Open access • Proceedings Article • DOI:10.1109/APEMC.2008.4559915

Characterization of the electromagnetic environment in a hospital — Source link

Oliver Lauer, Markus Riederer, N. Karoui, Ruediger Vahldieck ...+2 more authors

Institutions: Ofcom, ETH Zurich, University of Zurich

Published on: 19 May 2008 - International Symposium on Electromagnetic Compatibility

Topics: ISM band, Electromagnetic interference, Noise (radio), Electromagnetic compatibility and Electromagnetic environment

Year: 2008

Characterization of the electromagnetic environment in a hospital

Lauer, O; Riederer, M; Karoui, N; Vahldieck, R; Keller, E; Fröhlich, J

Characterization of the electromagnetic environment in a hospital

Abstract

The electromagnetic environment in a hospital is characterized in order to evaluate the conditions for failsafe operation of critical electronic equipment. Field strengths within the University Hospital Z¨urich were measured at more than 60 different locations in the frequency range from 9 kHz up to 10 GHz. To account for variations in both, time and location, 'stationary short term' and 'stationary long term' measurements over 24 h were carried out. The measurement uncertainty of the measurement equipment, calibration and measurement procedure is assessed. Measurement results are evaluated with respect to given immunity levels (EMC) and in-band interferences (EMI). The ISM band features a noise power density of -32 dBm/MHz while for Ultra Wide Band (UWB) there are different sub-bands with a maximum noise power density of less than -81 dBm/MHz. This suggests that communication in the UWB band requires significantly lower power levels than communication in the ISM band for equal dynamic ranges of the radio links.

Characterization of the Electromagnetic Environment in a Hospital

Oliver Lauer #1, Markus Riederer *, Naceur Karoui #, Rüdiger Vahldieck #, Emanuela Keller **, Jürg Fröhlich #

#*Laboratory for Electromagnetic Fields and Microwave Electronics, Swiss Federal Institute of Technology Zürich*
Gloriastrasse 35, 8092 Zürich, Switzerland
1 lauero@ifh.ee.ethz.ch
**Swiss Federal Office of Communication (OFCOM)*
***Neurocritical Care Unit, Department of Neurosurgery, University Hospital Zürich (USZ)*

***Abstract*— The electromagnetic environment in a hospital is characterized in order to evaluate the conditions for failsafe operation of critical electronic equipment. Field strengths within the University Hospital Zürich were measured at more than 60 different locations in the frequency range from 9 kHz up to 10 GHz. To account for variations in both, time and location, 'stationary short term' and 'stationary long term' measurements over 24 h were carried out. The measurement uncertainty of the measurement equipment, calibration and measurement procedure is assessed. Measurement results are evaluated with respect to given immunity levels (EMC) and in-band interferences (EMI). The ISM band features a noise power density of -32 dBm/MHz while for Ultra Wide Band (UWB) there are different sub-bands with a maximum noise power density of less than -81 dBm/MHz. This suggests that communication in the UWB band requires significantly lower power levels than communication in the ISM band for equal dynamic ranges of the radio links.**

I. Introduction

In recent years the electromagnetic (EM) environment has changed dramatically due to the deployment of different wireless communication services in hospitals. A large scale deployment of information & communication technologies like Bluetooth and WLAN can be observed in intermediate care and for non-critical patient monitoring. These systems are very popular because of their simple installation and the resulting advantages of wireless operation. However, wireless technologies cause a higher load of electromagnetic emissions and are themselves vulnerable to interference. This in turn can lead to performance degradation due to in band and out of band interference. Additionally EM fields can also cause malfunctions of devices. Different types of malfunctions of medical equipment have been reported due to electrical fields by various groups. An example of a severe case where a patient monitoring system was disrupted by electromagnetic fields leading to the death of two patients is described in, [1].

First effort to characterize the electromagnetic environment in hospitals dates back more than 30 years. In [2] the electromagnetic environment from 14kHz up to 1GHz of a hospital is assessed. In this paper first emission limits for narrowband and broadband emissions are recommended for devices that are used in hospitals. In 1997, the first 'long term measurements' over a period of 24 hours showing temporal dependencies of the measured fields within a hospital for frequencies up to 1GHz were described in [3]. Six years later the electromagnetic fields within the ISM band (2.4 GHz) were evaluated. The results are given in [4].

An extensive survey over the entire spectrum used by wireless telecommunication services has not been carried out so far. Progress in the area of low power transceivers made new applications like body area networks in healthcare possible, see [5]. These systems will most probably replace the cable based patient monitoring. This technology poses high demands on confidentiality, data integrity, accountability, availability and access control.

Possibly interfering systems have to be identified and characterized in order to allow the development of a fail-safe system in terms of EMI and EMC. Therefore an comprehensive measurement campaign was carried out in the University Hospital Zurich (USZ) in collaboration with the Swiss Federal Office of Communication (OFCOM) and the Neurointensive Care Unit of USZ.

The maximum field levels occurring over the entire spectrum used by telecommunication services are measured. Measurement points are selected according to the different services present at the location and due to expected emissions from specific medical equipment such as CT and MRI scanners, etc. and along patient transportation paths. Results are evaluated with regard to given immunity levels (EMC) and in-band interferences (EMI).

II. Equipment and Methods

The maximum electromagnetic fields within the frequency range from 9 kHz - 10 GHz were measured with a calibrated measurement system at more than 60 points in the USZ buildings. The list of measurement locations includes operating theaters, intensive care units, emergency unit, helicopter platform, and locations within corridors along typical patient transportation paths.

Two different types of measurements were carried out:

1) 'Stationary short term' measurements at specific locations with a calibrated Spectrum Analyzer (SA) provide results that describe the field characteristics over different locations.
2) 'Stationary long term' measurements were done to obtain time-based field characteristics.

’Stationary short term measurements’ have been performed only during daylight time within the hospital. To ensure that infrequent high peaks are not missed ’stationary long term measurements’ were done for 24 hours at three different locations.

A. Measurement Equipment

1) Stationary Short Term Measurements: ’Stationary Short Term Measurements’ were performed with a Rohde&Schwarz FSQ SA, different antennas from the HE-200 series (e.g. HE200-3000) and a Log.-Per. antenna (Grintek 470429-00000) for diverse frequency ranges.

2) Stationary Long Term Measurements: For ’stationary long term measurements’ the FSP SA from Rohde&Schwarz and a rod antenna was used which was directly connected to the SA. The SA was controlled by a macro to perform continuous measurements.

B. Measurement Method

For both measurement types the SA was set to ’Max-Hold’ mode. The used measurement methods are based on the recommendation of the Swiss Federal Office of Environment, Forests and Landscape [6], where general measurement principles and possible errors are described. This report follows the approved measurement references of ANSI [7], [8]. For our measurements we used ’Peak-Detector’ instead of ’RMS-Detector’. The reason for this is that we are analyzing EMC and EMI and not electromagnetic exposition (EME).

At every measurement point the maximum field strength was recorded in a height ranging from 0.5 to 1.8 m above the floor with put forth hand to minimize the influence of the person doing the measurement. At the same time the antenna was swept (sweeping method) to include all polarizations. The measurement has been continued until no further changes of the spectrum were observed.

For ’long term measurements’ the system was fix installed at specific locations. The system was also set to ’Max- Hold’ and the rod antenna was diagonally orientated to measure both horizontal and vertical electric fields. ’Max-Hold’ measurements were performed over periods of 5 minutes.

The measurement points are chosen to include all relevant telecommunication services and scenarios representing the electromagnetic environment in a hospital.

Therefore fields within the CT room, MRI room, emergency rooms, intensive care units and operating theaters were investigated during normal operation.

In order to find representative measurement points along transportation paths, test measurements were carried out on different floors using a Dosimeter [9]. The results showed a higher field variety at crossing points of corridors due to street canyon effect [10]. Hence we selected the crossing points as measurement locations for the transportation paths.

For ’long term measurements’ the emergency room, neurointensive care unit and one operating theater of the neurosurgery were selected, because these areas are most critical for wireless applications. The electromagnetic field levels are expected to be higher than at other locations due to the numerous electrical appliances that are in use during emergency care, surgery and intensive care, e.g electrosurgical units [11].

C. Data Preprocessing

Only the peaks of the measured frequency spectrum are considered for data evaluation. For this purpose the noise floor of the different measurement setups is characterized by its mean value μ and standard deviation σ. Based on these calculations a threshold value is determined as four times the standard deviation ($> 99\%$ of the noise distribution) of the system noise plus mean value of the noise

$$A_i = 4\sigma_i + \mu_i. \quad (1)$$

To account for the frequency selective properties of the measurement system, mean values and standard deviations are calculated for different frequency bands i separately. In a next step peaks bigger than the threshold value A_i are extracted and further evaluated. The standard deviation σ varied between 0.29μV/m and 0.61μV/m depending on the system constellation.

D. Measurement Uncertainty

The measurement uncertainties are calculated according to [12]. They are given in terms of the expanded uncertainty corresponding to a confidence interval of 95%.

III. Measurement Results

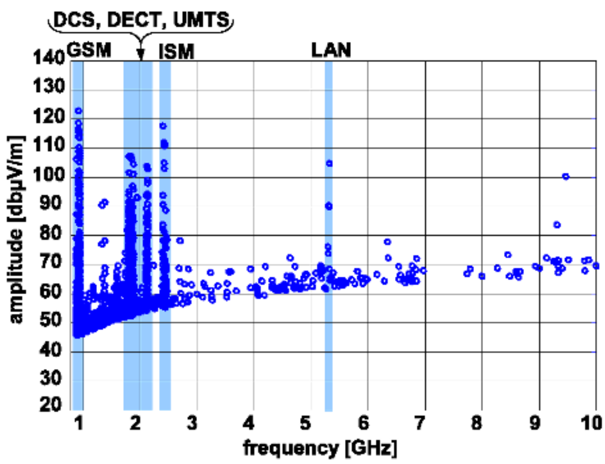

Fig. 1. Overview of all detected peaks from 800 MHz - 10 GHz measured by the sweeping method with the log-per antenna. The expanded measurement uncertainty is $\sigma_{total} = \pm 3.3$dB.

Fig.1 summarizes the peaks occurring at all measurement points within the frequency range from 900 MHz - 10 GHz. Accumulation of peaks occur around typical radio services like GSM900, GSM1800 and DECT reaching maximum field strengths up to 122dBμV/m. Further peaks occur within the ISM-band at 2.4 GHz and for Local Area Networks (LAN) at 5.3 GHz achieving maximum field strength of 118dBμV/m and 106dBμV/m respectively. Within the UWB regions from

3.1 - 5.3GHz and 5.4 - 10GHz levels are in the range from 70dBμV/m to $60dB\mu V/m$.

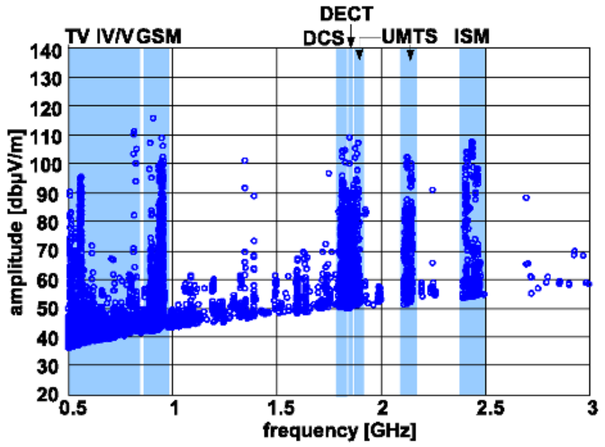

Fig. 2. Overview of all detected peaks from 500 MHz - 3 GHz measured by the sweeping method with a HE200-3000 antenna. The expanded measurement uncertainty is $\sigma_{total} = \pm 3$dB.

Fig. 2 covers the measurement results from 500 MHz - 3 GHz. Beside the expected peaks around the communication services, there are activities within the band of TV band IV/V. Notice that at the time of measurement the TV bands were used by Analog TV while now DVB-T and DVB-H are using these bands.

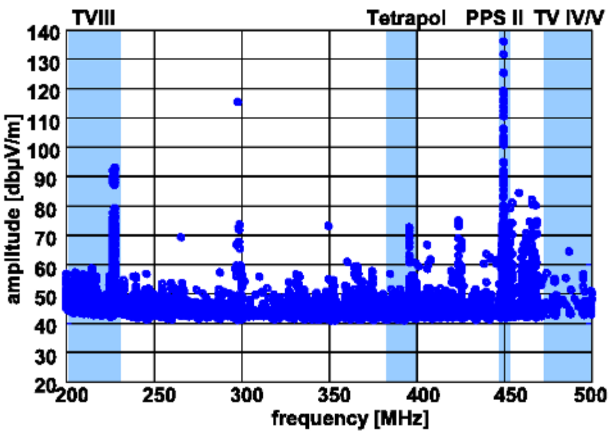

Fig. 3. Overview of all detected peaks from 200 MHz - 500 MHz measured by the sweeping method with a HE200-500 antenna. The expanded measurement uncertainty is $\sigma_{total} = \pm 3$dB.

For the frequency range from 200 - 500 MHz the obtained data is plotted in Fig. 3. Here the personal paging service (PPS II) features the highest field levels up to 135dBμV/m at 450 MHz.

Measurements between 20 - 200 MHz can be seen in Fig. 4. Noticeable are the influences of PPS I. PPS I is used as a redundant communication platform to PPS II for paging services inside the hospital with field strengths up to 133dBμV/m.

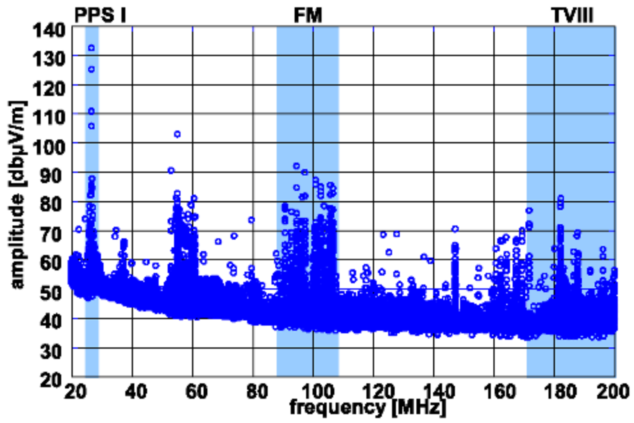

Fig. 4. Overview of all detected peaks from 20 MHz - 200 MHz measured by the sweeping method with a HE 200-20 antenna. The expanded measurement uncertainty is $\sigma_{total} = \pm 3$dB.

Measurements between 9 kHz and 20 MHz were also done with FSQ SA. As an antenna the HE200P-HF was used. Here the expanded measurement uncertainty is calculated to $\sigma_{total} = \pm 3.3$dB. This frequency band was mainly afflicted by wideband interferences with levels up to 82dBμV/m. These interferences covered most radio services within this frequency range and were mainly caused by power supply units of medical equipment and electrical power cars. This observation coincides with studies by Witters [13].

To ensure that infrequent high peaks are not missed by 'stationary short term measurements', 'stationary long term measurements' were done for 24 hours at three different locations in the frequency range from 20 MHz up to 6 GHz. The expanded measurement uncertainty for this measurement setup is $\sigma_{total} = \pm 4.3$dB. The average deviation of all measured field strengths for the highlighted services shown in Fig. 1 - Fig. 4 to the maximum field strength occurring at each of the three locations over a period of 24 hours was determined. The results show that the average deviation are smaller than the expanded measurement uncertainty for most services. For DECT, GSM900(uplink), GSM1800(uplink) and UMTS(downlink) we observed deviations with a maximum of 12.7 dB. This can be explained by the fact that the devices causing electromagnetic fields in the frequency bands of GSM900, GSM1800 and DECT are portable. The high variability of the UMTS(downlink) can be explained by the high dynamics of the power control for UMTS. Within the emergency room we also observed higher average deviation for three additional services, namely DAB, Tetrapol and PPS II. The maximum average deviation was 8.3dB smaller than the highest occurred field level. This can be explained by significant changes of the environmental conditions of the highly shielded emergency room during the frequently open doors. At all three measurement points the highest peaks for mobile services (phones) occurred during breakfast and lunch breaks.

The International Electrotechnical Commission (IEC) specified an immunity level of 3V/m $= 129.5$dBμV/m to prevent electronics in medical devices from interferences [14]. This limit was exceeded in one case for PPS I and in two cases for PPS II. The cumulation of multiple sources which are within the regulations at the same location operating in different frequency bands can easily lead to a field level $> 3V/m$. The worst case measured fields at one point constructively sums up to a field level of 3.4V/m. Which was measured on a corridor in the main building. This suggests that the evaluation of the cumulative maximum field levels is required in order to ensure compliance with current immunity levels defined for medical devices.

Based on measured peaks the received noise power density is calculated between 900 MHz - 10 GHz for an isotropic receiving antenna with no reflection and polarization losses, see Fig. 5. For wireless applications using ISM band for communication like Bluetooth, ZigBee and WLAN the maximum noise power density is -32dBm/MHz. In contrast one can find different UWB bands having a much lower power density with a maximum value of -81dBm/MHz, e.g. 3.1 to 5.3 GHz.

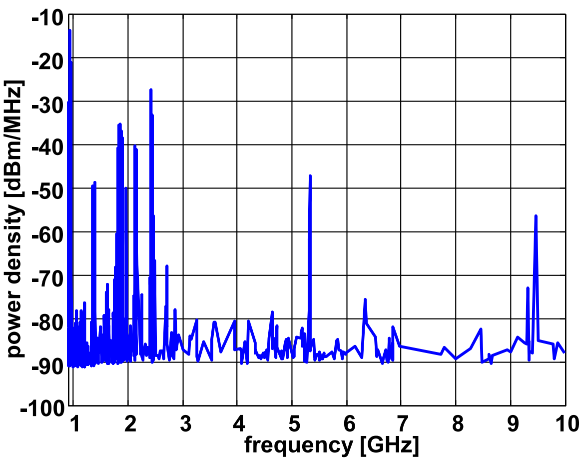

Fig. 5. Calculated received noise power density for an isotropic antenna with no reflection and polarization losses.

IV. Conclusions

This study represents an extensive survey of the electromagnetic environment from 9kHz up to 10 GHz in the university hospital in Zurich. Two different types of measurement were carried out in order to record worst-case time- and location-based characteristics. Measurement uncertainties have been evaluated to be ± 3.3dB for 'stationary short term measurements' and ± 4.3dB for 'stationary long term measurements'. The results allow to determine the link dynamic range of different wireless technologies which are potentially suited for short range applications like sensor networks. Based on the measured field levels the received power density for an isotropic antenna was calculated between 900 MHz-10 GHz. The ISM band features a noise power density of -32dBm/MHz while for UWB there are different sub-bands with a maximum noise power density of less than -81dBm/MHz. This suggests that communication in the UWB band requires significantly lower power levels than communication in the ISM band for equal dynamic ranges of the radio links.

In three cases the immunity level specified by the IEC was exceeded. The EM interference sums up to 3.4V/m for a worst case scenario where all the maximum field levels from all different services added up at one measurement point. For such a case the immunity level does not provide adequate protection of electric devices. The evaluation of the cumulative maximum field levels is required in order to ensure fail-safe operation for worst-case conditions and compliance with current immunity levels defined for medical devices.

Acknowledgment

The authors would like to thank Mr. Andreotti, Dr. Brüesch, Dr. Bernays, Prof. Lüscher, Prof. Marincek, Prof. Weidekuhn, Prof. Ulrich, Prof. Zimmermann, Mr. Schumacher, Mr. Senn, Ms. Norr and Mr. Lutta of the University Hospital Zürich for the support and providing access to their facilities.

References

[1] J. L. Silberberg, "Performance degradation of electronic medical devices due to electromagnetic interference," *Compliance Engineering*, pp. 25–39, 1993.

[2] U. A. Frank and R. Lodner, "The hospital electromagnetic interfernce environment," *Journal of the association for advancement of medical instrumentation*, vol. 5, no. 4, pp. 246–254, 1971.

[3] P. Vlach, C. Liu-Hinz, B. Segal, and T. Pavlasek, "The electromagnetic environment due to portable sources in a typical hospital room," *IEEE 17th Annual Engineering in Medicine and Biology Society Conference*, vol. 1, pp. 683–684, 1995.

[4] S. Krishnamoorthy, J. Reed, C. Anderson, M. Robert, and S. Srikanteswara, "Characterization of the 2.4 GHz ISM band electromagnetic interference in a hospital environment," *IEEE 25th Annual Int. Conf. on Engineering in Medicine and Biology*, vol. 4, pp. 3245–3248, 2003.

[5] B. V. Poucke and B. Gyselinckx. Ultra-wideband communication for low-power wireless body area networks. [Online]. Available: http://www.industrial-embedded.com/pdfs/IMEC.Oct05.pdf

[6] Bundesamt für Umwelt Wald und Landschaft. (1992, May) Messung nichtionisierender elektromagnetischen Strahlung. [Online]. Available: http://www.bafu.admin.ch/php/modules/shop/files/pdf/phpfWggLm.pdf

[7] American National Standards Institute (ANSI), "Recommended practice for the measuremente of hazardous electromagnetic fields – RF and Microwave," The Institute of Electrical and Electronic Engineers, Tech. Rep., 1981.

[8] —, "Recommended practice for the measuremente of hazardous electromagnetic fields – RF and Microwave," The Institute of Electrical and Electronic Engineers, Tech. Rep., 1991.

[9] Antenessa. EMF measurement system. [Online]. Available: http://www.antennessa.com/telechargement/1197641443.pdf

[10] R. Janaswamy, *Radiowave propagation and smart antennas for wireless communication*. Kluwer Academic Publishers, 2001.

[11] R. Nelson and H. Ji, "Electric and magnetic fields created by electrosurgical units," *IEEE Transactions on Electromagnetic compatibility*, vol. 41, no. 1, 1999.

[12] International Organization of Standardization, "Guide to the expression of uncertainty in measurement," Tech. Rep., 1993.

[13] D. Witters and P. Ruggera, "Electromagnetic compatibility (EMC) of powered wheelchairs and scooters," *IEEE 16th Annual Int. Conf. on Engineering in Medicine and Biology*, vol. 2, pp. 894–895, 1994.

[14] International Electrotechnical Committee IEC/TC, "Medical electrical equipment - General requirements for safety Collateral standard: Electromagnetic compatibility - Requirements and tests (IEC 60601-1-2:2001)," Classification of Electromagnetic Environments, Tech. Rep., 2001.