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RELIABILITY ANALYSIS OF THE MSC SYSTEM

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ABSTRACT

MSC (Multi-Spectral Camera) is the payload of KOMPSAT-2, which is being developed for earth imaging in optical and near-infrared region. The design of the MSC is completed and its reliability has been assessed from part level to the MSC system level. The reliability was analyzed in worst case and the analysis results showed that the value complies the required value of 0.9. In this paper, a calculation method of reliability for the MSC system is described, and assessment result is presented and discussed.

Keywords : reliability, KOMPSAT-2, MSC, payload, satellite, quality, failure, MTTF

1. INTRODUCTION

Reliability assessment is one of the major items for system engineering in the planning, design, and operation of satellites. Satellites are normally launched in a severe vibration condition and are revealed in hostile thermal condition in space. In order for satellites to keep operations during the lifetime, Quality Assurance (QA), together with maintainability and risk assessment, should be applied to the system throughout the whole phases of the development. It makes the safety of satellites predictable, and can reduce chances of failure.

One representative index is reliability figure, which is generally defined as the probability of the successful operation of an item during any predetermined period of its useful life (Badenius 1991, Eisner 1997). The value is represented as a relative number between 0 and 1 where 1 is the best. Reliability is considered in the phases of planning, designing, and operation of systems, which is derived from the lifetime of each parts and components and their controlling software.

Since the Second World War, the concept of reliability has been converted into a quantitative figure. It was first developed by the Advisory Group on the Reliability of Electronic Equipment (AGREE) for electronic systems (O'Connor 1990). Reliability became a parameter of design, as it can be traded off against other parameters such as cost, weight, power, performance, etc. Lack of control and direction can result in costly retrofits or poor service during the lifetime of the system (Dhillon & Singh 1981). Reliability identifies potential problems, which can be reviewed and

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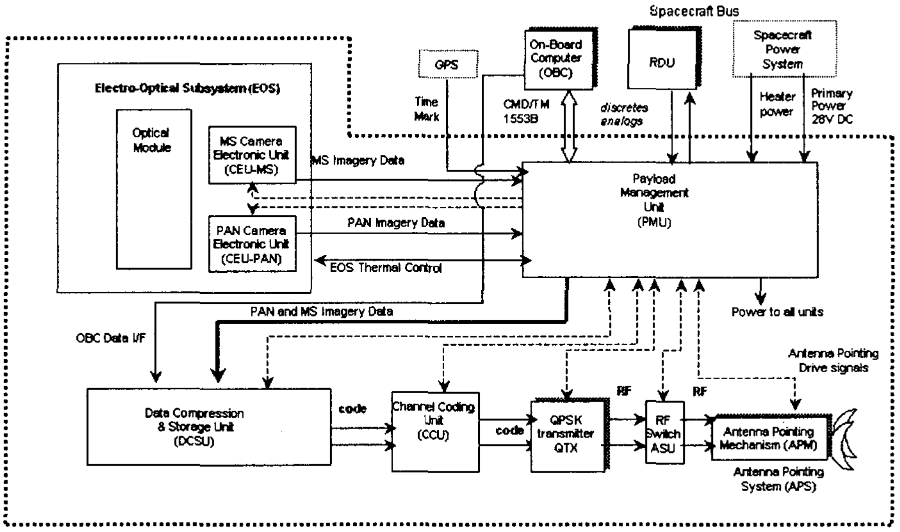


Figure 1. Configuration of the MSC.

whose design can be evaluated prior to testing. The reliability prediction provides input to further analyses, such as maintainability analyses, testability evaluations, and failure mode and effects analyses. Identified weak points by reliability analysis can be reinforced by adding redundancy or can be prepared by providing better accessibility for maintenance. (Morris 1990) Recently, the NASA strategy of better, faster, and cheaper has given more attention to the reliability aspect to achieve better performance on time and within cost (Lalli 1998).

Multi-Spectral Camera (MSC) is the only payload of KOMPSAT-2 (KOrea Multi-Purpose SATellite-2). The MSC is being developed in collaboration with KARI (Korea Aerospace Research Institute) and an Israeli company, EL-OP (Electro-Optics Industries LTD.). It contains both panchromatic (PAN) and multi-spectral (MS) channels for imaging the surface of earth at the height of 685km (KARI 1999, Kim et al. 2000).

The configuration of the MSC is shown in Figure 1 (EL-OP 2001). The MSC mainly consists of three subsystems, Electro-Optical Subsystem (EOS), Payload Management Unit (PMU), and Payload Data Transmission Subsystem (PDTS). The EOS contains optical units, telescope structures, CCDs, and their controllers, whose functions are achieving images and transforming the images into electronic signals. The PMU acts as a brain of the MSC, i.e. controls the MSC as a whole by giving commands, collecting telemetry data, refining image data, managing temperature, directing antennae maneuver, etc. The PMU also communicates with the spacecraft bus and relays powers to the subsystems of the MSC. The PDTS transmits images and ancillary data to ground stations. The PDTS also handles data by storing, compressing, and encrypting. Detailed constitution and functions of the units can be found from the papers of Kim et al. (2001, 2002), Heo et al. (2002), Kong et al. (2002), and Lee et al. (2002). The reliability of the MSC was set to comply with the value not less than 0.9 (KARI 1999).

This paper is focused on analysis of the system reliability, whether the MSC meets the requirement. Chapter 2 introduces the meaning of reliability and methods of reliability calculations. Actual reliability calculations on MSC are presented in chapter 3, and conclusion is followed.

2. BASIS OF RELIABILITY ANALYSIS

2.1 Reliability and MTTF

Reliability can be derived from failure rate. Failure rate of electronic parts used to be constantly degraded, except the early life failure in the early stage and wear out failure in the end of the lifetime. Therefore, the exponential failure distribution model is widely applied for predicting failure rate. It is one of the simplest distribution forms to actually calculate reliability value. The exponential failure density function $f(t)$ is defined as follows (Dhillon & Singh 1981):

$$f(t) = \lambda e^{-\lambda t}, \qquad t \geq 0 \quad \& \quad \lambda > 0 \tag{1}$$

where λ is a constant failure rate and t is time. The cumulative distribution function $F(t)$ and reliability function $R(t)$ are given by

$$F(t) = 1 - e^{-\lambda t}, \tag{2}$$

and

$$R(t) = 1 - F(t), \tag{3}$$

respectively.

Another measure of reliability is mean time to failure (MTTF), which is the expected duration until the time a unit or system is failed. MTTF of probability density function is given by

$$MTTF = \int_0^\infty tf(t)dt. \tag{4}$$

If the component has a constant failure rate λ, above relationship can be simplified as follows:

$$MTTF = \frac{1}{\lambda}. \tag{5}$$

2.2 Reliability calculations

Reliability can be calculated from a failure rate by the above equations. When several components are connected, the reliability should be assessed by the state of redundancy (Lee 2002).

- Non-redundant configuration (Series connection)

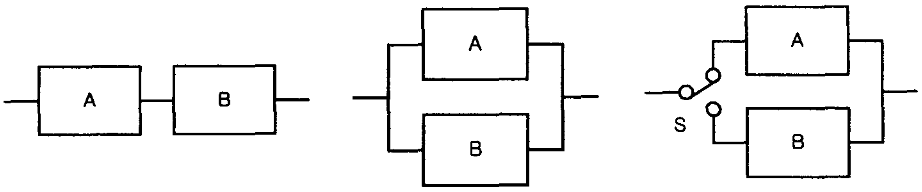
If two components are non-redundant, they are placed in a series of reliability configuration as shown in Figure 2a. It means that both A and B must be operative for the system if the system should work properly. Failure of one component results in failure of the whole components. The reliability of the system (R) is then,

$$R(t) = R(A)R(B) = \exp[-(\lambda_A + \lambda_B)t], \tag{6}$$

where $R(A)$ and $R(B)$ are the reliability of the component A and B, respectively. λ_A and λ_B are the failure rate of A and B, respectively.

- Redundant Configuration (Parallel connection)

Parallel configuration introduces redundancy and thus improves the reliability of the system. However, there is the penalty that the redundant component should be added. Redundancy is necessary when it is extremely important to keep a system alive in any case. Spacecraft or air traffic control



(a) Non-redundant system. (b) Active redundant system. (c) Standby redundant system.

Figure 2. Reliability configurations.

system is such a case. The parallel configuration of reliability can be divided into two categories, active redundant configuration and standby redundant configuration.

In active redundant configuration, more than one components are always active and failure of one component still makes the system alive and keep working. For a case of two components in parallel, the system reliability can be expressed as

$$R(t) = 1 - [1 - R(A)][1 - R(B)]. \tag{7}$$

Figure 2b shows an example of active redundant configuration, which is the block diagram of 1 of 2 active redundancy system. In general case, when m number of components are active among n number of components, the reliability equation is

$$R(t) = \sum_{i=0}^{n-m} \frac{n!}{(i!(n-i)!)} e^{-\lambda(n-i)t}(1 - e^{-\lambda t})^{i}. \tag{8}$$

In standby redundancy configuration, one or more backup components are added to primary component. The backup components are operated only when the primary component fails. The failure rate of backup components is much less than that of primary component, as the backup components are not active in normal operation. The ratio of the failure rate between backup and primary components can be defined as dormancy ratio, which used be set to 0.1 for satellites in low Earth orbit (Kim & Wrobleski 1996).

Figure 2c presents an example of standby redundancy configuration, which has a backup component and supposes no switching failure. The equation for reliability would be

$$R(t) = \frac{e^{-\lambda(1+r)t}}{r}[-1 + e^{\lambda rt}(1 + r)], \tag{9}$$

where r is dormancy ratio.

- Operation

The failure rates for the primary units are calculated as the average of operating and non-operating failure rates with weighting according to duty cycles, like equation (10). The failure rates for the redundant units are taken for non-operating conditions, and the calculation was performed for cold redundancy model.

$$\lambda = (\lambda_{op}\, t_{op} + \lambda_{nop}\, t_{nop})/(t_{op} + t_{nop}), \tag{10}$$

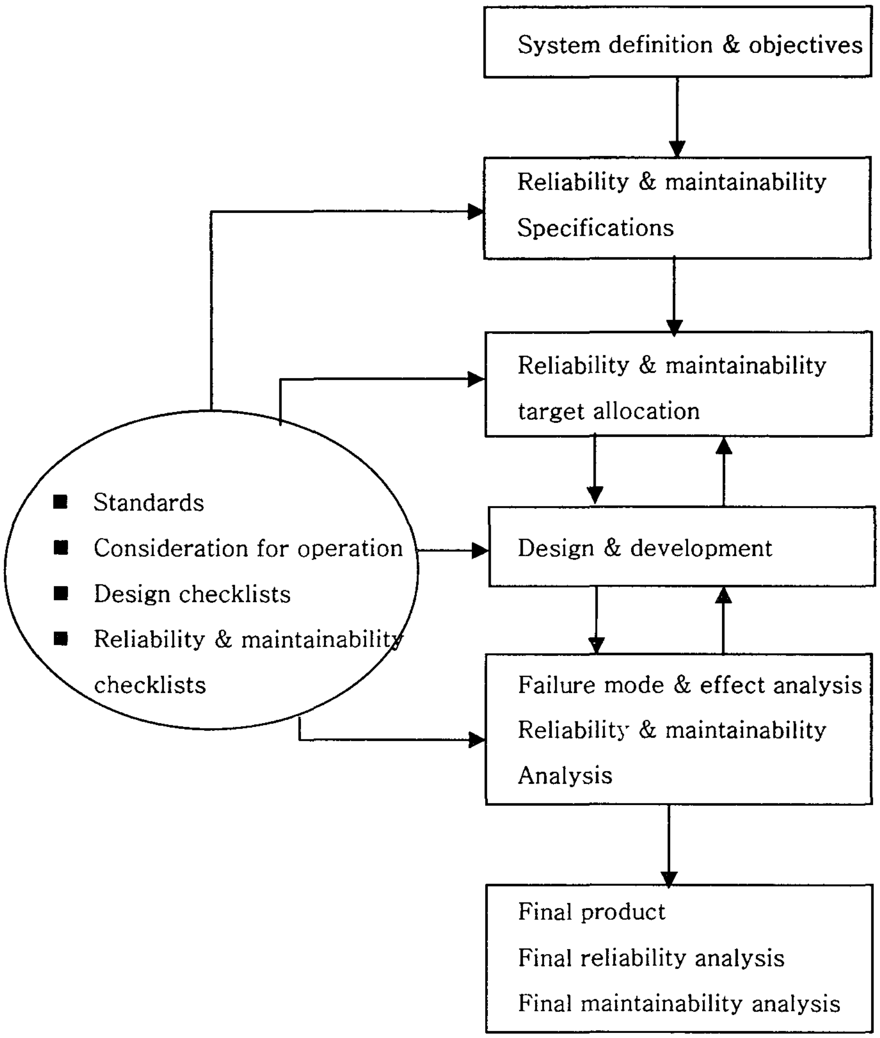


Figure 3. Process of quality assurance including reliability analysis.

where λ_{op} is failure rate during the operation phase, λ_{nop} is failure rate during the non-operation phase, t_{op} is the time period of operation phase, and t_{nop} is the time period of non-operation phase.

3. RELIABILITY ASSESSMENT OF THE MSC

3.1 Reliability Program Plan and Requirements

The MSC reliability program applies to the MSC payload and the mission unique elements. Applicable provisions of the program are flowed down to subcontractors via equipment specifications, control drawings and statements of work. KARI reliability engineer monitors reliability analysis and compliances to the requirements is monitored by EL-OP and KARI together throughout the program. The program follows a commonly used process for the reliability analysis, as shown in Figure 3. The reliability analysis is conducted together with maintainability analysis and FMEA (Failure Mode Effect Analysis), which are related each other and make it possible to assess the overall aspects of quality assurance of the system synthetically.

The design and analyses of the MSC should meet the reliability requirements. The reliability requirement of the MSC system is allocated to the unit level and incorporated into the unit level specifications. The allocations are established to each unit, accounting for the redundancy and duty cycle relevant to each unit (EL-OP 2001, Stern 2000). The reliability models for the MSC have been developed during the design stage and are continuously reviewed to update design changes which occur during manufacturing and testing of the units and the system. All the predictions are calculated according to the guidelines of MIL-STD-756B (US Department of Defense 1998) and the parts count method of MIL-HDBK-217F Notice 2 (US Department of Defense 1995). Equipments which require special operating condition, e.g. high temperature range, are analyzed by applying appropriate part stress methods. In the reliability model, reliability of the spacecraft bus and launch vehicle are assigned to 1.0. Failure rates of electronic parts are assessed by using MIL-HDBK-217F Notice 2 failure rates, while those of non-electronic parts are adopted from the orbital data bank in EL-OP's heritage. Duty cycle is identified for individual equipment. Failure rates for equipment in a non-operating condition are estimated as 10% of the active failure rate. A curve of reliability versus time should be maintained throughout the mission lifetime of 3 years.

3.2 Failure Rate Calculation

Reliability analysis has been performed with several assumptions, some of which were derived from the requirements and others from heritage and experience.

- Analysis was produced for worst case during the mission duration of 3 years (26,280 hours), with the duty cycle of 20% in operation and 80% in standby, and cold redundancy for standby units except thermal devices.
- Failure rates of components were assumed to be constant during life period, considering statistically independent failures for different components.
- A series of assembly reliability model is regarded, i.e. failure of any component causes assembly failure.
- Only hardware failures were considered, and failure rate in OFF state was assumed 0.15 times of that in ON state (Barel 2002).

The reliability prediction was performed under the environment conditions of the flight model and for the ambient temperatures derived by thermal analysis (Kaufman 2001). The summarized duty cycle and failure rate of each block is presented on Table 1. The back plane of the PMU is related to other blocks, and therefore the failure rate is distributed to related units. The failure rates assigned to the related units are listed on Table 2. The reliability values of the PDTS units are adopted directly from those given by subcontractors

3.3 MSC Reliability

The reliability of the MSC has been assessed based on the above assumptions. The assessments have been performed from the part level up to the MSC system level. Figure 3 represents the reliability diagram of subsystems and units in worst case, where the numbers in the diagram show failure rates. It can be seen that most of the units have redundant units. Heaters and thermostats should work all the time on orbit, while other units mostly have duty cycle of 20% for operation. That's why heaters and thermostats have many redundancies, as shown in Figure 4.

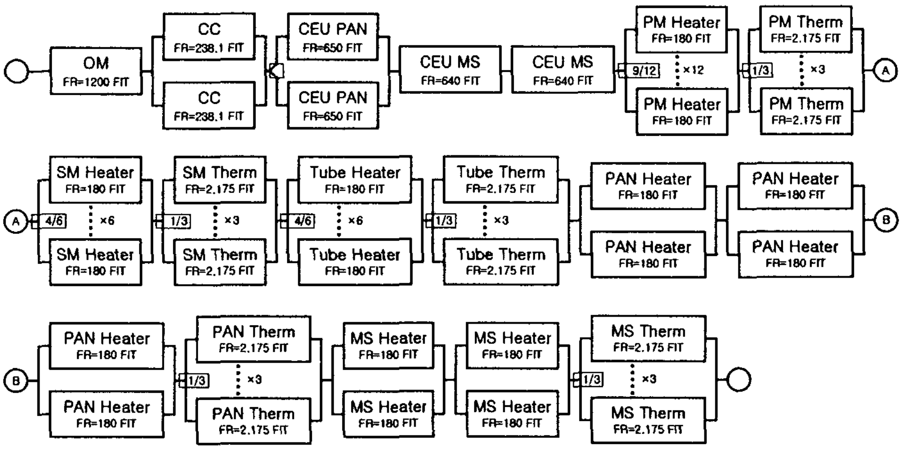
Table 1. Duty cycle and failure rate of each unit in the MSC.

UNIT	Duty cycle	λ(operating) Failures/10^6	λ(non-operating) Failures/10^6	λ(weighted) Failures/10^6
		EOS		
TCM:		8.33	0.88	4.61
Thermisters	100	0.002175	-	0.002175
Heaters	50	0.33	0.03	0.18
Optical Module	100	1.20	-	1.20
CEU PAN	20	1.75	0.18	0.49
CEU MS	20	2.0	0.20	0.65
CC	20	0.24	0.03	0.07
		PMU		
PSM	100	9.51	-	9.51
SBC	100	1.90	-	1.90
PSM THTM	100	2.76	-	2.76
TLM	100	1.38	-	1.38
NUC	20	3.19	0.32	0.89
APDE	20	0.53	0.05	0.15
Back Plane	-	2.86	Separated to other units (Table 2)	
		PDTS		
DCSU	20		R=0.9809	
CCU	20	4.18	0.418	1.17
QTX	20	-	-	0.956
ASU	20		R=0.99984	
APS	20		R=0.995	

Table 2. Failure rate of backplane distributed to the units.

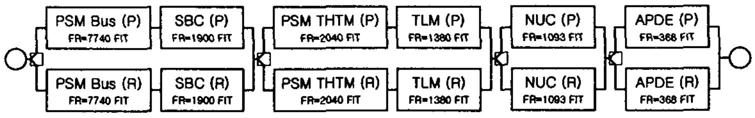
Unit connection	Failure rate /10^6	Unit connection	Failure rate /10^6
PSM 1 THTM	0.14	NUC Redundant	0.10
PSM 1 BUS	0.14	CC Primary	0.16
PSM 2 THTM	0.14	CC Redundant	0.16
PSM 2 BUS	0.14	CEU MS	0.16
DCSU Primary	0.08	CEU PAN Primary	0.16
DCSU Redundant	0.08	CEU PAN Redundant	0.16
DLS 1	0.08	APDE Primary	0.22
DLS 2	0.08	APDE Redundant	0.22
NUC Primary	0.10	PYRO Primary	0.17
NUC Redundant	0.10	PYRO Redundant	0.17
NUC Primary	0.10		

Figure 5 summarizes the reliability of the MSC system. The reliability of the MSC system is calculated to 0.91 for worst case, which comprises the required value of 0.9.



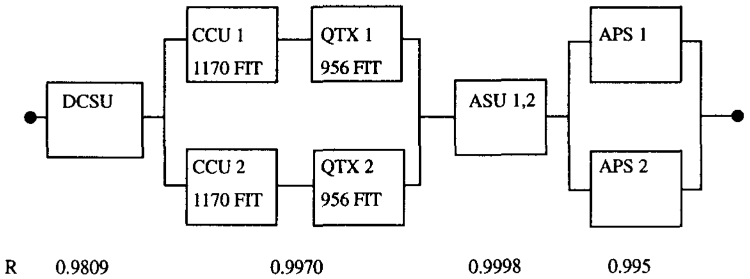
Note : For OM, number of faults to mission abort is 2.
Backplane interface and duty ratio is considered.

(a) Block diagram of EOS and thermal heaters in failure rate (Reliability R = 0.966).



Note : Backplane interface and duty ratio is considered.

(b) PMU reliability block diagram in failure rate. Units have standby redundant configuration (Reliability R = 0.966).



(c) PDTS reliability block diagram (Reliability R = 0.973).

Figure 4. Reliability diagram for each subsystem or unit in worst case. 1 FIT (failure in time) = 1×10^{-9} failure/hour.

4. CONCLUSION

As space flight is hardly repaired on orbit, products and its system should be assured to be functional before launch. Product assurance is therefore a key element to be performed in development phase. Reliability assessment is one way of examining the product whether to meet the target

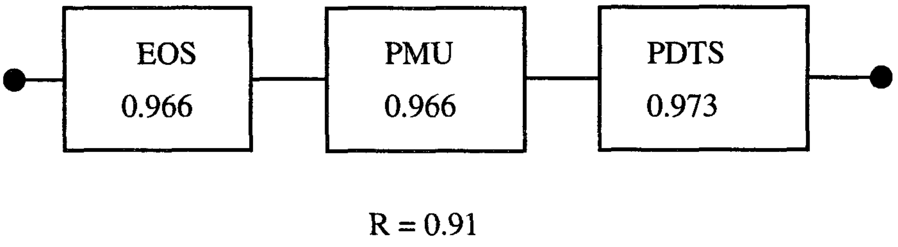


Figure 5. Reliability diagram of the MSC system. The numbers in the boxes are reliability values of the subsystems. The MSC system reliability is 0.91 in worst case for the mission lifetime of 3 years.

reliability value.

The reliability of the MSC is set to have 0.9 or more as a target value. Designs of system and units have been performed and parts have been selected to comprise the reliability. Reliability assessment has been performed for worst case and the calculation showed 0.91, which complies the required value.

The detailed design of the MSC has been completed and actual production of the parts and components is progressing. The reliability prediction will be continuously applied for configuration trades, changes, test, and operating results.

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