BIT ENABLED WDM AVIONICS OPTICAL NETWORK: A STUDY IN RELIABILITY, MTBF & COMPARISON WITH NON-BIT BASED AVIONICS MAINTENANCE CYCLE

Wg Cdr Nikhil Verma (IAF) (1), Md. Easir Arafat Papon (2),

(1) Instructor Class-A, Military Institute of Science and Technology
Email: nikhil.sarala@gmail.com,
(2) UG BSc Engg. (Aeronautical Engg- Avionics)- Level-4, Military Institute of Science and Technology
Email: a.easir@gmail.com

ABSTRACT

This paper describes the need and advantages of WDM optical network and its technical specifications to show it as a reliable and modular system to use in aircrafts. The paper explains the development in Avionics Optical Network Architecture, comparing Built In Tests and non-Built-In-Test based maintenance cycles. The paper has shown basic calculations to bring out the inherent advantages in failure rate and reliability in BIT enabled avionics optical architecture.

KEY WORDS: Avionics Optical Network, BIT, Reliability, Failure Rate, Aircraft Maintenance Cycle, Fault detection, Fault Isolation.

1.0 INTRODUCTION

The requirement of high bandwidth data communication networks for on-board avioniessystem is rapidly expanding in military & civil aircraft[1]. It is not possible for the conventional co-axial copper cable based avionics transmission system to meet the needsof a light weight, space saving, high bandwidth, electromagnetic interference free airborne avionics network along with high reliability. Optical avionics networking standards and All Optical Wavelength Division Multiplexing (AO-WDM) are emerging as next generation avionics network to meet bandwidth & reliability requirements.Built in Test (BIT), available as protocols of ARINC-429, ARINC-629 & MIL-1553B standards have now been developed for AO-WDM avionics networks. Reliability & MTBF calculation of optical WDM avionics networks are providing encouraging results.

2.0 AVIONICS OPTICAL NETWORK ARCHITECTURE (AONA) AND DEVELOPMENTS

The AONA can be divided into three optical fiber linked categories[2]: Star Link, Cross Lane Link &Point-to-Point Link; figure 1. Line replaceable units (LRUs) like Bus or Master Controller, flight control computer, air data computer, inertial flight control devices, avionics navigation systems etc. are placed in various locations in an aircraft. These devices are connected via star linked network.The cross link is used to transfer data between specific units and point-to-point link connects two points, not requiring the direction of the bus control devices. It is the system in which various data repeatedly sent from transmitter in a certain frequency are decoded but only the necessary data are accepted[2]. As in conventional ARINC or MIL 1553-B networks, AONA is also based on dual redundant architecture with two back bone buses having each LRU connected to both for fail safe operation, figure 2.

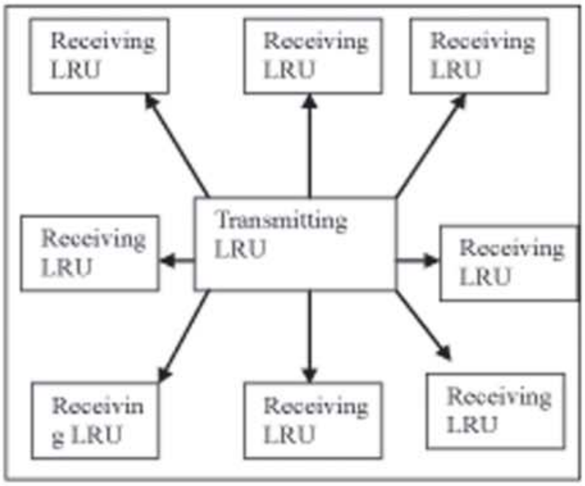

Figure 1: Optical fiber link

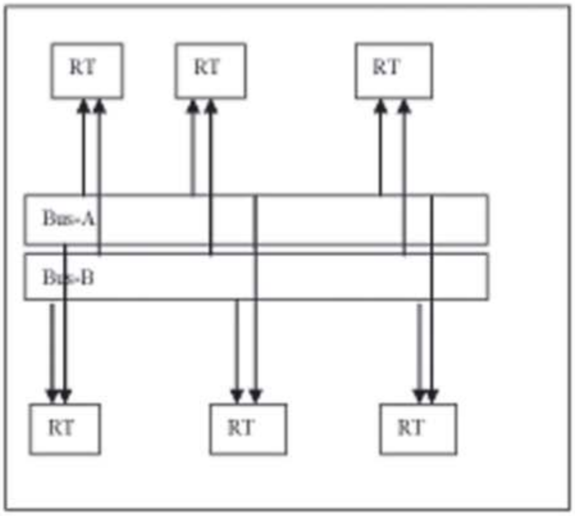

Figure 2: ARINC 629 Bus Configuration

Research and development as well as testing of variousconfigurations of AONA have been conducted in the past. The US-Navy carried out, ALOFT (Airborne Light Optical Fiber Technology) project in 1974-1977 to test the applicability of the optical fiber in aviation[2]. NAL (National Aerospace Laboratory) conducted research with the objective of applying the optical technology to the future STOL aircraft[2]. PHONAV(Photonic Network for Avionics), was aimed to identify main stream optical networking concepts applicable to avionics and defining suitable network architectures and protocols for a global optical bus using devices that can operate under hostile operating conditions[3], also NAVAIR (Naval Air System Command)initiated a series of science, technology and trade study program explaining technical approaches for implementing avionics fiber optic network Built-In-Test (BIT) in 2002[3]. In 2004, DASC (Digital Avionics Systems Conference), described the application of BIT technology for avionics fiber optic network health management diagnose[4]. ROBUS protocol was developed to show the method for no data lost at destination conflicts on congestion[3].

3.0 FAILURE RATE AND RELIABILITY IN AONA

Reliability can be stated as the probability that an item or asystem will perform under stated conditions for a stated period of time. For avionics systems, reliability, R, is expressed as[4];

$R(t)= \mathrm{Exp}^{-\lambda t}$ .... (1)

Where, R = Reliability; a number between 0 & 1

t = the operational time period

λ= failure rate; the total number of failures within the population divided by the total number of life units expanded by that population during a particular interval under stated conditions.

For AONA, backplane data rate of 1 Gbps, sensor/video network data rate of 2 Gbps and a maximum throughput >50 Gbps are foreseen[3].

Considering these values, for an average of 1 hour flying, at a maximum throughput of 50 Gbps, number of bits transmitted and received per hour

$$= (50 \times 10^{12} \times 3600) \text{ bits}$$

$$= 18 \times 10^{16} \text{ bits}$$

Hence, 18×10^{16} bits are the throughput or total bits transmitted or received per hour. Reliability relates to error free bits transmission or reception. Assuming reliability of 98%, then for a throughput of 18×10^{16} bits per hour, total live units or error free bits would be

$$= 18 \times 10^{16} \times 98\%$$

$$= 17.6 \times 10^{16} \text{ bits per hour.}$$

Undetected error rate is the number of error bits that will not be detected per unit time for total number of errors detected. For AONA, undetected error rate of 1×10^{-14} have been reported to be ideal condition [4]. Hence, out of 10^{14} detected errors 1 error will remain undetected. Failure rate, λ is defined in equation 1. Hence, for live unit throughput of 17.6×10^16 bits per hour, failure rate, λ would be

$$= \frac{10^{14}}{17.6 \times 10^{16}} \text{ or } 5.7 \times 10^{-4} \text{ bits per hour.}$$

MTBF (Mean Time Between Failure) is the inverse of failure rate (λ)[4], hence:

$$\text{MTBF} = \frac{1}{\lambda}$$

$$= \frac{1}{5.7 \times 10^{-4}}$$

$$= 0.175 \times 10^{4} \text{ hours.}$$

The results are summarized in table 1.

Flight Duration	1 hour
Data Throughput	$18x10^{16}$ bits/ hr
Reliability	98%
Total Live Units	$17.6x10^{16}$ bits/hr
Failure Rate	$5.7x10^{-6}$ bits
MTBF	0.175×10^{4} hours

Table-1: MTBF and Failure Rate Calculations

In aviation MTBF alone would not clearly define the reliability of a network. As system operation is directly related to the flight time and failures or snags would affect the flying hours. Hence, there are other terms necessary to be analyzed for complete studies on AON. MFHBF (Mean Flight Hour Between Failure) is the average time between failures, computed by dividing the length of time between failures by the accumulated number of hours. Failure free operating period is the period of time between first start-up and first failure.Other reliability terms applicable to avionics include MTBM (Mean Time Between Maintenance), MTBCF (Mean Time Between Critical Failure), MTTF (Mean Time To Failure), Mean Down Time, Operational Availability etc.[4].

4.0 FAULT DETECTION IN BIT BASED MAINTENANCE CYCLE

BIT is an invaluable feature of modular embedded system avionics architectures that are used of critical applications such as avionics mission sensors and weapons. BIT provides level of confidence in correct operation of each module in the network at both power-up & during normal operation. As more and more critical embedded system, either in hardware or software are included in avionics network, it is increasingly important to evaluate BIT performance and interaction with system software[5,6]. Reported benefits of BIT include shorter downtime due to reduced fault finding, fewer removals of LRU and reduced life cycle cost.However, there have been concerns about actual capabilities and limitations of BIT[6]. BIT can be carried out in three different ways. These are:

(a) *C-BIT (Continuous BIT):* This BIT is always being conducted in background whenever a system is operated. C-BIT is transparent to the user and does not affect normal operation or user interface of the system.

(b) *I-BIT(Interrupted BIT):* Operator can interrupt the normal operation of a system for a health monitoring test. P-BIT is a truncated version of C-BIT. The results of I-BIT are displayed on the user interface screen. During the time I-BIT is being conducted the system under test is not available for operation.

(c) *P-BIT (Power-on BIT):* Every time the system is powered on, BIT is conducted. The system is declared fit and handed over to the user for operation only on completion of the P-BIT.

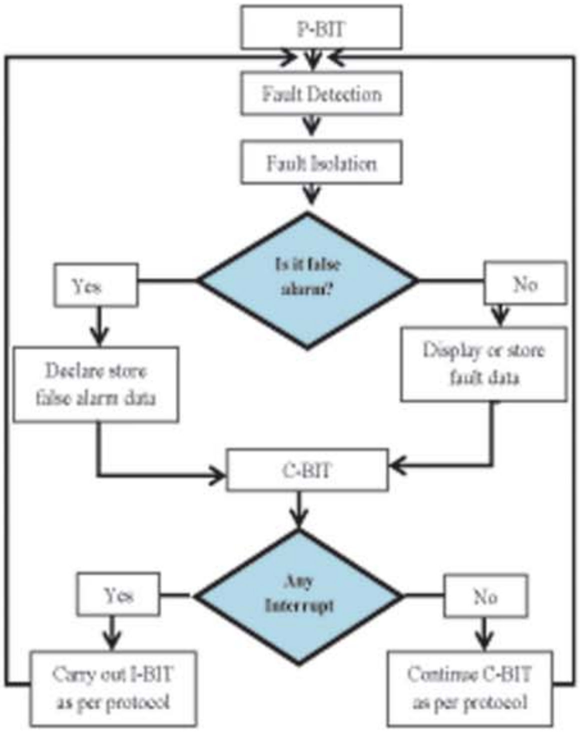

Figure 3: Sequential relation of fault detection, isolation & false alarm in BIT

Each of these tests is avionics protocol dependent and is complimentary to each other.Some of the results of BIT are displayed on the user interface while complete health monitoring data is stored in the avionics network master controller for retrieval and analyses or decisions by the master controller as per the protocol standards.

In the on-board avionics network, master controller computer after BIT provide its results either on a user interface in the cockpit, say a Multi Functional Display or a Heads Up Display, or stores the results in an onboard memory. However, both for displaying the result or storing it in an on-board memory, master controller must conclude that the

BIT has ensured that the fault is correctly detected, isolated and there is no false alarm. Hence, BIT reliability depends on all three parameters-fault detection, *fault isolation and false alarm rate*. The sequence of operation and relation to three categories of BIT is shown in figure 3 and details are explained below.

(a) Fault detection is the ratio of BIT detected failures divided by total system failure.

Fault Detection = (Bit detected failures/ Total Avionics Failure) x 100--------- (2)

Usually fault detection rate lies between 90-95% [4].

(b) Fault isolation is the percentage probability that the faulty avionics LRU or fiber optic cable segment is correctly isolated.

Fault Isolation = (Identified Specific Fault/ Total Faults Identified) --------- (3)

Assuming identification of specific fault from total fault identified to be 85% and fault detection to be 95%; Isolation rate would be

$(\frac{0.85}{0.95}) \approxeq 0.90$ or 90%.

(c) False Alarm is the measure of incorrectly detected failures which result in unscheduled maintenance actions[3]. It should be as small as possible.

False Alarm = Operational Time: Mean Time Between False Alarm------- (4)

From above relation, false alarm would be 1 to infinity. Ideally, false alarm should be 1 or figure as close as possible to 1; i.e. operational time and MTBFA to be equal.

Hence, with 95% of the total faults detected and out of these 95%, 85% faults are correctly identified it is possible to achieve approximately 90% isolation rate in a BIT enabled fault diagnoses and maintenance cycle in WDM AONA.

Figure 3 shows sequential relation of fault detection, isolation, false alarm and the three BITs protocols. As shown in flow chart, the system can detect a fault under any of the three BITs. A higher percentage of fault detection and isolation is preferred in a maintenance cycle. However a well-researched, robust and tested BIT protocol is desirable to ensure that MTBFA is as large as possible.

5.0 COMPARING NON-BIT AND BIT ENABLED MAINTENANCE CYCLES

In a non-BIT based maintenance/ servicing/fault rectificationcycle (MSRC), figure 4, the reliability of fault diagnose, fault isolation and fault rectification is restricted. Also, preventive maintenance is reduced to maintenance procedures/ manufacturer's manuals/directives etc. Pilot-Reported Snags (PRS) are analyzed as per experience of ground crew. Non-BIT MSRC is a hierarchical process with limited scope for fault analysis or system health monitoring. Although, using an external data bank of faults, causes and remedies etc. a cause-effect diagnostic tree can be developed. However, the system is more dependent of individual skill & experience for assimilation, analysis and diagnostics.

In comparison BIT based MSRC is based on *'if it isn't broke, don't repair it'* maintenance philosophy. The BIT based MSRC provides at every stage an option to analyze the BIT data for system health or failure parameters monitoring, figure 5, before actually proceeding with the rectification or maintenance. Application of BIT based MSRC, a digital avionics data bus protocol also provides feasibility for remote transmission of BIT error code from aircraft to aircraft maintenance base in real time or nearly-real time to ensure monitoring & timely decisions. BIT-enabled preventive maintenance may provide to minimize aircraft downtime. The on-board data bank of BIT parameters results in preventive or predictive maintenance rather than corrective maintenance associated with non-BIT MSRC. For example, inspecting and checking a marginally functional fiber optic connector terminals end face is much less time consuming than run on the aircraft. The aircraft downtime can be minimized via a BIT-enabled maintenance code by isolating the fault to the actual location on the craft[4].

NAVAIR (Naval Air Systems Command) also reviewed the optical BIT circuit technique findings to avionics fiber optic system prognostics health monitoring and integrated air vehicle health monitoring[3]. The BIT technology for avionics fiber optic network entails several development steps which includes start-up, continuous, initiated, breadboard, brass board, system & soft development, integration, test & evaluation and operational test & evaluation. Without BIT while doing hand inspection more signal loss may create than the detected fault itself. So, to improve reliability some companies are working on cables, connections and splices that can take more physical abuse than existing system [4].

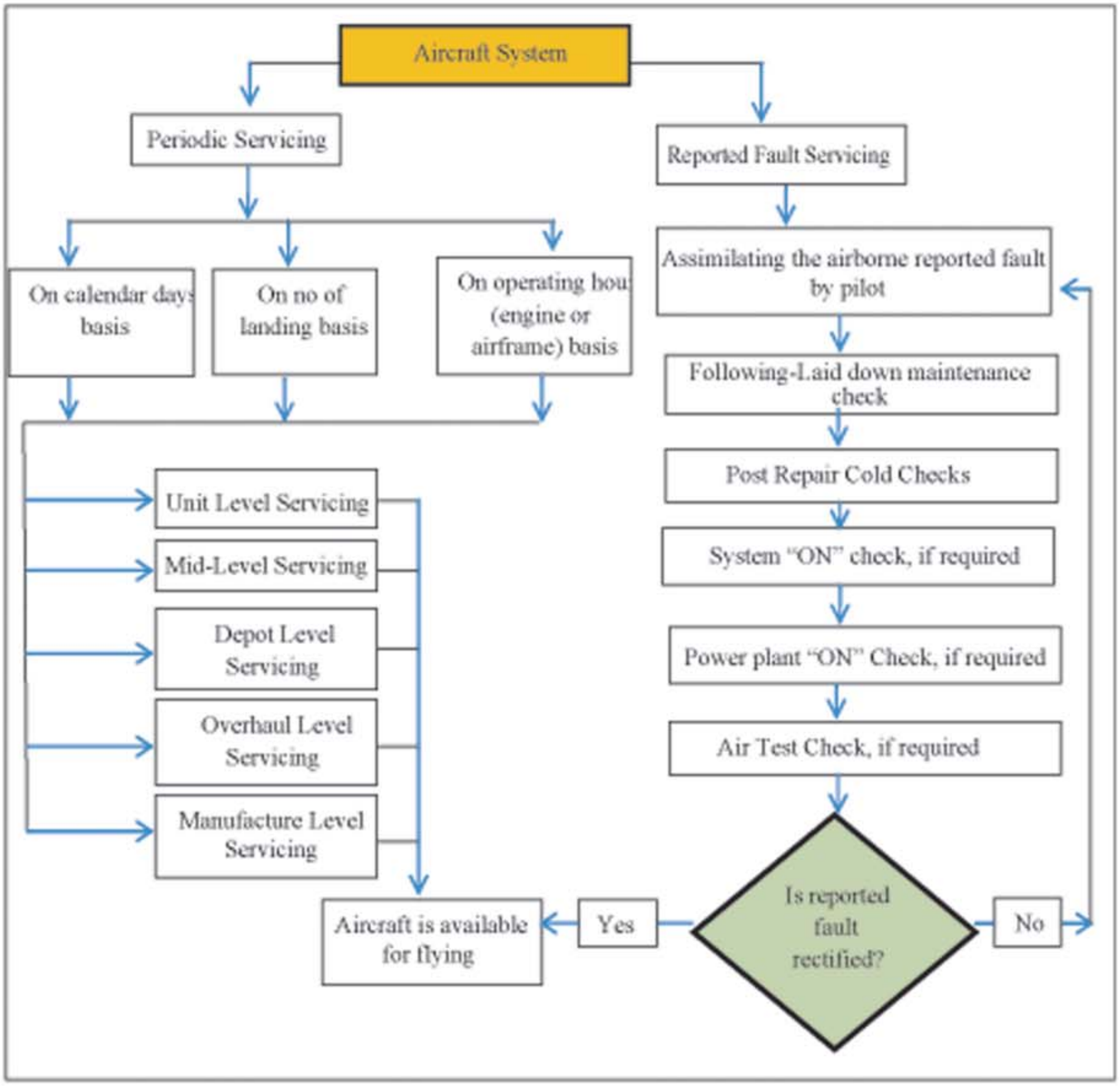

Figure 4: Non BIT based MSRC

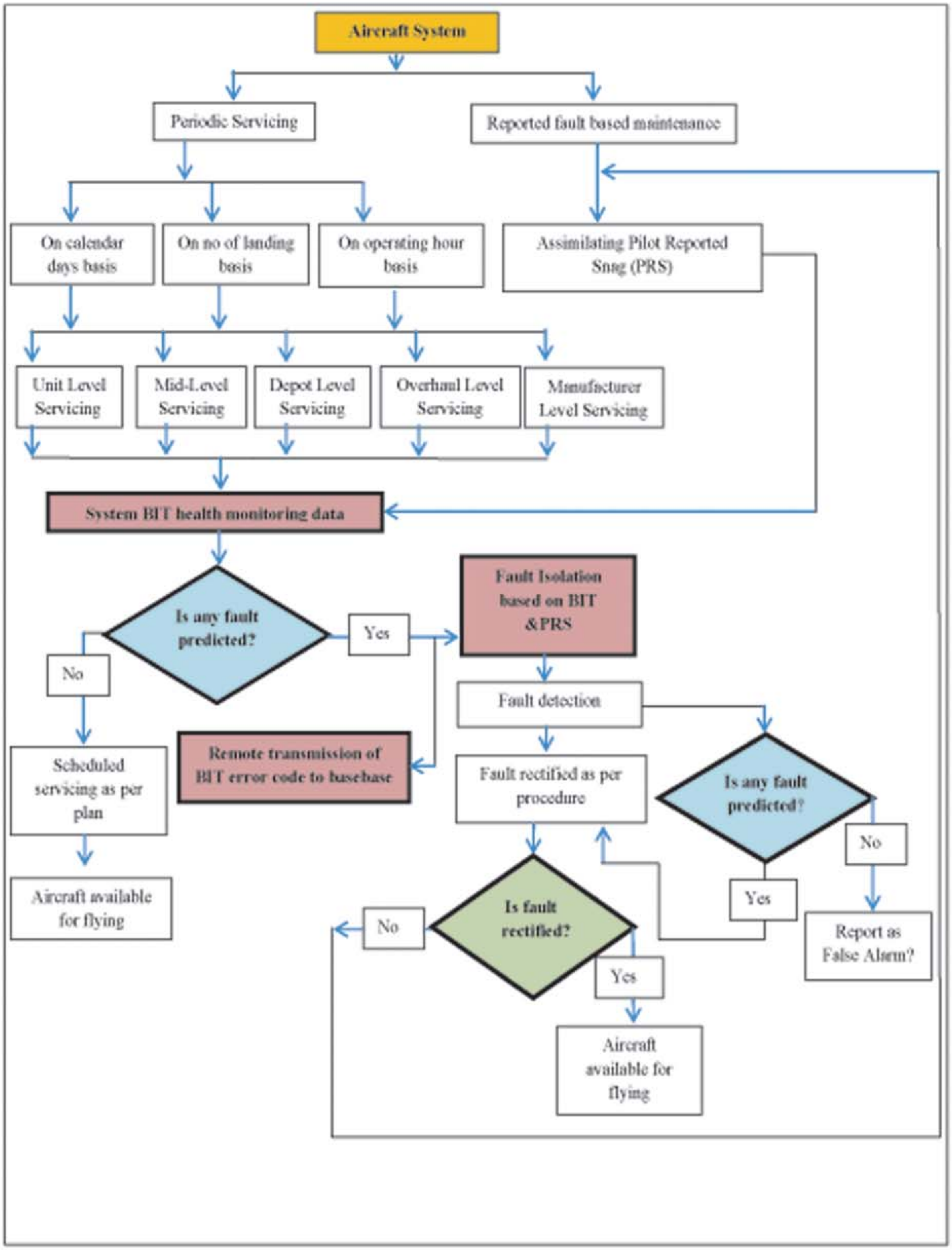

Figure 5: BIT-enabled MSRC

6.0 CONCLUSION

The requirement of reliable, higher bandwidth, low weight, space saving networking architecture in avionics is not fulfilled by the traditional copper cable based data transmission system. Hence, All Optical WDM technology is brought into existence. It is advantageous over traditional systems in terms of reliability, weight, environmental conditions, accidental viewpoints, redundancy and most importantly capacity of data handling and its accuracy. To support WDM, built in test procedure is being developed which follows some sequential stages to find out fault occurring in any of the systems and a fast, dynamic response to diagnose and restore the faulty system to its initial operating state. It gives the flexibility to work on module rather than component level. Compared to conventional non-BIT enabled MSRC, working is less time consuming and complexity is lessening. Encouraging results are possible in fault detection, fault isolation, failure rate and reliability in BIT enabled AONA.

7.0 REFERENCES

[1] Mohammad F. Alam, Mohammed Atiquzzaman, Bradley D. Duncan, Hung Nguyen and Richard Kunath," Fibre-optic network architectures for on-board digital avionics signal distribution", INTERNATIONAL JOURNAL OF COMMUNICATION SYSTEMS,Int. J. Commun. Syst. 2002; 15:175-190 (DOI: 10.1002/dac.526)

[2] Robert D. Gardner,IvanAndonovic,DavidK. Hunter& Andrew J. McLaughlin, J. Stewart Aitchison, John H. Marsh "High Performance Photonic Avionics Networking using WDM"

[3] Mohammad F. Alam, Mohammed Atiquzzaman, and Bradley B. Duncan, University of Dayton, Dayton, Ohio & Hung Nguyen and Richard Kunath, Glenn Research Center, Cleveland, Ohio "On-Board Fiber-Optic Network Architectures for Radar and Avionics Signal Distribution" International Radar Conference sponsored by the Institute of Electrical and Electronics Engineers, Alexandria, Virginia, May 7-12, 2000

[4] Mark W. Beranek and Anthony R. Avak, Naval Air Systems Command, Patuxent River, Md, "Improving avionics fiber optic network reliability and maintainability via Built-In Test"

[5] MIL-embedded.com/article/built-in-test-pledge-fey-roll-system-integrity;as on 06 Sept.

[6] Evaluation of Built In Test,IEEE Transaction on aerospace and electronic section volume 32 no.1,January 2001,M.PECST et al.