International Journal of Applied Research 2019; 5(9): 178-180

ISSN Print: 2394-7500
ISSN Online: 2394-5869
Impact Factor: 5.2
IJAR 2019; 5(9): 178-180
www.allresearchjournal.com
Received: 21-07-2019
Accepted: 25-08-2019

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Antenna for mobile communications

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Abstract
The use of mobile radio channels is expected to continue to grow quickly, driven by a combination of consumer demand for mobile services and advances in the enabling electronic and infrastructural technology. In this paper, using Fourier Transform Method, the transform relations are reviewed and interpreted for the mobile radio channel. The effective scattering distribution is the vector product of the antenna pattern and the incident waves and is a scalar function of angle and delay time. The space base-band frequency correlation function transforms with the averaged power of the effective scattering distribution. If the angular power density marginal of the effective scattering distribution is known, then the transform relations can be used for configuring antennas for spatial diversity.

Keywords: Mobile radio channel, Delay time, spatial diversity

Introduction
Basic antenna configurations must be as compact as possible, but also be able to retrieve from the multipath a variety of signals, which have different or uncorrelated multipath degradation. This paper presents the basic Fourier relations for multipath of mobile communications and applies them to finding the spacing requirement for directive antennas. The spacing requirement is well known for the situation at a mobile where omnidirectional antennas are often used and where less than a half-wavelength spacing provides diversity action [1-4]. However, at the base station and also with some mobile terminals, the antennas are directive and the conditions for space diversity are different, with the larger directionality requiring larger spacing. This paper also connects the spacing requirements and the directionality through the Bello channel relations [5] as applied to the mobile channel.

Multipath channels
The open circuit voltage at the receiving antenna terminal is a function of the incident fields E (θ, ϕ) and the receiving pattern- h (θ, ϕ). It is defined here, through introducing the base-band frequency ω and mobile terminal position z-dependence as

$$V0C\ (\omega, z) \int_{0}^{2\pi} \int_{0}^{\pi} E\ (\omega, z; \theta, \phi)\ h\ (\omega, z; \theta, \phi) \sin\theta\ d\theta\ d\phi \qquad \text{.... (1)}$$

Channel model
Over a space of typically many wavelengths, the transfer function for a mobile terminal is Modeled as a summation over many discrete, constant, scalar, effective sources, i.e.,

$$H\ (\omega, z) = V0c\ (\omega, z) = \Sigma i\ ai\ ej\psi i \cdot e{-}jkRri$$

where ai ejψi is the complex amplitude of the ith source, kR is the wave number of the radio frequency and ri is an equivalent distance to the ith source.

Fourier relations
In general, the summation for all the delays and ray directions can be expressed using its integral form [6-7], i.e.

$$H\ (\omega, z) = \frac{1}{2\pi} \int_{0}^{\infty} \int_{-kc}^{kc} a\ (\tau, u)\ e{-}j\omega\tau ejuz\ du\ d\tau \qquad \text{... (2)}$$

where a (τ, u) is the distribution density of signals received by the antenna from the scattering medium at delay τ direction u. The inverse transform is

$$a(\tau, u) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} H(\omega, z)\, e^{j\omega\tau}\, e^{-juz}\, d\omega\, dz \qquad \text{.... (3)}$$

Correlation functions

The correlation function of the effective scattering distribution Ra now relates to the space-frequency correlation functions R_H by

$$R_a(\tau_1, \tau_2; u_1, u_2) = 1/2\pi \int\int R_H(\Delta\omega, \Delta z)$$
$$\cdot\, ej^{(-\Delta\omega\, \tau 2 + u2\, \Delta z)}\, d\,\Delta\omega\, d\Delta z$$
$$\cdot\, \delta(\tau_2 - \tau_1)\, 2\pi\, \delta(u_2 - u_1) \qquad \text{.... (4a)}$$
$$= P(\tau_2, u_2)\, \delta(\tau_2 - \tau_1)\, 2\pi\, \delta(u_2 - u_1) \qquad \text{.... (4b)}$$

The average power of the effective scattering distribution is

$$P(\tau, u) = E\{[a(\tau, u)]^2\} \qquad \text{.... (5a)}$$
$$= 1/2\pi \int\int R_H(\Delta\omega, \Delta z)\, e^{-j(\Delta\omega\, \tau - u\, \Delta z)}\, d\,\Delta\omega\, d\,\Delta z \qquad \text{.... (5b)}$$

with a (τ, u) being the vector product of the antenna pattern and the incident waves, it follows that P (τ, u) is the averaged product of the antenna power pattern and the copolarized incident power pattern. The correlation function is the inverse transform of (5)

$$R_H(\Delta\omega, \Delta z) = 1/2\pi \int\int P(\tau, u)\, e^{j(\Delta\omega\, \tau - u\, \Delta z)}\, d\tau\, du \qquad \text{.... (6)}$$

Correlation distance for directional antennas or scenarios

The spatial correlation distance for a given angular distribution of effective sources can be found directly from the single-dimensional Fourier relation between the correlation function $R_H(\Delta z)$ of the channel H(z) and the Doppler power profile written as

$$R_H(\Delta z) \Leftrightarrow P(u) \qquad \text{.... (7)}$$

For either directional scenarios or directional antennas, it is convenient to use a circular function; the $\cos^n\theta$ form, proposed in the context of mobile communications by Lee [8], is the simplest. For very narrow beams, the asymptotic form for large n can be found from using the small 0 approximation $\ln(\cos\theta) \approx \ln(1-\theta^2/2) \approx -\theta^2/2$, which results in $\cos^n\theta \approx \exp(-n\theta^2/2)$, i.e., the cosine form becomes similar to Gaussian.

An amplitude pattern defined as

$$g_1(\theta) = \cos^n(\theta-\theta_0)/2, \quad |\theta-\theta_0| \le \pi \qquad \text{... (8)}$$

is single lobed over the complete angular region with a maximum at θ_0. Any sidelobe structure of a real-world pattern is assumed to have a secondary effect. If we take a model with 2–D scenario of uniform incident power [1], with pdf $p_\theta(\theta) = ½\,\pi$, then the power of the effective scattering distribution is

$$P_\theta(\theta) \propto P_\theta(\theta)\, g^2(\theta) \propto g^2(\theta), \qquad |\theta-\theta_0| \le \pi \qquad \text{... (9)}$$

Converting to a function of u,

$$P(u) = \frac{K}{\sqrt{k_c^2 - u^2}} \cos^{2n}\left[\frac{\cos^{-1}(u/k_c) - \cos^{-1}(u_0/k_0)}{2}\right] \qquad \text{... (10)}$$

where K is a scaling constant and $u_0 = k_c \cos\theta_0$ and so the spatial correlation function is

$$R_h(\Delta z) = K \int_{-k_c}^{k_c} \frac{1}{\sqrt{k_c^2 - u^2}} \cos^{2n}\left[\frac{\cos^{-1}(u/k_c) - \cos^{-1}(u_0/k_0)}{2}\right] e^{-ju\Delta z}\, du \qquad \text{... (11)}$$

In general, the correlation coefficient function of the Gaussian channel (the real and imaginary parts of the transfer function have zero mean, normally distributed amplitudes) is complex, denoted by

$$\rho_H(\Delta z) = \frac{R_H(\Delta z) - \langle | H | \rangle^2}{R_H(0) - \langle | H | \rangle^2}$$

$$= \frac{R_H(\Delta z)}{R_H(0)} \rho_H(\Delta z) - j\rho_{IQ}(\Delta z) \quad .... (12)$$

As noted above, an imaginary part arises when the mean angle is nonzero, i.e., when the Doppler spectrum is asymmetric, and this phenomenon is clear from basic Fourier transform theory. The correlation coefficient of the power signal is

$$\rho_{|H|^2} = |\rho_H|^2 = \rho^2_H + \rho^2_{IQ} \quad .... (13)$$

As example of the Doppler and correlation functions where ρ_H, ρ_{IQ} and $\rho_{|H|^2}$ are given for a directional scenario with the $\cos^n$ amplitude pattern, which has half-power beamwidth (HPBW)

$$\text{HPBW (rads)} = 4 \cos^{-1} (2^{-(1/2n)}) \quad .... (14)$$

Conclusion

The Fourier transform method for finding the conditions for diversity is convenient and insightful. The derivation of the transform relations are summarize and the quantities are discussed in order to clarify assumptions and the physical interpretation for the mobile communications case. The transfer function of the mobile channel as a function of frequency and position, is the transform of an effective scattering distribution, which is a function of delay time and spatial Doppler frequency (proportional to the directional cosine). The effective scattering distribution is the incident wave, distribution at the antenna weighted by the pattern of the antenna.

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