stress level is reduced to normal specification range, then it is called a soft failure. But if the product still does not operate in the specification range, it is a hard failure and the product needs maintaining.
In HALT Process, the product is stressed to hard failure and root causes of the failures are determined so that the design improvements can be made. To verify the success of design change, a second HALT test is necessary. If the failures are removed, greater design margins can be obtained. Effect of HALT process to the design margins can be observed from the below of Figure 5.

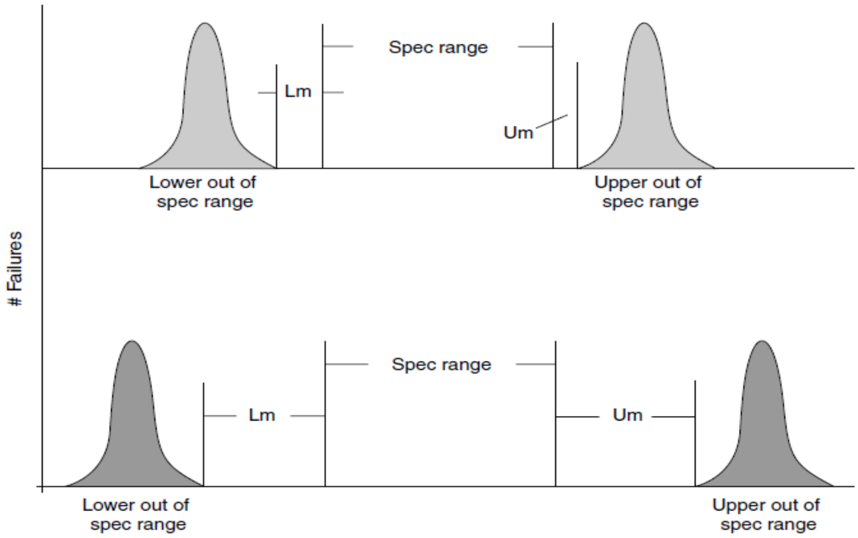

Figure 5. Default and Improved Margins by HALT of a System.

Standard HALT Process

A typical HALT test has 5 steps in row. Each of these steps checks the reliability of the product in different aspects. These 5 steps are Temperature Step Stresses, Temperature Ramps, Vibration Step Stresses, Combined Temperature & Vibration Stresses and Temperature Destruct Limits.

Temperature Step Stresses

The aim of this part is to determine the upper and lower operating points. The process starts with cold step stresses. Testing is started at ambient temperature and the temperature is decreased by 10ºC steps until the lower operating limit. The dwell time at each step is defined as the point when stabilization and saturation of the device and its components is achieved which is generally 15 to 20 minutes.

Then, temperature is set to 40 ºC and hot step stress is applied to determine the upper operating limit of the system. The dwell time will be established using the same procedure as for the cold step testing segment. There is a limitation of temperature for the chamber about between -100 ºC and +200 ºC. A simple example of this procedure can be observed from the graph in Figure 6.

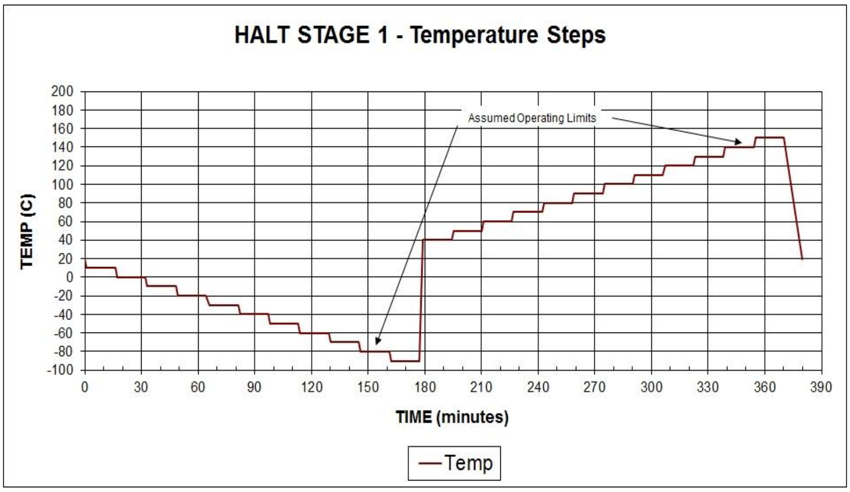

Figure 6. Stage 1: Temperature Steps [5]

Temperature Ramps

The aim of this stage is to observe the response of the system to the rapid temperature transitions. Temperature cycles with rapid transition rates (ramps) will be applied to the product. The chamber air temperature will be changed at 60-70 ºC/minute. The hot and cold temperatures will typically range from 10 ºC above the lower operating limit to 10 ºC below the upper operating limit. These 10 ºC reductions are to allow for over shooting caused by changing the temperatures extremely fast.

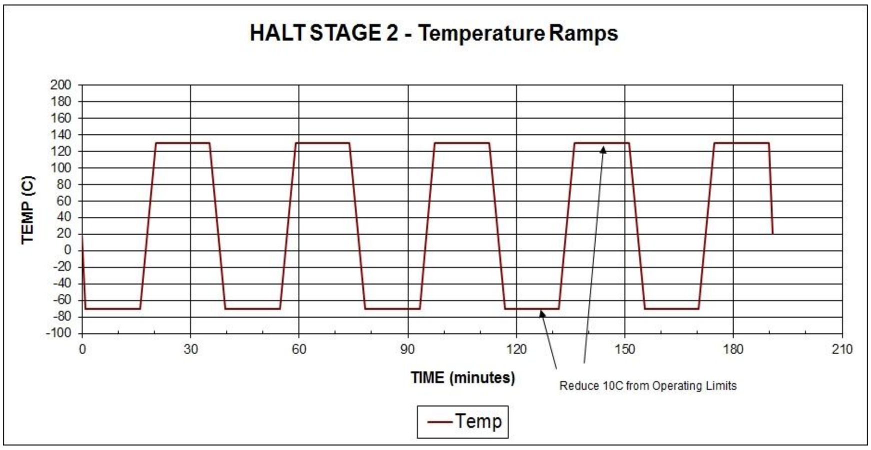

Figure 7. Stage 2: Temperature Ramps [5]

Vibration Step Stresses

A broadband vibration spectrum will be applied through the HALT chamber table. The HALT chamber table should apply random vibration energy from 10 Hz to 10,000 Hz in 6 DOF (degrees of freedom). Vibration step stresses will start at 10 Grms and increase in 5 Grms steps until either the operating, the destruct limits, or the chamber maximum vibration level of 60 Grms is reached. At 40 Grms levels and above, the vibration step will be returned to 10 Grms for 1 minute to detect failures that could be hidden by extreme forces occurring at higher vibration levels. Dwell time at each step, will be approximately 15 minutes to accumulate fatigue damage. Grms is measured with a 5 KHz bandwidth. This test is performed at room temperature of approximately 20 to 25 ºC. A typical vibration steps process can be observed from Figure 8.

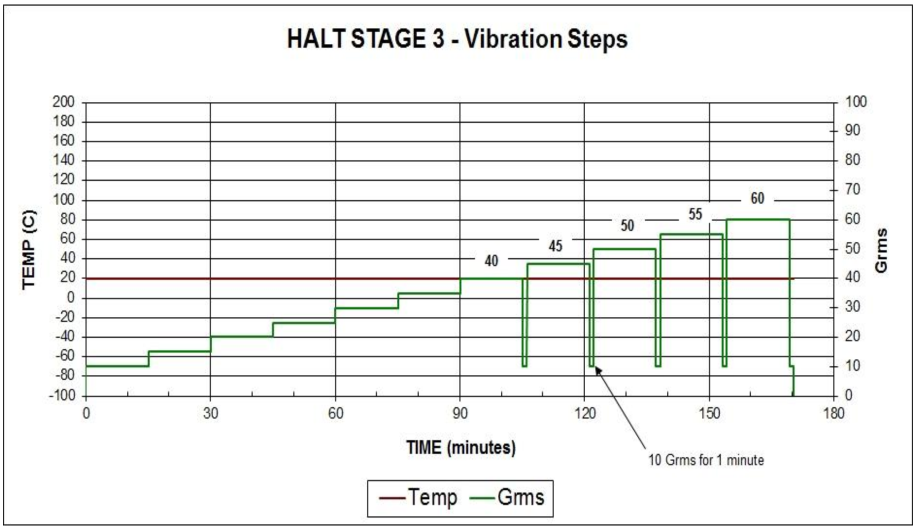

Figure 8. Stage 3: Vibration Steps [5]

Combined Temperature& Vibration Stresses

This stage is applied to observe the response of the product to temperature & vibration stresses applied at the same time. The temperature of chamber air is changed by at 60-70 ºC/minute (similar to the Stage 2) and the vibration level is fixed during each temperature step and increases with 10 Grms steps until 60 Grms level is reached. The representative process of this step can be seen from Figure 9.

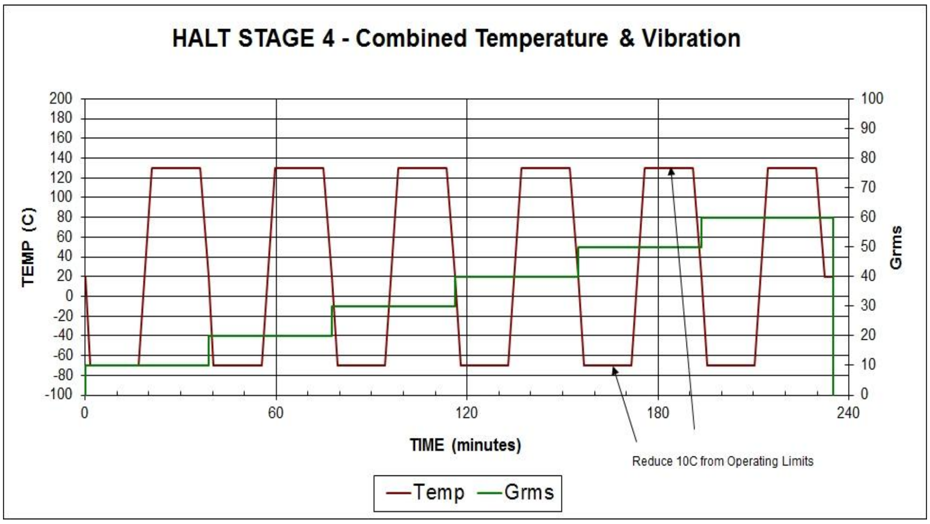

Figure 9. Stage 4: Combined Temperature & Vibration Stress [5]

Temperature Destruct Limits

This stage is applied to determine the destruction limits of the product. The temperature is started with lower operating point (found in Stage 1) and decreased by 10 ºC steps until achieving the low temperature destruct limit. Then, a similar process is applied to achieve the upper destruction limit. In this stage, we expect the product to fail so that we can define its margins and improve them.

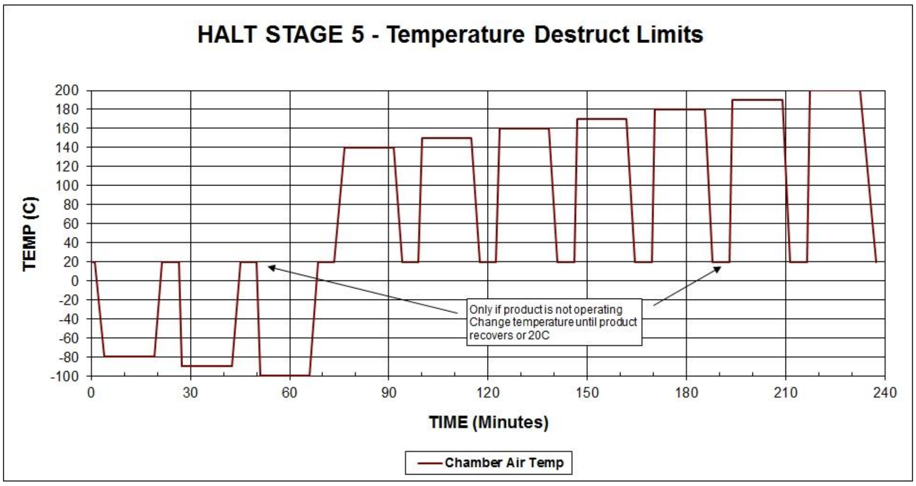

Figure 10. Stage 5: Temperature Destruct [5]

Reporting

This process of 5 stages is applied to the product to observe its response to extreme temperature & vibration conditions. But due to special requirements of the product, manually defined HALT process profiles can be applied. After testing a number of products (generally 1 to 4), a high-quality HALT report is prepared with the data & graphs taken from the testing results. In this report, important points like operating limits, destruction limits, conditions of the product to have soft & hard failures must be specified clearly. This report is shared with the design department so that they can improve the reliability of the product.

Practical Work with HALT Chamber

My department uses HALT Chamber to improve reliability of some products. I went to the HALT Chamber three times during my internship. In the first time, I tried to understand the working principles of the chamber. For cooling operation, the chamber uses liquid N_2 coming from a tank, and there are some strong heaters for heating operation. With these temperature controllers, an air circulation is created inside the chamber to change the temperature. The vibration is created by 16 air hammers placed below the test table. These hammers work with the compressed air pressure principle. A typical air hammer can be observed below in Figure 11.

Figure 11. Typical Air Hammer

Heating, cooling and vibration processes are done by heaters, liquid N_2 and air hammers (compressed air). But these tools must be controlled with the feedback coming from the instantaneous data. For this purpose, A PID Controller is used so that temperature and vibration can be controlled without an overshooting situation. The software of HALT System has a PID Controller menu and with changing values proportional (K_P), integral (K_I) and derivative constants (K_D) for heating, cooling and vibration processes, the control system can be optimized.

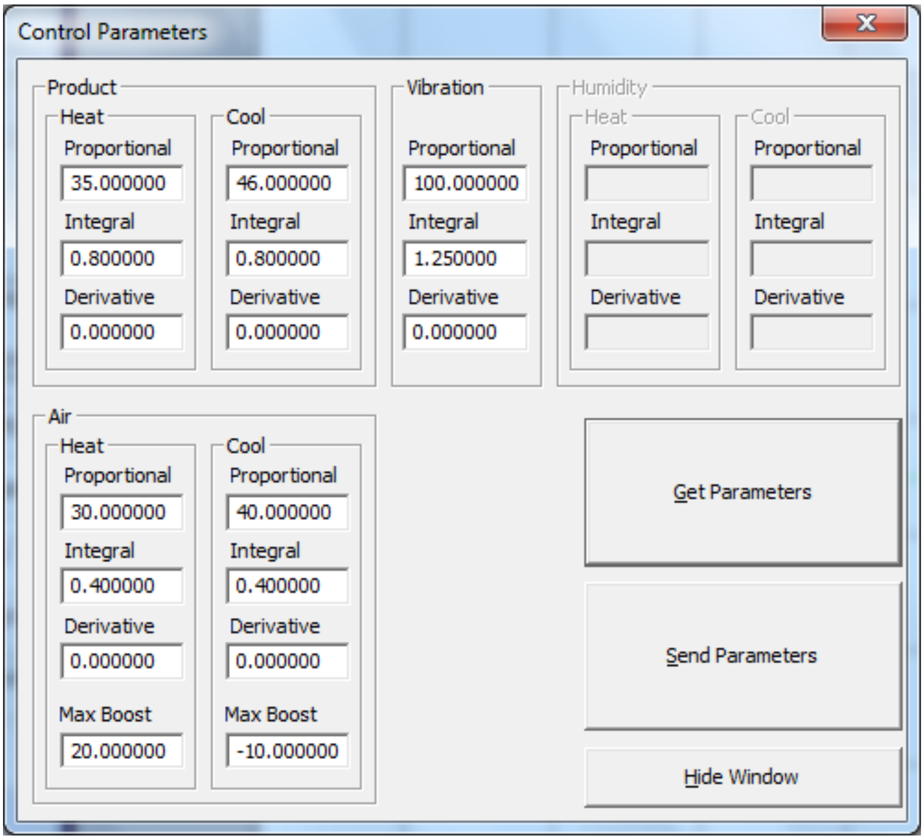

Figure 12. Control Parameters (KP, KI, KD) of the HALT Chamber

Due to the specifications of products designed by ASELSAN, necessary K_P, K_I and K_D values were calculated and set as default as these values can be observed from the Figure 12 above. We used these values during HALT tests and got a successful control system with no overshoot.

Creating Manual Procedure

After getting some knowledge of HALT Procedure, I created a manual test procedure to apply on a dummy load. Products are mostly tested with the standard procedure explained above. But for products with different specifications, it is possible to create manual testing procedures.

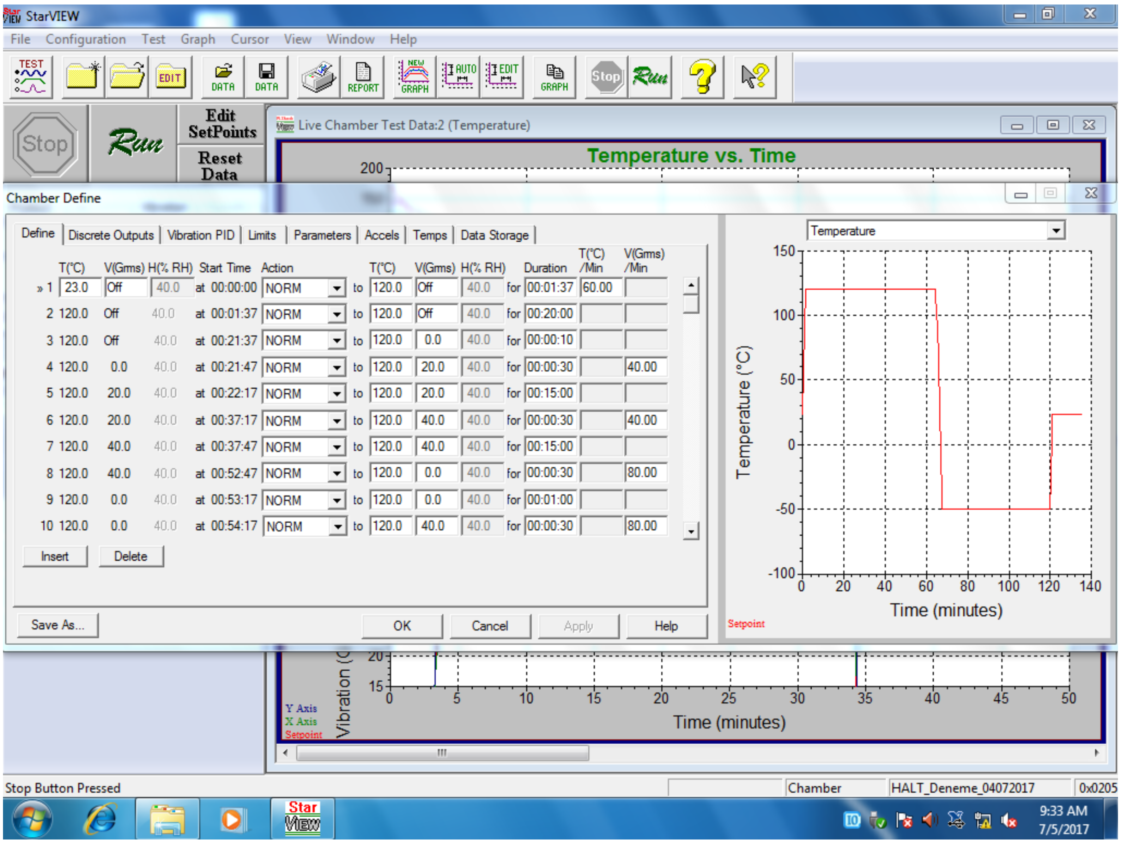

Figure 13. Chamber Test Procedure Defining Screen

As it can be seen from Figure 13, step lengths and transitions can be determined by duration or the slope value of the ramp. I created a profile for both temperature & vibration given in Figure 14 and 15.

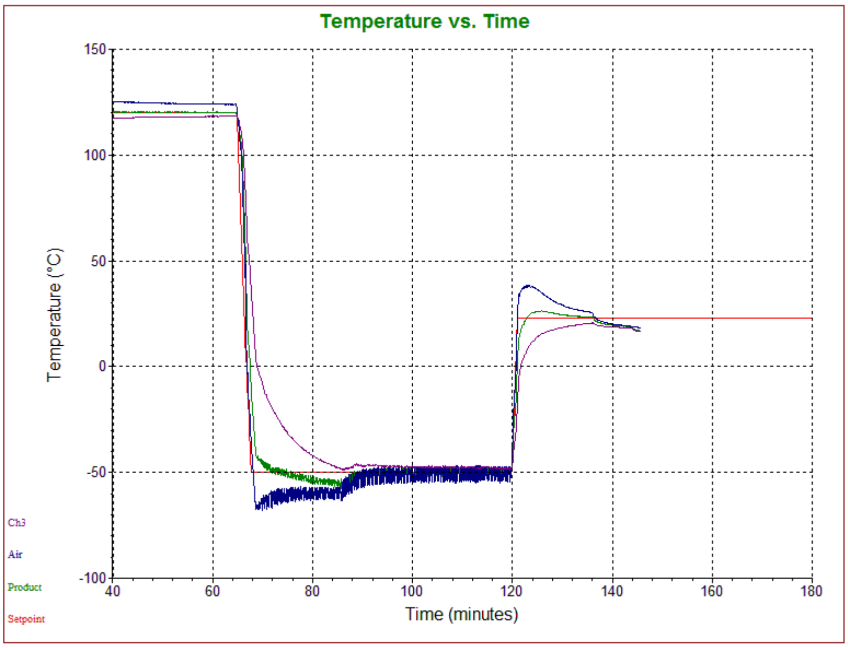

Figure 14. Temperature Data of the Chamber

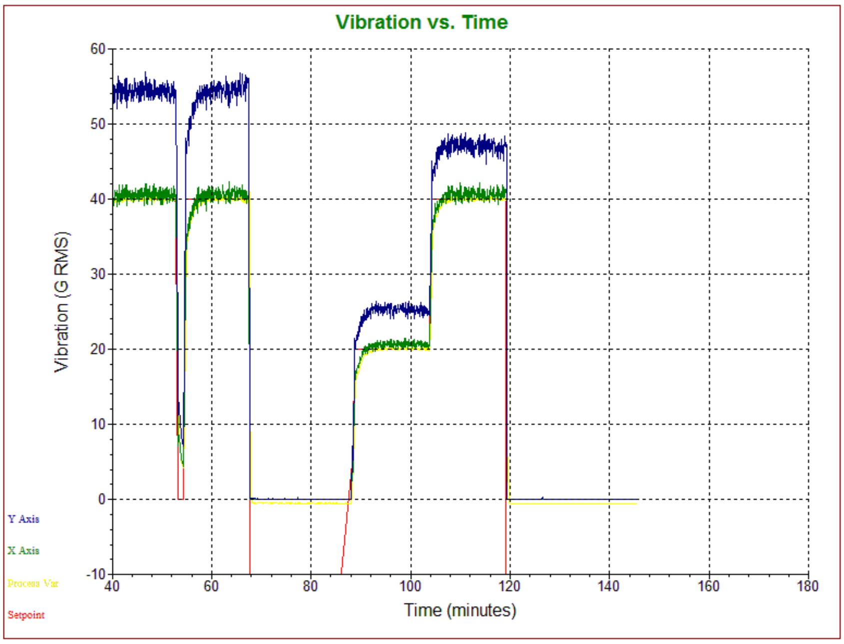

Figure 15. Vibration Data of the Chamber

The profile we manually determined is specified with the red line "Setpoint". It begins from 120 ºC and stays at this temperature about 25 minutes. Then with a sharp transition (with the slope about -60 ºC/min), it decays to -50 ºC and stays there about 50 minutes. During this time, there are some vibration changes to be explained below. Then, the temperature is brought to room temperature (23 ºC) and the procedure is ended. Manually set procedure is labelled as "Setpoint" with the red line on the graph. "Air" label with blue line corresponds to the temperature of circulating air in the chamber and "Ch3" label with the purple line gives the temperature of our dummy load. It can be seen that at very low temperatures (-50 ºC), there is a noisy distortion. Its reason can be thought as the failure of PID parameters but it is actually not. Cooling operation is done by the liquid N_2 and when liquid N_2 is pumped through the chamber, it creates a strong cooling effect with its very low boiling temperature (-195.8 ºC) and immediately converts into gas form. So, this noisy distortion is due to the fast cooling effect of liquid N_2. Heating process is controlled by the heaters in the chamber and it is much easier to control them. So, there is no distortion during the heating process.

For vibration, it is started from the 40 Grms and suddenly decreased and increased to 40 Grms for 1 minute to detect failures that could be hidden by extreme forces occurring at higher vibration levels. At the 75th minute, vibration is stopped to observe temperature effect (at -50 ºC). Then, again it is brought to 40 Grms gradually. In the graph, "Setpoint" corresponds to the procedure manually decided by us. Green label "X Axis" corresponds to the measured vibration level below the test table of chamber. Blue label "Y Axis" corresponds to the vibration level of our tested dummy product. Yellow label named as "Process Var" corresponds to the process variable that is the feedback parameter of the system. The procedure is controlled with respect to the changes of this parameter. As it can be observed from the Figure 15, the value of "Process Var" is almost equal with the "X Axis" for all the time. The reason of not using "X Axis" variable as the control parameter is the noisy characteristic of it. As the vibration level is increased to high levels (above 10Grms), the accelerometers cannot get a stable measure but a noisy one as can be observed in Figure 15. These noisy parts can make serious problems during the control process. So the system creates a new parameter of “Process Var” by finding the smooth average of “X Axis” values.

After completing the test of dummy load, I investigated the graphs of temperature and vibration and got some conclusions. One interesting point on the vibration graph was that despite applying to the chamber same level of vibration between 40th-65th minutes and 105th-120th minutes (40 Grms on “X Axis” Label on Figure 15), the measured stress level of dummy load (“Y Axis” Label on Figure 15) were completely different (about 55 Grms on the 40th-65th minutes and about 47 Grms on the 105th-120th minutes). I concluded with the following results:

- When applied the same stress level of vibration, the load under the high temperature condition may have vibrated strongly.
- The accuracy of the accelerometer may have been influenced by the environment temperature.

So, I decided to apply a HALT Procedure on an accelerometer to observe the reason of vibration stress level difference with changing temperature. So, I could understand the reason behind the vibration stress difference mentioned above.

Creating Test Procedure for Accelerometer

As the main purpose of this test is to observe the response of the accelerometer to the vibration stress under different temperature conditions, a constant vibration stress level is applied to the chamber. With the measured vibration stress level on accelerometer, some results can be concluded.

So, the applied vibration level (X Axis) is constant for the whole time (between 5th – 35th minutes), and in this duration the temperature will change significantly (from -50°C through +150°C). By this procedure, It will be possible to observe the effects of temperature to the vibration stress level felt on the accelerometer.

I set up the necessary test procedure and applied it to the accelerometer. Due to its datasheet, the operating temperature range of the accelerometer is from -54°C to 121°C. This information will be helpful to understand whether high temperature makes the felt stress level increase or the accelerometer does not work smoothly in its expected operating temperature range. The graphs showing the vibration and temperature stress levels with respect to time can be observed from Figure 16 and 17.

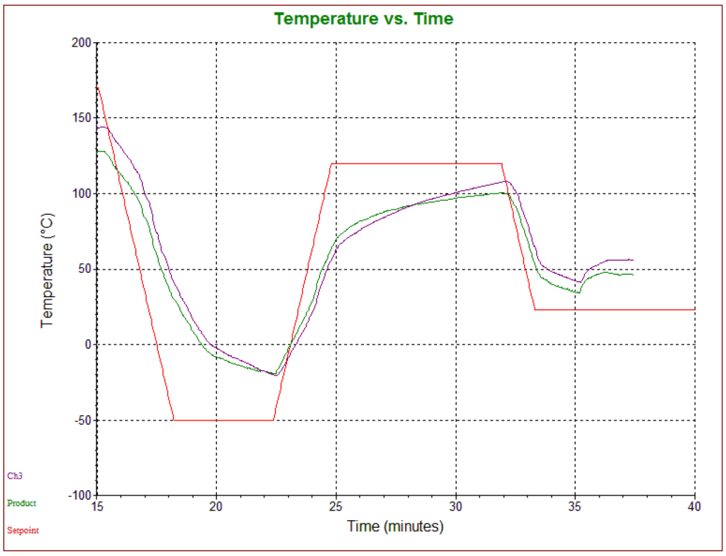

Figure 16. Temperature Data of the Accelerometer and the Chamber

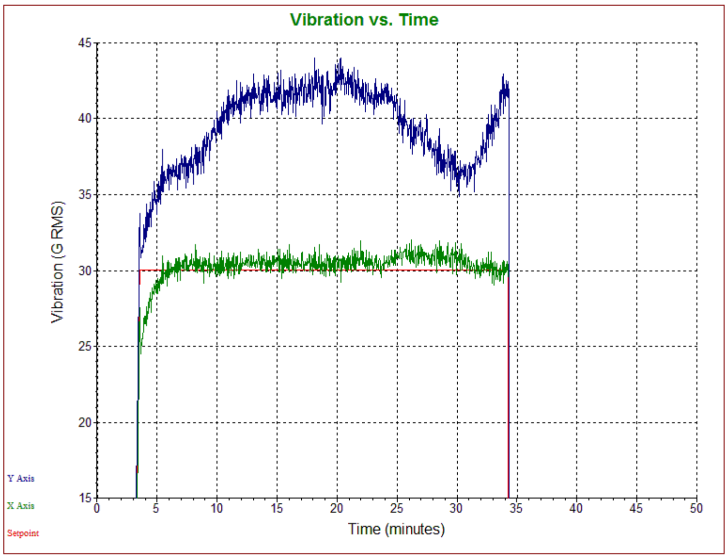

Figure 17. Vibration Data of the Accelerometer and the Chamber

There is an absolute temperature increase till 15th minute and vibration stress level felt in the accelerometer increases in a similar manner. This situation is the reason making me think that high temperature leads to high vibration transfer from the chamber through the accelerometer. But this pattern does not stay same between 25th and 30th minutes. There is an obvious fall in the vibration level on the accelerometer (Y axis) and this does not make sense with the previous situations. After observing the graph in Figure 17, I concluded that when the temperature goes too high/low (Although the temperature is still in the operating range), some distortion occurs and it becomes impossible to measure the true vibration stress level.

With this experiment, I concluded that the accuracy of the accelerometer is influenced badly by the environment temperature and the operating temperature range is not declared successfully as the accelerometer cannot operate its function anymore beyond some temperature value.

Conclusions

Before this internship, I had no idea about the reliability issue of electronic devices. So, in the beginning of my internship, I had some difficulties of trying to understand the reasoning and necessity of reliability for complex electronic systems. After that, I was assigned to make a presentation on reliability estimation calculations. While preparing for the presentation, I totally mastered the mathematical background of the topic. It was not that hard for me as most of the calculations are based on the probabilistic distributions which I am familiar with EE230 Probability and Random Variables Course. With this mathematical background, I was assigned to calculate the reliability of a pre-designed circuit board in ASELSAN MGEO.

After completing the reliability calculation assignment, I worked on the HALT (Highly Accelerated Life Test) Process. Many of the designed& fabricated electronic components are exposed to take this test to observe their response to the extreme conditions. I applied this test two times separately and concluded some results. Also, the setup of HALT Chamber gave me an intuition of the real-life applications and importance of control systems. By changing the K_I, K_D and K_P values, I could observe the quality of the system controlling the temperature and vibration level.

Besides, I had a great chance to learn the concepts of system engineering. I observed the progress of large projects and this issue was as important as the technical subjects for me.

I completed my 1st summer practice in TREDAŞ which operates in the power sector. Although my two summer practices are irrelevant and do not complement each other, I do not see this situation as a problem, quite the contrary as an advantage to see different working areas.

Consequently, I had a great chance to learn new engineering fundamentals and apply them in my summer practice. Besides, I was lucky to have a good working team. They tried to answer all my questions and helped me in many ways.

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Appendices

Appendix A:

ITEM NUMBER	DESCRIPTION	QTY	type	lambda_b	temp_2	C_1	v_3	sr_1	Q_R	Env_ARW	failure_rate	s_value	
1	100nF CAPACITOR,16V,CER	1	ck,ckr	0,000990	2,900000	0,810000	1,125000	1,000000	0,100000	40,000000	0,010464795	0,300000	
2	100nF CAPACITOR,16V,CER	1	ck,ckr	0,000990	2,900000	0,810000	1,296296	1,000000	0,100000	40,000000	0,0120582	0,400000	
3	100nF CAPACITOR,16V,CER	1	ck,ckr	0,000990	2,900000	0,810000	1,198495	1,000000	0,100000	40,000000	0,011148452	0,350000	
4	100nF CAPACITOR,16V,CER	1	ck,ckr	0,000990	2,900000	0,810000	1,421875	1,000000	0,100000	40,000000	0,013226338	0,450000	
5	10nF CAPACITOR,50V,CER	1	cdr	0,002000	2,900000	0,810000	1,421875	1,000000	0,100000	40,000000	0,026719875	0,450000	
6	10nF CAPACITOR,50V,CER	1	cdr	0,002000	2,900000	0,810000	1,296296	1,000000	0,100000	40,000000	0,02436	0,400000	
7	10nF CAPACITOR,50V,CER	1	cdr	0,002000	2,900000	0,810000	1,296296	1,000000	0,100000	40,000000	0,02436	0,400000	
8	10nF CAPACITOR,50V,CER	1	cdr	0,002000	2,900000	0,810000	1,198495	1,000000	0,100000	40,000000	0,022522125	0,350000	
9	10nF CAPACITOR,50V,CER	1	cdr	0,002000	2,900000	0,810000	1,198495	1,000000	0,100000	40,000000	0,022522125	0,350000	
10	1µF CAPACITOR 10V, CER	1	ck,ckr	0,000990	2,900000	0,810000	1,296296	1,000000	0,100000	40,000000	0,0120582	0,400000	
11	1µF CAPACITOR 10V, CER	1	ck,ckr	0,000990	2,900000	0,810000	1,296296	1,000000	0,100000	40,000000	0,0120582	0,400000	
12	1µF CAPACITOR 10V, CER	1	ck,ckr	0,000990	2,900000	0,810000	1,296296	1,000000	0,100000	40,000000	0,0120582	0,400000	
13	1µF CAPACITOR 10V, CER	1	ck,ckr	0,000990	2,900000	0,810000	1,198495	1,000000	0,100000	40,000000	0,011148452	0,350000	
14	1µF CAPACITOR 10V, CER	1	ck,ckr	0,000990	2,900000	0,810000	1,198495	1,000000	0,100000	40,000000	0,011148452	0,350000	
15	1µF CAPACITOR 10V, CER	1	ck,ckr	0,000990	2,900000	0,810000	1,198495	1,000000	0,100000	40,000000	0,011148452	0,350000	

	DESCRIPTION	QTY	type	lambda_b	temp_2	p_	power_Stress	Q_R	Env_ARW	failure_rate	power_dissip	rated power	
16	12 KOHM RESISTOR, FILM	1	rl, rn, rm	0,00370	1,30000	0,20872	0,97126	1,00000	63,00000	0,06143	0,01800	0,06300	
17	12 KOHM RESISTOR, FILM	1	rl, rn, rm	0,00370	1,30000	0,17819	0,87493	1,00000	63,00000	0,04724	0,01200	0,06300	
18	100 KOHM RESISTOR, FILM	1	rl, rn, rm	0,00370	1,30000	0,23350	1,07818	1,00000	63,00000	0,07629	0,02400	0,06300	

19	100 KOHM RESISTOR, FILM	1	rl, rn, rm	0,00370	1,30000	0,25473	1,19688	1,00000	63,00000	0,09239	0,03000	0,06300	
20	100 KOHM RESISTOR, FILM	1	rl, rn, rm	0,00370	1,30000	0,19439	0,92184	1,00000	63,00000	0,05430	0,01500	0,06300	
21	39 KOHM RESISTOR, FILM	1	rl, rn, rm	0,00370	1,30000	0,28497	1,10094	1,00000	63,00000	0,09507	0,04000	0,10000	
22	39 KOHM RESISTOR, FILM	1	rl, rn, rm	0,00370	1,30000	0,29576	1,15031	1,00000	63,00000	0,10310	0,04400	0,10000	
23	39 KOHM RESISTOR, FILM	1	rl, rn, rm	0,00370	1,30000	0,27051	1,04220	1,00000	63,00000	0,08543	0,03500	0,10000	
24	39 KOHM RESISTOR, FILM	1	rl, rn, rm	0,00370	1,30000	0,26122	1,00847	1,00000	63,00000	0,07983	0,03200	0,10000	
25	39 KOHM RESISTOR, FILM	1	rl, rn, rm	0,00370	1,30000	0,27933	1,07706	1,00000	63,00000	0,09117	0,03800	0,10000	
26	39 KOHM RESISTOR, FILM	1	rl, rn, rm	0,00370	1,30000	0,29837	1,16300	1,00000	63,00000	0,10515	0,04500	0,10000	
27	39 KOHM RESISTOR, FILM	1	rl, rn, rm	0,00370	1,30000	0,29837	1,16300	1,00000	63,00000	0,10515	0,04500	0,10000	
28	39 KOHM RESISTOR, FILM	1	rl, rn, rm	0,00370	1,30000	0,27350	1,05369	1,00000	63,00000	0,08733	0,03600	0,10000	
29	39 KOHM RESISTOR, FILM	1	rl, rn, rm	0,00370	1,30000	0,27933	1,07706	1,00000	63,00000	0,09117	0,03800	0,10000	

	DESCRIPTION	QTY	type	lambda_b	temp_2	Pİ_S	Pİ_C	Pİ_Q	Pİ_E	failure_rate	voltage_stress	voltage_rated	stress ratio
30	SCHOTTKY DIODE, 1A60V	1	power rectifier/schottky power diode	0,00300	4,40000	0,06928	1,00000	2,40000	24,00000	0,05267	20,00000	60,00000	0,333333333
31	SCHOTTKY DIODE, 1A60V	1	power rectifier/schottky power diode	0,00300	4,40000	0,10790	1,00000	2,40000	24,00000	0,08204	24,00000	60,00000	0,4
32	SCHOTTKY DIODE, 1A60V	1	power rectifier/schottky power diode	0,00300	4,40000	0,15692	1,00000	2,40000	24,00000	0,11931	28,00000	60,00000	0,466666667
32	SCHOTTKY DIODE, 1A60V	1	power rectifier/schottky power diode	0,00300	4,40000	0,05400	1,00000	2,40000	24,00000	0,04106	15,00000	60,00000	0,25
34	Transient Voltage Suppressor DIODE 24.4V, 1500W	1	transient suppressor	0,00130	3,40000	1,00000	1,00000	2,40000	24,00000	0,25459	8,00000	15,00000	0,533333333
35	Transient Voltage Suppressor DIODE 24.4V, 1500W	1	transient suppressor	0,00130	3,40000	1,00000	1,00000	2,40000	24,00000	0,25459	4,90000	15,00000	0,326666667
36	Transient Voltage Suppressor DIODE 24.4V, 1500W	1	transient suppressor	0,00130	3,40000	1,00000	1,00000	2,40000	24,00000	0,25459	7,60000	15,00000	0,506666667
37	Transient Voltage Suppressor DIODE 24.4V, 1500W	1	transient suppressor	0,00130	3,40000	1,00000	1,00000	2,40000	24,00000	0,25459	6,50000	15,00000	0,433333333

	DESCRIPTION	QTY	type	lambda_b	temp_2	Pi_K	Pi_Q	Pi_E	failure_rate	voltage_stress	voltage_rated		
38	RECTANGULAR CONNECTOR, 1.8A240V	1	rectangular	0,046000	1,500000	1,000000	1,000000	19,000000	0,655500				

	DESCRIPTION	QTY	type	lambda_b	temp_2	Pi_A	Pi_Q	Pi_E	failure_rate				
39	TRANSISTOR, MOSFET	1	si fet	0,012000	2,300000	0,700000	2,400000	24,000000	1,112832				
40	TRANSISTOR, MOSFET	1	si fet	0,012000	2,300000	0,700000	2,400000	24,000000	1,112832				
41	TRANSISTOR, MOSFET	1	si fet	0,012000	2,300000	0,700000	2,400000	24,000000	1,112832				

	DESCRIPTION	QTY	type	C1	Pi_T	C2	Pi_E	Pi_Q	Pi_L	failure_rate			
42	DRIVER RECEIVER, MICROCIRCUIT	1	gate=1 logic cga ...	0,010000	0,350000	0,007200	8,000000	2,000000	1,000000	0,1222			

	DESCRIPTION	QTY	type	C1	Pi_T	C2	Pi_E	Pi_Q	Pi_L	failure_rate			
43	OPAMP	1	5-3 linar bipolar	0,010000	1,400000	0,006200	8,000000	2,000000	1,000000	0,1272			

	DESCRIPTION	QTY	type	C1	Pi_T	C2	Pi_E	Pi_Q	Pi_L	failure_rate			
44	GATE, 3.3V	1	5-3mos digital gate	0,010000	0,350000	0,005300	8,000000	2,000000	1,000000	0,0918			