DESIGN, DEVELOPMENT AND OPERATION OF AN ELECTROMAGNETIC RADIATION MONITORING NETWORK IN GREECE: "HERMES" PROJECT

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Abstract

A network for the monitoring of the non-ionizing electromagnetic radiation levels in several areas of Greece is presented in this paper. During its 4-year operation more than 4,000,000 measurements of the electric field strength have been performed and recorded. The results aided by useful scientific information are open to the public through a devoted web site. The network measurement results have shown that the field values are several times below the EC recommended and Greek law safety values.

I. Introduction

During the last decade, the installation and operation of several wireless networks, such as the GSM, UMTS and TETRA system has led to increasing public concerns about the exposure to electromagnetic radiation emitted from these sources. In conjunction with traditional broadcasting systems such as FM Radio and TV services, RADAR systems etc. these concerns call for the continuous information of the public regarding their exposure to EM radiation levels. The conduction of repetitive, on site, "ad-hoc" measurements is a first step for estimating the exposure levels. Nevertheless, ad-hoc measurements refer to a specific time period (usually 1-2 hours). On the other hand the notion of continuous measurement of EM radiation levels on a 24-hour basis is more appealing to the concerned public. This is due to the fact that the recorded values can be compared to the public exposure safety values, called reference levels, which are set by the relevant organisations, such as the EC [5] and government authorities [6].

Therefore, a network for the measurement and recording of non-ionizing Electromagnetic Radiation (EMR) emissions on several sites and on a 24-hour basis is one of the best solutions for keeping the public informed. Another important parameter of such a network is the possibility to present the results via a public accessible and user-friendly web site.

As described above, monitoring networks are a valuable tool in attempting to deal with public concerns about the

potential health effects of non-ionizing radiation of electromagnetic radiation. As a result, several monitoring networks are implemented all over Europe and Africa (Italy, Spain, Portugal, United Kingdom, Malta, Egypt etc.) [1]-[4]. Moreover network deployment entails a number of challenges, in terms of hardware certification, network control and daily maintenance. With all the above considerations in mind an Electromagnetic Radiation Monitoring System was developed in Greece. It is known as the "Hermes" project [7], and it is fully operational since November 2002 and currently expanding in several areas around the country.

The paper below is structured as follows: Section II gives a general technical description of a monitoring network, as well as a framework which may be applied in any similar system. Section III presents the system developed for the "Project Hermes" and the measurement results to date. Finally, Section IV presents the current project phase and future planning.

II. Design Aspects of the Monitoring Network

The system architecture is depicted in Figure 1.

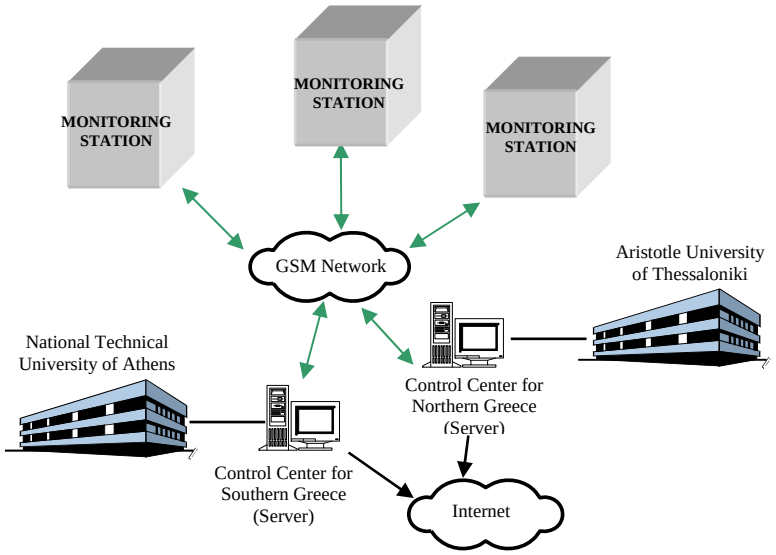


Figure 1: *Block diagram of the monitoring network.*

The system consists of:

(a) The remote monitoring stations, which are located on the desired sites and perform continuous measurements of the Radio frequency (RF) radiation levels and,

(b) The two central control stations (one for Southern and one for Northern Greece), which are located at the corresponding administrative authorities. The control units are responsible for the control of the monitoring stations and the publication of the measurement results on the web site.

a. The Measuring Equipment

The Measuring Equipment must be able to: (a) operate continuously (24 hours per day) (b) perform Electromagnetic Radiation measurements in the frequency range of interest covering the main sources that contribute to the total electromagnetic pollution, (c) store the measurements in its internal memory and transmit them to the Control Centre via a wireless interface for further elaborations, (d) supplied either by the main power supply or a solar panel (preferable), (e) be fully remotely controlled, which means that after their installation no human presence is needed on site and (f) detect abnormal operation of any kind (self diagnostics such as power loss and overheating problems) and inform the central control stations of the problem. To fulfil these requirements, the remote monitoring station consists of a broadband isotropic and triaxial electric field sensor, a module containing the necessary electronics, a GSM modem, as well as temperature and humidity sensors. A major problem encountered in this system is the periodic calibration of the monitoring stations. The calibration procedure requires the deinstallation of the stations, which means the interruption of the measurements, unless a spare station is available for the replacement.

Regarding the measurement quantities, either broadband or narrow-band measurements can be conducted. Broadband Measuring Stations record the Electric Field Strength for a given frequency range. A range of 100 KHz - 3 GHz is usually enough in order to take into account the multitude of the sources. Other possible ranges are for example 880 - 960 MHz (the GSM900 band), 1880 - 2100 MHz (GSM-1800 + UMTS bands), etc. In [8], [9] and [10] the interested reader could find a plethora of such monitoring units. Recently, selective (spectrum analysers) monitoring systems became commercially available. The referred stations are fully autonomous and can be remotely controlled via the GSM/GPRS protocol.

The main drawback of broadband stations is that they cannot estimate the radiation level from each source; rather they estimate the total exposure. Equipment such as a spectrum analyser is capable of measuring and quantifying the contribution of each electromagnetic radiation source to the total exposure level. Nevertheless, this equipment is not designed for continuous operation. If selective monitoring stations are not installed, the best solution is the use of a continuous broadband monitoring station for 24-hour recording and conducting "ad-hoc" narrow band measurements with a period of 3 - 6 months for every measurement site.

b. The Control Centre

The Control Centre is equipped with a Server Station, a wireless modem and the necessary software applications and it is responsible for: (a) controlling the remote monitoring stations and configuring the operational parameters, (b) downloading the measurement data via the wireless interface (e.g. GSM network), (c) storing the data in its hard disk and (d) processing the measurement results and publishing them to the corresponding web site.

The measurement data is stored in a Database (such as MS Access, SQL Server or MySQL) after their checking and processing. Therefore the full historical record for every measurement site is kept on the Server. In addition, a Web Server (such as MS IIS or Apache) hosts the web site.

c. The Web Site

The Web Site contains both static and dynamic pages and it aims at presenting the measurement results for every monitored site. It also provides thorough information concerning the electromagnetic radiation issue. Through the web site the user may view electric field strength graphs with custom time interval selection and statistical quantities about the measurements. Furthermore, a comparison of the measured quantity with the Greek legislation reference levels is presented. A feedback form can be also available to the public in order for them to express questions or comments to the administrators of the system.

III. The "Hermes" Monitoring Network

a. General Description

A monitoring network based on the principles described above has been developed and operating since November 2002. The system at its present state (April 2006) comprises 27 remote monitoring stations spread all over Greece (23 active and 4 inactive) and two control units located in two University laboratories (National Technical University of Athens – NTUA and Aristotle University of Thessaloniki – AUTH). The stations are located at schools, universities, public authorities' buildings and private flats. The following figure depicts the spreading of the monitoring stations.

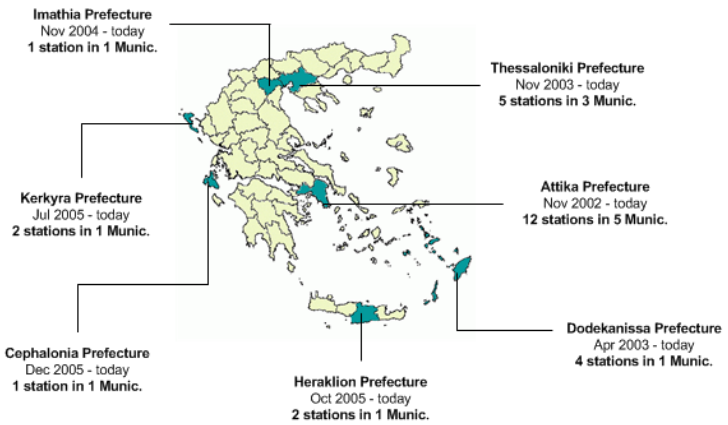


Figure 2 : *"Hermes" Monitoring Network*

The measuring devices record the broadband electric field strength quantity for the range 100 KHz - 3 GHz [10]. Three slightly different monitoring units' models are used.

- EE4070 - WB model which records the Electromagnetic Field Strength in the band 100 KHz - 3 GHz
- EE4070 - SL which records the field strength for three bands: 100 KHz - 3 GHz, GSM-900 Band and GSM1800 + UMTS band.
- MCE410 - SL, which records the field strength for two bands: 100 KHz - 3 GHz and 900 MHz - 3 GHz.

A detailed description of the specific units and the measurement procedure can be found in [11]. In the following figures several measurement sites are presented.

Figure 3: *EE4070-WB Station at Koskinou, Rhodes*

Figure 4: *EE4070-SL Station at Menemeni, Thessaloniki*

Figure 5: *MCE410-SL station at Heraklion, Crete*

Regarding the "ad-hoc" measurements, the guidelines proposed in the ECC recommendation [12] serve as the basis for our measurement procedure. A set of directional antennas covering the frequency range of 20 MHz – 3 GHz and a Spectrum Analyzer for measuring the received RF Power comprise the measurement apparatus (see Figure 6*).* Each frequency band is scanned and the power of each RF source, such as a FM or TV radio stations, a GSM channel etc is recorded. After the needed processing the total exposure levels and the contribution of each frequency band are estimated. A similar procedure is performed if we substitute the Spectrum Analyser with a Selective Radiation Meter such as the one presented in [13] and the directional antennas with broadband isotropic triaxial E-field probes (see Figure 7).

Figure 6: *"Ad-Hoc" Measurement Apparatus (Spectrum Analyser based)*

Figure 7: *"Ad-Hoc" Measurement Apparatus (SRM based)*

b. Measurement results

On the Web Site, both broadband and narrow-band measurement results are presented. The broadband measurements are updated on a daily base. Below, at first a table containing the most significant information about the monitoring stations is given. Afterwards in the following figures sample diagrams from the web site are drawn (Figure 8 - Figure 11). Finally, cumulative results regarding all the stations are presented (Figure 12 - Figure 13).

Table 1 *: Stations informative table*

Station ID	Site Name	Activation date	Mean 6-min Average value of electric field	Standard deviation of electric field	Maximum 6-min Average value of electric field	Number of recorded measurements	Status
1	1st & 6th Pr. Schools at Holargos	November 18, 2002	1.6	0.1	2.7	77,603	Inactive
2	2nd & 3rd Pr. Schools at Holargos	November 18, 2002	1.9	0.1	2.3	77,609	Inactive
3	5th Primary School at Holargos	November 22, 2002	2.6	0.2	3.2	72,726	Inactive
4	1st Primary School at Zefiri	March 31, 2003	1.7	0.2	2.5	263,276	Active
5	High School at Zefiri	April 1, 2003	1.7	0.6	8.9	250,005	Active
6	Municipal Office of Psinthos	April 23, 2003	0.9	0.8	5.8	209,517	Active
7	Municipal Office of Koskinou	April 23, 2003	1.5	0.3	4.0	209,808	Active
8	First Aid Station of Faliraki	April 23, 2003	0.0	0.1	1.5	91,620	Inactive
9	Building of E.C.E. School	November 6, 2003	2.9	0.2	4.6	172,585	Active
10	5th Primary School at Renti	November 10, 2003	0.7	0.1	1.0	209,315	Active
11	Kindergarten at Renti	November 10, 2003	1.5	0.3	2.1	206,892	Active
12	1st Primary School at Renti	November 10, 2003	1.1	0.5	4.3	193,026	Active
13	Kalithies, DEYAK	May 11, 2004	0.1	0.2	1.1	155,210	Active
14	1st Primary School at N. Erithrea	July 7, 2004	2.5	0.3	3.5	129,941	Active
15	2nd & 3rd Pr. Schools at N. Erithrea	July 7, 2004	2.5	0.2	3.1	132,297	Active
16	Esperia Build. - Town Planning Build.	October 5, 2005	1.6	1.0	3.5	45,115	Active
17	Dimokratias Avenue	October 5, 2005	2.1	1.0	7.8	44,061	Active
18	1st Primary School at Ilion	November 21, 2005	2.2	0.1	2.9	33,872	Active
19	3rd High School of Argostoli	December 21, 2005	0.1	0.4	6.5	18,336	Active
20	A.U.TH., Building of School of Science	November 1, 2003	1.3	0.2	3.5	206,279	Active
21	A.U.TH., Rectorate Building	February 27, 2004	3.7	1.4	17.7	173,067	Active
22	City Hall of Menemeni	June 12, 2004	2.7	0.5	7.7	155,283	Active
23	City Hall of N. Michaniona	June 9, 2004	0.9	0.2	1.8	153,406	Active
24	High School of N. Michaniona	June 4, 2004	1.8	0.4	3.4	163,964	Active
25	1st and 2nd High Schools of Naoussa	November 16, 2004	0.7	0.2	2.1	123,851	Active
26	City Hall of Lefkimi	July 22, 2005	1.7	0.3	3.0	57,957	Active
27	2nd Primary School of Lefkimi	July 22, 2005	0.8	0.2	1.7	63,977	Active

In Figure 8 the measured points correspond to 6-minute average electric field (E-field) values as is proposed in [5]. An immediate comparison with the reference levels can be done based on this diagram. Moreover the

variation of the field during one day or a longer period is distinguishable. The time span can vary from 1 hour to the whole measurement period (several years). In Figure 9(a) and 9(b), the mean and the maximum of the total set of 6-min average E-field values are presented and compared with the corresponding reference levels, for both EE4070 – SL and MCE410 – SL models.

Sample measurement results from two "ad-hoc" measurements are depicted in Figure 10. Specifically, one can see how many times below the safety values were the measured field values, in terms of the Power Flux Density (Watt/m^2) (Figure 10(a)) and in terms of the Electric Field Strength (V/m) (Figure 10(b)), for each frequency band such as FM, TV, GSM900, UMTS etc. The total exposure level is also evaluated and presented. The comparison between the results of Figures 9(b) and 10(b) (which correspond to the same measurement site) shows that the values of the monitoring station measurements are close to the "ad-hoc" measurement values. In addition, Figure 11 illustrates the percentage contribution of each frequency band to the total EMR exposure level.

Finally, the last two diagrams (Figure 12 and Figure 13) present cumulative results regarding the mean 6-min average E-field strength (continuous measurements) and the exposure level in terms of the Power Flux Density extracted by "ad-hoc" measurements.

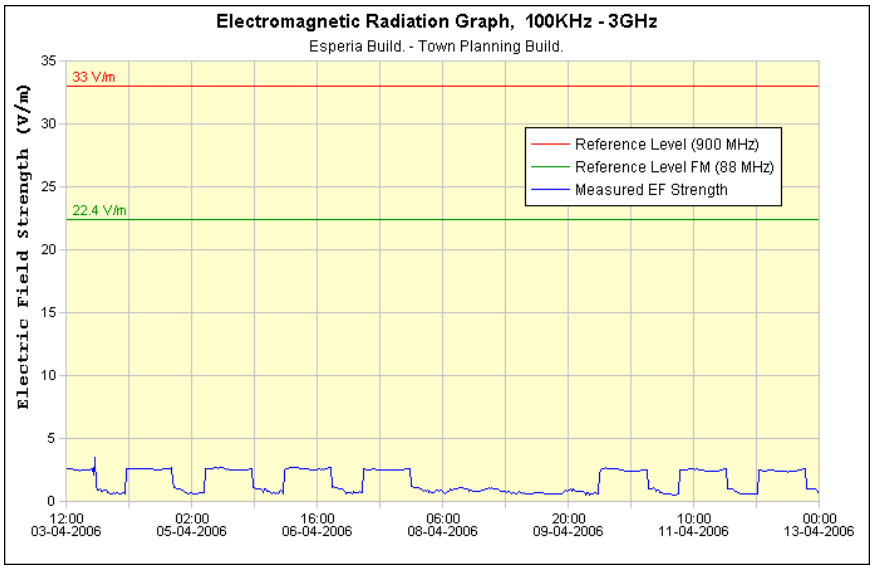
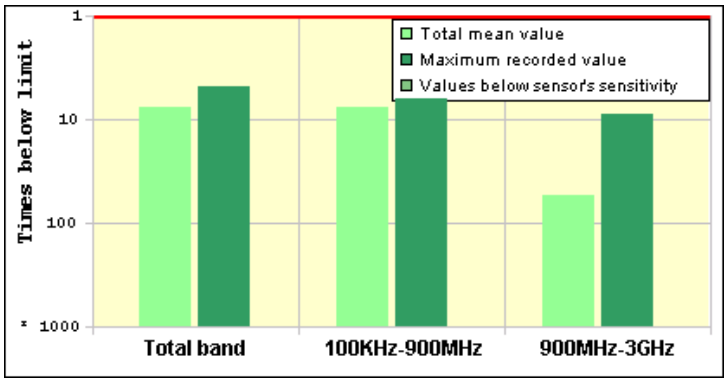
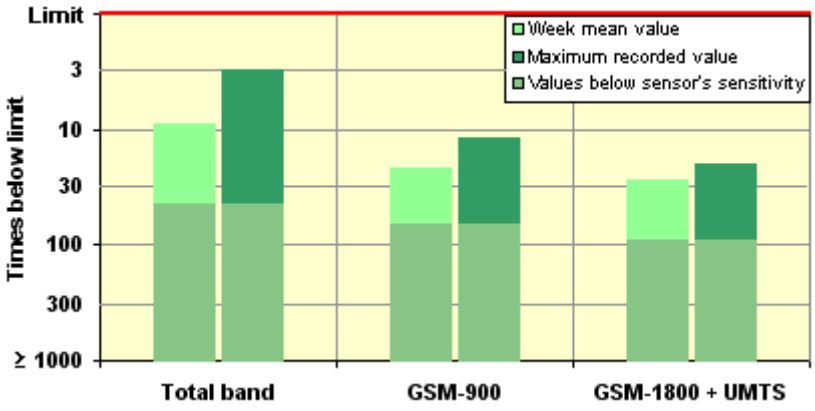


Figure 8: *Sample Electric Field Strength Diagram (Broadband)*

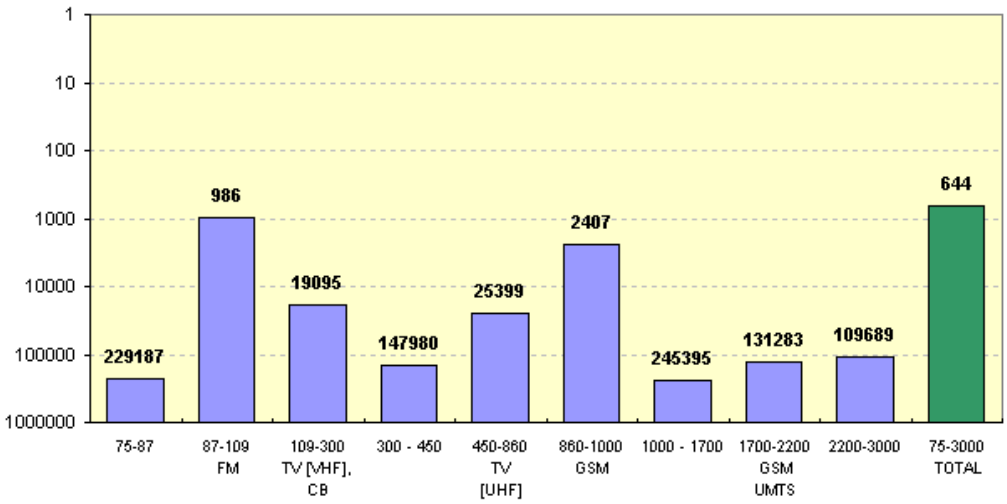


(a)

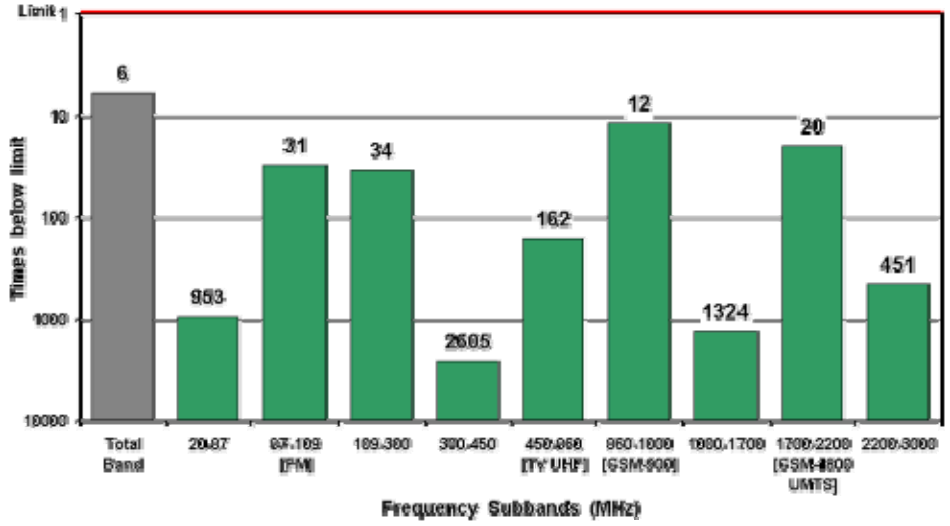


(b)

Figure 9. *(a) Sample Mean Electric Field Strength Diagram for Selective Stations (MCE410 – SL model). (b) Sample Mean Electric Field Strength Diagram for Selective Stations (EE4070 – SL model)*



(a)



(b)

Figure 10: *(a) Sample of Power Density Measurement Results conducted with SRM (Narrow-Band). (b) Sample Equivalent Electric Field Strength Measurement Results conducted with Spectrum Analyzer (Narrow-Band)*

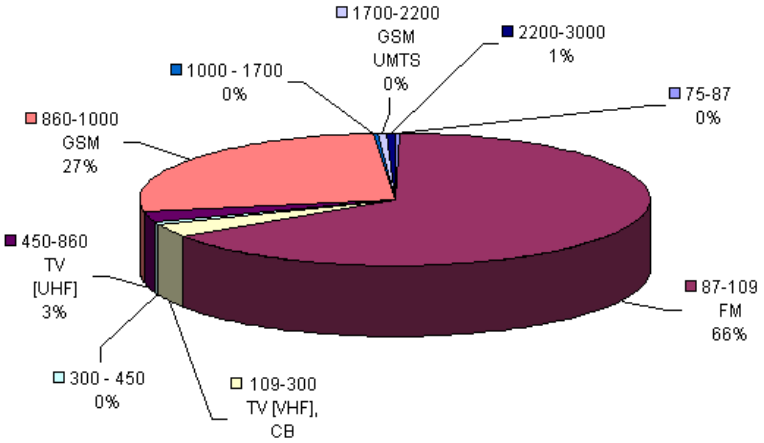


Figure 11: *Sample of Contribution of each band to the total electromagnetic radiation, calculated by SRM measurements (Narrow-Band)*

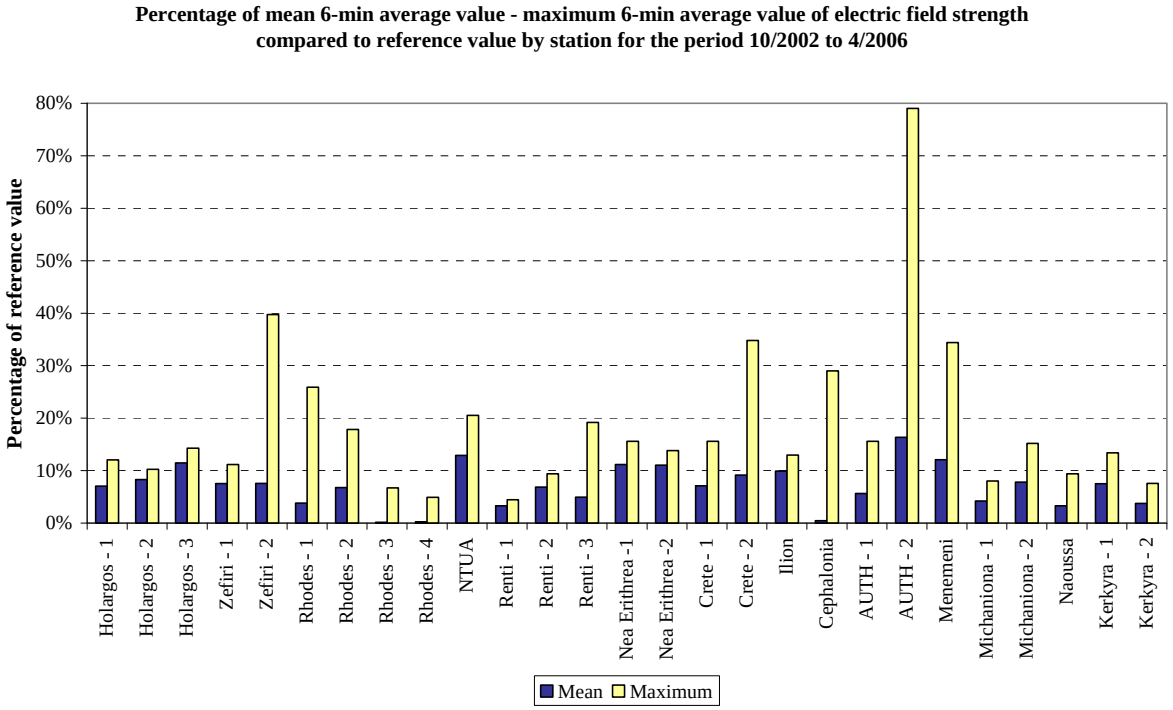


Figure 12 : *Percentages of electric field strength compared to reference value (overall)*

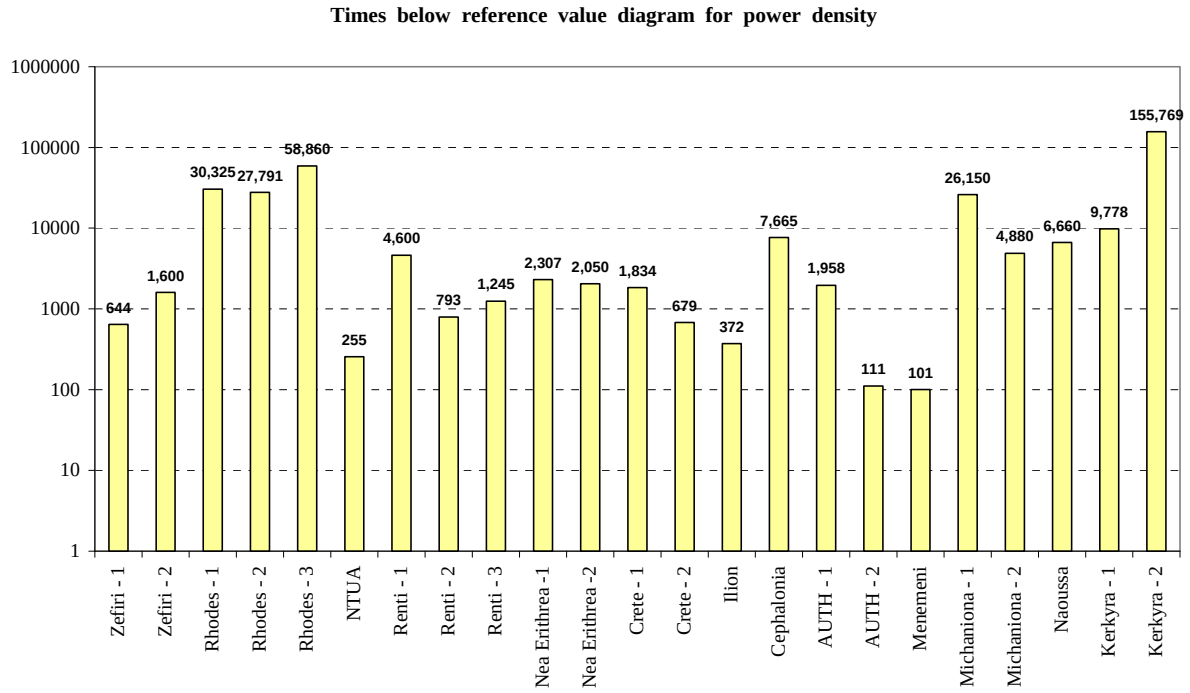


Figure 13: *Comparison of monitored power densities to reference value (overall)*

c. Comments on the Measurement results

Based on the above diagrams and the cumulative results from our measurement database, several general conclusions could be drawn:

- The electric field strength / power flux density values are several times lower than the safety reference levels, even on sites close to antennas (see Figure 4). As far as the mean E-field, the higher values have been recorded at the National Technical University of Athens (Table 1– Station ID 9) and at Aristotle University of Thessaloniki (Table 1– Station ID 21). The first is located near the Imittos Mountain hosting the Antenna Park of Attica (FM and TV broadcasting stations, Radars, etc.). The second measurement site is on the roof of the 9-floor Rectorate building, almost at the maximum of the main lobes of the antennas located at the Antenna Park of Hortiatis Mountain. Still, the mean values are respectively 2.9 V/m and 3.7 V/m, that is, 13% and 16.5% of the adopted reference level (22.4 V/m).
- The variation of the E-field on each site is negligible except for the two stations located in Heraklion, Crete. The standard deviation computed over the whole measurement period varies between 0.1 – 0.3 V/m for the majority of the sites.
- The measured E-field depends on the relative position between the site and the antennas, that is, the distance between them and the radiation pattern of the transmitting antenna(s).
- The recorded values to date indicate that in general higher E-fields are present on urban and dense urban sites in comparison with rural areas. Nevertheless, the contribution of mobile telephony cellular emissions to the total exposure is higher in rural areas.

IV. Summary - Future work

An automated nationwide monitoring network of the electric field strength in the RF spectrum was presented. The system uses reliable hardware based on electric field strength probes and the measured data is presented openly to the public using the Web. More than 4,000,000 E-field strength values have been recorded in our database and 63 “ad-hoc” measurements have been conducted in the context of “Hermes” Project. Since the commencement of operation the measured EM Radiation levels are significantly below the safety reference levels.

We are currently planning the installation of more remote stations in dense urban and rural environments. Our

intention is to extend the network of the monitoring stations. In the long-run and in conjunction with repetitive "ad-hoc" measurements using a Spectrum Analyser or a Selective Radiation Meter, a more detailed statistical analysis of the RF radiation levels in urban and rural areas is going to be performed. Our interest will be focused mainly in the proximity of cellular base stations.

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