2-IV C1

RECENT RESULTS ON MICROWAVE PROPAGATION

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The available information on propagation effects in microwave radio communication systems is generally insufficient for either satisfactory performance estimates or optimum system design. There is a current effort, both experimental and theoretical, to obtain results on the fundamental properties of microwave line-of-sight systems. A brief review of some of the recent results will be given here as based on the work of several investigators.

ANALYTIC MODEL FOR MULTIPATH PROPAGATION

Results have been obtained for the signal received during multipath fading conditions modeled by a constant vector plus an interfering random vector,

$$ve^{j\phi} = 1+Re^{j\theta}$$

a) The cumulative amplitude distribution is given by

$$P(v\leq L)=\pi g(1,\pi)L^2+g_4L^4+g_6L^6+\ldots$$

where g_4, g_6, etc., are linear combinations of $g(1,\pi)$ and higher derivatives of the joint probability density $g(R,\theta)$ evaluated at $R=1$, $\theta=\pi$.

b) The number of fades per unit time below the signal level L is given by

$$N(L) = \frac{\bar{\dot{v}}_+}{2}\frac{\partial}{\partial L}P(v\leq L)$$

$$= \bar{\dot{v}}_+ g(1,\pi)L + O(L^3)$$

where $\bar{\dot{v}}_+$ is the average positive derivative of the fading signal.

c) The average duration of fades below the signal level L is given by

$$\bar{t}(L) = \frac{P(v\leq L)}{N(L)} = \frac{2}{n\bar{\dot{v}}_+} L + \ldots$$

where n is the exponent of the dominant term in the amplitude distribution.

It can be seen from these results that if $g(1,\pi)$ is non-negligible then the deep fade behavior of the amplitude distribution and number of fades will be proportional to L^2 and L, respectively whereas if $g(1,\pi)$ is sufficiently small they will behave as L^n and L^{n-1}, respectively. However, the average fade duration will go as L for a much broader range of environmental conditions since it is less sensitive to properties of $g(R,\theta)$.

EXPERIMENTAL DATA

Experimental data on multipath propagation are difficult to obtain because long time periods of continuous coverage are needed to observe sufficient deep fading activity. With a considerable effort fine grain data (0.2 sec resolution) have been obtained at two different sites as given in Table I.

The fade depth distributions for the entire test period on all but the shortest path go as L^2. The coefficients are related to the physical environment which is represented by $\pi g(1,\pi)$ in the analytic model. The amount of fading increases with length and smoothness of the path and with frequency. The incidence of fading on the 25.4 km path was very low which can be interpreted as $g(1,\pi)$ being negligible; thus, the fading was controlled by higher order effects which resulted in the L^4 behavior.

The fade duration distributions have been obtained from the Ohio data. When the fade duration at level L is normalized to $\overline{t(L)}$ the resulting variable is log-normally distributed for long fades such that 1% of the fades are longer than 10 times the average.

The time derivative (slope) of the envelope has been estimated from the fade duration distributions. The results show that the probability of high slopes is significant, e.g., at a 40 dB fade depth, 10% of the slopes will exceed 70 dB/sec.

A brief characterization of multipath fading at 4 GHz on a 50 km path during the fading season would be roughly one 40 dB fade every two days with an average duration of 3.4 seconds (1% chance of being 34 seconds or longer) with a 10% change of fading at a rate of greater than 70 dB/sec.

ADDITIONAL RESULTS

Work is in progress on non-diversity and diversity propagation with particular emphasis on the detailed structure within a 30 MHz band. In the latter case considerable amplitude structure has been observed; some examples will be given in a movie which will accompany the oral presentation of this paper.

TABLE I - Microwave Propagation Data

Site	Ohio			Ohio	Georgia		Georgia		Georgia		Georgia	
Path Lengths	45.6 km			47.0 km	42.2 km		45.3 km		57 km		25.4 km	
Path Roughness(1)	16.0 m			8.5 m	19.0 m		20.8 m		40.8 m		40.6 m	
Time Period (T)	1966			1966	1968	1969	1968	1969	1968	1969	1968	1969
Frequency Band	4	6	11	4	4	4	4	4	4	4	4	4
Fade Depth Distribution $P(v \leq L)$	$.25L^2$	$.53L^2$	$.69L^2$	$.77L^2$	$.25L^2$	$.24L^2$	$.18L^2$	$.20L^2$	$.35L^2$	$.26L^2$	$.18L^4$	$.046L^4$
Number of Fades $[T\ N(L)]\ 10^{-2}$	37L	64L	120L	38L	38L	66L	33L	90L	42L	106L	55L	$31L^3$
Average Fade Duration $t(L)$	408L	490L	330L	1130L	350L	400L	270L	250L	420L	260L	180L	160L

Test Interval: 1966, Aug-Sept, 5.3×10^6 sec; 1968, Aug-Oct, 5.2×10^6 sec; 1969, May-Sept, 10.8×10^6 sec

(1) Path roughness is the standard deviation of terrain height measurements at one-mile intervals.