Technical Aspects of Specifying and Installing a New 3-Meter EMI Measurement Chamber for NASA Johnson Space Center

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Abstract
Recently, the Electromagnetic Interference (EMI) limits and test methods for the National Aeronautics and Space Administration (NASA) Space Shuttle Program (SSP) were revised to incorporate portions of MIL-STD-461E. Use of Commercial Off The Shelf (COTS) equipment is becoming the preferred solution for equipment integration whenever practicable. NASA Johnson Space Center (JSC) Electromagnetic Compatibility (EMC) engineers recommended a commercial 3-meter chamber as an optimal solution for EMI test and flight certification that would best serve the needs of the Program over the next decade. This paper discusses that recommendation and its background, together with other issues associated with the technical specification and installation of such a chamber.

INTRODUCTION
For many years, the NASA SSP has utilized MIL-STD-461A as a basis upon which to establish EMI requirements at the box level. In similar fashion, the International Space Station Program (ISSP) has utilized MIL-STD-461C as a basis for its box level EMI requirements. Both programs tailored the basic requirements to some extent, and both programs utilized MIL-STD-462 as a test methodology reference, again with some tailoring of the basic document. Thus, both Contractor Furnished Equipment (CFE) and Government Furnished Equipment (GFE) intended for operations on either the Space Shuttle, the International Space Station, or both, were designed and then tested in simple, shielded chambers located at various NASA facilities around the country, among them the Jet Propulsion Laboratory, Glenn Research Center, Goddard and Marshall Space Flight Centers, and Johnson and Kennedy Space Centers. Recently, the EMI limits and test methods for the SSP were revised to incorporate portions of MIL-STD-461E, including the use of radio frequency (RF) absorbing material when performing electric field radiated or susceptibility measurements inside a test chamber. This revision brings the SSP EMI requirements into alignment with the current state of the art within the EMC community, and will help to ensure satisfactory EMC performance of equipment utilized on the Space Shuttle for many years to come. However, it also means that simple, shielded chambers will no longer suffice for EMI testing and flight certification of equipment intended for operations on the Space Shuttle.

In addition to the above described requirements changes, NASA is more frequently turning to the use of COTS equipment as a solution to cost and schedule constraints in the design and production of GFE for SSP and ISSP operations. Similarly, many of NASA’s subcontractors are utilizing COTS equipment to design new, better and more flexible subsystems for use on both Programs. By definition this type of equipment is commercially available, is provided by suppliers located around the globe, and of course meets a wide variety of EMI specifications. Most of these specifications and their corresponding test methodologies differ in some degree from those defined in MIL-STD-461E, and thus their use poses a significant challenge to the NASA EMC engineer.

FACILITY STATUS BACKGROUND
At the present time, JSC has two EMI measurement chambers. The smaller of the two was installed in October 1987, and was originally built to accommodate small to medium sized equipment intended for utilization by the SSP. At the time this chamber was constructed, MIL-STD-461A was the driving EMI requirements source, as described previously, so the chamber design did not include any provisions for inclusion of RF absorber materials. This chamber has a central room used for equipment measurements, with two ancillary rooms on either side, and is shown in Figure 1 on the next page. The larger chamber was built in June 1995, and was built as a test facility for equipment intended for operations on the ISSP. Although the ISSP was and still is, using EMI requirements based on MIL-STD-461C, the chamber itself was designed to meet the requirements of MIL-STD-461D. This chamber also has two ancillary rooms, located together at one end of the larger room used for equipment measurements, and is shown in Figure 2 on the next page.

In 1999, the SSP began looking at the possibility of upgrading its box level EMI requirements. At that time, it was believed that the upgrade would incorporate the latest military specification, MIL-STD-461E. Since the existing
SSP chamber was too small to accommodate the addition of RF absorber material and still provide functional support, a new, larger measurement chamber for the SSP would have to be installed.

**CHAMBER SELECTION PROCESS**

Thus, a tentative decision was made to obtain a new measurement chamber, somewhat larger than the ISSP chamber. Of course, locating the chamber was the very next consideration, and several possibilities were examined. The existing building would not accommodate a new, larger chamber except possibly in the high bay area. The existing building laboratory area is shown in Figure 3 on the next page. However, it was felt the high bay was needed as is, and so this led to the conclusion that either a new building or an addition to the existing building would be required. Moreover, it was felt the new chamber needed to be capable of meeting commercial validation requirements as well as military. After deliberation, it was decided to pursue a chamber capable of meeting Federal Communications Commission (FCC) 3-meter chamber performance requirements, while also offering the capability to perform military EMI testing.

The next step was to draft a specification for the new measurement chamber. NASA Langley Research Center had just recently completed installation of a new 3-meter chamber for commercial EMI testing, and the specification for that chamber was borrowed to use as "boilerplate" for the new JSC chamber. The specification was reviewed, and additions were made to incorporate those characteristics necessary to allow for both commercial and military test applications.
Some of the finalized specification details are listed below.

- The test enclosure and control rooms shall conform to, or exceed, the requirements of MIL-STD-285, IEEE STD 299-1997, NSA 65-6, and MIL-STD-220A.
- The test enclosure shall meet the requirement of ± 4 dB maximum correlation to an FCC 3-meter Open Area Test Site (OATS) after installation of the anechoic absorber, as specified in ANSI C63.4-2001.
- The test enclosure shall function as an RF Immunity Test Enclosure as specified in IEC 61000-4-3.
- All enclosures shall be installed ungrounded in relation to the building structure and shall have a minimum of 10,000 ohms resistance to ground prior to connecting the single point ground lead.
- An electrically powered, remotely controlled, variable speed metal top turntable, 2 meters in diameter, shall be provided and installed inside the test enclosure. The test enclosure shall meet FCC requirements for listing as an alternate test site across the 2 meter turntable surface. The IEC 61000-4-3 field uniformity region shall be centered over the turntable.
- Anechoic RF absorber material shall be installed on the ceiling and walls of the test enclosure, and shall not sag or fall. The absorber material shall meet the MIL-STD-461E minimum requirements of 6 dB from 80 MHz to 250 MHz, and 10 dB from 250 MHz to 18 GHz.
- Shielding effectiveness, site attenuation, and field uniformity testing shall be performed on the test enclosure after assembly is completed. Shielding effectiveness testing shall be in accordance with MIL-STD-285, IEEE STD 299-1997, and NSA 65-6. Site attenuation testing shall be in accordance with ANSI C63.4-2001. Field uniformity testing shall be in accordance with IEC 61000-4-3, with appropriate modifications to extend the testing from 26 MHz to 18 GHz.

With the specification drafted, the next step was to begin the process of expanding the building to accommodate the new chamber. Unfortunately, building expansion cost estimates came back unexpectedly high, because of new requirements for construction materials and techniques to be used in a hurricane zone.

**Approach to a Solution**

At this stage, it became necessary to consider desired features of the new measurement chamber, and potential alternatives in terms of cost versus performance. In order to identify and assess these features and alternatives, a team was formed of three EMC engineers, an EMC facility manager, a deputy building/facility manager, a Center Operations Facility (COF) project officer, a technical group lead, and a supervisor. The team met in a series of engineering and facility design reviews to discuss the desired features, potential alternatives, and ramifications of all of these for the existing building and EMC/EMI facility.

In an effort to broaden the perspectives of the team, a visit was made to a nearby commercial EMI test facility to examine that facility's design, ease of operation, organization, and so forth. Many useful ideas and features were identified during this exercise that the team felt the new chamber design should address.

As it turned out, sixteen unique alternatives were identified. Several of these alternatives are listed below.

- Install the new chamber in the high bay
- Move the existing ISSP lab into high bay, and install the new lab in the vacated space
- Install the new chamber in a nearby building
- Install the new chamber under the apex of the large anechoic chamber
- Split SSP and ISSP test time with the existing ISSP chamber
- Buy the new chamber without a control room, install it in the same room as the existing ISSP chamber, and use the control rooms of the existing ISSP chamber to service both chambers
- Expand the existing building to accommodate the new test chamber only, and use common control rooms as in the previous alternative
- Upgrade the existing ISSP chamber
- Utilize the existing RF communications shielded laboratory room as the new chamber (previously used as an EMI test chamber)

After the alternatives were identified, each alternative was ranked from 1 to 10, 10 being the most favorable. In addition to this ranking, a number of weighting criteria...
were identified. These criteria are listed below (not necessarily in order).

- Expected operating cost
- Potential cost savings
- Schedule impact
- Number of requirements met
- Number of tests that can be run annually – single shift
- Number of people required to run a given test
- Ease of operation
- Flexibility of EMC facilities/chambers
- Flexibility of building/facility
- Opportunity for commercial capacity

Similar to the alternative ranking, each weighting criteria was also assigned a value from 1 to 10, with 10 being given the most weight. These weighting criteria were applied to each of the sixteen alternatives by multiplying the alternative ranking by each of the weighting factors. The resulting values were then summed together, and the composite value thus obtained became that alternative’s score.

Decision
The process described in the previous section enabled the team to carefully review and analyze the alternatives and their corresponding weighting criteria in a timely and efficient manner. By mutual agreement, some of the alternatives were quickly eliminated, while others gradually surfaced to be the least impact to overall cost and schedule. For example, relocation and/or modification of the existing chamber could result in a cessation of operations, possibly for several weeks, a situation not tolerable to either the SSP or the ISSP. Sharing control rooms was rated in the midrange because of several reasons, most important among them being the potential impact to operational safety. Perhaps the most beneficial aspect of using the described process was the stimulation of thought and mutual exchange of ideas. Additional areas of concern that were brought forth and discussed by the team included equipment and facility security and safety issues, minimum versus maximum chamber envelope (some locations offered large floor space, but restrictive overhead) for a given location and the impact to commercial capability, and the impact to and/or availability of appropriate equipment storage.

Ultimately, the decision boiled down to removing an older shielded room from the high bay, and installing the new measurement chamber in the vacated space. As well as the weighted alternatives and additional areas of concern as discussed above, the deciding reasons also included considerations such as

- The older shielded room was no longer functional as an RF tight enclosure, and could not be modified in a cost effective manner
- Footprints of the older shielded room and the new measurement chamber were very close
- Electrical and environmental services were already in place for the older shielded room, and could be easily adapted at minimal cost to the meet the needs of the new measurement chamber
- A building ground attachment point suitable for connection to the new measurement chamber was already in place and available
- Impact to existing high bay floor space and overhead crane mobility/access area was minimal
- Fire protection per NASA Standards could be easily implemented in the chosen location

EXPECTING A NEW EMI CHAMBER
The new EMI measurement chamber will thus be located in the high bay of the existing building. The chamber will consist of one Radio Frequency (RF) shielded anechoic chamber (the test chamber) and two adjoining RF shielded control chambers. The minimum interior dimension of the test chamber is 28 ft. long by 20 ft. wide by 18 ft. high. The freestanding chamber is to be of steel construction, employing laminated panels, and is installed with anechoic absorber treatment consisting of both ferrite tile and foam absorber. Also, it has a flush mount turntable and a movable, remotely controlled antenna tower. The chamber will have a double leaf door providing a minimum clear opening 8 ft. wide by 9 ft. high and an auxiliary access door at least 3 ft. wide by 7 ft. high. Each of the two adjoining RF shielded control chambers has minimum interior dimensions of 14 ft. long by 12 ft. wide by 8 ft. high, and an access door at least 3 ft. wide by 7 ft. high.

SUMMARY
This paper has addressed the impact of the revision of the SSP EMI requirements to the EMI measurement chamber installation at JSC, and the process used by a NASA technical team to select an optimal solution in terms of cost and schedule impact to the SSP and ISSP. Based on the recommendation of the NASA technical team, a commercial 3-meter chamber was specified as the optimal solution for EMI test and flight certification that would best serve the needs of the SSP over the next decade. Background information concerning the current facility status, together with other key issues associated with the technical specification and installation of such a chamber were also discussed. In particular, the decision process employed by a NASA technical team was described in some detail, and shown to produce the optimal solution in a timely and efficient manner.