REALIZE CONFIGURABLE AND INTEROPERABLE TT&C WITH COMMERCIAL COMPONENTS

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ABSTRACT

With explosive growth in the satellite communication market. there is an increasing need for the satellite network service providers to support many satellites with a common Telemetry, Tracking, and Commanding (TT&C) assets. The open bus technology, and Commercial Off The Shelf (COTS) Hardware and Software components, provides an opportunity to build a common IF and baseband systems that will support many satellites with different frequencies and protocols. However. the high frequency front end components of the ground station such as antenna or HPA can not be common due to different gain and polarization requirements of the various communication bands and frequencies. The system architecture presented in this paper offers such system that is interoperable and reconfigurable in near real-time to support multiple frequency and multiple communication protocols.

Keywords

Interoperable, Reconfigurable, TT&C, AF SCN, NASA, INTELSAT, Frequency band Unique Element (FUE), Common User Element (CUE), Telemetry Control and Status (TCS) processor COTS

1.0 Introduction

There are numerous satellite systems, both military and commercial, employing Telemetry Tracking & Commands (TT&C) ground stations. These TT&C systems will continue to operate on various frequency bands determined originally (and usually many years ago) by technical and regulatory factors. In addition to numerous frequencies, the TT&C waveforms, necessary for telemetry, tracking, command and ranging functions, use modulation techniques differing from one another depending on mission objectives, security, and data rates. This study investigates the frequency bands and modulation techniques (herein called protocols) used by selected satellite systems to see if there are interoperable characteristics that will allow processing by a single state-of-the-art multi-frequency, multi-protocol equipment string at ground stations.

A basic assumption is that only one downlink and uplink signal will be processed at a time. Also, the diversity of Radio Frequencies (RF) used by the various TT&C systems indicates that either a separate antenna is required for each frequency band or multiple feeds are needed. We assumed a separate antenna for each frequency. The antenna systems are different for each band because they are optimized (gain, polarization, etc.) for the particular satellite system and frequency band. The associated transmit wave guide and wave guide switches, if required, are different for each band because the size of the wave guide is frequency dependent. Another assumption is that the chosen frequency bands work with a common 70 MHz, first Intermediate Frequency (IF) for uplink and downlink streams.

Because this was a feasibility study, no interface engineering to ascertain the ease of interfacing this set of equipment was considered. Also, no implementation considerations were made such as environmental, packaging etc. At present EHF was excluded because there is no standard protocol in the larger space community.

2.0 Study Results

2.1 Analysis of Existing TT&C Systems

The TT&C systems and their frequency bands listed in Table 2-1, were selected and examined for this study. The satellite systems listed in Table 2-1, were chosen because they represent proven and operational TT&C systems, and their frequencies are representative of the heavily used frequency bands for satellite communications. SGLS is the primary AF SCN TT&C vehicle, which supports many DoD satellites. The DSCS system was chosen because it is an important user of X-band. The TDRSS network supports NASA Low Earth Orbit (LEO) satellites and Space Shuttle flights. INTELSAT is a commercial system using C-band as well as Ku-band. The NASA CCSDS system was chosen because its the system for deep space missions providing TT&C on S and X-bands.

2.2 Emerging Telemetry Standards and Frequencies

The study also examined the compatibility of the emerging telemetry standards and frequencies such as CCSDS and new Ka band frequency (23 GHz-26 GHz), recommended by the Space Network Interoperability Panel (SNIP) of NASA, with the existing frequencies described in section 2.1. The following table provides the details on the frequencies.

Table 2-1. Satellite Frequency Band Selection

Organization	Frequency Band	Uplink Frequency Range	Downlink Frequency Range
AFCSN	S-band	1.76 - 1.84 GHz	2.2 - 2.3 GHz
DoD - DSCS	X-band	7.9 - 8.4 GHz	7.600 - 7.604 GHz
NASA - TDRSS	Ku-band	14.6 - 15.25 GHz	13.4 - 14.05 GHz
NASA - CCSDS	S-band X-band	2.025 - 2.120 GHz 7.145 - 7.190 GHz	2.29 - 2.30 GHz 8.40 - 8.45 GHz
INTELSAT	C-band Ku-band	5.860 - 6.425 GHz 13.85 - 14.50 GHz	3.45 - 4.20 GHz 11.45 - 12.25 GHz

Table 2-2. CCSDS Frequency Allocations

Frequency Bands	Uplink Frequency Range	Downlink Frequency Range
S band	2025 MHz -2110 MHz	2200 MHz-2290 MHz
S band	2110 MHz -2120 MHZ	2290 MHz- 2300 MHz
X band	7190 MHz - 7235 MHz	8450 MHz- 8500 MHz
X band	7145 MHz -7190 MHz	8400 MHz -8450 MHz
Reserved Ku band	1325 MHz -1340 MHz 1340 MHz -1430 MHz	1440 MHz -1447 MHz 1450 MHz -1535 MHz
Reserved EHF band	3180 MHz - 3230 MHz	3420 MHz - 3470 MHz

2.3 Frequency Band Structure and Signal Protocol Analysis

In depth analysis of the frequency band of interest, signal structure, modulation and demodulation at sub-carrier, and at carrier frequencies was conducted. The efforts were concentrated to define the common elements such as base band data rates, data formats, telemetry, ranging and commanding signal characteristics, the symbol rates, and first and second IF frequency distribution among the selected frequency bands. The results of the analysis were tabulated and used to develop Interoperable TT&C architecture.

The wave form protocol analysis for SGLS, STDN, and CCSDS formats was also conducted. The SGLS, and STDN protocols apply to the physical layer of the transmission link, therefore the TT&C equipment must comply with them. On the other hand the CCSDS complies with the ISO 7 layer network model, and requires the application S/W at the user's workstation to process the packetize telemetry data. The error detection for CCSDS protocol must be handled immediately after the TT&C Bit Synchronizer.

2.4 Interoperable TT&C Functional Architecture

The architecture developed for interoperable TT&C, shown in Figure 2-1, is quite different from the traditional single stream TT&C systems. The major difference is that the new architecture must support the common TT&C processing as well as the frequency specific TT&C processing requirements. Accordingly, the architecture is partitioned in two segments, see Figure 2-1. They are, 1.) the Frequency band Unique Element (FUE), which includes the RF front end equipment for uplink and downlink, and 2.) the Common User Element (CUE), which includes the RF Receiver Pool, the Modem Pool, and the Uplink Signal Generator subsystems that are common to chosen frequency bands. The FUE of the architecture includes a set of dedicated diplexers, ACUs, Up Converters, Down Converters, RF Switches, LNAs, and HPAs that are replicated for each frequency band. These are the stand alone black boxes which communicates to TCS processor via IEEE 488 I/F, or Discrete I/F. Since the FUE uses the standard black box components the remaining of the paper will concentrate on CUE segment of the architecture.

The CUE of the architecture employs an open bus architecture that promotes the use of "Plug and Use" concept. Under this concept, as new requirements are identified, the necessary hardware and software modules can be added to the CUE with minimal changes to provide additional capabilities. The example architecture only shows uplink and downlink capabilities, and does not include any support equipment such as command echo check or test transponders, required for pre-pass test and verification.

The architecture shown in Figure 2-2, supports a single telemetry data stream at a time, and makes use of specific equipment in the FUE and the common H/W modules such as Bit Syncs, Modems, and Command Generators in the CUE. However the architecture is flexible enough to support simultaneous multiple telemetry data streams by simply adding necessary H/W and S/W modules to the CUE. The proposed architecture supports S-band, C-band, X-band, and Ku-band TT&C, and processes SGLS, STDN, and CCSDS protocols.

The CUE of the TT&C architecture uses the dual bus architecture; 1) the independent serial bus for telemetry, commanding, and ranging data that flow across the system through 8x8 switches, and 2) the VME64 bus to configure, control and monitor the performance of the various components. The VME64 bus is an extension of the present VME bus and is downward compatible to VME bus COTS H/W. The TT&C can be expanded by adding the modules as long as the aggregate data rate on VME64 bus doesn't exceed 80 Mbytes/sec.

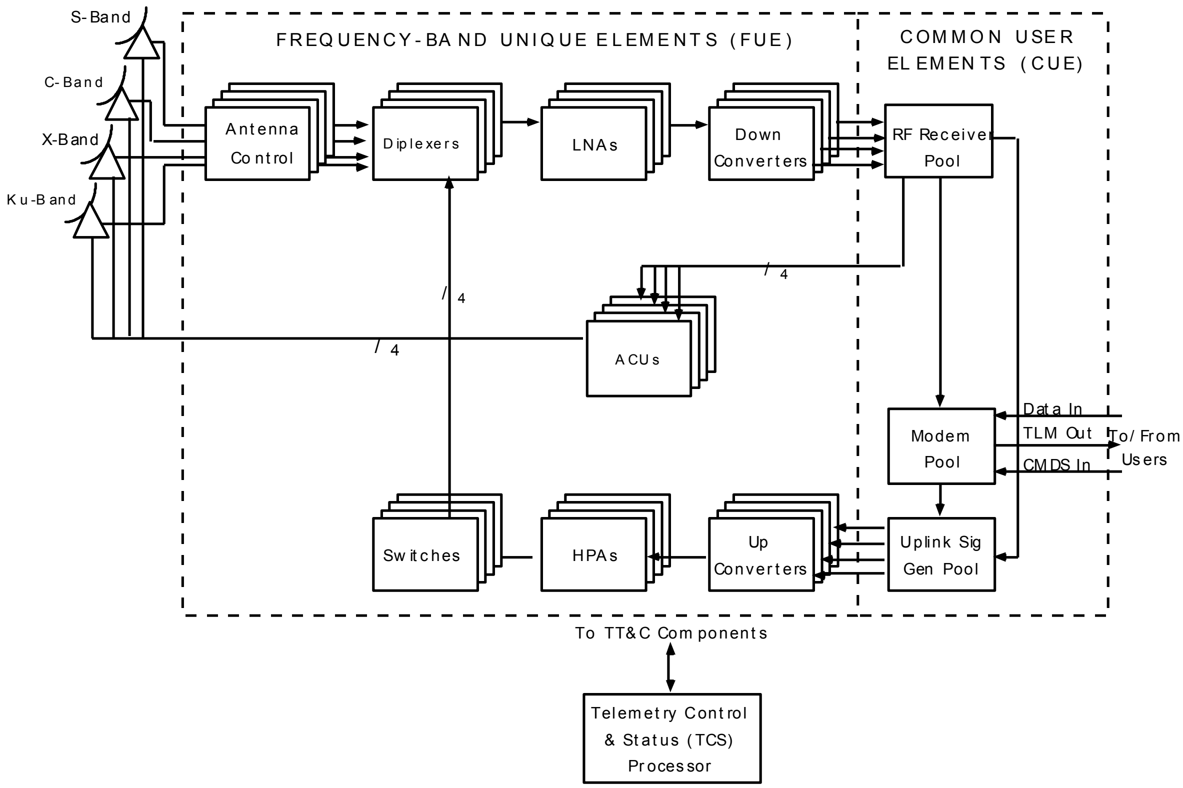

Figure 2-1. Interoperable TT&C System Simplified Block Diagram

The open bus architecture of the TT&C system, and the programmability feature of the various components allows standardization of some of the H/W and S/W components for this architecture. For example, the 8x8 switch, the SBCs and the Real Time Operating System (RTOS) are the common components that are used across the Uplink and Downlink streams. Section 2.4.1 describes the functionality of the common components used in the CUE.

2.4.1 CUE Common Components

8x8 VME Switch

The 8x8 VME Switch is used for analog and digital data routing within the RF Receiver Pool, the Modem Pool, and the Uplink Signal Generator sub-systems. The typical switch is configured in an 8x8 matrix using solid state cross points. The switch provides 40 dB isolation between the adjacent channels at 100 MHz. The switch is controlled and configured in real time from the SBC over the VME bus.

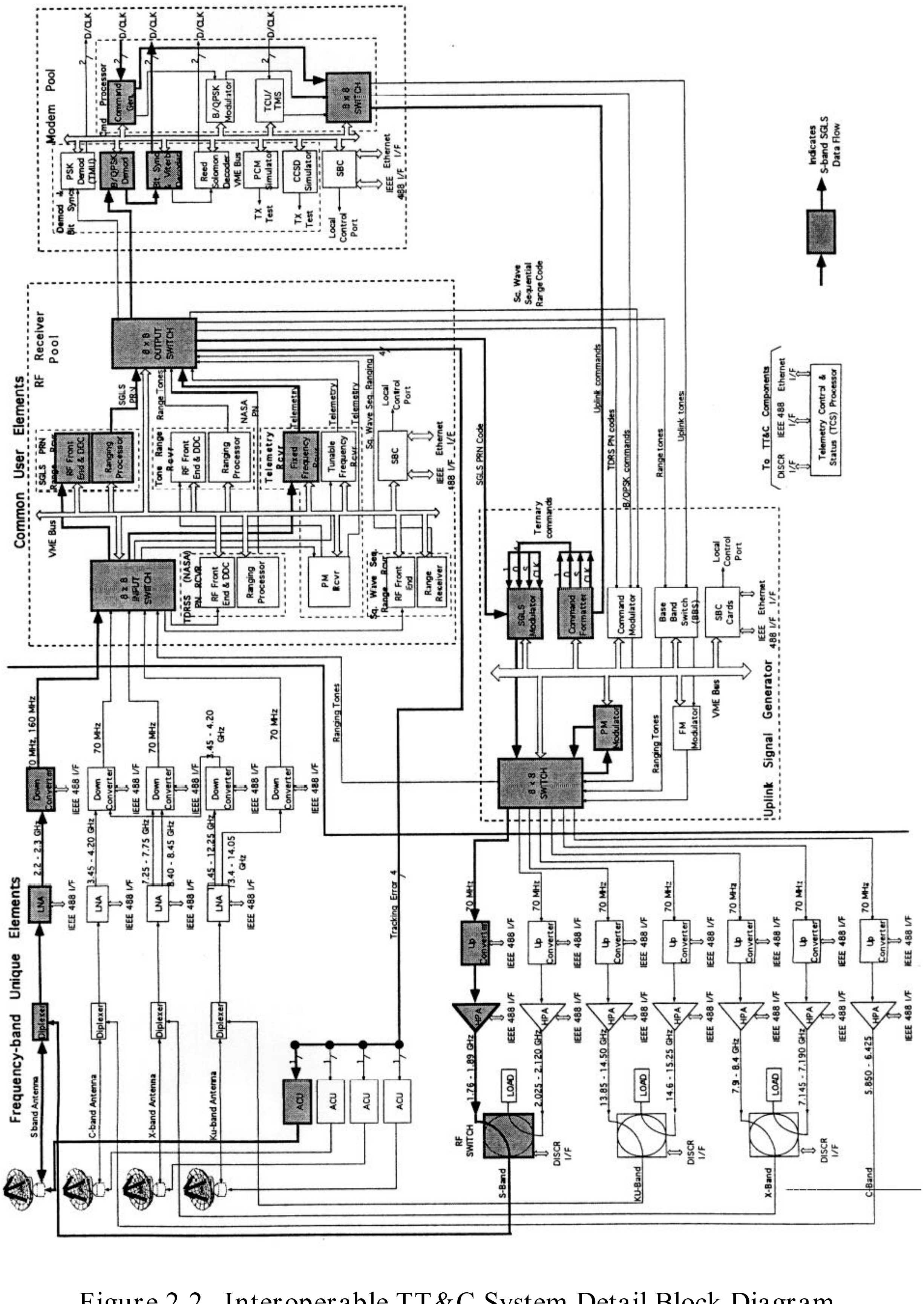

Figure 2-2. Interoperable TT&C System Detail Block Diagram

Single Board Computer (SBC) Card

The SBC card is a VME based component that uses COTS Central Processing Unit (CPU). This is a general purpose processor card that has on-board RAM, ROM and EEPROMs. The RTOS described in the following section provides a mechanism to manage the on-board H/W and S/W resources, the external events, and the real time execution of the application S/W. The SBC operates under the control of the TCS processor, and reports the status back to the TCS via the IEEE 488 bus or over the Local Area Network (LAN) via an ethernet I/F.

The local control port is provided to perform diagnostic and troubleshooting of the subsystems at the VME module level.

Real Time Operating System (RTOS)

The standard COTS RTOS provides basic operating structure to the SBC card which manages the local on-board resources, controls the execution of application specific S/W, and attends events external to the SBC. The RTOS required for this application will include a pre-emptive multitasking scheduler. This will control the operations of the various telemetry components, and control the execution of the application S/W residing in the RF Receiver Pool, the Modem Pool, and the Up-link Signal Generator subsystems.

2.4.2 Downlink Architecture

The traditional TT&C down link processes the telemetry signals in an analog fashion from the moment the signal is received by the antenna until it propagates to the base band stage. The proposed architecture in Figure 2-2 exploits the state-of-the-art DSP, DDS, and ADC technologies, and starts processing the telemetry signals digitally at the 2nd IF stage instead of the base band stage. In other words the telemetry signal that enters the RF Receiver Pool in the analog form via he 8x8 Input Switch, is converted into serial digital data streams by the telemetry and ranging receivers in the RF Receiver Pool, and propagates digitally through the rest of the downlink chain. The use of DSP starting at the 2nd IF improves signal selectivity, sensitivity, signal to noise ratio, dynamic range, and adjacent channel rejection. The following sections describe some of the architectural characteristics of various frequency bands.

2.4.2.1 Downlink CUE Components

The CUE establishes the base for the Interoperable TT&C. The open bus modular architecture together with the VME components and the 8x8 switches offer the necessary flexibility to configure the system in near real time to support chosen frequency bands. The following sections will describe the functional architecture of the CUE components in detail.

RF Receiver Pool

The RF Receiver Pool performs satellite ranging and telemetry data receiving functions, and includes Telemetry Receivers, Range Receivers, Single Board Computer (SBC), and 8x8 VME Switches

Telemetry Receivers

The telemetry receivers include Fixed Frequency, Tunable, and Phase Modulation (PM) receiver that support S-band, Ku-band, X-band, and C-band telemetry streams. The activation, configuration, control, data routing, and status monitoring of the telemetry receivers will be initiated by the SBC under the control of the TCS processor. The telemetry receivers accept the down converted 70 MHz IF signal, PM demodulates the signals, and provides the sub-carrier signals for further processing to the Demodulator and to the Bit Sync in the Modem Pool via the 8x8 Output Switch.

Range Receivers

Several range receivers are required to support the proposed architecture. They are PRN or PN Range Receiver, Square Wave Sequential range receiver, and Tone range receiver. The PRN/PN code range receivers, as shown in the block diagram, generate PRN code, and check the valid receipt of the code. The receivers also generate a tracking error signal for the Antenna Control Unit (ACU) to track the Satellite, and perform the doppler correction. The TDRSS PN Receiver uses a group of PN codes, while the SGLS PRN Receiver uses either a long or a short PRN code. The Tone Range Receiver generates 4 unique frequency tones, and measures the phase delay of the received tones to compute the range of the satellite. The tone range receiver outputs the tracking correction, and performs the doppler correction. The INTELSAT ranging signal uses the 4 tones, while the CCSDS S-band ranging uses 8 tones.

Signal Routing

The signal routing for the RF Receiver Pool is controlled by the 8x8 Input switch and by the 8x8 Output switch. The 8x8 Input switch routes the RF signal stream at first IF (70 MHz) to specific telemetry and range receivers, pre-determined by the type of the space vehicle. The 8x8 Output switch routes the digital telemetry, the ranging data, and the tracking error data to a specific demodulator in Modem Pool, to a specific command modulator in the Uplink Signal generator, and to the specific ACU, respectively.

Modem Pool

The modem Pool subsystem includes Demodulator and Bit Sync, Simulators, Command Processor, and SBC.

Demodulator and Bit Sync

The Demodulator and Bit Sync group includes B/QPSK and PSK Demods, Bit Sync, and Viterbi and CCSDS error decoders, and is capable of processing the digital telemetry data streams for S-band, C-band, Ku-band, and X-band frequencies. The Demodulator and Bit Sync can either process IRIG-106 PCM telemetry data or CCSDS telemetry data packets. Table 2.4-3 illustrates the VME module utilization examples for processing the various telemetry data types.

2.4.3 Uplink Architecture

The CUE for the uplink stream includes the Command Generator in the Modem Pool and the Uplink Signal Generator. The open bus modular architecture together with VME components and the 8x8 switches offers the flexibility to configure the system in near real time to support chosen frequency bands. The following sections describe the functional architecture of each CUE component in detail.

Command Processor

The proposed architecture shows the command processor as a part of the Modem Bit sync Pool, even though it generates the uplink commands. The command processor accepts user TT&C commands, bit synchronizes the commands with the system clock, and modulates the command with the sub-carrier frequency as required. The command processor includes Command Generator, B/QPSK Modulator, Telecommand Unit/Telemetry Simulator (TCU/TMS), and 8x8 Switch

Command Generator

The command generator accepts user command data and clock from the users of S-band, X-band, and Ku-band frequencies. The user data is bit synchronized with system clock. The output data is sent either to the 8x8 switch or to the B/QPSK modulator for further processing. Data time tagging facility is also available if required.

B/QPSK Modulator

The B/QPSK Modulator accepts the formatted, and bit synchronized commands from the Command Generator, and performs PSK modulations of the data with the sub-carrier frequency. The output of this module is routed to the Uplink Signal Generator via the 8x8 switch. The B/QPSK Modulator processes TDRSS Ku-band, and CCSDS S-band and X-band commanding signals.

TCU/TMS

The TCU/TMS unit accepts the INTELSAT Ku-band and C-band commanding data from the user, and generates Frequency Shift Keyed (FSK) command tones for the Base Band Switch (BBS) in the Uplink Signal Generator .

Uplink Signal Generator

The Uplink Signal Generator accepts the formatted command streams, the BPSK modulated command streams, or the FSK command tones from the Command Processor in the Modem Pool; along with the PRN code, the ranging tone, or the square wave sequential ranging signals from the RF Receiver Pool. The Uplink Signal Generator FM or PM modulates the commanding and ranging signals on to the IF frequency, and routes the 70 MHz modulated IF signals to an up-converter via the 8x8 switch for conversion to appropriate RF carrier frequency. The Uplink Signal Generator includes Command Formatter, SGLS Modulator, Command Modulator, BBS, PM Modulator, FM Modulator, SBC, and 8x8 Switch.

Command Formatter

The Command Formatter accepts Di-bits commands and outputs the ternary 1, 0, S, and CLK signals to SGLS modulator. The Command Formatter is also capable of receiving ternary echo check signals from the SGLS demodulator, and regenerates the command stream for the test scenarios.

SGLS Modulator

The SGLS Modulator accepts ternary commands and produces 65 KHz, 76 KHz, and 95 KHz FSK tones for SGLS S-band, and for DSCS X-band frequencies. The FSK tones are summed with the 1 Mbps digital PRN code and AM modulated to produce the composite SGLS wave forms at the base band frequency. The composite output is routed to the PM modulator via the 8x8 Switch.

Command Modulator

The Command Modulator accepts B/QPSK modulated command data and PSK modulates with the forward carrier, and TDRSS PN code. The Command Modulator processes the

Ku-band, S-band, and X-band data streams and outputs the composite signal at 370 MHz or 70 MHz.

Base Band Switch (BBS)

The BBS accepts the INTELSAT uplink commands from the TCU/TMS via the 8x8 switch and multiplexes the commands with the range tones from the Tone Range Receiver in the RF Receiver Pool. The BBS outputs the composite signal to the FM Modulator.

FM Modulator

The FM modulator accepts composite uplink signals from the BBS via the 8x8 switch, and FM modulates them to a 70 MHz IF output.

PM Modulator

The PM modulator accepts composite FSK tones from the SGLS modulator or PSK bit stream from the Command Modulator via the 8x8 switch and PM modulates the signal to a 70 MHz IF output.

Signal Routing

The 8x8 VME switch routes: (1) the composite FSK tones or PSK bit stream to either the PM modulator, or to the FM modulator, and (2) the 70 MHz IF, FM or PM signal to a specific up converter module.

2.5 COTS Component Availability to Support Interoperable TT&C Architecture

The vendor survey of the TT&C market has revealed that various combinations of the COTS components and COTS systems are available. The spectrum varies from the components in black box or modular open bus architecture configurations to turn key TT&C systems. However our survey has not found a TT&C system from a single vendor that supports the typical ground station. This section will examine the TT&C COTS components and systems and their applicability to the interoperable TT&C architecture.

The CUE consist of VME products. The vendor survey has provided data on available TT&C VME products. Our analysis indicates that a significant number of telemetry products, available now, will work in the proposed interoperable TT&C architecture. We will also identify the components that are not currently available in VME configuration. Where ever possible we will provide vendor supplied NRE cost to convert them into VME products.

Downlink Component List

Table 2.5-1 presents a matrix of VME modules that can be used to implement the CUE portion of the downlink architecture as shown in Figure 2-2. Most of the VME modules listed in Table 2.5-1 are readily available the implementation at present time. However one exception to this is the ranging receivers.

The Ranging Receiver are not used by all TT&C ground stations. In addition each organization such as NASA TDRSS, NASA CCSDS, Air Force, and INTELSAT uses a range receiver with some unique specification. Because of these differences, the demand for each receiver's type is low, and the vendors are discouraged from developing VME based range receivers on their own. Four types of ranging receivers are used in the proposed architecture. They are, 1.0) SGLS PRN Receiver, 2.0) TDRSS PN Receiver, 3.0) Tone Range Receiver, and 4.0) Square Wave Sequential Ranging Receiver. The VME version for Tone range receiver is readily available, see Table-2.5-1. The TDRSS PN Ranging Receiver is available in VME version, however it is designed to operate under STGT environment. Some modifications may be required to meet the requirements of the proposed architecture. The SGLS PRN Range Receiver is not available in VME version. The NRE cost for VME range receiver development for SGLS could be approximately $300K- $400K. Very little information is available on Square Wave.

Uplink Component List

The Table-2.5-2 presents a matrix of VME modules, that are available to implement the uplink architecture.

Our market survey has indicated that, compare to downlink VME modules, fewer uplink VME modules are available in the market at present time. This is due to the fact that uplink capability is not required at every ground station, which reduces total required quantity. Because of low market demand, the transition from black boxes to VME modules for the uplink equipment will be slow and vendors probably will ask for NRE cost assistance.

3.0 Conclusion

The Interoperable TT&C architecture shown in Figure 2-2 is implementable using the equipment listed in Table 2.5-1 and Table 2.5-2. The open bus and modular nature of the architecture offers the flexibility to support other frequency bands as well as protocols not discussed here. The architecture promotes the use of COTS S/W such as RTOS and OOD shell as the main core S/W to develop the application specific telemetry S/W and integrated configuration database.

Most of the components in the RF Receiver Pool, the Modem Pool, and the Uplink Signal Generator subsystems in the CUE are available in VME COTS hardware. However, the Command Generator in the Modem Pool, and the Command Modulator and the Command Formatter in the Uplink Signal Generator subsystem will require some modifications to meet the Interoperable TT&C requirements. The stand alone version of PM Modulator will require conversion into a VME card.

The Range Receiver function in the RF Receiver Pool requires further analysis to identify opportunities for standardization that may allow development of a common Range Receiver product with options usable across various frequency bands.

The FUE can not be implemented in a VME based architecture today due to lack of VME H/W availability. The low market demand and challenges imposed by the high frequency requirements of the RF components, does not offer enough incentive to vendors to pursue VME productization at this time. However, the technologies such as GaAs and MMIC are available today that can be used to convert stand alone boxes in the FUE into VME modules. The multi channel Global Positioning System (GPS) receiver on a chip is an excellent example of what these technologies can do if there is enough demand for these types of products. Perhaps there will be enough market interest to develop these products in the near future.

VME Modules	Frequency Bands						
	SGLS S-Band	INTELSAT Ku-Band	TDRSS Ku-Band	INTELSAT C-Band	DSCS X-Band	CCSDS X-Band	CCSDS S-Band
Telemetry Receiver Group							
Fixed Frequency Receiver	x		x		x		
Tunable Frequency Receiver	x	x		x		x	x
PM Receiver		x		x			
Ranging Receiver Group							
SGLS PRN Receiver	x						
TDRS PRN Receiver			x				
Tone Range Receiver		x		x			x
Telemetry Data Processing							
B/QPSK Demodulators	x	x	x	x	x	x	x
Bit Sync	x	x	x	x	x	x	x
Viterbi Decoder	x				x		
Reed Solomon Decoder						x	x
CUE Common Modules							
SBC	x	x	x	x	x	x	x
8 x 8 Switch	x	x	x	x	x	x	x

Table 2.5-1. Downlink VME Module Utilization List

VME Modules	Frequency Bands						
	SGLS S-Band	INTELSAT Ku-Band	TDRSS Ku-Band	INTELSAT C-Band	DSCS X-Band	CCSDS X-Band	CCSDS S-Band
Command Processor Group							
Command Generator	x	x	x	x	x	x	x
B/QPSK Modulator		x			x	x	
TCU/TMS		x		x			
Uplink Signal Generator Group							
Command Formatter	x				x		
SGLS Modulator	x				x		
Command Modulator			x			x	x
BBS		x		x			
FM Modulator		x		x			
PM Modulator	x		x		x	x	x
CUE Common Modules							
SBC	x	x	x	x	x	x	x
8 x 8 Switch	x	x	x	x	x	x	x

Table 2.5-2. Uplink Component List