High Power Microwave Tests of Media Converters

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***Abstract*—We report on high power microwave (HPM) susceptibility tests of vulnerable IT network components. The devices under test are five different commercial and industrial media converters, one military media converter and a shielded enclosure for commercial media converters. The report compares results of susceptibility tests in different configurations supplemented by transfer function measurements.**

Keywords- High- power microwaves (HPM), susceptibility tests

I. INTRODUCTION

In the past many test campaigns have shown a high vulnerability against High Power Microwaves (HPM) for IT network components. For example an upset of a switch has an impact on the whole network and data transfer [1]. To overcome these problems a wireless network is not a solution because the antennas are open gates for the electromagnetic waves (front-door coupling) [2]. Fibre optic cables are another method for data transmission which is used in many IT networks. Test campaigns with IT network components and C4I (Command, Control, Communications, Computers, and Intelligence) networks have shown that in this case one of the most vulnerable components is the media converter (MC) which transforms electrical signals from a network cable into optical signals for a fibre optic cable. This special part of IT networks has been tested in the present campaign.

II. TEST SETUP

A. *Media Converter*

This paper presents electromagnetic susceptibility tests on different types of media converters (MC), five commercial models, one military model and a shielding enclosure, using the TEM waveguide of Fraunhofer INT. All commercial media converters were COTS (commercial off the shelf) equipment, so the MCs were not especially hardened against HPM or High Altitude Electromagnetic Pulse (HEMP). Fig. 1 shows a commercial model. All types had different connectors for the ground of the power supply and for the ground of the RJ45 cable. In some cases the grounds were connected with the housing. The connectors of the fibre optic cable were made of plastic on every MC. All types had big apertures around the fibre optic connectors which could lead to field couplings into the housing at higher frequencies.

In comparison to the commercial versions of the media converters a military one was tested. This MC is designed for interconnection of LANs in harsh environmental conditions. The military MC in this test campaign consists of two media converters in one box. Both MCs are equipped with a fibre optic connector and both are connected to one network connector. The military media converter came tested for EMC according to MIL-STD 461E and MIL-STD 464E and has thus further EMC hardening measures in comparison to the commercial ones. For harsh environments the MC has tactical SFTP cable with EMC connectors and tactical fibre optic cable. Furthermore, the device has an EMC gasket between cap and case.

Additional tests were done with a shielded enclosure for commercial media converters. The box consists of a metallic body and a metallic cover plate with a metallic adhesive tape which functions as a gasket. The connectors for both power and network have filters. The apertures for the cabling are as small as possible and were sealed additionally with metallic adhesive tape.

B. *Susceptibility Tests and Transfer Function Measurements*

1) *The Fraunhofer INT Test Facility*

The test facility of Fraunhofer INT consists of a waveguide built as an open pyramidal asymmetric three plate TEM transmission line which is located within a shielded hall. Inside the waveguide homogeneous microwave fields can be realized in a maximum test volume of approximately 2 x 2 x 3 m^3.

Transfer function measurements can be carried out by continuous wave (CW) illumination of the EUT using digital tuneable sweep generators together with power amplifiers for frequencies between 1 and 8000 MHz and vector network analyzers as receivers. Susceptibility tests can be done with a pulse modulated generator in the frequency range from 150 to 3425 MHz for different pulse widths and repetition rates. The generator permits electrical field strengths at the EUT up to some kV/m. In order to find the susceptibility threshold we apply a field ramp of 20 s from minimum to maximum field.

Figure 1. Example of a commercial media converter

2) *Test Setup*

The tests have been done in different configurations to determine the influences of the coupling of high power microwaves into the MCs directly and via network cable and power cable, respectively. One recognises a network cable loop between the two test MCs with a cable length of two meters between the MCs in Figs. 2 and 3 which show a sketch of the overall test setup and the setup within the waveguide. The network cable and the media converters were fixed on a wooden frame. The effective length of the loop was 400 mm in horizontal direction and 750 mm in vertical direction. Two PCs were connected with fibre optic cable to the test MCs via additional MCs outside the shielded hall in order to generate data traffic from one PC to the other.

In order to determine the different coupling paths, especially on the network cable and power cable, we used three different test configurations with two kinds of network cables, namely unshielded UTP and shielded SFTP:

- Configuration 1: UTP cable loop between the MCs, power cable parallel to the electrical field component of the electromagnetic wave. Coupling paths over both cables are possible.
- Configuration 2: UTP cable loop between the MCs, power cable perpendicular to the electrical field component. In this configuration the dominant coupling path should be the UTP cable.
- Configuration 3: SFTP cable between the MCs, power cable perpendicular to the electrical field component to determine differences to coupling over the UTP cable by direct coupling into the MC housing.

a) *Military Media Converter*

For the military media converter we had to use three modified test configurations because it was equipped with tactical SFTP cable of a certain length and two of them had to be connected to form the cable loop between the MCs. In modification of the measurement setup from Fig. 2 two vertical parts of the cable were placed at the loop and the rest of the long cable was led through the waveguide perpendicular to the electrical field. The three test configurations for the military MC were:

- Configuration 1': SFTP cable between the MCs, power cable parallel to the electrical field component of the electromagnetic wave. Coupling paths over both cables are possible.
- Configuration 2': SFTP cable between the MCs, power cable perpendicular to the electrical field component. In this configuration the dominant coupling path should be the SFTP cable.
- Configuration 3': SFTP cable between the MCs without loop, i.e. perpendicular to the electrical field component, power cable perpendicular to the electrical field component.

As described the military MC was equipped with two media converters, A and B, and the tactical network connector contained two SFTP cables bundled with the power cable.

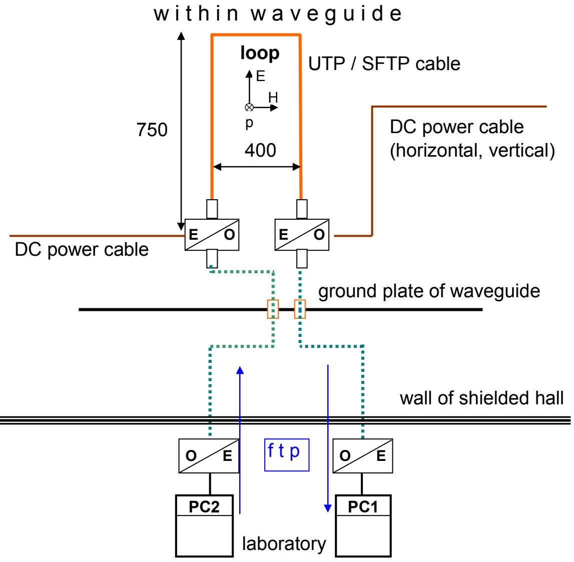

Figure 2. Test setup

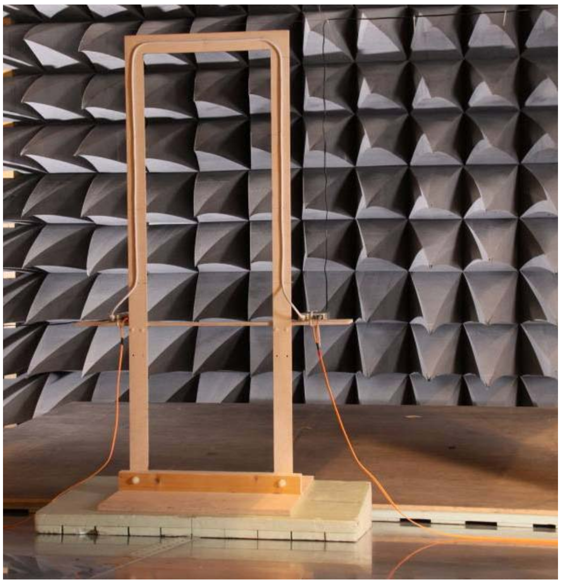

Figure 3. Photo of the wooden frame with a network cable loop and two media converters within the waveguide.

Therefore, the cable loop was formed from two SFTP cables connected to both media converters. The cable layout was close-by on the wooden frame of the loop. The computers PC1 and PC2 were connected with media converters A1 (of MC1) and A2 (of MC2) of the other military MC the relevant fibre optic connectors. The fibre connectors B1 and B2 of the other MCs inside the military MCs were not connected because the other MCs inside the military MCs have no function in the set up.

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b) *Shielded Enclosure*

For the tests with the shielded enclosure only one box was available and the measurement setup again had to be different from the regular one in Fig. 2. The goal was here to compare tests of one commercial device with and without the shielded enclosure. Therefore, only the MC in the enclosure and the network cable loop were illuminated with the second MC placed outside the field region.

c) *Transfer Function Measurements*

Transfer function measurements were done in order to determine the ratio between the electrical field and the current on the cables *I(f)/E(f)*. The transfer functions were measured on the SFTP cable and on the power cable. The probe was fixed on the cable directly behind the connector to measure the current at the connector. To determine the transfer functions on the SFTP cable we used configuration 3 in comparison to one with a 1 m long SFTP cable between the MCs. The currents were measured with a broadband (3 GHz) current probe F2000 from Fisher Company. The frequency range of the measurements was 25 – 2500 MHz with an increment of 2.5 MHz.

III. TEST RESULTS

A. *Susceptibility Tests*

First, susceptibility tests were conducted where two kinds of failures occurred as shown in table 1. Complete interruption of the FTP traffic as well as considerable reduction of FTP transfer speed during illumination were scored as failure level 2 as long as it recovered after switching off the disturbing field. If on the other hand FTP had to be restarted by the operator, the failure was scored as level 4.

Losses of ping packets were counted as second kinds of failure if they exceeded 5 % as losses of 5 % were observed during the normal operation, too. The tests showed only effect level 2 for this failure, i. e. recovery after switching off the illumination.

The tests revealed three susceptible regions which are indicated in the diagram in Fig. 4. All MCs show susceptibilities in the frequency range from 150 to 500 MHz which is labelled as region 1. One MC had susceptibility

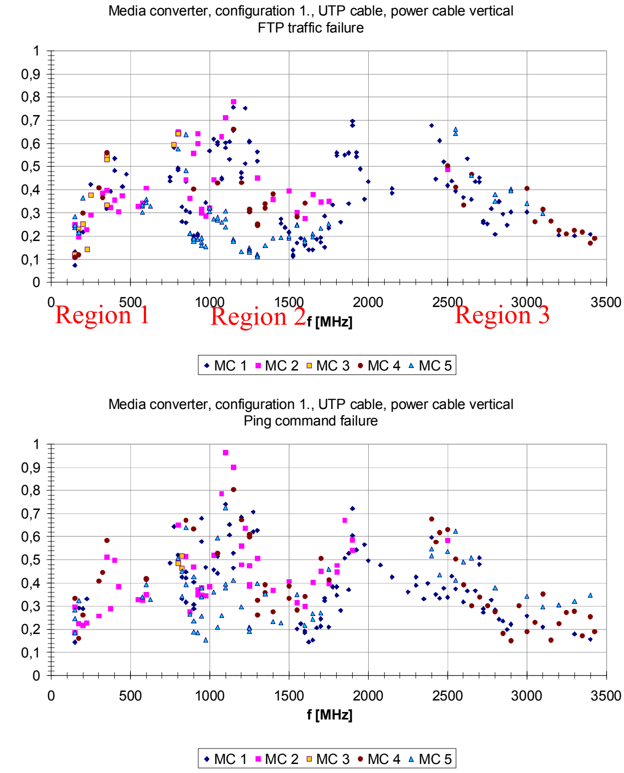

Figure 4. Failure thresholds for FTP traffic breakdown and for Ping failures for five commercial models. The tests were done in configuration 1.

thresholds only in the frequency ranges from 150 to 225 MHz and from 775 to 825 MHz. The other four MCs show a strong susceptibility for frequencies between 1000 and 2000 MHz, labelled as region 2. Three MCs had susceptibility thresholds in the higher frequency range between 2400 and 3425 MHz, which is labelled as region 3. These three regions were found in nearly all tests for the most MCs. The level 2 ping failures occurred in the most cases together with the FTP failures. They started, however often not at the same time during the field ramp. The susceptibility thresholds and the percentage of the losses of the Ping commands could not be reproduced in every case for repeated tests.

TABLE I. EM EFFECT LEVELS WITH FAILURE DISCRIPTION AND FAILURES OBSERVED IN THE TESTS.

Level	Effect	Description	Failures observed in tests
0	Unknown	Unable to determine due to effects on another component	-
1	No Effect		-
2	Interference	Effect is only present during illumination	FTP traffic went down to 0 % only during illumination
			Losses of Ping commands during illumination
3	Disturbance	Effect is present during illumination and self corrects over a short period of time once illumination is removed	-
4	Upset	Effect that occurs during illumination and requires human intervention to correct	FTP traffic went down to 0 %, after illumination FTP traffic had to be restarted
5	Damage	Effect that damages hardware to the point is must be replaced or software to the point it must be reloaded	-

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B. Transfer Function Measurements

This section presents results of transfer function measurements for two commercial media converters and the military one. The main concern of these investigations was the influence of coupling of the electrical field through the network cable and power cable and the correlation between measured cable currents and malfunctions of the media converters.

For these investigations we took two different commercial models, one with a metal case and another one with a plastic case. To determine the influence of the field coupling through the network cable we selected two configurations, a SFTP cable loop of 2 m length as in configuration 3 and a 1 m long SFTP cable between the MCs without any loop. The power cable was positioned parallel to the electrical field as in configuration 1. The diagrams in fig. 5 show the transfer function for the current on the SFTP cable and on the power cable for the two MCs. The large peaks in the first diagram below 500 MHz and the lower peaks between 500 MHz and 1 GHz indicate a coupling through the network cable. The resonances correspond to the length of the 2m loop and the part of the loop which is parallel to the electrical field. The second diagram in fig. 5 shows a comparison of the current with and without the network cable loop. The peaks of the current without the loop are much lower so the cable loop is responsible for the high current peaks. The lowest diagram in fig. 5 shows a comparison of the power cable of the two MCs. The resonances on the power cable are comparable with the resonances on the network cable for the parallel part to the electrical field. For the military MC we tested the configuration with the network cable parallel to the electrical field (configuration 1'), and the configuration with both SFTP and power cables perpendicular to the electrical field (configuration 3'). The results were similar to those for the commercial MCs.

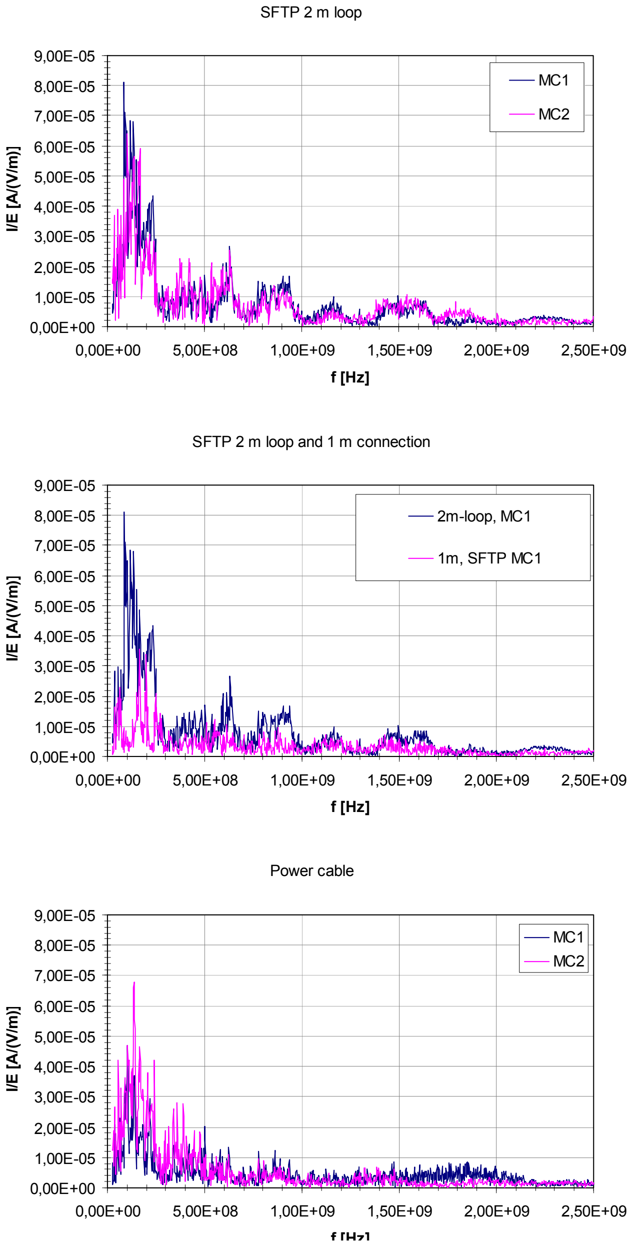

Figure 5. Transfer function for the current on the SFTP cable loop and on the power cable for two media converter models.

C. Comparison of Commercial and Military Media Converters

The comparison of the results for the civilian and military media converters shows that EMC hardening measures are not necessarily sufficient against HPM. On the other hand, results from test campaigns with computer networks indicate that an SFTP cable is a good solution to reduce the susceptibility in the low-frequency range if the shielded cable has a good ground connection and a shielded connector is used. The commercial media converters have poor RF connections between the screen of the SFTP cable and the case. According to Fig. 6 the military MC shows a high susceptibility in the frequency range below 1500 MHz where all commercial media converters, except one model, show a high vulnerability, too. Consequently, the use of the military MC in C4I networks has no advantage compared to the most commercial ones. The weak points of the military MC are the big holes in

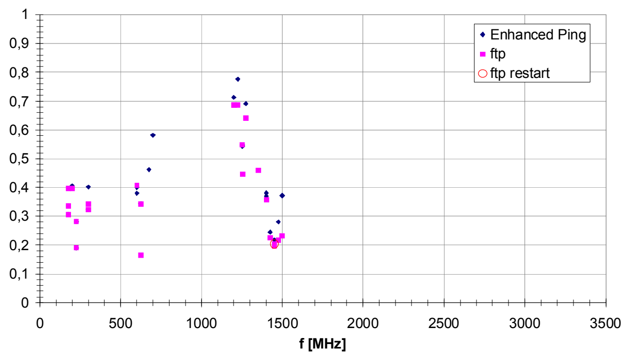

Figure 6. Thresholds for FTP traffic breakdown (level 2and 4) and for Ping failures for the military media converter in configuration 1'.

combination with a plastic made fibre connector which can be found in the most commercial MCs, too. These apertures are one of the relevant coupling paths in higher frequency regions above 1000 MHz.

The transfer functions of the commercial and military MCs look very similar with strong currents below 500 MHz. The difference is that the military MC has a shielded connector with a good ground connected to the case so that there is no coupling into the case. Consequently, this test method shows possible coupling paths but one cannot conclude about effects that the current will cause inside on the circuit board.

D. Shielded Enclosure

The first tests were done in configuration 1 but with media converters outside the field to determine possible effects of the setup itself. For these tests for MC1 and MC2 the military MCs were used. The results of the military MC show that it is hard enough with SFTP cable. In the configuration with the shielded enclosure we use the military MC for MC2, too. In this reference setup the MCs were outside the waveguide so no direct couplings through the cases were expected. For the tests with the shielded enclosure we placed a highly vulnerable MC inside the enclosure. This media converter showed failures in the whole frequency range in the previous tests which made it suitable for these tests. With the MCs outside the field region no effects were determined in the reference setup. The next step was a reference test with MC1 inside the field without shielded enclosure and MC2 outside the field. In difference to previous results with both MCs inside the field we found failures with losses of Ping commands and partial FTP losses, all of which were scored as level 2 failures. One possible reason for this is the different setup with only one media converter inside the field. In the next configuration MC1 was tested in the shielded enclosure. The results of the three tests are shown in Fig 7. In configuration 3 with shielded enclosure SFTP and UTP network cables were tested. In this configuration the unshielded MC shows a similar susceptibility as in configuration 1 to 3 in the previous tests. With the shielded enclosure and SFTP cable only failures occurred between 150 and 175 MHz caused by couplings over the network cable. In addition to the SFTP cable tests with UTP cable were done. The tests with the shielded enclosure and UTP cable showed a higher susceptibility in region 1 than in configuration 1 with the unshielded MC. The shielded enclosure works well in region 3 where no failures were found except one at 3.2 GHz which was only an irruption to 60 % of the FTP traffic. Failures for FTP traffic and Ping occurred at 1250 MHz for the UTP cable in region 2.

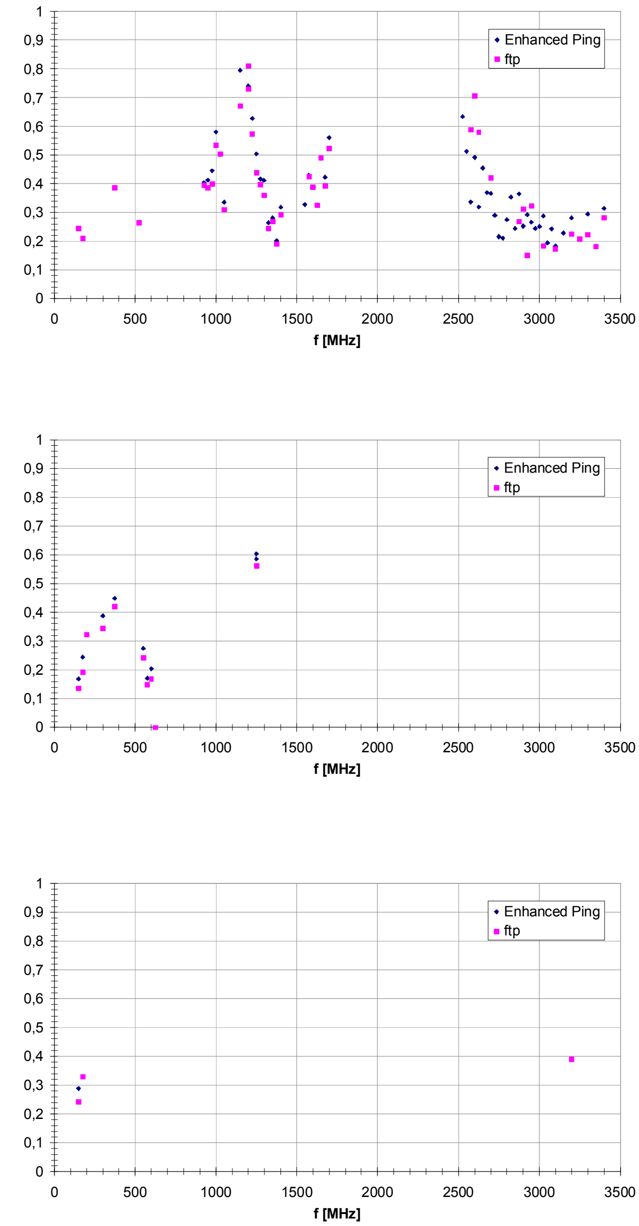

Figure 7. Failure thresholds for the media converter without and with shielded box and UTP cable and with shielded box and SFTP cable (top down).

IV. Conclusion

In conclusion the media converter is one of the most susceptible parts in computer networks. However, the test results show that failure thresholds and clustering of the different MC models vary very strong. The military media converter shows a similar behaviour to commercial versions and has no advantage regarding EMC. The shielded enclosure in connection with the SFTP network cable reduces the failures to a minimum and is the best solution found in this test campaign against HPM with moderate field strengths.

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