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Measurement and Analysis of Extremely Low Frequency Magnetic Field exposure in Swedish Residence

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Report no: EX004/2011

Master of Science Thesis

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ABSTRACT

The measurements were performed to understand the personal exposure of magnetic field (MF) at extremely low frequency in residents of Göteborg, Borås and Mark. The challenge was to perform measurement in 100 houses. And the houses were randomly selected to be in urban area and country side. The measurement of MF was made using three instruments. The results conclude that almost 90% of the measured houses have exposure of MF below 0.2µT with mean value of B_{Adjust} 0.11µT and median value 0.05 µT. This signifies that most of the houses are not exposed to high magnetic field. The comparison of MF exposure in three different areas (Göteborg, Borås and Others) shows that in other areas 97% houses have MF exposure below 0.2 µT with median value 0.04 µT, and around 85% of houses have 0.2 µT in rest of the regions. Magnetic field was found to be highest on the floor level in most of the houses as compare to middle and top level. About 36% of the houses have MF highest on floor level. Reason for this is underground heating systems and electric wiring in houses. The analysis among villas and apartment on the bases of adjusted average B_{Adjust} MF value shows that exposure of MF in 83% of the houses among apartment are below 0.2 µT and 89% of the houses among the villas are below 0.2 µT. Median value of B_{Adjust} for apartments is 0.07 µT and for villa is 0.04 µT, which shows that apartments have higher exposure of magnetic field as compare to villas. Total Harmonic Distortion (THD) was found to be high in some houses and the reason for this is large amount of non-linear loads. The median value of THD turns out to be 10.3%.

Acknowledgements

First and foremost, thanks to God Almighty who gave us courage and strength to complete the project in time.

We are thankful to Professor Lars Barregård who was kind to provide us with the participants list. We are grateful to our supervisor Prof. Yngve Hamnerius, who was a constant support and a wonderful guide for this thesis work to be accomplished successfully. We would also like to express the deepest gratitude to Jimmy Estenberg, who gave us this opportunity to work on this project. We are thankful to COMBINOVA who helped us a great deal in order to make the best use of their instruments throughout the thesis work. We thank our fellow project mates, who were instrumental in executing the work on time with high efficiency.

We would also like to thank the pillars of our life who kept supporting us unconditionally throughout our life up till now, our beloved parents.

Finally we whole heartedly thank all the participants who were very co-operative and kind to us, without them this project would not have been a reality.

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List of Abbreviations

Abbreviation	Description
2^{nd} L.S	**Second largest Signal**
B_{Adjust}	**Adjusted Average RMS**
B_{Bed}	**Average RMS in Bedroom**
ELF	**Extremely Low Frequency**
MF	**Magnetic Field**
Freq	**Frequency**
GHz	**Giga Hertz**
H.P	**Hot Plates**
ICNIRP	**International Commission on Non-ionizing radiation protection**
kHz	**Kilo Hertz**
L.S	**Largest Signal**
M.O	**Micro wave Oven**
MFM	**Magnetic Field Meter**
ML	**Magnetic Logger**
O.V	**Oven (Induction)**
RMS	**Root Mean Square**
THD	**Total Harmonic Distortion**
WG	**White Goods**

1. Introduction

Exposure to electric and magnetic fields is not a new phenomenon. However, during the 20th century, environmental exposure to extremely low magnetic fields has been increased because of growing electricity demand, advance technologies and changes in social behavior. Most of the peoples are exposed to a complex mix of weak electric and magnetic fields, both at home and at work, which are generated from the production and transmission of electricity, domestic appliances and industrial equipment.

Both electric and magnetic fields are present around appliances and electric power lines. However, it is easy to reduce the effect of electric fields by using shielded wires and they are also weakened by walls and other objects, whereas magnetic fields can pass through buildings, humans, and most other materials. Since magnetic fields are most likely to penetrate the body, they are usually the focus of study in relation to cancer.

The focus of this study is on extremely low-frequency magnetic fields. Measurement of magnetic field is used to characterize the sources and exposure level to humans. Measurements of MF in randomly selected houses have been done, and substantial, spatial and temporal variations of field have been considered. Three different types of instruments are used for assessment. For 24 hour logging of MF Enviro Mentor "Magnetic Field Logger ML-1" have been used depending on the location of house. If residence is close to railway lines then Combinova Magnetic Field Meter "MFM 10" has been used. For point measurements Combinova Magnetic Field Meter "MFM 3000" have been used in three different rooms, Kitchen, Bedroom and Living room in a house. Examples of devices that produce magnetic field include power lines and electrical appliances, such as electric shavers, hair dryers, computers, televisions, electric blankets, power sockets, domestic heating system and heated waterbeds. If electrical appliances are turned on there will be increase in magnetic field. The strength of a magnetic field decreases rapidly with increased distance from the source.

1.1. History and Background

Exposure to electromagnetic fields has been an issue of concern for many institutes and numerous biophysical researches has been performed. Thousands of articles have been published since last 20 years, and research is still on its way. In the late 1960s the discussion over biological effects of magnetic field was started. Higher voltage electric power transmission lines were the reason of this discussion. Because of detrimental health effects of these lines scientist were call upon to take care of this issue.

In 1979 the famous epidemiologist Nancy Wertheimer was the first scientist who starts doing serious study about this issue, who was trying to figure out the possible causes for a number of childhood cancer cases in the city of Denver in USA. Her research, performed with physicist Ed Leeper, found that houses near high current power lines, where the electromagnetic fields were stronger have more than twice chances of children with leukemia [7].

In 1969, the International Agency for Research on Cancer (IARC) initiated a program to evaluate the carcinogenic risk of chemicals to humans and to produce monographs on individual chemicals. The evaluation of carcinogenic risk is made by the international working groups of independent scientists and are qualitative in nature. There are limited evidence but ELF magnetic fields are classifies by IARC as possibly carcinogenic to humans [18].

In late of 1992 research study in Sweden revealed indication of a relation, with the number of cases of leukemia increasing where higher level of exposure exists [7]. The analyses have been made on large scale that brings out the results of several studies performed and the positive association still holds. Because of this consistent pattern of association in epidemiological childhood leukemia studies that has continued to keep the research into MF bio-effects.

1.2. Thesis Objective

This thesis represents a continuation of the previous work done over person exposure to MF on general population in Sweden. Thesis project is collaboration between the Swedish radiation Safety Authority and Chalmers.

The prime focus of this research study is to perform the measurements of MF in Swedish homes and perform the analysis to find out the distribution of MF in houses. Such measurements have been done earlier, but this time we try to consider the information about different frequency components as well. Magnetic field measurements were conducted at random houses in residential areas.

1.3. Organization of the Report

Chapter 2 explains MF theory. It includes the information about electromagnetic spectrum and concept related to electromagnetic field. Electric and magnetic fields are explained separately in detail. Furthermore a discussion is made about effects of current produced in human bodies and its negative effects over neurons. Add to this the exposure level to magnetic field in the environment is explained in detail. Towards the end of this chapter exposure to power lines for electricity supply, at railway track, and exposure to MF at domestic level from different electric appliances are also focused.

Chapter 3 contains detail information about Material and Methods that has been followed to perform measurement and handle the measured data. Detail description about the instruments used for the measurement purpose is provided. Also information about setting of instruments, to get them prepared for performing measurements are clearly explained. Later the discussion about calibration of instruments is provided. The chapter continues to provide details about the measurement method that was adopted to perform measurement, the procedure that was followed for 15-point measurement and 24-hour measurement methods are narrated as well. The chapter closes by providing explanation to the different terms used in the final result table, like THD, adjusted average etc. also the rules for calculating THD are discussed.

Chapter 4 is about the results and discussion. A detailed description of the measurement results in a table format is given. The output from point measurements and 24-hour logging data are provided. The results related to adjusted average magnetic field, flat average and THD calculated from the measured data of subject houses is represented in graphs.

In Chapter 5 a discussion about the results is provided. And it also contain information about the future work that is about to follow.

Appendix contains information about test measurement that was performed at a railway site and 24-hour logging in each room in several houses.

1.4. Residence as Subjects

The person address register was provided by Professor Lars Barregård, Dept. Occupational and Environmental medicine, Sahlgrenska University Hospital and Sahlgrenska Academy, University of Gothenburg.

The persons had been chosen by random method for earlier studies, performed by the Dept. Occupational and Environmental medicine and these addresses were re-used in this study. The addresses were in Göteborg, Borås and Mark. If the persons had moved within the region and we could identify the new address, the new address was used.

The target was to perform MF measurements in total 100 houses (apartments or villas). So in beginning it was decided to divide the 100 houses in to two groups, 50 houses in Göteborg and 50 houses in Borås. Later on we had some drop outs because of certain reasons, so we decided also to select some houses in Mark.

The address register contained totally 179 addresses. We were able to get permission to perform measurements at 97 addresses. We were not able to get in contact with 38 addresses, which in most cases depended on that the person had moved without an identifiable new address. We had the person's name and address and not the personal number, therefore new addresses could not be searched for those with common names.

1.5. ICNIRP Guidelines

ICNIRP being the International Commission for providing guidelines on radiation protection, recently (Nov 2010) came out with a set of guidelines to protect humans who are exposed to electric and magnetic field in the low frequency range of the electromagnetic spectrum. Their objective was to establish guidelines for limiting MF exposure thereby providing protection against adverse health effects [17]. From their studies they have concluded that most of the risks come from transient nervous system responses, which includes PNS, CNS, induction of retinal phosphenes and some possible damage to certain function of brain [17].

Table 1 shows the basic restriction for human exposure to time varying electric and magnetic field. The table shows General public exposure. As mentioned above, ICNIRP have concluded from their studies that brain tissues are more sensitive to these varying low frequency fields, so they have considered the facts while defining the guidelines, which can be seen from the separate a set of restricted frequencies exclusively for brain tissues (table 1). It should be noted that ‘f’ is in Hz in the tables 1 and 2.

Exposure Characteristic	Frequency Range	Internal Electric Field (Vm^{-1})
General public exposure CNS tissue of the head	1 – 10 Hz	0.1/f
	10 Hz – 25 Hz	0.01
	25 Hz – 1000 Hz	$4 \times 10^{-4}f$
	1000 Hz – 3 kHz	0.4
	3 kHz – 10 MHz	$1.35 \times 10^{-4} f$
All tissues of head and body	1 Hz – 3 kHz	0.4
	3 kHz – 10 MHz	$1.35 \times 10^{-4} f$

Table 1: Basic Restrictions for human exposure to time varying electric and magnetic fields according ICNIRP.

Notes:- All values are rms. In the frequency range above 100 kHz, RF specific basic restrictions need to be considered additionally.

Table 2 is the reference level for general public exposure to time varying electric and magnetic fields respectively. They are calculated in order to provide maximum protection to the person who is been exposed to maximum coupling of the field [17]. In table the frequency range and the corresponding reference level is provided in terms of Magnetic flux density.

Frequency range	Magnetic flux density B (T) (General public exposure)
1 Hz – 8 Hz	$4 \times 10^{-2}/f^2$
8 Hz – 25 Hz	$5 \times 10^{-2}/f$
25 Hz – 50 Hz	2×10^{-4}
50 Hz – 400 Hz	2×10^{-4}
400 Hz – 3 kHz	$8 \times 10^{-2}/f$
3 kHz- 10 MHz	2.7×10^{-5}

Table 2: Reference level for general public exposure to time varying electric and magnetic fields.

Notes: In the frequency range above 100 kHz, RF specific reference levels need to be considered additionally

2. Physical Science Concepts

To figure out the relation between external physical agents and biological systems it is important to talk about science concepts and make their understanding. In the surroundings of any wire or conductor carrying electric current, there exists an electric and magnetic field, collectively referred to as electromagnetic fields, or EMF. These fields often extend for considerable distances around the wire. It is quite obvious that anywhere electricity is in use, electric and magnetic fields will be present, often at significant intensities. The power distribution lines running throughout residential and commercial neighborhoods either they are overhead or underground, the wirings of different types inside houses or different other structures, as well as many common electrical devices used in daily life.

2.1. Electromagnetic Spectrum

Electromagnetic waves span a wide range of frequencies (and, accordingly, wavelengths). This range of frequencies and wavelengths is called the electromagnetic spectrum. The part of the spectrum most familiar to humans is probably light, the visible portion of the electromagnetic spectrum. The electromagnetic spectrum comprises ionizing radiation and non-ionizing radiation [1].

Our focus is given towards the non-ionizing radiation range, which is further subdivided into Static fields (0 Hz), Extremely Low Frequency Field (0-300 Hz), intermediate frequency fields (300 Hz to 100 kHz) radio frequency field (100 kHz to 300 GHz) and optical radiation [3], shown in Figure 1.

Non-ionization radiations					Ionization Radiations
Extremely Low Frequency (ELF)		Radio Frequency Field (RF)		Non-ionization radiations	
Direct Current Power Lines	AM Radio	TV FM Radio	Cell Phone Radar Microwave	Infrared Visible Light	X-Rays Gamma rays Cosmic rays

0 1000 Hz 1 Millon Hz 1 Billion Hz 1 Trillion Hz 1 Quadrillion Hz 1 Billion Billion Hz

Figure 1. Electromagnetic Spectrum.

In this research study we did measurement of ELF (extremely low frequency) magnetic field.

2.2. Electric and magnetic Field

Electricity is the movement of electrons, or current, through a wire. The type of electricity that runs through power lines and in houses is alternating current (AC). AC power produces two types of fields, electric field and a magnetic field, shown in figure2. An electric field is produced by voltage, which is the pressure used to push the electrons through the wire, much like water being pushed through a pipe. As the voltage increases, the electric field increases in strength. A magnetic field results from the flow of current through wires or electrical devices and increases in strength as the current increases. These two fields together are referred to as electric and magnetic fields, or MFs.

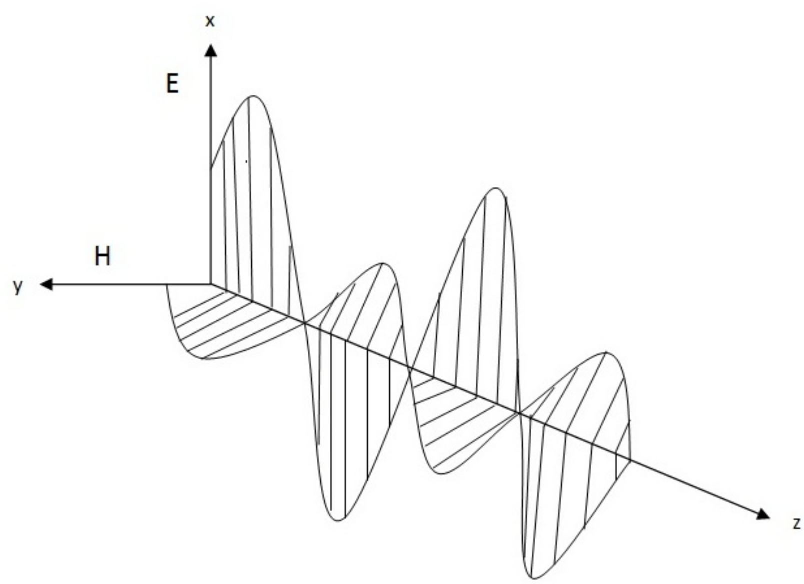


Figure 2. Electric and Magnetic Field.

2.2.2. Electric Field

Concept of electric field was introduced by Michael Faraday. The electric field is a vector field with SI units of Newton's per coulomb ($N\ C^{-1}$) or, equivalently, volts per meter ($V\ m^{-1}$). The magnitude of the field at a given point is defined as the force that would be exerted on a positive test charge of 1 coulomb placed at that point; the direction of the field is given by the direction of that force [1].

The electric field is defined as the force per unit charge that would be experienced by a stationary point charge at a given location in the field

$$\mathbf{E} = \frac{\mathbf{F}}{\mathbf{q}}$$

F is the **electric force** experienced by the particle

q is its charge

E is the electric field wherein the particle is located

An electric field that changes with time due to the motion of charged particles influences the local magnetic field. That is, the electric and magnetic fields are not completely separate phenomena; what one observer perceives as an electric field, another observer in a different frame of reference perceives as a mixture of electric and magnetic fields. For this reason, one speaks of "electromagnetic fields".

2.2.3. Magnetic Field

Magnetic fields are important part of nature. Magnetic fields are part of discussion in wide range of studies. Magnetic fields are the complicated phenomenon than electric fields. Magnetic field is a vector quantity. The ultimate reason for the asymmetry between electric and magnetic fields is that, unlike electric charges, nature chooses not to have any “magnetic charges" otherwise known as magnetic monopoles. Magnetic field is produced by motion of charges instead of magnetic charges. The units of the magnetic field **B** is given by Newton per (coulomb-meter/sec), which is abbreviated to **tesla** (T). We have

$$\mathbf{1T} = \frac{\mathbf{N}}{\mathbf{Cms}} \qquad \textbf{Equation 1}$$

$$= 1\,\frac{\mathrm{N}}{\mathrm{Am}}$$

All moving charged particles produce magnetic fields. Moving point charges, such as electrons, produce complicated but well known magnetic fields that depend on the charge, velocity, and acceleration of the particles.

2.2.4. Stray Currents & Magnetic Field

The stray currents can give rise to magnetic fields. In Sweden, for example, the electricity systems generally entail four conductors leading to each building, which can result in major problems because of stray currents. The stray current can pass through the neutral conductor as intended, but it can also pass through the earth conductor and into the plumbing pipe work to the transformers earth point. This increases the magnetic field both along the path of the stray current and along the supply cable. It is also common place for stray currents to exist in computer networks. As well as causing magnetic fields, they can also lead to communication problems.

Magnetic field lines form in concentric circles around a cylindrical current-carrying conductor, such as a length of wire. The direction of such a magnetic field can be determined by using the "right hand rule" (see figure 3). If we orient right hand such that curl of fingers follows the direction of current in the circular wire, then extended thumb points in the direction of magnetic field at its center. The strength of the magnetic field decreases with distance from the wire.

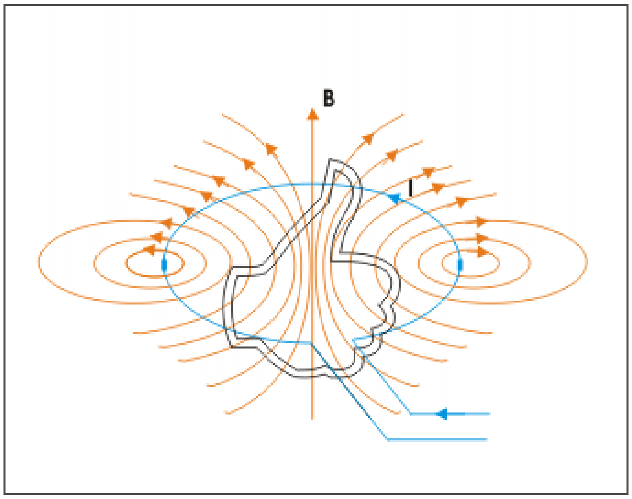


Figure 3. Figure shows Direction of magnetic field with right hand rule.

There are two Types of Magnetic field produced by flow of charges.

Static Magnetic Field

A static field does not vary over time. A direct current (DC) is an electric current flowing in one direction only. In any battery-powered appliance the current flows from the battery to the appliance and then back to the battery. It will create a static magnetic field. The earth's magnetic field is also a static field. So is the magnetic field around a bar magnet which can be visualized by observing the pattern that is formed when iron filings are sprinkled around it.

Time-varying magnetic Field

In contrast, time-varying magnetic fields are produced by alternating currents (AC). Alternating currents reverse their direction at regular intervals. In most of the European countries the electricity changes direction with a frequency of 50 cycles per second or 50 hertz. Equally, the associated electromagnetic field changes its orientation 50 times every second. North American power system has a frequency of 60 hertz.

2.3. Effects of MF on Human Body

A small amount of electrical currents exist in the human body due to the chemical reactions that occur as part of the normal bodily functions. For example, nerves relay signals by transmitting electric impulses. Most biochemical reactions from digestion to brain activities go along with the rearrangement of charged particles. Even the heart is electrically active, which can be traced with the help of an electrocardiogram.

The human body is affected by ELF Fields just as they influence any other material made up of charged particles. Low-frequency MF induce current within the human body. The strength of these currents depends on the intensity of the outside magnetic field. If the amount of current is large then it can effects biological processes and could simulate the nerves and muscles [4].

Heating is the main biological effect of the magnetic fields of radiofrequency fields. In microwave ovens this fact is used to warm up food. The levels of radiofrequency fields to which people are normally exposed are very much lower than those needed to produce significant heating.

There are different studies that have been performed about the MF exposure at the residence level. A number of epidemiological studies report indicates that the exposure to low frequency magnetic fields in the home increased risk of childhood leukemia. Some individuals report "hypersensitivity" to electric or magnetic fields. They ask whether aches and pains, headaches, depression, lethargy, sleeping disorders, and even convulsions and epileptic seizures could be associated with electromagnetic field exposure [4]. None of these symptoms have however been confirmed in replication studies, despite decades of extensive scientific research.

2.4. Typical exposure levels at home and in the environment

The exposure levels to magnetic field are discussed in detail below. Magnetic fields are present everywhere in our environment but are invisible to the human eye. The earth's magnetic field is used in several fields for navigation purposes. Besides natural sources the human-made sources like X-rays also generate magnetic field. The electricity that comes out of every power socket has associated low frequency magnetic fields. TV stations, radio stations and mobile phone networks use some higher frequency radio waves to transmit information.

2.4.1. Electromagnetic field levels from electricity transmission and distribution facilities

Electricity is transmitted over long distances via high voltage power lines, shown in figure 4. Electricity transmission and distribution facilities and residential wiring and appliances account for the background level of power frequency electric and magnetic fields in the home. In homes not located near power lines this background field is normally up to 0.2 μT. Close to power lines the fields are stronger. Magnetic flux densities at ground level can range up to several μT. However, the fields (both electric and magnetic) reduce when we move away from lines. At 50 m to 100 m distance the fields are normally at levels that are found in areas away from high voltage power lines. In addition, the house walls and pillars also reduce the strength of electric fields but not of magnetic field.

Figure 4. Power Lines passing near residences.

2.4.2. Electric appliances in the household

The field strength does not depend on the size, power or complexity of devices. Furthermore, even between apparently similar devices, the strength of the magnetic field may vary a lot. Strength of Magnetic Field depends upon the design of device. For example, while some hair dryers generate very strong field, others hardly produce any magnetic field.

Computer screens and television produce static and alternating EMF at numerous frequencies. However, screens with liquid crystal displays (LCD) do not give rise to significant electric and magnetic fields. Modern computers have conductive screens which reduce the static field from the screen to a level similar to that of the normal background in the home or workplace.

Domestic microwave ovens operate at very high power levels. However, because of effective shielding the microwaves are not leaked out. Furthermore microwave leakage falls very rapidly with increasing distance from the oven [5].

2.4.3. Some other Magnetic fields in the environment

At the airport we come across very strong MF, which are generated for security purposes. And metal detectors and airport security systems generates a strong magnetic field of up to 100 μT. Close to the frame of the detector, magnetic field strengths may approach and occasionally exceed the reference level for general public exposure [5].

In trains exposure comes mainly from the electricity supply lines to the train. Magnetic fields in the passenger cars of long-distance trains can be several hundred μT near the floor. Swedish Radiation Safety Authority, formerly the Swedish Radiation Protection Authority, during the years 1993-2010 performed several measurements of MF in Swedish trains. Magnetic field strength in trains was around 2 to 27 μT, depending on the type of train and coach. On single occasions, measurements in commuter trains showed a magnetic field strength of up to 80 μT. The recommended limit for the general public's exposure to magnetic fields from the railway network is 300 μT [19].

3. Materials and Methods

In this section the materials and the methods that were used for this thesis work are explained briefly.

3.1. Materials

For this thesis work, three models of magnetic field meters were used. They are as follows,

- Enviro Mentor ML -1
- Combinova MFM 10
- Combinova MFM 3000

Clear description about each of the magnetic field meter's characteristics and properties are given in the following paragraphs:

3.1.1. Enviro Mentor ML-1

This is a magnetic field logger which can measure and store the RMS values of alternating magnetic field in the X, Y and Z direction. Placing the instrument in a particular direction during the measurement does not make any difference in the reading of magnetic values. The instrument can be set to take values at regular intervals of between 1 to 150 seconds and it can store a maximum of 8,192 readings [10]. The instrument is capable of measuring the magnetic field at a particular time and also series of reading on a continuous basis is possible. The stored values can be transferred to a computer with a help of cable connected to the RS 232 port. The obtained data can be analyzed with the software that is provided, which is capable of producing the data's in form of diagram and picture. All the necessary details like mean, median, std. dev can be easily obtained with the use of the software. Figure 5 shows picture of ML-1.

The measurement range of the instrument is from 0.05 μT-100 μT, with an accuracy of ±10% ±0.05 μT and frequency range of 30 Hz-2 kHz (-3dB) [10].

Figure 5. Picture showing Enviro Mentor ML -1 magnetic field logger[11].

3.1.2. Combinova MFM 10

This instrument is handful and advantageous in certain cases. It has an orthogonal coil which makes it independent of the direction it is placed to obtain measurement, with a range of 10 nT-10 µT [12]. Here the gain is set automatically by the instrument itself. The filter in the instrument provides an attenuation of -3 dB at 5 Hz and 2000 Hz. The accuracy is better than ±2% of reading or ±0.005 µT [12]. It has a memory which can store 4000 results. The instrument is specially designed to measure magnetic field from power lines, office and industry levels. Like the ML-1 it can take single measurement as well as continuous measurements. In ML-1 it is operated by two AA batteries so they have to be replaced at regular intervals but Combinova MFM 10 has rechargeable battery which can stand for more than 100 hours. The stored values can be transferred to a computer with a software interface. Figure 6 shows the image of MFM 10 instrument.

Figure 6. Picture shows the Combinova MFM 10[12].

3.1.3. Combinova MFM 3000

Like all the above instruments it is capable of performing spatial measurement because of its orthogonal coil but its special feature is to provide a real time wideband spectrum analysis of the obtained value. The touch panel digital display with numerical and graphic representation is something that the other instruments lack. This has a wide frequency range of 5 Hz-400 kHz and other predefined specific settings like ICNIRP are available. Figure 7 shows the graphical representation of the frequency range of MFM 3000. The frequency range can be altered manually according to the need. It is mainly designed to handle measurements of household appliances, occupational & public exposure. It has the options to perform single, burst or continuous measurement [12]. The accuracy is about ± (1% of reading +2 nT) [13]. Figure 8 shows the MFM 3000.

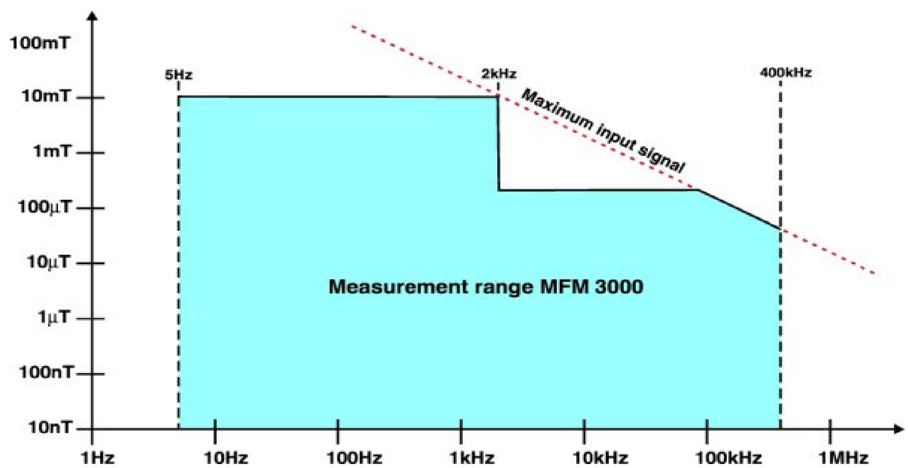


Figure 7. Graphical representation of the frequency range of MFM 3000[13].

Figure 8. Picture shows Combinova MFM 3000[13].

3.2. Methods

In this section the method that was followed during the course of the measurement is explained.

3.2.1. Calibration

It was required to make sure that the instruments used were calibrated before starting the thesis work. The calibration process was performed at the Swedish radiation Safety Authority in Stockholm on the 16th of June 2010. Following equipments were used for the calibration purposes

- Signal generator (SPN) – 1Hz to 1.3MHz
  SSI575/ 336.3019.02
- Amplifier – gain 16.1 for load of 5 ohm
  SSI IJ41
- Shunt Resister– 3.3 ohm, 1 ohm
  SSI IJ26
- Helmholtz coil (dimension of the box is 56x79)
- Multi Meter HP3458A
  SSI IJ30

The setup that was used for performing the calibration of the magnetic field meters are shown in the form of a block diagram in the below figure 9.

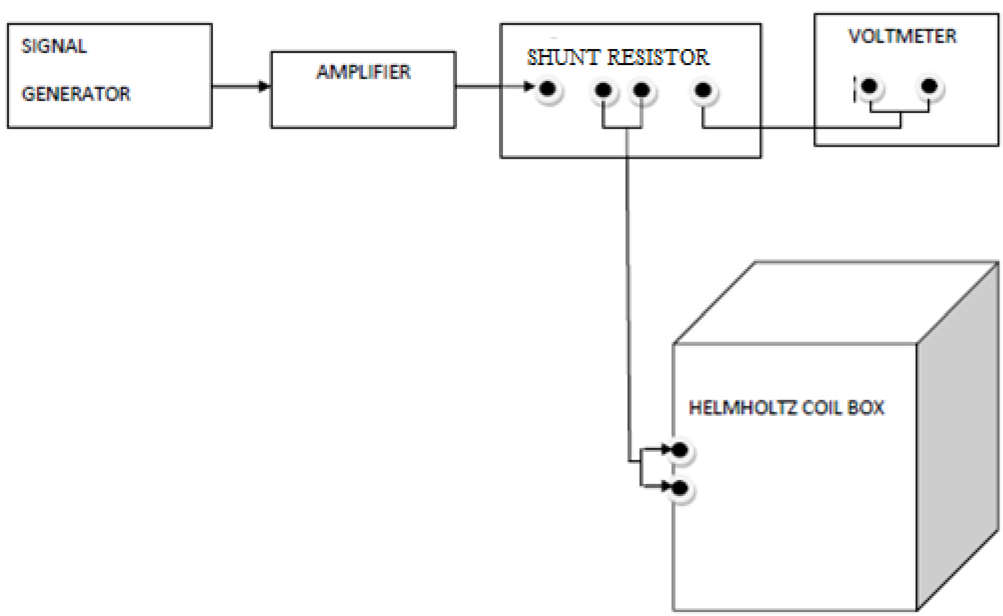


Figure 9. Entire set up of the calibration procedure.

The signal generator was connected to the amplifier which amplifies the signal with a gain of 16.1. A three way coupler (Shunt Resister) was used to provide a fine resistance of 1ohm, the voltage drop at shunt resister was measured by voltmeter to access the current going to Helmholtz coil. The output of the three way coupler leads to the Helmholtz coil box made of wood with wires on the outside, inside which the calibration was performed. The magnetic flux density was calculated using the following formula.

$$B= (1.703 * V/1.0\ \text{ohm})\ \mu T \qquad \textbf{Equation 2}$$

To obtain the voltage "V" value, magnetic field was considered to be 1 µT in the above formula; this value was set in the signal generator. After setting the signal generator to a frequency of 50 Hz, the instruments were placed inside the Helmholtz coil box one by one and the calibrations were made.

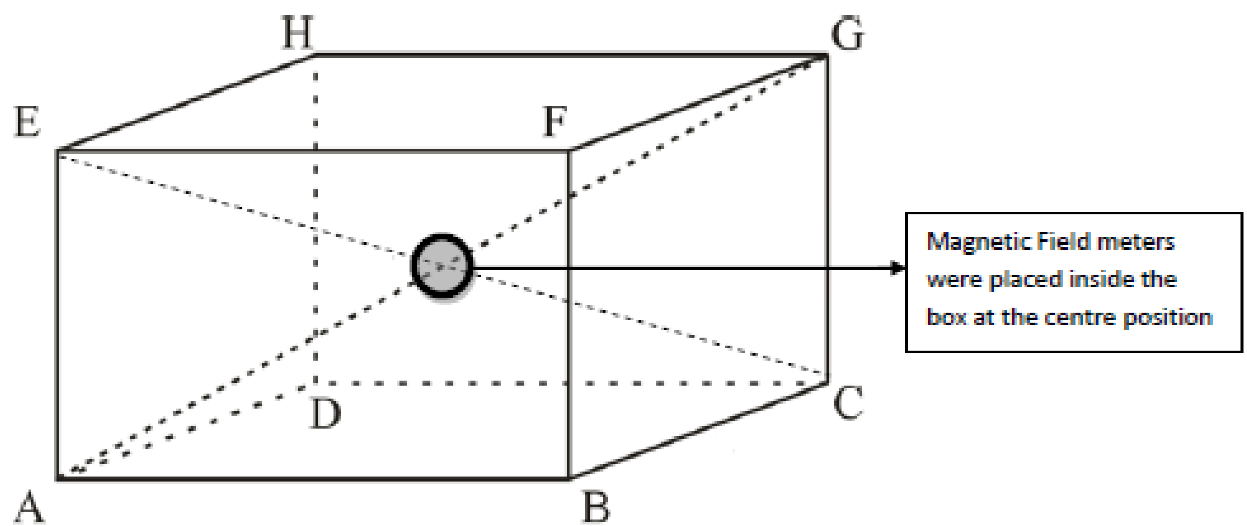


Figure 10: Helmholtz coil box with centre point indicated inside the box

After the set up was made the magnetic field meters were placed at the centre of the box as shown in the figure 10 and the readings were noted in the meters. Instruments that showed values close to 1 µT were considered to be calibrated and devices with highly varying values were not considered to be calibrated. Once the calibration process was performed, the same steps were repeated for a frequency of 150 Hz. The results of the calibration can be found in the following tables 3 and 4 for 50 and 150 Hz respectively. From the results it can be seen that every instrument was calibrated to 1 µT or close to it, except one which was sent to the manufacturer for repair and calibration before it was used during the measurement.

Equipment	Serial no	Observed reading (µT)		
Enviromentor ML 1	132	1		
Enviromentor ML 1	137	1.03		
Enviromentor ML 1	135	0.96		
Enviromentor ML 1	144	1.01		
Enviromentor ML 1	332	1		
Enviromentor ML 1	108	Did not function		
Combinova MFM 3000	106	x-axis	y-axis	z-axis
		0.99	1	1.07
Combinova MFM 10	198	0.995	0.99	0.98
Combinova MFM 10	100	0.995	0.994	0.997

Table 3: Calibration results of magnetic field meters for 50 Hz

Equipment	Serial no	Observed reading (µT)		
Enviromentor ML 1	132	1		
Enviromentor ML 1	137	1.04		
Enviromentor ML 1	135	0.97		
Enviromentor ML 1	144	1.01		
Enviromentor ML 1	332	1.01		
Enviromentor ML 1	108	Did not function		
Combinova MFM 3000	106	x- axis	y-axis	z-axis
		0.97	0.994	0.98
Combinova MFM 10	198	0.990	0.992	0.989
Combinova MFM 10	100	0.985	0.983	0.992

Table4: Calibration results of magnetic field meters for 150 Hz

3.2.1.1. Setting of the instrument

This section provides detail about how the instruments were set before taking measurement and also some relevant data about the instruments used.

3.2.1.1.1. Combinova MFM3000 (Magnetic Field Meter)

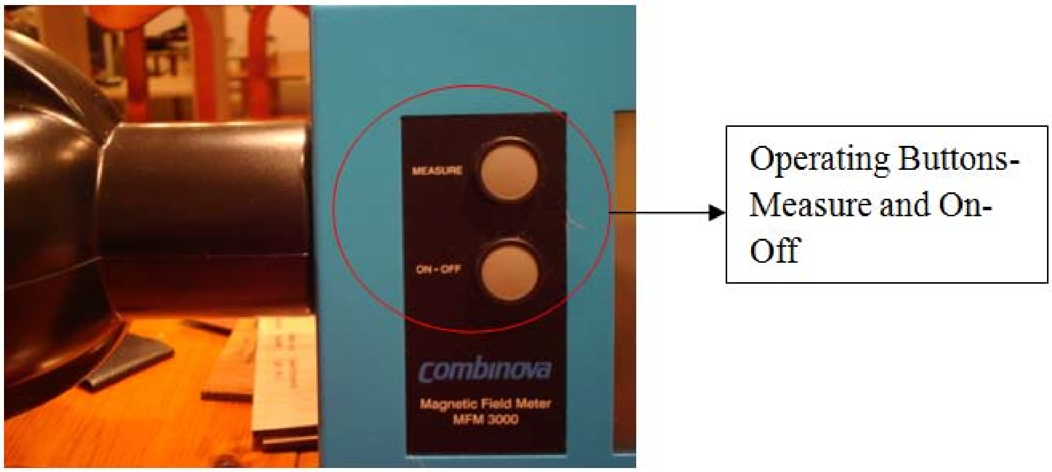


Figure 11. Picture showing Combinova MFM 3000 operating buttons.

The instrument has two push buttons (on–off and measure) as circled red in the above figure 11, to perform the operation. Once the on-off button is pressed the instrument starts and when the instrument is ready it displays "Init Ready". The screen has touch panel features so all the required adjustments can be made using the features on the screen, as shown in figure 12.

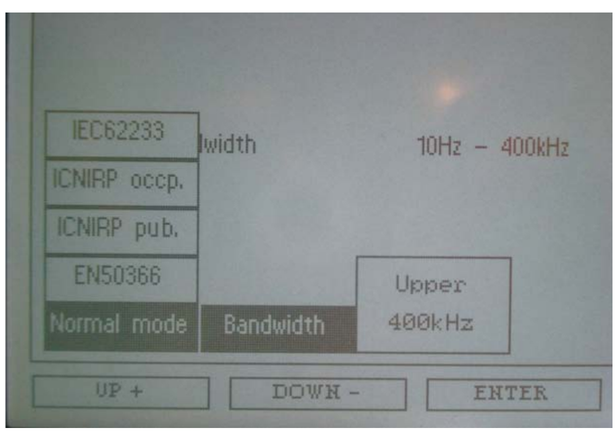


Figure 12. Touch screen panel of MFM 3000.

There are several modes of operation provided by the manufacturers. For the magnetic field measurement normal mode was selected from the measurement menu. This mode provides flat response throughout the full frequency range with very steep filters at the upper and lower frequency limit [14], which can be seen from figure 13.

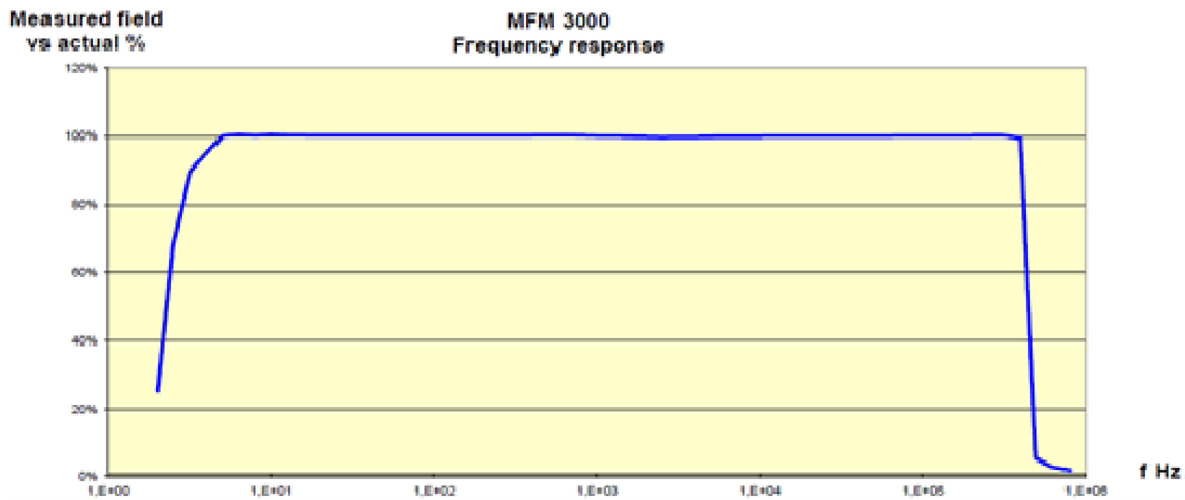


Figure 13. Frequency response for normal mode [14].

The upper and lower bandwidth can be set manually. Initially the lower frequency was considered as 5 Hz and the upper frequency to be 400 kHz but during THD measurement it was found that shaking of the instrument in the earth magnetic field gave rise to erroneous values. So the lower frequency was set to 10 Hz to get rid of erroneous signals. Once the frequencies are set the measurement can be made by placing the instrument at the required position and pressing the measure button. The values will be displayed on the screen and there is an option to save these values to retrieve later as DAT file. It should be taken care that before starting any measurement the instrument should be checked whether it is charged enough to withstand the duration of the measurement. Most of the measurements lasted about half an hour to 45 minutes.

3.2.1.1.2 Magnetic Field Logger ML-1

This instrument is quite simple and useful. This was used for 24 hour logging for houses that were not near to rail lines, the reasons for which are given in the section 3.2.4. Just like the MFM 3000 it contains two push buttons which can be seen from the figure 14, but it has no touch screen features only a small display screen.

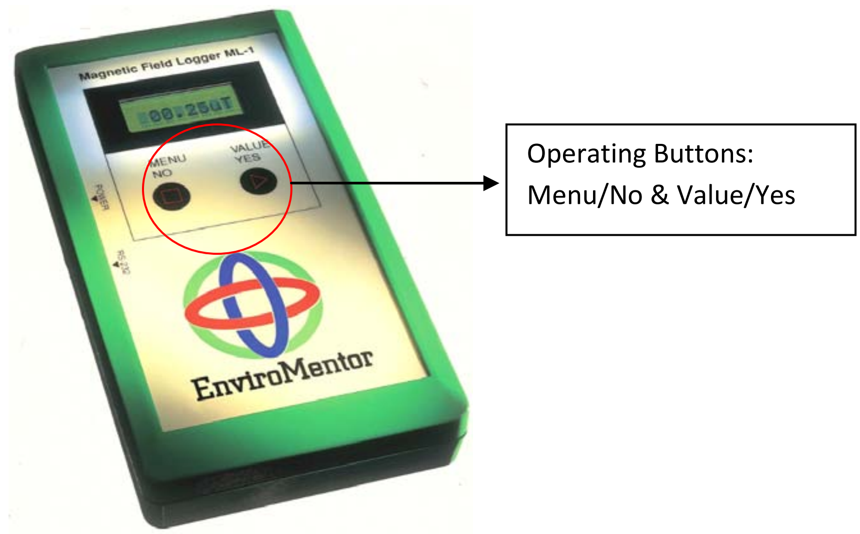


Figure 14. Figure shows the picture of Enviro Mentor ML-1

Before every measurement the readings from the instrument were dumped to the computer using the software. The instrument provides options to delete the earlier stored readings manually before starting the 24 hours logging. The intervals were chosen to be 40 seconds as it can last for more than a day. The batteries were changed after measuring two houses in a row.

3.2.1.1.3. (Magnetic Field Meter) MFM 10

This instrument is not as complex as MFM 3000. This instrument is used for 24-hour logging measurement near rail lines (more explanation shall be found in section 3.4.4). Diagrammatic representation of Combinova MFM 10 is shown in figure 15.

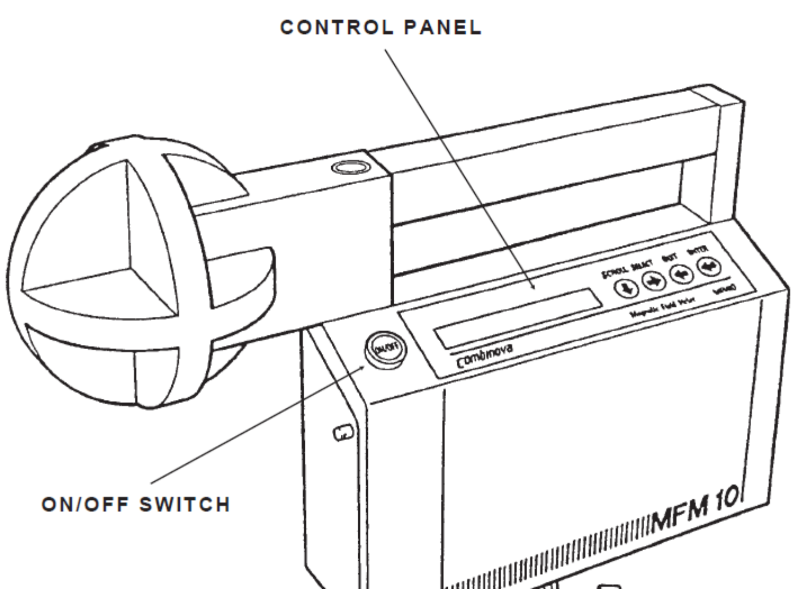


Figure 15. Figure shows the picture of Combinova MFM 10[15]

The instrument has several parameters to make use of but for the 24 hours measurement, two parameters have to be adjusted. The period parameter determines the length of each logging period. The instrument has certain values to choose from and by default it is set to 3600 seconds. For 24 hour logging the period was set to 360 seconds. The other parameter that has to be set was sample rate. This defines the number of samples to be taken in each logging period. By default it is set to 5 samples per second and this was followed throughout the measurement. These parameters should be set according to the requirements of what is to be measured. The higher the measurement rate then shorter the time the data logging can be used. When data logging mode is selected the time available will be shown in the display.

Once the instrument starts to log, the memory gets cleared and a new logging sequence starts. It is very important to keep the instrument to be still when taking the measurement to avoid the influence of Earths' magnetic field

3.2.3. 15 point measurement

For single point measurement MFM 3000 was preferred to others, because the frequency can be set manually and it not only shows the RMS value of the magnetic flux density at a point but also shows the amplitude of largest frequency component (L.S), second largest frequency component(2^{nd} L.S) and their respective frequencies. In every house three rooms were mandatorily measured; Bedroom, living room and kitchen. The measurements were done at different height level; ground, 80 cm from the ground and 160 cm from the ground. Single point measurement was done close to the four corners and centre of the chosen room.

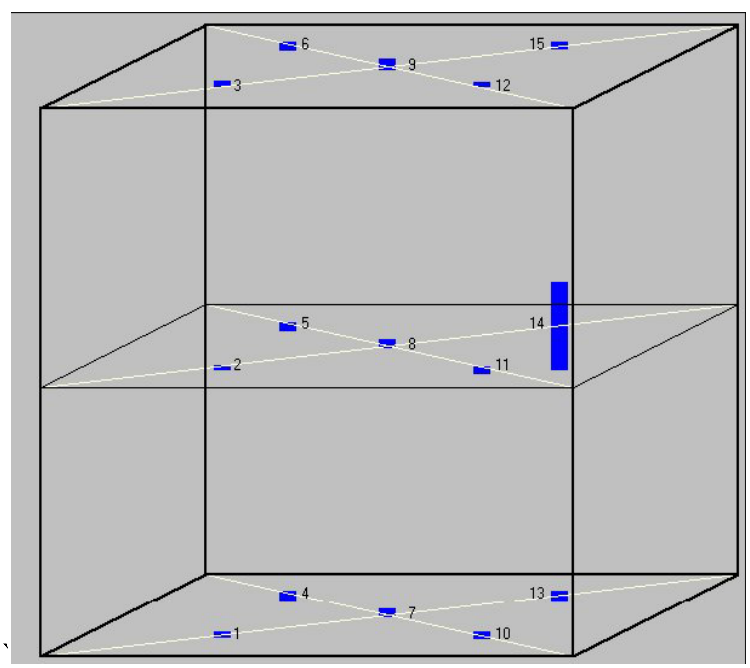


Figure 16. 15 point measurement positions [6]

The numbers from 1 to 15 in the figure 16 shows the position of the single point measurements in a particular room at different height level. MFM 3000 was placed at these points and measurements were done. The placement of the instrument was dependent on the situation of each room. It was not exactly placed at the corner all the times if the corner was blocked. The value obtained at each point was stored in the instruments memory for later retrieval. But as a backup the values were hand written on a hardcopy in case of emergency. Eventually it was useful as the data retrieved from the instrument was not in a format expected. The DAT file obtained from the instrument had values that were rounded off which made it difficult during the harmonic distortion calculation as the amplitude of largest frequency component (L.S) and RMS were the same, so the hand written hard copies were depended more. The following table, as shown in figure 17 was used to note down the values that were obtained using the MFM 3000.

UNIQUE CODE	TABLE FOR POINT MEASUREMENT: BEDROOM/LIVING ROOM/KITCHEN	DATE:

GROUND	A	B	C	D	E
L.S (µT)					
Freq (Hz)					
2^{nd} L.S(µT)					
Freq (Hz)					
RMS (µT)					
MIDDLE 80 cm					
L.S (µT)					
Freq (Hz)					
2^{nd} L.S(µT)					
Freq (Hz)					
RMS (µT)					
TOP 160 cm					
L.S (µT)					
Freq (Hz)					
2^{nd} L.S(µT)					
Freq (Hz)					
RMS (µT)					

Figure 17. Table to note down the obtained values.

Every participant was given a unique code so that their personal details remain anonymous. The unique code was entered at the left top corner, the room in which the measurement was performed is indicated after that, the date of measurement is also noted. In the table it can be seen that it is divided into three sections based on the height level. A, B, D, E is the four corners of a room respectively and C is the centre. Below the table a rough plot of the room was made to have a sketch of the room, in which the positions of the measurements taken are noted. Along with the measured values other details like the position of home appliances are also made note of. A sample of the room plot that were made during the measurement is shown in the below figure 18.

Plot over the room:

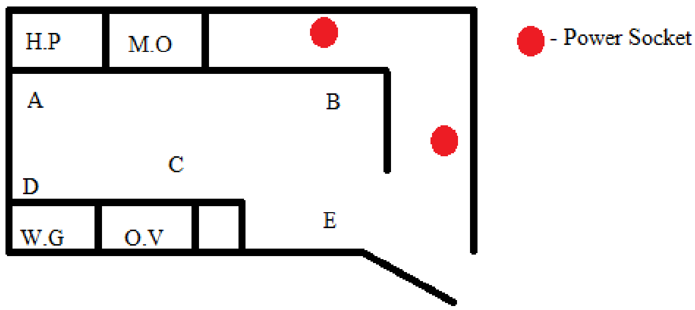
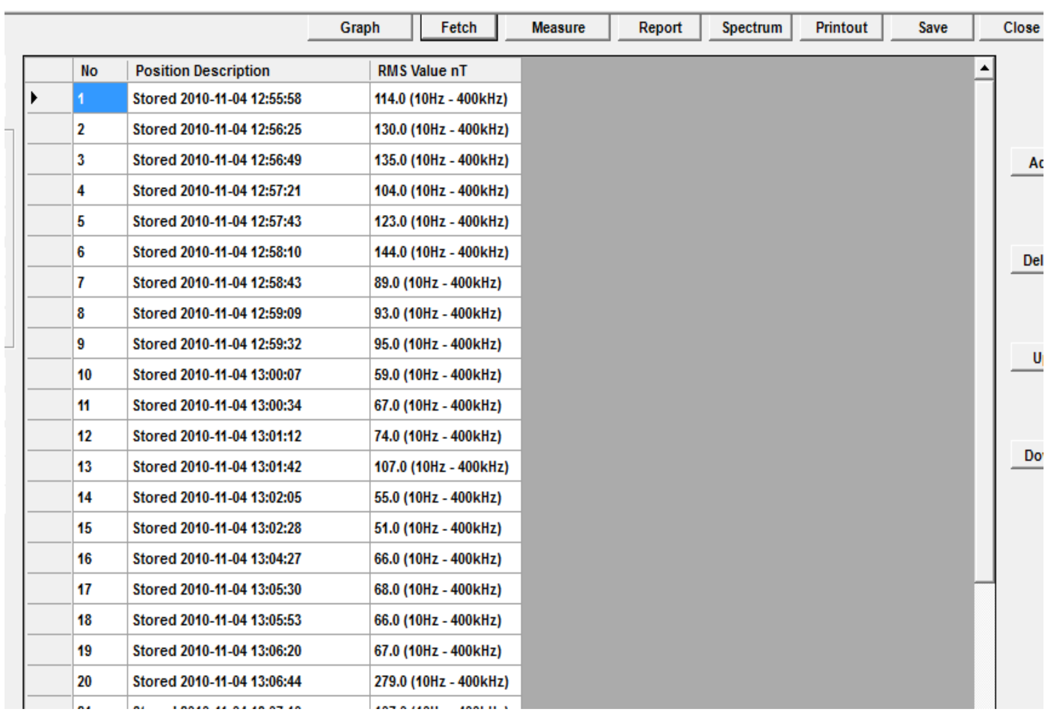


Figure 18. Example of plot over the room, abbreviations is explained on page 7.

This way of rough plots were of good use as it shows the position of the measurement and also where the magnetic field emitting devices were present during the time of measurement.

The data stored in the instrument can be transferred to a computer. With the help of the software provided by the instrument manufacturers the data can be analyzed. It is important to do the measurement in an order, for instance first the bedroom was done, followed by kitchen and the living room because it is hard to figure out which value is from which room as all the values are stored in one file with no means of separation. It can be better understood with figure 19 showing the values of the measurement at a house with the aid of MFM 3000 software.



No	Position Description	RMS Value nT
1	Stored 2010-11-04 12:55:58	114.0 (10Hz - 400kHz)
2	Stored 2010-11-04 12:56:25	130.0 (10Hz - 400kHz)
3	Stored 2010-11-04 12:56:49	135.0 (10Hz - 400kHz)
4	Stored 2010-11-04 12:57:21	104.0 (10Hz - 400kHz)
5	Stored 2010-11-04 12:57:43	123.0 (10Hz - 400kHz)
6	Stored 2010-11-04 12:58:10	144.0 (10Hz - 400kHz)
7	Stored 2010-11-04 12:58:43	89.0 (10Hz - 400kHz)
8	Stored 2010-11-04 12:59:09	93.0 (10Hz - 400kHz)
9	Stored 2010-11-04 12:59:32	95.0 (10Hz - 400kHz)
10	Stored 2010-11-04 13:00:07	59.0 (10Hz - 400kHz)
11	Stored 2010-11-04 13:00:34	67.0 (10Hz - 400kHz)
12	Stored 2010-11-04 13:01:12	74.0 (10Hz - 400kHz)
13	Stored 2010-11-04 13:01:42	107.0 (10Hz - 400kHz)
14	Stored 2010-11-04 13:02:05	55.0 (10Hz - 400kHz)
15	Stored 2010-11-04 13:02:28	51.0 (10Hz - 400kHz)
16	Stored 2010-11-04 13:04:27	66.0 (10Hz - 400kHz)
17	Stored 2010-11-04 13:05:30	68.0 (10Hz - 400kHz)
18	Stored 2010-11-04 13:05:53	66.0 (10Hz - 400kHz)
19	Stored 2010-11-04 13:06:20	67.0 (10Hz - 400kHz)
20	Stored 2010-11-04 13:06:44	279.0 (10Hz - 400kHz)

Figure 19. Magnetic flux density values shown with MFM 3000 software.

As said above the values are stored one after other, so it is not easy to differentiate one from the other, whereas with the hardcopy it is easy to verify the values at any time. But both the soft copy and hard copy were saved.

3.2.4. 24-hour logging measurement

For 24 hour logging two instruments were used depending on the location of the house. If the house was located near rail line or power lines were passing nearby Combinova MFM 10 was used. Combinova MFM 10 can measure extremely low frequencies especially frequency of 16.7 Hz (railway frequency). ML-1 was not preferred for these houses because it has a band pass filter that filters values less than 30 Hz, so Combinova MFM 10 was used for this purpose. For other houses, ML-1 logger instruments were used.

ML-1 was set to take readings for every 40 seconds, so it took about 1500 or more readings for 24 hours. The instrument was placed under the bed in the master bedroom. It should be noted that no electrical appliances or magnetic field emitting devices should be near the instrument as it can have considerable effect on the readings. The time is noted at the start of the reading and the instrument is left at the participants' house, the following day it is picked up after completion of 24 hours of measurement.

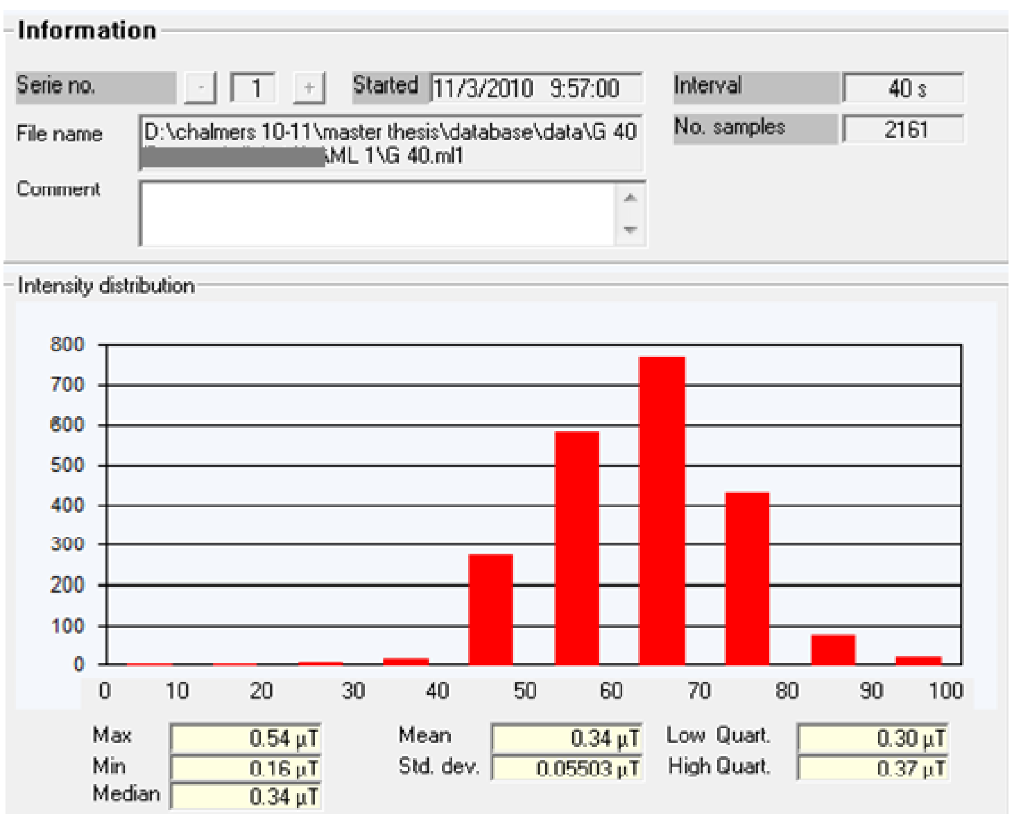


Figure 20. Diagram of 24 hour readings obtained using the ML-1software field analyzer.

Field analyzer is the software interface that helps to analyze the values obtained through ML-1. An effective software which provides all the necessary details from the measured data, like mean, median, std. dev, graphs and pictures. It can be easily understood with figure 20 showing the output of ML-1 logger. The values on x-axis in graph shows the number of samples and y-axis shows that the total MF measure is divided in 100 divisions and each division of range 10 provides the amount of MF strength.

As mentioned earlier, Combinova MFM 10 was decided to be used to for houses near railway lines. Combinova MFM 10 was set to measure for 24 hours or more and just like the ML-1 it was left at the participants' house for a day. It is also provided with software that can read the values from the instrument.

3.2.5. Calculations

The values obtained from the instruments were analyzed in a specific manner and this section shows how the analysis was performed. The details that were concentrated for this project to make the analysis can be seen from the Table 5. Each column from left to right in the table is explained in the following paragraphs.

Max of logging	Min of logging	Standard deviation of logging	Adjusted Average	Flat Average	THD	Frequency 2nd largest value	Fields highest on level	Bed room on floor	Apartment / building
RMS (µT)	RMS (µT)	(µT)	RMS (µT)	RMS (µT)	(%)	(Hz)	(level)	(floor)	(A or V)

Table 5. Summary Table for analysis.

3.2.5.1. Min, Max and standard deviation of logging

The Max and Min of 24 hours logging can be obtained directly from the ML-1 software, it is the RMS value expressed in µT, so also for standard deviation. In case of MFM-10 we obtained the text file of RMS values of MF for 24-hour and we modified that file and using matlab functions we calculated average MF, maximum and minimum MF values and standard deviation.

3.2.5.2. Adjusted Average

Depending upon the number of rooms that were considered for the measurement at a particular house adjusted average is calculated to represent the in home exposure of an "average" person. The following formulas were used to obtain the adjusted average

3 rooms: $B_{adjust} = B_{bed}*(9*B_{sleepR}+2*B_{kitchen}+4*B_{livingR})/(15*B_{sleepR})$ **Equation 3**

2 rooms: $B_{adjust} = B_{bed}*(13*B_{sleepR}+2*B_{kitchen})/(15*B_{sleepR})$. **Equation 4**

1 room: $B_{adjust} = B_{bed}$ **Equation 5**

B_{bed} = 24 h average from the measurement point at the bed.

B_{sleepR} = Room average for sleeping room.

$B_{kitchen}$ = Room average for kitchen

$B_{livingR}$ = Room average for living room

As said earlier, above formulas were chosen according to the number of rooms measured. Throughout the thesis work three rooms were measured mandatorily; Bedroom, Living room and Kitchen. B_{sleepR}, $B_{kitchen}$, $B_{livingR}$, were obtained from the average of 15 point measurement. It is assumed that a normal person spends at least 9 hours in bedroom, 2 hours in kitchen and 4 hours in living room.

3.2.5.3. Flat Average

Furthermore we were interested to obtain the Flat average of a house. We use the equation 3 and 4 depending upon the number of rooms but multiplying waiting factor 1 instead of 9, 2 and 4 in numerator and 3 instead of 15 in denominator.

3.2.5.4. Total Harmonic Distortion

We calculated THD as it is the expression of the distortion that gets added at the harmonics of the original frequencies when a signal passes through a non-ideal, non-linear device.

THD is expressed in two ways, power and amplitude ratio. According to the power ratio, considering the input a pure sine wave, the measurement is the ratio of the sum of the powers of all frequencies to the power of the fundamental frequency, whereas the amplitude ratio is the ratio of the square root of the squares of the RMS voltages. For this thesis work, power ratio definition was considered and it is expressed as shown in the equation 6.

$$THD = \frac{P_2 + P_3 + P_4 + \cdots P_\infty}{P1} = \frac{\sum_{n=2}^{\infty} P_n}{P_1}$$

Equation 6

The above expression (equation 6) can be re-written as

$$THD = \frac{P_{total} - P_1}{P_1} \%$$

Equation 7

Usually the THD is expressed in terms of percentage as a distortion factor or in dB as distortion attenuation. Here it is expressed in percentage. These equations were correlated with the readings that were obtained using MFM 3000.

Figure 21 shows a sample reading that MFM 3000 displays on its screen

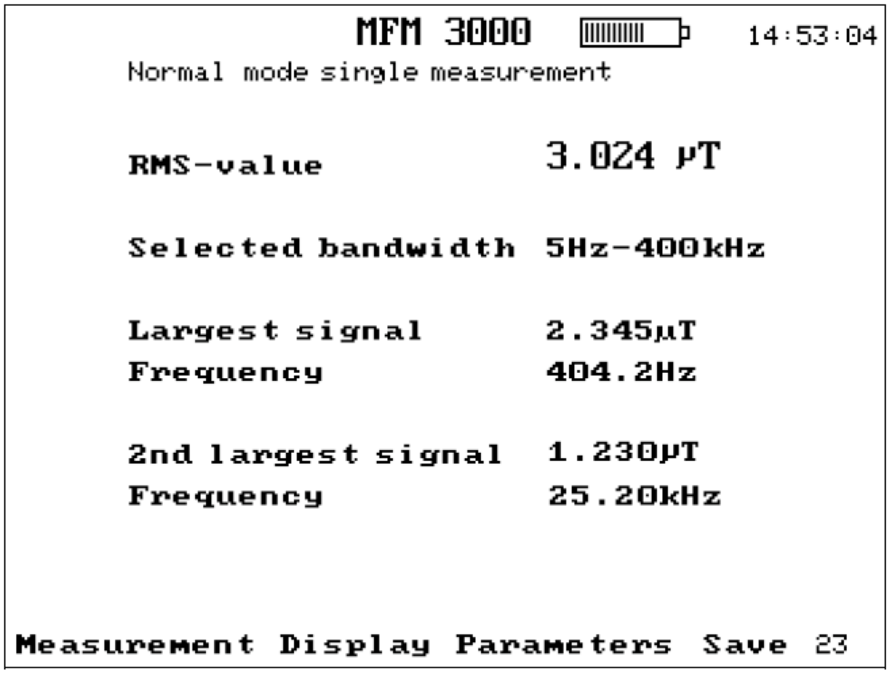


Figure 21. MFM 3000 sample reading.

The frequency of Largest Signal should be 50 Hz, but this picture is taken just as an example. The RMS value and largest signal obtained from MFM 3000 is proportional to the P_{Total} and P_1 of the THD expression (equation 6) so the THD for the readings of MFM 3000 can be written as

$$\boldsymbol{THD = \frac{((B_{RMS})^2 - (B_{LS})^2)}{(B_{LS})^2}}$$

Equation 8

B_{RMS} = Root mean square of the magnetic field

B_{LS} = largest signal measured

3.2.5.4.1. Considerations for calculating THD

Few considerations were made for the calculation of THD; this was made to avoid the errors that were present in the reading. The errors may have occurred because of some disturbances or noises that were present during the measurements of low values.

Case 1: **L.S>RMS**

THD was considered to be zero. Because in real scenario the L.S cannot be greater than the RMS, which is the combined square root value of L.S and 2nd L.S, but the RMS was considered for the calculation of RMS_{Avg}. For cases were the L.S was considerably greater than the RMS then both THD and RMS were not considered.

For the following cases the THD's were considered to be zero in order to calculate THD_{Avg}. But the corresponding RMS values were considered to calculate the RMS_{Avg}. For case4 "0" means that no frequency could be determined. It means that instrument is not able to decide any frequency so it gives us zero value.

Case2: **L.S = 0**

Case3: **L.S freq ≠ 50 Hz**

Case4: **2nd L.S freq ≠"0"[1], 16.7 or 150**

Case5: **L.S< 30 nT**

3.2.5.5. Frequency of second largest signal

It is not the only the largest signal frequency which has high significance but the frequency of the 2nd largest signal gives the most common value of the n measurements. So the frequency of the second largest signal were considered as well

For each house totally 45 single point measurements were taken and the average THD was given by dividing the sum of all the THD's to the total number of measurements made

$$THD_{Average} = \frac{(THD_1 + THD_2 + \cdots THD_n)}{n} \qquad \text{Equation 9}$$

THD_1= THD of the first measured point

[1] The instrument gives 2nd L. S. frequency "0" if the frequency cannot be determined.

n= last measurement point

Because of the FFT some frequencies were not exact, frequencies of 149, 151 Hz were considered as 150 Hz and frequencies of 16-18 Hz were considered to 16.7 Hz, which is the frequency from railways.

3.2.5.6. Fields on highest level

The measurements were made at three different levels (ground, middle and top) in each room of the house at each point. So in a room totally 15 readings were obtained, 5 for each level. By comparing the RMS values for each level the highest level was decided, like this it was followed for ever room. After deciding the highest levels for each room, they are in turn compared with each other. For instance if the bedroom and kitchen has highest RMS values in the middle level, then the whole house was considered to have highest magnetic field in the middle level even if the living room has highest RMS value in any of the other two level. But if each room has the highest values at various levels, then it was mentioned in the final result as "none". By doing this we were able to find out at which level the maximum exposure was present.

3.2.5.7. Bedroom on floor

Two systems of floor numbering are commonly in use, British and American convention.

Displacement from ground level	**British convention**	**American convention**
3 story heights above ground	"3rd floor"	"4th floor"
2 story heights above ground	"2nd floor"	"3rd floor"
1 story height above ground	"1st floor"	"2nd floor"
at ground level	"Ground floor"	"Ground floor or First Floor"

Table 6. British and American floor convention [7].

In the above table 6 it is clearly shown how the two systems vary, here the British system were followed.

3.2.5.8. Apartment or Building

The last column indicates whether the house measured was an apartment or villa. This information is important because exposure to MF varies because of the architecture of house. And wiring is done also different in both architectures. Cooling and heating system is centralized in apartments but in villa it is been built inside the house. These factors can effects the amount of MF in house.

4. Results

4.1. Results

The results from the point measurements and 24-hour logging measurements performed in 97 houses of Gothenburg, Borås and Mark are summarized in the Table 7.

House	Average of 24 h logging	Max of logging	Min of logging	Standard deviation of logging	Adjusted Average	Flat Average	THD 10 Hz filter	Frequency 2nd largest value	Fields highest on level	Bed room on floor	Residence A=Apart. V= Villa
Unique Code	RMS (µT)	RMS (µT)	RMS (µT)	(µT)	RMS (µT)	RMS (µT)	(%)	(Hz)	(level)	(floor)	(A or V)
B2	0.06	0.15	0.02	0.012	0.073	0.075	320	150	Top	1st	A
B10	0.04	0.14	0.01	0.013	0.045	0.05	18.81	-	Top	2nd	V
B11	0.03	0.08	0.01	0.006	0.03	0.03	-	-	Middle	2nd	V
B12	0.07	0.15	0.03	0.018	0.06	0.054	20.9	-	none	1st	A
B13	0.07	0.1	0.05	0.012	0.074	0.074	-	-	Middle	2nd	V
B14	0.07	0.1	0.05	0.012	0.06	0.05	218	-	Top	1st	V
B15	0.07	0.1	0.05	0.012	0.07	0.07	-	-	Middle	2nd	V
B18	0.04	0.27	0.01	0.024	0.04	0.035	10.9	-	Ground	4th	A
B17	1.64	5.45	0.46	0.724	1.505	1.13	240	150	none	1st	A
B19	0.02	0.02	0.01	0.004	0.3	0.038	4.16	-	Top	1st	A
B20	0.05	0.24	0.03	0.03	0.078	0.094	4.33	-	Middle	1st	V
B23	0.03	0.8	0.01	0.018	0.037	0.047	46.8	-	Ground	1st	V
B24	0.07	0.34	0.01	0.053	0.107	0.147	33.16	150	Ground	2nd	A
B25r	0.149	0.24	0.05	0.016	0.113	0.095	16.1	-	Top	1st	V
B26	0.22	0.25	0.07	0.01	0.2	0.19	-	-	none	2nd	V
B27	0.04	0.07	0.02	0.007	0.4	0.84	3.16	-	Ground	1st	V
B30	0.03	0.07	0.01	0.002	0.057	0.076	2.44	-	Ground	1st	V
B31	0.08	0.22	0.02	0.028	0.073	0.071	4.57	-	Ground	2nd	A
B32	0.05	0.27	0.01	0.048	0.048	0.047	372	-	Top	2nd	V

House	Average of 24 h logging	Max of logging	Min of logging	Standard deviation of logging	Adjusted Average	Flat Average	THD10 Hz Filter	Frequency 2nd largest value	Fields highest on level	Bed room on floor	Residence A=Apartm .V= Villa
B34r	0.29	1	0.05	0.194	0.525	0.073	10.8	150	Ground	1st	A
B35	0.03	0.06	0	0.005	0.081	0.15	0.428	-	none	1st	V
B36r	0.05	0.21	0.017	0.021	0.057	0.06	77	150	Ground	1st	V
B37r	0.22	0.25	0.01	0.011	0.168	0.136	41.1	-	Ground	1st	A
B39r	0.07	0.19	0.07	0.028	0.082	0.088	1.77	-	Ground	2nd	A
B40	0.02	0.04	0.01	0.003	0.015	0.012	10.6	-	Top	1st	V
B41r	0.05	0.12	0.05	0.014	0.054	0.061	6.83	-	Ground	3rd	V
B42	0.03	0.1	0.01	0.009	0.035	0.047	10.05	-	Ground	1st	V
B44	0.06	0.2	0.01	0.025	0.075	0.086	1.15	-	Ground	1st	V
B48	0.04	0.07	0.02	0.007	0.04	0.04	21.07	-	Ground	1st	V
B5	0.04	0.08	0	0.008	0.038	0.038	-	-	Top	1st	V
B52	0.03	2.23	0.01	0.044	0.03	0.03	20.9	-	none	1st	V
B53	0.02	0.06	0.01	0.006	0.025	0.032	22.6	-	none	2nd	V
B54	0.00008	0.02	0	0.0009	0.00007	0.00007	1.53	-	Ground	1st	V
B57	0.03	0.06	0.01	0.005	0.044	0.05	7.9	-	Middle	1st	V
B58r	0.22	0.25	0.01	0.011	0.011	0.023	6.85	-	none	1st	V
B59r	0.003	0.07	0	0.003	0.08	0.19	3.62	-	Top	1st	V
B6	0.04	0.12	0.02	0.013	0.046	0.05	19.3	-	Middle	2nd	V
B60	0.03	0.08	0	0.007	0.073	0.13	2.34	-	Top	1st	V
B61r	0.02	0.064	0	0.011	0.037	0.048	38.57	150	Ground	2nd	V
B7	0.07	0.1	0.05	0.012	0.065	0.061	-	150	Top	2nd	V
B8	0.07	0.1	0.05	0.012	0.082	0.098	-	150	Middle	1st	A
G10	0.07	0.24	0.03	0.035	0.068	0.067	64.48	150	Middle	10th	A
G11	0.03	0.07	0.01	0.005	0.032	0.033	-	-	Middle	2nd	V
G12	0.07	0.17	0.03	0.018	0.071	0.072	272	150	Middle	3rd	V
G13	0.03	0.08	0.02	0.006	0.033	0.035	-	-	Ground	4th	A
G14	0.05	0.18	0.02	0.017	0.061	0.07	2.38	150	Ground	7th	A

House	Average of 24 h logging	Max of logging	Min of logging	Standard deviation of logging	Adjusted Average	Flat Average	THD 10 Hz filter	Frequency 2nd largest value	Fields highest on level	Bed room on floor	Residence A=Apartm .V= Villa
G15	0.43	1.07	0.09	0.172	0.405	0.22	21.7	150	none	1st	A
G17	0.06	0.21	0.02	0.038	0.053	0.046	-	-	Middle	2nd	V
G18	0.04	0.11	0.02	0.01	0.041	0.042	-	150	Middle	2nd	V
G2	0.04	0.1	0.01	0.011	0.057	0.052	363	150	Middle	2nd	V
G20	0.05	0.08	0.03	0.005	0.036	0.027	-	-	Middle	3rd	A
G21	0.04	0.14	0.02	0.018	0.041	0.043	-	150	Top	4th	A
G22	0.18	0.34	0.06	0.052	0.162	0.15	97	50	Ground	1st	A
G24	0.04	0.07	0.01	0.007	0.043	0.047	-	-	Top	2nd	V
G25	0.06	0.24	0.02	0.026	0.058	0.05	141	-	Middle	2nd	A
G26	0.06	0.13	0	0.027	0.058	0.05	54.8	150	Middle	3rd	A
G27	0.28	0.33	0.16	0.016	0.264	0.27	-	-	Ground	1st	V
G29	0.03	0.08	0.01	0.005	0.272	0.024	-	-	none	2nd	V
G3	0.04	0.12	0.02	0.013	0.06	0.08	-	150	Middle	1st	A
G30	0.02	0.07	0	0.005	0.017	0.016	-	-	Top	1st	V
G31	0.03	0.07	0.01	0.002	0.031	0.032	9.475	-	Middle	3rd	V
G32	0.03	0.07	0.01	0.002	0.026	0.025	-	-	Middle	1st	V
G33	0.2	0.8	0.04	0.114	0.157	0.121	26.86	150	Ground	3rd	A
G34	0.04	0.12	0.02	0.011	0.136	0.064	2.6	-	Ground	3rd	V
G35	0.03	0.07	0.01	0.003	0.03	0.027	87.95	-	none	1st	V
G36	0.03	0.14	0	0.007	0.03	0.018	-	99	Middle	3rd	A
G37	0.03	0.09	0.01	0.005	0.021	0.016	6.513	-	Ground	2nd	V
G38	0.09	0.21	0.03	0.033	0.096	0.101	25.3	150	none	2nd	A
G39	0.09	0.4	0.02	0.045	0.09	0.101	12.8	150	Ground	2nd	V
G4	0.06	0.13	0.01	0.024	0.083	0.078	283	-	Middle	5th	A
G40	0.34	0.54	0.16	0.055	0.316	0.3	28.6	150	Middle	1st	V
G41	0.11	0.39	0.02	0.07	0.152	0.18	64.49	150	Ground	2nd	A
G42	0.08	0.4	0.08	0.057	0.095	0.131	4.654	-	Ground	1st	V

House	Average of 24 h logging	Max of logging	Min of logging	Standard deviation of logging	Adjusted Average	Flat Average	THD 10 Hz filter	Frequency 2nd largest value	Fields highest on level	Bed room on floor	Residence A=Apartm V= Villa
G43	0.03	0.1	0.01	0.005	0.038	0.053	5.076	-	Middle	1st	V
G44	0.51	1.21	0.08	0.203	0.391	0.323	257.2	15	Ground	1st	A
G46	0.22	0.31	0.1	0.057	0.221	0.22	0.771	-	Ground	1st	V
G49	0.02	0.08	0	0.005	0.02	0.02	3.795	-	Top	2nd	V
G50	0.03	0.07	0.01	0.002	0.021	0.016	4.07	-	none	2nd	V
G51	0.03	0.08	0.01	0.002	0.025	0.024	21.35	-	Ground	1st	V
G52	0.09	0.68	0.04	0.053	0.071	0.06	29.7	150	none	4th	A
G7	0.03	0.08	0	0.008	0.054	0.09	-	-	Middle	1st	V
M1	0.05	0.19	0	0.031	0.052	0.052	440	150	Ground	2nd	V
M10r	0.005	0.03	0	0.003	0.007	0.008	5.66	-	none	1st	V
M12	0.03	0.07	0.02	0.007	0.05	0.06	4.34	50	Ground	2nd	V
M14	0.03	0.07	0.01	0.002	0.042	0.042	438	-	Ground	1st	V
M15	0.03	0.07	0.01	0.004	0.03	0.03	-	150	none	1st	V
M16	0.06	0.18	0	0.031	0.052	0.03	9.69	-	none	1st	V
M17	0.03	0.19	0.01	0.006	0.03	0.03	114	-	none	1st	V
M18r	0.01	0.25	0.01	0.01	0.01	0.001	21.76	-	Ground	1st	V
M19r	0.08	1.5	0.08	0.136	1.81	1.93	3.057	-	Ground	2nd	V
M2	0.03	0.07	0.02	0.004	0.02	0.02	-	-	Middle	2nd	V
M21	0.02	0.07	0	0.005	0.021	0.022	0	-	none	1st	V
M3	0.02	0.04	0.01	0.004	0.021	0.024	4.84	-	Ground	2nd	V
M7	0.06	0.16	0.01	0.027	0.053	0.05	243	-	Middle	1st	V
M8	0.04	0.13	0.01	0.015	0.05	0.06	-	0	Ground	2nd	V
M9	0.05	0.15	0	0.016	0.058	0.06	198	0	none	1st	V
M4	0.03	0.07	0.01	0.003	0.026	0.025	25.1	0	Top	2nd	V

Table 7. Summary Table of Results.

In the first column of Table 7 the unique code of all the subject houses is given. The codes with alphabet “r” represent the houses in the vicinity of railway lines e.g. M18r. In second column the value of average magnetic field from 24 hour logging data is given, which is performed in bedroom. The 24 hour logging is done in bed room because the persons in houses spend most of their time either sleeping or watching T.V in their bedroom. So they might be exposed to MF sources most of time while staying in their bedroom.

Third and fourth column in table contains the maximum and minimum MF value from the series of values calculated during 24 hour logging measurements in bedroom. Fifth column contains standard deviation of 24 hour logging data. This shows that how much MF values deviates from its mean value. The first four columns are related to the results from bedroom of the houses. While observing the values in first four columns we can see that most of the houses have average MF below 0.2 μT. And maximum RMS value is 1.64 μT which belongs to House B17. The Further discussion about 24-hour logging is done below with more facts and figures.

Column six contains the average adjusted value of magnetic field B_{Adjust}. Which is been calculated using equation 3. All the houses contain three rooms for which we use equation 3 to calculate B_{Adjust} except some of the houses like M16, in which living room was used as bedroom. So for houses like M16 with two rooms, we use equation 4 to calculate B_{Adjust}. B_{Adjust} provides the exposure of average person in a house to MF. Column seven contains the flat average calculated at each house using equation 3 and 4, except using 1 as a weighting factor multiplied in numerator and 3 with denominator. Flat average provides the average exposure of the house to MF.

In column eight the value of Total Harmonic Distortion is given. Which is calculated using equation 8 for each point measurement in the room and then we took the average of those 45 points from three rooms in the house. The dash instead of numerical value of THD is used because the houses which were measured before using 10 Hz filter shows non considerable values of THD. More detailed results and discussion over THD is provided in further section of report.

Column nine contains the respective frequency of second highest/largest value of magnetic flux. Most of the time frequency of second largest signal was non recognizable by instrument, which is been shown by dash in table above. Tenth column contains the information that at which level in a house the amount of exposure to MF is maximum. Most of the houses have MF highest at Ground level. The reason for this is discuss further below.

Column eleven shows that the bedroom is located on which floor in a particular house. It is important to know this information because bedroom is the place in which subject spends its most of time while staying at home. In column twelve it is mentioned that either a particular house is apartment or villa. We will use all this information from Table 7 in order to provide results of our research study further below.

4.1.2. 24-hour MF Exposure

MF is found wherever electricity is generated, delivered or used. Power lines, wiring in homes, workplace equipment, computers, appliances and motors all produce MF. Our exposure to MF varies throughout the day depending on the sources of fields we encounter and how close we are to them. For example, Figure 22 below illustrates a person's exposure to magnetic fields over a 24-hour period in a bedroom. As you can see, the person was briefly exposed to low magnetic field levels on numerous occasions. All of these instantaneous exposures over the 24-hour period are averaged together to produce a time-weighted average. In this example, the person's 24-hour time-weighted average is 0.02µT. The median value is also 0.02 µT. And maximum value of MF is 0.04 µT. This only appears at small time instant as we can see in figure 22.

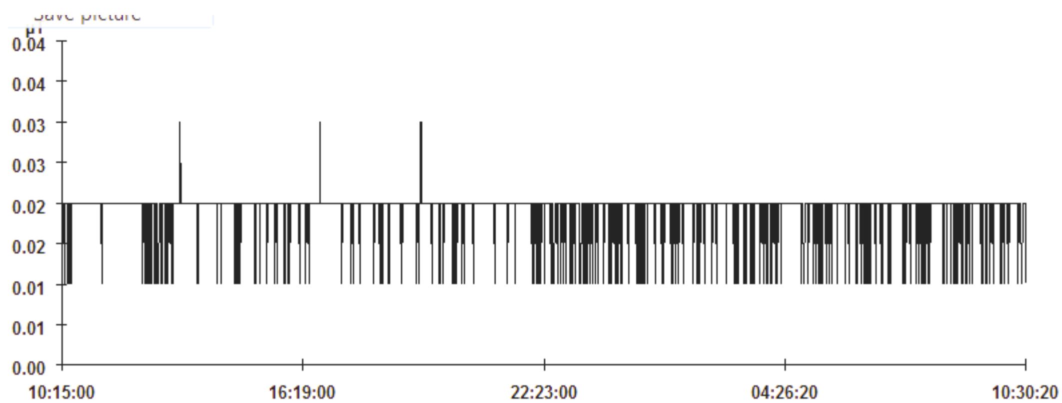


Figure 22. 24-hour Logging of MF from ML-1.

If we observe from the Table 6, we can see that most of the houses have average MF B_{bed} for 24-hour period around 0.05 µT or below. But in some cases we get higher MF values e.g house B17, which has average value of B_{bed} = 1.64 µT and median is 1.46 µT. MF over a 24-hour period for B17 is shown in Figure 23. The Figure 24 shows the bar graph of 24-hour logging data, and brief picture of all results including Mean, Median, Maximum/Minimum and Standard deviation values of 24-hour logging.

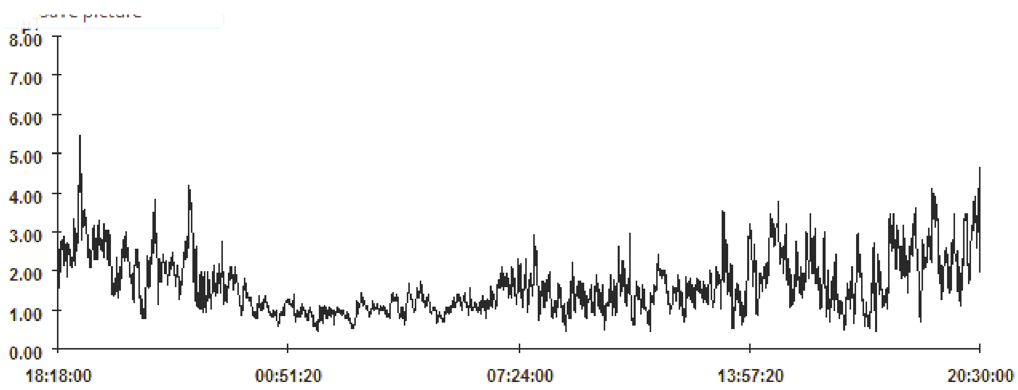


Figure 23. 24-hour Logging of MF from ML-1.

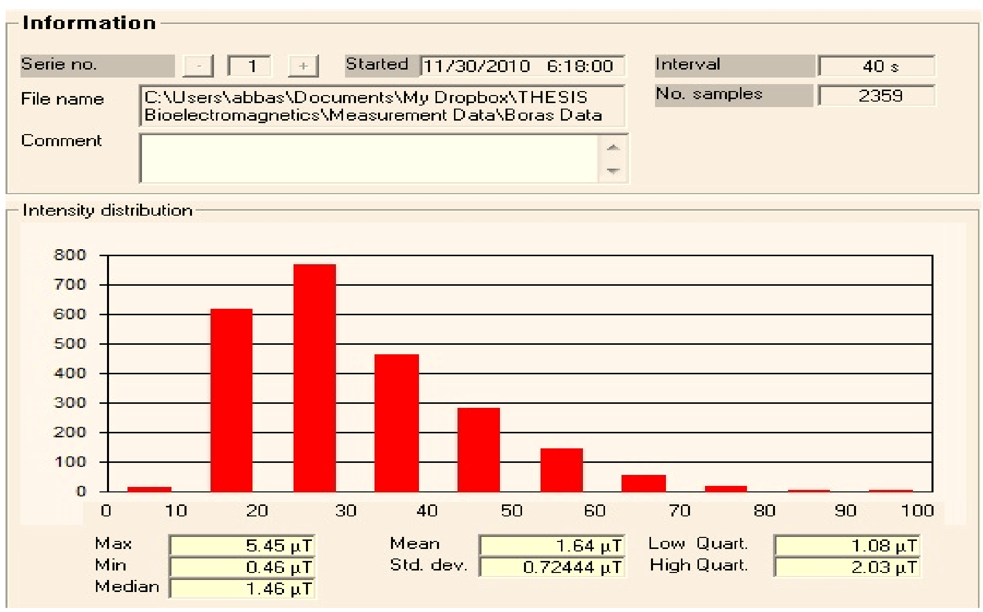


Figure 24. 24-hour Logging of MF from ML-1.

In house B32 we got high exposure to MF in bedroom during 24 hours. Figure 25 shows variation of magnetic field levels on many occasions during entire period of 24-hour logging. The reason of this variation of MF level in house was an underground heating system. Figure 26 explains the results from 24 hour logging in shape of bar graph.

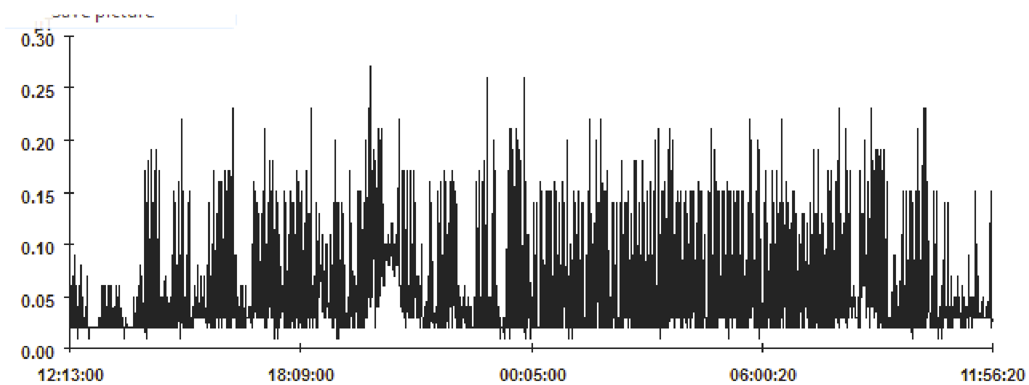


Figure 25. 24-hour Logging of MF from ML-1.

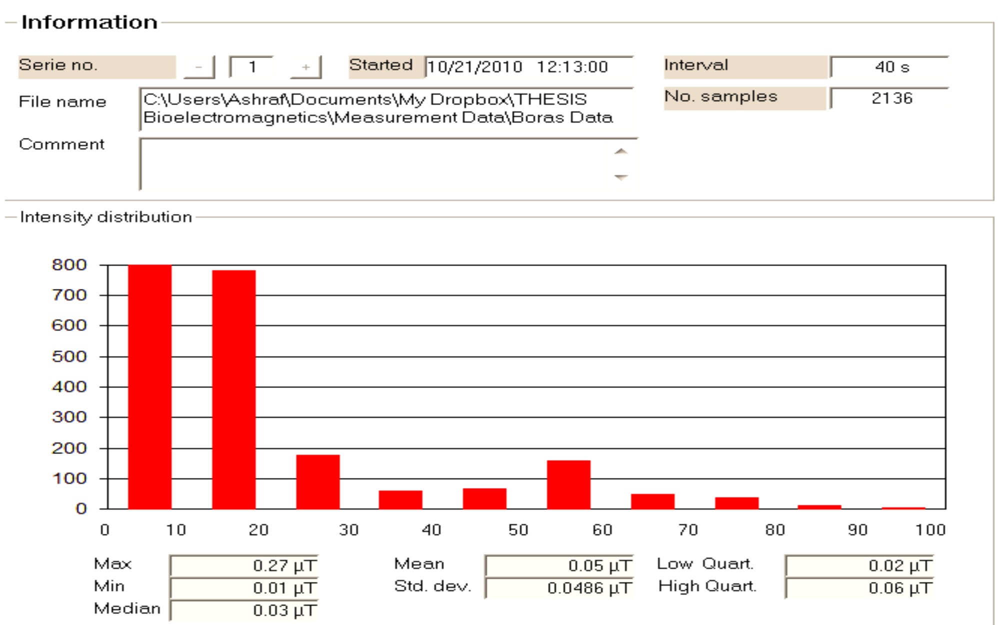


Figure 26. 24-hour Logging Result from ML-1.

The MF exposures in bedroom of houses which are close to railway line are discussed in this section. The 24-hour logging was performed with MFM10, because the house is close to railway track. For example the house G44r, it has high RMS value of MF B_{Bed}, which is around 0.51 µT. The maximum value of 24-hour logging in G44r is 1.21 µT. Median value of RMS values is 0.45 µT. The graph for 24-hour logging data is shown in figure 27. We can see that there are quite high values of MF during 24-hour period. The MF shows periodicity in figure 27. The reason for this might be the passing of train after every certain period of time, which give rise to the MF inside house.

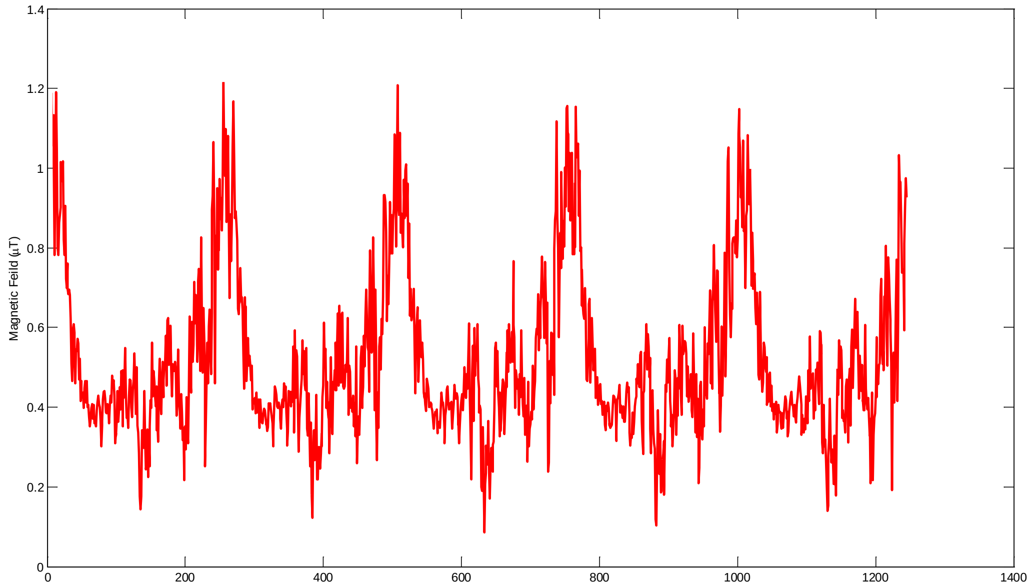


Figure 27. 24-hour Logging data from G44r.

Among the houses close to railway line the minimum value of MF (B_{bed}) is 0.003 µT which belongs to house B59r. Median value is 0.004 µT. And the pattern of MF for 24-hour period is shown in figure 28.

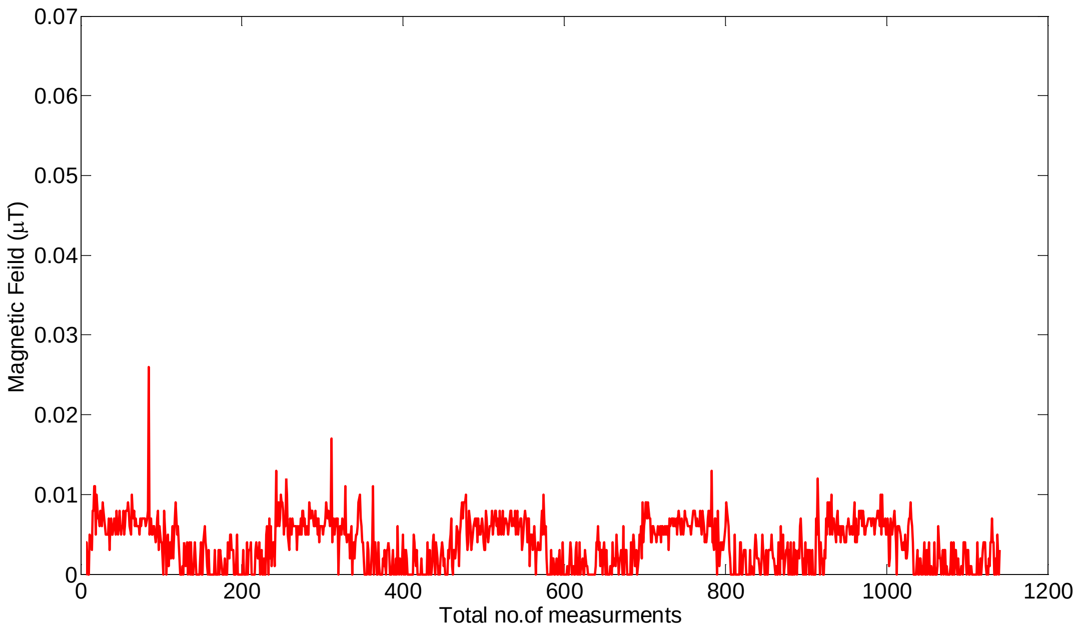


Figure 28. 24-hour Logging data from G44r.

The results that we achieved after observing 24-hour logging data inside bedroom for 97 houses, is shown in figure 29, we find out that in 90% of the houses the B_{Bed} (average RMS at bedroom) is below 0.2 µT. The mean of B_{bed} from all the houses is 0.08 µT and median value is 0.04 µT. This value is well below the ICNIRP reference level.

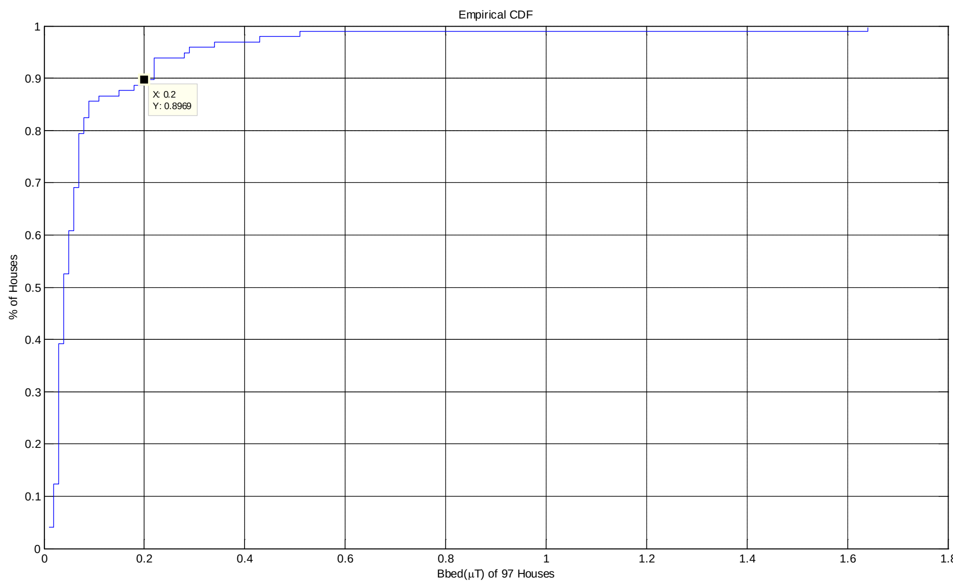


Figure 29. CDF curve of B_{Bed} 24-hour Logging Data in 97 Houses.

4.1.3. Average Adjusted MF

Further analysis involved combining measurements from three rooms into a time-weighted average, to estimate overall residential exposure. The average adjusted value of MF (B_{Adjust}) is an average MF level in up to three rooms in each house. This value provides us information person exposure to MF.

The CDF curve of adjusted average value of MF in 97 houses has been plotted in matlab. And it is shown in Figure 30. We can observe from the plot that average adjusted MF is below 0.2 µT in almost 90% of the houses. Around 7% of the houses have B_{Adjust} between the range of 0.2-0.4 µT. The mean value of B_{Adjust} is 0.11 µT and median value is 0.05 µT.

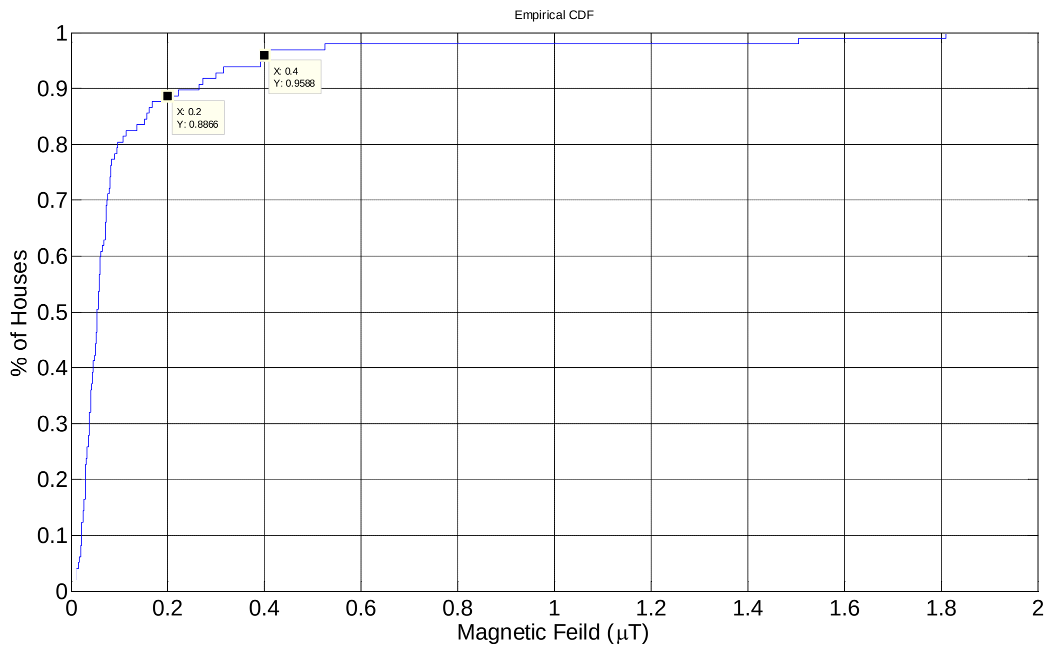


Figure 30. CDF curve of MF (BAdjust) in 97 Houses.

According to ICNIRP guidelines the median value 0.05 μT of B_{Adjust} (Adjusted average) is quite reasonable for human exposure. And it is obvious from the graph in figure 28 that all houses are well below ICNIRP exposure level limits.

4.1.3.1. Comparison of B_{Adjust} in Different regions

The houses from different regions are grouped in to three different parts, Göteborg, Borås and Others. Others group contains all the houses which are not in Göteborg and Borås district e.g like Kinna, Rydboholm etc. The idea is to know how much each area has exposure of average person to MF. Comparison is made by doing analysis over the plot of CDF curve of B_{Adjust} values. The graphs of three different regions are shown in figure 31, 32 and 33.

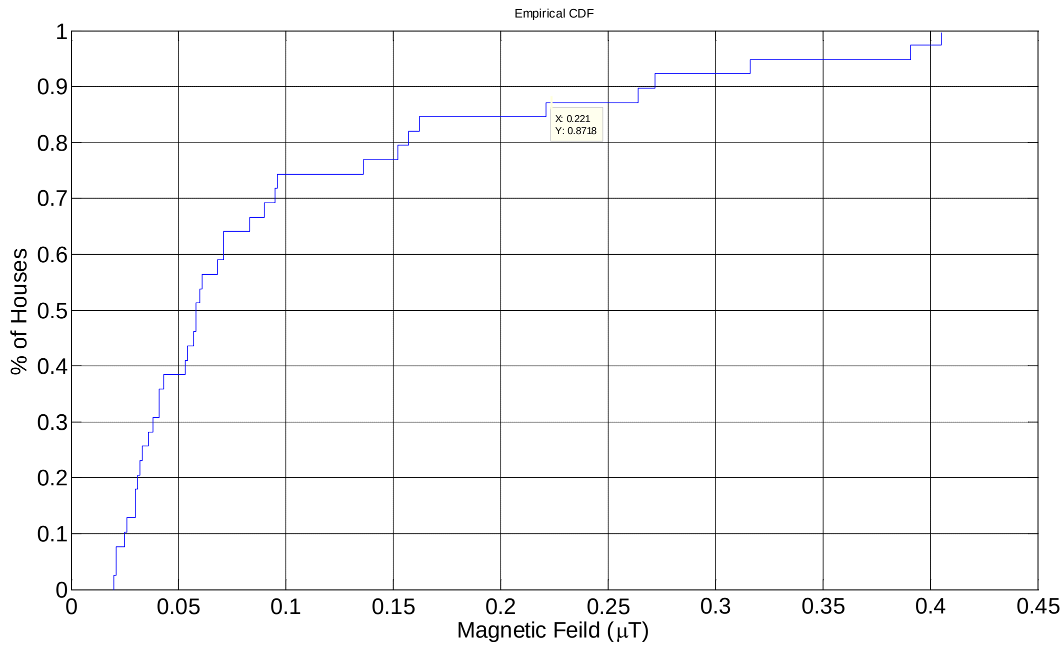


Figure31. CDF curve of Average Adjusted MF of houses in Göteborg.

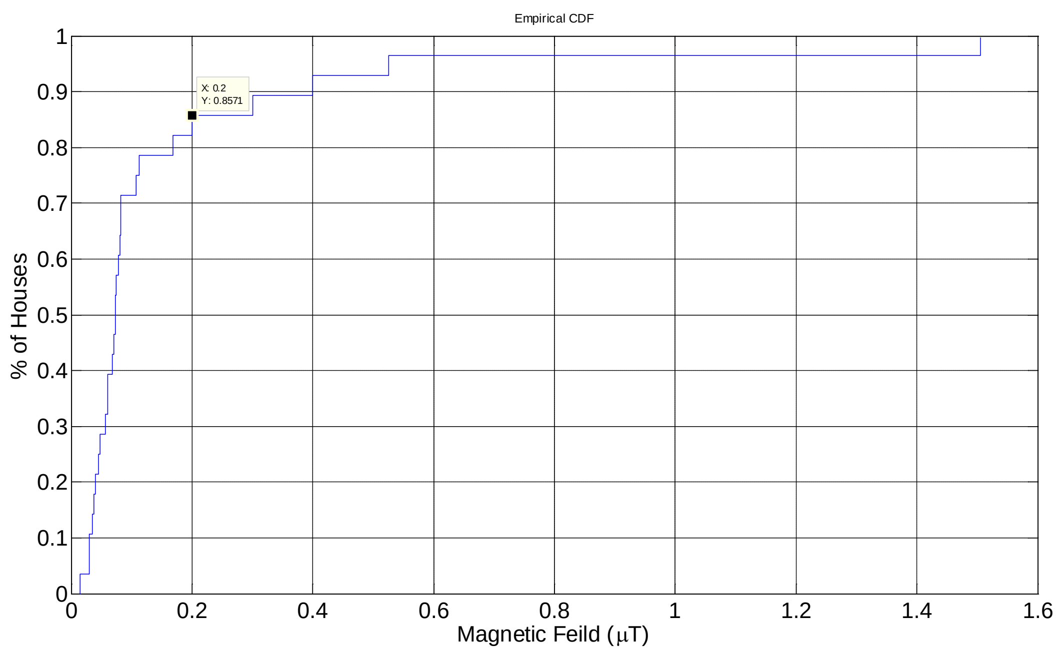


Figure 32. CDF curve of Average Adjusted MF of houses in Borås.

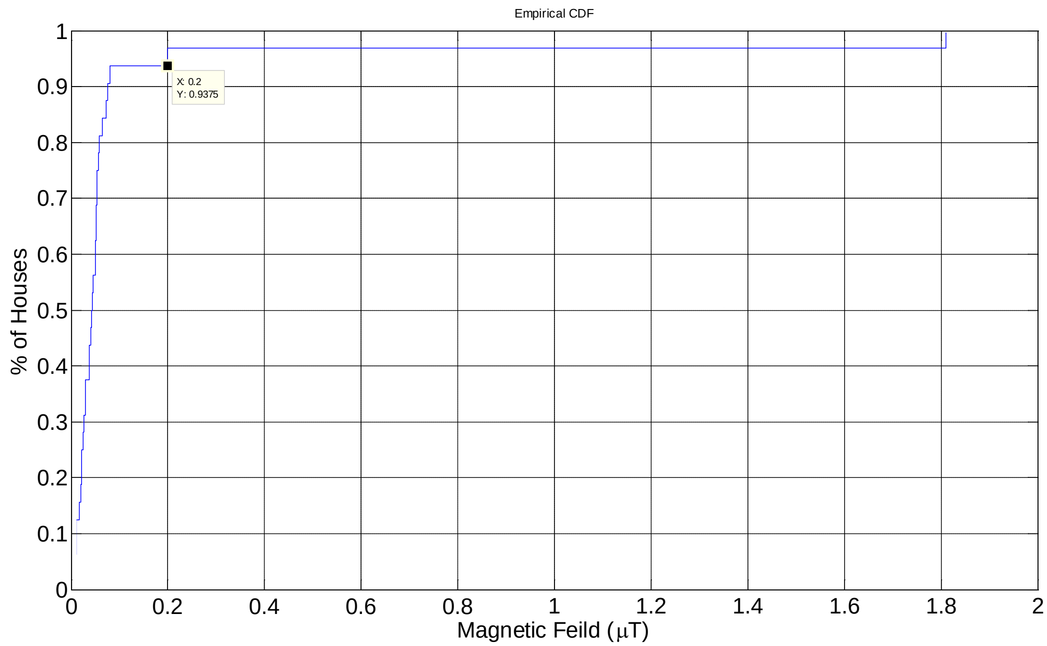


Figure 33. CDF curve of Average Adjusted MF of houses in Other Districts.

Properties	Göteborg	Borås	Others
No of Houses	38	27	31
% of Houses < 0.2μT	87	85	93
Median	0.05 μT	0.07 μT	0.04 μT
Mean	0.10 μT	0.15 μT	0.09 μT

Table 8. Comparison Table for Three Districts.

The summary of results is provided in the Table 8. We can observe that 93% of the houses in other areas have B_{Adjust} below 0.2 μT. The reason might be that these areas are not very congested as compare to other two, so they more come into countryside of Sweden. The houses which are in country side have very low MF level, if there is no unusual heating or electric power facility in the basements. Comparatively the houses in urban areas or the houses close to railway lines have higher MF level.

4.1.4. Flat Average of MF

Flat Average as explained in previous sections, is average exposure of a house to MF. The CDF curve of flat average values of MF in 97 houses has been plotted in matlab, and shown in Figure 30. We can observe from the plot that flat average MF is below 0.2 µT in almost 91% of the houses. Around 5% of the houses have flat average between range of 0.2-0.4 µT. The mean value of flat average is 0.1 µT and median value is 0.05 µT.

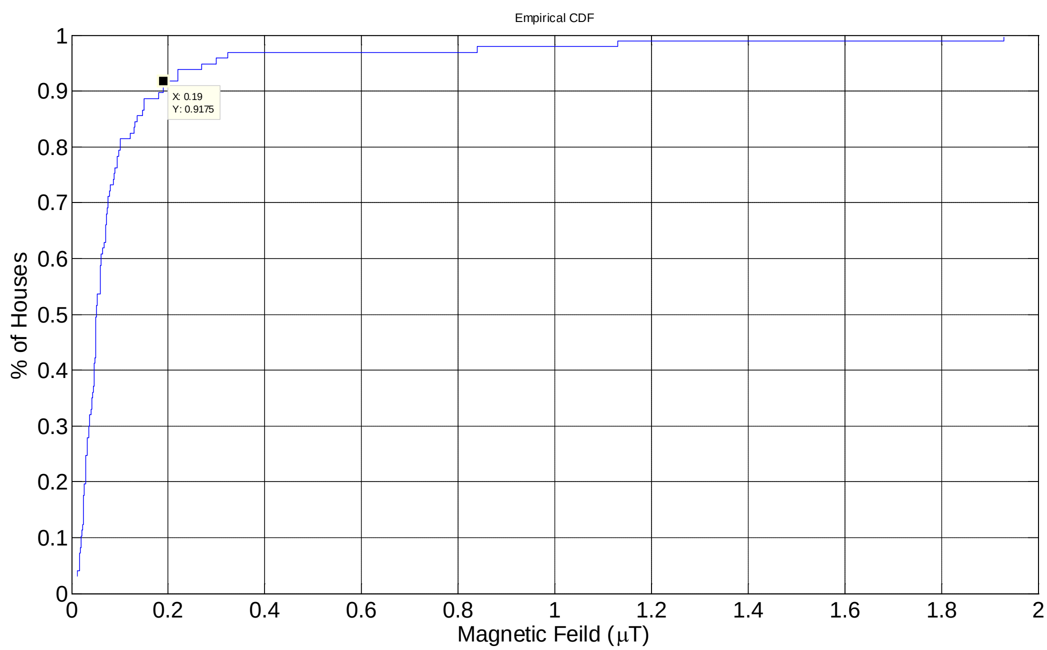


Figure 234. CDF curve of flat average in 97 houses.

4.1.5. Total Harmonic Distortion

There are several reasons for presence of total harmonic distortion in the magnetic field. THD may arise because of background noise during measurement and it is also possible because of shaking of instrument during performing measurements. The value of THD indicates the amount of non-linear loads in the house.

In the beginning we decided to have frequency band from 5 Hz to 400 kHz for MFM 3000. The measurements which were performed with this setting were showing quite high THD values. That was not a promising result.

But later after looking at the results we observed really high THD values, more than 100 %. We figure out that this might be because of background noise or shaking of instrument during taking measurements. So after consulting Combinova Tech, we decided to narrow the frequency band to start at 10 Hz, so that we can get rid of signals from measurements due to movement in the earth static field. After this adjustment we did get more percentage of houses having value of THD < 20 % as we can see in the Table 7. The figure 36 shows the CDF curve of THD against the houses which were measured after adjustment of frequency range 10 Hz-400 kHz. We can see that around 63% of the houses have THD < 20 % and 85 % of houses have THD < 46 %. The median value of THD turns out to be 10.3 %. Figure 35 shows the THD value for each house measured at 10 Hz filter.

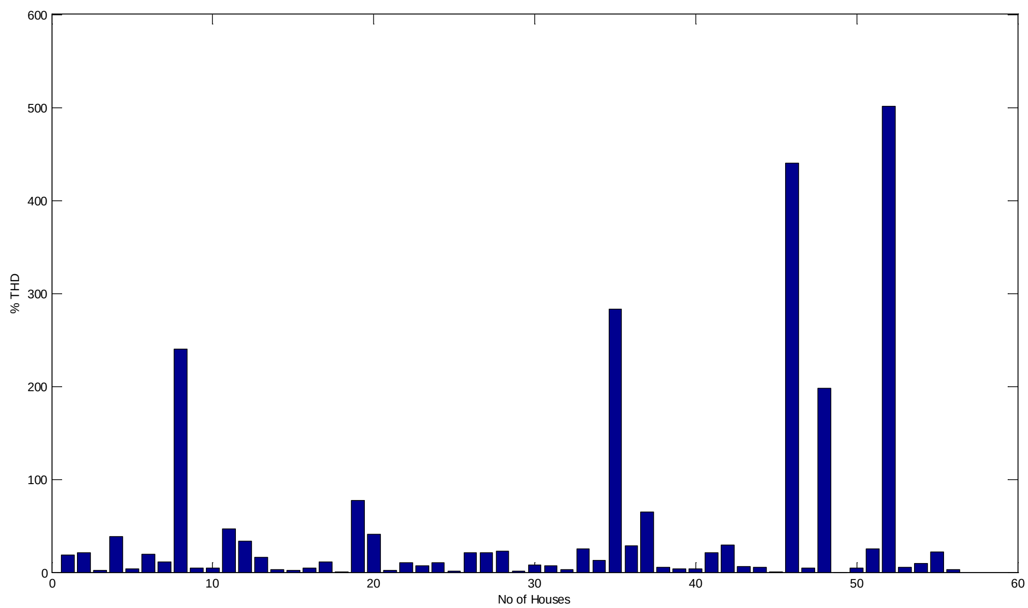


Figure35. Average THD for each house.

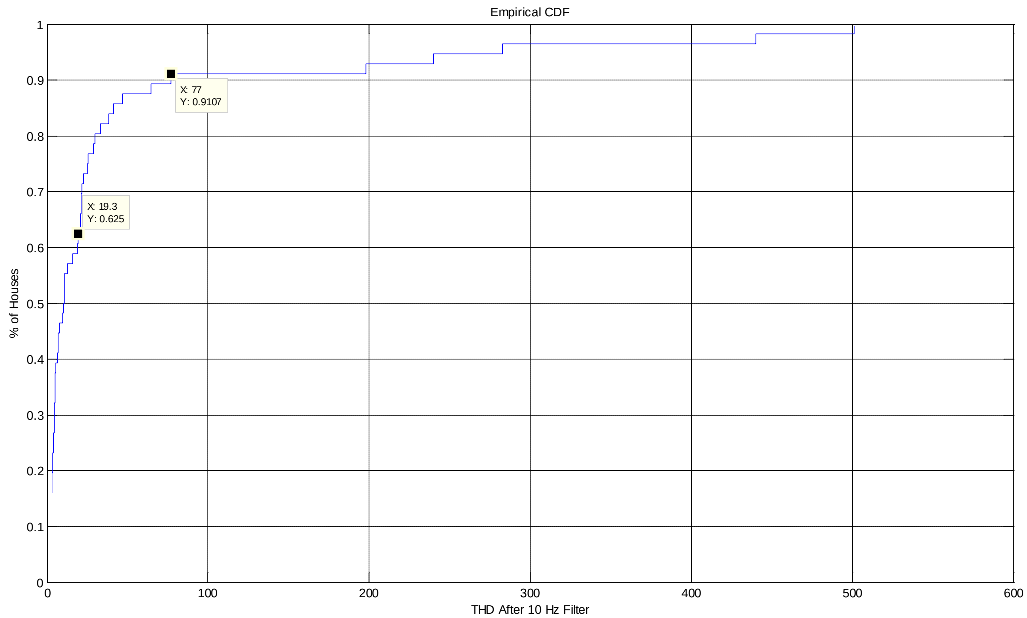


Figure 36. CDF curve of Average THD in houses.

It is hard to pinpoint a particular reason for the high THD that was encountered during the measurement, but factors like non-linear loads may play a significant role. One reason could be the florescent lights and lamps present in room. These lights have steady AC voltage circulating in their circuitry but the current fluctuate quite a lot which causes high THD in measured signal. Most of the power sockets and cables were located around the corners and the measurements were made at the four corners of the rooms. Though necessary precautions were taken to keep the instrument away from appliances, at times they were unavoidable.

4.2. MF Highest at level

The point measurements are performed in up to three rooms in house. After calculating average RMS in each level for each room, we gathered information of which level in a house is the highest MF. The detail about selecting the highest level is discussed in section 3.2.5.5. While looking at figure 37 we can observe that most of the houses (36%) have MF highest at floor level. From Table 7, we have observed that most of the houses which have MF highest at ground level are villas. One prominent reason could be that the villas have underground heating systems either electric or district heating, which can be the effective source of MF. For the case of bedroom most of sources of MF are at ground floor in living room and kitchen as mostly they are at ground levels in houses, and that can be the reason of high MF at ground level in bedroom. In case of both villas and apartments the wiring is mostly laid under the floor of room.

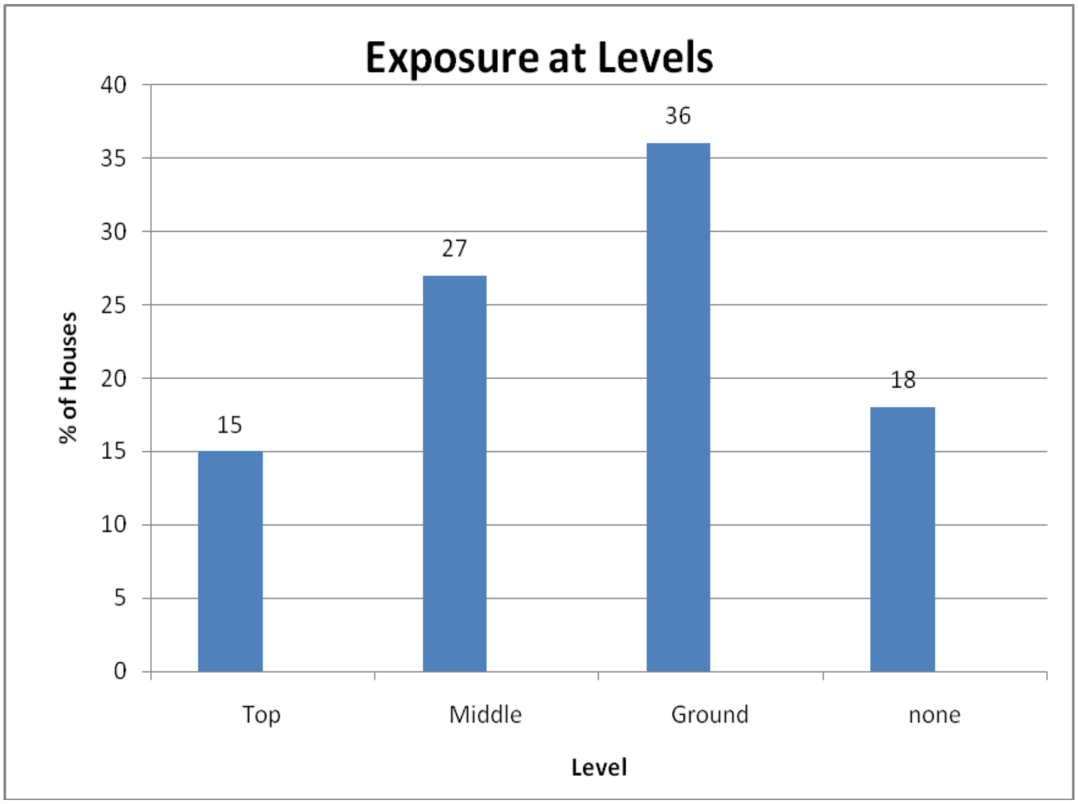


Figure 37. Exposure at certain levels in 97 houses.

4.3. Adjusted Average MF in Apartment & Villa

The comparison is made on the bases of adjusted average B_{Adjust} among apartments and villas. Houses of these two types are grouped separately and there CDF curves are plotted for values of B_{Adjust}. Figure 38 shows the CDF curve of B_{Adjust} in apartments and figure 39 shows CDF curve of B_{Adjust} in villas.

We can observe from the figure 38 that 83% of the houses among apartment are below 0.2 μT. In figure 39 we can see that 89% of the houses among the villas are below 0.2 μT.

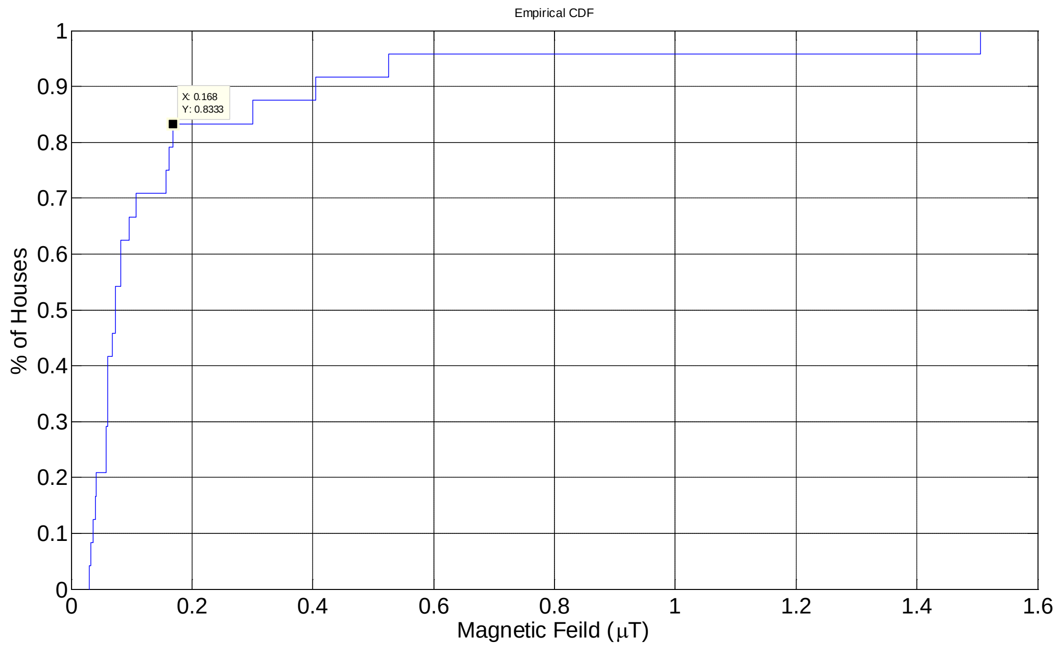


Figure 38. CDF curve of Average Adjusted MF in Apartments.

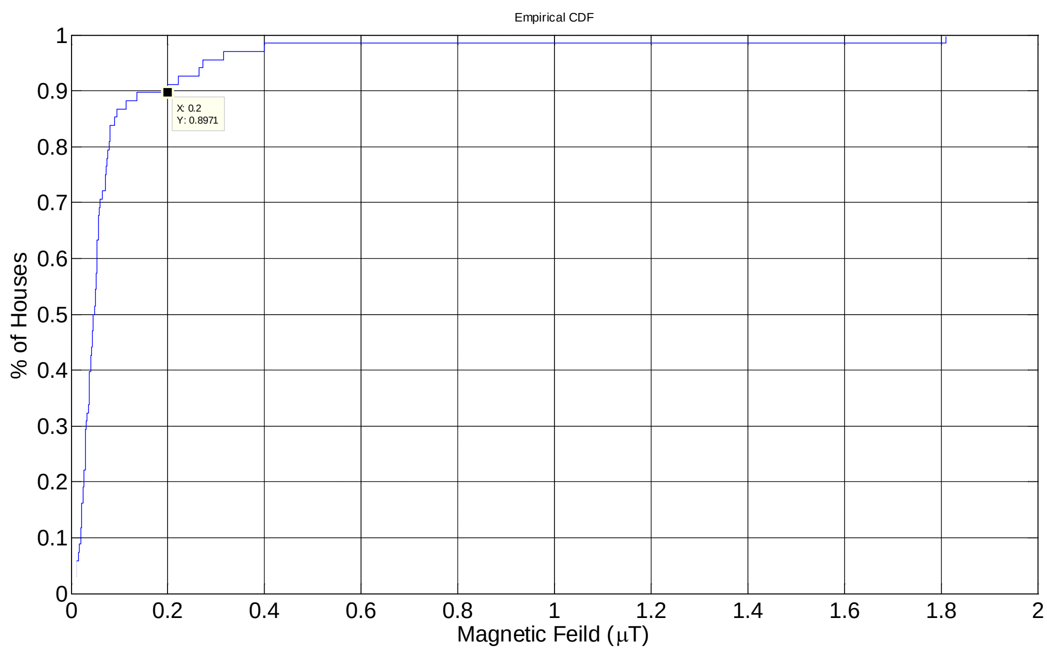


Figure 39. CDF curve of Average Adjusted MF in Villas.

From total of 97 houses, 28 houses are apartment and 68 houses are villas. So CDF plots for both types of houses indicate that most of them are below 0.2μT. But if we look at the mean and median values of them we can make comparison that which type of houses has higher exposure to MF. So the median value of B_{Adjust} for apartments is 0.07 μT and mean is 0.17 μT. Median value of B_{Adjus} for villas is 0.04 μT and mean is 0.09 μT. It is obvious from the difference between the median values that apartments have higher exposure of magnetic field as compare to villas.

5.1. Discussion

This section is about evaluating the results that we achieve from the measurement and analysis of magnetic field.

The distribution of magnetic field in 90 % houses by looking at the amount of B_{Adjust}, which is below 0.2 μT is quite normal. We have seen through the results that some of the houses have higher magnetic fields. But overall the maximum houses have shown quite normal personal exposure to magnetic field. The reason for this normal behavior might be underground electric wiring system, which contains the phases and neutral wires close to each other in a single shield. Hence they cancel each other magnetic fields. Also compared to overhead power lines the underground power lines have low magnetic field. We have observed that very few houses have high exposure. High fields can come from electric single wire floor heating system and large amount of electric appliances operating in the house or vicinity of railways and power lines.

We calculated flat average of MF as compare to adjusted average, which provides us average exposure of houses to magnetic field. The result from flat average is quite similar to adjusted average. 91 % of the houses have a flat average MF below 0.2 μT. The median value is same in both cases, which is 0.05 μT.

We have measured up to three rooms in each house, which are bedroom, living room and kitchen. It was important to find out the exposure of average person to MF in each room in house. We have calculated the average of RMS values in each room and furthermore average of B_{Bed}, $B_{Kitchen}$ and $B_{Living\ room}$ from all the houses is calculated. It is observed that highest exposure to MF is found to be in kitchen whose average value is 0.14 μT. The lowest exposure to MF is found out to be in living room which is 0.1 μT. The reason of high MF in kitchen is because of many types of electric equipments, like refrigerator, dish washer, microwave oven etc operating in several time instants during 24-hour period.

Then we perform the comparison of houses in three regions (Göteborg, Borås and Others) on the bases of average adjusted magnetic field. We observe that highest percentage of houses, having B_{Adjust} below 0.2 μT, among the three regions are in other region which is 97 %. The reason might be that these areas are not the big cities as compare to other two Göteborg and Borås. Hence in rural areas there is not big congestion between the houses. Mostly they are villas or apartment building at distance to each other. While in big cities we have quite crowded and populated environment which is the reason for higher magnetic field.

We were also interested in calculating the amount of total harmonic distortion (THD) of the magnetic field. THD provide us information about the noise or unwanted signal contributed to the measured signal, and tell us that how many non-linear loads present in a house. We observe from the results related to THD calculation that around 63 % of the houses have THD < 20 %. We have seen that many houses have quite high THD value which is above 100 %. One reason for high amount of THD in houses is the presence of non-linear loads like florescent lights and lamps. Because in florescent lights the voltage is nice sinusoidal AC wave but current does not follow the voltage. So this way THD is high when we measure the magnetic field in a house with large number of florescent lights and lamps or other non-linear loads.

The exposure of MF varies with height from floor to roof. We perform analysis over the bases of RMS value of magnetic field which were measured at three different levels (Ground, Middle and Top). Hence it is observed that maximum percentage of houses 36 % have highest exposure of MF at ground level. In some houses distribution of MF is similar in three different rooms. The prominent reason for MF highest at ground level is underground wiring system, and also the single wire electric floor heating system in villas.

The exposure of MF also depends upon the building type of the premises. We made analysis among villas and apartment from 97 houses on the bases of adjusted average B_{Adjust} MF value. We try to figure out what is the amount of exposure in the two types of residences. Hence it is observed that 83 % of the apartments are below 0.2 µT and 89 % of the villas are below 0.2 µT. Observing the median value of B_{Adjust} for apartments which is 0.07 µT and median value of B_{Adjust} for villas which is 0.04 µT. It is obvious from the difference between the median values that apartments have higher exposure of magnetic field as compared to villas. Apartments are more congested and are build one over other, so the effects of MF from surrounding buildings are also the factor of high adjusted average value.

5.2. Future works

An immediate follow up will be made in Stockholm in regard to the project work executed here. This work is planned to be executed by Swedish Radiation Safety Authority employees. It will be good to have more houses measured in different parts of Sweden as it expands the limits to understand the behavior of ELF magnetic field. Also with the experience of handling the instruments for about 100 houses, we are aware of the problems that one will encounter during the course of the measurement. By passing on the relevant information unnecessary issues can be avoided at the very beginning of the work as it can save valuable time and the result can expected to be more precise. We already developed a protocol for performing the measurements and analyzing the obtained data which will be fruitful for the workers in future. It will be interesting to compare the results later and see how it varies or is there anything similar.

Though the focus of this thesis work was towards the MF exposure in residents, we are also interested and encourage MF analysts, future workers in this field to make measurements at schools, as kids spend a considerable time at schools apart from houses. There is no dependable fact currently to describe the effect of 16.7 Hz in regard to health risks in children, so collecting data's related to it can prove to be vital for the later studies.

References

1. “Electric Field”, cited[19 Nov 10],Available at http://en.wikipedia.org/wiki/Electric_field
2. International Commission on Non-Ionizing Radiation Protection, “Fact Sheet on the Guidelines on limit of exposure to Static Magnetic Field” [2009], Available at http://www.icnirp.de/documents/FactSheetStatic.pdf
3. J.Schuz and A.Ahlbom “Exposure to Electromagnetic fields and the risk childhood leukemia”. Published at 16 October 2008, Vol. 132, No. 2, pp. 202-211.
4. World Health Organization, [1999], “Electro Magnetic Fields”, cited [15 Oct 2010], Available at http://www.who.int/peh-MF/about/WhatisMF/en/
5. Scientific Committee on Emerging and Newly Identified Health Risks, [21 Markh 2007] “Possible effects of Electromagnetic Fields (MF) on Human Health” Available at http://ec.europa.eu/health/ph_risk/committees/04_scenihr/docs/scenihr_o_007.pdf
6. Enviro Mentor, [1999] “Magnetic Field Logger ML-1 user instruction” cited [23 Nov 2010], Available at http://www.enviromentor.se/manualer/ml1en.pdf
7. Wertheimer N, Leeper E, “Electrical wiring Configurations and childhood cancer”, Am. J. Epidemiology 1979; 109(3): 273-84.
8. Electric and Magnetic Fields [2009], by National gridus cited (Nov 30, 2010). Available from www.nationalgridus.com
9. Enviromentor AB, “*Magnetic Field logger ML-1 instructions”* reg. 98-013-1/Eng, pp: 5, 1999.
10. Enviromentor AB, “*Magnetic Field logger ML-1 instructions”* reg. 98-013-1/Eng, pp: 1, 1999
11. Combinova AB, “*MFM 10 Brochure”* [internet].2010[cited 2010 Nov 2]. Available from : http://www.combinova.se/Text/DL/MFM/MFM10/Brochures/m10broch.pdf
12. Combinova AB, “*MFM 3000 Brochure”* [internet].2010[cited 2010 Nov 2]. Available from : http://www.ergonomicsusa.com/pdf/mfm3000brocB-low.pdf
13. Combinova AB, *“MFM 3000 operators manual”* Edition 4, pp: 21, Sep 2007
14. Combinova AB,*“Magnetic Field Meter 10 operators manual”* Revised Edition.2A, pp:17
15. Chisholm, Hugh, ed (1911). "storey". *Encyclopædia Britannica* (Eleventh ed.). Cambridge University Press
16. “Total Harmonic Distortion” , cited (12 Nov 2010), Available at http://en.wikipedia.org/wiki/Total_harmonic_distortion
17. ICNIRP guidelines,” Guidelines for Limiting Exposure to Time-Varying electric and Magnetic Fields (1 Hz To 100 Khz)” Health Physics 99(6) pp: 825-827, Nov 2010.
18. World Health Organization, [2002], “IARC Monographs on the evaluation of Carcinogenic risks to humans”, IARC Monographs Volume 80
19. Strålsäkerhetsmyndigheten, “Low-frequency magnetic fields in different modes - a study based on measurements from the years 1993-2010” pp:03, 22 June 2010

Appendix

Test Measurements

A. Near Railway lines

Apart from the measurements that were made for this thesis, certain test measurements were also performed near railway lines to understand the nature of the MF. These experiments were made at the early stage of the thesis.

DIFFERENT MEASURE-MENT CASES (Hz)	NEAR (5m)		FEW METERS (25m)		FAR AWAY 50m*1 , 100m*2		Time and date
	A	B	A	B	A	B	
Case 1. No train passes by	0.726µT 16.6Hz	0.635µT 16.6Hz	0.100µT >2khz	0.098µT Mixed	0.054µT*1 1111Hz	0.061µT*1 Mixed	Date: 28/07/2010
					0.108µT*2 Mixed	0.080µT*2 Mixed	
	20:37:19	18:53	20:48	18:57:27	20:53*1 20:57:10*2	19:05:59*1 19:09:04*2	Noted Time
Case 2: One train passes by	1.061µT 16.6Hz	1.624µT 16.6Hz	0.213µT Mixed	0.274µT Mixed	0.089 Mixed	0.104µT*1 Mixed	Date: 28/07/2010
					0.317µT*2 Mixed	0.135µT*2 Mixed	
	20:39:01	18.50	20:51:15	19:01:58	20:54:37*1 21:17:10*2	19:11:49*1 19:16:01*2	Noted time

Table 9: MF near railways lines

The table 9 shows the RMS and frequency values provided by COMBINOVA MFM 10 near railway lines. The measurements were made at Floda (A) and Kåhög (B). Two cases were considered for performing the measurements; when there was no train passing by and when a train did pass. The distance from which the measurements were made can also be seen in the table; near (5 m from the rail line), Far (25 m from the rail line) and long (50 and 100 m from the rail line)

Considering the results from both the places (A & B), one thing was evident; 16.7 Hz frequency is very much present near the railways when the train passes and it stays for few minutes, but in the absence of train 16.7 Hz frequency is disappeared. Added to this, the RMS values suggest that there exist high MF, which was expected. Moving few meters away from the railway line 16.7 Hz disappeared the RMS values were found to be less compared to measurements that were taken so close to the rail lines. Moving far away from the railway lines Combinova MFM 10 could not indicate a particular dominating frequency so it mostly showed (Mixed) and RMS values were less compared to the earlier results

It can be clearly inferred from the results that when a train passes by, whether the measurement was done near the railway line or far away, it does increase the MF in that particular area, which can be confirmed by comparing the RMS values that were taken when trains did not pass by. Also as the distance from the railway line increases the MF experienced decreases, the table clearly reflects this evidently.

B. 24-hour Measurements in three rooms in a House

In this section the results and discussion regarding test measurements performed at certain houses are provided. Idea was to find out the distribution and variation of MF in the house.

The three houses were chosen to perform 24-hour logging in three rooms simultaneously in each house using ML-1. These test measurement were performed to find out the behavior of MF and its distribution in a house. Table 10 below contains the median and mean values of MF for each room in three houses. In figure 1, 2 and 3 are the time graphs of MF for 24-hour period from house no 3.

Properties	House1			House2			House3		
	Bedroom	Living room	Kitchen	Bedroom	Living room	Kitchen	Bedroom	Living room	Kitchen
Median	0.05	0.05	0.07	0.11	0.14	0.14	0.12	0.12	0.20
Mean	0.06	0.06	0.11	0.11	0.14	0.14	0.13	0.12	0.19
Max	0.16	0.16	6.22	0.22	0.24	0.41	0.39	0.29	0.29
Min	0.02	0.02	0.03	0.03	0.05	0.03	0.04	0.03	0.13

Table10. Results of 24-hour logging in houses

Figure 1 is of 24-hour logging from kitchen. Figure 2 and 3 are from bedroom and living room. If we observe figure 2 and 3 we can see that there is some correlation between 24-hour MF in both rooms. Both line curves almost follow the same pattern. We can see that there is similar variation of MF in both rooms. Beside that Kitchen has some high amplitude of MF on certain time periods which is because of electric appliances operating.

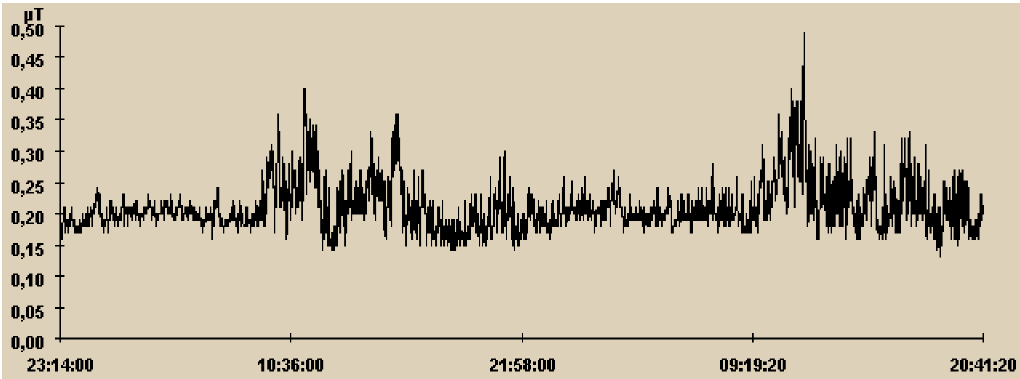


Figure 1. 24-hour Logging of MF in Kitchen.

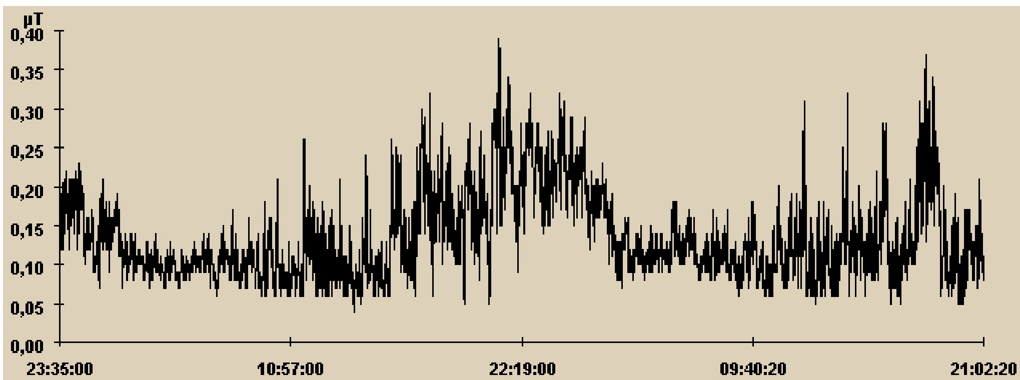


Figure2. 24-hour Logging of MF in bedroom.

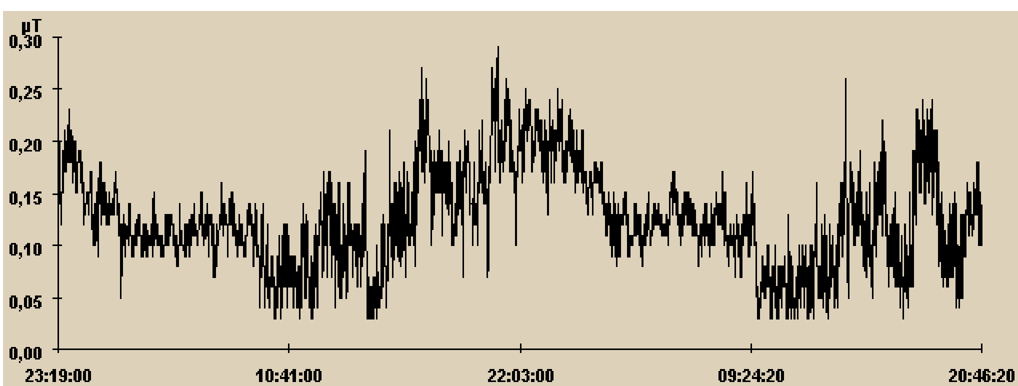


Figure3. 24-hour Logging of MF in living room.