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Estimation of microwave pollution

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ABSTRACT

The aim of this work is to investigate the strength of microwave signals in microwave polluted environment. In this paper the signal strength is estimated by assuming a statistical model of microwave sources. The location of the source around the observer is assumed to be random. The source emits band limited stochastic signals which are radiated as electromagnetic waves with random polarization and phase. The expression for mean square values of power density at observation point are derived using two different source location probability distribution models. The model is applied to estimate total incident power on human body area in the presence of specific number of sources.

1. Introduction

Recent advances in mobile technology have increased human exposure to microwave radiation. Indeed, we are immersed in a sea of microwave radiation. Microwave signals affect the natural environment. A number of international organizations have established limits for human exposure to microwave radiation [1–4]. At any given instant and location, signals arrive from different directions with varying strengths and polarizations. Theoretical estimation of microwave signal strength is very difficult, if not intractable, unless some simplifying assumptions are made. There are various path loss models [5] that can be used to find wireless signal strength. Different models have different limitations. Models presented in [5–8] are suitable for a specific range of frequencies. Some models are suitable for a specific type of terrain [9–16] where [9] is only for linearly polarized signals. These models are to find signal strength due to a single base station at a known location. Quantitative measurements of human exposure to microwave signals are also available [17]. Models based on measurement depend on many factors such as receiving antenna parameters, location and polarization. Therefore, there is a need to develop a model that can be used to estimate total signal strength in the microwave environment, independent of frequency, polarization and location of sources.

In this paper, average coherent density of microwave signals due to random sources above a perfectly conducting ground plane is estimated. Microwave sources are considered to be randomly located around an observer who is in the far zone of these sources. Each source is assumed to emit a band limited, wide sense stationary, random signal whose electric field is oriented in a random direction. Random sources are assumed to be statistically independent, therefore the power from 'N' such sources can be added. Signal arriving after reflections from objects other than ground plane has been neglected. Therefore, the model is appropriate for outdoor signal estimation. The randomness in the problem is due to three parameters of the source. The signal itself is a wide sense stationary random process, source polarization and location. Since it is necessary that the source must be visible to the observer, the statistical behavior of the location will be developed taking the curvature of the earth into account. The statistical description of the signal as well as the polarization will depict our total ignorance of these quantities.

2. The electric field

Consider random sources placed at some height over a perfectly conducting earth. Although the earth is spherical, in this paper the sources and observation points located near earth's surface are considered, therefore the curvature of the earth will be neglected when image theory is used. It is assumed that these sources radiate zero mean, band limited, statistically independent random signals, therefore power radiated by these sources is additive. At this point our attention is confined to a single source. The electric field corresponding to each source has to satisfy the boundary condition

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that the total tangential electric field on the ground plane is zero. Let the source radiate a band limited random signal $v(t)$. The far zone electric field due to this random signal source is a TEM wave, propagating with velocity 'c' and is given as

$$\bar{E}(r,t)=\frac{\bar{a}(r)}{4\pi r}v\left(t-\frac{r}{c}\right) \tag{1}$$

where, r is displacement from source point to the field point and a is a random unit vector orthogonal to r showing the orientation of the radiated electric field vector. The time average power associated with this random electric field is given as

$$W=\int\frac{|\bar{E}|^2}{2\eta}r^2d\Omega=\int\frac{1}{32\pi^2\eta}v^2\left(t-\frac{r}{c}\right)d\Omega=\frac{\sigma_v^2}{8\pi\eta} \tag{2}$$

where, η is the impedance of free space and ${\sigma_v}^2$ is the variance of the wide sense stationary random process $v(t)$. The band limited random signal source can be replaced by a time harmonic source at center frequency ω and radiating total power 'W'. The amplitude of this equivalent source is $\sigma_\nu=\sqrt{8\pi\eta W}$. It may be regarded as a random variable which is uniformly distributed between $[-\pi,\pi]$ so that the source signal may be considered a stationary process. The electric field for this equivalent source can be written as

$$\bar{E}=\bar{a}(r)\frac{\sigma_{\mathrm{v}}}{4\pi r}\exp\left(i\frac{\omega}{c}r+i\psi\right)\exp(-i\omega t) \tag{3}$$

The time harmonic factor $\exp(-i\omega t)$ will be suppressed throughout this paper. The factor ω/c is the wave number denoted by 'k'. The geometrical configuration of the problem is given in Fig. 1. The observer is located at point 'O' which is the origin of a cylindrical coordinate system (ρ,φ,z). The perfectly conducting ground plane is located at a distance 'h' vertically below the observer at $z=-h$. The source is located at point 'S' whose coordinates are given as (ρ_s,φ_s,z_s) having unit vectors e_ρ, e_φ and e_z. The electric field, due to the source, observed at 'O' is a sum of two fields along two propagating paths. One of them is a direct path having length R_1 and the field on this path is given as

$$\bar{E}_1=\frac{\sigma_\nu}{4\pi R_1}\exp\left(-ikR_1+i\psi\right)\left(-\frac{z_s}{R_1}Qe_\rho+Pe_\phi+\frac{\rho_s}{R_1}Qe_z\right) \tag{4}$$

where, P and Q are complex random numbers, such that

$$|P|^2+|Q|^2=1 \tag{5}$$

The complex random numbers P and Q determine the random state of polarization of electric field. The sign in the propagation factor has been reversed because the field is due to an incoming

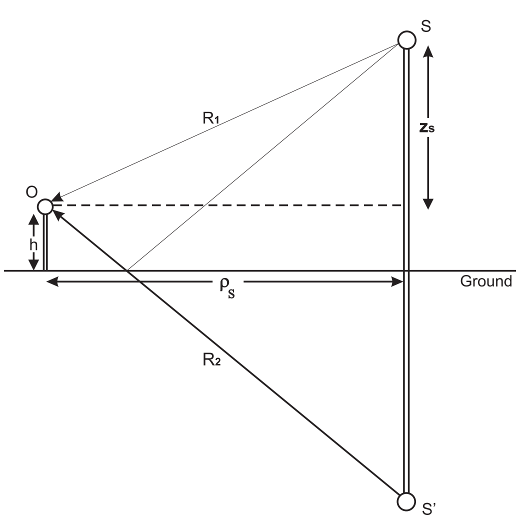

Fig. 1. Observer and the source coordinate systems.

wave in the observer coordinates. The other path from the source to the observer is due to the reflected wave which seems to come from image source point S', with path length R_2. Due to reflection the direction of horizontal field components will be reversed to satisfy the boundary condition on the ground plane. The field on the reflected path is given as

$$\bar{E}_2=\frac{\sigma_\nu}{4\pi R_2}\exp\left(-ikR_2+i\psi\right)\left(\frac{z_s+2h}{R_2}Qe_\rho-Pe_\phi+\frac{\rho_s}{R_1}Qe_z\right) \tag{6}$$

The total electric field $\mathbf{E}$ at O will be the sum of $\mathbf{E_1}$ and $\mathbf{E_2}$. The expression for total electric field intensity can be written as

$$|\bar{E}|^2=\frac{\sigma_\nu^2}{16\pi^2R_1^2}+\frac{\sigma_\nu^2}{16\pi^2R_2^2}+\frac{\sigma_\nu^2}{8\pi^2R_1R_2}\times\left(\frac{\rho_s^2-z_s(z_s+2h)}{R_1R_2}|Q|^2-|P|^2\right)\cos(k(R_1-R_2)) \tag{7}$$

It may be noted that the above expression is independent of random phase ψ. The remaining randomness is in the source location and its state of polarization which will be discussed next.

3. Random polarization of wave

The random polarization is described by complex variables P and Q. Since the incoming wave has random state of polarization, therefore P and Q must also be random except that they have to satisfy the constraint given in Eq. (5). It is assumed that randomness in polarization of a source is independent of its random location. Poincare sphere specifies all polarization states of an arbitrarily polarized wave. P and Q can also be specified in terms of state of polarizations on Poincare sphere. According to Balanis [6], latitude and longitude on the Poincare sphere can be specified as 2τ and 2ε respectively. It can be shown that

$$|P|^2=\frac{1}{2}(1-\cos(2\tau)\cos(2\varepsilon)) \tag{8}$$

$$|Q|^2=\frac{1}{2}(1+\cos(2\tau)\cos(2\varepsilon)) \tag{9}$$

The aim is to calculate average incident electric field intensity at the observation point O, where the averaging needs to be carried out over all the polarizations. Therefore ε and τ are random variables where, τ is uniformly distributed over $[0,\pi]$ and ε is uniformly distributed over $[-\pi/4,\pi/4]$. The joint PDF of ε and τ is given as

$$f_{\varepsilon,\tau}(\varepsilon,\tau)=\frac{2}{\pi^2} \tag{10}$$

Expected value of $|P|^2$ can be calculated as

$$\overline{|P|^2}=\int_{\pi/4}^{\pi/4}\int_0^{\pi}|P|^2+_{\varepsilon,\tau}(\varepsilon,\tau)\mathrm{d}\varepsilon\mathrm{d}\tau=\frac{1}{2} \tag{11}$$

Similarly the expected value of $|Q|^2$ will be

$$\overline{|Q|^2}=\int_{-\pi/4}^{\pi/4}\int_0^{\pi}|Q|^2f_{\varepsilon,\tau}(\varepsilon,\tau)\mathrm{d}\varepsilon\mathrm{d}\tau=\frac{1}{2} \tag{12}$$

The conditional mean square value of the total electric field intensity at a given location $\mathbf{r}$ can now be calculated by averaging over all states of polarization on Poincare sphere. This is achieved by using (2), (11) and (12) in Eq. (7) resulting in

$$|\bar{E}|^2=\frac{W\eta}{2\pi}\left[\frac{1}{R_1^2}+\frac{1}{R_2^2}+\left(\frac{\rho_s^2-z_s(z_s+2h)}{R_1^2R_2^2}-\frac{1}{R_1R_2}\right)\times2\cos(k(R_1-R_2))\right] \tag{13}$$