iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 8 **Issue:** VI **Month of publication:** June 2020

DOI: http://doi.org/10.22214/ijraset.2020.6143

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 8 Issue VI June 2020- Available at www.ijraset.com

Analysis and Validation of Cryocooler Software used in GSAT Satellite

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Abstract: ISRO has established itself in the area of satellite technology both for remote sensing and communications. There is different category of satellites based on the application requirement. The geostationary satellite series of spacecraft provide operational services in the area of communication and meteorology. One of the geostationary satellite pulse tube cryocoolers are used for cooling IR (Infrared) detectors to minimize the signal noise, thus improving their SNR.

Cryocoolers operates on the principle of Stirling cycle, with isothermal expansion and compression processes and constant volume heat addition and heat rejection processes. High purity Helium gas is used as a working medium and is charged to a working pressure. Pulse Tube Cryo-coolers are active cryogenic devices used to generate cryogenic temperatures in the required range. This paper describes the complete testing of cryo drive electronics unit which is designed to drive the linear motors of PTC.

Keywords: AOCE (Attitude and Orbit Control System), PTC (Pulse Tube Cryo-coolers), CDEU (Cryo Drive Electronics Unit), TCP (TeleCommand Processor), BC (Bus Controller), RT (Remote Terminal), TM (TeleMetry), TC (TeleCommand), FPGA (Field Programmable Gate Array), EDAC (Error Detection and Correction) , WDT (Watch Dog Timer) , SEC (Single Error Correction), POR (Power-On Reset). Pulse Width Modulation (PWM), SNR (Signal-to-Noise Ratio)

I. INTRODUCTION

PTC consists of two compressors C1 and C2 mounted back to back to achieve a cooling effect by removing the heat load. Two types of heaters are mounted at the cold tip of PTC in order to simulate the load to the PTC. One heater generates a constant heat load and another heater derives variable power from CDEU. At any given time, only one heater is powered for characterizing Cryo-cooler system. CDEU delivers sinusoidal drive to both compressors C1and C2. The drive can be programmed for parameters like voltage, phase, offset and frequency Ref [1]. CDEU monitors voltage, current and frequency, temperature of the cold tip and pressure of the gas in both compressors. The software mainly consists of various requirements for operation of CDEU. CDEU is a remote terminal to TCP. TCP is the bus controller. Mission team will operate the CDEU once it is operational. The operating instructions will be provided as part of user manual to them Ref [2].

II. CDEU SYSTEM OVERVIEW

There are 5 modes which are used for the operation of CDEU. It will receive the telecommand from TCP through mil-1553 interface. Command decoding and execution is carried out. Health parameters of CDEU are transferred to telemetry subsystem through 1553 interface. Safety logic is built in to take care of various telemetry parameters to check against the specified limit. Cryo drive electronics modes are shown in Figure1. Mode can be changed through data command. Two step sequential commands shall be provided to prevent any inadvertent mode change. Mode change is possible always by mode change enable command. Mode is automatically changed on detection of some critical parameters to take care of the system Ref [3].

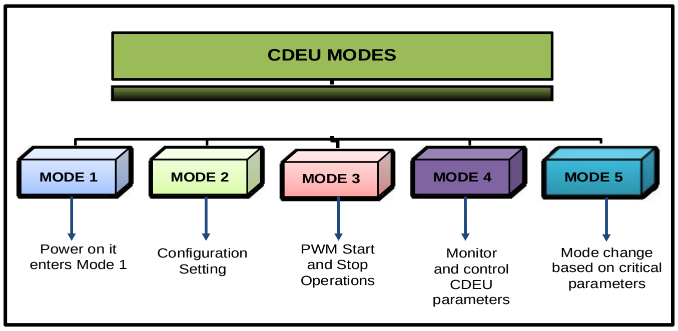

Figure 1: Different modes of CDEU

III. DIFFERENT MODES OF OPERATION

A. Mode M1

At power on it will enter Initialization mode and the required variables and hardware registers shall be initialized to default values. Raw bus voltages and CAL voltages shall be verified against limits, if it is within the limits it will automatically enter into Mode M2. If the raw bus voltage and CAL voltage is not within the limit then it will enter Mode M5. Testing was carried out for the same and the 1553 register, FPGA input output register initialization verification is carried out as part of database verification.

B. Mode M2

In M2 mode provision to configure compressor drive voltage, offset voltage, phase and select the required heater load for the cold tip is done from ground command. Other than this some functions can be enabled and disabled for admin access, EDAC and WDT in configure mode. It can go to Mode M3 only if raw bus voltage is switched on and is within maximum limit. Being in this mode if raw bus voltage exceeds maximum limit, system transitions to Mode M5. Mode transition to any other mode is possible from this mode.

C. Mode M3

Various compressor drive parameters like drive voltage, offset voltage and drive phase, soft start can be set for both compressors by ground command. Heater load command is used to on/off the individual heater by ground command. Figure 2 shows both compressors at different phase.

1) *Start PWM:* The soft start flag is set in software and default voltage will be loaded. Once the PWM start command is issued the voltage increases from the default voltage to the commanded voltage based on the steps commanded. Otherwise it will reach the required voltage by default step fixed during power on. Once the set voltage becomes equal to the commanded voltage the soft start flag is made false in software. This was verified by testing and by code walk through.
2) *Stop PWM:* Once this command is requested by ground the stop PWM flag is set in the software. The drive voltage in hardware is decremented by Soft Start voltage increment value for both compressors. This step is repeated until the set voltage in hardware becomes equal to minimum. PWM Enable register control bit is reset to zero and the soft stop flag is reset at the end of soft stop completion Ref [4].

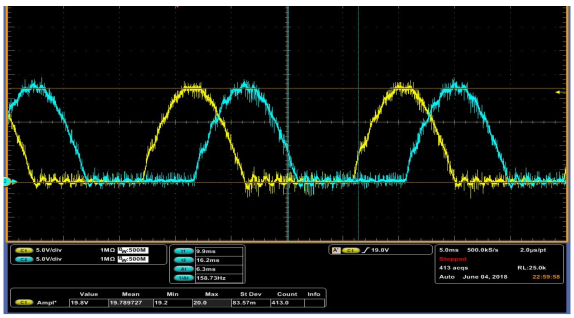

Figure 2: Compressors at 90 deg phase

D. Mode M4

In this mode, the variables are initialized to the default values. In this mode, specific parameter of CDEU/PTC parameter is monitored in faster rate based on ground command selection. The value of the parameter is displayed in the allocated words for analog parameters in telemetry. Selected telemetry repeats in all the allocated telemetry words.

E. Mode M5

In this mode PWM disable command is issued. Also, based on CDEU and PTC parameters monitored during telemetry acquisition, appropriate mode change is done from Mode M5 to Mode M2/ Mode M3/ Mode1 based on the critical parameters.

IV. SOFT START AND SOFT STOP TESTING

On enable PWM command in operation mode, drive to the compressors shall be initiated from a default voltage value and shall reach the final required value in steps defined by the 'soft start voltage increment'. Between successive voltage changes, a duration defined by 'soft start duration' shall be allowed. On disable PWM command, the drive to the compressor shall be gradually reduced in steps defined by soft start voltage increment and shall finally reaches zero. Figure 3 shows the sample plot for soft start and soft stop operation.

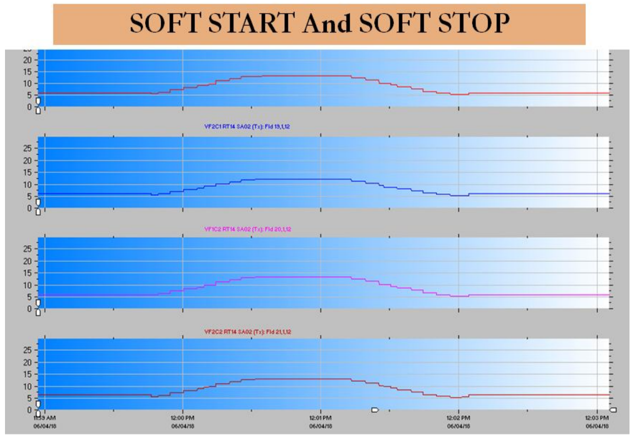

Figure 3: Soft start and soft stop with PWM enable and disable

V. ABORT PWM ON ANOMALY

In case of detection of a monitored parameter of CDEU or PTC not meeting minimum/maximum limits, based on definition of particular mode, the cdeu system shall reach Mode M5 and disable pwm.

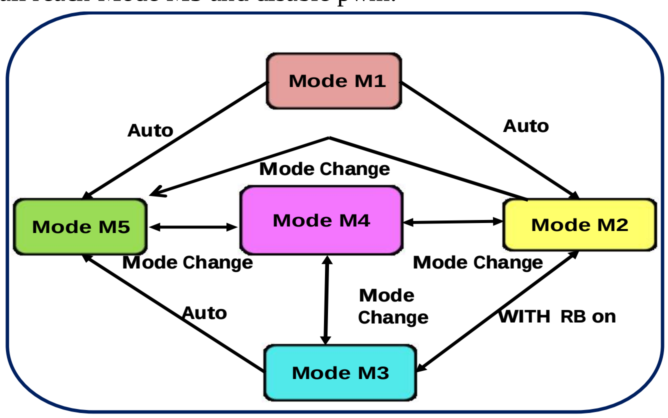

Figure 4: CDEU Mode transitions

A message id indicating the reason for transition to Mode 5 is telemetered. There are various message identifiers for different types of anomalies, based on the message ID in the telemetry we can identify the cause of going to Mode 5 automatically. Figure 4 shows the mode transitions possible. Final version of the software was tested for all the requirements Ref [5].

VI. FAILURE DETECTION, ISOLATION AND RECOVERY

A. *Watch Dog Timer*

1) At power on and at processor reset, WDT is disabled. WDT is enabled by ground command. This allows the user to safely configure the system before operation.
2) If the software does not issue the WDT Hardware counter reset for over 1 second. Then WDT Reset is triggered by the hardware.
3) There is 2 bits register which is read by software every cycle. This register is incremented every one seconds. On single occurrence of it no variables are reset, the software returns to the working mode prior to the WDT reset occurrence.
4) On the maximum defined occurrences within 10 seconds the system enters power on state and all the software and hardware registers are reset, except the summit registers.

B. *Error Detection and Correction*

Provision shall exist to enable/disable hamming code based EDAC protection for SRAM variables. This shall be capable of correcting single bit errors in RAM variables.

C. Scrubbing and 1553 Summit Activity

The RAM is provided with EDAC which takes care of single event upsets. But if upsets are more than one bit, it may result in corruption of memory which may result in undesired operations. To take care of such condition, memory scrubbing is introduced. In memory scrubbing, periodically each memory location is read and written back, so that every location gets refreshed continuously. This operation is carried out in steps of a predefined block size. Refreshing the 1553 descriptor table is done. This ensures SEUs in the descriptor table are removed every software cycle Ref [6].

VII. CONCLUSION

Codewalk through was carried out for all these fault detection, isolation and recovery modules. Testing was carried out for all the requirements but some requirements which are not possible to clear by testing are cleared through codewalk through. But as part of software quality assurance activity codewalk will be done for all the modules.

The firmware allows CDEU operation and mission team to configure and operate CDEU system during its operational and testing phase. The user team is expected to have knowledge of commanding and housekeeping data for controlling and monitoring of the CDEU system during testing and mission operations.

VIII. ACKNOWLEDGMENT

We wish to convey our gratefulness to all our colleagues in Onboard Software Quality Assurance Division, Mission Software Quality Assurance Division and sub system designers for their help, and also desire to thank office staff of Reliability and Quality Assurance of software Group (RQSG) for their support.

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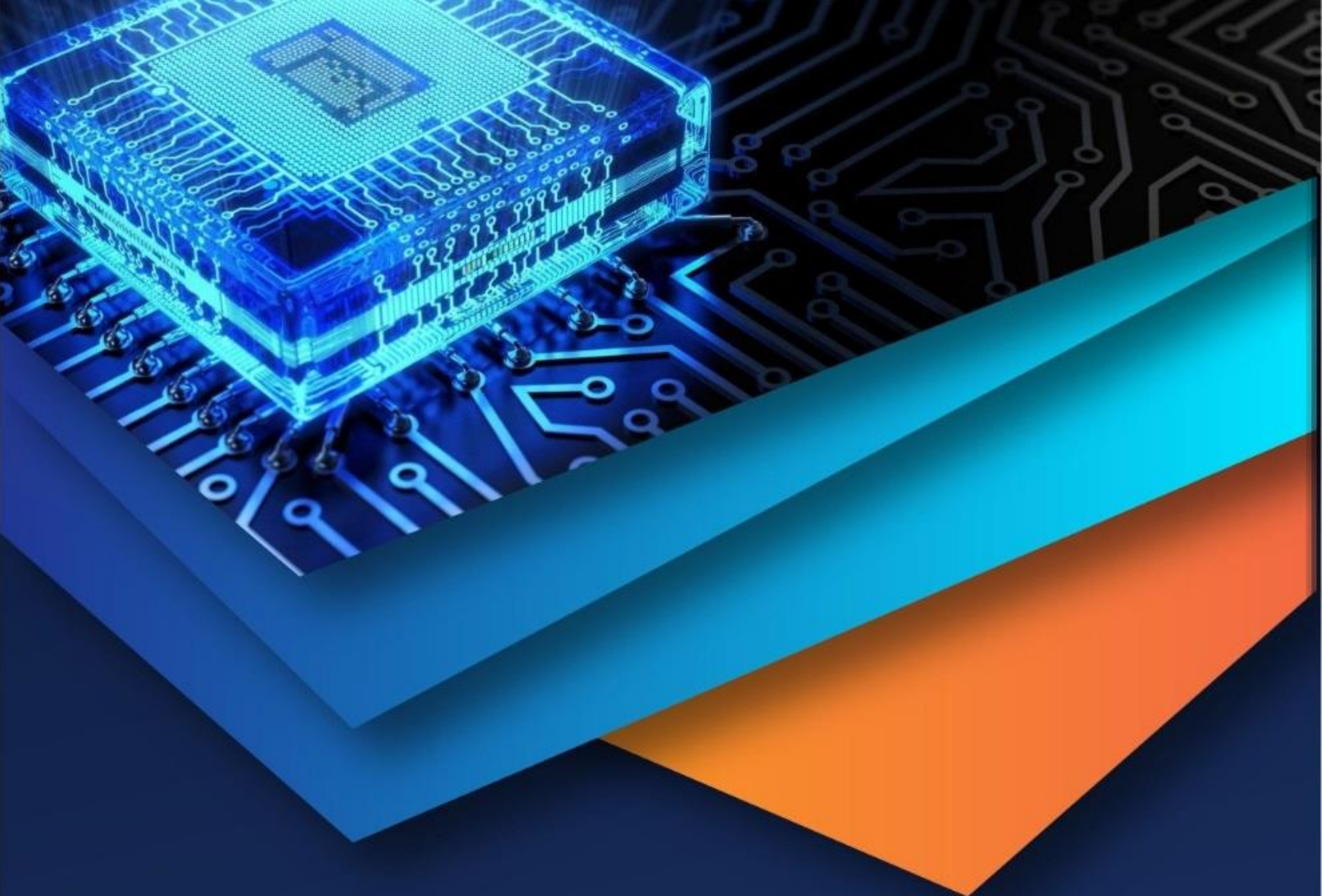

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