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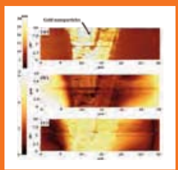

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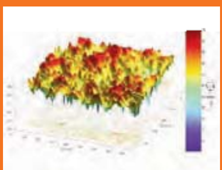
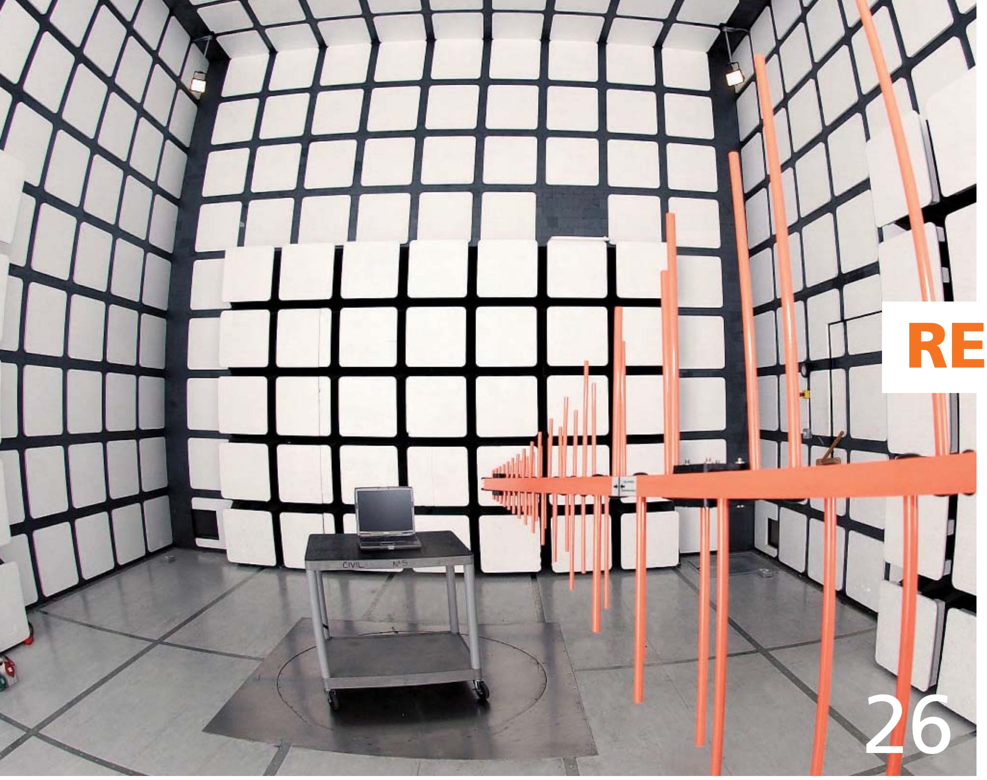


GSM
PROPAGATION STUDY OF GSM DIMENSIONS INDOORS – PART 2

PRODUCTS
MEASUREMENT SUITES, DRIVER ICS,CONNECTORS AND MUCH MORE

ALSO IN THIS ISSUE: ANALYST COLUMN • ON THE BUG HUNT • DESIGN



FEATURES

REGULARS

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ALD: FROM STRENGTH TO STRENGTH IN THE UK?

BY DR ALEC READER

What this piece states is that despite the strengths of the UK in the field of Atomic Layer Deposition (ALD), there are definite areas that need improvement for it to become a clear leader.

ALD processes allow for the creation of easy building structures measuring 100 nanometres and smaller, for use in advanced applications of electronics, catalysis and sensors. And it is the general consensus of many professionals in the industry that the UK could be a leader in the implementation of ALD if the gaps in the basic infrastructure, already present in the UK, be identified and filled.

However, there seems to be lack of communication between all facets of the industry; albeit all working in the same area and on very closely related topics. Furthermore, it is apparent that these industry practitioners are not aware of how the opportunity to collaborate could identify and bridge the gaps they are struggling to fill.

ALD is currently being used in a number of developing markets, including nano-electronics to deposit high-k gate oxides, high-k memory capacitor dielectrics, ferroelectrics and metals and nitrides for electrodes and interconnects. The need to control extremely thin films is essential in high-k gate oxides.

Fuel cells and the highly conformal coatings used in the production of micro-fluidic and Nano Electronic Mechanical Systems (NEMS) also require the flexible and precise thickness control processes offered by ALD, to produce wear resistant, anti-stiction and chemical resistant coatings.

With the introduction of a low-temperature plasma step in the ALD reaction cycle, it is possible to deliver additional reactivity to the surface in the form of plasma-produced species. This allows ALD to be used in an even wider range of applications by improving the film quality, particularly at lower temperatures, and it also increases the number of materials that can be deposited.

Producing efficient devices is a continual challenge to the electronics market and ALD has been recognised as a vital innovation in doing this, as it is a self-limiting service that offers the benefit of giving precise thickness control. As mainstream semiconductor and other nano-electronic applications start to require a reduced dielectric layer thickness, ALD is becoming more frequently used and ever more critical.

Using remote plasma ALD means damages can be kept to a minimum, as well as the end result being higher quality films as a result of improved removal of impurities that lead to lower resistivity and higher density. Plasma ALD processes also offer the widest choice of precursor chemistry available and higher quality films with more process control.

It is apparent that the UK's main strength is its expertise of industry and academia, throughout the supply chain, most of which are available in the UK. The UK is clearly defined in R&D, new product development and process. The UK nanotechnology market has a diversity of interest, with academic expertise in less developed areas such as metrology.

Despite the strengths, there are definite areas that need improvement. There is a clear lack of knowledge about what facilities are available in the UK and the NanoKTN has suggested that if this is going to change, there needs to be a clearer defined and published asset list, available to everyone in this industry. More worryingly there is limited availability of UK suppliers of versatile and experimental facilities that include all techniques and as well as this, there is as yet no equipment supply for high volume production. With gaps between one off and production scale processes not easy to fill in the UK, this could be the downfall of development in this area within the UK.

Once the gaps have been identified and filled, we will start to see the commercial benefits of establishing an end-to-end supply chain, to enable UK technology innovators to get products to market faster and easier.

By ensuring that the whole of Europe continues to invest in ALD technology, and by working in partnership with universities to push the boundaries, we can build on Europe's position as global technology innovators.

Dr Alec Reader is director of NanoKTN

> **"DESPITE THE STRENGTHS, THERE ARE DEFINITE AREAS THAT NEED IMPROVEMENT; THERE IS A CLEAR LACK OF KNOWLEDGE ABOUT WHAT FACILITIES ARE AVAILABLE IN THE UK"**

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Propagation Study of GSM DIMENSIONS in Indoor

This article is in two parts. This is the second part, where **José Carlos Gamazo**, **Juan Blas**, **Rubén Lorenzo** and **Jaime Gómez**, from the Department of Signal Theory, Communications and Telematic Engineering at the University of Valladolid in Spain, present the material, methods, results and conclusion of the propagation study of GSM power in indoor environments. The first part was published in the last issue of *Electronics World*

THIS ARTICLE IS based on the application of an experimental system to measure the power of the electric field indoors. A robotic system is used to automatically position an antenna in a fixed grid within an environment. The collected data is then processed, analyzed and demonstrated graphically, in order to explain the 2D and 3D pattern of the electric power signal.

Finally, a concrete environment is studied and the measured data evaluated in order to characterize the electric field radiated by a GSM base station and to analyze its impact on the human body. The results show that the measured signals have space and temporal variability in a concrete point of their propagation, which produces slow and fast variations with the distance.

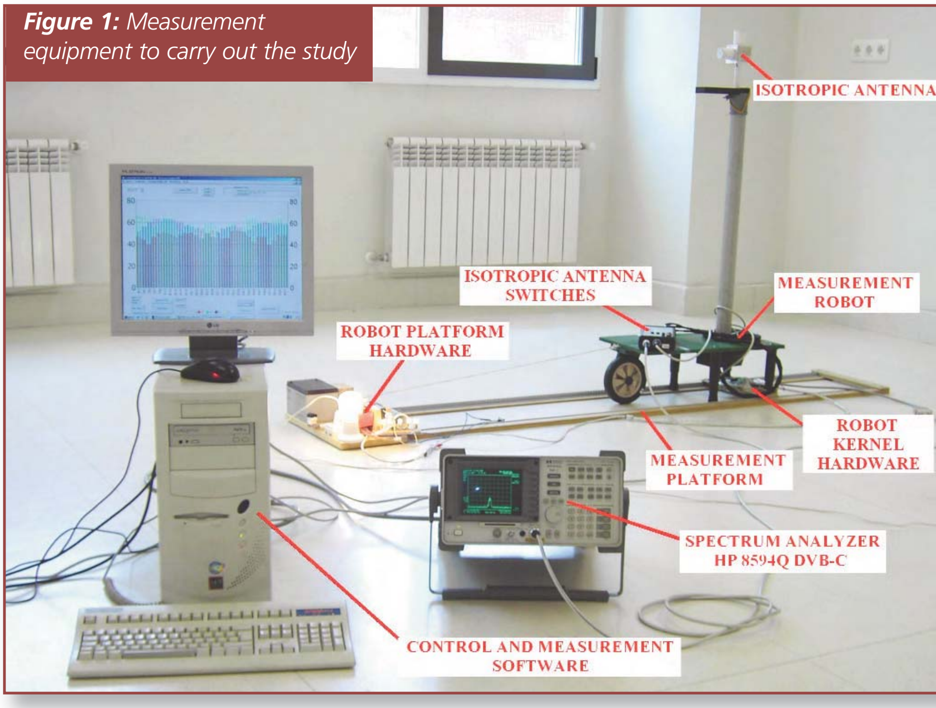


Figure 1: *Measurement equipment to carry out the study*

The Measurement Equipment Used

The most important measurement equipment, besides an isotropic antenna and control probe switches (both made by Antennessa), is composed of two spectrum analyzers: Hewlett-Packard 8594Q DVB-C (9kHz-2.9GHz) and Rohde&Schwarz FSH3 (100kHz-3GHz) (see **Figure 1**).

The isotropic antenna consists of three probes (or monopole antennas). Probe 1 measures the vertical polarization of the GSM signal (Z direction) and probes 2 and 3 the horizontal polarization (X and Y directions, respectively). The antenna measures a range of frequencies from 100kHz to 3GHz, so that the structure of three orthogonal monopoles optimizes the operation and the isotropy of the three-dimensional probes in a wide range of frequencies (the antenna radiates or receives the same in all the directions, being ideally the radiation pattern a circumference in 2D or a sphere in 3D).

The electric field is measured by each monopole (in X, Y and Z), which can be written as in **Equations 1, 2** and **3**:

$$E_X = AF_X \cdot V_X \qquad (1)$$

$$E_Y = AF_Y \cdot V_Y \qquad (2)$$

$$E_Z = AF_Z \cdot V_Z \qquad (3)$$

where E is the electric field measured in X, Y and Z directions, AF is the antenna factor of each monopole and V is the voltage measured in each space direction by the spectrum analyzer.

Once each one of the components of the electric field has been obtained (X, Y and Z), the total electric field (in volts per meter) can be calculated as it appears in **Equation 4**:

$$E_{TOTAL}\left(\frac{V}{m}\right) = \sqrt{E_X^2\left(\frac{V}{m}\right) + E_Y^2\left(\frac{V}{m}\right) + E_Z^2\left(\frac{V}{m}\right)} \qquad (4)$$

The probe switch allows selecting one or another axis of the antenna by hand or by means of a software program. In addition, the switch contains an amplifier to improve sensitivity of the sensors to LF (Low Frequency). Then, the measured electric

Power in TWO Environments – Part 2

field can be written as in **Equation 5**:

$$E_i\left[dB\left(\frac{V}{m}\right)\right] = P_M(dBm) - 13 + |L| + AF(dBm^{-1}) \quad (5)$$

where i is the index X, Y or Z, PM is the measured power (in dBm), L is the losses of the wire and the switch, and AF is the antenna factor.

Figure 2 shows a schematic drawing of the location of the environment with respect to the electromagnetic field source, a base station of GSM-900 mobile phone. The angle whereupon this station is located with respect to the plane of the building facade (where there are two windows) is approximately 25º. In addition, the distance from the windows to the base station has been measured, obtaining 300m. It is important to say that the emission antennas are approximately the same height as the roof of the building (less than 10 meters over this environment).

The area of the environment to characterize has these dimensions: 4.77m in the X dimension and 4m in the Y dimension, presenting an area of approximately 19m^2 (see **Figure 3**).

The Main Criteria

Two objective criteria of evaluation have been applied in the comparative study. One of them is duration, with an assigned score according to the time measured, and the other one quality, with an evaluated score according to the simplicity with which the results of the measurements are interpreted, number of errors and so on.

This study is based on analyzing the 2D graphics obtained, similar to the graphs shown in **Figure 4** and **5**. Taking into account these considerations, the method and resolution which obtains the best balance of the score in both criteria will be chosen. Also, it is necessary to consider the duration of each measurement method, that is the time that the robot needs to move until the next sampling slot and the time necessary to take measurements in all three space directions.

In order to select the measurement method and the most appropriate grid resolution, one the following have been used:

- **Measurements method:** using the duration criteria, the method with the smaller measurement time will have the maximum score.
  - – *One standard measurement:* it is the measurement that takes a lower time in realizing. It uses around six seconds for a measurement with the three probes (one measurement per probe).
  - – *Arithmetic mean of three standard measurements:* nine measurements are taken (three per probe) in each sampling slot, and later (off-line) the arithmetic mean is computed (using a Matlab program). It uses 18 seconds.
  - – *A measurement Video Avg using an acquisition time of 7 seconds:* it takes 26 seconds to realize three measurements (one per probe).
  - – *A measurement Video Avg using an acquisition time of 4 seconds:* it takes 19 seconds to realize three measurements.
  - – *A measurement Video Avg using an acquisition time of 1 second:* it takes 11 seconds to realize three measurements.
- **Grid resolutions:** 1cm, 3cm, 6cm and 10cm for the X direction; and 1cm, 5cm, 9cm, 13cm and 17cm for the Y direction (where the electromagnetic field pattern will have a bigger wavelength with respect to the X direction). Also, the necessary time for moving the robot between sampling slots has been measured. For example, the robot takes two seconds in moving in a grid of 1cm; five seconds in a grid of 3cm; eight seconds in a grid of 6cm and 12 seconds in a grid of 10cm in the X direction.

Measurements have been realized taking into account that the wavelength for GSM-900 (the central frequency used is 946.988MHz), see **Equation 6**:

$$\lambda = \frac{c}{f} = \frac{3\cdot 10^8}{946.988\cdot 10^6} \cong 0.3168m = 31.68cm \quad (6)$$

In addition, measurements have been taken with a fixed measurement method but varying grid resolutions (and number of samples) and vice versa, with a fixed resolution and varying measurements method. Using these measurements, 2D graphs have been obtained to realize the comparisons and the assessments in order to select the best method and resolution. Two examples of these 2D plots are shown in Figures 4 and 5.

In the graph shown in Figure 4, the arithmetic mean of the three standard measurements method has been used for

Figure 2: *Location of the studied indoor environment with respect to the location of the electromagnetic field source*

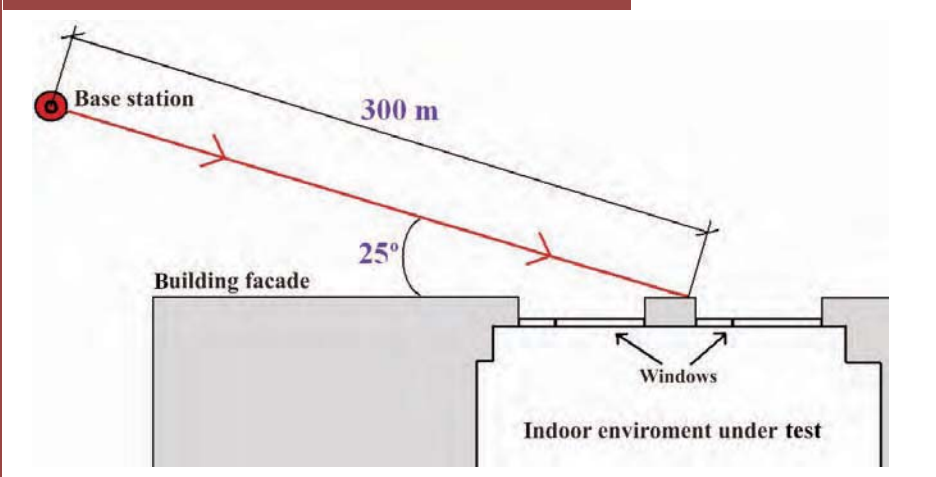


Figure 3: Plan view (in metres) of the selected area for the studied indoor environment

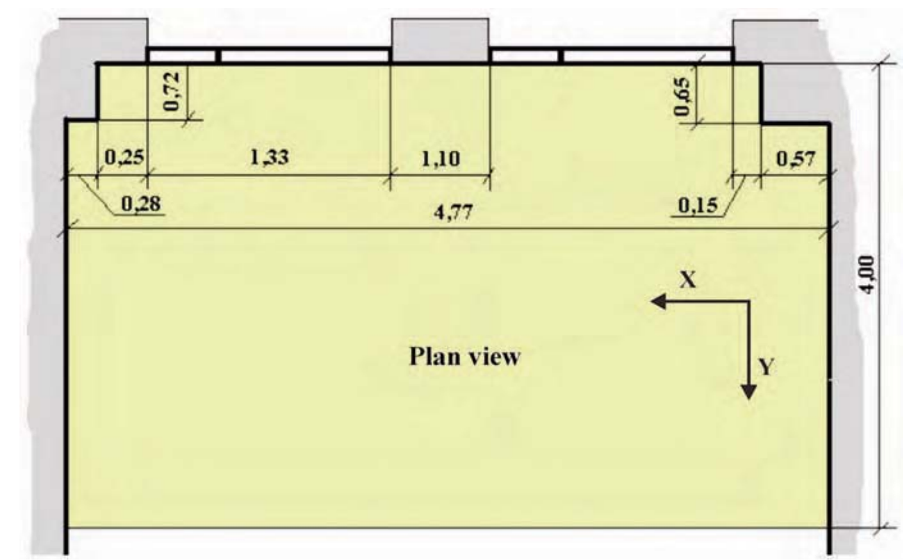
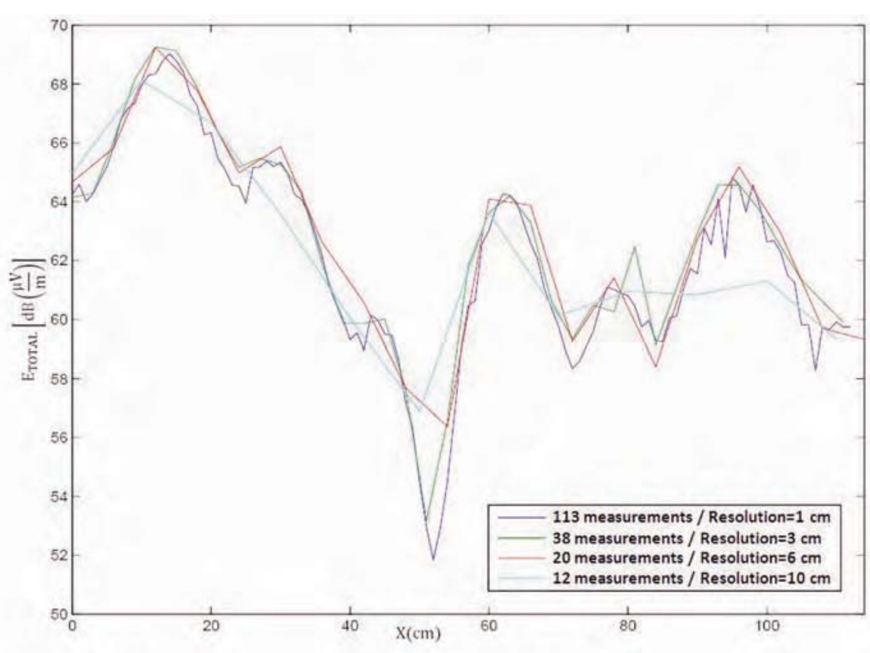


Figure 4: Electric field strength (dB [µV/m]) versus distance (cm) in the X direction. Evaluation of arithmetic mean of the three standard measurements method using four different values as grid resolutions



SLOTS NO. / RESOLUTION	T_M	T_D	T_T	$\%T_M$	$\%T_D$
113 / 1 CM	2,034 s	226 s	2.260 s	91%	9%
38 / 3 CM	684 s	185 s	869 s	79%	21%
20 / 6 CM	360 s	152 s	512 s	70%	30%
12 / 10 CM	216 s	132 s	348 s	62%	38%

***Table 1:** Measurement time (T_M), displacement time (T_D), total time (T_T) and $\%T_M$ and $\%T_D$ ratios with respect to T_T for the arithmetic mean of the three standard measurements method, using different slot numbers and grid resolutions*

computing the total electric field power. The data have been measured with four different values of grid resolution: 1cm, 3cm, 6cm and 10cm.

In Figure 5 we have the total electric field plotted with a resolution of 3cm for different measurements method, for example one standard measurement, arithmetic mean of three standard measurements and Video Avg with several acquisition times (7s, 4s and 1s).

In **Table 1** we analyze the percentage of the measurement time (T_M) and displacement time (T_D) with respect to the total time (T_T) when the arithmetic mean of the three standard measurements method is applied for different grid resolutions. These percentages ($\%T_M$ and $\%T_D$) are obtained dividing T_M and T_D between T_T.

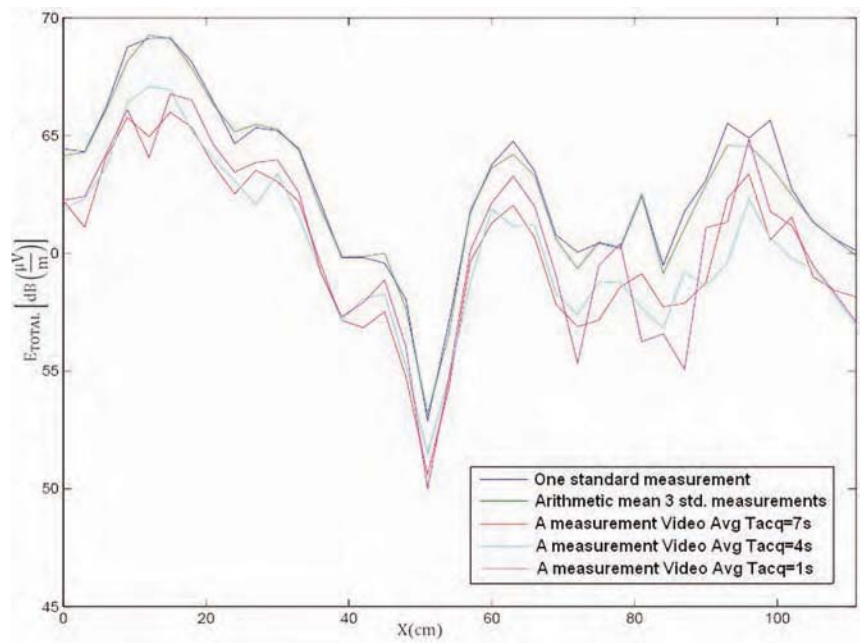
Studying the results in this table, it can be seen that the measurement time increases in inverse proportion to the displacement time, when a greater resolution is applied, so the total time also increases. Thus, in order to score the tests with different grid resolutions, a gradation can be established, considering that approximately all the percentages differ among them by 30% at the most, for example 38%-9% = 29% or 30%-21% = 9%. In addition, it is necessary to consider that whichever grid resolution is better, it takes a shorter time in moving the robot between measurement slots, but a greater number of measurements have to be acquired. Therefore, the best resolutions for $\%T_M$ and $\%T_D$ ratios are between 3cm and 6cm.

Finally, once all the measurements have been realized, the graphs with the electric field power have been obtained and the statistics of the measurement duration have been calculated and tables with the evaluation scores of the measurement results for each method and resolution have been constructed for two dimensions of the horizontal polarization (X and Y).

The tables have been done according to the measurement duration and measurement quality criteria. For example, weightings for each method and resolution evaluated in direction X are shown in **Tables 2** and **3**.

Analyzing Tables 2 and 3, the method and resolution which obtain the best balanced score in both criteria will be selected, that is, it must be good in both criteria (and not very good in one and very bad in another). The assigned scores go from 1 to 10 according to the following intervals: very bad, [1,3); bad, [3,5); medium, [5,7); good, [7,9) and excellent, [9,10].

Figure 5: Electric field strength (dB [μV/m]) versus distance (cm) in the X direction. Evaluation of five different measurements method using a resolution of 3cm



Taking into account these weightings, it could be said that the best grid resolution is between 3cm and 6cm (or between 20 and 38 sampling slots), since the total score is good (or medium-good) and these scores are balanced in both criteria. These conclusions agree with the obtained ones when Table 1 is analyzed.

But, on the other hand it is observed clearly that the measurement method which has obtained a better balanced score is the arithmetic mean of the three standard measurements method (good-excellent). This is followed by the Video Avg/4 s method, which has a worse total score (medium) than the one of the arithmetic mean, but it has scores balanced in both criteria, unlike the rest of the methods (that are good according to one criterion and bad according to another).

Similar conclusions for the Y direction can be obtained by means of the analysis of equivalent tables and graphs.

SLOTS NO. / RESOLUTION	DURATION CRITERION	QUALITY CRITERION	TOTAL SCORE
113 / 1 CM	very bad	excellent	medium
38 / 3 CM	medium	excellent	good
20 / 6 CM	good	medium	medium-good
12 / 10 CM	excellent	bad	medium

***Table 2:** Scores for different sampling slot numbers (or grid resolutions), taking into account the measurement duration and measurement quality criteria*

MEASUREMENT METHOD	DURATION CRITERION	QUALITY CRITERION	TOTAL SCORE
ONE STANDARD MEASUREMENT	excellent	bad	medium
ARITHMETIC MEAN 3 STANDARD MEASUREMENTS	good	excellent	good-excellent
VIDEO AVG TACQ=7 S	bad	excellent	medium
VIDEO AVG TACQ=4 S	medium	medium	medium
VIDEO AVG TACQ=1 S	good	very bad	bad-medium

***Table 3:** Scores for different measurements method having into account two criteria: measurement duration and measurement quality*

Useful Insight

This study provides a useful insight into the spatial and temporal variability of the electric field, which is derived from the use of wireless devices, with special emphasis on the mobile phone.

In a previous study it is verified that the most appropriate method is the arithmetic mean of three standard measurements with resolutions of 4cm and 7cm for the X and Y axis, respectively. Using this method, 198 measurement rows have been obtained (29 measurement points per row) and 50 hours were needed to complete the measurement.

Although the arithmetic mean of the three standard measurements method has been selected, the Video Avg/4s method could have been chosen as a second option, taking into account that the quality of the results is greater in the arithmetic mean method than in the Video Avg method for the same measurement duration (around 18s). In addition, Video Avg methods have the dependence on a functionality of a concrete spectrum analyzer, such as the automatic computing of the average of the samples during an acquisition period.

A Video Avg method is not a good option because it could be necessary for certain applications using an economic or less sophisticated analyzer, which may not feature this utility. This disadvantage does not affect to the arithmetic mean method, since samples are only acquired and their average is calculated off-line later.

In this study, the environment was divided in four sectors in order to acquire the samples. Each sector consists of 54 measurement rows and each row is split into 29 sampling points, which are separated by 4cm (that is 28 segments).

The measurement segment has a maximum length of 112cm (28 × 4cm). All the measurements have been realized within a time slot of 5 hours and 30 minutes (between 13:30 and 19:00), for this reason it can be considered that the GSM base station, whose central frequency is 946.988MHz, transmits with a similar electromagnetic power in that range of time.

Finally, 3D graphs for each probe of the isotropic antenna have been obtained with different values of azimuth (30° and 110°) and the same angle of elevation (50°). In addition, contour graphs, which result from 3D graphs, have been realized in order to identify the maximums and minimums of the signal clearly. In **Figure 6**, the 3D graph showing the total power of the electric field is presented.

Results Analysis

All things considered, the distribution of the electric field power and the standing wave

Figure 6: *Three dimensional graph showing the total electric field (dB [µV/m]) in the indoor environment*

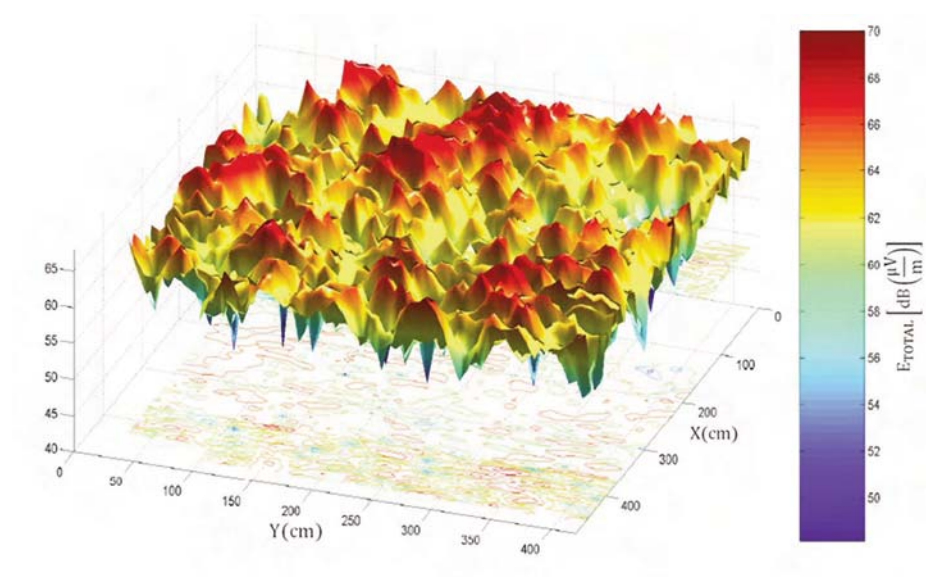
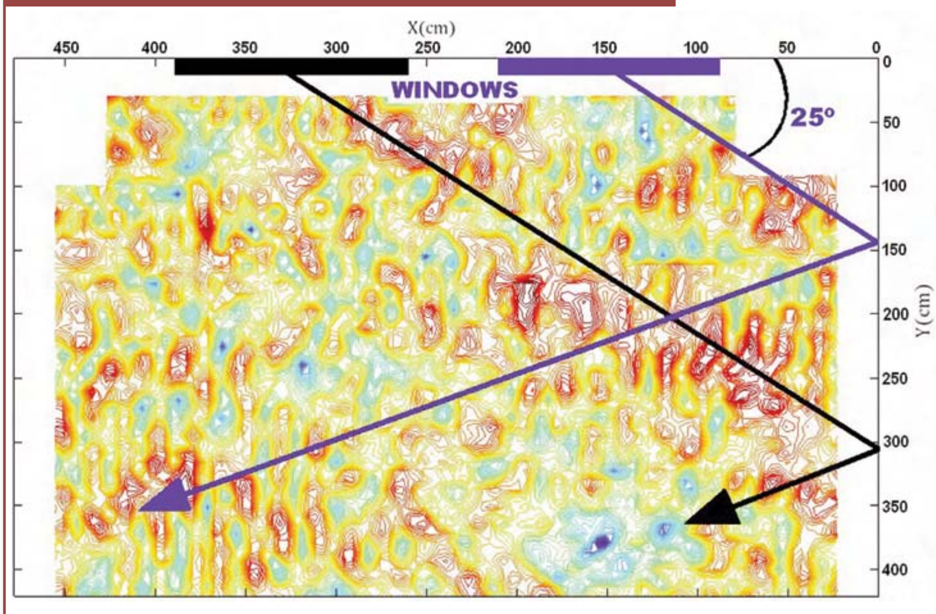


Figure 7: *Two dimensional graph (contour graph) showing the electric field (dB [µV/m]) in the X and Y directions (cm)*



pattern are shown in Figure 6. Some parameters, such as the signal period or the peak power, can also be obtained from this graph.

Due to the existence of two windows in the environment, they can be considered as aperture antennas and they are the main radiation source inside the environment, thanks to the emitted radiation by the GSM base station. Then, using the Ray Theory, in the point where the main radiation beams of the "virtual antennas" (windows) come together, there are constructive interferences, that are maximums of power, as shown in brown/red in **Figure 7**. But, in the areas where the radio frequency power is smaller (areas near the left wall), there are destructive interferences and, therefore, minimums of power (coloured in yellow).

Likewise, when the possible risks involved in using radio transmitters are evaluated, some considerations must be taken into account. Firstly, the operational frequency could be considered, since the exhibition guides impose limits that vary with the frequency (the operational frequency is 946.988MHz in this article).

A second consideration to keep in mind is the transmitted power and the distance between the human body and the mobile device. The handheld devices (mobile phones, PDAs and so on) operate on low powers, but they are used near the body, whereas the devices mounted in vehicles operate with a greater power and the distance between the antenna and the body is also greater. So, when someone is exposed to the radio frequency energy, this influence can be measured in different ways.

If devices are used near the body, the most useful magnitude is SAR (Specific Absorption Rate). Several organizations have defined limits for the human exposure to the RF fields. Some of the most important are the IEEE's (Institute of Electrical and Electronics Engineers) or ICNIRP's (International for Commission Non-Ionizing Radiation Protection). A SAR value of 4W/kg, temporally and spatially averaged over the whole body mass, was accepted as the working threshold for adverse biological effects in humans. Above this limit value, disruption of work schedules in trained rodents and primates, and other adverse biological effects, have been demonstrated. Some hypothesis state that depositions in this range of power in human bodies would produce similar effects, although they have not been verified experimentally. For higher values of SAR, it could produce a thermal effect in the human body, equivalent to an increase as a result of intense exercising.

Finishing Touches

The developed method for realizing radio electric field analyses in environments works correctly, as predicted and in line with the theoretical models of propagation (Ray Theory, space-temporal models and so on). Thanks to the acquired samples, important conclusions have been obtained, such as the importance of spatial and temporal variability of the signals. This signal variability is known as Short-Term Fading or Multipath Fading. An automatic system (hardware and software) has been developed for studying indoor environments, which allows a fast and reliable characterization and simplifies the off-line analysis.

Both the methodology and the implemented system can be used to characterize the distribution of the radiated electric field by a GSM base station (or other radiating devices, such as repeaters, electric transformers and so on), and to be able to analyze the impact on the human body, comparing the field distribution in presence or absence of people in the environment under test. ■

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