SPECIFYING ZONES FOR CELLULAR TELEPHONE OPERATION IN HOSPITAL HALLWAYS

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Abstract - Critical-care medical equipment can malfunction if exposed to radio-frequency (RF) fields greater than the equipment's immunity. For newly purchased equipment, such immunity levels are at least 3 V/m. Since fields near a 600-mW, 850-MHz cell phone can greatly exceed this immunity level, hospitals often restrict locations where cell phone usage is permitted, some even banning cellphone usage throughout the hospital. To clarify whether such restriction is appropriate, this paper employs geometrical optics to investigate field strengths in a patient room due to cell phone usage in an adjacent hallway. Cellular-usage zones are maximized when wall construction employs both shielding and absorber elements. Criteria are suggested for specifying zones where cellphone usage should be restricted.

INTRODUCTION

Although there is an increasing need for access to wireless information in healthcare, there has been concern that radio-frequency (RF) sources might cause medical critical-care equipment to malfunction. The next Medical EMC Standard (IEC 60601-1-2, 2nd edition) will require that manuals accompanying all new critical-care equipment specify a minimum-separation operation distance between the equipment and a given-power RF source. This is separation is based on the RF radiated power, the immunity of the equipment (e.g., 3 V/m field strength), and the assumption of free-space propagation [1]. To clarify the utility of separations obtained this way, both measurement and computation have been used to investigate the decrease in field strength with distance in indoor propagation [2,3,4]. In many cases, the attenuation with distance was found to be slower than that in free space. Measurements with real cellular handsets indicated that usage of free-space separation criteria would prevent medical-equipment malfunction in many situations because such criteria implicitly include generous margins of safety [2]. The current paper investigates the required separation of a transmitter from critical-care equipment when a realistic propagation model is used to compute the interference field.

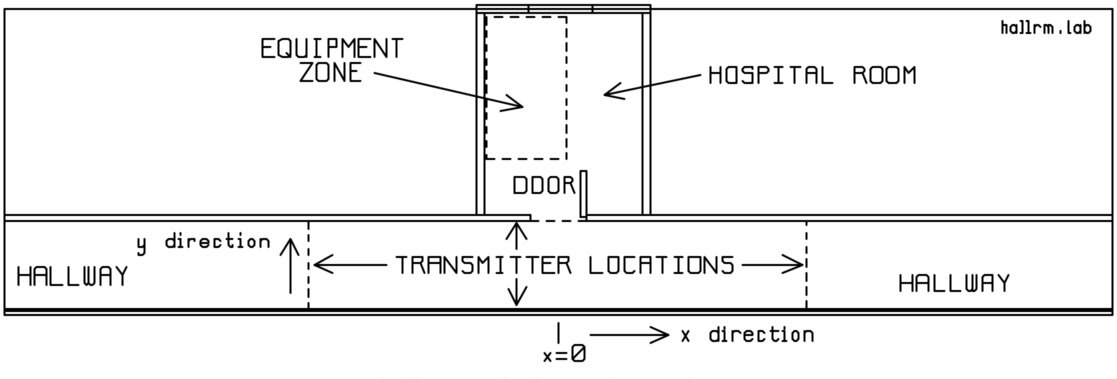

Fig. 1 A hallway and adjacent hospital room.

In the simulations, a 600-mW, 850-MHz cellular telephone is operated in a hallway adjacent to a patient room, as shown in Fig. 1. A region of the patient room called the "equipment zone" is designated for the use of critical-care equipment by hospital staff. This paper identifies locations in the hallway where the transmitter can be operated such that maximal fields within the equipment zone are less than 3 V/m, the immunity level of equipment assumed to be operating within the zone.

THE GEOMETRY OF THE HALLWAY AND PATIENT ROOM

Fig. 1 shows a hallway 20 m long and 2.34 m wide, with a ceiling height of 2.48 m. The hallway is open at either end, so that it represents a 20 m section of a much longer corridor. In the simulations, the floor and ceiling are made of concrete, 30 cm in thickness. At the center of one side of the hallway, there is a 1-m wide doorway leading into a patient room, which is 4.11 m deep and 2.84 m wide. The region in the room designated as the "equipment zone" is 1.45 m wide and 3 m deep, and surrounds the head of the patient bed. Within the equipment zone, the field strength due to cellular telephone operation must be maintained less than the immunity level of 3 V/m. Both the transmitter and the receiver are at a height of 1.6 m above the floor.

Four types of wall construction are examined. A *sheetrock wall* consists of surface sheets of drywall 1 cm thick, separated by a 12 cm air layer. The sheetrock material is represented with the electrical properties of concrete, $\varepsilon_r = 6.1, \sigma = 60.1$ mS/m. A *solid-brick wall* consists of a 12 cm layer of brick, with $\varepsilon_r = 5.1, \sigma = 10$ mS/m at 850 MHz. A *clay-block wall* is constructed of hollow clay blocks with a wall thickness of 8 mm, faced with plaster, and is represented with a layered structure with a 1.5 cm plaster (concrete) facing, a 0.8 cm brick wall of the clay block, a 9.4 cm thick air space inside the clay block, the 0.8 cm block wall and the 1.5 cm plaster facing on the other side of the wall. Some clay-block walls have metal screen embedded within the plaster. A *plaster-and-wire wall* is represented with a 1 cm thick plaster (concrete) layer, backed by a very highly conducting metal layer. Such walls are almost perfectly reflecting.

The reflection coefficient at a wall surface is a function of the frequency and the angle of incidence of the plane wave. To characterize the reflective properties of the walls at 850 MHz using a single number, the reflection coefficient can be averaged over all angles of incidence. The reflection coefficient approaches unity for grazing incidence. Hence the reflection coefficient averaged over all angles is often larger than that for normal incidence. The reflection coefficient of the 10 cm wood door to the patient room averaged for incidence angles from 1 to 90 degrees is 32%. The lightest wall construction is sheetrock, with an average reflection coefficient of 52%. The next heavier construction is the clay block wall, which reflects about 83% of the field incident on it. The heaviest construction is the brick wall, but at 850 MHz, the average reflection coefficient is 64%, less than that of the clay block wall. The plaster-and-wire wall reflects 99.4% of the field, on the average. Note that the intuitive notion that heavier wall construction leads to a larger reflected field is *incorrect* and can be misleading. The fraction of the field that is reflected is dependent on the thickness of the various layers in the wall, on their electrical properties, and on the frequency.

CALCULATING THE FIELDS WITH GEOMETRICAL OPTICS

The cell phone is modeled as a vertical half-wave dipole antenna radiating 600 mW at 850 MHz. Free-space locations within 2.6 m of the cell phone have fields greater than 3 V/m. With the half-wave dipole located in the hall, the field for a receiver in the equipment zone is found using geometrical optics with a program called GO_3D [5]. Ray paths are found that connect the transmitter location to the receiver location including transmission through the walls and spectral reflection from the walls. Walls are modeled as having a layered structure. The method accounts for the angle dependence and the polarization dependence of both the reflection coefficient and the transmission coefficient. The code is three-dimensional, hence the results account for reflections from the ceiling and floor of hallways and rooms as well as from the walls.

Rays originating at the transmitter can be reflected once, twice, or indeed many times, before reaching the receiver, as well as being transmitted through the walls. At each reflection or transmission, the field strength associated with the ray is reduced. After many interactions the field is sufficiently small that it can be neglected. Most geometrical optics codes require the user to pre-set the number of reflections that will be accounted for. For walls with a high reflection coefficient, such as the plaster-and-wire construction, or for near-grazing incidence, the reflection coefficient is large and the field will not be negligible even after many reflections. The GO_3D code asks the user specify the minimum field strength or "threshold" to be accounted for and then the code itself chooses the number of reflections required to compute all rays that carry field strengths above the threshold. The code constructs an image tree [5] including all the image sources that can give rise to fields above threshold.

SUITABLE LOCATIONS FOR TRANSMITTER OPERATION

For a given cell phone location in the hallway, the GO_3D program is used to compute the field strength over a grid of "receiver" locations, 3.5 cm apart, covering the equipment zone. If the field at any point in the equipment zone exceeds the assumed hospital-equipment immunity level of 3 V/m, then that transmitter position is considered unsuitable for cellphone usage. The largest field found in the equipment zone for a given transmitter location will be called the *maximum interference field*. A suitable location for the transmitter is one for which the maximum interference field is less than the 3-V/m immunity level.

A search technique is used to determine what transmitter locations in the hallway are suitable. The hallway is covered with a grid of transmitter locations at 5 cm intervals. At each transmitter location, the maximum interference field is calculated according to the above procedure. Then the transmitter is moved on to the next position in the hallway grid, and the maximum interference field is again computed. Figure 2 is a gray-scale contour map of the maximum interference field as a function of the transmitter location in the hallway. The field strength is shown as decibels above 1 V/m. The immunity level of 3 V/m corresponds to 9.54 dB. The 9.54 dB contour is shown as a heavy white line. Operation of the transmitter inside this contour is unsuitable because it leads to a field strength somewhere in the equipment zone that exceeds the 3-V/m-immunity level.

Sheetrock Walls

Fig. 2 shows the maximum interference field in the hallway for sheetrock wall construction. Transmitter locations very near the doorway lead to the strongest maximum interference field. In the hall opposite the door, the contour map shows a pattern reminiscent of a standing wave. For some transmitter locations, the ray directly from the transmitter and the ray reflected from the opposite wall of the corridor arrive at the receiver in phase and their fields add; for other nearby locations, the two rays arrive in phase opposition and their fields subtract. The average reflection coefficient for sheetrock walls is 52%, suggesting that rays following zigzag paths along the hall are rapidly reduced in field strength. Conversely, rays traveling through the wall from the hall into the patient room retain large field strengths, as the wall material absorbs only a small fraction of the energy. Fig. 2 shows that the 9.54 dB contour crosses the hall following a jagged, irregular path. With sheetrock walls, all suitable transmitter locations are further than 2.8 m from the center of the doorway.

Brick Walls

Fig. 3 shows the maximum interference field for solid brick walls, which have an average reflection coefficient of 64%. With brick walls, the standing-wave-like patterns in the maximum interference field are less sharply defined than with sheetrock walls. The 9.54 dB contour crosses the hall more cleanly, making an angle of roughly 30 degrees to the wall at right. With brick walls, all transmitter locations with $x < -2.9$ or $x > 3.2$ m are suitable.

Clay-Block Walls

Fig.4 shows the maximum interference field in the hall for clay-block wall construction, with an average reflection coefficient of 83%. This increased reflection tends to reduce the importance of transmission through the walls, but increase the field strengths associated with rays following zigzag paths along the hallway. The standing-wave-like structure of the maximum interference field is clearer than in Fig. 3, and the maxima and troughs are more nearly parallel to the walls than in Fig. 2. The 9.54 dB contour makes a shallower angle to the wall at left in Fig. 4 than in Fig. 3. At right in Fig. 4, the 9.54 dB contour breaks up, with several fingers reaching along the hall. With clay-block walls, all transmitter locations with $x < -3$ m or with $x > 3.8$ m are suitable.

Plaster-and-Wire Walls

The plaster-and-wire wall construction has an embedded metal mesh and is almost perfectly reflecting, with an average reflection coefficient greater than 99%. There is zero transmission through the walls into the room. Fields enter the room through the doorway, following zigzag paths along the hall. Also, with this highly reflective wall construction, the patient room resembles a reverberation chamber. Energy entering the room cannot escape by being transmitted out through the walls. It can only leave the room via the door or the small window opposite the door. Fig. 5 shows that the standing-wave-like structure of the maximum interference field in the hall is quite well defined and extends for long distances. The 9.54 dB contour is irregular and broken, especially at the right end of the hall. Transmitter locations with $x < -3.4$ and $x > 4$ m are suitable. Thus the cell phone must be considerably farther from the door to the patient room when wall construction is highly reflective.

DISCUSSION AND CONCLUSION

Transmitter locations with a line-of-sight path from the hall into the equipment zone are unsuitable if closer than 2.6 m to any part of the equipment zone. Hence the transmitter cannot be operated in any part of the patient room, nor in the hallway within roughly 2 m of the door. For transmitter locations with no line-of-sight path through the doorway into the equipment zone, there are two propagation mechanisms into the equipment zone. Rays can be transmitted through the wall of the hallway into the equipment zone, perhaps after one or more reflections from the walls. Or, rays can follow zigzag ray paths along the hallway, through the doorway into the patient room, thence into equipment zone, perhaps with one or more reflections from the walls of the patient room. Surprisingly, things don't always happen as expected. It is incorrect to expect that employing wall construction with high RF shielding will necessarily reduce fields of external transmitters within a room. Such walls are poor RF absorbers; so high shielding is associated with high reflection coefficient leading to effective propagation via zigzag paths along the hallway and into the room.

In this paper, various simplifying and unrealistic assumptions have been made that may affect the results. Walls are modeled as being made of homogeneous layers of material, ignoring interior details such as wood or metal studs, wiring, pipes and ducts. Real walls may scatter the field to a much greater extent than the idealized walls used here. The ceiling is assumed to reflect the signal spectrally, and again, the complex array of wiring, pipes and ducts commonly found in ceilings tends to scatter the signal rather than reflect it spectrally. It might be more realistic to omit the ceiling in the computations.

The computations reported here represent the worst-case scenario. One reason for this is that our simulations employed an ideal dipole, which requires a separation of 2.6 m for fields to fall to 3 V/m, whereas the more common isotropic point-source model requires separations of 2 m for fields to fall to 3 V/m. However, both representations overestimate fields of real cellphones. In the present paper, we have assumed that the full 600 mW power is radiated by the cell phone into the E_θ polarization of the electric field, whereas real cell phones radiate less than 600 mW at full power output due to antenna mismatch, and due to absorption of power by the user's hand and head. Also, real handsets radiate comparable amounts of power into both polarizations of the electric field. Typically, the fields radiated by a handset are 11 dB or more smaller than those computed using the idealized scenario in this paper [2]. Hence we would expect the fields reported in the current paper to be much stronger than those that might be found when a person in the corridor operates a real cell phone handset. Thus, the theoretical criterion that cell phones be operated more than 4 m from the doorway is probably more conservative than is required in practice.

This paper has shown that wall construction strongly affects suitable locations where a cell phone can be operated in hallways. As the wall-surface reflection coefficient increased, the transmitter was required to operate *farther* from the equipment zone. In the most reflective case, the transmitter was required to operate more than 4 m from the center of the room's doorway. For the wall constructions examined here, high shielding was associated with high-reflection-coefficient wall surfaces because the walls absorbed little power. The results presented here suggest that wall construction that achieves high shielding by using RF absorption with a low reflection coefficient should maximize the size and number of suitable transmitter locations in hospitals, thereby maximizing opportunities to use wireless information in hospitals.

REFERENCES

[1] D. Davis, B. Segal, G. Tait, and T. Pavlasek, *Evaluation of Free-space propagation in hospital corridors*. Proc 1998 Symp on Antenna Technology & Applied Electromagnetics. p. 25-28, 1998.
[2] D. Davis, B. Segal, C.W. Trueman, R. Calzadilla, and T. Pavlasek. *Measurement of Indoor Propagation at 850 MHz and 1.9 GHz in Hospital Corridors*. Proc 2000 IEEE Antenna Propagation Soc Meet. Waltam, Mass (submitted).
[3] C.W. Trueman, D. Davis, B. Segal. *Ray Optical Simulation of Indoor Corridor Propagation at 850 and 1900 MHz.* Proc 2000 IEEE Antenna Propagation Soc Meet. Waltam, Mass (submitted)
[4] Rappaport TS *Wireless Communications, Principles and Practice*, Prentice Hall PTR, New Jersey, 1996.
[5] C.W. Trueman, R. Paknys, J. Zhao, D. Davis, and B. Segal. *Ray Tracing Algorithm for Indoor Propagation* 16th Annual Review of Progress in Applied Computational Electromagnetics, pp. 493-500, March 20-24, 2000, Monterey, California.

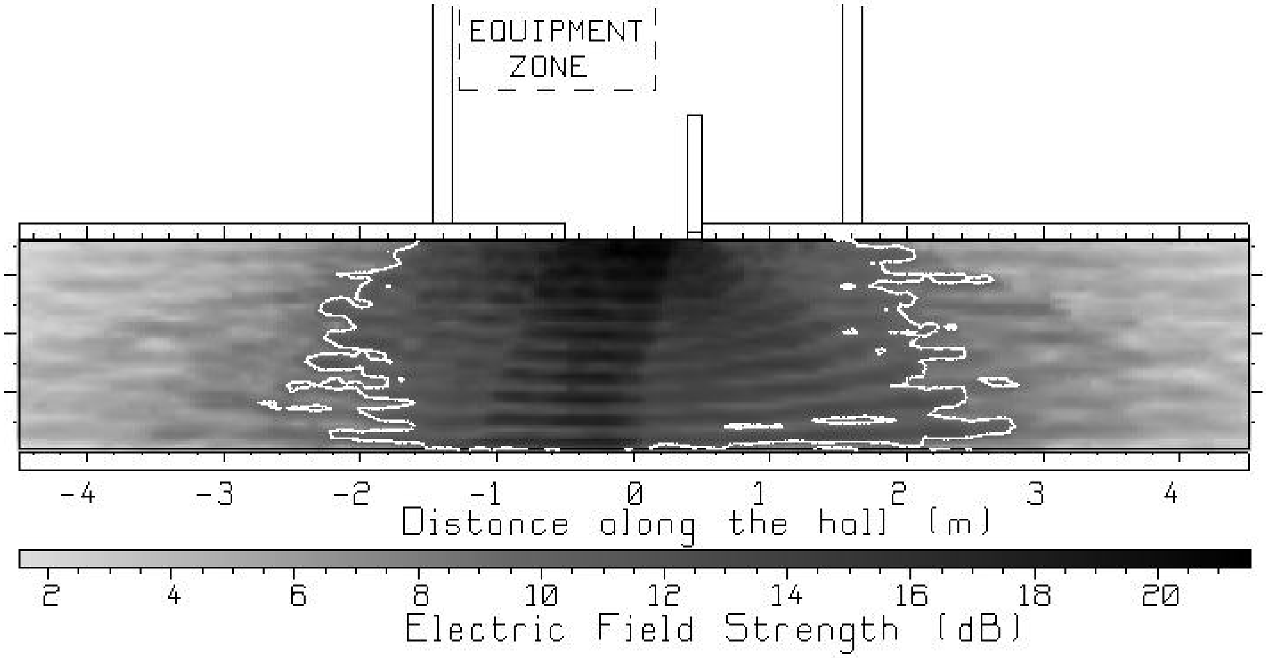

Fig. 2 The “maximum interference field” as a function of the transmitter location in the hallway, with sheetrock walls.

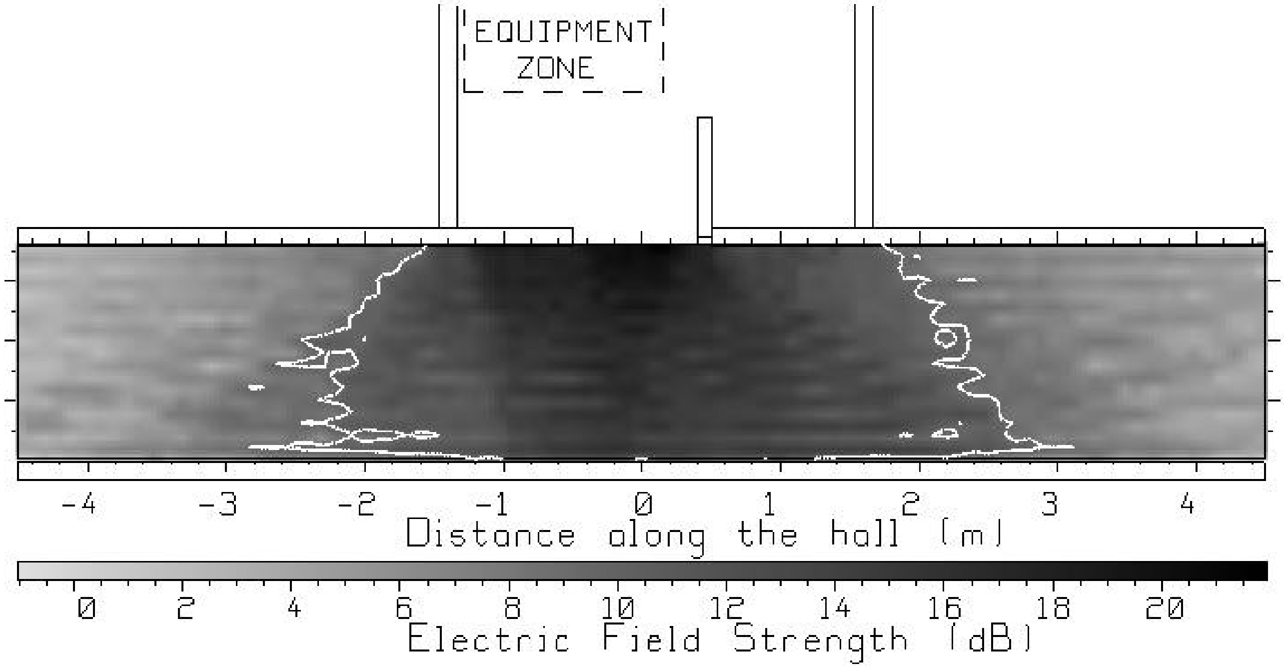

Fig. 3 The maximum interference field with brick walls.

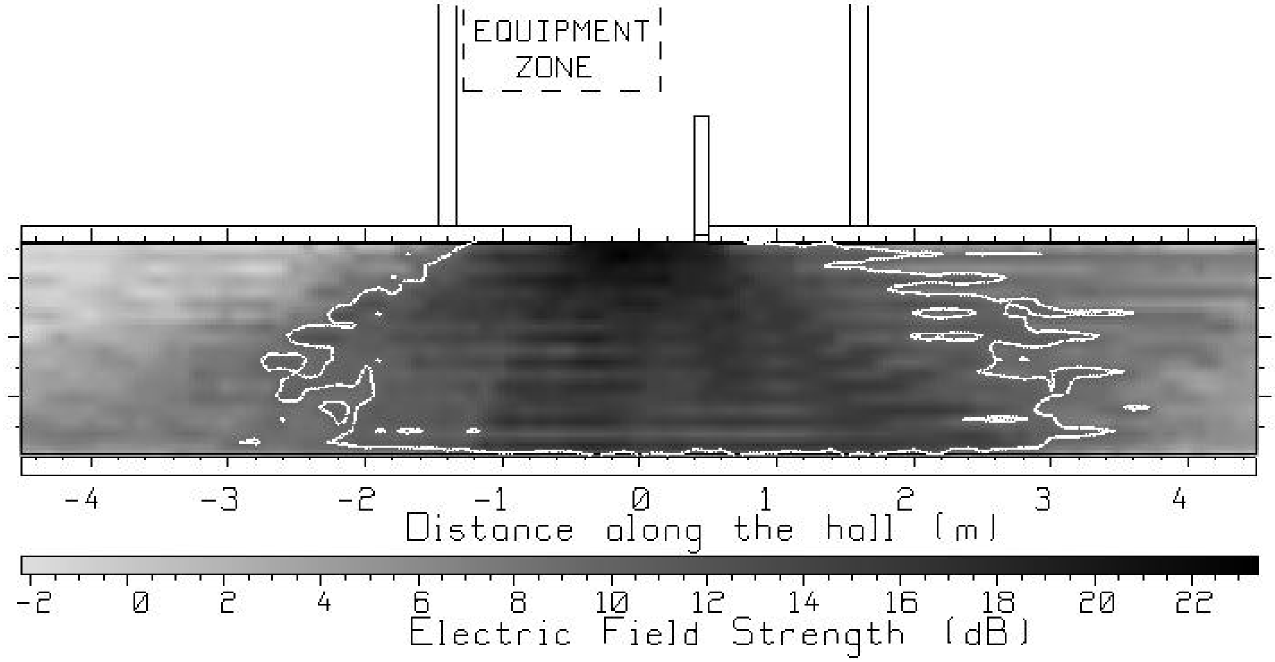

Fig. 4 The maximum interference field with clay-block walls.

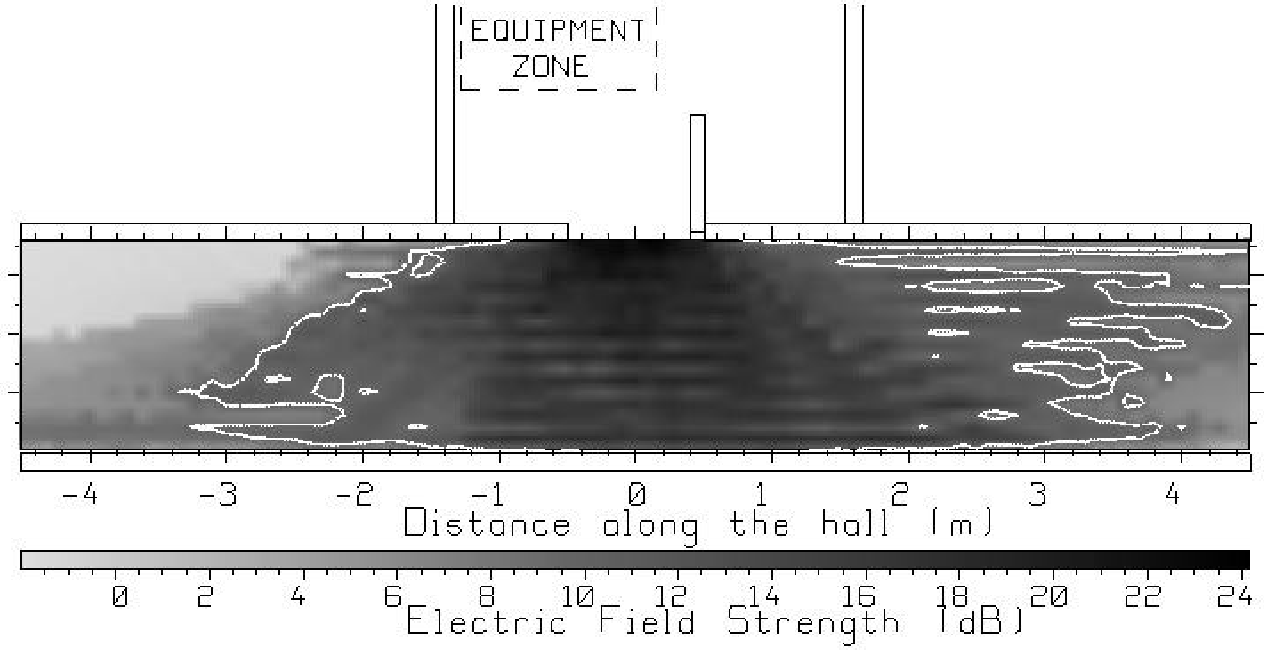

Fig. 5 The maximum interference field with plaster-and-wire walls.