SAFE USAGE OF RADIO-FREQUENCY SOURCES IN HOSPITALS: ASSESSING ELECTROMAGNETIC-INTERFERENCE RISK WHEN USING MINIMAL SEPARATIONS

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INTRODUCTION

Wireless (radio-frequency, RF) technology is expected to improve healthcare delivery and should reduce incidence of “mobile” medical errors [e.g., 1]. However, wireless usage must not cause electromagnetic-interference (EMI) malfunction of critical-care medical-devices, which might threaten patient safety. To reduce such “EMI risks”, the current healthcare electromagnetic compatibility (EMC) standard [2], IEC 60601-1-2-2001, requires that new-equipment manuals state that RF-sources be operated no closer than an approximate “triple-free-space” minimal separation from critical-care medical devices. However, the ensuing EMI risk is unknown. We now propose a method to estimate this risk, the “minimal-separation risk” (MSR) method.

ESTIMATION OF MINIMUM-SEPARATION RISK

Estimation of the minimal-separation risk is straightforward for an isotropic point RF source operating in free space at a given separation from a medical device of given immunity, E_I. The radiated electric field declines as the reciprocal of the separation. If no ambient electric fields are present, a medical device could be operated safely (EMI risk is 0 %) at a separation where the radiated field just falls below the immunity of the medical device. However, if the ambient electric field has a symmetrical zero-mean noise distribution, then at any instant of time, the EMI risk is 50 %. To find the separation where the EMI risk is, say, 5 %, the cumulative distribution function of the noise can be used to obtain a field level, E_N, that exceeds 95% of the noise, and then the 5% minimum-separation risk would be found at the separation where the source field falls to $E_I + E_N$.

Although a hospital is clearly not a free-space environment, a similar approach can be used to estimate the minimum-separation risk within hospitals: measure how fields decline indoors; fit an appropriate model to the measured data; obtain the residual between measurements and the model; then use the residual’s statistics to obtain EMI risks associated with minimum separations. This approach is illustrated by estimating the MSR in hospital corridors.

METHODS

To estimate the minimum-separation risk in corridors, electric-fields behavior was measured as follows [3]. An analog cellular phone, operating at about 850 MHz was placed 1.2 m from one end of a corridor (50m x 3m x 2m, clay-block walls, concrete floors and ceilings). Resultant fields were sampled at 3.2-cm intervals with a wheeled robot supporting a calibrated dipole (Electromechanics 3121C-db4) connected to a spectrum analyzer (Anritsu MS2601B). Both the cellphone and moving dipole antennas were 1.6 m above the floor, oriented vertically, and centered between walls. All cellphone transmissions were at the 600-mW level, as was confirmed by a special cellphone display mode, and by monitoring the output of an additional stationary receiving antenna (see Discussion). Fields were measured twice, by having the robot travel down the corridor twice, and averaged.

A bi-exponent model was fitted to the measured data:

$$E(r)=\begin{cases}\dfrac{E_o}{r} & r\le 1\\ \dfrac{E_o}{r^n} & r>1\end{cases} \qquad \ldots (1)$$

where r is separation (m),
E_o is reference field strength (V/m) given by

$$E_o=\frac{\sum_{i=1}^{M}E_i'+\sum_{i=1}^{M}n\log(r_i)}{M}, \qquad \ldots (2)$$

where M is the number of measurement points, and $\{r_i, E_i'\}$ are the separations from the transmitter at which the measurements were taken, and the measured electric field strengths, respectively. Fields within one meter of the source fell as r^{-1} because near the source direct-ray fields dominate indirect-ray multi-path fields. Fields farther than 1 m from the source were fitted to a path loss exponent, n, using least-mean-square regression, where

$$n = \frac{M\sum_{i=1}^{M}\log(r_i)E_i' + \sum_{i=1}^{M}\log(r_i)\sum_{i=1}^{M}E_i'}{M\sum_{i=1}^{M}(\log(r_i))^2 + \left(\sum_{i=1}^{M}\log(r_i)\right)^2}. \qquad \ldots (3)$$

The residual (difference between measured data and fitted model) was computed, as was the residual's cumulative distribution function.

RESULTS

Figure 1 compares measured fields (irregular solid line) to fields predicted by the fitted bi-exponent model (solid line with squares) at various separations from the RF source.

Figure 2 shows the residual between the measured data and the fitted model. Figure 3 shows the cumulative distribution function of this residual. It shows that at any separation, 95 % of all measurements were no greater than 1 V/m larger than the fitted model. Thus, when 1 V/m is added to the fitted model, the resultant curve (dashed line in Fig. 1) shows the immunity required of a medical device if it is to operate with a 5 % EMI risk at various minimal separations. Specifically, there is a 5 % EMI risk when a 3-V/m-immunity (9.54 dB V/m) medical device operates 4.9 m from the source, and when a 10-V/m-immunity (20 dB V/m) device operates 0.6 m from the source.

The cumulative distribution function of the residual also permits estimation of the EMI risk of medical devices operating at the triple-free-space minimal separations recommended by the new IEC EMC standard. For a 600-mW source, the free-space and triple-free space minimal separations for a 10-V/m-immunity medical device are 0.54 m and 1.8 m, respectively. Applying analogous restrictions on 3-V/m-immunity devices yields corresponding separations of 1.8 m and 5.9 m, respectively. Using the cumulative distribution function, the EMI risk for a 10-V/m device is 0.32 %, and is 2.5 % for a 3-V/m device.

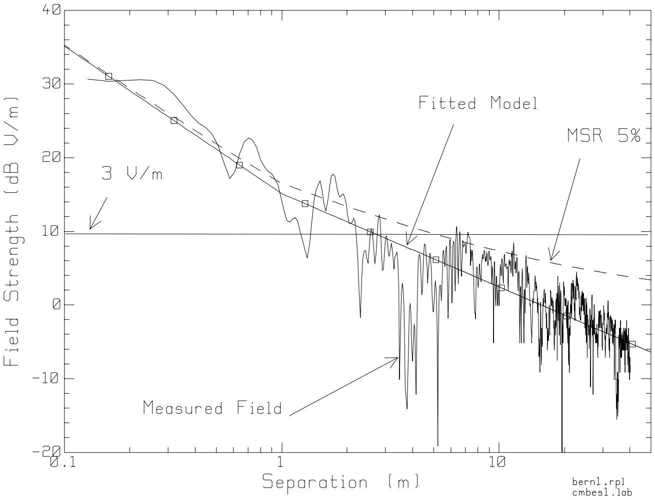

Figure 1: Corridor fields (irregular solid line), fitted model (squares, solid line), and immunity required for 5% EMI risk at given separation from source (dashed line)

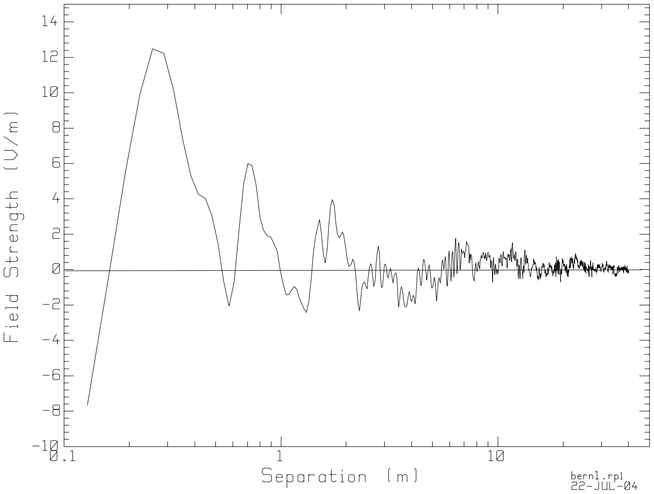

Figure 2: Residual between fitted model and measured data. Note field strength is plotted differently in Fig. 1 (Logarithmically) and in Fig 2. (linearly).

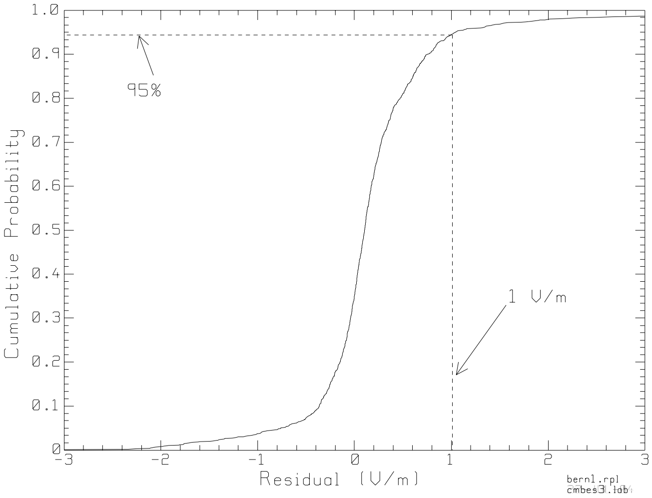

Figure 3: Cumulative distribution function of residual shown in Figure 2. The residual approaches unity at 10 V/m (0.9982)

DISCUSSION

Comparison to simulations

Predictions of fields were obtained using 3D geometrical-optics simulations of a model that accounted for the major architectural elements (walls, floor, ceiling, doors, windows etc) and electrical properties (conductivity, permittivity, etc) of the same corridor used for measurements. Simulations gave results that were very similar to those obtained by measurements [4, 7].

Cellphone power-level considerations

The transmission-power-level of cellphones, being controlled by the service-provider base station, can vary by several orders of magnitude. Thus it is important to monitor such levels.

In the current study, the cellular phone used always transmitted at maximal power (600-mW), presumably due to shielding effects of the hospital's clay-block construction, and due to the relative distance of the base station. Transmission-power level was obtained by putting the phone into a special transmission-power-level-display mode (after contacting manufacturer for guidance). To confirm power levels, we also monitored them using a second fixed antenna, whose output was periodically connected to the spectrum analyzer. Note that such monitoring would have also permitted normalization of data had power-level changes actually occurred.

It should be noted that even though tests were performed using an older AMPS-modulation analogue cellphone, results are also relevant to usage of newer (e.g., CDMA-modulation), lower-maximal-power (125-mW) cellphones. This is because the newer phones will revert to the older analogue mode when newer-mode signals are lost, or unavailable.

Limitations

The bi-exponent model has been shown [4] to effectively characterize field behavior in corridors. Although, the rate of decrease of fields is dependent upon location within the volume of corridors [3,5], the centerline shows the lowest rate of attenuation and therefore represents a worst-case risk scenario.

However, it is known [e.g., 3,6] that fields in reflective (e.g., metallic, clay-block, concrete) rooms may not tend to decline with distance. In addition, small rooms may not be able to provide sufficient space for adequate separations (i.e. room dimensions smaller than separation distance). Thus in both of these cases, neither usage of minimal separations, nor the MSR method, would be useful in such areas.

Although, usage of minimal separations should promote electromagnetic compatibility within hospitals, the large minimal separations associated with triple-free-space may be very disruptive to medical staff work flow, even when using moderate power RF sources. Usage of both lower-power sources and higher-immunity (e.g. 10 V/m) medical devices would be preferable.

CONCLUSIONS

The value of the minimum-separation with risk method is that it provides a *quantitative* EMI risk measure, which would be required for development of wireless policies in hospitals.

The lowest risk levels were obtained using devices with 10-V/m immunity. However, even when using the IEC recommended minimal separations for devices with 10-V/m immunity, the risk of EMI was non-zero for 600-mW sources.

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