Teletext Reception in a Mobile Channel for a Broadcast Tele-Information System

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***Abstract*— In this paper, a system is proposed for informing passengers who travel by train during their journey. An important part of the system is mobile communication. Teletext is chosen as an information medium, and the possibility of mobile teletext reception is analyzed considering selection diversity (SD) and maximal ratio combining (MRC). The bit error probability is calculated by modeling the channel as a shadowed-Rician fading channel. Picture quality is measured with average number of errors per page (ANEP). Thus performance is measured in terms of bit error probability (BER) and average number of errors per page. Finally, the level crossing rate, average fade, and average nonfade durations are also evaluated.**

I. Introduction

In this age of mobility, people should be advised to travel by train instead of by car. This will help in protecting the environment from pollution and road traffic jams. To make train journeys more attractive, it is necessary to provide a good information system for the passengers.

The tele-information system discussed here can be used for informing passengers who travel by train. Because of the many stations and tracks, it is at present impossible for the railway company to inform the passengers about each delay or accident in any country. With the proposed system, it is very simple to inform people on platforms and even in trains. This can be done by displaying on television monitors some teletext pages which contain information about delays.

The organisation for such a system can be very simple, as shown in Fig. 1. Generally a railway company divides the country into several regions. The headquarters of each region can be informed about events which are important for travellers in that region. Every region can send all its important information to an information center, which processes the data and sends it to the teletext center. From the teletext center it can be transmitted in some pages of the normal broadcast teletext channel. Because the teletext is sent via normal television distribution channels, it is in principle possible to receive information all over the country in homes, on platforms, and in trains. The information for the travellers has to be present at such places where the travellers have to make decisions about their journey. In this paper, the possibility of receiving the teletext in a moving train is investigated.

Teletext is proposed as the information medium, because:

- Teletext can be received all over the country.
- Teletext is very attractive for displaying text and simple graphics.
- A great number of teletext television receivers is already available in many countries, e.g. in the UK, The Netherlands, and France.

In the proposed system, the reception of a page does not have to be instantaneous because the information is not expected to change often. If the receiver does not receive any useful signal and the previous page which is displayed can be stored, the viewer will not notice the distortion of the signal. Once a new page has been received correctly, the previous page will be replaced. This approach requires a special decoder with a buffer to store information which is received correctly.

The performance of the teletext reception in a mobile environment is evaluated first considering Rician fading and then lognormal shadowed-Rician fading [7], [8]. To combat multipath fading in the radio channel diversity schemes are used. Two diversity techniques are considered, namely, selection diversity and maximal ratio combining. In this paper, the bit error probability (BER) is used to evaluate the performance of the proposed tele-information system. The average number of errors per page (ANEP) is used for evaluation of the picture quality. The influence of repeated reception of teletext on the performance is also investigated. For repeated reception, the receiver uses the parity bit of the character bytes to check the integrity of each byte. After the last reception of the teletext page, the correct received bytes are merged and displayed. Finally, formulas for the level crossing rate, the average fade and average nonfade duration are derived and calculated. The performance is evaluated by considering the UK teletext system, which is also used in The Netherlands, as an example. However, the model can be used for any teletext system.

It is worth mentioning here that the analysis presented in this paper is based on the assumption that the mobile teletext environment is a frequency-nonselective channel, i.e., $0.1T > \Upsilon$. Here, T is the symbol length, and Υ is the delay spread. This assumption has been made because of nonavailability of the delay time measurements in a mobile teletext channel. Although based on the nonmobile teletext channel results [7], it appears that the mobile teletext channel will be a frequency-selective channel. However, to get the first estimate of the characteristics of the UK broadcast teletext

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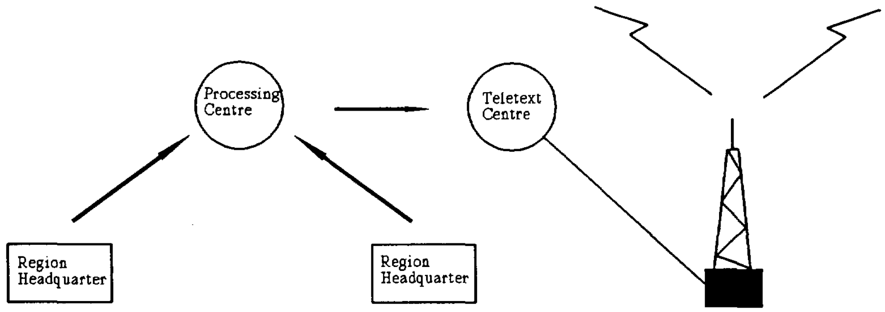

Fig. 1. Information flow in the proposed system.

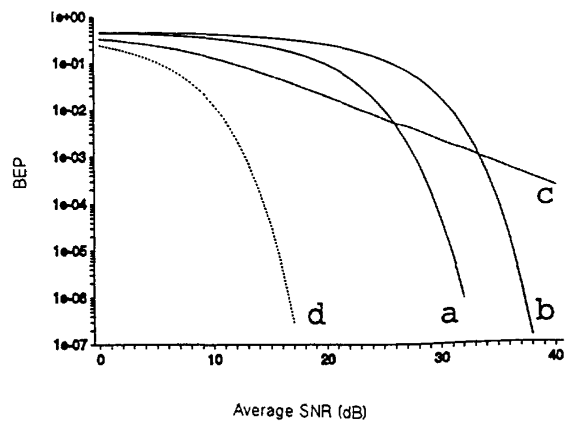

Fig. 2. Comparison between frequency-selective channel; (a) $\Upsilon = 2$ μs, (b) $\Upsilon = 8$ μs, (c) Frequency-nonselective Rayleigh fading channel, and (d) Ideal case (no fading).

system, the complexity in the analysis is avoided by considering frequency-nonselective Rayleigh, Rician, and shadowed Rician channels.

Further, it should be noted that frequency non-selective channel yields optimistic results, which is obvious from Fig. 2. A comparison between frequency-selective and frequency-nonselective Rayleigh fading channel is depicted in Fig. 2 for delay spread $\Upsilon = 2$ μs and 8 μs in a mobile UK teletext environment using computer simulation.

Thus it is clear that the frequency-nonselective channel is assumed for two main reasons: i) simplicity in analysis and ii) performance estimation. The effect of considering frequency-nonselective channel on the performance is that the results are optimistic. The usefulness of the present investigation is to motivate the policy makers by bringing out the advantages of train teletext and providing basic results to system designers.

The paper is organized as follows. Section II describes the UK teletext system. Performance analysis is presented in Section III, considering frequency-nonselective Rayleigh, Rician, and shadowed Rician fading channels. The effect of selection diversity and maximal ratio combining scheme on the performance is also discussed. The ANEP is evaluated in Section IV. Section V explains the level crossing rate and fade duration and finally, Section VI contains the concluding remarks.

II. UK Teletext

Teletext was developed mainly in the UK, Japan, France, and Canada in the 70's. There are several teletext systems: the UK teletext system [1]–[3], the Japanese teletext system, the French Antiope system, and the Canadian Broadcast Teletext system. The Japanese system differs considerably from the UK system in that it uses scanning because of the many characters in the Japanese script.

The information is sent as digital data inserted in the Vertical Blanking Interval (VBI) of a normal television signal. A PAL 625-line TV-signal consists of two rasters, each containing 312.5 lines out of which 25 lines are reserved for the vertical blanking of the electron beam. In this VBI there is enough room for sending analog or digital signals. For the transmission of teletext, a maximum of 16 lines in the VBI can be used, which results in a transmission capacity of 32 kilobytes per second.

A. Principles of Teletext:

A teletext page (Fig. 3) consists of 24 rows, each with 40 characters. Every character represents a codeword of 7 bits and an odd parity bit to avoid too many zeros or ones in a row, which can cause a loss of clock synchronization. A row, which can be inserted exactly on a television line, starts with 2 bytes of clock-run-in, a pattern of 0's and 1's to synchronize the clock. Modern teletext receivers synchronize using the 2 clock-run-in bytes; older receivers synchronize at every transition of the character bits. The third byte is for byte synchronization. The fourth and fifth bytes are address bytes which contain the page and line number. The next 40 bytes contain the characters or display functions. In total there are $(2 + 1 + 2 + 40)*8 = 360$ bits.

If four lines are used for transmitting teletext, we have a transmission capacity of 64 kb/s data (without clock-run-in, synchronization word, and address information). These bits are added to the video signal using Nonreturn-to-Zero (NRZ) coding where a '0' agrees with the blacklevel, which is 300 mV, with 0% of the white level, and a '1' with 66% of the white level (0.462 V). A bit frequency of 6.9375 MHz is used. To avoid data energy falling outside the 5 MHz bandwidth, the signal is lowpass filtered with a cosine roll-off filter which also gives an optimum eye pattern.

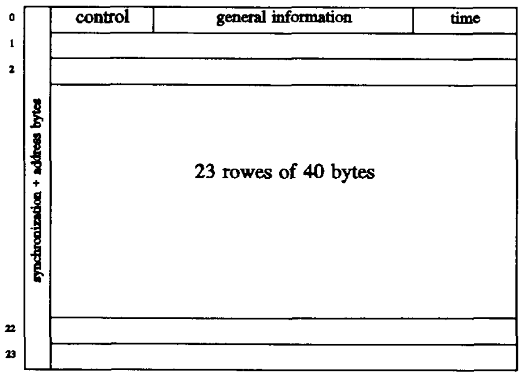

Fig. 3. Example of the teletext page format.

The first row of each page is the header, which contains some control codes and 32 bytes which can be filled with general information, such as date, time, and the name of the broadcasting organization. The first 8 bytes are Hamming-coded; only 4 bits of eight are used for information, while the other 4 are used for error detection to protect the important information in the header. In those 8 bytes, general information about the page is sent, e.g., the text font used and whether it is a normal page or an undertitling page.

The 40 codewords of a row can also contain control characters to change the color or choose double height characters. One problem with these control characters is that they occupy one position; this causes a blank space on the display.

At the lowest level of the system, defined in 1976, we can also use simple graphics. Every position is divided into a matrix of 2×3 small squares which gives a resolution of 72×80 for a page. This is enough for very simple pictures like weather maps. The colors of the squares are dependent on position and can only have one background and one foreground colour. If we want to display graphics with higher resolution, we can use differential chain coding (DCC) [4] for efficient transmission.

B. Organization of Teletext:

The teletext information is organized in pages, every page consisting of 24 rows with 40 characters. This format was chosen because this amount of information can be easily read on a television screen. The text can be embellished by some attributes, as there are colors (white and six others), colored background, double height, blinking text, and hiding information for games.

A classical decoder recognizes 96 characters; this is enough for normal characters, capitals, and punctuation-marks. Later versions are able to use more character sets for special characters which are used in some countries.

The pages are bundled into groups of a maximum of 100 pages numbered from 0–99; such a group is called a magazine. There are eight magazines numbered from 1 to 8. The magazine number is also the first number of the page number, so the pages can have numbers from 100 to 899. Even more than 800 pages can be sent because the transmitted pages are cyclically repeated, and, therefore, different pages with the same number can be inserted.

C. Quality of Teletext:

During the field tests of teletext in the 70's, searching for a parameter to measure the quality of the received teletext signal led to the eyepattern. The eyepattern can be obtained by superimposing the various bit transitions in the datastream. The eyepattern gives three measures for the quality of the signal.

- Eyeheight, which is important for level detection at the receiving end.
- Eyewidth, which is important for the moment of sampling.
- Overshoot level, because high overshoot can cause a buzz during a normal television broadcast.

Another method for measuring the quality of the teletext is obtained by counting the bits in error and calculating the bit error probability. The bit error probability can be calculated from the signal-to-noise ratio (SNR) at the receiver. Teletext uses a NRZ code, which is a unipolar signal, and this gives a theoretical bit error probability (BEP) [5], [6].

$$\text{BEP} = Q\left(\sqrt{\frac{1}{2}\,\text{SNR}}\right) \tag{1}$$

where $Q(\cdots)$ is the area under the Gaussian tail. A SNR of 11 dB gives a BEP of 10^{-3}. In this paper, the BEP is calculated for teletext reception in a mobile environment. The average number of erroneous bytes per page (ANEP) is calculated by using the bit error probability. ANEP gives a good measure for the quality of teletext reception.

III. Performance Analyses

The part of the system concept which will be presented in this paper is the mobile reception of teletext in a train.

In the Netherlands, the television broadcast transmitters are located at several places in the country. The most central transmitter, located in Lopik, transmits Nederland 1 in channel 4 of the VHF band (66–72 MHz) and Nederland 2 and Nederland 3 in the UHF band (channel 27 and channel 30, respectively, at 548–554 and 566–572 MHz).

Following [7] we will use two propagation models, Model 1 for the VHF band and Model 2 for the UHF band. The VHF model has Rician fading, and the UHF model has shadowed Rician fading.

A. Model 1 (VHF Channel—Rician Fading Channel):

The cause of the multipath fading, which is called short-term fading in the mobile VHF channel, is mainly the multipath reflections of a transmitted wave by local scatterers such as houses, buildings, and other man-made structures. Natural obstacles such as a forest surrounding a mobile unit can also cause this kind of fading. These reflections of the signal add up and cause signal peaks or dips in the received signal. The multipath fading of this model is considered to be Rician distributed.

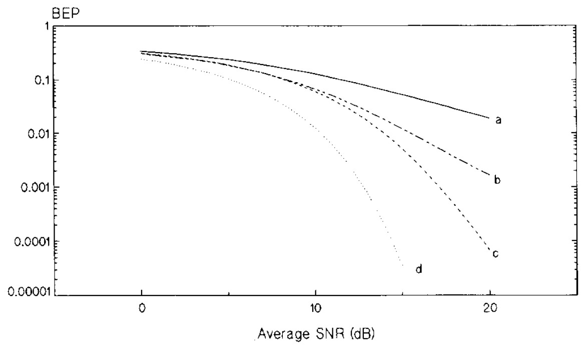

Fig. 4. Effect of Rician parameter (R) on BEP; (a) $R = 0$ (Rayleigh fading), (b) $R = 7$ dB, (c) $R = 12$ dB, and (d) No fading.

Teletext is a digital signal inserted into a television line with NRZ coding, giving a unipolar signal. A minimum possible error probability for these signals is given in [5]

$$P_e = Q\left(\sqrt{\frac{1}{2}\,\mathrm{SNR}}\right) \tag{2}$$

where SNR is the signal-to-noise ratio and

$$Q(k) \triangleq \frac{1}{\sqrt{2\pi}}\int_k^\infty e^{-\lambda^2/2}\,d\lambda. \tag{3}$$

The Rician probability density function (PDF) of the ratio of instantaneous power and noise density γ is given by

$$p(\gamma) = \frac{1}{\gamma_r}\exp\left(-\frac{2\gamma+\gamma_o}{2\gamma_r}\right)I_0\left(\frac{\sqrt{2\gamma\gamma_0}}{\gamma_r}\right) \tag{4}$$

where $I_o(\cdots)$ is the modified Bessel function of the first kind and zero-th order, $\gamma_o/2$ is the ratio of power of the direct wave and noise density, and γ_r is the ratio of average power of the fading signal and noise density. The Rician parameter R is defined as the ratio of the line-of-sight power and the power received from the specular paths:

$$R = \frac{\gamma_o}{2\gamma_r}. \tag{5}$$

The average BEP can be calculated from

$$\mathrm{BEP} = \int_0^\infty P_e(\gamma)p(\gamma)\,d\gamma. \tag{6}$$

Equation (6) becomes, using (2) and (4):

$$\mathrm{BEP} = \frac{1}{\sqrt{2\pi}}\int_0^\infty\int_{\sqrt{\frac{\gamma}{2}}}^\infty \exp\left(-\frac{\lambda^2}{2}\right)\frac{1}{\gamma_r} \cdot\exp\left(-\frac{2\gamma+\gamma_o}{2\gamma_r}\right)I_0\left(\frac{\sqrt{2\gamma\gamma_0}}{\gamma_r}\right)d\lambda\,d\gamma. \tag{7}$$

Note that γ_r is average SNR. Fig. 4 shows the BEP for different Rician parameters. It can be seen that the performance increases for greater Rician parameters.

B. Model 2 (UHF Channel—Shadowed Rician Fading Channel):

For higher frequencies, the signal also suffers from shadowing or long-term fading. This is caused by the terrain configuration (e.g., hilly terrain, flat terrain) and the man-made environment (e.g., rural area, urban area) between the mobile unit and the transmitter.

This model assumes that the multipath fading has a Rician distribution with a log-normal distributed shadowed line-of-sight component. The conditional PDF of γ is given by [8]

$$p(\gamma\mid\gamma_o) = \frac{1}{\gamma_r}\exp\left(-\frac{2\gamma+\gamma_o}{2\gamma_r}\right)I_0\left(\frac{\sqrt{2\gamma\gamma_o}}{\gamma_r}\right). \tag{8}$$

The direct line-of-sight component γ_o is assumed to be log-normally distributed [8]

$$p(\gamma_o) = \frac{1}{\gamma_o\sigma_s\sqrt{2\pi}}\exp\left(-\frac{\left(\ln\sqrt{\frac{\gamma_o}{\xi_o}}\right)^2}{2\sigma_s^2}\right) \tag{9}$$

where σ_s is the standard deviation and ξ_o is the ratio of area mean and noise density

$$\xi_o = \frac{\xi^2}{N},\quad \mu = \ln\xi \tag{10}$$

and μ is the mean of the lognormal distribution. The PDF of γ can be obtained using

$$p(\gamma) = \int_0^\infty p(\gamma\mid\gamma_o)p(\gamma_o)\,d\gamma_o. \tag{11}$$

Substituting (8) and (9) in (11) the distribution function for γ is found:

$$p(\gamma) = \int_0^\infty \frac{1}{2\gamma_r\gamma_o\sigma_s\sqrt{2\pi}} \cdot\exp\left(-\frac{\left(\ln\sqrt{\frac{\gamma_o}{\xi_o}}\right)^2}{2\sigma_s^2}-\frac{2\gamma+\gamma_o}{2\gamma_r}\right)I_0\left(\frac{\sqrt{2\gamma\gamma_o}}{\gamma_r}\right)d\gamma_o. \tag{12}$$

The equation for the BEP can be obtained using (2), (6) and (12):

$$\mathrm{BEP} = \frac{1}{\sqrt{2\pi}}\int_0^\infty\int_{\sqrt{\frac{\gamma}{2}}}^\infty \exp\left(-\frac{\lambda^2}{2}\right)\int_0^\infty\frac{1}{2\gamma_r\gamma_o\sigma_s\sqrt{2\pi}} \cdot\exp\left(-\frac{\left(\ln\sqrt{\frac{\gamma_o}{\xi_o}}\right)^2}{2\sigma_s^2}-\frac{2\gamma+\gamma_o}{2\gamma_r}\right) \cdot I_0\left(\frac{\sqrt{2\gamma\gamma_o}}{\gamma_r}\right)d\gamma_o\,d\lambda\,d\gamma. \tag{13}$$

In (13) γ_r is average SNR, μ is taken to be -0.115, and σ_s is taken to be 0.161. These values are found in [9] for a land-mobile satellite link (also in the UHF band) for small elevation angles and average shadowing.

For this model, we define a "Shadowed Rician parameter" as:

$$R_s \triangleq \frac{m^2}{2\sigma_r^2} \tag{14}$$

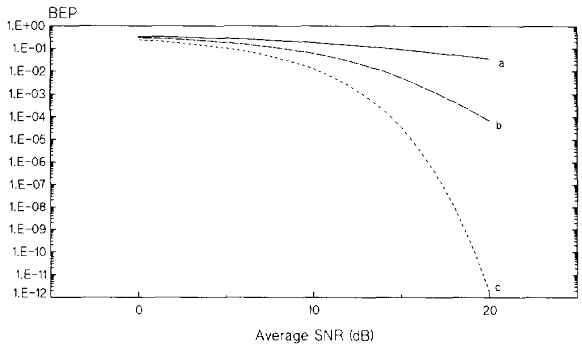

Fig. 5. Difference in BEP between (a) Shadowed Rician fading, (b) Rician fading ($R = 12$ dB), and (c) No fading.

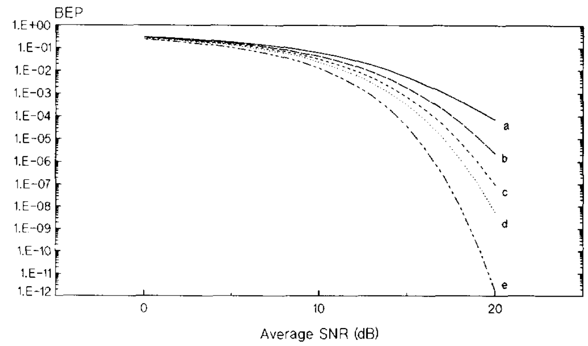

Fig. 6. Effect of order of diversity (M) on BEP for a Rician fading channel with a Rician parameter (R) of 12 dB and selection diversity. (a) No diversity, (b) $M = 2$, (c) $M = 4$, (d) $M = 8$, and (e) No fading.

where

$$m = \exp(\mu + 0.5\sigma_s^2). \tag{15}$$

Fig. 5 shows the BEP for a shadowed Rician fading channel. It can be seen from Fig. 5 that teletext cannot be received in an UHF environment even for a SNR of 20 dB.

C. Diversity:

A method to reduce the extreme and rapid variations of the signal is to use diversity systems instead of the chirp signal used in [10]. The method used here is space diversity, which is easy to implement. We make use of more than one antenna, with the basic requirement that the spacing of the antennas be chosen so that the individual signals are uncorrelated. Experiments show that a spacing of a half wavelength should be sufficient. Each of the antennas provides an independent signal to the diversity combiner which combines the signals to yield the best result. There are several combining techniques. For our application we have used selection diversity and maximal ratio combining.

D. Selection Diversity (SD) for a Rician Fading Channel:

Selection diversity connects the antenna with the best signal to the output. Systems with selection diversity are used for receiving television in cars, and the selection between antennas was done in the VBI [11], [12]. This is not possible for the proposed system because now we want to receive teletext which is sent in the VBI, so the switching moment for our system has to be chosen between the VBI's.

We assume the signals in the diversity antennas to be uncorrelated. If the antennas are spaced at a distance of half a wavelength, it is reasonable to assume that the individual signals in each diversity branch are uncorrelated [13]. If the order of diversity is M, this gives M identically distributed variables $\{\beta_1 \cdots \beta_M\}$. For the strongest one, $\beta_{\max}$, [13]

$$\beta_{\max} > \beta_i; \qquad i \in \{1, \cdots, M\}. \tag{16}$$

This means that the probability that $\beta_{\max} < b$ ($P_\beta \max(b)$) (where b is some specified value) is

$$P_{\beta_{\max}}(b) = P_{\beta_1}(b) P_{\beta_2}(b) \cdots P_{\beta_M}(b). \tag{17}$$

The cumulative density function (CDF) of $\beta_{\max}$ is the product of the CDF's of the M path gains. The CDF of a Rician distributed variable is

$$P_{\beta_i} = 1 - Q(a, b) \tag{18}$$

where

$$Q(a, b) = \int_b^\infty x \exp\left[-\frac{a^2 + x^2}{2}\right] I_0(ax)\, dx. \tag{19}$$

$Q(a, b)$ is the Marcum Q-function. Here,

$$a = \sqrt{\frac{\gamma_0}{\gamma_r}}, \quad b = \sqrt{\frac{2\gamma}{\gamma_r}}. \tag{20}$$

The CDF for $\beta_{\max}$ is now given by

$$CDF_{\beta_{\max}} = [1 - Q(a, b)]^M. \tag{21}$$

The PDF can be found by calculating the derivative of (21) with respect to b:

$$P_{\beta_{\max}} = M[1 - Q(a, b)]^{M-1} \left[-\frac{dQ(a, b)}{db}\right]. \tag{22}$$

Using (19), (21) can be written as

$$P_{\beta_{\max}} = M[1 - Q(a, b)]^{M-1} \cdot \frac{1}{\gamma_r} \exp\left(-\frac{2\gamma + \gamma_o}{2\gamma_r}\right) I_0\left(\frac{\sqrt{2\gamma\gamma_o}}{\gamma_r}\right). \tag{23}$$

The BEP can be derived using (2), (6), and (23):

$$\text{BEP} = \frac{1}{\sqrt{2\pi}} \int_0^\infty \int_{\sqrt{\frac{\gamma}{2}}}^\infty \exp\left(-\frac{\lambda^2}{2}\right) M[1 - Q(a, b)]^{M-1} \cdot \frac{1}{\gamma_r} \exp\left(-\frac{2\gamma + \gamma_o}{2\gamma_r}\right) I_0\left(\frac{\sqrt{2\gamma\gamma_o}}{\gamma_r}\right) d\lambda\, d\gamma. \tag{24}$$

Fig. 6 shows the calculated BEP's for a Rician parameter of 12 dB. This plot shows that the BEP is very close to the ideal case until 10 dB for $M = 2$, 4, and 8.

E. Selection Diversity for a Lognormal Shadowed Rician Fading Channel:

For the derivation of the PDF for shadowed Rician fading with selection diversity, we use the same approach as with Rician fading. There is no simple mathematical expression for the CDF of a lognormal shadowed Rician distributed parameter. The PDF of a lognormal shadowed Rician distributed parameter can be written as in (12). The CDF can be calculated from

$$\text{CDF} = \int_0^{\gamma} p(\gamma)\, d\gamma. \qquad (25)$$

Combining (12), (21), and (23) gives the PDF of the strongest path with selection diversity for lognormal shadowed-Rician fading as:

$$P_{\beta_{\max}} = M \int_0^{\gamma} [p(\gamma)\, d\gamma]^{M-1} p(\gamma). \qquad (26)$$

Equation (26) can be written as (27) at the bottom of this page. The equation for the BEP can be found using (2), (6), and (27) as in (28), also given at the bottom of the page. Fig. 7 shows the BEP for the various order of diversity. It can be seen from Fig. 7 that teletext can be received for $M = 8$ and a high SNR of about 20 dB.

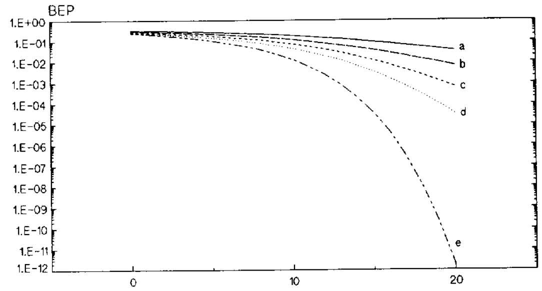

Fig. 7. Effect of order of diversity (M) on BEP for a shadowed Rician fading channel and selection diversity; (a) No diversity, (b) $M = 2$, (c) $M = 4$, (d) $M = 8$, and (e) No fading.

F. Maximal Ratio Combining (MRC) for a Rician Fading Channel:

The combiner which achieves the best performance is one which multiplies the output with a signal which compensates for the phase shift and weights the signal by a factor proportional to the signal strength. Thus a stronger signal carries a larger weight than a weak signal. After this the signals are summed.

The PDF for MRC can be derived easily if we realize that summing n Gaussian random variables with nonzero mean gives a noncentral chi-square distribution with n degrees of freedom [14].

$$p(\gamma) = \frac{1}{\gamma_r}\left(\frac{2\gamma}{M\gamma_o}\right)^{(M-1)/2} \cdot \exp\left(-\frac{2\gamma + M\gamma_o}{2\gamma_r}\right) I_{M-1}\left(\frac{\sqrt{2M\gamma\gamma_o}}{\gamma_r}\right) \qquad (29)$$

where I_{M-1} is the modified Bessel function of the first kind and order $M-1$. If we average the formula for P_e using this equation, we get the formula for the BEP as:

$$\text{BEP} = \frac{1}{\sqrt{2\pi}} \int_0^{\infty} \int_{\sqrt{\frac{\gamma}{2}}}^{\infty} \exp\left(-\frac{\lambda^2}{2}\right) \frac{1}{\gamma_r}\left(\frac{2\gamma}{M\gamma_o}\right)^{M-1/2} \cdot \exp\left(-\frac{2\gamma + M\gamma_o}{2\gamma_r}\right) I_{M-1}\left(\frac{\sqrt{2M\gamma\gamma_o}}{\gamma_r}\right) d\lambda\, d\gamma. \qquad (30)$$

Fig. 8 shows that even with a diversity of order two, the BEP curve is very close to the no fading curve, so teletext can be received. Fig. 9 shows the differences between the diversity methods for two Rician parameters. It appears that MRC with a higher Rician parameter gives the best performance.

$$P_{\beta_{\max}} = M\left[\int_0^{\gamma}\int_0^{\infty} \frac{1}{2\gamma_r\gamma_o\sigma_s\sqrt{2\pi}} \exp\left(-\frac{\left(\ln\sqrt{\frac{\gamma_o}{\xi_o}}\right)^2}{2\sigma_s^2} - \frac{2\gamma+\gamma_o}{2\gamma_r}\right) I_0\left(\frac{\sqrt{2\gamma\gamma_o}}{\gamma_r}\right) d\gamma_o\, d\gamma\right]^{M-1} \cdot \int_0^{\infty} \frac{1}{2\gamma_r\gamma_o\sigma_s\sqrt{2\pi}} \exp\left(-\frac{\left(\ln\sqrt{\frac{\gamma_o}{\xi_o}}\right)^2}{2\sigma_s^2} - \frac{2\gamma+\gamma_o}{2\gamma_r}\right) I_0\left(\frac{\sqrt{2\gamma\gamma_o}}{\gamma_r}\right) d\gamma_o \qquad (27)$$

$$\text{BEP} = \frac{1}{\sqrt{2\pi}}\int_0^{\infty}\int_{\sqrt{\frac{\gamma}{2}}}^{\infty} \exp\left(-\frac{\lambda^2}{2}\right) M\left[\int_0^{\gamma}\int_0^{\infty} \frac{1}{2\gamma_r\gamma_o\sigma_s\sqrt{2\pi}} \exp\left(-\frac{\left(\ln\sqrt{\frac{\gamma_o}{\xi_o}}\right)^2}{2\sigma_s^2} - \frac{2\gamma+\gamma_o}{2\gamma_r}\right) I_0\left(\frac{\sqrt{2\gamma\gamma_0}}{\gamma_r}\right) d\gamma_0\, d\gamma\right]^{M-1} \cdot \int_0^{\infty} \frac{1}{2\gamma_r\gamma_o\sigma_s\sqrt{2\pi}} \exp\left(-\frac{\left(\ln\sqrt{\frac{\gamma_o}{\xi_o}}\right)^2}{2\sigma_s^2} - \frac{2\gamma+\gamma_o}{2\gamma_r}\right) I_0\left(\frac{\sqrt{2\gamma\gamma_o}}{\gamma_r}\right) d\gamma_o\, d\lambda\, d\gamma \qquad (28)$$

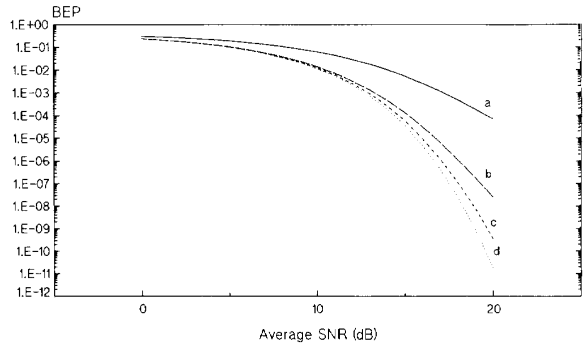

Fig. 8. Effect of order of diversity (M) on BEP in a Rician fading channel with a Rician parameter (R) of 12 dB and maximal ratio combining; (a) No diversity, (b) $M = 2$, (c) $M = 4$, and (d) No fading.

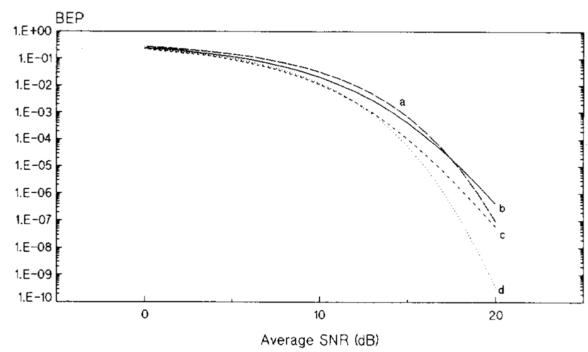

Fig. 9. Effect of Rician parameter and diversity method on BEP in a Rician fading channel with order of diversity 4; (a) Selection diversity, $R = 7$ dB, (b) Selection diversity, $R = 12$ dB, (c) Maximal ratio combining, $R = 7$ dB, and (d) Maximal ratio combining, $R = 12$ dB.

G. Maximal Ratio Combining for a Shadowed Rician Fading Channel:

The PDF for maximal ratio combining in a shadowed Rician fading channel can be derived using (9), (11), and (29) and is given by

$$p(\gamma) = \int_0^\infty \frac{1}{2\gamma_o\gamma_r\sigma_s\sqrt{2\pi}}\left(\frac{2\gamma}{M\gamma_o}\right)^{(M-1)/2} \cdot \exp\left(-\frac{2\gamma + M\gamma_o}{2\gamma_r} - \frac{\left(\ln\sqrt{\frac{\gamma_o}{\xi_o}}\right)^2}{2\sigma_s^2}\right) \cdot I_{M-1}\left(\frac{\sqrt{2M\gamma\gamma_o}}{\gamma_r}\right) d\gamma_o. \tag{31}$$

The equation for the BEP can be found using (2), (6), and (31):

$$\text{BEP} = \frac{1}{\sqrt{2\pi}}\int_0^\infty \int_{\sqrt{\frac{\gamma}{2}}}^\infty \exp\left(-\frac{\lambda^2}{2}\right)\int_0^\infty \frac{1}{2\gamma_o\gamma_r\sigma_s\sqrt{2\pi}} \cdot \left(\frac{2\gamma}{M\gamma_o}\right)^{(M-1)/2} \exp\left(-\frac{2\gamma + M\gamma_o}{2\gamma_r} - \frac{\left(\ln\sqrt{\frac{\gamma_o}{\xi_o}}\right)^2}{2\sigma_s^2}\right) \cdot I_{M-1}\left(\frac{\sqrt{2M\gamma\gamma_o}}{\gamma_r}\right) d\gamma_o\, d\lambda\, d\gamma. \tag{32}$$

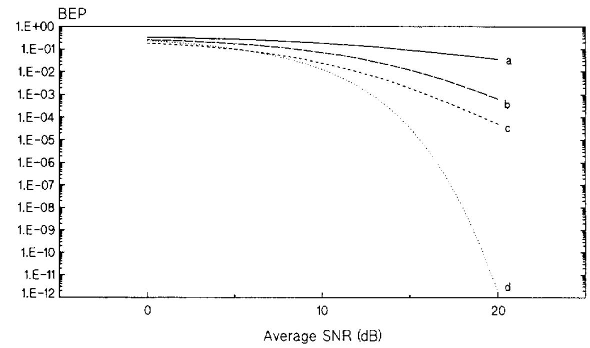

Fig. 10. Effect of diversity method on BEP in a shadowed Rician fading channel; (a) No diversity, (b) Selection diversity, $M = 4$, (c) Maximal ratio combining, $M = 4$, and (d) No fading.

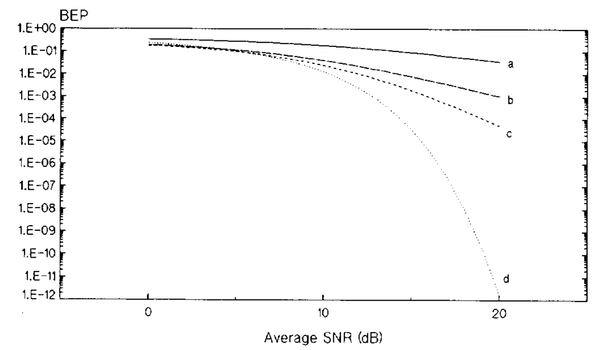

Fig. 11. Effect of order of diversity (M) on BEP in a shadowed-Rician fading channel and maximal ratio combining, (a) No diversity, (b) $M = 2$, (c) $M = 4$, (d) No fading.

Fig. 10 shows the difference in BEP between selection diversity and maximal ratio combining. From Fig. 10 it can be seen that maximal ratio combining gives better performance than selection diversity. Fig. 11 shows the improvement in performance when the order of diversity increases for maximal ratio combining. Fig. 12 presents the comparison between the performance for Rician fading and the performance for shadowed Rician fading. As expected, Rician fading gives better performance.

IV. Average Number of Errors Per Page

According to [4] the page error rate (PER) is not used as a performance measure because this does not convey information about picture quality. Two errors in a packet prefix cause loss of a complete row, while two bit errors in a byte cause a change in one character. The bit errors are assumed to be independent. The ANEP was considered as for the measure of the quality of reception [17].

Each line of data in the UK teletext system is preceded by 5 prefix bytes, 2 clock-run-in bytes for bit synchronization, 1 frame code for byte synchronization and two Hamming-protected bytes indicating magazine and row number of the data packet. Depending on the design of the decoder some number of 1's and 0's of the clock-run-in must be received correctly to synchronize with the incoming data.

TABLE I
AVERAGE NUMBER OF ERRORS PER PAGE FOR A SIGNAL-TO-NOISE RATIO OF 15 dB AFTER SINGLE RECEPTION

SNR = 15 dB	Rician fading $R = 12$ dB		Rician fading $R = 7$ dB		Rayleigh fading $R = 0$		Shadowed-Rician fading	
	SD	MRC	SD	MRC	SD	MRC	SD	MRC
$M = 1$	42	42	100	100	200	200	697	697
$M = 2$	14	1	18	4	116	66	316	64
$M = 4$	5	0.4	3	0.8	19	16	98	15
$M = 8$	2	0.3	0.6	0.3	2	4	27	4

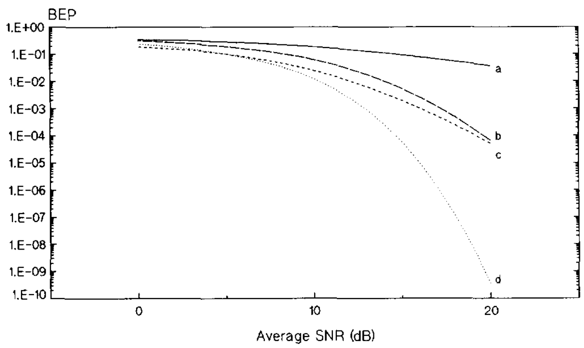

Fig. 12. Comparison between shadowed Rician and Rician fading; (a) Shadowed Rician fading, no diversity, (b) Rician fading, $R = 12$ dB, no diversity, (c) Shadowed Rician fading, maximal ratio combining, and $M = 4$, and (d) Rician fading, $R = 12$ dB, maximal ratio combining, and $M = 4$.

In the following analysis it is assumed that the bit synchronization is always established. The frame code and Hamming-protected address bytes are incorrectly received when two or more errors occur.

Thus 3 prefix bytes must be received, each with fewer than two errors. The probability of a lost packet due to errors in the packet prefix thus equals

$$P_{1p} = 1 - (q^8 + 8pq^7)^3 \tag{33}$$

with $q = (1 - p)$ and p the BEP. An error in one of these prefix bytes causes the loss of 40 bytes. The average number of byte errors per page can thus be written as

$$\text{ANEP} = 24[40P_{1p} + 40(1 - q^8)(q^8 + 8pq^7)^3]. \tag{34}$$

Equation (34) becomes, using (33)

$$\text{ANEP} = 960[1 - q^8(q^8 + 8pq^7)^3]. \tag{35}$$

Because the effect of lost bit synchronization is not considered ANEP can be considered as a lower bound. A loss of bit synchronization causes an increase in BEP, i.e., increase in ANEP. However, a system may be designed in such a way that for SNR equal to or greater than a threshold SNR, the probability of losing the synchronization is so small that it has a negligible effect on ANEP.

To improve data transmission and picture quality, error-correcting codes can be used. In the UK teletext system the (8, 4) extended Hamming code is used for the magazine and row address information. This code is able to correct one error per byte. For the data bytes, only a parity bit is added, which allows the decoder to detect a single error. Other error-correcting codes use redundant data which is added to a line of data. Examples are Reed-Solomon codes and the (272,190) difference-set cyclic code (used in the Japanese teletext system) [18]–[25]. With the (272,190) code, the decoder is able to correct 11 errors per packet. A disadvantage of these error-correcting codes is the decrease in transmission efficiency.

It is also possible to reduce errors by repeated reception of teletext data. For this the data should be stored when parity bits are correct and discarded if parity bits are not correct. With the next reception of the data, the data can be merged with the bytes correctly received earlier, which leads to refreshed data with fewer errors. This form of redundancy is applied in most conventional teletext decoders. The ANEP after double reception of data can be calculated from

$$\text{ANEP} = 24\left[40P_{1p}^2 + 40\binom{2}{1}P_{1p}(1 - P_{1p})(1 - q^8) + 40(1 - P_{1p})^2(1 - q^8)^2\right]. \tag{36}$$

Although the CCIR [1] does not give a minimum SNR for the output of the demodulator in a television receiver, there is a threshold value given, the mid-opinion value. This mid-opinion value is approximately 13 dB, which gives a BEP of $1.1{*}10^{-3}$. This value of the BEP gives a maximum of 8 byte errors in one page. Generally the picture quality is much higher with a BEP of $6{*}10^{-5}$ or lower, with a SNR of about 15 dB and $3{*}10^{-1}$ byte errors per page.

From Table I we can see that for a Rician fading channel, teletext can be received with a maximal ratio diversity combiner with diversity of order 2. However, for Rayleigh fading and shadowed Rician fading we need $M = 8$. Remarkable is the increase of performance from $M = 1$ to $M = 2$ for maximal ratio combining in the different fading channels.

Table II shows that after double reception we can also receive teletext with $M = 4$ in a Rayleigh and shadowed Rician fading channel. The information will then be displayed after the information in the pages received twice is combined.

V. LEVEL CROSSING RATE AND FADE DURATION

The level crossing rate is defined as the expected rate at which the envelope crosses a specified signal level, R_*, in the positive direction [15]. The probability that the envelope passes through the value R_* per time interval t, $t + dt$ with positive slope is [16]:

$$N_R = \int_o^\infty R'_* p(R_*, R'_*)\, dR'_* \tag{37}$$

TABLE II
AVERAGE NUMBER OF ERRORS PER PAGE FOR A SIGNAL-TO-NOISE RATIO OF 15 dB AFTER DOUBLE RECEPTION

SNR = 15 dB	Rician fading $R = 12$ dB		Rician fading $R = 7$ dB		Rayleigh fading $R = 0$		Shadowed-Rician fading	
	SD	MRC	SD	MRC	SD	MRC	SD	MRC
$M = 1$	2	2	10	10	65	65	500	500
$M = 2$	0.2	$1*10^{-3}$	0.3	$2*10^{-2}$	14	5	100	4
$M = 4$	$3*10^{-2}$	$2*10^{-4}$	$1*10^{-2}$	$7*10^{-4}$	0.4	0.3	10	0.2
$M = 8$	$6*10^{-3}$	$8*10^{-5}$	$4*10^{-4}$	$7*10^{-5}$	$5*10^{-3}$	$2*10^{-2}$	0.7	$1*10^{-2}$

TABLE III
LEVEL CROSSING RATE, AVERAGE FADE DURATION AND AVERAGE NONFADE DURATION FOR A RICIAN FADING CHANNEL AT A RECEIVER THRESHOLD OF −15 dB

Rician fading	LCR (Hz) Level crossing rate		AFD (sec) Average fade duration		AND (sec) Average nonfade duration	
	$R = 7$ dB	$R = 12$ dB	$R = 7$ dB	$R = 12$ dB	$R = 7$ dB	$R = 12$ dB
$v = 30$ km/h	1.2 *E*-2	1.6 *E*-6	5.8 *E*-3	8.7 *E*-4	85.6	6.2 *E*5
$v = 90$ km/h	3.5 *E*-2	4.9 *E*-6	1.9 *E*-3	2.9 *E*-4	28.5	2.1 *E*5

where $p(R_*, R'_*)$ is the joint probability density function of R_*, and its time derivative R'_*. Rice [16] gives the expression for this PDF:

$$p(R_*, R'_*) = \frac{R_*(2\pi)^{-3/2}}{\sqrt{B\sigma^2}} \int_{-\pi}^{\pi} d\theta \cdot \exp\left[-\frac{1}{2B\sigma^2}[B(R_*^2 - 2R_*A\cos\theta + A^2) + (\sigma^2 R'_* + b_1 A \sin\theta)^2]\right] \tag{38}$$

where Θ is the phase angle of the signal and B the square root of the determinant of the moment matrix, given as

$$B = \sigma^2 b_2 - b_1^2. \tag{39}$$

Combining (37), (38), and (39) gives an expression for the level crossing rate

$$N_R = \sqrt{\left(\frac{b_2}{2\pi}\right)} p(R_*) \tag{40}$$

where b_2, if the fading spectrum due to multipath is assumed to be symmetrical and Gaussian, can be expressed as

$$b_2 = \sigma^2(2\pi f_m)^2 \tag{41}$$

where f_m is the maximum Doppler-shift frequency defined as

$$f_m = \frac{v}{\lambda} \tag{42}$$

and λ in this equation is the wavelength and v the speed of the vehicle. The average fade duration is related to level crossing rate (LCR) by

$$T_f = \frac{1}{N_R}\int_0^{R_*} p(r)\, dr. \tag{43}$$

The average nonfade duration can be calculated from

$$T_n = \frac{1}{N_R}\left(1 - \int_0^{R_*} p(r)\, dr\right). \tag{44}$$

The integral in (43) and (44) can be written as a Marcum Q-function which is defined as:

$$Q(\alpha, \beta) = \int_\beta^\infty x \exp\left[-\frac{1}{2}(x^2 + \alpha^2)\right] I_0(\alpha x)\, dx \tag{45}$$

with

$$\alpha = \sqrt{2R}; \qquad \beta = \sqrt{2}P \tag{46}$$

where R is the Rician parameter, and P is the ratio of fading threshold, R_*, and the root mean square of the scattered power $(\sqrt{2}\sigma^2)$.

In Table III the results of the calculations are displayed for a receiver threshold of −15 dB, which seems to be an acceptable value for a normal teletext receiver. The bit rate of the teletext data is 6.9375 MHz which gives a bit duration of 144 ns. A television frame consists of 625/2 lines, so every line takes 64 μs, of which 52 μs (360*144 ns) is teletext information. If we assume that 4 consecutive television lines in the VBI contain teletext information, this period will last 256 μs. A frame is sent every 20 ms (50 Hz). The average fade duration during which we cannot receive a signal is always shorter than one frame period and a nonfade duration is much longer than one frame period. This implies that the probability of teletext information not being received after a first faded teletext period is very low.

Similarly, the LCR can be derived for a shadowed Rician fading channel [8]

$$N_R = \frac{\sqrt{(1-\rho^2)}}{\sqrt{2\pi}} \frac{b_2(b_2 + 2\rho\sqrt{b_2 d_2} + d_2)^{1/2}}{b_2(1-\rho^2) + 4\rho\sqrt{b_2 d_2}} p(R_*) \tag{47}$$

where ρ is the correlation coefficient. With the assumption that the fading spectrum due to shadowing and multipath is symmetrical and Gaussian b_2 equals $b_0(2\pi f_m)^2$, and d_2 equals $d_0(2\pi f_m)^2$ in which f_m is the Doppler-shift frequency given by (42). Table IV shows the calculated results for a receiver threshold of −15 dB and a correlation coefficient of 0.5.

TABLE IV
LEVEL CROSSING RATE, AVERAGE FADE DURATION AND AVERAGE NONFADE DURATION FOR A SHADOWED RICIAN FADING CHANNEL AT A RECEIVER THRESHOLD OF −15 dB AND A CORRELATION COEFFICIENT ρ OF 0.5

Shadowed Rician fading	LCR (Hz) Level crossing rate	AFD (sec) Average fade duration	AND (sec) Average nonfade duration
$v = 30$ km/h	4.4 *E*-1	5.2 *E*-3	2.25
$v = 90$ km/h	1.3	1.7 *E*-3	7.5 *E*-1

VI. CONCLUSIONS

The calculations in this paper show that it should be possible to receive teletext in a moving vehicle. If we assume a Rician fading channel, the signal can be received using the maximal ratio combining technique and order of diversity $M = 2$. For a Rayleigh or shadowed Rician fading channel an order of diversity of 8 is needed with the maximal ratio combining technique.

If the teletext information is displayed after double reception and merging with the correct data, the number of errors will decrease. If this technique is used, it is possible to use only $M = 4$, with maximal ratio combining for the reception of teletext in a shadowed Rician or a Rayleigh fading channel. If we want to reduce the number of antennas even more, the number of repetitions of reception has to be increased.

As expected, the Rician fading channel gives better performance than Rayleigh fading and shadowed Rician fading channels. Larger Rician parameters give better performance too. Also, it was found that of the two diversity combining techniques, the maximal ratio combining technique is superior to the selection diversity technique.

For receiving teletext, we might need a more complex decoder because if we want to take advantage of repeated (double or even triple) receptions, correct data has to be stored and merged with earlier received correct data.

From average fade and nonfade duration calculations we can see that a nonfade duration is much longer than a frame period (20 ms). Thus in this case the bit errors can be assumed to be independent. A fade duration is always shorter than one frame period.

Measurements and field tests have to be done to validate the model. The Rician parameter and the mean and standard deviation of the lognormal shadowing used in the calculations are values from the literature and are not yet validated for this model. The results presented in this paper are a little optimistic because the mobile teletext channel is assumed to be frequency-nonselective. Therefore, it is recommended that the performance of the mobile UK teletext system using frequency-selective channels be studied next.

In this model the possible influence of high-voltage power lines, always around in trains, is not taken into account. Field tests have to be conducted to study the influence of these on the performance of the proposed system.

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