EMC Engineering of Military Systems using Off-The-Shelf Products Hobart Class Air Warfare Destroyer

Mr. Greg Gallagher
Raytheon Australia Pty Ltd
Building C, 5 Talavera Road
MACQUARIE PARK NSW 2133
Australia
Greg.Gallagher@raytheon.com.au, greg1gallagher@aol.com

***Abstract*— The Air Warfare Destroyer (AWD) Project is based on the existing design of the Spanish F100 class ship fitted with the core Aegis Weapon System. The F100 design has been modified for unique Australian Combat System requirements including systems for underwater warfare, electronic warfare, navigation, electro-optical surveillance and close-in surface defence. Combat Systems equipment acquired as part of the AWD project meets the Australian Government policy that the Australian Defence Force (ADF) must consider Commercial-Off-the-Shelf (COTS) and Military-Off-the-Shelf (MOTS) equipment design solutions. The use of COTS/MOTS equipment presented a challenge to design and certification authorities in making subjective assessments as to the acceptability of COTS/MOTS EMC qualified equipment and the associated technical residual risks when used in the ADF's intended operational environment. This paper outlines the process and techniques used to define the EMC risk of using COTS/MOTS equipment within the Hobart Class Air Warfare Destroyer combat system.**

***Keywords*— Commercial-Off-the-Shelf (COTS); Military-Off-the-Shelf (MOTS); Hobart Class Air Warfare Destroyer; Combat Systems; EMC Risk analysis.**

I. Introduction

In order to comply with the Australian Government policy that the Australian Defence Force (ADF) must consider Commercial–off-the-Shelf (COTS) and Military–off–the-Shelf (MOTS) equipment in ADF procurements, a decision was made at the inception of the Air Warfare Destroyer (AWD) program to use off-the-shelf products to develop and deliver the Hobart Class ship. The AWD Combat System (CS) consists of more than 3,400 items, many of which meet a variety of Electromagnetic Compatibility (EMC) standards. These items are integrated into the Hobart Class ship to achieve functional and non-functional EMC specifications and meet the requirements of Defence Materiel Organisation (DMO) and the Royal Australian Navy (RAN).

II. EMC Requirements

The baseline EMC specification for AWD combat systems MOTS equipment was based on the Spanish F100 class EMC equipment requirements, in that the AWD Combat System MOTS equipment is required to comply with United States (US) military standard MIL-STD-461D. The MIL-STD-461D tests required were: conducted and radiated emissions from the equipment CE101, CE102, RE101 and RE102 and for susceptibility/immunity from conducted and radiated emissions generated from other equipment and the ADF's operational electromagnetic environment CS101, CS114, CS116, RS101 and RS103.

The AWD program did not disqualify COTS and MOTS equipment that did not meet MIL-STD-461D requirements, rather such equipment was permitted for use in the Combat System provided that an EMC risk assessment confirmed that there was no risk of interference or the risk of interference could be mitigated by modification of equipment installation through the application of filters, shielding, cable segregation, grounding and bonding, or other electromagnetic hardening techniques.

As a minimum, COTS equipment used in the AWD program is required to meet Government regulations and comply with the Australian Communications & Media Authority (ACMA) EMC Compliance Framework.

III. EMC Qualification Program

Standards such as MIL-STD-464C (US DoD 01 Dec 2010) and DEFSTAN 59-411 (UK MoD 23 Jan 2007) define how to manage and plan an EMC qualification program for new equipment. These documents formed the basis of the Hobart Class Electromagnetic Environmental Effects (E3) Management Plan and the Platform System Design (ship) EMC Management Plan for the AWD program.

COTS equipment are developed to meet the anticipated requirements of a commercial market which is generally overseen by government and industry certification bodies such ACMA, USA (FCC), European Union (CE), Canada (Industry Canada), and Japan (VCCI). COTS equipment vendors typically do not modify their product to meet the requirements of military customers. COTS equipment is continually and rapidly evolving to maintain a competitive edge as new technologies become available. Many COTS equipment are evaluated for their ability to cause electromagnetic interference only and not vulnerability to the emissions from other equipment. Further, COTS equipment is designed for the commercial use environment which differs from that found in a military environment such as a Naval ship where noisy electrical machinery, sensitive receivers and high power transmitters are co-located. Typically a military system has to be designed around the COTS equipment EMC vulnerabilities.

Many MOTS equipment are usually developed to meet requirements of military customers like the USA, UK, and NATO. Most MOTS equipment undergo an evolutionary EMC qualification program that may include a sequence of prototypes, frequent modification, technical evaluations, and operational evaluations over a period of many years to meet the needs of the principle customer. This results in evolved MOTS equipment with different levels of EMC qualification after each stage of the equipment evolution. These evolved MOTS equipment may then be offered to other customers to use. The use of MOTS equipment presents a dilemma between the need to meet functional and non-functional program requirements and the desire to take advantage of existing MOTS equipment which may have unknown or undesirable EMC characteristics when applied to the Electromagnetic Environment (EME) of a military system such as the Hobart Class AWD.

Designers and integrators of military systems using EMC qualified COTS/MOTS equipment that have been qualified for other military customers and government agencies are likely to have residual EMC technical integrity risks associated with their use. To address this risk, a suitability assessment process is applied to all AWD CS equipment and documented within the Hobart Class E3 Management Plan. The assessment process evaluates the platform installation environment, in particular above deck and compartment level evaluation, the COTS/MOTS equipment's EMI characteristics through a review of existing data, review of equipment design, equipment cable segregation, grounding and bonding, and risk prioritised retesting to AWD project EMC specifications.

The following questions and issues are often raised during the assessment:

1. Is the other military and government defined operational environments the same as or similar to the expected operational environment of the Hobart Class ship?
2. What are the differences between MIL-STD-461D and commercial EMC standards with respect to measurement methods, frequency range and limits and the applicability of the test methods used?
3. COTS/MOTS equipment has often evolved due to requirements of other military customers or advancement in the commercial market and may not have EMC qualification data that is representative of the currently available configuration.
4. Does a qualification of fit for purpose based on equipment pedigree where a long field history with another defence force or another platform within the ADF mean the equipment is fit for purpose?
5. Original EMC qualification evidence and test reports are sometimes not available due to intellectual property restrictions; International Traffic in Arms Regulations (ITAR), vendors declaration of conformity (DoC) using (EU) notified body for CE mark, USA FCC markings and (Australian) competent body for C-tick, A-tick and Regulatory Compliance Mark (RCM) markings.
6. Partial compliance to EMC standards, where not all of the required EMC tests has been performed requiring the equipment to undergo partial or full requalification.
7. No explicit EMC test results for the intended EME or the exact equipment configuration.

Consequently, the benefits of using COTS/MOTS equipment as a way to reduce costs is eroded as the cost vs. technical integrity risk trade-off must be assessed. The cost of managing requalification to AWD EMC requirements, EMC hardening and solving EMC incidents after the equipment warrantee period is not insignificant.

IV. EQUIPMENT EMC TECHNICAL INTEGRITY RISK

An EMC equivalent standards assessment procedure is used for AWD combat systems equipment. The assessment procedure is based on the Defense Industry EMC Standards Committee (DIESC) EPS-0178: "Results of Detailed Comparisons Of Individual EMC Requirements And Test Procedures Delineated In Major National And International Commercial Standards With Military Standard MIL-STD-461E."
A summary of comparative characteristics of the different equipment EMC standards offered by equipment vendors is carried out and documented in the Hobart Class E3 Management plan providing a uniform approach in reporting COTS/MOTS EMC technical integrity risk to the AWD project authorised design approval and certification authorities.

A determination of the EMC technical integrity risk is conducted using the Navy (RAN) Technical Regulatory System (NTRS) described in the NAVY (RAN) Technical Regulatory Manual (NTRM) [ABR6492]. ABR6492 technical integrity risk is defined as the chance of the loss of technical integrity of the equipment that can lead to harm i.e. the lack of COTS/MOTS EMC qualification data. Technical Integrity risk includes:

1. Fitness-For-Service – The ability of the system to perform its required functions with the performance and reliability necessary to complete the missions for which it was intended.
2. Safety - The ability of the system to operate without unintentionally harming people within its sphere of influence.
3. Environmental Compliance – The ability of the system to operate without harming the natural environment within its sphere of influence.

For the AWD program the technical integrity risk assessment applied used the RAN Hazard Risk calculator summarized from ABR6303 Navy Safety Systems Manual. A hazard risk assessment (HRA) based on qualitative analysis using descriptive scales terms of likelihood and consequence. The consequence and likelihood determined the risk severity using a hazard risk indicator (HRI) ranging from 1-5 (extreme), 6-9 (high), 10-17 (medium) and 18-20 (low). Figure 1 shows the technical integrity risk assessment matrix used.

	Consequence (of EMC technical integrity risk)			
Likelihood	**Catastrophic**	**Critical**	**Major**	**Minor**
Frequent	1	3	7	13
Probable	2	5	9	16
Occasional	4	6	11	18
Remote	8	10	14	19
Improbable	12	15	17	20

FIG. 1 Technical Integrity Risk Assessment Matrix

Table 1 shows the ABR6303 "Risk Consequence" descriptions used along with the corresponding definitions of each level used to assess the severity of EMC technical integrity risk for fitness for service.

TABLE 1 Risk Consequence Descriptions

Consequence	Fitness for Service
Catastrophic	Prevent the platform, system or equipment from meeting the primary operational requirements.
Critical	Significantly degrade the platform's systems or equipment's ability to perform its primary mission
Major	Temporary loss of one or more significant capabilities within the platform, system or equipment.
Minor	Temporary degradation or loss of one or more capabilities within the platform, system or equipment.

Table 2 shows the ABR6303 "Hazard Likelihood" descriptions used along with the corresponding definitions of each level used to assess the likelihood of EMC technical integrity risk for fitness for service.

TABLE 2 Risk Likelihood Descriptions

Likelihood	Individual Item	Total Inventory
Frequent	Likely to occur REGULARLY.	CONTINUOUSLY experienced in the inventory.
Probable	Will occur SEVERAL TIMES in the life of the item.	Will occur REGULARLY in the inventory.
Occasional	Unlikely but can be REASONABLY EXPECTED to occur in the life of the item.	Will occur SEVERAL TIMES in the inventory.
Remote	Unlikely but possible to occur in the life of the item.	Unlikely but can be REASONABLY EXPECTED to occur in the inventory.
Improbable	So unlikely it MAY NOT BE EXPERIENCED.	UNLIKELY to occur, but possible.

Once the level of EMC technical integrity risk has been established through the use of the HRI table a determination of the acceptability of the risk is made. Acceptability of risk is broadly categorized into four levels as listed in Table 3.

TABLE 3 Acceptability of Risk

HRI	Risk Level	Risk Acceptability
1 to 5	Extreme	Intolerable.
6 to 9	High	Tolerable with continuous review.
10 to 17	Medium	Tolerable with periodic review.
18 to 20	Low	Acceptable with periodic review.

V. EMC Technical Integrity Risk Treatment

Where the EMC technical integrity risk associated with each of the CS equipment was deemed to be unacceptable, preliminary mitigation plans were established which often involved the use of RF equipment cabinets, extra shielding of cables, improved grounding and bonding of equipment, analysis via modeling of system equipment source vs. victim pairs, operating procedures, spatial separation of equipment, and re-qualification testing of equipment to MIL-STD-461D.

The EMC technical integrity risk was treated as per any other program risk, the cost and schedule impacts of implementing mitigation plans were considered and acceptance of any residual risk was acknowledged by the project authorised design approval and certification authorities. The project Design Acceptance Representative (DAR) was informed of what EMC technical integrity risk controls were planned within the scope of the project; what controls the RAN would be asked to implement and what residual risk would exist after these controls had been implemented. This ensued that the customer (DMO and RAN) through the DAR had the opportunity to influence mitigation plans through formal engineering change proposal for all CS equipment EMC technical integrity risks.

VI. EXAMPLE I-COTS/MOTS EQUIPMENT ABOVE DECK

An above deck system product specification listed EMC test standards included MIL-STD-461C & D and EMC directive 2004/108/EC commercial standards. An unacceptable fit for service EMC risk was identified with the possible malfunction of the system above deck equipment when exposed to above deck transmitters and radars. The topside electromagnetic field was predicted through modeling to be greater than that specified in MIL-STD-461D RS103.
An evaluation of the EMC technical integrity risk was carried out as per figure 2 and the severity of risk (HRI) determined. The resultant HRI was deemed unacceptable. To address the fit for service EMC risk the system equipment was successfully re-tested for radiated susceptibility at the topside predicted levels and the risk mitigated to As Low As Reasonably Practicable (ALARP).

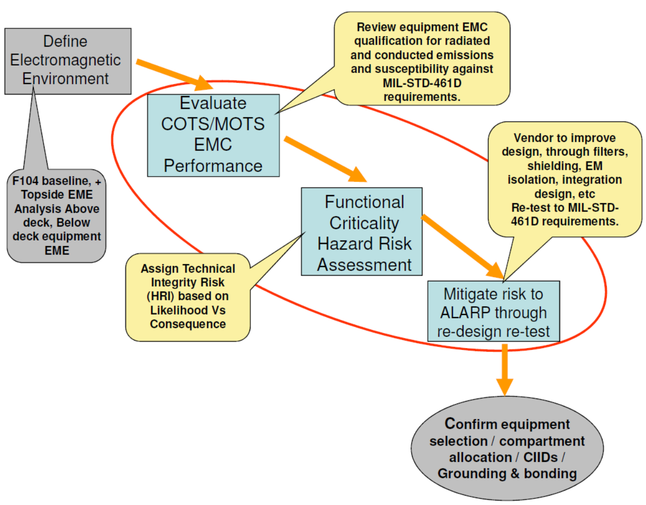

FIG. 2 COTS/MOTS EMC Fit For Service Process

VII. EXAMPLE II - COTS EQUIPMENT BELOW DECK

Some system equipment installed below deck had no available EMC compliance evidence, or were EMC certified to EN60945, while other system equipment was certified to generic commercial EMC standards.
An evaluation of the EMC technical integrity risk was carried out as per figure 2 and the severity of risk (HRI) determined. The resultant HRI was deemed acceptable with low risk as the commercial EMC certified system equipment was widely used by commercial shipping and the equipment exposure to EMI was low, being installed below deck.
However, in order to mitigate the residual EMC technical integrity risk some of the system equipment was installed in an EMI hardened equipment cabinet fitted with EMI gaskets. The cabinet with the installed equipment was then successfully tested to MIL-STD-461D and the residual EMC low risk was mitigated to ALARP.

VIII. EXAMPLE III – COTS EQUIPMENT ABOVE DECK

Some of the COTS systems equipment installed above deck was EMC certified to EN 60945. The location of the system equipment on the deck was assessed against the predicted topside electromagnetic field.
An evaluation of the EMC technical integrity risk was carried out as per figure 2 and the severity of risk (HRI) determined. The resultant HRI was deemed acceptable with a not credible risk for fit for service. Further EMC mitigation was not required.

IX. CONCLUSION

The decision to use off-the-shelf products in the Air Warfare Destroyer (AWD) program to develop and deliver the Hobart Class ship resulted in a level of CS equipment EMC technical integrity risk.

The AWD program implemented an EMC technical integrity risk assessment process for using off-the-shelf equipment that provided a best fit for purpose outcome for the customer (DMO and RAN). The process ensured that the program cost and schedule constraints, as well as technical integrity risk of fit for purpose was mitigated to As Low As Reasonably Practicable (ALARP) using qualitative analysis with descriptive scales terms of likelihood and consequence to the satisfaction of all Hobart Class AWD program stakeholders.

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