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MULTIBAND SENSORS FOR WIRELESS ELECTROMAGNETIC FIELD MONITORING SYSTEM – SEMONT *

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Abstract. *Substantial effort has been made to employ wireless sensor network and Internet technologies for environmental and habitat protection. Several monitoring systems are designed to collect data regarding temperature, humidity, pressure and some other environmental parameters, amongst which recently there is the exposure to electromagnetic field. In this paper, some basic features of the multiband sensors that are incorporated into the Serbian electromagnetic field monitoring network – SEMONT are presented. The SEMONT information network is designed and aimed for the remote, long-term, 24 hours a day, permanent broadband monitoring of the electromagnetic field in the environment.*

Key words: *electromagnetic field, monitoring, sensor network*

1. INTRODUCTION

Wireless sensor network (WSN) consists of dozens, battery-powered computerized devices, also known as sensor nodes, which are scattered throughout a physical environment [1].

The capabilities of the sensor nodes can differ widely – from simple sensors that monitor a single physical phenomenon, to the more complex devices that may combine various sensing techniques (acoustic, optical, magnetic, etc) [1].

The sensors can also differ in communication capabilities, using for example the ultrasound, infrared or radio frequency technologies with different data rates and latencies. While the simple sensor nodes may collect and disseminate information about the observed environment parameters only, some more complex sensors, developed in recent years, may have large processing, energy and storage capabilities. These modern sensors perform extensive data processing and aggregation functions [2].

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Using such sensors, the WSNs are capable of monitoring, gathering and aggregating data for further processing, dissemination, visualization, analysis and storing into appropriate storage systems.

In the last decades, the exposure to the man-made sources of the electromagnetic (EM) field became a very important physical phenomenon for observation. Generation of the various EM fields that range from extremely low frequencies (power lines), through the intermediate frequencies (computer screens), up to the radio frequencies (radio and TV broadcasting, as well as wireless communications), has increased dramatically, resulting in the so-called EM pollution of the environment.

Power generation development and rapid technological progress in a variety of electricity applications have multiplied sources of the EM fields and diversified their characteristics. Devices that are currently in widespread use generate the non-ionizing radiation, covering the spectrum of up to 300 GHz [3].

Scientists devote huge efforts to the research of the potential health effects on people who are exposed to the EM fields in their everyday lives (epidemiological evidences). Equal efforts are made to discover some effects in laboratory experiments carried out on human volunteers, animals and cell cultures (experimental evidences) [4]-[5].

Possible unwanted daily exposure of general population has intensified the public reactions and concerns. Demands to the municipal agencies for the non-ionizing radiation protection introduced a need for a constant surveillance of the EM fields in the environment. Due to such demands, development of the area monitoring and control systems became one of the major innovations in the sense of the methodological evaluations and measurements of the so-called environmental EM pollution [6]-[6].

The Ministry of Environment, Mining and Spatial Planning of the Republic of Serbia and the Municipal Agency for the Environmental Protection – City of Novi Sad, [8]-[9], responsible for the EM pollution protection of the environment, have encouraged the development of the area broadband Serbian electromagnetic field monitoring network – SEMONT [10]-[14].

The SEMONT system is based on the WSN technology and is intended for the broadband, remote, automated and permanent monitoring of the EM fields in the real-time. It includes measurements of the overall field strength in the entire frequency range of the non-ionizing radiation.

SEMONT system has been recognized by the Government of the Republic of Serbia and Ministry of Education and Science of the Republic of Serbia [15], which approved its development within the framework of technological development of the Republic of Serbia, for the period of 2011–2014.

In this paper, some of the features of the sensor elements employed in the information network for continuous EM field monitoring – SEMONT are presented. Section 2 briefly explains the network topology, while Section 3 considers several features of the SEMONT multiband area monitor sensor. In Section 4, some conclusions are offered.

2. THE SEMONT TOPOLOGY

The SEMONT system is designed and adjusted for the area EM field monitoring over the territory of interest [14]. The sensor nodes are to be spatially distributed over the supervised territory and employed for monitoring of the cumulative EM field level from all sources in the vicinity of the sensor node.

Since at the particular location a number of various radiation sources can produce the EM field simultaneously, the data on the overall EM field level can bear significant information and improve efforts to take systematic care about the potential health risks of the non-ionizing EM radiation. Thus, the foundation of the SEMONT system enables a wideband examination of the EM fields, based on the measurements [13].

2.1 Star topology

The SEMONT system is designed for supervision and control of various EM field sources. The SEMONT system consists of the

- autonomous sensors spatially distributed over the supervised territory,
- centralized control station (CCS) that supervises activities of the remote sensors, collects, processes and stores the data in to the centralized database,
- communication network, which provides connection and interaction between the remote sensors and the CCS, and
- managing software that supports employment of the information network.

The SEMONT system is organized in a simple and basic star network topology [13], where all network nodes are wirelessly connected to the CCS, as presented in **Fig. 1**

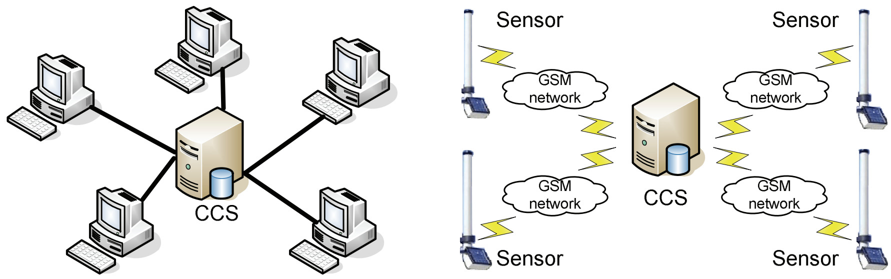

Fig. 1. SEMONT network topology

The SEMONT system also implements centralized management over the remote sensor nodes. Additional details and reasons for such network topology are presented in [13].

2.2 Broadband area monitoring

Depending on the topology of the territory to be supervised, it is possible that a frequent physical access to the sensor nodes is difficult or unnecessary. Thus, the wireless communication emerges as a logical choice for the remote monitoring system. Since the mobile phone companies have already covered over 95% of the territory of the Republic of Serbia, the communication in the SEMONT information network relies on the digital cellular networks and the GSM standard [10]-[14].

Using the GSM communications the SEMONT system provides a high degree of mobility and thus the monitoring network can be set up to cover any area of interest, as shown in **Fig. 2**.

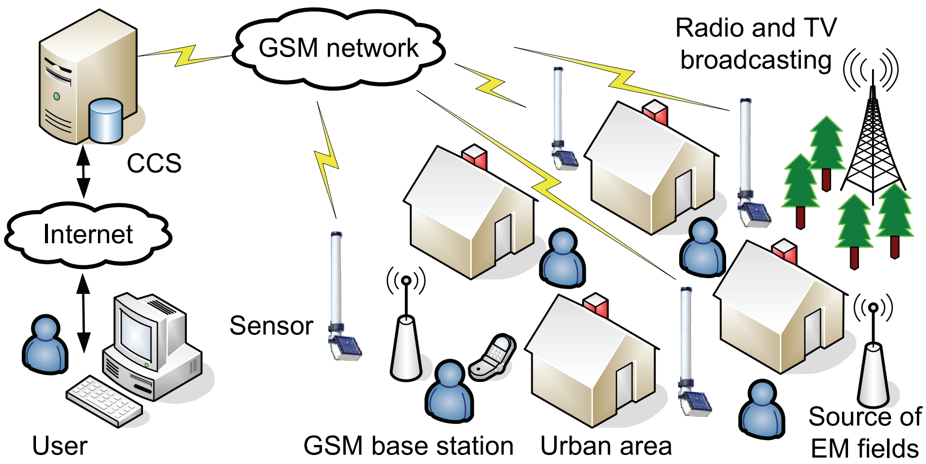

Fig. 2. Example of the SEMONT implementation

The SEMONT system is suitable for covering the urban areas, especially the zones of the increased sensitivity, as defined in Serbian "Rules for non-ionizing radiation sources of interest, types of sources, the manner and period of their investigation" [16]. These zones are typically residential areas where people can stay up to 24 hours a day, schools, homes, hospitals, tourist facilities and playgrounds.

Furthermore, the proposed SEMONT information network can build a reliable monitoring system, which can cover large geographical area, including nationwide coverage [10]-[14].

THE SEMONT SENSOR

The SEMONT sensor elements correspond to the nodes of the WSN [1], playing essential part in the SEMONT monitoring system. The main function of the SEMONT sensor is acquisition of the information about the electric and/or the magnetic field strength as well as transfer of the measurement results to the CCS unit.

The sensor element described in this paper is suitable for investigation of the EM fields and for assessment of the general population exposure to the cumulative influence of the sources, such as parts of the power systems, radio and TV broadcasting systems, GSM/UMTS digital cellular networks and some other wireless systems [11]-[14].

The sensor element is a small sized, solid weather-proofed unit that can be installed for indoor or outdoor applications [17]-[19]. When mounted on an appropriate pole the sensor can be placed at any place/surface such as a public square or playground in the vicinity of the base station, the roof top of the surrounding buildings or even on the side wall of a building. Also, it can be placed inside any object of interest, for example a school playground, shown in **Fig. 3**.

Fig. 3. a) Sensor unit, b) Sensor located in a school playground [17]

The sensor consists of four main parts:

- interchangeable field probes,
- post-processing data logger with internal memory,
- communication block (GSM modem and RS232 connector) and
- internal rechargeable battery power supply, as shown in Fig. 4.a.

Beside these parts, the sensor element has a solar panel used both as external power supply and as internal battery charger. In the case of total darkness, the internal battery provides full operation of the sensor for 80 days or longer [17]-[19].

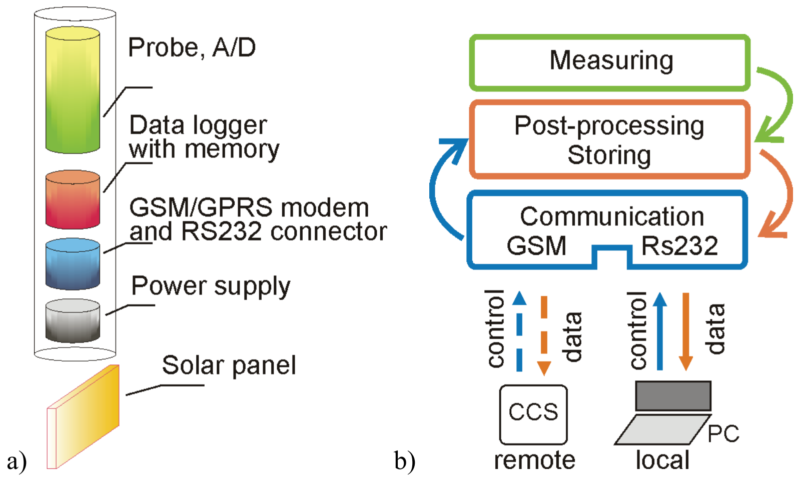

Fig. 4 a) Components of the sensor, b) Block diagram of the sensor

The functioning of the sensor is presented with the block diagram, shown in Fig. 4.b, and can briefly be described trough three steps [17]-[19]:

- first, the field probe takes samples of the measured electric or magnetic field strength,
- second, the post-processing block processes the samples obtained from the probe and stores them into the internal memory, and
- third, the communication block sends the measurement results to the CCS, frees up the memory for the new data and receives instruction from the CCS.

The main advantage of the SEMONT sensor elements is their high level of autonomy, due to the:

- solar panel power supply – allowing continuous measurement on the 24 hours basis, in arbitrary long period,
- internal memory – storing amount of the measurement results and enabling the long-term data acquisition, and
- remote and wireless control and data collection – which avoids presence of any technical personnel on the site.

The sensor element provides the continual broadband measurement of the overall electric or magnetic field strength in the probe's frequency range. The type of the field measurements, the frequency range and the measuring range depend on the used field probe.

During measurements, the sensor element performs processing of the measured data estimating the average (AVG or RMS) or the maximum (MAX) value of the field strength, regardless of the employed field probe [17]-[19].

The most important characteristics of the sensor element are described in Table 1.

Table 1. Some basic characteristics of the sensor element.

Field measured	Total electric or magnetic field
Sampling	1 measurement every 3 seconds
Functions	AVG, RMS, Maximum peak Daily report via SMS
Consumption	0.65mA with GSM off 16mA with GSM on stand by 300mA with GSM transmitting
Duration of measurement	24 hours per day
Operating time	more than 80 days in total darkness at a 1 min transmission every day
Recharge time	48 hours
Environment temperature	-10 / +50ºC
Dimensions and weight	(W×D×H) 60×60×780mm, 2.4 kg

3.1 Probes

The main part of the sensor element is the interchangeable filed probe, which can be electric or magnetic field probe [17]-[19]. In order to accomplish the appropriate application demands, regarding the type or the frequency range of the filed, the probe can be easily replaced on the sensor node without interrupting other functions of the sensor.

a) Magnetic field probe

The SEMONT magnetic field probe is suitable for monitoring the low frequency magnetic field in the frequency range from 10 Hz to 5 kHz [17].

The main sources of the low frequency magnetic fields can be found in the power system and the system for the power transmission, such as power lines, distribution lines, power stations and sub-stations [20]. These sources generate both the electric and magnetic fields.

In order to perform the electric field measurements representing the unperturbed field at a given location, the area of investigation should be as far as possible from other power lines, towers, trees, fences, tall grass or other irregularities [21]. It is preferable that the location is relatively flat, because even vegetation influence on the electric field can be significant [21]. Thus, measurement of the electric field is much more difficult than the measurement of the magnetic field.

The magnetic probe performs isotropic three-axis measurements, capturing the separate components of the magnetic flux density $B_x(t)$, $B_y(t)$ and $B_z(t)$, as shown in **Fig. 5**. The internal logic of the probe processes the components and returns the overall magnetic flux density B(t), irrespective of the tri-axial orthogonal arrangement and in accordance with the standards for the low frequency field measurements [22].

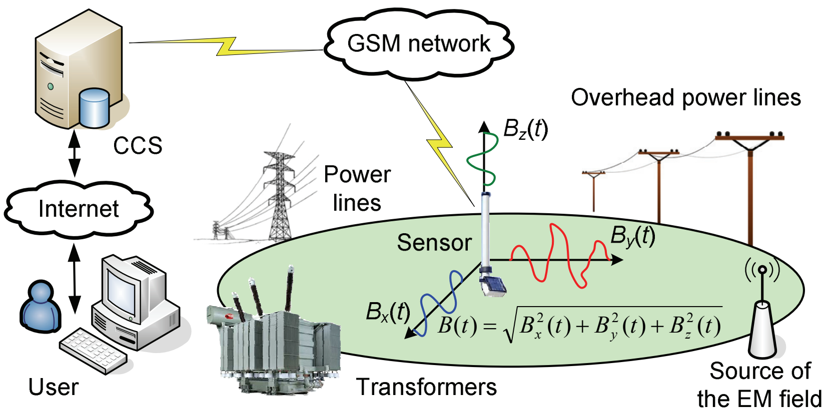

Fig. 5. Isotropic magnetic field probe monitors all sources in the vicinity

The magnetic field probe performs the broadband monitoring of the all surrounding field sources, irrespective of their radiation direction or position. The main characteristics of the magnetic field probe are presented in Table 2.

Table 2. Magnetic field probe characteristics.

Frequency range	10 Hz to 5 kHz
Measuring range	50 nT to 200 μT
Resolution	1 nT
Flatness	1 dB in range from 40Hz to 1kHz
Anisotropy	0.3 dB, at 50Hz and 3μT
Rejection of electric field	> 20dB

In addition to the magnetic field sensing part, the probe has an internal pass band circuit and an A/D converter that performs sampling of the signal as shown in **Fig. 6**.

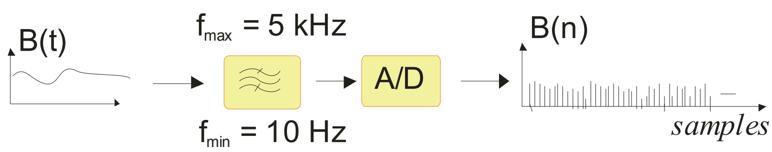

Fig. 6. Filtering and A/D conversion of the magnetic field probe

The field probe output contains the samples of the total magnetic flux density, with a 20 samples per minute rate, allowing calculation of the average and maximum peak features by the sensor element.

b) Electric field probe

For the high frequency EM field monitoring the electric field probe is used [17]-[19]. The main sources of the high frequency EM fields are various wireless systems, such as radio and TV broadcasting, GSM or WLAN systems. The sources generate both the electric and the magnetic field.

According to the standards for the high frequency EM field measurements, [23]-[25], three regions around the EM filed source are defined. Their boundaries depend on the largest dimension of the radiation antenna, D, and the field wavelength, λ. In the first induction region, closest to the source, defined by distances less than λ or D, it is necessary to measure both electric and magnetic field. In the second region the electric or magnetic field should be measured, while in the third, so-called far-field region, roughly determined by distances greater than 5λ or 5D, the electric field and the magnetic field components are mathematically related, so it is sufficient to measure only one of these components [23]-[25].

The SEMONT system uses a multiband quad electric probe [17]-[19], as the most appropriate field probe for the high frequency EM field measurements and the public exposure assessment. The electric field probe also performs isotropic three-axis measurements, as shown in **Fig. 7**.

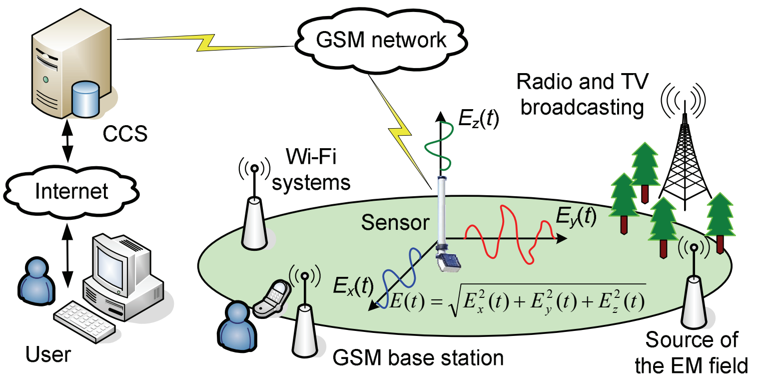

Fig. 7. Isotropic electric filed probe monitors all sources in the vicinity

The probe measures the total electric field strength irrespective of the tri-axial orthogonal arrangement and captures the values of the overall electric field, E(t), generated by all surrounding sources. The main characteristics of the electric field probe are described in Table 3.

The electric field probe possesses internal pass band circuits (probe filters) and A/D converters. The probe filters allow discrimination of the fields generated by different sources in the frequency bands of the EGSM 900, EGSM 1800, UMTS 2100 and inside a wide range of frequencies [17]-[19]. Such feature is useful to determine the GSM and the UMTS contributions to the overall electric field strength.

Table 3. Electric field quad-band probe.

	Wide band	GSM	EGSM	UMTS
Frequency range [MHz]	0.1 - 3000	925 - 960	1805 - 1880	2110 - 2170
Measuring range [V/m]	0.2 - 200	0.03 - 30	0.03 - 30	0.03 - 30
Resolution [V/m]	0.01	0.01	0.01	0.01
Flatness at 6V/m [dB]	+/- 1.5	+0.5/-2.5	+0.5/-2.5	+0.5/-2.5
Anisotropy at 3V/m [dB]	±0.8	±0.8	±0.8	±0.8
H field rejection [dB]	>20	>20	>20	>20
Temp. error for all bands	-20ºC ÷ 0ºC : -0.1dB/ºC,		0ºC ÷ 50ºC : ±0.3dB	

The A/D circuits of the quad band probe generate samples, as depicted in **Fig. 8**.

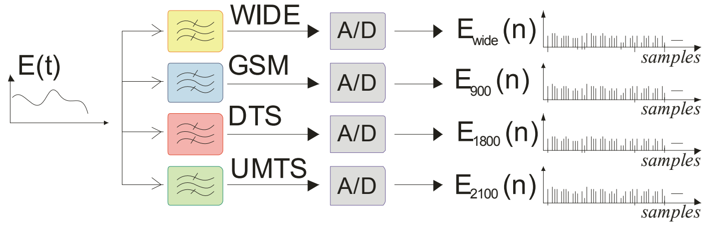

Fig. 8. Filtering and A/D conversion of the electric quad-band probe

The sampling rate of the probe is also 20 samples per minute. The samples obtained from the probes are sent to the data logger as the consecutive unit of the sensor element.

3.2 Data logger

The second essential part of the sensor element is the data logger, which performs post-processing and storing of the data obtained from the probes. Its functioning depends on the sensor setup parameters, such as threshold level, averaging period, storing time, sending date/time and some others. The parameters of the sensor can be set remotely or can be set locally trough the communication part [26]-[27]. In the following section the averaging period and the storing time is explained in detail.

a) Averaging

The post-processing of the measured samples corresponds to the averaging of the sampled data. In order to meet the different legal demands [3], [28]-[30], the sensor enables averaging over a specific averaging time and processing a number of the collected samples, as shown in **Fig. 9**.

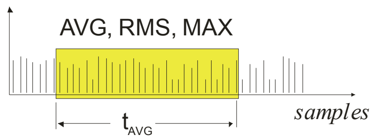

Fig. 9. The probe averaging

The number of the samples, N, depends on the averaging time interval, t_{AVG}, due to the expression $N = 20 \times t_{AVG}$, where t_{AVG} is expressed in minutes. For example, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) recommends that for the frequencies between 100 kHz and 10 GHz, an electric field is to be averaged over a 6 minutes period [3]. The time of 6 minutes corresponds to 120 samples.

The averaging can be arithmetic (AVG), appropriate for the frequencies below 10 MHz [3], [18], [24], [30], and is defined by the equations

$$B_{AVG} = \frac{\sum_{n=1}^{N} B(n)}{N}, \quad \text{or} \quad E_{AVG} = \frac{\sum_{n=1}^{N} E(n)}{N}. \tag{1}$$

The quadratic averaging (RMS), appropriate for the frequencies between 100 kHz and 10 GHz [3], [18], [24], [30], is defined as

$$B_{RMS} = \sqrt{\frac{\sum_{n=1}^{N} B^2(n)}{N}}, \quad \text{or} \quad E_{RMS} = \sqrt{\frac{\sum_{n=1}^{N} E^2(n)}{N}}. \tag{2}$$

Moreover, the sensor element detects the maximum (MAX) value during the same time period [17]-[18], performing the functions

$$B_{max} = \max\{B(n)\}, \text{ or } E_{max} = \max\{E(n)\}, \ n=1..N. \tag{3}$$

In the case of the quad-band electric field probe, the functions AVG, RMS and MAX of the electric field are simultaneously estimated in all bands.

b) Storing

The estimated values, AVG or RMS and MAX are stored into the internal memory during one of the selectable time intervals, as described in Table 4 [17]-[19].

Table 4. Memory capacity of the sensor element.

Storing time	Memory capacity
30 sec	5 days
1 min	10 days
2 min	20 days
6 min	60 days
15 min	169 days

The storing time, t_{store}, depends on the sensor setup parameters and can be shorter or longer than the averaging time, t_{AVG}, as shown in **Fig. 10**.

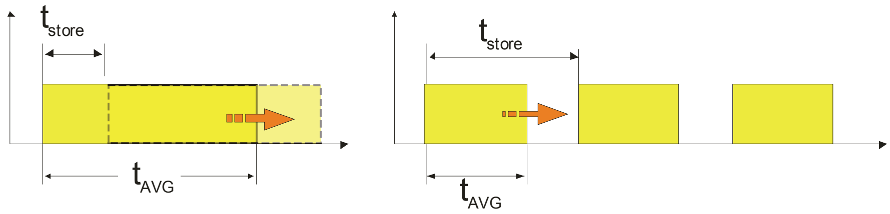

Fig. 10. The probe storing options

The processing time window, of the length t_{AVG}, slides through the samples. At every storing time interval, t_{store}, the sensor element memorizes the estimated values based on the samples inside the current position of the processing time window. Depending on the storing time interval, the sensor element can memorize different amounts of the estimated values as shown in Table 4.

One of the advantages of the sensor is a 4MB internal memory, which can store up to 32512 records of the 16 bytes data [17]. When the memory is full, the new data overwrites the oldest to ensure the availability of the memory for the most recent measurement period. In order to avoid the data overwriting, the SEMONT system, based on the predefined time interval, performs the automatic data downloading from the sensor nodes.

Additionally, the reduced amount of the internal memory also enables energy conservation thus avoiding frequent downloading of the stored data [13].

3.3 Communication

The third unit facilitates the remote communication between the sensor and the CCS via GSM modem [26]-[27]. The small amount of data in form of a daily report can be sent as an SMS message to a mobile phone. Additionally, the communication block has the ability to receive instructions from the CCS in order to perform the setup of the data logger.

Besides the GSM modem, an RS232 interface enables local connection to the sensor element for the measurements and collection of the stored data [26]-[27].

Every time when the connection is established between the sensor node and the CSS, a certain amount of hardware resources is employed, increasing power consumption. Thus, the SEMONT system is designed to minimize the number of accesses to the sensor nodes, in order to preserve energy [13].

CONCLUSION

This paper briefly presents some of the technical details of the sensor elements implemented in the SEMONT information network for continuous and 24 hours a day EM fields monitoring.

The sensor elements, equipped with the described field probes, have several advantages over the conventional measuring equipment. First, the sensor performs a long-term, 24 hours a day measurement of the overall electric or magnetic field strength. Second, the sensor elements estimate the average and the maximum field level in the arbitrary period of time. Third, the wireless communication of the sensors relies on the wide spread GSM digital cellular networks. Moreover, the size and the shape of the sensors make them suitable for the indoor or outdoor mounting at any surface (ground, roof top or even side wall).

The SEMONT system is based on the wireless sensor elements that communicate via the GSM network in a simple star network topology. The central control station of the system collects and stores the data in the centralized database. It also supervises the activities of the remote sensor elements. Furthermore, the SEMONT system presents the results through a dedicated Internet web service.

By implementing the SEMONT system municipal agencies for the environmental protection gain a valuable tool for informing the interested public timely and for carrying out other tasks in prevention and protection of the population against the exposure to the EM fields.

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