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The Common Berthing Mechanism (CBM) for International Space Station

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ABSTRACT

The International Space Station (ISS) Program utilizes the Common Berthing Mechanism (CBM) hardware to mate/berth or demate/deberth two pressurized elements on-orbit. Berthing and deberthing of two elements together on-orbit occurs many times throughout the Space Station Assembly Sequence to provide pressurized access between the module vestibules via hatches. The CBM system was developed by Boeing at Marshall Space Flight Center (MSFC) in Huntsville, Alabama, under contract to NASA, and the CBM Control and Actuation Components were developed by Honeywell Engines & Systems in Torrance, California, under contract to Boeing.

INTRODUCTION

The Common Berthing System provides for Space Station growth and flexibility, both in configuration and in assembly sequence. The CBM system is separated into two halves, consisting of **active** and **passive** rings (Figures 1 and 2, respectively). Each ring is structurally mounted to a pressurized element for berthing/deberthing. Usually, the active ring of the CBM is placed on-orbit first, and made ready to support berthing to the passive ring. The rings are universal in design so that any passive CBM ring can be berthed with any active CBM ring.

CBM system components are attached via passive and active structural rings to their respective element ports. Whether to incorporate a passive or an active ring into an element is determined by the planned assembly mission sequence for each element. The active CBM ring contains the Actuation System hardware components developed by Honeywell Engines & Systems. (i.e., Controllers and Bolt & Latch Actuators)

After the passive ring is captured and drawn into the desired position by the capture latches, the bolting operation may be initiated. Bolting is conducted in several stages. The first stage acquires all 16 bolts and their mating nuts and torques them to an "acquire bolt preload" of 1500 pounds (as measured by strain gages within the bolts, and monitored by the CBM Bolt Controllers). After the preload torque is complete, further torquing is discontinued so that temperatures between the passive ring and active ring can equalize. Once the temperatures are equalized, the torquing operation resumes. Bolts are commanded, in-groups of four, through several more torquing stages, proceeding from the initial preload of 1500 pounds up to a final load of 19,300 pounds per bolt. The module is then in its fully berthed position. The CBM system hardware has successfully performed berthing and deberthing operations during Space Station assembly flights 3A/STS-92 and 5A/STS-98. The operations performed on those missions were:

1. Z1 Truss berthing to the Unity module zenith port.
2. PMA-3 berthing to the Unity module nadir port.
3. PMA-2 deberthing from the Unity module forward port.
4. Destiny module berthing to the Unity module forward port.
5. PMA-2 berthing to the Destiny module forward port.

Each pressurized module contains one or more active (ACBM) and/or passive (PCBM) ring(s) to support assembly to the Space Station. A passive ring contains no active elements; the active ring uses the CBM closed loop Actuation System to perform berthing/deberthing operations. The CBM Actuation System is assembled onto the active Module ring as shown in Figure 1. Each active CBM ring contains 4 Control Panel Assemblies, 4

Capture Latch Assemblies, and 16 Powered Bolt Assemblies. The Capture Latch Assemblies provide the initial link between the ACBM Module and the incoming PCBM Module. Four Capture Latch arms (see Figure 3) provide the mechanical linkage between the platform and the module. Each latch arm is driven by a Capture Latch Actuator as shown in Figure 3. This Capture Latch Actuator is controlled for each of the four CPA's by the closed loop speed control system in the CBM Latch Controller.

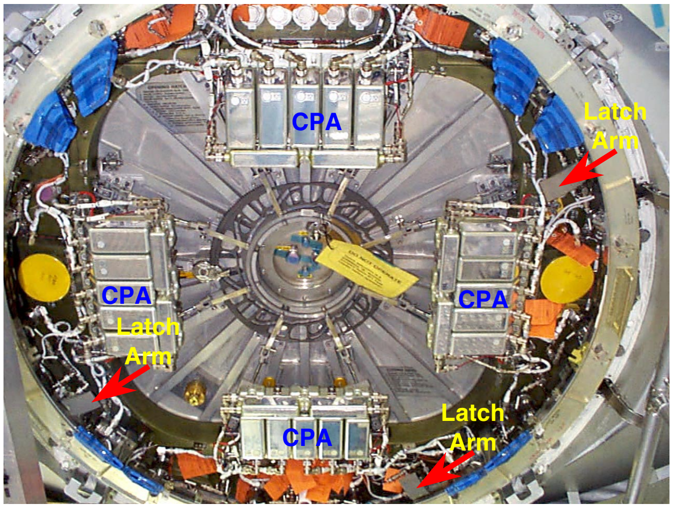

Figure 1: CBM Installation on Module Ring

Extensive qualification and acceptance testing has been completed on the Actuation System Orbital Replacement Unit (ORU) CPA's and Bolt/Latch Actuators by Honeywell Engines & Systems. Boeing MSFC completed the CBM System qualification and acceptance testing.

Berthing Sequence

Module ports can be berthed and de-berthed when new modules are assembled to the on-orbit Space Station.

After the 4 Capture Latches have pulled the PCBM Module into position, the 16 powered bolts are commanded to complete the rigidization of the structural joint to seal the vestibule between the passive and active elements. The Powered Bolts are driven into position and torqued by the closed loop speed control system of the CBM Bolt Controllers and Bolt Actuators.

While deploying Capture Latch Assemblies on a radial port, the Latch mechanism releases deployable petals that protect the ring mating surface and allow the spring loaded petal covers to open without interference, thus exposing the ring for berthing (see Figure 5). The passive ring (shown in Figure 2) contains the mating nuts for the bolts, and is guided toward the active ring by the Shuttle or Station Remote Manipulator System (RMS) arm. Once in position, a Ready To Latch signal is sent via the latch controllers to the on-orbit crew or ground. When this signal is received, it indicates that the passive ring is in position, and is ready for capture operations. At this time, the latches are commanded to capture the approaching passive ring in a two-stage operation. The first stage commences when the command is given to begin the latch operation and engage the latch arms with the passive ring. The second stage involves activating the Latch Actuator to draw the passive ring into the bolting position.

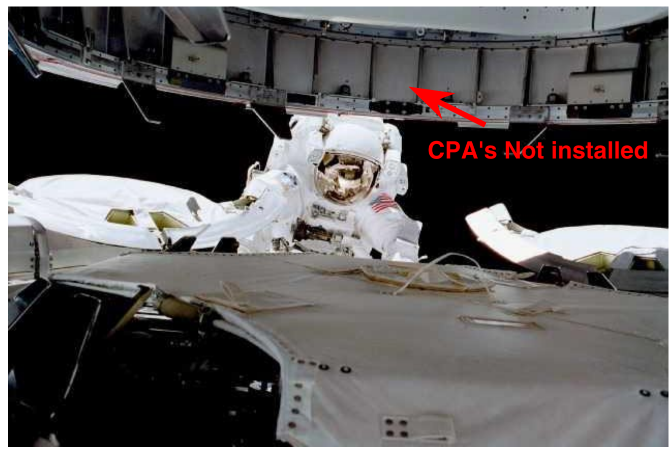

Figure 2: CBM Passive Ring

THERMAL EQUILIZATION

After the active ring captures the passive ring, the initial bolting activity, "A Bolt" operation, will bring the two rings together and apply a force level to an "acquire bolt preload" of 1,500 pounds for all sixteen bolts at 5 RPM. The bolting activity is then halted for a period of up to 12 hours to allow the temperatures of the two structures to equalize before continuing on to the final levels. The module temperature equalization period prevents abrasion of the seals (between the two rings) that can occur following engagement; during this time, temperature changes between the two structures create relative motion that would abrade the seals.

During operation, the CBM power consumption generates heat that is transferred from the CPA to the hatch beam mechanical mounting structure and to the ring from the actuators in the active ring. This heat is conducted through the mechanical metal-to-metal interface of the CPA and actuators. The greatest heat buildup occurs during the final bolt drive operations.

For the preload "I Bolt" operation, four bolts are driven at 0.6 RPM in five stages. Two bolts for each of two CPA's located on diagonally opposite sides of the ring are driven simultaneously to the initial preload level. Next in this sequence are the two CPA's 90 degrees from the first two. This pattern continues for each stage until all sixteen bolts have been driven from the initial force level of 1,500 lbs. incrementally for each of the five stages. Stage one is driven to a level of 2,500 lbs., stage two to a level of 3,500 lbs., stage three to a level of 4,500 lbs., the fourth stage to a level of 5,500 lbs. and stage five to the level of 10,500 lbs. Once all five stages are completed, all sixteen bolts will be at the 10,500 lb-level. The total time for all five stages is thirty-three minutes maximum.

To keep the ΔT between the active and passive rings less than 100°F the engagement remains at this level of force for a period of up to 12 hours. During this time power is applied to all four CPA's and heat is transferred to the mechanical structure. For the final force level "F Bolt" operation, where maximum drive power is required, four bolts are driven in the same sequence as that used for the initial engagement, but for only one stage, and at 0.4 RPM at 19,300 lbs. This operation lasts a maximum of seven minutes with maximum power required.

The power dissipation for these operations is limited to 600 Watts for the ring of four CPA's. The quiescent power for each CPA is 36 Watts. This means that when power is applied to the CPA's, the power that needs to be transferred to the ring through the mechanical interface is a minimum of 144 Watts. The maximum power applied occurs during the final force level of the two rings. The maximum power for each of the four bolts being driven is 45 Watts. This adds 180 Watts to the total transferred through the mechanical interface, given the time required to achieve the final torque levels. The total power to be transferred at this level is 324 Watts. The period of time for this activity is a maximum of seven minutes. The power as shown here is only 54% of the rated power dissipation allowed; therefore, the worst-case operations of the four CPA's on the ring is far less than the designed capabilities for thermal transfer.

ACTIVE CBM SYSTEM

The four Control Panel Assemblies (CPA's) provide the closed loop control of the active berthing system Actuators. The configuration of the CPA is shown in Figure 4. The transmitted commands to control the CBM are received from a Space Station Command & Data Handling (C&DH) system through the Multiplexer/DeMultiplexer (MDM) over the MIL-STD-1553 serial digital data bus. Commands may originate from the ground or from the on-orbit crew. One of the CBM Capture Latch Controllers on each ring is designated as the Master Capture Latch Controller by the C&DH MDM. The CBM Master Capture Latch Controller provides the communications link between the C&DH, MDM, and the CBM ring. Operating information is transmitted and received through either of two RS485 serial buses. This information is processed by the Master Capture Latch Controller and is passed trough through the RS485 bus to command the other 19 controllers as slaves. The CPA Controllers monitor and control the operation of the Bolt and Latch Actuators during the berthing/deberthing operation. The Latch Actuator is mechanically linked to the Latch Arm mechanism (see Figure 3), which engages the mating interface of the passive module ring. The Latches are also used during the first phase of deployment.

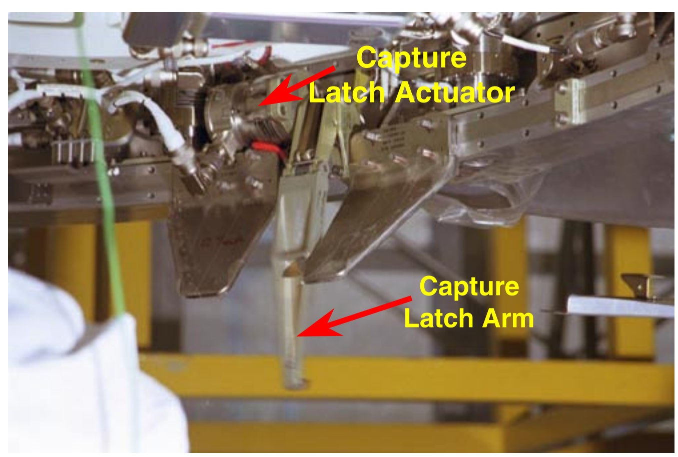

Figure 3: Capture Latch Mechanism

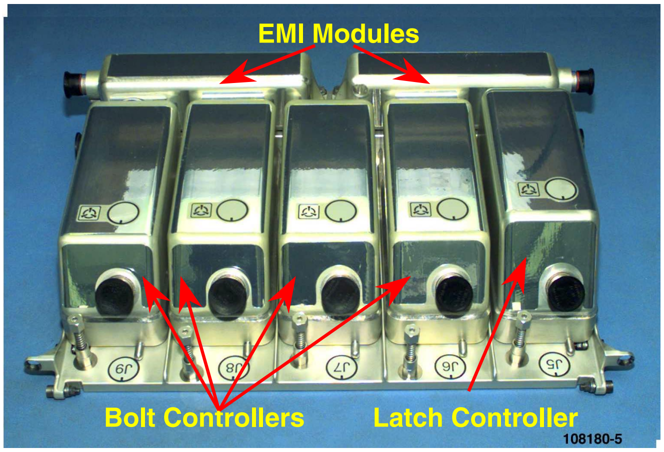

Figure 4: Controller Panel Assembly

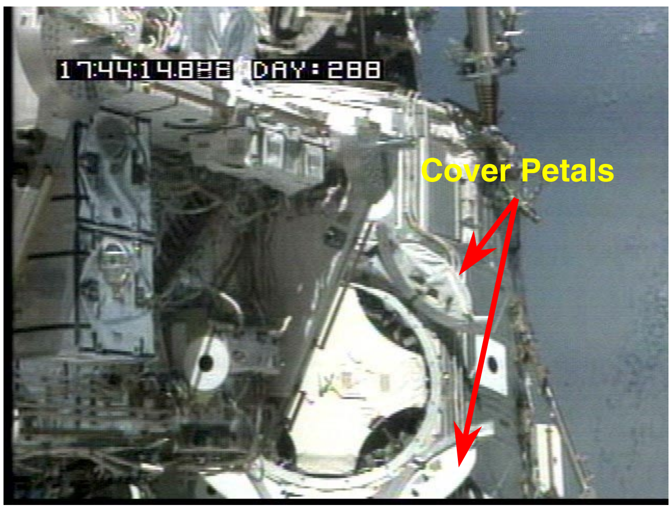

Figure 5: On-Orbit Berthing Operation

Honeywell Node Elements

Honeywell provides the Controller Panel Assemblies, the 16 Bolt Actuators and 4 Latch Actuators used to manipulate the Boeing MSFC-designed mechanisms (Powered Bolt and Capture Latch Assemblies). The CPA contains the drive electronics to control the Bolt and Latch Actuators. Each CPA contains four Bolt Controllers, one Latch Controller, and two EMI Modules. Each active Node port contains 4 CPA's, located one in each port quadrant (see Figure 1).

The mechanical Capture Latches have position limit switches. The Latch controller will drive the Latch Actuator to a designed torque limit relative to the Latch Arm position of travel during engagement.

The Bolts incorporate strain gages. The Bolt controller drives the bolt to a desired joint preload and limits the torque of the actuator during engagement.

Honeywell also provides the CBM interconnecting cables that connect the four CPA's of a Node port to each other, and to their respective actuators and sensors. Figure 8 presents a diagram of these interconnections.

<u>Controller Panel Assembly (CPA)</u>

The Controller Panel Assembly (see Figure 4) is the mounting platform for the Bolt and Capture Latch Controllers and the EMI modules. Each CPA contains four Bolt Controllers, one Capture Latch Controller, and two EMI Modules.
The 120VDC input power received from the Space Station energizes the two EMI modules. One EMI module is the CPA primary power source; the second functions as an alternate power source. The input power is filtered, and in-rush current is limited via the EMI module.

<u>Bolt Controller</u>

The Bolt Controller provides the drive power and the control electronics for closed-loop speed and current control of the Bolt Actuator. This Controller also contains an RS-485 communication link that transfers data to and from the Latch Controller. (In the lab, the RS-485 communication is employed to load the controller firmware.) In addition, the controller possesses input power current-monitoring and 120VDC bus-isolation capability.

<u>Capture Latch Controller</u>

The Capture Latch Controller provides the drive power and control electronics for closed-loop speed and current control of the Capture Latch Actuator. In addition to all the circuits contained in the Bolt Controller, the Capture Latch Controller contains the MIL-STD-1553 communication link that interfaces with the Space Station Multiplexer/DeMultiplexer, computer (MDM) that is part of the Command and Data Handling system (C&DH). In each ACBM port, the twenty controllers are commanded and monitored by one unit designated as the Master Capture Latch controller. All four Capture Latch Controllers in each port are capable of being the Master Capture Latch Controller if commanded so by the MDM. All Slave Bolt/Capture Latch Controller information is communicated to the Master Capture Latch

Controller via an RS485 bus, then through the Master Capture Latch Controller to the MDM via the MIL-STD-1553 Digital Data Bus; and vice-versa. The RS-485 communication is employed to load the controller firmware. The controller also possesses input power supply current-monitoring and 120VDC bus-isolation capability.

EMI Modules

The two EMI modules provide a filtered interface, power bus isolation, and current and voltage isolation between the input 120VDC-supply power and the CPA. One module is the primary interface; the other is a secondary or backup source for input power.

Figure 6: Bolt Actuator

Bolt Actuator Drive Capabilities

The Bolt Actuator (Figure: 6) incorporates a 3-phase, 10-pole, brushless DC motor and a 1242:1 gearbox. The Bolt Actuator gearbox is sufficiently mechanically robust to support 3,500 in-lbs. of output torque.

Bolt actuator and controller logic torque limits are as follows:

- 1,600 in-lbs., up to 2 minutes, at 0.5 RPMs
- 200 in-lbs., continuous at 5 RPMs.

Figure 7: Latch Actuator

COMMUNICATIONS AND COMMANDS

Capture Latch Actuator Drive Capabilities

The Capture Latch Actuator (Figure 7) uses the same motor and gearbox as the Bolt Actuator. The difference between the Capture Latch Actuator and the Bolt actuator consists only of the physical mounting provision and the interface. Communication between the MDM and the CPA is conducted through the MIL-STD-1553 Serial Data Bus operating at one million bits per second. The commands are issued from the MDM to the Master Latch Controller on each ring, and data from each ring is sent back to the MDM via the Master Latch Controller. Communication and commands between CPA's on the ring are conducted via the RS-485 communication bus to and from the Master controller. Each controller on each CPA has a unique address that permits independent operation and control. This in turn allows the bolt or latch actuator to be driven independently.

Bolt and Latch Motor Control Loop

Figure 8: illustrates the interconnection between the CPA, the Actuators, and the load sensors. In the control loop operation, the controller output drivers provide a three-phase, pulse-width-modulated drive to the bolt and capture latch actuator motors. The motor position is detected

via Hall-Effect sensors that provide information on rotation/commutation. Currents in each phase of the drive circuits provide feedback in the motor control loop. In the event that the motor does not begin to rotate, the current sensing will determine that there is no change in current, and the Hall-Effect devices will detect no rotation. These conditions will shut down the drive electronics and flag an error.

Controller Torque Feedback Loop

A load cell mounted on each bolt provides the preload feedback to the controller. Each bolt controller monitors the bolt preload level and determines when the desired preload has been reached. At this point, the output drive from the controller to the motor is shut down. Each bolt is driven to the desired preload level for each step of engagement. The bolting sequence used for ring engagement during station integration requires that all bolts of each CPA be engaged and driven to a 1500-pound preload force (as measured by the strain gauge) for each bolt. Following successful completion of the initial acquire command, bolts are driven four at a time. The first set of bolts is driven to the desired force, then the subsequent sets are driven until all sixteen bolts reach the desired preload.

Communication Data – Bolt & Latch

During operation, data relative to each module is transmitted from the Master Latch Controller to the MDM Computer over the MIL-STD-1553 data bus. Status messages provide the MDM with operational status of the ring as follows:

CBM 1553 Status Message BIT Primer

Within the CBM 1553 status message there are two fields containing Built-In-Test (BIT) information. A typical CBM status message is shown below. CBM Controller background BIT Status is contained in data word 3. Active BIT status is contained in data word 4.

CBM "Status" 1553 Format

Bit Position	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Headers	RT Address					1553 Status Field										
Index Word	Status code				0	0	1	Index = 29H								
Extension	Command Code								Subsystem ID							
Data Word 1	Master Status								Slave Status							
Data Word 2	Bus Used				CMD Status				Time Code (Minutes*)							
Data Word 3	Background BIT Status															
Data Word 4	BIT Status								Ready to Bolt Status							
Data Word 5	Motor Current Status								Motor Speed Status							
Data Word 6	Bolt Load Status/RTL Switch/CSCI Version								Shaft Status							
Data Word 7	Mask Fault															
XMIT Delimiter	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0

* Originally this was supposed to be seconds.

Logic 0's are the nominal condition for BIT results. Logic 1's indicate abnormal BIT results. A typical MDM to CBM Master STATUS request and the CBM Master to MDM STATUS response is shown below. In this case the CBM Master Capture Latch RT address was **17d** as is seen in the MDM "command word" 8C8A (**1000 1**100 1000 1010). The CBM response is what follows the command word.

8C8A	8800	4229	0344	0000	4032	**0000**
CmdWd	Header	IndxWd	ExtnWd	DWd-1	DWd-2	DWd-3

0200	0000	0A7E	0000	CCCC
DWd-4	DWd-5	DWd-6	Dwd-7	Delimiter

Here, there are no BIT errors indicated (0000 0200). (Note: The 02 indicates a motor direction CCW as determined by a state machine logic output which, in turn, is derived from a sequence of motor position sensor codes. The motor needs to perform some actual rotation for this indication to change states between CCW to CW (or vice versa.) Digital motor current is monitored to determine the command value. The value for motor current is determined by using the conversion as a linear 19.5 mA per thousand RPM. This is converted from current to the desired torque at a desired motor speed. This data is communicated over the RS-485 data bus between CPA's on the ring through the Master Latch Controller. The maximum command torque is 2325 in-lb., which is converted to 255 data bits. The maximum motor current represented by the 255 data bits is 2.088 Amps. The maximum motor speed is 6000 RPM.

CONCLUSION

The Common Berthing Mechanism has been successfully used in space for multiple berthing and de-berthing operations. The Actuation System allows the berthing/deberthing operations to be conducted as a combination of command sequences for attaching the PCBM ring element to the ACBM ring element. The system allows for operating the bolts individually, in pairs, in pairs diagonally, four at a time, or all sixteen at once to achieve the desired berthing or deberthing functions. This system can be adapted for a variety of applications where remote commanded attachment or detachment is required.

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

CBM Common Berthing Mechanism

CPA Control Panel Assembly

C&DH Command and Data Handling System

MDM Multiplexer DeMultiplexer

NASA National Aeronautics and Space Administration

RMS Remote Manipulator System

PMA Pressurized Mating Adaptor

PCBM Passive Common Berthing Mechanism

ACBM Active Common Berthing Mechanism

MSFC Marshall Space Flight Center

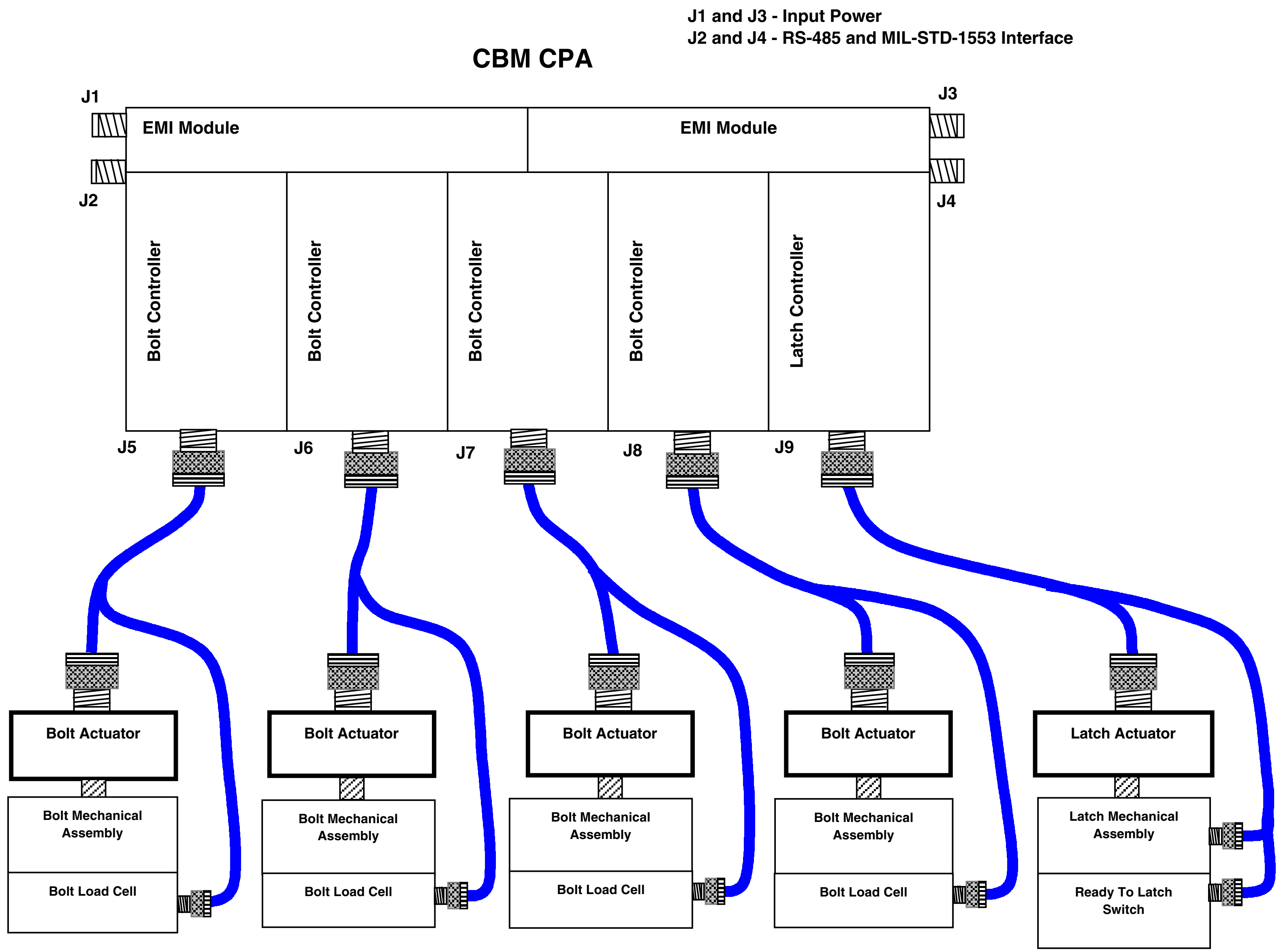

Figure 8: CBM Control Loop Connection Diagram