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GEBZE TECHNICAL UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

FREQUENCY SELECTIVE ELECTROMAGNETIC POLLUTION MEASUREMENTS

CAFER BAHADIR TEKTAŞ

A THESIS SUBMITTED FOR THE DEGREE OF

MASTER OF SCIENCE

DEPARTMENT OF PYHSICS

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2018

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FEN BİLİMLERİ ENSTİTÜSÜ

FREKANS SEÇİCİ ELEKTROMANYETİK KİRLİLİK ÖLÇÜMLERİ

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YÜKSEK LİSANS TEZİ
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2018

GEBZE TEKNİK ÜNİVERSİTESİ	**YÜKSEK LİSANS JÜRİ ONAY FORMU**

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SUMMARY

Nowadays, electrical/electronic devices and communication instruments that are emerged as a result of rapidly progressive scientific and technological developments are a very important point in our lives because of the convenience of life they provide. But besides the benefits they provide that have some harmful effects. All of these devices and communication instruments are exposed as electromagnetic pollution source. Electromagnetic pollution is become a part of our lives as a consequence of our ever increasing dependency of technology. Our country's become acquainted with the concept of electromagnetic pollution was become with the high-voltage transmission line. With the launch of cell phones, the establishment of base stations has begun to attract people's attention to the fact that the pollution of the electromagnetic field is reaching a riskier level. As the number of radiators such as base stations, TV transmitters and wireless devices increases, people are getting more and more concerned about the exposure and their health. As a result, it has become necessary to measure the level of electromagnetic exposure that is being exposed. There are two common methods to measure the exposure level of EM pollution; broadband and frequency selective, alias narrow-band, measurement methods. In this work, we developed a software solution that can perform frequency-selective measurements and finally can collect the powers and calculate the total exposure level. Thereafter, we have been made a good comparison between broadband measurement results obtained with a field probe and frequency-selective ones which are obtained by using a spectrum analyzer and a mini-biconical antenna. This study was performed both at the Scientific and Technological Research Council of Turkey (TÜBİTAK) campus and at the National Metrology Institute (UME) which is located at TÜBİTAK campus. UME is an institution that guarantees the measurements made in our country and provides the integration of these measurements into the international system. In the introduced study, it was aimed to perform the pollution measurements with frequency selective and to move to the European level thanks to national software.

Key Words: Broadband, EM, Frequency-Selective, Measurement, Pollution, Communication.

ÖZET

Günümüzde hızlı bir şekilde gerçekleşen bilimsel ve teknolojik gelişmeler sonucunda ortaya konan elektrik/elektronik cihazlar ve haberleşme araçları sağladıkları yaşam kolaylıkları nedeniyle hayatımızda çok önemli bir noktada yer almaktadır. Ancak sağladıkları faydaların yanı sıra bazı zararlı yanları da bulunmaktadır. Bu cihazların ve haberleşme araçlarının tamamı yayın yapan birer elektromanyetik kirlilik kaynağı olarak karşımıza çıkmaktadır. Teknolojiye olan bağımlılığımız sonucunda, her geçen gün elektromanyetik kirlilik hayatımızın bir parçası haline gelmiştir. Ülkemizin elektromanyetik kirlilik kavramı ile tanışması yüksek gerilim hatlarıyla birlikte olmuştur. Cep telefonu kullanımının başlamasıyla beraber baz istasyonlarının kurulması elektromanyetik kirliliği çok daha tehlikeli bir seviyeye ulaştırmış ve oluşan bu durum zamanla insanların dikkatini çekmeye başlamıştır. Baz istasyonları, TV vericileri, kablosuz cihazlar gibi aktif antenlerin sayısı arttıkça insanların elektromanyetik maruziyetten ve sağlıklarından giderek daha fazla endişe etmesine sebep olmuştur. Bunun bir sonucu olarak, maruz kalınan elektromanyetik maruziyet seviyesinin ölçülmesi gerekli hale gelmiştir. EM kirliliğinin maruziyet düzeyini ölçmek için kullanılan, geniş bant ve frekans seçici diğer adıyla dar bant olmak üzere iki yaygın ölçüm yöntemi vardır. Bu çalışmada, frekans seçici ölçümleri gerçekleştirebilen ve sonucunda güçleri toplayıp toplam maruz kalma seviyesini hesaplayabilen bir yazılım çözümü geliştirdik. Daha sonra, bir elektromanyetik alan probu ile elde edilen geniş bant ölçüm sonuçları ile bir spektrum analizörü ve bir mini-bikonik anten kullanarak gerçekleştirilen frekans seçici ölçüm yöntemi ile elden edilen sonuçları arasında iyi bir karşılaştırma yapılmıştır. Bu çalışma, Türkiye Bilimsel ve Teknolojik Araştırma Kurumu (TÜBİTAK) kampüsü ve kampüs bünyesindeki Ulusal Metroloji Enstitüsü'nde (UME) gerçekleştirilmiştir. UME, ülkemizde yapılan ölçümleri güvence altına alan ve bu ölçümlerin uluslararası sisteme entegrasyonunu sağlayan bir kurumdur. Tanıtılan çalışmada, frekans seçici elektromanyetik kirlilik ölçüm sistemi ile kirlilik ölçümlerini ulusal bir yazılım ile gerçekleştirmek ve Avrupa seviyesine taşımak amaçlanmıştır.

Anahtar Kelimeler: Genişband, Elektromanyetik (EM), Frekans-Seçici, Ölçüm, Kirlilik, Haberleşme.

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LIST of ABBREVIATIONS and ACRONYMS

Abbreviations and Acronyms		**Explanations**
∇	:	Nabla
ρ	:	Charge Density
σ	:	Conductivity
ε	:	Permittivity
Ω	:	Electrical Resistance
η	:	Wave Impedance
μ	:	Permeability
f	:	Frequency
eV	:	Electron Volt
c	:	Speed of Light
Hz	:	Hertz
F	:	Farads
AF	:	Antenna Factor
ANSI	:	American National Standards Institute
BCCH	:	Broadcast Control Channel
CENELEC	:	European Committee for Electrotechnical Standardization
CF	:	Correction Factor
CPICH	:	Primary Common Pilot Channel
EC	:	European Commission
EIRP	:	Equivalent Isotropic Radiated Power
EM	:	Electromagnetic
EMF	:	Electromagnetic Field
ERP	:	Effective Radiated Power
EU	:	European Union
FCC	:	Federal Communications Commission
FDD	:	Frequency Division Duplex
GSM	:	Global System for Mobile Communications
ICNIRP	:	International Commission on Non-Ionizing Radiation Protection

ICTA	:	Information Technologies and Communications Authority
IEC	:	International Electrotechnical Commission
ILO	:	International Labour Organization
LTE	:	Long Term Evolution
MIMO	:	Multiple Input – Multiple Output
OFDMA	:	Orthogonal Frequency Division Multiple Access
RB	:	Resource Block
RBW	:	Resolution Bandwidth
RF	:	Radio Frequency
RMS	:	Root Mean Square
SAR	:	Specific Absorption Rate
TCH	:	Traffic Channel
TDD	:	Time Division Duplex
UMTS	:	Universal Mobile Telecommunications System
VBW	:	Video Bandwidth
WCDMA	:	Wideband Code Division Multiple Access
WHO	:	World Health Organization
WLAN	:	Wireless Local Area Networks
WPAN	:	Wireless Personal Area Networks

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1. INTRODUCTION

There are two common methods to measure EM pollution. One of them is the broadband measurement which requires broadband field sensors and which are generally less time-consuming than the frequency-selective measurement. With the broadband measurement, the measurement can be performed simply and fast. Due to the isotropic characteristic of the field probe the direction of maximum field is unknown. On the other hand, broadband field probes are not designed to distinguish between emissions of different frequencies like radio, TV broadcast or GSM base stations and also the comparison of measured field levels with the standard limits is very problematic due to the lack of frequency selectivity. In addition, broadband field probes are unable to respond to rapid changes of signal strength due to modulations of the signal under measurement. The calibration factor of a field probe is usually valid for CW (Continuous Wave) signals, therefore additional errors occur when modulated signals are measured. Another issue with the field probe is undulating factors throughout its frequency range. Moreover, exposures of the general public are often in the region or below the detection thresholds of broadband field probes. The aforementioned limitations do not arise when the frequency-selective measurement is utilized by means of a spectrum analyzer, a coaxial cable and a suitable antenna.

With the frequency-selective narrowband measurement, for each reading, the measurement frequency is known and the frequency dependent antenna factor can be applied. The appropriate frequency dependent limits can be easily also applied to reach a correct verdict of the exposure. Despite the mentioned advantages of the frequency selective measurement, it can be very time-consuming and exhaustive in comparison to the broadband measurement as measurements must be performed in different orientations of the antennas due to their limited directivity. In this work, we firstly designed a frequency-selective measurement software solution by using Visual C++.

The software is able to determine the peaks separately and calculate the total exposure based on the measured peaks and the defined limits. It is based on the instrument driver system and all the required vital measurement parameters such as resolution bandwidth, detector type, averaging mode..etc can be adjusted on a

separate driver file and any measurement is started after selecting the suitable driver file without changing on the main software core. Thereafter, we experimentally investigated the two methods and compared them by simultaneously measuring the artificially-produced multi-signals in different frequencies in laboratory and office environments. In the second stage, the measurements were performed at near the base station. At this stage, measurements of GSM and UMTS bands were performed using the same two methods.

2. THEORETICAL BASICS

2.1. Electromagnetic Field

A time-varying electric field causes the local magnetic field. This indicates that the electric and magnetic fields are not independent of each other. While an observer sees only as an electric field, another observer can observe it as a mixture of electric and magnetic fields. For this reason, instead of talking about electric and magnetic fields separately, these two are considered together as "electromagnetic field". The electromagnetic field is a natural effect that occurs in the vicinity of electrically charged particle, causing these particles to exert force on other charged particles. This force can be pushing, pulling or perpendicular to the straight line. The electromagnetic field can be defined as a series of waves, oscillating at a certain frequency and with a certain distance from each other. In other words, the electromagnetic field is the combined state of the electric field and the magnetic field.

Electromagnetic fields have a very wide frequency range. This range; ranging from low frequency energy transmission lines to radio and visible light frequencies and to very high frequency medical x-rays with a short wavelength to be expressed by a nanometer. The electromagnetic field consists of two components be about the electric and magnetic field that oscillate perpendicular to each other. The electric wave and the magnetic wave are displaced together at the speed of light. Electromagnetic fields typical characteristic is frequencies and wavelengths. "Frequency" is the number of vibrations (oscillations) of a wave in a second and the unit is Hertz (Hz). The wavelength is the distance covered by the wave during a vibration and is in meters (m). As the frequency increases, the wavelength is shortened and the radiant energy in the field increases [1].

2.1.1. Electric Field

An electric field is a feature of space that surrounds an electrical charge or magnetic field. It acts on the charged objects by means of electrical power. This concept has been gained in physics by Michael Faraday. Electric field is indicated by

"E", unit is Volt / meter (V/m). Electric field is dependent the electric flux density (D) and the electrical permittivity (ε) of the material. This relation is expressed by the equation (2.1):

$$E = D / \varepsilon \tag{2.1}$$

The flux density vector is the represented by D, has the same direction as the electric field vector, and its intensity is proportional to the charge forming the electric field. The unit of electric flux density is Coulomb/square meter (C/m^2). Electrical permittivity is a criterion of the number of loads constrained within a material. Electrical permittivity is indicated by "ε". The unit is Farad / meter (F/m) [2]. The electrical permeability is equal to the product of the electrical permittivity (ε_0) of the free space and the relative dielectric constant (ε_r) of the material, and this is expressed by the equations (2.2) and (2.3) respectively:

$$\varepsilon_0 = \frac{10^{-9}}{36\pi} = 8.854 \times 10^{-12} \quad \text{F/m} \tag{2.2}$$

$$\varepsilon = \varepsilon_0 \cdot \varepsilon_r \tag{2.3}$$

2.1.2. Magnetic Field

The magnetic field is a vectorial quantity that is generated internally by electrical charges moving in time, by electric fields that change over time, or by fundamental particles. The magnetic field appears when electric charges are displaced. If the current is too high, the magnetic field, which is an end result, will be so high. Just as with the electric field, the magnitude of the magnetic field decreases rapidly with distance. In short, the magnetic field is the field that the smooth linear (non-accelerated) moving charges (particles) generate. The magnetic field is also a vector quantity (such as magnitude and direction), such as an electric field. The magnetic field is indicated by "H" and the unit is Ampere/meter (A / m) [3, 4]. It depends on the magnetic flux density (B) and the magnetic permeability (μ) of the material. This relation is expressed as equation (2.4):

$$H = B / \mu \tag{2.4}$$

Here, the unit of magnetic flux density denoted by B is expressed as Tesla (T) or Weber / square meter (Wb/m2). The magnetic flux density in the SI unit system is used as Tesla. According to this; 1 T = 1 Wb/m^2. Magnetic permeability is indicated by "μ". The unit is Henry/meter (H/m) depending on the material. Magnetic permeability is expressed in terms of relative magnetic permeability (μ_r) and magnetic permeability (μ_0) of free space. Also, the relative magnetic permeability of the free space is 1. The unit equation (2.5) shows magnetic permeability of free space:

$$\mu 0 = 4\pi \times 10^{-7} (H / m) \tag{2.5}$$

The magnetic permeability value of any material is calculated according to the equation (2.6):

$$\mu = \mu 0 \bullet \mu r \tag{2.6}$$

2.1.3. Maxwell's Equations

The equations obtained as a result of Maxwell's work have pointed out the way for the electromagnetic theory and therefore the communication. These equations, which are known as Maxwell's equations due to formulation by James Clerk Maxwell, are expressed by the equations in free space where there is no dielectric and magnetic material stated in Table 2.1 [5].

Table 2.1: Maxwell's equations.

Differential Form of Maxwell Equations	Integral Form of Maxwell Equations
$\vec{\nabla} \cdot \vec{E} = \frac{\rho}{\varepsilon_0}$	$\oint \vec{D} \cdot d\vec{s} = -\int_v \rho_v . dv$
$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$	$\oint \vec{E} \cdot d\vec{l} = -\int_s \frac{\partial \vec{B}}{\partial t} \cdot d\vec{s}$
$\vec{\nabla} \cdot \vec{B} = 0$	$\oint \vec{B} \cdot d\vec{s} = 0$
$\vec{\nabla} \times \vec{B} = \mu_0 \left[\vec{J} + \frac{\partial \vec{D}}{\partial t} \right]$	$\oint \vec{H} \cdot d\vec{l} = \int_s \left[\vec{J} + \frac{\partial \vec{D}}{\partial t} \right] \cdot d\vec{s}$

The description of the equations is given in below respectively.

- The Gauss Law

The Gauss Law is defined as the ratio of the net flux of an electric field to the enclosed electric charge along a closed surface.

- The Faraday Law

The Faraday Law defines the electric field created by a changing magnetic field.

- The Magnetic Gauss Law

The Magnetic Gauss Law remarks that the net magnetic flux passing through a closed surface is zero.

- The Ampere Law

The Ampere Law defines as the formation of a magnetic field created by a changing electric field and electric currents [6].

2.1.4. Wave Equation

When the Faraday and Ampere equations of Maxwell take a rotational in the free space without charge and current, equations for electric and magnetic field are obtained separately as stated in equations (2.7) and (2.8) [7].

$$\nabla^2 \vec{E} = \varepsilon_0 \mu_0 \frac{\partial^2 \vec{E}}{\partial t^2} \tag{2.7}$$

$$\nabla^2 \vec{B} = \varepsilon_0 \mu_0 \frac{\partial^2 \vec{B}}{\partial t^2} \tag{2.8}$$

When the equation (2.9) is examined for the electric and magnetic field, the correctness of this equation is observed.

$$\nabla^2 f = \frac{1}{c^2} \frac{\partial^2 f}{\partial t^2} \tag{2.9}$$

This equation is the Classical Wave Equation; c indicates the motion of a wave moving at the speed of light. The wave velocity is stated as seen in equation (2.10).

$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} = 2{,}99.10^8 \frac{m}{s} \tag{2.10}$$

2.2. Electromagnetic Wave and Spectrum

Radiation is the propagation of energy in space in the form of waves or particles. Electromagnetic radiation consists of electromagnetic waves that are synchronized oscillations of electrical and magnetic fields that propagate at the speed of light along a vacuum [8]. The radiations are defined by wavelengths or frequencies. The chart that shows all the electromagnetic wave types on the frequency axis is an electromagnetic spectrum. Electromagnetic spectrum includes High-energy Gamma rays, high-energy x-rays just below, and "extremely low frequency" areas on the other end of the spectrum [9].

The frequencies of the energies in the electromagnetic energy range are 10-10^{24} Hz and the wavelength is 10^{7}-10^{-16} meter. The electro-magnetic spectrum is separated by frequencies as shown in figure 2.1.

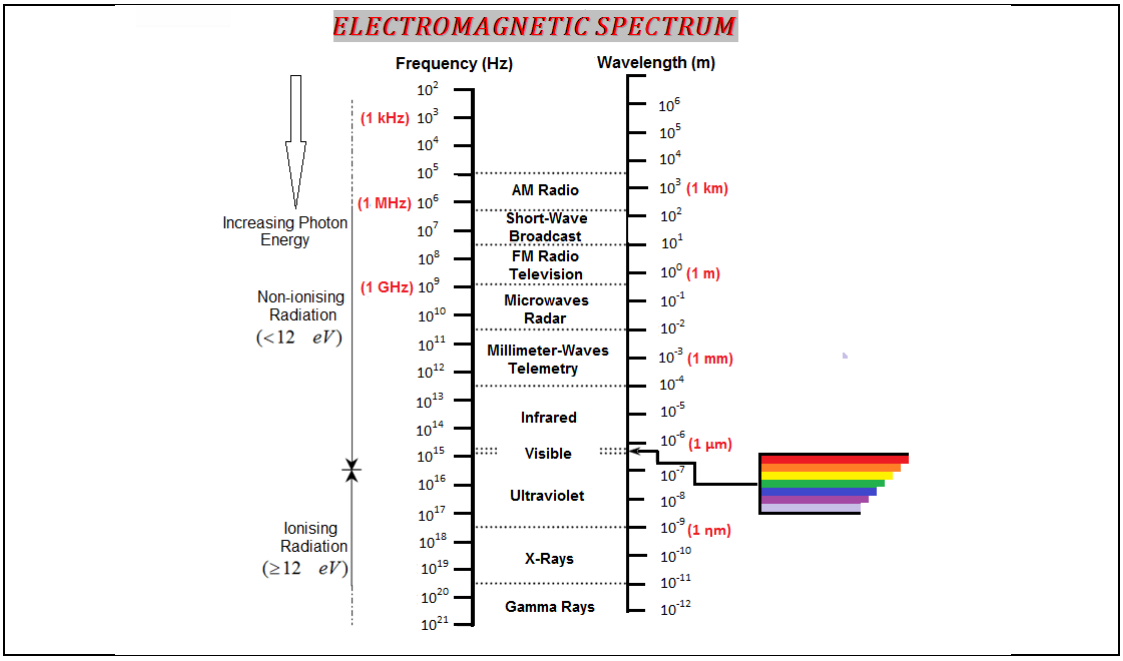


Figure 2.1: Electromagnetic spectrum.

According to the general acceptance in the literature, RF waves below 300 GHz in the RF spectrum are defined as non-ionizing while above the 300 GHz which are defined as ionizing.

Electromagnetic wave consists of the electric field and the magnetic field as shown in figure 2.2. The physical field generated by the electrical charges is defined as the electromagnetic field. The characteristics of electric and magnetic fields are different from each other and the effects on living things are also different. It is assumed that the fields of influence of magnetic fields are wider. One of the reasons for this assumption is that the electric fields cannot pass through the walls, they lose their intensity when passing through the human skin and the magnetic fields know no limit except for specific materials [10, 11].

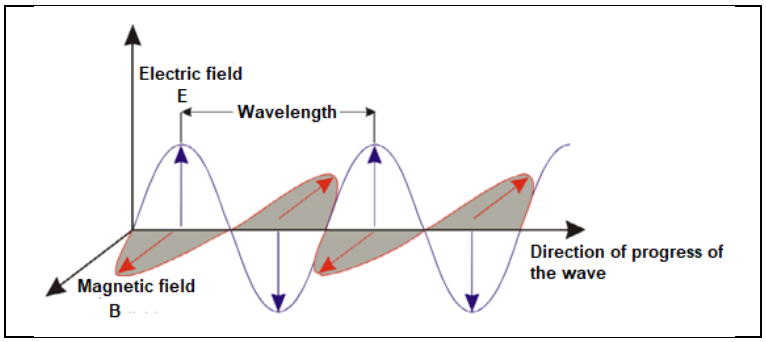


Figure 2.2: Representation of electric field (E) and magnetic field (H).

2.2.1. Electromagnetic Wave Energy (Poynting Vector)

Electromagnetic waves with wave and radioactivity characteristics such as heat, light, and particles, which encompass a wide range of wavelengths that are constantly present in the environment, transport energy and transmit energy to the objects they encounter while spreading in space. Electromagnetic energy is carried by electrical and magnetic fields in space. The accelerated movement of a charged particle forms the electromagnetic energy source. Electromagnetic energy has dual characteristics, both wave and particle. The wave has the feature of sine wave property and has frequency and wavelength. The magnitude of the Poynting vector expresses the transit velocity of the energy from the unit surface of perpendicular to the flow direction. For that reason, the magnitude of the Poynting vector expresses power per unit surface. The direction of the S vector is throughout of the wave propagation direction [12].

Equation (2.11) shows the Poynting vector, also referred to as the power flux density depending on the magnitude of the electric and magnetic fields.

$$S = E / H = E^2 / 377 \tag{2.11}$$

The 377 scalar value expressed in the equation (2.11) is defined as the resistance of free space and is the resistance shown against to electromagnetic wave propagation in space. In other words, it is called wave impedance or free space impedance. The wave impedance is indicated by "η" and the unit is ohm (Ω). Since the relative magnetic permeability and the relative dielectric constant of the free space are 1, the wave impedance is expressed as in equation (2.12).

$$\eta = \eta_0 = (\mu_0 / \varepsilon_0)^{1/2} = 120\pi = 377\Omega \quad (2.12)$$

Also, the current density used in Maxwell's equations is the electric current per unit area of cross section. The current density vector is defined as a vector whose magnitude is the electric current per cross-sectional area at a given point in space, its direction being that of the motion of the charges at this point. The current density is indicated by "J" and unit is A/m.

2.3. Antennas

An antenna can be used as a receiving antenna or a transmitting antenna. When used as a transmitting antenna, it converts electrical signals into electromagnetic waves and broadcasts them, however when used as a receiving antenna receiver, converts the received electromagnetic waves into electrical signals [13].

The antennas were used in 1888 by James Clerk Maxwell to prove the existence of electromagnetic waves foreseen. This experiment was carried out by placing a dipole in front of the hertz parabolic reflector. Horn or parabolic-like antennas work by focusing incoming wave to a spot. Such antennas are called directional antennas. Non-directional antennas radiate or receive electromagnetic energy evenly at points of equal distance on space [14].

There are many types of antennas that give superiority to each other with different characteristics according to usage areas. Receiver and transmitter characteristics of the same types of antennas that do not contain external structures such as amplifiers and filters are the same in the world. In order to obtain maximum efficiency from the antennas, the characteristics of the antennas are very well known and the optimum antenna structure should be preferred according to the usage conditions in this information.

Data transmission between long distances is difficult and costly in terms of laying cables when done with cable. In addition, install a long line and their maintenance make many technical problems. In order to transmit data wirelessly with electromagnetic waves, the used equipment need to send the waves with high energy to the atmosphere or space. In addition, it is necessary to transfer the electromagnetic waves that are suitable for the electromagnetic waves spreading in

the space to the receiving device. The antennas are basically the components that perform these two tasks [15].

2.3.1. Antenna Parameters

Antennas convert into photons or convert photons into electrons. Regardless of the antenna types, all antennas generate radiation by accelerating or slowing the charge, which is the fundamental principle. In communication systems, antennas are one of the most important elements that determine the qualities and characteristics of systems. In general, antenna characteristic properties should be known in order to select the appropriate antenna. Thanks to these antenna characteristics, it is possible to have information about the performance of the antenna types according to the ambient conditions.

2.3.1.1. Antenna Directivity, Gain and Propagation Pattern

The rate of the antenna maximum radiation intensity in question to the radiation intensity of an isotropic or reference antenna giving the identical total power is named directivity. Generally, the antennas used in electronic communication systems are directional and emit or receive electromagnetic energy more effectively in certain directions than in other directions [13].

Antenna Gain defines the ratio of the power density a point of a directional antenna to the power density of the omni-directional antenna at the same point is defined as the gain at that point of the directional antenna. Antenna gain is an indication of what ratio the antenna is oriented [16].

Radiation Pattern of the antennas determines the spatial distribution of the energy propagating in the medium. According to the gain, the radiation pattern of the directional antenna has more energy compaction in the main propagation direction than the other directions so the main effect of antenna radiation pattern must be investigated in terms of exposure [17].

It is necessary to use antennas with high directivity and gain characteristics in order to calibrate antennas for measurement, to minimize the influence of other signals in

the environment in order to find the correct value of a certain measured signal and to maintain high efficiency in weak signals [18].

2.3.1.2. Equivalent Isotropic Radiated Power (EIRP)

The Equivalent Isotropic Radiated Power (EIRP) is defined as the power distributed equally in all directions when the point is an evenly radiated beam in all directions from a source. If the radiation energy of an antenna is concentrated in a direction or a specific direction where the radiation is equivalent to the isotropic radiation power of that antenna, such a radiation will be referred to as EIRP, or Equivalent Isotropic Radiated Power [17]. EIRP is expressed by the equation (2.13):

$$EIRP = P_t / G_t \tag{2.13}$$

Here, Pt is defined as the transmit power while Pg as the transmitter antenna gain.

2.3.1.3. Effective Radiated Power (ERP)

Effective Radiated Power (ERP) is used instead of the Equivalent Isotropic Radiated Power (EIRP) to indicate the maximum propagation power when a half-wave dipole antenna is used [13]. When the EIRP value is known, the ERP value is calculated as in equation (2.14):

$$ERP(dBW) = EIRP(dBW) - 2.15\,dBi \tag{2.14}$$

2.3.1.4. Antenna Factor

Antenna Factor (AF) is defined as the rate of voltage (V) on the line where the electric field component (E) of the electromagnetic wave from the antenna is connected to the antenna [19]. The antenna factor shows as equation (2.15):

$$AF = \frac{E}{V} \tag{2.15}$$

Here,

- AF = Antenna Factor (1/m)
- E = Electric Field Strength (V/m)
- V = Voltage (V)

are expressed as.

The decibel representation of the antenna factor shows as equation (2.16):

$$AF(dB) = E(dB\mu V/m) - V(dB\mu V) \tag{2.16}$$

2.3.1.5. Antenna Regions

There are 3 space zones surrounding an antenna [19]. These,

- Reactive near field region
- Active near-field region (Fresnel)
- Far field region (Fraunhofer)

These areas are given in figure 2.3. Each of these regions in the electromagnetic field has a different structure.

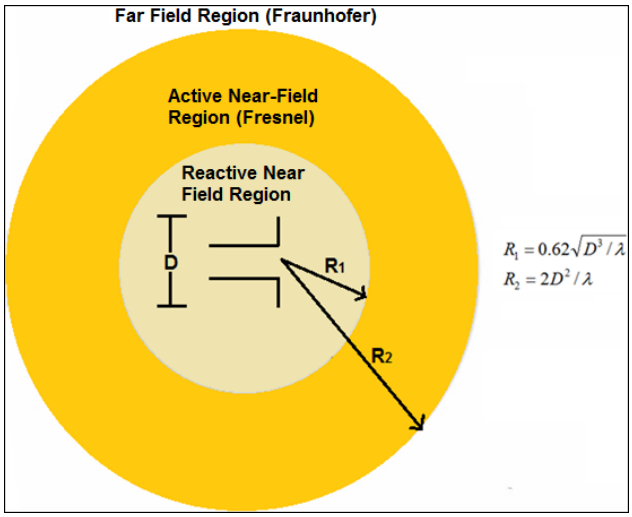


Figure 2.3: Radiation regions of an antenna.

The reactive near-field region is located in the immediate vicinity of the antenna and the reactive field is dominant in this region.

For many antennas, $R < 0.62\sqrt{D^3/\lambda}$ region is considered as a reactive near field region. In this expression, D is the largest dimension of the antenna and λ is the wavelength. The active (warming) near-field region is the transition area region between the reactive near-field region and the far-field region. If the dimensions of the antenna are comparable with wavelength, this region may not exist. If the dimensions of the antenna are very small compared to the wavelength, this region is present and is considered to be between $R \geq 0.62\sqrt{D^3/\lambda}$ and $R < 2D^2/\lambda$. The most important feature that distinguishes this field from the far field region is that the angular field distribution in this region is dependent on the R distance from the antenna. The angular field distribution in the far field area is nondependence on the distance from the antenna. That is, the antenna'st radiation pattern is nondependence on the R parameter, and the pattern does not change [20]. For many antennas the far field is defined as $R > 2D^2/\lambda$.

In accordance with EN 50492 standard, near and far field boundary distances are given in Table 2.2 [21].

Table 2.2: Near and far fields boundary distances.

	Reactive near field	**Active near-field**	**Far field**
Boundary distance*	$< \lambda$ $< D$ $< D^2/4\cdot\lambda$	$\lambda....5\cdot\lambda$ D....5·D $D^2/4\cdot\lambda....0.6\cdot D^2/\lambda$	$> 5\cdot\lambda$ $> 5\cdot D$ $> 0.6\cdot D^2/\lambda$
E perpendicular H?	No	Nearly	Yes
E,H ~ 1/r	No	No	Yes
$Z_F = E/H$	$\neq 377\ \Omega$	$\approx 377\ \Omega$	$= 377\ \Omega$
To measure	E and H	E or H	E or H

*: Maximum value of the three formulas.

λ: Signal wavelength ($\lambda = c_0/f$; c_0 = speed of light; f = signal frequency).

D: Largest dimension of the antenna; e.g. diameter of a parabolic antenna

2.4. Electromagnetic Pollution

Electromagnetic pollution is a phenomenon that creates harmful effects on people and other living things, such as electric current carrying cables, radio and television transmitters emitting radio frequency waves, mobile phone base stations, high voltage lines, transformers, microwave emitting household appliances, etc. Technology and developments in the industry have made human life easier, however, with these developments the problem of environmental pollution has arisen and it has begun to threaten human and animal life.

Prior to the 1990s, electromagnetic pollution caused by radio and TV transmitters in remote areas and in very high places, caused serious increases in electromagnetic pollution in cities and rural areas, with the establishment of telephone networks in the 1990s. During the last years, the level of pollution has reached a maximum level with microwave and RF signals from various sources such as GSM, UMTS / 3G and LTE wireless phones and base stations, WLAN (Wireless Local Area Networks), WPAN (Wireless Personal Area Networks) [22, 23].

The use of the next generation communication systems 3G and 4G has caused these changes to increase rapidly. Especially, possible effects of RF electromagnetic fields spreading from the GSM band of base stations on public health have become a source of serious concern among people and have reached the level of law case. In recent years, with the widespread use of 3G systems operating at 2,1 GHz of frequency, the debate about increasing the potential hazards of electromagnetic fields has reached serious dimensions. With the variety of service offered by 3G systems operating at approximate the frequency of a microwave oven (2,45 GHz), concerns over possible cancer effects with a long time use trend in humans are increasing day by day [24, 25].

In addition to these "artificial" sources which cause electromagnetic pollution, there are also some natural pollution sources. These include, for example, UV rays emitted from the sun, lightning and volcanic eruptions resulting from an earthquake.

2.5. Biological Effects of Electromagnetic Fields

In addition to power density and distance, electromagnetic field exposure is determined by physical characteristics such as the duration of exposure, type (near and far field), frequency of source, magnitude of electrical and magnetic field, and modulation (continuous wave or pulse modulation).

Maximum RF energy communication in biological systems is determined by penetration and distribution in biological tissues, energy absorption, power storage, generated electrical and magnetic fields. Their quantities show a change in relation to the size and physical form of the body. The total factor is accepted to be the same intensity, local or a different distant part of the body, or the exposure of whole body's, and mostly the warm up of the tissues. Heat effect occurs by absorption in biological systems resulting from local, partial or whole body exposure, or by RF energy storage. Absorption in the body resulting from exposure is depended the electrical conductivity of the body, its electrical permeability, and its mass properties [26, 27].

Depending on the magnitude of the EMF, the heat effect causes the external energy to be loaded into the cells that are formed by the molecules and molecules that are formed by the atoms. As it is known, In living things, when cells come together consist of tissues, when the tissues come together consist of organs and when the organs come together living things come into being. Each tissue characteristic is different in every living thing. Each of the soft and hard tissues also has different density and conductivity values. The photon that transfers the own energy to the cell actuation the water in the direction of arrival. Depending on the frequency, for example, 1 second; 10 times at 10 Hz and 500 million times at 500 MHz. The friction caused by the water movement turns into heat energy and the heat in the cell increases. One of the influences of the electromagnetic field on the living things is the heat effect which occurs in this way [28].

The depth of effect decreases at high frequencies and becomes deeper at low frequencies. Heating near the skin surface is easily felt through the ground receptors. Body; It has contact heating capacity as a consequence of the small amount of EM energy. EM fields above 10 GHz are absorbed on the skin surface. Only a small

portion of the energy penetrates into the underlying tissue. To solve problems such as cataracts or skin burns, very high field intensities are needed [29].

Such effects do not occur through normal daily exposure to radiation; but they can occur, for example, in the immediate vicinity of powerful radar systems. Some facilities usually cordon a large area [30].

- Up to 30 MHz: Grand depth of influence is large in the human body; inhomogeneous absorbed power distribution.
- 30 - 300 MHz: "Resonance interval"; here, the wave length is very close to the typical human size (or the measure of one-dimensional body parts). The field is absorbed to a large extent in energy. The lowest limits were found in this frequency range.
- 300 MHz-10 GHz: The effect depth of the EMF in the human body decreases within this range.
- Extreme 10 GHz: Increase in temperature at the body surface (skin burns possible).

Short-term exposure to RF energy, as noted above, may not be important enough to cause temperature rise in the tissue. What is important here is the velocity of heat increase versus time, which is proportional to the specific absorption rate (SAR) of the tissue. During the very long exposures duration, consisted of heat increase is depended the biological structure, the wave angle to the tissue, the heat regulation response of the tissues and the active compensation process. If RF energy absorption is too high for some part of the body or for exposure to a local area, rapid temperature increase and local tissue damage can occur here [31].

Thus, reactions can accelerate due to unwanted heat pressure on the body. The mainstay for protection against exposure to temperature increases is the ICNIRP (International Non-Ionizing Radiation Protection Committee) exposure guidelines, widely accepted in the World and accepted by the World Health Organization. In this guideline, 1 ° C excess heat increase is taken as a reference for humans, and violation of this threshold is considered harmful [32, 33].

2.6. Specific Absorption Rate (SAR)

SAR refers to the rate at which the electromagnetic radiation existing in the environment is absorbed by the human body when exposed to the electric and magnetic field in radio frequency. The unit is defined as the absorbed power per tissue mass and is expressed in W / kg. The SAR is averaged over the entire body or over a small sample volume (typically 1 g or 10 g tissue) [34, 35]. The measurement of the SAR value is very complex but can be calculated simply by the equation (2.17):

$$SAR = \sigma E^2 / \rho \quad [\text{W/kg}] \tag{2.17}$$

Here,

- σ: Conductivity EB/μ [S/m]
- E: Electric field [V/m]
- ρ: Density [kg/m^3]

are expressed as.

Since the SAR value is a parameter that is not directly measured, it is sufficient to measure one of the values of power flux density or magnetic field which can be directly converted to electric field or electric field in practice. Here, the power flux density indicates the energy flow through the unit surface perpendicular to the flow direction of the electromagnetic waveguide and is shown by the equation (2.18):

$$S = EB / \mu \quad [\text{W/m}^2] \tag{2.18}$$

The equation (2.19) shows, the power flux density depends on the impedance of the medium and the electric field strength as follows.

$$S = E^2 / 377 \tag{2.19}$$

Researches have shown that an exposure of SAR = 4 W/kg is required for a person's of average body weight temperature to increase by 1ºC. This has led to the setting of the limit values through the heat increase measure.

The formula used to calculate power flux density was found using Maxwell Equations.

It is said by experts that the values above 1.0 SAR are at high risk. Legal SAR values; the legal SAR value limit in the US is 1.6W / kg. Sales of phones exceeding 1.6 W / kg are prohibited in the United States. The upper limit is determined by Europe in case 2.0W / kg. In our country, this value is set at 2.0 [36, 37, 38].

2.7. Exposure Limits and Measurement Standards for Human Health

There are international standards and reference levels as well as standard and boundary values established in many countries on the effects of electromagnetic fields on human health. The reference values set by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) are among the most widely accepted values in many European countries and in the different countries of the world. ICNIRP is an independent research organization officially recognized by the World Health Organization (WHO) and the International Labour Organization (ILO) [39]. The work in the ICNIRP Guidelines has been carried out by a multidisciplinary team of engineers, biologists, physicists, and other related scientists in cooperation with universities and research institutions. The adaptation of the ICNIRP guideline to the EU was provided by the European Council Recommendation (1999/519 / EC) and the European Directive (2013/35 / EC). On 12 July 1999, the "Council of Europe Recommendation" on the limitation of public exposure to electromagnetic fields was published in the Official Journal (L 199, 1999) [40].

On June 26, 2013, the "European Parliament and Council Directive" concerning workers' exposure to risks from physical areas (electromagnetic fields) and minimum health and safety requirements was published in the Official Journal of the European Communities (L179 / 14, 2013).

In the United States, these levels are determined by the FCC (Federal Communications Commission) and are based on standard values established by IEEE (Institute of Electrical and Electronics Engineers) and ANSI (American National

Standards Institute) in defining these levels. IEEE / ANSI standards are also widely accepted and based on defining reference level.

The reference levels for the effects of electromagnetic fields on human health vary according to the frequency. Basic restriction and general exposure reference levels according to the ICNRP standard are given in Table 2.3 and Table 2.4. According to these reference values, limits may be specified in accordance with the worked frequency range [41].

Table 2.3: ICNIRP 1998 Basic Restrictions.

Exposure characteristics	Frequency range	Current density for head and trunk (mA/m^2) (rms)	Whole body average SAR (W/kg)	Localized SAR (head and trunk) (W/kg)	Localized SAR (limbs) (W/kg)
Occupational exposure	up to 1 Hz	40	-	-	-
	1-4 Hz	40/f	-	-	-
	4 Hz-1 kHz	10	-	-	-
	1-100 kHz	f/100	-	-	-
	100 kHz- 10 MHz	f/100	0.4	10	20
	10 MHz-10 GHz	-	0.4	10	20
General public exposure	up to 1 Hz	8	-	-	-
	1-4 Hz	8/f	-	-	-
	4 Hz-1 kHz	2	-	-	-
	1-100 kHz	f/500	-	-	-
	100 kHz- 10 MHz	f/500	0.08	2	4
	10 MHz-10 GHz	-	0.08	2	4

Table 2.4: ICNIRP 1998 Reference Levels (General Public).

Frequency range	E-field strength (V/m)	H-field strength (A/m)	B-field (μT)	Equivalent plane wave power density S_{eq} (W/m^2)
up to 1 Hz	-	3.2×10^4	4×10^4	-
1-8 Hz	10,000	$3.2 \times 10^4/f^2$	$4 \times 10^4/f^2$	-
8-25 Hz	10,000	4.000/f	5.000/f	-
0.025-0.8 kHz	250/f	4/f	5/f	-
0.8-3 kHz	250/f	5	6.25	-
3-150 kHz	87	5	6.25	-
0.15- 1 MHz	87	0.73/f	0.92/f	-
1-10 MHz	$87/f^{1/2}$	0.73/f	0.92/f	-
10-400 MHz	28	0.073	0.092	2
400-2,000 MHz	$1.375f^2$	$0.0037f^{1/2}$	$0.0046f^{1/2}$	f/200
2-300 GHz	61	0.16	0.20	10

Some important points need to be emphasized regarding the reference levels in the tables. Here f is the frequency in Hertz. The limits of E, H and S are RMS values without perturbation. For the range of 100 kHz to 10 GHz, the average of S, E^2 and H^2 over a 6-minute period should be taken. Peaks at frequencies above 10 MHz

should not exceed 1000 × S_{eq} (32 × E-field strength). Compliance is given, If E and H are below the limit. Reference Levels are intended to be spatially averaged values over the entire body of the individual (but it must also be ensured, that local SAR is not above the limits). Because ICNIRP is a safety standard, worst case should be measured (operational state of the transmitter, local field maximum).

According to the information in Table 2.3 and Table 2.4, the change of reference electric field levels depending on frequency is given in figure 2.4 for occupational exposure and general exposure.

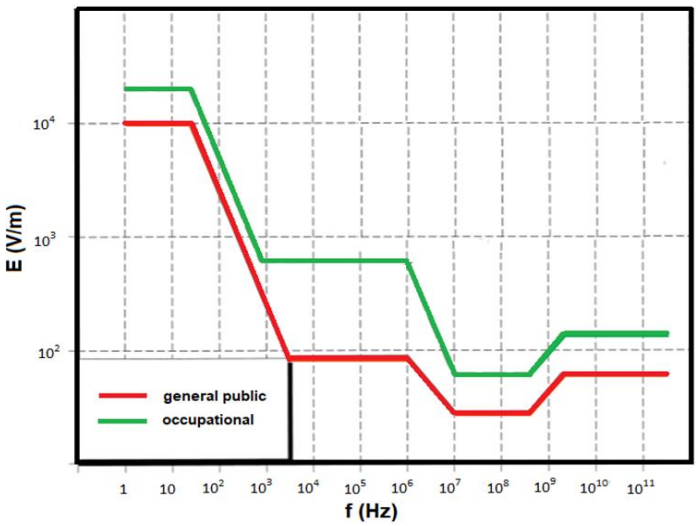


Figure 2.4: Change of ICNIRP reference levels depending on frequency.

This reference levels are determined by the Telecommunications Authority in Turkey. Firstly, "By-Law on Determination, Measurement Methods and Inspection of the Limit Values of Electromagnetic Field Force from the Fixed Telecommunication Devices Operating in the 10 kHz-60 GHz Frequency Band" was published in the Official Gazette on 12.07.2001 and its limit values were determined. The name of this authority was changed in 2008 as Information Technologies and Communications Authority (ICTA). The first regulation published was updated in different years and it was named as "By-Law on Determination, Control and Inspection of the Limit Values of Electromagnetic Field Force from the Electronic Communication Devices According to International Standards". The most recent update of the Regulation has been published in the newspaper with the number 29497, dated 9/10/2015. The limit values set out in this Regulation have been taken as the basis for the limit values set out in the ICNIRP Guideline, and in addition, a

limitation has been introduced for each base station. Accordingly, for the single device, the limit values in the ICTA regulation for general public in the frequency band of 400-2000 MHz are given as $0{,}305f^{1/2}$ V/m for electric field strength, $0.00082\ f^{1/2}$ A/m for magnetic field strength and $f/3200$ W/m^2 for power density. In the regulation, the frequency f is given in MHz. The limit values are the average values to be obtained as a result of the measurement of six minutes [42].

There are also important European and international standards for RF exposure measurements near radio base stations which have an important place in thesis work.

These standards are given in below.

- EN 50413: Basic measurement and calculation standard 0 Hz - 300 GHz (2013).
- EN 50492: In-situ measurements in the vicinity of base stations, 100 kHz - 300 GHz (2014).
- CEPT ECC Rec. 02(04): Measuring non-ionizing electromagnetic radiation (9 kHz - 300 GHz), (2007).
- IEC 62232: Determination of RF field strength and SAR in the vicinity of radio-communication base stations for the purpose of evaluating human exposure (Ed. 2.0, 2017).
- ITU-TK.100: Measurement of radio frequency electromagnetic fields to determine compliance with human exposure limits when a base station is put into service (12/2014).

3. ELECTROMAGNETIC POLLUTION MEASUREMENTS

There are some important points to consider when performing electromagnetic pollution measurements show the real exposure situation at the measurement location (including influence of attenuation and reflections). For this reason, measurements must be done during times of maximum operational state of the exposure source. If this is not possible, an extrapolation of the measurement results to maximum traffic (maximum transmitter power) should be calculated. For example, the radiated power of mobile phone base station antennas such as GSM, UMTS (3G), LTE (4G) is not constant over time, it is depending on the actual traffic. Therefore special measurement and extrapolation methods are required for an accurate exposure determination. When calculations are made, the influence of reflections and the attenuation of vegetation and buildings can only be taken into account with reduced precision and reliability. To be able to make a correct measurement, the measuring point must be chosen far enough away from humans and all conducting objects. If more than one signal is present at the measurement point, a summation of the exposure has to be performed. Due to the thermal model, the temporal average ("RMS") value (over any 6 min interval) of the exposure must be used for the comparison with the reference values. This does not mean that the measurements have to be done over a period of ≥ 6 min. If the corresponding 6 min average can be determined by the smaller time interval, also shorter measurement times are possible. But depending on the kind of measuring instrument, some special adjustments are necessary, to get the correct RMS value. A whole body average is referenced in many standards, but the maximum local exposure must also be taken into consideration.

According to the measurement method, the equipments to be used must be selected correctly. The measurement parameters of these equipments must also be in accordance with the frequency band to be measured.

These steps for required perform of accurate pollution measurement are described in detail in the methods of electromagnetic pollution measurement and GSM base station measurements parts [43, 44].

3.1. Exposure Measurements at RF Transmitter Sites

Exposure measurements from RF transmitters can be classified into three groups. The first group is measurements performed for safety check to exposure limits for workers. Places with restricted access (rooftops, platforms of radio towers) can be shown as an example. The second group is measurements performed for safety check to exposure limits for general public. Places of public access can be shown as an example. The third group is measurements performed for safety control according to exposure at places of public focus. Examples of this group can be given schools, nurseries and hospitals [21].

3.1.1. Typical Measurements of RF Exposure

RF exposure measurements can be divided into classes in terms of the location of the measurements, the purpose of the measurement, and the magnitude of the measured [45].

Type 1- Measurements of safety areas around transmitter antennas (occupational exposure): Next to radio tower platforms and base station antennas measurements can be shown as an example as in figure 3.1.



Figure 3.1: Measurements in the vicinity of a base station antennas.

Type 2- Measurements of general public exposure: Measurements performed at the balcony in the vicinity of GSM/UMTS base station antennas can be shown as an example. Measurements should be performed if calculations made theoretically at

such points yield an indeterminate result. An example image of the measurement is given as in figure 3.2.



Figure 3.2: Exposure measurements on the balcony in the vicinity of the base station antennas.

Type 3- Measurements at places of public focus: Measurements performed next to a school or hospital can be shown as an example. Measurements are informed the public about the exposure values. An example image of the measurement is given as in figure 3.3.



Figure 3.3: Exposure measurements at the playground.

Type 4- Measurement campaigns within research projects: Measurements made to create the exposure map of college campuses, a certain region or the entire city can be shown as an example.

Type 5 - Dosimetric measurements: It is widely used to measure the amount of radiation that people in radioactive environments are exposed to.

Type 6- Long term measurements: Measurements are performed a long time such as daily, weekly, monthly etc. The long-term measurement of a base station can determine the distribution of the data traffic for that base station. This distribution will give us different situations such as maximum, minimum and average value.

3.2. Electromagnetic Pollution Measurement Methods

There are two common methods for measuring electromagnetic pollution. These are the broadband measurement method and the frequency selective measurement method. These two methods have different measurement techniques, advantages and disadvantages. These are detailed in sections 3.2.1 and 3.2.2.

3.2.1. Broadband Measurement Method

Broadband measurement is the method used when the total value of the electrical or magnetic field in a very wide frequency range (eg. 100 kHz-90 GHz) is measured with an electric field probe or a magnetic field probe. The general structure of the electric / magnetic field probes used in this method is as in figure 3.4.



Figure 3.4: Electric/magnetic field probe.

The probes have three axes be about x, y and z. The value of the measurement field level of each axis is summed and given as a single value due to the isotropic property of the probe. With this method, measurements can be done very simply and quickly. However, there are some disadvantages. Since the field probes have an isotropic structure, the direction of the maximum field measured is unknown. Besides, broadband area probes are not designed to distinguish the emissions of different frequencies, such as radio, TV, radar or GSM base stations. Also, it is very difficult to compare the measured area levels to the standard limits, because there is no frequency selectivity. Probes calibrations are performed for continuous wave (CW). For this reason, probes cannot respond to the rapid changes of modulated signals. If there is more than one source in a measurement to be made in a region, the field probe will measure and collect all signals there [46]. If only one source is requested to be measured, the result of the performed measurement will not be correct, or if some of the sources do not radiate, it is impossible to determine it with the field probe [47].

For this reason, the use of field probes, that is, the broadband measurement method is not viable and should be avoided [48].

3.2.2. Frequency Selective Measurement Method

Although the broadband measurement method is fast and practical, it should not be preferred due to the disadvantages it has. In this point, frequency selective measurement method comes to the forefront. These limitations will not occur when frequency selective measurements are performed via a receiving antenna, coaxial cable and spectrum analyzer. Narrowband measurements can be performed with broadband antennas and spectrum analyzer. The spectrum analyzer can be used to display amplitude changes in a specific section of the spectrum over a very wide frequency band. This state will only give the ability to measure the desired frequency band. The antenna factor can be applied according to the measured frequency. Thus, it can be easily applied at the frequency-dependent limits for the exposure is accurately determined. In addition to these advantages, the characteristics of the antennas used as receivers in frequency selective measurements are of great importance. The directivity of the used antenna will affect the measurement method

and results. For antennas having certain directivity, the measurements must be carried out different polarizations [49].

Although frequency selective measurements have many advantages over broadband measurements which have disadvantages such as being expensive, difficult to use, and time consuming to measure [50].

3.2.2.1. Spectrum Analyzer and Antenna Characteristics for Frequency Selective Method

The components of the frequency selective measuring method are schematically shown in figure 3.5.

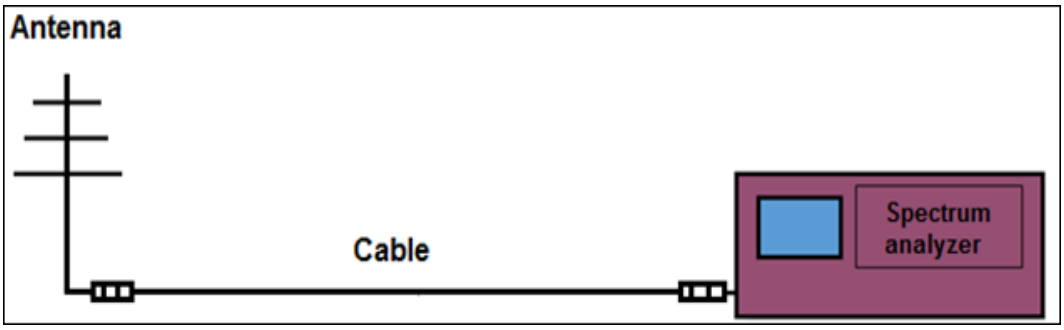


Figure 3.5: Schematic diagram of frequency selective measurement method.

In the measurements carried out with this method, the measured value is determined as seen in equation (3.1) by adding the antenna factor and the loss of the used cable to the values read through the antenna.

$$E[dB\mu V/m] = U_{Display}[dB\mu V] + K_{Antenna}[dB] + a_{Cable}[dB] \quad (3.1)$$

Where $U_{Display}$ is the displayed value by the spectrum analyzer, $K_{Antenna}$ is the antenna factor given by the calibration certificate, a_{Cable} is the cable attenuation given by the calibration certificate.

However, there are some features that should be significant for the spectrum analyzer and antenna used when performing these measurements. The following examples can be given to antennas that can be used as measurement antenna in the frequency selective method.

- Loop antenna (9 kHz - 30 MHz)
- Biconical antenna (30 MHz - 1 GHz; 800 MHz - 3 GHz)
- Logarithmic-periodic dipole antenna (300 MHz - 3 GHz)
- Horn antenna (above ≈1 GHz)

Among these, biconical antennas are the most ideal. Since the biconical antennas have an omni-directional structure, they may measure the signals from the front and back in polarity. During the frequency selective measurement, because of the fact that the direction of incidence and the polarization of the wave are not known at the measuring point, the direction of the main lobe and the polarization of the antenna must be varied to find the maximum signal level. That is, the measurements must be repeated for the x, y, and z axes. The measurement result is RMS of the values read in these polarizations. Since the horn antenna is a directional antenna, the measurement of only the x, y, and z axes will be incorrect. For an accurate measurement, the + and - directions of each axis will have to be measured. However, since the phase information of the horn antenna cannot be known, a proper summation cannot be made. If the source is known, the horn antenna is suitable for the sweep method [51].

The spectrum analyzer, another equipment used for frequency selective measurement, has some features that need to be known and set before measurements.

To these, the following examples can be given.

- Resolution Bandwidth (RBW)
- Video Bandwidth (VBW)
- Span
- Sweep time
- Measure point number
- Detector type (Peak or RMS)
- Average type
- Frequency (Start, Stop, Center)
- Measurement quantity
- Trace mode (Act, Max, Min)

These parameters must be set according to the system to be measured. In addition to these, other important parameters are RMS and Peak evaluations. The evaluation parameter is determined depends on the type of signal being measured. RMS detection is essential for the typical modern services with high signal crest factor such as UMTS (3G), LTE (4G) systems. A spectrum analyzer is calibrated to the RMS value of a non modulated sinus-shaped carrier. With other words, averaging over one period of a non modulated carrier is automatically done by the analyzer. Therefore, It must be ensured, that the measurement instrument delivers the RMS value of the exposure. However, a special RMS evaluation is not required if the signal envelope is fixed (e.g. FM radio).

3.2.2.2. Methods for Local Maximum Search

There are some techniques used to find the maximum level in pollution measurements. These are "Rotation Method", "Sweeping Method" and "Raster Method" [52, 53].

- Rotation Method

As can be seen in figure 3.6, measurements are performed three different axes (x, y, z). The sum of the power density values obtained from three different axes gives the power density value of the environment at the measured frequency value. The point where the measurement is to be performed should be at least 50 cm away from the reflective surfaces. The height values to be positioned of the measurement antenna should be determined according to a human size (eg. 0.75 m, 1 m, 1.5 m). In this measurement technique, omni-directional biconical antennas should be preferred. Measurements should not be made with directivity antennas such as a horn antenna. Measuring only the x, y, and z axes will not suffice on directional antennas. Horizontal / Vertical and ± 45 ° measurements must be made which is impossible to achieve. The RMS detector should be used in this method.

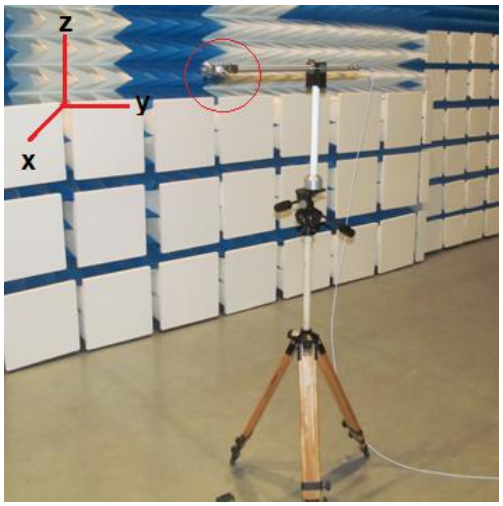


Figure 3.6: Rotation method.

- Sweeping Method

As shown in figure 3.7, the receiving antenna is manually directed and the measurements are performed by scanning the volume. During the sweeping, the antenna is randomly scanned to take measurements at different polarizations. During the measurements, a specific area at a height of at least one person's height is scanned to find the maximum level. Since the aim is to find the maximum level, the max peak detector should be used in this measurement technique. As with the rotation method, the point where the measurement is to be performed should be at least 50 cm away from the reflective surfaces. Although the sweeping method is useful, it measures a single component. In systems with 2 antennas like LTE, only one antenna is measured, so a +3 dB correction factor should be used. Unlike the rotation method, omni-directional and directional antennas can be used in this method. However, it is important to know the position of the source and the orientation of the measurements to be performed with the directional antenna.



Figure 3.7: Sweeping method.

• Raster Method

It is very suitable to perform long term measurements with isotropic probes. Because control + traffic channels must be measured together. "Long Term" measurement cannot be done only by measuring the control channel. This is because the power of the control channel is constant. Long term measurements should be made at more than one point, not at one point. In the raster method used for long term measurements, the number of points and the volume ratio vary according to different standards. The measurements are performed, 9 points in ANFR / DR-15 France standard, EN 50492, 6 points in CENELEC standard, 3 points in EN 50492, CENELEC, CEPT standards. In the IEC 62232 standard, it is carried out at different points as given in figure 3.8.

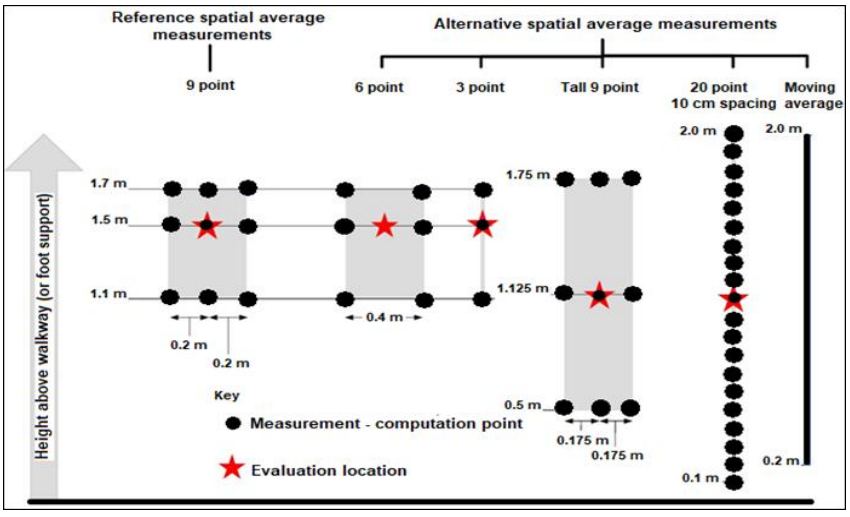


Figure 3.8: Raster method points for IEC 62232 standard.

In this method, the probe is placed at the point to be measured, the measurement is performed and the other points are passed. For each point x, y, z measurements are made and the power average is taken. The electric field and the magnetic field are found as in equation (3.2) for the n points [54].

$$E_{spatial_average} = \sqrt{\frac{\sum_{i=1}^{n} E_i^2}{n}}, \quad H_{spatial_average} = \sqrt{\frac{\sum_{i=1}^{n} H_i^2}{n}} \tag{3.2}$$

4. BASE STATIONS

4.1. Phone Cell Base Station

Base stations; consists of antenna units installed in places such as tower, mast, roof, building surfaces to spread signals with cabinet consisting of receiver, transmitter and power units and are systems that provide communication with mobile devices. Base stations are set up to communicate with mobile devices and it is not possible to establish mobile communications in places that are not covered by base stations. Mobile phones communicate with each other by signals interchange between an antenna on the phone and the antennas connected to the base station. The connection from the phone to the base station is known as the uplink, and the call is transported from user of the mobile phone [55]. Another connection from the base station to the phone is known as a downlink and is transported from the person the phone user listens to [56]. This structure is shown in figure 4.1.

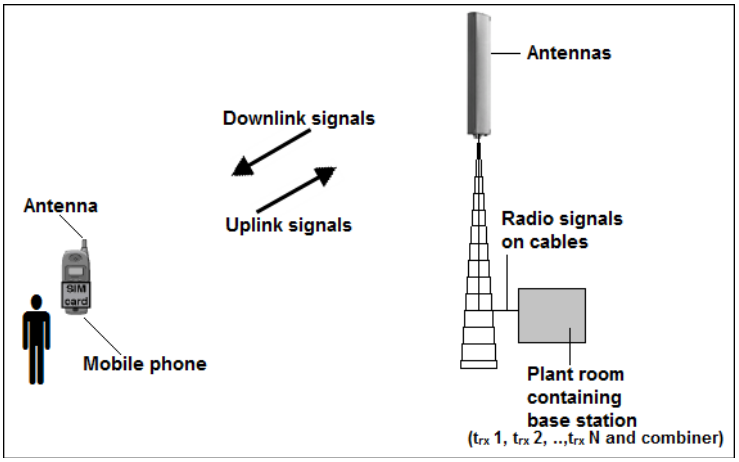


Figure 4.1: Communication of mobile phone and base station.

Mobile phone base stations are located in urban areas above ground level and on the roof of high-rise buildings. Antennas used with macro cellular base stations are often found in towers for coverage zone in rural areas. The altitude of base stations varies depending on where they are located. The height of the base stations to be installed on the roof is usually 15 m to 50 m from the ground as in figure 4.2

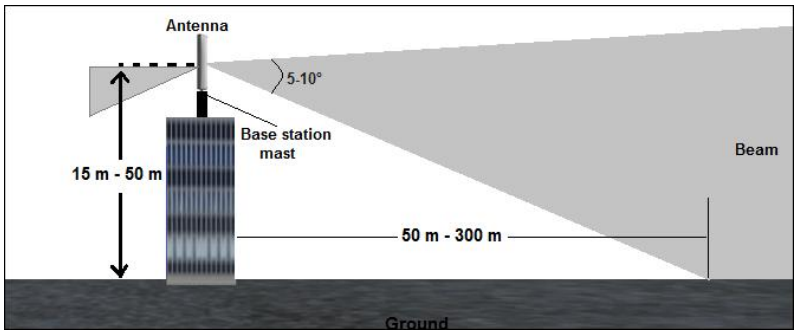


Figure 4.2: Typical antenna beam shape and heights of macro cellular base station.

The elevations of the towers built in rural areas are between 40 m and 100 m. Microcellular base stations are located near the ground because the coverage zone is several hundred meters. Each base station can reach a maximum number of users at a given time and can easily cause call blocking in some places in urban areas. To eliminate this problem, service providers have a common approach. In such cases, more base stations are installed in the affected areas. This increase in base stations causes an increase in people's anxieties about health effects [57, 58].

Base stations have a certain coverage area. When the power level of the signal received from the base stations goes to a certain distance, it falls. This situation requires the identification of distance ranges for the coverage area [59]. The area covered by base stations is defined as a cell and shown as in figure 4.3.

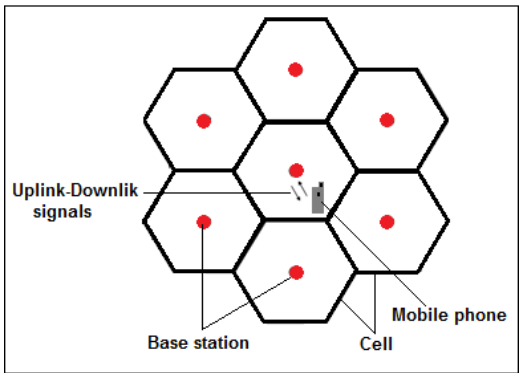


Figure 4.3: Cell structure of base station.

Base stations typically consist of three sector antennas covering area a 360 ° area which each have with an angle of 120 °. Each base station usually has 3 sector antennas, and each sector has 2 antennas with a 180 ° angle between them or 4 antennas with a 90 ° angle between them [59]. An example image of sector antennas of the base station is given in figure 4.4.



Figure 4.4: Sector antennas of base station.

The antennas in the sectors broadcast in vertical and ± 45 ° angles. The internal structure of the sector antenna is as shown in figure 4.5. It is not enough for the base stations to only have a connection between the phone and itself, at the same time that connected to the different cell calls must be connected and able to communicate. These connections are usually provided by microwave connections, except for the cable. Microwave communication between base stations is provided via dish antennas. Nowadays, important cellular mobile base stations contain GSM, UMTS (3G) and LTE (4G) communication technologies.

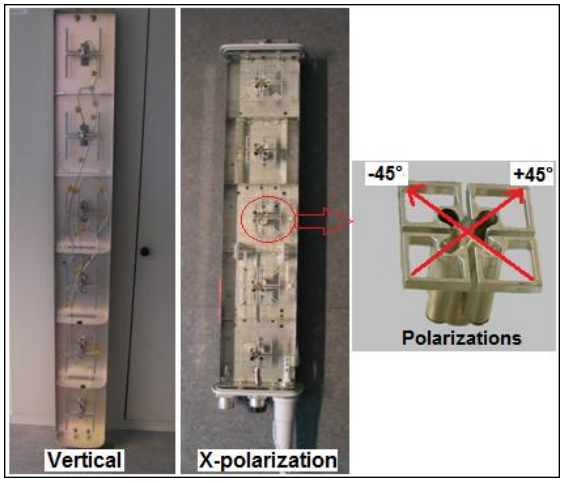


Figure 4.5: Internal structure of sector antennas.

The frequency bands in which GSM, UMTS (3G) and LTE (4G) technologies used in our country are used are determined by the "Information and Communication Technologies Authority Spectrum Management Department" (ICTA). Mobile

frequency bands used to be active in Turkey "FREQUENCY BAND USAGE DOCUMENTATION IN SATELLITE COMMUNICATION SERVICES" is located in. If requested, the inquiry can be made online from the "National Frequency Plan" page of the ICTA's website [60].

4.2. GSM Base Station Measurement for Frequency Selective Method

GSM (2G) base stations typically comprise of 3 sector antennas, which are used to transmit voice and data signals. In GSM base stations the signal of a transmitter (GMSK modulated) is divided into 8 time slots (pulse width = 577μs, pulse period = 4600μs). A minimum one time slot is used for data transmission to the phone. So theoretically a maximum of 8 phones can be served with a transmitter frequency. However, this situation can only be removed with additional frequency channels. GSM base stations in our country have the uplink and downlink frequencies as in Table 4.1. The table shows the red colour TURKCELL frequency band, the green colour VODAFONE frequency band and the yellow colour TURK TELECOM frequency band. Downlink frequencies are measured in GSM base station measurements [61].

Table 4.1: Turkey GSM (2G) band uplink and downlink frequencies.

Bands	FDD uplink (MHz)		
GSM900	880.1-890.1	890.1-902.5	902.5-914.9
GSM1800	1710.1-1745.1	1745.1-1774.9	1774.9-1784.9
Bands	FDD downlink (MHz)		
GSM900	925.1-935.1	935.1-947.5	947.5-959.9
GSM1800	1805.1-1840.1	1840.1-1869.9	1896.9-1879.9

In the standards, the exposure limits are given in terms of power flux density (W/m^2) or electric field strength E (V/m) respectively magnetic field strength H (A/m). Below 300 MHz, it is generally recommended that both the electric and magnetic field strengths are measured as the measurement point may not be in the far field and E=H*377 may not be correct. Above 300 MHz, the measurement point is likely to be in the far field of the radiator such as a GSM base station, the measurement of the electric field is sufficient as given in equation (4.1) [62].

It is specially noted that the exposure levels are always given as RMS value unless otherwise specified and exposure limits are frequency dependent. In multi-signal, multiple-frequency environments, each signal must be summed as a ratio of its corresponding exposure limit [57, 63]. The combined ratios for all signals must not exceed unity as given in equation (4.2).

$$S\left(\frac{W}{m^2}\right)=\frac{E^2(V/m)}{377(\Omega)} \tag{4.1}$$

$$\Sigma\frac{S_{meas}(f_1)}{S_{\lim}(f_1)}+\Sigma\frac{S_{meas}(f_2)}{S_{\lim}(f_2)}+\Sigma\frac{S_{meas}(f_3)}{S_{\lim}(f_3)}+\cdots\cdots\leq 1 \tag{4.2}$$

While a frequency selective receiver such as a spectrum analyzer is used, the resolution bandwidth (RBW) should be sufficient to convert the spectrum into discrete signals. For example, for GSM-based measurements, GSM uses several frequency channels with an interval of 200 kHz. Each base station provides a base channel with information about the transmission network and the base station itself. This channel uses a specific frequency band and is called the Broadcast Control Channel (BCCH). This channel is transmitted by constant field force. As shown in figure 4.6, one or more traffic channels called traffic channels (TCH) are added to transmit voice and data signals. Since operators have a high number of subscribers, it is necessary for a cell to be presented to more than one frequency. If additional TRX modules are installed and traffic channels become necessary, they are automatically activated.

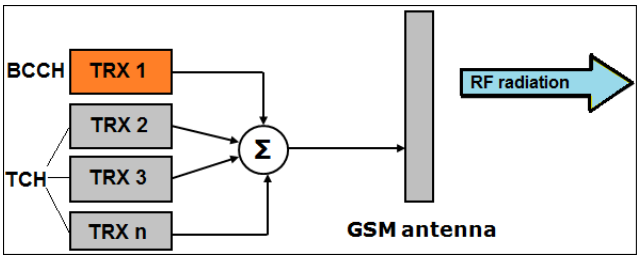


Figure 4.6: Typical channel structure for one sector GSM antenna.

The field intensity of these channels varies depending on the load and can be turned off completely. Since GSM uses a channel spacing of 200 kHz, a resolution

bandwidth of 100 kHz is sufficient to separate the spectrum into individual channels. The measurement must be performed per orientation; x, y and z axes of the antenna at any given measurement location for a frequency. The electric field intensity to be obtained for each direction is determined using the equation (4.3).

$$E_i = V_i \cdot AF \cdot C_L \cdot K_{MOD} \tag{4.3}$$

Where E_i, i is the field level oriented parallel to the antenna direction, V_i is the voltage value read on the spectrum analyzer display, AF is the antenna factor, C_L is the cable loss, and K_{MOD} is the correction factor used to compensate the response of the spectrum analyzer to the modulated signals. K_{MOD} for a specific RBW of the spectrum analyser is simply measured using equation (4.4) with the comparison of the responses of the spectrum analyser and a power meter (with a thermocouple sensor) to CW and the modulated signal under investigation [64, 65].

$$E_{control} = \sqrt{E_x^2 + E_y^2 + E_z^2} \tag{4.4}$$

Generally, measurements are simple if the respective BCCH channel frequencies are known. Even if they are not known, the field strengths of BCCH channel frequencies are easily recognizable because they are much more balanced than TCH channels. Another method of detection is to do max. hold and min. hold. While the BCCH channels are always on the spectrum analyzer display, the TCH channels are reset. First, the BCCH channel is measured as E_{BCCH} as in equation (4.3) for the components x, y, and z of the radiation. If we know that the cell is not operated at its maximum permitted power level P_{max}, E_{BCCH_Max} is calculated as given in equation (4.5). It is very clear that we should skip this step, if there is no information from the service provider about the current base station power and the maximum allowable power [64].

$$E_{BCCH_max} = E_{BCCH} \cdot \sqrt{\frac{P_{max}}{P_{BCCH}}} \tag{4.5}$$

The total field strength E_{max} of a cell that would occur if all TCHs were fully loaded is extrapolated from the field strength of the BCCH s given in equation (4.6).

$$E_{\max} = E_{BCCH_\max} \cdot \sqrt{n} \tag{4.6}$$

Where n is the total number of traffic channels, including BCCH channels. Of course, if possible, the number of traffic channels should be given by the service provider. When a GSM measurement of a particular region is performed, typically there will be three BCCH channels from one provider which covering an area of 360 ° with three antennas with each an angle of 120 °, as well as possible BCCH channels from other providers. In this case the total area exposure level for the GSM band should be as in equation (4.7).

$$E_{sum} = \sqrt{E_{\max 1}^2 + E_{\max 2}^2 + E_{\max 3}^2 + \cdots + E_{\max n}^2} \tag{4.7}$$

Where n is the number of BCCH channels. To obtain a "successful" or "unsuccessful" decision at a particular point in terms of GSM radiation, the determined E_{max} values are used as seen in equation (4.8) and the final result is expected to be smaller than "1".

$$\sum \frac{E_{\max 1}^2}{E_{\lim 1}^2} + \sum \frac{E_{\max 2}^2}{E_{\lim 2}^2} + \sum \frac{E_{\max 3}^2}{E_{\lim 3}^2} + \cdots \leq 1 \tag{4.8}$$

There are a number of factors that can cause a fault in base station measurements. One of them is "frequency hopping". Frequency hopping is only applied on the TCH's; BCCH signals are always stable in frequency. For this reason, snapshot measurements (broadband) are dangerous. It is best to measure and extrapolate the BCCH channel by frequency selective measurement method. The rotation method or the sweeping method can be used to find the maximum level by frequency selective measurement method.

4.3. UMTS (3G) Base Station Measurement for Frequency Selective Method

UMTS (Universal Mobile Telecommunications System), the third generation (3G) mobile phone standard, is widely used in Europe. The main difference between GSM (2G) is that the data transmission rate is much higher. As it needs to be capable of high-speed transmission in a short frequency band, more transmission stations than GSM are required. UMTS and GSM systems share the same antenna in a base station. This is why frequency-selective measurements are required to find the total level of exposure resulting from UMTS signals. In our country, the uplink and downlink frequencies of UMTS base stations are as in Table 4.2. The table shows the red colour TURKCELL frequency band, the green colour VODAFONE frequency band and the yellow colour TURK TELEKOM frequency band [62]. Downlink frequencies are measured in UMTS base station measurements [66].

Table 4.2: Turkey UMTS (3G) band uplink and downlink frequencies.

Bands	FDD uplink (MHz)			
UMTS-2100	1920-1940	1940-1955	1955-1970	1970-1980
Bands	FDD downlink (MHz)			
UMTS-2100	2110-2130	2130-2145	2145-2160	2160-2170

When we look at a UMTS spectrum, from the three broadcasting sectors each have at least one UMTS signal with a channel bandwidth of 5 MHz as shown in the figure 4.7. The resolution bandwidth (RBW) must be 5 MHz, unlike the GSM signal. UMTS signals are WCDMA (Wideband Code Division Multiple Access) modulated signals.

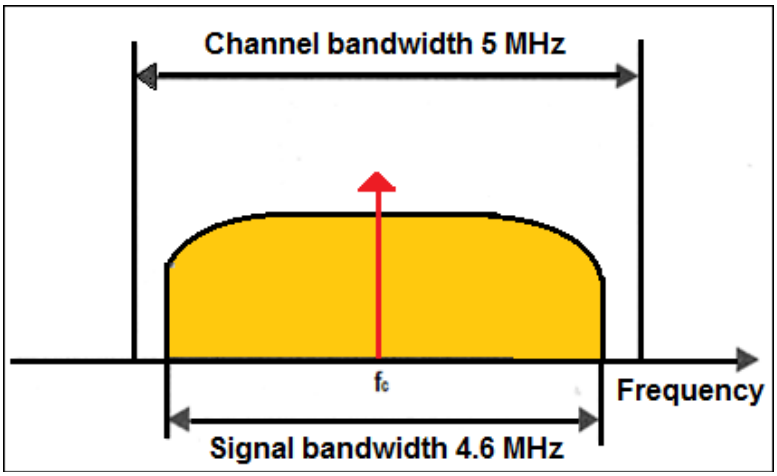


Figure 4.7: Spectrum of sample UMTS (3G) signal.

UMTS signals have two different modes. These are the FDD mode in which a single common frequency channel is used for uplink and downlink, and the TDD mode in which separate channels are used. TDD is rarely used, usually FDD mode is used. Although the UMTS spectrum in figure 1 does not seem to be separated in the spectral measurement, determining and measuring the center frequency will give the correct result in the instantaneous measurement. If the extrapolation factor (K) is known on the operator side and the measured signal is assumed to be P_{min} if the traffic load is assumed to be absent, then the maximum power P_{max} of the spectrum is found as in equation (4.9). RMS detector should be used in measurements [67, 68].

$$P_{\max} = K \cdot P_{\min} \tag{4.9}$$

If there are adjacent channels in the frequency band, it becomes impossible to distinguish them by spectral method. Another method which is more preferred than spectral measurement in frequency selective measurement method is "channel power measurement". With this method, center frequencies are used for each channel and only the measured signal is displayed on the spectrum display. Resolution bandwidth (RBW), video bandwidth (VBW), sweep time, number of point, span and detector type are set. Integration time is a very important parameter that needs to be set.

However, if there are channels in the measurement that will cause traffic such as speech channels, P_{max} will be significantly more than expected. Another method used to avoid these disadvantages of spectral measurement is "code decoding" measurements. The code decoding measures the field strength generated by the

CPICH (Primary Common Pilot Channel) signal of each antenna. The power of this signal is distributed over the full signal bandwidth of 5 MHz and is encoded by the encryption codes. If a base station is considered, the electric field for each of the 3 sector antennas belonging to this station is determined as in equation (4.10). The total level, as in equation (4.11), is obtained by the collection of the electric field levels of these sector antennas [69, 70].

$$E_{\mathrm{sec}torN} = CPICH_{\ powerN} \cdot \sqrt{\frac{P_{\max N}}{P_{CPICH(N)}}} \tag{4.10}$$

$$E_{sum} = \sqrt{E^2_{\mathrm{sec}tor1} + E^2_{\mathrm{sec}tor2} + E^2_{\mathrm{sec}tor3}} \tag{4.11}$$

Finally, the verdict of “pass” or “fail” at a particular point in terms of UMTS (3G) radiation, all other UMTS channels detected at that point are measured individually as above, and are summed as seen in equation (4.12) and the final result is expected to be smaller than "1".

$$\Sigma \frac{E^2_{UMTS_Channel1}}{E^2_{\mathrm{lim}1}} + \Sigma \frac{E^2_{UMTS_Channel2}}{E^2_{\mathrm{lim}2}} + \Sigma \frac{E^2_{UMTS_Channel3}}{E^2_{\mathrm{lim}3}} + \cdots\cdots \leq 1 \tag{4.12}$$

With the frequency selective measurement method, the rotation method or the sweeping method can be used to find the maximum UMTS signal level.

4.4. LTE (4G) Base Station Measurement for Frequency Selective Method

Newly come into used LTE (Long Term Evolution) technology is rapidly spreading and developing worldwide. Unlike GSM and UMTS, they have a higher data rate, which means they have less latency. According to other technologies, the frequency spectrum is used much more efficiently. LTE base stations in our country have the uplink and downlink frequencies as in Table 4.3. The table shows the red colour TURKCELL frequency band, the green colour VODAFONE frequency band

and the yellow colour TURK TELEKOM frequency band. Downlink frequencies are measured in LTE base station measurements [62].

Table 4.3: Turkey LTE (4G) band uplink and downlink frequencies.

Bands	FDD uplink (MHz)		
LTE-800	832-842	842-852	852-862
LTE-2600	2500-2525	2525-2540	2540-2550
Bands	FDD downlink (MHz)		
LTE-800	791-801	801-811	811-821
LTE-2600	2620-2645	2645-2660	2660-2670

When we look at the LTE spectrum, each broadcasting sector consists of 2 or 4 antennas. Signals with different channel bandwidths (1.4/ 3/ 5/ 10/ 15/ 20 MHz) and signal bandwidth (1.08 / 2.7 / 4.5 / 9 / 13.5 / 18 MHz) can be found for each sector. These signals are OFDMA (Orthogonal Frequency Division Multiple Access) modulated signals. LTE technology is also operated in two modes, FDD and TDD as it is in UMTS. However, networks are usually run in FDD mode. They have an output power of about 20 W to 50 W. This level is close to the transmitting power of GSM and UMTS base stations. In LTE base stations, the signals are provided over MIMO (Multiple Input - Multiple Output). The MIMO given in figure 4.8 is a technique for increasing the data production. The two separate physical signals are spread simultaneously over the two separate antennas in the same way at ± 45 ° in the X polarization [71].

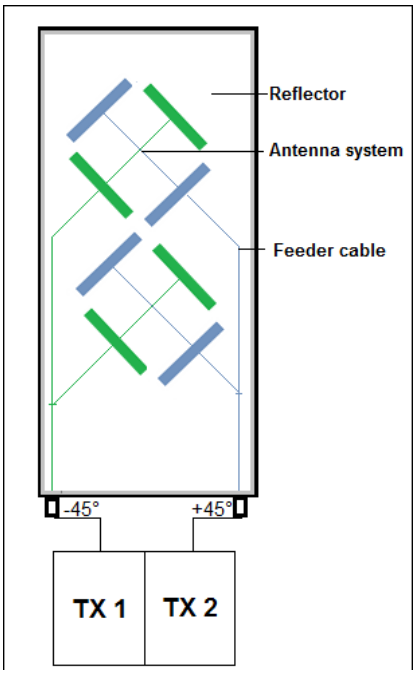


Figure 4.8: Two channels MIMO.

The smallest unit of the LTE signal is the "symbol" and is 70µs. Seven consecutive symbols form a "slot" and have duration of 0.5 ms. 20 consecutive slots form a "frame" and are 10 ms long. LTE signals have a carrier range of 15 kHz. In this case, 1 symbol and subcarrier are created Resource Element (RE) . Consecutive 12 subcarriers and 7 symbols form Resource Block (RB). In the control channel measurement in the LTE spectrum, a sample spectrum analyzer image will appear as in figure 4.9 [72, 73].

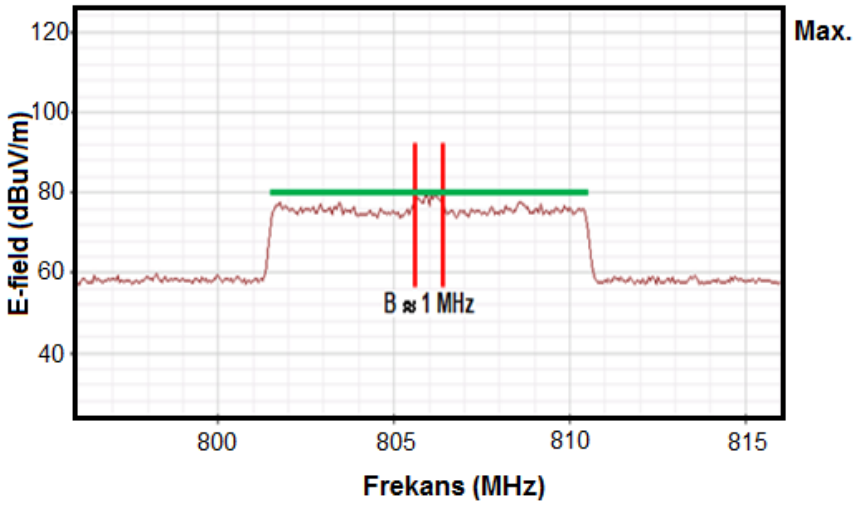


Figure 4.9: Spectrum of sample LTE (4G) signal.

Here, the ratio of the chimney bandwidth (1MHz) between the two red lines in the spectrum to the total bandwidth of the LTE signal will give us the extrapolation factor (K). From here the maximum electric field (E_{max}) will be obtained as in equation (4.13). When this calculation is made, it is necessary to set the sweep time for the RMS (average square root) detector used in the spectral measurements. The scan period is determined as in equation (4.14).

$$E_{\max}[dB\mu V/m] = E_{meas}[dB\mu V/m] + K[dB] \tag{4.13}$$

$$\text{Sweep time} = n \cdot 70\mu s \tag{4.14}$$

Where n is the number of horizontal scan points. The "channel power measurement" method can be used as in UMTS for frequency selective measurements. After focusing on the chimney, sweep method or rotation method can be applied. If there is a "boosting" on the LTE channel, the chimney is subtracted by 3 dB from the measurement. If the sweep method is used with a directional antenna, + 3 dB should be added to the result due to there are 2 antennas in LTE. This is not necessary for the rotation method. Normally, the chimney will disappear when all speech channels are full, but if there is a boosting, the chimney will not be lost even in maximum traffic. However, as in UMTS, there are certain disadvantages of spectral measurements in LTE measurements. For example, the spectral measurement will not be able to separate signals from different antennas in a base station. Even if one of the sector antennas is passive during measurement, it is impossible to determine it by spectral measurement. The extrapolation factor we use when calculating the maximum electric field level varies from the antenna to antenna.

This change in the factor will also cause mismeasurement. The method to avoid these situations is still the "code decoding" method. Looking at the LTE base stations, the Primary Synchronization Signal (P-SS), Secondary Synchronization Signal (S-SS) and Reference Signal (RS) signals are specifically encoded into the antennas. The RS signal from these signals is the most stable signal. For this reason, in an LTE channel, the RS values of each antenna are measured and proportional to the maximum power of the channel. This ratio gives the extrapolation factor K as in

equation (4.15). Using the K factor, the maximum electric field for each antenna is calculated as in equation (4.16). Total LTE will be the sum of these maximum levels [74].

$$K_i[dB] = 10 \cdot \log\left(\frac{P_{\max,i}}{P_{RS,i}}\right) \tag{4.15}$$

$$E_{i,\max}[dB\mu V/m] = E_{i,RS}[dB\mu V/m] + K_i[dB] \tag{4.16}$$

Where K_i is the extrapolation factor of the i antenna, $P_{max,i}$ is the maximum power of the i antenna, $P_{RS,i}$ is the reference signal strength of the i antenna.

5. SOFTWARE

5.1. Electromagnetic Pollution Measurement Software

This software that was developed as part of this thesis has been developed in Microsoft Visual C ++ 2012 programming language to perform frequency selective electromagnetic pollution measurements. This software is 32 bit Windows based software which can run on Microsoft Windows XP, 7 and 10 operating systems.

This software developed in the scope of the thesis can work in harmony by communicating with the laboratory device detailed in Table 5.1. If a manufacturer or model device other than the specified in Table 5.1 is desired to be used, the driver loading required for the relevant laboratory device can be made by the programmer.

Table 5.1: Laboratory device of compatible with software.

Instrument Name	Manufacturer	Type/Model	Frequency Range	Communication Port
Spectrum Analyzer	Agilent	E4402B	9 kHz – 3 GHz	GBIP (IEEE 488)

Coupled with operating the software, after the opening screen shown in figure 5.1, the main measurement screen shown in figure 5.2 is displayed.

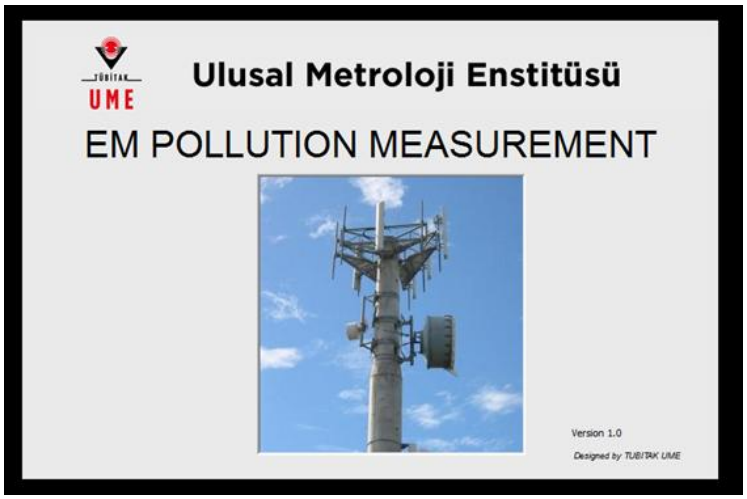


Figure 5.1: The opening screen of the software.

The main measurement screen that appears after the opening screen is as shown in figure 5.2.

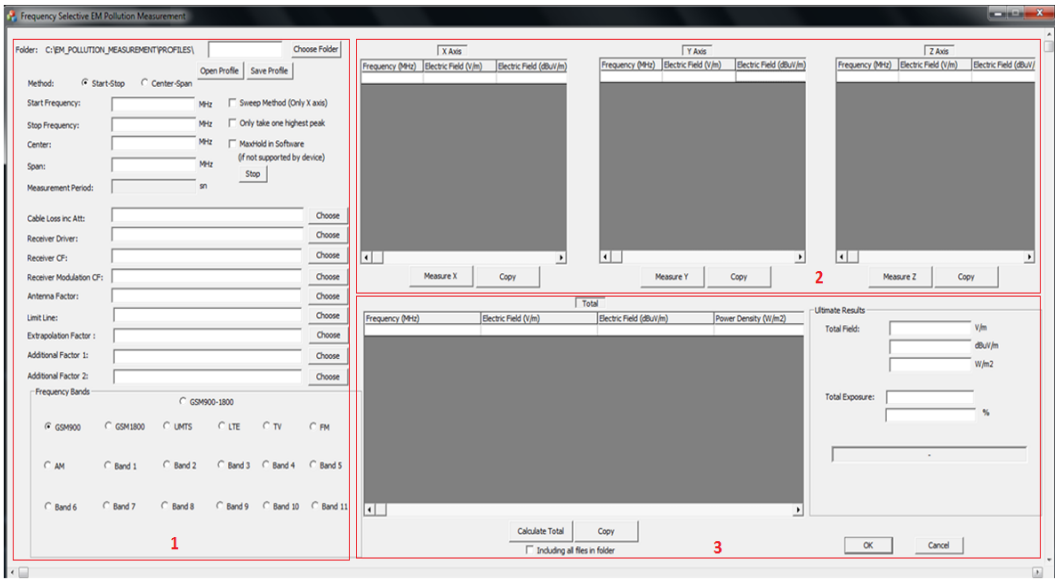


Figure 5.2: Main measurement screen of the software.

The software generally consists of three main parts. Section 1 contains the adjustments to be made before the measurements and the parameters to be entered. Section 2 contains the buttons where the commands necessary to start the measurements are given. In case of section 3, provides the calculation and display of the results obtained after the measurements are completed. In the following lines step by step sections of the software will be introduced.

- "Section 1":

This section is designed on the left side of the software main screen also the sub-section and buttons in this section are described in below.

- "Folder":

It shows where the test file is saved on the computer which will be created before the measurement.

• “Choose Folder”:

The part of the test file where the measurement results obtained during the measurement are recorded is given the desired name. In addition, a previously created file can be recalled by pressing this button.

• “Open Profile”:

The appropriate profile for the measurement to be perform is called. In addition, a previously saved measurement profile result is also brought and displayed on the software main screen with this button. The "PROFILES" screen shown in figure 5.3 contains the profiles created in the driver maker or previously saved when this button is pressed.

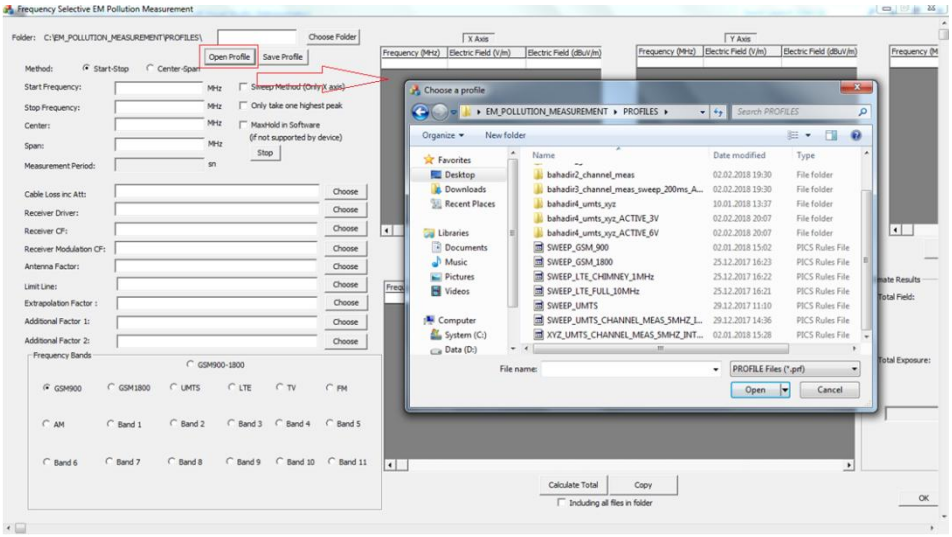


Figure 5.3: “PROFILES” screen of the software.

• “Save Profile”:

The profile that is called at the before of the measurement ensures that it is saved with the new data that is generated after the measurements are performed.

• “Method”:

During base station measurement, a start-stop or center-span is entered according to the frequency band being measured. While the start-stop frequency is selected in GSM base station measurements, center-span is selected in UMTS and LTE base station measurements.

- “Start Frequency”:

When start-stop is selected as the method, the start frequency is entered according to the frequency band to be measured.

- “Stop Frequency”:

When start-stop is selected as the method, the stop frequency is entered according to the frequency band to be measured.

- “Center”:

When the center-span is selected as the method, the center frequency of the frequency band to be measured is entered.

- “Span”:

UMTS and LTE signals have different channel bandwidths. In UMTS and LTE measurements, the span value of the spectrum to be measured is entered here from.

- “Measurement Period”:

The measurements to be performed by the rotation and sweeping methods used in base station measurements are entered here from in case there is a specific measurement time. In this case the measurement will be terminated automatically by the software. If desired, this field can be left blank and the measurement can be terminated manually.

- “Sweep Method (Only X Axis)”:

This option should be selected in the measurements to be performed via the sweeping method. When this option is checked, only the button X in the second section remains active. This option should not be selected for measurements to be performed with the rotation method.

- “Only take one highest peak”:

When this option is checked, only the maximum peak in the frequency spectrum is measured. The "Only take one highest peak" box shall be selected for measurements to be made with the channel power measurement. It can be used for sweeping method and rotation method.

• “MaxHold in Software”:

It is used when "channel power measurement" is performed in UMTS and LTE measurements. In this mode, this option is checked if the measurement device does not have the capability of maxhold. The " MaxHold in Software" box shall be selected for measurements to be made with the channel power measurement.

• “Stop”:

If a value is not entered in the "measurement period" section before the measurement starts, the measurement is stopped manually by pressing the button.

• Frequency Bands”:

Before the measurement the appropriate option for the frequency band is selected. Since more than one channel measurement is performed in UMTS and LTE base station measurements, the number of bands is created too much. Thus, different bands can be selected for each channel.

In the following sections, driver files created in "Driver Maker for EM Pollution Software" in 5.2 are called. Correction factors for the instruments and equipment used during the measurement, limits, extrapolation factors for UMTS and LTE measurements, and other additional factors are selected as appropriate. It is clicked on its "choose" button for each segment and the appropriate factor file is selected from previously created factor files as shown in Figure 5.4. Details are given in below.

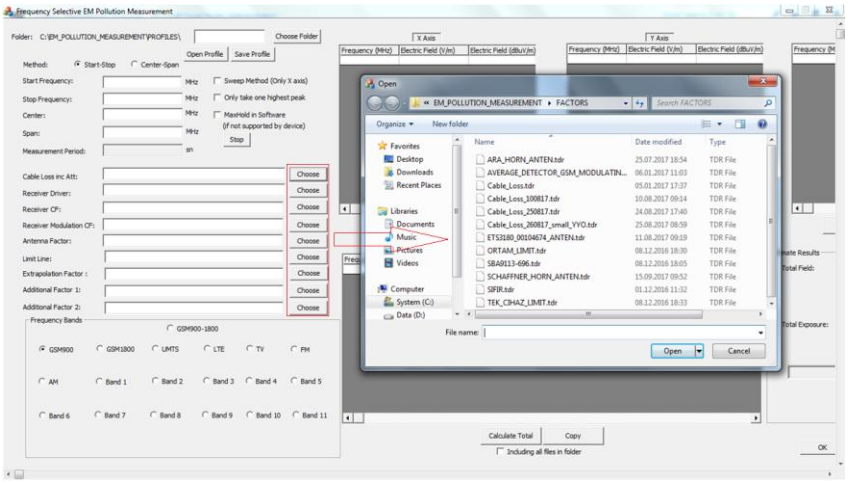


Figure 5.4: “FACTORS” screen of the software.

- “Cable Loss inc Att”:

During the measurement, the corresponding driver file created in the driver maker is called up to recover the losses caused by the attenuator and measuring cable used on the receiver antenna side.

- “Receiver Driver”:

This option calls the driver file for which the parameters of the receiver measurement device are defined. In this driver file defines resolution bandwidth, measurement time, measurement detector type and maxhold properties of the spectrum analyzer device.

- “Receiver CF”:

It provides to call the driver file containing the correction factors found in the calibration certificate of the spectrum analyzer.

- “Receiver Modulation CF”:

It provides to call the driver file containing the correction factors used by the spectrum analyzer device when analyzing the modulated signals.

- “Antenna Factor”:

The antenna used as the receiver in the pollution measurements provides the driver file containing the antenna factors included in the calibration certificate to be called up.

- “Limit Line”:

Provides the appropriate limit driver file to be called to determine if the exposure level achieved as a result of measurements made is within or out of limit.

- “Extrapolation Factor”:

In UMTS and LTE measurements, it is necessary to multiply the measured signal by the extrapolation factor (K) so that the maximum power of the spectrum

can be determined. This section provides to call the driver files of the extrapolation factors given by the operators.

- “Additional Factor 1” and “Additional Factor 2”:

Extra factors that need to be defined apart from the instruments and equipment used during the measurement can be called up from additional factor sections after the driver file has been created.

- “Section 2”:

This section is designed at the top right of the software main screen. This section contains the keys that are required to start measurements. The subsections and keys in this section are described in below.

- “X axis”:

Measurements are performed separately for each axis in the rotation method which is used in frequency selective measurements. This part contains the results of the measurements performed on the X axis. In this part, the measured frequencies are given in Hz and the measured electric field values are given in V/m, dBµV/m and W/m^2. In the sweeping method used for frequency selective measurements, only this part is actively used, while the Y axis and Z axis parts are in the passive state.

- “Measure X”:

It is used to start the measurements to be performed on the X axis. In the sweeping measurement method, only this button is actively used and the measurements are started. In the UMTS and LTE measurements, the bands are selected in order from the "frequency bands" section for each frequency band, and the measurements are performed separately by pressing the "measure X" button after each selection. As long as the button is not pressed again, the last measurement results remain in the "X axis" area.

- “Y axis”:

This part contains the results of the measurements performed on the Y axis. In this part, the measured frequencies are given in Hz and the measured electric field values are given in V/m, dBμV/m and W/m^2.

- “Measure Y”:

It is used to start the measurements to be performed on the Y axis. As long as the button is not pressed again, the last measurement results remain in the "Y axis" area.

- “Z axis”:

This part contains the results of the measurements performed on the Z axis. In this part, the measured frequencies are given in Hz and the measured electric field values are given in V/m, dBμV/m and W/m^2.

- “Measure Z”:

It is used to start the measurements to be performed on the Z axis. As long as the button is not pressed again, the last measurement results remain in the "Z axis" area.

- “Copy”:

It provides the obtained measurement results for each axis are copied from the X axis, Y axis and Z axis screens.

- “Section 3”:

This section is designed at the bottom right of the software main screen. In the frequency selective measurement method, the total exposure level according to the result of the measurements performed for each axis is calculated. In this section is where the result is shown to be successful or unsuccessful according to the limits. The subsections and keys in this section are described in below.

- “Calculate Total”:

Once the measurements on the x, y, and z axes for the rotation method are completed in sequence, the total exposure level is calculated by pressing this button.

Exposure levels are always given in as RMS value. This calculation is given by the vector sum of the RMS values of each axis. This performed calculation is given in chapter 4.2 as equation (4.7). Unlike GSM measurement in UMTS and LTE measurements, the extrapolation factor described in section 1 is used. The software performs the calculation using this factor. These calculations are given in chapter 4.3 as equation (4.11) for UMTS and in chapter 4.4 as equation (4.16) for LTE.

- "Total":

This screen is active when "Calculate Total" button is pressed. On this screen, the results of the frequencies measured separately for each axis are displayed as a single value. The electric field value of each frequency and frequency read by the receiver antenna and analyzed by the spectrum analyzer is shown as a single value. In addition, the sum of the RMS values of the electric field levels of these frequencies is given in this screen. The "Total Field" value is given in V/m, dBμV/m and W/m^2.

- "Ultimate Results":

In this window, the total electric field value obtained as a result of the calculations made by the software and therefore the total exposure level results are given. The electric field results are given separately as V/m, dBμV/m and W/m2. Total exposure is given in both % and normal. The software performs the calculation of the total exposure level using the equation (4.8) given in chapter 4.2. The total exposure level calculated at the end of the measurement is compared with the limits described in section 1 to determine whether the result is "pass" or "fail". This result is at the bottom of the "Ultimate Results" window.

- "Copy":

This button will copy the data on the "Total" screen, where the measurement results are displayed.

- "Cancel":

This button provides to exit from the software main screen.

5.2 Driver Maker for Electromagnetic Pollution Software

When the driver maker program is started, the "Choose an Instrument" screen shown in figure 5.5 is displayed after the opening screen shown in figure 5.6.



Figure 5.5: The opening screen of driver maker.

The "Choose an Instrument" screen coming after the opening screen is like the one in Figure 5.6.

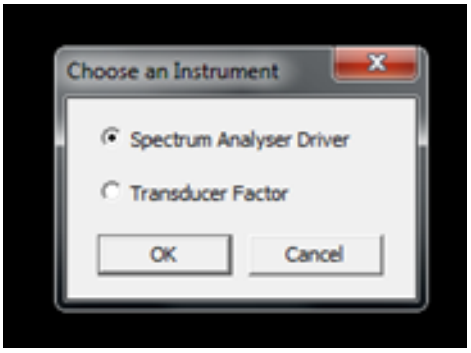


Figure 5.6: The screen of “Choose an Instrument”.

There are two different options on this screen. Details of the options are given in below.

- “Spectrum Analyser Driver”:

This option provides to create a "Receiver Driver" driver file for the spectrum analyser device. If you check this option and press the "OK" button, the screen shown in figure 5.7 will appear.

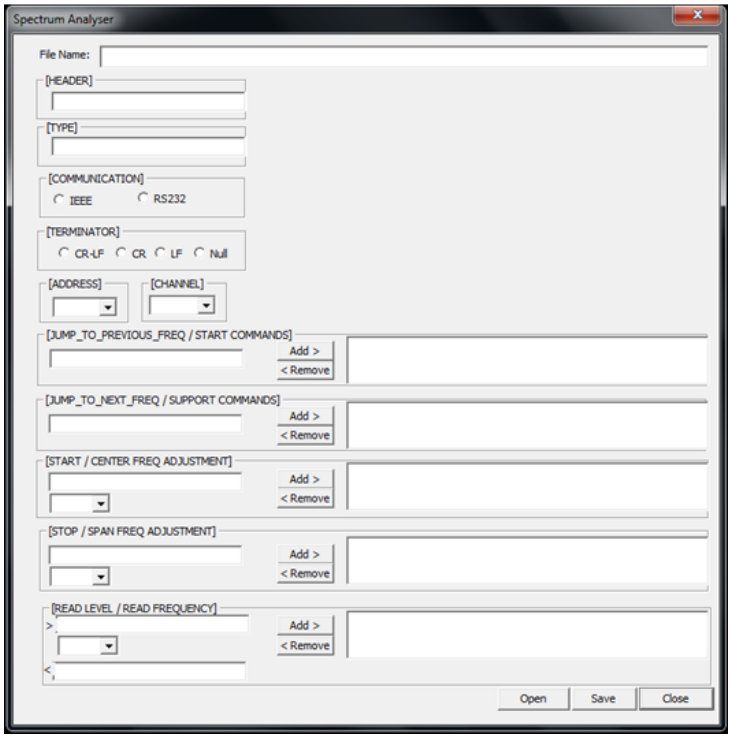


Figure 5.7: Driver maker screen of the Spectrum Analyzer.

This screen contains the sections where the spectrum analyzer makes the necessary definitions to perform its functions in the software. The details about the sections are given in below.

- "File name":

For different drivers that will be created for GSM, UMTS and LTE measurements, it is the part where different file names are given. Often the features included in the driver are written as a file name, which makes it easier during the measurements.

- "HEADER":

The title to be assigned to the driver file is defined.

- "TYPE":

The appropriate name is given to indicate the driver file type.

- “COMMUNICATION”:

The appropriate type of communication is selected for the spectrum analyzer to communicate with the software.

- “TERMINATOR”:

The appropriate terminator is selected to terminate the dataflow. "Null" is selected unless any terminator is used.

- “ADRESS”:

This option provides to be accessed the address information of spectrum analyzer by the software. The appropriate address for the device is entered here.

- “CHANNEL”:

The channel to be used by the spectrum analyzer during measurement is determined from this section.

According to the spectrum analyzer model, the commands generated using the coding language of C is entered into the required fields. The appropriate code for each field is found in the "Measurement Guide and Programming" document of the spectrum analyzer [75].

- “JUMP_TO_PREVIOUS_FREQ/STAR COMMANDS”:

This command is available to move the marker from the peak to previous left peak. CAL:MARKER:MAX:LEFT command is added to the driver using the "Add" button after it is written on the right screen . A misspelled command is removed using the "Remove" button.

- “JUMP_TO_NEXT_FREQ/SUPPORT COMMANDS”:

This command is available to move the marker from the peak to next left peak. CAL:MARKER:MAX:RIGHT command is added to the driver using the "Add" button after it is written on the right screen . A misspelled command is removed using the "Remove" button.

- “START/CENTER FREQ ADJUSTMENT”:

This command is used by the spectrum analyzer device to set the start and center frequencies. The unit of frequency is selected from the section below the command head. Usually "MHz" is used. “SENS:FREQ:START/CENTER freq” command is added to the driver using the "Add" button after it is written on the right screen . A misspelled command is removed using the "Remove" button.

- “STOP/SPAN FREQ ADJUSTMENT”:

This command provides to sets the end frequency and span value of the spectrum analyzer device. Commands are entered on the right screen, such as opening the sweep mode, sweeping and waiting for finish the sweeping, reading and printing the emergent measurement result, and disabling the signal peak. The commands are saved in the "Receiver Driver".

- “READ LEVEL/READ FREQUENCY”:

This command provides to query and read the marker frequency and amplitude. “CALC:MARKER:Y?” command is added to the driver using the "Add" button after it is written on the right screen . A misspelled command is removed using the "Remove" button.

- “Open”:

Pre-created driver files are called by pressing this button.

- “Save”:

Newly created or edited driver files are saved by pressing this button.

- “Close”:

By pressing this button, the driver maker screen of spectrum analyzer is closed.

- “Transducer Factor”:

This option is the part where the correction factors (CF), which must be used for the spectrum analyzer, equipment and limits is created. In order for the results obtained from the measurements to be accurate, these factors are entered in the

software. These factors prevent losses from the device and from the equipment. In addition, the limits used to determine the level of exposure are created in this section and contribute to the determination of the measurement result. When this option is checked and the "OK" button is pressed, the screen shown in figure 5.8 appears.

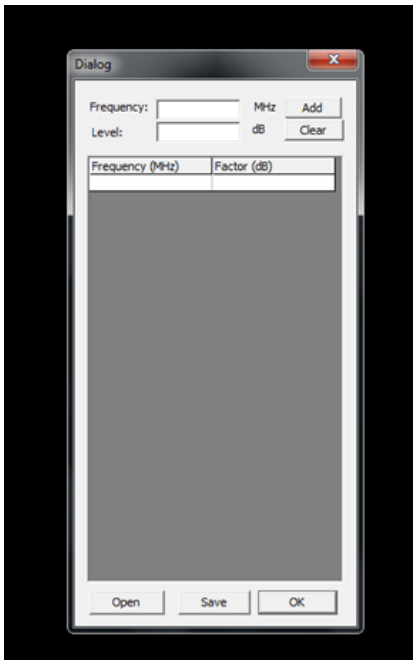


Figure 5.8: The screen of transducer factor.

On this screen, factors are created according to the information given above. Factors for each frequency are entered separately. Details about the sections on the screen are given in below.

- “Frequency”:

The factors to be used for the device, equipment or limit must belong to the appropriate frequency. In this section, the frequency values are entered for the factors. The unit of frequency is given in MHz.

- “Level”:

Factor values to be used for device, equipment or limit are entered according to the appropriate frequency. The correction factor (CF) is given in dB.

- “Save”:

The driver file created as a result of the correction factors entered depending on the frequency is saved by pressing the "Save" button. During the save, the appropriate names are given for device, equipment and limit.

- “Open”:

It provides to call a previously created CF file. When this button is pressed, the "FACTORS" screen shown in figure 5.9 appears. This folder contains pre-created files.

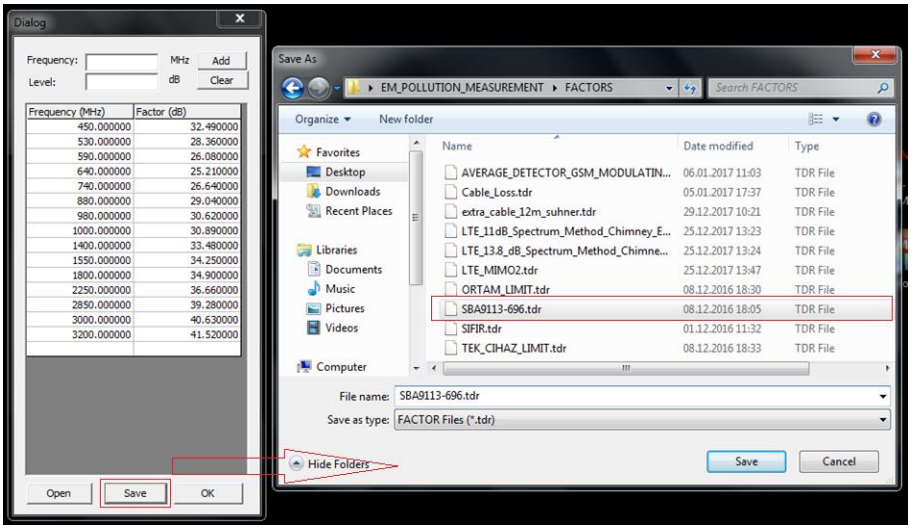


Figure 5.9: “FACTORS” folder of transducer factor screen.

- “OK”: When this button is pressed, the "Transducer Factor" screen is closed.

6. EXPERIMENTAL STUDIES

6.1. The Devices and Equipments Used

During the studies, various devices and equipments were used. Detailed information about these is given below.

- Spectrum Analyzer

During the measurements, Agilent, E4402B ESA-E model spectrum analyzer was used as the receiver device. The operating frequency range of the spectrum analyzer is between 9 kHz and 3 GHz. The spectrum analyzer driver files were prepared in accordance with the software. The driver preparation section is also integrated into the software. The spectrum analyzer device analyzes the electromagnetic field measured by the receiving antenna. The analyzed results are presented to us via software. The image of the spectrum analyzer device is given in figure 6.1. As shown, the connection between the receiving antenna and the spectrum analyzer was provided by "INPUT 50Ω". Communication between the spectrum analyzer and the computer on which the software was located was provided with "GPIB (IEEE 488)" [76].



Figure 6.1: Agilent, E4402B ESA-E model Spectrum Analyzer Device.

Although modern digital modulation schemes have noise-like characteristics, sample detection does not always provide us with the information we need. For instance, when taking a channel power measurement on a W-CDMA signal, integration of the rms values is required. During the measurements, be on the point

of being RMS detector and Peak detector, two different detector types belonging to the spectrum analyzer were used.

- RMS detector: Power (rms) averaging averages rms levels are divided by the characteristic input impedance of the spectrum analyzer, taking the square of the sum of the squares of the voltage data measured during the bucket interval, normally 50 ohms. The power average is the best to measure true average power and measure the power of complex signals measuring the power of complex signals.
- Peak detector: One way to be sure that all the sinusoids are reported at their true amplitudes is to show the maximum value that each bucket has. This is the positive peak detection mode or peak point. Peak is the default mode offered in many spectrum analyzers since the resolution provides that no matter what the ratio among the bandwidth and the bucket width, the sinusoid is not missed. However, unlike the example mode, random peaking does not give a good representation because the peak shows the maximum value in each cube and ignores the real randomness. For this reason, spectrum analyzers that use peak detection as the primary mode often provide an alternative to the sample mode.

- Signal Generators

During the measurements performed in the laboratory and office environment that three different signal generators were used. The signal generators were used to simulate the signal of 3 different frequencies in the band GSM900 and GSM1800. CW signals and GMSK modulated artificial signals were produced with signal generators. Along the measurements, Agilent, E8257C PSG (250 kHz-20 GHz) model, Agilent, E8257C PSG (250 kHz-40 GHz) model and Rohde & Schwarz SMP04 (100 MHz-40 GHz) model signal generators were used. The outputs of the signal generators used during the measurements were merged with microwave combiners. The frequency and level information in the signal generators were entered manually by the user. During the measurements, it is aimed that the levels of the 3 different signals to be displayed on the spectrum analyzer screen are close to each other. For this reason, the signal generator levels were set to proper this situation. When determining the levels, the losses caused by the cables and microwave combiners used at the outputs of the devices were accounted for. The

image of the signal generators used is given in figure 6.2 as appropriate for the above sequence of model [77, 78].



Figure 6.2: The signal generators used.

- RF Amplifier

The Amplifier Research, 200S1G4M1 model RF amplifier was used during the measurements performed in the laboratory and office environment. The operating frequency range of the RF amplifier is between 0.8 GHz and 4.2 GHz and has 200 W powers. The operating frequency range of the amplifier involves the frequencies GSM900 and GSM1800. Therefore, the same amplifier was used during the measurements performed in the laboratory and office environment. The outputs of the signal generators used during the measurements were connected to the input of the amplifier using microwave combiners. The RF amplifier was used to amplify the signal levels given by the signal generators. The RF amplifier was manually controlled during measurements. Before starting the measurements, the antenna gain was set to 100% as the rate and it was used in that way. At first the RF amplifier in the "STANDBY" position was set to "OPERATE" position during the measurements. The image of the used RF amplifier is given in figure 6.3 [79].



Figure 6.3: Amplifier Research, 200S1G4M1 model RF Amplifier Device.

• Power Splitter

The two Agilent, 11667B model "power splitter" was used in the laboratory and office measurements to could give output of 3 different signal generators as a single output. The power divider is connected to each other as shown in figure 6.4.



Figure 6.4: Agilent, 11667B model Power Splitter.

The two signal generators used are passed through the power divider twice according to the structure, while the other signal generator is passed once. The two signal generators used were passed over through the power divider twice, while the other signal generator was passed over once. Each power divider caused a 6 dB loss in the system. Therefore, these losses were considered when the signal producer levels are determined.

• Receiving Antennas

The Schwarzbeck, SBA9113 model mini-biconical antenna and Schaffner BHA9118 model horn antenna were used as the receiver antennas during the measurements performed in the laboratory and office environment. During the base station measurements, only the mini-biconical antenna was used. The operating frequency range of the mini-biconical antenna is 500 MHz - 3 GHz while the operating frequency range of the horn antenna is between 1 GHz and 18 GHz. Although a mini-biconical antenna with an omni-directional structure was identified as a measurement antenna, measurements were repeated with a horn antenna to demonstrate the effect of antenna directivity on pollution measurements. Between these two antennas were compared according to the measurement results performed

in the laboratory and the office. The images of the antennas are given in figures 6.5 and figure 6.6 respectively [80, 81].



Figure 6.5: Schwarzbeck, SBA 9113 model Mini-Biconical Antenna.

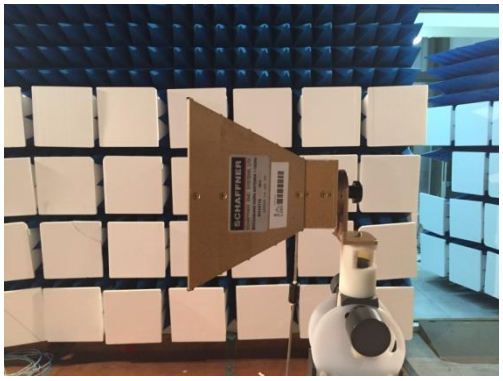


Figure 6.6: Schaffner, BHA9118 model Horn Antenna.

- Transmitting Antennas

The two pieces ETS-LINDGREN 3115 horn antennas were used as transmitter antenna during the measurements performed in the laboratory and office environment. The operating frequency range of the antennas is between 750 MHz and 18 GHz. The signals generated by the signal generator were amplified by RF amplifiers and then transmitted through the transmitting antennas. The image of the transmitting antennas is given in figure 6.7 [82].



Figure 6.7: ETS-LINDGREN, 3115 model Horn Antenna.

- Broadband Field Probes

During the electromagnetic pollution measurements, two different broadband field probes were used to performed broadband measurements. During the pollution measurements of the laboratory and office environment, ETS-LINDGREN, HI6053 model probe (10 MHz - 40 GHz) was used while the NARDA, NBM 550 model electromagnetic field measurement system and NARDA, EF 0691(100 kHz - 6 GHz) model electric field probe were used during the measurements of the base station. The images of broadband area probes are given in figure 6.8 and figure 6.9 [83, 84].



Figure 6.8: ETS-LINDGREN, HI6053 model Broadband Field Probe.



Figure 6.9: NARDA, NBM 550 model Electromagnetic Field Measurement System and NARDA, EF 0691 model Broadband Field Probe.

- Cables

During the laboratory, office and base station measurements, RF cables were used in different sizes and structures. The details of the cables used were given in the sections of explained the experimental setups.

6.2. Experimental Setups and Measurements

In this research, we developed a piece of "Electromagnetic Pollution Measurement" software given screen shot in chapter 5.1, figure 5.1 by using Visual C++. The software is not only designed for the measurement of GSM, UMTS (3G) and LTE (4G) frequencies which are the contents of this work at the same time which is designed with the ability to measure TV, radio and radar etc. signals as frequency selective. The software is able to control any spectrum analyzer as long as its driver file is prepared accordingly.

The driver preparation section is also integrated into the software. Spectrum analyzer measurement parameters such as resolution bandwidth (RBW), detector type and average type were adjusted inside these separate driver files and recorded in measurement profiles. Parameters such as start frequency, center frequency, stop frequency, antenna factor, modulation response correction factor, cable losses, exposure limits were entered from on the software main screen after they were created in the driver maker. The software was designed in accordance with the measurements to be performed by the rotation method and sweeping method

described in chapter 3.2.2.2. Both methods can be used to perform "spectral measurement" and "channel power measurement". In the measurements carried out by the rotation method, the software is able to measure x, y and z separately and perform vector summation for each detected frequencies. During a measurement for an axis, the software is able to detect every peak which exceeds noise level by a pre-defined threshold (typically 6 dB) and measure the detected peaks one by one. For a given frequency range, before starting any measurement, the software firstly seeks the first peak on the screen and measure it. Thereafter, the software seeks and detects the next peak that exceeds the noise level by the predefined threshold and measures it similarly. The procedure continues as far as the last detected peak on the spectrum analyse screen in the same manner.

Thereafter, the same procedure is applied to the other orientations of the receiving antenna (Y and Z) in turn. Finally, the total field level and total exposure level can be calculated for a specific frequency band for example only for the GSM900 band for all the detected peaks or, if requested, all the measured frequency bands such as GSM, LTE, TV,...etc can be integrated into the calculation in order to obtain an overall exposure level. Finally the verdict of “pass” of “fail” is reached by the software itself based on the loaded limit lines by using equation (4.8). The spectral measurement perform by the sweeping method is similar to the rotation method, but with the difference of rotation method, the operations performed separately for the x, y, z axes are performed in one operation with the manual scanning. Spectral measurement is suitable for measuring GSM frequency channels. However, another method which is more preferred than spectral measurement in frequency selective measurement method is channel power measurement method. In the channel power measurement method, only the signal to be measured is displayed on the spectrum screen by entering the frequency band of the channel to be measured, start, end and center frequencies.

The resolution bandwidth (RBW), video bandwidth (VBW), sweep time, measure point, span and detector type are adjust according to the frequency channel structure to be measured. Also the "integration time" is a very important parameter that needs to be adjusted. For measurements to be performed with channel power measurement the checkboxes "Only take one highest peak" and "MaxHold in Software" should be selected on the software main screen before the measurement starts. When the measurement is started, the software is detected and measures the

maximum peak point on the screen for a specified frequency range. If no value is entered in the "Measurement Period" section of the software main screen before the measurement starts, the measurement should be finished after confirming that the maximum peak is detected.

Finally, the total field level and total exposure level are calculated for the specific frequency band. According to the measurement result, the verdict of "pass" or "fail" is reached by the software itself based on the loaded limit lines by using equation (4.12) as in spectral measurement. The channel power measurement is suitable for measurement of UMTS (3G) and LTE (4G) frequency channels.

6.2.1. Laboratory and Office Environments Measurements

As a first step of the studies, broadband and frequency selective measurement methods were compared in laboratory and office environments. The aim was to evaluate the performance of our measurement system and the software before the base station measurements and to make accurate measurements during field measurements. "Semi Anechoic Chamber" (SAC) in TÜBİTAK UME electromagnetic laboratory was used as laboratory environment. Office environment measurements were also carried out in an office belonging to TÜBİTAK UME electromagnetic laboratory.

In this research, to be able to compare the broadband and frequency-selective measurement methods, we produced a variety of artificial signals at different frequencies by using three signal generators and some RF combiners which merge the signals and divert them to the input of the amplifier. After the amplifier, the amplified summed signal was connected to a transmitter horn antenna to produce the required field level. As a receiving antenna, we utilized a mini-biconical antenna (Schwarzbeck SBA 9113) which has an omni-directional radiation pattern and which covers the frequency range from 500 MHz to 3 GHz at a distance of 3 m from the transmitting antenna. The heights of the antennas were set to 1.5 m from the floor. Screened RF cables were used at the input of the receiver and transmitter antennas, also ferrite beads were placed at 30 cm intervals on the cable on the receiver antenna side. The aim was to prevent the interference which was caused by the reflections in

the environment on the cable. The schematic view of the setup is shown in figure 6.10.

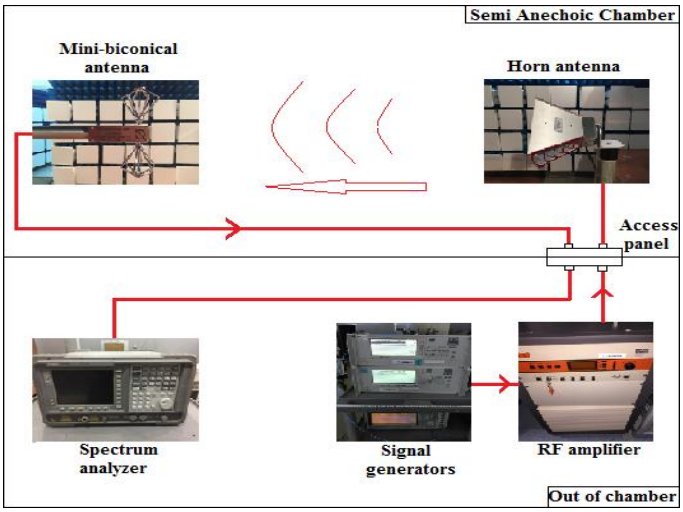


Figure 6.10: Schematic view of measurement setup established with the receiving mini-biconical antenna.

The same measurement setup was established as shown in figure 6.11 used the receiver horn antenna (Schaffner, 9118) which was directional in order to show the impact of the antenna direction on the measurements results. In the measurements, the receiving antenna was positioned in X, Y and Z axes in turn to be able to measure each axis separately. In addition, in all the measurements, to produce radiation in the X,Y and Z axes on the receiving antenna instead of only one axis, the transmitting antennas were rotated by around 45° degree.

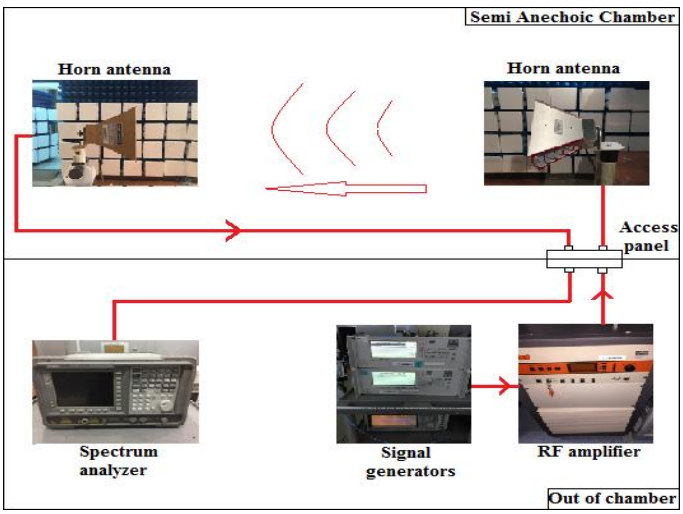
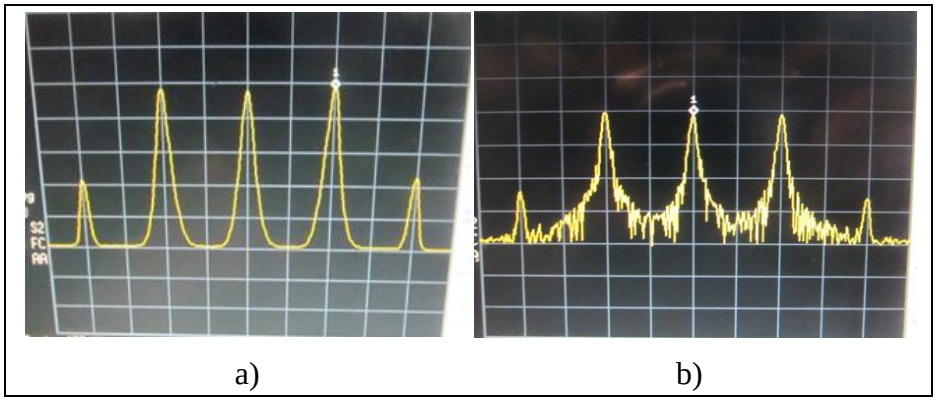


Figure 6.11: Schematic view of measurement setup established with the receiving horn antenna.

The measurements were started in the laboratory environment (semi-anechoic chamber). As a first step, to simulate the measurements in the GSM900 downlink band, three different CW signals and pulse modulated signals were produced and merged with microwave combiners were adjusted to 935 MHz, 940 MHz and 945 MHz respectively. An example of the spectrum analyzer screen images of artificially generated CW and pulse modulated signals in the GSM900 band was given in figure 6.12.



a) b)

Figure 6.12: GSM900 band, a) CW signals, b) Pulse modulation signals.

Firstly, the signal levels of the signal generator were determined so as to generate an electric field of around 15 V / m to 25 V / m on the broadband field probe for CW signals. Frequency and level information of signal generators are given in Table 6.1.

Table 6.1: Frequencies and levels of signal generators for single source.

Band	GSM900			GSM1800		
Signal generator	Agilent (40 GHz)	R&S SMP 04	Agilent (20 GHz)	Agilent (40 GHz)	R&S SMP 04	Agilent (20 GHz)
Frequency (MHz)	935	940	945	1810	1840	1860
Level (dBm)	- 8	- 8	- 14	- 10	- 10	- 16

Afterwards, without changing anything in the setup, start and stop frequencies were entered and the necessary drivers were loaded into the developed software. The frequency-selective measurements were performed with a RBW of 200 kHz, a measurement time of 20 seconds by using the mini-biconical antenna and horn

antenna in turn. During the measurements, two prominent detector types, the max peak and RMS detectors were used which are widely used in pollution measurements. The images related to the measurement setups are given in figure 6.13 and figure 6.14, respectively.

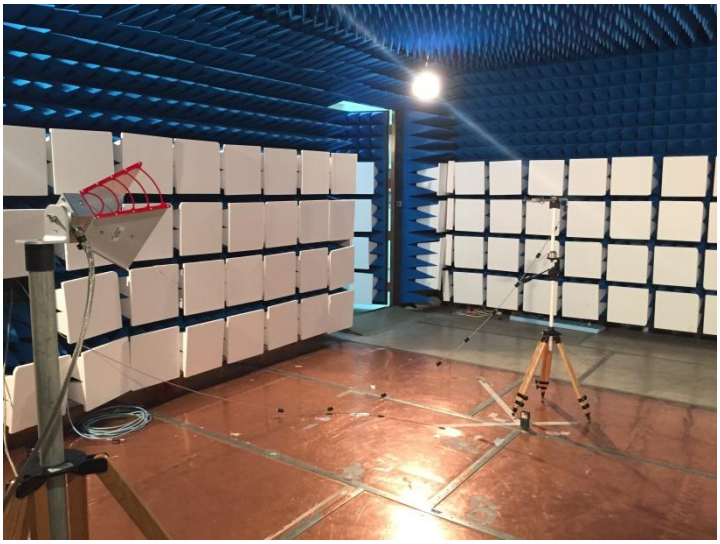


Figure 6.13: Measurement setup established with the receiving mini-biconical antenna in the laboratory environment.



Figure 6.14: Measurement setup established with the receiving horn antenna in the laboratory environment.

After each measurement made with the receiving antennas, ETS_LINDGREN HI 6053 broadband electric field probe was positioned at the same point, as shown in figure 6.15, and the results of these two methods were compared for CW signals. Then, in order to simulate GSM radiation and complex GMSK (Gaussian Minimum

Shift Keying) modulation, these three signals were applied with pulse modulated (pulse width = 577μs, pulse period = 4600μs) at the same frequencies and a same comparison was also repeated in this case [85]. All these measurement steps were also applied to the GSM1800 band at the frequencies 1810 MHz, 1840 MHz and 1860 MHz. The signal generator frequency and level information for the GSM1800 band are given in Table 6.1 above.

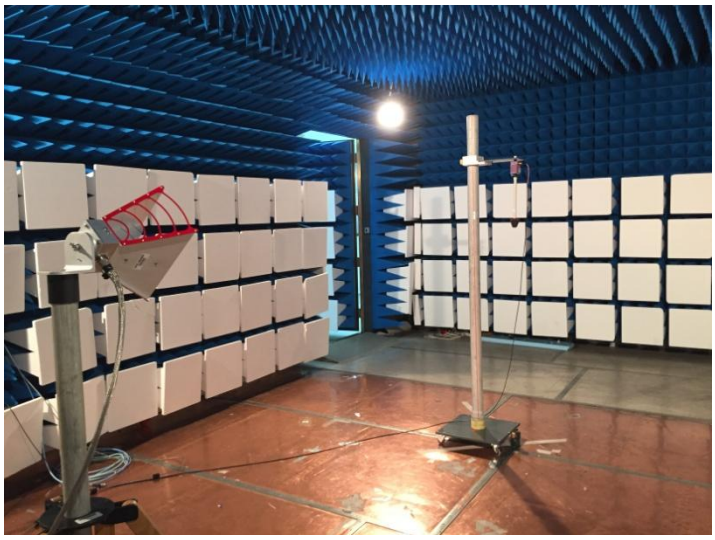


Figure 6.15: Measurement setup established with the broadband field probe in the laboratory environment.

As a second step, in order to simulate a multi-source environment and check the performance of the omni-directional receiving biconical antenna and the highly directive receiving horn antenna, two transmitter antennas were placed in the different positions of the chamber to create an environment with multi-sources which produce radiation coming from different directions of the receiving antenna as seen in figure 6.16.

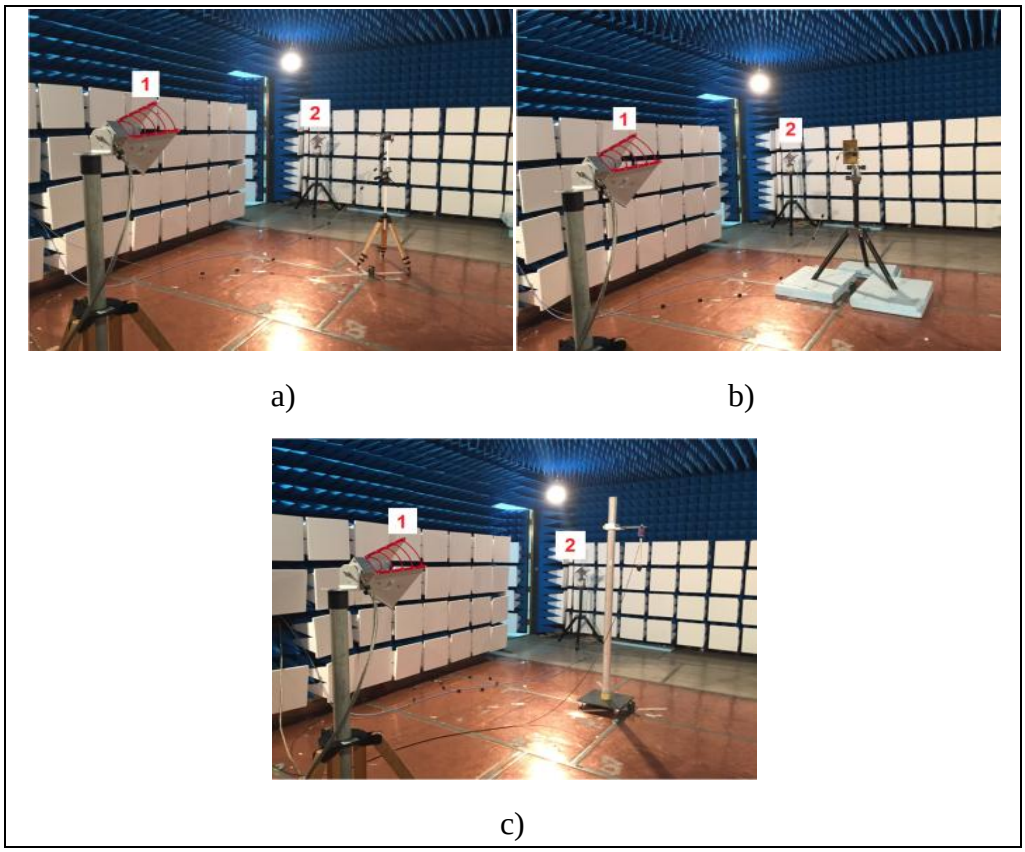


Figure 6.16: The measurement setup established with double source in the laboratory environment, a) the receiving mini-biconical antenna, b) the receiving horn antenna, c) the broadband field probe.

In this setup, two of the signal generators were connected to the number 1 transmitting antenna and another number 2 transmitting antenna. The shielded RF cable was used at the entrance of the number 2 transmitter antenna. The target electric field was adjusted to be between 15 V / m and 25 V / m as in the previous case. The frequency and level information of the signal generators in the system in which the double source is used are given in Table 6.2. The same comparison was made also in this step and the effects of the antenna directivities on the measurement performance were clearly demonstrated.

Table 6.2: Frequencies and levels of signal generators for double source.

Band	GSM900			GSM1800		
Signal generator	Agilent (40 Hz)	Agilent (20 GHz)	R&S SMP 04	Agilent (40 Hz)	Agilent (20 Hz)	R&S SMP 04
Frequency (MHz)	935	940	945	1810	1840	1860
Level (dBm)	- 15	- 9	- 5	- 17	- 11	- 12

Finally, we repeated the comparison between the frequency-selective and broadband measurements in a reflective office environment as seen in figure 6.17 and figure 6.18 to check the influence of ambient reflections on the measurement results and the comparison.



Figure 6.17: Measurement setup established with the receiving mini-biconical antenna at the office environment.



Figure 6.18: Measurement setup established with the broadband field probe at the office environment.

The heights of the antennas, the distance between the antennas, the equipment and devices used were chosen to be same with the laboratory environment. In the measurements, also three signal generators were connected to the antenna from a single output. The target electric field value to be generated in the environment was determined in a similar way with the laboratory environment. The frequency and level information of the signal generators used to simulate GSM900 and GSM1800 bands are given in Table 6.3.

Table 6.3: Frequencies and levels of signal generators for office environment.

Band	GSM900			GSM1800		
Signal generator	Agilent (20 GHz)	R&S SMP 04	Agilent (40 GHz)	Agilent (20 GHz)	R&S SMP 04	Agilent (40 GHz)
Frequency (MHz)	935	940	945	1810	1840	1860
Level (dBm)	- 4	- 4	- 10	- 10	- 10	- 16

6.2.2. Base Station Measurements

After the measurements performed in the laboratory and office environments, frequency selective measurement method and broadband measurement method were compared in the vicinity of a base station belonging to TURKCELL operator. The base station where the measurement was performed is located on the roof of

TÜBİTAK UME building. The location on the earth of the measurement point was obtained through the Google Earth program, depending on the GPS coordinates. The latitude and longitude coordinates of the measurement point are 40,78 and 29,44 respectively. The location of the base station and the measurement point on the earth is given in figure 6.19.

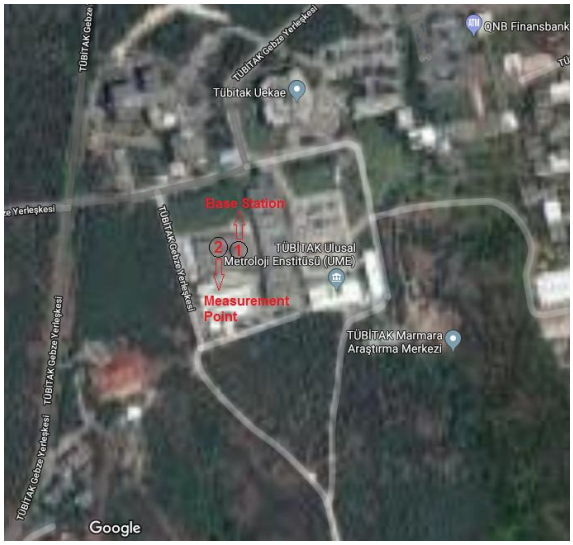


Figure 6.19: The location of the measurement point on the earth.

The base station has a single sector antenna as shown in figure 6.20. For this reason, the measurements were performed on the side where the maximum power density as to the position at which the sector antenna was directed.



Figure 6.20: The base station of single sector antenna.

Before starting the measurements, the base station spectrum was investigated to determine which ones radiated of from the GSM, UMTS (3G) and LTE (4G) broadcasts of the sector antenna using the spectrum analyzer and receiver mini-biconical antenna. As a result of the spectrum analyzer screen image given in figure 6.21 was obtained. When we looked at the spectrum, it was seen that UMTS (3G) downlink band power density belonging to TURKCELL operator in the frequency range 2110 MHz - 2130 MHz was dominantly. Besides, it has been determined that GSM900 band is in the frequency range 935.1 MHz - 947.5 MHz, but there is no broadcast in the LTE (4G) frequency band except very low power density at 1800 MHz band. This situation was shown us that the base station was established for UMTS (3G) broadcasting. At the lower frequencies in the spectrum, it was seen that broadcasts belonging to radio, TV and radio frequency channels that were coming from outside the base station broadcasting were seen.

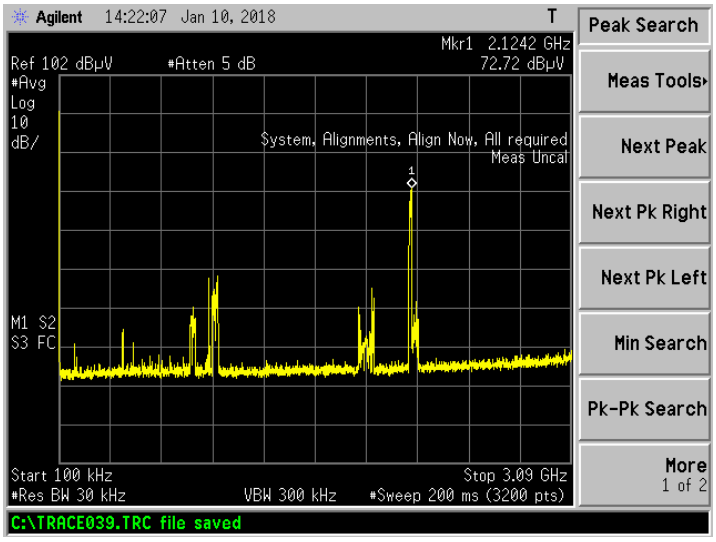


Figure 6.21: The spectrum analyzer screen for broadband.

In the spectrum, the contribution of the GSM900 frequency band in terms of dBµV to the electromagnetic pollution in the environment was found to be very low when compared with the power of the UMTS (3G) frequency band. When we look at it proportionally, it is calculated that the GSM frequency band close to the ambient noise level is about 1.4% of the contribution to the electromagnetic pollution in the environment. Numerical values giving this ratio are given in the measurement results section. In order to focus on the UMTS (3G) spectrum, the start and stop frequencies of the band were entered via the spectrum analyzer. In order for the UMTS (3G)

spectrum to be clearly visible on the screen, the resolution bandwidth (RBW) adjusted 30 kHz was obtained and the screen image given in figure 6.22 is obtained. The resulting spectrum has shown us that there are four different UMTS (3G) channels with a bandwidth of 5 MHz broadcasting in this frequency band.

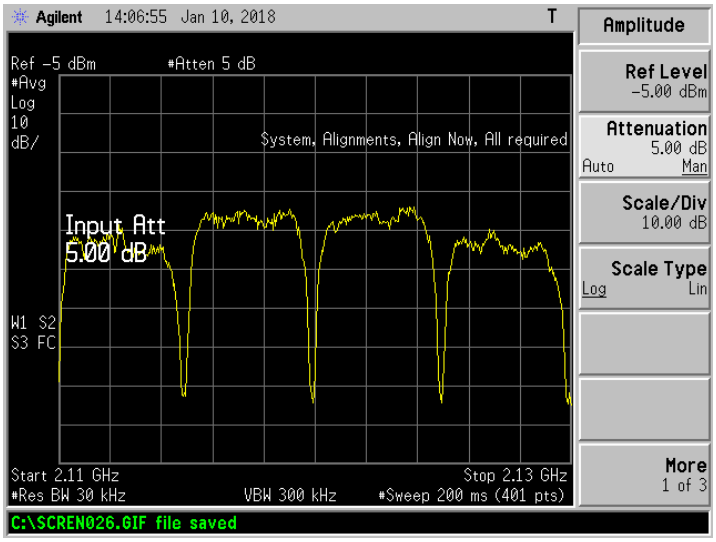


Figure 6.22: Channels of UMTS (3G) frequency band.

Base station measurements were started by measuring the channels of the UMTS (3G) spectrum. Thereafter, the GMS900 frequency band was measured and its contribution to the electromagnetic pollution in the environment was investigated. The measurements were carried out using the frequency selective measurement method and the broadband measurement method, respectively. After the measurements were completed, the results obtained by these two methods were compared. At the same time, frequency selective measurements were performed using two different measurement techniques. Thus, make another comparison was performed between the results of these two measurement techniques.

6.2.2.1. Comparison Between Broadband and Frequency Selective Measurements for UMTS (3G) Band

6.2.2.1.1. The Sweeping Method

Base station measurements were started using broadband measurement method. As receiver NARDA, NBM 550 model electromagnetic field measurement system device and NARDA, EF 0691 model electric field probe were used in broadband measurement. After the electric field probe was operated, it is set to "Max Hold" position for measurement. Thereafter, the measurement was performed with the broadband field probe at the region where the maximum power density was obtained according to the directed position of the base station sector antenna. It was strived to determine the maximum level by performing a random scanning with the field probe in the region where the measurement is performed. The scanning was continued for an average of 6 minutes. When observed that there is no change in the field probe screen, the measurement was finished and the value on the screen was recorded as the maximum electric field level. The setup in which the measurements were carried out with the broadband field probe during broadband measurement is given in figure 6.23.



Figure 6.23: UMTS (3G) measurement setup for broadband measurement.

Thereafter, we started the frequency selective measurements for we make comparisons with broadband measurement results. During the measurements, the

sweeping and rotation measurement methods were used as measurement techniques. Before starting measurements, the spectrum analyzer and software computer were located at the as remotest as possible point according to the direction the base station was broadcasting. The mini-biconical antenna (Schwarzbeck SBA9113) used as the receiving antenna was connected to the input of the spectrum analyzer device with a screened RF cable with a total length of 15 m. The 5 m of the cable used was a shielded and ferritic cable used in laboratory measurements. The remaining 10 m was added to the end of the other cable with an N female to N female connector, as shown in figure 6.24. The emergent cable loss was measured with the added cable and entered the software via driver maker.



Figure 6.24: N female to N female connector.

During measurements, "channel power measurement" method was used, in which center frequencies are used for each channel and only the measured signal is displayed on the spectrum display. Measurements were started using sweeping measurement method. Firstly, the center frequencies of the four channels in the UMTS (3G) spectrum given in figure 6.22 were determined and recorded separately. These frequencies are 2112.405 MHz, 2117.405 MHz, 2122.405 MHz and 2127.405 MHz, respectively. Thereafter, the software was operated and the "SWEEP_UMTS_CHANNEL_MEAS_5MHZ_INTEGRATION.prf" profile created for this method was called. Here, the driver files containing the measured cable losses, antenna factors, limit values, and the measurement parameters of the spectrum analyzer to be used during the measurement were loaded into the profile. The parameters and values used in UMTS (3G) measurement in the spectrum analyzer driver are given in Table 6.4.

Table 6.4: Spectrum analyzer driver parameters for UMTS (3G) measurement.

Detector Type	RMS detector (root mean square, max hold)
Resolution Bandwidth (RBW)	30 kHz
Video Bandwidth (VBW)	300 kHz
Sweep Time	300 ms
Span	5 MHz
Measurement Points	3200
Attenuation	5 dB

Firstly, the name was given for the file where the measurement is to be saved. Then the center frequency of the first channel in the UMTS (3G) spectrum was entered. "Band 1" was selected from the "Frequency Bands" section of the software main screen. Measurement was initiated by pressing the "Measure X" button which is the only active button to be used to start measurements within the profile. Started together with measurement, the scanning was performed with receiving mini-biconical antenna was directed as manually. During the scanning, measurements were performed at different polarizations of the antenna and using an RMS detector. In order to find the maximum level, a large region was scanned at an average human height and in the direction that the sector antenna was broadcasted. During the measurement, the screen of the "Band 1" channel with 5 MHz channel bandwidth on the spectrum analyzer screen is given in figure 6.25. When the maximum power density of Band 1 was determined, the measurement was completed.

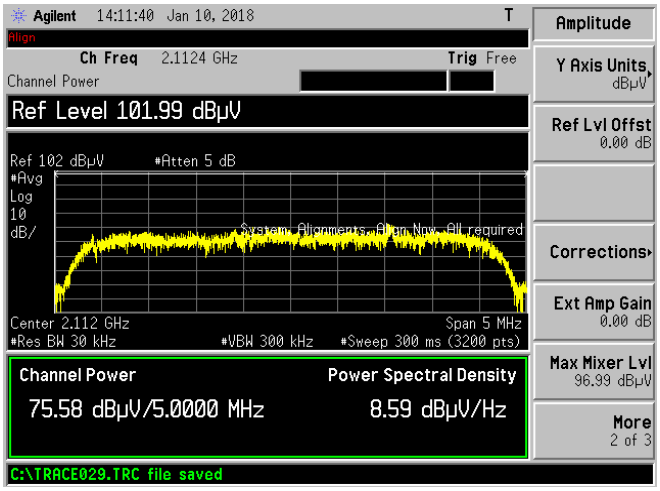


Figure 6.25: Channel power measurement screen of Band 1.

After the first channel measurement was completed, the center frequency of the second channel was entered on the software screen and measurement was started by selecting "Band 2" and performed in a similar way. During the measurement, the screen of the "Band 2" channel on the spectrum analyzer screen appeared as in figure 6.26. The measurement was complete when the maximum power density of Band 2 was determined.

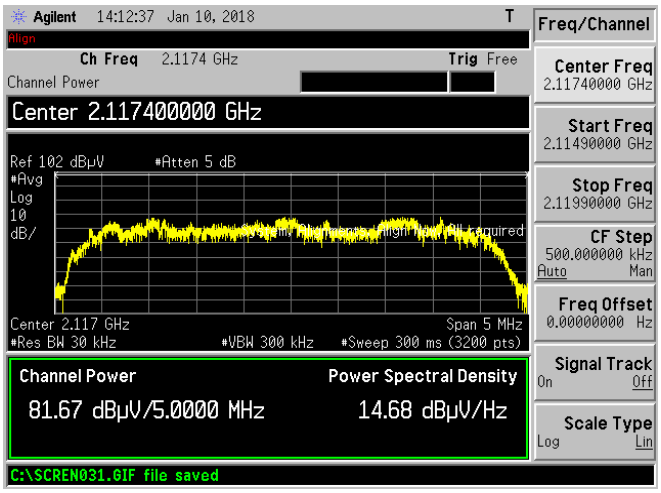
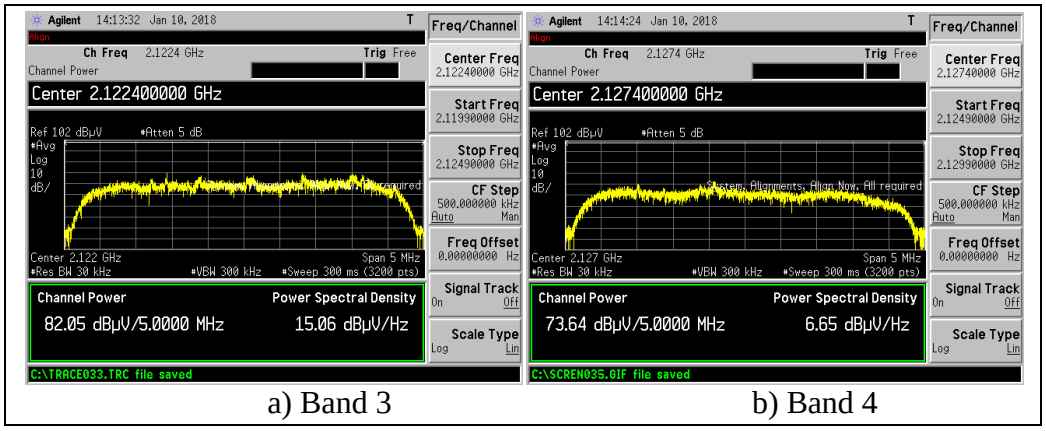


Figure 6.26: Channel power measurement screen of Band 2.

Thereafter, the same sequences of operations were carried out for the third and fourth channels, respectively. During the third and fourth channels measurements, the center frequencies and bands of the channels were selected. Spectrum analyzer screen images of Band 3 and Band 4 channels obtained after the measurements are shown in figure 6.27.



a) Band 3 b) Band 4

Figure 6.27: Channel power measurement screens, a) Band 3, b) Band 4.

After all channel measurements were completed, analysis was performed to calculate the measurement result by the software. The setup in which the positions of the devices during measurements and the measurements with the receiver mini-biconical antenna were performed is given in figure 6.28.



Figure 6.28: UMTS (3G) measurement setup for sweeping method.

Finally, a comparison was made between the results of the frequency selective measurements carried out by the broadband method and the sweeping method.

6.2.2.1.2. The Rotation Method

As a second step in the study, frequency selective measurements were performed by the rotation method and compared with broadband measurements. This step was started by repeating the broadband measurement. As in the first measurement, the field probe was brought to the "Max Hold" position and a random scan was performed to determine the maximum power density level at the region where the sector antenna was directed. The measurement was terminated when it is observed that there was no change in the maximum electric field value displayed on the field probe scree during the average 6 minute measurement period. It was the point marking that the maximum level was measured in order to be able to make a comparison with the frequency selective measurements to be performed by the rotation method.

Thereafter, the tripod was located at this point to position the mini-biconical antenna to perform frequency selective measurements. The apparatus, designed to

provide a smooth transition between the X and Z axes of the antenna on the tripod, was placed on the tripod. With the apparatus used, it was aimed to make 90 ° displacement movement without changing the center of the antenna. The raw material of the apparatus was selected as castermid so as not to affect the measurements. The receiving mini-biconical antenna was fixed on a tripod on the point where measurement is to be made. The height of the system is set to 1.5 m. The RF cable used in the previous measurement was connected between the antenna and the input of the spectrum analyzer device. The lobes of the antenna were initially set to the Y-axis position.

After the adjustments on the receiving antenna side, we passed on the spectrum analyzer and the software side adjustments. Firstly, the software was operated and the profile "XYZ_UMTS_CHANNEL_MEAS_5MHZ_INTEGRATION.prf" was called. The content of the profile was very similar to the profile called for the sweeping method. Unlike the other profile, the "Sweep Method" box was unchecked and the "Measure X", "Measure Y" and "Measure Z" buttons to be used for measurement were active. After the profile was called, the start-stop frequencies of the previously determined UMTS (3G) band and the 2112.405 MHz center frequency of the first channel in the spectrum were entered. Band 1 was selected from the "Frequency Bands" section and measurement was started by pressing "Measure Y" button. A spectrum similar to that of Fig. X with a channel bandwidth of 5 MHz was observed on the spectrum analyzer screen. The measurement was completed when the maximum electric field value was observed for the radiation that Band 1 channel made in the Y-axis in the spectrum.

Thereafter, Band 2, Band 3 and Band 4 were selected for the second, third and fourth channels respectively and center frequencies of 2117.405 MHz, 2122.405 MHz and 2127.405 MHz were entered. Measurements were performed by pressing the "Measure Y" button for each channel. Thus, the radiation levels of X, Y and Z axes were measured separately for the 4 channels in the UMTS (3G) band. After all the measurements were completed, the "Calculate Total" button on the software main screen was clicked and the measurements were analyzed and the results were calculated. Thereafter, we compared the results of frequency selective measurements performed with the rotation method and the results of broadband field measurement. The images of the adjustments made before the measurements performed with the broadband field probe and receiving mini-biconical antenna are given in figure 6.29.



a) b)

Figure 6.29: UMTS (3G) measurements, a) broadband method, b) rotation method.

Then, the measurements were repeated for a point where the measured electric field value was lower than the first point. In the same way, we compared the results of frequency selective measurements and the results of broadband field measurement. The aim here was to demonstrate the accuracy of our frequency selective measurement system by performing this comparison at a point where the level is lower. The images of the broadband and frequency selective measurements for the second point to be measured are given in figure 6.30 respectively.



a) b)

Figure 6.30: UMTS (3G) measurements for second point, a) broadband method, b) rotation method.

6.2.2.2. Frequency Selective Measurements for GSM900 Band

Measurements of the GSM900 frequency band in the spectrum were performed after the electromagnetic pollution measurement of the UMTS (3G) channels broadcast by the base station sector antenna was performed. Broadband

measurements were not repeated during the UMTS (3G) measurements due to the maximum electric field level in the vicinity of a base station was measured with the field probe which operating frequency range 9 kHz to 6 GHz. Our goal here was to show the contribution of the GSM900 channel to the level of electromagnetic pollution resulting from the radiation of the sector antenna. In GSM900 channel measurements, the sweeping method we used for UMTS (3G) measurements was preferred and a similar measurement setup was established.

During the GSM900 channel measurement, spectral measurement was performed instead of channel power measurement, distinctly from UMTS (3G) channel. Firstly, the software was operated and the pre-created profile "SWEEP_GSM_900" was selected. Unlike previous measurements, only the "Sweep Method (Only X axis)" box is selected on the software screen whereas "Only take one highest peak" and "MaxHold in Software" boxes were not selected. Along with the selected profile, the driver files containing the losses of the cables, antenna factors, limit values and the spectral analyzer parameters to be used during measurement were loaded into the profile. The values in the driver file containing the settings made by the spectrum analyzer during measurements are given in Table 6.5.

Table 6.5: Spectrum analyzer driver parameters for GSM900 measurement.

Detector Type	RMS detector (root mean square, max hold)
Resolution Bandwidth (RBW)	100 kHz
Video Bandwidth (VBW)	1 MHz
Sweep Time	300 ms
Span	12 MHz
Measurement Points	3200
Attenuation	5 dB

Firstly, the start and stop frequencies of the GSM900 channel (935.1 MHz - 947.5 MHz) were entered by selecting "Start-Stop" as the method. Then "GSM900" was selected from the "Frequency Bands" section. All of the necessary settings outside of them were loaded into the software along with the selected profile. Measurement was started by pressing the active "Measure X" button after the settings made in the software were completed. Started together with measurement, the scanning was performed with receiving mini-biconical antenna was directed as

manually. During the scanning, measurements were made at different polarizations of the antenna and using an RMS detector. In order to find the maximum level, a large region was scanned at an average human height and in the direction that the sector antenna was broadcasted. During the measurement, the screen-shot of the "GSM900" channel with 12 MHz channel bandwidth on the spectrum analyzer screen is shown in figure 6.31.

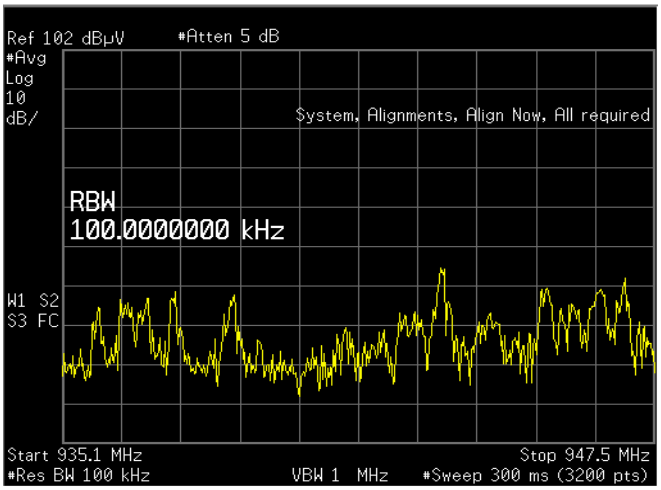


Figure 6.31: Spectral measurement screen of GSM900 band.

During the scan, the software was detected every peak in the spectrum which exceeds noise level by a pre-defined threshold (typically 6 dB) and software was measured the detected peaks one by one. The measurement was completed when the last peak point on the spectrum analyzer screen was detected and measured. Thereafter, the measurement was analyzed by pressing the "Calculate Total" button on the software main screen and the electromagnetic exposure level was calculated. The obtained result was showed the contribution of GSM900 channel to total exposure level.

7. EXPERIMENTAL MEASUREMENT RESULTS

7.1. Laboratory and Office Environment Measurement Results

The results of the frequency selective and broadband measurement methods were obtained for artificially generated CW and GMSK modulated three signals in GSM900 and GSM1800 downlink bands. Firstly, measurements were performed with a receiver mini-biconical antenna and a receiver horn antenna in the laboratory environment. After each measurement performed with the receiving antennas, a broadband electric field probe was placed at the same point, measured by broadband measurement method and the results of these two methods were compared for CW signals. As a second step, measurements were repeated in a semi-anechoic chamber with two transmitting antennas in order to simulate a multi-source environment and check the performance of the omni-directional receiving mini biconical antenna and the highly directive receiving horn antenna. The results of single source measurements performed in the laboratory environment are given in Table 7.1 and Table 7.2 for CW signal and GMSK modulated signal, and the results of double source measurements are given in Table 7.3 and Table 7.4.

Table 7.1: Laboratory environment, single source, CW signal measurement result.

Single Source		CW Signal							
		Mini-Biconical Antenna		E-Field Probe		Horn Antenna		E-Field Probe	
Band	Detector	V/m	W/m^2	V/m	W/m^2	V/m	W/m^2	V/m	W/m^2
GSM 900	RMS	15.9	0.671	17.6	0.822	16.8	0.749	17.5	0.812
	Max. Peak	15.4	0.629			17.0	0.767		
GSM 1800	RMS	18.1	0.869	19.3	0.988	17.1	0.776	19.1	0.968
	Max. Peak	19.1	0.968			17.1	0.776		

Table 7.2: Laboratory environment, single source, GMSK modulated signal measurement result.

Single Source		GMSK Modulated Signal							
		Mini-Biconical Antenna		E-Field Probe		Horn Antenna		E-Field Probe	
Band	Detector	V/m	W/m^2	V/m	W/m^2	V/m	W/m^2	V/m	W/m^2
GSM 900	RMS	5.4	0.0774	6.1	0.0987	6.0	0.0954	6.3	0.105
	Max. Peak	15.5	0.637			17.7	0.831		
GSM 1800	RMS	6.1	0.0987	6.8	0.1228	5.7	0.0861	6.6	0.1157
	Max. Peak	18.7	0.928			17.2	0.785		

Table 7.3: Laboratory environment, double source, CW signal measurement result.

Double Source		CW Signal							
		Mini-Biconical Antenna		E-Field Probe		Horn Antenna		E-Field Probe	
Band	Detector	V/m	W/m^2	V/m	W/m^2	V/m	W/m^2	V/m	W/m^2
GSM 900	RMS	20.3	1.093	22.0	1.284	13.5	0.4835	22.2	1.307
	Max. Peak	20.4	1.104			13.5	0.4835		
GSM 1800	RMS	18.6	0.918	20.2	1.082	11.6	0.357	20.7	1.137
	Max. Peak	18.8	0.938			11.6	0.357		

Table 7.4: Laboratory environment, double source, GMSK modulated signal measurement result.

Double Source		GMSK Modulated Signal							
		Mini-Biconical Antenna		E-Field Probe		Horn Antenna		E-Field Probe	
Band	Detector	V/m	W/m^2	V/m	W/m^2	V/m	W/m^2	V/m	W/m^2
GSM 900	RMS	6.5	0.1120	7.5	0.1494	4.8	0.0611	7.6	0.1534
	Max. Peak	20.2	1.082			13.6	0.4904		
GSM 1800	RMS	6.4	0.1088	7.0	0.130	3.9	0.0403	7.3	0.1415
	Max. Peak	20.2	1.082			11.8	0.3693		

Finally, comparisons were repeated using a single source and mini-biconical antenna between the frequency-selective and broadband measurements in a reflective office environment to check the influence of ambient reflections on the measurement results and the comparison. Similarly, the measurement results belonging to the single source measurements performed with using the mini-biconical antenna in the office environment, for the CW signal and the GMSK modulated signal are given in Table 7.5 and Table 7.6.

Table 7.5: Office environment, single source, CW signal measurement result.

Single Source		CW Signal			
		Mini-Biconical Antenna		E-Field Probe	
Band	Detector	V/m	W/m^2	V/m	W/m^2
GSM 900	RMS	22.0	1.284	22.5	1.343
	Max. Peak	21.1	1.181		
GSM 1800	RMS	19.1	0.9677	21.0	1.170
	Max. Peak	18.5	0.9078		

Table 7.6: Office environment, single source, GMSK modulated signal measurement result.

Single Source		GMSK Modulated Signal			
		Mini-Biconical Antenna		E-Field Probe	
Band	Detector	V/m	W/m^2	V/m	W/m^2
GSM 900	RMS	8.1	0.174	8.1	0.1740
	Max. Peak	22.5	1.3430		
GSM 1800	RMS	6.4	0.1086	7.3	0.1415
	Max. Peak	18.8	1.3430		

7.2. Base Station Measurement Results

The measurements were performed in the vicinity of the real base station belonging to the TURKCELL operator after the performed measurements in the laboratory and office environment. As a result of the studies done before measurements, it was seen that UMTS (3G) downlink band power density belonging to TURKCELL operator in the frequency range 2110 MHz - 2130 MHz was dominant. In addition to UMTS (3G) broadcasting, GSM900 band broadcast was observed in the frequency range 935.1 MHz - 947.5 MHz. When the power of the GSM900 frequency band was compared with the UMTS (3G) frequency band in the spectrum, it was seen that the contribution to the electromagnetic pollution in the environment is very low.

Base station measurements were first started by measuring the UMTS (3G) downlink band. In UMTS (3G) band measurements, frequency selective measurements were performed using sweeping method and rotation method, respectively. During the frequency selective measurements carried out by the rotation method, the measurements were repeated at two different points where the maximum and the minimum of the detected electromagnetic exposure level. After each measurement performed with the receiving mini-biconical antenna, measurements were carried out by broadband measurement method using a broadband electric field

probe in the same region or point and the results of these two methods were compared.

The comparison results of frequency selective and broadband measurement methods for the performed UMTS (3G) band measurements in the vicinity of the base station were given in Table 7.7, Table 7.8 and Table 7.9 respectively. The comparison results of the frequency selective sweeping method and the broadband measurement method are given in Table 7.7. The frequency selective rotation method and the broadband measurement method are given in Table 7.8 for the point at which the maximum level is measured and finally, for the point at which the minimum level is measured is given in Table 7.9.

Table 7.7: Frequency selective measurement result performed by the sweeping method and broadband measurement result.

Frequency Selective Measurement Method (Sweeping Method)										Broadband Measurement Method	
Band 1		Band 2		Band 3		Band 4		Total		Total	
V/m	W/m^2	V/m	W/m^2	V/m	W/m^2	V/m	W/m^2	V/m	W/m^2	V/m	W/m^2
2.92	0.0226	2.86	0.0217	3.56	0.0336	3.52	0.0328	6.20	0.1021	6.06	0.0974

Table 7.8: Frequency selective measurement result performed by the rotation method and broadband measurement result for maximum level.

Axes	Frequency Selective Measurement Method (Rotation Method)										Broadband Measurement Method	
	Band 1		Band 2		Band 3		Band 4		Total		Total	
	V/m	W/m^2	V/m	W/m^2	V/m	W/m^2	V/m	W/m^2	V/m	W/m^2	V/m	W/m^2
X	2.44	0.0158	2.19	0.0127	2.31	0.0142	3.02	0.0242	6.04	0.0969	5.63	0.0841
Y	1.59	0.0067	1.70	0.0076	1.82	0.0088	1.20	0.0038				
Z	0.63	0.0010	0.55	0.0008	0.52	0.0007	0.42	0.0005				

Table 7.9: Frequency selective measurement performed by the rotation method and broadband measurement results for minimum level.

Axes	Frequency Selective Measurement Method (Rotation Method)										Broadband Measurement Method	
	Band 1		Band 2		Band 3		Band 4		Total		Total	
	V/m	W/m^2	V/m	W/m^2	V/m	W/m^2	V/m	W/m^2	V/m	W/m^2	V/m	W/m^2
X	1.59	0.0067	0.38	0.0004	0.51	0.0007	1.96	0.0102	3.92	0.0407	4.1	0.0445
Y	1.41	0.0053	1.48	0.0058	1.81	0.0087	0.84	0.0019				
Z	0.38	0.0004	0.20	0.0001	0.19	0.0001	0.43	0.0005				

Measurements of the GSM900 frequency band were performed as a second step after the electromagnetic pollution measurement of the UMTS (3G) channels broadcast by the base station sector antenna was performed. During the GSM measurement only frequency selective measurement method was used. Frequency selective measurement was performed using the sweeping method.

The result obtained using the frequency selective screening method for GSM900 band measurements performed around the base station is given in Table 7.10. This result was showed the contribution of GSM900 channel to total exposure level.

Table 7.10: Frequency selective measurement result performed by the sweeping method.

Frequency Selective Measurement Method (Sweeping Method)	
Total	
V/m	W/m^2
0.087	2.008e-5

8. CONCLUSION

We have experimentally investigated the frequency selective and broadband measurement methods used for electromagnetic pollution measurements in thesis studies conducted under the topic of Frequency Selective Electromagnetic Pollution Measurement. For the frequency selective method, we developed a software solution to make the measurements fully automatic. In order to make measurements independent of the equipments used on the receiver side; we integrated the separate device driver system into software. Studies were started with performed measurements in the laboratory and office environments. The CW and GMSK modulated signals were produced artificially in the downlink frequencies belonging to GSM900 and GSM1800 frequency bands were performed measurements using the frequency selective and broadband measurement methods. In the laboratory and office performed measurements, it was observed that the results are compatible with each other with less than 1 dB difference, except for the measurements that are used together with the double source and the horn antenna. In the setup where the double source and horn antenna were used together was observed not compatible, in the results between the two methods as shown in Table 7.3 and Table 7.4. In the states in which that the location and the direction of the source are unknown, the use of the horn antenna as a receiving antenna showed that wrong measurement results can be obtained due to the directivity of the antenna. In addition, the use of the RMS detector when measuring GMSK-modulated signals was seen with measurement results which are more suitable for measurements to be performed with the frequency selective method.

As a second step of the studies, frequency selective measurement method and broadband measurement method were compared in the vicinity of base station belonging to TURKCELL operator after measurements performed in laboratory and office environment. When the measured base station spectrum was analyzed, it was seen that UMTS (3G) downlink band power density belonging to TURKCELL operator in the frequency range 2110 MHz - 2130 MHz was dominantly, also GSM900 band power density is in the frequency range 935.1 MHz – 947.5 MHz was lowly. Firstly, when the UMTS (3G) broadcast spectrum was examined closely, it was determined that there are 4 channels belonging to the UMTS (3G) downlink

frequency band having 5 MHz channel bandwidth. Frequency selective measurements of these 4 UMTS (3G) channels have been performed using the scanning and rotation methods. During the measurements carried out with the rotation method, the measurements were carried out for the points at which both the maximum and minimum electric field levels were determined. Thereafter, the same measurements were repeated with broadband measurement method using the electric field probe. Finally, comparisons were made between the results of the measurements performed with the two methods. The comparison result was showed that the measurement results obtained by the two methods were compatible with each other with less than 1 dB difference as shown in Table 7.7, Table 7.8 and Table 7.9. After finished the UMTS (3G) measurements, GSM900 channel measurements were started using the frequency selective method. During the measurements, only spectral measurements were performed using the sweeping method. The obtained result was showed the contribution of the GSM900 channel to the electromagnetic pollution level resulting from the radiation of the base station sector antenna.

All thesis studies conducted under the topic of Frequency Selective Electromagnetic Pollution Measurement, while stressing the effectiveness of the designed frequency selective measurement system and software, have presented very important results in terms of demonstrating the advantages and capabilities of the frequency selective method. Although actively performed broadband measurements at the present time have many advantages, it has been observed that the frequency selective method for measuring electromagnetic pollution of UMTS (3G) and LTE broadcasts made by base stations was inevitable. In addition, if the level of electromagnetic pollution exceeds the limit levels specified in the Regulation published in the Official Gazette No. 27912, it is necessary to perform a measurement for a single device. The ability of "frequency selective electromagnetic pollution measurement system and software" to perform these measurements when such a situation is encountered in one of the important gains of the work was gained to TÜBİTAK UME.

Although the frequency selective measurement system has many advantages, it has some inadequate points. Due to the development of new technologies and the inadequate of frequency bands used, nowadays, different sector antennas are served by different power levels use on the same spectrum. For this reason, accurate measurement of the target frequency and target power values are required so that

accurate measurement can be performed. In base station measurements, it will not be possible to separate the signals belonging to different cells of the sector antennas by spectral measurement or channel power measurement. Measurements obtained using extrapolation factors in the frequency selective method may prevent obtaining accurate results depending on the channel's traffic load. The method that should be used for avoiding such situations is the "code decoding" measurement method. The target study to be done in the next stage is developing our frequency selective electromagnetic pollution measurement system and our software to integrate into the decoder measurement method. When this target study is carried out, the level of measurement method used in Europe will be reached and electromagnetic pollution measurements will be realized with high accuracy and low uncertainty.

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BIOGRAPHY

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