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HIGH SPEED DIGITAL DATA TRANSMISSION IN AN UNDERWATER CHANNEL

A. Falahati, S.C. Bateman, B. Woodward

Dept. of Electronic & Electrical Engineering, University of Technology, Loughborough, Leicestershire.

ABSTRACT

In order to model a mobile underwater channel, one is faced with wide-ranging issues for which there is not enough information. Such issues must be considered carefully to combat multipath fading, adjacent and co-channel interference. At the receiver end, the performance of various system components must be determined, for example, modem and speech codec performance must be evaluated in the presence of echo, ambient noise, fading, attenuation and other impairments.

The model that is described here is a mobile underwater channel simulator in hardware that has sufficient flexibility to accommodate many forms of tests and experiments.

INTRODUCTION

The acoustic signal as it propagates between a transmitter and receiver is seriously distorted by multipath propagation. This term describes the condition which causes the signals from a given transmitter to be received via a number of paths, each involving a different transit time. Two major factors contribute to this multipath propagation. First, the turbulent and thermal microstructure of the sea produces small continuous variations in the acoustic refractive index. This in turn leads to multipath refraction of the sound waves (usually termed forward scattering) and the received signal is subject to random fluctuations in amplitude, phase and transit time.

Multi-path propagation is also produced by reflections from the boundaries of the medium. The signal then consists of a direct signal plus a number of distorted, delayed replicas. In general, this factor has far more effect upon acoustic communication than forward scattering owing to the much larger transit time differentials that can occur, typically 4 to 50 ms.

Therefore, signals can experience fading, either collectively or independently, implying that multipath fades can vary from Rayleigh to various degrees of Rician; the carrier frequency in the present research can assume values 70 kHz to 110 kHz.

Important link features such as propagation effects, Doppler shift, underwater nonlinearity and ambient noise have been incorporated in the channel simulator.

The ambient noise background of the sea, in the absence of wave crashes, ice cracking and biological noise has been found to have a Gaussian amplitude distribution.[1] This can be observed by adding all individual noise sources from the sea surface or ships.

The following sections describe first the propagation environment in which the mobile underwater channel must operate. Next, the architecture of the simulator is described and system sophistications are pointed out. Finally, the results of some of the application experiments conducted by the channel simulator are presented.

SIGNAL FLUCTUATION STATISTICS

The multipath phenomenon arises from bottom bounce propagation paths, refracted paths in ducts, and the paths involved from scatterers in the body or on the boundaries of the sea. There are also inhomogeneities that could arise due to rough sea surface, the temperature, pressure, salinity microstructures, and the biological matter existing in the body of the sea. It is evident that turbulence, currents and mobile receiver or transmitter cause various inhomogenieties to be in motion relative to each other. The result is that a received signal is likely to consist, in whole or in part, of a number of contributions of random time varying phase and amplitude. These random multipath contributions will be negligible near the transmitter but, with increasing range, will tend to overwhelm the steady direct path component and produce at a long range a resultant consisting only of components of varying phase and amplitude. For instance, the propagation through a random microstructure may be viewed conceptually as consisting of a steady, direct path component that decreases with range, together with scattered or diffracted components that increase with range and eventually dominate the received signal. At any distance, the resultant is the sum of a steady and a random component, with an amplitude distribution that depends only on the fraction of the total average power in the received random component.

The distribution function of the envelope of a sine-wave plus narrow-band Gaussian noise was first derived by Rice(2). This is the same as the distribution of the sum of a constant vector and a random vector whose x and y coordinates are Gaussian time functions. This so-called Rice Distribution can be described as follows:

Let C be the magnitude of the constant vector, and let D be the magnitude of the sum of the constant vector and a random vector whose x and y coordinates have unit variance. The probability density of C is given by

$$P(C) = C \exp\left[-\left(\frac{C^2+D^2}{2}\right)\right] . I_o(CD) \qquad (1)$$

where $I_o(CD)$ is a modified Bessel function of zero order and of argument CD.

When the constant component vanishes, the result is the Rayleigh distribution,

$$P(C) = C \exp\left(-\frac{C^2}{2}\right) \qquad (2)$$

The signal is made up entirely of random components. At the other extreme, when the constant component is very large[3,4] i.e.; CD>>1, the distribution is essentially Gaussian with unit variance.

$$P(C) = \left(\frac{C}{2\pi D}\right)^{\frac{1}{2}} \exp\left[-\frac{(C-D)^2}{2}\right] \qquad (3)$$

THE SEA CHANNEL MODEL

The input signal to the receiver may be modelled as the sum of three vectors consisting of two coherent components (surface and bottom bounce, reflections) and a diffused one (the body of the sea),(5) i.e. $\bar{P} = \bar{P}_o + \bar{P}_1 + \bar{P}_2$

where $\bar{P} = \bar{P}_o, \bar{P}_1,$ and $\bar{P}_2$ denote the input to the receiver, diffuse component, bottom bounce reflection and surface reflection component respectively [Fig.1]. The diffuse component has a bandwidth of u/λ, where u and λ are the receiver's speed and carrier wavelength respectively. Relative to the diffuse component, the changes in bottom reflection are very slow with negative elevation angle, and the receiver can substantially attenuate this component. Hence, the input signal into the mobile receiver can be effectively modelled as the sum of two vectors, the diffuse and specular components. As mentioned earlier, the diffuse component $\bar{p}_o$ which is distributed in amplitude and phase can be modelled by a Rayleigh distributed envelope and uniformly distributed phase. [Figure 2].

The occurrence of a specular component (assuming a calm sea) can be included in the model as Rician distribution which is a Rayleigh distribution with a non-fading component as a result of a direct reflection that could be received.

RAYLEIGH FADING SIMULATOR

Figure 3 shows the Rayleigh multipath fading simulator which consists of two Gaussian white noise generators $q_1(t)$ and $q_2(t)$, which are the in-phase and quadrature components of q(t) respectively.(6,7) They are both random processes with zero mean, equal variance (0.5) and uncorrelated. The simulater also includes two variable lowpass Bessel filters(8) and two balanced mixers. The selection of the cut-off frequency of the lowpass filter depends on the Doppler frequency $|f_D| = \frac{u}{\lambda}$, and consequently on the speed of the vessel, u, where λ is the carrier wavelength and $|f_D|$ is the absolute value of f_D.

The output of the simulator represents the envelope and the phase of the Rayleigh faded signal, and the impulse response of the channel is modified by the simulator output.

As mentioned earlier, the underwater channel transmission path is assumed to be composed of one diffused reflected component. However, if the second diffused reflection component (non-calm sea condition) is also present and is received by a delay of τ seconds, the corresponding model of the underwater channel can also be obtained (Figure 4). The two signals $q_1(t)$ and $q_2(t)$ give the first diffused reflection, and the signals $q_3(t)$ and $q_4(t)$ which are statistically independent of $q_1(t)$ and $q_2(t)$, give the second diffused component. When the signal at the input of the underwater link is x(t), then from Figure 4, the output signal z(t) is

$$z(t)=x(t)q_1(t)+\hat{x}(t)q_2(t)+x(t-\tau)q_3(t)+\hat{x}(t-\tau)q_4(t) \qquad (5)$$

where x(t) is the inphase, and $\hat{x}(t)$ represents the quadrature components or the Hilbert transform of x(t).

Furthermore, it should be noted that if the model is implemented for, say, three diffused components (body, surface and bottom), it surely works for two (extreme case), given the adequate delay, and also operates for one diffused component.(9)

COMPUTER SIMULATION TESTS AND RESULTS

It is assumed that a vessel travels with a speed of 5 mph, the frequency of the radiated carrier is 100 kHz and velocity of sound is 1500 ms^{-1}. This leads to a constant Doppler frequency, $f_D \sim 130$ Hz.

The input signal to the simulator was tested for 600, 1200 and 2400 bits per second digital binary polar (+1 and -1) signal. As the number of bits was increased, the deeper fades were observed (Figure 5 normal and Figure 6 the expanded version). This occurrence is common in time-variant channels and can be dealt with in the detection process.

Moreover, the model is also modified for more than one diffused component. This, plus the detection process and the echo cancellation technique, will be revealed in future publications.

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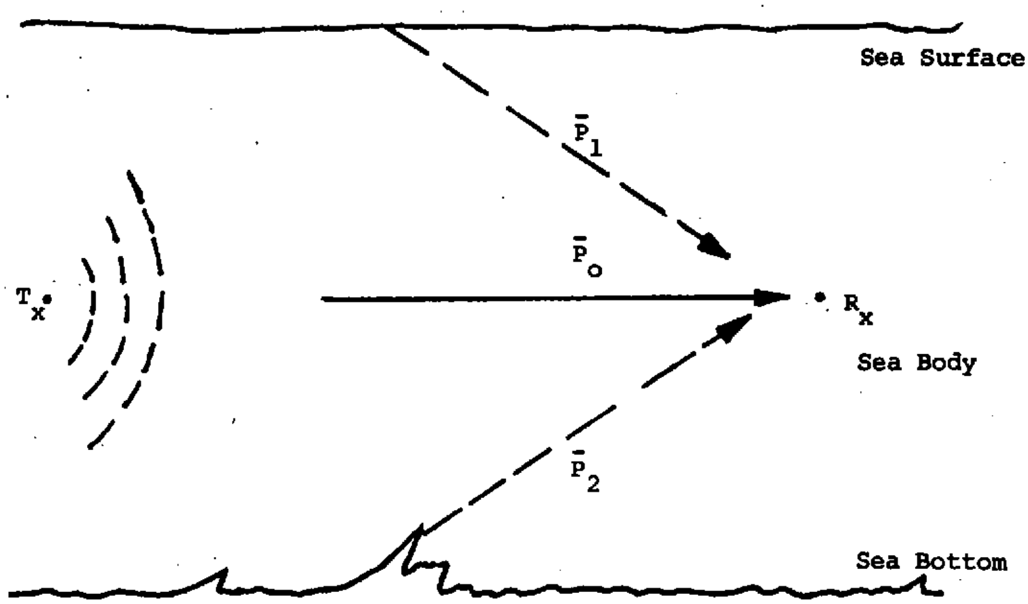

Figure 1 Each path could be taken as direct or specular, or could be considered as diffused reflections depending on the environmental conditions, but $\bar{P}_o$ is a diffused component due to microstructure of the sea body

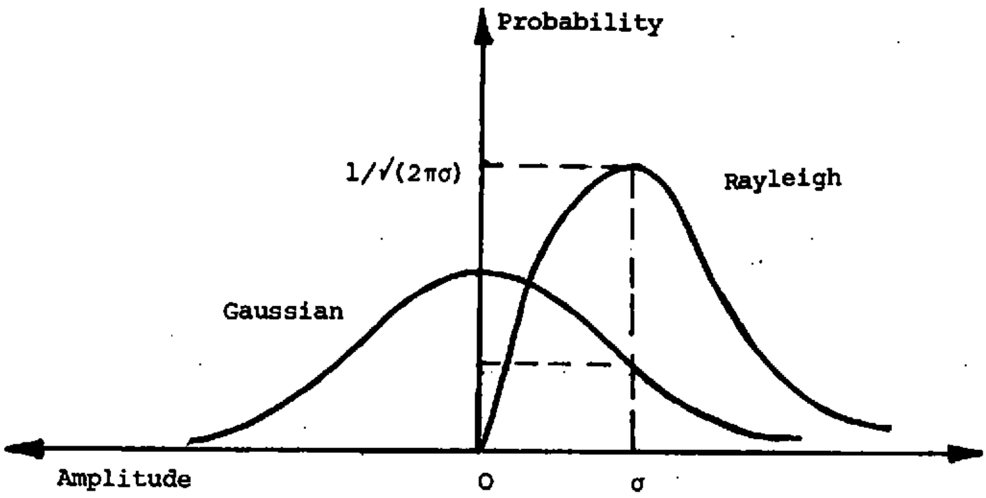

Figure 2 Rayleigh and Gaussian probability distribution functions

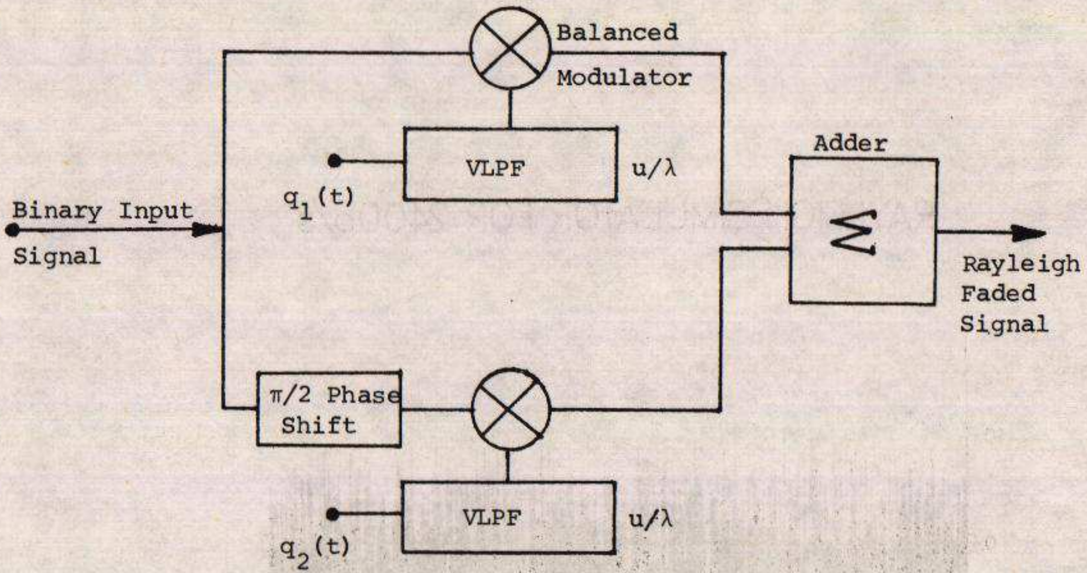

Figure 3 Rayleigh fading simulator block diagram

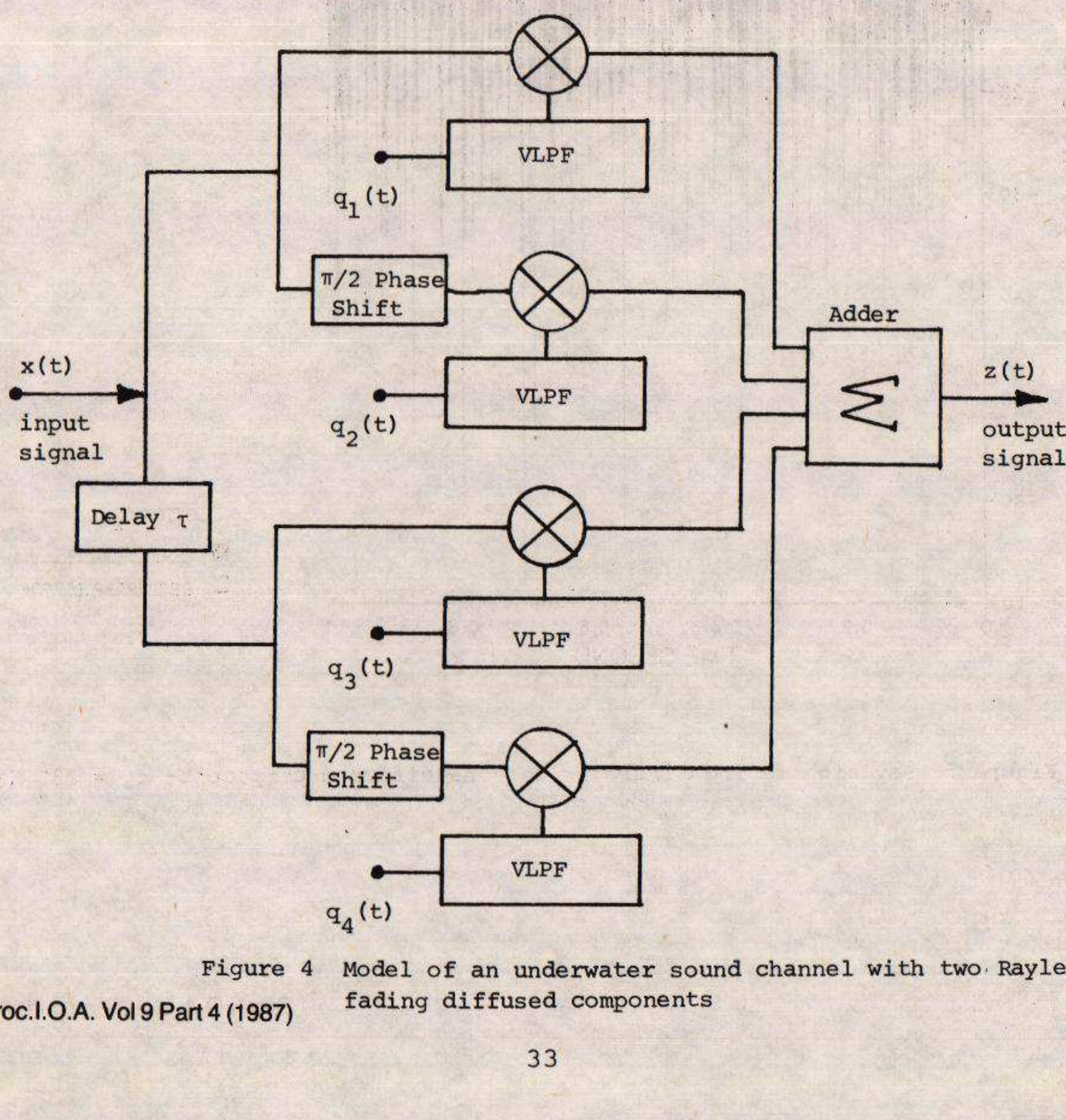

Figure 4 Model of an underwater sound channel with two Rayleigh fading diffused components

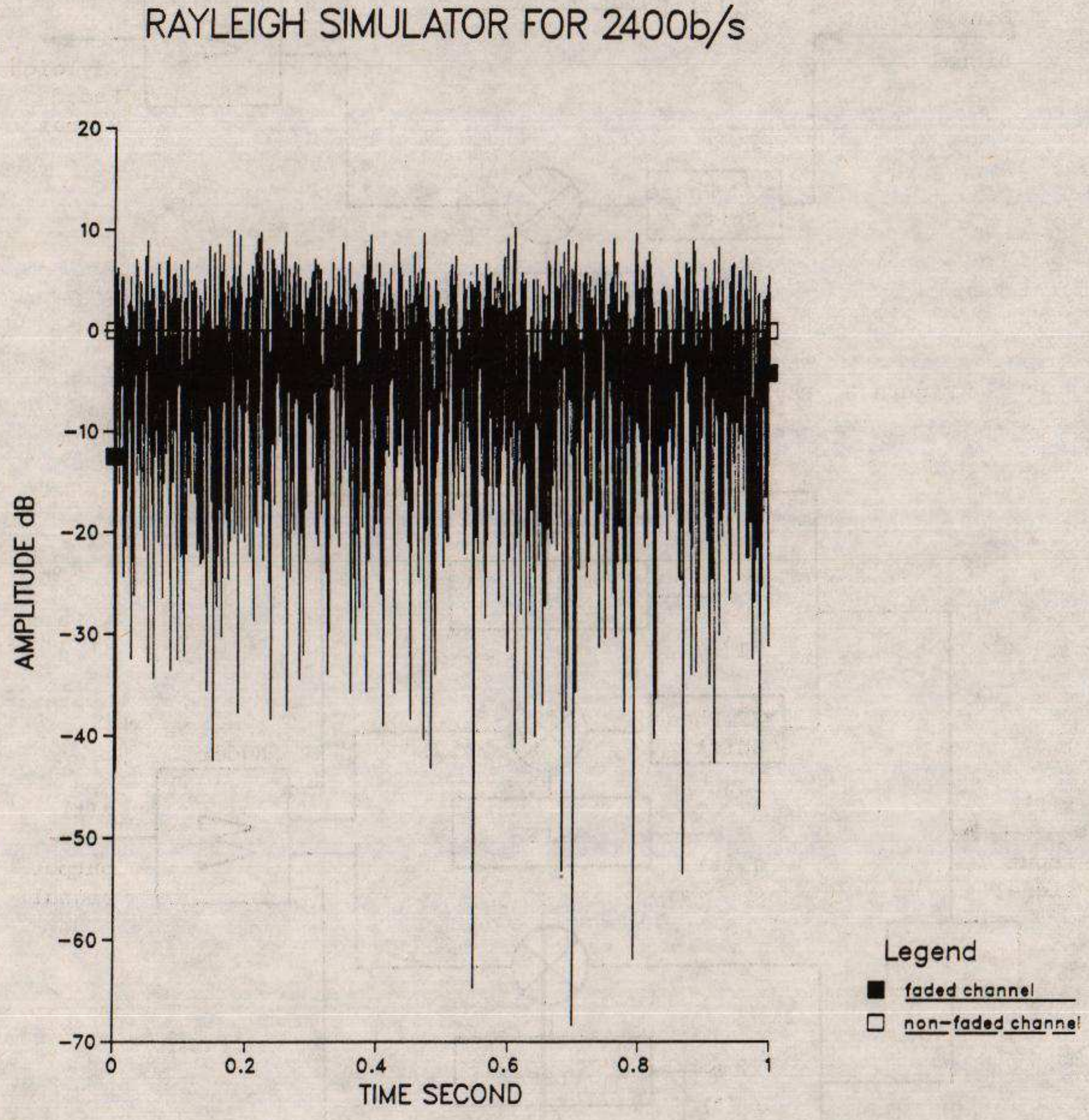

Figure 5 Rayleigh fading simulator for one diffused component: f_D = 130 Hz

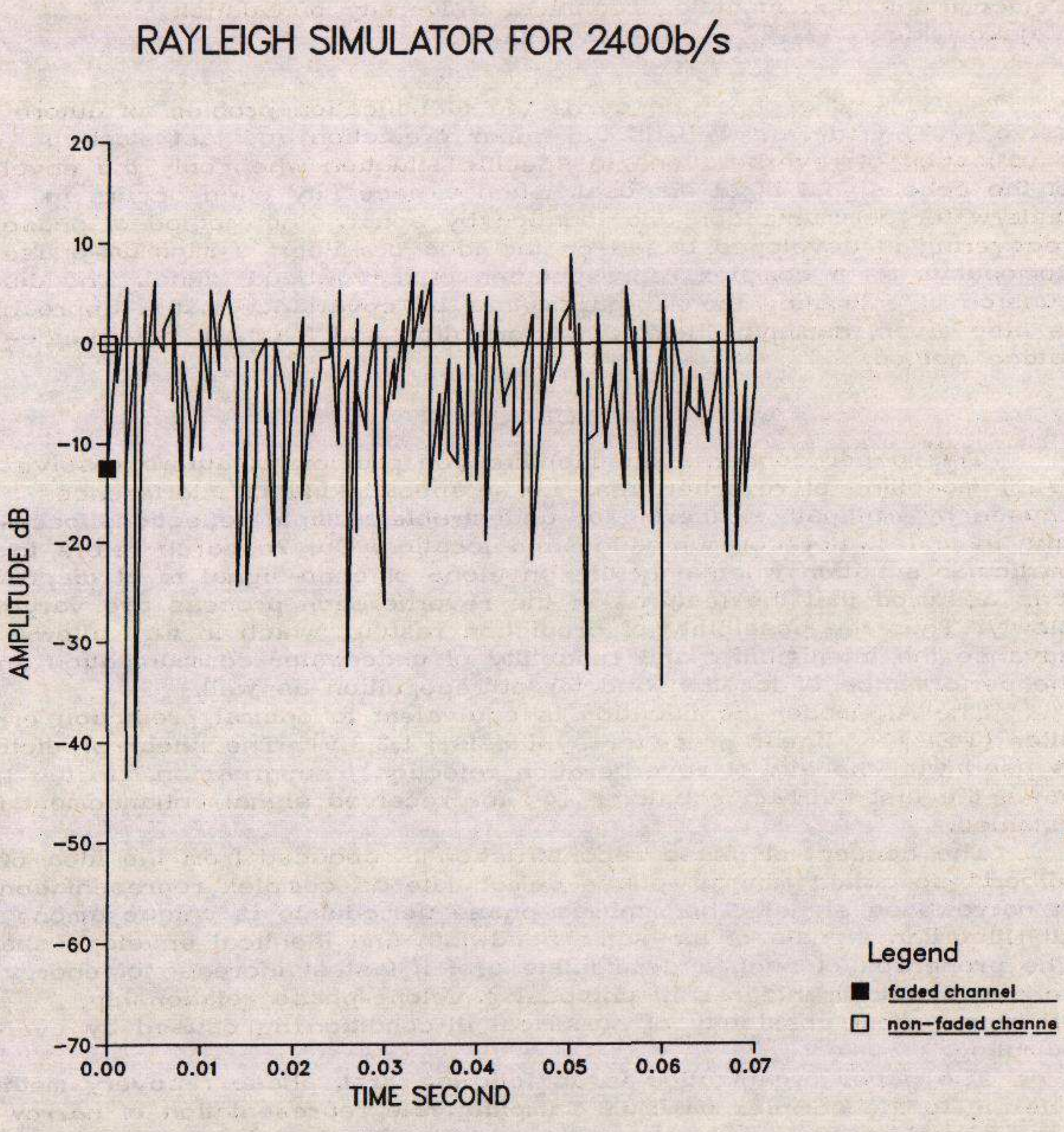

Figure 6 Expanded version of Figure 5