

# HIGH POWER MICROWAVE EFFECTS ON CIVILIAN EQUIPMENT, Invited

**Odd Harry Arnesen<sup>(1)</sup>, Ernst Krogager<sup>(2)</sup>, Mats Bäckström<sup>(3)</sup>, Sighjörn Bø-Sande<sup>(4)</sup>, Jostein Godø<sup>(5)</sup>, Seppo Härkönen<sup>(6)</sup>, Karl G. Lövstrand<sup>(7)</sup>, Mikko Moisio<sup>(8)</sup>, Barbro Nordström<sup>(9)</sup>, Jouni Peltonen<sup>(10)</sup>, Ole Øystad<sup>(11)</sup>**

- <sup>(1)</sup> Norwegian Defence Research Establishment, Box 25, NO-2027 Kjeller, Norway. [Odd-Harry.Arnese@ffi.no](mailto:Odd-Harry.Arnese@ffi.no)  
<sup>(2)</sup> Danish Defence Research Establishment, Box 2715, DK-2100 Copenhagen Ø, Denmark. [ek@ddre.dk](mailto:ek@ddre.dk)  
<sup>(3)</sup> Swedish Defence Research Agency FOI, Box 1165, SE-581 11 Linköping, Sweden. [mats@foi.se](mailto:mats@foi.se)  
<sup>(4)</sup> NDLO CIA, Box 130, NO-4097 Sola, Norway, [sbosande@mil.no](mailto:sbosande@mil.no)  
<sup>(5)</sup> Norwegian Defence Estates Agency, Box 405, Sentrum, NO-0103 Oslo, Norway, [jostei.godo@forsvarsbygg.no](mailto:jostei.godo@forsvarsbygg.no)  
<sup>(6)</sup> Finnish Defence Forces Technical Research Centre PvTT, Box 10, FIN-11311 Riihimäki, Finland, [seppo.harkonen@mil.fi](mailto:seppo.harkonen@mil.fi)  
<sup>(7)</sup> Swedish Defence Materiel Administration (FMV), Chief of Operations Test and Evaluation, Box 13400, SE-580 13 Linköping, Sweden, [karl-gunnar.lovstrand@fmv.se](mailto:karl-gunnar.lovstrand@fmv.se)  
<sup>(8)</sup> As (6) above, but Email: [mikko.moisio@pvtt.mil.fi](mailto:mikko.moisio@pvtt.mil.fi)  
<sup>(9)</sup> Swedish Defence Materiel Administration (FMV), Competence Centre for Test and Evaluation, Box 13400, SE-580 13 Linköping, Sweden, [barbro.nordstrom@fmv.se](mailto:barbro.nordstrom@fmv.se)  
<sup>(10)</sup> As (6) above, but Email: [jouni.peltonen@pvtt.mil.fi](mailto:jouni.peltonen@pvtt.mil.fi)  
<sup>(11)</sup> NDLO ADK, EMC/Power Supply Lab., Box 10, NO-2027 Kjeller, Norway, [ooystad@mil.no](mailto:ooystad@mil.no)

## INTRODUCTION

We present results from a joint Nordic (DK, FI, NO, SE) HPM susceptibility experiment using the Swedish Microwave Test Facility (MTF) [1]. The test objects entailed a multitude of technologies grouped into three categories; computer networks, perimeter defense systems and handheld wireless technologies. This paper will focus on results from irradiation of Local Area Computer Network (LAN) components. Please note that brand names and results from military systems are omitted due to classification issues.

The rationale behind these trials was actually to give personnel from DK, FI, and NO military research organizations experience in HPM susceptibility testing. Accordingly, Sweden as the owner of the test facility funded the operation of the MTF, while the other nations provided the bulk of test objects. Other results from the trials, mainly from wireless systems, have been published elsewhere [2].

## RADIO FREQUENCY WEAPONS

In later years a growing attention has been paid to the threat posed by HPM (High Power Microwaves) against the function of important electronic systems of the civilian infrastructure. Targets could be telecom, radio/television and power networks or traffic control, financial systems, computer networks etc. The increased awareness of the threat is reflected both in the scientific community and in the public debate. As a result of the former, a special issue on *EM terrorism* or *Intentional EMI*, was recently published [3].

There are three main reasons why the threat against civilian systems has to be taken with great seriousness: The society's huge dependence on electronic systems, the lack of immunity requirements against HPM and the possibility for a perpetrator to come close to the system under attack. This latter means that an attacker does not need to have access to military HPM weapons, it will suffice to get hold of e.g. a radar transmitter or even simple "home-built" devices.

## THE MICROWAVE TEST FACILITY

The Microwave Test Facility, MTF, was designed by the US Company TITAN Beta and delivered in 1993 to Aerotech Telub AB, who operates the system for the Swedish Defence Materiel Administration, FMV. It was mainly specified and designed for aircraft HIRF (High Intensity Radiated Fields) 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.

## GENERAL MTF SYSTEM DATA

The MTF is mobile and contained in a 12 m ISO container, see Figure 1. Also visible on the right hand side of Figure 1 is a shielded control trailer, from which the MTF is remotely controlled. It is also equipped with optical monitors and a measurement system for recording the generated environment having real time resolution of individual generated microwave pulses. Power is provided 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 Ku 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 Cassegrain antennas (CA). All maximum characteristics cannot be attained simultaneously, e.g. the maximum PRF cannot be attained at maximum pulse length.

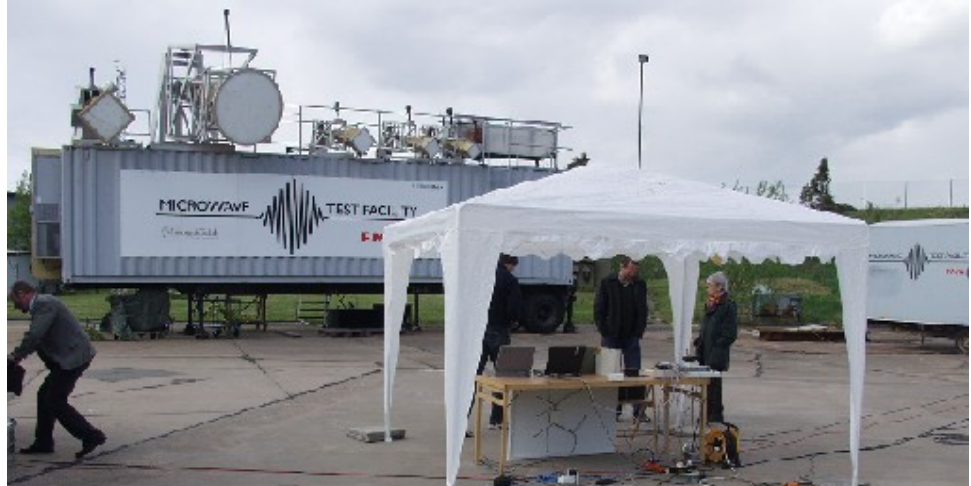


Figure 1. The MTF during preparation for the 2004 Nordic HPM experiments.

## 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.

Radar band	f (GHz)	Average Power (kW)	Maximum Power (MW)	Gain (dB) Outdoor antennas	PRF (pps)	Pulse duration (μs)	E <sub>peak</sub> @ 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

Table 1: FMV Microwave Test Facility, maximum characteristics, from[4]. PCS: Pulse compression System, see text. CA: Cassegrain antenna. E<sub>peak</sub> is given as the RMS peak value.

## DIAGNOSTICS AND CONFIGURATION OF THE TEST OBJECTS

The rationale behind our test setup was an attempt to evaluate effects of possible Intentional EMI attacks on a fairly realistic and typical civilian COTS based LAN. Due to time constraints we used simple load and diagnostics for the components, with a focus on Denial of Service (DoS), i.e., what sort of incident fields that were required to jam, upset or damage the components. Configurations and mode of operation was kept as realistic as possible. Data traffic through

the LAN was kept at realistic levels, only about 5% of the total bandwidth. The intent was to create a normal rather than worst case scenario. Failures at low stress in a realistic setup indicate that the components really are hurt by EMI.

Type	Name	Comments	Zone	Owner
PC	PC1	Three identical stationary PCs.	S	NO
	PC2		P	
	PC3		K	
Laptop	Lap1	Identical laptops. No external wires on Lap4.	K	NO
Laptop	Lap2		P	DK
Laptop	Lap3		K	DK
Laptop	Lap4		K	DK
Switch	Switch1	Identical 8 port, metal cased switches.	K	NO
	Switch2		P	
Switch	Switch3	4 port switch, plastic casing.	K	DK
WLAN AP	AP1	2.46 GHz carrier frequency.	K	NO
WLAN Card	Card1	Installed in LAP1.	K	NO

Table 2. The LAN Components.

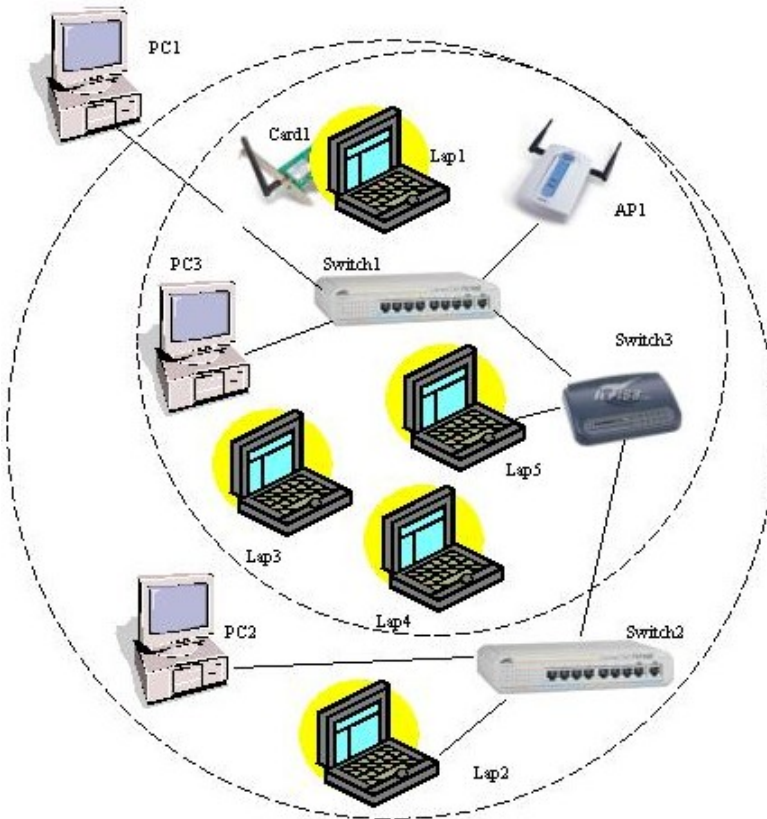


Figure 2. Configuration of the LAN.

Freq. (GHz)	Max. Peak field (kV/m)	PRF / Pulse length (Hz / $\mu$ s.)		Polarization
		Long	Short	
1.3	29.0	390 / 4.5	950 / 1.0	H
2.857	17.5	200 / 4.5	950 / 1.0	V
9.3	7.8	95 / 3.8	95 / 0.4	V

Table 3. Frequencies and pulse parameters used.

The components were grouped into three zones; a central 'Kill zone' within the main beam, a 'Peripheral zone' 4m outside the 3 dB boundary, and a 'Shielded zone' inside the control trailer. In Table 2 these zones are referred to as K, P and S respectively. The topology of the LAN is shown in Figure 2, where circles indicate boundaries between the S, P and K zones. All equipment were facing the MTF, except Lap1 which was turned away from it. Lap4 was running on batteries without any external connections.

Standard CAT 5 UTP cables were used in the entire network. Unfortunately WLAN AP1 was damaged during a low level pre-test, so WLAN Card1 failed to connect to it. Card1 was connected to another WLAN instead. Both were specified as IEEE 802.11g.

During irradiation data flowed through the LAN in both directions. I.e. mpeg movies were played from one computer and displayed on another at the opposite end of the network. The Monitors were videotaped.

## FREQUENCIES AND PULSE PARAMETERS

Tests were made at three spot frequencies: 1.3 GHz, 2.86 GHz and, 9.30 GHz. The calibrated peak field strengths at the 15 meter test distance as well as other pulse parameters are shown in Table 3.

In most cases a burst length of 10 seconds were used, due to a need to sweep the antennas. We also used burst lengths of 1 and 3 seconds in order to observe the effects of the duration of the irradiation. For all frequencies we used two combinations of low PRF-long pulse and high PRF-short pulse.

## RESULTS

Observed effects were grouped into three categories. When test objects suffered from degraded performance during irradiation but recovered afterwards, it was labelled as 'Disturbed'. 'Upset' is when equipment deadlocked or failed to recover without operator intervention. If we could not immediately restart or repair failed equipment, it was

Test Objects	1.3 GHz			2.857 GHz			Comments
	Disturbance	Upset	Damage	Disturbance	Upset	Damage	
PC2	(8)	(8)		(8)	(8)		In P-Zone.
PC3		2*	22.5*		2	8	
Lap1		0.5	22.5		2		
Lap2	(4)	(8)			(12)		In P-Zone.
Lap3		1	29.5		8	17.5	
Lap4		2	2		4	12	No wires
Lap5		2	8	8		12	
Switch1	4	8		0.5	8		In P-Zone.
Switch2							
Switch3		8		8	12		
AP1	n.o.		8	n.o.		12	Out of order
Card1	n.o.	n.o.		n.o.	n.o.		Survived.

Table 4. Test results. Threshold values, units in kV/m. 'n.o.' not observed. ' ( ) ' indicate values in the main beam, even if the test object was 4 m outside the 3dB limit. PC1 was in a shelter, and not irradiated. '\*' in BIOS mode.

considered 'Damaged'. But Damage is not necessarily permanent. Broken test objects will often recover after a while, ranging from hours to weeks. This is due to dissipation of parasitic charges, annealing of crystal damage etc. Several test objects sustained Physical Damage, but recovered in time to reappear later in the trials.

Threshold values for the various effects are shown in Table 4, units are in kV/m. Results for 9.3 GHz are omitted because the only effect was that the mouse on PC3 deadlocked at 7.8 kV/m, long pulse. There was no pronounced effect of PRF/Pulse length or burst length. This is consistent with a theory that disturbance depend mainly on the amplitude, while physical damage depend on the total energy. One might have expected a stronger influence of the PRF on digital systems. But the threshold levels were stable, with one notable exception; at 1.3 GHz, 950 Hz PRF, 1  $\mu$ S pulse length Lap4 died at 0.5 kV/m! This was a highly irregular result, as Lap4 actually died 5 min. after the shot. Results from the WLAN components are flawed, because AP1 already was broken. It was permanently damaged during low level pre-tests, at 2.85 GHz CW and 175 V/m. So the damage levels in Table 4 indicate when it's status LED's were permanently changed. WLAN Card1 was installed in a laptop highly susceptible to Upset, so we were unable to observe any effects on it. Card1 survived the entire trial though, and is still in perfect working order. The hard disk in PC3 died at 2.857 GHz 8 kV/m, before we had tested it against 1.3 GHz. This was very unfortunate, so we reintroduced it in the set up in BIOS mode. Accordingly the 1.3 GHz threshold values are for PC3 in BIOS mode.

Susceptibility levels for Laptops were up to 10 times higher than for a stationary PC, although there were exceptions. The identical Lap4 and Lap5 were much more susceptible than the other Laptops. Of the two, Lap4 was more susceptible to both Upset and Damage even without any external cables at all.

All our switches were susceptible to Disturbance from 500 V/m at 2.857 GHz and 4 kV/m at 1.3 GHz as well as Upset from 8 kV/m for both frequencies, but we were unable to cause Damage to any of them. They were of robust and self-configuring designs that quickly returned to normal operation after Disturbance and Upset.

## SUMMARY AND FUTURE WORK

The results indicate that WLAN technologies should be used with caution, as an AP was damaged at only 175 V/m. The HPM trials proved the entire LAN susceptible to disturbance from 2 kV/m, and massive DoS occurred from 4 kV/m for both 1.3 and 2.86 GHz. Physical damage of components started at 8 kV/m, although field strengths in excess of 12 kV/m would be needed to cause massive damage to our equipment. Further and more detailed studies of the individual component susceptibilities and designs are required to fully understand the behaviour of the LAN.

[1]. M. Bäckström, K. G. Lövstrand, B. Nordström, "The Swedish Microwave Test Facility: Technical Features and Experience from System Testing", URSI XXVIIth General Assembly, Maastricht, the Netherlands, August 17 – 24 2002.

[2]. O. H. Arnesen et al., "High Power Microwave Effects on Civilian Wireless Equipment", EMC Europe Conference, Rome, September 2005.

[3]. IEEE Transactions on Electromagnetic Compatibility, Vol. 46, No. 3, August 2004.

[4] "Microwave Test Facility", issued by Aerotech Telub AB, Electromagnetic Technology, SE-581 88 Linköping, Sweden.