RF electromagnetic field levels extensive geographical monitoring in 5G scenarios: dynamic and standard measurements comparison

Claudia Carciofi, Andrea Garzia, Simona Valbonesi
Fondazione Ugo Bordoni
Bologna, Italy
{ccarciofi, agarzia, svalbonesi }@fub.it

Alessandro Gandolfo, Roberto Franchelli
Narda Safety Test Solutions
Cisano sul Neva, Italy
{Alessandro.Gandolfo, Roberto.Franchelli}@L3T.com

***Abstract*— The document presents a potentially innovative methodology for carrying out large-scale measurements of radiofrequency electromagnetic field. The system consists in performing dynamic measurements using a control unit equipped with the appropriate probes positioned on the roof of a car moving along the territory. Aim of the work is to provide a methodology to assess field strength variability which characterize future 5G scenarios with a combination of measurements carried out in a dynamic way in comparison with the static measurement approach which is commonly adopted for environmental impact assessment. The possibility to perform massive measurements in a short time could become extremely useful in the next future to evaluate electromagnetic field levels, when the implementation of the new 5G services will lead to an increased complexity in the use of the spectrum and new antenna systems (Active Antenna Systems).**

Keywords— electromagnetic field levels; EMF measurement ; 5G; innovative measurement methodology; radiofrequency fields

I. INTRODUCTION

The problem of radiofrequency electromagnetic field levels and exceeding exposure limits is still relevant, especially in urban areas. Numerical simulations performed by FUB in cooperation with ARPA Emilia Romagna [1] on sites located in Italian cities have shown that over 70% of the active sites are saturated. The percentage becomes 100% if we consider the city centers. Sites saturation conditions implies the need to resort to new deployments and, if this is not possible, operators may be forced to stop some of the currently available services and to reduce the number of sites hosting less evolved technologies such as GSM or 3G. In this scenario it could be extremely important to carry out extensive geographic monitoring in order to verify the actual levels of electromagnetic field present in the air.

Recommendation ITU-T K.113 [7]provides a series of tools to assess exposure levels in extensive areas with the aim of building radiofrequency electromagnetic field level maps and identify with extreme precision the areas with the greatest impact. These tools complete the numerical simulations, the standard on site measures and the continuous monitoring that will still be carried out in any case at national or local level [8][9].

The paper intends to validate the drive test methodology in standard and estreme scenarios to verify its applicability for extended monitoring.

The paper presents a dynamic measurement approach for carrying out rapid extensive monitoring of radio-frequency electromagnetic fields that can be used to characterize dynamics of electromagnetic field levels in new 5G systems. The purpose of the present work consists to validate the measurements carried out by drive test in all the possible exposure scenarios, including the most complex ones.

The measurement system is composed of a monitoring station on the roof of a car that moves at a maximum speed of 60 km/h recording the electromagnetic fields levels that can subsequently be made available on google maps. The article describes the measurement campaign, the characteristics of the monitoring station and of the probes, and provides a comparison with static standard measurements carried out following the technical indications reported in the Guidelines CEI 211-7[1] .

II. SCOPE AND GOALS

Scope of this work is to verify if the results of the dynamic measurements are comparable with the results of the measurements carried out following the standards reported in Italian CEI 211-7 guidelines. Thorough the execution of dynamic and static measurements in the same scenarios we mean to:

- validate the dynamic methodology for radiofrequency electric field measurements up to 7 GHz;
- verify the possible effects of the movement of the car on the results of the radiofrequency field measurements carried out in areas characterized by high levels of 50 Hz magnetic and electric field ;
- point put any critical aspects of the dynamic methodology.

Drive test measurements can be certainly extremely useful in the characterization of the mobile networks emission level on large scale, as they allow to obtain, in short times, indications of radiofrequency field levels present in air related to large or very large areas. This goal is difficult to be achieved with standard measurements techniques, except with considerable investments of time and money.

III. MEASUREMENT CAMPAIGNS

In motion measurements have been performed using a Narda AMB-8059 continuous monitoring station [4] installed on the roof of a car moving on the territory making continuous E field levels measurements. The system allows to connect the control unit to a laptop PC to view real-time measured field levels on a satellite map. The data can then be saved in gpx format and displayed on satellite maps, providing the electromagnetic field values related to the path followed by the car. The control units can be equipped with probes with different characteristics. Three probes have been used for the campaign:

- EP-1B-03 – wideband E-field probe - range 100 KHz – 7 GHz
- EP-4B-02 - quad-band E-fields probe - range 100 KHz – 7 GHz

Dynamic measurements have been performed installing the monitoring station on the roof of a car with sensors at 190 cm above ground floor. The car moved along an established path at an average speed of 40 km/h and in any case never exceeding the 60 km/h. The sampling frequency have been set at 300 ms. The following measurements have been carried out:

- low levels radiofrequency E-field (< 1 V/m);
- high levels radiofrequency E-field (> 1 V/m);
- radiofrequency field levels in a scenario characterized by the presence of high ELF (E and H) fields;

Static measurements have been performed, following the criteria set out in the CEI 211-7 guidelines, using a PMM8053 [5] wideband meter equipped with different probes according to the specific relief to be performed. The probes used with their technical features are shown in Section III.A.

To perform static radiofrequency field measurements, the PMM8053 has been installed on a dielectric stand with sensors at 190 cm from the ground. This choice was driven by the need to keep both probes at the same height in order to obtain comparable results. According to CEI 211-7 guidelines [2], measures of 6 minutes have been carried out in a set of pre-established points.

A. *Probes technical characteristics*

The specific characteristics of the probes used for dynamic measurements are illustrated in TABLE I. The specific characteristics of the probes used for static measurements are reported in TABLE II. The EP333 is particularly suitable for the measurements of OFDM signals [6].

TABLE I. RF FIELD PROBES FEATURES (DYNAMIC MEASUREMENTS)

Main characteristics	**Probe**	
	EP-1B-03	***EP-4B-02***
Frequency range	0.1 – 7000 MHz	0.1 – 7000 MHz
Reading range	0.2 – 200 V/m	0.2 – 200 V/m
Overload	600 V/m	600 V/m
Resolution	0.01 V/m	0.01 V/m
Sensitivity	0.2 V/m	0.2 (@wideband)
Analized bands	Wide	Wide, EGSM900, EGSM1800, UMTS

EP-1B-03 probe performs only wideband measurements, while the EP-4B-02, being a quad band, allows to perform both wideband measurements and narrowband measurements GSM900, GSM1800 and UMTS bands.

TABLE II. RF FIELD PROBES FEATURES (STATIC MEASUREMENTS)

Main characteristics	**Probe**	
	EP-330	***EP-333***
Frequency range	0.1 – 3 GHz	0.1 – 3.6 GHz
Reading range	0.3 – 300 V/m	0.15 – 300 V/m
Overload	600 V/m	600 V/m
Resolution	0.01 V/m	0.01 V/m
Sensitivity	0.3 V/m	0.15
Analized bands	Wide	Wide(OFDM)

B. *Scenarios and selected paths*

For what concerns measurement activity, three paths have been selected corresponding to three different environmental and radio-electric scenarios. The main characteristics of each path are reported in the table below.

TABLE III. SELECTED SCENARIOS GLOBAL CHARACTERISTICS

Path	**Start/Stop**	**Scenario**	**Lenght**
1	44°23’16.03’’N 11°14’5.68’’E 44°28’47.84’’ N 11°16’8.53’’E	Suburbs Industrial Rural	11 km
2	44°33’33.10’’N 11°22’35.72’’E 44°33’33.10’’ N 11°22’35.72’’E	Suburbs Industrial	1.3 km (ring)
3	44°30’47.88’’N 11°18’7.75’’E 44°30’49.32’’ N 11°18’17.7209’’E	Suburbs	468 m

Path 1 is a straight path of about 11 km characterized by extremely low levels of radio frequency electromagnetic field, near or above the instrumental sensitivities.

Path 2 consist of a 1.3 km ring with expected radiofrequency electromagnetic field levels higher than 1 V/m due to the presence of three radioTV broadcasting antennas arrays counting a total of 24 radio and television stations in co-siting. In the nearby there are also some mobile telephony radiobase stations and a WiMax station. This path has been selected to compare the two measurement methodologies in case of electromagnetic field levels higher than one V / m.

Path 3 consist of a 468 m half-ring running around a primary transformer cabin with expected high levels of 50 Hz electric and magnetic fields. This specific path has been selected to verify possible effects of low frequency electric or magnetic fields on the result of the dynamic measurements.

IV. RF FIELDS MEASUREMENTS

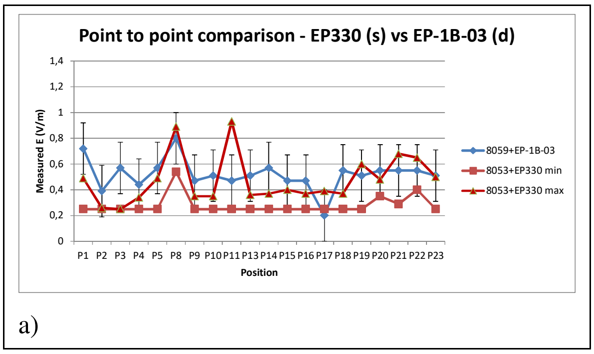
A. RF field levels near instrumental sensitivity

To perform a comparison between static and dynamic measurements methods for expected E-field levels comparable with the instrumental thresholds, path 1 has been selected. Only 20 of the 23 points, present electric field levels comparable with the instrumental thresholds (0.25 V/m for the chain PMM8053+EP330 and 0.2 V/m for the chain 8059+EP-4B-02 and 8059+EP-1B-03) or slighty higher. Three points (P6, P7 and P12) presented measured E field levels higher than 1 V/m and have been excluded from this survey.

The first data processing concerned only the electric field levels measured in static and dynamic modality at the specific point GPS coordinates ("point to point" processing (PP)).

Unfortunately, due to logistical problems (traffic congested roads, unsafety areas), it has often been impossible to make static measurements within the exact GPS coordinate of the point at which the corresponding dynamic measurement have been made. In order to take this problem into consideration a second elaboration mode, called "nearest point processing (NPP)" have been carried out.

NPP processing consist in averaging the field levels dynamically measured in a cluster of points located in a 2.0 m radius circle centred in the GPS coordinate and compare the results with static measurements. Fig. 1. shows the results of a comparison between the measurements carried out in static mode with the PMM8053 equipped with EP330 probe and in dynamic mode with the chain 8059+EP-1B-03. The upper part of the figure shows the results of the "point to point" data processing, while the lower part presents the electric field values obtained with NPP data processing.



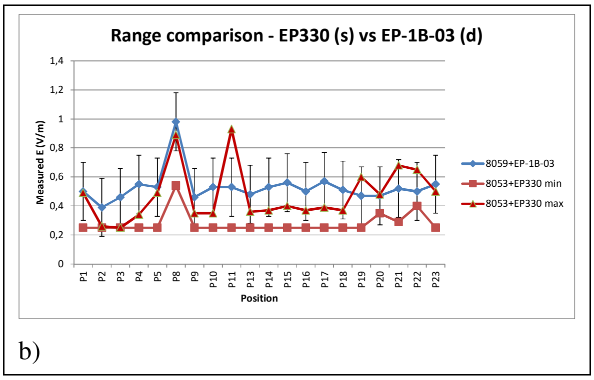


Fig. 1. Static/dynamic measurements comparison- E<1 V/m

From the graphs analysis emerges a slight overstimation of the electric field levels measured using the dynamic procedure, more evident in the "point to point" processing. In any case, within the limits of the instrumental errors the values obtained through the two modalities present an excellent agreement. The same agreement is obtained if the comparison is made with the values measured with the chain 8059+ quad-band probe EP-4B-02.

B. RF field levels higher than 1 V/m

For this survey path 2 has been selected. Only 9 of the 16 points fitted the stringent boundary condition of presenting a dynamically measured E field greater than 1 V/m. These points have been taken into consideration, the others have been rejected. The whole path 2 have been travelled four times (two times with 8059+EP-1B-03 probe and two times with 8059+EP-4B-02 probe) and the related data have been processed separately.

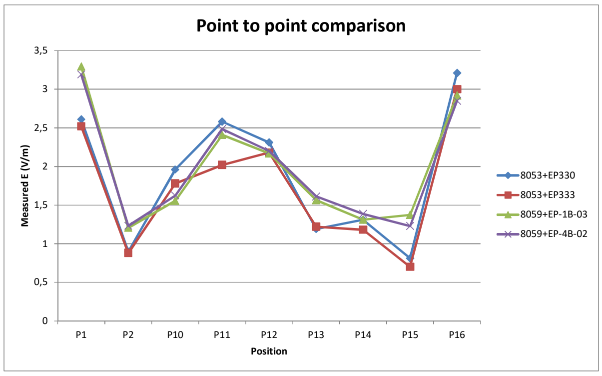


Fig. 2. Static/dynamic measurement comparison-point to point

Data have been analysed using "PP" and "NPP" data processing as described in section A.

Fig. 2. presents the results of the "point to point" comparison between the measurements carried out in static mode with the PMM8053 equipped with the EP330 and EP333 probes and in dynamic mode using the PMM8059 with the wideband EP-1B-03 probe and the quad-band EP -4B-02 probe. The graph shows a good agreement between the measured values within the limits of the instrumental error. Measured E-field levels deviated only in two points (P1 and P11).

Fig. 3. shows a comparison between the electric field levels measured in static mode with 8053 + EP330 (a) and EP333 (b) and the levels measured in dynamic mode with the 8059 equipped with wideband probe EP-1B-03. The electric field level measured in motion have been obtained averaging on a group of points located in a 2.0 m radius from the exact GPS coordinate area. The comparison took place between the dynamic value calculated as described in section A and the maximum and minimum electric field level obtained with static measurements. The graphs refer to path 2, second run and show that the electric field level obtained through dynamic measurements are mostly contained within the minimum and maximum E-field levels measured following the CEI 211-7 guidelines standards.

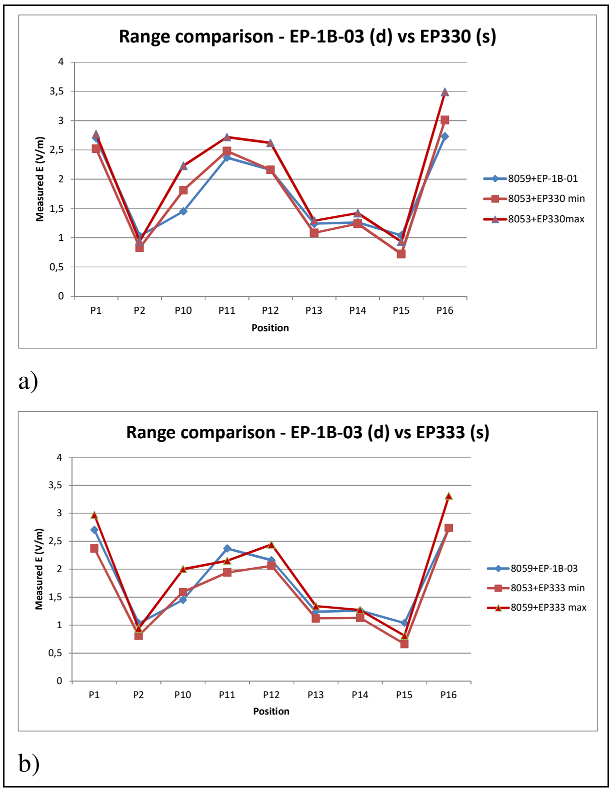


Fig. 3. 2.0 m radius area comparison (probe EP-1B-01)

Fig. 4. shows a comparison between E-field levels measured with PMM8035+EP333 (static) and the values obtained from the processing of dynamic data coming from monitoring unit 8059+EP-4B-02. Electric field levels measured in dynamic mode are contained within the min-max range of values obtained in static mode.

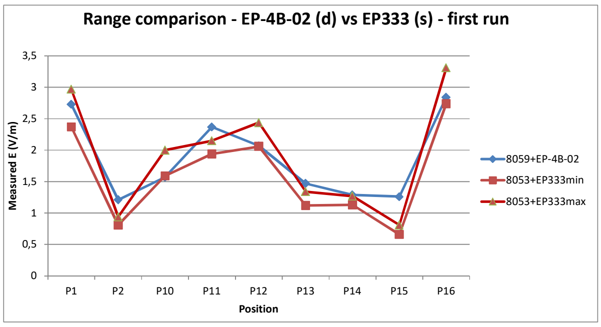


Fig. 4. 2.0 m radius area comparison (probe EP-4B-02)

C. *RF field probes performance comparison*

In motion radiofrequency electric field measurements have been carried out with two different probes, in order to make a comparison. The comparison have been performed on the bases of the measurements carried out along path 2 which have been selected for its hybrid characteristics; in fact, it alternates zones with RF electric field levels close to the instrumental thresholds and areas where the electromagnetic field level exceeds some V / m. To carry out this comparison the path has been travelled twice with each probe, the E- reported represents the average of the electric field measured on the two turns.

The graph in Fig. 5. shows that the two probes, used in wideband mode have comparable performances.

No specific investigations have been made on the behavior of the EP-4B-02 probe in quad-band mode. This topic could be the subject of a possible study continuation.

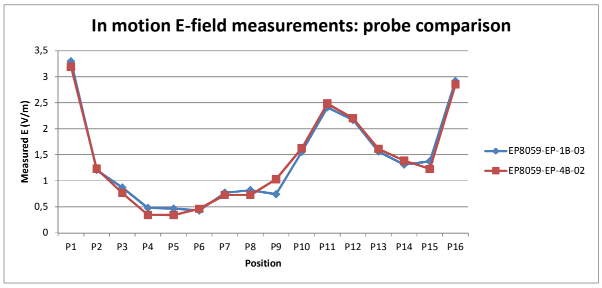


Fig. 5. E-field probes comparison

V. RF FIELD MEASUREMENT IN HIGH-ELF LEVELS SCENARIOS

To complete the survey, it was decided to carry out a specific study on the AMB-8059 monitoring unit performance in measuring radiofrequency fields in areas characterized by the presence of power lines or primary electric substations and high ELF field levels Therefore only 6 points of the whole data pack have been selected being close to potential low-frequency field sources (see TABLE IV.).

TABLE IV. POINTS SELECTED FOR THE ADDITIONAL SURVEY

Point	Path	ELF source	E (V/m)	H(μT)
P7	1	Primary substation	320	0.09
P17	1	Power line	192.3	0.11

P0	3	Primary substation – Power Line	1669.8	1.14
P2	3	Primary substation	265.7	0.04
P3	3	Primary substation	418.4	0.03
P4	3	Primary substation	216.2	0.09

To perform this specific survey ELF field measurements have been performed following the indications reported in CEI 211-6 guidelines [3]; those have been performed using an instrumental chain composed by PMM8053+EHP50 probe.

Elaborations and comparisons have been carried out only in "point-to-point" mode to maintain consistency with the values measured with the PMM8053 + EHP50 chain which are relative to a specific point of the space or to a very small area around it. The graph in Fig. 6. compares the radiofrequency field levels measured with the 8059 + EP-1B-03 (on the roof of the car) chain with the maximum and minimum values of the electric field measured with the PMM8053 broadband meter equipped with EP330. (on its dielectric tripod) As can clearly be seen from the graph the agreement is excellent in all points except in P0, a point presenting the higher values of low frequency magnetic and electric field levels. This specific anomaly could be due to two different causes:

a) Problems related to the dynamic measurement mode

b) Problems inherent the monitoring unit mode of operation in the presence of high low frequency electric and/or magnetic fields

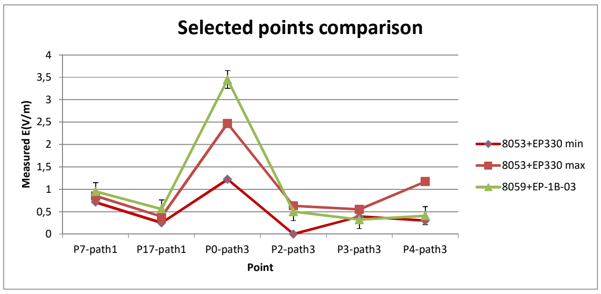


Fig. 6. Static/dynamic RF field measurement comparison (High ELF)

This criticality required further investigations.

The selected area for this survey has been a 4 m radius zone surrounding point P0 (path3). In 7 different points static radiofrequency field measurement have been performed with the 8059 control unit equipped with the two probes (EP-1B-03 and EP-4B-02). To carry out this specific survey the control unit has been installed on the roof of the car not moving. Within the same points, radiofrequency field measurements with PMM8053 and the EP330 probe and low frequency electric and magnetic field measurements with the appropriate instrumentation on a dielectric tripod have been performed.

The coincidence within the limits of the error between the data measured statically with the 8059 and the data measured with the PMM8053 would mean a problem related to the dynamic measurement mode that would not be reliable in the case of areas characterized by high low frequency fields. A confirmation of the misalignment instead would lead to hypothesizing some rejection performance difference, or effects due to the E-field reflection on the metallic car top.

The additional investigations carried out led to the following results (TABLE V.):

TABLE V. Additional investigations results

	PMM8053			8059	
Point	***E (V/m)***	***H (V/m)***	***E (V/m)***	***E (V/m)***	***E (V/m)***
1	1185	0.204	1.35	2.00	
2	1109	0.118	1.69	3.35	
3	1111	0.248	2.03	4.29	
4	1132	0.264	2.06	4.57	
5	1185	0.204	2.20		4.54
6	1194	0.213	2.13		4.35
7	1111	0.248	1.38		2.34

The results of the measurements performed not in mobility exclude an effect due to the car movement, most likely the problem detected is due to apparently different rejection of the probes to the 50 Hz fields and to E-field reflection caused by the metallic car top. Additional measuring campaigns recently carried out by Narda had already shown that 50 Hz electric field level, measured under OHTL, can be 6 to 8 dB higher when under the probe is place the vehicle. ELF field is so locally increased and the constant rejection of the probe is apparently lower.

VI. Conclusions

Measurement activities carried out in different scenarios have shown an good agreement between dynamic and static measurements. This opens the possibility to perform large-scale radiofrequency field monitoring using the dynamic measurement approach in addition to the consolidated static methodology described in [2].

The measurement campaign carried out and presented in this work using a control unit with the appropriate probes on a van can be extensively used in different environments and frequency bands extended to perform large-scale dynamic measurements of radiofrequency fields environmental impact assessment

This dynamic measurement methodology represents a useful innovation because it allows to carry out massive measurement campaigns providing a reliable indication on field levels present in air, allowing to cover large areas in a relatively short time. The possibility of making measurement results directly available online on a satellite map is an addedvalue also from the point of view of communication as citizens can connect to the internet and have an idea of the electromagnetic field levels present near their residence or workplace.

The use of a moving control unit can also support the Environmental Agencies to get information on the real electromagnetic field levels present in the air. The easiness of the measurement procedure makes it easily repeatable, giving the possibility to obtain levels maps that can be repeated over time for a simple comparison or after the installations of radio base stations. Moreover, thanks to the maps that can be created starting from the measurement results, it is possible to identify with extreme precision any so-called critical areas, in which the field levels are higher; in these areas it is justifiable to intervene with standard measurement campaigns. Moreover, in an indirect way, measurements of the electromagnetic field levels carried out on a large scale by drive tests can also be useful in providing indications on the coverage or on the presence of cases of saturation of the electromagnetic space.

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