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Currents induced on wired I.T. networks by randomly distributed mobile phones – a computational study

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Currents induced on wired I.T. networks by randomly distributed mobile phones – a computational study

Abstract

The probability density and exceedance probability functions of the induced currents in a screened cable connecting two enclosures, resulting from the close presence of single and multiple mobile phones working at 900 MHz, are investigated. The analysis of the problem is undertaken using the Method of Moments, but due to weak coupling, the impedance matrix was modified to reduce the memory and time requirements for the problem, to enable it to be executed multiple times. The empirical probability distribution functions (PDFs) and exceedance probabilities for the induced currents are presented. The form of the PDFs is seen to be quite well approximated by a log-normal distribution for a single source and by a Weibull distribution for multiple sources.

Keywords

Method of Moments, mobile phones, empirical probability distribution functions, exceedance probabilities, induced currents, wired IT networks, currents, scatterer

Disciplines

Computer Engineering | Digital Communications and Networking

CURRENTS INDUCED ON WIRED I.T. NETWORKS BY RANDOMLY DISTRIBUTED MOBILE PHONES – A COMPUTATIONAL STUDY

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Abstract - The probability density and exceedance probability functions of the induced currents in a screened cable connecting two enclosures, resulting from the close presence of single and multiple mobile phones working at 900MHz, are investigated. The analysis of the problem is undertaken using the Method of Moments, but due to weak coupling the impedance matrix was modified to reduce the memory and time requirements for the problem, to enable it to be executed multiple times. The empirical probability distribution functions (PDFs) and exceedance probabilities for the induced currents are presented. The form of the PDFs is seen to be quite well approximated by a log-normal distribution for a single source and by a Weibull distribution for multiple sources.

I. INTRODUCTION

With increased handset power levels projected for some future generations of personal communication systems, and concern over possible radio frequency hazards and the electromagnetic interference (EMI) that may result, it is desirable that the probable scale of these effects in real operational scenarios be predicted. For example, some theoretical and experimental results on use of mobile handsets next to the human head, or the resulting voltage induced in Ethernet computer cables, have already appeared in the literature [1-4]. Increasingly, it has been seen that deterministic models do not serve the needs of present-day EMI analyses (e.g. for prediction of bit error rate in digital systems) and probabilistic analyses are needed [5]. In the present paper, a statistical investigation of the EMI problem due to mobile phones is considered, using a numerical technique. The problem studied is a standardised canonical scenario developed by the European COST 261 consortium on EMC in complex and distributed systems [6].

The problem posed concerns the EMI induced in a screened cable connecting two conducting enclosures placed above an infinite perfectly conducing ground plane, as shown in Figure 1 [4,6]. The source is a notional GSM mobile phone, represented by a dipole, working at 900MHz and located at an arbitrary point in a defined volume. The size of the volume corresponding to the geometry given is $32m^3$.

A numerical solution using the frequency-domain Method of Moments (MoM) was adopted [7], using polynomial basis functions in a Galerkin solution. The method is capable of handling wire, strip, conducting surfaces and small regions of inhomogeneous dielectric. Appropriate attachment-mode basis functions were used when connecting wire segments and surface patches. Since repeated runs are required to obtain statistical results, the method was modified by storing the impedance matrix that defines the cable and the two enclosures after the first program execution, to be re-used in the rest of the tests. This technique is expected to reduce the computation time by a factor of more than 50, compared with repeated execution of the basic program.

Due to the weak coupling of the source to the scatterer a further reduction in computation time was effected by evaluating the induced voltage on the scatterer from the forward fields of the source. In this case the inverse impedance matrix of the scatterer was also stored and the induced currents were then computed by matrix multiplication only.

Since near-field coupling is negligible, a half wavelength dipole was used to represent the mobile phone throughout the simulation. Due to the symmetrical geometry of the screened cable and enclosures, the possible positions of the dipole were only computed over half of the volume, to reduce the size of the computational task (see Fig. 1).

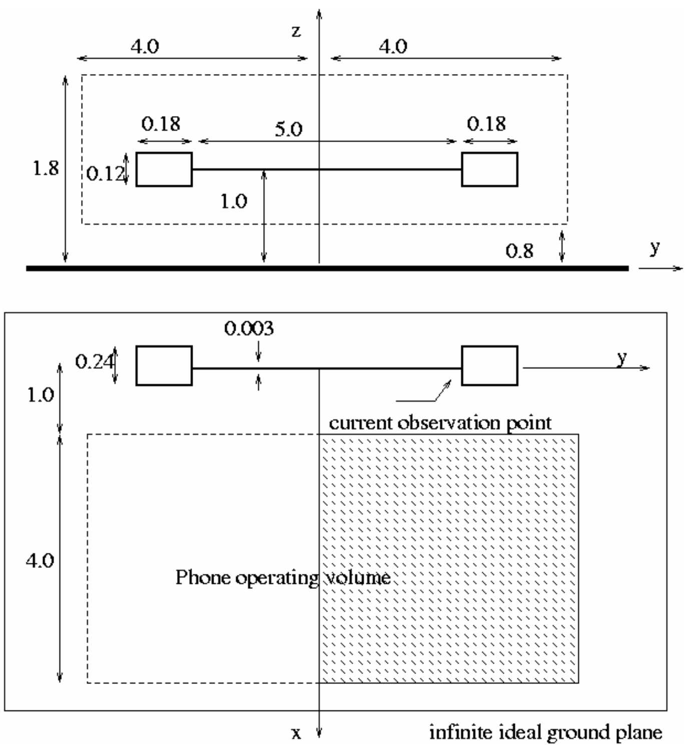

Figure 1: The geometry of the problem

Thus the induced currents in both ends of the screened cable were recorded, to represent two different phone positions in the whole working volume. The probability density and exceedance probability functions of the induced currents at the attachment node of the cable to the enclosure, due to several sources with different polarisations, were computed. The current values for all sources were normalised to 1 Watt dipole input power.

II. METHOD OF MOMENTS FORMULATION

Any arbitrary surface shape can be modelled by a number of surface patches to represent a discretised version of a complex current distribution. The currents were represented by overlapping surface dipoles, where the current basis functions are generally continuous and may have continuous derivatives. The Electric Field Integral Equation was applied to evaluate the current distribution by using the MoM. For the problem shown in Fig. 1, wire segments, rectangular patches and a disk attachment mode of a wire to a surface were used as discretising elements of the geometry. The self and mutual impedances of these surface dipoles were obtained from:

$$Z_{ww} = j\omega\mu \int_{l'}\int_{l} (\hat{a}_{l'}.\hat{a}_{l}\, f(l')f(l) - \frac{1}{k^2} f'(l')f'(l))\; G(R)dldl' \qquad (1)$$

$$Z_{rr} = j\omega\mu \iint_{s'}\iint_{s} (\hat{a}_{p'}.\hat{a}_{p}\, f(p')f(p') - \frac{1}{k^2} f'(p')f'(p))\; G(R)dsds' \qquad (2)$$

$$Z_{dd} = j2\pi\omega\mu \int_{l'}\iint_{s} (\pm\cos(\theta) f(\rho)f(\rho) \mp \frac{1}{k^2} f'(\rho')f'(\rho))\; G(R)d\theta d\rho d\rho' \qquad (3)$$

$$Z_{wr} = j\omega\mu \int_{l'}\iint_{s} (\hat{a}_{l'}.\hat{a}_{p}\, f(l')f(p) - \frac{1}{k^2} f'(l')f'(p))\; G(R)dldl' \text{ and } Z_{rw} = Z_{wr} \qquad (4)$$

$$Z_{dr} = j\omega\mu \iint_{s'}\iint_{s} (\pm\hat{a}_{r'}.\hat{a}_{p}\, f(\rho')f(p) \mp \frac{1}{k^2} f'(\rho')f'(p))\; G(R)dsds' \text{ and } Z_{dr} = Z_{rd} \qquad (5)$$

$$Z_{wd} = j\omega\mu\int_{l'}\iint_{s} \pm \hat{a}_r.\hat{a}_{p'} f(\rho) f(l') \mp \frac{1}{k^2} f'(\rho) f'(l'))\ G(R) ds dl' \text{ and } Z_{dw} = Z_{wd} \qquad (6)$$

where Z_{ww}, Z_{rr} and Z_{dd} are the self-impedances of the current basis functions on wire segments, rectangular patches and disk patches respectively. Z_{wr}, Z_{wd} and Z_{dr} are the mutual impedances between the current basis functions on a wire segment and a rectangular patch, a wire segment and a disk patch, and a disk and a rectangular patch, respectively. $f(p)$ and $f(l)$ and $f(\rho)$ are the current basis functions on the rectangular patch, wire segment and disk patch respectively: $f'(p)$ and $f'(l)$ and $f'(\rho)$ are their derivatives. $\hat{a}_p$, $\hat{a}_l$ and $\hat{a}_r$ are the unit vectors that specify the current basis function directions for the rectangular patch, wire segment and the disk patch respectively. $k = 2\pi/\lambda$ is the propagation constant, and λ is the operating wavelength. $G(R)$ is the free space Green function.

A standard thin-wire treatment would normally be used for the current basis function on a wire segment [8]. This was adopted in this case, but using the approximated kernel formulation to reduce the computational task. The current basis mode of a wire attached to a surface is represented by a disk of radius 0.16667λ, to conform to the requirement for current continuity. A closed analytical form solution can be easily obtained for this particular radius, and the exact kernel was used in this case, because of the strong coupling to the surface.

The impedance matrix for the problem shown in Fig. 1 can be evaluated and may be given in the following form:

$$Z = \begin{bmatrix} Z_{ss}(n,n) & Z_{sa}(n,m) \\ Z_{as}(m,n) & Z_{aa}(m,m) \end{bmatrix} \tag{7}$$

where $Z_{sa} = Z_{as}{}^{T}$

Z_{ss} and Z_{aa} are the self-impedances of the scatterer and the source respectively, whereas Z_{sa} and Z_{as} are their mutual impedances. n and m are the index numbers of the unknowns on the scatterer and the source respectively. Since the scatterer is fixed, the matrix Z_{ss} can be stored and reused from the first execution of the program. Taking account of the weak coupling between the source and the scatterer (and presuming that the current on the source region has been determined, by running the program without the scatterer), the current induced on the scatterer can be evaluated as follows [9]. From Eqn. (7) the induced currents can be expressed by:

$$J_s = Z^{-1}{}_{ss}(Z_{sa} J_a) \tag{8}$$

where J_s and J_a are the currents induced in the scatterer and the source respectively. The factor denoted by $(Z_{sa} J_a)$ can be reduced to:

$$(Z_{sa} J_a)_{tp} = \tfrac{1}{2}\hat{a}_s(t).\hat{a}_a(p) J_a(p) \tag{9}$$

where $\hat{a}_s(t)$ and $\hat{a}_a(p)$ are the unit vectors for the t and p current basis direction for the scatterer and the source respectively. $J_a(p)$ is the current at p on the source region.

The results obtained from inversion of the total matrices in Eqns (7) and (8) are found to agree very well, since the minimum distance between the scatterer and the source is around 3λ. This implies that the mutual coupling is negligible, and so if the inverse of the Z_{ss} matrix is also stored the computational time can be reduced by a factor of more than 50. In order to verify the assumption of negligible mutual coupling, a simulation of two half-wavelength dipoles placed above a ground plane by a distance of three wavelengths was performed. The distance between the centres of the dipoles was varied between 0.25 and 3.0 wavelengths and the input impedances computed. Only the case where the two dipoles are parallel to each other and to the ground plane was examined on the basis that this arrangement provides the greatest coupling effect. The impedance variation is shown in Figure 2. The input impedances of the dipoles are approximately similar to that computed for a single dipole parallel to the ground plane when the distance between the dipoles is greater than two wavelengths.

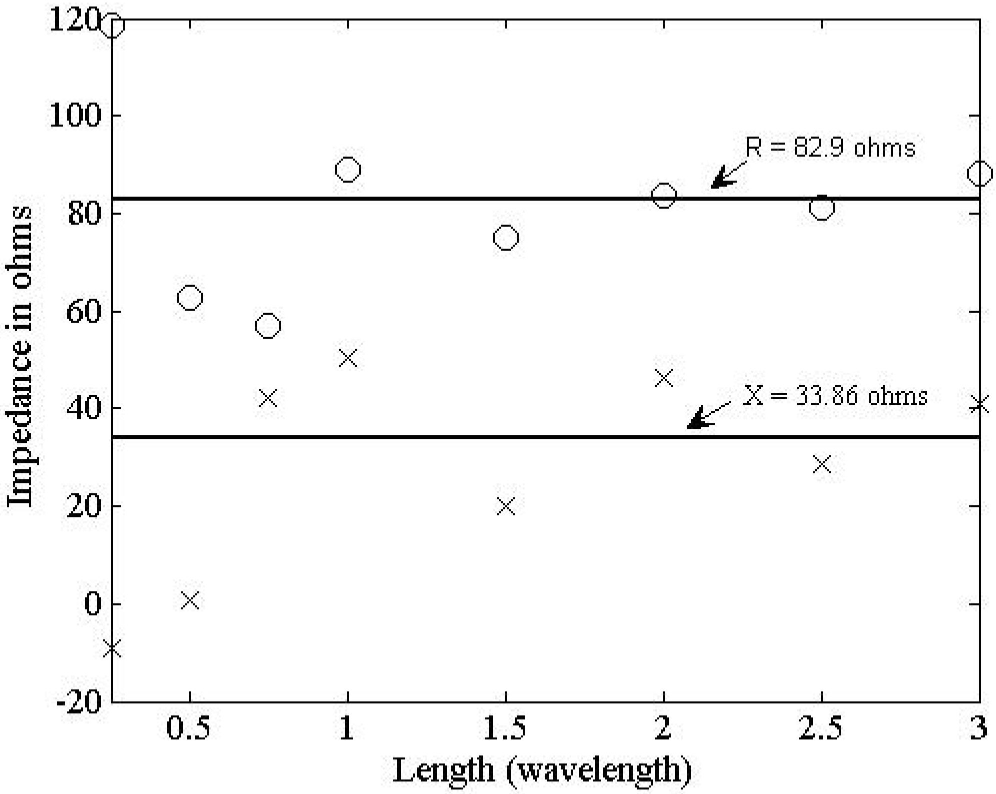

Figure 2: The variations of the input impedance of two dipoles polarized in x and parallel to ground plane against the distance between their centres (input resistance ‘o o o’, input reactance ‘× × ×’).

III. SIMULATION AND RESULTS

A program was written which implemented all of the requirements presented in previous sections. The segment length and surface patch width were taken to be less than or equal to 0.1λ. A uniformly spaced set of 7938 discrete points was chosen for the source position in the shaded volume in Fig. 1. The induced current at both ends of the cable was computed for a single source located at each position and in three orthogonal polarisations, parallel to the x, y, and z axes, respectively. This gives a total of 5166 spatial locations throughout the phone operating volume and 15498 current data values. The relevant statistics were estimated from this finite population using an additional short program to select random samples from the population data. The probability density and exceedance probability of the current in the presence of one or more sources were then estimated and plotted using a statistical computing environment, 'R' [10]. When obtaining the statistics in cases where more than one source was present a restriction was imposed such that each source was at least one metre distant from its nearest neighbour.

Samples of the population data were chosen using a (uniform) pseudo-random number generator. For all cases 1000 samples were used to generate the density and exceedance probability graphs. Also, the data was fitted to theoretical log-normal and two-parameter Weibull distributions to examine possible models for the induced currents. The Weibull distribution is a general case of the Rayleigh distribution, which may be expected to provide a good model when multiple sources are present in the operating volume.

Figure 3 shows the probability density function of the current for one source in the phone operating volume. The exceedance probability for a single source is shown in Fig. 4. It is noted that the log-normal distribution gives a better fit to the data for the single source than the Weibull distribution.

Using the finite population already available, the statistics for the induced current when more than one source is present in the operating volume were computed using a repeated random selection of the appropriate number of sources. At each selection the minimum separation distance criterion was checked and those selections that failed were ignored. The selection process was repeated until 1000 valid samples were obtained. This procedure was adopted to obtain the density and exceedance probability graphs for two to six dipoles in the operating volume.

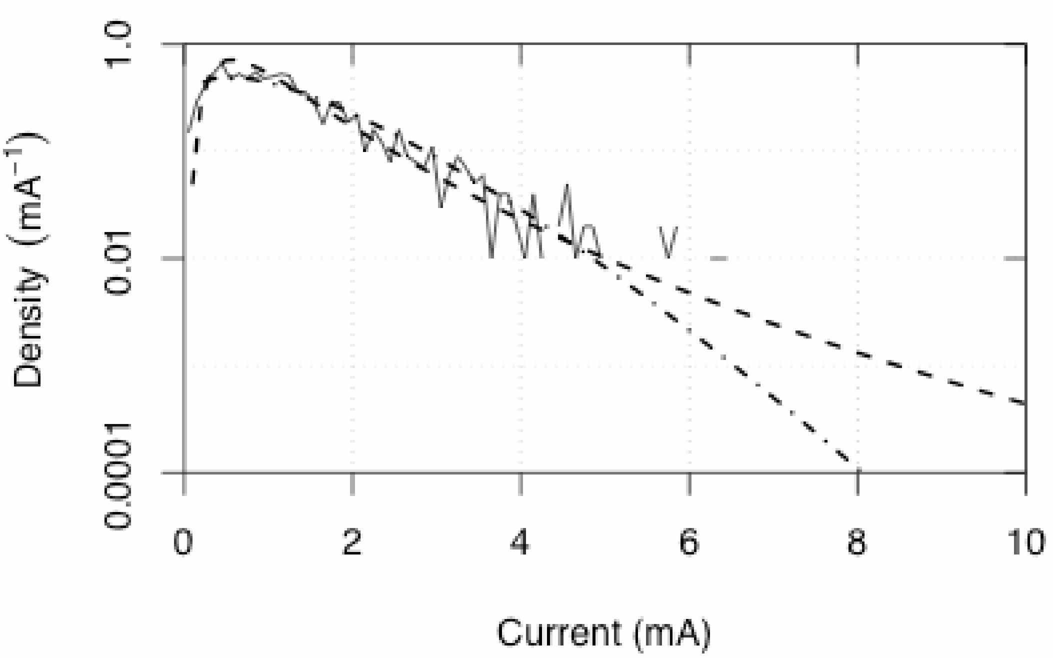

Figure 3: Probability density function for one source in the operating volume, with fitted log-normal (---) and Weibull (-··-) curves.

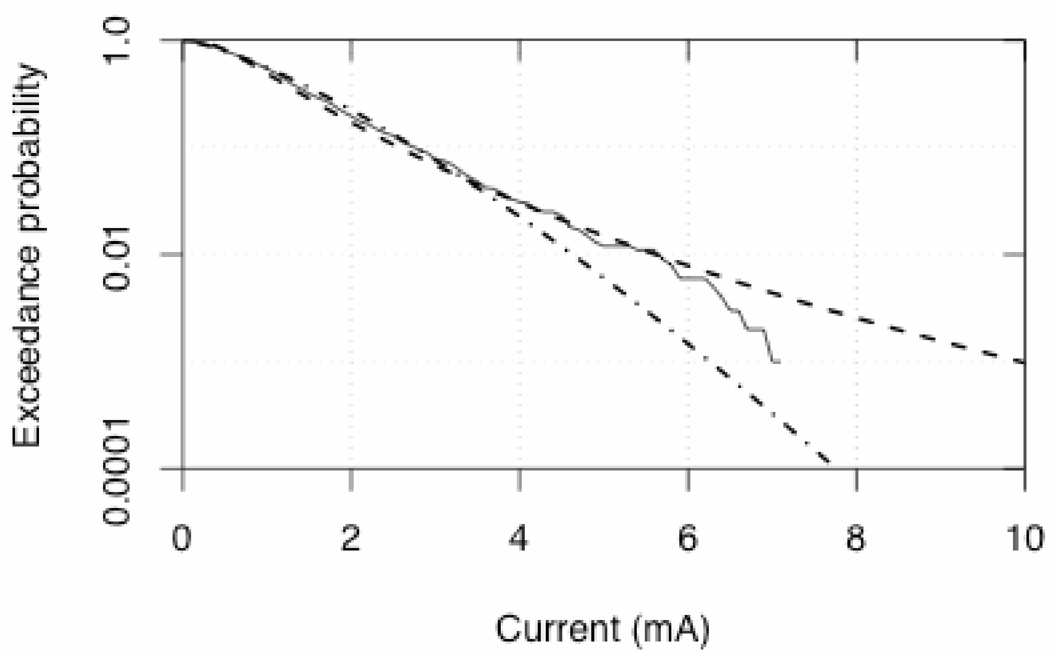

Figure 4: Exceedance probability of the current for one source in the operating volume, with fitted log normal (---) and Weibull (-·-) curves overlaid.

Figure 5 shows the empirical density function for the current with two sources present in the operating volume. Figure 6 shows the exceedance probability graph for two sources. Of particular note in these two figures is the correspondence between the data and the fitted theoretical distributions. Clearly, the Weibull distribution fits the data much better than the log-normal distribution for this case.

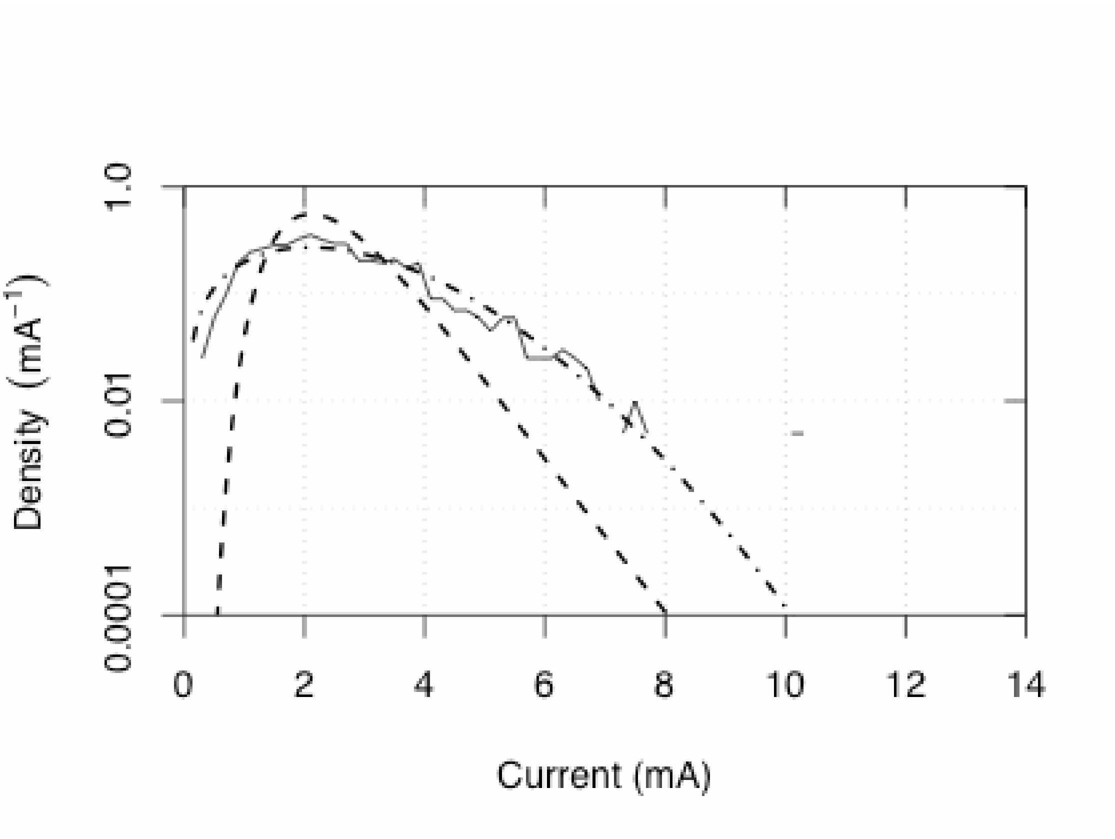

Figure 5: Probability density function for two sources in the operating volume, with fitted log-normal (---) and Weibull (-·-) curves overlaid

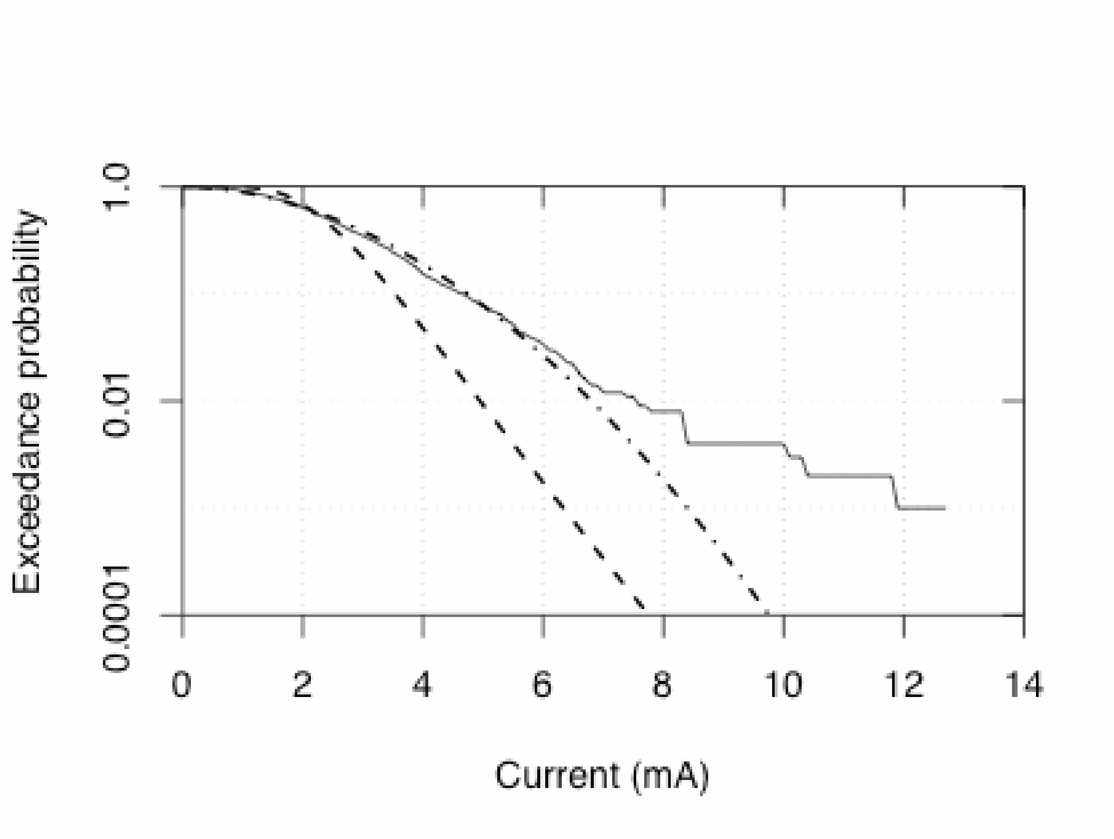

Figure 6: Exceedance probability for two sources in the operating volume, with log-normal (---) and Weibull (-·-) curves overlaid.

The empirical density function and exceedance probability of the induced current when six sources are present are presented in Figs. 7 and 8, respectively. Similarly to the case of two sources, the Weibull distribution fits the data reasonably well, whereas for an increasing number of sources the log-normal distribution gives a increasingly poor fit to the data. Fig. 9 shows the exceedance probability of the induced current when the operating volume contains between one and six sources. The trend in these curves is as expected.

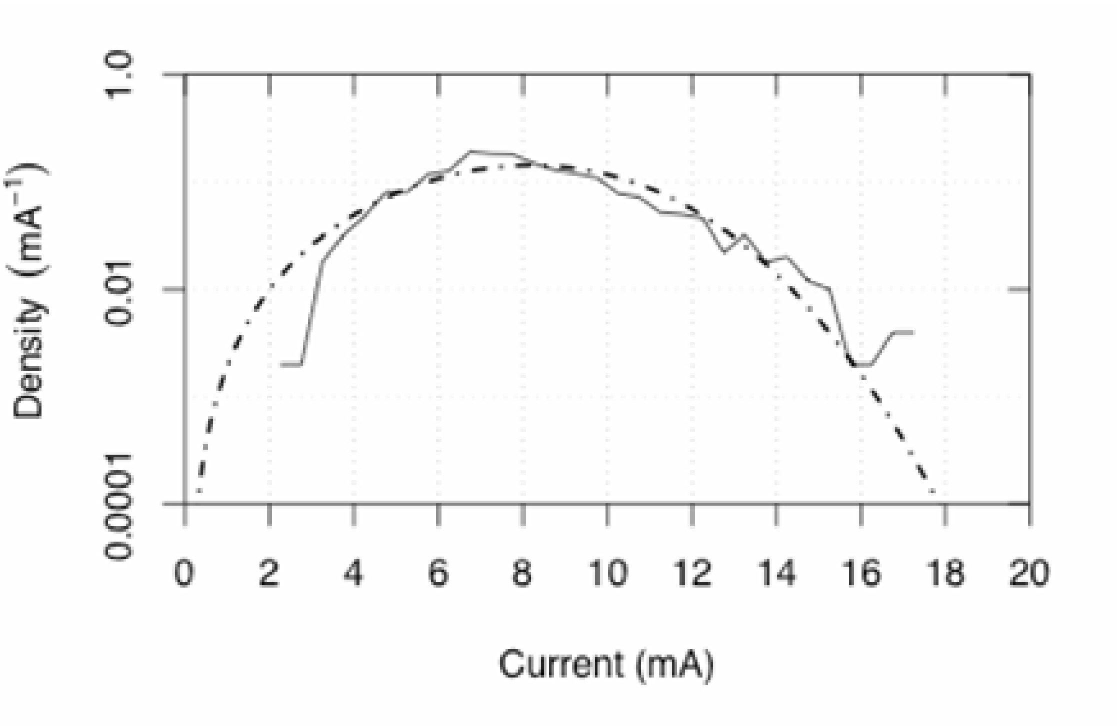

Figure 7: Probability density function for six sources in the operating volume with a fitted Weibull curve (-·-) overlaid.

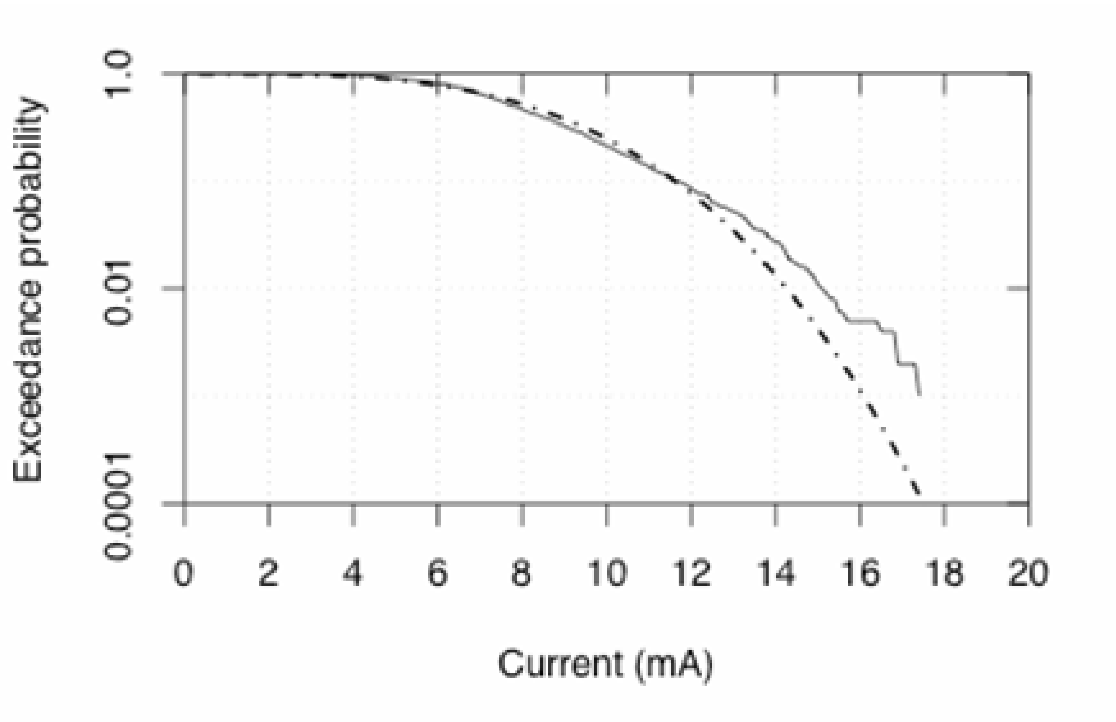

Figure 8: Exceedance probability for six sources in the operating volume, with a Weibull fitted curve (-·-) overlaid.

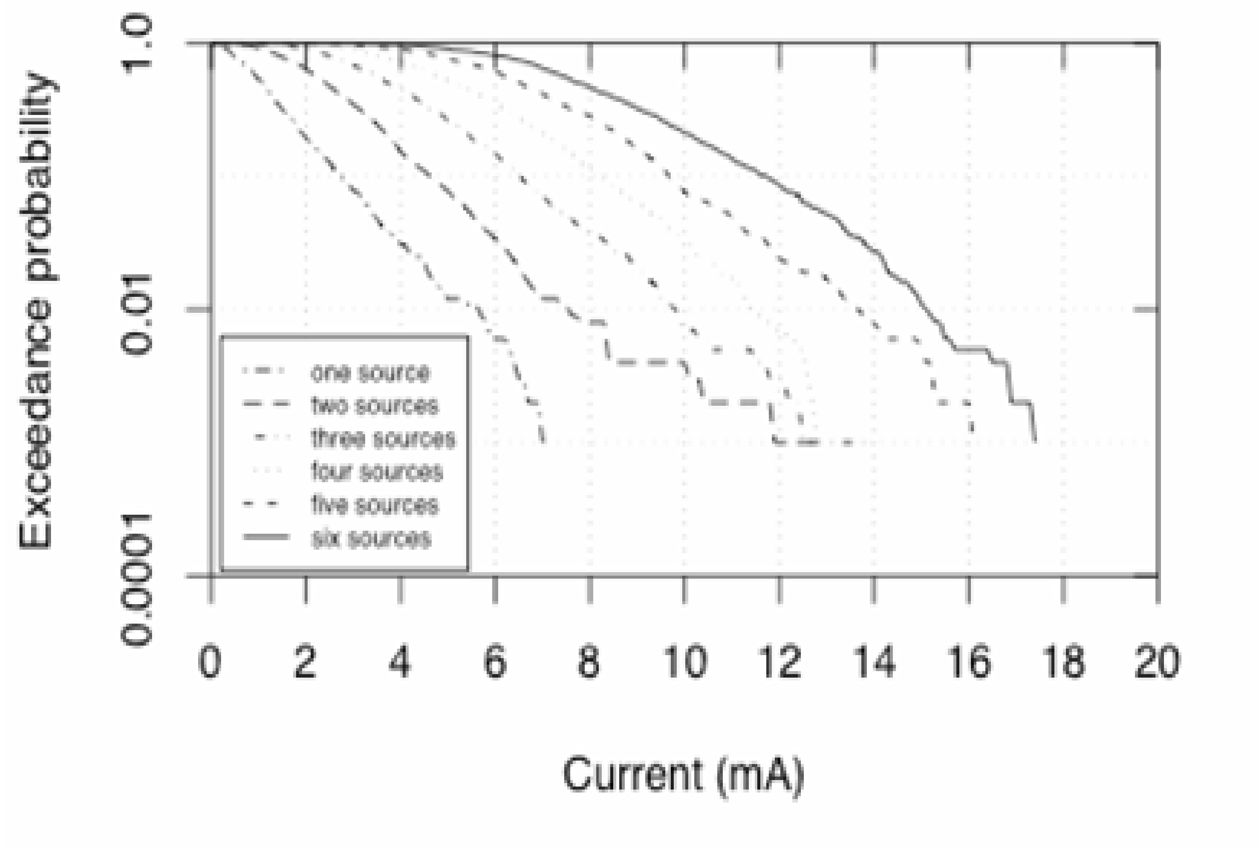

Figure 9: Exceedance probability of the current with one to six sources in the operating volume.

IV. CONCLUSIONS

For simulation of interference currents induced in cables by a random distribution of mobile phones, a Moment-Method approach, using rectangular surface patches, wire segments and disk attachments as surface dipoles has been presented. The solution was simplified by ignoring the weak mutual coupling between the source(s) and the scatterer, implemented by manipulation of the self and mutual impedance matrices between the source and the scatterer. A great reduction in memory requirement and computation time was obtained without significant loss of accuracy. Probability density and exceedance probability functions of the induced current on the scatterer were computed. The effect of adding sources to the operating volume was shown. Specific examples of the PDF and exceedance probability were examined and it was shown that at, least over a large part of the relevant range, a log-normal approximation to the PDF of the current gives a good fit to the data. This is suggestive of a possible theoretical model that could be developed to aid interference analysis in communications cables.

On the other hand, the curves showed the greatest deviation from the log-normal approximation at high induced current values and it is possible that this is caused by the distortion of the data resulting from the imposition of the one-metre minimum distance criterion. This criterion is reasonably realistic, and these high induced current situations are the ones of greatest practical interest in EMC analysis, hence the log-normal approximation may be useful only in limited circumstances. As an alternative, a Weibull distribution showed better correspondence with the results when multiple sources (phones) were involved, and hence this is an appropriate and convenient model for many practical interference scenarios.

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