The communication between the ground and satellite is separated into packets. This document specifies the form and function of these packets.

Packet Protocol

Detailed Description of Communication Packet

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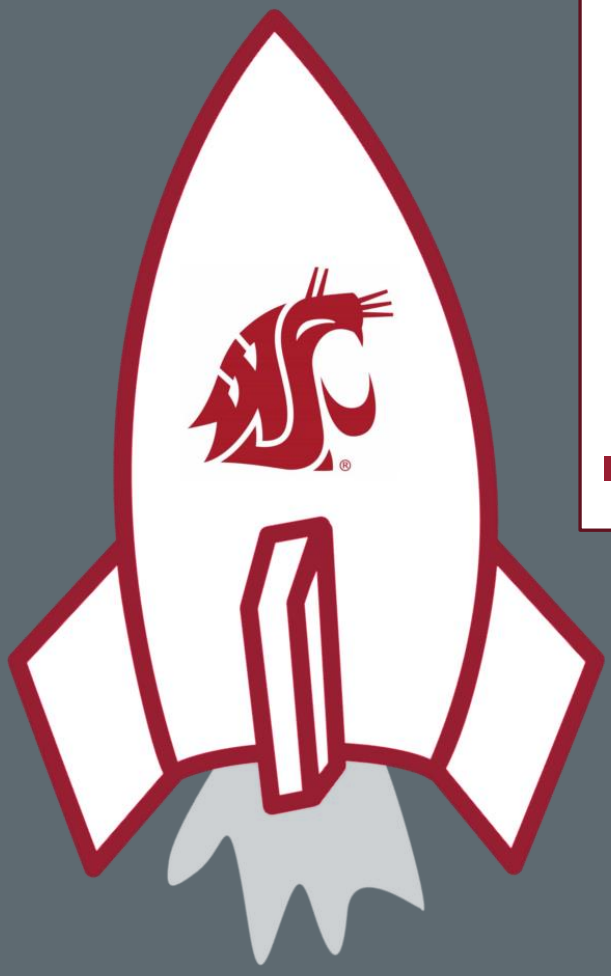

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1 Packet Header

The function of the packet header is to convey the recipient, sender, and type of each packet. Specific command IDs for specific recipients use multipacket as the command is transferring a file larger than one packet can fit. See command lists for which ones are multipacket.

The header is two bytes long. The first byte contains the recipient, sender, and command ID, see bit allocation in table 1. The second byte is the length of the packet in number of dwords ($32b$), including header, minus one. A value of `0x00` indicates the packet is $4B$ long. The choice of dwords allows packet lengths up to $2^8 \cdot 32b = 1024B$, usable data is $1022B$. A packet might require padding at the end of the body to increase the body length to a multiple of single dwords, this padding should be zeros.

Table 1: Packet Header First Byte

Bit index	7	6	5	4	3	2	1	0
Function	Sender `0x0`: Ground `0x1`: CougSat-1 ~~`0x2`: CougSat-2~~[1] ~~`0x3`: CougSat-3~~[1] ~~`0x4`: CougSat-4~~[1] ~~`0x5`: CougSat-5~~[1] ~~`0x6`: CougSat-6~~[1] ~~`0x7`: CougSat-7~~[1]			Recipient `0x0`: ADCS `0x1`: IFJR `0x2`: IHU `0x3`: PMIC `0x4`: Comms `0x5`: Payload 1 `0x6`: Payload 2 `0x7`: Payload 3			Command ID Up to 4 commands per recipient See Section 2 for list of commands	

[1] These CougSats don't exist yet

1.1 Multipacket Additional Header

For a multipacket, there are an additional two bytes appended to the packet header. These represent a 16b long serial number for the packet. By analyzing the serial numbers of all packets received for a multipacket, the recipient can figure which packets were lost and request those specific packets from the sender.

2 Packet Body

The packet body takes two distinct forms: a single packet, or multipacket. The different forms are described below.

2.1 Single Packet

In a single packet, the data directly follows the packet header. This data is specific to the command, this data is described in section 3 under each command.

2.2 Multipacket

The function of a multipacket is to transfer data that is longer than a single packet can support. The primary uses of a multipacket are images and processor binaries. Every packet, except the last packet, will be completely full. There is a low chance that the last packet is also completely full. From the file size given in the first packet and the knowledge on the length of packets, the recipient can immediately figure the number of packets it is going to be.

2.1.1 First Packet

The first packet provides details on the file being transferred, including length and file name. The first 4 bytes represents the file length as an unsigned integer, file sizes are limited to $2^{32}b \approx 4GB$. The next five bytes are a cyclic redundancy check (CRC32) on the file contents used to verify validity. The next several bytes, until a null character is reached, represents the filename as a string. Immediately following the null character is the start of the file.

2.1.2 Second to (n – 1)th Packet

The second and onward packet, to one before the last, just contains the data of the file.

2.1.2 nth Packet

The last packet also contains just the data of the file; however, there is a likely possibility that this packet will not be completely full. If so, the same padding rules apply as normal packets: add padding until the body is an even multiple of dwords. Once this packet is received, or communication times out, the recipient will identify which packets were lost in transmission and request them again using their serial numbers

2.1.3 Lost Packet Request

If a packet is lost, the recipient will send a request for retransmission of that specific packet. The body of this message will be a byte to indicate lost packets (`0xFF`) and the serial numbers of lost packets sequentially appended. If number of lost

packets exceeds the number that fit in a single packet, send additional requests. Once all packets are accounted for, send a multipacket transfer success message and begin assembling packets.

3 Commands

Every command has a specific format which is detailed here. In the byte table, the first two byte are the packet header outlined in section 1. The first byte is bitwise ORed with the satellite ID when sent from a CougSat, only the five least bits are listed in the byte tables.

3.1 ADCS

3.2 IFJR

3.2.1 Processor Binary Image Upload

A binary image is sent by the Ground with command ID 0, see the table below. The file is sent using multipacket, see section 2.2. The IFJR stores this file indefinitely. The IFJR expects the following file name:

[Processor].[Major].[Minor].[Patch].bin

e.g. "IHU.1.0.5.bin"

Byte Offset	0x00	0x01	0x02	0x03	0x04	0x05	0x06	0x07
0x0000	0x04	Packet Length	Serial Number		Data	Data	Data	Data...

After the multipacket transfer, the IFJR sends a reply with command ID 0, see the table below.

Byte Offset	0x00	0x01	0x02	0x03	0x04	0x05	0x06	0x07
0x0000	0x04 | Sat ID	0x01	File Good	CRC32 using 0x04C11DB7				Empty Pad

3.2.2 Reprogram a Device

A request for a reprogramming of a device is sent by the Ground with command ID 1, see the table below.

Byte Offset	0x00	0x01	0x02	0x03	0x04	0x05	0x06	0x07
0x0000	0x05	0x01	Device ID[1]	Ver. Major	Ver. Minor	Ver. Patch	Empty Padding	

[1] See the table below for a list of device IDs

0x00	ADCS	0x01	IFJR	0x02	IHU	0x03	PMIC
0x04	Comms						

After the programming, the IFJR sends a reply with command ID 1, see the table below.

Byte Offset	0x00	0x01	0x02	0x03	0x04	0x05	0x06	0x07
0x0000	0x05 | Sat ID	0x01	Device Good	Programming Duration ($1ms/LSB$)			Empty Padding	

3.3 IHU

3.3.1 Telemetry

A request for a telemetry packet is sent by the Ground with command ID 0, see the table below. This packet contains data on every subsystem of the satellite bus (no payload). This packet is remade and sent at regular intervals during the IHU's periodic event. A request for a telemetry packet is normally not required.

Byte Offset	0x00	0x01	0x02	0x03	0x04	0x05	0x06	0x07
0x0000	0x08	0x00	Empty Padding					

A telemetry packet is prepared and sent by the IHU with command ID 0, see the table below.

Byte Offset	0x00	0x01	0x02	0x03	0x04	0x05	0x06	0x07
0x0000	0x08 | Sat ID	0x31	Mode	IHU Temp	Current Time			
0x0008	SD Card Used Size				Reset Count	Error Status	ADCS Temp	
0x0010	Latitude				Longitude			
0x0018	Roll		Pitch		Yaw		X PWM Out	
0x0020	Y PWM Out		Z PWM Out		X Current		Y Current	
0x0028	Z Current		IFJR Temp	PMIC Temp	Batt A Temp	Batt B Temp	3.3V A Temp	3.3V B Temp
0x0030	PV 0 Temp	PV 1 Temp	PV 2 Temp	PV 3 Temp	PV 4 Temp	PV 5 Temp	PV 6 Temp	PV 7 Temp
0x0038	MPPT 0 Temp	MPPT 1 Temp	MPPT 2 Temp	MPPT 3 Temp	MPPT 4 Temp	MPPT 5 Temp	MPPT 6 Temp	MPPT 7 Temp
0x0040	PV 0 Voltage		PV 0 Current		PV 1 Voltage		PV 1 Current	
0x0048	PV 2 Voltage		PV 2 Current		PV 3 Voltage		PV 3 Current	
0x0050	PV 4 Voltage		PV 4 Current		PV 5 Voltage		PV 5 Current	

0x0058	PV 6 Voltage		PV 6 Current		PV 7 Voltage		PV 7 Current	
0x0060	Battery A Voltage		Battery A Current		Battery B Voltage		Battery B Current	
0x0068	3.3V Regulator A Voltage		3.3V Regulator A Current		3.3V Regulator B Voltage		3.3V Regulator B Current	
0x0070	PR_3.3V-0 Current		PR_3.3V-1 Current		PR_3.3V-2 Current		PR_3.3V-3 Current	
0x0078	PR_3.3V-4 Current		PR_3.3V-5 Current		PR_3.3V-6 Current		PR_3.3V-7 Current	
0x0080	PR_3.3V-8 Current		PR_3.3V-9 Current		PR_3.3V-10 Current		PR_3.3V-11 Current	
0x0088	PR_3.3V-12 Current		PR_BATT-0 Current		PR_BATT-1 Current		PR_BATT-2 Current	
0x0090	PR_BATT-3 Current		PR_BATT-4 Current		PR_BATT-5 Current		PR_BATT-6 Current	
0x0098	PV_3.3V-0 Current		PV_3.3V-1 Current		PV_3.3V-2 Current		PV_3.3V-3 Current	
0x00A0	PR_BH-0 Current		PR_BH-1 Current		PR_DEPLOY Current		PV Switching State[1]	
0x00A8	Output Switching State[1]							Energy Level
0x00B0	Comms Temp	RX Temp	TX Temp	Amp Temp	RX Power		RX Signal to Noise Ratio	
0x00B8	Bad Packet Count		RX Center Frequency			TX Center Frequency		
0x00C0	TX Power		TX Amplifier Voltage					

[1] See PMIC switching states in its documentation for conversion details

3.4 PMIC

3.5 Comms

3.5.1 Radio Configuration

A change to the radio configuration is sent by the Ground with command ID 0, see the table below.

Byte Offset	0x00	0x01	0x02	0x03	0x04	0x05	0x06	0x07
0x0000	0x10	0x05	TX Baseband Frequency			RX Baseband Frequency		
0x0008	CW TX Power		Voice Beacon TX Power		High Speed TX Power		CW Data Rate	
0x0010	Voice Beacon Data Rate		High Speed Data Rate					

A reply is generated and sent by the Comms with command ID 0, see the table below.

Byte Offset	0x00	0x01	0x02	0x03	0x04	0x05	0x06	0x07
0x0000	0x10 | Sat ID	0x05	RX Good	TX Good				

3.6 Payload 1

CougSat-1's Payload 1 is health data logging

3.6.1 Configuration

A change to Payload 1's operation is sent by the Ground with command ID 0, see the table below. The file is sent using multipacket, see section 2.2. The file is specific to the payload, see Payload 1 documentation for details.

Byte Offset	0x00	0x01	0x02	0x03	0x04	0x05	0x06	0x07
0x0000	0x14	Packet Length	Serial Number		Data	Data	Data	Data...

After the multipacket transfer, Payload 1 sends a reply with command ID 0, see the table below.

Byte Offset	0x00	0x01	0x02	0x03	0x04	0x05	0x06	0x07
0x0000	0x14 | Sat ID	0x01	File Good	CRC32 using 0x04C11DB7				Empty Pad

3.6.2 Data Download

A request for the next enqueued data package is sent by the Ground with command ID 1, see the table below. The file is sent using multipacket, see section 2.2. If Ack is a 0, the rest of the message will be ignored and Payload 1 will start a multipacket transfer of the next data. If Ack is a 1, the status flag is success, and the CRC32 is valid, the file was successfully downloaded, and it will be removed from the queue.

Byte Offset	0x00	0x01	0x02	0x03	0x04	0x05	0x06	0x07
0x0000	0x15	0x01	Ack	File Good	CRC32 using 0x04C11DB7			

If ACK is a 0, Payload 1 will send a multipacket with command ID 1, see the table below.

Byte Offset	0x00	0x01	0x02	0x03	0x04	0x05	0x06	0x07
0x0000	0x15 | Sat ID	Packet Length	Serial Number		Data	Data	Data	Data...

3.7 Payload 2

CougSat-1's Payload 2 is a ground facing camera.

3.7.1 Configuration

A change to Payload 2's operation is sent by the Ground with command ID 0, see the table below. The file is sent using multipacket, see section 2.2. The file is specific to the payload, see Payload 2 documentation for details.

Byte Offset	0x00	0x01	0x02	0x03	0x04	0x05	0x06	0x07
0x0000	0x18	Packet Length	Serial Number		Data	Data	Data	Data...

After the multipacket transfer, Payload 1 sends a reply with command ID 0, see the table below.

Byte Offset	0x00	0x01	0x02	0x03	0x04	0x05	0x06	0x07
0x0000	0x18 | Sat ID	0x01	File Good	CRC32 using 0x04C11DB7				Empty Pad

3.7.2 Data Download

A request for the next enqueued data package is sent by the Ground with command ID 1, see the table below. The file is sent using multipacket, see section 2.2. If Ack is a 0, the rest of the message will be ignored and Payload 2 will start a multipacket transfer of the next data. If Ack is a 1, the status flag is success, and the CRC32 is valid, the file was successfully downloaded and it will be removed from the queue.

Byte Offset	0x00	0x01	0x02	0x03	0x04	0x05	0x06	0x07
0x0000	0x19	0x01	Ack	File Good	CRC32 using 0x04C11DB7			

If ACK is a 0, Payload 2 will send a multipacket with command ID 1, see the table below.

Byte Offset	0x00	0x01	0x02	0x03	0x04	0x05	0x06	0x07
0x0000	0x19 | Sat ID	Packet Length	Serial Number		Data	Data	Data	Data...

3.8 Payload 3

CougSat-1's Payload 3 is a germination experiment

3.8.1 Configuration

A change to Payload 3's operation is sent by the Ground with command ID 0, see the table below. The file is sent using multipacket, see section 2.2. The file is specific to the payload, see Payload 3 documentation for details.

Byte Offset	0x00	0x01	0x02	0x03	0x04	0x05	0x06	0x07
0x0000	0x1C	Packet Length	Serial Number		Data	Data	Data	Data...

After the multipacket transfer, Payload 3 sends a reply with command ID 0, see the table below.

Byte Offset	0x00	0x01	0x02	0x03	0x04	0x05	0x06	0x07
0x0000	0x1C | Sat ID	0x01	File Good	CRC32 using 0x04C11DB7				Empty Pad

3.8.2 Data Download

A request for the next enqueued data package is sent by the Ground with command ID 1, see the table below. The file is sent using multipacket, see section 2.2. If Ack is a 0, the rest of the message will be ignored and Payload 3 will start a multipacket transfer of the next data. If Ack is a 1, the status flag is success, and the CRC32 is valid, the file was successfully downloaded and it will be removed from the queue.

Byte Offset	0x00	0x01	0x02	0x03	0x04	0x05	0x06	0x07
0x0000	0x1D	0x01	Ack	File Good	CRC32 using 0x04C11DB7			

If ACK is a 0, Payload 3 will send a multipacket with command ID 1, see the table below.

Byte Offset	0x00	0x01	0x02	0x03	0x04	0x05	0x06	0x07
0x0000	0x3D | Sat ID	Packet Length	Serial Number		Data	Data	Data	Data...

4 Units

When a number is sent down, it is raw byte data that needs to be reassembled and converted to appropriate units. Below is a list of all numbers transferred and how to convert their byte data to a real number. Unless otherwise specified, these conversion factors are used for every value of the appropriate type.

All values use big-endian byte ordering. The most significant byte is located in the first index.

4.1 Voltage

Unsigned $16b$ integer with $100\mu\frac{V}{LSB} = 0V\ to\ 6.55V$

4.2 Current

Signed $16b$ integer with $150\mu\frac{A}{LSB} = \pm 4.92A$

4.3 Power

Unsigned $16b$ integer with $250\mu\frac{W}{LSB} = 0W\ to\ 6.4W$

4.4 Energy

Unsigned $8b$ integer with $500\frac{J}{LSB} = 0J\ to\ 127kJ$

4.5 Latitude and Longitude

Signed $32b$ integer with $10\mu\frac{min}{LSB} = \pm 358°$

4.6 Time

Unsigned $32b$ integer, UNIX Epoch time

4.7 Temperature

Signed $8b$ integer with $1\frac{°C}{LSB} = -128\ to\ 127°C$

4.8 Euler Angles

Unsigned $16b$ integer with $2^{16} = 360°$

4.9 Decibels

Signed $16b$ integer with $1m\frac{dB}{LSB} = \pm 32.8dB$

4.10 Frequency

Unsigned $24b$ integer with $100\frac{Hz}{LSB} = 0\ to\ 1.67GHz$

4.11 Unitless

Unsigned integer (variable bit length) with $1\frac{ul}{LSB}$

4.12 "Good" Flags

Unsigned $8b$ integer representing an error code, see Code SOP, section 6.4.1

4.13 Data Rate

Unsigned $16b$ integer with $1\frac{\sqrt{bps}}{LSB} = (value)^2\ bps = 0\ to\ 4.29Gbps$