DESIGN OF CAMERA CONTROLLER FOR HIGH RESOLUTION SPACE-BORN CAMERA SYSTEM

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In order to get high quality and high resolution image data from the space-borne camera system, the image chain from the sensor to the user in the ground-station need to be designed and controlled with extreme care. The behavior of the camera system needs to be controlled by ground commands to support on-orbit calibration and to adjust imaging parameters and to perform early stage on-orbit image correction, like gain and offset control, non-uniformity correction, etc. The operation status including the temperature of the sensor needs to be transferred to the ground-station. The preparation time of the camera system for imaging with specific parameters should be minimized. The camera controller needs to synchronize the operation of cameras for every channel and for every spectral band. Detail timing information of the image data needs to be provided for image data correction at ground-station. In this paper, the design of the camera controller for the AEISS on KOMPSAT-3 will be introduced. It will be described how the image chain is controlled and which imaging parameters are to be adjusted The camera controller will have software for the flexible operation of the camera by the ground-station operators and it can be reconfigured by ground commands. A simple concept of the camera operations and the design of the camera controller, not only with hardware but also with controller software are to be introduced in this paper.

KEY WORDS: Camera Controller, Focal Plane Assembly, Relay Switch Matrix, AEISS, CEU

1. INTRODUCTION

The AEISS (Advanced Earth Imaging Sensor System) is being developed to provide high resolution electro-optical images required for geographical information systems establishment and the applications for environmental, agriculture and ocean monitoring. It is a space-born push-broom camera system and will be mounted on the KOMPSAT3 satellite.

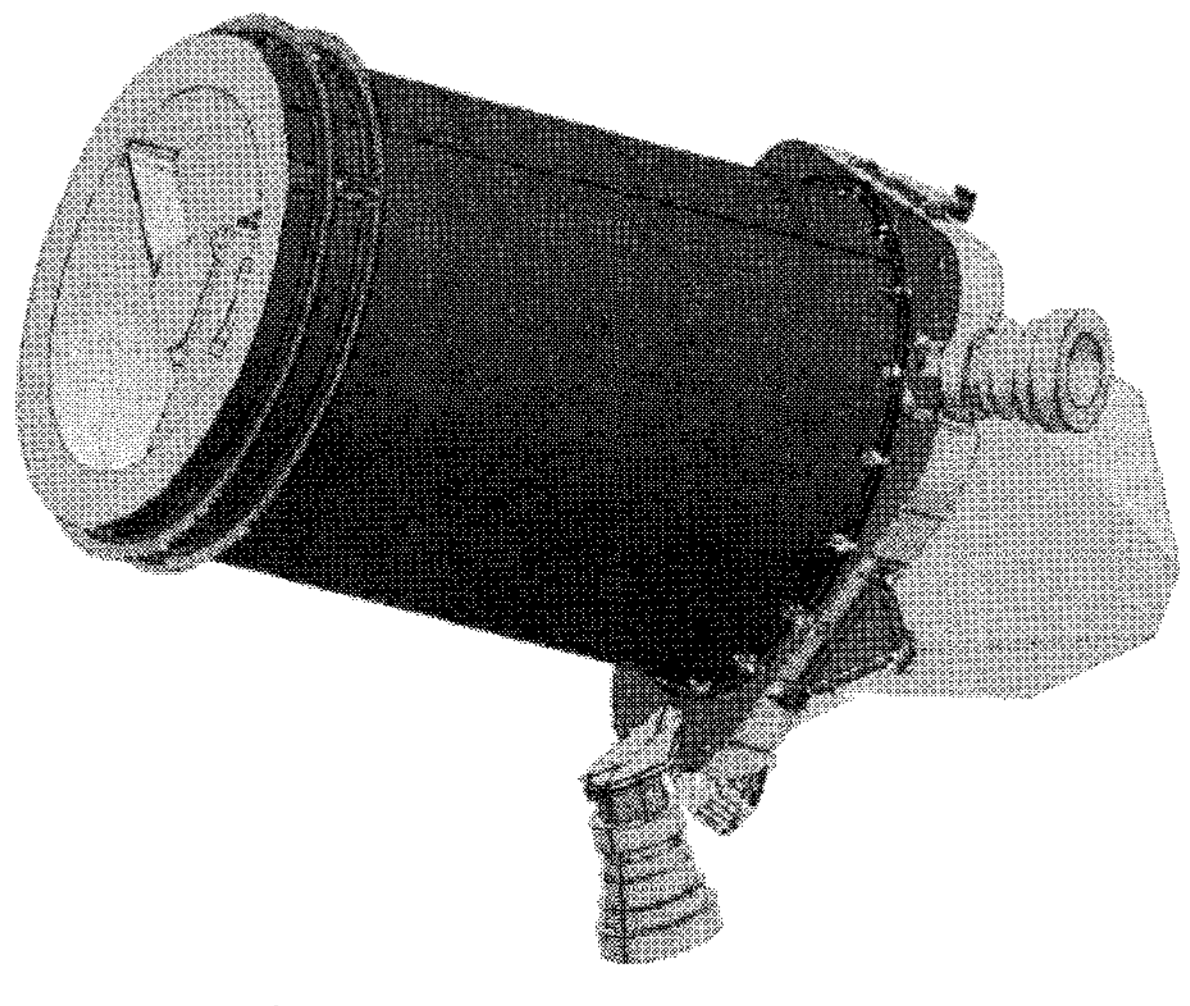

Figure 1. The EOS of the AEISS

The AEISS consists of EOS (Electro-optical sub-system) and PDTS (Payload Data Transmission Sub-system). The OM (Optical Module) and CEU (Camera Electronic Unit) form the EOS. The general configuration of the EOS is shown in the figure 1. The PDTS receives digitized image data from the CEU and performs compression, storage, encryption and packetization of the data and transmit them to the ground-station after QPSK (Quadrature Phase Shift Keying) modulation.

2. THE CEU DESIGN CONCEPT

The CEU has both panchromatic and multi-spectral camera that are sharing the same OM. The multi-spectral camera has four colour bands; blue, green, red and near infrared. The CEU consists of FPA (Focal Plane Assembly), CC (Camera Controller) and CEUP (CEU Power Supply). The CEU will be operated with the duty cycle of 10% in orbit. Whenever it performs an imaging mission, it needs to be on but it can be initialized and be ready for a mission execution in a few minutes. It will take only a few seconds for the CEU to change its imaging parameters, which makes it possible to perform the multi-point imaging scenarios. That is, the satellite camera can take pictures of multiple ground targets in a short time period.

The CEUP receives 28volt main power supply from the spacecraft bus and converts it various kinds of clean voltages which are required for whole CEU. The CEUP is designed to have full redundancy and it is separated into two boxes to spread out the heat. Half of the primary CEUP will be in the first box and the rest of the primary CEUP will be in the second box. The same is also for the redundant CEUP. Therefore, only half of the electronics in each box will generate heat at any time. Seven voltages are produced for the FPA and the CC.

The FPA consists of six independently functioning FPM (Focal Plane Module) and two of them are full redundant panchromatic channels and the rest four modules are multi-spectral channels of which spectral bands are decided by the spectral filters of its own. These FPMs convert incident optical energy to the electrical signal and converts them to the digital pixel stream. It also performs early stage signal conditioning to be converted to the digital data. The gain and offset adjustment will be applicable by the ground commands. Minimum on-board image data correction, like a nun-uniformity correction is also implemented in the FPM. All these treatments of the image data can be controlled individually by commands from the spacecraft. The FPA is operating in a very high frequency to generate high resolution (therefore, high line rate), wide swath width image data. The effective and detail control of the FPA, which is achieved by the CC, makes it possible to fulfil the system operational and performance requirements.

3. REQUIREMENTS OF THE CC

The CC (Camera Controller) will have following detail requirements for manipulating the FPA to produce high resolution ground image.

The CC has a MIL-STD-1553B interface with the spacecraft bus to get commands and imaging parameters for camera operation. The CC collects the status of the whole CEU and transmits them every second to the spacecraft bus. The CC has serial communication interfaces with six FPMs to send commands and to set imaging parameters which are originated from the spacecraft bus and the ground-station. The CC synchronizes the imaging operation of the FPA, therefore, the generated images from the panchromatic and four multi-spectral cameras will observe exactly the same ground target simultaneously. The CC receives 1Hz time-mark signal from the spacecraft bus and distributes to the FPA and it will be used to synchronize the operation not only with the spacecraft bus but also between each FPM. The CC controls the refocusing mechanism of the OM. The refocusing mechanism of the OM is being operated by controlling the temperature difference of some opto-mechanical elements in the OM. Therefore, very accurate closed-loop temperature control algorithm is required to be implemented in the CC. The CC provides direct analogue house-keeping telemetry interfaces to the spacecraft bus, like temperature of the each CEU sub-units (FPA, CEUP and CC). This temperature telemetry will be read directly by the spacecraft bus not only when the CEU is operational, but also when the CEU is completely off state. The CC will be designed to have full redundancy to fulfil the system reliability. Simply by turning on the CEU without sending any commands via MIL-STD-1553B interface, the CEU can be made to be operational; that means the CEU can performs the imaging mission. The memory in the CEU will be able to be dumped to the spacecraft bus via MIL-STD-1553B upon requesting by relative commands. Whenever the CC detects some anomalies or internal events, they will be reported to the spacecraft bus via MIL-STD-1553B interface. The application software in the CC will be able to be updated by commands from the spacecraft bus. But, the boot software will not be updated by commands.

4. HARDWARE DESIGN OF THE CC

The CEU has three main sub-units as stated before; CC, CEUP and FPA. The CC is in charge of interfacing with spacecraft bus and controlling the camera operation. The FPA is controlled by the CC and powered by the CEUP. The electrical interfaces around the CC can be simplified as described in the figure 2.

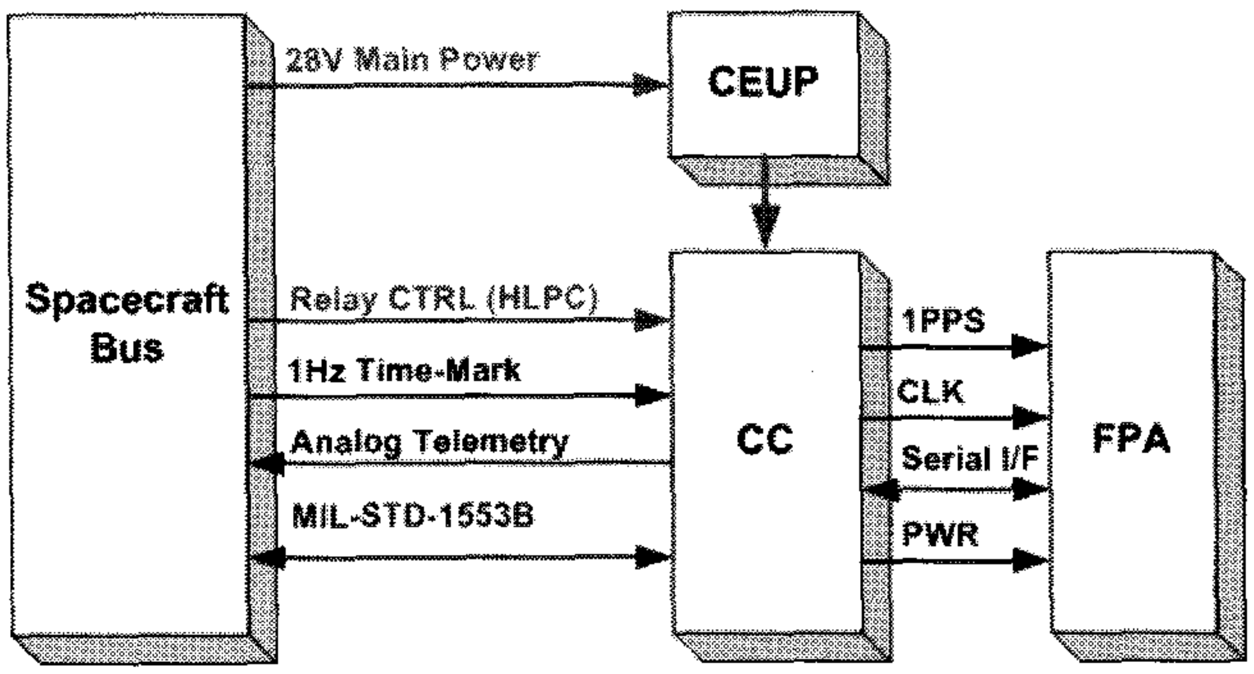

Figure 2. CC Electrical Interface

There are six FPMs in the FPA; panchromatic primary and redundant, multi-spectral blue, green, red and infra-red. These FPMs are functionally independent and do not have any electrical interface between them. They have connections only with the CC and there is full cross-strap between these FPMs and the primary and redundant CC. These FPMs are synchronized by sharing the same master clock located in the CC and distributed to each FPM via LVDS (Low Voltage Differential Signal) interface. Because the integration time can be down to 90us at the maximum line rate and the imaging time can be up to 10 minutes, a very accurate master clock is required to be used. If the master clock has some degree of jitter or drift during the imaging time, the resulting image data will have poor quality because the charge transfer in the sensor and the movement of the ground objects are not synchronized. The ground mapping of the image might be distorted in that case. Because of the importance of the master clock, the CC is designed to have four identical clock modules and only one of them is used for the imaging mission at any moment.

In order to synchronize the operation of the FPA with the absolute time of the spacecraft bus, a dedicated 1Hz time-mark clock is also distributed to the CC and finally to each FPM. By receiving OBT from the spacecraft bus via MIL-STD-1553B channel and inserting it to the image data header in the FPA, received image data at the ground-station can be corrected geometrically by utilizing the ancillary data which is also in the image header. The 1Hz time-mark can also be used for synchronizing the FPMs by resetting all internal registers upon receiving a broadcasted command from the CC.

All imaging parameters, like a gain and offset for each sensor output port, line rate, non-uniformity correction table, digital offset, will be transferred to the FPA from the CC. The size of the non-uniformity correction table is enormous because it has the correction vales for each pixel and for each TDI mode. These parameters will be stored in the EEPROM in each FPM. Therefore, it doesn't need to be uploaded repeatedly for each mission. In addition to the theses imaging parameters, detail behaviour of the FPA will be controlled by the CC using the command interface channel.

The CCDs in the FPA require various kinds of voltages to collect and transfer the charges proportional to the incident energy. These voltages are generated by the CEUP and routed to the FPA via the CC.

There is a RSM which is a combination of the relays. It is required to be used to configure the FPA. For example, the redundant PAN FPM can be selected instead of the primary and only half of the blue channel can be operational. By selecting the positions of the relays in the RSM, each FPM which is independently functioning can be activated or disabled. There are relays in the RSM for selecting one of four master clock modules.

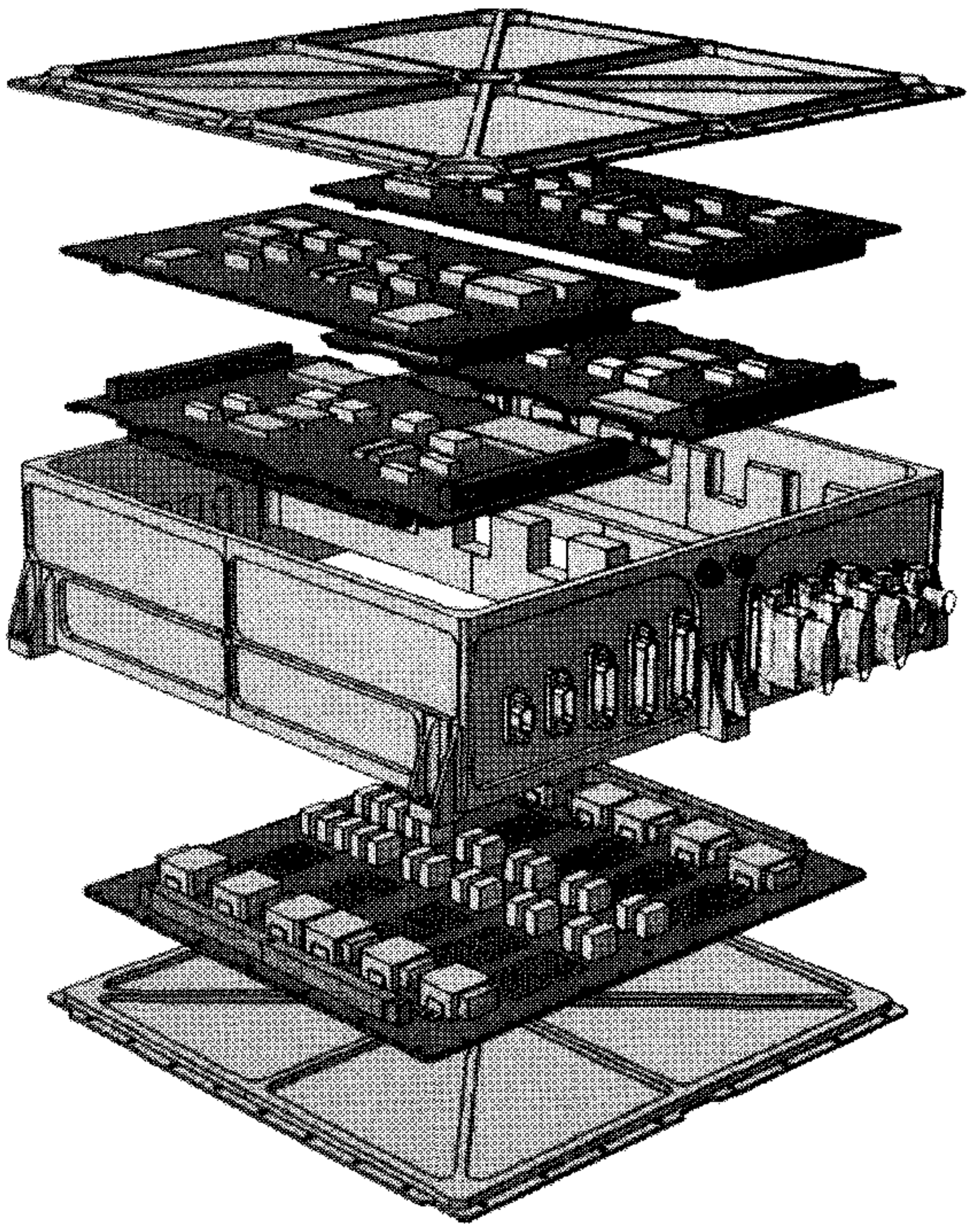

Figure 3. The internal configuration of the CC

The CC is designed to have three functional sub-modules as shown in the figure 3; RSM (Relay Switch Matrix), CC processor module, a focusing mechanism interface module. The RSM is located at the bottom in the CC box and two CC processor board is positioned in the middle and there is two analogue focus mechanism interface module on the upper part of the CC box.

The conceptual description of the RSM is shown in the figure 4. There is a RSM between the power supply and FPA to set up the configuration of the camera. The relays in the RSM are controlled directly by the spacecraft bus using HLPC (High Level Pulse Commands).

The CC processor board is designed using LEON3 SPARC8 IP core. It is implemented on the FPGA which is loaded and configured from the ROM where the design file is stored. The software for the CPU will be stored in the EEPROM and it can be updated by a series of commands. The primary and redundant processor board will be physically separated into two different PCBs. It has a MIL-STD-1553B interface control device and it receives the 1Hz time-mark signal via RS-422 differential interface. There are full duplex serial interface drivers in the processor board to communicate with six FPMs. The LVDS devices are used for these asynchronous serial interfaces. The master clock will also be delivered from the processor board to each FPMs using the LVDS devices.

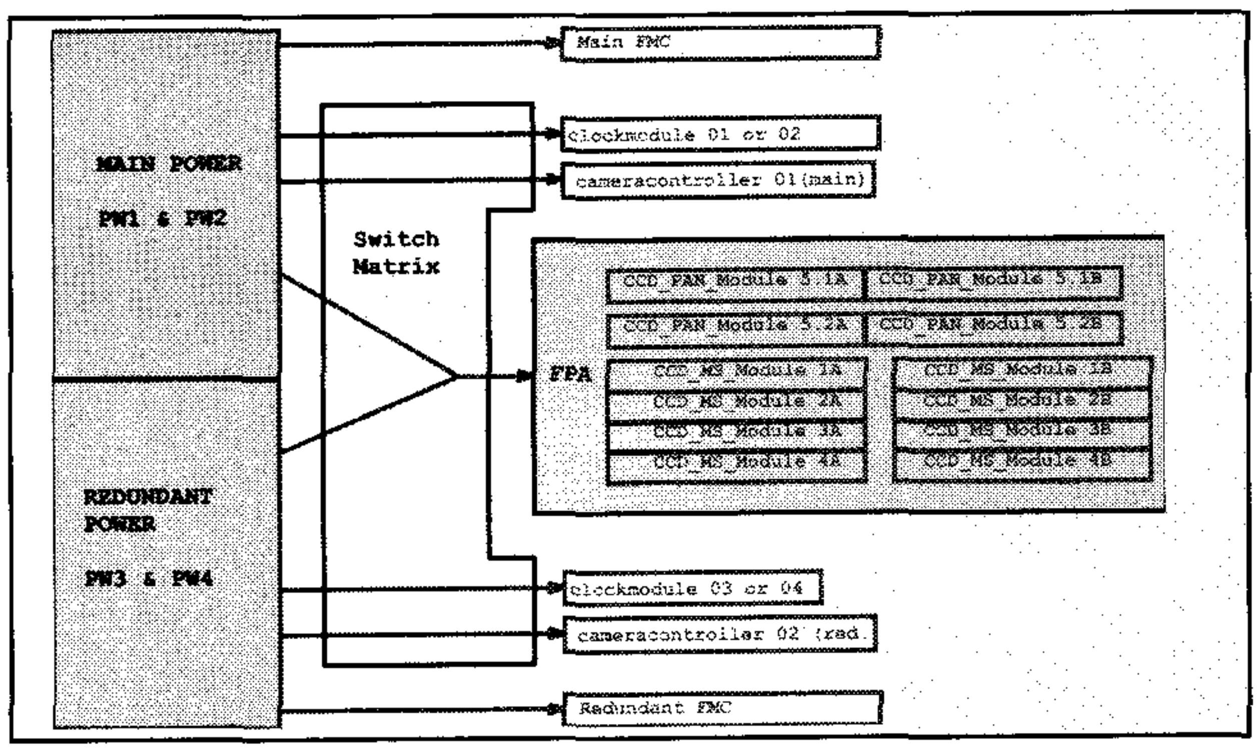

Figure 4. RSM (Relay Switch Matrix)

The CC is designed to have full redundancy and full cross-strap for internal and external interfaces, which results in a very high reliability. In addition to that, the FPA and CC is designed to make it possible that the camera system can be fully operational simply by providing the power without sending any commands via MIL-STD-1553B interface. All the imaging parameters previously configured and used will be stored to the EEPROM and they are always available to the camera whenever it is powered on. This design concept increased the system reliability drastically.

The focus mechanism interface board which is located in the top of the CC has a temperature reading circuits. Sensed temperatures will be used by the control algorithm in the software. The temperature difference between two points in the OM is controlled to be within a range specified by a command from the spacecraft bus.

The FPA will be mechanically attached to the OM and the CC will be mounted on the spacecraft bus structure. The distance between the FPA and the CC will be designed to be as short as possible.

5. SOFTWARE DESIGN OF THE CC

The CC processor board has software which manages the general operation of the FPA for the imaging mission by interchanging the command and telemetry with the spacecraft bus via MIL-STD-1553B and with the FPA via asynchronous serial interface. It is developed based on the SPARC8 architecture and no real-time operating system is incorporated.

The software is divided into two parts; PBS (Primary Boot Software) and APS (Application Program Software). The PBS resides in the PROM and it can not be updated after it is programmed before it is assembled on board. The PBS is activated first whenever the processor is reset or powered on. The work scope of the PBS will be as small as possible. When the PBS is running, the command from MIL-STD-1553B will be accepted and executed and the telemetry will be transmitted. But, the FPA interface will not be available and the focus mechanism is not visible to the PBS. The transition of the CEU operational mode and software boot-up sequence in the PBS and APS are described in the figure 5.

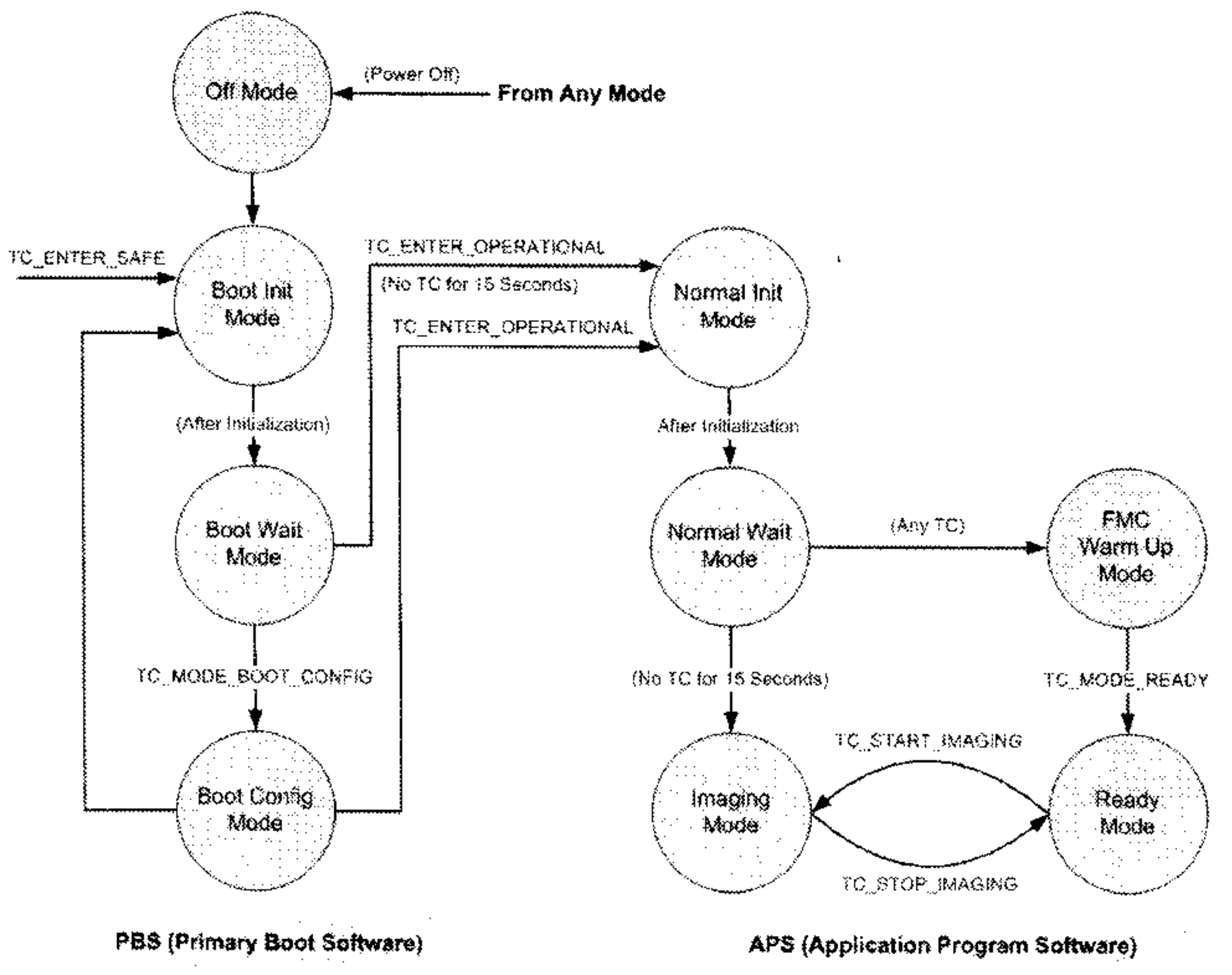

Figure 5. CEU Operational Mode

After the PBS finishes initialization, if no command is arrived for about 15 seconds, the PBS handovers the CPU to the APS. The imaging with default parameters will be started if no command arrives for 15 seconds after the APS finishes the initialization. Therefore, the default imaging mission can be initiated after turning on the CEU without any command. However, the time from turning on to the imaging mode can be reduced by sending proper commands when the software is in the wait mode.

The APS resides in the EEPROM and on-board reprogramming of the APS is possible by sending a series of commands. There will be more than two valid versions of the APS in the EEPROM. The selection of the working version will be selected by a command. It will be referred to when the PBS handover the CPU to the APS. The function of the APS extends to the FPA interface and focus mechanism control.

The PBS and APS have similar architecture and there are several software tasks and ISR (Interrupt Service Routine)s and device drivers. Each task will perform its own function and occupy the CPU only a limited time slice. These tasks will be scheduled in a cooperative multitasking manner (round-robin algorithm). If one of the tasks monopolizes the CPU, the hardware watchdog will reset the CPU. Unexpected exception will be designed to be recorded before the software restarts and the recorded information of the previous exception will be reported to the spacecraft bus. Most of the hardware devices are managed by polling and there are only three interrupt sources. The interrupt service routine will be as short as possible. The detail architecture design of the CC software is described in the figure 6.

The camera imaging parameters are managed by the software and transferred to the FPA. The data in the FPA can also be downloaded to the CC and to the spacecraft bus. The memory in the CC can also be dumped upon request by a command. Using this mechanism, the exact behaviour of the CC can be understood at the ground-station.

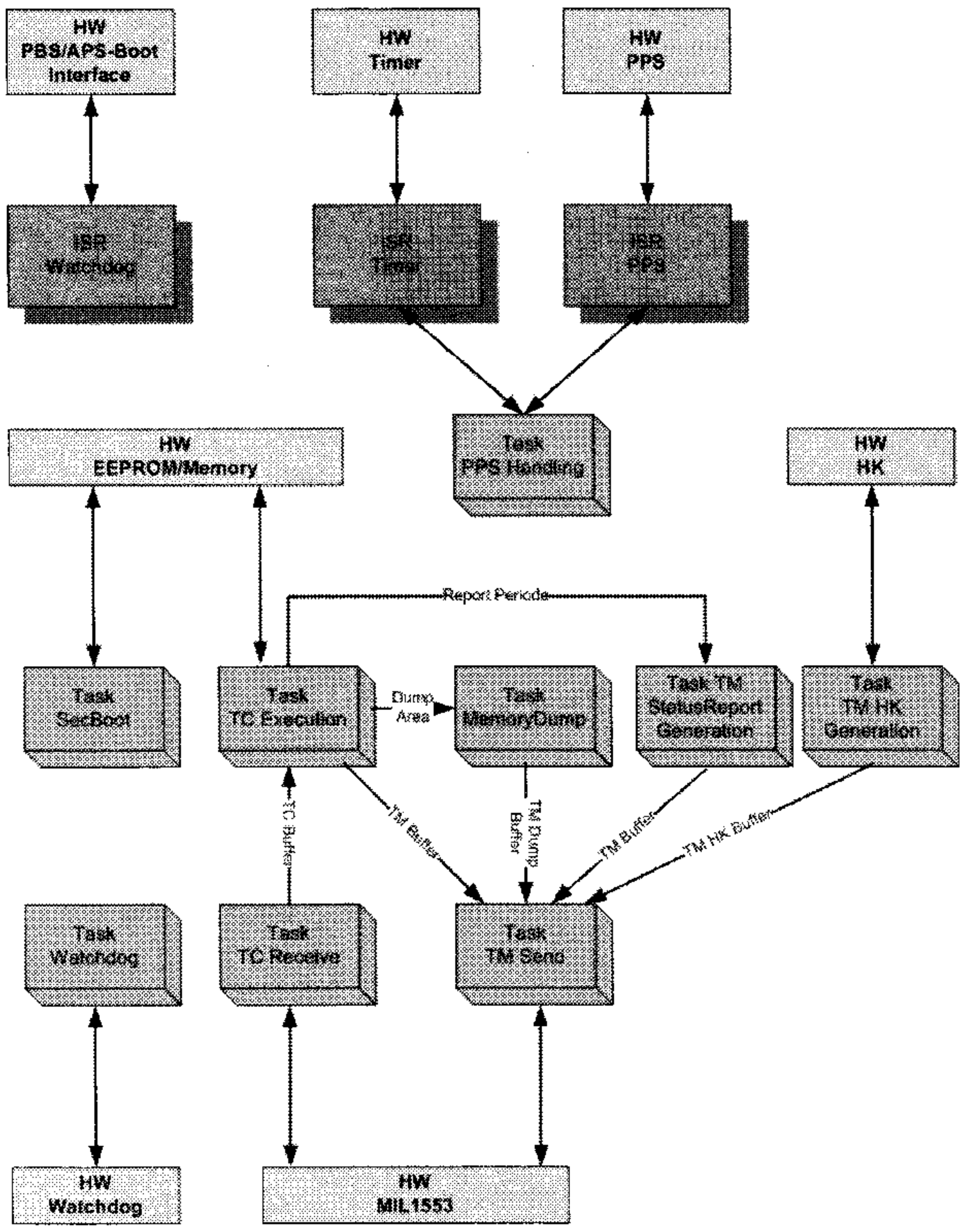

Figure 6. CC Software Architecture

The telemetry of whole CEU, like the status of RSM, temperature of the FPA, temperature of the focus mechanism are collected by the software and transmitted to the spacecraft bus every second. The system event or unexpected error will be reported whenever they occur.

6. CONCLUSION

The CC is effectively designed to control the FPA and provide necessary parameters for imaging. The FPA simply performs image generation and processing and all the other necessary supporting functions are separated into the CC. It is mechanically separated from the FPA in order not to disturb the FPA electrically and thermally.

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