# INCREASED LEVELS OF ELECTRICAL FIELDS IN BUILDINGS

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**Abstract**. In order to save energy and improve the performance, various electrical apparatus are equipped with power electronics. Normally power electronic equipment produce harmonics and high frequency noise. To handle noise emission, power electronic equipment uses EMC filters and are tested according to EMC standards. But the question is whether these tests are enough to avoid noise emissions in buildings?
It has been shown, that electrical equipment distributes electrical fields inside a building using the PE wire. In order to avoid or limit electrical field it is necessary to find the sources and stop the distribution. The levels of electrical fields in the frequency range between 10 kHz and 30 MHz in office buildings and homes are rather unknown. One reason is lack of civil standards, another is lack of and difficulties in measurements.
In this paper results from measurements of electrical fields in the frequency range between 10 kHz and 30 MHz at different locations is shown. An interesting result from these measurements is that the level of the electrical fields from a HF–fittings are approximately 10 times the level from video display units (VDU). This paper also shows a method to analyze sources of electrical fields.

Keywords. EMC, electrical field, protective earth, power line noise.

## I. INTRODUCTION

The use of power electronics in industry, offices and apartments is rapidly growing. The reason is to save energy and improve performance. Besides the benefits the new technology facilitates it also introduces disturbances [1]. To handle both radiated and conducted noise emissions, power electronics are tested according to EMC standards in authorized laboratories. Normally no more tests are required. *It is supposed that equipment tested according to EMC standards will work satisfactory on site. If not, the owner of the building and equipment is responsible for EMC problems.*

To handle EMC problems a cooperation between tested equipment and the building itself is needed. This includes all the wiring in the building. Nitta [2] claims that: ”As there is no correspondence between the electro-magnetic environment measured at installation site and the evaluation value specified by regulations, the matter that noise reduction/tolerant techniques are separate from regulation and still remain in skillness of trial and error shows the fundamental features of EMC techniques”. *This implies a need of new standards of or measurement on site to handle the EMC problems.*

EMC standards have been harmonized in Europe for the last ten years. That means that it is not possible to have different EMC standards in different European country. A building including all wiring and media systems may be fifty years old or more, and only made for resistive loading, loads without harmonics and high frequency switching. New loads, such as computers and motor drives introduce high frequency switching and harmonics, and also need new wiring for communication. New technology is introduced fast, due to competition between companies and countries, and delays will increase costs. *There is a difference in the electrical system in buildings in the different European countries. This difference could denote a higher cost for a whole country when introducing a new technology.*

When the separate technologies, communications and energy saving, develop in parallel there is a risk for interference. Unfortunately this problem often becomes obvious too late, when the two technologies meet on the market. Sometimes the interference between technologies is solved by small changes in construction, but frequently completely new technology has to be created. The changes result in higher costs the later the interference is detected.

One example of an established technology that was changed in order to solve a problem is when electronic lighting interfered with analog hearing aids. The first solution, working well, was to shield the hearing aid. A second solution, that was ultimately chosen, was acomplished by using digital technology in the hearing aid. [3].

An example where new technology is modified is when Electronic Magnetic Interference (EMI) between newly introduced electronic ballasts and noise-sensitive applications in airplanes where detected. The solution in this case was to modify the electronic ballasts [4]. These two examples show that there is very little or no communication between engineers and technicians who create and develop different technologies. For the purchaser and for the community there is no guarantee that the best technology survives.

R.Wayne Devereux et al [5] has worked with EMI in airplanes. The team tested “how susceptible installed avionics are to different low power RF sources located in passenger cabin and baggage compartments, and avionics and cargo bay areas”. They measured the threshold for disturbance in different systems in aircraft avionics and found that “These series of installed avionics susceptibility experiments have confirmed that avionics certified to the special 100 V/m HIRF requirements are still highly vulnerable to electromagnetic interference threats when installed in complete system. Obviously, EMI must be reconsidered at the total aircraft system level”. *To handle EMI in aircraft it is obvious that it is not enough to use equipment tested according to EMC standards. There is also a need to do on site testing.*

Besides aircraft, another area of high safety interest is the health care service. Hospitals, health centers and other buildings for health service have special standards for handling EMC. Due to safety reasons these EMC standards are more demanding than the EMC standards for normal consumer products. A combination of telecommunications and health care service is in Sweden called “Tele-medicine”. The idea is to shorten queues and management time, avoid unnecessary travel and to reduce costs. With this program it will be necessary to install equipment made for use in hospitals in homes. When doing this it is necessarily to ensure that both the medical equipment and the telecommunications equipment will not be disturbed, now or at a future date.

The knowledge other technologies can gain from aircraft systems is that there is a need of more on site testing and measurements. In industry, offices, hospitals, homes et cetera, almost no EMC on site testing and measurements are done, with the exception of troubleshooting. Besides on site testing there is need for tools for troubleshooting and methods of designing the buildings for handling EMI.

The Swedish Council for Work Life Research [6] says in their report “it is noted that research results are limited in several areas, foremost in the intermediate frequency range (between approx. 20 kHz and 1 MHz), and at extremely high frequencies (over 2–3 GHz). This lack of knowledge will become more apparent with continuing technical developments, which will likely bring about increased exposures in these frequency ranges.”

In this study measurements in the frequency range of 10 kHz to 30 MHz have been made in Swedish offices, industrial- and business locations. The measurements were mainly performed during daytime in spring and summer 2001. No changes or special arrangements were made in the room or the building before or during measuring. Since the same people, using same instrumentation and method have made the measurements, comparison between the different places can be made. The paper also discusses a method to analyze the source of the electrical field, without the need to switch on and off the loads in the buildings.

## II. OBJECTS, METHOD

### A. BUILDINGS AND INSTALLATIONS IN SWEDEN

**Buildings construction**

Houses and other buildings in Sweden are normally made of wood, concrete or brick and sometimes of stone. Houses are often constructed of frames placed on a concrete fundament with or without a cellar. An office or an apartment house with more than two floors are usually made of concrete.

**Principle of power distribution**

A three-phase power distribution to a building in Sweden is made with either four- or five-conductor system, see figure 1. A five-conductor power distribution system uses three phase wires $L_1$, $L_2$, $L_3$, a neutral wire (N) and a protective earth wire (PE). The wires $L_1$, $L_2$, $L_3$ and N are needed for power delivery while the PE wire is a safety arrangement. In a five-conductor power distribution system the N and PE wires must be separated all the way from the distribution transformer. A four-conductor system, which is the most common used, has tree phase wires $L_1$, $L_2$, $L_3$ and a common wire called PEN which combines protective earth (PE) and neutral (N).

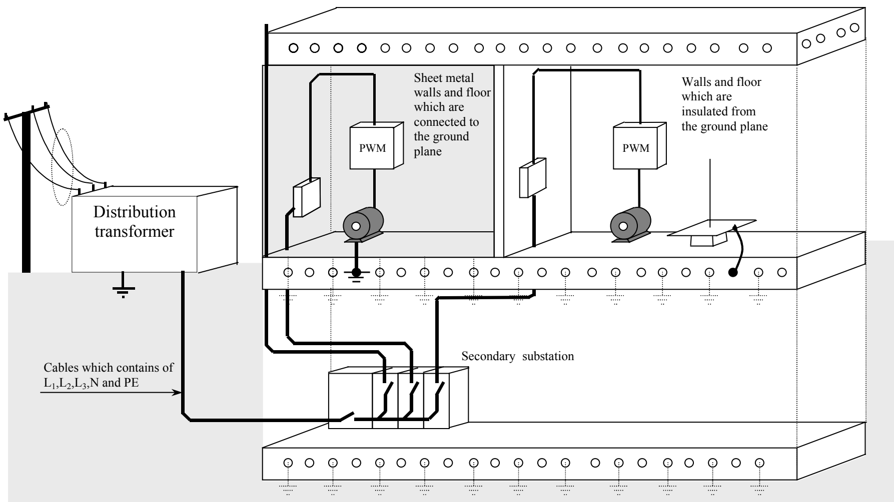


**Figure 1.** *Grounding system for a building. The distribution transformer has a grounding point for the grid. The fundament for the building acts like a grounding point and at the same time as a ground plane for the entire installation. Depending on how the electric equipment is connected to the ground plane, different situations arise in the electrical field.*

**Grounding, protective earth and ground plane**

The distribution transformer has a grounding point for the grid. In Sweden, a direct connection between PE and reinforced concrete in the building has normally not been used. If a house is build in wood the electrical water heater including the heating and water system could be the only connection between the building construction and the PE. The use of PE in houses exept from rooms with conducted floors were not required in Sweden before 1994.

The method to measure and handle electrical fields in buildings and power line noise above the fundamental frequency needs a ground plane and a connection between PE and this ground plane. It has been shown earlier that his connection must have low inductance [7]. The principle is the same as handling noise and electrical fields flowing into computers and other electronic equipment. Reducing 50 Hz magnetic field by isolating the connection between the PEN and the building could increase the electrical field above 10 kHz in buildings. A common method when reducing 50 Hz magnetic field is to isolate the connection between the PEN and the water and the water heating system in the building.

B. MEASUREMENT

**Measurement of electrical fields and power line noise**
Measurement of electrical fields could be done with regard to exposure of human beings or as a part of the Electromagnetic Compatibility (EMC), control of the electromagnetic emission and susceptibility characteristics of electrical and electronic equipment. There is a difference in standards when measuring electrical fields regarding to exposure of human beings and in regard to EMC. The difference lies in method, levels and frequency span.

Measurement of electrical fields and power line noise radiated from electrical and electronic equipment are performed in accordance to EMC standards in authorized laboratory, more seldom on site. In this paper measurement of electrical fields and power line noise is performed in accordance to MIL-STD-461E [8] and CISPER 16 [9, 10] respectively. For frequencies between 10 kHz and 30 MHz, according to MIL-STD-461E, the measuring antenna should be a 104 cm rod with an impedance matching network and a square counterpoise, measuring at least 60 cm per side. The measuring antenna is to be placed 1 meter from the equipment during testing (EUT), see figure 2. A measuring receiver or spectrum analyzer connected to the antenna measures the voltage induced in the rod, with respects to the counterpoise.

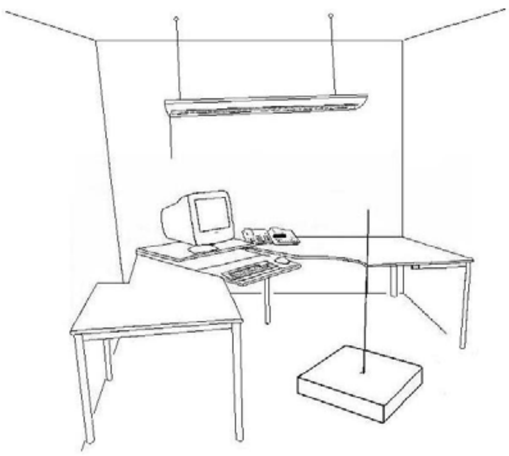

**Figure 2.** *Illustration of the measurements shows the object, antenna and spectrum analyzer.*

The use of PE instead of a ground plane to measure electrical fields or for screening purposes in frequencies above 10 kHz is normally a source of problem. MIL-STD-461E [8] says in applications guide "Safety grounds used in equipment enclosures have been the source of problems during EMI testing. Since they are connected to the equipment enclosure, they would be expected to have a very low potential with respect to the ground plane and a non-contributor to test results. However, the wire lengths within enclosures are often sufficiently long that coupling to them results from noisy circuits. Also, safety grounds can conduct induced signals from external sources and reradiate within the equipment enclosure. Therefore, they must be treated similar to other wiring."

**Electrical field**
The electrical field was measured with a spectrum analyzer and an active rod antenna in frequency area 10 kHz to 150 kHz and 150 kHz to 30 MHz according to MIL-STD-461E. The part of the standard applied in this study is RE102, radiated emissions, electric field, 10 kHz to 18 GHz. The antenna is a 104 cm rod with 60 cm square counterpoise, without any other connection to the building.

Measuring electric fields outside a shielded enclosure in buildings with isolation material in floor and walls is not easy done. The rod antenna counterpoise shall according to MIL-STD-461E be connected to the ground plane, a metallic ground plane, the floor ground plane or to earth ground. The metallic ground plane is defined as "The EUT shall be installed on a ground plane that simulates the actual installation. If the actual installation is unknown or multiple installations are expected, then a metallic ground plane shall be used. Unless otherwise specified below, ground planes shall be 2.25 $m^2$ or larger in area with the smaller side no less than 76 centimeters"

Other standards describe how to handle the ground plane when measuring electrical fields in screened rooms and in other places. For open site testing the counterpoise shall according to the Defense Standard 59-41 [11] be a metal sheet having an area of at least 5 $m^2$ or a system of at least 20 equally spaced radial flexible conductors on which the antenna is mounted.

As mentioned earlier, all measurements are performed using a 104 cm rod with 60 cm square counterpoise, without other connections to the building. The reasons for this decision was, that only a few places had the opportunity to connect the square counterpoise to the building ground plane. Almost all measurement sites were inside buildings with insulation material in floor and walls. And that will be the same problem according measurements in the future. Tests have been completed in a few places where it was possible to measure with or without connections to the building ground plane. In other places measurements have been made with and without a 3 $m^2$ (1.5m x 2m) aluminum foil connected to the square counterpoise. No differences were observed with or without a ground plane connection or the aluminum foil, however more testing must be completed.

In small room the antenna was placed in the middle of the room and for larger rooms the antenna was moved with each measurment to cover the room equally. This means that in some cases with limited space in a room, the distance could be less than one meter to equipment in the room.

**Power line noise**
In some cases it also was possibly to measure the power line noise. This was done for frequencies between 10 kHz and 30 MHz and in according to CISPER 16 [9, 10]. The power line noise was measured with a spectrum analyzer and a probe connected to phase and neutral (N), and use protective earth (PE) or building construction in form of reinforced concrete, water conduit and so on as a reference.

**Disturbance from the spectrum analyzer**
To minimize disturbance the spectrum analyzer was enclosed in metal and powered by a separate battery. The result was stored in a battery-powered computer connected to the spectrum analyzer by an optic fiber cable.

## III. RESULT

### A. SPECTRUM ANALYZER PRESENTATION

The result from the spectrum analyzer is a graph representing the peak level in a frequency range from 10 kHz to 150 kHz shown in figure 3. The amplitude scale in µV/m on the vertical axis is logarithmic and the frequency scale in Hz on the horizontal axis is linear. In figure 3 it is possible to detect peak levels both in amplitude and frequency in the range from 10 kHz to 150 kHz.

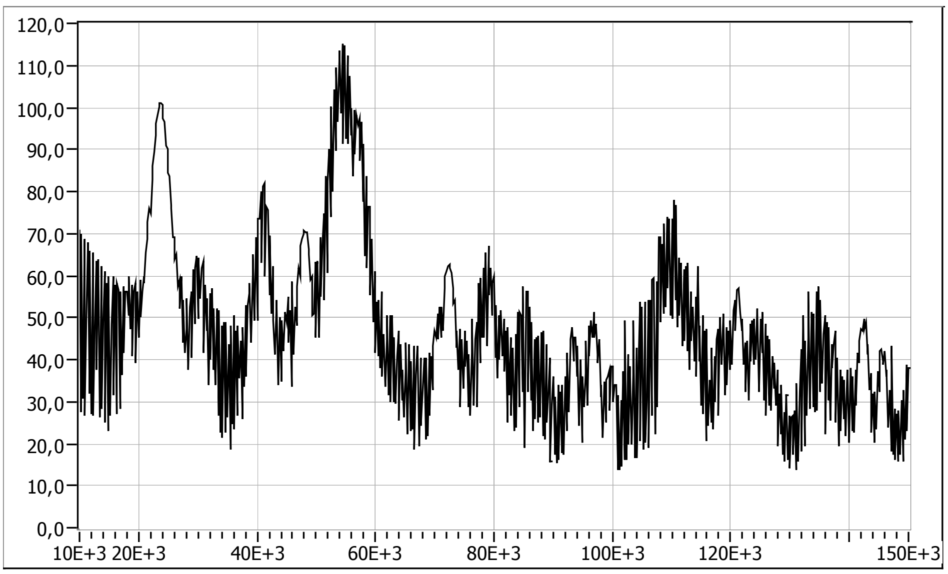


**Figure 3**. *An example of electrical field measured in the frequency range from 10 kHz to 150 kHz. The amplitude scale in µV/m on the vertical axis is logarithmic, the frequency scale in Hz on the horizontal axis is linear.*

B. Box and Whisker Plot

The result from a spectrum analyser can also be presented as a Box and Whisker Plot. In a Box and Whisker Plot the peak values in a frequency range are sorted and divided into four equal areas, see figure 4. The box, also called interquartile, encloses the middle 50 percent, where the median is represented as a vertical line inside the box. The mean of the peak values is plotted as a +. The values marked with a square are between 1,5 and 3 times the interquartile range from the 25% or 75% quartile.

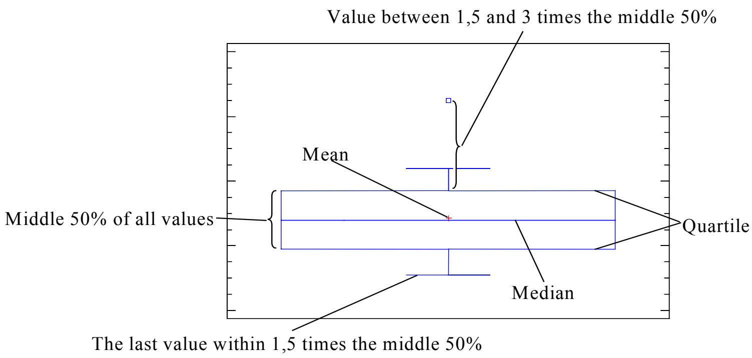


**Figure 4**. *An example of a Box and Whisker Plot.*

C. ELECTRICAL FIELD IN GENERAL

In total measurement was performed at 82 different places such as offices, industrial- and business locations. The amplitude of the electrical fields varies at different locations primarily in the frequency range from 10 kHz to 150 kHz , see figure 5. There are mainly electrical fields from local electrical equipment that dominate below a few MHz in buildings. Above a few MHz distant radio transmitters are often the strongest sources to the electric field.

As can be seen in figure 5, the highest measured level in the frequency range from 10 kHz to 150 kHz was 115 dB µV/m (approximately 0.6 V/m). The lowest measured level was just above 35 dB µV/m (approximately 60 µV/m). In the frequency range above 150 kHz the amplitude was lower. 115 dB µV/m is a not high amplitude in sight of what technical equipment normally should withstand. The expression “should withstand” is used since standards for electrical equipment in office and homes often have the limits of electrical field below 30 MHz ”under consideration”. An often mentioned level in standards is 132 dB µV/m (3 V/m).

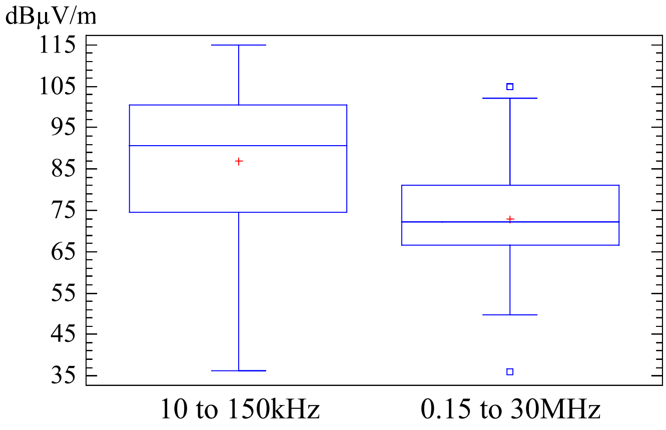


**Figure 5**. *A comparison between amplitude in electric fields at two frequency ranges, 10 kHz to 150 kHz and 150 kHz to 30 MHz. The comparison comprises measurements from 82 different places.*

D. ELECTRICAL FIELD IN OFFICE

In offices at 42 different locations it was possible to identify at least two of the strongest sources of electrical fields. Also in this case highest measured level 105 dB μV/m (approximately 0.2 V/m) was in the frequency range from 10 kHz to 150 kHz, see Figure 6. The lowest measured level just above 55 dB μV/m (approximately 600 μV/m) were measured in the frequency range above 150 kHz.

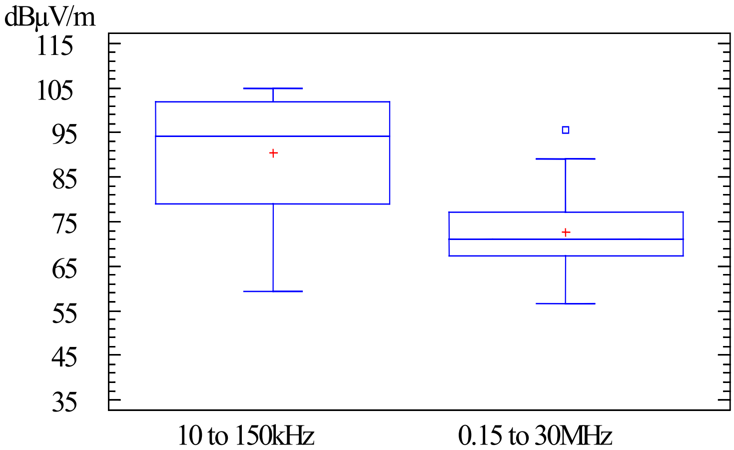


**Figure 6**. *A comparison of the amplitude of electrical fields in offices at two frequency ranges, 10 kHz to 150 kHz and 150 kHz to 30 MHz. The comparison comprises measurements from 42 different offices.*

The highest amplitude occurred in office using HF–fittings. The common light source in most Swedish offices are fittings or armatures containing two or three 1,2 meter long fluorescent tubes equipped with high-frequency electronic ballasts. These fittings or armatures are in the paper called HF-fittings. As seen in Figure 7 the measured peak level of the electrical field was approximately ten times higher from the HF–fittings than from VDU. Ten times corresponds to 20 dB. Only a few of the highest amplitudes from VDU reaches the weakest HF–fittings.

The frequency spectra of the electrical fields measured in a room with the lights turned on was identical with the frequency spectra in the electrical power grid and in other rooms in the same building. When the lights were switched off, the amplitude decreased but the frequency spectra was almost the same. In these cases it is possible that the fields are distributed [7]. More measurements are needed in order to verify if the fields are distributed or not.

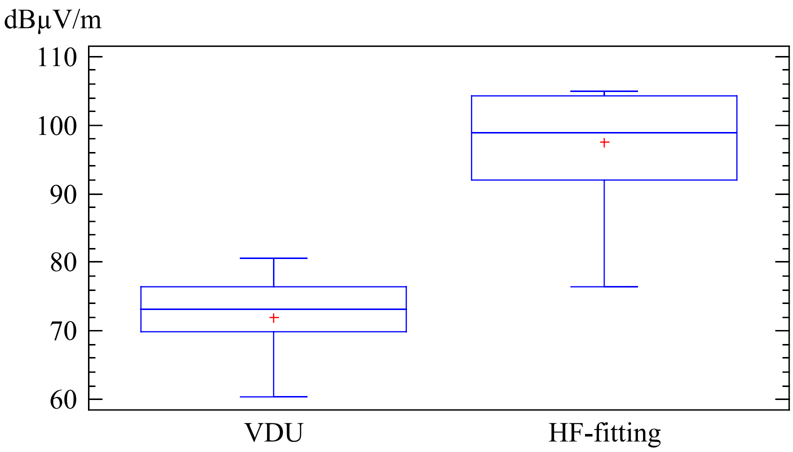


**Figure 7**. *A comparison between measured amplitude of electrical fields from VDU (to the left) and HF–fittings (to the right) in the frequency range 10 kHz – 150 kHz. The amplitude from HF–fittings were about 10 times the VDU.*

Levels ten times higher from the HF–fittings than from VDUs were surprising in sight of the great interest in reducing the electric and magnetic near field from VDUs. Even if disturbances from HF–fittings were noticed years ago [3] almost no measurements in office and public rooms in Sweden have been performed. The knowledge of the growing levels of electrical fields seems to be rather unknown.

The Swedish Council for Working Life Research published in December 2000 their report "Hypersensitivity and the health risks posed by electric and magnetic fields" [6]. The mission was to present a "research review and evaluation of the results of both Swedish and international research into electromagnetic hypersensitivity and the health risks posed by electric and magnetic fields (EMF)".

The report included frequencies between 300 Hz and 1 MHz. The results of studies on a VDU have not revealed any real evidence for health problems caused by the low levels of electric and magnetic fields that occur in these situations. Apart from the VDU work situation, research activity within this frequency region is very limited." Nowhere in the 119-page report is the use of high-frequency compact fluorescent lamp (HF-CFL) or HF–fittings mentioned as a source of an electrical field. The report states that the wide use of VDUs both at work and at home most likely will make VDUs to the commonest source of electric and magnetic field in the intermediate frequency range between 300 Hz to 1 MHz.

## IV. ANALYZE METHODS

Switching loads on and off and comparing measured amplitudes make it possible to find strong sources of electrical fields in offices. This method is not effective, especially when the source of disturbance may be located outside the room were the measurement is performed. More powerful methods to identify sources to electrical fields and power line noise in buildings are needed.

### A. MULTIVARIATE METHOD

Chemistry, industry and wood are examples of research fields were Multivariate Data Analysis is used. Multivariate Data Analysis is a powerful tool to analyze complex data consisting of many variables [12]. The input, observations are often data similar to a fervency spectrum. One way is to use projection methods such as *principal component analysis* and *projection to latent structures by means of partial least squares* method. Some useful features with these analysis tools are that they can be used to give a simple overview of the information, find relationship between the variables and to make predictions. Using projections methods like principal component analysis gives the possibility of revealing groups of observations, trends and outlines. It also gives information about relationships between variables and between observations and variables. Partial least squares is a method used to show a relationship between the factors and the responses. This analysis tool creates a method to predict and classify responses.

Multivariate Data Analysis has been tested as an analysis method for the measurements in the present study. The material consists of measurements of electrical field and power line noise made in different buildings together with other measurements made on electric equipment in an almost noiseless room. The results, at this early point, are promising. The results show that Multivariate Data Analysis is an interesting way of analysing data and it may be a useful help to detect the kind of equipment used within a building.

## V. CONCLUSIONS

The present study has shown the importance of making observations on site. Tests in aircraft using different low power RF sources has shown avionics certified to 100 V/m still highly vulnerable to low level of EMI when installed in a complete system. To handle EMI in airplane it is obvious that it is not enough to use equipment tested according to EMC standards, on site testing is needed.

The cases where established technology was disturbed by electronic lighting has shown out that EMI problems also occur in office, business locations and houses. To handle EMC problem at an early stage and to a low cost there is a need of on site measurements. The owner of a building or installed equipment has the responsibility for EMC problems not the manufacturer. The owner has to pay for solving the EMC problems.

The EMC standard for equipment has been harmonized in Europe for many years. One problem is that the building itself, including all wiring and media systems, could be fifty years old or more. New technology is introduced fast, due to competition between companies and countries, and delays will increase costs. There is a difference between different European countries in the way buildings and electric wiring have been constructed. This difference could denote a higher cost for a entire country when introducing new technology.

Measurements have been performed at 82 offices, industrial- and business locations. The highest measured electrical field (115 dB µV/m, approximately 0.6 V/m) and is not a high amplitude in sight of what technical equipment normally should withstand. It is although surprising that the knowledge of the increasing levels of electrical fields seems to be rather unknown.

In offices the electrical fields from HF–fittings was ten times higher than from VDUs. This result is surprising in sight of the large interest of reducing the electric and magnetic near field from VDUs. Even if disturbances from HF–fittings was noticed years ago almost no measurements in office and public rooms have been performed in Sweden.

For example, nowhere in the 119-page report “Hypersensitivity and the health risks posed by electric and magnetic fields” made by the Swedish Council for Working Life Research publish in December 2000 was the use of HF–fittings mentioned as a source of electrical fields. That does not mean that the problem was unknown, just that nearly no measurements have been published.

Without field measurements it is nearly impossible to know the actual level of electrical field and power line noise. If new technologies like the Swedish “Tele-medicine” will work properly it is necessarily to be sure that the equipment and telecommunications not will be disturbed now or in the future. The cost is less if the problem is handled at an early stage.

In 42 of the places, all offices, it was possible to identify at least two of the strongest sources of electrical fields. In this case highest measured level was 105 dB µV/m (approximately 0.2 V/m). Identification of the sources was made by switching them on and off. This method takes a long time. Multivariate Data Analysis could be a powerful tool when analyzing sources of electrical field and power line noise.

In this paper measurement of electrical fields are performed in accordance with MIL-STD-461E. The only difference from MIL-STD-461E was to use a square counterpoise without any other connections to the building. The reasons for this decision was, that only a few sites had the opportunity to connect the square counterpoise to the building ground plane. Tests performed at a few sites showed no difference in the measured fields with and without connection to the building ground plane. More measurements and tests at various sites and frequencies are needed to verify this observation.

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