THE SWEDISH MICROWAVE TEST FACILITY: TECHNICAL FEATURES AND EXPERIENCE FROM SYSTEM TESTING

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ABSTRACT

A Swedish test facility for microwave high-level radiated susceptibility testing of large systems is presented. Its specification was based on HIRF and HPM environment data. The facility has been in operation for a decade. It has proven its importance for hardness verification of aircraft and other objects, as well as its importance as an instrument for HPM effects experimental work and testing. The advantages of a flexible system for generation of microwave bursts, having variable pulse parameters and repetition rates, as well as its limitations, especially concerning the limited number of test frequencies, have been explored.

INTRODUCTION

Electronic functions in modern systems are given high authority. In a modern fighter aircraft, the flight performance, communication and weapons control functions are based on fast and high precision input data handled by tens of fast computers. Continuous high accuracy system operation is critical for both system functionality and safety. For safety clearance and system verification, it is necessary to test such systems with a multi-components simulated worst-case environment.

High Intensity Radiated Fields (HIRF) was internationally recognised about 15 years ago as a highly significant factor of the electromagnetic environment. Modern digital electronics can, if they are not well protected, respond to bursts of short but very intense radar pulses. In addition, a new class of electromagnetic High Power Microwave (HPM) weapons could generate a similar and even worse environment. HPM demonstrator weapons have been presented having output peak pulse power of more than 1- 10 GW.

Fig. 1. The Swedish *Microwave Test Facility* (MTF). Photo: Saab Avionics, Linköping, Sweden.

Fig. 2. Cassegrain antennas for S-band, 37 dB_i (left) and C-band, 40 dB_i.

THE MICROWAVE TEST SYSTEM SPECIFICATION

The Microwave Test Facility, MTF, was designed by the US Company TITAN Beta and delivered to Saab Avionics, who operates the system for the Swedish Defence Material Administration, FMV. It was mainly specified and designed for aircraft HIRF testing. The overall requirement on the system was to generate a sub-set, at five spot frequencies, of the worst-case environment for Swedish fighter aircraft. The HIRF environment for Swedish and international air operations has been mapped in terms of the mean and peak radiation intensity in the radio and radar bands, as a function of frequency.

The microwave test facility features were based on the knowledge of the microwave operational environment for civil and military systems. Also, research work indicated some desirable features of the MTF design such as need for a certain exposure area, pulse and burst length, pulse duration and repetition rate.

Aircraft testing requires a high efficiency of the test system. Thus, it was necessary to find reliable and flexible test system solutions. This added system mobility and all weather operations capability to the requirements

General MTF System Data

The MTF is mobile and contained in a 12 m ISO container, see figure 1. It is powered by a 230V, 540 kVA, AC, diesel generator. The generator is installed on an ordinary trailer.

The capability of the system consists of five microwave sources at fixed frequencies in the L, S, C, X and K_u radar bands. Parameters, such as the pulse repetition frequency (PRF), the pulse and burst length, and the output power, can be varied. The generator data maximum characteristics are given in table 1. The data are for normal outdoor operation, without the pulse compression system (PCS) for the S-band and without the Cassegrain antennas (CA), see below. All maximum characteristics cannot be attained simultaneously, e.g. the maximum PRF cannot be attained at maximum pulse length.

The MTF is remotely controlled from a shielded control trailer, which is also equipped with optical monitors and a measurement system for recording the generated environment having real time resolution of individual generated microwave pulses.

A large flat 20m by 8m metal mesh plane can be placed on the remote side of the test sector. The plane is tilted and reflects the main radiation beam upward, away from any buildings or other sensitive areas.

System Data for Outdoors Testing

For outdoors HIRF testing of tied aircraft with engines running, the system is equipped with +/- 30 degree horizontally and +/- 15 degree vertically sweeping antennas.

The diagonal horn antenna patterns were decided for a test object distance of 15-25 m. The radiation footprint at the test distance was specified to have a diameter of at least 10 wavelengths and should well cover any access door of an aircraft. At 15 meter distance the 3 dB beam width is 2.8 m at 1.3 GHz, 2.4 m at 2.857 GHz, 2.0m at 5.71 GHZ, 1.6 m at 9.3 GHz and 1.1 m at 15.0 GHz. Horn antennas with dielectric lenses were designed to meet the required antenna pattern. The near field limit of the antennas is 12 meters or less.
The radiation polarity can be remotely shifted between vertical and horizontal mode.

Table 1: FMV Microwave Test Facility, maximum characteristics, from[1].

Radar band	f (GHz)	Average Power (kW)	Maximum Power (MW)	Gain (dB) Outdoor antennas	PRF (pps)	Pulse duration (μs)	E_{peak} @ 15 meter (kV/m)
L-band	1.300	49	25	ca 30	1000	5	30
S-band	2.857	20	20 (PCS: 140)	ca 30 (CA: 37)	1000	5 (PCS: 0.4)	30 (PCS: 80)
C-band	5.710	5	5	ca 30 (CA: 40)	1000	5	17
X-band	9.300	1	1	ca 30	1000	3.8	10
Ku-band	15.00	0.28	0.25	ca 30	2100	0.53	6

PCS: Pulse compression System, see text.
CA: Cassegrain antenna, see text.

System Data for Indoors Testing

The system can be used indoors for HIRF/HPM testing of avionics and general electronics. It is then docked to a shielding test chamber equipped with high power air-cooled anechoic absorbers.

For indoor use another set of antennas is used having less gain but with a near field limit of 1 m. The indoor system can thus generate extreme field intensities at 1 - 3 m distance. At 1 meter distance the following maximum field strengths can be reached: L-band: 120 kV/m, S-band: 160 kV/m (PCS: 420 kV/m), C-band: 110 kV/m and K_u-band: 30 kV/m.

HPM Testing

For HPM-test purposes a pulse compressor (PCS) was integrated in the S-band system. The pulse compressor consists of two tuned cavities. The saturation time constant of each cavity is about 10 μs. The cavities can be pumped by the S-band klystron with 4.5 μs long pulses at a maximum PRF of 300 Hz. Triggering is achieved by phase shifting the microwave input to one cavity. The two cavities then interact constructively at the output. The pumped energy in the cavities empties into the output waveguide to the antenna with a declining pulse having a 0.4 μs time constant. The pulse compressor amplifies the 20 MW S-band generator output by 8 dB. In practical operation 140 MW output power is thus achieved at a repetition rate of maximum 300 Hz with a pulse length of 0.4 μs Bursts of 10 s duration can be generated.

Cassegrain antennas having 37 dB and 40 dB gain respectively can replace the S- and C-band horn antennas. Realistic HPM-effects have thus been demonstrated at distances of 100-200 m, where peak field strengths of many kV/m, and a PRF of 300 Hz-1 kHz. The Cassegrain antennas are shown in figure 2.

Test experiences

A wide variety of objects have been tested with the MTF. Several versions of military and civil aircraft, cars and other land vehicles, weapons, EED:s and PC's. Some general conclusions can be drawn from the testing:

- Since we have not seen any clear dependence of the PRF for damage, it seems that permanent damage is usually caused by the first pulse of a pulse train. In other words, there does not seem to be any thermal stacking nor any gradual erosion (e.g. due to electric discharges) between subsequent pulses (maximum PRF is 1 kHz).
- The repetition rate, PRF, is crucial for some types of disturbances. It seems that this can normally be related to an operation cycle of a critical electronic function. In some cases it rather seems to be just a statistical effect, i.e. by using a high PRF the chance is greater to hit an operational cycle at a critical moment. Low repetition rates show a very low disturbance probability while high repetition rates can cause disturbances at low intensities. L- and S-band radiation disturbs unshielded electronics typically from a few 100 V/m, i.e. from just below 500 W/m^2 and upwards, and destroys electronics from about 20-25 kV/m, i.e. above roughly 1 MW/m^2. Few effects occur below 100 kW/m^2 peak power density at X- and Ku-band testing except for front door effects on systems operating in those bands.
- The radiation burst length has been of importance for effects on control systems incorporating slow analogue functions or inherent recovery such as engine control systems and missile flight control systems.

An internal signal disturbance detected by some diagnostic means cannot directly be interpreted as a malfunction but has to be supported by disturbance analysis of the system function. Realistic system operation and exercise is vital for a realistic test.

Basic HPM-research has revealed that the pronounced trend of lower susceptibility at higher frequencies, usually seen in system testing, can be understood from the fact that field-to-cable coupling decreases (as a trend) by the square of the wavelength [2]. Furthermore, measurements of component susceptibility show a similar dependence versus frequency [3]. This pronounced decrease in susceptibility can however in some cases be counteracted by variations in shielding effectiveness (SE) as function of frequency. The SE, i.e. the transfer function into a shielded enclosure measured by a field probe, is usually a rapidly varying function versus frequency, while its envelope shows a much slower variation. The fast variation is due to changes in the standing wave pattern of the cavity, while the slow variation of the envelope is due to resonances in the transmission properties of the apertures causing the leakage [4,5].

The combination of the frequency variations of SE, coupling to cables and component susceptibility often means that the total “transfer function” from incident field to malfunction of an internal component often shows large variations versus frequency. It can often change tens of dB’s across an octave. This means a severe limitation for the MTF since it generates radiation only at one fixed frequency in each of the five radar bands. This has to be taken into account by supporting MTF testing with a comprehensive analysis based on low level swept frequency coupling measurements, in combination with knowledge about the susceptibility of the internal equipment. On the other hand, since these kinds of analyses often involve considerable uncertainties high level MTF testing is an invaluable tool for validation of these indirect (low level) methods.

Another weakness at MTF testing, which is rather due to financial than technical reasons, is the fact that usually only a limited number of angles of incidence and polarizations can be afforded at testing. Extensive, angular resolved, swept frequency coupling measurements on many different types of real and generic equipment show large variation, typically 20 – 30 dB and sometimes 40 – 50 dB, in coupling as function of angle of incidence [2,4,5,6]. For the size of the investigated equipment, typically decimeter to meter, the angular resolution has to be at least around 5 degrees at 3 GHz in order to, without prior knowledge of the receiving pattern, hit the receiving lobes corresponding to the maximum coupling. A recent comparison between low level coupling measurements and MTF testing essentially confirms the results of the low level measurements [7]. It is also clear that it is in general not possible to guess beforehand what are the worst angles of incidence, which is illustrated by the fact that those typically also varies with frequency [8,9]. Of course, this problem of insufficient angular resolution is not unique for high level testing, it is a general problem for all plane wave EMC testing. To some extent, we believe, the problem can be solved by instead using a reverberation chamber for susceptibility testing [4,8].

CONCLUSIONS

The MTF is a vital test tool for functional and safety HIRF testing. It is also an efficient HPM research tool. The system has several good features for such testing, but system analysis and low level testing is often required as a complement for accurate system characterisation. The test efficiency has been acceptable but depends, as always on detailed test planning and careful system operation.

REFERENCES

[1] “Microwave Test Facility”, issued by Saab Avionics, Electromagnetic Technology Division, SE-581 88 Linköping, Sweden, www.avionics.saab.se.

[2]. S. Silfverskiöld, M. Bäckström and J. Lorén, “Microwave Field-to-Wire Coupling Measurements in Anechoic and Reverberation Chambers, *IEEE Trans. on Electromagnetic Compatibility*, Vol EMC-44, No.1, February 2002.

[3]. G. Göransson, “HPM Effects on Electronic Components and the Importance of This Knowledge in Evaluation of System Susceptibility”, Proceedings of *1999 IEEE International Symposium on Electromagnetic Compatibility*, Seattle, USA, August 2 – 6, 1999.

[4]. M. Bäckström, J. Lorén, G. Eriksson, and H-J Åsander, “Microwave Coupling into a Generic Object. Properties of Measured angular Receiving Pattern and its Significance for Testing”, Proceedings of *2001 IEEE International Symposium on Electromagnetic Compatibility*, Montreal, Canada, 13 – 17 August, 2001.

[5]. Mats Bäckström, Jörgen Lorén, “Microwave Coupling into a Generic Object. Properties of Angular Receiving Pattern and its Significance for Testing in Anechoic and Reverberation Chambers”, FOI Scientific Report, FOI-R—0392—SE, February 2002. Swedish Defence Research Agency FOI, Sensor Technology, P.O. Box 1165, SE-581 11 Linköpng, Sweden.

[6]. L Jansson, M Bäckström, ”Directivity of Equipment and Its Effect on Testing in Mode-stirred and Anechoic Chamber”, Proceedings of *1999 IEEE International Symposium on Electromagnetic Compatibility*, Seattle, USA, August 2 – 6 1999.

[7]. M. Höijer, M. Bäckström and J. Lorén, ”Comparison between Radiated Susceptibility Testing and Coupling Measurements”, Proceedings of *AMEREM 2002*, Annapolis, USA, 2 – 7 June 2002.

[8]. G. Freyer and M. Bäckström, “Comparison of Anechoic and Reverberation Chamber Coupling Data as a Function of Directivity Pattern – Part II”, Proceedings of *2001 IEEE International Symposium on Electromagnetic Compatibility*, Montreal, Canada, 13 – 17 August 2001.

[9]. G. Freyer and M. Bäckström, “Some Implications of a Single Aspect Angle Electromagnetic Compatibility Test”, Proceedings of *19th Digital Avionics Systems Conference,* Philadelphia, USA, 7 – 13 October 2000.