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Retrospective study of radiofrequency electric-field levels in a residence adjacent to a cellular-telephone base station before and after the installation of a steel-mesh wall

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Abstract
Shielding effectiveness of a steel wire mesh installed in walls of a house against radio-frequency (RF) radiation emitted from a cellular base station is estimated from archived measurements of the RF electric field in the house taken in 2000 before and after installation of the wire mesh under plaster of the walls without connection to earth. The base station operated in GSM-900. The measurements were made with a spectrum analyzer, and the levels have been corrected with the antenna factor and cable loss. Out of 169 numerical observations in the archived Excel workbook, 86 have been identified as made before installation of the wire mesh and 75 after installation by a line-by-line check of the Excel file and by contacting the original measurer; eight more observations made outdoors have no such indication. At 41 measurement locations both before and after values have been identified; the mean decrease of the level after installation of the wire mesh is 5.20 dB at the ground floor (13 locations), 4.66 dB at the first floor (21 locations) and 0.84 dB at the roof (7 locations). Taking the latter as a reference level for shielding effectiveness, the shielding effectiveness at the ground and first floors becomes 4.36 dB and 3.82 dB, respectively. At three locations the carrier frequencies are the same before and after installation of the wire mesh and the shielding effectiveness is estimated as 16.65 dB, 3.66 dB and 3.24 dB. The decrease of the RF level indoors after installation of the wire mesh seems reasonable as moderate shielding effectiveness of the walls by installing the wire mesh. However, it is not possible to attribute the decrease solely to the shielding effect of the wire mesh because of differences in the measurement conditions such as RF carrier frequency, time of measurements, conditions of the base-station transmitter, etc. Recommendations are given for measurements to estimate reliably the shielding effectiveness of a similar shielding treatment of walls of buildings.
Keywords: electromagnetic shielding; steel wire mesh; residential building; cellular base station; GSM-900; RF electric field; retrospective field study.

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Nomenclature

Symbol	Meaning	Unit
AF	Antenna factor	dB/m
CL	Cable loss	dB
E	Corrected electric-field level	dBμV/m
$\bar{E}_s$	Mean corrected level at site s in one campaign	dBμV/m
f	Frequency	MHz
N_A	Number of sites in area A	–
S	Power density	W/m^2
V	Receiver (analyzer) reading	dBμV
Δ_s	Site-level difference, before minus after	dB
$\bar{\Delta}_A$	Mean site-level difference in area A	dB
Γ	Magnitude of the reflection coefficient	–
λ	Wavelength	m

Abbreviations: GSM, Global System for Mobile communications; RF, radio frequency; SE, shielding effectiveness; VSWR, voltage standing-wave ratio.

I. INTRODUCTION

Base-station antennas for mobile telephone services were often installed on or in close proximity to dwelling houses when these networks were rapidly rolled out in the late 1990s. While exposure of members of the public to RF fields from these antennas is generally limited to below reference levels such as those in [1] (since updated as [2]), some house owners nevertheless tried to reduce RF field levels inside their homes out of concern for possible adverse health effects from long-term exposure. One approach to accomplish this is to incorporate some conductive material, e.g., conductive paint, metal foil or a metallic wire mesh, into the construction of a house or into the renovation of an existing one. In order to answer questions of interest to house owners, builders and public authorities as to whether and how much RF shielding can be expected from such measures, measurements in a dwelling house before and after incorporation of a steel wire mesh into the plaster of the walls were re-analyzed. The shielding effectiveness (SE) of a shield is defined as the ratio, usually expressed in dB, between the magnitude of an electromagnetic field quantity of interest at some location in the absence of the shield and that at the same location in the presence of the shield, when illuminated by the same source under otherwise identical conditions [3], [4]. The SE of an electrically continuous conductive shield is the sum of the reflection loss, the absorption loss and a multiple-reflection correction factor [3]. In practice, however, the SE of a shield is usually dominated by its electrically imperfect features, e.g., seams, joints, mesh holes and other apertures. As a rule of thumb, apertures with at least one dimension larger than half a wavelength provide little shielding [3]. As an example, in the downlink band of the GSM-900 system (frequencies between 935 and 960 MHz [5]) corresponding to a wavelength of approximately 32 cm, doors and windows with uncovered dimensions larger than approximately 16 cm may allow a considerable portion of an incident RF field to enter a building. Therefore, it is evident that a metallic mesh applied to the walls of a building does not necessarily constitute an RF shield in the sense of a closed conductive enclosure and that its shielding properties cannot be deduced from those of the mesh alone.

Some laboratory measurements of the RF shielding properties of building materials have been reported in the open literature. In [6], for example, SE measurements on building materials such as (reinforced) concrete with and without modifications of the reinforcement according to IEEE 299-1997 are presented for frequencies between 80 MHz and 10 GHz in an anechoic chamber. It is shown that the SE can be influenced by modifications of the reinforcement. In [7], electromagnetic properties of common building materials are summarized, and numerical results are presented illustrating the influence of the geometry of rooms and of apertures on RF fields inside buildings. SE, reflection and absorption coefficients of some commonly used building materials measured in a laboratory for frequencies between 1 and 9 GHz are presented in [8]. In [9], it is shown that metallic meshes and reinforcement details can improve the RF shielding effectiveness of reinforced concrete walls for RF-shielded buildings. However, these laboratory measurements were not performed on building materials as incorporated into actual buildings and, in part, at frequencies higher than those of the GSM-900 downlink band. There are also some examples of measurements of the RF shielding effectiveness of buildings or building components in-situ. In [10], for example, attenuation factors of building walls were determined in-situ for frequencies between 700 MHz and 5 GHz using a portable vector network analyzer and signal processing in the time domain in order to minimize the influence of multipath propagation. In [11], which can be considered a follow-up to [10], attenuations of RF signals from a mobile communication base station between outdoors and indoors of 6 dB to 27 dB are reported depending on the type of wall and on the furnishing of the rooms. In [12], in-situ measurements of the attenuation of RF signals due to walls, roofs and ten different types of state-of-the-art windows are presented for frequencies used in mobile communication. In [13], it is pointed out that, for a frequency of 3.5 GHz, the attenuation due to penetration into a building can depend on the angle of incidence and the

polarization of the incident wave and can vary by up to 8 dB. However, these measurements characterize the RF shielding effectiveness of buildings as they were and not that due to some renovation measure such as incorporation of a metallic mesh into the plaster of the walls. Furthermore, it is evident from these publications that the geometry of a measurement set-up can influence measured attenuations by values of a similar order of magnitude as those reported in this paper.

To the best knowledge of the author, only a handful of publications can be found in which RF field measurements in-situ before and after installation of some RF shielding measure into a dwelling house are reported and, so far, it has not been analyzed how far such measurements can be used to substantiate shielding effectiveness. In this paper, therefore, RF electric field strength measurements archived from 2000 in a dwelling house in the vicinity of a GSM-900 base-station antenna before and after installation of a steel wire mesh under the plaster of the walls are re-analyzed with the following goals in mind:

- determine differences between electric field strengths measured before and after installation of the mesh and analyze how far these differences can be attributed to shielding due to the mesh;
- reanalyze the data set with explicit indication (tagging) of the measurement data as “before” or “after” on a record-by-record basis;
- analyze differences between electric field strengths measured on different floors of the house (ground floor, first floor and roof) as well as outdoors;
- evaluate how far the carrier frequencies measured before and after installation of the mesh are comparable;
- examine the influence of different reference levels for the electric field strength on conclusions about shielding effectiveness; and
- suggest a measurement procedure for characterization of RF shielding due to incorporation of conductive materials into buildings.

After a description of the dwelling house, the measurement procedure and equipment as well as of the measured quantity and data tagging in Section 2, measurement results are presented in Section 3 and discussed with respect to shielding effectiveness and limitations of such an analysis in Section 4. Conclusions are drawn in Section 5. An audit of data sources is given in Appendix A.

II. Materials and methods

2.1 Site and wall treatment

The measurements have been performed in a house located in the vicinity of a base station. Measurements have been made at different points on the ground floor (GC1, GC2, …), the first floor (FI1, FI2, …), the roof (RF1, RF2, …) and outdoors (OT1, OT2, …). On the walls a steel wire mesh has been put and afterwards plastered. The mesh was not connected to electrical earth (intentionally). Nothing is mentioned in the documentation about the aperture of the mesh, the diameter of the wires, the bonding of the wires at overlaps, the plaster thickness etc. Also nothing is mentioned about doors, windows, roof slab, ceilings, … Therefore, nothing will be assumed on these topics in the analysis.

2.2 Instrumentation and cable checks

The instrumentation used for the measurements is summarized in Table 1. The antenna factors have been interpolated from the calibration data to the actual measurement frequencies. Prior to the measurements the return and transmission loss of 3 m RG213 and RG214 cable pieces have been measured using a Wiltron 6409 network analyzer. Results are summarized in Table 2. It can be seen that both cables are quite well matched at 1000 MHz (reflection coefficient smaller than 0.07, mismatch loss smaller than 0.03 dB). So the influence of the used cable on the measurement accuracy should not be significant. The RG214 cable is the best matched.

Table 1. Measurement equipment (from the original project records).

Item	Model	Range / role
EMC analyzer	HP 8591EM	9 kHz–1.8 GHz; receiver reading V
Receiving antenna	CBL6111C BiLog	30–1000 MHz; antenna factor AF
Coaxial cable	RG213 / RG214, 3 m, 50 Ω	Cable loss CL
Network analyzer	Wiltron 6409	Return-loss and transmission-loss checks

Table 2. Cable return-loss checks at 1000 MHz. Γ and mismatch loss are derived from the reported return loss.

Cable (3 m)	Return loss (dB)	VSWR	Γ	Mismatch loss (dB)
RG213	23.26	1.148	0.069	0.021
RG214	28.09	1.082	0.039	0.007

2.3 Field quantity and site-level difference

The corrected electric-field level was obtained from each analyzer reading as

$$E = V + AF + CL \quad (1)$$

where E is the corrected level (dBμV/m), V is the receiver reading (dBμV), AF is the antenna factor (dB/m) and CL is the cable loss (dB). For each site s, the corrected levels were grouped by the explicitly recorded before/after status and averaged, and the site-level difference was defined as

$$\Delta_s = \bar{E}_{s,\text{before}} - \bar{E}_{s,\text{after}} \quad (2)$$

The averages in Eq. (2) are taken over logarithmic levels, as in the original analysis; they are therefore equivalent to geometric means of the field amplitudes and should not be confused with the level of an arithmetic-mean amplitude. Δ_s is positive when the later recorded level is lower and, as the difference of two levels in dBμV/m, it is expressed in dB. The mean for an area A containing N_A sites is

$$\bar{\Delta}_A = (1/N_A)\,\Sigma\,\Delta_s \quad (3)$$

For the same frequency and comparable far-field conditions, a difference Δ corresponds to the amplitude and power-density ratios

$$E_{\text{after}}/E_{\text{before}} = 10^{-\Delta/20}, \quad S_{\text{after}}/S_{\text{before}} = 10^{-\Delta/10} \quad (4)$$

For example, Δ = 5.20 dB gives an amplitude ratio of 0.55 and a power-density ratio of 0.30. Note that Δ_s is not an SE value: SE requires the incident field to be the same with and without the barrier [4], a condition the archived surveys do not meet (Section 2.5).

2.4 Data sources and classification

Locations were included in the primary analysis if they had at least one reading with an indication of before or after installation. The indication had to be explicit in the data, i.e. stated as “Before Shielding” or “After Shielding”; indications based on the order of the readings, dates, etc. were not used. The comparison did not necessarily have to be at the same frequency or exact same time, but at the same location. Eight measurements at four different outdoor locations did not contain indications in the same line; these locations are therefore only included in a scenario analysis where these measurements are considered after installation. The source is the archived comparison workbook (Data_comp_2-10_presen copy.xlsx, Sheet1), summarized in Table 3.

Table 3. Inventory of the comparison workbook and of the analysis sets.

Category	Count
Observations labeled "Before Shielding"	86
Observations labeled "After Shielding"	75
Outdoor observations without a status label	8
Total numeric corrected-field observations	169
Primary locations (labeled before and after)	41 (13 ground, 21 first, 7 roof)
Outdoor locations (conditional scenario only)	4
Primary locations with a shared nominal frequency	3 (GC2, FI2, FJ)

2.5 Analysis plan and comparability

In theory, controlled SE measurements are repeatable and comparable as long as measurement geometry and excitation conditions are kept unchanged [4]. In this case study, repeatability was not ensured as the two measurement campaigns were not done at the same time, at most of the locations different set of carriers were present in the two campaigns, and other excitation conditions such as antenna orientation, traffic in the network, multipath conditions, transmit powers etc. were not controlled. The analysis of the measurement data was thus performed at different levels of generality and comparability as follows:

1. Difference between before and after measurements at all the 41 measurement locations using Eq. (2) (primary analysis). Location averages per measurement area are reported using Eq. (3).
2. Comparability of the carrier frequencies present at each of the measurement locations in the two measurement campaigns.
3. Difference between before and after measurements at measurement locations and at carrier frequencies present in both measurement campaigns.
4. As an illustration of how the indoor differences would change if the incident field changed between the campaigns, the average difference on the roof or the conditionally averaged outdoor difference (averaged over all outdoor locations in the same measurement area) or the combination of both was subtracted from the indoor differences.

Formal statistical significance tests were not performed since statistically independent replicate measurements were not available. Measurement locations within the same building are correlated both spatially and electromagnetically and the wall treatment was only done once. Statistical significance tests using all the 41 measurement locations as statistically independent would lead to an overestimation of the significance of the results.

III. Results

3.1 Site-level differences

Site-level differences are summarized in Table 4 and Figure 1. At the 34 indoor locations, the level was lower after installation at every site. The average reduction was 5.20 dB on the ground floor (13 locations) and 4.66 dB on the first floor (21 locations); averaging over all 34 indoor locations the reduction was 4.87 dB. The corresponding medians were 4.38 dB (ground floor) and 4.03 dB (first floor). Reductions ranged from 2.08 dB (GF) to 13.94 dB (GC2) on the ground floor and from 0.54 dB (FD) to 9.62 dB (FC2) on the first floor. On the roof the average reduction was smaller, being only 0.84 dB (median 1.26 dB), with the level being higher after installation at two of the seven roof locations. If the (unlabeled) results at the four outdoor locations are assumed to be 'after' values, the reduction was between 1.26 and 2.27 dB (mean 1.72 dB). Averaging over all 41 'primary' locations the reduction was 4.18 dB. The distribution of differences on the ground floor is noticeably skewed with two values above 10 dB (raising the mean by ca 0.8 dB above the median). On the roof the two negative differences cause the mean to be less than the median.

Table 4. Site-level differences in corrected field level (before minus after). Outdoor values are conditional and excluded from the primary analysis.

Area	Sites	Mean Δ (dB)	Median Δ (dB)	Range Δ (dB)
Ground floor	13	5.20	4.38	2.08 to 13.94
First floor	21	4.66	4.03	0.54 to 9.62
Roof	7	0.84	1.26	−1.17 to 2.88
Indoor (ground + first)	34	4.87	–	0.54 to 13.94
All primary sites	41	4.18	–	−1.17 to 13.94
Outdoor (conditional)	4	1.72	1.68	1.26 to 2.27

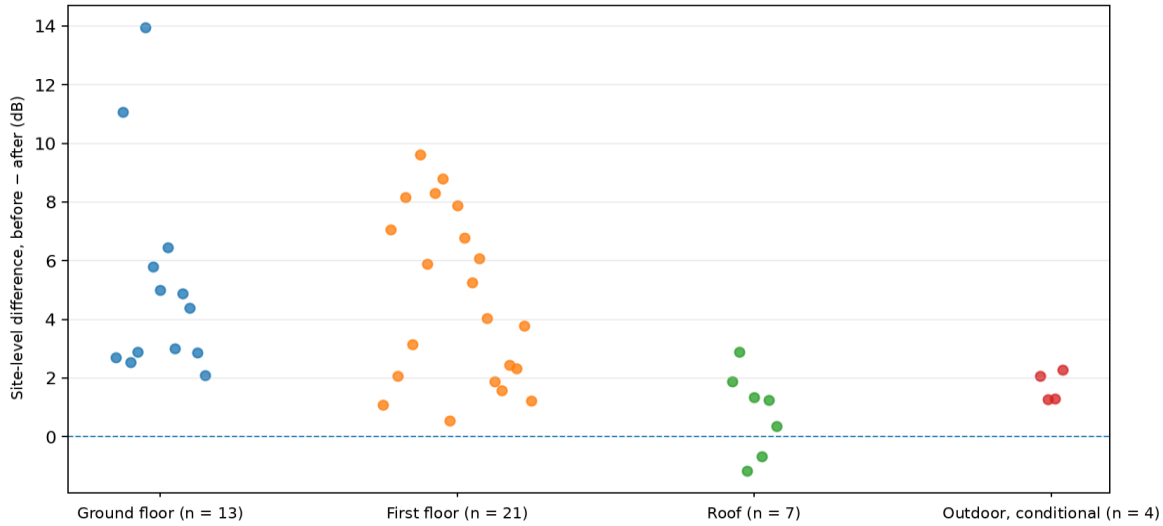

Figure 1. Corrected electric-field level, difference between before and after values, by site (each point corresponds to one site; points are offset horizontally for visibility). Outdoor data depend on the allocation of eight unlabeled measurements to the second measurement campaign. The dashed line represents no change.

3.2 Frequency comparability

Table 5 lists the sets of carrier-frequencies for each of the 41 primary locations for both measurement campaigns. Apart from the locations GC2, FI2 and FJ, for which at least one nominal carrier-frequency is common to both measurement campaigns, and OT1, which fulfils this condition if the outdoor assumption is made, the sets of frequencies at all locations are completely different for the two campaigns.

All frequencies listed in Table 5 belong to the extended downlink frequency band for GSM-900 (925 to 960 MHz) [5], with the exception of 901.0 MHz measured after the antenna installation at location GC2. This frequency lies within the GSM-900 uplink band (880 to 915 MHz) [5]. In this band, mobile handsets (instead of base stations) transmit, so it is possible that the measured signal originated from a mobile handset in the vicinity of location GC2. It is recommended to double-check this frequency in the original measurement worksheet.

Table 5. Recorded frequency overlap at the 41 primary locations and the four conditional outdoor locations.

Area	Sites	Any shared frequency	Identical frequency sets	Negative Δ_s
Ground floor	13	1	0	0
First floor	21	2	0	0
Roof	7	0	0	2
Outdoor (conditional)	4	1	0	0

Table 6 shows same-site, same-frequency comparisons only. The mean difference was 7.85 dB (median 3.66 dB, range 3.24-16.65 dB at FJ, FI2 and GC2, respectively).For OT1 it was not possible to include same-site comparisons as it is not recorded whether comparisons were made at the same site.

Table 6. Locations with a shared nominal carrier frequency and the corresponding same-frequency comparison (explicitly labeled rows only).

Site	Area	Before set (MHz)	After set (MHz)	Shared (MHz)	Before (dBµV/m)	After (dBµV/m)	Δ (dB)
GC2	Ground	932.5, 938.4	901.0, 938.4	938.4	105.08	88.44	16.65
FI2	First	945.8, 948.2	939.3, 948.2	948.2	107.28	103.62	3.66
FJ	First	938.4, 938.9	938.4, 939.3	938.4	106.93	103.70	3.24
OT1*	Outdoor	941.5	941.5, 942.0	941.5	–	–	–

* Conditional: overlap exists only if the unlabeled outdoor readings belong to the later campaign. Δ was calculated from unrounded levels and may differ by 0.01 dB from the rounded values shown.

3.3 Reference-field scenarios

Another interesting point is that the decrease of the indoor mean field level between campaigns is of about 3-5 dB in all cases (for example, 4.36 dB and 3.82 dB, respectively for ground floor and first floor indoor locations, if the roof locations are approximately considered as reference points for the variation of the incident field, as reported in Table 7; if only the conditional outdoor scenario is considered, 3.48 and 2.94 dB; if both the roof and outdoor locations are jointly considered as reference points, 4.04 and 3.50 dB). It must be stressed that these are only indicative figures, since the roof and outdoor measurements were not performed simultaneously with the indoor ones and, above all, they were not conceived as reference channels.

Table 7. Illustrative reference-subtraction scenarios. Rows marked conditional depend on assigning eight unlabeled outdoor readings to the later campaign.

Reference assumption	Reference Δ (dB)	Ground residual (dB)	First residual (dB)
No adjustment	0.00	5.20	4.66
Roof only (7 sites)	0.84	4.36	3.82
Outdoor only (4 sites, conditional)	1.72	3.48	2.94
Roof + outdoor (11 sites, conditional)	1.16	4.04	3.50

IV. Discussion

4.1 Interpretation of the floor-level pattern

A clear pattern is seen when comparing indoor and roof measurements. The mean decrease indoors is several times larger (4.87 dB over 34 measurement sites) than on the roof (0.84 dB) and there are no measurement sites indoors with an increase. Such behavior could be explained by the attenuation due to wall treatment, as measurement sites surrounded by treated walls show a decrease while those outside

show changes of about 1 dB in both directions. It is however not mesh specific, as a change in the serving cell (carrier, Tx power level, position of the antenna, etc.) between the two campaigns could also lead to more variations indoors (multipath affected measurements) than outdoors (open area on the roof). Differences between ground floor and first floor results (4.66 dB on the first floor and 5.20 dB on the ground floor) are small compared to the variations observed on each floor and are therefore not further discussed.

4.2 Magnitude of the indoor decrease

As noted in Section 1, at about 940 MHz, doors and windows without metal screens or other closures are typically much larger than the 16-cm half-wavelength, so RF energy can easily penetrate a building through such apertures, even with a good RF shield covering other portions of the structure. Thus, undocumented openings or seams could adversely affect the performance of the RF shielding, but a lack of grounding probably is not the most significant weakness of the installation. At radio frequencies, the RF shielding effectiveness of a conducting surface for an impinging electromagnetic wave is related primarily to the conductivity, continuity, and presence or size of apertures, and not significantly related to grounding [3]. Under comparable conditions, an RF attenuation of 4.7 to 5.2 dB corresponds to only moderate shielding (a factor of 0.55 to 0.59 reduction in amplitude, or 0.30 to 0.34 reduction in power density, after relative to before RF shielding, from Eq. (4)).

4.3 Same-frequency comparisons

Although not simultaneous, three pairs of same frequency measurements provide the archive's closest approximation to controlled measurements. Of these, two measurements taken on the first floor (3.24 and 3.66 dB) are close to the roof-corrected first floor average (3.82 dB), while the third, taken on the ground floor at GC2 (16.65 dB), is about four times as large (GC2 also has the largest of the site averages differences, 13.94 dB). There's no way to tell from the archive which of several possibilities (e.g., a multipath null at GC2 in the second measurement, changes in transmit power or antenna location) best explains the disparity at GC2. In any case, three measurements aren't enough to characterize average attenuation.

4.4 Exposure context

It is important to note that RF exposures were not assessed in this study and Table 6 provides field strengths for individual carriers not broadband, time-averaged RF exposure levels. Thus, no conclusions can be made about exposures relative to any guideline or standard (e.g., the ICNIRP general-public reference level for 938 MHz is $1.375\sqrt{f} \approx 42$ V/m where f is in MHz [1]) or health effects. The purpose of providing the RF field strength data in Table 6 is to show that, before installation of the wire mesh, the single-carrier field strengths (0.18 to 0.23 V/m) were already 45 to 47 dB below the ICNIRP reference level, and that a numerical decrease was recorded after installation (no statistical significance test was performed). The corrected single-carrier field levels prior to installation (105.1 to 107.3 dBµV/m; Table 6) are presented for reference only. Personal dosimetry, individual exposure assessment, and clinical endpoints were not assessed in this study.

4.5 Limitations

- Outdoor reference data. For some measurements an outdoor reference measurement with a second receiver at the same time and place would have been helpful to estimate changes of the incident field. This was not done. Note that in 38 of the 41 locations different carriers were measured during the two campaigns. Averaging over locations does not allow estimating the frequency dependence of the insertion loss but preserves the comparison between the two campaigns at the same locations.
- Undocumented installation. It is not possible to reconstruct from the project documentation what exactly was done (mesh size, wire diameter, how mesh pieces have been connected, how windows, doors etc. have been shielded, thickness of plaster applied etc.).
- Dates. Some dates in the Excel worksheets are given as Excel date values, some as text. For some dates in text format contradictory entries exist whether the mesh has been

applied or not (see Appendix A). For eight outdoor measurements no entry whether the mesh has been applied or not exists.

- Statistical independence. All measurements were performed in one and the same treated building and therefore are not independent.
- Antenna calibration factors and instrument specifications are those given in the project documentation. A verification with calibration certificates has not been done.

4.6 Recommended protocol for future retrofits

A prospective before-and-after assessment of a wall retrofit would permit a defensible estimate of frequency-dependent attenuation if it follows these steps:

1. Selecting the frequencies before hand. This could be done by using a transmitter in accordance with the IEEE 299 [4] test procedure or by using the same carrier frequencies from a base station.
2. Taking simultaneous measurements with a reference receiver located in fixed position outdoors.
3. Repeatability of indoor measurement positions (location, antenna height, polarization, orientation). This could be aided by taking photos.
4. Repeatability of the measurement in general (number of measurements, time of day effects etc.) to get an idea of variability.
5. Documentation of mesh installation (mesh aperture, wire thickness, overlap, bonding, special considerations e.g. doors, windows, penetrations, plaster thickness etc.)
6. Presentation of measurement results as difference to the reference corrected results including information about uncertainty of measurement for every location and frequency

V. Conclusions

The RF measurements were taken in 2000 in a building close to a GSM-900 base transceiver station. Steel wire mesh was installed on the walls and covered with plaster. RF measurements were performed in the same building before and after plastering. In this paper only measurements explicitly labeled as made before or after installation were used in the primary analysis. The results show the following:

1. On the ground and first floor the electric field strength was lower after the walls were plastered with steel wire mesh. The mean decreases were 5.20 dB (13 measurement sites) and 4.66 dB (21 measurement sites), respectively. On the roof the mean decrease was 0.84 dB (7 measurement sites) and the electric field strength increased in two measurement sites.
2. When taking the roof into account as reference, the attenuations on the ground and first floor would be 4.36 and 3.82 dB, respectively. Using other references, it still seems that there is some attenuation of 3 to 5 dB within the building after plastering with steel wire mesh.
3. In only three measurement sites the electric field strength could be compared on the same frequency (the differences were 16.65, 3.66 and 3.24 dB). In the remaining 38 measurement sites the electric field strength was measured on different carrier frequencies before and after plastering with steel wire mesh.

In conclusion it seems that plastering walls with steel wire mesh attenuates the electric field strength moderately. However, the measurements cannot be separated from other influences like different carrier frequencies, transmission situations and measurement geometries. The measurementsare not shielding effectiveness (SE) measurements and no conclusions about health protection can be drawn. It should be emphasized that for shielding purposes apertures greater than about 16 cm at 900 MHz cannot be neglected. It is recommended that before and after measurements should be performed in a well-defined way to verify the shielding properties of buildings. Such measurements should also be performed in buildings like the one in this report, following the measurement procedure proposed in Section 4.6. Measurements on 1800 MHz and in other frequency ranges used in mobile communications should be done in the future.

Declarations

Data availability. This study uses archived engineering worksheets and project records from 2000.

Ethics. The work analyzes historical RF field measurements; no human participants or clinical outcomes were investigated.

Funding. This research received no external funding.

Appendix A. Source audit and provenance

A.1 Origin of the data

No new measurements were made for this study. The original measurements were made in 2000 as part of an engineering project. The wall construction information comes from the project documentation. The publications cited in this paper were used only to place the archived results in a scientific context. The summary of field data contains, for each site, the site identification number, the number of labelled data prior to and after remediation, the number of unlabeled data, average corrected levels, and the difference. The summary of frequencies tabulates the frequencies in each survey and those in common.

A.2 Status labels

Status labels ("before" or "after") are available for 161 of the 169 numeric observations in the comparison workbook (Table 3). Of the 85 observations in the collection worksheet, only seven have a status label (three "without shield" and four "with shield"). The 78 observations with missing status labels were not used to form additional before/after comparisons.

A.3 Dates

Some of the dates given in the collection worksheet are Excel dates (2000-08-05 and 2000-11-09) and some are day-month-year strings (18-5-2000 and 22-9-2000). The same-frequency records are associated with 8, 16 and 18 May, whereas the project narrative also mentions September, and two records dated 18-5-2000 carry opposite status labels. It might be that some of the day-month dates have been interpreted as month-day dates when entering Excel dates (2000-08-05 being 8 May 2000 and 2000-11-09 being 11 September 2000 which would be coherent with the dates referred to in the description). This should be checked in the field notes. This assumption has not been made in the analysis presented in this paper and no assumption on the installation date or chronology of the measurement campaigns has been made. These questions do not necessarily indicate any problem with the measurements per se, but lack of further information makes it impossible to assess their origin and comparability and therefore to make a causal SE estimate.

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