Low cost highly reliable telemetry module for space applications

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Abstract: - In this paper we demonstrate a low cost highly reliable telemetry module design suitable for low orbit satellites based on commercial or industrial components. The proposed telemetry module configuration employs on shelf components to achieve 3 Kg weight, 3 watt power consumption, serially interfaced to other satellite subsystems, fully redundant, and 0.98 probability of non failure for three years and 0.95 for five years.

Key-Words: - Telemetry Module, Low Orbit Satellite, Highly reliable design, Space Application.

1 Introduction

The main objective while designing any space product is to maximize the device reliability and minimize its cost and risk factors. To maximize the reliability it is recommended to use space qualified components which meet the space environment requirements such as radiation hardness, temperature, pressure, power consumption, size, weight, and stability of operation with supply variations. To minimize the system cost on shelf commercial components are employed against the system reliability. Using full redundant commercial components reduces the system cost, risk of receiving high qualified components in the proper time, complicates the design, increases weight and size and prolongs the space product design procedure, implementation and testing cycle.

Low Earth Orbit satellites LEOs orbit from 400 to 1600 miles above earth. LEO satellite systems have been developed to provide global real-time voice communications, but due to the complexity, cost of the systems and widespread growth of cellular technology, limited such systems success. Examples of such systems are Iridium and Globalstar which are still in partial operation. Nowadays Remote-sensing satellites study Earth's surface from 300 miles (480 km) up in the range of the LEOs. The LEO environment is getting very crowded so the United States Space Command USSC keeps track of the number of satellites in orbit. According to the USSC, there are more than 8,000 objects larger than a softball now circling the globe. Some people worry about the number of things now in low earth orbit knowing that not all of these things are working satellites. There are pieces of metal from old rockets, broken satellites and even frozen sewage and at a speed of 17,000 mph even a small bolt can hit a space shuttle with the impact of a hand grenade, which is exactly why the US Space Command keeps track of such things? This restriction prevents launching of any defected, low quality or non approved satellite by an expert organization.

Remote sensing satellites usually consist of specific subsystems including telemetry module which monitors and records its health allover its life period. Even, when the satellite is in failure mode its status has to be well defined to enable designers analyzing the satellite fault reason and to try solving the problem in due time.

In this paper we demonstrate a full redundant telemetry module design for small low orbit satellites in the range of 3kg mass, 3 watt power consumption, supports 64 digital sensors and 46 analog sensors (ranging from -1V up to 7V with accuracy less than1.5%) and 66 temperature sensors (with accuracy less than 3%), has UART interface to be connected to other subsystems of the satellite to receive commands/data and reply with telemetry data frames, and any component failure may not affect any other in the system.

This paper is organized as follows: in section 2 we demonstrate different design philosophies, in section 3 the proposed telemetry module block diagram is introduced, in section 4 the telemetry module reliability calculations are reported and compared for different categories of the used components then we conclude the results of this paper work to approve the utilization of using commercial components to manufacture space qualified products.

2 Design of small satellite subsystems

Small satellite is not a miniature of large satellite and may deploy readymade devices and modules as we have two ways of thinking: first one is to equip necessary/minimum components using space qualified ones to increase the system probability of non-failure

PNF; second one is to use commercial of the shelf components (COTS) to gain short production cycle, low cost, cheap service, and availability in the markets.
To use commercial or industrial components full redundancy design techniques have to be employed. For example suppose a Device D1 used in a transmitter has failure rate ($\lambda d1 = 9*10-6$) and for a working mission time of 17,520 hours (2 years) so the approximate reliability for the no redundant configuration is calculated as $R1 = e{-}\lambda d1*T = e{-}(9*10{-}6)*17.520 = 0.85$. If we duplicate the device D_1 for simplicity, parallel redundant configuration, the approximate reliability is calculated as: $R_s = 1-(1-R_1)*(1-R_2)$, *where* $R1 = R2 = 0.85$; Then $R_s = 0.98$. Obviously, the use of redundancy can greatly enhance the transmitter reliability and give high confidence that the two year mission with high reliability will be met. However, there are additional considerations that need to be taken into account. Specifically, we need to address the additional components added by the redundancy, such as switches, sensors, and/or activators as shown in figure 1.

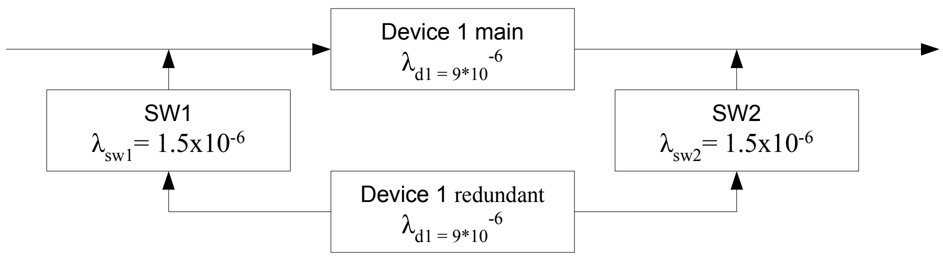


Figure 1 Switched Redundant device Block Diagram

In this case, two switches are added in order to activate the redundancy. If we assume the first switch failure rate is $\lambda sw1 = 1.1x10{-}6$ and the second switch failure rate is $\lambda sw2 = 1.1x10{-}6$ the equivalent reliability in this case is calculated as the composition of all used components as $R_{redundant} = 0.94$ where $\lambda_{redundant} = \lambda_{sw1} + \lambda_{eqTX} + \lambda_{sw2} = 1.1x10^{-6} + 1.15x10^{-6} + 1.1x10^{-6} = 3.35\ x10^{-6}$. This is still a big improvement over the single component reliability of 0.85. On the other hand, the disadvantages of using redundancy to solve a reliability problem are increased weight, size, cost, and complexity.

3 Telemetry module building blocks

The telemetry module consists of the building blocks shown in figure 2 where: the 1st block is the Control and command unit which includes relays to receive relay commands from the satellite onboard computer to connect the supply voltage to the telemetry circuits for example; the 2nd block is the secondary power supply which is responsible for converting the bus voltage to the necessary voltages to all the telemetry boards; the 3rd block is the Microcontroller board which contain Intel microcontroller and its peripherals (ROM, EEPROM) and serial interfaces to communicate with the onboard computer and the communication subsystems, which is responsible for data receiving and packing into frame of CCSDS (Consultative Committee for Space Data Systems) format; finally the last three blocks are the three types of multiplexers which pass the satellite sensors to the signal conditioning circuit according to each type of sensor to suite the microcontroller input for processing and storing.
We have to note here that the design meets the space environment condition of radiation hardness by shielding the components, boards and the full module with very thin aluminum sheets to reduce the effect of radiation. The only restriction of using such metal sheets is the telemetry module desired size and weight. Reducing the operating frequency of the module reduces the probability of the components' failure rate.
Thermal survival is taken into consideration while designing the printed circuit boards and common heat sinks to ensure that the heat will be conducted away from components. Special protection circuits are used in the design to switch OFF any overheated module for a certain period of time to avoid the system damage due to such problem.

4 Telemetry Module Reliability Calculations

To calculate the NFP for the telemetry module, first it should be partitioned to its main parts, which are five parts in our case. The 1st part is the control and power supply unit which comprises of five different components (3 relays, 2 relays and fuse, control unit, power supply, and 3 relays). The 2nd part is the controller and channel transceivers which comprises of

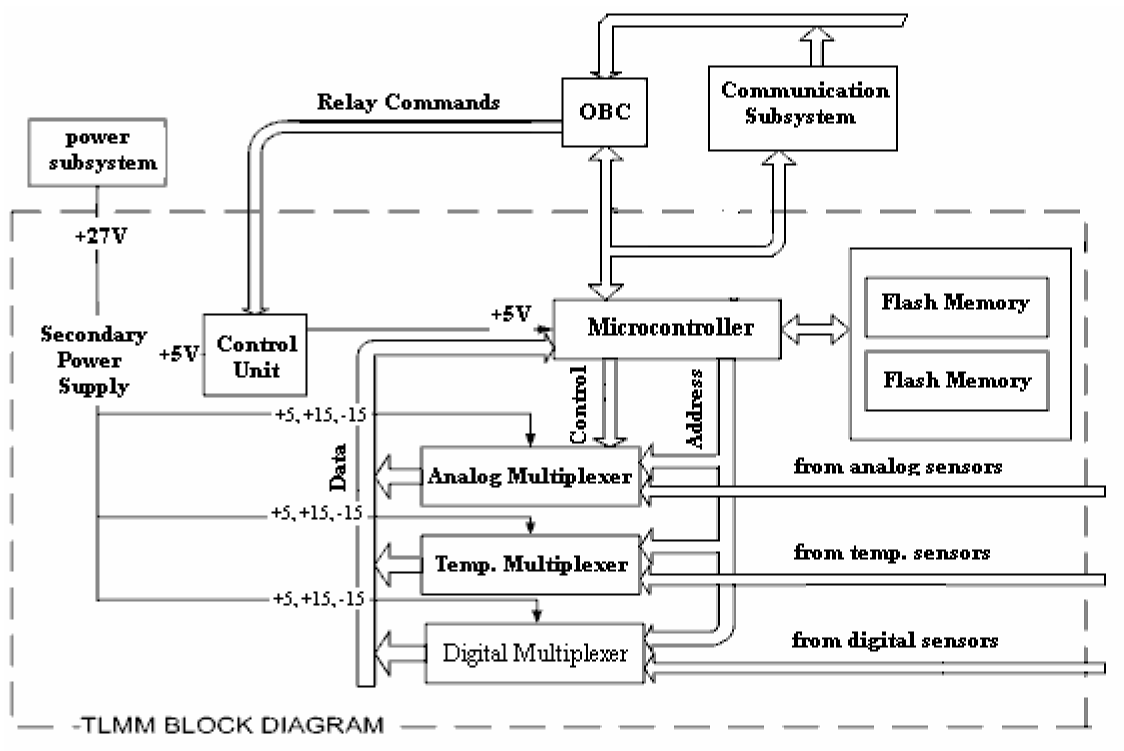
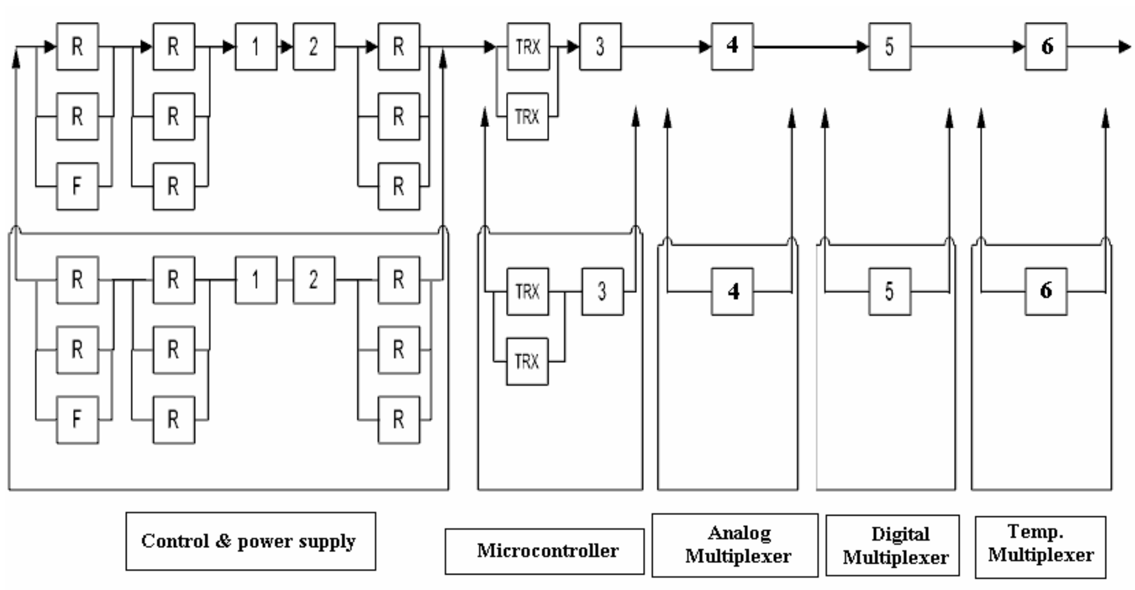


Figure 2 telemetry module Block Diagram



R: Relay, $\lambda=0.037*10^{-6}$
F: Fuse, $\lambda=0.045*10^{-6}$
TRX: transceiver, $\lambda=0.036*10^{-6}$

1: Control circuit, $\lambda=4.3*10^{-6}$
2: Secondary power supply, $\lambda=0.67*10^{-6}$
3: Microcontroller board, $\lambda=2.99*10^{-6}$

4: Analog multiplexer, $\lambda=1.82*10^{-6}$
5: Board of digital multiplexer, $\lambda=2.46*10^{-6}$
6: Board of temperature multiplexer, $\lambda=6.7*10^{-6}$

Figure-3 telemetry module reliability Block Diagram

two different components (transceivers, and microcontroller). The 3rd part is the analog multiplexer. The 4th part is the digital multiplexer. The 5th part is the temperature multiplexer.
The reliability block diagram of the telemetry module is shown in figure 3 and its reliability can be calculated with the aid of table 1 formulas. The resultant calculations for space qualified components realization, commercial components realization and full redundant commercial components realization are reported in figure 3 for comparison where the main components' failure rates of the used components in our design are given in table 2.

Table -1: probability equations for various connections [2], [3]

Unit Description	mathematical equation
Without backup n≥1	$P(t)=\exp\left(-\sum_{i=1}^{n}\lambda_i\cdot t\right)$
Fully Hot backup	$P(t)=1-\left[1-\exp(-\lambda_0\cdot t)\right]^{m+1}$
Fractional Hot backup	$P(t)=(R-n+1)\cdot C_R^{n-1}\cdot\sum_{j=n}^{R}\frac{(-1)^{j-n}}{j}\cdot C_{R-n}^{j-n}\cdot\exp(-j\lambda t)$
Cold backup	$P(t)=\exp(-n\lambda t)\cdot\sum_{j=0}^{m}\frac{(n\lambda t)^j}{j!}$
effective failure rate for electronic component	$\lambda eff := \frac{\lambda op\cdot Top+\lambda st\cdot Tst}{Tt}$

Where: P (t) is the non failure probability of the circuit, n is the number of basic elements, m is the number of reserve components, λ_{st} is the component Failure rate during storage or switching off, λop is the component failure rate during operation, Top is the component operation time, Ts is the time of switching off the component, Tt is the total mission time and the total number of system elements R = n + m. We have to note here that the operation time for each component depends on its mode of operation.

5 Simulation Results

In figure 4 we demonstrate a comparison among the three possible designs based on different realization component types: space qualified; full redundant commercial and commercial components without redundancy. The upper trace is calculated for the space qualified components and has the highest reliability for the telemetry module. The lower trace demonstrates the reliability values for the telemetry module using commercial components without redundancy which has the lowest value for any time period and may not be approved for any space or high quality product. The middle trace shows the reliability values of the telemetry module using fully redundant commercial components. This trace does not have the best value for the product life time but can be satisfactory in our mission as it satisfies the required reliability value by the end of the product life time and in the mean time this solution reduces the cost of the module which may be in the factor of 1:50 compared with using space qualified components. Based on this design if we mix the used component types the system reliability has to be improved.
The achieved simulation results are proven through qualification testing of the telemetry module including burn in test among the other subsystems of the satellite in different environmental and electrical conditions.

Table 3: reliability configuration status and the NFP results for the three variants

Internal Components		State of reserve/ratio	$\lambda_{op}.10^6$, 1/hour	Operating hours	$\lambda_{st}.10^8$, 1/hour	storage time	$\lambda_{eff}.10^8$, 1/hour	P(t)	COTS with redundancy		COTS without redundancy		Space without redundant	
									3 Y	5 Y	3 Y	5 Y	3 Y	5 Y
Control unit	2 Relays, 1fuse	Hot 1of 3	0.04	43800	0.04	0	4	0.99999	0.985	0.96173	0.8775	0.8411	0.99869	0.99782
	3 relays	Hot 2 of 3	0.037	43800	0.037	0	3.7	0.99999						
	control unit	hot	4.3	43800	4.3	0	430	0.804377						
	power	hot	0.67	43800	0.67	0	67							
	3 relays	hot 2 of 3	0.037	43800	0.037	0	3.7	0.99999						
Microcontroller	channel transceivers	hot	0.036	43800	0.036	0	3.6	0.9999975	0.997	0.9921	0.9244	0.877	0.999214	0.99869
	controller	cold	2.99	43800	2.99	0	299	0.87724						
temperature sensor Multiplexer		cold	6.07	4560	25000	6.07	25000	0.99642	0.99868	0.99642	0.949	0.916	0.99947	0.999129
digital signal Multiplexer		cold	2.11	4560	25000	2.11	25000	0.999783	0.999921	0.999783	0.9875	0.9792	0.999874	0.99979
analog sensor Multiplexer		cold	1.82	4560	1.82	39240	20	0.9999596	0.99998	0.9999596	0.9946	0.991	0.999946	0.9999
total telemetry module									0.98	0.95	0.756	0.627	0.997	0.995

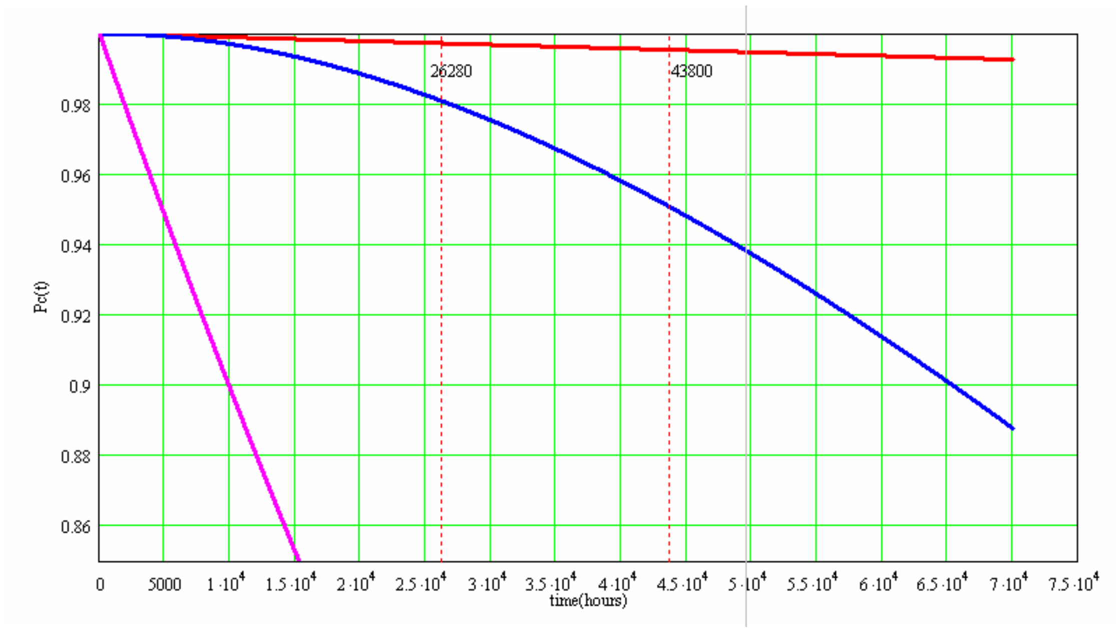


Fig.4 NFP for telemetry module with time (3-years and 5-years are marked for comparison)

5 Conclusion

For that mission assigned to design a telemetry module for LEO satellite with high reliability and low cost in a short time period among all other traditional restrictions especially having space qualified components in the proper time the decision of using commercial of the shelf components is a must. As the commercial components have a lot of problems in space environment, may fail at any time, no other party can guarantee for the designer their use in space the use of COTS components with redundancy can greatly enhance the telemetry reliability and give high confidence that the five years mission with high reliability (0.95) requirement can be met without a huge cost. Such solution enables the designer to use available design tools and gain from the pre-stored experience using commercial components taking into consideration that the modules exhaustive testing is the only guarantee for the design success in the phase of telemetry module qualification. After that if we receive some space qualified components and employed in the module implementation the full reliability of the module has to be improved and can be done at any time.

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