Networks of EMF Area Monitor for Distributed Human Exposure Monitoring: Performances Assessment in Simulated Realistic Scenarios

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***Abstract*—Multi-Band Area Monitors are currently employed by national authorities and agencies in order to implement monitoring networks able to evaluate the exposure generated by EMF sources in a given geographical area. In most of the cases the focus is the evaluation of the exposure generated by sources operating in High Frequency Bands, but in some particular case the sources operate in Low Frequency Bands, e.g. high power transmitters for long distance communications. Depending from the different applicative scenarios present in the different nodes of the network, an Area Monitor can be equipped or not with a cabling for the connection to an external power source. Since it is well known that low frequency electric fields are very sensitive to environmental boundary conditions, represented e.g. by interconnecting conductive cablings, some experimental activities have been performed in order to evaluate this kind of adverse phenomena and the effectiveness of possible countermeasures. The results of this experimental activity are described in the paper.**

Keywords — RF EMF Monitoring System, Exposure to Electromagnetic Fields, Sensor Network, Area Monitor, Geographical Monitoring

I. Introduction

Due to the continuous development and implementation of new wireless communications techniques and of system based on the use of intentionally generated electromagnetic energy, the exposure to electromagnetic fields is one of the concern both of general public and workers, especially in areas surrounding the installations where group of antennas having different dimensions and shapes are clearly visible. As a consequence of this concern there is a strong demand of information about the exposure levels generated by source of electromagnetic energy, especially in areas surrounding radio base stations for mobile communication and in general surrounding infrastructures of telecommunication system operating from lower to higher frequency bands. An effective answer to this kind of demand can be geographically distributed measurements of the electromagnetic emissions from the different kind of sources; this can be accomplished by means of the implementation of networks of measurements systems able to continuously detect exposure levels, to present the results to the public in a easily accessible and understandable format, and to compare the results with the maximum level given by the different applicable standards [1]-[4]. In this framework the Recommendation K.83 of the ITU (International Telecommunication Union) [5] establishes that the measurements carried out for electromagnetic field levels monitoring should meet three requirements: must be objective, reliable, and continuous. In order to implement measurement systems able to satisfy the general requirement of [5], in the recent years some researchers from academia have proposed and described distributed real time monitoring systems based both on the integration of field probes with a WSN (Wireless Sensor Network) [6]-[8] and on the use of commercially available Area Monitors interconnected by means of radio interfaces based on the GSM/GPRS standard [9]-[14]. Recently also an innovative methodology for carrying out extensive electromagnetic field geographical monitoring in 5G scenarios has been experimented by employing an Area Monitor integrated in a car [15]. As a consequence Area Monitors integrated in a geographically distributed network can operate in scenarios with different electrical boundary conditions, e.g. depending on the presence or not of a cabling and a power supply unit for connection to the mains power supply. It is well known that low frequency electric fields are very sensitive to environmental boundary conditions; this kind of analysis has been carried out e.g. in [16] in the case of an active rod antenna with integrated Electromagnetic Interference (EMI) receiver for low level electric field measurements from 10kHz to 30MHz.

Fig. 1. An example of battery operated EMF Area Monitor (by courtesy of NARDA Safety Test Solutions S.r.l.).

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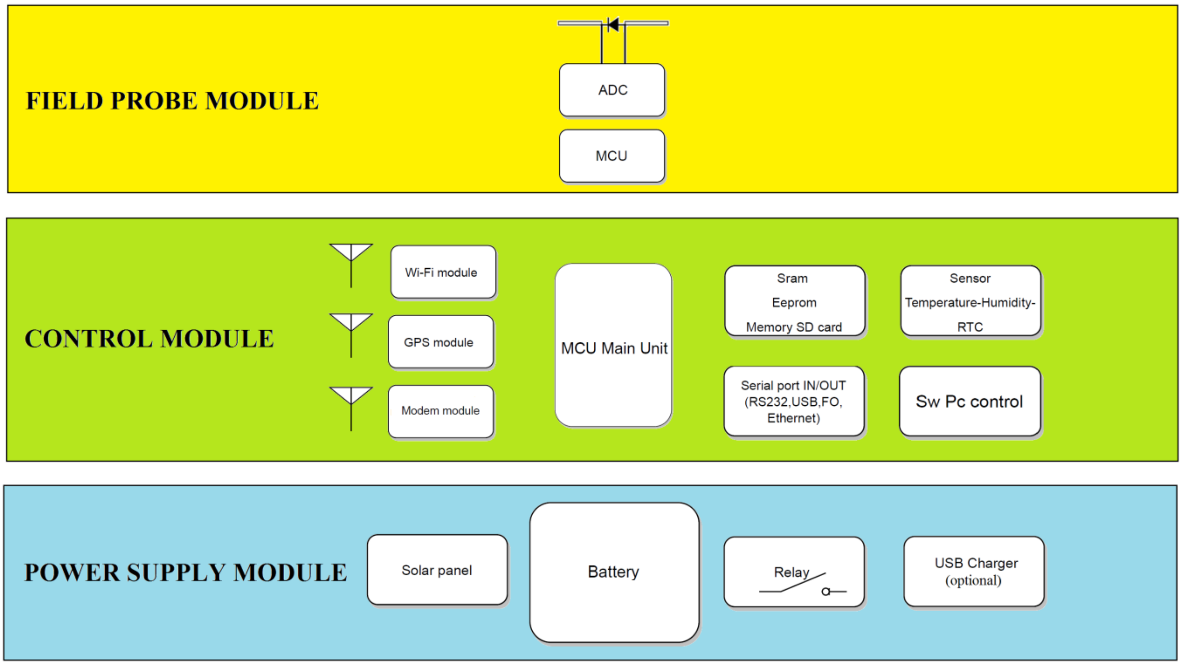


Fig. 2. Modules composing the NARDA AMB-8059 Area Monitor.

Then the connection to different cablings to an Area Monitor can lead to some measurement errors due to field perturbations introduced by cablings connected to the physical structure of the Area Monitor itself. In order to evaluate this kind of phenomena and the effectiveness of possible countermeasures, some experimental activities have been performed by exposing an Area Monitor (i.e. a NARDA AMB-8059) to electric field in a controlled environment and simulating conditions equivalent to realistic scenarios. The NARDA AMB-8059 is equipped with a relay that can be employed in the case of use of a Power Supply Unit (PSU) in order to automatically disconnect the electrical connections if the battery is enough charged and mark the time intervals devoted to measurements.

II. EMF Area Monitor Architecture

The architecture of the Area Monitor AMB-8059, used in order to carry out the activities described in this paper, is composed by a set of modules useful in order to perform activities of monitoring of electromagnetic field levels according to the requirement of the ITU-T K.83 Recommendation [5]. This kind of instrument allow national authorities, agencies and anyone interested in performing this type of measurements to provide clear and easily available data concerning electromagnetic fields levels in the form of results of continuous measurements. The main modules composing the Area Monitor AMB-8059 are shown in Fig. 2. The Field Probe Module hosts the broadband probes that cover the frequency bands of interest and contemporarily measures three orthogonal field components in order to detect the correct total field result. The signals coming from the field probes are converted by an Analog to Digital Converter (ADC) and acquired by a Micro Controller Unit MCU. A very important and critical task is related to the calibration of the field probe according to suitable standard. The Control Module provides the Area Monitor with all the functions necessary to perform continuous and unsupervised measurement, i.e. acquisition, memorization and transmission of the measurement results. In order to accomplish this last task the module comprises radio interfaces operating according different standards (e.g. Wi-Fi, GSM/GPRS) and a communication port that allow the connection to a PC with a control software. Finally a very important task is performed by the Power Supply Module, since the Area Monitor has to guarantee its functions in unsupervised conditions for long time intervals; toward this end firstly the Area Monitor has been designed in order to minimize power consumptions, secondarily it is equipped with a suitable battery that can be charged by solar panel and if necessary by means of an optional PSU, i.e. a USB charger, connected to the mains power supply (where available). The autonomy of the AMB-8059 Area Monitor obviously depends on its parameters setting, e.g. it can properly operate, and with the highest measurement accuracy, by employing the onboard battery for more than 80 days in total darkness and in a full-autonomy mode when the solar panel can provide electrical energy.

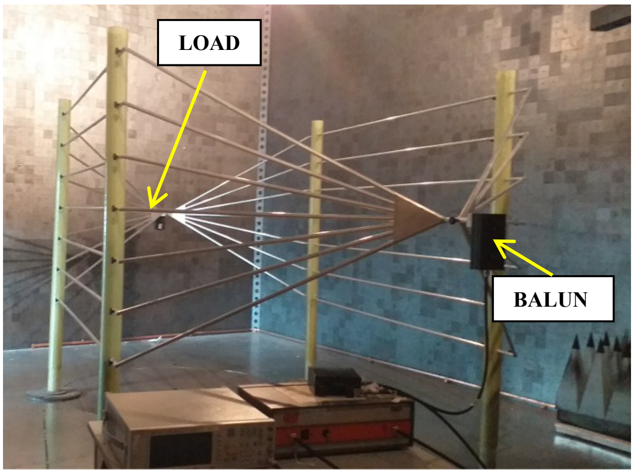
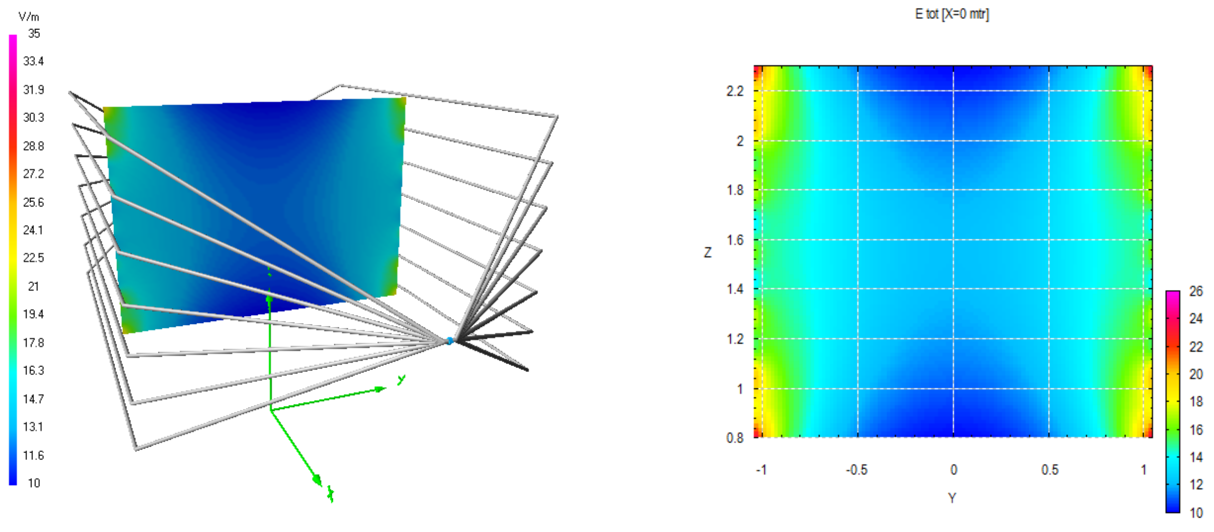


Fig. 3. A view of the Multi-Wire TEM transmission line in the setup employed during the experimental activities.



(*a*) (*b*)

Fig. 4. Electric field simulated amplitudes in the central ($x=0$) transversal section of the MWTEM transmission line (f = 20 MHz, V_{rms} = 40,3 V, Z = 58-j51 Ω): (*a*) field amplitudes and line geometry, (*b*) detailed plot of the field amplitudes.

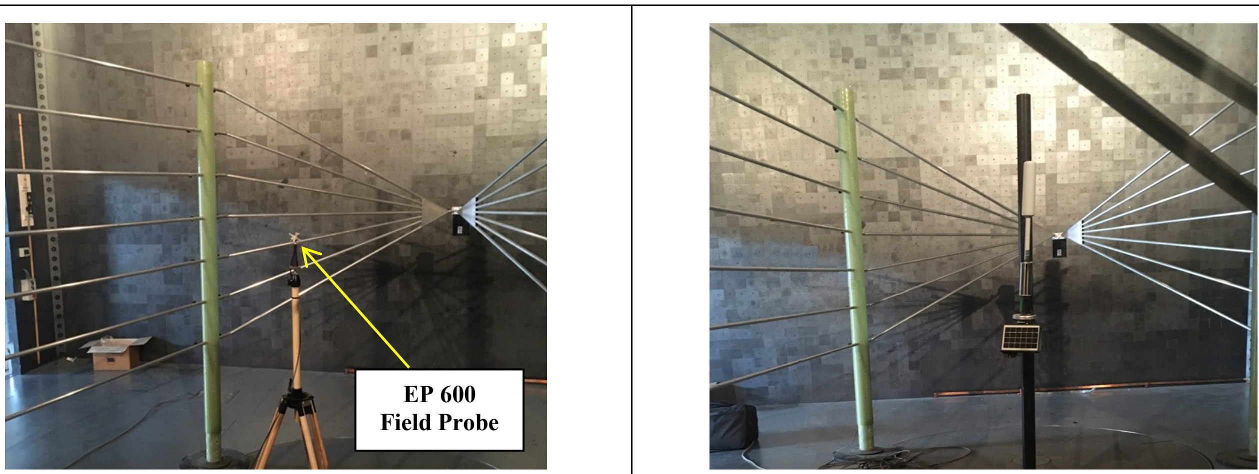
As anticipated in the previous section, the presence of cablings that electrically connect the Area Monitor with the surrounding environment can introduce unwanted perturbations that can lead the Area Monitor to operate in non-ideal conditions, with possible measurement errors. To minimize this kind of measurement errors, the Area Monitor AMB-8059 is equipped with a relay that can be employed in the case of use of a PSU in order to automatically disconnect the electrical connections when is not needed.

III. Experimental Setup

The simulation of a realistic electromagnetic scenario is not a trivial task, since it not easy to generate a controlled and uniform electric field in a volume sufficient to host the entire body of an Area Monitor. At higher frequencies (i.e. for $f>30MHz$) this can be easily accomplished by employing standard radiating devices like simple dipoles, biconical, logperiodic and horn antennas. Conversely this task becomes quite difficult at lower frequencies (i.e. for $f<30MHz$), since in general the efficiency of a standard antenna is strictly related to its physical size and then at lower frequencies very large radiating elements are required to obtain high field levels. In addition the use of large antenna in general implies to operate in near field conditions, then in a not realistic scenario, and to spread a large amount of RF power in the nearby region. A good solution for the generation of high field levels in a confined region is based on the use of Transverse Electro-Magnetic (TEM) transmission lines that in the enclosed region support a uniform and linearly polarized plane wave [17] [18] [19]. In the case of exposition to electromagnetic fields of equipment having non negligible dimensions, e.g. in the case of an Area Monitor, a good practical solution is represented by the Multi-Wire TEM (MWTEM) transmission line [20] [21] [22]. As it can be observed in Fig. 3, where the MWTEM employed during the activity described in this paper is shown, this kind of structure is made of a central uniform multi-conductors transmission line (enclosing the volume used for testing) and two tapered transmission lines having at one end the input port (equipped with a balun/matching network *50Ω/200Ω*) and at the other end a dummy load (*200Ω*). In order to minimize the power radiated in the nearby zone, the MWTEM transmission line has been placed inside a semi-anechoic chamber and it has been driven by a 75 W power amplifier connected to a signal generator.

IV. Experimental Assessment

Before the execution of the experimental activities, the uniformity of the electric field generated in the useful volume of the MWTEM transmission line has been evaluated by means of numerical simulations. For simulations, at the input port of the line (between the balun and the tapered section) the same set of voltage amplitudes used during the experimental activities (detected by means of a suitable differential probe) have been considered. The numerical simulations have been performed with a Method of Moment algorithm by using a model of the experimental setups developed according to the guidelines of the employed software [23]. In Fig. 4, generated by using the 4NEC2 software package [24], an example of the simulated values of the amplitudes of $\vec{E}_{tot}$ is shown. In Fig. 4(*a*) both the geometry of the MWTEM transmission line and the plot of $\left|\vec{E}_{tot}\right|$ in a plane transversal to the line axis (x-axis) placed in the centre of the length of line ($x=0$) can be observed; in Fig 4(*b*) the field amplitude of the same transversal section of Fig. 4(*a*) is shown in a way more convenient for the field uniformity evaluation. The simulations have been performed for the same set of frequency values considered during the experimental activities, defined between $f=300kHz$ and $f=20MHz$. The results shown in Fig. 4(*a*)-(*b*) have been obtained for the highest frequency value ($f=20MHz$), by considering at the input section of the line a voltage $V_{rms}=40,3V$ and at the output section an impedance $Z=(58-j51)\Omega$. In view of the simulations the complex values of the load impedance have been measured with a network analyzer since, as expected, the values are very different from the nominal one (*200Ω*). As can be observed in Fig. 4(*b*) the field amplitude is sufficiently uniform for $f=20MHz$, the highest among the considered frequencies and then it can be considered the worst case.



(*a*) (*b*)

Fig. 5. Experimental assessment of the Area Monitor in a simulted realistic scenario: (*a*) reference value acquisition with a NARDA EP600 field probe, (*b*) measurements with a NARDA AMB-8059 Area Monitor.

In the central position (*x=0, y=0, z=0*) the simulated electric field amplitude $\left|\vec{E}_{tot}\right|_{sim}$ is equal to 12,14 V/m while the corresponding field value $\left|\vec{E}_{tot}\right|_{mis}$, measured with a EP600 field probe, is equal to 15,31 V/m. Similar results have been obtained at the lower frequency values, where a similar level of uniformity and a better accordance between measured and simulated result in (*x=0, y=0, z=0*) has been observed. After the uniformity assessment of the field generated by means of the MWTEM transmission line, the reference electric field values have been acquired by means of a NARDA EP600 field probe for the frequency values considered during the activity (i.e. *0.3, 0.5, 1, 2, 3, 5, 7, 9, 10, 12, 15, 18* and *20MHz*). The EP600 probe, shown in Fig. 5(*a*), is able to guarantee high measurement accuracy since it has very limited dimensions and it operates without any metallic cabling but by employing a fiber optic interconnection with a PC in order to exchange the information necessary for measurements. The adoption of a fiber optic interconnection allow to minimize the perturbation of the electric field under measurement and then to maximize the measurement accuracy. After, as shown in Fig. 5(*b*), the measurement done with the EP600 field probe have been repeated with the NARDA AMB-8059 Area Monitor equipped with a solar panel and with a EP-1B-02 probe, working in the frequency band 0.1-3000MHz (amplitude range 0,2-200V/m). The AMB-8059 is able to operate for long time intervals by using its internal battery and the solar panel, but when necessary it can be powered by means of an external Power Supply Unit connected to the AC power mains. As already anticipated in Section I and evidenced in Fig. 2, in order to minimize measurement errors due to metallic cabling, the Area Monitor AMB-8059 is equipped with a relay that, driven by the control software of the system, is able disconnect the metallic electrical connections with the PSU during the time intervals devoted to measurements. Overall the measurements have been repeated for each of the selected frequencies in four different realistic operative conditions: battery operated (then without any cabling, but equipped with a fiber optic that obviously doesn't cause any perturbation), powered by an external power supply unit (PSU) with and without the GND connection provided by the AC mains power cord. In the case of power supply provided by a PSU, also the effects of connecting and disconnecting (by means of the relay) the metallic cabling between the PSU and the Area Monitor have been evaluated. The measurement results are shown in Fig. 6, where they are represented in terms of deviations (in dB) from the reference value (obtained by means of the EP600 field probe). As expected the battery operated is the best condition, while in the case of presence of an external PSU, the GND connection allow to reduce deviations in all the considered frequency band. This last improvement can be probably explained assuming that the GND connection is able to provide a path towards ground for undesired current spectral components generated by the PSU, that without the GND connection can propagate toward the measurement system and cause error contributions. Moreover it can be observed that the deviations can be further reduced at higher frequencies by disconnecting the metallic cabling between the PSU and the Area Monitor (i.e. by opening the relay contacts). This last observation confirms to effectiveness of the integration in the measurement system of the relay that disconnect metallic wires during measurements time intervals.

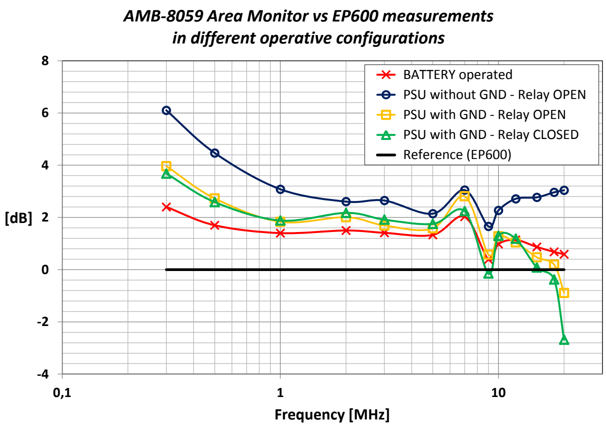


Fig. 6. Deviation of EMF Area Monitor measurement results from reference values in different simulated realistic conditions.

The assessment described in this paper has been performed by considering the effects on the measurement accuracy of the electric field under measurement itself, but more in general it can be considered valid also in order to evaluate the immunity of the Area Monitor when measuring electric field components localized in higher frequency bands (*f>30 MHz*); as a matter of fact the Area Monitor can be locally exposed to the effects of low frequency electric field spectral components generated in lower frequency bands (*f<30MHz*) by equipment operating in the nearby zone of the Area Monitor installation (e.g. often Area Monitors are installed on the roof of large buildings where usually are also installed the electrical equipment of conditioning systems, that largely employ electronic switching modules, well known unintentional generators of undesired emissions, especially in the lower frequency bands).

V. Conclusions

An Area Monitor can operate in different operative scenarios and then with different electrical boundary conditions. In particular the connection of cablings to an Area Monitor can lead to some measurement errors due to field perturbations introduced by the cablings connected to the physical structure of the Area Monitor itself. In order to evaluate this kind of phenomena and the effectiveness of possible countermeasures, some experimental activities have been performed by exposing the entire structure of an Area Monitor (i.e. a NARDA AMB-8059) to electric fields in a controlled environment and simulating conditions equivalent to realistic scenarios. The results have confirmed the effectiveness of the adopted countermeasures, in particular the integration in the measurement system of a relay that disconnect metallic wires when battery operated and during measurement time intervals.

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