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Reliability analysis of GAN based transmit modules for active array antenna of phased array radar

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ABSTRACT

Reliability is one of the most important requirements in our day to day life considering consistency, availability and failure free performance of the product over it’s define mission time. As complexity of the system increases, design for reliable systems is a big challenge. The objective of the reliability prediction analysis is to evaluate the predicted reliability of the active transmit receive modules (TRMs) under specified operating conditions, and to demonstrate that the predicted reliability meets the requirements, also to identify any parts present in the design which leads to higher failure rates. The research shows reliability of generative adversarial network (GAN) based TRMs covering from design to finalization of components as early as practicable in today's short product lifecycles. Using the reliability prediction process, we describe a method for providing design engineers with reliability feedback on their decisions. Using a conventional reliability prediction model, the Telcordia (Bellcore) parts stress prediction model, and some standard rules of thumb, we describe an initial implementation of this technique. It provides systematic identification of likely modes of failure, possible effects of each failure, and the criticality of each failure with regard to reliability, system readiness, mission success, and demand for maintenance/logistic support.

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1. INTRODUCTION

In recent days, the establishment of many private sector manufacturing industries either the small scale or the large scale have come into picture when compared to the antiquity. Simultaneously the worker ship has also increased a bit for these manufacturing industries. The main intension of both the sectors is to provide a good quality of the product with a few expenses. The solution to eliminating design errors can be illustrated with the above divergence-from-randomness (DFR) models starting from scratch. The layer-by-layer DFR model supports robust and error-free circuitry. The first step, schematic stress simulation, aims to eliminate electrical and stress errors during the schematic design phase. A model was initially used first to primarily to simulate component stresses (i.e. P, V, I, and Tj). Its capability is to perform stress and load reduction analysis on any size circuit diagram (i.e. hundreds of pads to tens of thousands of pads) and any type of electrical circuit (e.g. analog, digital, radio frequency (RF) or source) at the schematic level prior to layout and fabrication [1]–[4]. Therefore, there is a high degree of flexibility to improve the design at a lower cost than fixing the product after testing the first article. The second step, mean time between failures (MTBF) part stressing, uses simulated stresses to achieve circuit reliability with more accurate and realistic

MTBF predictions, thereby eliminating the weakest links in the conductive design to poor performance and high failure rates. Figure 1 shows the DFR model to build a reliable product.

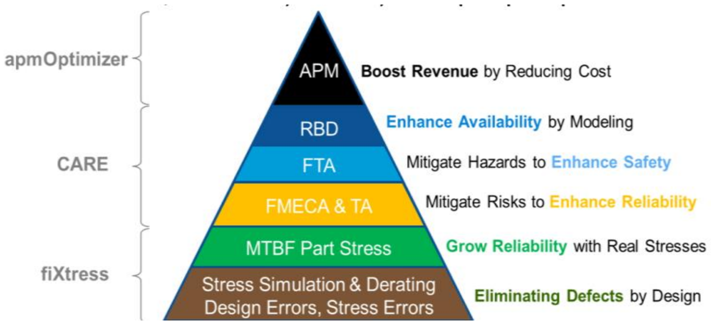

Figure 1. DFR model to build a reliable product

The third step, failure mode, effects, and criticality analysis (FMECA) failure mode on machine and tree analysis (TA), further improves circuit reliability by predicting critical failure modes in advance and thus can mitigate the technical risks detected by FMECA, followed by analysis [5]–[9]. Analyze test capabilities to detect error coverage and isolate errors. The fourth phase, the fault tree analysis/event tree analysis (FTA/ETA), prevents the security risks that defense, aerospace and automotive or any other critical industry needs. This takes design to the next level in improving availability with reliability block diagram (RBD) model redundancy and increasing revenue-using asset performance management (APM) to reduce O and M optimization costs [5]. The next one is FMECA is a reliability evaluation/layout approach, which examines the capability failure modes inside a machine and its gadget, with the intention to decide the consequences on gadget and machine overall performance. Each capability failure mode is classed in keeping with its effect on venture fulfillment and personnel/gadget protection [6]. The FMECA consists of separate analyses, the failure mode and effects analysis (FMEA) and the criticality analysis (CA). FMECA determines the consequences of every failure mode on machine overall performance: i) it provides statistics for growing fault tree evaluation and RBD fashions, ii) it provides a foundation for figuring out root failure reasons and growing corrective movements, iii) it facilitates research of layout options to do not forget excessive reliability at the conceptual ranges of the layout, and iv) it aids in growing take a look at strategies and troubleshooting strategies.

FMECA also provides a basis for qualitative reliability, maintainability, protection, and logistics analyses. The outcomes of the FMECA is: it highlights those factor that are used to requiring corrective movement, also rank every failure in keeping with the severity category of the failure impact on venture fulfillment and personnel/gadget protection. FMECA provide estimates of machine vital failure costs, aids in providing a quantitative rating of machine and/or subsystem failure modes and identify reliability/protection vital additives [7], [8].

FTA/ETA is the dynamic process of accident occurrence and development can be described using FTA. Finding the direct and indirect causes as well as combinations of these causes is convenient. Qualitative analysis can determine the importance of causes and hidden hazards and can forecast the likelihood that accidents will occur. However, the FTA closely combines both professional expertise and mathematics [9]. A strong mathematical foundation and significant professional expertise are required for the formulation and analysis of the fault tree. The FTA is used to demonstrate how a mixture of individual contributing failures, events, and/or mistakes may result in an unwanted top-level failure (or event). Figure 2 shows the FTA model to perform risk analysis of a product. A system is a group of parts assembled into a certain architectural configuration for the sole purpose of carrying out the function of that system [10]–[12]. The integrity of the constituent parts and the architecture of the systems both affect the functional failure probability of that function. The necessity for a thorough analytic technique to pinpoint every potential failure combination that could lead to the loss of the system's integrity increases with system complexity. One such method is FTA [13].

FTA is diagrammatic depiction of reliability, availability, and maintainability (RAM) analysis. It is a top-down approach (also called deductive approach). Used to study those progresses through progressively more intricate (i.e. lower) layers of the design until the likelihood of the top event the feared event occurring in light of its surroundings and mode of operation can be foreseen [14]. The top event often indicates the observed symptom when using FTA for fault diagnosis as opposed to the system problem as when it is used for reliability analysis. FTA is a reasonably easy method that can be used to get information about known system flaws from system professionals [15]–[18]. One of the benefits of the approach, particularly when used in complicated systems, is that it can depict the occurrence of multiple errors at once [19].

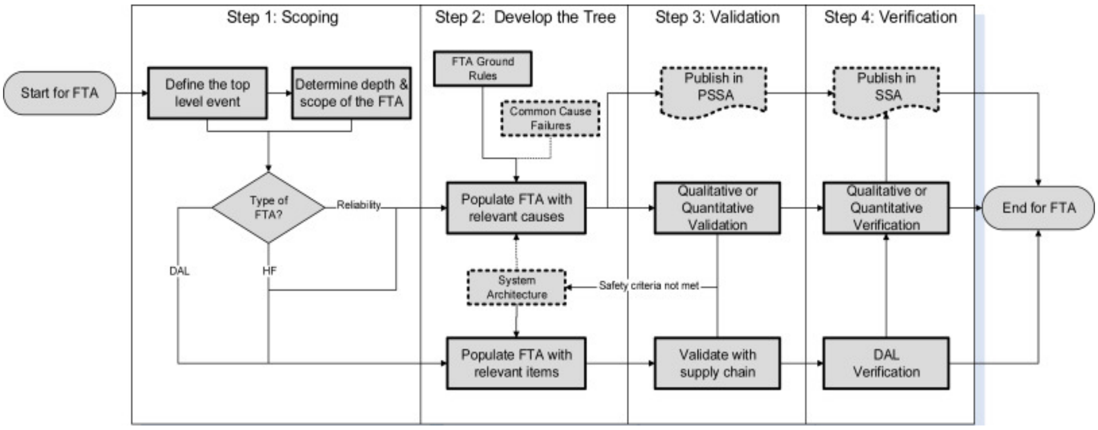

Figure 2. FTA model to perform risk analysis of a product

RBD is a graphical representation of the system's components and their relationships with regard to reliability is called a RBD [20]. The figure depicts the system's functional state (i.e., success or failure) in terms of the states in which each of its constituent parts is functioning. For instance, in a simple series configuration, every component must be operational for the system to function, in a simple parallel configuration; at least one component must be operational, and so on [21], [22].

APM is a method of asset management that prioritizes business goals in addition to the usual objectives of asset availability and reliability [23]. In industrial companies, APM has emerged as a key enabler of digital transformation for asset management. Modern APM blends classic asset management approaches with new digital technologies for dramatic breakthroughs in dependability, maintenance execution, and business performance [24], [25].

2. PROPOSED METHOD

To begin with system reliability prediction which is the way, which helps us to measure reliability, availability, maintainability, and safety of the system from component failures. This prediction also helps to compare the quantitative proposed design with respect to the design objective, which helps to meet the design requirements. Reliability prediction assists us to find the unreliability of the system and helps to assess the life cycle of the product. Mathematically it is defined as the probability of a failure free occurrence of a system, which should undergo through certain time and environmental conditions as shown in (1):

$$R(t) = e^{-\lambda t} \tag{1}$$

$R(t)$ is reliability of the system with respect to time, λ is failure rate per million hours (10^6 hours), and t is mission time in hours. These failures occurred in a period of time was expressed as $MTBF$ which was formulated as shown in (2) and (3).

$$MTBF = \frac{Total\ hours\ operated\ at\ time\ t}{Total\ number\ of\ failures\ occured\ at\ time\ t} \tag{2}$$

$$MTBF = \frac{1}{\lambda} \tag{3}$$

Here λ is failure rate per million hours (10^6 hours). Reliability was calculated on the system dual transmit receive module (DTRM) it contains a transmit and a receive block in it. The T/R modules are the basic building blocks of the active aperture phased array radar. The dual transmit/receive module consists of two independent T/R modules of 100 W each with individual output and common input connectors. The power supply is common to digital control circuitry and active monolithic microwave integrated circuit

(MMIC) devices. DTRMs are generative adversarial network (GAN) device technology based pre-amplifier and amplifier, hence onwards DTRMs are called GAN based DTRM. DTRM unit consists of RF/microwave hardware, digital subsystems, and power supply modules with system and application software. The DTRMs provide suitable power with relative phase for transmit and suitable taper with relative phase in receive. There are two transmit and receive channels in each DTRM. The functionality of DTRM is to transmit a desired waveform in a pre-determined spatial direction and receive signal from multiple channels in spatially excited volume.

Based on the results of reliability prediction MTBF and failure rate were calculated. The operational data, which was used to find the failure rate of the component, may get overstressed. This operational data, which was overstressed, is used to find the derating of the component. The term derating is explained as the probability of rising of reliability of the system based on the stress levels under the manufacturers stress ratings. It tells how the component has often been overstressed due to temperature, mechanical and electrical stresses. The main objective this paper is to find out the reliability prediction using part stress method, which provides MTBF and the failure rate of the system, and to observe the derating components of the system. Reliability of a certain individual component can be processed using MIL-HDBK 217FN2. This includes the military standard componential formulae and total description of reliability prediction including manual calculations. Reliability prediction can be calculated using two ways like parts count and parts stress methods.

2.1. Parts count method

In the process of parts count method input values like operating voltage, rated voltage, junction temperature, and power dissipation. Will not be used as the board was still in preliminary design phase. The occurred failure rate and the MTBF depends on the given quality factor for individual componential level. This parts count method is calculated using a mathematical formula as shown in (4):

$$\lambda Equip = n\Sigma i = 1Ni(\lambda G\pi Q) \tag{4}$$

where, $\lambda Equip$ is total failure rate in million hours, λG is generic failure for the ith generic parts, πQ is quality factor for the ith generic part, Ni is quantity of the ith generic part, and N is number of different generic part categories.

2.2. Parts stress method

The part stress analysis is used to determine parts failure rates in the detailed design stage when few assumptions about the parts used their stress derating, their quality factor, and operating stresses. This method is one of the most important method, which provides estimate of reliability based on parts stress data, for each component as formulated in (5):

$$\lambda P = \lambda b(\pi T\ \pi A\ \pi R\ \pi S\ \pi C\ \pi Q\ \pi E) \tag{5}$$

where, λP is the part failure rate, λb is the base failure rate, πE is the environment factor, πQ is the quality factor, πC is complexity factor, πS is stress factor, πR is resistance factor, πA is application factor, and πT is temperature factor.

3. PERFORMANCE ANALYSIS

Reliability analysis of the DTRM was calculated for both Tx and Rx. Reliability prediction i.e. failure rate and MTBF were calculated using ITEM software Ver.8.3.3. Some assumptions were used to calculate failure rate, MTBF and derating as mentioned.

3.1. Assumptions for reliability prediction

- The following assumptions have been made in order to complete this analysis.
- The analysis has been performed using parts stress method in accordance with MIL-HDBK-217FN2.
- The operating environment considered for DTRM is airborne inhabited fighter (AIF) controlled at 55 °C.
- Operational duty cycle is 100% continuous.
- In some cases, the part classification did not match those available in the reliability software. The closet match was chosen.
- Failure rates of the components which are not supported by the ITEM software have been obtained from MTBF values of the components from manufacturer/data sheet.

- Product of generic failure data and other π- factors as per MIL-HDBK-217F as applicable for parts stress method for reliability prediction has been considered.
- For unknown junction to case thermal resistance (θJC) value of some of the semi-conductors the assumed θJC value is 700 C/W.
- For tantalum capacitors (congestion window reduced (CWR) style), the circuit resistance is considered as 0.6 ohms.
- Mechanical items such as housings, screws, and base plates. we are not included in the analysis and assumed to have negligible failure rate.
- Chip type resistors were assumed RM resistors styles with non-established reliability quality level (depends on datasheet).
- Ceramic chip, micro commercial component (MCC) capacitors were assumed clock and data recovery (CDR) capacitor styles with non- established reliability quality level (depends on datasheet).

3.2. Failure rate prediction and mean time between failures analysis for overall dual transmit receive module

Reliability analysis was done for AIF environment at 55 °C using parts stress method. The occurred failure rate was 133.1306 failures per million hours (FPMH) and the corresponding MTBF was 7,511.4149 hours. Table 1 shows the analysis of MTBF and failure rate. The total mission reliability for 24 hours was 0.99680996. Failure rate is 133.1306 FPMH.

Table 1. Analysis of MTBF and failure rate

Part number	Description	Qty	F.r. X e-6	F.r. (k,qty) xe-6	Contrib. To NHA [%]
Xxxx	DTRM RX PCB	1	87.1289	87.1289	65.4462
Xxxx	DTRM TX PCB	1	46.001	46.001	34.5537

The Figure 3 shows failure rate of DTRM over the temperature and it can be seen from the above bar chart as temperature increases failure rate of the DTRM increases, hence adequate cooling need to be provided for these solid state devices to maintain better reliability and failure free performance. The Figure 4 shows failure rate of DTRM over the various types pf platform ranging from ground benign (controlled) (GB), ground mobile (GM), ground fixed (GF), AIF aircraft to multiple platforms. The quality level is accordingly varying as the platform complexity increases, as we can see from the above graph for ground benign the failure rate is less as compared to AIF, and missile launch (ML), as the quality level is dynamically varying based on the platform environmental conditions. Acronyms for different environment: airborne inhabited cargo (AIC), airborne uninhabited cargo (AUC), airborne uninhabited fighter (AUF), missile flight (MF), naval sheltered (NS), naval unsheltered (NU), and space flight (SF).

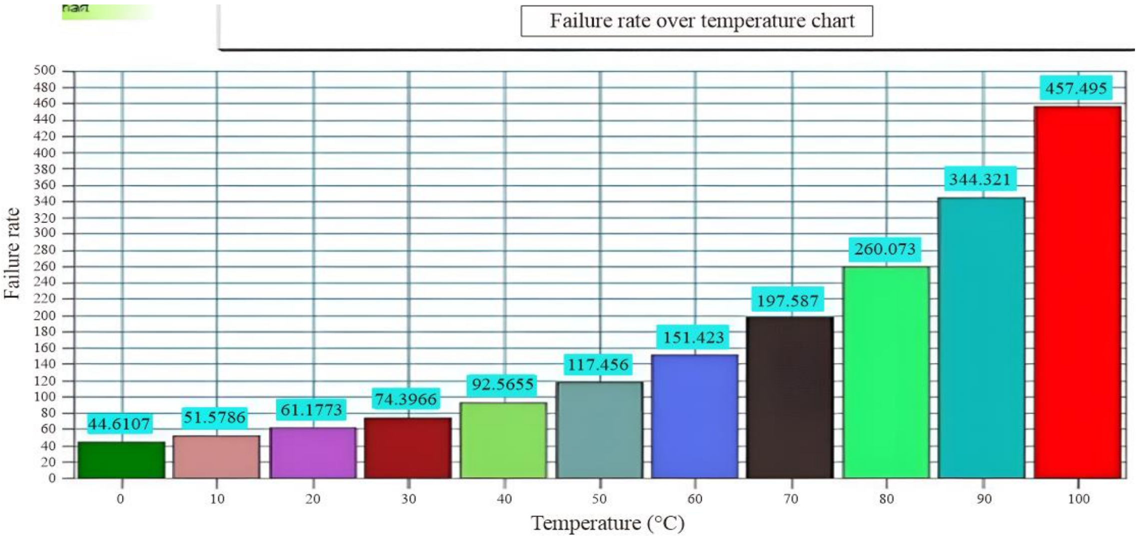

Figure 3. Failure rate vs temperature

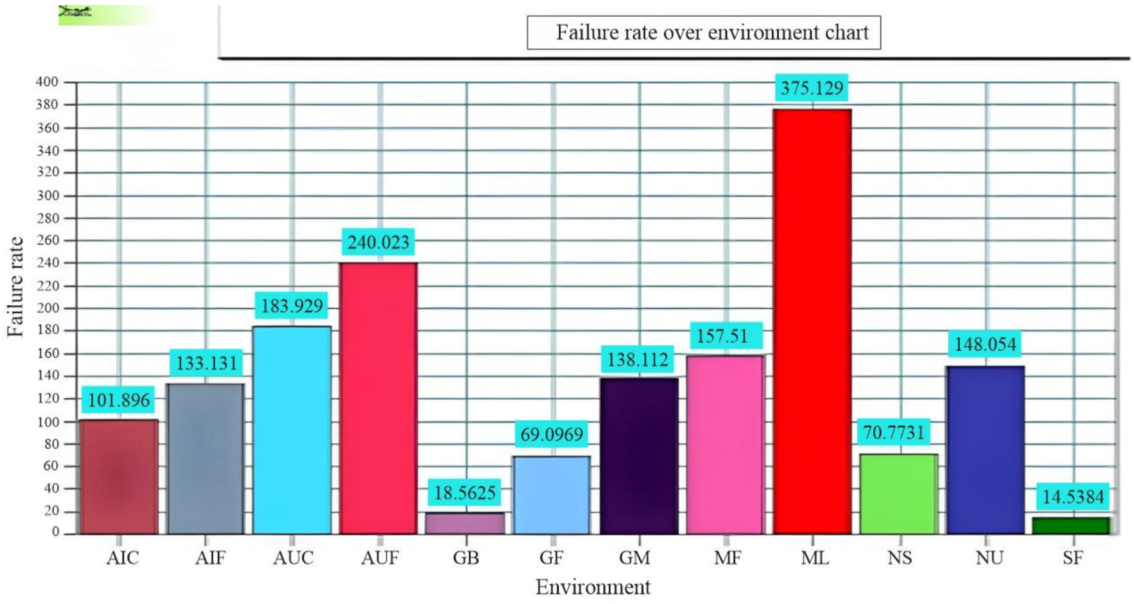

Figure 4. Failure rate vs environment

MTBF can be described as the number of hours to pass before a failure for a component, assembly or a system occurs. MTBF is inverse of failure rate whereas the MTBF increases reliability of the system increases gradually. As graphed in Figure 3 as the temperature increases the failure rate of the system increases and MTBF decreases. As there was a down, fall in MTBF reliability of the system increases. Figure 5 shows the MTBF vs temperature.

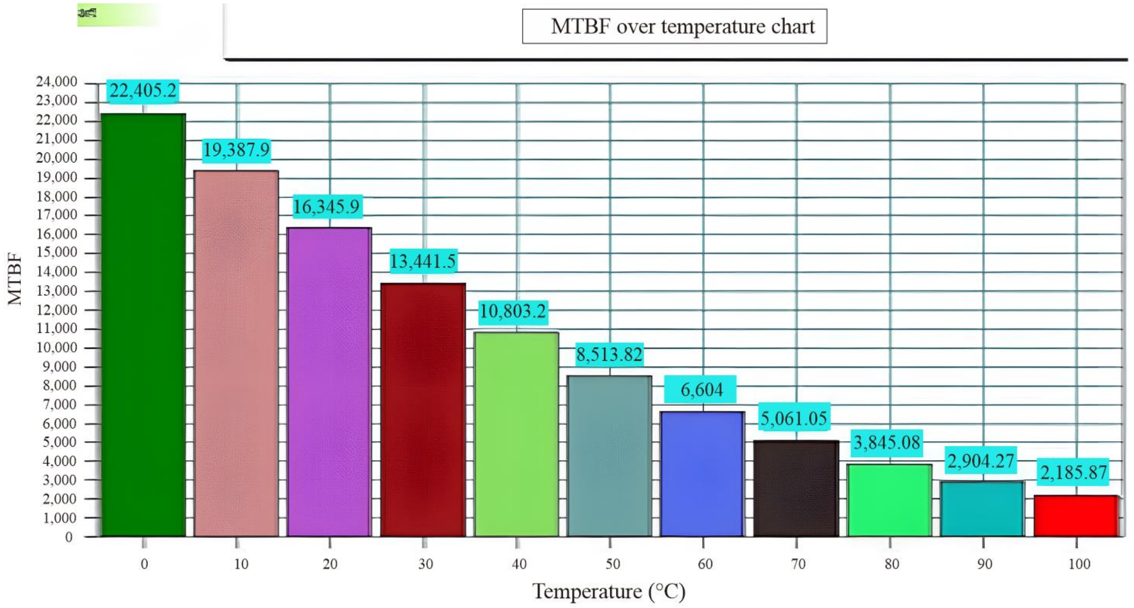

Figure 5. MTBF vs temperature

MTBF may also varies due to the environment. We were aware that the MTBF. Based on different types of environments MTBF varies accordingly. Among them AIF environment was chosen and the occurred MTBF is 7,511.42 as shown in Figure 6.

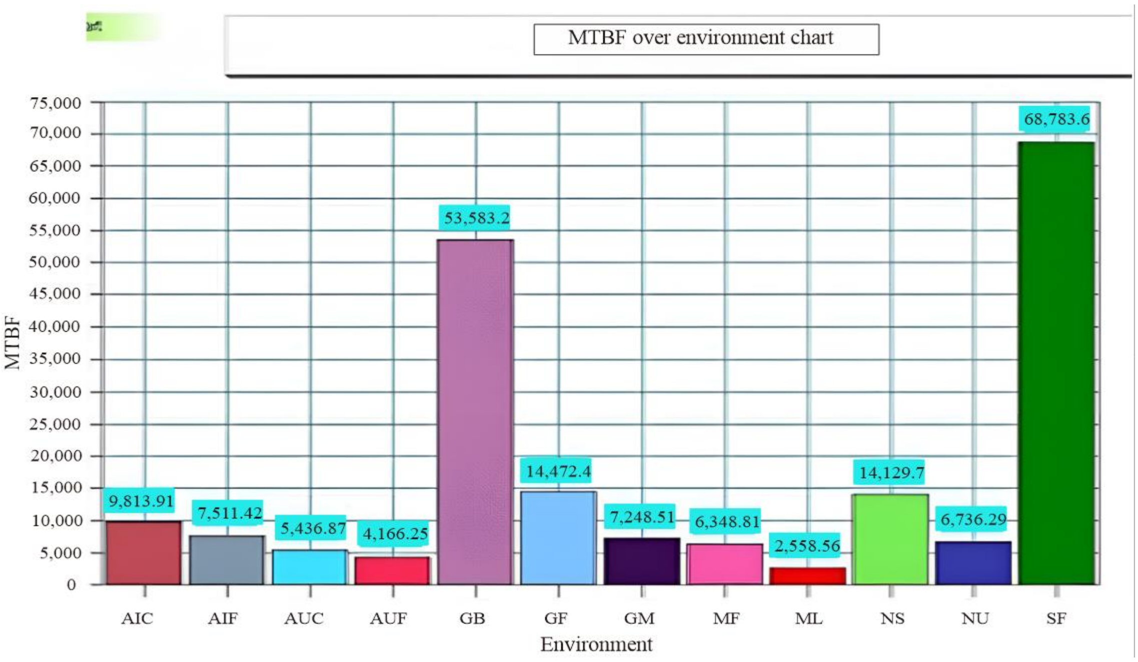

Figure 6. MTBF vs environment

4. CONCLUSION

In accordance with MIL-STD-217FN2, we investigated the failure rate and predicted the MTBF of GAN-based TRMs operating at 55 °C. A look at the individual block failure rate, the MTBF, and the percent contribution can provide insight into the failure rate of the DTRM over the course of time. However, because the failure rate of the DTRM increases in tandem with the temperature, these solid-state devices need to be cooled in the appropriate manner in order to maintain their dependability and prevent any issues from occurring. At a temperature of 55 °C, the failure rate of the entire system is 26.7367 FPMH. This indicates that the MTBF of the GAN-based TRM is 37,401.71 hours (1/λ).

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