INSIGHT INTO THE REQUIREMENTS OF SELF-AWARE, ADAPTIVE AND RELIABLE EMBEDDED SUB-SYSTEMS OF SATELLITE SPACECRAFT

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Abstract: This position paper gives an insight for self-aware and adaptivity requirements of the sub-systems embedded in a satellite spacecraft. The most significant and considerable issues of self-aware and adaptive systems that are necessary in present and future on-board satellite spacecraft are illustrated in this paper. An attempt has been made to discuss several embedded sub-systems and space environment scenarios of the spacecraft. As a case study, an adaptive sierpinski based dual band antenna has been devised. The adaptive nature of this antenna provides a foundation of longer and more reliable mission life of a spacecraft. Through this paper it will be shown that adaptive, reconfigurable and reliability issues are the most prominent and potential area of research for outer space communication technology.

1 INTRODUCTION

A sub-system or system in a satellite spacecraft is called space hardware. Space hardware consists of several parts (electronics and mechanical) and materials with suitable surface treatment for withstanding environmental effects while on ground and on space. As maintenance in space during mission life is impossible, so the parts, materials and the processes used for making spacecraft sub-systems must be highly self-aware, adaptive and reliable.

This position paper describes different self-aware and adaptive issues that spacecraft sub-systems encounter during its useful life period. The nature of the spacecraft sub-systems are supposed to be extremely insensitive to the external environment. The need for achieving mass efficient adaptive designs, selection and control of parts, materials and processes of the sub-systems are the major challenges in structuring a satellite spacecraft. Structure also plays an important role in the thermal control of the spacecraft by providing conductive paths, radiating surfaces and acting as heat sinks.

A spacecraft sub-system begins its life in ground and usually long storage time is envisaged in different environmental conditions. While on ground, the spacecraft materials and components encounter all classical aging problems like oxidation and corrosion, effect of variable humidity, biological attack, losses due to evaporation, metal migration etc. The launch environment encompasses a range of simultaneous applied energy loads created due to random vibration, acoustical noise, pressure variations and acceleration. Space hardware including their components and materials are assessed by different mechanical and environmental tests for their suitability in the launch environment.

When a satellite is positioned in the parking slot in space, its mission life starts (Maral and Bousquet). During this period, sub-systems of satellite spacecraft encounter environment which is made of vacuum, extreme high and low temperature (+80^{0}C to -180^{0}C in GEO) and radiation of different dose levels. The embedded onboard sub-systems of

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spacecraft must follow the space qualification. The activity by which it is ensured that the parts and materials used in satellite sub-system will be able to withstand effects of the above three environments without degrading performance is known as space qualification.

Motivated by the evidence of adverse space environment for satellite spacecraft, our aim is to develop an understanding the issues and importance of self-aware, reconfigurable and adaptive designs for the onboard spacecraft sub-systems. Through this paper, we are aiming to grab the reader's attention at self-aware and adaptive sub-systems of satellite spacecraft are the most potential and prominent area of research.

Our paper is structured as follows. Section II describes the existing literature in context with our research work. The next two sections provide the practical underpinnings of satellite sub-systems and space environment respectively. Section V describes a list of self-aware and adaptability issues related to satellite spacecraft. The development of adaptive dual band antenna is discussed in section VI, conclusion and future works are presented in Section VII.

2 RELATED WORKS

Substantial research has been conducted on several key areas related to the self-aware and adaptive space hardware sub-systems. The recent existing literatures (Maral and Bousquet), (Vassev et al., 2010), (Striemer and Akoglu, 2010), (Kang et al., 2010), (Lee and Choi, 2010), (Jung, 2010), (Santambrogio et al., 2010), (Cheng et al., 2010), (Stauffer, 2009) of adaptive systems for space applications include self-configurable swarm-based space exploration systems, low density parity check (LDPC) engine for space based communication systems and several papers on reconfigurable and self-aware computing architectures for onboard spacecraft embedded sub-systems. In the same way, a number of papers can be found for reconfigurable multi core architectures, built-in self-test and self-repair, adaptive signal processing, image data compression and power amplifier.

The most available literature do not focus on reconfigurable, adaptive and self-aware issues for each of the embedded onboard satellite sub-systems and satellite payload. Therefore here our work is to enlighten those several issues that spacecraft encounters during its mission life. We also make an effort to describe several problems that takes place in on-board spacecraft concerning adverse space environment.

3 SATELLITE SUB-SYSTEM

Communication satellites are very complex and extremely expensive to construct & launch. Currently communication satellites are designed and developed for 12 to 15 years of life time during which the communication capability of the satellite earns revenue, to recover the initial and operating costs. Since the satellite has to operate over a long period out in the space, the sub-systems of the satellite are required to be very reliable. Major sub-systems of a satellite are bus sub-systems and payload. The satellite-bus-sub-systems include mechanical structure, attitude and orbit control system (AOCS), propulsion system, electrical power system, tracking telemetry and command (TTC) system and thermal control system. Similarly satellite payload comprises of communication transponder and antennas. Since a communication satellite earns revenue, the satellite must carry as many communications channels as possible. However, a large communication channel capacity necessitates large electrical power from large solar arrays and battery, results larger mass and volume of the satellite. Parking a heavy satellite in geosynchronous orbit is very expensive; therefore it is logical to keep the size and mass of the satellite small. Lightweight materials optimally designed to carry the load and withstand vibration and large temperature cycles are considered to be significant parameters for the structure of the satellite.

Attitude and orbit control system (AOCS) (Yoon and Tsiotras, 2002), (mackunis et al., 2008) maintains the orbital location of the satellite and controls the attitude of the satellite by using different sensors and firing small thrusters located in different sides of the satellite. Liquid fuel and oxidizer are carried in the satellite as part of the propulsion system for firing the thrusters in order to maintain the satellite attitude and orbit. The amount of fuel and oxidizer carried by the satellite also determines the effective life of the satellite.

The electrical power in the satellite is derived mainly from the solar cells. The power is used by the communication payload and also by all other electrical sub-systems in the satellite for housekeeping. Rechargeable battery is used for supplying electrical power during eclipse of the satellite spacecraft. Telemetry, tracking and command (TTC) system of the satellite works along with its counterparts located in the satellite control earth station. The telemetry system collects data from sensors on board the satellite and sends these data via telemetry link to the satellite control centre which monitors the health of the satellite. Tracking and ranging system located in the earth station provides the information related to the range and location of the satellite in its orbit. The command system is used for switching on/off of different sub-systems in the satellite based on the telemetry and tracking data.

The thermal control system maintains the temperature of different parts of the satellite within the operating temperature limits and thus protects the satellite sub-systems from the extreme temperature conditions of the outer space.

4 SPACE ENVIRONMENT

Space environment consists of zero gravity condition, vacuum with thermal cycling (high and low) and diverse solar radiation. Zero gravity condition does not impose considerable effects on space hardware except loose conductive and non conductive particles entrapped in the spacecraft. These particles can move freely inside creating blockage or shorting of sensitive electrical circuits resulting damage in few sub-systems. Precautions are taken to prevent such entrapment during hardware fabrication using clean room fabrication and associated protection.

Vacuum of the order of 10^{-13} Torr or higher exists at geosynchronous orbit. Any sliding and rubbing of surfaces as in bearing and for rotating movements tend to get vacuum welded. Use of dry lubricant material is a solution to this problem. Outgassing of polymeric substances, sealing and potting compound etc create total weight loss and condensable volatile mass in thermo vacuum environment in space.

The outgassing products can cause low voltage corona of the electrical circuit and change the physical properties of optical surfaces inside spacecraft. It is a practice to screen these materials before using in space hardware so that total mass loss (TML) and collection volatile condensable mass (CVCM) are less than a predetermined level.

5 SELF-AWARE AND ADAPTIVE ISSUES

This section describes the potential self-aware and adaptive issues which need to be considering while designing a spacecraft. The most prominent issue is to supply a regulated electrical power to each of the sub-systems of the spacecraft. Embedded solar cells are the primary source of energy during the mission life of a satellite. During eclipse period the electrochemical batteries are the most appropriate means of secondary energy source. Nickel-cadmium and Nickel-hydrogen cells have been normally used for the storage of electrical energy since the advent of communication satellites. A number of self-aware and adaptive issues have been devised in electrical power supply sub-system of the spacecraft. They are as follows:

- The solar generator consists of small groups of cells arranged in series or in parallel. The choice of combination is such that it maximizes the relative adaptability and reliability, taking into account of failure rates of the cells.
- The solar generator wings of the satellite are rotated in order to maintain the apparent movement of the sun. Hence it must employ self-aware solar sensors and adaptive control circuits so as to check out the proper dimensioning of the power at the time of summer solstice and equinoxes.
- The design of secondary energy sources must be adaptable in varying temperature conditions. The key issues for battery energy sources are dimensioning, depth of discharge (DOD), protection against overcharging and several battery technologies.

In the same way the potential self-aware and adaptive designs are required in attitude control of the satellite spacecraft. Maintaining attitude is fundamental for the satellite to fulfill its function. The embedded self-aware sensors measure the orientation of the satellite axes with respect to external references. Embedded sun, earth, star, radio frequency and laser detector sensors should be adequately designed so as to adapt in adverse space environment and to provide the accurate orbit attitude and alignment errors.

Telemetry, Tracking and Command (TTC) and On Board Data Handling (OBDH) are another two important mutual sub-systems in satellite spacecraft. Adaptive electronic systems should be employed in TTC and OBDH sub-systems so that they ensure enduring availability of the links with the ground stations. One of the important characteristics of the command link is security. Hence the embedded sub-systems are not only supposed to be self-aware and adaptive but also adequately secured so that the system is insensitive to the signals transmitted by intruders.

The purpose of the thermal control is to maintain the sub-systems and equipments within the temperature ranges which enable it to operate reasonably. A self-aware temperature sensor adjusts the thermal conductivities among various parts of the satellite. The thermal reliability of the on-board equipments and sub-systems depend on adaptability of the components in different temperature conditions.

6 ADAPTIVE ANTENNA- A CASE STUDY

The payload is one of the most important sub-systems of satellite spacecraft. Antenna is a part of the payload. We have chosen development of an adaptive multi-layered antenna as a case study. Here the emphasis has been given to explore the self-aware and adaptability issues of the developed dual band, self-tunable and sierpinski based fractal antenna. The detail design methodologies, result analysis and development mechanisms are demonstrated in (Kanth et al, 2010), (Kanth et al., 2010), (Kanth et al., 2009). The major challenges during the development of this adaptable antenna were selection of space qualified materials and meet the required specifications. The work was performed satisfactorily using the materials copper, duroid, foam, glass epoxy and coaxial probe to achieve the required specifications in terms of return loss, gain radiation and coverage area. The multi-layered layout of the proposed adaptive antenna is shown in Fig. 1.

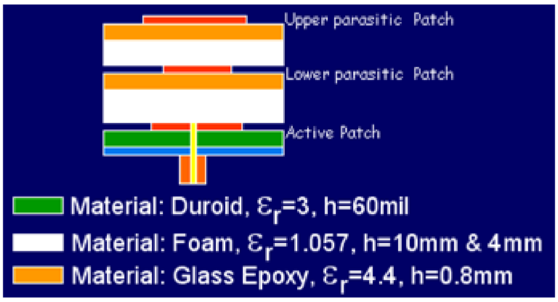

Figure 1: Multi-Layered Layout.

The adaptive nature (dual band self-tunable) of the proposed antenna has been described in (Kanth et al., 2009). The adaptability of the on-board sub-systems must qualify space adverse ranges of the temperatures, outgassing properties in vacuum, zero gravity and random vibration resistance. The selection of the materials for fabricating this antenna is such that it surpasses all the space qualification tests and ensures the required performance as per the specifications. The return loss of the developed adaptive dual band self tunable antenna is presented in Fig. 2. Several iterations and new optimizations techniques were involved to achieve the desired performance. The developed multi-layered, sierpinski based adaptable dual band antenna is shown in Fig. 3.

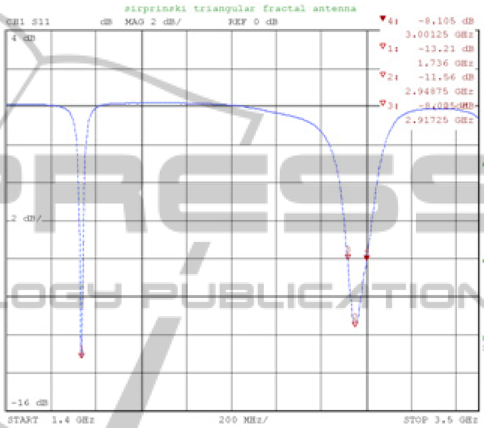

Figure 2: Return Loss Diagram- Adaptive Nature.

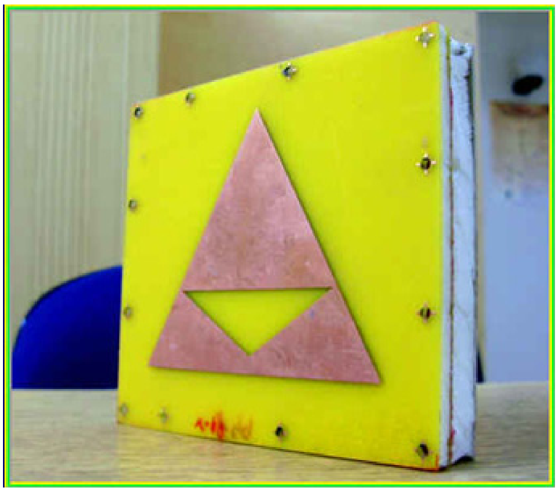

Figure 3: Dual Band Adaptive Satellite Navigational Antenna.

7 CONCLUSIONS AND FUTURE WORKS

This position paper explicitly introduces, analyzes and reflects on important issues and problems related to the topic. Obvious practical implications of these investigations illustrate that adaptive and self-aware issues are the potential research areas for outer space communication technology. We have developed a space qualified payload antenna which is adaptive in nature. Undoubtedly, the realization of adaptive, self-aware and reconfigurable sub-systems of the spacecraft not only enhances the reliability but also lengthen the mission life of spacecraft. The list of self-aware and adaptive issues of the embedded sub-systems of satellite spacecraft, mentioned in this paper gives guidelines to a designer to ensure corrective actions before it is launched. Here we conclude that self-aware and adaptive designs are the most important issues in developing a successful satellite spacecraft.

There are many avenues for further research. The first important future work is to measure the degree of reliability considering the self-aware and adaptive design issues for the embedded sub-systems of the spacecraft. One should focus on related parameters of these issues and explore the significances in terms of reliability and mission life enhancement. Another imperative future work is to consider the adaptive designs in realization of high power amplifier, attitude control systems, TTC, propulsion sub-system and on-board processing systems. Finally, it would be worthwhile to examine the role of self-aware and adaptive designs in minimization of failure rate of the sub-system in its mission life.

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