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Risk Analysis and Mitigation Strategy for ACD

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Abstract

Schedule slips and cost overruns are warning signs that the test program will be impacted. To minimize the risk and ensure that reliability is not compromised, this paper outlines a system engineering approach to analyze the risk and develop a mitigation strategy to reduce the cost overruns without impacting operational or functional reliability. This paper will describe space instrument system that was deployed, and provide a hypothesis on how the strategy could have minimized the schedule slips within the bounds of cost and quality.

1. Introduction

With the advent of the increasing use of custom integrated circuits in the implementation of sensor devices in outer space, NASA developed two custom Application Specific Integrated Circuits, labeled as A1 (analog ASIC) and D1 (digital ASIC) in this paper, used in the detection or absence of gamma rays incident on the sensor surface of the Anti Coincidence Detector (ACD) instrument. The ACD is a the first instrument to detect the absence or presence of gamma rays and as such provides a go/no-go decision metric to the other instruments, ergo to the scientist, to measure the real event and its approximate magnitude, or to reject the event based on its magnitude and persistence. This entails the following capabilities:

- Ingest of the event at the source
- Delivery of the information to the discriminator
- Analysis of the translated information
- Validation of the result
- Notification of the information and data to the command system
- Dynamic adjustment to the command response

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- Measurement of the analyzed data
- Reset to accept the next event

The command and data flow are asynchronous in that the decision to accept or reject the data emanates form a different entity. The block diagram shown in Figure 1 describes the high level data and command flows. Preliminary analysis was based on the initial prototypes of the A1 and D1 ASICs, and was performed to evaluate the risk in real numbers and developing a risk mitigation strategy to reduce the inevitable cost overruns. The analysis was carried out based on the results of the analysis presented at the Critical Design Review, where the schedule slips were reported and the performance of the subsystems measured to date.

The next step was to assign a weighting factor to each of these flows in terms of criticality of valid information. To evaluate or compare the weights the analysis normalized the weights in terms of cost of quality of information. To perform this step, the system Reliability Block Diagram was developed whereby the bottle-necks in the data flow were identified and analyzed.

2. Background

Each sensor tile has two Photomultiplier Tubes (PMTs) connected to it via fiber. Each if these PMT directs the ingested data to a custom designed PCB card. However, each PCB card has 18 PMTs feeding it, of which one is redundant. Figure 2 shows the block diagram for the ACD SYSTEM.

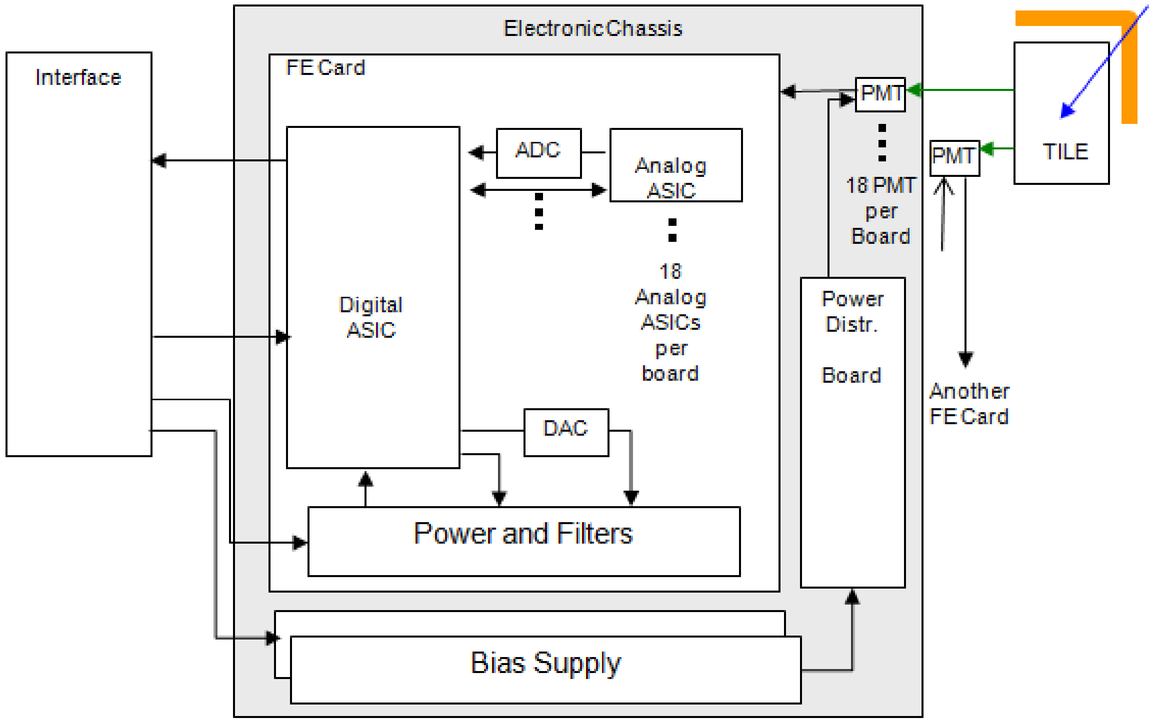

Figure 1. ACD Block Diagram

Thus from the Figure it is seen that there is some redundancy built into the FE card in that we have a 17 out of 18 Active Redundancy in a data flow from a PMT to a D1. Similarly it is seen that the Power and the AEM Connection have a one of two standby and active redundancy built in. These strategies though improving the overall Reliability of the system also increase the complexity to a certain extent. For example, in Figure 1, the addition of the 18th A1 has reduced the flexibility of tuning the card for anomalies inherent in an analog design by using up the real estate on the card. Though this may increase the overall reliability in terms of a redundant circuit, it has also increased the risk of failure by NOT affording the flexibility of tuning.

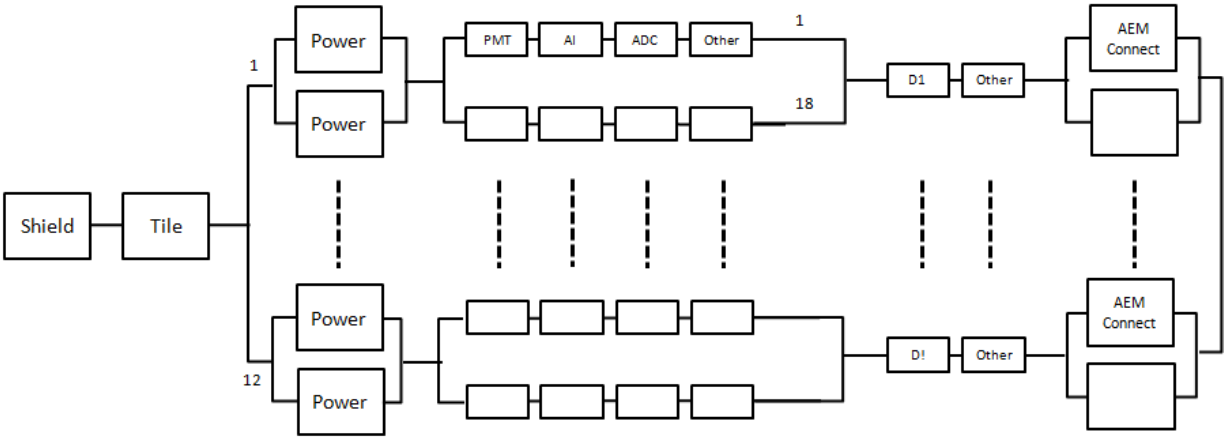

Figure 2. Reliability Block Diagram (DiVenti)

3. Risk Model:

Honour [1] describes relationships between technical value and the complexity, size and quality. The paper describes these terms as follows:

- Complexity: Related to the degree of interaction of the system components.
- Size: Includes the number of requirements, the number of function points, the number of new-development items and the overall development cost.
- Quality: Compares the actual resulting product system with the intended objective.

In the system under test, the complexity has been defined not only as the degree of interaction but also as the degree of test required to ensure compliance with the requirement. For example, if the sensors are measuring phenomena that have limited historical data; it is quite possible that the parameters set to measure compliance may be either over stated or understated. In this case the uncertainty has to be modeled and this increases the level of complexity in the test vectors.

The complexity of the ACD is based on the eight top level functions that are listed in the previous section. Each of these functions can be given a complexity score which is directly proportional to its interactions in terms of time and number of interactions; and criticality of the functional requirement.

$$\text{Complexity } C = \Sigma\, n_i\, t_i\, c_i \qquad (1)$$

where,

n_i = Number of interactions
t_i = Interaction time
c_i = Criticality of function

The ACD system's size attributes under can be broadly allotted to the hardware requirements and the software requirements. The hardware requirements are new and modified depending on the elements that we are dealing with. For example, the ASICs A1 and D1 have new functional requirements, whereas the power, ADC and shields have different attributes that have to be verified based on the functionality that the overall system needs.

$$Size = N_i \times W_i \times Td_i \quad (2)$$

where,

N_i = Number of requirements
W_i = Weighting
Td_i=Development time

The total number of HW, SW and System level requirements is shown in Table X. There are functional requirements for A1 and D1 and in addition to the normal HW requirements that they have to meet, these chips have also got new functional requirements. These requirements have a weighting added to them to signify standard requirements or new requirements.

Quality is one of the most important and difficult attribute to qualify. Since quality is seen differently by the different viewpoints, i.e. stake holders can vary from the customer to the implementer with many concurrent engineering disciplines in between. In the system under test we had two quality objectives; (1) the resulting pulse measurements have to be accurate and (2) the number of pulse measurements has to be realistic. This implies that the discriminator circuitry has to be fast and accurate in detecting the pulses.

The fidelity of the design (Mirchandani []) is defined as the accuracy and quality of the information received, processed and delivered. This is further qualified as the quality of the processing algorithms in terms of the accuracy, integrity, and correctness of the output. The metric is measured as Performance Quality and defined as data processed per unit time and is expressed as a function of the processing rate, error rate and reliability.

$$Q = (a.D_i - D_i/e)\eta = (a.D_i - E).b.R = (a.D_i - E).b.e^{-KQ.t} \quad (3)$$

where,

D_i	= Input data in bytes per second		
e	= Number of errors in a 1,000,000 bytes		
E	= Error bytes per second		= D_i /e
η	= Efficiency, proportional to Reliability		= b.R
b	= Percentage of requirements met, function of phase		
K_Q	= Failure Rate number of failures per unit time, function of phase		
t	= Test time		
R	= Reliability	= $f(K_Q.t)$	= EXP($-K_Q$.t)
a	= Criticality or Importance constant from 0 to 1		

This is directly proportional to the quality and specification of the detector and the speed and quality of the processing element. In certain instances a faster processing time allows a more accurate translation of raw data to meaningful information, but at the cost of higher power consumption and perhaps higher cost.

Honour [1] goes on further elaborate that the technical value is directly proportional to size, complexity and quality. However, for a given duration, cost and risk, these factors are inversely proportional. This means that for a given technical value, any further increase in size would decrease the quality of the system, or any further increase in complexity would decrease the size of the system and so on. Given that cost and duration are defined and set by the program, the most basic definition of risk maybe stated thus: Risk represents problems that have not yet occurred. Thus given this definition and the fact that duration and cost are 'fixed', we can develop a heuristic to evaluate RISK and thus minimize it within the constraints. We could also go a step further to show that any relaxation of the management mandated constraints will give the system a greater technical value in terms of quality, complexity or size.

4. Analysis:

It is the intention of the analysis to show that the optimization in size is not feasible since it entails a further draw on system resources, i.e. power, development schedule, and testing. Thus the increase in technical value would most certainly increase either the complexity of the system or the quality. The decision to choose one over the other can then be made using a pair wise comparison either by plotting the Risk vs. Technical value according to Honour and the selected dependencies or by using AHP. This paper uses the AHP to analyze the data.

AHP is a decision tool that takes pair wise comparison and allows the decisions to be made on pre-agreed criteria. It is the contention that that AHP can remove biases if used with a large group of participants with domain expertise and independent thought. The factors that were used to optimize the technical value were selected taking into consideration the environment that the system was going to be used in, the uncertainty of the environment in terms of the radiation, gamma ray frequency and test time available to meet the launch schedule for the instrument. Integer programming methods could have been used to maximize the objective in terms of cost variables; but since that process would require actual measurements to obtain a more realistic solution a relative comparison method using AHP has been used.

5. Requirements Analysis:

Table 1 shows the requirement analysis for the functional elements that are shown in Figure 1. It should be noted that these requirements were derived at the top level and all interactions were allocated on the basis of the functions that the different elements will perform. The number of requirements and the weighting is based on the overall objective of the instrument. The main objective is the capture and translation of gamma rays to electrical format. This would highly weight the criticality of the tile, power source and PMT.

Table 1. Requirements

Subsystem	Objective	Weight	Requirements	Development time (mths)
Shield	Protects the sensor	7	1	1
Tile	Sensor	10	1	1
Power	Provide power	10	7	1
PMT	Capture the optical sensor data	10	5	1
Resistor NW	Down converts optical sensor data for A1	8	5	2
A1	Translate the optical sensor data into electrical format	8	14	12
ADC	Translate the electric data to digital data	8	16	10
D1	Analyze the digital data	10	12	12
AEM	Control (ACD Electronics Module)	9	3	10
Other	Infrastructure functions	5	5	6

The software and firmware components have been given equal time even though they are of different size in terms of instructions. The ASICS were not complicated to design but the lead time required using external resources to obtain the finished product. The circuit boards had the same outsourcing issues and were evaluated thus. Based on their development time the other elements are relatively allocated time as shown in Table 1.

6. Performance Analysis:

Table 2 shows the performance and quality characteristics for these subsystems and values entered for the beginning of the system test process. This assumes that when the system is turned over to system test, some useful life of the PMT and ASICs has been depleted; and that sufficient string and integration tests by the developers have eradicated most of the level 1 and 2 failures that cannot be recovered without manual intervention.

Table 2. Performance and Complexity

Subsystem	Requirement Goal	Criticality	MTBF	Time of Interaction	Interactions	Complexity	Performance
Shield	1	0.7	1,000,000	0.1	1	1	0.70
Tile	0.9	1.0	1,000,000	0.1	1	1	0.90
Power	1	0.8	48,083	0.7	7	289	0.07
PMT	0.9	0.9	9,617	0.2	2	18	0.53
Resistor NW	0.9	0.9	2,000,000	0.3	3	41	0.18
A1	0.9	0.8	4,980	0.5	5	288	0.07
ADC	0.9	0.9	17,627	0.3	3	146	0.12
D1	0.9	0.8	4,980	0.5	5	248	0.07
AEM	0.9	0.4	80,585	0.5	5	33	0.18
Other	0.8	0.5	98,045	0.4	32	358	0.38

7. Reliability Analysis:

To evaluate the performance with respect to the reliability or dependability of the system requires an understanding on how the system has been configured to maximize fault tolerance since once the instrument is in space it is not accessible for corrective maintenance. The options used were to provide redundancy for the elements that are more prone to environmental fluctuations. The reliability block diagram shown in Figure 2 has been analysed and is shown in Figure 3. The analysis considers recovery actions, coverage and common mode failure events to provide an overall availability calculation for the system. The analysis was carried out with a k out of n system for the system, which in this case was the Front End Electronics Card. The analysis was performed for 1 of 12 and 11 of 12 cards and the RBDs shown in Figure 3 show that there was a very slight difference in the overall availability of the system. From Table 2 it is seen that the allocated reliability that the ASICs and the PMTs have the lowest reliability numbers. The PMTs have a fixed life time and it is imperative that they are tested to eliminate infant mortality but at the same time not tested too much so as to lose their useful life. In a similar analysis it is seen that the ASICs have a predicted reliability based on their complexity and the fact that they are new designs with a limited operational usage. It should be stated here that space instrumentation bases the range of measurements on known information which is sparse as for any space data.

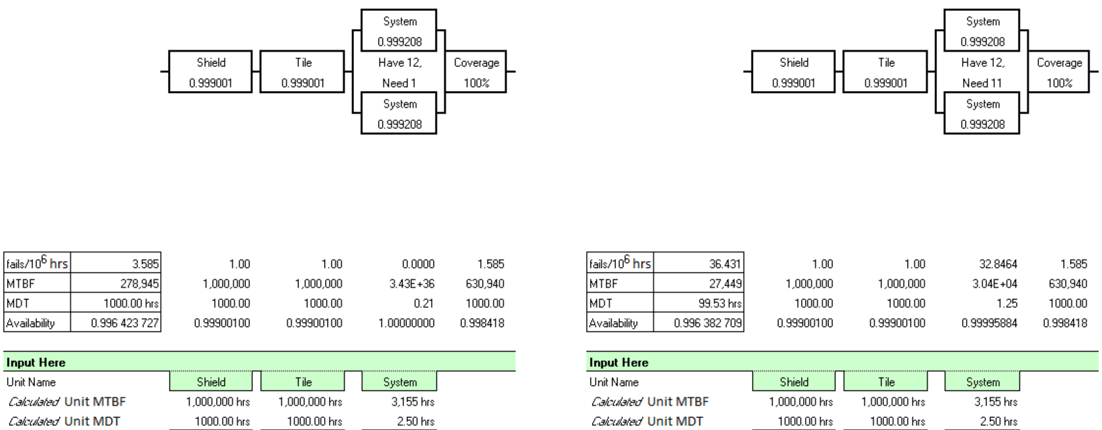

Figure 3. Reliability Block Diagrams

Thus a decision has to be made to widen the range so as to not overload the system at the expense of performance or narrow the range based on known information and accept the probability of an overload which could cause a failure. However, the reliability growth achieved through a well planned test regime could optimize the overall system reliability.

8. Analytical Hierarchical Processing Results:

The AHP analysis was performed comparing schedule with cost to achieve the goal of Complexity, Size and Quality.

Table 3. Analytical Hierarchical Processing

	Complexity	Size	Quality	Combined Scores
Development Time	0.714	0.333	0.429	0.491
Test Time	0.286	0.667	0.571	0.509

The results from the AHP gave the Test Time Attribute the higher score with respect to Complexity, Size and Quality minimizing risk.

9. Future Work:

The technical value using the test time as a variable and developing a utility model is the basis for future work in this area.

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