PREPARING A COTS GROUND TELEMETRY RECEIVER FOR USE IN THE INTERNATIONAL SPACE STATION

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ABSTRACT

Within the industry, telemetry receivers are used in ground-based telemetry receiving stations to receive telemetry data from air or space-based sources. Equipment for the typical telemetry application is widely available. But when requirements create the need for a space-based telemetry receiver to uplink data from the ground, what are the choices for equipment? In such situations, adapting COTS equipment may present the only solution to meet delivery and budgetary constraints.

The first part of this paper provides technical and contractual points a COTS supplier needs to consider when bidding on a COTS contract. The second part of this paper covers a project concerned with modification of a general-purpose ground telemetry receiver for use on the International Space Station. The information within the paper is useful to other engineers and companies considering contracts to modify COTS equipment for use on Shuttle or other space-based projects.

KEY WORDS

Commercial-off-the-Shelf, COTS, telemetry receiver, International Space Station, and Space Shuttle.

INTRODUCTION

In an era of lower budgets and a cost effective space program, NASA frequently looks for available COTS equipment that can be modified for use to meet mission needs. While specially built equipment is necessary for mission critical equipment, other less important applications are often filled using available COTS equipment. Generally, COTS equipment is not used for requirements that are critical to the safety of the crew or craft.
There are many things a potential supplier must consider when asked to provide COTS equipment for a Space Shuttle flight or for the International Space Station project.

**TECHNICAL AND CONTRACTURAL POINTS FOR THE COTS SUPPLIER**

Modifying a COTS piece of equipment for space flight presents many contractual, modification, and packaging challenges. Careful attention to the requirements are needed to avoid situations that could be expensive to both the supplier and customer. Specifications that would normally never be considered in ground-based equipment, such as radiation hardness, moisture, outgassing, and ease-of-use by unfamiliar personnel must be carefully considered.

COTS equipment for space applications will always require analysis, testing, modification, and support. This process can be time consuming in both contract negotiations, and in technical requirements and engineering support. This is not the typical equipment sale. Companies that frequently modify equipment to meet a customer’s requirements will be better prepared.

**TECHNICAL CONSIDERATIONS**

The Space Shuttle and International Space Station are designed to have a “shirt sleeve” working environment with conditions similar to a standard sea-level office. At first glance, the environment may appear to be an easy one for equipment to function. But the conditions resulting from Zero-G, limited air volume, close quarters with people, and radiation pose problems that would never be considered in the design of ground based equipment. Your existing COTS equipment design will need to be examined for the new application.

1. Most ground use equipment is designed with controls and displays for setup and operation. However, flight personnel cannot use their limited training or flight time setting up equipment. Even in situations where performing an experiment requires direct use of equipment, the equipment must be simple to operate. Frequently, the only control provided to the flight crew will be a power switch. Most equipment must power-up ready-to-run and complete a task without intervention.

2. Circuit boards must be conformal coated. Moisture may condense on equipment. Also in a Zero-G environment liquids may spill and circulate with air into equipment. Air is continuously re-circulated. The conformal coatings used must be approved, primarily for outgassing properties.
A. Most likely, your COTS equipment was designed with no anticipation of being conformal coated. An analysis of all circuit boards will be needed. All connectors, trimmers, moving mechanical items, and mounting points will need to be masked from the coating.

B. In military applications, a thick coating is used for protection from high humidity, dirt, and shock. For space-use the purpose of the coating is to prevent problems from condensation, liquids, or a random “loose screw”. Generally, a thin spray coating, free of voids, will meet the requirement.

C. RF circuits may not operate if they are coated. If your equipment has such limitations, be sure to have the necessary wording in the contract.

D. Remember – the thicker the coating, the more outgassing that will occur later. This could result in additional testing and lengthy temperature bake for your equipment.

3. All chemicals used in the construction or assembly of the equipment must be identified and approved. In the small enclosed environments present on the shuttle or space station, outgassing from material and trace chemicals used in equipment may be a health hazard over time.

4. LCDs are not permissible. The fluid from a broken LCD is a health hazard and in a Zero-G environment can easily spread. If LCDs are used they will require a rugged enclosure.

5. Batteries are not permissible. Batteries can corrode. The metallic lithium or sodium found in small batteries for non-volatile memory or clock circuits are highly reactive and unacceptable.

6. Vinyl and vinyl wiring are not acceptable. Teflon is the wiring of choice.

   A. As vinyl decomposes from age and heat, hydrogen chloride gas will be released. The HCl combines with moisture to form hydrochloric acid that can corrode other delicate equipment.

   B. With time and moisture, vinyl can provide a good organic medium for bacterial or fungus to grow. This can result in short-circuits as the insulation breaks down.

7. For short circuit current tolerance, minimum wire sizes will be required on any wire carrying a supply voltage. This will insure minimum wire heating under failure conditions.
8. Equipment in orbit will be subjected to increased radiation. Expect your equipment to be tested with a cobalt radiation source to determine its radiation tolerance.

A. Flash RAM should not be used for program storage. EPROM or NVRAMS or PROMS are preferred. Flash RAM has a low radiation tolerance and will quickly fail.

B. Equipment used for longer periods may experience bit failures of the memory devices. Redesign to use other technologies is contrary to the idea of COTS equipment use. Instead, it may be possible to use a larger device (i.e. EPROM) in which the operating program is compiled two or more times. A simple “boot-strap” memory checksum test can then test the memory and direct program execution at a tested good copy of the operating program.

C. Examine electronics to locate unused gates or other devices. Are they tied to ground or power according to manufacturer recommendations? Look also at unused inputs to other active devices. These can be sources of device latch-up that can cause equipment not to operate, or to fail altogether under radiation.

D. To radiation test equipment, it will usually be disassembled and spread-out so individual circuit boards can be radiated separately. A special test harness will be required so your equipment can be connected and functioning for this test.

9. Equipment must be subjected to conditions to simulate explosive decompression. The purpose of this testing is to verify that no electronics module will rupture if the internal atmosphere is lost. This will require venting of enclosed modules or other large contained air spaces. A small hole drilled in a sealed module will usually meet the need. Small sealed devices such as crystals or power transistors will sustain decompression and do not need to be considered.

10. Examine heat-producing sources within your equipment. Items such as power devices, transformers, high-speed ICs or other components may overheat. Remember - in Zero-G, heat doesn’t flow upwards. Normal cooling convection air currents will not form without gravity. Forced-air cooling may be required.

11. Equipment space is limited. COTS equipment may require re-packaging to meet the space and packaging limitations for equipment on the shuttle or space station.
CONTRACTUAL CONSIDERATIONS

Request for COTS equipment generally will not come directly to your company. Another company will usually have the primary contract with NASA to provide an experiment, flight package, or module. In the course of this contract, the need for COTS equipment will arise and your company will be requested to provide a bid.

Supplying equipment for the Space Shuttle or the International Space Station is very prestigious. However, most companies that provide COTS equipment do not have the necessary equipment or expertise in house to perform the required modifications and testing. This does not need to be a roadblock. The primary contractor will be the company with the experience, equipment, and ability to help in the process. The importance of the COTS equipment to the task or mission being performed will have been previously analyzed. This failure assessment will influence the contract specifications.

1. If your company is uninterested in becoming involved, then sell a standard piece of equipment to the primary contractor and have him make all necessary modifications. Anticipate that even with minimal involvement, they will need copies of many of your drawings, and will possibly need you to retest the equipment after they modify it.

2. Examine the contract carefully. Put your technical people in contact with theirs early in the contract discussion phase. Involve your technical people in contract discussions to make sure the modifications requested can be performed. But, make sure your technical people place all verbally agreed upon points in the preliminary contract before final approvals.

3. As much as possible, use the primary contractor to perform the acceptance testing and modifications to your equipment. Work with them in this – you both benefit from the sale and success of the project. They know the requirements and have the properly qualified people to perform the work. They already have access to sources that can perform the unusual items, such as radiation testing.

4. If the primary contractor performs much of the testing, support them with the modified cables, harnesses, or other accessories for your equipment. You will have the special crimping tools and raw parts to quickly make these specialized, limited-use items for the test of your equipment.

5. Your equipment will most likely be repackaged. If the primary contractor performs this task, support them with modified cables or harnesses. Again, you will have the special crimping tools and raw parts to do this quickly. You may have to support these modified parts with documentation.
6. If there is a reference to a process specification or procedure specification, request it and read it. Compare these procedures to your own internal procedures. Watch for, and attempt to eliminate from the contract, unnecessary “boiler-plate” processes and procedures that have no added functional value to the equipment being provided. Make the primary contractor responsible for these items – they will already have personnel who do this paper work.

7. Anticipate software changes and the associated development costs. Your equipment must power-up and operate without intervention. Your software will have to operate without battery-backup RAM.

8. Expect that your technical personnel will be involved in weekly conference calls, meetings, and information requests. Check the contract for after-shipment support or an at-the-launch on-site presence of your engineers. Estimate your time and travel cost accordingly.

9. The sale will be more than a single item. The contract will involve the sale of several pieces of your equipment. Typically, there will be a flight unit, a backup, and a third unmodified unit that will be used for radiation, vibration, and environmental testing.

10. Arrange for the “test unit” to be loaned back to you for development and to work bugs in your modification processes. This will help you find unanticipated problems without risking damage to one of the primary units. This also results in an additional unit that can be used to resolve problems when the primary units are shipped and unavailable. You will benefit by producing a better final product and the end customer (NASA) will benefit from having a real unit for mockup or training.

A COTS EXAMPLE: A Telemetry Receiver for the International Space Station

For the International Space Station (or ISS) a contract to develop and provide a telemetry, voice, video, and data communications system was obtained by a division of Boeing. However, this system would not be available until the final modules were added to the space station. An interim solution for video and data reception was needed for the early stages of space station use.

The required receiver would need to fit a NASA standard “4 PU SIR drawer”. This package size is different from the 19” rack size of ground equipment. The first choice was to use a Microdyne 700 series telemetry receiver as it was of modular construction and already proven in extensive use by NASA ground stations.
In the fall of 1997, two DC powered 700-MR telemetry receivers with 758-D multi-mode demodulators, bit syncs, and IF filters were ordered by the Space Mission Systems & Services division of Lockheed Martin. This division of Lockheed Martin works closely with the NASA Johnson Space Center. These receivers were only for test and evaluation of the COTS design to see if they would meet space station requirements. After extensive testing of these units, it was determined that the design of the 700-MR could be modified to meet the requirements of the ISS.

In the summer of 1998, two more 700-MR receivers were ordered. These receivers would become the primary flight unit, and a spare backup. Only one of the receivers would be installed on the station. The receiver was scheduled for delivery to the ISS on a shuttle mission in the late spring of 1999.

Lockheed contracted with Microdyne to perform the necessary NRE software modifications, rewire the unit with Teflon wire, and conformal coat the circuit boards. Lockheed would also; repackage the receiver into the 4 PU SIR drawer, perform environmental testing and arrange for radiation testing. The time schedule was critical. Weekly conference calls between Lockheed, Microdyne, and NASA JSC were held.

Although the conformal coating used internally at Microdyne met Military Specifications, it had not been tested or approved by NASA. To speed the process Lockheed worked with NASA to approve the coating. Microdyne requested one of the test radios from the first shipment to prove the modifications and conformal coating process for the many RF circuit boards involved.

Lockheed arranged for radiation testing using first shipment test receivers. The receiver was tested for a radiation dose equivalent to five years in low earth orbit. The 700-MR design contains active devices made using a variety of semiconductor families: TTL, Bipolar, MOS, CMOS, ECL, EPROM, EEPROM, NvRAM, SRAM, FPGA, Schottky, PIN, MOSFET, JFET, and GASFET. It is not known if equipment with such a complex mixture of technologies has ever been radiation tested before.

For radiation testing, the receiver was disassembled and the individual modules spread on three sheets of plywood separated by six feet. A special wire harness was constructed to interconnect the modules. Using a 1 x 3 inch aperture, modules were radiated one at a time to pinpoint sensitive devices. The receiver was powered during the test so any failure could be detected remotely. Due to short-term radiation effects, it would not be possible to handle or repair the radio for several days afterwards.
The receiver passed radiation testing and experienced upset only when the synthesizer module was radiated. The synthesizer recovered as soon as the incident radiation was removed.

The receiver software was modified to remove software dependence on normal battery-backup RAM, and to have the receiver power up to a preset state ready-to-run. All the normal adjustments a technician would perform regularly on the ground (i.e. 0 dB C/N settings, COR adjustments) had to be predetermined and set in the software.

The before-repackaging appearance of the radio in the first photo is very similar to that of a standard 700-MR radio. The new receiver was designated as a 700-SS for Space Station. Module wiring has been changed to Teflon and the 28 circuit boards of the radio have been conformal coated.

The second photo shows the receiver repackaged in the 4 PU SIR drawer configuration. 28 VDC power, RF input, data output, and forced-air cooling are provided on the rear of the 4 PU SIR drawer.

The front of the 4 PU SIR drawer provides additional video outputs, bit-sync data outputs, and an RS-422 I/O port for remote control. LED indicators are provided only for “power”, and “demod lock”. The front panel of the receiver is located under the top cover and is not available for operation. Through the front panel RS-422 port all the controls of a standard 700-MR telemetry receiver are available. Should a different use arise in the future the crew could use a laptop computer to control the receiver.

The primary use of this receiver is on the uplink from the NASA TDRSS satellite system. The crew will use this receiver for data (station equipment software updates) and for family-to-crew personal video communication. The 700-SS made the trip to the International Space Station as one of the cargo items on shuttle mission STS-96 that launched May 27, 1999.
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