AN INVESTIGATION OF RADIO WAVE PROPAGATION IN MOBILE RADIO FREQUENCY BANDS

by

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SYNOPSIS

Comprehensive sets of measurements at 139, 441, and 900 MHz in London and Liverpool have provided a data base for investigation of radio wave propagation in urban and suburban areas. Propagation prediction models estimating the median path loss have been derived from the experimental data. These involve parameters such as distance from the transmitter, transmission frequency, base station antenna height, mobile antenna height, and the calculation of diffraction losses.

Measurements at 139 MHz in rural areas provided a means by which the accuracy of the JRC prediction model could be assessed. Suggestions have been made to improve the prediction accuracy of the model.

Comparisons have been made with measurements carried out by previous investigators, and the prediction model has been proved to be quite accurate in the frequency range of 85-900 MHz.

Finally investigations have been carried out on the signal variability, in order to estimate the q% quantiles related to the median value. This meant employing the Suzuki model for describing the mixed distribution of Rayleigh and log-normal processes.

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LIST OF SYMBOLS

a_o	Amplitude
Φ_o	phase angle
λ	wavelength (m)
V	velocity of vehicle
β_o	$2\pi/\lambda$
ψ	azimuthal angle of arrival of signal
X_o	mean power
μ	mean value
σ	standard deviation
P_t, P_1	transmitted power (W)
P_r	received power (W)
h_m, h_1	mobile antenna height
h_b, h_2	base antenna height
g_m, g_1	mobile antenna gain relative to an isotropic antenna
g_b, g_2	base antenna gain relative to an isotropic antenna
β	clutter factor
d, R	range from transmitter
PL	median path loss between two isotropic antennas
ρ	reflection coefficient of the ground
η	intrinsic impedance of free space
Δ	phase difference between the direct wave and the reflected wave
E	electric field strength
f	transmission frequency in MHz
F_q	q% quantiles
PL_u	median path loss when the transmitter is situated in an urban area

PL_s	median path loss when the transmitter is situated in a suburban area
p_s	the probability density of the combined distribution (Suzuki distribution)
F	the field strength level
F_{OR}	mean square value of the field strength of the Rayleigh distribution
F_{OS}	mean square value of the field strength of the overall distribution
S	Suzuki parameter

CONTENTS

CHAPTER 1

INTRODUCTION

The continuously increasing pressure on the available mobile radio spectrum to provide expanded or new services to users, makes it mandatory to re-examine the current definition of service area for given facilities, or a given system, and to devise new or improved methods for defining and determining what constitutes useful service. Many studies and measurements have been carried out on propagation characteristics in the VHF and UHF bands. However, a more detailed analysis of propagation is required for efficient utilization of the radio frequency spectrum. In particular a quantitative analysis of environmental structures (buildings, trees, etc.) is an important subject as it has a large effect on the received field strength, and the service often tends to concentrate in built up areas particularly at the higher frequencies.

By definition, the term "mobile radio communications" describes any radio communication link between two terminals one or both of which are in motion or halted at unspecified locations and of which one may actually be a fixed terminal such as a base station. This definition applies to both mobile-to-mobile and mobile-to-fixed radio communication links. The mobile-to-mobile link could in fact consist of a mobile-to-fixed-to-mobile radio link system which employs the "talk-through" mode. Mobile radio systems may be classified as :

1. Radiophones, such as CB (citizens band) radios, which are allocated 40 channels in the 27 MHz band, for anyone to use whenever the channel is free. No privacy is offered to the user.
2. Dispatch systems, which use a common channel. Any vehicle driver can hear the operator's message to other drivers unless some form of selective calling is used. The drivers can only talk to the central

operator. In some military applications, the users can also talk to each other on an open channel. Two-frequency simplex (half duplex) operation is normal in the U.K.

3. Radio paging systems. In these systems a portable radio is carried by the user. Each unit reacts only to signals addressed to it by an operator. A 'beep' sounds to alert the bearers, who then may go to a nearby telephone to receive the message.

4. Packet radios. This requires a form of multiple-access control that permits many scattered devices to transmit on the same radio channel without interfering with each other's transmissions. This type of system may become important in the future. A receiving device receives any packet addressed to it and transmits an acknowledgement if the packet appears to be free of error.

5. Radiophones also known as mobile 'phones. In the U.K., up to the present time these have operated in the VHF band, using full-duplex systems, but with mainly "operator-assisted" connections. However as from 1985, two operating companies have been licensed to provide a service in the 900 MHz band with multiple frequency reuse using a cellular layout. Automatic dialling facilities will be available as on normal line telephone links.

1.1 DEVELOPMENT OF MOBILE COMMUNICATION

The development of mobile communication stems from the first experiments of the radio pioneers. The startling demonstration of Hertz in the 1880s inspired the entrepreneur Marconi to seek a market for this marvellous new commodity. After limited use of radio communication in World War I, more as a curiosity than anything else, the first land mobile radiotelephone system was installed in 1921 by the Detroit Police

Department for police car dispatch. The New York City Police Department followed suit in 1932.

These first systems operated in the 2-MHz frequency bands. However, as technology and needs increased during the next decade, the trend was to higher frequencies. In 1933 the Federal Communication Commission (FCC) authorized use of four channels in the 30-40 MHz based on an experimental basis. Experimental work at 150 MHz directed specifically towards mobile systems was started in 1945 at Bell Telephone Labs and other places with the twofold objective of improving existing services and pushing on to higher frequencies. In 1914 a new 150 MHz Bell telephone system was made available which provided full duplex operation, automatic channel search, and dialling to and from the mobile station. This was followed in 1969 with the introduction of the same kind of improved operation at 450 MHz.

The future of mobile-radiotelephone communication is dependent upon techniques of network planning and mobile equipment design that will enable efficient and economical use of the radio system. One possible solution to the problem of meeting the steadily increasing customer demand for the mobile-radiotelephone, is to develop a workable plan for reusing the assigned channels within each band of frequencies. To encourage the USA mobile-radiotelephone industry in its development of advanced high-capacity systems, the FCC in 1974 allocated a 40 MHz band in the 800-to-900 MHz frequency range for this purpose. Subsequent research and trial tests conducted by the Bell Telephone Labs concluded that high-capacity systems based on the reuse of assigned channel frequencies in a celleluar planned network were a practical solution.

The extent of interest in mobile communications in the U.K. may be judged by the fact that there were over 100,000 mobile radios in

1972, and this was expanding at a rate of 17% per year. In 1977 there were over 200,000 mobile radios licensed in the private mobile radio service and the use of the mobile radiotelephone grew at a rate of 10% per annum. At present there are over 300,000 users, and the use of mobile radio has been increasing by 8-10% per annum for many years. By 1990 the number of mobile radios is expected to exceed 700,000 and could well approach 2 million by the end of the century. There is no reason to suppose that this growth will slow down. Since the introduction of private mobile radio into the U.K. in 1947, the market has largely been AM. With the introductionof UHF FM equipment in the late sixties, the dominant AM position has declined, and now the market is roughly 60% AM and 40% FM.

Following the interim recommendation of the independent review of radio spectrum in 1983, the U.K. government has decided to release band I and III of the radio spectrum primarily for mobile radio. This will constitute one of the biggest ever additions to the land mobile spectrum in the U.K. Synchronously detected SSB pilot carrier has attracted much attention as an efficient, bandwidth economic modulation technique for mobile radio applications. In recent developments the use of SSB in band III has been proposed. This might be a practical solution to the problem of the explosively growing demand for mobile radiotelephones. The demand for more channels in limited frequency bands allocated has led up to now to the introduction of progressively narrower channel separation i.e. the frequency spacing between carrier frequencies. As the technology advanced the channel spacing was reduced from 100 KHz to 12.5 KHz in the VHF band and 25 KHz in the UHF band. Further channel spacing reductions may be made possible by use of a more appropriate modulation scheme such as SSB.

Thus, since the early days of mobile radiotelephones in the 1920s the picture has been one of steady growth characterized by advancing technology and increasing demand for a service that always exceeded the available system capabilities. The ultimate objective of mobile communication is to enable anyone on the move to communicate quickly, easily and effectively with anyone else. The fundamental problem has already surfaced, lack of frequency bandwidth to handle the service channel in regions of the frequency spectrum where modern technology can provide reasonably economical hardware and systems. In order to provide a mobile telephone service to many thousands of users in a metropolitan area, it is quite clear that the available radio channels must be re-used within the overall service area, in order to use the assigned spectrum most efficiently. There is thus a potential problem of mobiles simultaneously using the same channel in different locations interfering with each other. The severity of this interference depends on the various factors governing radio transmission at these high frequencies.

The following can be considered as steps that could be taken towards reducing the pressure on the available spectrum for mobile radio communication :

1. Change of modulation scheme (e.g. SSB)
2. Dynamic channel assignment (or trunking)
3. reduction of channel spacing
4. Frequency re-use within reasonable geographical spacing.

One immediate solution is to re-use the available frequencies within a reasonable geographical spacing, but this demands a powerful tool by means of which the optimum power required for covering a certain area could easily and efficiently be deduced. It is this problem that is addressed in this thesis. A versatile signal strength and data logging experiment has been designed and built, and extensive field trials have been carried out in urban, suburban and rural areas. The urban trials have been carried out mainly at 900 MHz as this frequency is to be used in the new cellular radiotelephone system, due to start operation early in 1985. Rural trials have been conducted at ranges up to 40 km at a frequency in the VHF band.

The field trial results have been analysed to provide information about the median path loss and its variability. Ordnance survey map squares 500m x 500m have been used as the unit of area to facilitate the introduction of terrain and land usage data where appropriate. Simple propagation models are proposed for urban areas and these are able to provide accurate predictions over a wide range of frequencies.

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CHAPTER 2

FUNDAMENTALS OF MOBILE RADIO PROPAGATION

2.1 INTRODUCTION

Radio signals transmitted from a mobile-radio base station are not only subject to the same significant propagation-path losses that are encountered in other types of atmospheric propagations, but are also subject to the path loss effects of terrestrial propagation. Terrestrial losses are greatly affected by the general topography of the terrain. The low mobile antenna height, usually very close to ground level, and an ever-changing environment around the mobile unit, contributes to this additional propagation path loss. In general, the texture and roughness of the terrain tend to dissipate propagated energy, reducing the received signal strength at the mobile unit and also at the base station. Losses of this type, combined with free-space losses, collectively make up the propagation path loss.

Mobile radio signals are also affected by various types of scattering and multipath phenomena - which can cause some signal fading attributable to the mobile radio communications medium. Due to motion from place to place, an everchanging and very large number of propagation paths are formed between the base station and a mobile unit, and between the mobile units themselves. This multipath interference causes the signal to fade rapidly and deeply, and can be a serious problem in highly built-up urban areas where a large number of propagation paths may be formed. Mobile radio signal fading compounds the effects of long-term fading and short-term fading. Long-term fading is typically caused by relatively small-scale variations in topography along the propagation path. Short-term fading is typically caused by the reflectivity of various types of signal scatterers, both stationary and moving. Fading of this kind is termed "multipath" fading.

This chapter reviews the basic propagation phenomenon starting with simple situations such as "free space" and plane earth. Various diffraction theories for isolated and multiple knife-edge obstacles are compared. The influence of environmental structures on the path loss is examined and finally characteristics of short-term fading and fast-term fading are considered.

2.2 FREE-SPACE TRANSMISSION FORMULA

The power received by a receiving antenna separated from a radiating antenna is given by a simple formula, provided there are no objects in the regions that absorb or reflect energy. This free-space transmission formula [2.1] is given by :

$$P_r = P_t \left(\frac{\lambda}{4\pi d}\right)^2 g_b\, g_m \tag{2.1}$$

The path loss in dB is therefore given by

$$P_L = 20 \log d - 20 \log\lambda - 10 \log g_b\, g_m + 21.9 \tag{2.2}$$

From equation (2.2), doubling the distance reduces the signal by 6dB.

2.3 PLANE EARTH FORMULA

A simple propagation situation also exists when a base-station transmitter and a mobile receiver are separated by a large distance d, and the terrain between the two sites is flat as shown in Fig. 2.1. Three possible kinds of waves may occur at the mobile reciever : a direct wave, a reflected wave, and a surface wave. The resultant received signal power [2.2] is then:

$$P_r = P_t\, g_m\, g_b \left(\frac{\lambda}{4\pi d}\right)^2 . \left|1+ \rho e^{j\Delta} + \eta\right|^2 \tag{2.3}$$

For mobile radio communications, the grazing angle Ψ, as shown in

Fig. 2.1 is always small and d >> h_1h_2 hence it is reasonable to assume that $\Delta << 1$ and $\rho \approx -1$ for both vertical and horizontal polarisation hence equation 2.3 becomes

$$P_r = P_t \, g_m \, g_b \left(\frac{h_1 h_2}{d^2}\right)^2 \qquad (2.4)$$

and the path loss is given by

$$P_L = 40 \log d - 20 \log h_1 h_2 - 10 \log g_m g_b \qquad (2.5)$$

From the above equation, doubling the distance reduces the signal by 12dB, and the path loss is independent of frequency.

2.4 DIFFRACTION LOSS

Diffraction of radio waves occurs when the propagation path is wholly or partially obstructed by features of the intervening terrain between the transmitting antenna and the receiving antenna. The severity of signal attenuation depends on whether the obstruction extends through the propagation path, extends beyond the line-of-sight propagation path (Fig. 2.2a), or merely approaches the line-of-sight propagation path (Fig. 2.2b). In practice, it is not always possible to select the highest point along the propagation path as the ideal location for the base station. In hilly areas, even with good siting of the base station, there will frequently be occasions when no line of sight path exists to the mobile unit. When the shadowing is caused by a single object such as a hill, it is instructive to treat the object as a diffracting knife-edge to estimate the amount of signal attenuation.

2.4.1 Knife-edge Diffraction Theory

In classic electromagnetic theory applications, the field strength of a diffracted radio wave associated with a knife edge can be expressed as:

$$\frac{E}{E_o} = F\, e^{j\Delta\Phi} \qquad (2.6)$$

The loss in dB due to diffraction is normally added to the free-space

path loss and is given by :
where E_o is the free-space electromagnetic field with no knife-edge diffraction present, F is the diffraction coefficient, and $\Delta\Phi$ is the phase difference with respect to the path of the direct wave.

$$L_D = 20 \text{ Log } F \qquad (2.7)$$

$$F = \frac{S_0 + 0.5}{\sqrt{2}\,\sin(\Delta\Phi + \pi/4)} \qquad (2.8)$$

$$\Delta\Phi = \tan^{-1}\left(\frac{S_0 + 0.5}{C + 0.5}\right) - \pi/4$$

and C and S_0 are the Fresnel integrals

$$C = \int_0^{v} \cos(x^2\pi/2)\,dx$$

$$S_0 = \int_0^{v} \sin(x^2\pi/2)\,dx$$

$$v = -h\sqrt{(1/r_1 + 1/r_2)\,2/\lambda} \qquad (2.9)$$

r_1 and r_2 are the separation distances, and h_1 is the height of the knife-edge as shown in Fig. 2.2. The parameter v is known as the Fresnel parameter.

Two possible situations can arise : first, when the wave is not obstructed; second, when the wave is diffracted by the knife edge obstruction. Fig. 2.2 illustrates the two possible situations. In the first case h is a negative value and v becomes a positive value. In the second case h is positive and therefore v becomes negative. The exact solution of equation (2.8) is shown graphically in Fig. 2.3. An approximate solution can be obtained for v in certain ranges as follows :

$v \geq 1 \qquad L_D = 0 \text{ dB}$

$0 \leq v \leq 1 \qquad L_D = 20 \log (0.5 + 0.62 v)$

$-1 \leq v \leq 0 \qquad L_D = 20 \log [0.5 \exp(0.95 v)]$

$-2.4 \leq v < -1 \qquad L_D = 20 \log (0.4 - \sqrt{0.1184 - (0.1 v + 0.38)^2})$

$v < -2.4 \qquad L_D = 20 \log (-\sqrt{2} / 2 \pi v)$

2.4.2 Multiple Diffraction

The extension of single knife-edge diffraction concepts to the problem of a two obstacle transmission path involves considerable mathematical complexity. Although it cannot easily be extended to cases involving three or more obstacles, an exact solution for two obstacles exists [2.3]. Consequently, the trend has been for the continued use of simple approximations, the most notable of which are outlined below.

2.4.3 The Bullington Method

In Bullington's method [2.4], two tangential lines are extended, one over each knife-edge obstruction, and the effective height of an equivalent knife-edge obstruction is measured as shown in Fig. 2.4. The disadvantage with this method is that terrain paths having several significant obstructions are oversimplified since only two of these will ever be relevant in the construction of the equivalent knife-edge as shown in Fig. 2.4. In general, the method tends to overestimate the losses.

2.4.4 The Epstein-Peterson Method

In the Epstein and Peterson model [2.5], the heights h_1 and h_2 of the two effective knife-edge obstructions are obtained as shown in Fig. 2.5a. The excess path loss is the loss due to h_1 plus the loss due to h_2. This model is difficult to apply when the two obstructions are relatively close together as shown in Fig. 2.5b and large errors often occur.

2.4.5 The Japanese Model

The Japanese [2.6] and Epstein-Peterson models are similar except in the geometric construction in positioning of the hypothetical transmitter. For the Epstein-Peterson model this conceptual radiator is placed at the summit of the previous obstacle while the Japanese construction places it at the point where the projected horizon ray meets the plane of the true transmitter as shown in Fig. 2.6a. The construction for a path obstructed by many obstacles is indicated in Fig. 2.6b.

2.4.6 The Deygout Method

The principle of this method [2.7] for two obstructions is illustrated in Fig. 2.7a. The Fresnel parameter is calculated for each of the edges. If $v_1 > v_2$ then edge 01 is considered as the main edge and its loss is calculated as if the obstacle 02 were absent and the loss T-01-R is determined. The additional loss resulting from 02 is then determined as the loss between the main edge and the obstructed terminal, in this case R.

This technique can be extended for a path with many obstacles, as illustrated in Fig. 2.7b. The process divides the path into sections on either side of the main edge, 03. On the receiver side, first v_4 and v_5 are calculated taking the line 03-R as the base line and then proceeding in the two-obstacle case described above. A similar procedure is carried out on the transmitter side. In the case illustrated a main edge is established and edges between the main edge and either terminal the section on that side of the main edge is split into further subsections; the problem rapidly becomes quite complicated, and the solution correspondingly lengthy. Hence, this method is not recommended for problems involving more than four obstacles.

2.5 INFLUENCE OF ENVIRONMENTAL STRUCTURES ON PATH LOSS

In mobile radio communications systems, the condition of propagation paths varies as a function of time because of the very low mobile antenna height. This usually ranges from 1 to 3m above ground, and a mobile station continually traces the service area. Therefore, the propagation characteristics are influenced by terrain and environmental shielding structures, and location variability occurs.

2.5.1 Effect of Buildings

A quantitative analysis of the effect of environmental buildings is an important subject as it has a large influence on the received field strength, and the service often tends to concentrate in built-up urban areas. The effect of environmental buildings on signal strength has been measured by different authors [2.8] - [2.9] and similar approaches have been considered to characterise the effects.

Changes of as much as 10 dB in median signal strength can be observed in adjacent locations only a few hundred metres apart if the building density changes substantially.

2.5.2 Effect of Foliage

The propagation of radio waves at UHF frequencies can be greatly affected behind a grove of trees. Precise estimates of attenuation are difficult because tree heights are not uniform; also, the type, shape, density and distribution of the trees influence the propagation. In addition, the density of the foliage depends on the season of the year. However, some success has been obtained by treating trees as diffracting obstacles with an average effective height [2.10]. The effect of foliage is more pronounced at X-band than at UHF. In cases where the shadowing obstacle is tree covered, signal level at UHF might typically be 10 dB lower when the trees are in full leaf, whereas at X-band this additional loss could be as high as 20 dB.

2.6 SHORT TERM FADING

Short term fading is mainly caused by multipath interference; it consists of very rapid and deep fades, depths of 30 dB being quite common. To properly understand the effects of multipath phenomena, it is necessary to understand the concept of standing waves as applied to radio signals. If a radio signal arrives from one direction and is reflected in the opposite direction by a perfect reflecting scatterer, as shown in Fig. 2.8a, then the resultant signal received by a mobile unit moving at a speed v is as expressed in equation [2.10]. For simplicity, it can be assumed that the arrival angle $\theta = 0$.[1.2]

$$S(t) = a_o \exp [j (\omega_o t + \Phi_o - \beta_o v t)] - a_o \exp [j (\omega_o t + \Phi_o - \omega_o \tau)] \quad (2.10)$$

$$= - j 2a_o \sin (\beta_o vt - \omega_o \tau/2) \exp [j (\omega_o t + \Phi_o - \omega_o \tau/2)]$$

and τ is the time it takes for the wave to travel to the scatterer and return to the $t = o$ line.

The envelope of this signal is the resultant standing wave pattern, Fig. 2.8b. In a real life situation scatterers are randomly situated around the mobile unit and reflected waves arrive at the unit from all directions, hence giving rise to a much more complex fading pattern. One such fading pattern in an urban area at 900 MHz is shown in Fig. 2.9. This represents a typical segment of a fading signal received at a mobile unit. Variations as large as 40 dB in signal amplitude can occur as a result of fading, with nulls occurring approximately every half wavelength. Such severe fading will degrade the signal and produce poor voice quality in speech systems or high error rates in data systems.

2.6.1 Short Term Fading Characteristics

Measurements by many workers over the frequency range from 50 MHz to 11200 MHz have shown that the envelopes of the mobile radio signal is Rayleigh distributed [2.11] - [2.12] when measured over distances of a few tens of wavelengths where the mean signal is sensibly constant. This suggests that at any point the received field is made up of a number of horizontally travelling plane waves with random amplitudes and angle of arrival for different locations. The phases of the waves are uniformly distributed from zero to 2π. The amplitudes and phases are assumed to be statistically independent. Furthermore, the signal x(t), at a point in space may be written as :

$$x(t) = \sum_{i=1}^{N} x_i \cos\left[(\omega_c + (2\pi/\lambda)\, v \cos \Psi_i)\, t + \Phi_i\right] \qquad (2.11)$$

As a consequence of the central limit theorem the vector sum of a large number of sinusoids with random amplitudes and phase angles is a Gaussian random variable. The envelope of a Gaussian random process can easily be shown to be Rayleigh distributed. Thus for short term fading in a radio channel the probability density p (r) for the amplitude is given by :

$$p(r) = (r/x_o) \exp(-r^2 / 2x_o) \qquad (2.12)$$

Where x_o = mean power

The instantaneous signal power is $x = \frac{1}{2} r^2$.

When changing the variable the following must hold :

$$p(r) \cdot dr = P(x) \cdot dx$$

and $\quad dx / dr = r$

Hence

$$p(x) = (r / rx_o) \exp(-x / x_o)$$

$$p(x) = (1 / x_o) \exp(-x / x_o) \qquad (2.13)$$

Fig. 2.13 shows that the instantaneous power of a signal with a Rayleigh distributed amplitude will be exponentially distributed. It is worth noting that the only parameter necessary to completely describe the distribution is the mean value, x_o.

2.7 LONG-TERM FADING (LOCAL MEAN) CHARACTERISTICS

One experimental result that has been consistently observed is that the distribution of the received signal averaged over a distance of 10–20 m at fixed base and mobile antenna heights, frequency and separation distance from the base station within the same environment class (urban, for example) have very nearly a normal distribution when the distribution is plotted for the received signal measured in decibels. Such a probability distribution is often referred to as log-normal [2.13].

In order to understand the properties of log-normal distribution a knowledge of Normal distribution properties is essential.

Any distribution defined by the expression

$$p(x)= (1/\sqrt{2\pi}\,\beta)\exp-(1/2)[(x-\alpha)/\beta]^2 \tag{2.14}$$

where α and β are positive constants, is known as a normal or Gaussian distribution.

The mean of a continuous random variable is given by

$$\mu = \int_{\min x}^{\max x} x.P(x)\,dx$$

Hence for a Normal distribution

$$\mu = \int_{-\infty}^{+\infty} (x/\sqrt{2\pi}\,\beta)\exp-(1/2)[(x-\alpha)/\beta]^2 \tag{2.15}$$

Unfortunately, the operations indicated in equation (2.15) are extremely difficult to execute. It is thus necessary to develop and make use of the normal moment generating function to find the mean.

$$M_x(t) = E(e^{xt}) = \int_{-\infty}^{+\infty} e^{xt}.(1/\sqrt{2\pi}\,\beta)\exp-(1/2)[(x-\alpha)/\beta]^2\,dx$$

After a little algebraic manipulation,

$$M_x(t) = e^{[\alpha t + (\beta^2 t^2 / 2)]} \int_{-\infty}^{+\infty} (1/\sqrt{2}\pi\beta)\, e^{-(1/2)[(x - (\alpha + \beta^2 t))/\beta]^2}\, dx$$

The expression following the integration sign has the form of a normal density function. Hence the integration over the range $-\infty$ to $+\infty$ is equal to one. Thus :

$$M_x(t) = e^{[\alpha t - (\beta^2 t^2 / 2)]}$$

and

$$\mu = E(x) = [\, d M_x(t) / dt \,]_{t=0} = \alpha$$

and

$$E(x^2) = \alpha 2 + \beta 2$$

and the variance is

$$\sigma^2 = E(x^2) - [\, E(x)\,]^2 = \beta^2$$

If an essentially positive variate x ($0 < x < \infty$) such that $y = \log x$ is normally distributed with mean μ and variances σ^2, then it is said that x is lognormally distributed. Following the rules of probability when changing variables, the log-normal density function will be given by :

$$P(x) = (1 / x\ \sigma\ 2\pi)\, e^{-(1/2)[(\log x - \mu)/\sigma]^2} \qquad (2.16)$$

and using methods similar to those described above, the mean α and variance σ^2 are given by

$$\alpha = e^{\mu + (1/2)\sigma^2}$$

$$\beta^2 = \alpha^2 (e^{\sigma^2} - 1)$$

The median of the distribution is at $x = e^{\mu}$ and the mode is at $e^{\mu - \sigma^2}$.

Fig. 2.10 gives a comparison of the frequency curves of a normal and log-normal distribution when $\mu = 0$ and $\sigma^2 = 0.5$.

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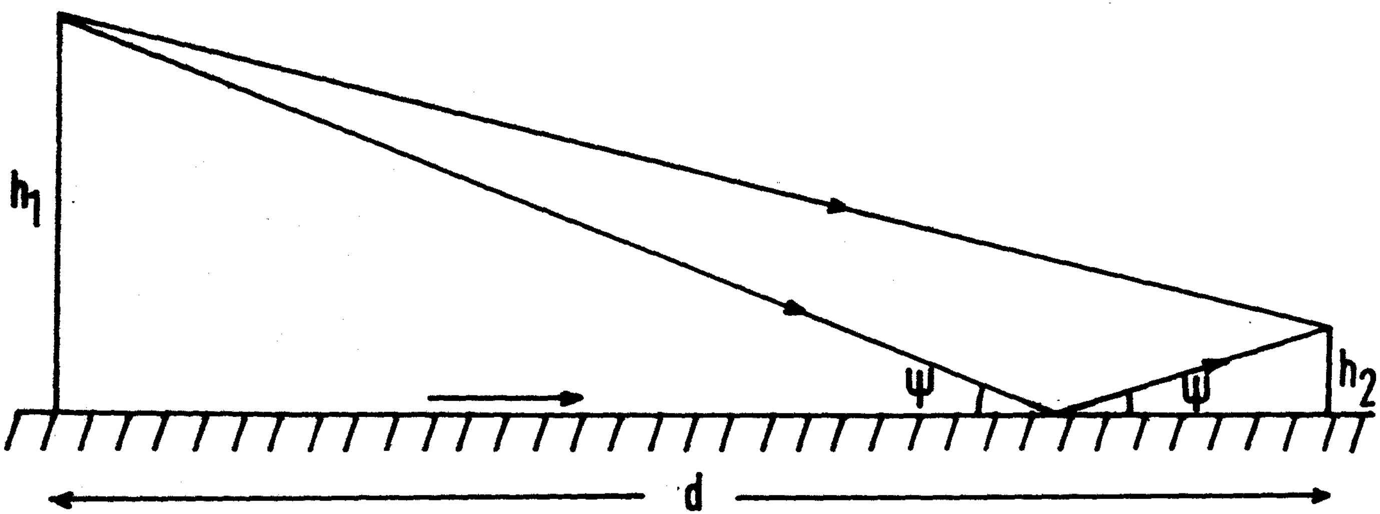


Fig. 2.1 Model for propagation over flat terrain.

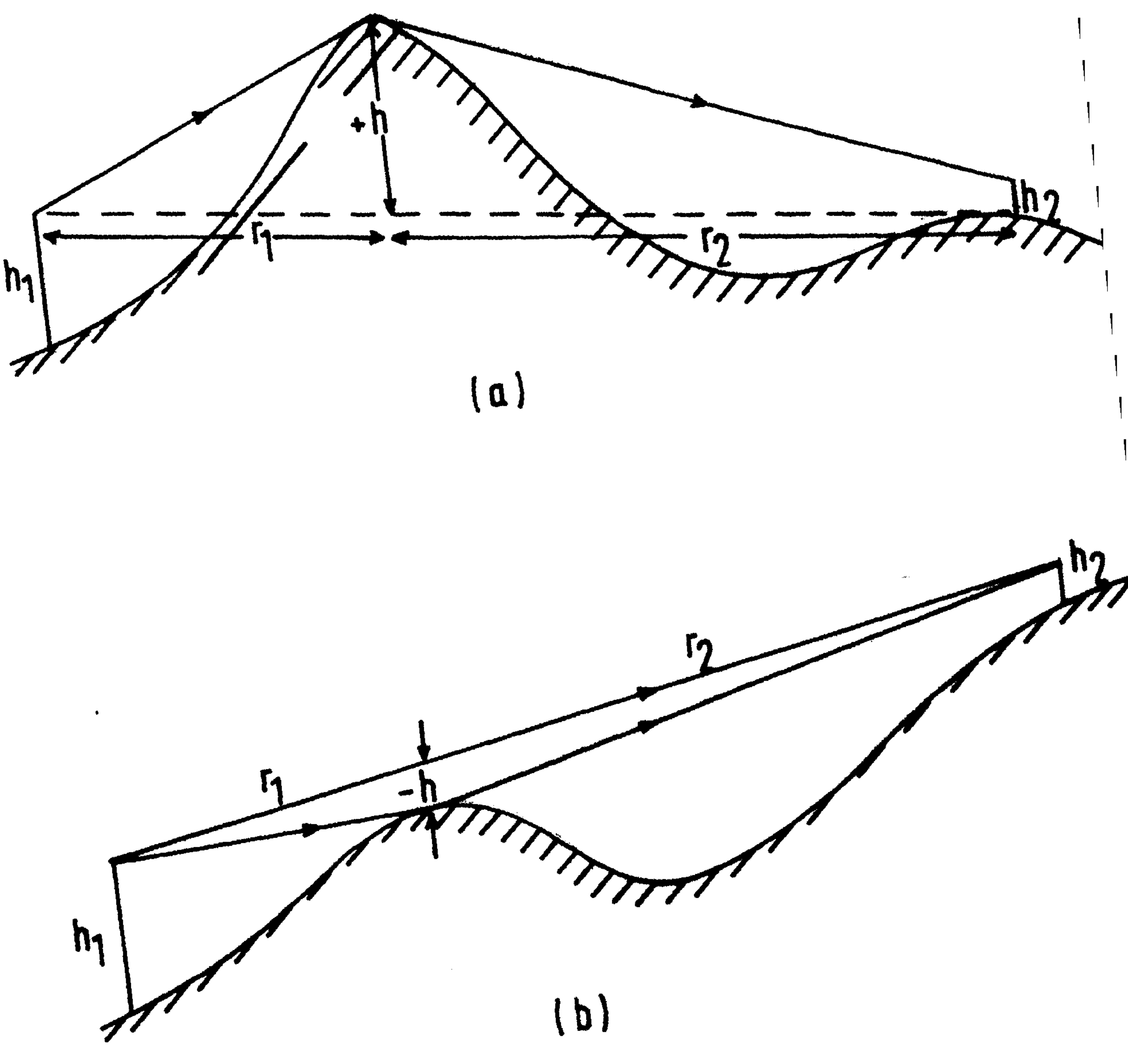


Fig. 2.2 Effect of knife-edge obstruction on transmitte[d] radio waves: (a) knife-edge diffraction; (b)no[t] obstructed knife-edge propagation effect.

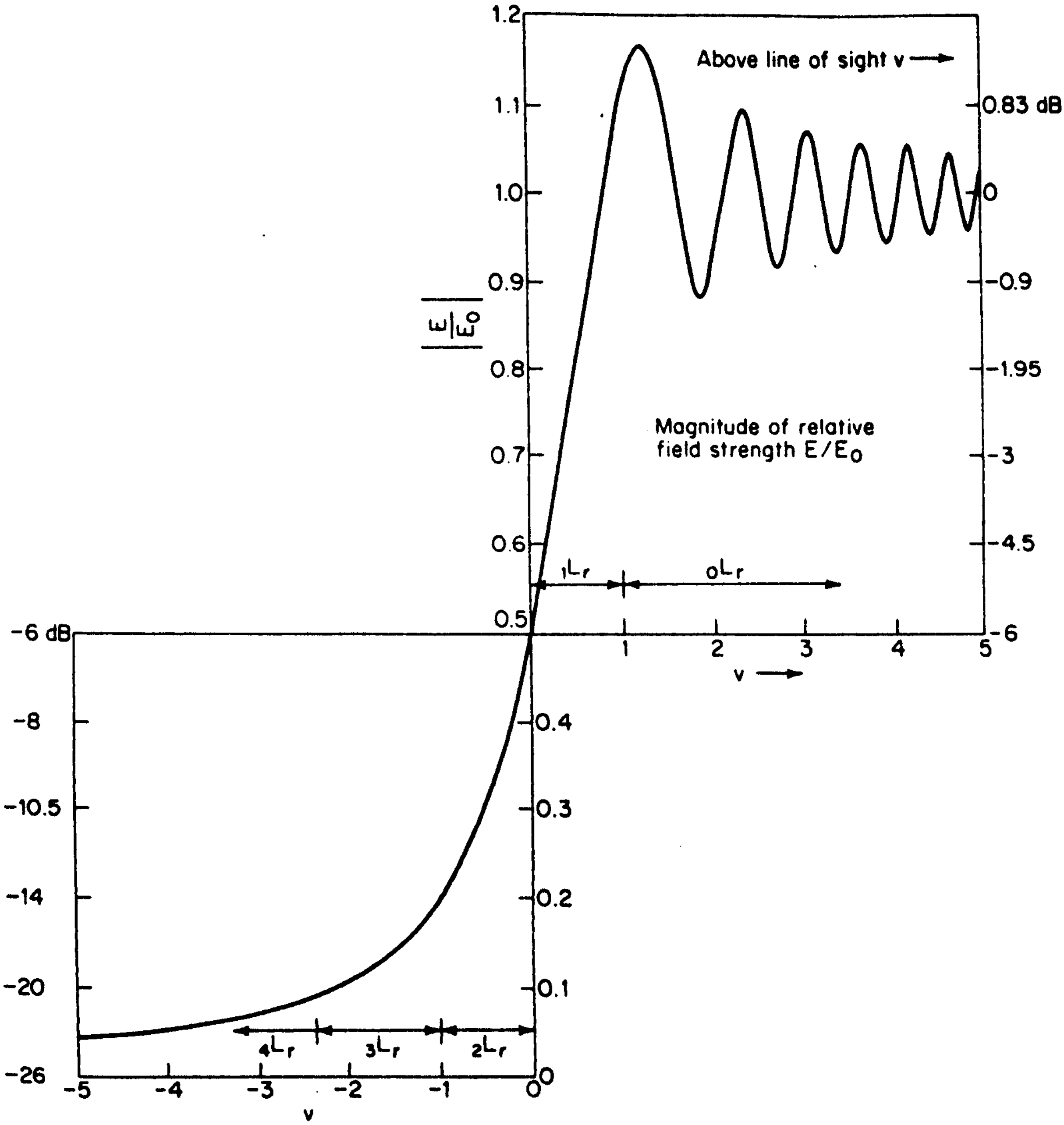


Fig. 2.3 Magnitude of relative field strength E/E_0 due to diffraction loss.

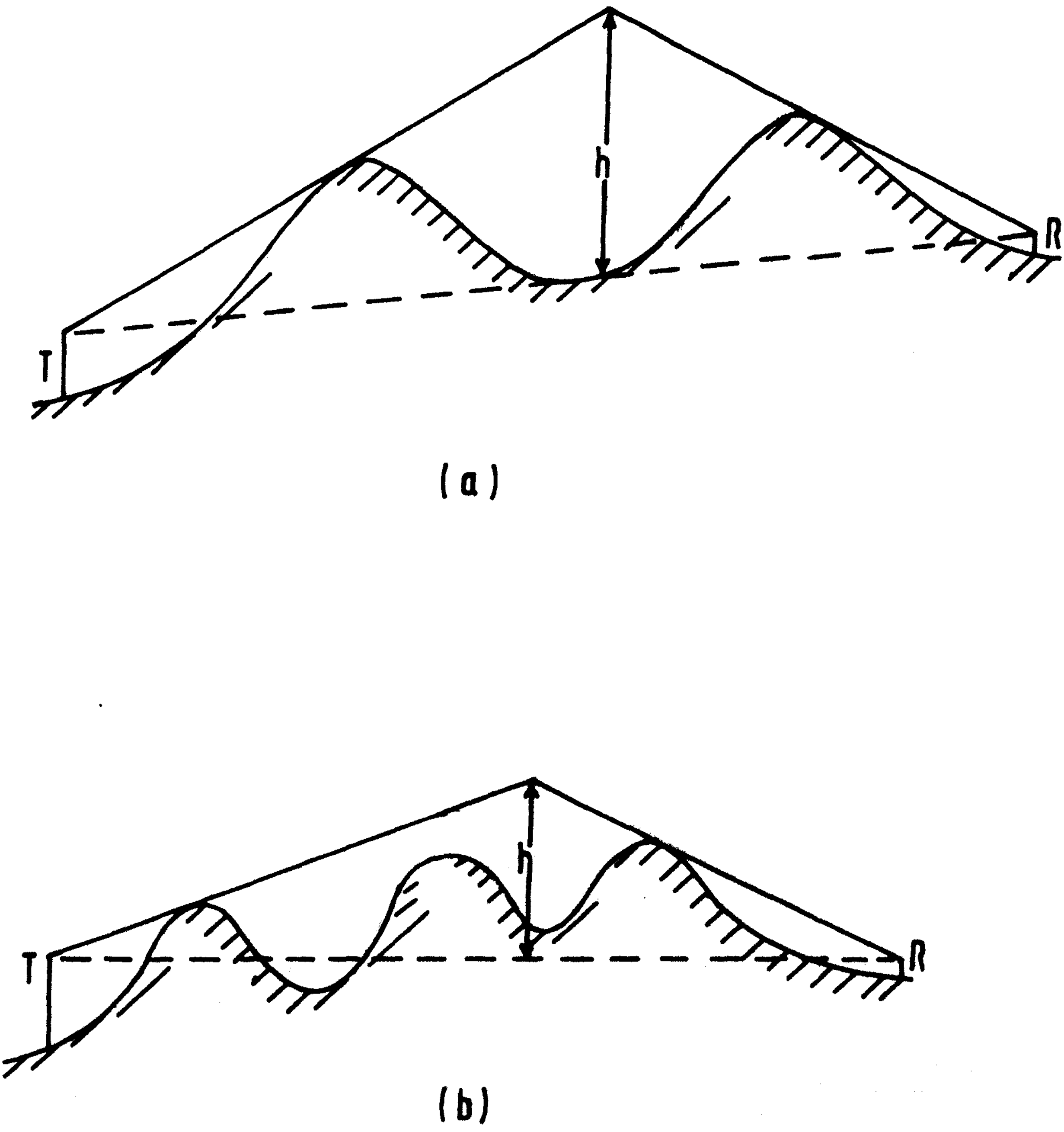
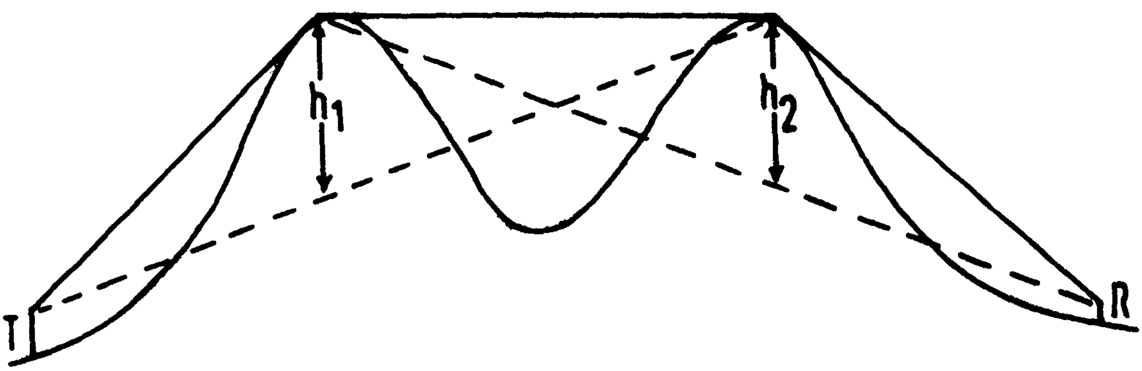
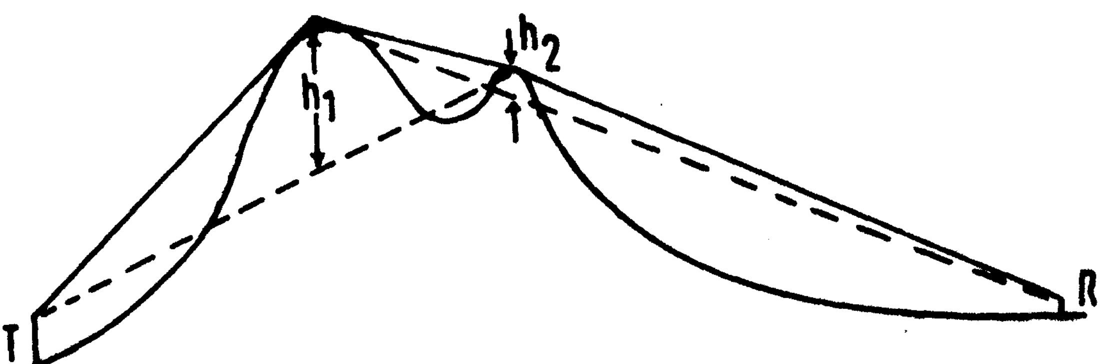


Fig. 2.4 The Bullington model.



(a)



(b)

Fig. 2.5 The Epstein-Peterson method.

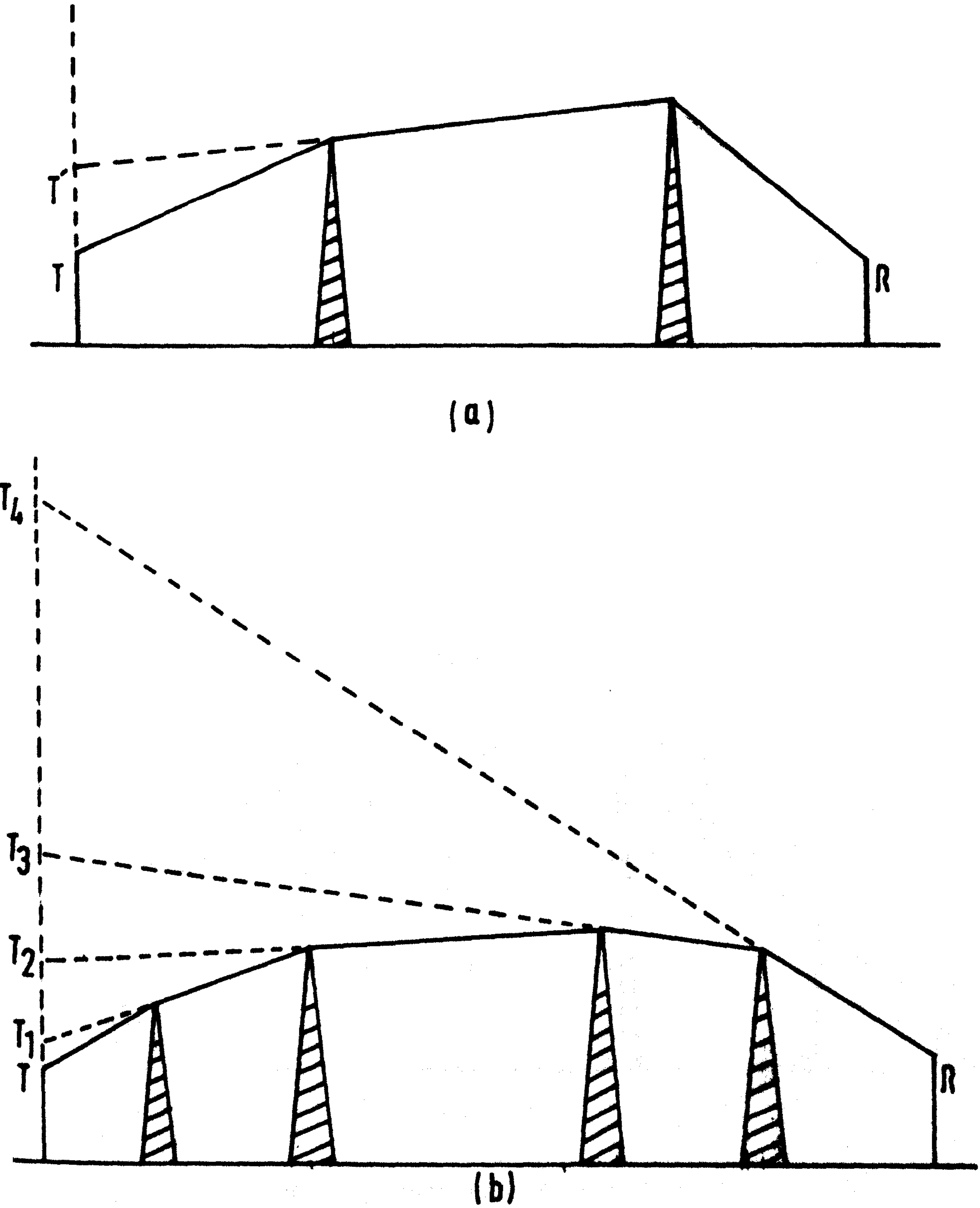
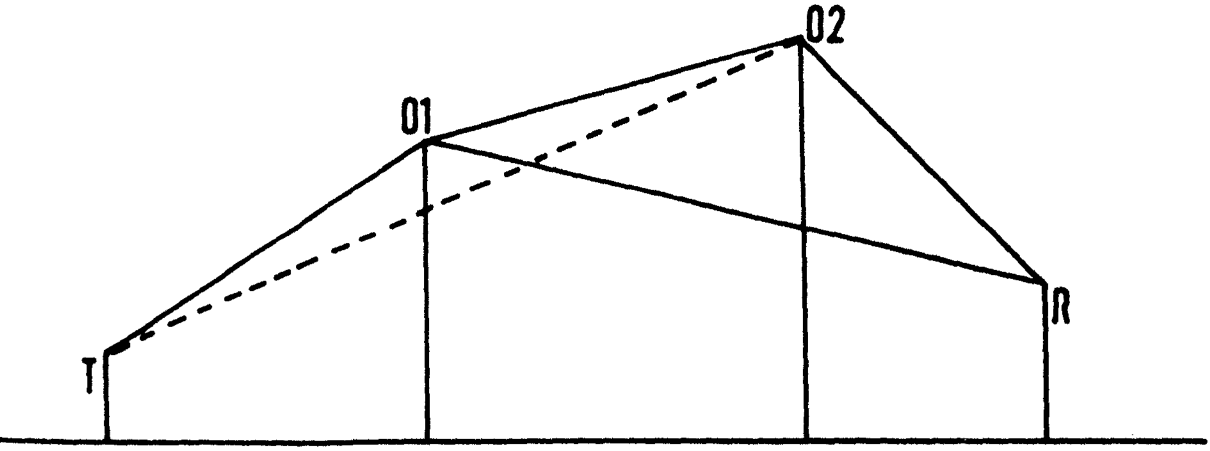
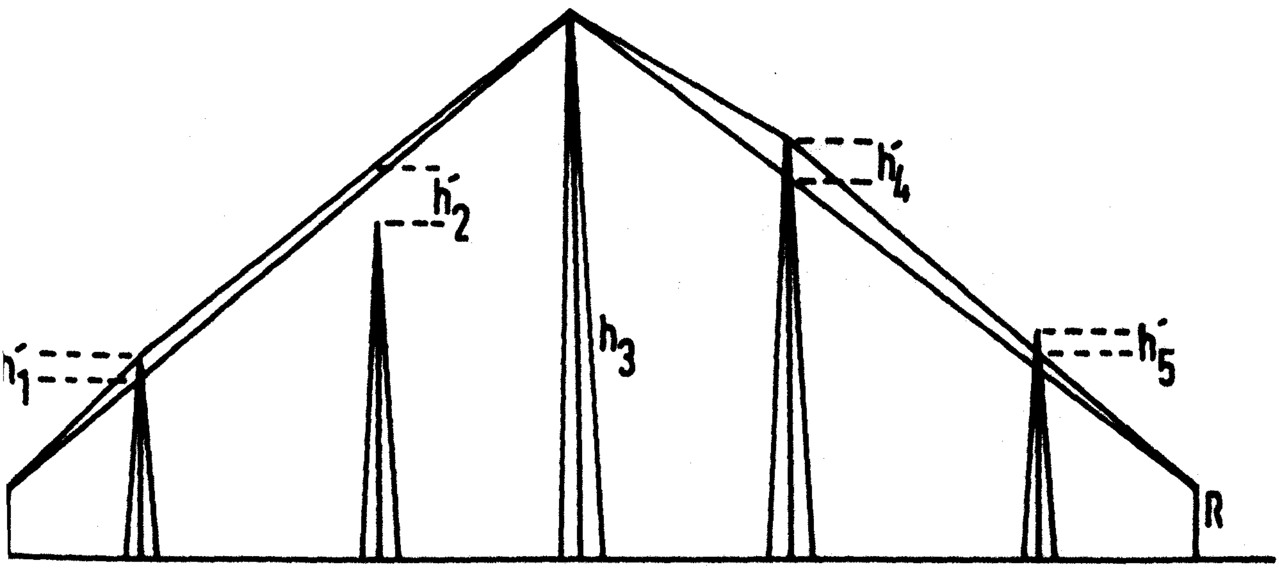


Fig. 2.6 The Japanese model.



(a)



(b)

Fig. 2.7 The Deygout model.

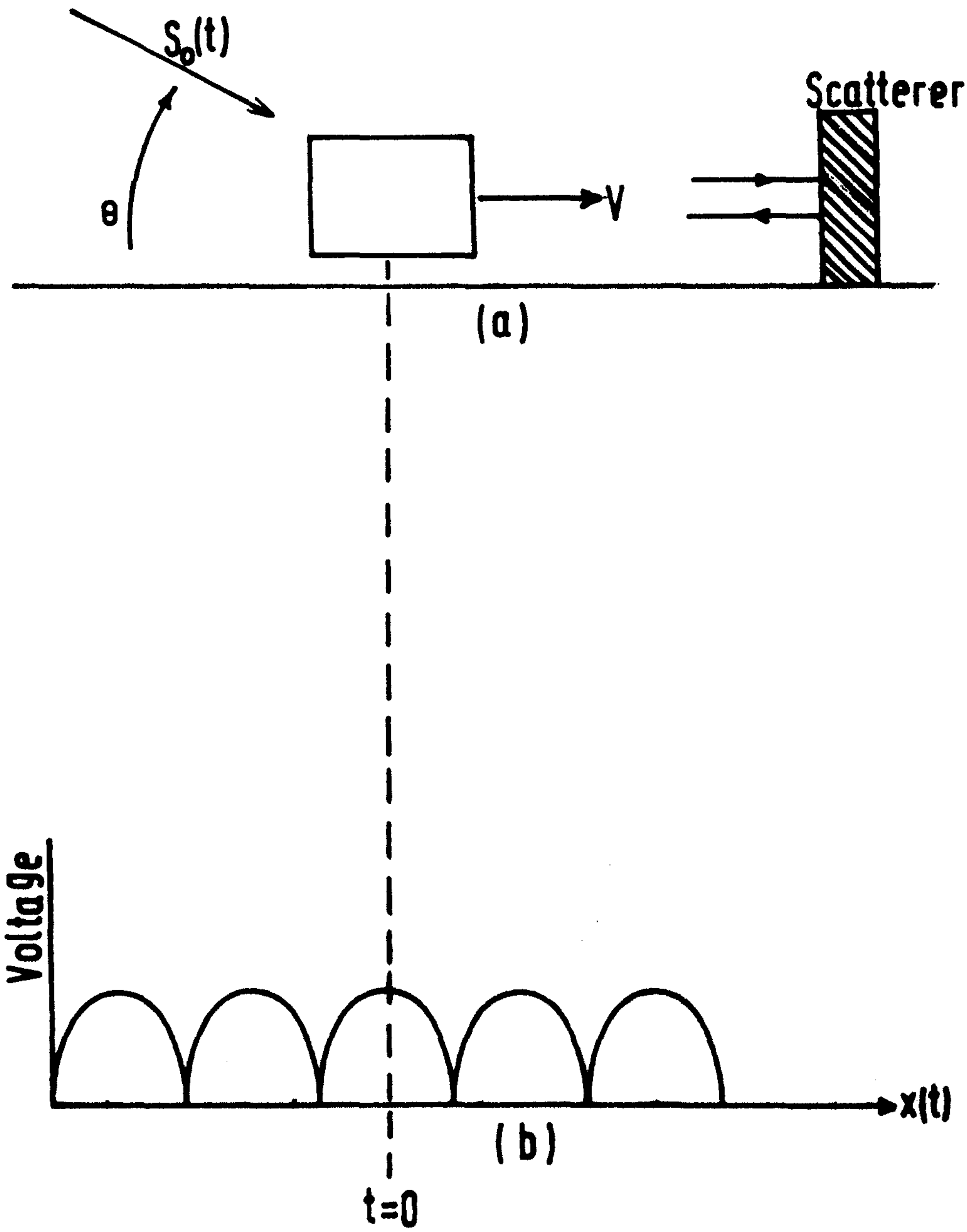


Fig. 2.8 Signal reception while the mobile is in motion.

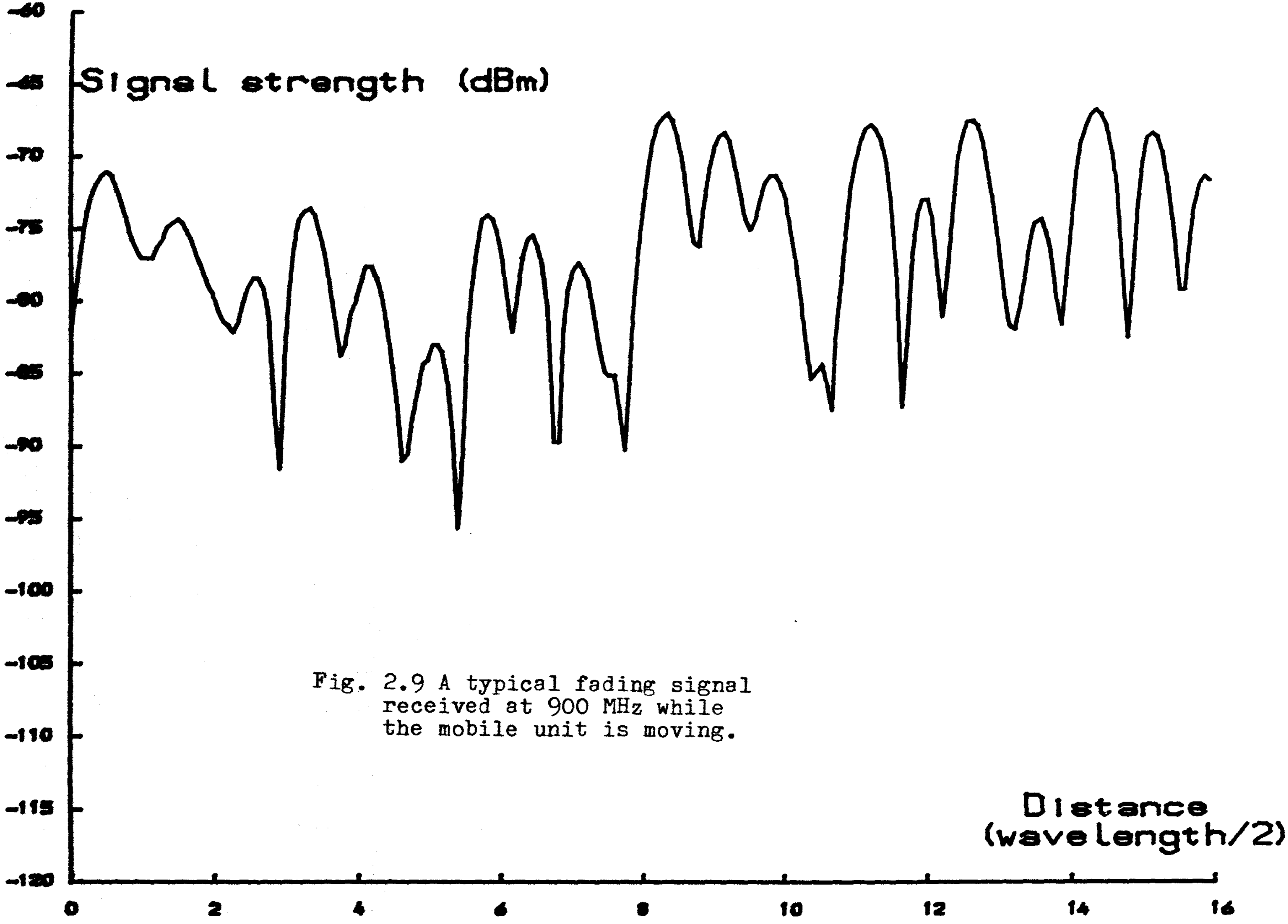


Fig. 2.9 A typical fading signal received at 900 MHz while the mobile unit is moving.

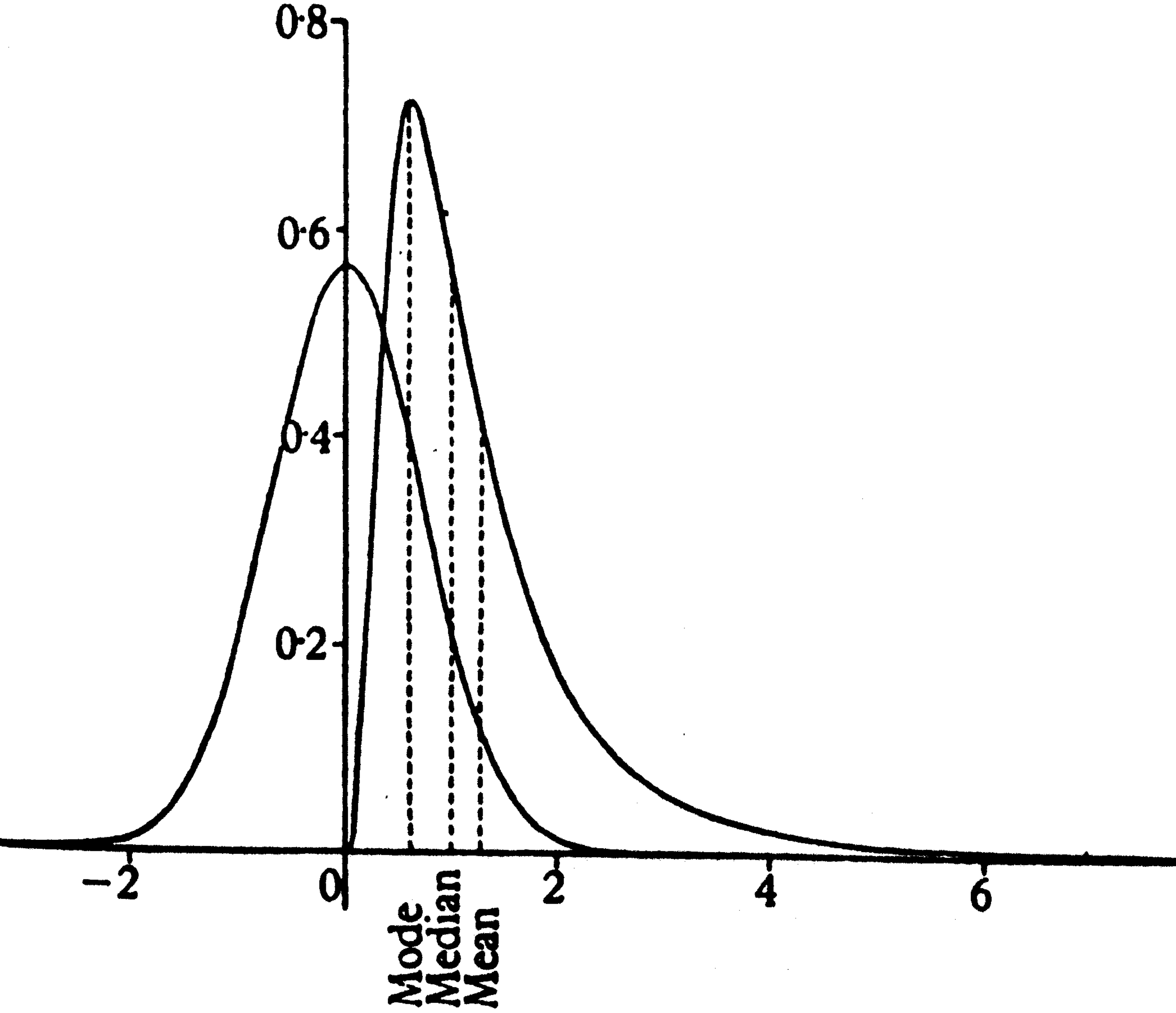


Fig. 2.10 Frequency curves of the normal and lognormal distributions.

CHAPTER 3

REVIEW OF EARLIER WORK

3.1 INTRODUCTION

Many investigators have tried to develop ways to predict median values of propagation loss in built-up areas - where buildings and trees may cause severe attenuation of the radio signals [3.1] - [3.4]. Others have been concerned with describing path-to-path variability and multipath fading in statistical terms [3.5]-[3.6]. In order to obtain the median path loss in built-up areas, many investigators first calculated the propagation loss to be expected if the buildings and other surface features were not present. The additional observed loss is then assumed to be caused by the urban, or suburban development. Over relatively smooth terrain, theoretical plane earth values have first been calculated and the differences between these and the measured values have then been variously referred to as the shadow loss, excess loss, urban factor, clutter factor etc. In a similar manner some investigations have compared measured losses with calculated free space values.

3.2 PROPAGATION MODELS FOR IRREGULAR TERRAIN

3.2.1 Bullington Method

Bullington [3.7] started from the basic theory of free space propagation for his investigation of signal strength prediction. Since most radio paths cannot be considered to be free space paths, he next went on to determine the effect of perfectly flat earth, and this was followed by the effect of earth curvature. In all his discussions he assumed earth to be a perfectly smooth sphere. He claimed that the effect of hills, trees and buildings is difficult or impossible to compute, but that the order of magnitude of these effects may be obtained from a consideration of the rather extreme case which is propagation over a perfectly absorbing knife edge.

Bullington started from the fundamental equation

$$E_o = \sqrt{30\, g_1\, p_1}\, /d \qquad \text{Volts per metre} \qquad (3.1)$$

where E_o is the field intensity at a distance d meters from the transmitting antenna.

He then expressed the maximum useful power P_2 that can be delivered to a matched receiver in terms of the received field strengths;

$$p_2 = (E\, \lambda / 2\pi)^2\, g_2 /120 \qquad \text{Watts} \qquad (3.2)$$

From equations (3.1) and (3.2) and using the principal effect of plane earth on the propagation of radio waves Bullington obtained

$$\frac{p_2}{p_1} = \left(\frac{h_1' h_2'}{d^2}\right)^2 g_1\, g_2 \qquad (3.3)$$

where $h' = h + jho$ where h is the actual antenna height and $h_o = \lambda/2\pi Z$ has been designated as the minimum effective antenna height

Where

$$Z = \sqrt{\epsilon_o - \cos^2\theta} / \epsilon_o \qquad \text{for vertical polarization}$$

$$Z = \sqrt{\epsilon_o - \cos^2\theta} \qquad \text{for horizontal polarization}$$

$$\epsilon_o = \epsilon - j\, 60\, \sigma \lambda$$

The magnitude of $|h_o|$ can be found from a set of graphs given by

Bullington (Fig. 3.1).

Bullington gave a nomograph that could be used to calculate the diffraction loss over a knife edge as shown in Fig. 3.2.

The height of the obstruction H is measured from the line joining the two antenna to the top of the ridge.

3.2.2 Egli's Method

Egli [3.8] suggested the use of theoretical plane earth field strength equation

$$E = (h_t h_r f / 95 d^2) \sqrt{P_t} \qquad (3.4)$$

For irregular terrain Egli defined a median field strength E_{50} as the theoretical plane earth field intensity, less the median deviation therefrom. Egli noted that the deviation from the plane earth field strength varied inversely with the frequency and was independent of distance. By taking 40 MHz as the reference frequency he obtained

$$E_{50} = (40 h_t h_r / 95 d^2) \sqrt{P_t} \qquad (3.5)$$

Egli also gave the theoretical plane earth received power between half-wave dipoles as :

$$P_r = 0.345 (h_t h_r / d^2)^2 P_t . 10^{-14} \quad \text{Watts} \qquad (3.6)$$

Egli defined P_t as the effective radiated power, however, the transmitting antenna gain of 1.46 dB has already been used in the derivation of equation (3.6).[3.4] Therefore P_t should be defined as the transmitter output power. Making use of his earlier conclusion :

$$P_{50} = 0.345\ (\ h_t\ h_r\ /\ d^2\ )^2\ (\ 40\ /\ f\ )^2\ .\ 10^{-14} \quad \text{Watts} \qquad (3.7)$$

Egli noticed that the deviation of median field strength from the theoretical plane earth when described in dB was log-normally distributed. Hence, using the expected standard derivation at different frequencies he established a correction factor to the E_{50} field strength when the received field strength other than the 50 percentile location is desired.

3.3 COMPUTER BASED MODELS

3.3.1 The JRC Method

The method [3.9] - [3.10] is used to predict the coverage area of a base station using a computer and a topographical data base, the output being presented in the form of a plotting of the predicted field strength and path losses at half-kilometer intervals over the service area. The topographical data base has been extracted from Ordnance Survey maps, providing 800,000 height reference points at 0.5 km intervals for Britain.

To calculate the received signal level, the computer reconstructs the ground path profile between the transmitter and the receiver; it then tests for the existence of a line of sight path and whether Fresnel-zone clearance is obtained over the path. If both tests are satisfied, both free space and plane earth losses are calculated and the higher value is chosen. If the test fails, the programme evaluates the loss caused by obstruction, grading them into single or multiple diffraction edges. Calculations are made for up to three diffracting edges, and any greater number of obstructions are converted into three edges by approximating the profile between the outer two diffraction edges to an equivalent knife edge Fig. (3.3). This construction was first suggested by Bullington [3.7]. In this way the profile is reduced to the three-diffraction-edge, and computation proceeds as before.

The JRC method is of interest to major mobile users in the UK, France and Scandinavia, hence a close examination of its prediction accuracy is carried out in a later chapter, using experimental data.

3.3.2 Longley & Rice Model

The Longley & Rice model [3.11] is based on electromagnetic theory and on a statistical analysis of both terrain and radio measurements. It predicts the median attenuation of a radio signal as a function of distance and the variability of the signal in both time and space. Table 3.1 lists the input parameters required by the model.

Table 3.1

System parameters	
Frequency	20 MHz to 20 GH$_3$
Distance	1 km to 2000 km
Antenna height	0.5m to 3000m
Polarization	Vertical or horizontal
Environmental parameters	
Terrain irregularity parameter Δh	
Electrical ground constants	
Surface refractivity	250 - 400 N-units
Climate	
Deployment Parameters	
Siting criteria	Random, careful, or very careful

Statistical Parameters

Reliability and confidence level	0.1% to 99.9%

The terrain irregularity parameter Δh is defined as the interdicile range of terrain elevations, that is, the total range of elevation after the highest 10% and the lowest 10% have been removed. Given values for the input parameters, the irregular terrain model first computes several geometric parameters related to the propagation path. Next, the model computes a reference attenuation, which is a certain median attenuation relative to free space. This reference attenuation is defined in three regions, line-of-sight, diffraction and forward scatter region. The line-of-sight is defined to be the region where the general bulge of earth does not interrupt the direct radio waves, but it still may be that hills and other obstructions do so. In this region, the reference attenuation is computed as a combined logorithmic and linear function of distance. In the diffraction region there is a rather rapid linear increase; and this is followed in the scatter region by a much slower linear increase. The reference attenuation is a good representative value to indicate to a designer how a proposed system will behave. For some problems a knowledge of it alone will be sufficient. For most problems, however, the statistics of the attenuation are important and must be known.

3.3.3 The BBC Model

The BBC model [3.12]-[3.13] is a computer based model for predictions of area coverage at UHF. The computer program assumes that the transmitter sites are well clear of any local obstructions and the receiving aerials are taken to be at a standard height of 10m, typical of a two storey residential building. The total path loss comprises of three separate losses.

1. The free space loss
2. Diffraction loss due to terrain irregularities
3. A correction factor due to the surroundings of the receiver (buildings and trees).

The diffraction loss is calculated using a topographical data base extracted from ordnance survey maps. The loss due to building and tree density within 2km from the receiver constitutes the correction factor. This loss is weighted in inverse proportion to the distance from receiver. Modification would be necessary to enable the model to be used for prediction with receiver heights below roof-top level, as is typical in mobile radio.

3.4 PROPAGATION MODELS FOR BUILT-UP AREAS

3.4.1 Young's Measurements

Young's work [3.1] is based on a series of experiments, conducted at 150, 450 and 900 and 3700 MHz in New York. He concluded that at 3700 MHz, transmission suffers an additional impairment due to the fact that the fluctuations in the received carrier level (multipath fading) occur at an audible rate as the mobile unit moves at normal speeds. He also concluded that transmission above 1 GHz would be difficult to employ in mobile radiotelephone services.

Young realized that the path loss between a land radio transmitter and a mobile receiver increases as the frequency is increased. He came to the conclusion that the geographical features, buildings, and the like, influenced the propagation loss at different locations, even when the locations are only a fraction of a wavelength apart and that the only meaningful measure of signal strength is a statistical one. He observed that when the sample measurements were confined to a relatively small area of about 100m to 200m, the amplitude distribution of the sample followed a Rayleigh distribution. Another point that he observed was that, although an inverse fourth-power range law was applicable in the area that he tested the losses were in the order of 30 dB greater than the value computed over smooth earth. He termed this excess loss the "shadow" loss arising from the presence of many buildings and structures.

3.4.2 Okumura's Model

Okumura [3.2] carried out an extensive series of tests at VHF (200 MHz) and UHF (453, 922, 1310, 1430, 1920 MHz) under various conditions of irregular terrain and of environmental clutter.

He produced a set of graphs which described the distance and frequency dependencies of median field strength, location variabilities and antenna height gain factor for the base and the vehicular station, in urban, suburban and open areas over quasi-smooth terrain. He also produced a set of graphs from which various correction factors corresponding to terrain parameter describing different types of irregular terrain such as rolling-hill terrain, isolated mountain area, general sloping terrain, and mixed level sea path could be extracted.

As a result, Okumura presented a method for predicting the field strength and service area over the frequency ranges of 150 to 2000 MHz for distances of 1 to 100km, and for base station antenna heights of 30 to 1000m.

The basic equation presented by Okumura is

$$E_{mu} = E_{fs} - A_{mu}(f, d) + H_{tu}(h_{te}, d) + H_{ru}(h_{re}, f) \tag{3.8}$$

where E_{mu} is the median field strength (dB rel.1 μV/m) for an urban area in quasi-smooth terrain under a given condition of transmission.

E_{fs} is the free space field strength (dB rel. 1μV/m) for a given condition of transmission.

$A_{mu}(f, d)$ = the median attenuation relative to free space in an urban area, where the base station effective antenna height h_{te} = 200m, mobile station antenna height h_{re} = 3m, expressed as a function of frequency and distance by the curve in Fig. 3.4.

$H_{tu}(h_{te}, d)$ = the base station antenna height gain factor (dB) relative to h_{te} = 200m, expressed by the curve in Fig. 3.5 as a function of distance.

$H_{ru}(h_{re}, f)$ = the mobile station antenna height gain factor (dB) relative to h_{re} = 3m, expressed by the curve in Fig. 3.6 as a function of frequency.

The difficulty with this method is that, for efficient and accurate prediction, it needs to be formulated or computerized.

3.4.3 Hata's Formulation

Hata [3.14] used Okumura's measurements to derive an empirical formula for propagation loss in order to put his propagation prediction method to computational use. He presented the propagation loss in an urban area in the form of : A + B $\log_{10}$ R, where A and B are frequency and antenna height functions and R is the distance. Hata's formulation is applicable to system design for UHF and VHF land mobile radio services, and the agreement with Okumura's measurements is quite good, under the following conditions : frequency range 100-1500 MHz, distance 1-20km, base station antenna height 30-200m, and vehicle antenna height 1-10m.

Table 3.2 gives the experimental formula for propagation loss.

<u>**Table 3.2**</u>

$$L_p = 69.55 + 26.16 \log f_c - 13.82 \log h_b - a(h_m) + (44.9 - 6.55 \log h_b) \log R \quad (dB)$$

where

Urban area	$a(h_m) = (1.1 \log f_c - 0.7).h_m - (1.56 \log f_c - 0.8)$ for medium-small city.
	and
	$a(h_m) = 8.29 (\log 1.54h_m)^2 - 1.1 \quad f_c \leq 200$ MHz
	$a(h_m) = 3.2 (\log 11.75h_m)^2 - 4.97 \quad f_c \geq 400$ MHz
	for large city
Suburban area	$L_{ps} = L_p(\text{urban area}) - 2 (\log (f_c/28)^2 - 5.4 \quad (dB)$
Open area	$L_{po} = L_p(\text{urban area}) - 4.78 (\log f_c)^2 + 18.33 \log f_c - 40.94 \quad (dB)$

3.4.4 <u>Kozono and Watanabe Investigations</u>

The investigation by Kozono and Watanabe [3.3] leads to the production of correction factors for signal strength prediction at UHF due to buildings around the mobile station.

Four parameters were proposed in order to express the effect of buildings around a mobile station quantitatively. These parameters are as follows :

α, area factor for occupied buildings

α', extended area factor of occupied buildings

β, building volume over a sampled area

β', building volume over an extended area

The examination was carried out for each parameter in the 400 MHz and the 800 MHz bands.

α was defined as

$$\alpha = \frac{\text{Total occupancy area of building in a sampled area}}{\text{whole area of a sampled area}} \times 100\,\%$$

$$\alpha' = \frac{\text{Total occupancy area of building in an extended area}}{\text{whole area of an extended area}} \times 100\,\%$$

A sampled area is a circle about 250m in radius and an extended area extends the sampled area towards the base station, about 500m in width and length as shown in Fig. 3.7a.

Since the frequency, effective radiated power and base station antenna height differ for an individual base station, and the base-mobile distance differs in each sampled area, these were unified to the given reference values. The mobile antenna height was also unified to 1.5m. A relation between the local-section median E and each parameter was obtained :

$$E = -24.9 \log \alpha + 66 \quad \text{dB}\mu\text{V/m}$$

$$E = -24.6 \log \alpha' + 63.2 \quad \text{dB}\mu\text{V/m}$$

$$E = -20.5 \log \beta + 72.5 \quad \text{dB}\mu\text{V/m}$$

$$E = -20.9 \log \beta' + 73.6 \quad \text{dB}\mu\text{V/m}$$

Kozono and Watanabe claimed that highest prediction accuracy was obtained when β' was used. However, it was recommended that α was a more suitable parameter, considering the balance of prediction accuracy and the efforts required to calculate a parameter for a wide service area.

These experimental results were presented as a correction factor S for the basic median field strength curve [3.2]. The relationship between S and the parameter α is shown in Fig. 3.7b. An experimental equation was given as follows :

$$S = -25 \log \alpha + 30 \qquad \text{dB} \quad 3\% < \alpha < 50\%$$

3.4.5 Ibrahim's Model

Ibrahim [3.4] suggested two different models for land mobile propagation. 1) is an empirical model 2) a semi-empirical model. In both his models he introduced two factors U and L. U is a measure of the degree of urbanization of built-up areas, defined as the percentage of the building-site area, within the area under consideration, occupied by buildings having 4 or more floors.

He used 24 test squares in inner London at 2km range from the transmitter, and found the following relationship between path loss and U at two frequencies 168 MHz and 455 MHz.

$$PL_{168} = 117.7 + 0.085\ U$$

$$PL_{455} = 123.8 + 0.081\ U$$

L is a measure of building site area and was defined as the percentage of the test area that is covered by buildings regardless of their height. To examine the relationship between L and path loss he used test squares at 9 km range, except those severely shadowed from the transmitter by a rather prominent rise in the terrain. The following relationships were obtained as a result of this investigation :

$$PL_{168} = 137.95 + 0.150\ L$$

$$PL_{455} = 142.52 + 0.219\ L$$

He later on combined the two factors together to obtain the following equations :

$$PL_{168} = 117.37 + 0.154\ (L.U.)$$

$$PL_{455} = 123.6 + 0.144\ (L.U.)$$

The combined factor is the percentage of the test square area that is covered by buildings of a certain number of floors or more.

He also considered the influence of the relative mobile spot height on the median path loss, and obtained the following equations :

$$PL_{168} = 142.98 - 0.45\ H$$

$$PL_{455} = 154.16 - 0.56\ H$$

In the empirical model Ibrahim used a multiple regression analysis to derive an equation describing path loss in terms of range (m), U, L, and H (m). The equation obtained is :

$$PL_{455} = -42.33 + 47.76 \log d + 0.268\ L - 0.39\ H + K_{455}$$

Where $K_{455} = 0.087U - 5.2$

The parameter K is used for highly urbanized areas of the city, otherwise it is set to zero.

And

$$PL_{168} = -33.76 + 43.29 \log d + 0.261\ L - 0.35\ H + K_{168}$$

Where

$$K_{168} = 0.088U - 5.78$$

Ibrahim used his measurements at different frequencies to derive a frequency dependent expression for path loss prediction.

$$PL = 11.25 - 20 \log f + [40 + 14.15 \log \frac{f + 100}{156}] \log d + 0.265L - 0.37\ H + K$$

His semi-empirical model was based on Eglis method by assuming that the median path loss is the sum of the theoretical plane earth loss and an excess "clutter factor" termed B, and hence he proposed the following model

$$PL = 40 \log d - 20 \log (h_t\ h_r) + 20 + \frac{f}{40} + 6.18L - 0.34\ H + K$$

where $K = 0.094\ U - 59$

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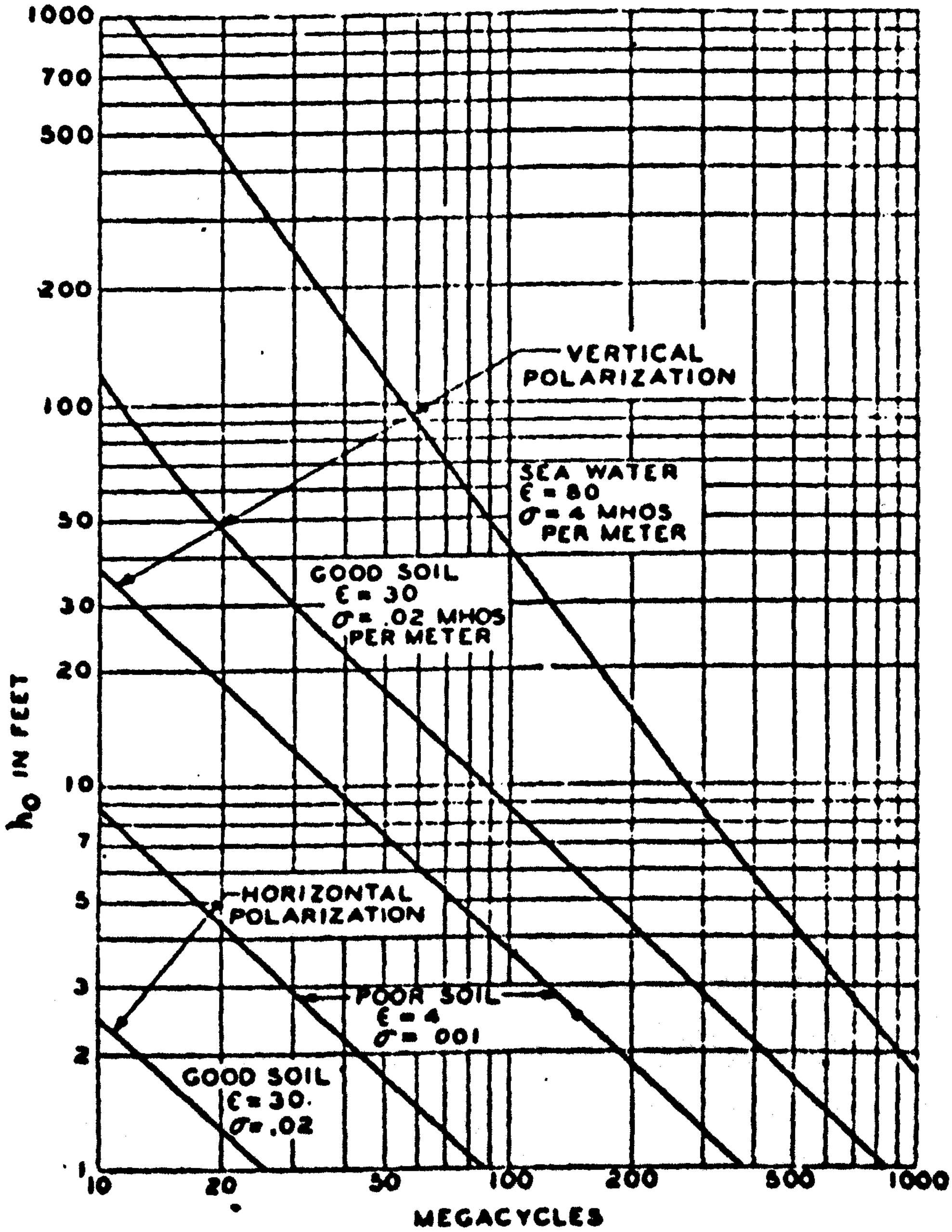
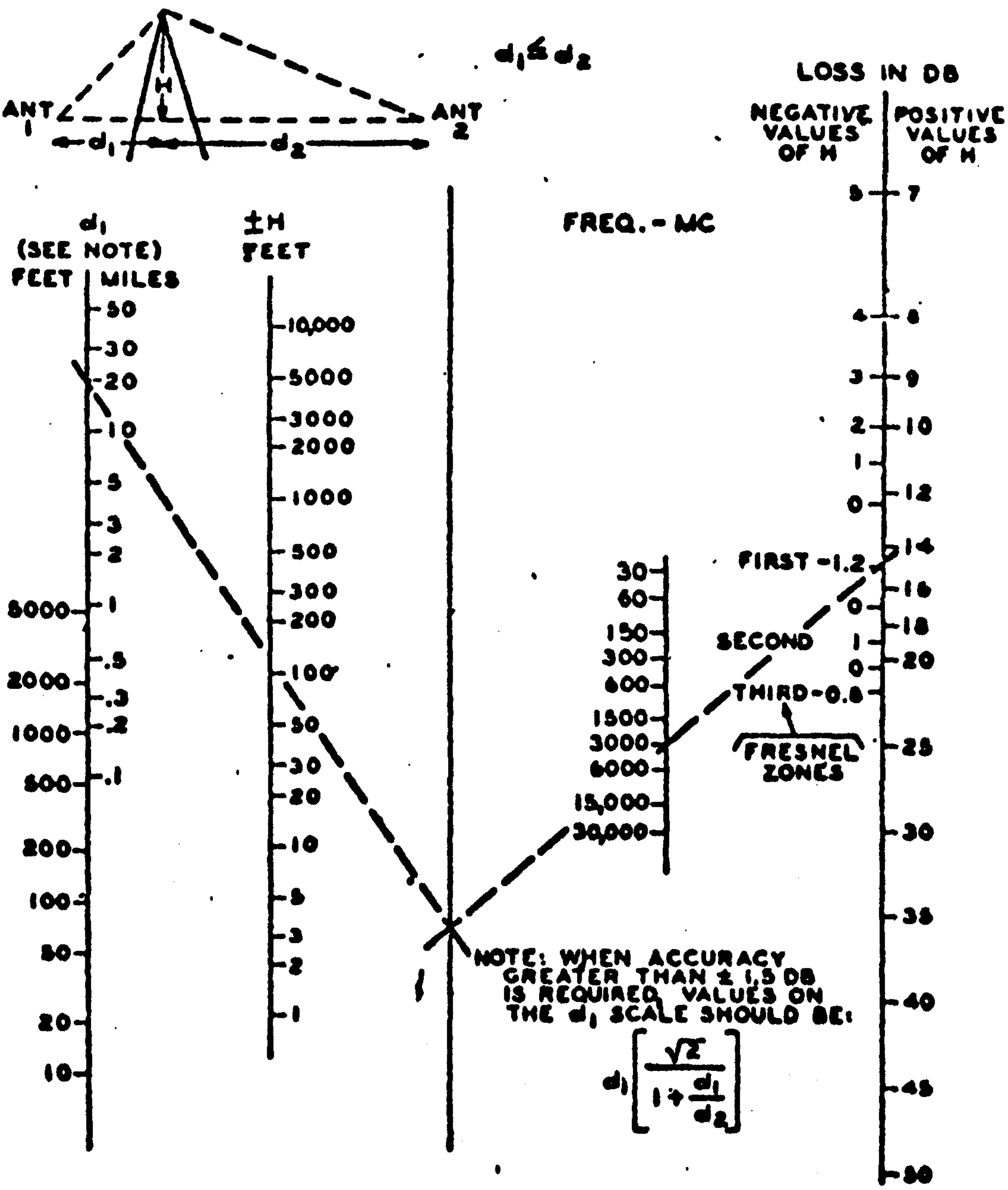


Fig. 3.1 Minimum effective height.



$$d_1\left[\frac{\sqrt{2}}{1+\frac{d_1}{d_2}}\right]$$

Fig. 3.2 Shadow loss relative to free space.

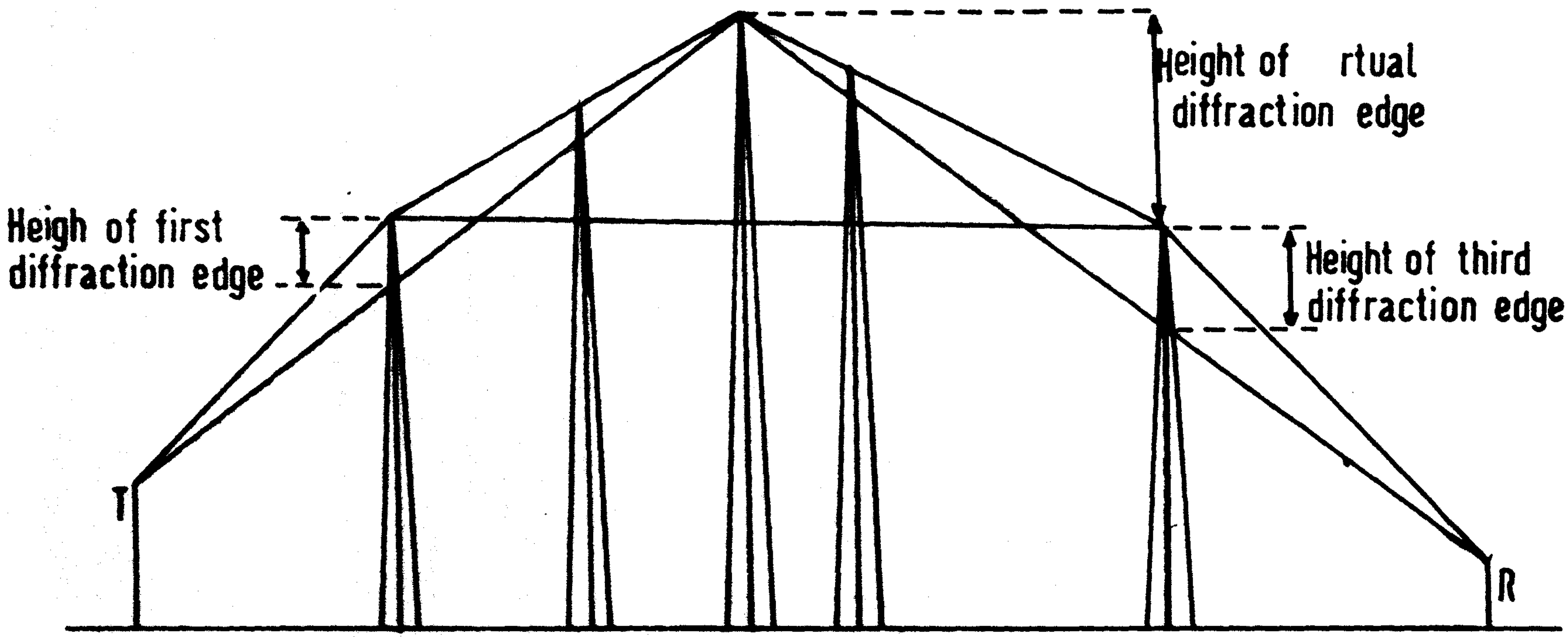


Fig. 3.3 Construction of virtual
diffraction edge.

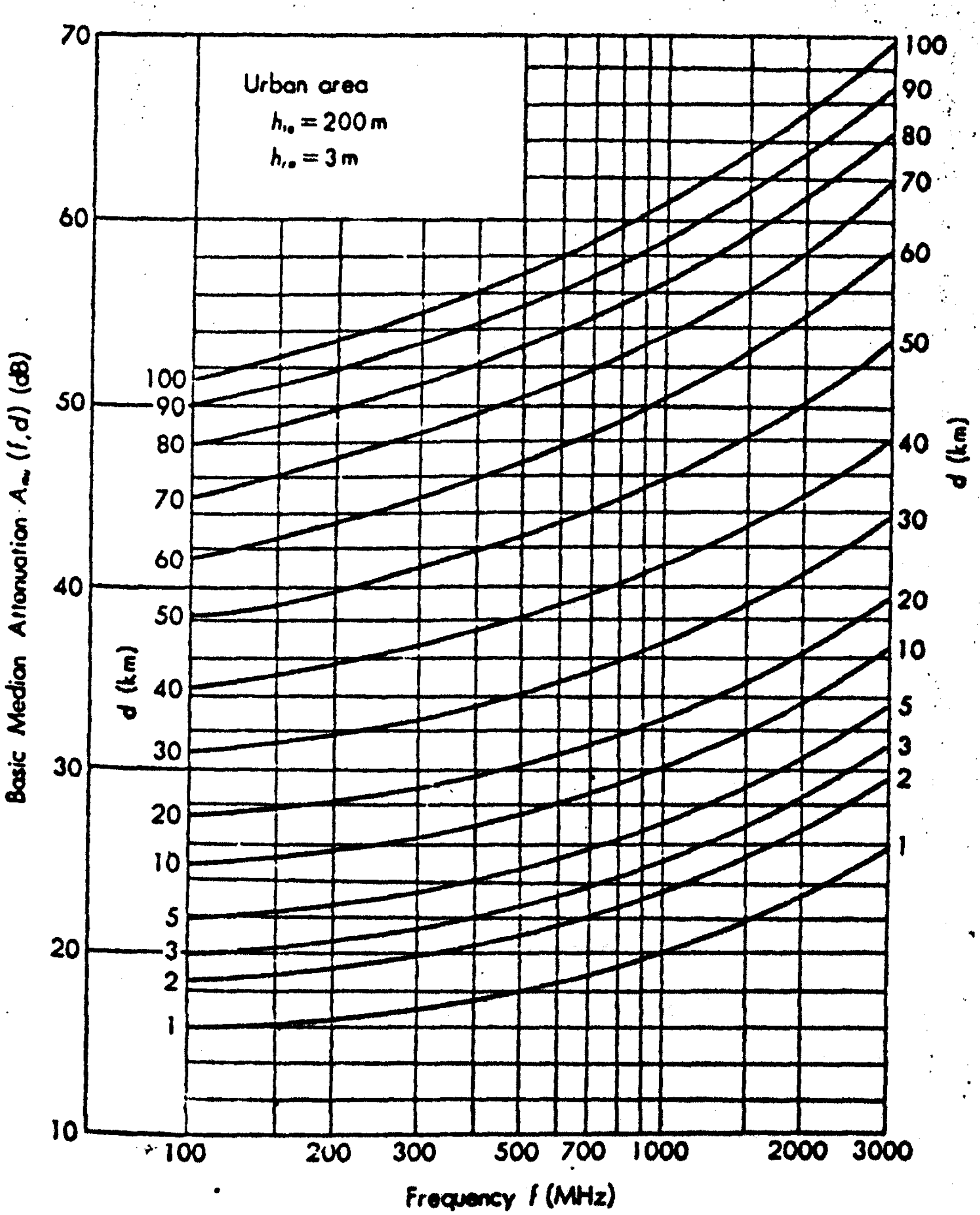


Fig. 3.4 Prediction curve for basic median attenuation relative to free space in urban area over quasi-smooth terrain, referred to h_{te}=200m, h_{re}=3m.

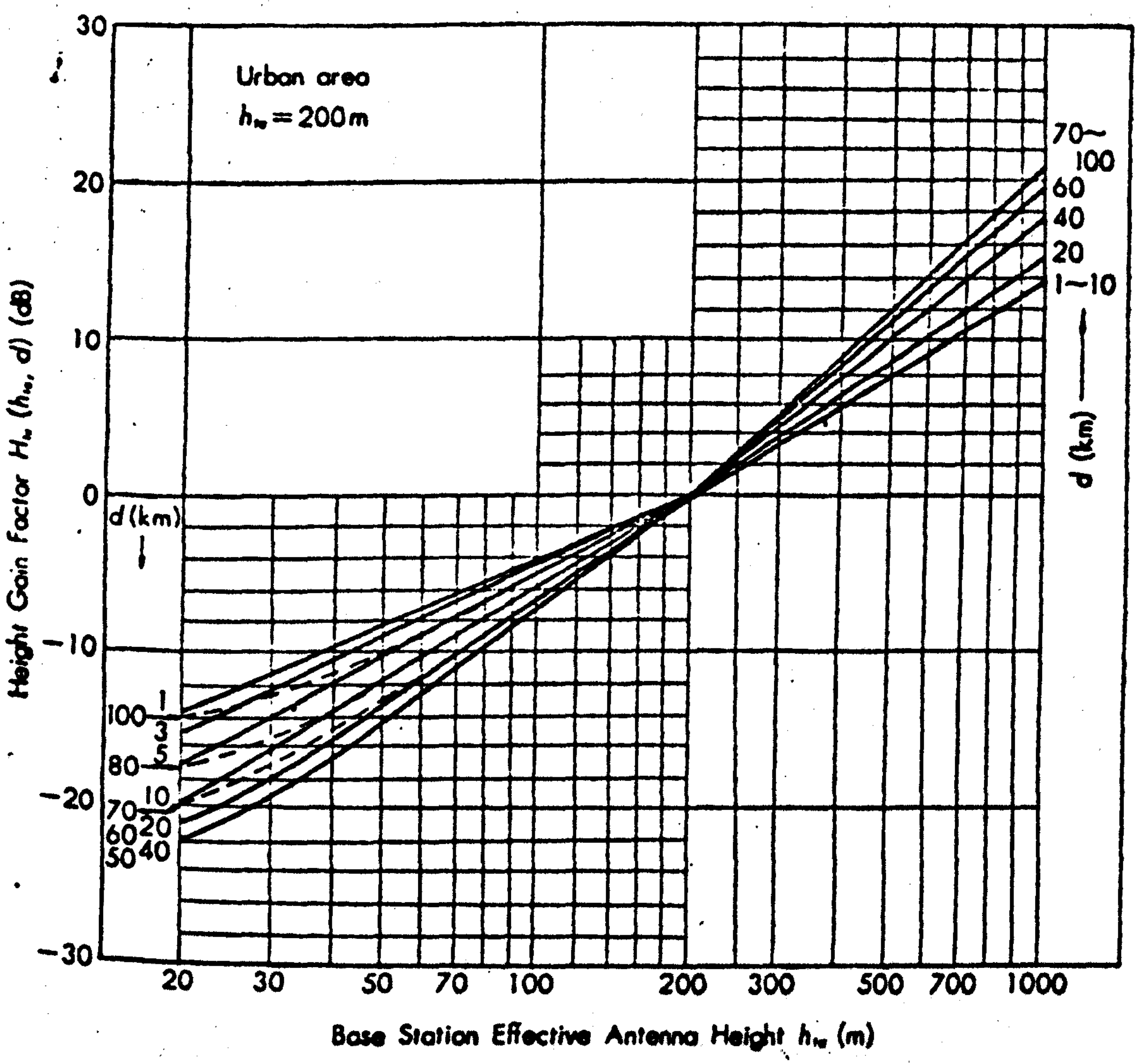


Fig. 3.5 Prediction curve for basic station antenna height gain factor referred to h_{re}=200m, as a function of distance.

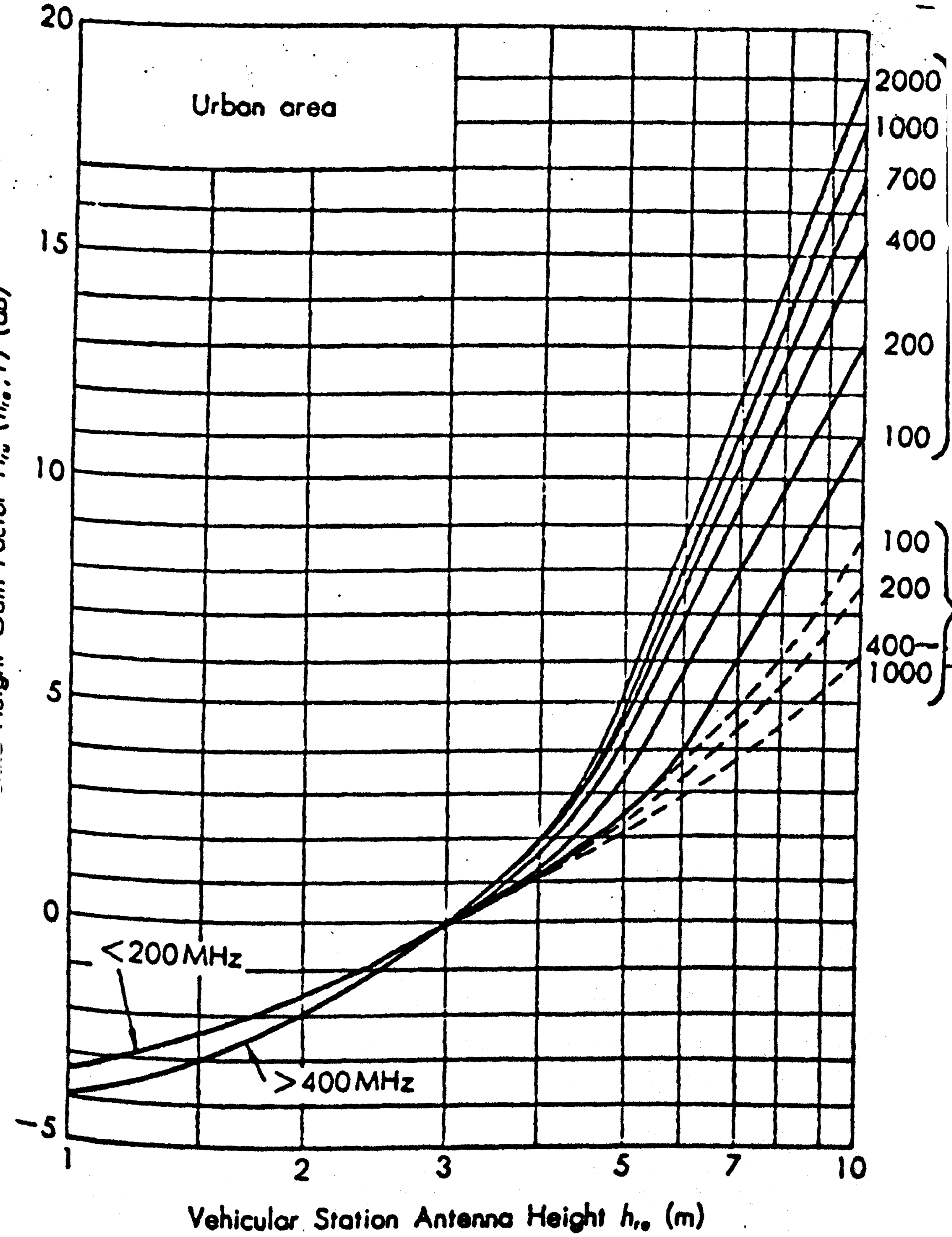


Fig. 3.6 Prediction curves for vehicular antenna height gain factor in urban area.

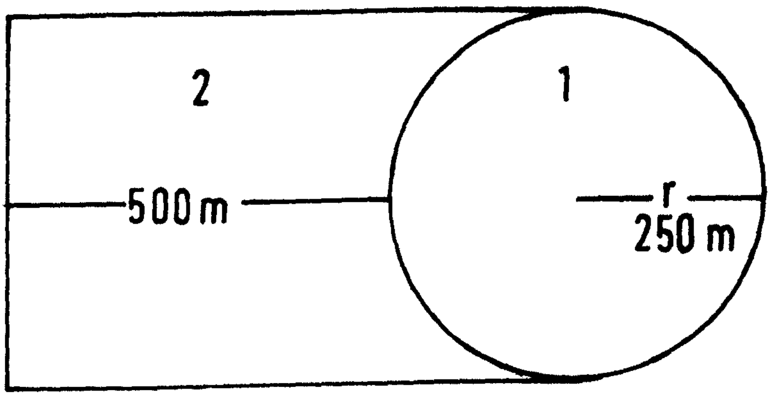


Fig. 3.7(a)

1: A sampled area to define local-section mdian.

2: An extended area.

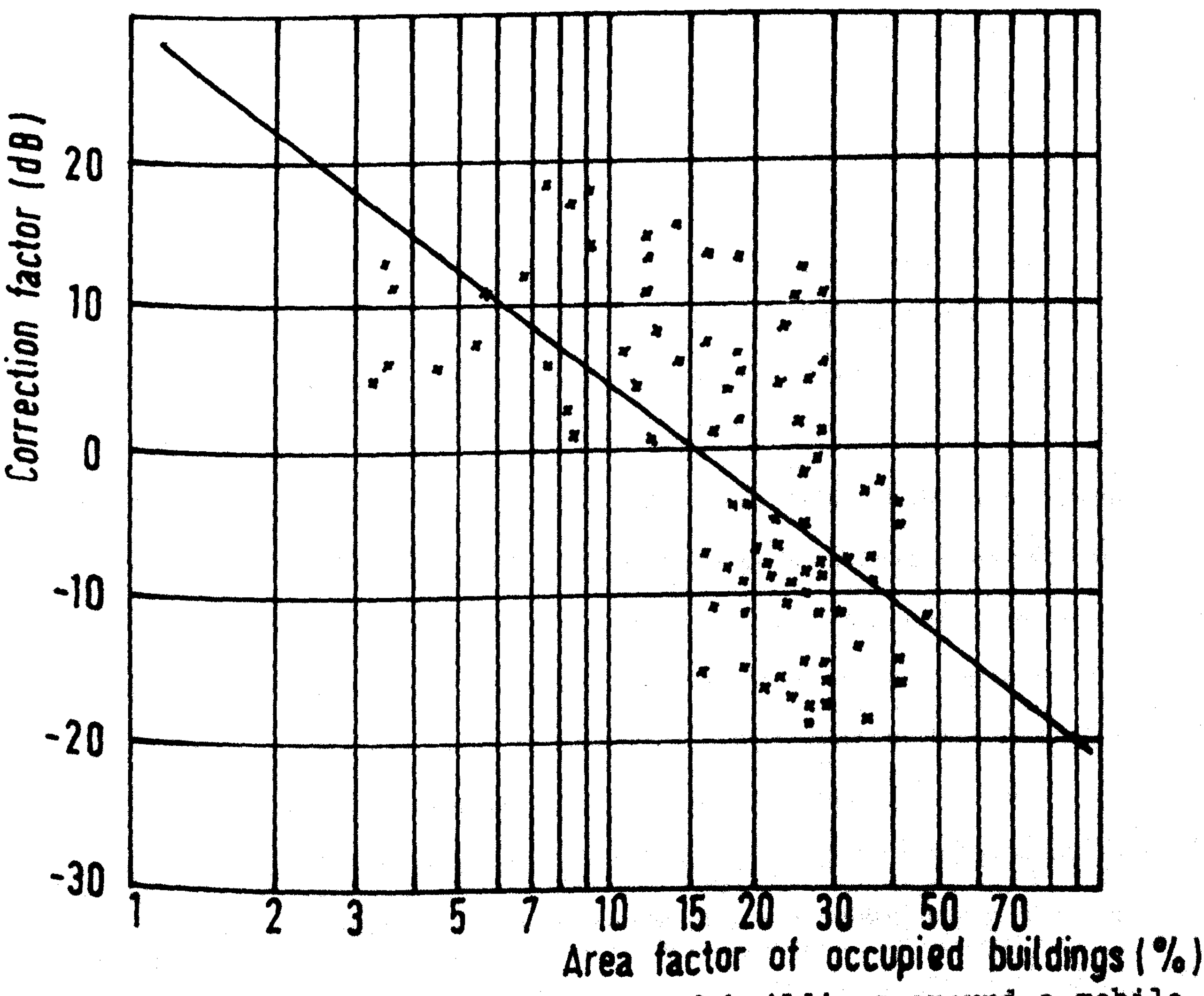


Fig. 3.7(b) Correction factor of buildings around a mobile station for the basic median field strength curve.

CHAPTER 4

EXPERIMENTAL EQUIPMENT

A detailed investigation of the spatially distributed r.f. signal patterns created when the propagation path contains many obstructions necessitates the collection of large amounts of data. Several methods of recording the data are available and it therefore pays to give careful consideration to this matter in order to choose the best method of recording the data in any particular case. The data can be recorded on a multichannel analogue FM tape with appropriate facilities, but this involves the problem of digitizing the analogue signal in a way which is suitable for analysis by digital computers. The other obvious method is to convert the analogue signal into a digital signal and directly record it on a suitable medium. The difference is that of analogue versus digital, continuous versus discrete. But the advent of the microprocessor has made digital recording even more attractive. With a digital system a cheap and reliable bulk storage medium is necessary.

A decision was therefore made to go for a digital data logging system and some time was spent on choosing the best storage medium. Several different storage media are available, such as hard disc, floppy disc, cartridge and magnetic tape. Hard disc and floppy disc can easily be eliminated, because of problems involved in using them in a mobile environment. Therefore a decision had to be made between a cartridge and magnetic tape. If an industry-compatible system was required, one would opt for magnetic tape, which is also cheap and offers a large storage capacity. Since the data is generated continuously in this system, a buffered tape unit is required.

A block diagram of the complete system is given in Fig. 4.1. It consists of a Singer NM37/57 receiver, a 380Z microcomputer and a SE 8800 buffered tape unit.

4.1 THE RECEIVER NM-37/57

The NM-37/57 is a programmable, precision electromagnetic interference/field intensity (EMI/FI) meter for the measurement of conducted or radiated RF interference within the frequency range 30 MHz to 1 GHz in accordance with standard military and commercial EMI test specifications. The instrument performs automatic and semiautomatic testing when supplied with appropriate command signals and provides outputs of signal amplitude and frequency that are suitable for input to a digital data processing system. The instrument is all solid-state, rugged and portable, and operates from internal rechargeable batteries. It is an ideal unit for use in conjunction with a simple lightweight computer and recorder to form a high-speed, high-volume mobile test station.

A three-position rotary switch provides selection of three calibrated bandwidths of 10 KHz,100 KHz and 1 MHz , there is also a five-position pull-turn-push switch which allows 80 dB attenuation to be inserted in 20 dB steps. A dB meter displays signal levels in microvolts, dB referred to 1μV, and dBm on three scales: a logarithmic microvolt scale from 1 to 1000 μV, a linear dB scale from 0 to 60 dB referred to 1μV, and a linear dBm scale from -107 to -47 dB referred to 1mW.

4.1.1 Characteristic of the Receiver

The characteristic of the receiver was plotted, using the LOG video terminal as the output (Fig. 4.2). It is observed that the receiver possesses a dynamic range of about 70 dB. The linear section of the characteristic is between -114 dBm (i/p) = 0.07V (o/p) and -40 dBm (i/p) = 0.65V (o/p). A relatively good signal to noise ratio at -114 dBm allowed the whole range to be used. The next stage is to put this characteristic into a suitable form, as the input to the ADC.

4.2 INTERFACE TO THE ADC

A suitable voltage range for the ADC would be 0–2.5V. If the linear section of the receiver o/p is converted to this range (0–2.5V) then a resolution of $\frac{114 - 40}{255} = 0.29$ dB (for an 8-bit ADC) would be achieved. The circuit used is shown in Fig. 4.3. One of the inputs to the operational amplifier is varied by R_1 to give 0V for an input of 700mV from the receiver; using R_1 the output can be set to 2.5V for an input of 0.65V. Once the second step is carried out the first step would need re-checking. Therefore the two steps are repeated iteratively until the range (0–2.5V) is achieved. Obviously this circuit has a bandwidth wider than is necessary, therefore a knowledge of what minimum bandwith is needed would be useful. The obvious way is to calculate the maximum slow rate of a typical fade, from which the bandwidth can be deduced. An approximate method is used to find the minimum bandwidth in this case.

In a typical fading pattern (Fig. 4.4), a fade is expected every $\lambda/2$. If the maximum operating frequency is 900 MHz and the maximum permissible speed of the vehicle is 100 m/s then one typical fade lasts for $\frac{3 \times 10^8}{2 \times 900 \times 100 \times 10^6}$ = 1.6m sec. Assuming that the fading pattern is repetitive with this period, the fundamental harmonic of this pattern would be 600 HZ. Allowing for the significant harmonics to go through and due to the sharp edges, a bandwidth of 16 KHz was used.

A low pass Butterworth filter (Fig. 4.5) was built using one low pass filter of -40 dB/decade cascaded with another of -20 dB/decade to give an overall roll-off of -60 dB/decade. For a Butterworth filter, the magnitude of the overall closed loop gain must be 0.707 (0dB) at ω_c. To guarantee that the frequency response is flat in the passband, the following design values were used :

$$R_1 = R_2 = R_3 = 10\ K\Omega$$

$$C_3 = (1/\omega_c R) = 1\ nf$$

$$C_1 = \tfrac{1}{2} c_3 = \tfrac{1}{2}\ nf \qquad C_2 = 2C_3 = 2\ nf$$

4.3 THE TAPE UNIT

The buffered tape unit envisaged for this system consists of a UBI (Universal Buffered Interface), a formatter and a digital tape transport (Fig. 4.6).

4.3.1 The UBI

The SE 8800 Universal Buffered Interface consists of a single microprocessor-controlled printed circuit board that mounts on the SE 8800 Digital Tape Transport and is interfaced to the transport-mounted SE 8800 Formatter. It provides read or write data buffering in a single buffer store of up to 4K bytes. The input/output to/from the UBI can be either 8 bit parallel (centronic type) or serial (RS232 C/V24) information, where both data and commands share the same lines.

A series of DIL switches allows the selection of the serial/parallel modes of operation, and additionally, when in the serial mode, selection of the data format (length of data bits 5, 6, 7 and 8 and the number of stop bits and parity) and transmission speed (300 to 19200 bauds). Connection to users equipment is made via a cannon 25-way connector (serial mode) or 50-

way ribbon cable (parallel mode).

The UBI controls the writing and recording of data, tape motion and status signals, and interprets the various commands between the computer and formatter. To do this, the interface uses a microprocessor (an Intel 8748 or 8035) and 2K EPROM plus 4K RAM for data storage. The 4K RAM limits the data record length to 4K bytes.

4.3.2 The Digital Tape Transport

The SE 8800 digital magnetic tape transport is designed for use with 0.5 in. computer tape for digital recording. Electrical and physical compatibility with similar industry-standard equipment is incorporated into the design. The transport is a modular rack-mountable machine, it produces NRZ1 (Non-return-to-zero) or PE (Phase encoded) tapes, compatible with IBM, ECMA, ANSI and BSI magnetic tape recording formats, using 0.5 in. computer grade magnetic tape of up to 10.5 in. reel diameter. A microprocessor is employed to provide sequential control, interlocks and diagnostic functions within the transport. A micro-diagnostic unit is built into the transport, it is accessible from the front and provides complete off-line checks. The transport is software controlled as well as hardware controlled. The data density is 1600 chars/inch. The data format is 9-track (8 data bits and one pority bit), and the recording method is phase encoding. The tape read/write speed is 45 inch/sec and the rewinding speed is 200 inch/sec. The data transfer rate between the UBI and the tape transport is dependent upon the recording format and the tape speed. The synchronous data ratio is 72K bytes/s for a 45 i.p.s. transport in PE mode, or 36K bytes/s for NRZ mode. To determine the average transfer rate, consideration should be given to : record length (including postamble and preamble for PE), inter-recording gap, recording density, tape speed and formatter start/stop delays. These will determine the maximum mean data rate, but allowance must be made for error routines; i.e. backspace-erase-rewrite sequences, which are user-transparent except for the elapsed time.

Data transfer to the UBI may be achieved in short bursts (e.g. 1 record) up to a maximum rate 165k bytes/s parallel mode or 1.9k bytes/s serial mode.

4.3.3 Average Data Rate

Assuming 45 i.p.s. transport, 2k bytes/record and PE time for commands = 0.2 ms

Time for commands = 0.2 ms

Data transfer to store = 125 k bytes/sec

Time to fill store = $(2048/125 \times 10^3) = 16$ ms

Time to accelerate tape deck to 45 i.p.s. ready for writing = 10 ms

Time taken from write-to-read head (0.15in) = 3.3 ms

Time taken to transfer data = $(2048/72 \times 10^3) = 28.45$ ms

Time taken to stop = 11.5 ms

Total time/record (2k bytes) = 69.45

Therefore average data rate for 2k byte records P.E is

$$(2 \times 10^3/69.45 \times 10^{-3}) = 28\text{k byte/s}$$

Since the tape unit is software controlled as well as hardware controlled, it seems reasonable to employ a microcomputer to control the flow of data to/from the tape unit.

4.4 380Z RESEARCH MACHINE MICRO-COMPUTER

For the basic mini disc system the hardware comprises a 380Z central processor and two disc drives (housed in a single cabinet), a keyboard and a visual display. Additional items of hardware can be added to the basic system, for example a printer.

The basic 380Z used with a mini disc system is a two board microcomputer (CPU and VDU) with 4K of ROM and 56K RAM. The system includes an I/O connector which supplies and accepts TTL-level signals through a memory mapped part. It can be used to drive a centronics printer or a variety of other devices. It provides a serial interface part which can drive an RS232 interface at speeds from 110 baud to 19200 baud. The system uses double sided mini-floppy discs each of which can store 144K bytes of programs and data.

An ADC is now required to digitize the output of the receiver, and suitable software should be written to take these samples and output thus to the tape unit. The 380Z analogue input/output board was carefully studied and found to be suitable for this purpose.

4.4.1 236-222 380Z Analogue I/P-O/P Board

The Analogue I/O board is a completely compatible 380Z board. It provides 16 channels of analogue input and two analogue outputs, both with 10-bit resolution. The ADC may be set to one of seven voltage ranges and the outputs independently set to one of four voltage ranges compatible with most analogue circuitry and industrial/process control applications. The board also provides a serial I/O interface and a real time clock/timer. Software control of this board must be written in machine code.

4.4.2 Analogue Input Characteristics

No. of channels	16
ADC gain ranges	±2.5V, ±5V, 0-5V, +10V, 0-10V
Amplifier gain	X1

Input impedance	> 100KΩ
Filter Fc	500 KHz
Input settling time	4μs
Conversion time	22μs
Throughput time	50μs/channel
Resolution	10 bits
Interrupt comparator	
Input impedance	1 MΩ

The input data rate to this ADC can be as high as 20K byte/sec which is much higher than that of the serial interface. Therefore it seems reasonable to use the parallel interface to allow maximum possible use of the ADC, hence the PIO/RTC interface development board was included in the system. Since there is more than one board containing interrupt generating devices, the boards must be patched to determine the priority of interrupts. The Interrupt Enable O/P (IEO) of the PIO board was connected to the IEI of the ADC board, since the PIO has the highest priority and the IEI of the PIO and the IEO of the ADC were left unconnected. Pulses from a speed transducer drive the ADC interrupt.

4.5 S8013 SPEED/DISTANCE TRANSDUCER

The S8013 speed/distance transducer is made of aluminium alloy; it can be rotated in either direction and is totally sealed and resistant to oil, water, petrol, antifreeze and brake fluid. Its operating temperature is -20°C to +60°C and it can be rotated at up to 4000 rpm. The output is square-wave pulses from open-collector TTL, CMOS and LSI compatible. The output frequency is 100 pulses/revolution, it is a high specification transducer for vehicle testing, decoding of mechanical instruments etc. The required power supply is in the range 5-28 volts.

4.6 SYSTEM POWER REQUIREMENTS

The power requirements for individual items of equipment are as below :

Tape unit	400 W
Receiver	30 W
380Z (complete system)	100 W

demanding a total power of 530 W. The fact that two of these items are mains driven, requires the provision of an invertor.

4.7 APLAB STATIC SINE WAVE INVERTOR

Static sine wave invertors are used in all cases where only D C sources such as batteries are available, and an A C mains supply is required, such as in a mobile lab. The Aplab invertor is lightweight, and has a small volume, high stability of frequency, stabilized output voltage, low waveform distortion, protection against short circuit, overload and polarity reversal and very high efficiency. The sine wave O/P (as opposed to the rectangular waveform) offers additional advantages as highly sensitive precision equipment such as a magnetic tape recorder, can be driven from this invertor. Since it does not interfere with radio communication (due to the fact that it is operated with a sine oscillator and only sine-wave voltages are being produced) the simultaneous operation of radio and high frequency measuring equipment is possible.

The invertor is fed from two 12V high duty batteries connected in series. The specifications are :

D C input voltage	24V ± 10%
O/P input voltage	115/230V ± 5V
Frequency	50 Hz ± 2%
Max continuous power O/P	1000 VA
Efficiency	60%

The batteries are charged by an alternator drivern by an extra pulley available on the engine. Table 4.1 presents the current supplied by the alternator at different speeds.

Table 4.1

Gear	MPH	Current (AMPS)
	5	14
1ST		
	10	25
	10	36
2ND		
	20	40
	20	47
3RD		
	25	50

At stand-still, normal tickover speed, charging current is 8 amp, only a quarter of battery load. Therefore, this imposes a minimum vehicle speed of at least 10 miles/hour.

4.8 SYSTEM REQUIREMENTS

The system should be capable of sampling the signal at required intervals, digitizing it and storing the data in a first in, first out (FIFO) buffer; it should keep looking at the "T.U. busy" line to see if it is ready to accept data, and should conduct a transfer if possible. A facility is necessary, by which a file mark can be put on the tape whenever required. It was decided to write the data in blocks of 2K bytes (Fig. 4.7). The system is also required to read the data back and do some on line analysis. This is useful when the tests are carried out away from a main frame computer facility since it provides a knowledge of how successful the data collection has been, hence saving time and money if anything goes wrong. A flow chart of the system software is shown in Fig. 4.8.

An interrupt to the ADC board from the speed transducer causes the CPU to attend to the ADC board and put the digitized data in the FIFO. The busy line of the T.U. is checked constantly and if it is ready, then the data is sent to the T.U. The software also checks if a key on the keyboard has been pressed (except ESC or LF) and if so, it puts a file mark on the tape and continues to collect data. If ESC or LF has been pressed, a file mark is put on the tape and data collection is terminated. If the vehicle speed is much too high and the FIFO overflows, a message is printed on the monitor to indicate the loss of data, and data collection is automatically terminated. This may not be necessary in this particular system since the maximum vehicle speed is 180 km/h. But for other systems which might be interfaced to this one, several recordings might be necessary following each sampling, hence reducing the maximum speed.

4.9 SOFTWARE PREPARATION

The following software were written :

1) ADC1P - this is a program to send the data from the FIFO buffer to the T.U buffer and also accepts the interrupt from the speed transducer to sample the signal, digitize it and write it in the FIFO buffer. It prints a message "buffer full" when the FIFO buffer is overloaded.

2) ADC2 - this program does the same job as ADC1P but instead of sending the data to the T.U. it writes it on the monitor in hex. This program is particularly useful when the system is being calibrated. By feeding the receiver from a signal generator, a series of readings can be taken in order to plot a graph of input signal level versus output of ADC which appears on the VDU screen in hex.

3) READX - this program produces an exact copy of any file from the tape

onto the disc. The name of the file can be specified by typing READX FILENAME. BAS. BAS is added to specify that the file is to be read in Basic. This file can now be analysed in Basic, but the snag is that the available memory size on 5½ inch disc is only 150K bytes, and a file with 40K bytes on tape requires 160K bytes on disc to enable Basic to read the file, since each byte on tape requires 3 bytes on disc (eg 11001110 on tape means 190 on disc which is 3 bytes) and each number is followed by a carriage return which makes it 4 bytes. Therefore some on line analysis must be carried out.

4) RDHIS - this program carries out some on line analysis before writing the file onto the disc. The so called row data is processed and formed into a histogram and then recorded onto the disc, an example of a histogram is shown in Fig. 4.9. Since there are only 255 levels in each histogram, (these 255 levels are then coverted to dBm), the required memory size is 255 x 4 x 3 = 3060 bytes, 3 being a factor to account for files with a large number of blocks.

A small program was written to enable the operator to communicate with the T.U. using the keyboard and the program starts at location 0100 as follows:

0100	F7	0108	01
0101	02		
0102	28		
0103	FC		
0104	F7		
0105	05		
0106	C3		
0107	00		

The operator is now able to communicate with the T.U. Table 4.2 describes different commands.

Table 4.2

CTRL P	0	read
CTRL P	1	write
CTRL P	2	space forward
CTRL P	3	space reverse
CTRL P	4	rewind
CTRL P	5	reverse off line
CTRL P	6	write file mark
CTRL P	7	status request
CTRL P	8	read continuous
CTRL P	:	clear
CTRL P	;	edit.

5) SFD - this is a program to enable the operator to take the tape to any desired position provided there is already data on the tape, since the program relies on counting the blocks of data. This program becomes useful if one tape is to be used in a few series of tests when the system is switched off in between, or when a specified block or file of data is to be read.

6) ANALHIS - this program was written in Basic and uses the file created by RDHIS to calculate the various statistical parameters such as standard deviations and the 1%, 5%, 10%, 50%, 90%, 95%, 99% quantiles of the data in each test square.

Copies of all the computer programs can be found in Appendix A.

4.10 THE CHOICE OF VEHICLE

One of the main objectives of this part of the project was to construct a measuring and recording system that could be installed in a vehicle typical of those used to carry mobile radio installations. At first it was thought that a Ford Escort would be a good choice, but it was soon realized that there was not sufficient space in the engine compartment to mount the generator. The car should clearly have enough space for all the equipment and also have enough room by the engine to accommodate a generator. After careful consideration a Rover 2600 was thought to be most suitable for this purpose. The various items of equipment were carefully mounted on anti-vibration mountings. The back seat had to be removed in order to find enough room for the T.U. The receiver and 380Z were mounted in the space between the back seat and the boot and there was sufficient room in the boot to put the inverter and the batteries. These were all arranged in such a way as to ease access to all the equipment. There was enough space under the dashboard on the left of the driver to accommodate the 380Z monitor; the keyboard simply went on the dashboard. Extra facilities were added to make the job of the operator easier, such as indications by the driver to show if all equipment is on standby; a series of switches enables the operator to choose either serial or parallel interface and to stop data collection simply by disconnecting the interrupt coming from the speed transducer. This is useful when data is not to be collected on part of the preplanned route. Two switches at a distance from each other on the control board were employed to reset the 380Z by pressing them both at the same time. The reason for this is to avoid accidental reset. An LED indicates if the T.U. is ON LINE. In order to make sure that data is being collected a mini amplifier was connected to the T.U. to monitor the movement of the tape.

Figs. 4.10a and 4.10b show two photographs of the car and the equipment installed in it.

4.11 OPERATION OF THE SYSTEM

The procedure to start the system for data collection is as follows :

1) Switch the invertor and all the other equipment on.

2) Load the 380Z with appropriate disc (ie ADC1P)

3) Bring the tape to BOT and make sure the T.U. is ONLINE.

4) Press B on keyboard to load the system program.

5) Enter ADC1P to load the program.

6) Set the serial/parallel switch to parallel position.

7) Put the interrupt switch to on position.

8) Enter K on the keyboard.

The system is now ready to collect data and at the end of data collection either LF or ESC is entered after which no data is accepted, and the 380Z loads the system program, ready for next command. If only a file mark is required, any key except LF or ESC can be pressed and after this the next batch of data would be recorded.

To read the data back, change to serial interface, bring the tape to BOT, enter RDHIS - file name, file type, and then 0 followed by 4 and 6 to specify printer option and baud rate. By pressing K the system starts to read data from the tape on to the disc.

4.12 ANALYSIS OF DATA

The system was initially designed to do some on site preliminary analysis before introducing the tape to the main frame, but later on the system was found to be quite sufficient in itself for most of the analysis.

After producing the histograms on the disc a simple program in any language can be used to analyse the data. The program was called ANALHIS and it was written in Basic; this program draws the histogram on the monitor and computes various statistical parameters such as the 1%, 5%, 10%, 50%, 90%, 95% and 99% values of the sample and also the variance and standard deviation and some other parameters that will be explained in another chapter. A copy of all this information can be obtained from a suitable printer connected to the 380Z.

4.13 FIELD TRIALS

An extensive series of field trials were carried out in Liverpool (445, 900 MHz), London (940 MHz) and the Cheshire (139 MHz) area; the first two were classed as urban and suburban areas and the last as a rural area.

The analysis was based on London data, since there was more data available in these tests than any other tests to make the analysis statistically valid. A quite different analysis was carried out on the Cheshire data, since it was classed as rural.

The routes were planned prior to the tests. They were planned using ordnance survey maps to cover as much area as possible in a 500m square and each square was named as a file.

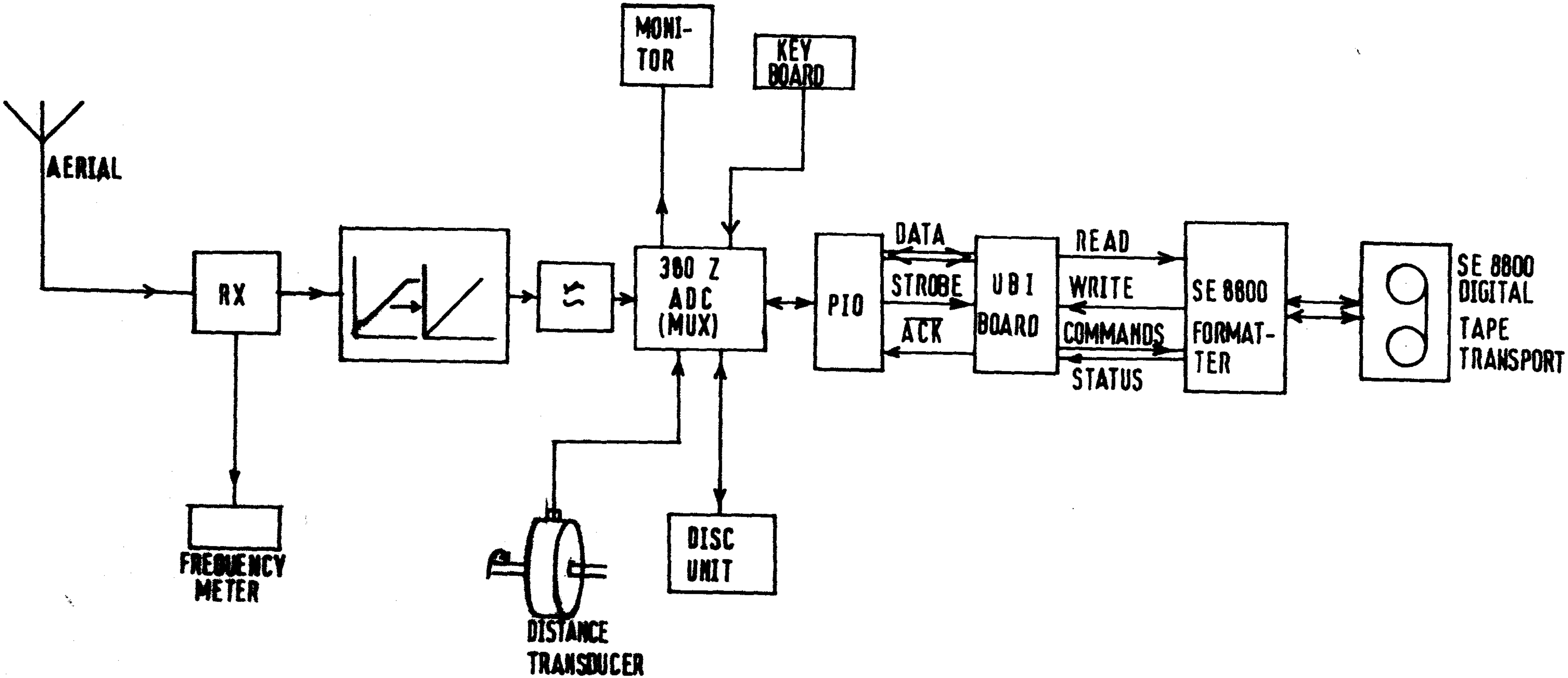


Fig.4.1 BLOCK DIAGRAM OF DATA LOGGING SYSTEM

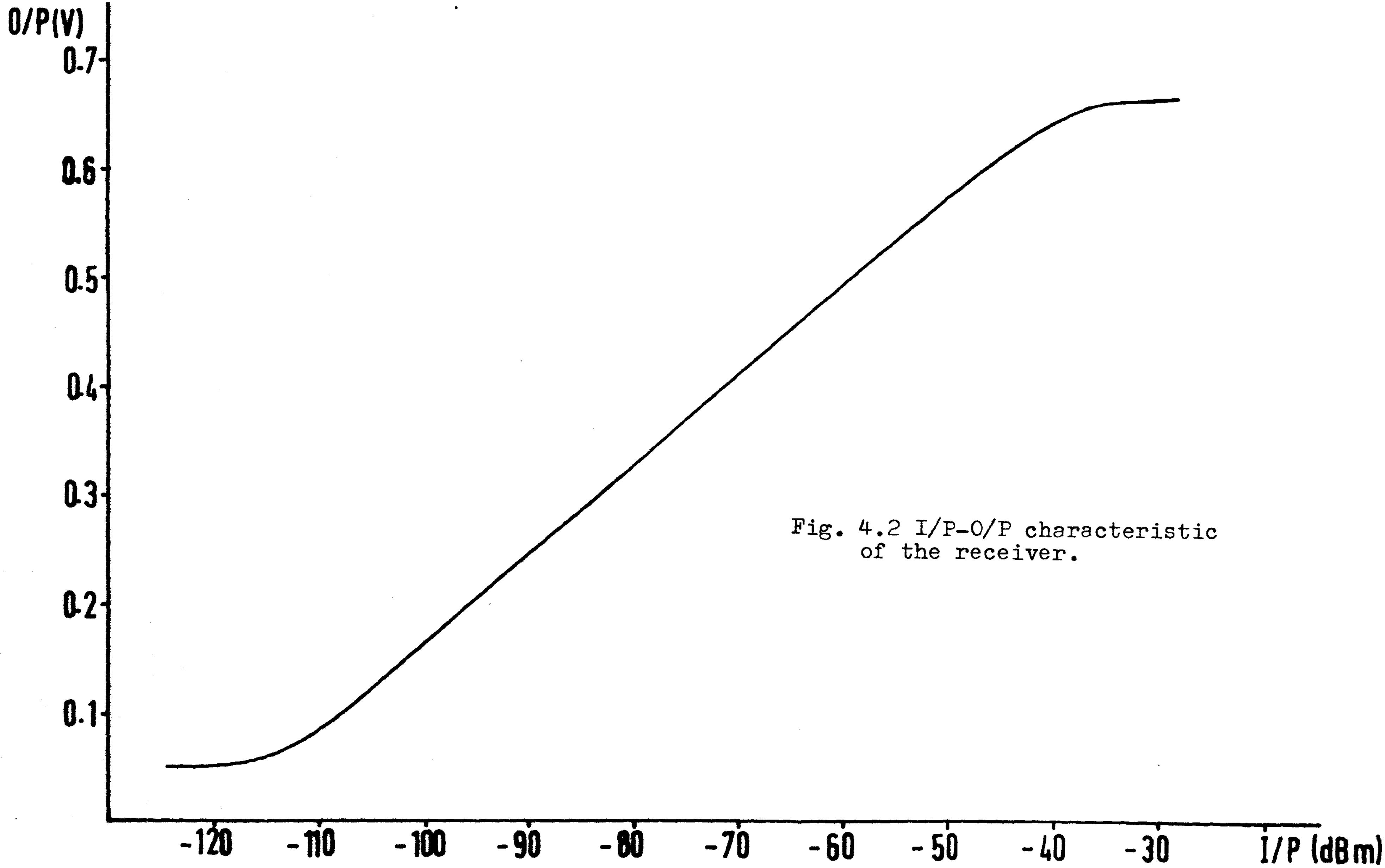


Fig. 4.2 I/P-O/P characteristic of the receiver.

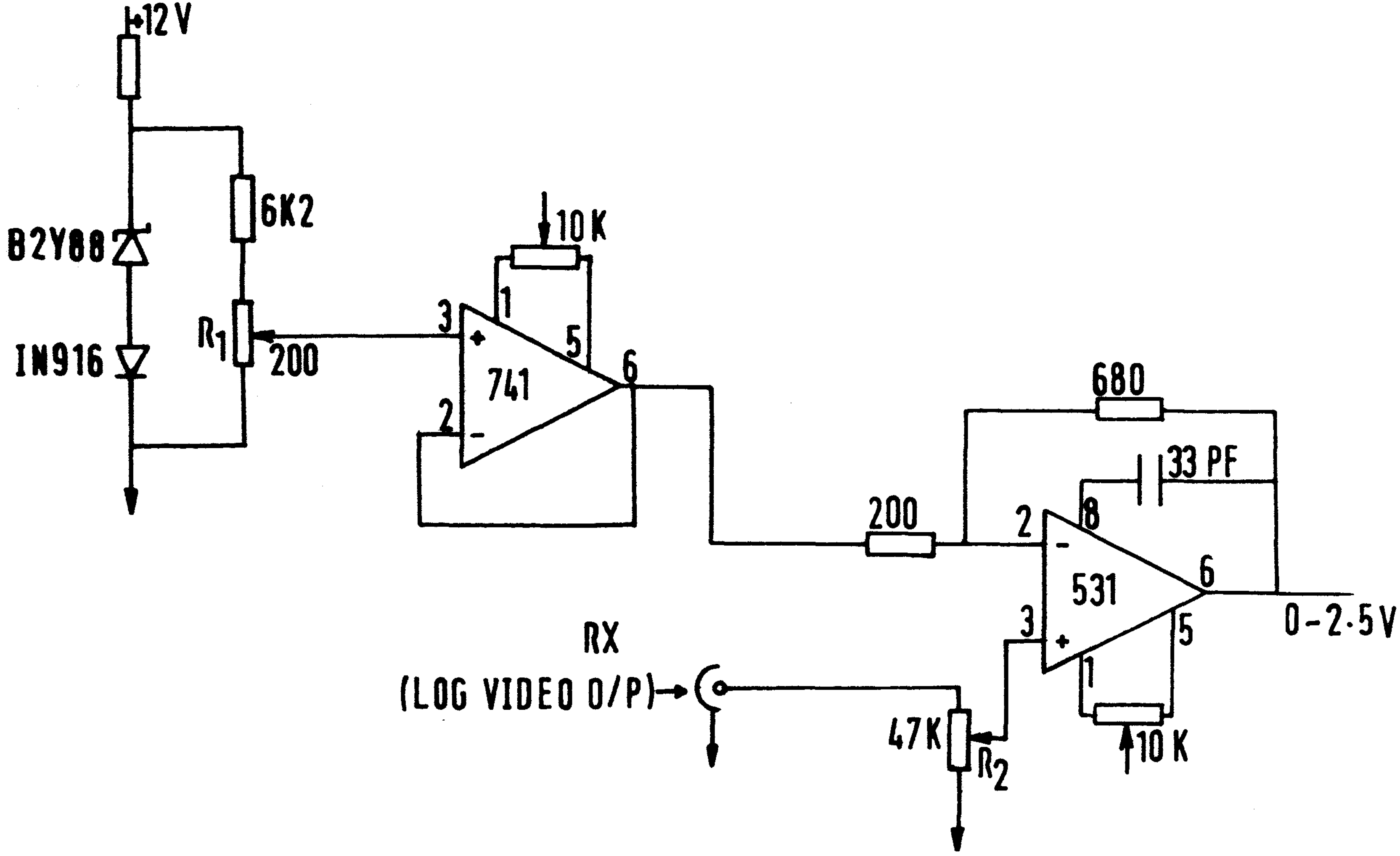

+12V
B2Y88
IN916
6K2
R1
200
10K
3
1
5
2
6
741
680
33 PF
200
2
8
531
6
3
5
1
0-2.5V
RX
(LOG VIDEO O/P)
47K
R2
10K

Fig. 4.3

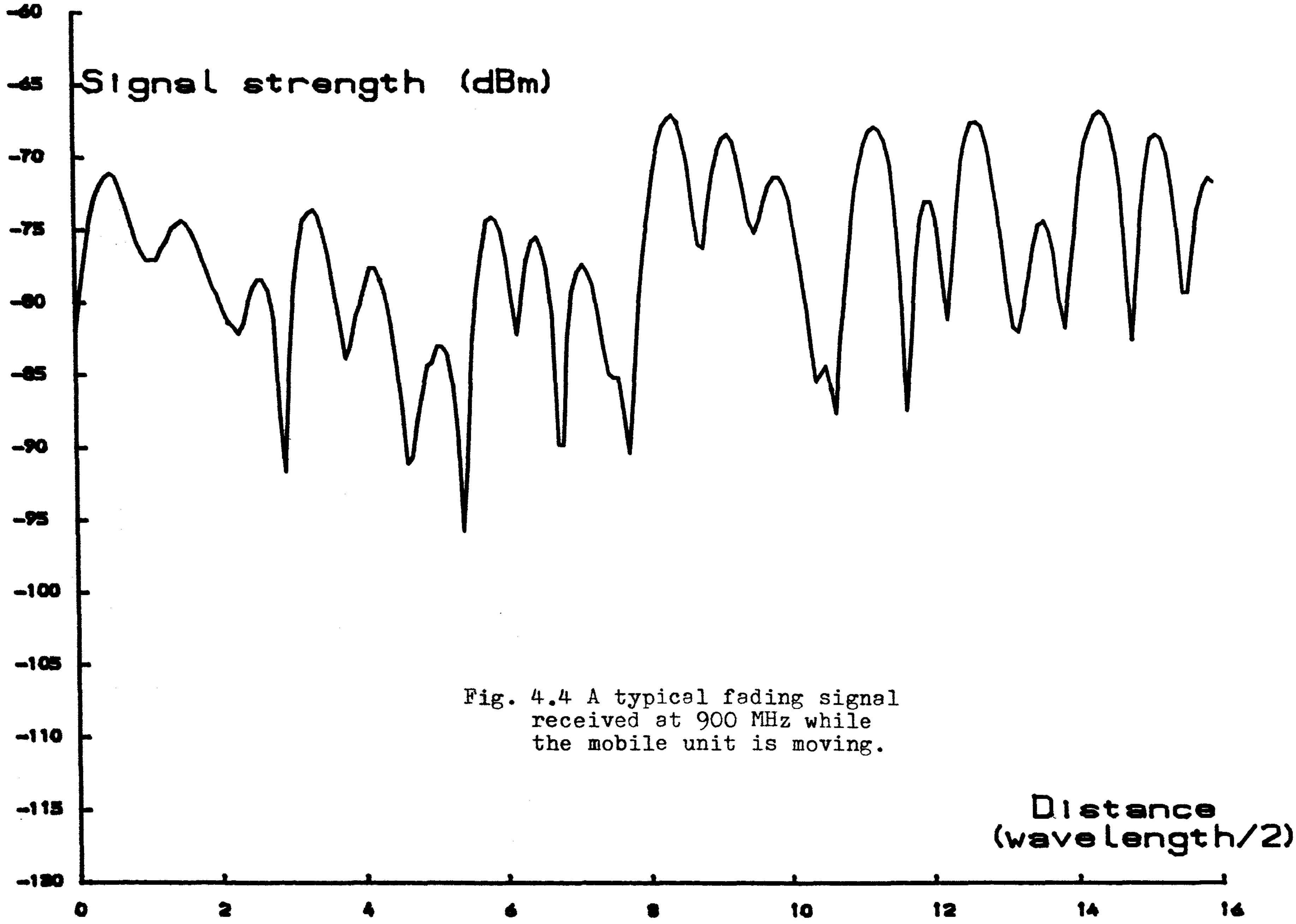


Fig. 4.4 A typical fading signal
received at 900 MHz while
the mobile unit is moving.

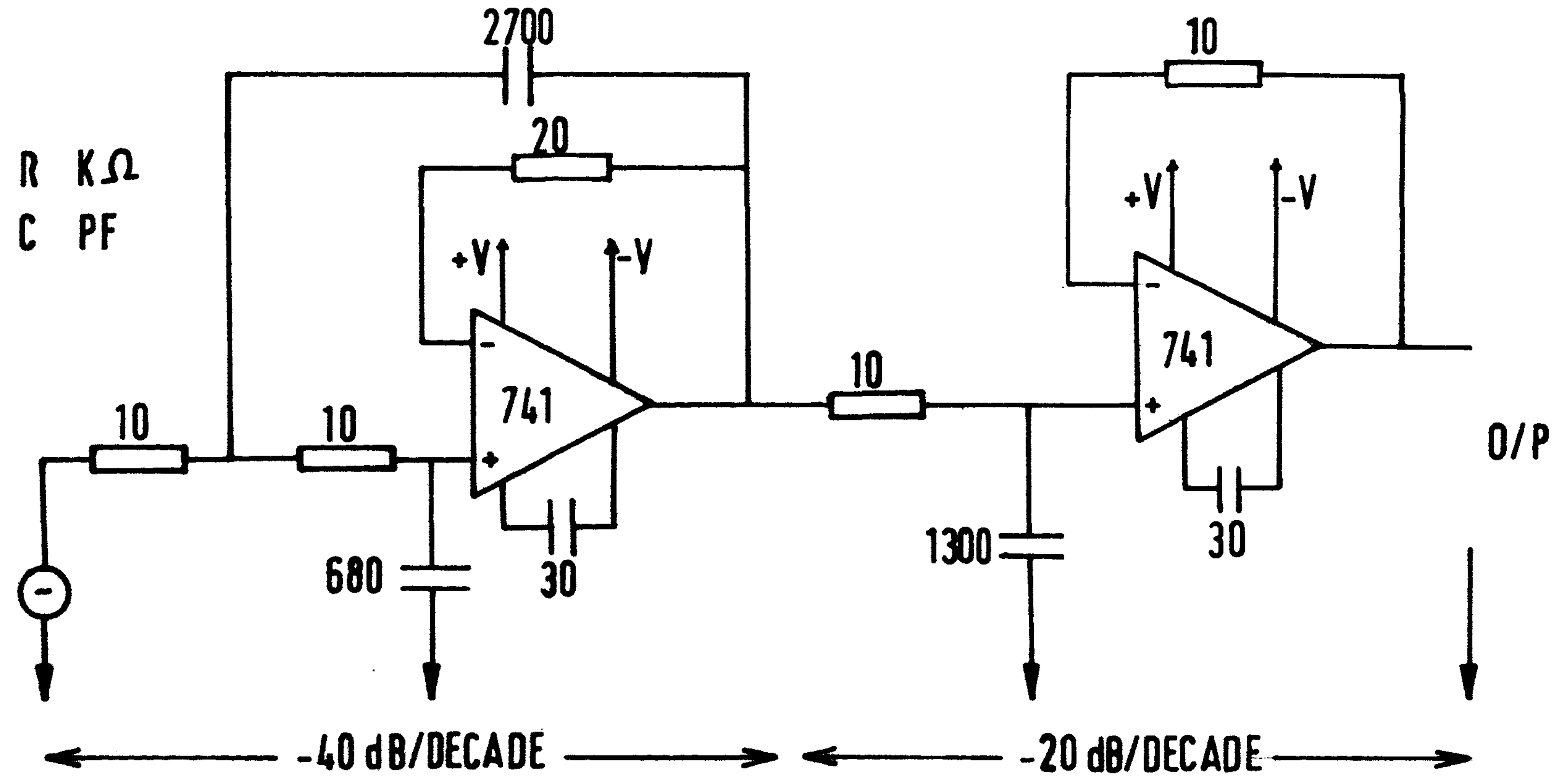


Fig. 4.5 LOW-PASS FILTER -60 dB/DECADE

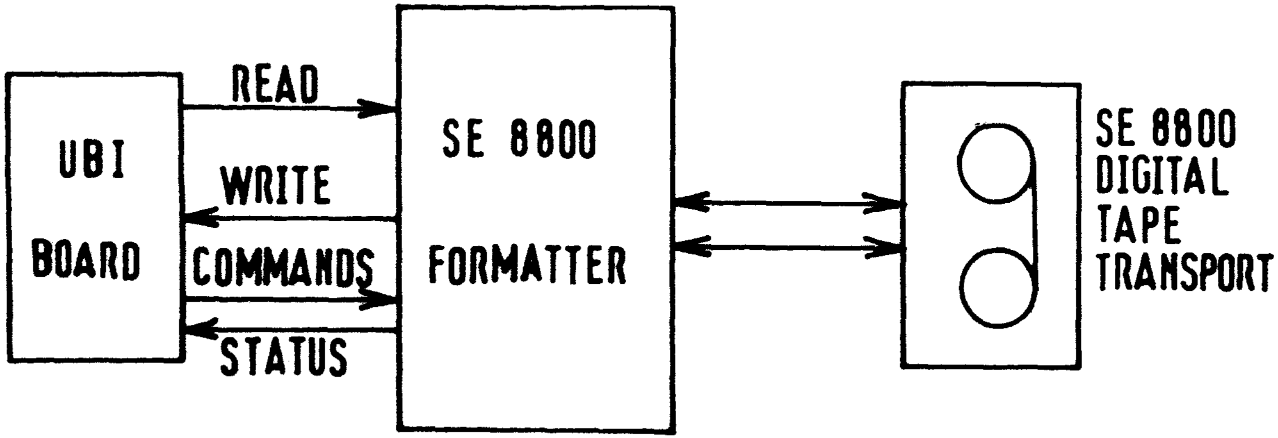


Fig.4.6 BUFFERED TAPE UNIT

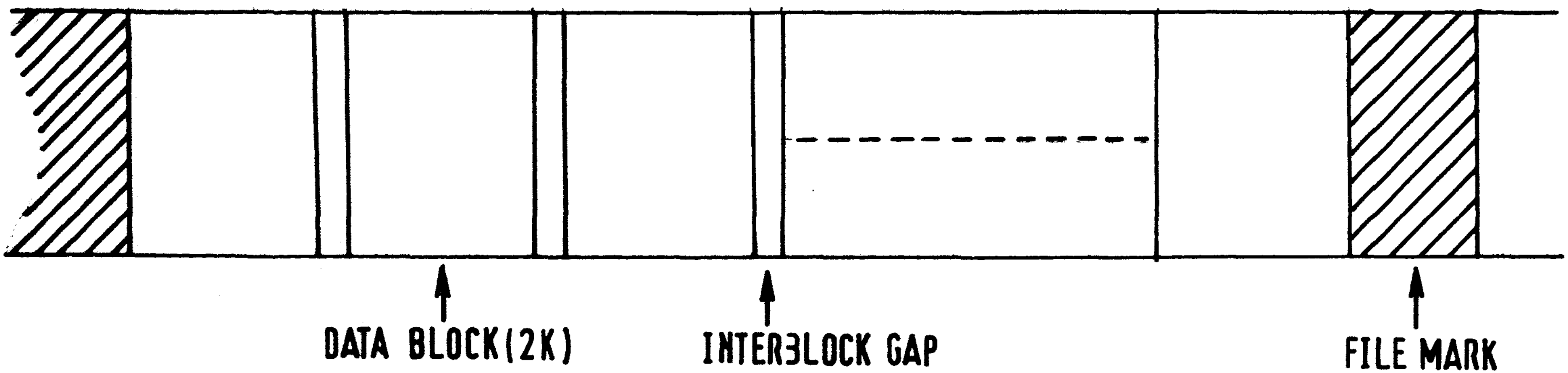


Fig.4.7 TAPE FORMAT

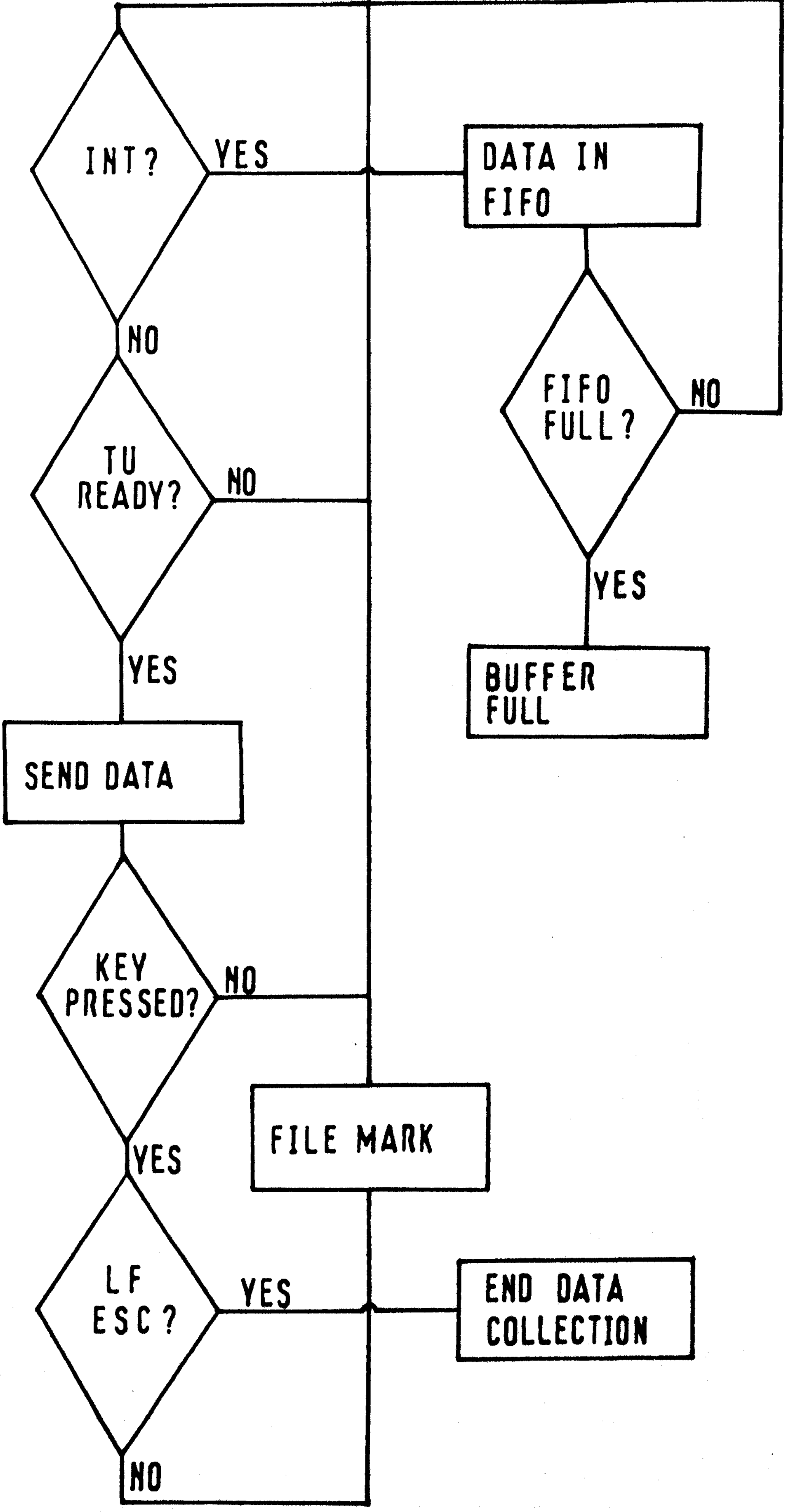


Fig 4.8 SYSTEM FLOWCHART

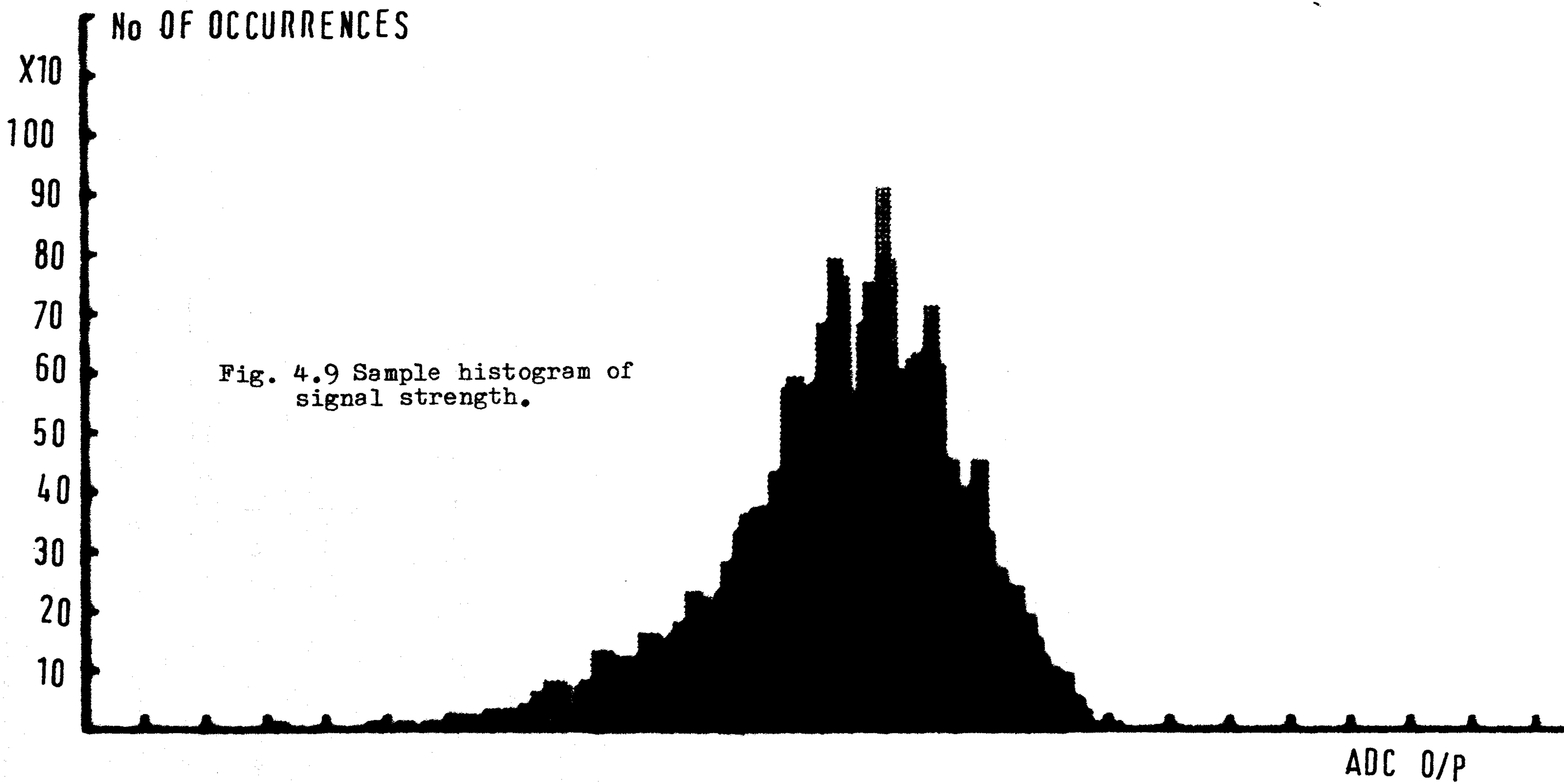


Fig. 4.9 Sample histogram of signal strength.

Fig. 4.10(a) Trials vehicle and equipment from the side

Fig. 4.10(b) Trials vehicle and equipment from the rear

CHAPTER 5

URBAN AND SUBURBAN FIELD TRIALS

Investigation of as yet unknown radio wave propagation characteristics necessitate the collection of a large data base. The data base should be the outcome of a number of field trials involving several transmitter sites with different environmental characteristics and heights typical of those likely to be encountered in practice. Two comprehensive sets of field measurements were conducted in London and Liverpool in order to produce such a data base.

5.1 LONDON MEASUREMENTS

The tests were conducted in the summer of 1983, and six different transmitter sites were used; some were situated in urban areas and others in suburban areas. The relevant details of the transmitter sites are listed in Table 5.1.

Antenna heights ranging from 21m to 190m (above sea level) facilitate the investigation of the effect of antenna height on path loss. The views from the roofs of two transmitter sites in four different directions (N, W, S, E) are shown in Figs. 5.1-5.4. One of these sites is situated in the inner city centre (Figs. 5.1 and 5.2) and the other in a suburban area (Figs. 5.3 and 5.4).

A 1:20,000 OS map was used to plan the routes to be covered. The method of data collection was to select routes within a 500m x 500m square to provide reasonable coverage of that square. An average route length of about 2km was covered within each square and signal strength samples were taken every 1.8cm of travel. When leaving a square a file marker was put onto the tape to indicate the end of the square and the start of the next. The selected squares were located at distances between 2km and 9km from the transmitter. Some squares were chosen to provide a circumferential route at a fixed distance from the transmitter, others were chosen in a radial direction. Some of the test squares were used from more than one transmitter site, in one case, the same squares were covered from 3 different sites. The relative position of the squares in this particular case is shown in Fig. 5.5, together with the three transmitter locations. Overall nearly 300 squares were covered in these trials.

Table 5.1

Transmitter location	Height of local ground above sea level (m)	Overall antenna height (m)	ERP (W)
Bunhill Row	15	76	61.84
Colombo House	5	65	55
Gresham St.	15	56	64
Eltham SSC	61	88	72
Westle House	31	85	72
Ebury Bridge Rd.	5	22	72

5.2 LIVERPOOL MEASUREMENTS

Only one transmitter site was used in Liverpool (Dept. of Electrical Engineering Building, University of Liverpool). The height of the local ground above sea level was 45m and the overall height of the antenna was 80m. The objective of these measurements was to have available a set of data that could be used for comparison purposes and for validating models. Two sets of field measurements were conducted at 900 MHz and 441 MHz. Relevant information about the transmitters is given in Table 5.2.

Table 5.2

Frequency MHz	Type of aerial	Gain over ½ wave dipole	Transmitter O/P
900	Colinear array	5.8dB	5W
441	Four-stacked Centre-fed Folded dipole	5.6dB	5W

The relative position of the squares to the transmitter is shown in Fig. 5.6.

5.3 ANALYSIS OF DATA

As discussed in Chapter 3, the original concept of the data logging and analysis system was that it should be capable of some preliminary on-site analysis before introducing the tape to the main frame computer. However, it was found to be quite sufficient in itself for most of the analysis. The various statistical parameters such as variance, standard deviation and the 1%, 5%, 10%, 50%, 90%, 95% and 99% values of the sample belonging to each test square were computed using the program "ANALHIS" outlined in Chapter 4. A copy of all the information was obtained using a suitable printer connected to the 380Z computer.

The formation of the propagation model was based on the London measurements, since sufficient data was available to validate the statistical analysis. The Liverpool data was used as an independent set of measurements to validate any conclusion drawn using London data.

All the necessary information relating to the test squares such as distance from transmitter and terrain height was extracted from an OS map.

5.4 STATISTICS OF SHORT TERM VARIATION

As a starting point in the analysis of the data, it seems essential to examine the statistics of the short term variation.

Many authors have carried out extensive surveys on such statistics [5.1], [5.2], and similar results have been achieved. It was mentioned in Chapter 2, that such short term variations can adequately be described by Rayleigh distribution, given by :

$$p(r) = (r/ \sigma^2) \exp(-r^2/2 \sigma^2) \tag{5.1}$$

and that the cpd of r, the probability that r is less than level R is

$$P(r \leq R) = 1 - \exp(-R^2 / 2 \sigma^2) \tag{5.2}$$

The function of equation (5.2) is plotted on a Rayleigh graph paper in Fig. 5.7. The difference between the 50% and 1% values is about 20 dB and this can be used as a preliminary check on any experimental results plotted on a Rayleigh graph paper, claiming to have a Rayleigh distribution.

The distance over which the data can be treated as a stationary Rayleigh process is 32 λ (λ = wavelength) at 441 MHz [5.1]. To validate this assumption a test square was randomly selected and an appropriate analysis was carried out on the data collected over several sections each 32 λ long. A typical result is shown in Fig. 5.8. This result can be compared with a Rayleigh process plotted on the same graph, having an arbitrary value for σ. The points can indeed be treated as having Rayleigh distribution.

Similar analysis was undertaken at 900 MHz; the results are given in Fig. 5.9. The same conclusions were drawn at this frequency.

5.5 STATISTICS OF LONG TERM VARIATION

Measurements by many investigators [5.1]-[5.3] have consistently shown that the local mean value is lognormally distributed.

A test square was again selected at random and the local mean at the two frequencies over the distance 32 λ was computed over the entire route covered within the square. The Histogram of the local mean values was constructed. Figs. 5.10 and 5.11 show the cdf, plotted on a normal probability graph paper, at frequencies of 441 MHz and 900 MHz respectively. The results agree closely with a lognormal distribution. At both frequencies the local mean standard deviation of 5.5dB was obtained, which is in good agreement with measurements by other investigators [5.1]-[5.3].

5.6 THE GROUND REFERENCE LEVEL

When employing some prediction models, a knowledge of terrain features is necessary to calculate an average ground level or any appropriate reference height defined by the author. For example, Okumura defines the effective antenna height as shown in Fig. 5.12. He calculates the average ground level within 3 to 15km (or less if the entire distance does not exceed 15km) from the base station antenna, hga. He then defines the effective antenna height as

$$h_{te} = h_{ts} - h_{ga}$$

where h_{ts} is the antenna height above sea level.

An alternative method is discussed here. A circle of radius 10km (or more if the radio survey extends beyond 10km) with the transmitter in the centre is considered and terrain heights along at least eight 10km radia equally spaced are obtained. Enough samples must be taken along each radius in order to adequately describe the terrain profile along that radius. These readings must be rounded off to the nearest integer or if an OS map is used the terrain heights are given in steps of 5m. A histogram of such readings is then formed and the most commonly occurring height (the mode value) H_c is taken as the reference level.

One such histogram obtained in Liverpool is shown in Fig. 5.13. Problems might arise when two or more peaks are present in the histogram or even when the peak spreads over a wide range. The trend is to always select the smallest value. For instance if in the frequency histogram, peaks occur at 10m, 45m, 90m, the lowest value ie 10m should be selected as the reference level. The value of H_c was 5m in London and 40m in Liverpool.

References

[1] Ibrahim, M.F.A."Signal strength prediction for mobile radio communication in built-up areas", Ph.D. thesis, University of Birmingham, September 1981.

[2] Reudink, D.O."Properties of mobile radio propogation above 400 MHz", IEEE Trans. on veh. tech., vol. VT-23, no. 4, November 1974.

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Fig. 5.1(a) The view looking Southwards (Colombo Hse)

Fig. 5.1(b) The view looking Northwards (Colombo Hse)

Fig. 5.2(a) The view looking Westwards (Colombo Hse)

Fig. 5.2(b) The view looking Westwards (Colombo Hse)

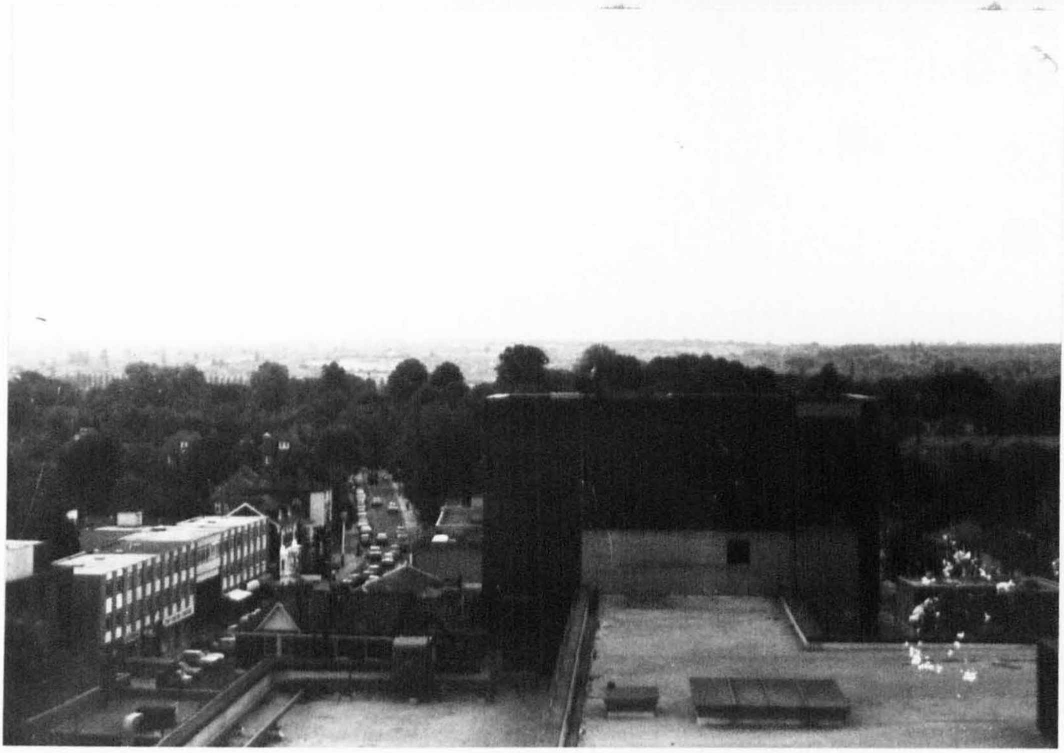
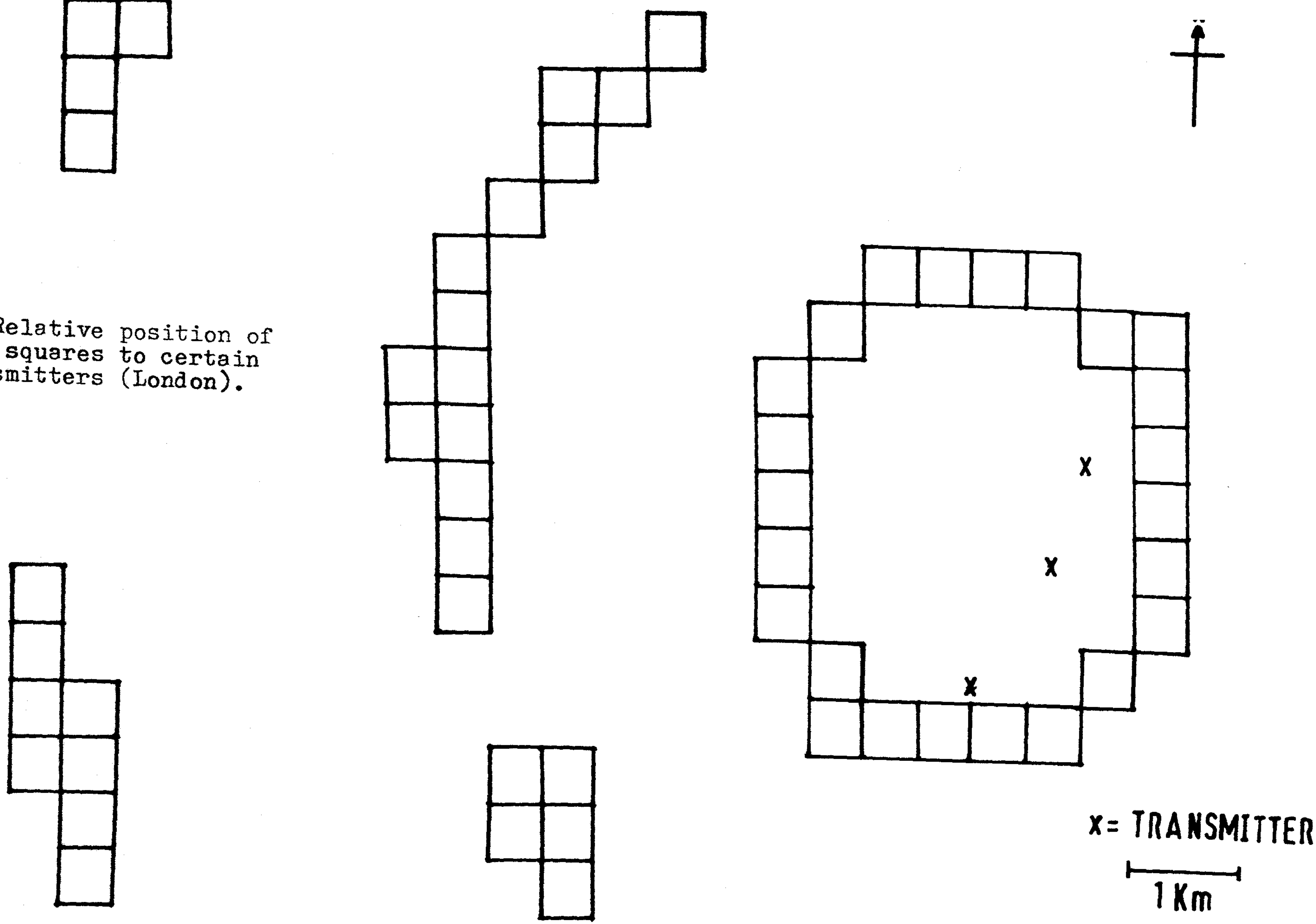


Fig. 5.3(a) The view looking Southwards (Eltham SSC)

Fig. 5.3(b) The view looking Northwards (Eltham SSC)

Fig. 5.4(a) The view looking Westwards (Eltham SSC)

Fig. 5.4(b) The view looking Eastwards (Eltham SSC)



ig. 5.5 Relative position of test squares to certain transmitters (London).

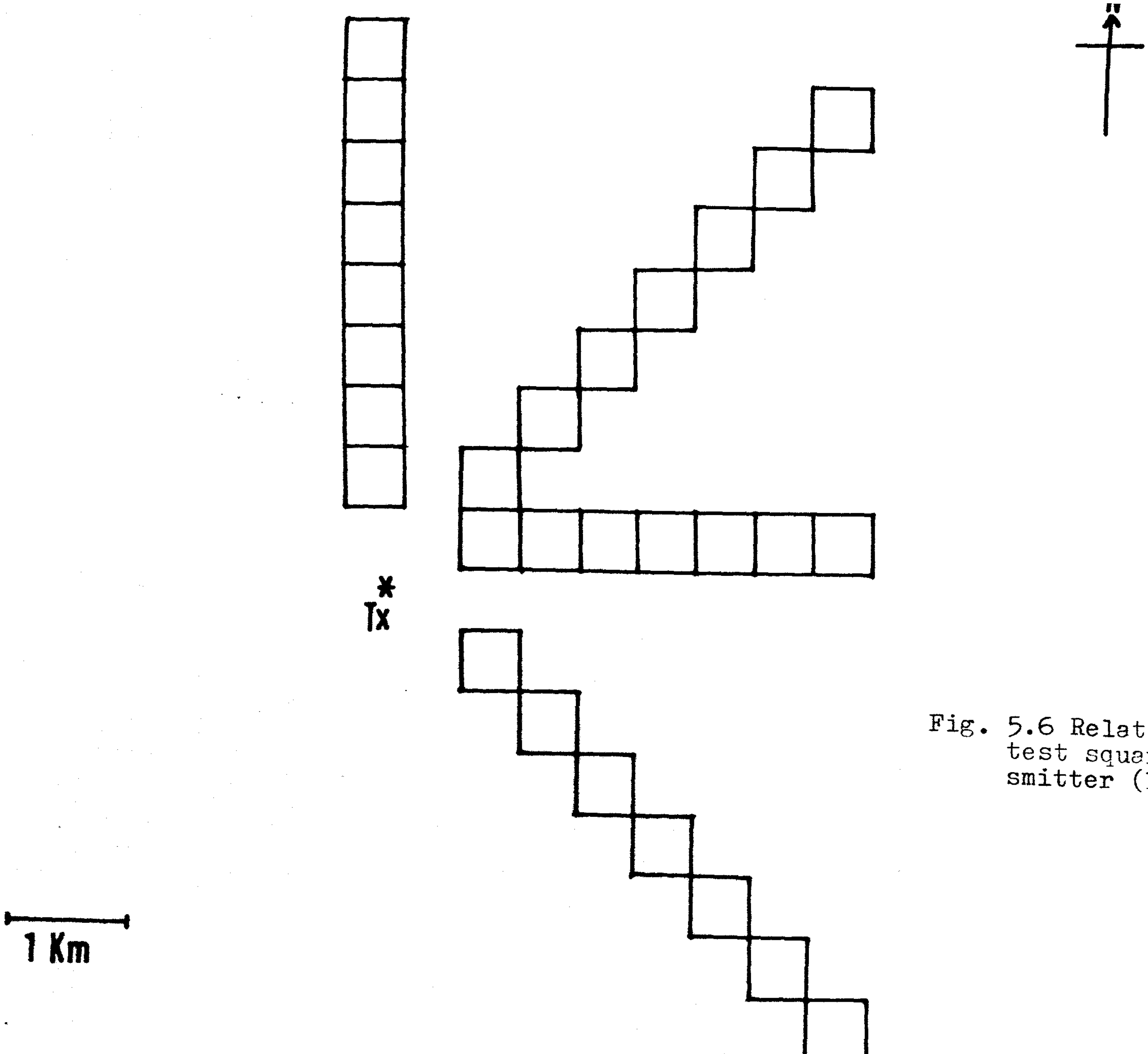


Fig. 5.6 Relative position of test squares to the transmitter (Liverpool).

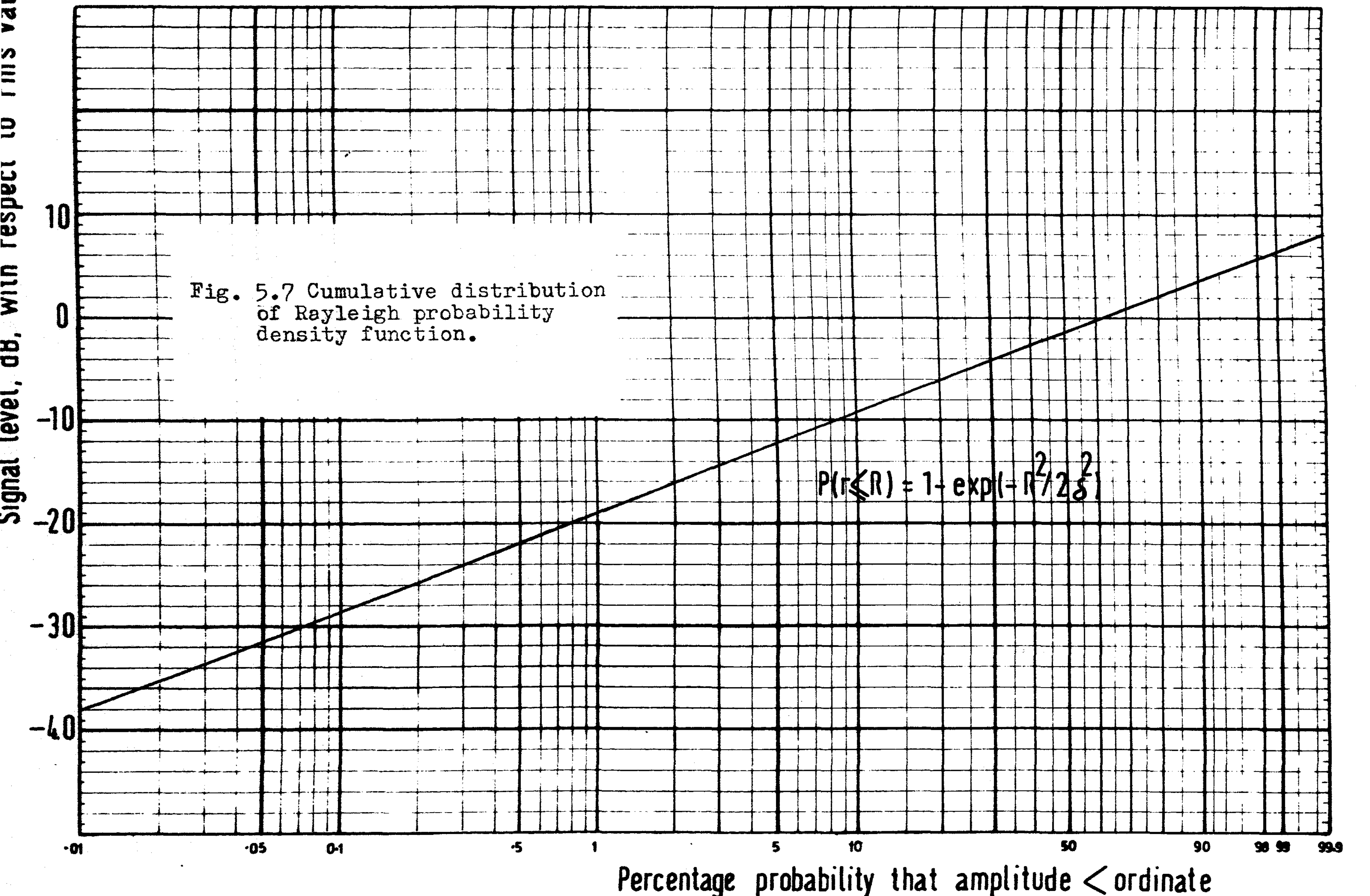


Fig. 5.7 Cumulative distribution of Rayleigh probability density function.

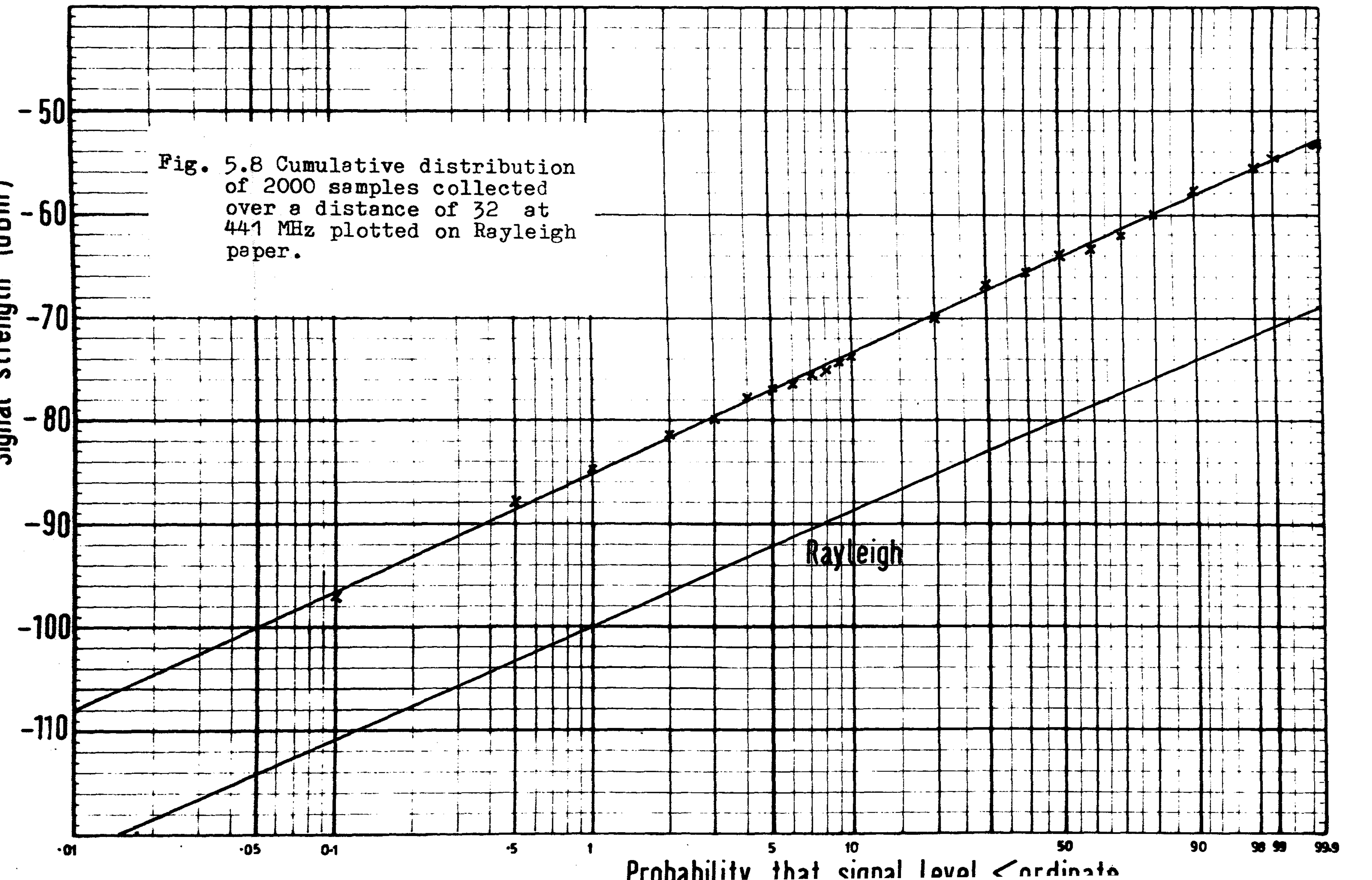


Fig. 5.8 Cumulative distribution of 2000 samples collected over a distance of 32 at 441 MHz plotted on Rayleigh paper.

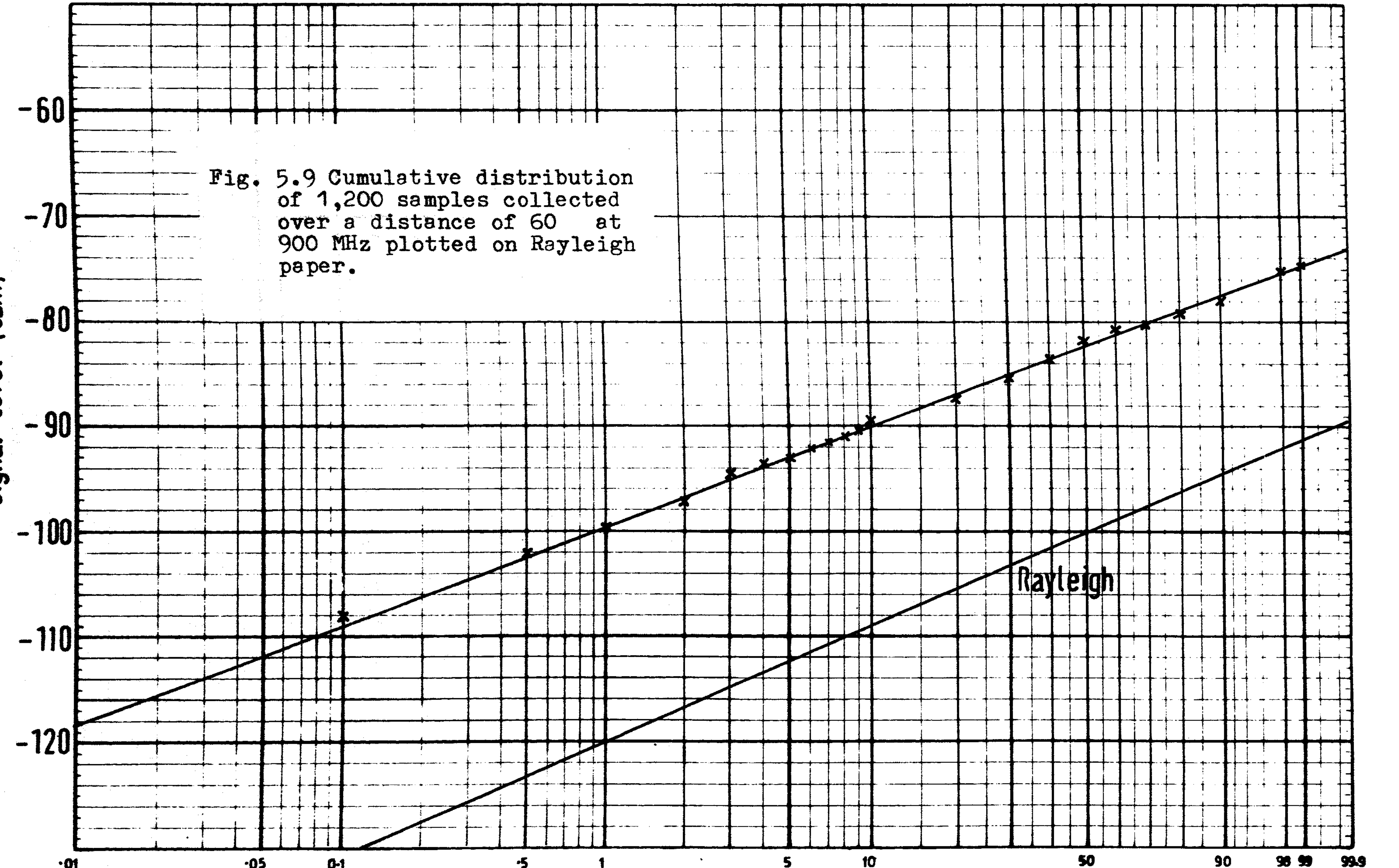


Fig. 5.9 Cumulative distribution of 1,200 samples collected over a distance of 60 at 900 MHz plotted on Rayleigh paper.

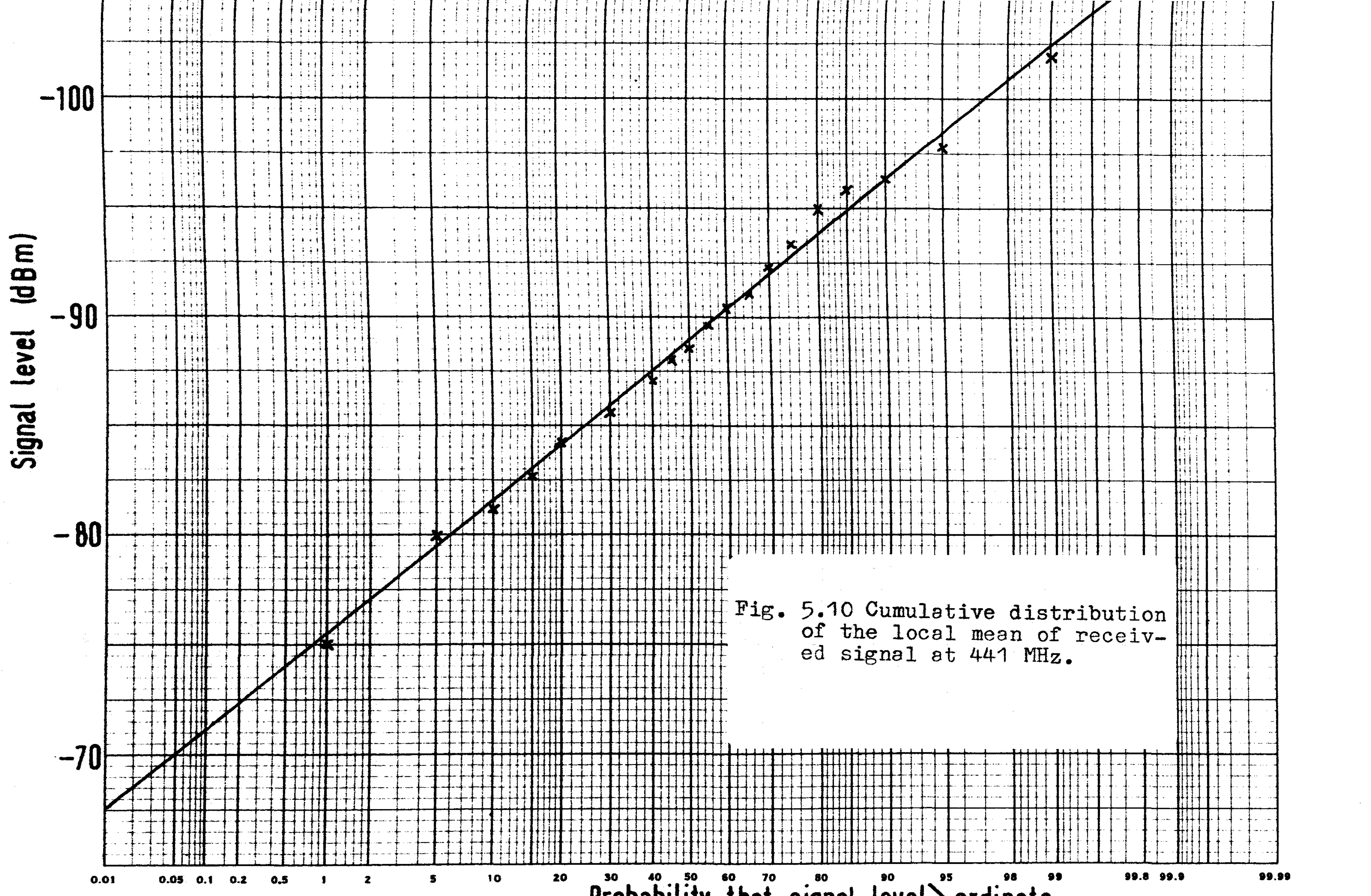


Fig. 5.10 Cumulative distribution of the local mean of received signal at 441 MHz.

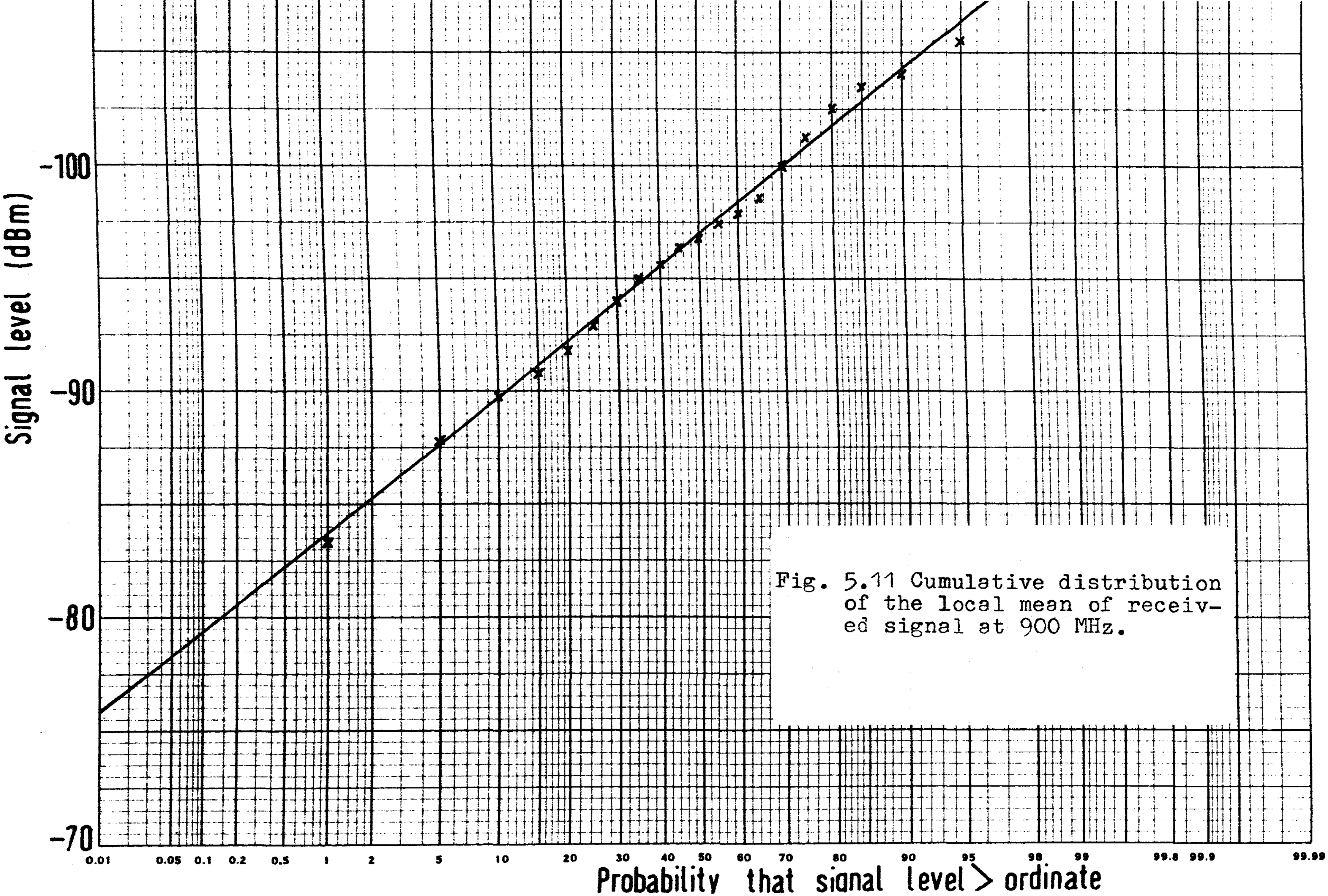


Fig. 5.11 Cumulative distribution of the local mean of received signal at 900 MHz.

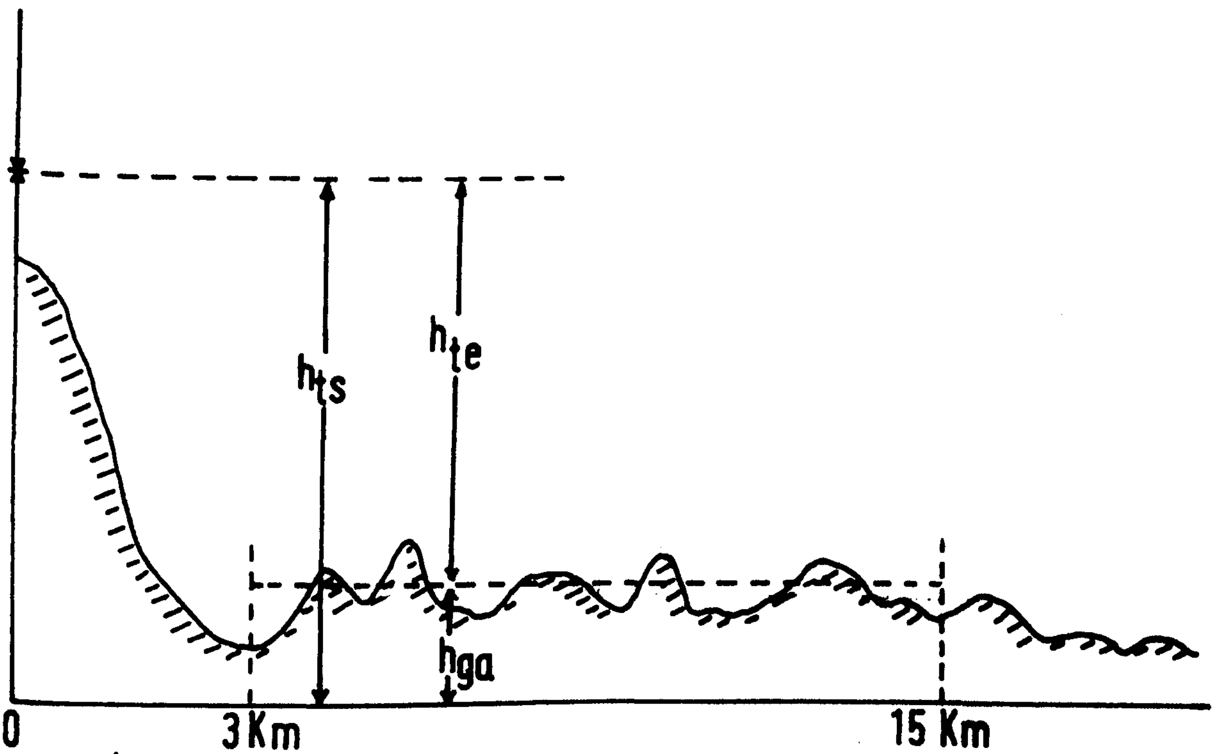


Fig. 5.12 Okumura's definition of effective antenna height

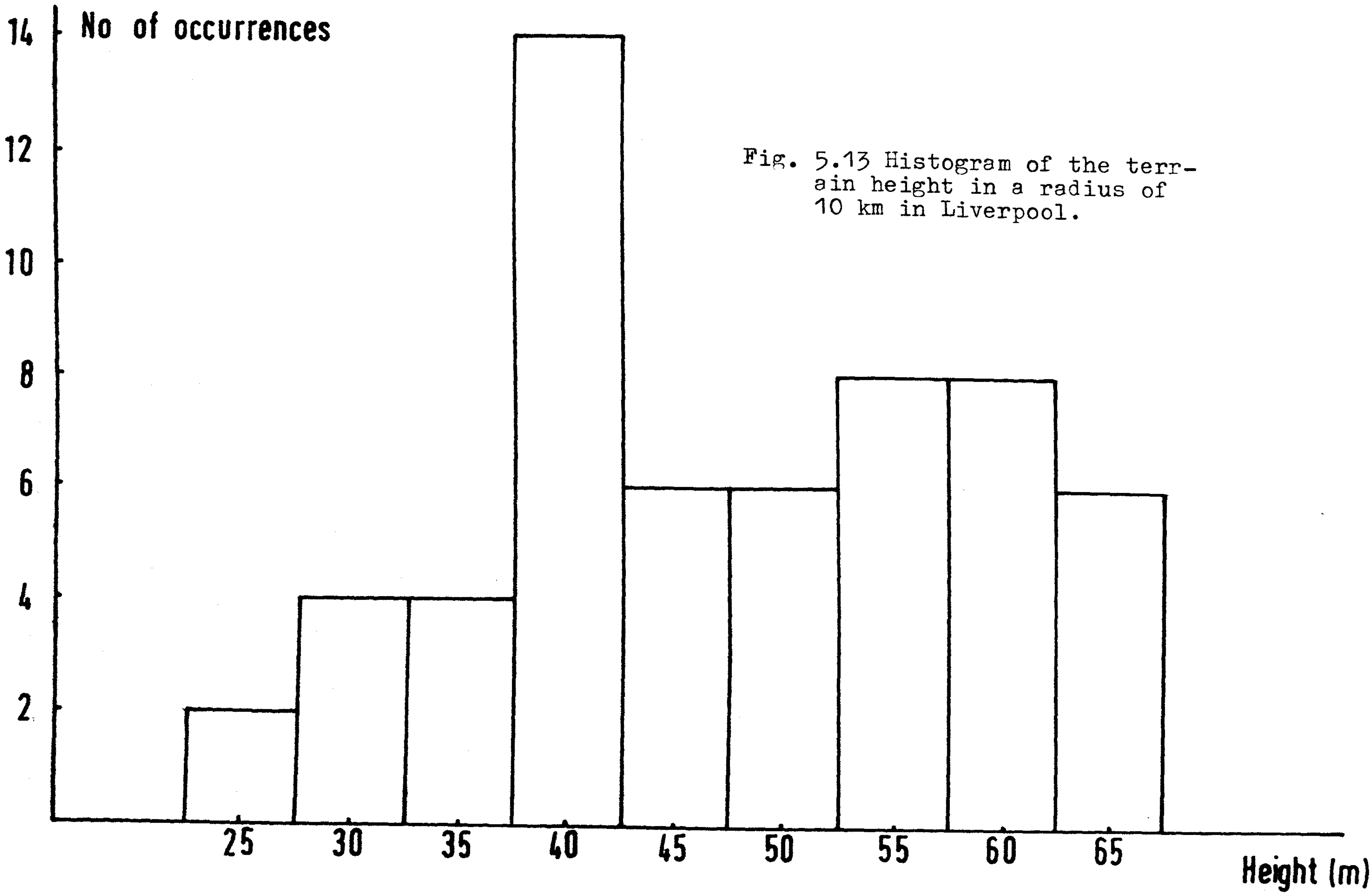


Fig. 5.13 Histogram of the terrain height in a radius of 10 km in Liverpool.

CHAPTER 6

PREDICTION MODELS

6.1 INTRODUCTION

Great care is needed in the design of radio systems if expensive mistakes are to be avoided. In the traditional method of selection of sites and transmitter power, a large number of very costly and time-consuming measurements are required. Much of this can be avoided by prior prediction. Predictor methods exist in the form of graphs [6.1] or formulated mathematical expressions [6.2]. Several of these methods were reviewed in Chapter 3.

6.2 ANALYSIS OF LONDON DATA

The basis of a well structured statistical model is a large data base, acquired under all the possible combinations of parameters, which might influence the data. The London data possesses such a property, and therefore a prediction model could be based on this data with confidence.

For each of the six sets of measurements the 50% (median) values were used to compute the path loss between two isotropic antennas. This was plotted as a function of range. One such plot, typical of those obtained, is shown in Fig. 6.1. The best fit straight line through these points was calculated by minimising the r.m.s. error, and equations were computed to express these best fit lines. If each equation is expressed in the form $PL = A + B \log_{10} R$, where R is the range from transmitter in Km, the values of A and B for the six sites used are as given in Table 6.1. The value of clutter factor β, defined as the difference between the best fourth law fit and a line calculated using the plane earth equation, is also included in Table 6.1.

Table 6.1

Transmitter at	A dB	B dB/decade	β dB
1) Bunhill Row	118	37	41
2) Colombo Hse	122	38	41
3) Gresham St	123	40	42
4) Eltham SSC	116	36.5	38
5) Westle Hse	114	35	34
6) Ebury Bridge Rd	123	40	44

The same process of minimizing the r.m.s. error was employed, but this time using the entire set of data for all six transmitters, to obtain an overall best fit line. The following equation was then obtained :

$$PL = 119.6 + 34 \log R \qquad \text{dB} \qquad (6.1)$$

An r.m.s. error of 7.07 dB was apparent, where equation (6.1) was used to predict path loss for the London data.

In order to improve this rather crude global model, one can look at the variation of A and B with various factors such as base transmitter height. A knowledge of how A and B vary with h_b, allows equation (6.1) to be modified to give a better estimation, for given situations with a consequent reduction in the r.m.s. error.

6.2.1 Effect of Transmitter Height on A

Using the values tabulated in Table 6.1, a graph of h_b versus A was plotted on a 1 cycle log linear graph paper, with h_b on the logarithmic scale (Fig. 6.2). In this manner the relationship between A and h_b could more easily be observed. The best fit line through these points was computed as;

$$A = 140.1 - 12.2 \log h_b \qquad dB \qquad (6.2)$$

where h_b is in meters.

Having achieved this result, it can be compared with Okumura's measurements [6.1], which were conveniently presented in the same manner, and can be expressed as;

$$A_{ok} = 146 - 14 \log h_b \qquad dB \qquad (6.3)$$

Equations (6.2) and (6.3) are plotted in Fig. 6.2 together with the measured results. The slope of the two lines can be observed to be similar, but Okumura's equation predicts a smaller value for A by about 3–4 dB than equation (6.2). Nevertheless the definition of Okumura's transmitter height is quite different from the way it is defined here. It is the slope of these lines which should be looked at as the important feature for comparison. The above results are considered very promising.

6.2.2 Effect of Transmitter Height on B

Making use of values given in Table 6.1, a graph of B versus h_b was plotted on a log linear graph paper, again with h_b on logarithmic scale. The graph is illustrated in Fig. 6.3. The best fit line describing the relationship between h_b and B was computed, and given by :

$$B = 49.3 - 6.8 \log h_b \qquad dB/decade \qquad (6.4)$$

Okumura's measurements describing the relationship between h_b and B equation (6.5) were plotted on the same graph paper as Fig. 6.3 for comparison with equation (6.4).

$$B_{ok} = 45 - 6.5 \log h_b \qquad \text{dB/decade} \qquad (6.5)$$

The slope of equations (6.4) and (6.5) are again similar, but predictions of B based on Okumura's measurements are consistently smaller than those derived from equation (6.4). The difference is about 4 dB. The comparison is very encouraging in the sense that it is based on two sets of entirely independent measurements and yet leads to very similar conclusions.

6.2.3 Effect of Transmitter Height on the Clutter Factor

The existence of a relationship between h_b and β is the next step to be investigated. A graph of β versus h_b was plotted on a linear graph paper (Fig. 6.4). At first sight it might seem that the dotted curve (Fig. 6.4) is a better fit than a straight line. If the dotted curve is adopted as the best fit, it indicates that as h_b approaches 90m, a sudden reduction in the clutter factor is observed, which does not seem reasonable. Hence, a straight line was adopted as the best fit given by :

$$\beta = 48.1 - 0.12\, h_b \qquad \text{dB} \qquad (6.6)$$

This merely indicates that over the range of heights considered the rate of decrease of β as transmitter height is increased is -0.12 dB/m i.e. increasing h_b by a factor of 10, decreases β by 12 dB.

Now having deduced all these relationships, the model described by equation (6.1) can be improved. Several different methods investigated are described below. In all the models considered, a multiple regression analysis was employed with path loss, range, transmitter height, etc. as variables.

(I) It has been shown that path loss is strongly affected by transmitter height, hence the model can be improved by the inclusion of transmitter height in equation (6.1), giving an expression of the form of :

$$PL = 157.6 + 37.75 \log R - 21.8 \log h_b \text{ (dB)} \quad (6.7)$$

where R is in km and h_b is in m.

Equation (6.7) gives the path loss between two isotrophic antennas. This seems a convenient point to make some comparisons with the theoretical model for plane earth, given by :

$$P_r = P_t g_m g_b (h_b h_m / R^2)$$

where R is in m and $h_m = 1.5m$

Taking log from both sides, describing the path loss as (p_t (dB) $-P_r$(dB)) and changing the units of R from m to km, the following expression is obtained :

$$PL = 115 + 40 \log R - 20 \log h_b \quad \text{dB} \quad (6.8)$$

Comparing equations (6.7) and (6.8) the range and transmitter height dependence coefficients are very similar, but the constant term differs by about 42 dB. An explanation for this can be found by calculating the average clutter loss, using equation (6.6), and substituting the average value of h_b as approximately 65m :

$\beta = 48.1 - 0.12 \times 65$

$\beta = 40.3$ dB

This comparison indicates how all the different theoretical and experimental equations lead to similar conclusions.

(II) An alternative method for producing an improved model is to express path loss in the form of :

$$PL = A + B \log R \qquad \text{dB}$$

Making use of equations (6.2) and (6.4) to substitute for A and B we obtain

$$PL = (140.1 - 12.2 \log h_b) + (49.3 - 6.8 \log h_b) \log R \qquad (\text{dB}) \qquad (6.9)$$

(III) A semi-emperical model can be employed by adding a clutter factor to the plane earth equation, as given below

$$PL = 40 \log R - 20 \log h_b h_m + 120 + \beta$$

using eqution (6.6) to substitute for β

$$PL = 40 \log R - 20 \log h_m h_b + 168.1 - 0.12 h_b \qquad (6.10)$$

(IV) Finally a semi-emperical model in the form of

$$PL = 40 \log R + C$$

can be used where C is given by

$$C = -23.3 \log h_b + 156.8 \qquad \text{dB}$$

therefore

$$PL = 40 \log R - 23.3 \log h_b + 156.8 \quad \text{dB} \qquad (6.11)$$

Table 6.2 summarises the proposed models with their corresponding r.m.s errors.

TABLE 6.2

Proposed model (path loss in dB)	r.m.s error (dB)
$PL = 119.6 + 34 \log R$	7.07
$PL = 157.6 + 37.75 \log R - 21.8 \log h_b$	5.6
$PL=(140.13-12.2\log h_b)+(49.3-6.8 \log h_b) \log R$	5.87
$PL = 40 \log R - 20 \log h_b h_m + 168.1 - 0.12 h_b$	6.2
$PL = 40 \log R - 23.3 \log h_b + 156.8$	6.2

The procedure adopted now is to select the model which produces the smallest r.m.s error i.e model 2, and to carry out further improvements to minimize the r.m.s error. The next logical step is to include another variable in the multiple regression analysis, the effective mobile antenna height (h_m) which is very commonly used in any propagation model. h_m is measured above the same reference level as defined for the base antenna. The following equation was obtained:

$$PL = 159.1 + 37.8 \log R - 21.8 \log h_b - 0.17 h_m \quad (\text{dB}) \qquad (6.12)$$

where h_m is in meters, and it is positive if mobile antenna is above the reference level and negative if mobile antenna is below the reference level. Using equation (6.12) an r.m.s error of 5 dB was achieved.

Since London is not a completely flat city, diffraction losses must be taken into account. For each test square the terrain profile was extracted using an OS map, and utilizing the Epstein and Peterson method the diffraction loss was calculated. Using these calculations, an improved model was introduced as :

$$PL = 160 + 38 \log R - 21.8 \log h_b - 0.15\, h_m + L_D \qquad dB \qquad (6.13)$$

An r.m.s error of 4.5 dB was achieved. Further improvements in the model were made possible by classifying the transmitter surroundings. Four transmitter sites were classified as being situated in heavily built up urban areas, and two other transmitter sites were classified as being situated in suburban areas. Hence the predictions made using equation (6.13) were divided into two groups of data representing urban and suburban areas. In urban areas the predictions were observed to be optimistic by an average of about 5.5 dB, and pessimistic by an average of about 2 dB in suburban areas. Therefore two separate models are suggested, one for use in urban areas and another for use in suburban areas given by :

$$PL_u = PL + 5.5 \qquad (dB) \qquad (6.14)$$

where PL_u = predicted path loss when the transmitter is situated in urban areas, and PL is computed using equation (6.13), and

$$PL_s = PL - 2 \qquad (dB) \qquad (6.15)$$

where PL_s = predicted path loss when the transmitter is situated in suburban areas. These equations (6.14) and (6.15) produced an r.m.s error of 3.32 dB.

Further improvements on the model could still be possible, but the price to pay is probably too high. Parameters described in Chapter 3, such as land usage factor (L), or urbanization factor (U), can be employed to improve the model. On the other hand a model producing an r.m.s error of less than 1 dB would not make sense, since different measurements taken on the same day, along the same route probably lead to median values which differ by about 2-3 dB.

Strictly speaking the proposed model is only valid at 900 MHz. In order to expand its use it is necessary to find a way of including carrier frequency as a parameter. Since there is good agreement between the London data and Okumura's measurements, and he conducted measurements at several different frequencies, the results obtained by Okumura can be combined with the results obtained from the London data in order to obtain a frequency dependent parameter for inclusion in the model.

Using Okumura's measurements [6.1] and Hata's formulation [6.2] A is given by :

$$A_{OK} = \alpha(fc) - 13.82 \log h_b \qquad (6.16)$$

$$\text{where } \alpha = 69.55 + 26.16 \log fc \qquad (6.17)$$

Using equations (6.13) and (6.17)

$160 = x + 26.16 \log fc$

for $fc = 900$ MHz

$x = 82$ dB

Therefore the final model can be written in the form :

$$PL = 82 + 26.16 \log f_c + 38 \log R - 21.8 \log h_b - 0.15 h_m + L_D \quad dB \qquad (6.18)$$

It should be noted that the equation (6.18) is more accurate at 900 MHZ.

6.3 ANALYSIS OF LIVERPOOL DATA

A similar analysis was undertaken on the Liverpool data. The 50% values were computed for each 500m square and a graph of path loss versus range in km was plotted at 900 MHz and 441 MHz. These are shown in Figs. 6.5 and 6.6 respectively. The best fit line through the data was calculated and for the 900 MHz results is given by :

$$PL_{900} = 130.3 + 38.5 \log R \quad dB \qquad (6.19)$$

An opportunity now exists to put the proposed model to the test. Equation (6.18) was used to predict the expected path loss expressed in the form of PL = A + B log R, giving :

$$PL_{P900} = 128 + 38 \log R \quad dB \qquad (6.20)$$

This was plotted in Fig. 6.5 with best fit line equation (6.19). The result is extremely encouraging, since there is hardly any difference between the predictions and the measurements. The expression for the best fit line at 441 MHz is given by :

$$PL_{441} = 119 + 41.8 \log R \quad dB \qquad (6.21)$$

and the predicted equation is :

$$PL_{p441} = 119.4 + 38 \log R \qquad dB \qquad (6.22)$$

This was plotted in Fig. 6.6 along with the best fit equation (6.2). The excellent agreement obtained at 900 MHz could not be expected at 441 MHz, since the model was based on data collected at the higher frequency. Comparing equations 6.21 and 6.22, the slopes differ by about 3.8 dB and the intercepts on the PL axis differ by about 0.2 dB. Nevertheless the prediction is reasonably acceptable and it is suggested that the model could be employed at frequencies as low as 400 MHz.

6.4 PERFORMANCE OF THE MODEL ON ALLSEBROOK'S DATA

Allsebrook [6.4] conducted several sets of measurements in Birmingham at frequencies of 85.87 MHz, 167.2 MHz and 441 MHz. These measurements provide a good base for testing the model on independent data.

Table 6.3 summarises the performance of the model on the measurements.

Table 6.3

Allsebrook's equation of best fit line	Prediction	Frequency MHz
117 + 39 log R	116.2 + 38 log R	441
101 + 38 log R	105.1 + 38 log R	167.2
98 + 38 log R	97.4 + 38 log R	85.8

These equations are plotted as shown in Figs. 6.7, 6.8 and 6.9. The model proves to be very successful when used with Allsebrook's data at much lower frequencies than might be expected. This suggests that the model could be used successfully in the frequency range of 85-900 MHz.

6.5 TESTING THE MODEL ON IBRAHIM'S DATA

Ibrahim [6.5] conducted two sets of measurements at 441 MHz and 168 MHz in London. These measurements were conducted employing a different transmitter site from the seven transmitter sites mentioned in Chapter 4. The measurements and predictions are compared in Table 6.4.

Table 6.4

Frequency MHz	Ibrahim's equation for best fit line	Prediction
441	114 + 43 log R	115 + 38 log R
168	109.8 + 36 log R	106 + 38 log R

He also carried out measurements at 900, 441 and 168 MHz in London, for which the information required to carry out analysis on each individual test square was available. Table 6.5 gives a quantitative comparison of measurements and predictions in each test square. The error histogram at 900 MHz is shown in Fig. 6.10.

Table 6.5

PL_{168}	PL_{P168}	PL_{441}	PL_{P441}	PL_{900}	PL_{P900}
124.8	119.7	130.5	131.0	139.8	137
128.0	121.5	133.5	132.8	143.1	136
128.3	119.6	135.0	130.9	144.5	133.6
120.3	116.8	127.5	128.1	138.9	133
120.3	117.3	129.3	128.6	139.3	133
118.3	116.8	126.8	128.1	136.0	135
118.5	113.5	127.3	124.8	133.7	133.6
120.0	118.1	125.0	129.4	133.0	132.3
120.0	117.8	126.5	129.1	135.8	135.1
118.8	114.5	125.3	125.8	133.2	133.9
122.5	119.5	127.3	130.8	135.6	135.5
122.5	119.6	129.8	130.9	138.1	133.9
122.0	117.9	129.0	129.2	137.4	132.6
124.75	119.8	131.8	131.1	137.7	132.6
126.7	120.8	133.3	132.1	142.6	133.3
128.0	122.0	131.8	133.3	144.0	135.4
126.0	126.0	130.5	129.5	140.3	137
122.5	122.6	126.8	133.9	134.6	137
120.3	121.3	124.5	123.6	131.1	136
122.8	122.2	126.2	133.5	137.2	136
118.8	118.2	119.8	129.5	130.4	137.7
124.5	124.9	129.3	136.2	139.3	139.9

r.m.s. error = 4.4 dB   r.m.s. error = 3.9 dB   r.m.s. erro = 4.5 dB

6.6 CONCLUSION

The proposed model has proved quite successful, when put to the test against independent measurements taken in London, Birmingham or even Japan by independent researchers. The inclusion of the frequency in the model has made it very flexible in the sense that the model is not restricted for use only at 900 MHz. The model works with a reasonable accuracy and at the same time it is quite simple and efficient to use. The input parameters needed for prediction are those which are readily available or can be easily extracted from an OS map. The model would be more efficient if it was computerized and a terrain data base was available.

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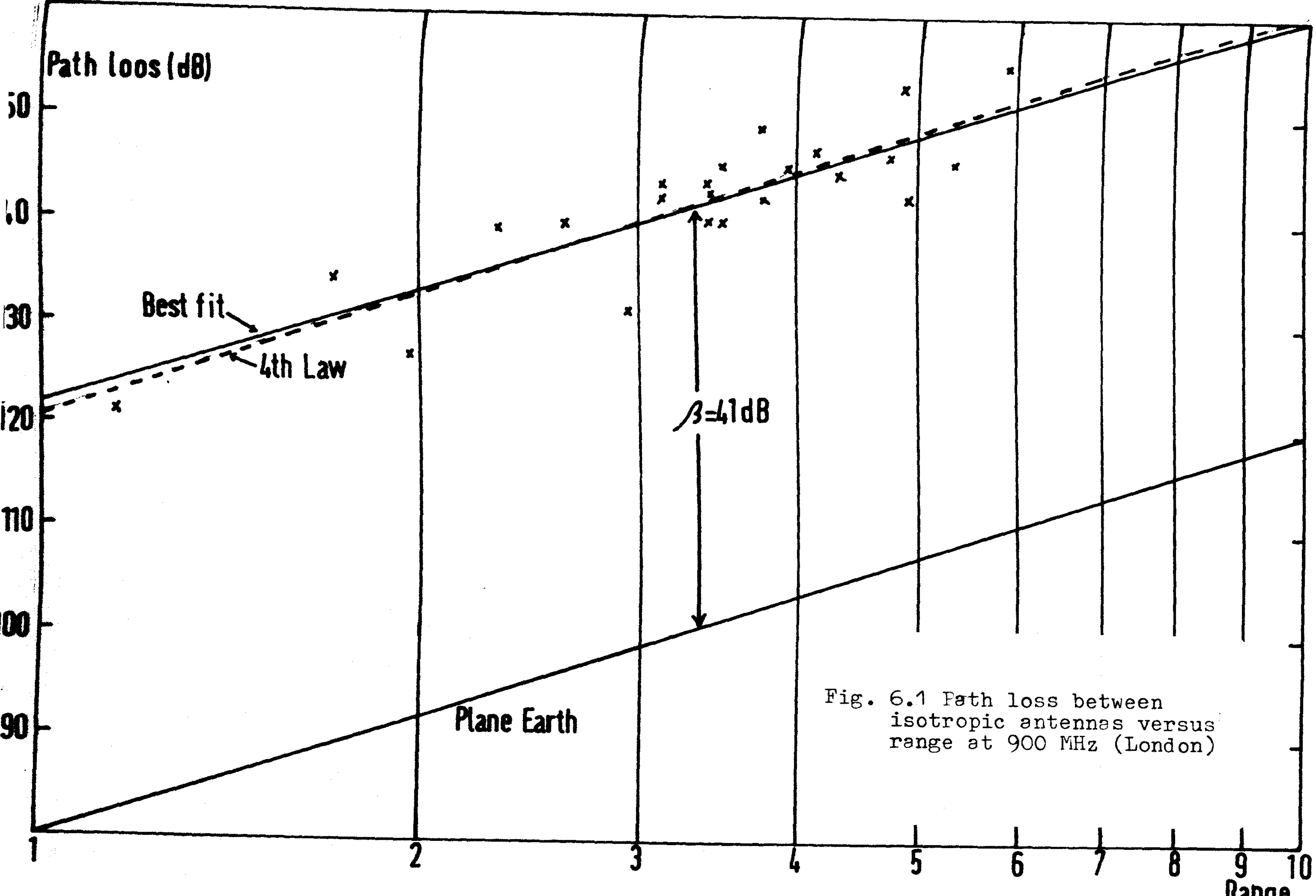

Fig. 6.1 Path loss between isotropic antennas versus range at 900 MHz (London)

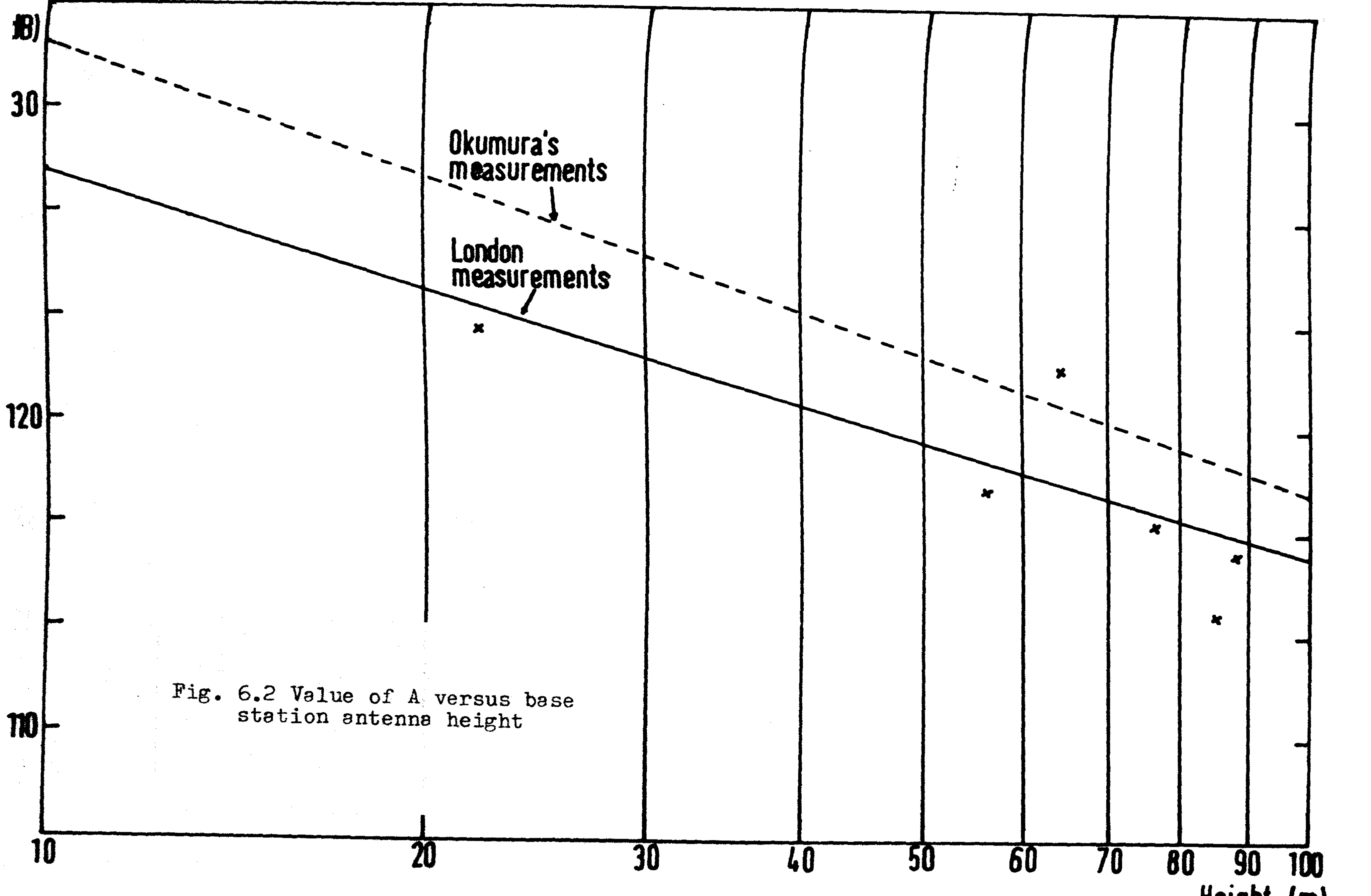

Fig. 6.2 Value of A versus base station antenna height

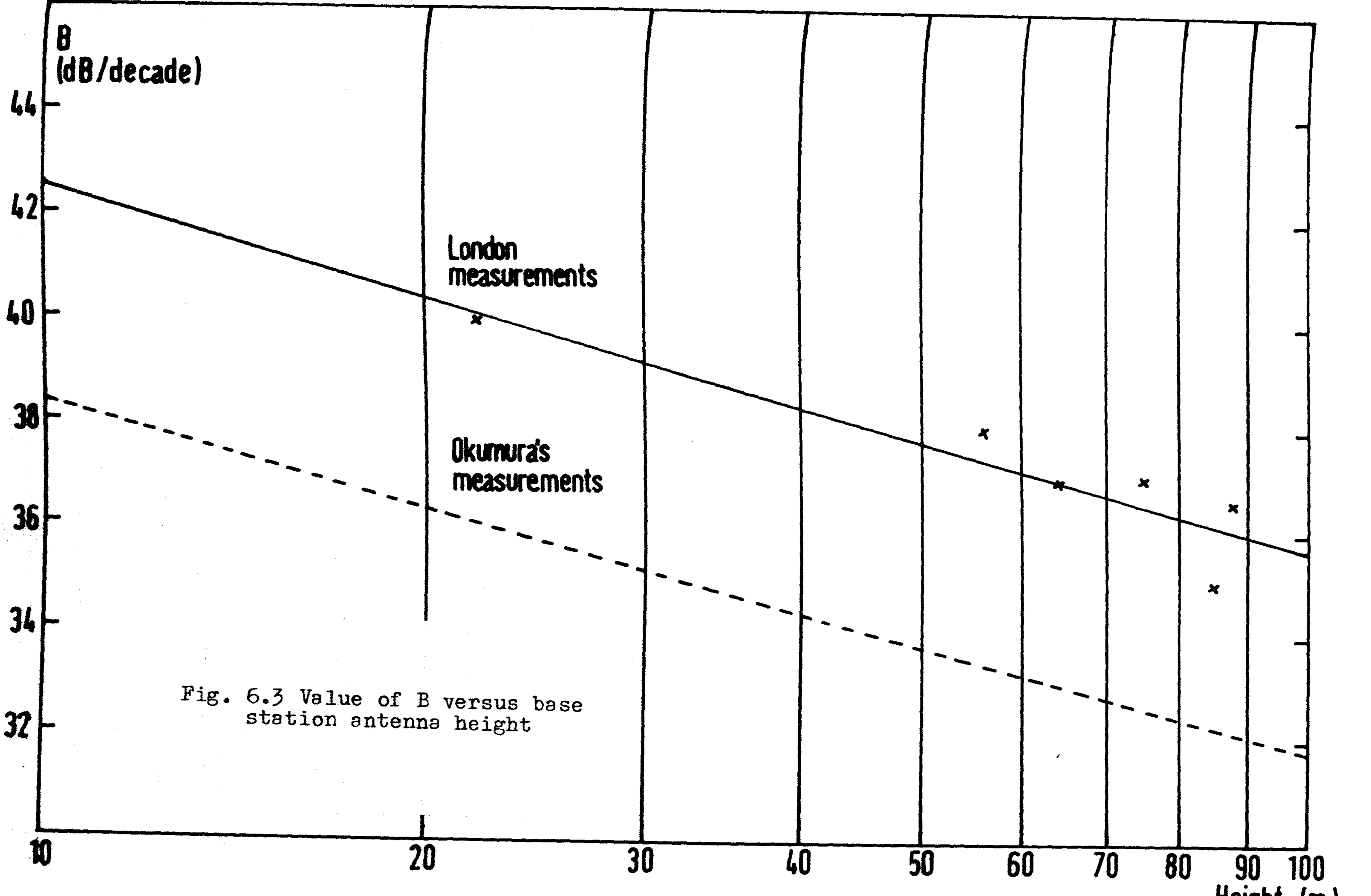

Fig. 6.3 Value of B versus base station antenna height

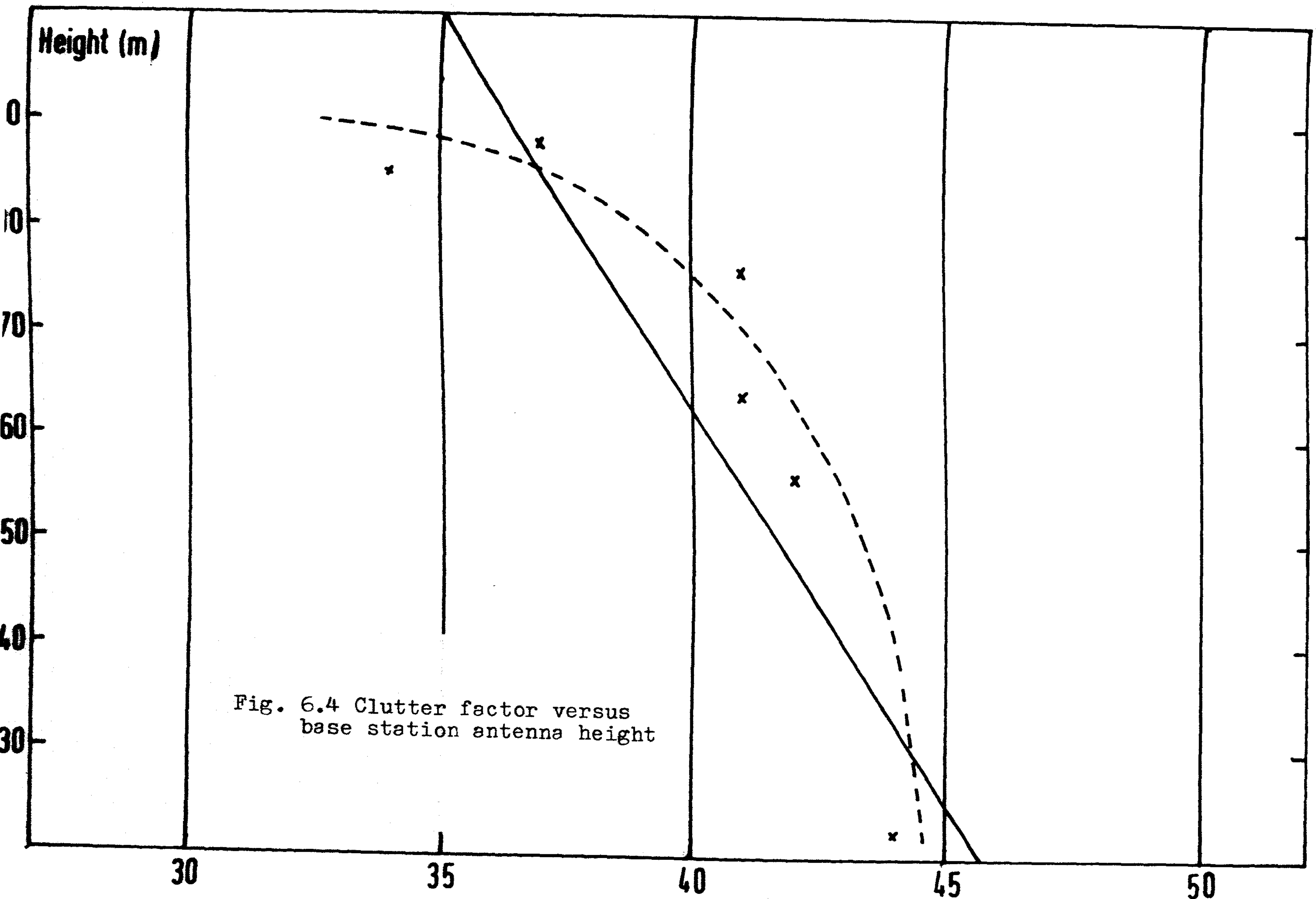

Fig. 6.4 Clutter factor versus
base station antenna height

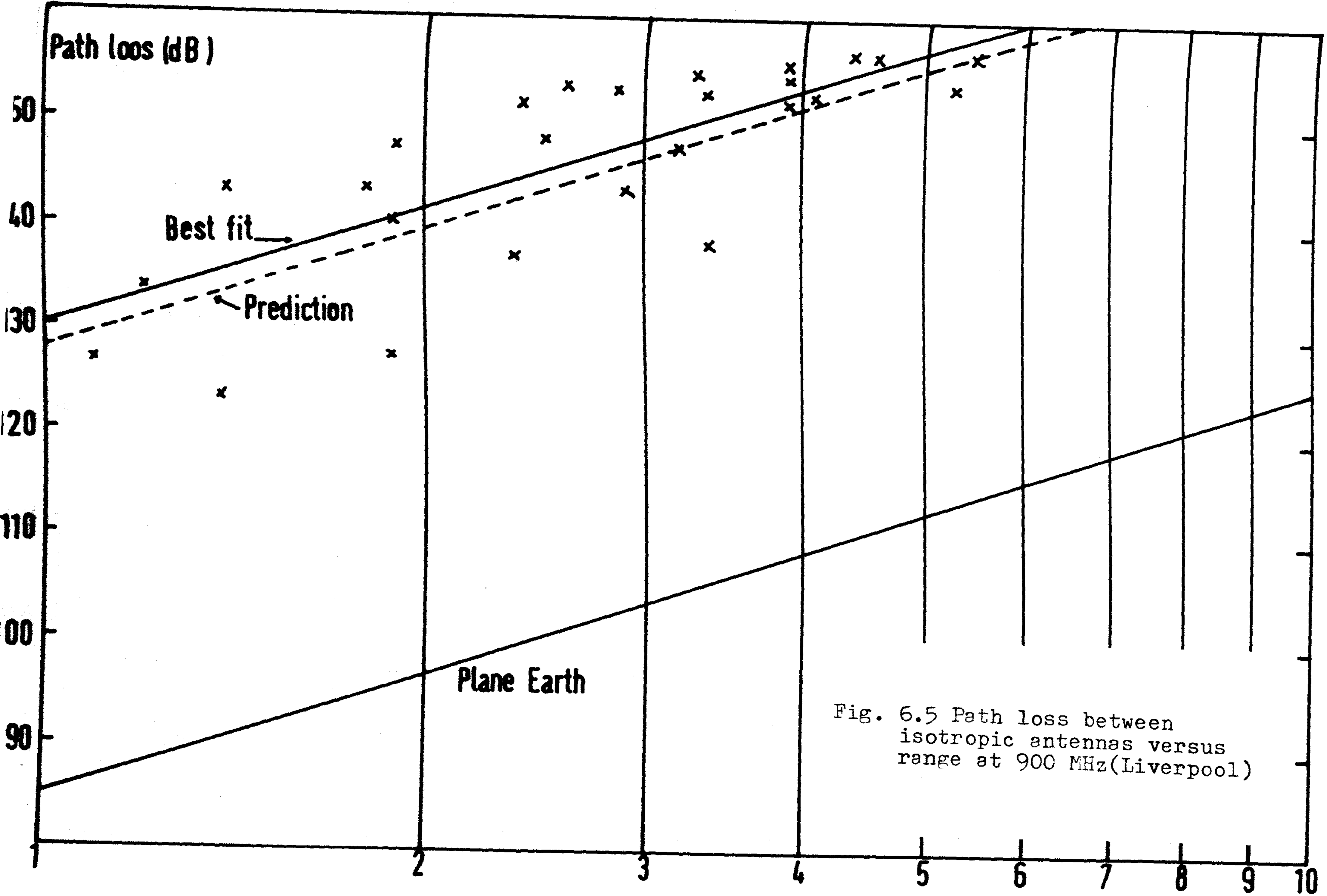

Fig. 6.5 Path loss between isotropic antennas versus range at 900 MHz(Liverpool)

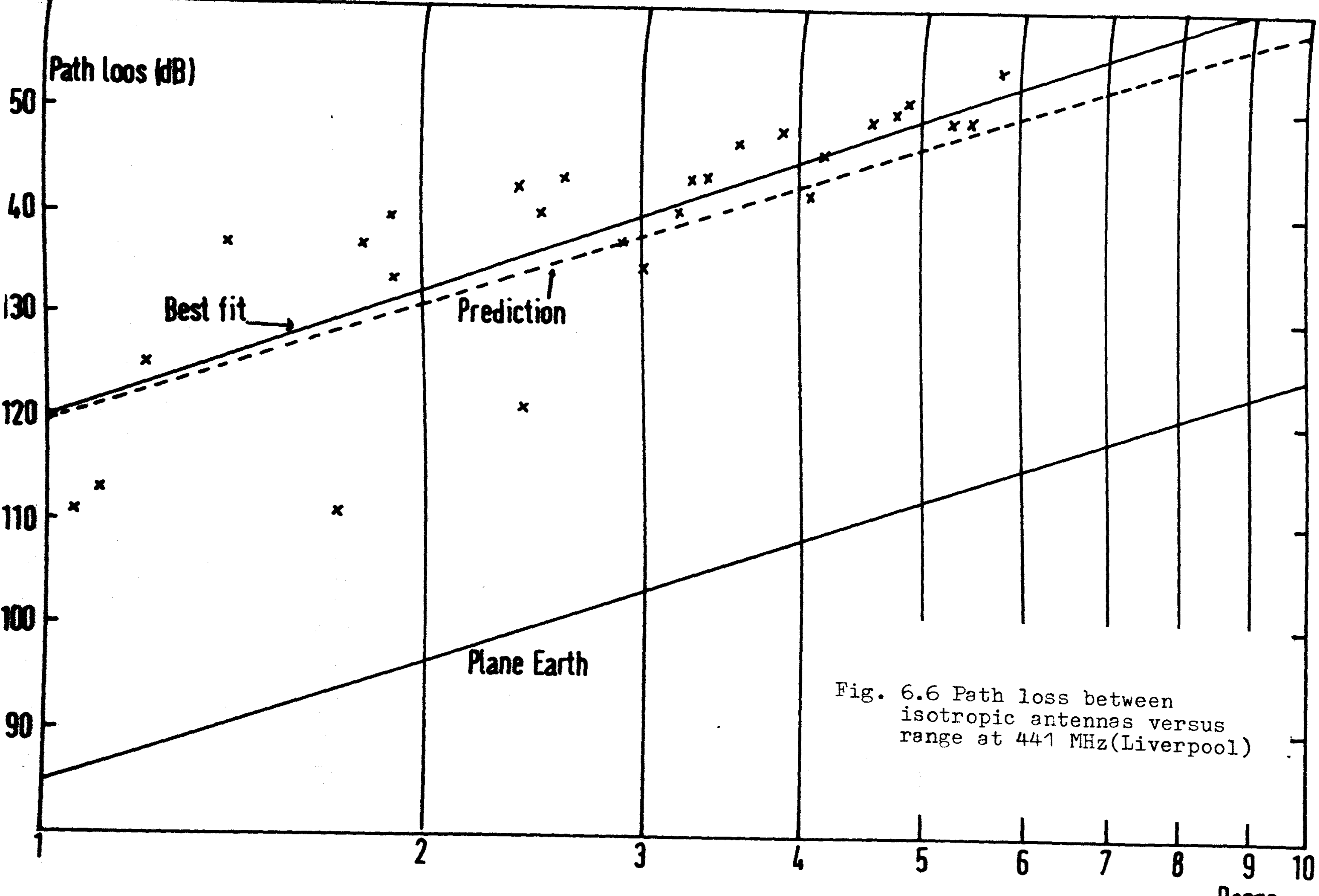

Fig. 6.6 Path loss between isotropic antennas versus range at 441 MHz(Liverpool)

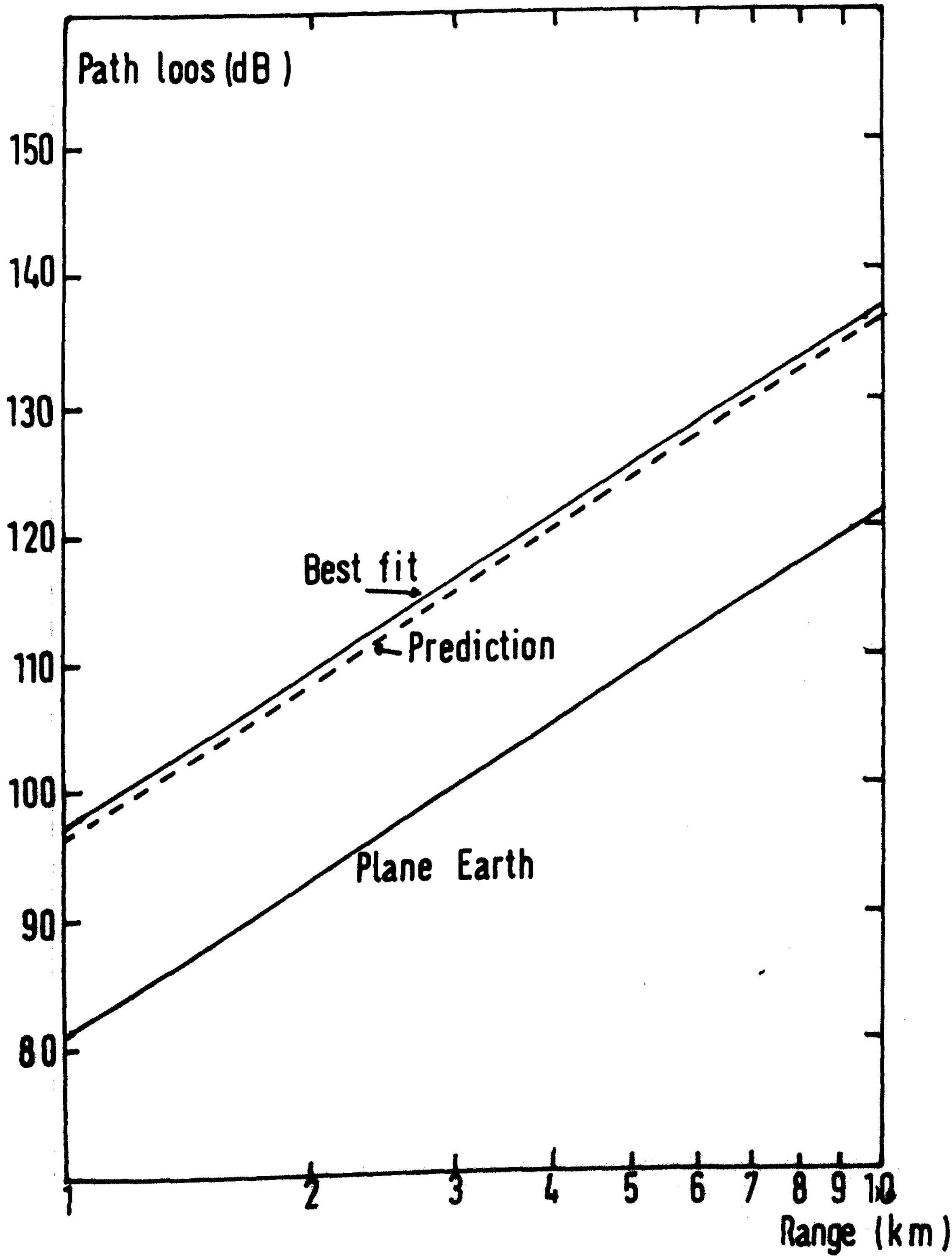

Fig. 6.7 Testing the prediction model on Allsebroke's data at 85.8 MHz.

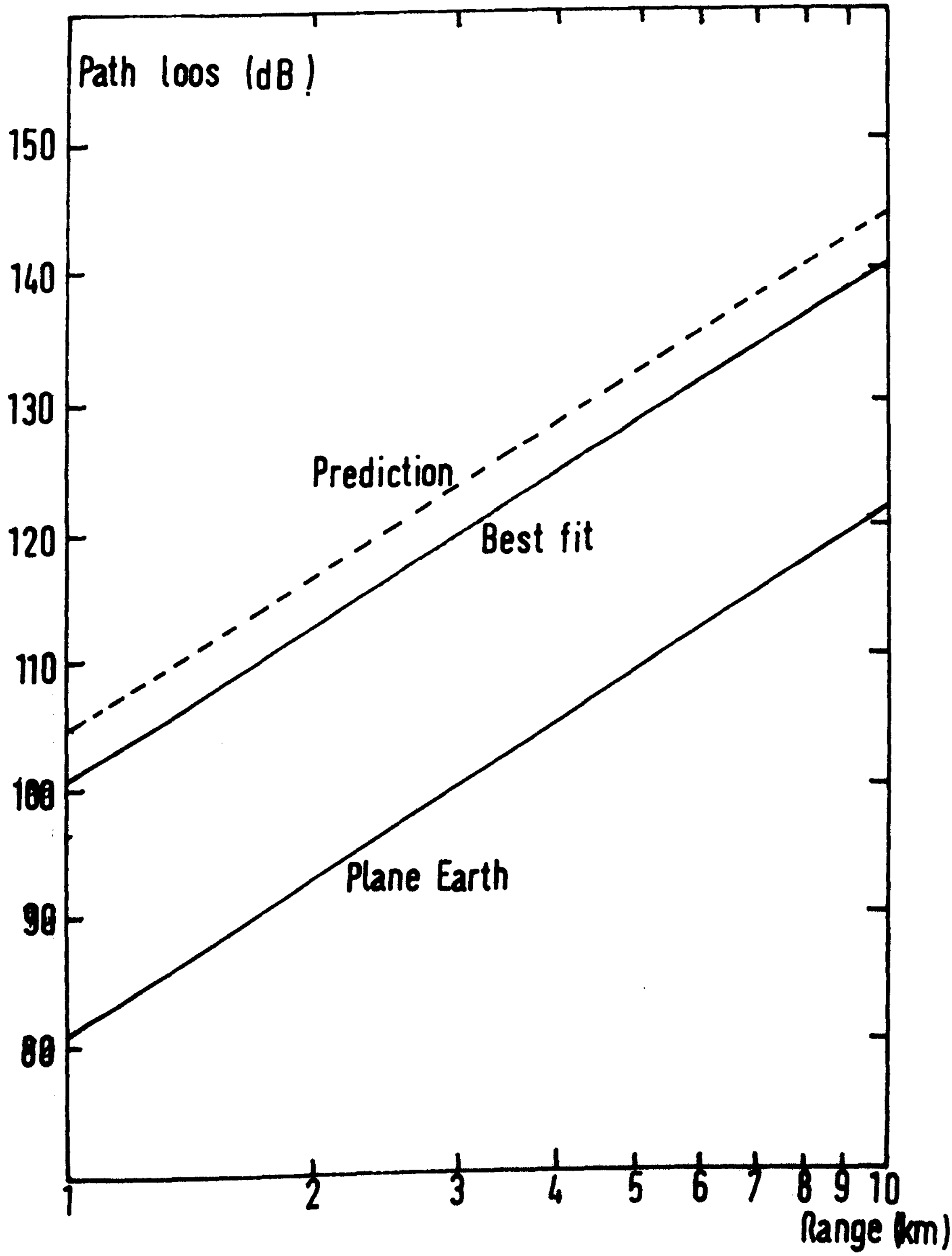

Fig. 6.8 Testing the prediction model on Allsebroke's data at167.2MHz.

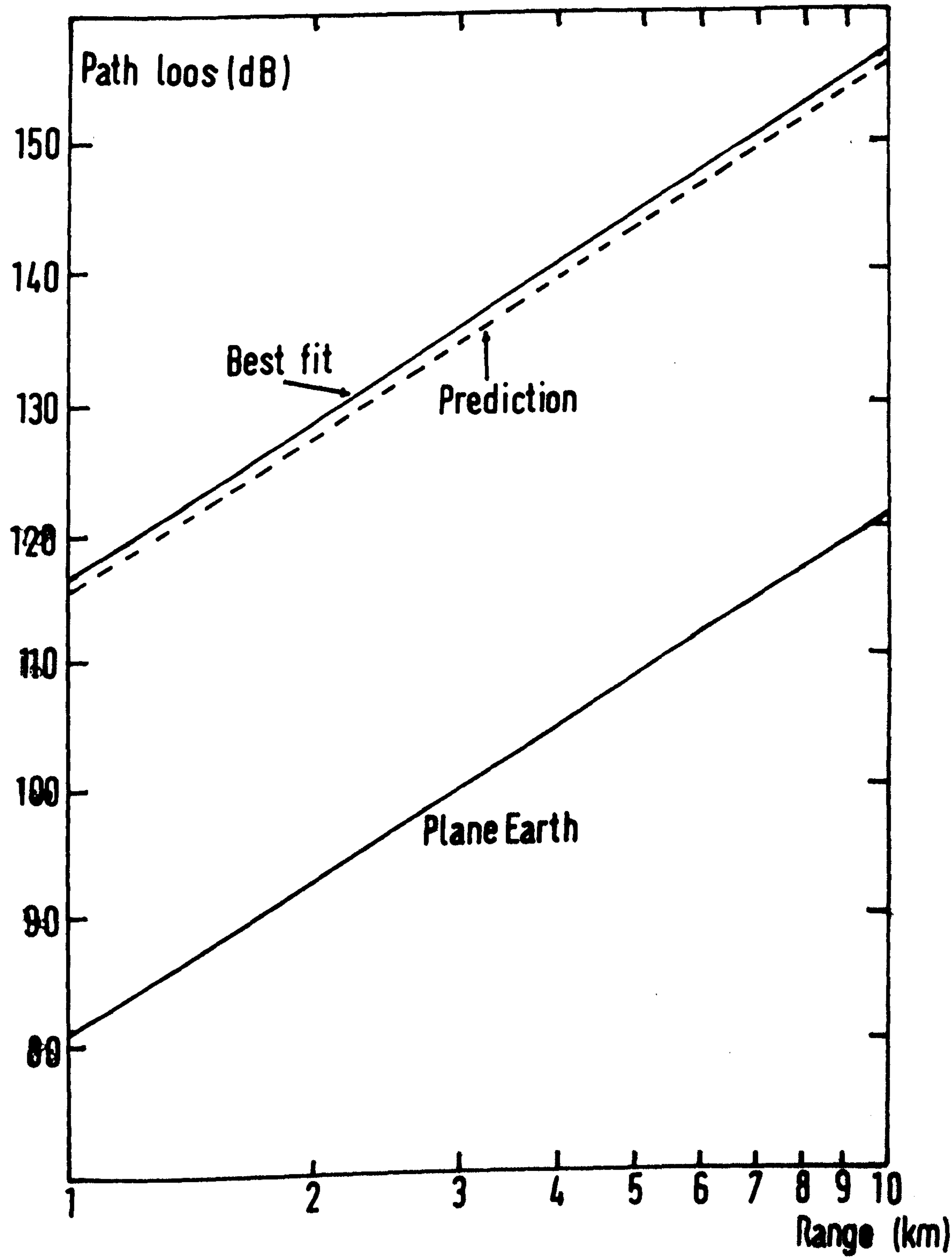

Fig. 6.9 Testing the prediction model on Allsebroke's data at 441 MHz.

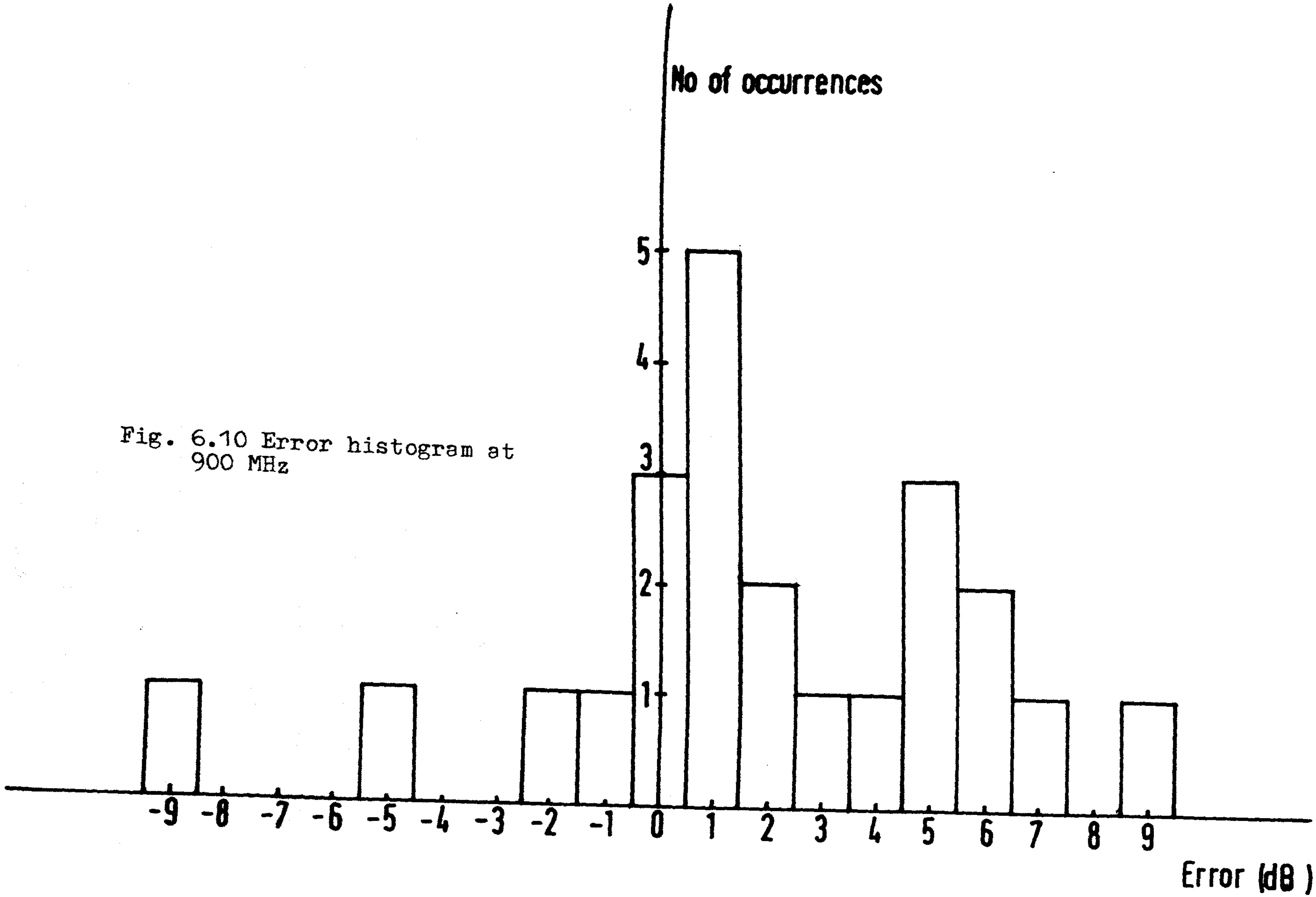

Fig. 6.10 Error histogram at 900 MHz

CHAPTER 7

SIGNAL VARIABILITY

7.1 GENERAL

In planning service areas of mobile radio communications systems, it is necessary to have as accurate a knowledge as possible of the median path loss values, ie., the path loss exceeded at 50% of locations within the area, in relation to the topography of the region between the stationary transmitter and the vehicle, and the nature of the vehicle's surroundings, ie., vegetation and buildings. It is also important to know the nature of the signal variation about this median value. This can be described either in terms of scatter or quantiles. The q% quantile is the path loss exceeded at q% of locations within the locality.

7.2 STATISTICS OF THE RECEIVED SIGNAL OVER A LARGE AREA

Several models have been suggested to describe the signal statistics over a large area. These are :

1) The Weibull distribution
2) The Nakagami-m distribution
3) The combination of Rayleigh and lognormal distributions. (Also known as the Suzuki distribution).

Ibrahim [7.1] investigated the three models listed above, and suggested that the Suzuki model described the distribution of the experimental results in urban areas thus confirming the conclusion previously reached by Lorenz [7.2]. The purpose of this chapter is to test the Suzuki model on the measured data, and also to relate the quantiles to an easily obtainable parameter.

7.2.1 Testing the Suzuki Model on the Measured Data

The probability density function of the Suzuki model is given by the following expressions :

$$p(F) = (2/\sqrt{2\pi}\, S.M) \int_{-\infty}^{+\infty} \exp\{(F-F_{OR}) - \exp[(F-F_{OR})\, 2/M]\}.$$
$$\exp[-(F_{OR} - F_{OS} + S^2/M)^2 / 2S^2].dF_{OR} \quad (7.1)$$

and the exceedence probability is given by;

$$Q(F) = (1/\sqrt{2\pi}\, S) \int_{-\infty}^{+\infty} \exp\{-\exp[(F-F_{OR})\, 2/M]\}.$$
$$\exp[-(F_{OR} - F_{OS} + S^2/M)/2S^2].\, dF_{OR} \quad (7.2)$$

Lorenz [7.2] showed that for a given set of experimental points drawn from an (assumed) Suzuki distribution the value of S is given by;

$$S = \sqrt{\mu - 31} \quad (7.3)$$

where μ is the variance of the experimental results.

and $$M = 20 \log e$$

Quantiles related to median value i.e $F_q - F_{50}$ are often of practical interest. These quantiles can be obtained using equation (7.2) and numerical integration methods. Fig. 7.1 shows the 1%, 5%, 10%, 99%, 95%, 90% quantiles related to the median value, plotted against the Suzuki parameter S. The measured quantiles for each test square were plotted against the Suzuki parameter, along with the theoretical quantile curves in Figs. 7.2, 7.3 and 7.4. The curves fit the data very closely although the spread of points about the line tends to increase as q gets very large (99%) or very small (1%). Nevertheless, as mentioned by Ibrahim [7.1] the Suzuki distribution is found to be a feasible model in urban areas. Hence if the median value of a sample was known, and the sample could be described by the Suzuki distribution, then in order to calculate the resulting quantiles, all that is needed is an estimate of the Suzuki parameter S. The experimental values of S range from 1 dB up to 9 dB but generally, the value tends to concentrate in the region between 4 and 5 dB.

7.3 EFFECT OF STREET ORIENTATION ON RECEIVED SIGNAL

Generally the received signal strength varies according to the orientation of the road on which the car travels with respect to the direction to the transmitter. Especially in urban areas a clear disparity in median attenuation presents itself, according to whether the course is parallel (along the path) or perpendicular (across the path) to the direction of propagation from the transmitter; the width of the road, too, has some effect.

A test square at 3km distance from the transmitter in Liverpool was selected, in which all the roads were either along the line of propagation or perpendicular to the line of propagation. The reason for choosing this test square was to maximise the effect of street orientation and hence to be able to quantify its effect. Measurements were taken along almost all possible routes in the test square, and a graph of signal strength along the route was plotted as shown in Fig. 7.5 by taking a moving average of every 100 samples. The regions where the route is parallel or perpendicular to the propagation path are coloured red and blue respectively. A significant difference in received signal strength is observed between radial and circumferential streets. On average the signal strength is about 15 dB higher in radial streets than in the corresponding circumferential streets.

By way of comparison, Okumura's measurements [7.3] at 922 MHz produced a difference of about 11 dB at a distance of 5km from the transmitter but only 5 dB at 100km.

The fluctuations in received signal strength caused by the street orientation could very well contribute to the variance of the sample obtained in any test square. When one type of route dominates the other, less variation and hence a smaller variance would be expected.

Of course street orientation is not the only parameter that contributes to the spatial variability. The width of the street and the inhomogenuity of buildings within the test square also contribute. However, their effect may not be as significant as street orientation. The intention in this work has always been to keep any proposed model as simple as possible, but without making major sacrifices in accuracy and reliability. The problem is that not all the routes lie exactly along or across the path; they may be at many different angles to the line of propagation.

Measurements by Reudink [7.4] showed that the signals received on radial and nearly radial streets were usually 10 dB or more greater than the signals received on similar circumferential or nearly circumferential streets. This suggests that for the purposes of modelling the roads can be divided into two simple categories, ie., those roads which seem to be radial or nearly radial and those which seem to be circumferential or nearly circumferential. Admittedly, this is a rather crude classification, but further measurements could lead to a possible refinement of this statement.

7.3.1 Street Orientation Factor

The above argument leads us to suggest the use of a street orientation factor which, for a particular test square is defined as the difference between the total route along the line of propagation and the total route perpendicular to the line of propagation, expressed as a percentage of the total route, ie.,

$$F = \left| \frac{l_R - l_A}{l_R + l_A} \right| \qquad (7.4)$$

where l_R is total radial route (or nearly radial)

l_A is total perpendicular route (or nearly perpendicular)

Streets at < 45° from radial were counted as radial and those at > 45° counted as circumferential.

The value of F ranges from 0 to 1. F was calculated for various test squares in Liverpool using an OS map and plotted in Fig. 7.6 versus the Suzuki parameter S on log-linear graph paper, with S along the logarithmic axis. The points lie reasonably close to a straight line expressed by :

$$F = 1.41 - 1.58 \log s \qquad (7.5)$$

or S is given by

$$S = 10^{(1.41 - F)/1.58} \qquad (7.6)$$

7.3.2 Theoretical Approach

The above results can be examined by comparison with an approximate theoretical model. By making the assumption that the signal level remains fairly constant on radial or circumferential routes but with a difference of 15 dB (ignoring the short term variation), the variance of the signal in a particular test square is given by

$$\text{Variance} = [\,(15\, l_R / l) - 15\,)^2\,].\, l_R / l \qquad (7.7)$$

where $$l = l_R + l_A$$

Experimental results have shown that the variance (due to short term variations) of the signal level along only one type of route (either radial or circumferential) is about 36 dB, hence using equation (7.3) the Suzuki parameter is expressed by :

$$S = [((15\, l_R / l) - 15)^2 . (l_R/l) + 5]^{\frac{1}{2}} \qquad (7.8)$$

Using equation (7.4) and the fact that;

$$l = l_R + l_A$$

hence

$$S = (((7.5 (1 + F) - 15)^2 (1 + F) / 2) + 5)^{\frac{1}{2}}$$

or

$$S = (28.1 (F^3 - F^2 - F + 1) + 5)^{\frac{1}{2}} \qquad (7.9)$$

Equation (7.9) is plotted along with equation (7.5) as shown in Fig. 7.6. Although several approximations have been made, there is a good measure of agreement between theoretical and measured results in the range of $0.2 < F < 0.8$. The theoretical curve does not fit the data for values of $F > 0.8$ and $F < 0.2$; the reason for this could be that the constant 36 dB added to equation (7.7) could very well be a function of F.

7.4 TESTING THE MODEL ON LONDON DATA

The applicability of equation (7.6) to the London data was examined using only 20 squares. The reason for this was that since many of the preplanned routes had to be altered to a greater or lesser extent at the time of measurement, the exact route covered was not available. An r.m.s. error of about 1.4 dB was achieved, which is quite reasonable compared to the r.m.s. error of 0.68 dB obtained in Liverpool.

Having obtained an equation from which the Suzuki parameter S can be estimated, the quantile relating to the median value can be extracted from the curves shown in Fig. 7.1. Since approximate formulae exist for the set of curves in Fig. 7.1 [7.2] a complete model can be suggested, from which the path loss exceeded for % of the time can be derived. Table 7.1 summarises all the equations.

Table 7.1

Path loss exceeded for q%	S	P_{Lq}
$1 \le q \le 20$	$S \le 6$ dB	$82 + 26.16 \log f + 38 \log R - 21.8 \log h_b - 0.15 h_m + L_D + Q_{us} + 4.34 \ln. \ln[-\ln(q/100)] + 1.59 + 0.4 q^{-0.3}. 10^{(1.41-F)1.75/1.58}$
$1 \le q \le 20$	$S > 6$ dB	$82 + 26.16 \log f + 38 \log R - 21.8 \log h_b - 0.15 h_m + L_D + Q_{us} + (2.2-0.456 \ln q). 10^{(1.41-F)/1.58} + 3.8 - 0.7 \ln q$
$99 \ge q \ge 80$	$S \le 6$ dB	$82 + 26.16 \log f + 38 \log R - 21.8 \log h_b - 0.15 h_m + L_D + Q_{us} + 4.34 \ln(-\ln q/100) + 1.59 - 0.1 (100-q)^{-0.23} .10^{(1.41-F) 2.1/1.58}$
$99 \ge q \ge 80$	$S > 6$ dB	$82 + 26.16 \log f + 38 \log R - 21.8 \log h_b - 0.15 h_m + L_D + Q_{us} + (0.7 \ln(100-q)-1.8). 10^{(1.41-F)/1.58} - 11 + 3 \ln(100-q)$

Q_{us} = 5.5 dB if Transmitter in urban area

Q_{us} = -2 dB if Transmitter in suburban area.

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[1] Ibrahim, M.F.A. "Signal strength prediction for mobile radio communication in built-up areas," Ph.D. thesis, University of Birmingham, Department of Electronic and Electrical Engineering, 1981.

[2] Lorenz, R.W. "Theoretical distribution functions of multipath propagation and their parameters for mobile radio communication in quasi-smooth terrain". NATO AGARD conf. publ. no. 269, 1979.

[3] Okumura, Y. "Field strength and its variability in VHF and UHF land-mobile radio service." Review of the Electrical Communication Laboratory, vol. 16, no. 9-10, September-October, 1968.

[4] Black, D.M. and Reudink, D.O. "Some characteristics of mobile radio propagation at 836 MHz in the Philadelphia area". IEEE Transaction on Vehicular Technology, vol. VT-21, no. 2, May 1972.

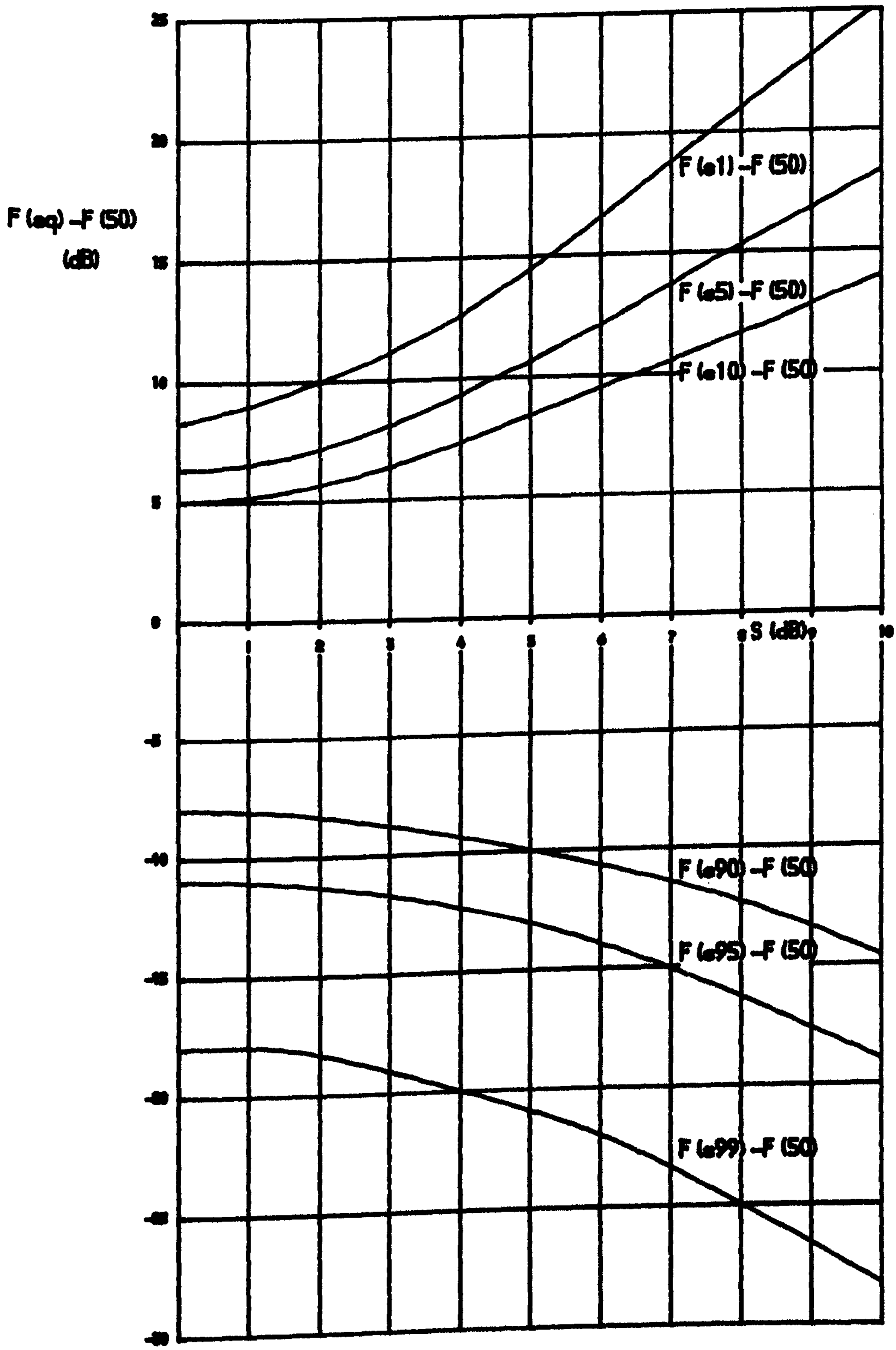

Fig. 7.1 Quantiles of Suzuki distribution in relation to the median value.

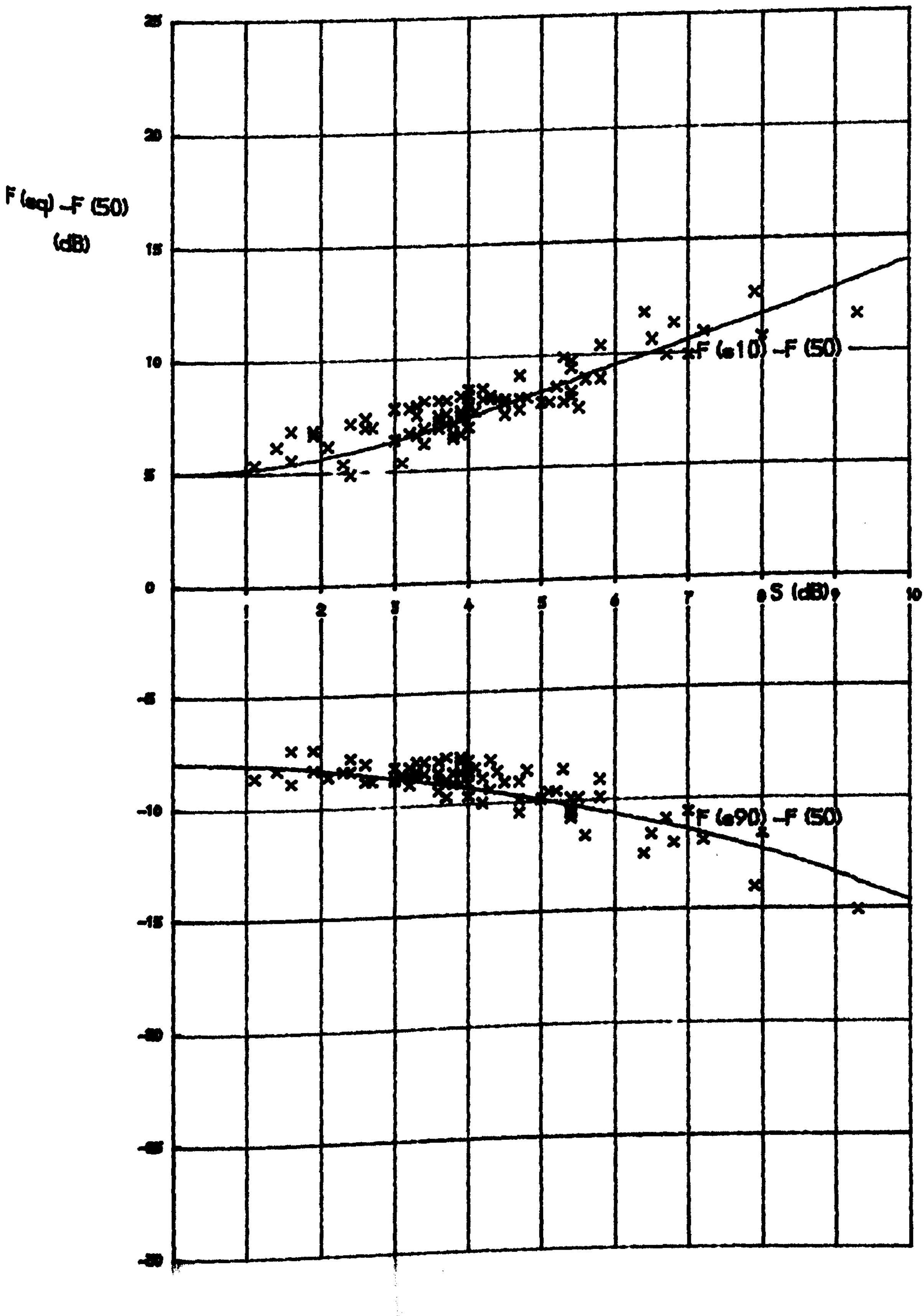

Fig. 7.2 Plot of 10% and 90% quantiles relative to the median value of the received signal at 900 MHz.

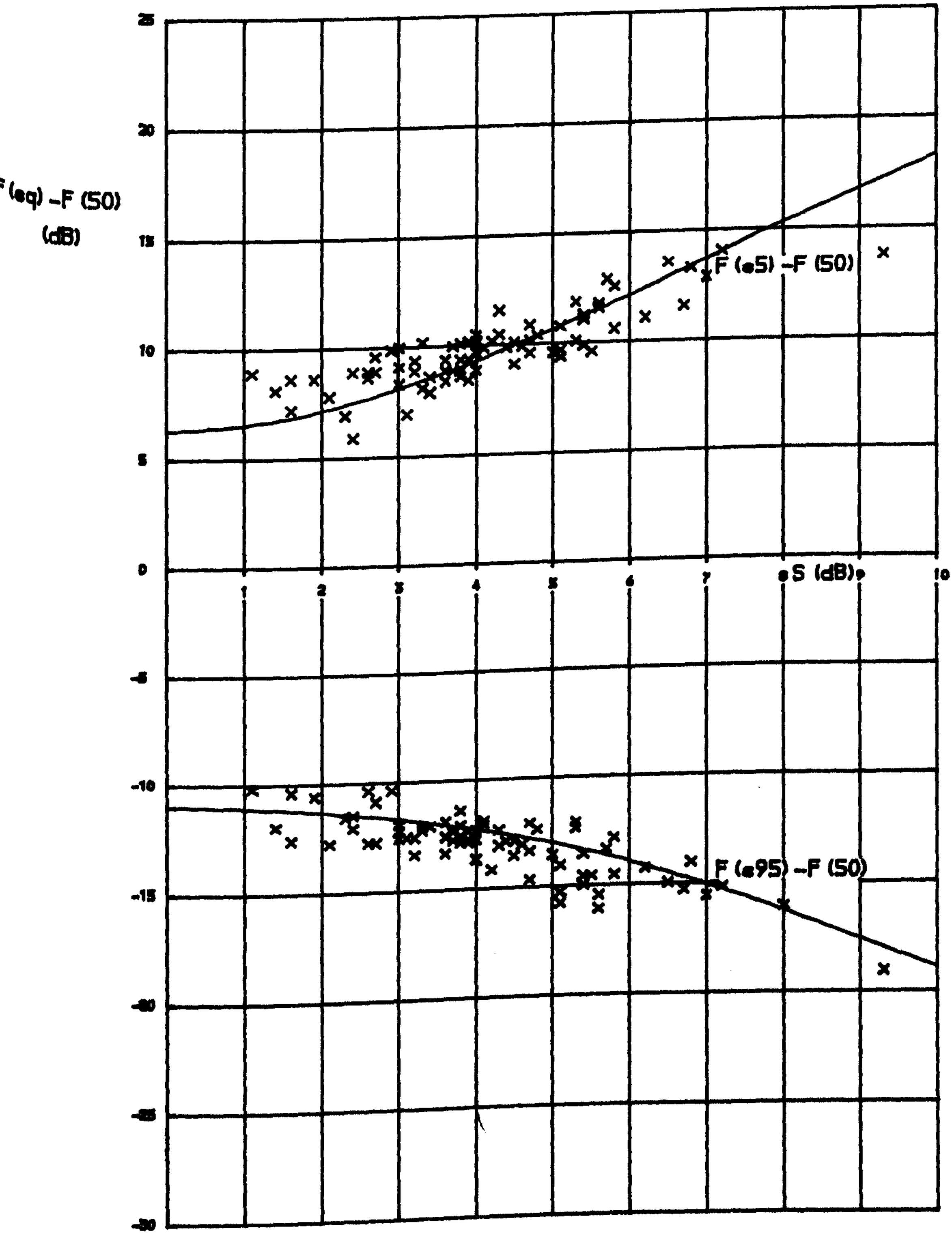

Fig. 7.3 Plot of 5% and 95% quantiles relative to the median value of the received signal at 900 MHz.

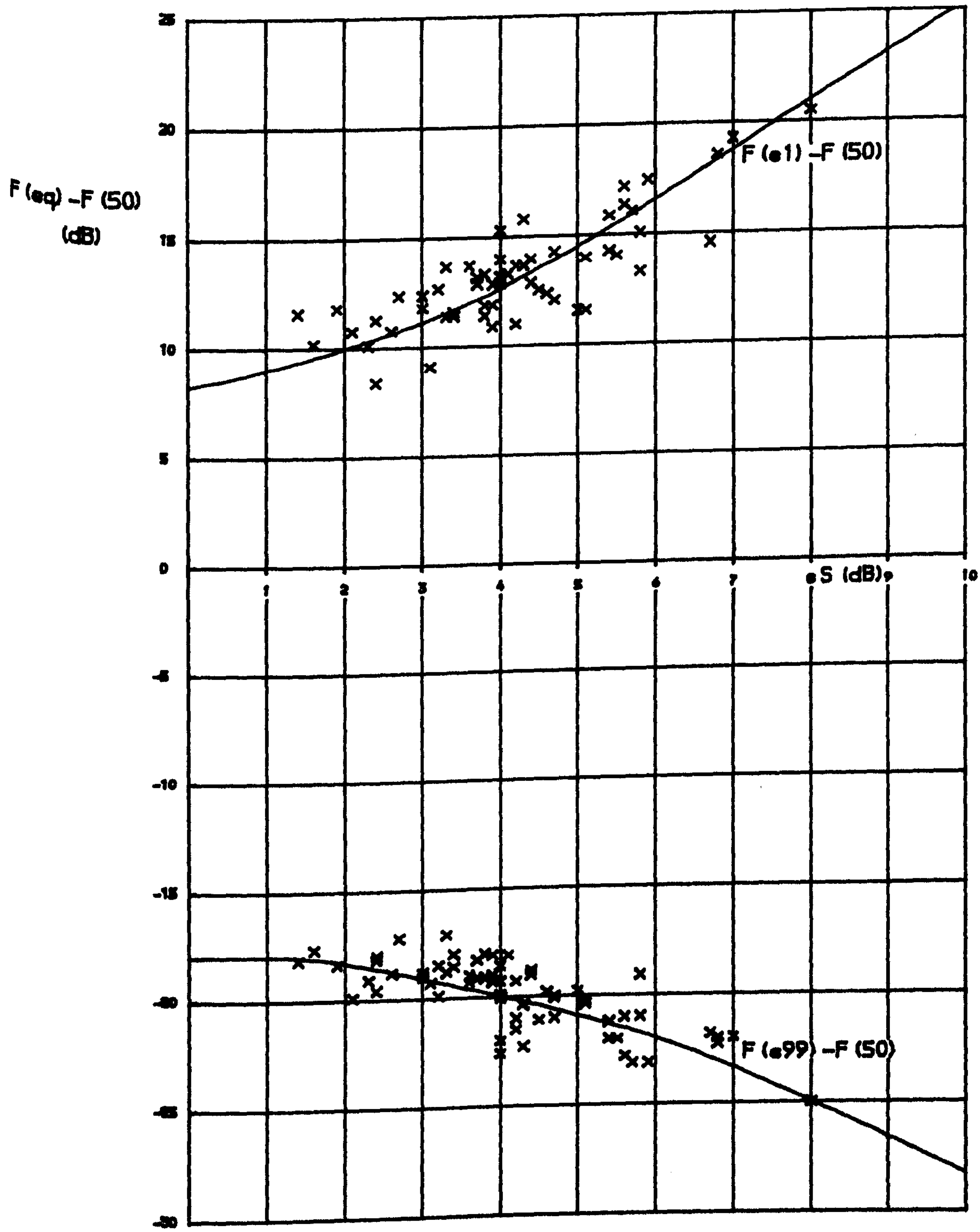

Fig. 7.4 Plot of 1% and 99% quantiles relative to the median value of the received signal at 900 MHz.

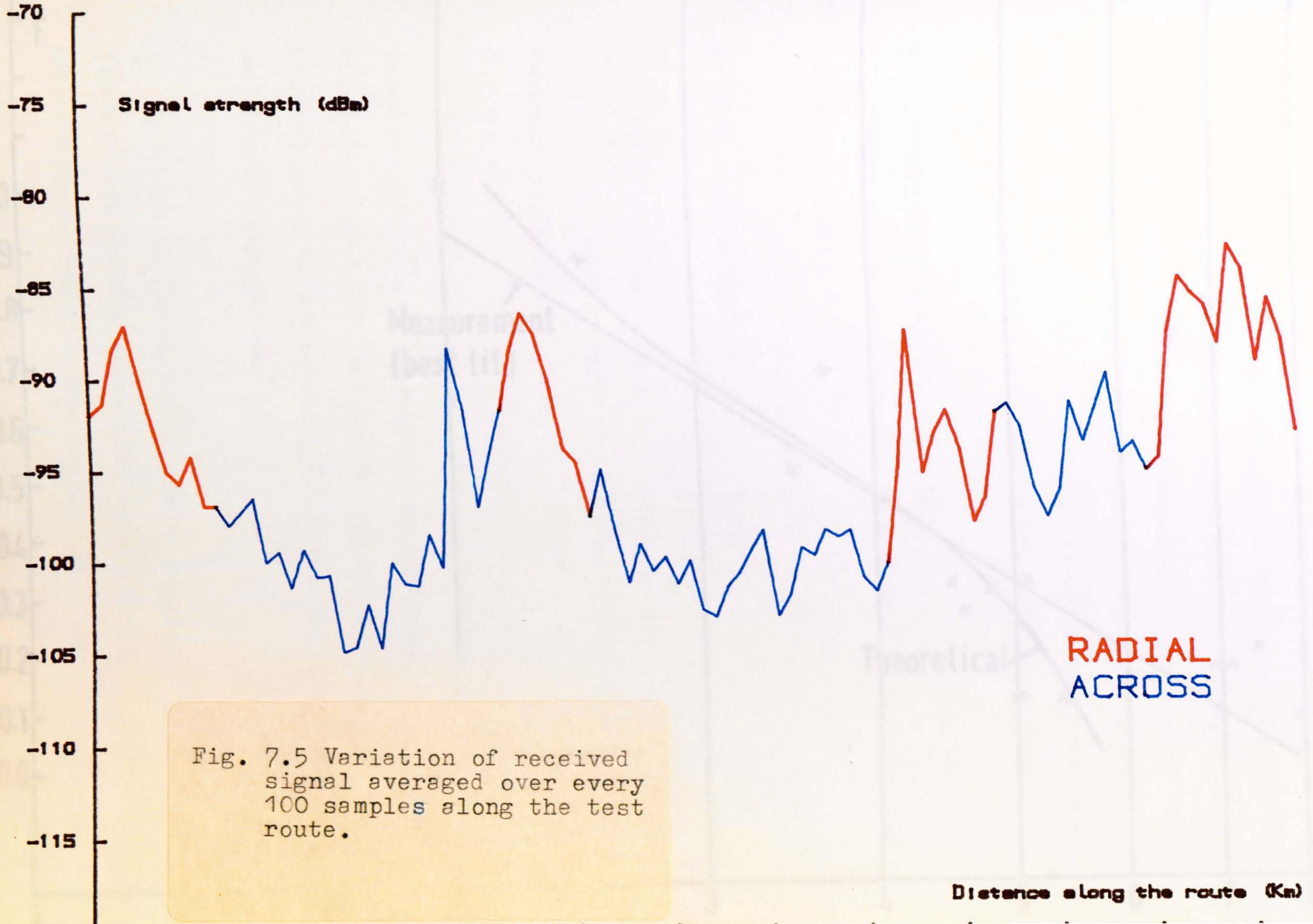

Fig. 7.5 Variation of received signal averaged over every 100 samples along the test route.

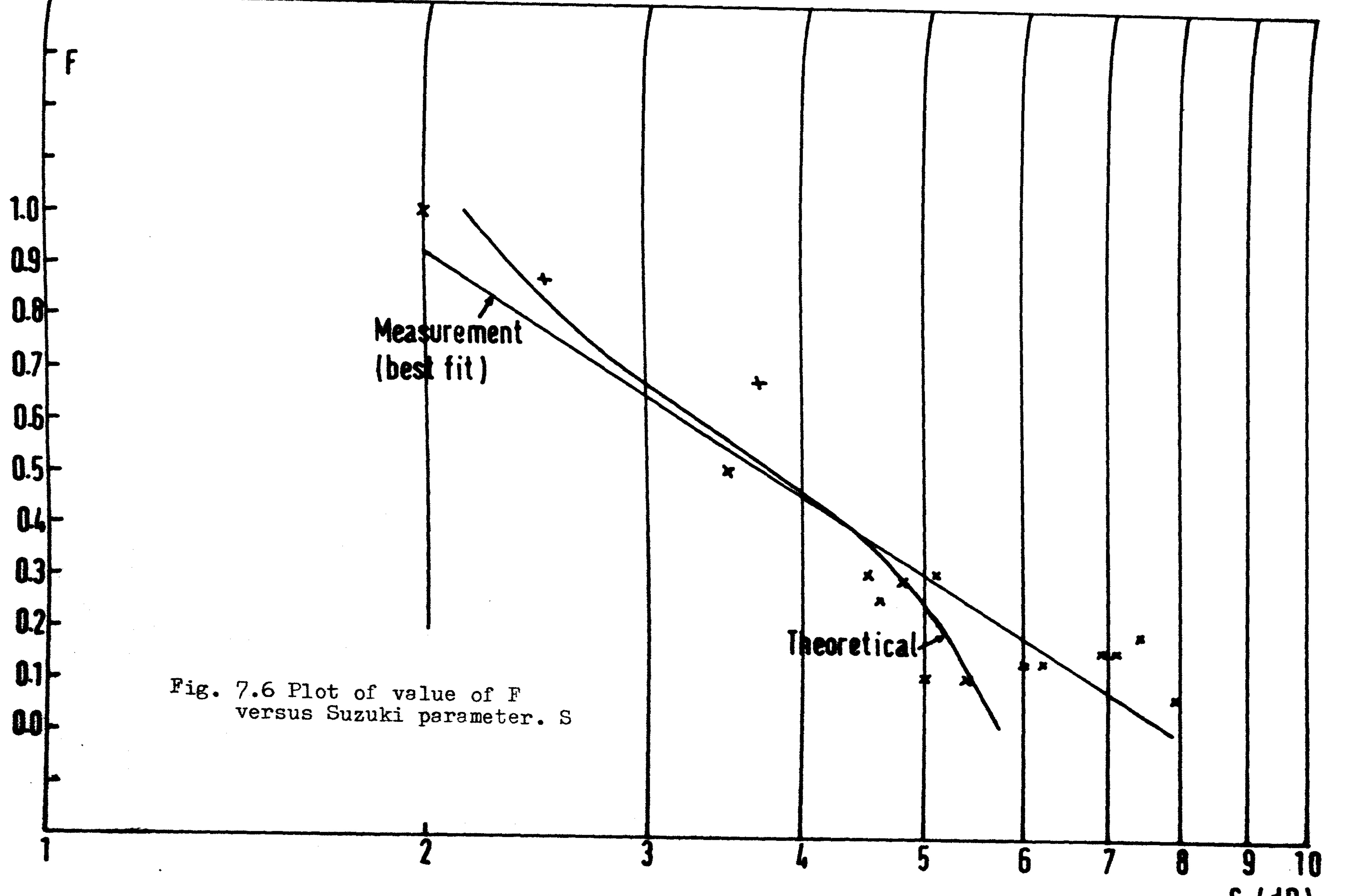

Fig. 7.6 Plot of value of F
versus Suzuki parameter. S

CHAPTER 8

RURAL FIELD TRIALS AND RESULTS

8.1 INTRODUCTION

As previously discussed in chapter 2, the JRC method is one of the most commonly used prediction techniques in the U.K. and Europe. Several comprehensive measurements were conducted in rural areas, with transmitter sites located in rural, suburban and urban areas, to provide a data base for testing the JRC prediction technique, and finally some recommendations were made to improve the JRC prediction technique.

8.2 TRANSMITTER SITES AND TEST AREAS

Three transmitter sites were used in this series of field trials. These were as listed below :

Table 8.1

Location	OS Grid Ref.	Height of Local Ground	Overall Antenna Height	ERP	f (MHz)
Newton Firs	SJ 527749	150m	194.2m	18W	139
Altrincham	SJ 776876	31m	87.4m	24W	139
Wavertree	SJ 376898	50m	113m	11W	139

The first transmitter site is located in a completely rural area, the second in a small town and the third in a completely urban area surrounded by high-rise buildings (Liverpool Centre). The transmitting frequency was 139.01 MHz. Fig. 8.1 shows a view of the Newton Firs mast together with the Southward-looking outlook.

A 1:25,000 OS map was used to plan the routes to be covered. The method of data collection was to select routes within a 500 x 500 metre square to provide reasonable coverage of that square. When leaving a square a file marker was put on to the tape to indicate the end of that square and the start of the next. The squares selected were located at distances between 10 and 40 Km from the transmitters. A small section of the routes covered is illustrated in Fig. 8.2. In the first test (Newton Firs) nearly 180 squares of 500m x 500m were covered. In the second test (Altrincham) over 200 squares were covered, and finally in the last test (Wavertree) over 150 squares were covered. Some of the squares covered from Altrincham were also covered using the Newton Firs transmitter so that a comparison could be made.

8.2.1 The Newton Firs Trials

The area chosen for the Newton Firs tests was completely rural. The ground was substantially flat and only a few squares included very hilly areas. For each square the signal strength value exceeded at 1% and 99% of locations was obtained. The median or 50% values were also obtained and comparisons were made with predictions obtained using the JRC SERV program. The 50% values were used to compute the path loss between two isotropic aerials and this was plotted against range as shown in Fig. 8.3. The best fit straight line through these points was calculated by minimising the r.m.s. error, and it was found to be very close to a square law function with range (20 dB/decade). The slope of the line was found to be 20.6 dB/decade.

A clutter factor can now be determined by finding the difference between the best square law fit and a line calculated using the free space equation. This factor was found to be 25 dB.

A graph of median signal strength (i.e. 50% value) for both measurement and prediction was then plotted for each square in order to observe the relationship between predictions and measurements. This is shown in Fig. 8.4. The graph clearly indicates that the predictions are optimistic for the majority of locations, the notable exception being the areas indicated by the arrow. These areas were found to correspond to the hilly areas. These squares are SJ500545, SJ500550, SJ500555, SJ505555, SJ510510 and SJ510515. The difference between the predictions and measurements were calculated and a histogram of error was drawn and is shown in Fig. 8.5. Since the predictions are given to ± 1 dB the errors were also calculated in steps of 1 dB. The number of ±X dB errors were accumulated in the same histogram bin, therefore this particular histogram only indicates the magnitude of the error and does not indicate whether the predictions are optimistic or pessimistic. However, if positive and negative errors are plotted on two separate histograms as shown in Fig. 8.6, it is possible to observe how optimistic or pessimistic the predictions are. The lower half of Fig. 8.6 represents the optimistic results (path loss less than the predicted value) and the upper half represents pessimistic results. It is clearly observed that in general the predictions are optimistic.

The standard error defined as

$$\sqrt{\Sigma(x_p - x_m)^2 / N}$$

where x_p = prediction, x_m = measurement and N = number of samples, was calculated to be 8.58 dB with a standard deviation of 4.8 dB. The correlation coefficient was found to be 0.82 which is very high, indicating that the predictions follow the trend of the measurements very closely with the exception of a fairly constant difference. The predictions can be improved in these rural areas by subtracting about 5 dB from the predicted values and if this is done the r.m.s. error is reduced to approximately 3.5 dB.

8.2.2 The Altrincham Trials

A similar analysis was carried out on data collected using the transmitter at Altrincham.

A graph of path loss as a function of distance is shown in Fig. 8.7 and a slope of about 30 dB/decade was measured for the best fit straight line through the points. Factors contributing to the difference between this result and that obtained using the Newton Firs site could be that the Altrincham transmitter is located in an urban area and its height is less than the height of the Newton Firs site. The clutter factor was calculated to be 37 dB, a much higher value than for Newton Firs, again possibly for the same reasons. These results seem to suggest that the immediate surroundings of the transmitter have a major effect on the measurements.

A plot of both measured and predicted signal strength against square number was plotted in Fig. 8.8. In general the measured data agrees quite closely with the predictions except in those areas indicated by arrows on Fig. 8.8 where errors were observed. It is apparent that the prediction programme has assumed a direct line-of-sight path (power transmitted = 24 W, distance = 9 km, frequency = 139 MHz, therefore P free space = $10 \log 24000 - 20 \log \frac{300}{139} - 20 \log 4\pi - 20 \log 9000 = 50$ dBm, prediction = 49 dB) for the set of squares marked S1 (Fig. 8.8), which in reality does not exist. The same reasoning applies to the squares marked S2 and S3 and it is interesting to observe that all these squares lie in the same radial direction to the south of the transmitter. A direct line-of-sight probably rarely exists in reality because the transmitter is located in an urban area and high-rise buildings probably block the path in the majority of cases.

Error histograms similar to those drawn for the Newton Firs results are produced in Figs. 8.9 and 8.10. For low values of error (< 9 dB), Fig. 8.10 shows that predictions are optimistic as often as they are pessimistic but for higher values of error, predictions are more often optimistic. The reason again is that a direct line-of-sight path was assumed in the predictions related to some of the squares, hence giving rise to a much higher predicted signal strength. The correlation coefficient was found to be 0.74, standard error 10.7 dB and standard deviation 8.2 dB.

8.2.3 The Wavertree Trials

It was regarded as very important to find whether similar observations applied to measurements from the third site (Wavertree) which is located within the city of Liverpool. A graph of path loss versus distance was again plotted and this is shown in Fig. 8.11. The slope was found to be around 40 dB/decade indicating a fourth power relationship between path loss and range.

Two clutter factors can be deduced for these results

(i) deviation of the best second law fit from free space.

(ii) deviation of the best fit fourth law equation from plane earth.

The first calculation gives 35 dB and the second gives about 40 dB. A graph of signal strength prediction and measurement versus square number was again plotted to identify those areas where there are significant differences. It again became clear that a direct line-of-sight was being assumed on the predictions for some squares which is not borne out by the measurements. One example is square SD530000 which is indicated by an arrow on Fig. 8.12. From Fig. 8.12 it can be seen that there is an area (marked SD61) in which there is not a good agreement between predictions and measurements. This area is very hilly and the predictions differ markedly from the measurements. Histograms of error were plotted as in the previous cases and these are shown in Figs. 8.13 and 8.14. The standard error was computed to be 11.6 dB and the correlation coefficient was 0.65 which is quite poor compared to previous results. This is probably due to the fact that the tests were conducted in a hilly area.

8.3 SIGNAL VARIABILITY IN RURAL AREAS

Examinations were carried out on the variability of the received signal at 139 MHz in rural areas at distances greater than 20km from the transmitter. The signal variability in rural areas would undoubtedly be expected to differ from that in urban areas. First of all the distance covered in a 500m x 500m square in a rural area is probably limited to less than 1km, and this limits the extent to which the signal can vary. Secondly, the rarity of manmade obstacles is certainly one of the causes for the difference.

Graphs of the cumulative distribution of the received signal in test squares at 30km were plotted on a Rayleigh graph paper (Fig. 8.15). The results indicate that the samples are described by a Weibull distribution. Fig. 8.16 shows the plot of 10% and 50% quantiles in relation to the median value of the received signal versus the standard deviation. The standard deviation was never below 2 dB and occasionally was found to exceed 7 dB. The best fit lines through the data were computed and given by :

$$PL(10) - PL(50) = 0.88\sigma + 0.24 \quad \text{dB} \qquad (8.1)$$

$$PL(90) - PL(50) = -1.5\sigma \quad \text{dB} \qquad (8.2)$$

where σ is the standard deviation.

Equations (8.1) and (8.2) are plotted in Fig. 8.16.

Therefore an estimation of the value of σ is essential in calculating the 99% quantile. It does not seem possible to choose the most occurring value of σ, since it is evenly distributed in the range of 2 dB to 7 dB. Further research is required to relate σ to some known parameter.

8.4 DISCUSSION OF RESULTS

The problem of whether or not a direct line-of-sight path exists appears to be very important, because if its existence is assumed, the predictions invariably turn out to be much higher than the actual measurements. This was found to be the case in all three series of tests. To show how easily the line-of-sight path can be blocked a simple idealized situation is shown in Fig. 8.17 and an elementary calculation leads to the equation

$$D_B = \frac{D_R \, H_B \, (H_T - H_B)}{H_R \, (H_T - H_B) - H_T \, (H_R - H_B)}$$

where the symbols are identified in Fig. 8.17.

So for a transmitter height of 100m and a receiver height of 2m an obstacle 4m high only needs to be within 200m of the receiver to block the direct line-of-sight path when D_R = 10km. When D_R = 40km, the same obstacle needs to be within 800m of the receiver. It is clear that a 4m obstacle could very well be only a 1 or 2 storey building.

Comparing the results for the different transmitters, the predictions for the first site (Newton Firs) were much better than for the other two sites and this appears to be mainly due to the fact that the transmitter is located in a rural area, is well elevated and the test area was flat and rural. However whilst it is pleasing to note this fact, it is also necessary to realise that it is equally desirable to produce similarly good results in hilly areas no matter whether the transmitter is situated in an urban or rural location. It was clearly noted from analysis of the results that the clutter factor increased as the degree of urbanization around the transmitter was increased and this is a fact that cannot be ignored.

Table 8.2 gives a quantitative comparison of the results for the different sites.

Table 8.2

Location	Range Dependence Coefficient (dB/decade)	RMS Error (dB)	Clutter Factor (dB)	Correlation Coefficient
Newton Firs	20.6	8.58	25	0.82
Altrincham	30	10.7	37	0.74
Wavertree	40	11.6	35	0.65

8.5 RECOMMENDATIONS FOR IMPROVING THE JRC METHOD

A possible model that could be proposed is as follows :

P_L = a basic path loss using an appropriate range law (Table 8.3)

+ diffraction loss

+ gain due to transmitter height

+ gain due to receiver height

+ clutter factor

The advantage of this model is that it can never assume a direct line-of-sight path even if the diffraction loss is zero since there is always a clutter factor which has to be taken into account. Another important point is that it takes care of the surroundings of the transmitter through the use of the clutter factor and by using either plane earth or free space laws as appropriate. The following table describes the various possibilities.

Table 8.3

Transmitter Location	Test Area	Range Law
Rural	Rural	Free space 20 dB/decade
Urban	Rural	30 dB/decade
Urban	Urban	Plane earth 40 dB/decade

Unfortunately it did not prove possible to obtain measurements with the transmitter in a rural area and the vehicle moving in an urban area.

Fig. 8.1(a) The view looking Southwards (Newton Firs)

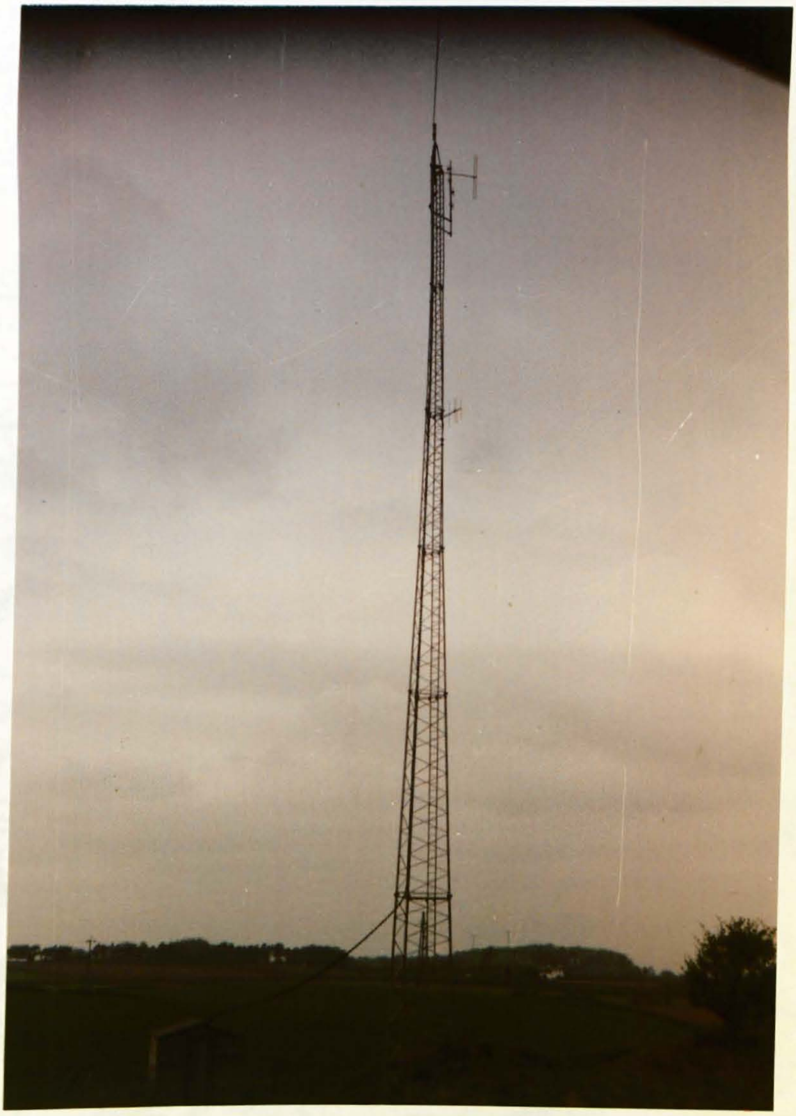

Fig. 8.1(b) The Newton Firs mast

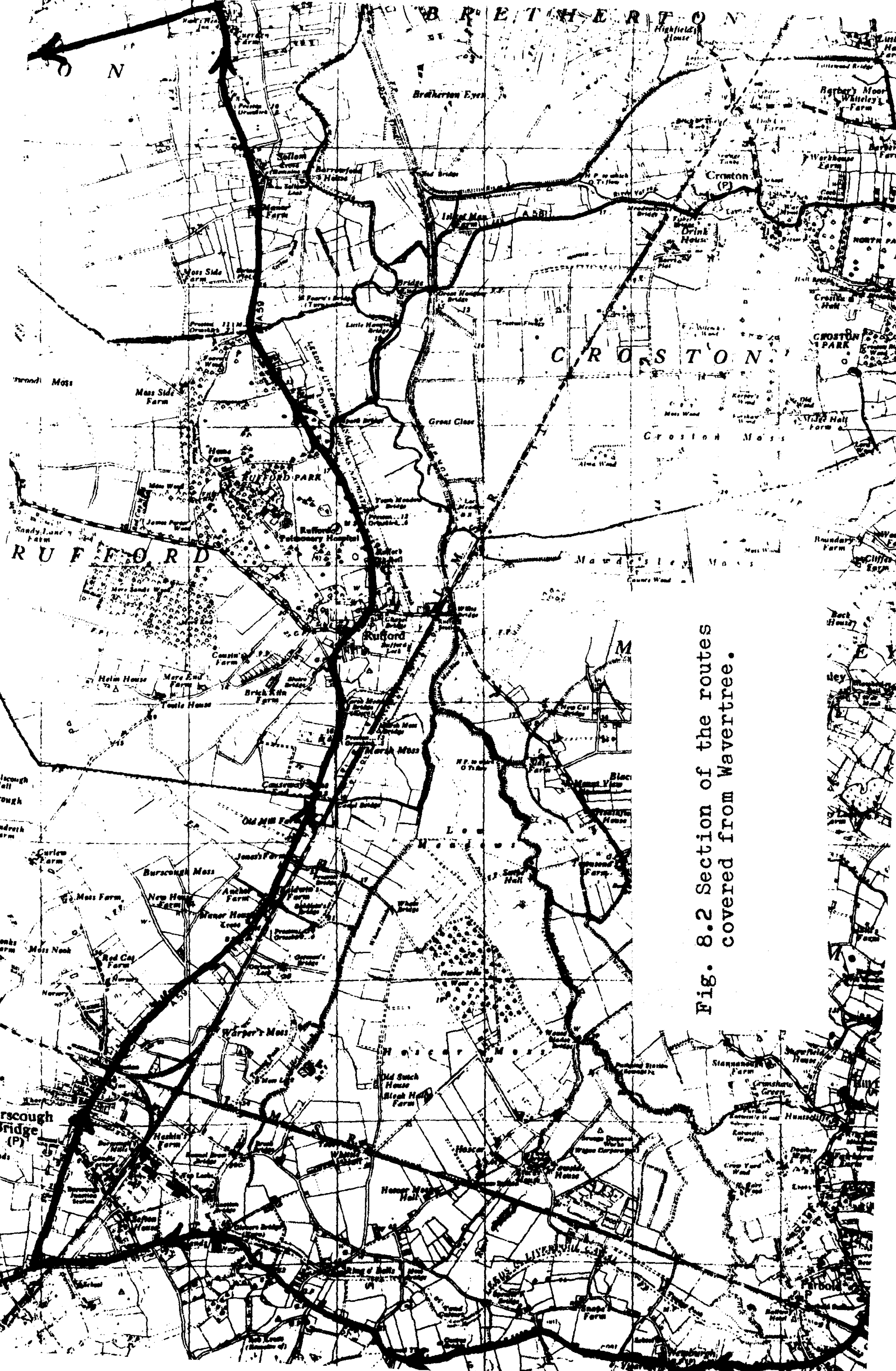

Fig. 8.2 Section of the routes covered from Wavertree.

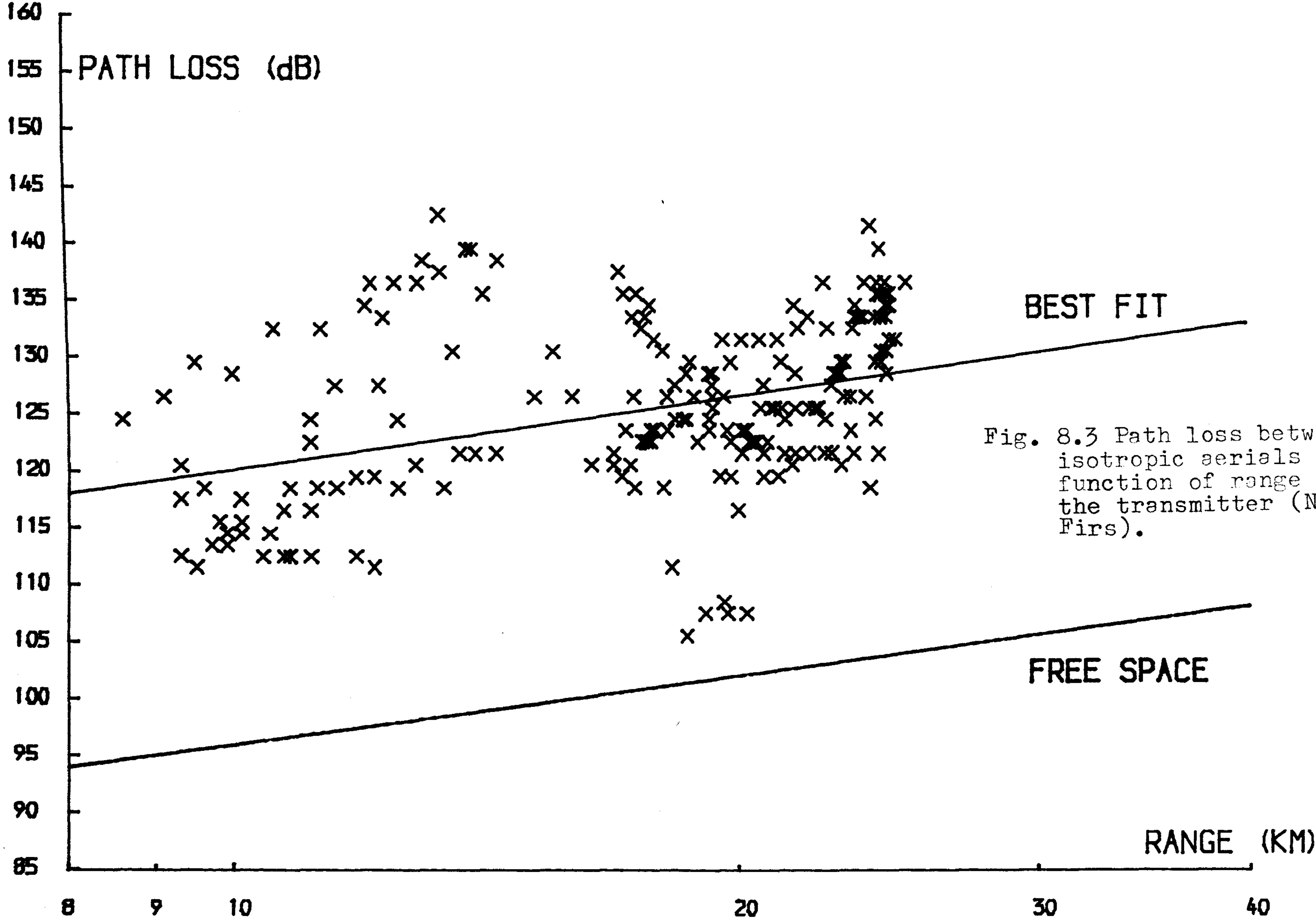

Fig. 8.3 Path loss between isotropic aerials as a function of range from the transmitter (Newton Firs).

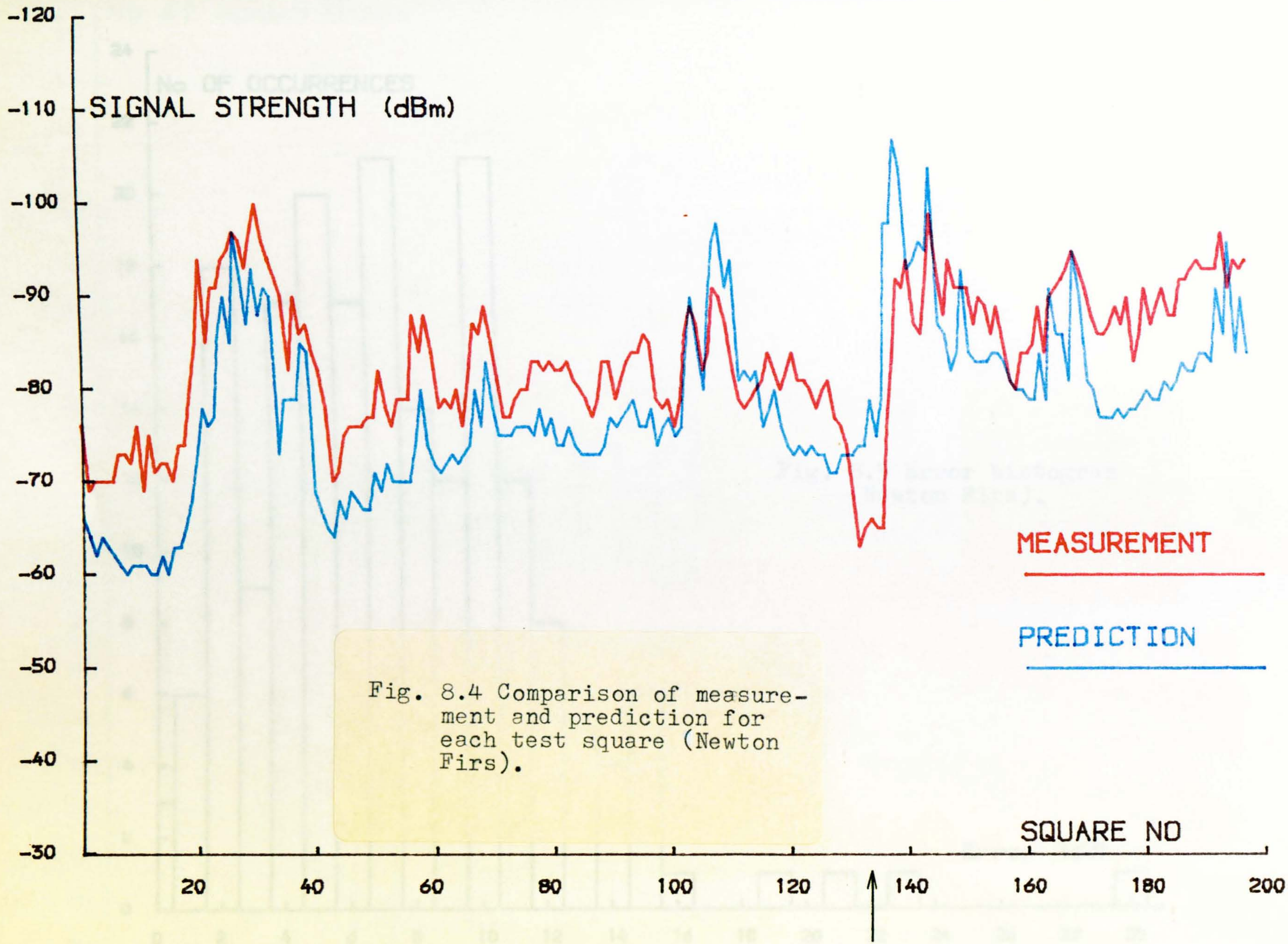

Fig. 8.4 Comparison of measurement and prediction for each test square (Newton Firs).

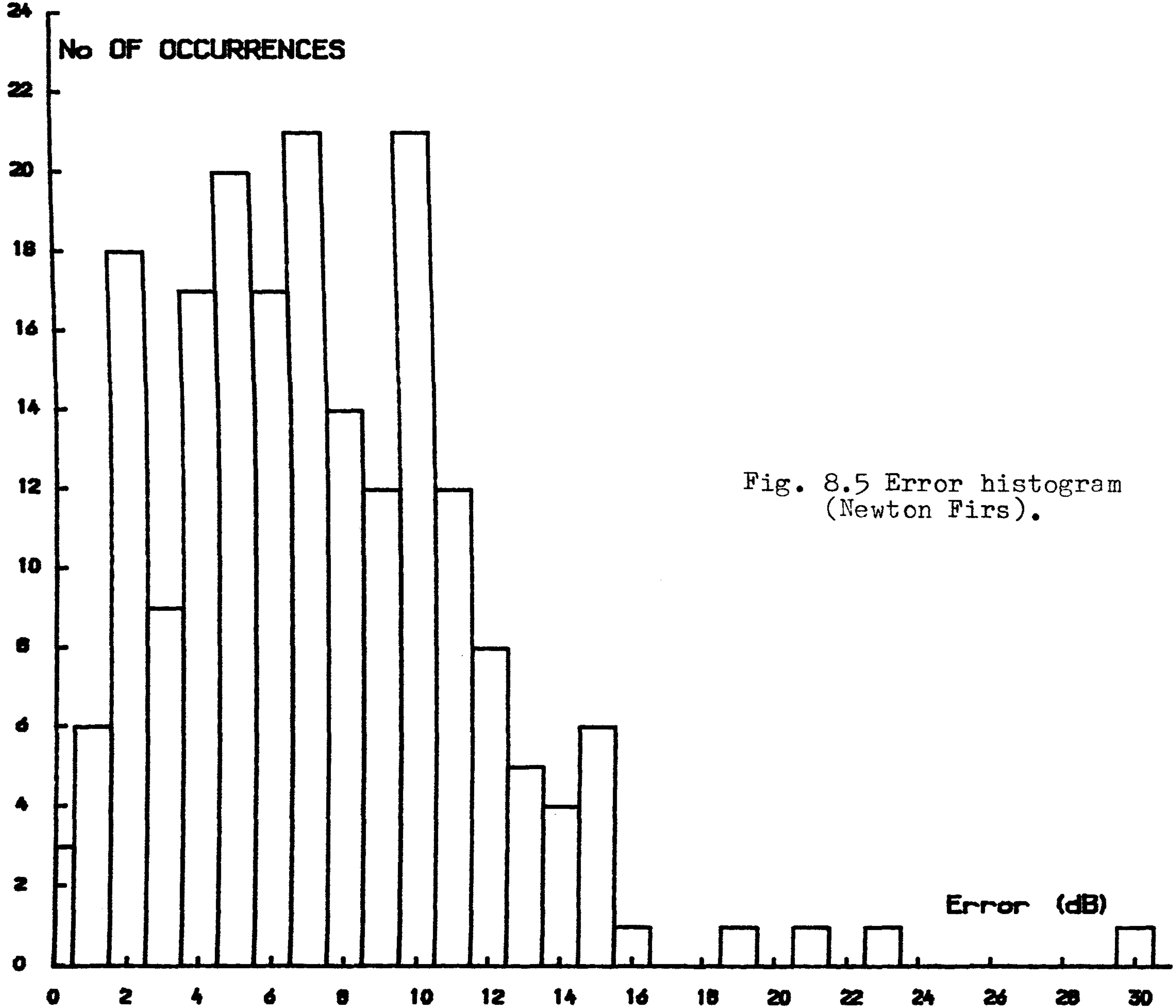

Fig. 8.5 Error histogram
(Newton Firs).

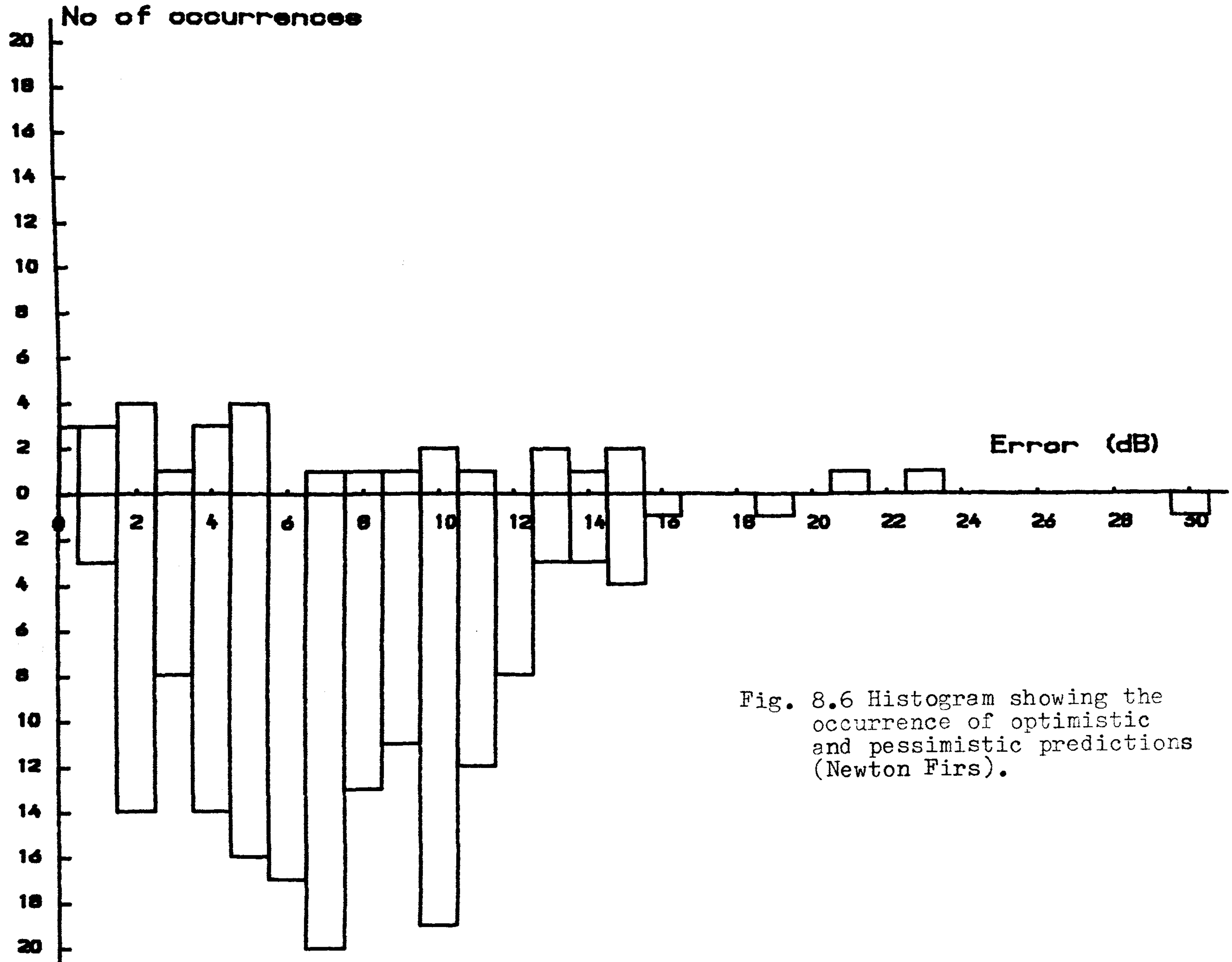

Fig. 8.6 Histogram showing the occurrence of optimistic and pessimistic predictions (Newton Firs).

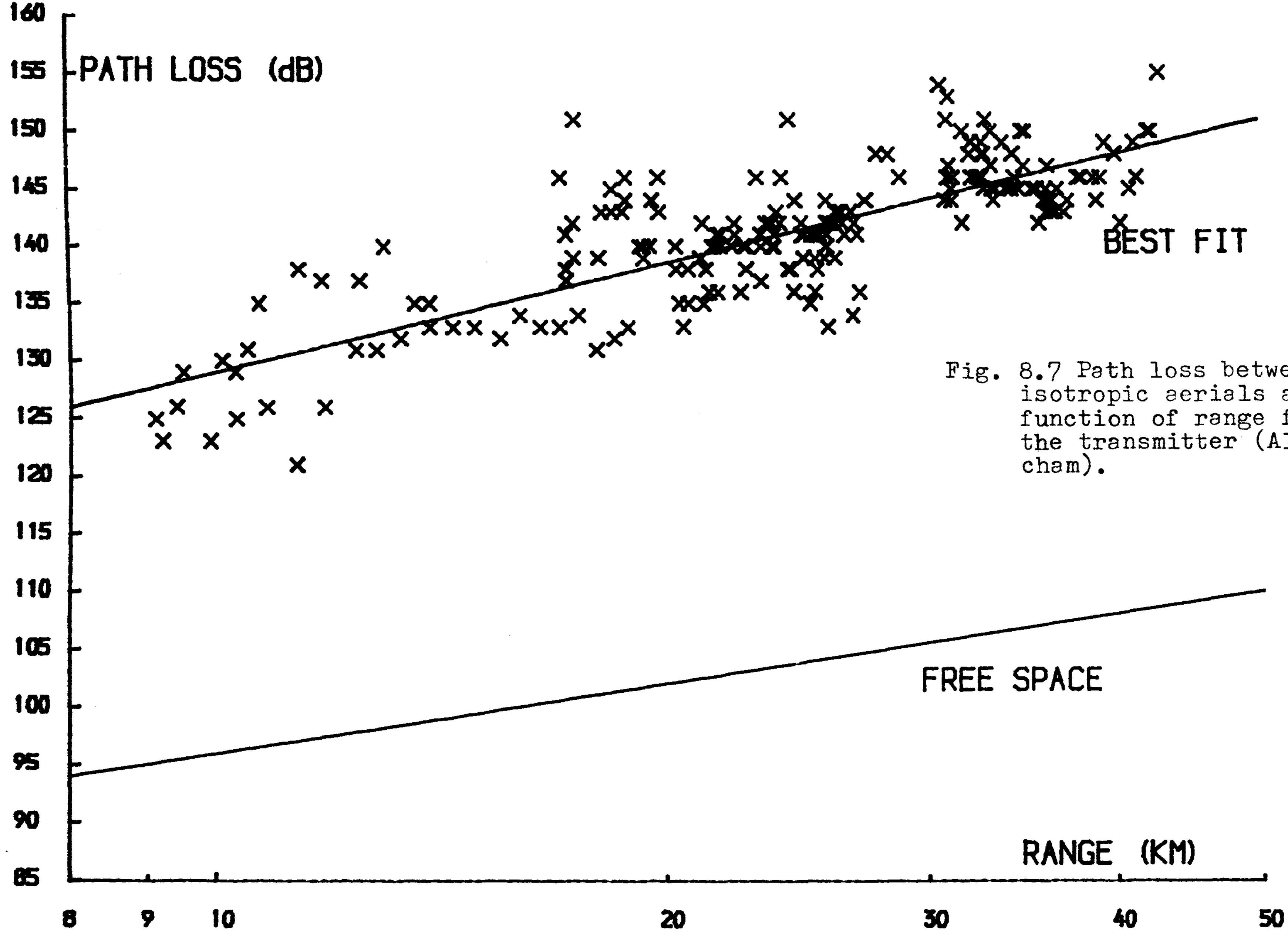

Fig. 8.7 Path loss between isotropic aerials as a function of range from the transmitter (Altrincham).

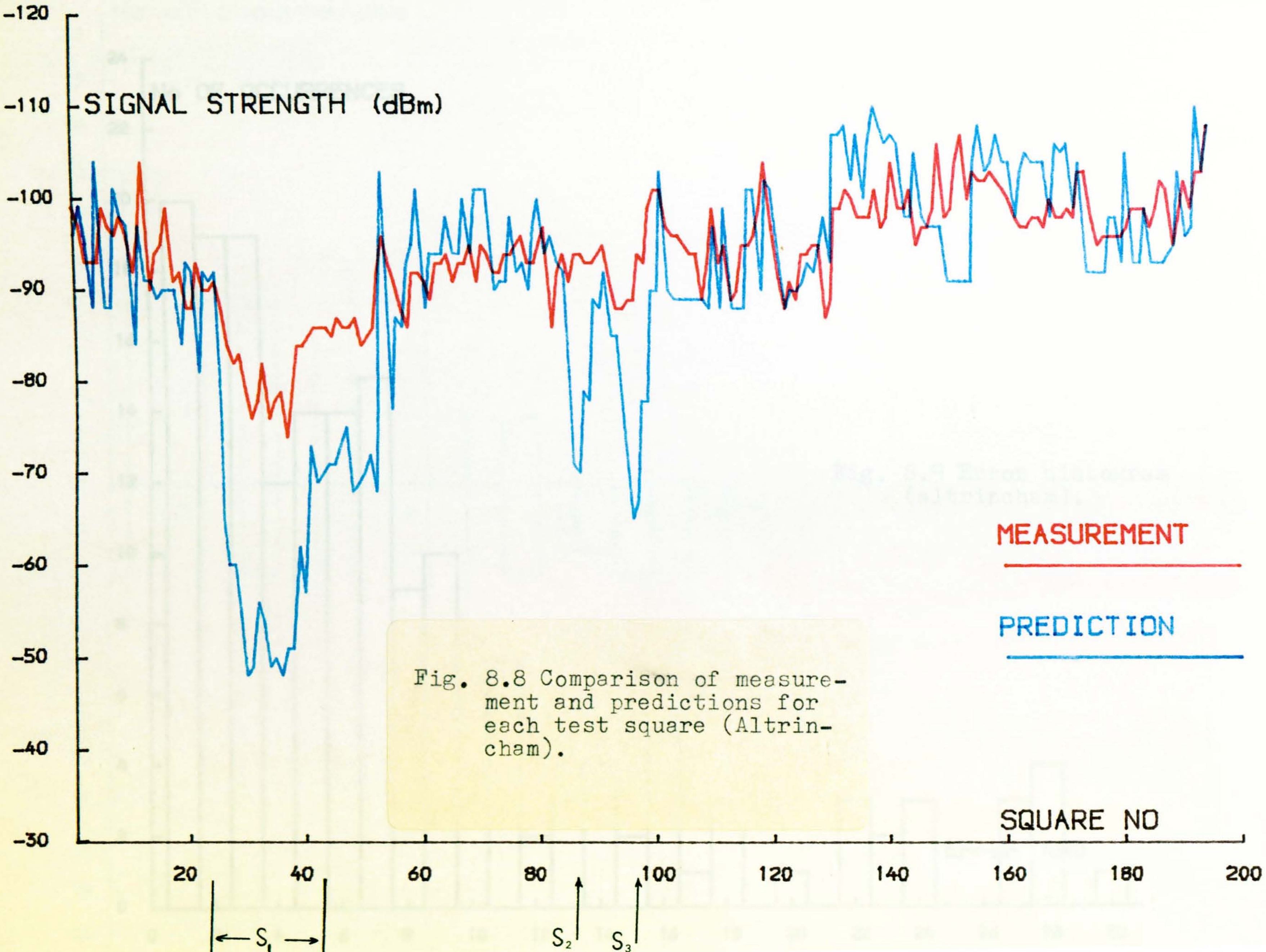

Fig. 8.8 Comparison of measurement and predictions for each test square (Altrincham).

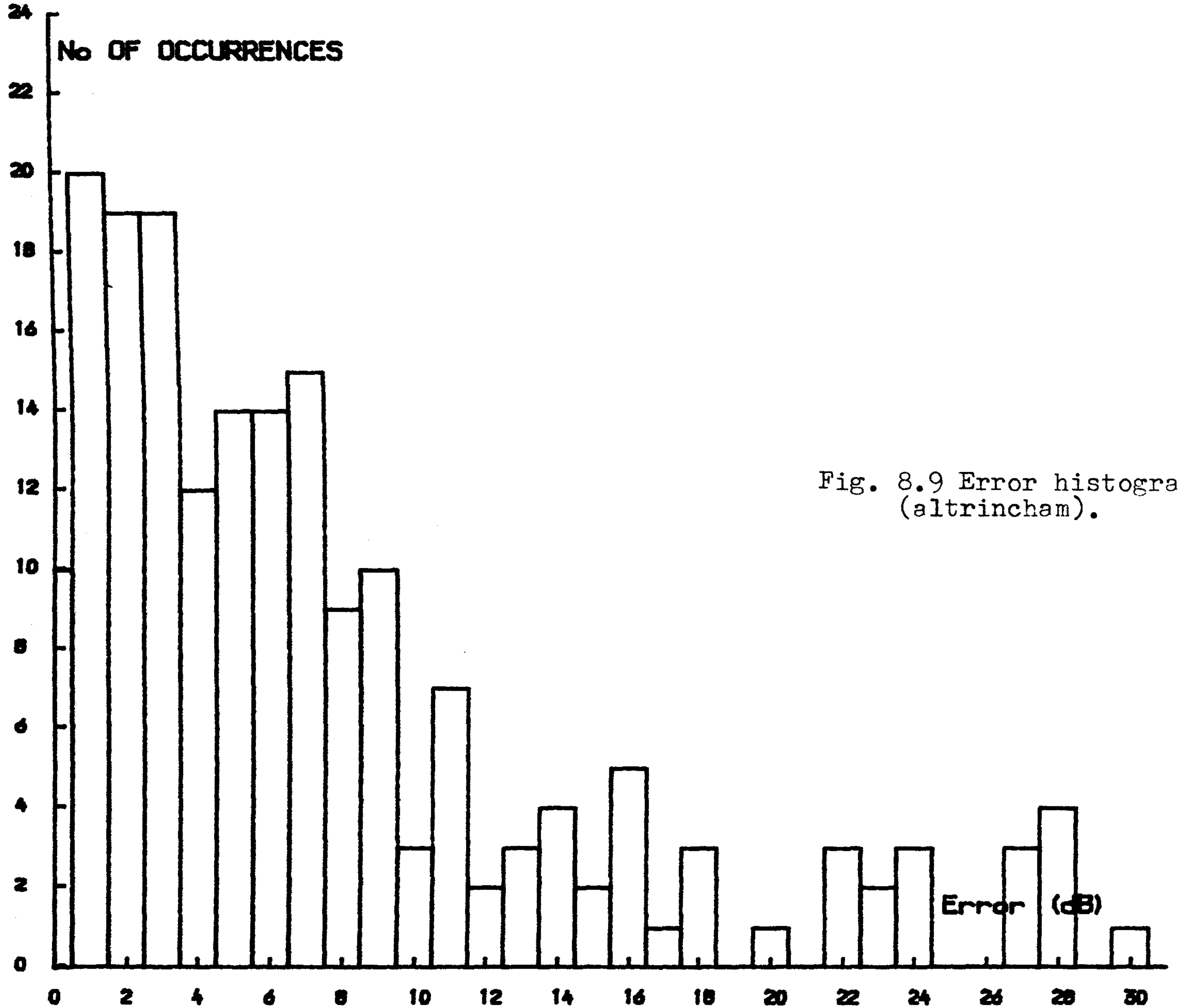

Fig. 8.9 Error histogram (altrincham).

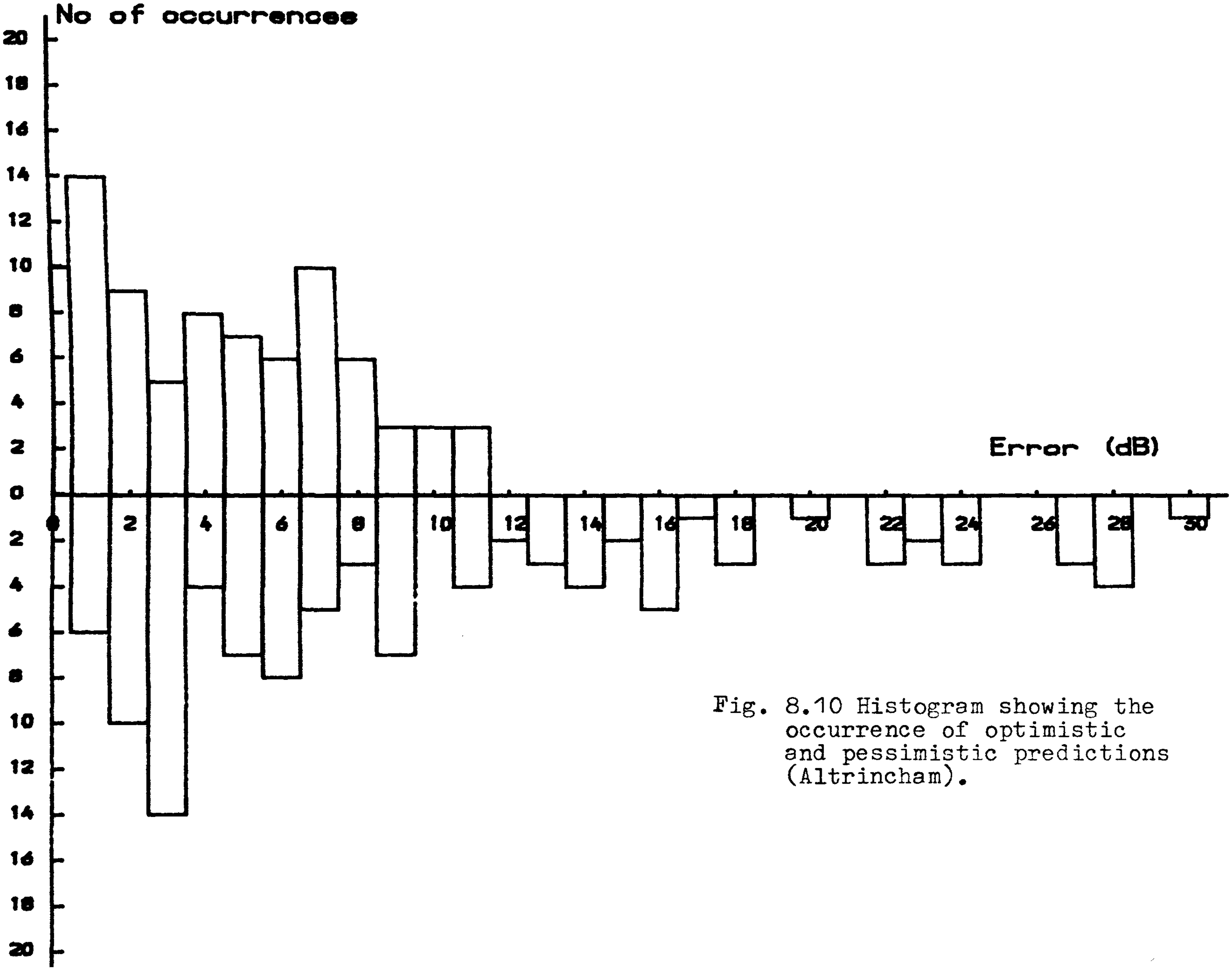

Fig. 8.10 Histogram showing the occurrence of optimistic and pessimistic predictions (Altrincham).

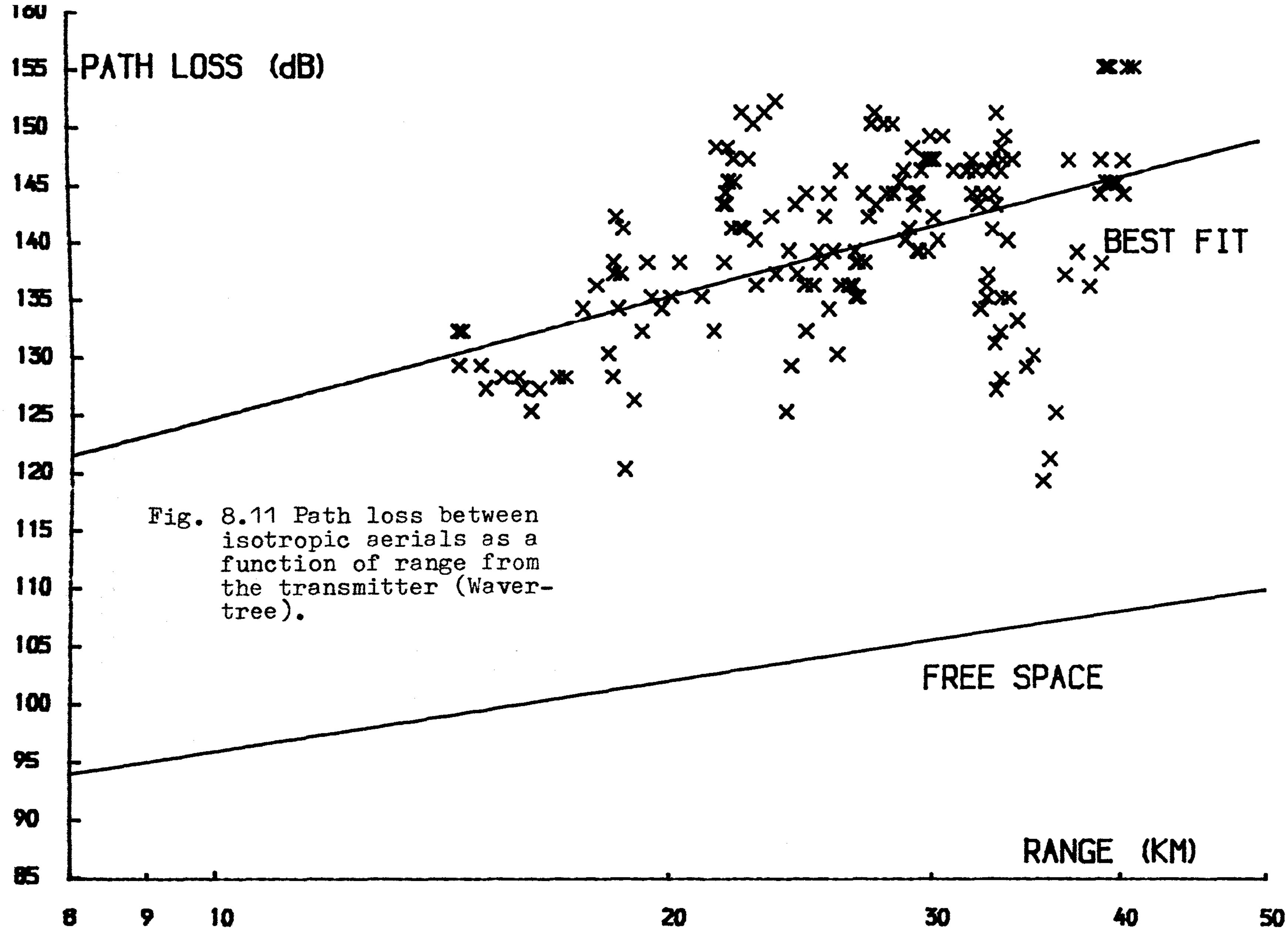

Fig. 8.11 Path loss between isotropic aerials as a function of range from the transmitter (Wavertree).

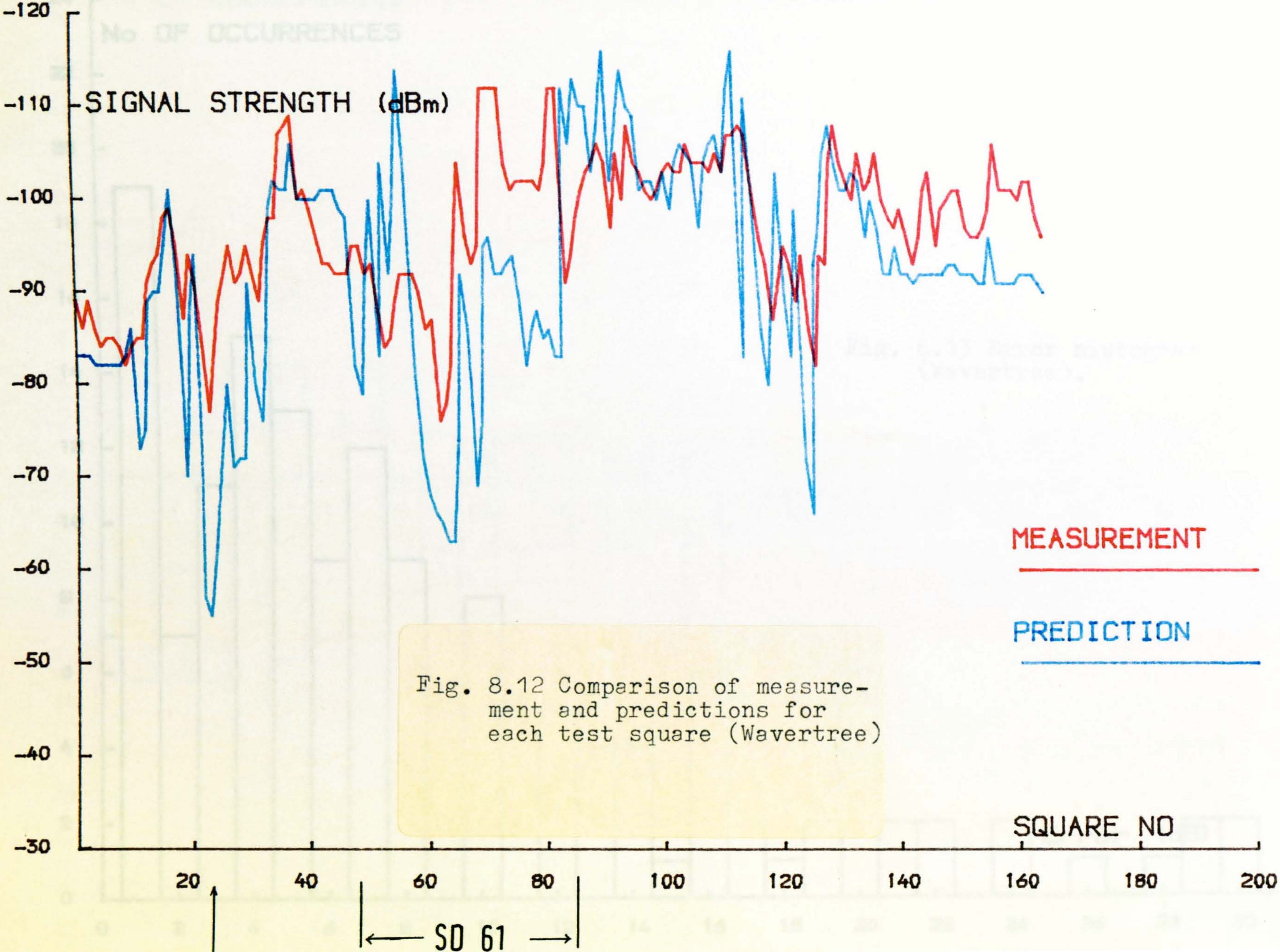

Fig. 8.12 Comparison of measurement and predictions for each test square (Wavertree)

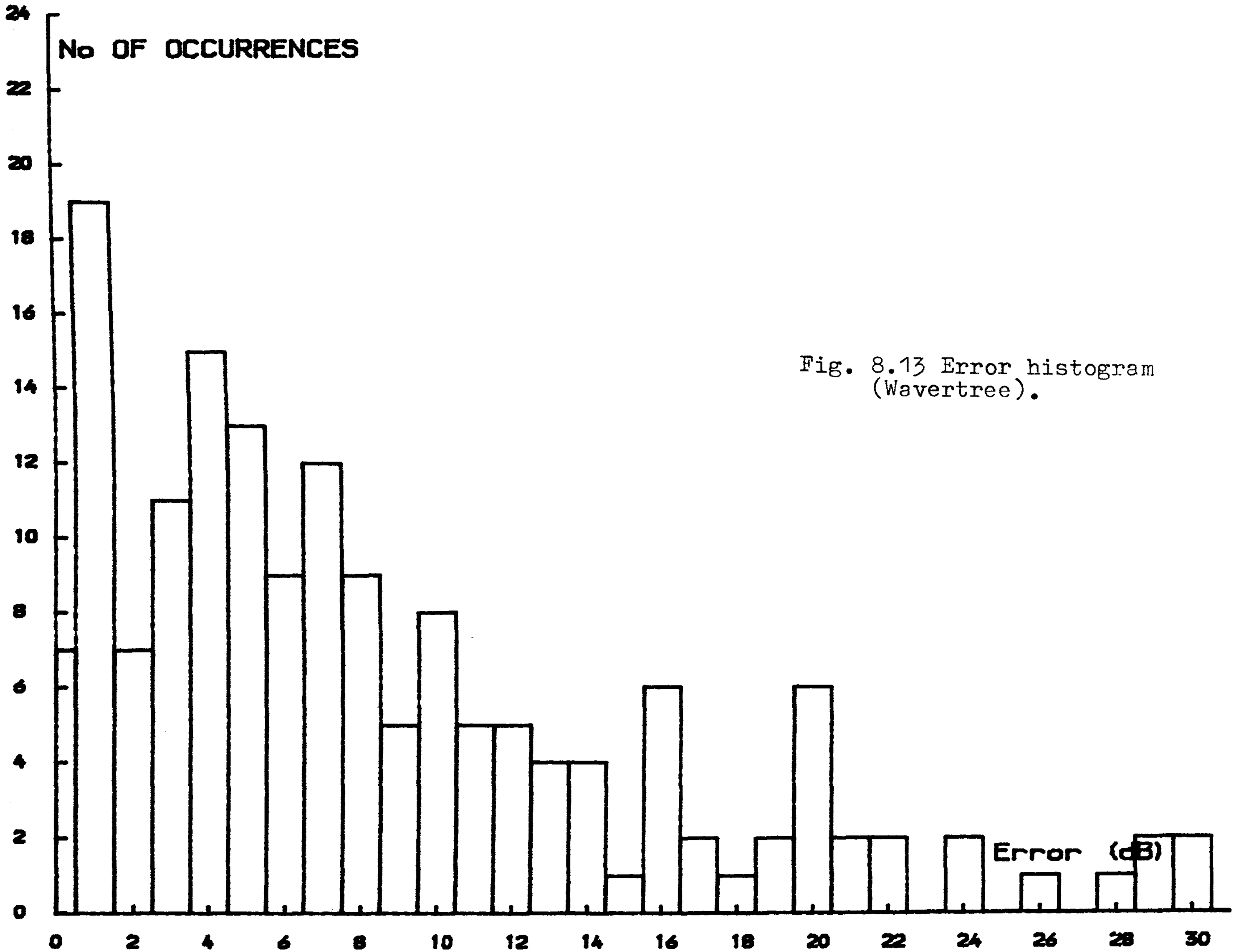

Fig. 8.13 Error histogram (Wavertree).

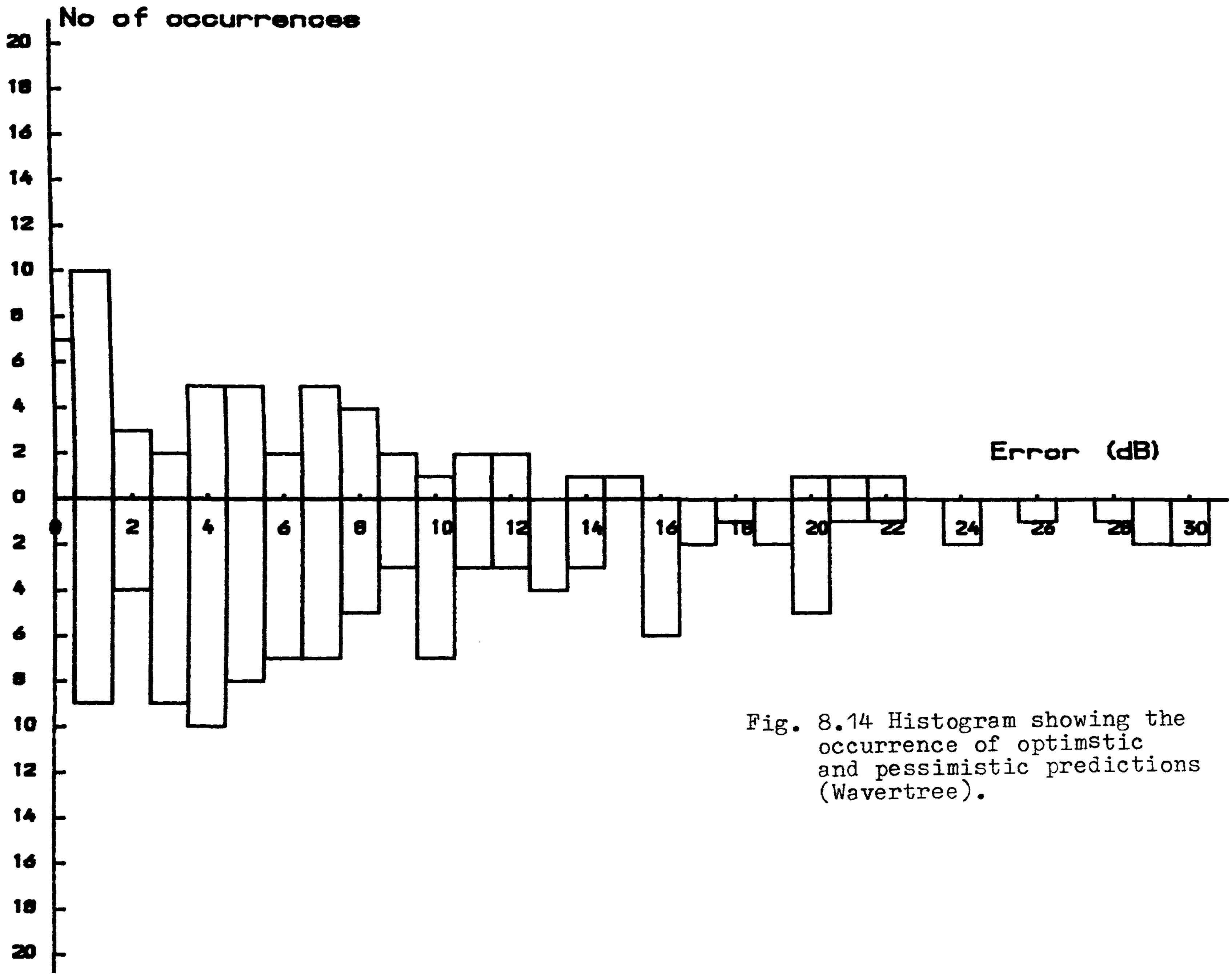

Fig. 8.14 Histogram showing the occurrence of optimstic and pessimistic predictions (Wavertree).

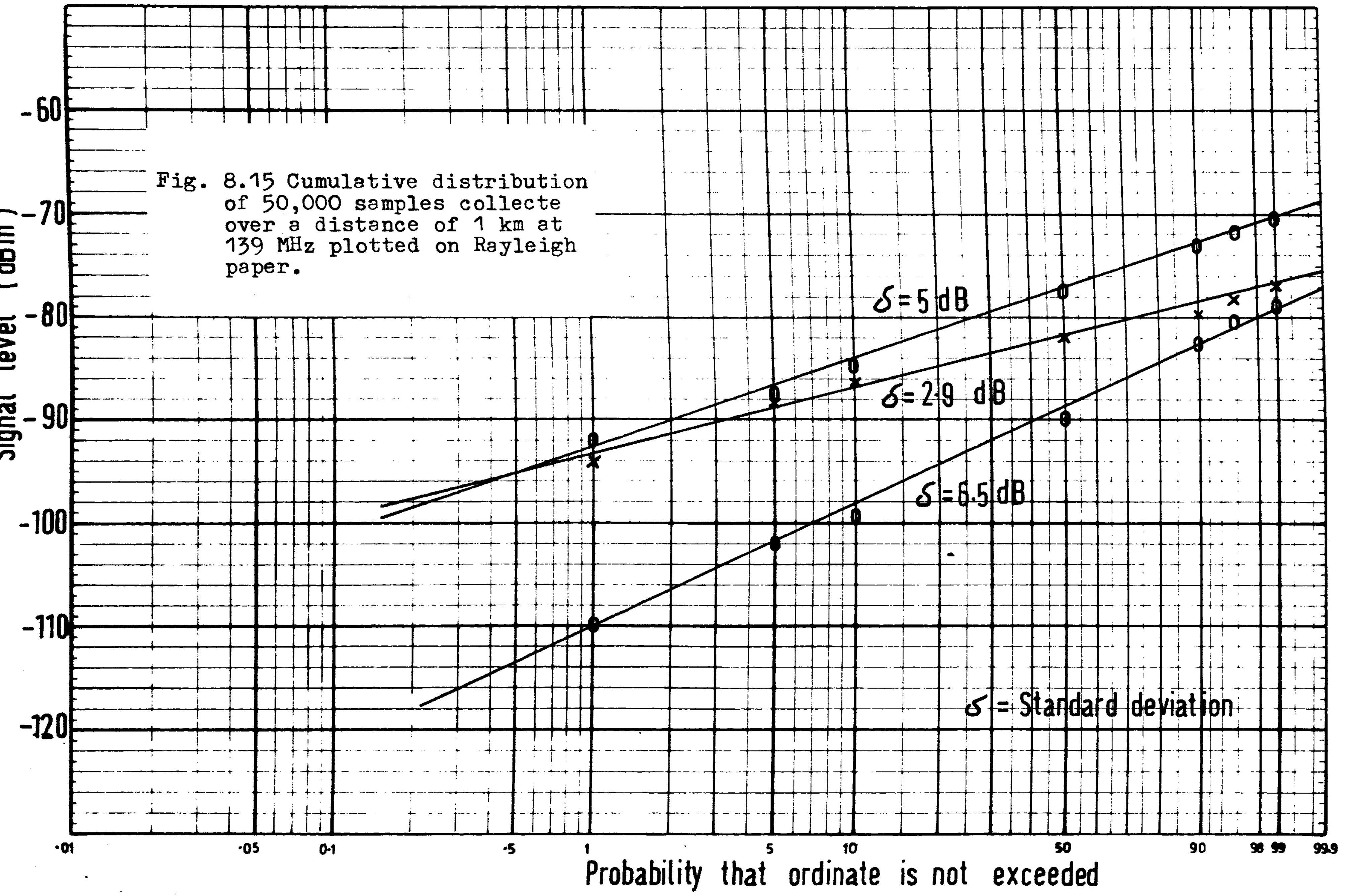

Fig. 8.15 Cumulative distribution of 50,000 samples collecte over a distance of 1 km at 139 MHz plotted on Rayleigh paper.

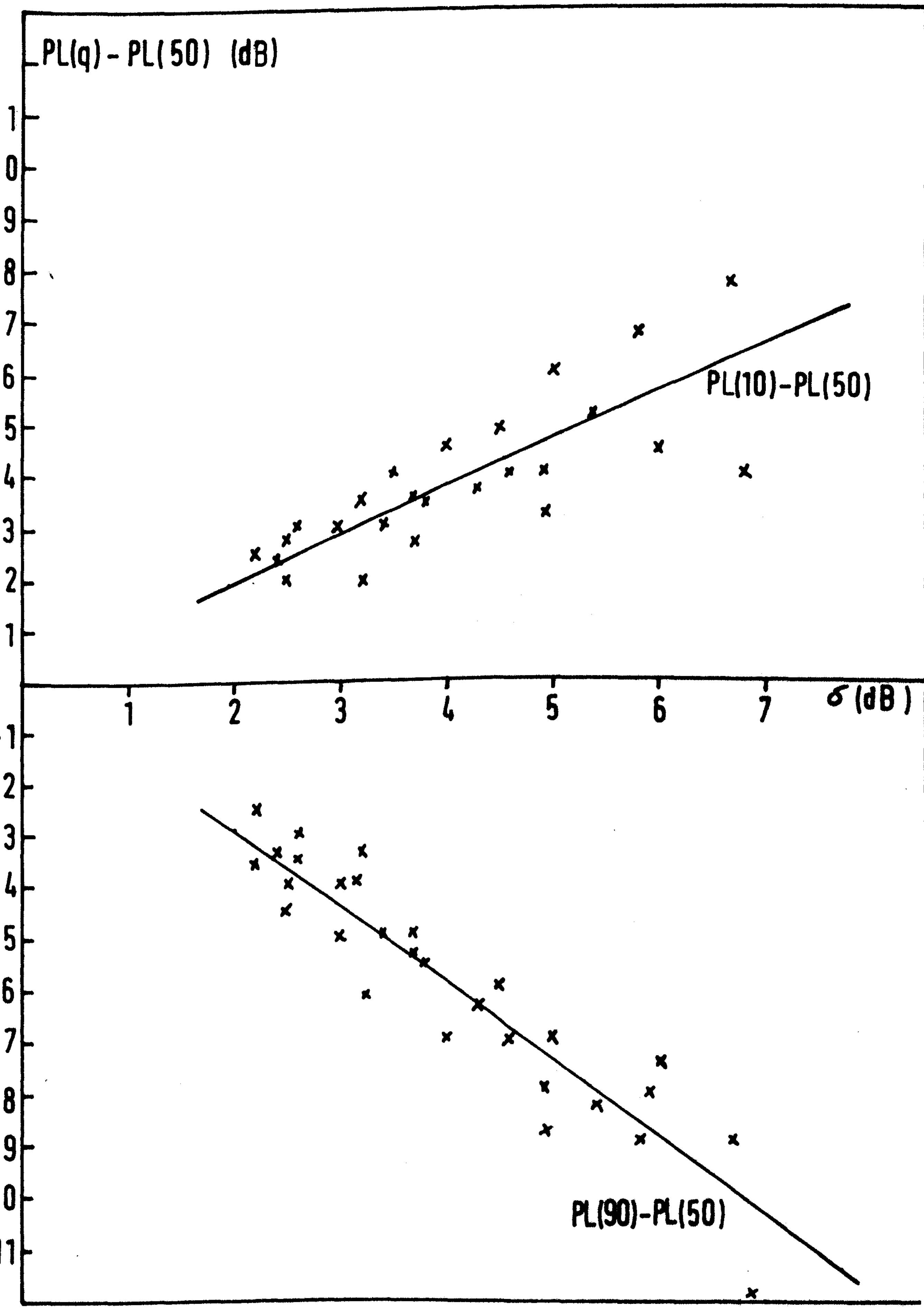

Fig. 8.16 Plot of 10% and 90% quantiles relative to median value versus standard deviation.

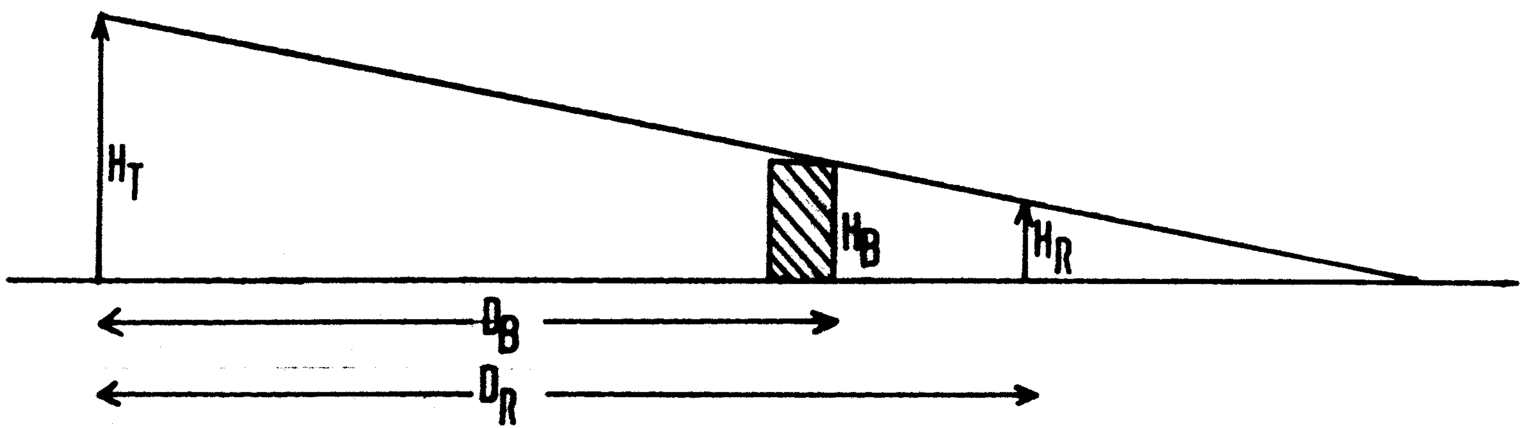

Fig. 8.17 Diagram illustrating path blocking
H_T=transmitter height
H_B=building height
H_R=receiver height
D_B=distance between transmitter and building
D_R=distance between transmitter and receiver.

CHAPTER 9

DISCUSSION AND CONCLUSION

The basis of a viable method of predicting coverage area is a substantial data base. Hence the preparation of a data bank was the initial task of this research; this demanded the use of a sophisticated data logging system, which had to be speedy, economic, easy to use and accurate. Several methods of recording the data were considered, and a microcomputer was proved to be an indispensable element in the data logging system.

Using a 380Z microcomputer, an SE8800 buffered tape unit and a Singer NM-37/57 receiver, the data logging system was constructed. Utilizing the data logging system, over 40 million samples were recorded, which provided the basis for a valid prediction model. Altogether ten different transmitter sites were used, six being situated in London, two in Liverpool, one in Cheshire and one in Altrincham.

The prediction model was based entirely on the London data. It was later tested on data collected in Liverpool and also on data acquired by four other investigators. The derivation of a prediction model having global application is not an easy task; a model could very well describe the behaviour of radio wave propagation at the place of data collection, but applying the model to a totally different environment may prove it to be an unsuccessful model. Nevertheless in an area of similar environmental structure the model could be found to be a useful guide for predicting area coverage.

The variations of the measured small sector median transmission loss values at 900 MHz with the total link range were described by the best fit line through the measured points for all six transmitters in London. The best fit line obtained utilizing a least squares method was in line with results published by other authors.

The best fit lines were expressed in the form of $PL = A + B \log_{10} R$, where PL is the path loss between two isotropic antennas and R is the link range in km. A clutter factor β (dB) was then defined as the difference between the best fourth law fit through the experimental points and the plane earth propagation curve.

The variations of A, B and β with transmitter height were investigated. This investigation showed that A decreased as the base transmitter height (h_b) was increased (A was linearly related to $\log_{10} h_b$). This would normally be expected, since less path loss is expected with an increase in transmitter height.

The dependency of B on transmitter height was investigated by plotting B versus the log of transmitter height. B decreased as the transmitter height was increased. Okumura [7.3] conducted similar experiments and he expressed A & B as a function of transmitter height in the same manner. The two independent expressions (by Okumura and the author) describing A and B in terms of log h_b lead to the same conclusions, but with only very slight differences. The fact that different ground references were taken in calculating the transmitter height and different environmental structure surrounded the transmitter could be the cause of this difference.

At first sight it seems surprising that β could be a function of transmitter height. The plane earth equation would lead us to expect a transmitter height dependence coefficient of 20 dB/decade. However, if the measured coefficient is greater or less than this value then it must be concluded that in reality β does vary with h_b.

A graph of β versus h_b was plotted, and β was noted to be linearly dependent on h_b. This suggested that the coefficient of transmitter height dependence should be more than 20 dB in practice. β is also very well known to be a function of frequency but unfortunately this fact could not be verified since measurements were taken only at 900 MHz in London. However, there are quite a few researchers who have carried out work at different frequencies. With a little modification their results were employed to enable the prediction model to be used over a wide range of frequencies.

Several empirical and semi-empirical models were suggested in the initial stages of modelling, making use of only the transmitter height and the distance from the transmitter. One of these empirical models deduced from a regression analysis least square method proved the most successful of all, with an r.m.s. error of 5.6 dB. Another empirical model in the form of $PL = A + B \log R$ with appropriate equations in terms of h_b substituted for A and B proved to be almost as successful, due to the fact that it produced an r.m.s. error of 5.8 dB. However, this second model has shown an outstanding performance, since although the values of A and B were derived by the least squares method, i.e., minimising the r.m.s. error, the overall equation was not.

For the calculation of the transmitter height, a ground reference level has to be defined. Many workers take this reference level as the sea level. Some others take an average ground level within a certain range from the transmitter as the reference level. It was decided that a number of samples of the spot height within a 10km range from the transmitter should be taken in height steps of 5m or less. The reference height is then defined as the lowest possible mode of the entire sample. Care must be taken if noticeable irregularities are observed in different directions, ie., one direction up the hill, another direction down the hill, etc. These irregularities should be divided into different categories and treated separately.

The next step was to include the mobile antenna height h_m above the reference level. In order to clearly observe the effect of h_m on the received signal, diffraction losses (L_D) had to be included at this stage. The inclusion of h_m and L_D in the model reduced the r.m.s. error by 1.1 dB to 4.5 dB.

The predictions were noted to be optimistic for four of the transmitters used in London and pessimistic for the other two. Careful consideration of the transmitter sites and predictions produced the argument that, when the transmitter was situated in an urban area, the predictions were optimistic by an average of 5.5 dB, and when the transmitter was situated in a suburban area, the predictions were pessimistic by an average of 2 dB. Hence correction factors were introduced into the model for urban and suburban areas. This correction factor reduced the r.m.s. error to 3.3 dB.

Further improvements on the model would be possible at the expense of introducing other parameters which would not be so readily available. Having achieved relatively good accuracy by a simple model, with easily accessible parameters, it seemed wise to leave the model as it is.

The model as derived would only be of use for predicting at 900 MHz.

If the frequency parameter was somehow included in the model, it would make it useful probably over a quite wide range of frequency. Measurements made at several different frequencies by Okumura would seem to be a good source of information on the variation of received signal with frequency. The comparable results by Okumura and the author made it possible to use Okumura's measurements to include the frequency parameter in the model. The model then produced an excellent performance in the frequency range of 80 MHz to 900 MHz. It would probably be possible to use the model even at frequencies above 900 MHz, but lack of any measurements above 900 MHz made it impossible to prove this.

Street orientation would be expected to have a significant effect on the local mean of the signal strength. Streets running radially should have a higher mean signal strength than those running circumferentially because of reduced obstruction between the base and mobile. A significant difference in signal strength was observed between radial and circumferential streets. At a distance of 3km from the base station, the signals received on radial and nearly radial streets were usually 15 dB greater than the signals received on the corresponding circumferential streets.

The statistical distribution of the signal within a test square is of great importance, since it is this distribution from which various percentage quantiles are derived. Suzuki [7.2] proposed a statistical model for the mobile radio signal in urban areas to explain the transition from the local distribution to global distribution. Measurements in London and Liverpool showed consistency with the Suzuki model. The only parameter needed for describing the quantiles relative to median value is the Suzuki parameter S defined as $S = \sqrt{\mu^2 - 31}$, where μ is the variance of the measured signal in a test square. Lorenz [7.2] gave the quantiles relative to the median value in terms of S parameter, in a graphical form.

Street orientation has a great effect on signal strength and hence on the variability of the signal. The S parameter was then discovered to be related to a parameter defined by the author. This parameter is defined as the difference between total radial (or nearly radial) streets and the total circumferential (or nearly circumferential) streets, described as a percentage of the total route covered within a test square. The proposed parameter could very easily be obtained from an OS map. Utilizing this the S parameter can be deduced and therefore various quantiles can be estimated.

Measurements in rural areas gave some remarkable results. The coefficient of range dependence factor is of great importance. It could either be 20 dB (free space) or 40 dB (plane earth) or any other recommended value. The measurements showed that it varies from 20 dB to 40 dB depending on where the transmitter is situated, in an urban, suburban or rural area, and whether the area under radio survey is situated in an urban, suburban or rural area, as explained below.

1) Transmitter in rural area and test area in rural area; this gave a range law of 20 dB/decade.

2) Transmitter in urban area and test area in rural area; a range law of 30 dB/decade was obtained.

3) Transmitter in urban area and test area in urban area; this gave a range law of 40 dB/decade.

The variability of signal within a test square was examined, and it was shown to exhibit a Weibull distribution with standard deviation ranging from 2 dB to 7 dB.

Some measurements were conducted with the vehicle stationary to observe the effect of traffic on received signal. Six sets of measurements were carried out, three at 900 MHz and three at 441 MHz. Each measurement lasted for 2 minutes. The signal varied with fades up to 20 dB, and the sample obtained over a period of 2 minutes proved to have a Weibull distribution. The measurements are fully explained in Appendix 2.

In mobile radio communication ambiguity always exists in any conclusion drawn from a set of measurements. This is worsened by the fact that several factors influence the performance of this type of communication system. Therefore it is recommended that more measurements are carried out at different frequencies, especially frequencies above 900 MHz. Also more measurements are required to observe the effect of street orientation on received signal, not only in radial and circumferential streets but also in streets subtending various angles to the line joining the transmitter to the mobile.

APPENDIX A

COMPUTER PROGRAMS

Data Logging System Software :

1) ADC1P
2) ADC2
3) READX
4) RDHIS
5) ANALHIS

ADC1P

```
M2
;BUFFERED ADC READ ON 380Z ONE CHANNEL

;
BLKLEN   EQU 2048;T/R BLOCK LENGTH
         PSECT ABS
         ORG 100H;CPM START
KBDTC    EQU 29
LPOUT    EQU 5;380Z EMT PRINTER
EMT      EQU 0F7H:EMT
64KIN    EQU 48
         DEFB 0FFH
         XOR A
         LD (TAPRDY),A
         LD A,2
         LD (TWCNT),A
;
         LD SP,STACK
;SET UP UART
         LD A,40H;RESET
         OUT (0C9H),A
         LD A,0CDH
         OUT (0C9H),A;X1
         LD A,37H
         OUT (0C9H),A
         LD HL,INTABL;INTERRUPTS
         LD A,H
         LD I,A
         LD A,L
         OUT (ADCBAS+CTC0),A;VECTOR
         LD A,RSTCTC;DISABLE INTERRUPTS
         OUT (ADCBAS+CTC0),A
         LD HL,INT2T
         LD A,L
         OUT (PIOBAS+CONTR+PA),A
         LD A,00001111B
         OUT (PIOBAS+CONTR+PA),A
         LD A,10000111B
         OUT (PIOBAS+CONTR+PA),A
         IM 2
         EI
         CALL NEWBLK
         LD A,0;ADC CHANNEL 0
         OUT (ADCBAS+MPXCH),A
         LD IX,BUFFER;(IX)->BUFFER
         LD DE,BUFSIZ;NO. BYTES
         CALL SFIFO;BUFFER SET UP
         LD A,LDCTC:START CTC AS
         ;COUNTER FROM 1
         OUT (ADCBAS+CTC0),A
         LD A,1;TIME CONSTANT
         OUT (ADCBAS+CTC0),A
         LD HL,BLKLEN;BYTE COUNTER
         PUSH HL
         EI
```

```
;NOW READY TO LOG
;
LOOP:    DI;KEEP BUFFER CONSTS INTACT
         CALL RFIFO;GET BYTE
         EI
         CALL NC,TOTAPE;CY=EMPTY
         JR LOOP;LOOP INDEFINITELY
TOTAPE:  ;SEND BYTE IN A
         CALL WRTAPE
         PUSH IY;COUNTER
         POP BC;BYTE COUNT
         CPI;DEC BC
         PUSH BC
         POP IY
         RET PE

NEWBLK:  LD IY,BLKLEN
         DEFB EMT,KBDTC;KEYPRESS?
         JR Z,CONT1
         PUSH AF
         LD A,10H;DLE
         CALL WRTAPE
         LD A,35H;FILEMARK
         CALL WRTAPE
         POP AF
         AND 11100100B
         JR NZ,CONT1
ESC:     DI
         JP 0
CONT1:   LD A,10H;DLE
         CALL WRTAPE
         LD A,31H;WRITE BLOCK
         CALL WRTAPE
         LD A,BLKLEN/64
         CALL WRTAPE
         LD A,BLKLEN-BLKLEN/64*64
         CALL WRTAPE
         RET
;
;
DATA     EQU 0
PIOBAS   EQU 60H
CONTR    EQU 2
PA       EQU 0
PB       EQU 1
TAPINT:  EI
         PUSH AF
         XOR A
         LD (TAPRDY),A
         POP AF
         RETI
WRTAPE:  PUSH AF
TAP1:    LD A,(TAPRDY)
         OR A
         JR NZ,TAP1
```

```
          INC A
          LD (TAPRDY),A
          POP AF
          OUT (PIOBAS+DATA+PA),A
          RET
ADCBAS    EQU 20H;8BIT ADC BOARD
ADCGO     EQU 1;START ADC
ADCLO     EQU 3;LOW BYTE
ADCHI     EQU 2;HIGH BYTE
CTC0      EQU 0CH;CTC CHAN 0
MPXCH     EQU 0
;INTERRUPT ROUTINE FOLLOWS
RETCTC    EQU 01010011B;CLEAR INTERRUPTS,STOP
LDCTC     EQU 11010111B;COUNTER,TC FOLLOWS
ADCRD:    EX AF,AF'
          EXX
          OUT (ADCBAS+ADCGO),A;START ADC
ADCR1:    IN A,(ADCBAS+ADCHI);TEST STATUS
          BIT 7,A
          JR Z,ADCR1;NOT READY
          AND 00000011
          JR Z,LIMIT
          LD A,255
          JR MAX
LIMIT:    IN A,(ADCBAS+ADCLO);LOW BYTE
MAX:      LD C,A
          CALL WFIFO;PUT TO BUFFER
          CALL C,OVERR
          EXX
          EX AF,AF'
          EI
ERR1:     RETI
OVERR:    ;BUFFER FULL MESSAGE
          LD HL,ERRM1
          DEFB EMT,MSG
          RET
MSG       EQU 29;EMT
ERRM1:    DEFM 'BUFFER FULL'
          DEFB 0DH,0FFH
;
;= SFIFO , WFIFO , RFIFO
;   first in first out buffer suite
;/ class: 1
;/ description: SFIFO sets up an empty
; fifo buffer at (IX), WFIFO writes a
; byte to it,RFIFO reads a byte
; from it.
;/ action: sets up buffer in memory,
; first byte at (IX), buffer variables
; stored below (IX) to (IX-8), buffer
; above any length. Recirculates.
;/ subr dependance : none external
;/ interfaces none
;/ input: IX=? buffer for all entries
; SFIFO: DE=max size
; WFIFO: C =character to be put
;/ output: AF destroyed, cy set if
```

```
; full for WFIFO,emoty for RFIFO.
; RFIFO returns character in A.
;/ AF destroyed all entries
;/ stack use: 8 bytes
;/ size: 121 bytes
;/ CPU Z80
;
;IX points to buffer base & pointers
;as follows
NXGETH EQU -1
NXGETL EQU -2;offset getplace
NXPUTH EQU -3
NXPUTL EQU -4;offset putplace
BFCOH EQU -5
BFCOL EQU -6;bytes in buffer
BFMAXH EQU -7
BFMAXL EQU -8;length
;
;SFIFO set buffer empty
;IX->position,DE = size destroys HL
SFIFO:  PUSH HL
        LD A,6;counter
        PUSH IX
        POP HL;base to HL
FZ1:    DEC HL
        LD (HL),0
        DEC A
        JR NZ,FZ1; zero place,size
        DEC HL;bfmaxl
        LD (HL),D
        DEC HL
        LD (HL),E;buffer size
        POP HL
        RET
;
;Put byte to buffer from C cy set=full
WFIFO: PUSH DE
        PUSH HL
        LD E,(IX+BFCOL)
        LD D,(IX+BFCOH);DE=count
        INC DE;update it
        CALL CPBFMX;<= ok
        JR C,INF1;if full exit
        LD (IX+BFCOL),E
        LD (IX+BFCOH),D;update count
        LD E,(IX+NXPUTL)
        LD D,(IX+NXPUTH);DE=put place
        CALL RECIRC;gets next DE
                ;gets abs addr to HL
        LD (IX+NXPUTL),E
        LD (IX+NXPUTH),D;update
        OR A;set nc
        LD (HL),C;put byte
INF1:   POP HL
        POP DE
        RET
;
;Byte from fifo to A,cy set=empty
RFIFO: PUSH DE
        LD E,(IX+BFCOL)
```

```
            LD D,(IX+BFCOH);DE=COUNT
            LD A,D
            OR E
            SCF;set empty flag
            JR Z,OUF1;if empty
            PUSH HL
            DEC DE
            LD (IX+BFCOL),E
            LD (IX+BFCOH),D;update
            LD E,(IX+NXGETL)
            LD D,(IX+NXGETH)
            CALL RECIRC;inc DE,circulate
            LD (IX+NXGETL),E
            LD (IX+NXGETH),D;update
            LD A,(HL)
            OR A;nc=ok
            POP HL
OUF1:       POP DE
            RET
;
;RECIRC DE->place in buffer ,incs &
;circulates if outside buffer
;on return HL-> current address
RECIRC: INC DE
        CALL CPBFMX;outside buffer?
        JR NZ,RC1;if not within buffer
        EX DE,HL;set 0 if so
RC1:    PUSH IX
        POP HL
        ADD HL,DE;absolute addr
        RET
;
;CPBFMX subtracts Bfmax,DE
CPBFMX: LD L,(IX+BFMAXL)
        LD H,(IX+BFMAXH)
        OR A;clear cy
        SBC HL,DE
        RET
;
;
TAPRDY: DEFS 1
TWCNT:  DEFS 1
        ORG $/32*32+32;INTERRUPT TABLE
INTABL: DEFW ADCRD
        DEFW ERR1
        DEFW ERR1
        DEFW ERR1
INT2T:  DEFW TAPINT
;
        DEFS 256;STACK SPACE
STACK:
        DEFS 8;BUFFER CONSTANT SPACE
BUFSIZ  EQU 5000;BUFFER SIZE
BUFFER: ;(IX) POINTS HERE FOR BUFFER
        NOP;DON'T END ON DEFS
        END
```

ADC2

```
;BUFFERED ADC READ ON 380Z ONE CHANNEL
;O/P TO SERIAL PORT
;
        PSECT ABS
        ORG 100H;CPM START
LPOUT   EQU 5;380Z EMT PRINTER
EMT     EQU 0F7H;EMT
        DEFB 0FFH
;
        LD SP,STACK
        LD HL,INTABL;INTERRUPTS
        LD A,H
        LD I,A
        LD A,L
        OUT (ADCBAS+CTC0),A;VECTOR
        LD A,RSTCTC;DISABLE INTERRUPTS
        OUT (ADCBAS+CTC0),A
        IM 2
        LD A,0;ADC CHANNEL 0
        OUT (ADCBAS+MPXCH),A
        LD IX,BUFFER;(IX)->BUFFER
        LD DE,BUFSIZ;NO. BYTES
        CALL SFIFO;BUFFER SET UP
        LD A,LDCTC;START CTC AS
        ;COUNTER FROM 1
        OUT (ADCBAS+CTC0),A
        LD A,1;TIME CONSTANT
        OUT (ADCBAS+CTC0),A
        EI
;NOW READY TO LOG
;
LOOP:   DI;KEEP BUFFER CONSTS INTACT
        CALL RFIFO;GET BYTE
        EI
        CALL NC,TOTAPE;CY=EMPTY
        JR LOOP;LOOP INDEFINITELY
TOTAPE: ;SEND BYTE TO SCREEN IN HEX
        CALL CHOUT
        LD A,H
        DEFB EMT,1
        LD A,L
        DEFB EMT,1
        LD A,' '
        DEFB EMT,1
        RET
;
CHOUT:  CALL CHFRBI
        LD H,L
CHFRBI: RRCA
        RRCA
        RRCA
        RRCA
        PUSH AF
        AND 0FH
```

```
        OR '0'
        CP '9'+1
        JR C,HXC1
        ADD A,'A'-('9'+1)
HXC1:   LD L,A
        POP AF
        RET
;
;
;
ADCBAS  EQU 20H;980Z ADC BOARD
ADCGO   EQU 1;START ADC
ADCLO   EQU 3;LOW BYTE
ADCHI   EQU 2;HIGH BYTE
CTC0    EQU 0CH;CTC CHAN 0
MPXCH   EQU 0
;INTERRUPT ROUTINE FOLLOWS
RSTCTC  EQU 01010011B;CLEAR INTERRUPTS,STOP
LDCTC   EQU 11010111B;COUNTER,TC FOLLOWS
ADCRD:  EX AF,AF'
        EXX
        OUT (ADCBAS+ADCGO),A;START ADC
ADCR1:  IN A,(ADCBAS+ADCHI);TEST STATUS
        BIT 7,A
        JR Z,ADCR1;NOT READY
        AND 00000011B
        JR Z,LIMIT
        LD A,255
        JR MAX
LIMIT:  IN A,(ADCBAS+ADCLO);LOW BYTE
MAX:    LD C,A
        CALL WFIFO;PUT TO BUFFER
        EXX
        EX AF,AF'
        EI
ERR1:   RETI
;
;= SFIFO , WFIFO , RFIFO
;  first in first out buffer suite
;/ class: 1
;/ description: SFIFO sets up an empty
; fifo buffer at (IX). WFIFO writes a
; byte to it.RFIFO reads a byte
; from it.
;/ action: sets up buffer in memory
; first byte at (IX). buffer variables
; stored below (IX) to (IX-8). buffer
; above any length. Recirculates.
;/ subr dependance : none external
;/ interfaces none
;/ input: IX-> buffer for all entries
; SFIFO: DE=max size
; WFIFO: C =character to be put
```

```
;/ output: AF destroyed, cy set if
; full for WFIFO,empty for RFIFO.
; RFIFO returns character in A.
;/ AF destroyed all entries
;/ stack use: 8 bytes
;/ size: 121 bytes
;/ CPU Z80
;
;IX points to buffer base & pointers
;as follows
NXGETH EQU -1
NXGETL EQU -2;offset getplace
NXPUTH EQU -3
NXPUTL EQU -4;offset putplace
BFCOH EQU -5
BFCOL EQU -6;bytes in buffer
BFMAXH EQU -7
BFMAXL EQU -8;length
;
;SFIFO set buffer empty
;IX->position,DE = size destroys HL
SFIFO:  PUSH HL
        LD A,6;counter
        PUSH IX
        POP HL;base to HL
FZ1:    DEC HL
        LD (HL),0
        DEC A
        JR NZ,FZ1; zero place,size
        DEC HL;bfmaxl
        LD (HL),D
        DEC HL
        LD (HL),E;buffer size
        POP HL
        RET
;
;Put byte to buffer from C cy set=full
WFIFO: PUSH DE
        PUSH HL
        LD E,(IX+BFCOL)
        LD D,(IX+BFCOH);DE=count
        INC DE;update it
        CALL CPBFMX;<= ck
        JR C,INF1;if full exit
        LD (IX+BFCOL),E
        LD (IX+BFCOH),D;update count
        LD E,(IX+NXPUTL)
        LD D,(IX+NXPUTH);DE=put place
        CALL RECIRC;gets next DE
                ;gets abs addr to HL
        LD (IX+NXPUTL),E
        LD (IX+NXPUTH),D;update
        OR A;set nc
        LD (HL),C;put byte
INF1:   POP HL
        POP DE
        RET
;
```

```
 ;Byte from fifo to A,cy set=empty
 RFIFO: PUSH DE
        LD E,(IX+BFCOL)
        LD D,(IX+BFCOH);DE=COUNT
        LD A,D
        OR E
        SCF;set empty flag
        JR Z,OUF1;if empty
        PUSH HL
        DEC DE
        LD (IX+BFCOL),E
        LD (IX+BFCOH),D;update
        LD E,(IX-NXGETL)
        LD D,(IX+NXGETH)
        CALL RECIRC;inc DE,circulate
        LD (IX+NXGETL),E
        LD (IX+NXGETH),D;update
        LD A,(HL)
        OR A;nc=ok
        POP HL
OUF1:   POP DE
        RET
;
;RECIRC DE->place in buffer ,incs &
;circulates if outside buffer
;on return HL-> current address
RECIRC: INC DE
        CALL CPBFMX;outside buffer?
        JR NZ,RC1;if not within buffer
        EX DE,HL;set 0 if so
RC1:    PUSH IX
        POP HL
        ADD HL,DE;absolute addr
        RET
;
;CPBFMX subtracts B*max,DE
CPBFMX: LD L,(IX+BFMAXL)
        LD H,(IX+BFMAXH)
        OR A;clear cy
        SBC HL,DE
        RET
;
;
        ORG $/32*32+32;INTERRUPT TABLE
INTABL: DEFW ADCRD
        DEFW ERR1
        DEFW ERR1
        DEFW ERR1
;
        DEFS 256;STACK SPACE
STACK:
        DEFS 8;BUFFER CONSTANT SPACE
BUFSIZ  EQU 5000;BUFFER SIZE
BUFFER: ;(IX) POINTS HERE FOR BUFFER
        NOP;DON'T END ON DEFS
        END
```

READX

```
        ORG 100H
        DEFB 0FFH
        CALL NEWSTK
        LD DE,5CH
        CALL CREATE
        LD IX,BUFF2
        LD DE,1024
        CALL SFIFO
QUART   EQU 0ECA2H
LPOUT   EQU 5
EMT     EQU 0F7H
64KIN   EQU 48
LAB3:   LD A,10H

        DEFB EMT,LPOUT
        LD A,30H
        DEFB EMT.LPOUT
        LD B,2
LOOP1:  CALL UARTIN
        PUSH AF
        DJNZ LOOP1
        POP AF
        LD E,A
        POP AF
        LD D,A
        BIT 3,E
        JR Z,LAB2
        LD IX,BUFF2
        LD DE,5CH
        CALL WRFIN
        JP RETCPM
LAB2:   LD B,2
LOOP2:  CALL UARTIN
        PUSH AF
        DJNZ LOOP2
        POP AF
        RLA
        RLA
        LD E,A
        POP AF
        AND 00111111B
        LD D,A
        SRL D
        RR E
        SRL D
        RR E
        LD IX,BUFFER
        CALL SFIFO
LAB1:   CALL UARTIN;GET CHAR
        LD C,A
        CALL WFIFO
        DEC DE
        LD A,D
        OR E
        JR NZ,LAB1
```

```
LAB4:   LD IX,BUFFER
        CALL RFIFO
        JR C,LAB3
        CALL BTODEC
        JR LAB4
UARTIN: CALL QUART
        JR Z,UARTIN
        IN A,(0C8H)
        RET
BTODEC: LD B,3
        LD HL,DECAD
CONV1:  LD C,'0'-1
CONV:   INC C
        SUB (HL)
        JR NC,CONV
        ADD A,(HL)
        PUSH AF
        LD IX,BUFF2
        LD DE,5CH
        CALL WRCH
        POP AF
        INC HL
        DJNZ CONV1
        LD C,CR
        CALL WRCH
        LD C,LF
        CALL WRCH
        RET
DECAD:  DEFB 100,10,1
RECLEN EQU 128;CP/M RECORD LENGTH
TBUF EQU 80H;CP/M DEFAULT DMA
EOF EQU 1AH;CP/M END OF FILE CHARACTER
;=RDCH,BUFFERED READ FROM DISK
;/CLASS 1
;/TIME CRITICAL: NO
;/DESCRIPTION: BUFFERED READ
;/  BUFFER A MULTIPLE OF 128 BYTES
;/  E.G. TO SET UP BUFFERED READ:
;/
;/  LD IX,BUFFER;(IX)=N*128 BUFFER
;/  LD DE,BUFLEN;DE=N*128,SIZE
;/  CALL SFIFO;CREATE BUFFER
;/  LD DE,FCB;(DE)=FILE CONTROL BLOCK
;/  CALL OPEN;OPEN READ FILE
;/
;/  NOW CALL RDCH TO GET A CHARACTER
;/ACTION: GETS CHARACTER FROM BUFFER
;/    IF NONE,FILLS BUFFER
;/SUBR DEPENDENCE: USES RFIFO,WFIFO
;/USER NEEDS SFIFO,FIRST IN FIRST
;/OUT BUFFER HANDLERS.ALSO CPM FILE
;/HANDLING PACKAGE
;/INPUT: FCB AT (DE),BUFFER AT (IX)
;/OUTPUT: CHARACTER RETURNED IN A
;/NC=O.K,CY=READ PAST END OF FILE
```

```
;/REGS USED AF,DE,IX,OTHERS SAVED
;/STACK USE: DEPENDS ON CP/M
;/MEMORY USED:-SEE SFIFO
;/PROCESSOR Z80
;
RDCH:   CALL RFIFO
        RET NC;NORMAL EXIT
        PUSH HL;NONE IN BUFFER
        PUSH BC
        CALL WFIFO;WRITE DUMMY CHARACTER
RDC1:   LD B,RECLEN
        CALL READ
        JR NZ,RDC3;PAST EOF,EXIT
        LD HL,TBUF
RDC2:   LD C,(HL)
        INC HL
        CALL WFIFO;CY=FULL BUFFER
        JR NC,RDC4
RDC3:   CALL RFIFO;REMOVE DUMMY
        CALL WFIFO;WRITE LAST CHARACTER
        POP BC
        POP HL
        JP RFIFO;CY=EOF,NO CHAR
RDC4:   DJNZ RDC2
        JR RDC1 ;loop another record
;
;=WRCH: BUFFERED WRITE TO DISK
;/CLASS 1
;/TIME CRITICAL NO
;/DESCRIPTION: WRITES CHARACTER
;/ TO BUFFER,EMPTIES TO DISK
;/  IF FULL.
;/ TO CREATE A BUFFERED WRITE:
;
;/  LD IX,BUFFER;BUFFER TO IX
;/  LD DE,BUFLEN;DESIRED SIZE (N*128)
;/  CALL SFIFO
;/  LD DE,FCB;FILE CONTROL BLOCK
;/  CALL ERASE;DELETE FILE IF EXISTS
;/  CALL CREATE;MAKE NEW FILE
;/
;/  CALL WRCH TO PUT CHARACTER IN C
;/ACTION: PUTS CHARACTER IN C TO BUFFER
;/  IF FULL,EMPTIES TO DISK
;/SUBR DEPENDENCE: USES FIFO BUFFER
;/  PACKAGE & CPM FILE HANDLING PACKAGE
;/INPUT: CHARACTER IN C,BUFFER AT (IX)
;/  FCB AT (DE)
;/OUTPUT: ERROR EXITS TO CP/M
;/REGS USED DE,IX,C,AF DESTROYED
;/STACK USE: DEPENDS ON CP/M
;/MEMORY USED: SEE SFIFO
;/PROCESSOR Z80
;
WRCH:   CALL WFIFO
```

```
        RET NC;NORMAL EXIT
TODSK:  PUSH HL;BUFFER FULL,EMPTY IT
        PUSH BC
WCH1:   LD B,RECLEN
        LD HL,TBUF
WCH2:   CALL RFIFO
        JR C,WCH3 ;NONE LEFT
        LD (HL),A;PUT TO DMA
        INC HL
        DJNZ WCH2
        CALL WRITE;DMA TO DISK
        JR WCH1;LOOP NEXT RECORD
WCH3:   LD A,B
        CP RECLEN;EMPTY DMA?
        CALL NZ,WRITE
        POP BC
        POP HL
        JR WRCH;PUT CHAR & EXIT
;
;=WRFIN: TERMINATES WRITE FILE
;/TIME CRITICAL: NO
;/DESCRIPTION: WRITES END OF FILE
;/EMPTIES BUFFER TO DISK
;/SUBR DEPENDENCE: REQUIRES WRCH (LOCAL)
;/INPUT: (DE)=FCB,(IX)=BUFFER
;/OUTPUT: NONE
;/REGS USED: AF,C DESTROYED,DE,IX USED
;/STACK USE: DEPENDS ON CP/M
;/PROCESSOR Z80
;
WRFIN:  LD C,EOF;WRITE END OF FILE
        CALL WRCH
        CALL TODSK ;EMPTY BUFFER
        JP CLOSE
;
;= SFIFO , WFIFO , RFIFO
;   first in first out buffer suite
;/ class: 1
;/ description: SFIFO sets up an empty
; fifo buffer at (IX). WFIFO writes a
; byte to it.RFIFO reads a byte
; from it.
;/ action: sets up buffer in memory
; first byte at (IX). buffer variables
; stored below (IX) to (IX-8). buffer
; above any length. Recirculates.
;/ subr dependance : none external
;/ interfaces none
;/ input: IX-> buffer for all entries
; SFIFO: DE=max size
; WFIFO: C =character to be put
;/ output: AF destroyed, cy set if
; full for WFIFO,empty for RFIFO.
; RFIFO returns character in A.
;/ AF destroyed all entries
```

```
;/ stack use: 8 bytes
;/ size: 121 bytes
;/ CPU Z80
;
        GLOBAL WFIFO;byte to buffer
        GLOBAL RFIFO;byte from buffer
        GLOBAL SFIFO;initialise
;IX points to buffer base & pointers
;as follows
NXGETH EQU -1
NXGETL EQU -2;offset getplace
NXPUTH EQU -3
NXPUTL EQU -4;offset putplace
BFCOH EQU -5
BFCOL EQU -6;bytes in buffer
BFMAXH EQU -7
BFMAXL EQU -8;length
;
;SFIFO set buffer empty
;IX->position,DE = size destroys HL
SFIFO:  PUSH HL
        LD A,6;counter
        PUSH IX
        POP HL;base to HL
FZ1:    DEC HL
        LD (HL),0
        DEC A
        JR NZ,FZ1; zero place,size
        DEC HL;bfmaxl
        LD (HL),D
        DEC HL
        LD (HL),E;buffer size
        POP HL
        RET
;
;Put byte to buffer from C cy set=full
WFIFO: PUSH DE
        PUSH HL
        LD E,(IX+BFCOL)
        LD D,(IX+BFCOH);DE=count
        INC DE;update it
        CALL CPBFMX;<= ok
        JR C,INF1;if full exit
        LD (IX+BFCOL),E
        LD (IX+BFCOH),D;update count
        LD E,(IX+NXPUTL)
        LD D,(IX+NXPUTH);DE=put place
        CALL RECIRC;gets next DE
                ;gets abs addr to HL
        LD (IX+NXPUTL),E
        LD (IX+NXPUTH),D;update
        OR A;set nc
        LD (HL),C;put byte
INF1:   POP HL
        POP DE
        RET
```

```
;
;Byte from fifo to A,cy set=empty
RFIFO: PUSH DE
        LD E,(IX+BFCOL)
        LD D,(IX+BFCOH);DE=COUNT
        LD A,D
        OR E
        SCF;set empty flag
        JR Z,OUF1;if empty
        PUSH HL
        DEC DE
        LD (IX+BFCOL),E
        LD (IX+BFCOH),D;update
        LD E,(IX+NXGETL)
        LD D,(IX+NXGETH)
        CALL RECIRC;inc DE,circulate
        LD (IX+NXGETL),E
        LD (IX+NXGETH),D;update
        LD A,(HL)
        OR A;nc=ok
        POP HL
OUF1:   POP DE
        RET
;
;RECIRC DE->place in buffer ,incs &
;circulates if outside buffer
;on return HL-> current address
RECIRC: INC DE
        CALL CPBFMX;outside buffer?
        JR NZ,RC1;if not within buffer
        EX DE,HL;set 0 if so
RC1:    PUSH IX
        POP HL
        ADD HL,DE;absolute addr
        RET
;
;CPBFMX subtracts Bfmax,DE
CPBFMX: LD L,(IX+BFMAXL)
        LD H,(IX+BFMAXH)
        OR A;clear cy
        SBC HL,DE
        RET
;
;=CP/M FILE HANDLING PACKAGE
;AUTHOR R.J.CHANCE 3 AUG '80
;
;/CLASS 2 (NOT ROMABLE)
;/DESCRIPTION:
  ;NEWSTK:SAVES CP/M STACK,GETS NEW ONE
  ;OPEN: OPENS READ FILE
  ;READ: READS RECORD
  ;CREATE: MAKES FILE IF DOES NOT EXIST
  ;WRITE: WRITES A RECORD
  ;ERASE: DELETES A FILE
```

```
    ;CLOSE: CLOSES WRITE FILE
    ;RETCPM: RESTORES CPM STACK,EXITS
 ;
 ;/ACTION: SEE INDIVIDUAL ROUTINES
    ;CALL NEWSTK BEFORE ANY OTHER ACTION
    ;ALL ROUTINES SAVE ALL REGISTERS
    ;EXCEPT AF
    ;ERRORS GIVE MESSAGE & RET TO CP/M
 ;/NO SUBROUTINE DEPENDENCE
 ;/INPUT:FCB REFERS TO A CP/M FILE
    ;CONTROL BLOCK WITH PARSED FILENAME
    ;(DE)=FCB WHERE APPROPRIATE
 ;/OUTPUT SEE INDIVIDUAL ROUTINES
 ;/STACK USE: 2 (CREATES NEW STACK)
 ;/LENGTH:510 BYTES (INCLUDES 256 FOR STACK)

 ;/PROCESSOR: Z80
 ;

 ENTRY EQU 5H ;CPM ENTRY ADDR
 ;
 ;=CREATE: MAKES DISK FILE
 ;/INPUT: (DE)=FILE CONTROL BLOCK
    ;CONTAINING FILENAME
 ;/OUTPUT: COMPLETED FCB WITH DISK MA    ;ETC.
 ;/REGS USED DE,AF
 CREATE: PUSH HL
         PUSH DE
         PUSH BC
         CALL QFILE
         JR NZ,XMSG1 ;FILE EXISTS,EXIT
         LD C,22 ;MAKE FILE
         CALL ENTRY
         INC A
         JR Z,XMSG2
         POP BC
         POP DE
         POP HL
         RET
;
;QFILE: DE-> FCB ,OPENS READ FILE IF
;POSSIBLE - ON RETURN Z IF NO FILE
;ONLY SAVES DE
QFILE:  PUSH DE
        LD HL,32;NR PLACE
        ADD HL,DE
        LD (HL),0 ;ZERO NR
        LD HL,12;ZERO EXTENTS
        ADD HL,DE
        LD (HL),0
        LD C,15 ;OPEN FILE
        CALL ENTRY
        INC A
        POP DE
        RET
```

```
;
;=OPEN: OPENS A READ FILE
;/INPUT: (DE) = FCB
;/OUTPUT: POINTS FCB TO FILE START
;/REGS USED DE,AF
OPEN:   PUSH HL
        PUSH BC
        CALL QFILE ;OPEN FILE
        JR Z,XMSG3 ;ERROR
        POP BC
        POP HL
        RET
;
;=CLOSE: CLOSES WRITE FILE
;/INPUT: (DE)= FCB
;/OUTPUT:FILE PUT TO DIRECTORY
;/REGS USED DE,AF
CLOSE:  PUSH HL
        PUSH DE
        PUSH BC
        LD C,16 ;CLOSE
        CALL ENTRY
        INC A
        JR Z,XMSG4
        POP BC
        POP DE
        POP HL
        RET
;
;=READ:GETS 128 BYTE RECORD
;/INPUT: (DE)=FCB
;/OUTPUT: NEXT 128 BYTES AT DMA
    ;Z =NORMAL READ
    ;NZ = PAST END OF FILE
READ:   PUSH HL
        PUSH DE
        PUSH BC
        LD C,20 ;READ
        CALL ENTRY
        CP 2 ;ERROR?
        JR Z,XMSG5
        POP BC
        POP DE
        POP HL
        OR A ;NZ=EOF,Z=NORMAL
        RET
;
;=WRITE:PUTS 128 BYTES TO DISC
;/INPUT:128 BYTE RECORD IN DMA BUFFER
;/     (DE) = FCB
;/OUTPUT:NONE
;/REGS USED DE,AF
WRITE:  PUSH HL
        PUSH DE
```

```
            PUSH BC
            LD C,21  ;WRITE
            CALL ENTRY
            OR A
            JR NZ,XMSG4
            POP BC
            POP DE
            POP HL
            RET
;
;=ERASE: REMOVES FILE FROM DIRECTORY
     ;NON EXISTANT FILE IS ACCEPTABLE
;/INPUT: (DE)= FCB
;/OUTPUT: NONE
;/REGS USED DE,AF
ERASE:   PUSH HL
         PUSH DE
         PUSH BC
         LD C,19
         CALL ENTRY
         POP BC
         POP DE
         POP HL
         RET
;
;ERROR ROUTINES LOAD MESSAGE TO HL
;DD LOADS SUBSEQUENT MESSAGES TO IX
XMSG1:   LD HL,MSG1
         DEFB 0DDH ;IGNORE NEXT
XMSG2:   LD HL,MSG2
         DEFB 0DDH
XMSG3:   LD HL,MSG3
         DEFB 0DDH
XMSG4:   LD HL,MSG4
         DEFB 0DDH
XMSG5:   LD HL,MSG5
         EX DE,HL  ;HL->MSG
         LD C,9  ;PRINT
         CALL ENTRY
         LD DE,XCRLF ;NEWLINE
         LD C,9 ;WRITE IT
         CALL ENTRY
;
;=RETCPM: RESTORES CP/M STACK,EXITS
RETCPM: LD SP,(OLDSP)
        RET
;
;=NEWSTK:GETS NEW STACK,SAVES CP/M
;     STACK POINTER
;/OUTPUT:CP/M SP AT (OLDSP)
    ;SP = STACK
NEWSTK: EX (SP),HL;RET ADDRESS TO HL
        LD (STACK-2),HL;TO NEW STACK
        LD HL,2;FOR CALL
        ADD HL,SP
        LD (OLDSP),HL
```

```
            POP HL;GET HL
            LD SP,STACK-2
            RET
;
MSG1:       DEFM 'WRITE FILE EXISTS$'
MSG2:       DEFM 'NO DIRECTORY SPACE$'
MSG3:       DEFM 'I CANNOT FIND READFILE$'
MSG4:       DEFM 'WRITE ERROR$'
MSG5:       DEFM 'READ ERROR$'
XCRLF:      DEFB ODH,OAH,24H ;CR,LF,$
;
OLDSP:      DEFS 2 ;STORE CPM SP HERE
;
            DEFS 100H ;STACK AREA
STACK:      DEFW 0;INITIAL SP ADDR
;=CPM CONSOLE INPUT/OUTPUT PACKAGE
;/CLASS 1
;/DESCRIPTION:
    ;IPCHAR:GETS A KEYBOARD CHARACTER
    ;IPLIN: GETS A KEYBOARD LINE
    ;OPCHAR:PUTS A CHARACTER TO VDU
    ;OPMSG: O/PS A MESSAGE IN (HL)
    ;OPTHIS:O/PS MESSAGE FOLLOWING CALL
    ;OPCRLF:O/PS LF,CR (NEWLINE)
;/ACTION: SEE INDIVIDUAL ROUTINES
    ;ALL REGISTERS SAVED
;/NO SUBROUTINE DEPENDANCE
;/INPUT SEE INDIVIDUAL ROUTINES
;/OUTPUT SEE INDIVIDUAL ROUTINES
;/STACK USE 10 MAXIMUM
;/LENGTH
;/PROCESSOR Z80
;
;=IPCHAR: GETS KEYBOARD CHARACTER TO A
;/INPUT NONE
;/OUTPUT A CONTAINS CHARACTER
IPCHAR: PUSH BC
        PUSH DE
        PUSH HL
        LD C,1 ;CPM KBD CALL
        CALL ENTRY ;CPM CALL
        POP HL
        POP DE
        POP BC
        RET
;
;=IPLIN GETS LINE TO TBUF
;/INPUT NONE
;/OUTPUT (HL)=LAST CHAR (EXCEPT CR)
  ;(DE)=1ST CHAR,A=NO. CHARACTERS
IPLIN:  PUSH BC
        LD DE,TBUF;BUFFER START
        LD C,10;CP/M BUFFERED READ CODE
        LD A,80 ;MAX ALLOWED CHARACTERS
        LD (DE),A
```

```
          PUSH DE ;SAVE BUFFER
          CALL ENTRY ;GET LINE
          POP HL ;GET BUFFER
          INC HL ;(HL)=NO. CHARACTERS
          LD A,(HL) ;A=NO. CHARACTERS
          LD C,A
          LD B,0 ;BC=NO. CHARACTERS
          LD D,H
          LD E,L ;HL=DE=BUFFER+1
          ADD HL,BC ;(HL)=LAST CHARACTER
          INC DE ;(DE)=1ST CHARACTER
          POP BC ;RSTORE BC
          RET
;
;=OPCHAR:OUTPUTS CHARACTER IN A TO VDU
;/INPUT: CHARACTER IN A
;/OUTPUT:NONE
OPCHAR:   PUSH AF
          PUSH BC
          PUSH DE
          PUSH HL
          LD C,2 ;CP/M CHAR O/P CODE
          LD E,A ;CHARACTER IN E
          CALL ENTRY
          POP HL
          POP DE
          POP BC
          POP AF
          RET
;
;=OPMSG: OUTPUTS MESAGE IN (HL)
    ;'$' TERMINATES MESSAGE
    ;'@' IS TRANSLATED TO NEWLINE
;/INPUT MESSAGE AT (HL)
;/OUTPUT (HL)=LAST MESSAGE CHARACTER+1
OPMSG:    PUSH AF
OPM1:     LD A,(HL)
          INC HL;NEXT CHARACTER
          CP '@'
          CALL Z,OPCRLF;'@'=NEW LINE
          JR Z,OPM1 ;LOOP FOR CHARS
OPM2:     CP '$' ;END MESSAGE?
          JR Z,OPM3 ;EXIT IF '$'
          CALL OPCHAR
          JR OPM1 ;LOOP FOR CHARS
OPM3:     POP AF
          RET
;
;=OPTHIS:SENDS MESSAGE FOLLOWING CALL
    ;'@' TRANSLATED TO CR,LF
    ;'$' TERMINATES
;/INPUT MESSAGE FOLLOWS CALL
;/OUTPUT NONE
OPTHIS: EX (SP),HL ;HL=MESSAGE,SAVE HL
```

```
         CALL OPMSG ;SEND MESSAGE
         EX (SP),HL ;RESTORE HL,RETURN
         RET
;
;=OPCRLF:SENDS NEWLINE
;/INPUT NONE
;/OUTPUT NONE
OPCRLF: PUSH AF
        LD A,CR
        CALL OPCHAR
        LD A,LF
        CALL OPCHAR
        POP AF
        RET
CR      EQU 0DH
LF      EQU 0AH
;
        DEFS 8
BUFFER: NOP
BUFF2   EQU BUFFER+4096
        END
```

ROHIS

```
        DJNZ LOOP2
        POP AF
        RLA
        RLA
        LD E,A
        POP AF
        AND 00111111B
        LD D,A
        SRL D
        RR E
        SRL D
        RR E
LAB1:   XOR A
        LD B,A
        CALL UARTIN
        LD C,A
        LD HL MEM1
        ADD HL,BC
        LD B,C
        LD C,(HL)
        INC C
        LD A,C
        SUB 0FFH
        JR Z,INCM1
        LD (HL),C
        DEC DE
        LD A,D
        OR E
        JR Z,LAB3
        JP LAB1
INCM1:  LD (HL),0
        LD C,B
        XOR A
        LD B,A
        LD HL,MEM2
        ADD HL,BC
        LD B,C
        LD C,(HL)
        INC C
        LD A,C
        SUB 0FFH
        JR Z,INCM2
        LD (HL),C
        DEC DE
        LD A,D
        OR E
        JR Z,LAB3
        JP LAB1
INCM2:  LD (HL),0
        LD C,B
        XOR A
        LD B,A
        LD HL,MEM3
        ADD HL,BC
        LD C,(HL)
```

```
        INC C
        LD (HL),C
        DEC DE
        LD A,D
        OR E
        JR Z,LAB3
        JP LAB1
UARTIN: CALL QUART
        JR Z,UARTIN
        IN A,(0CBH)
        RET
GETCH:  LD A,(HL)
        INC HL
        RET
DISC:   LD DE,765
        LD HL,MEM1
        LD IX,BUFFER
        CALL SFIFO
LAB5:   CALL GETCH
        LD C,A
        CALL WFIFO
        DEC DE
        LD A,D
        OR E
        JR NZ,LAB5
LAB6:   LD IX,BUFFER
        CALL RFIFO
        JR C,RET1
        CALL BTODEC
        JR LAB6
RET1:   RET
BTODEC: LD B,3
        LD HL,DECAD
CONV1:  LD C,'0'-1
CONV:   INC C
        SUB (HL)
        JR NC,CONV
        ADD A,(HL)
        PUSH AF
        LD IX,BUFF2
        LD DE,5CH
        CALL WRCH
        POP AF
        INC HL
        DJNZ CONV1
        LD C,CR
        CALL WRCH
        LD C,LF
        CALL WRCH
        RET
DECAD:  DEFB 100,10,1
DEXBC:  LD A,16
        LD HL,0
HXB1:   SRL B
        RR C
```

```
        JR NC,HXB2
        ADD HL,DE
        RET C
HXB2:   EX DE,HL
        ADD HL,HL
        EX DE,HL
        RET C
        DEC A
        JR NZ,HXB1
        RET
MEM1:   DEFS 256
MEM2:   DEFS 256
MEM3:   DEFS 256
ZMEM:   PUSH BC
        PUSH HL
        LD HL,SUMSQ
        LD B,4*3
ZMEM1:  LD (HL),0
        INC HL
        DJNZ ZMEM1
        POP HL
        POP BC
        RET
SUMSQ:  DEFS 4
SUM:    DEFS 4
SCRATC: DEFS 4
CNTR:   DEFS 1
RECLEN  EQU 128;CP/M RECORD LENGTH
TBUF EQU 80H;CP/M DEFAULT DMA
EOF EQU 1AH;CP/M END OF FILE CHARACTER
;=RDCH,BUFFERED READ FROM DISK
;/CLASS 1
;/TIME CRITICAL: NO
;/DESCRIPTION: BUFFERED READ
;/   BUFFER A MULTIPLE OF 128 BYTES
;/   E.G. TO SET UP BUFFERED READ:
;/
;/   LD IX,BUFFER;(IX)=N*128 BUFFER
;/   LD DE,BUFLEN;DE=N*128,SIZE
;/   CALL SFIFO;CREATE BUFFER
;/   LD DE,FCB;(DE)=FILE CONTROL BLOCK
;/   CALL OPEN;OPEN READ FILE
;/
;/   NOW CALL RDCH TO GET A CHARACTER
;/ACTION: GETS CHARACTER FROM BUFFER
;/    IF NONE,FILLS BUFFER
;/SUBR DEPENDENCE: USES RFIFO,WFIFO
;/USER NEEDS SFIFO,FIRST IN FIRST
;/OUT BUFFER HANDLERS,ALSO CPM FILE
;/HANDLING PACKAGE
;/INPUT: FCB AT (DE),BUFFER AT (IX)
;/OUTPUT: CHARACTER RETURNED IN A
;/NC=O.K,CY=READ PAST END OF FILE
;/REGS USED AF,DE,IX,OTHERS SAVED
;/STACK USE: DEPENDS ON CP/M
```

```
;/MEMORY USED:-SEE SFIFO
;/PROCESSOR Z80
;
RDCH:   CALL RFIFO
        RET NC;NORMAL EXIT
        PUSH HL;NONE IN BUFFER
        PUSH BC
        CALL WFIFO;WRITE DUMMY CHARACTER
RDC1:   LD B,RECLEN
        CALL READ
        JR NZ,RDC3;PAST EOF,EXIT
        LD HL,TBUF
RDC2:   LD C,(HL)
        INC HL
        CALL WFIFO;CY=FULL BUFFER
        JR NC,RDC4
RDC3:   CALL RFIFO;REMOVE DUMMY
        CALL WFIFO;WRITE LAST CHARACTER
        POP BC
        POP HL
        JP RFIFO;CY=EOF,NO CHAR
RDC4:   DJNZ RDC2
        JR RDC1  ;loop another record
;
;=WRCH: BUFFERED WRITE TO DISK
;/CLASS 1
;/TIME CRITICAL NO
;/DESCRIPTION: WRITES CHARACTER
;/ TO BUFFER,EMPTIES TO DISK
;/   IF FULL.
;/ TO CREATE A BUFFERED WRITE:
;
;/  LD IX,BUFFER;BUFFER TO IX
;/  LD DE,BUFLEN;DESIRED SIZE (N*128)
;/  CALL SFIFO
;/  LD DE,FCB;FILE CONTROL BLOCK
;/  CALL ERASE;DELETE FILE IF EXISTS
;/  CALL CREATE;MAKE NEW FILE
;/
;/  CALL WRCH TO PUT CHARACTER IN C
;/ACTION: PUTS CHARACTER IN C TO BUFFER
;/   IF FULL,EMPTIES TO DISK
;/SUBR DEPENDENCE: USES FIFO BUFFER
;/  PACKAGE & CPM FILE HANDLING PACKAGE
;/INPUT: CHARACTER IN C,BUFFER AT (IX)
;/  FCB AT (DE)
;/OUTPUT: ERROR EXITS TO CP/M
;/REGS USED DE,IX,C,AF DESTROYED
;/STACK USE: DEPENDS ON CP/M
;/MEMORY USED: SEE SFIFO
;/PROCESSOR Z80
;
WRCH:   CALL WFIFO
        RET NC;NORMAL EXIT
TODSK:  PUSH HL;BUFFER FULL,EMPTY IT
```

```
            PUSH BC
  WCH1:     LD B,RECLEN
            LD HL,TBUF
  WCH2:     CALL RFIFO
            JR C,WCH3 ;NONE LEFT
            LD (HL),A;PUT TO DMA
            INC HL
            DJNZ WCH2
            CALL WRITE;DMA TO DISK
            JR WCH1;LOOP NEXT RECORD
  WCH3:     LD A,B
            CP RECLEN;EMPTY DMA?
            CALL NZ,WRITE
            POP BC
            POP HL
            JR WRCH;PUT CHAR & EXIT
;
;=WRFIN: TERMINATES WRITE FILE
;/TIME CRITICAL: NO
;/DESCRIPTION: WRITES END OF FILE
;/EMPTIES BUFFER TO DISK
;/SUBR DEPENDENCE: REQUIRES WRCH (LOCAL)
;/INPUT: (DE)=FCB,(IX)=BUFFER
;/OUTPUT: NONE
;/REGS USED: AF,C DESTROYED,DE,IX USED
;/STACK USE: DEPENDS ON CP/M
;/PROCESSOR Z80
;
WRFIN:  LD C,EOF;WRITE END OF FILE
        CALL WRCH
        CALL TODSK ;EMPTY BUFFER
        JP CLOSE
;
;= SFIFO , WFIFO , RFIFO
;   first in first out buffer suite
;/ class: 1
;/ description: SFIFO sets up an empty
; fifo buffer at (IX). WFIFO writes a
; byte to it.RFIFO reads a byte
; from it.
;/ action: sets up buffer in memory
; first byte at (IX). buffer variables
; stored below (IX) to (IX-8). buffer
; above any length. Recirculates.
;/ subr dependance : none external
;/ interfaces none
;/ input: IX-> buffer for all entries
; SFIFO: DE=max size
; WFIFO: C =character to be put
;/ output: AF destroyed, cy set if
; full for WFIFO,empty for RFIFO.
; RFIFO returns character in A.
;/ AF destroyed all entries
;/ stack use: 8 bytes
;/ size: 121 bytes
```

```
;/ CPU Z80
;
          GLOBAL WFIFO;byte to buffer
          GLOBAL RFIFO;byte from buffer
          GLOBAL BFIFO;initialise
;IX points to buffer base & pointers
;as follows
NXGETH EQU -1
NXGETL EQU -2;offset getplace
NXPUTH EQU -3
NXPUTL EQU -4;offset putplace
BFCOH EQU -5
BFCOL EQU -6;bytes in buffer
BFMAXH EQU -7
BFMAXL EQU -8;length
;
;BFIFO set buffer empty
;IX->position,DE = size destroys HL
BFIFO:  PUSH HL
        LD A,E;counter
        PUSH IX
        POP HL;base to HL
FZ1:    DEC HL
        LD (HL),0
        DEC A
        JR NZ,FZ1; zero place,size
        DEC HL;bfmax
        LD (HL),D
        DEC HL
        LD (HL),E;buffer size
        POP HL
        RET
;
;Put byte to buffer from C cy set=full
WFIFO: PUSH DE
        PUSH HL
        LD E,(IX+BFCOL)
        LD D,(IX+BFCOH);DE=count
        INC DE;update it
        CALL CPBFMX;<= ok
        JR C,INF1;if full exit
        LD (IX+BFCOL),E
        LD (IX+BFCOH),D;update count
        LD E,(IX+NXPUTL)
        LD D,(IX+NXPUTH);DE=put place
        CALL RECIRC;gets next DE
              ;gets abs addr to HL
        LD (IX+NXPUTL),E
        LD (IX+NXPUTH),D;update
        OR A;set nc
        LD (HL),C;put byte
INF1:   POP HL
        POP DE
        RET
;
```

```
;Byte from fifo to A,cy set=empty
RFIFO: PUSH DE
        LD E,(IX+BFCOL)
        LD D,(IX+BFCOH);DE=COUNT
        LD A,D
        OR E
        SCF;set empty flag
        JR Z,OUF1;if empty
        PUSH HL
        DEC DE
        LD (IX+BFCOL),E
        LD (IX+BFCOH),D;update
        LD E,(IX+NXGETL)
        LD D,(IX+NXGETH)
        CALL RECIRC;inc DE,circulate
        LD (IX+NXGETL),E
        LD (IX+NXGETH),D;update
        LD A,(HL)
        OR A;nc=ok
        POP HL
OUF1:   POP DE
        RET
;
;RECIRC DE->place in buffer ,incs &
;circulates if outside buffer
;on return HL-> current address
RECIRC: INC DE
        CALL CPBFMX;outside buffer?
        JR NZ,RC1;if not within buffer
        EX DE,HL;set 0 if so
RC1:    PUSH IX
        POP HL
        ADD HL,DE;absolute addr
        RET
;
;CPBFMX subtracts Bfmax,DE
CPBFMX: LD L,(IX+BFMAXL)
        LD H,(IX+BFMAXH)
        OR A;clear cy
        SBC HL,DE
        RET
;
;=CP/M FILE HANDLING PACKAGE
;AUTHOR R.J.CHANCE 3 AUG '80
;
;/CLASS 2 (NOT ROMABLE)
;/DESCRIPTION:
   ;NEWSTK:SAVES CP/M STACK,GETS NEW ONE
   ;OPEN: OPENS READ FILE
   ;READ: READS RECORD
   ;CREATE: MAKES FILE IF DOES NOT EXIST
   ;WRITE: WRITES A RECORD
   ;ERASE: DELETES A FILE
   ;CLOSE: CLOSES WRITE FILE
   ;RETCPM: RESTORES CPM STACK,EXITS
```

```
;
;/ACTION: SEE INDIVIDUAL ROUTINES
    ;CALL NEWSTK BEFORE ANY OTHER ACTION
    ;ALL ROUTINES SAVE ALL REGISTERS
    ;EXCEPT AF
    ;ERRORS GIVE MESSAGE & RET TO CP/M
;/NO SUBROUTINE DEPENDENCE
;/INPUT:FCB REFERS TO A CP/M FILE
     ;CONTROL BLOCK WITH PARSED FILENAME
     ;(DE)=FCB WHERE APPROPRIATE
;/OUTPUT SEE INDIVIDUAL ROUTINES
;/STACK USE: 2 (CREATES NEW STACK)
;/LENGTH:510 BYTES (INCLUDES 256 FOR STACK)

;/PROCESSOR: Z80
;

ENTRY EQU 5H ;CPM ENTRY ADDR
;
;=CREATE: MAKES DISK FILE
;/INPUT: (DE)=FILE CONTROL BLOCK
    ;CONTAINING FILENAME
;/OUTPUT: COMPLETED FCB WITH DISK MA      ;ETC.
;/REGS USED DE,AF
CREATE: PUSH HL
        PUSH DE
        PUSH BC
        CALL QFILE
        JR NZ,XMSG1 ;FILE EXISTS,EXIT
        LD C,22 ;MAKE FILE
        CALL ENTRY
        INC A
        JR Z,XMSG2
        POP BC
        POP DE
        POP HL
        RET
;
;QFILE: DE-> FCB ,OPENS READ FILE IF
;POSSIBLE - ON RETURN Z IF NO FILE
;ONLY SAVES DE
QFILE:  PUSH DE
        LD HL,32;NR PLACE
        ADD HL,DE
        LD (HL),0 ;ZERO NR
        LD HL,12;ZERO EXTENTS
        ADD HL,DE
        LD (HL),0
        LD C,15 ;OPEN FILE
        CALL ENTRY
        INC A
        POP DE
        RET
;
;=OPEN: OPENS A READ FILE
```

```
;/INPUT: (DE) = FCB
;/OUTPUT: POINTS FCB TO FILE START
;/REGS USED DE,AF
OPEN:    PUSH HL
         PUSH BC
         CALL QFILE ;OPEN FILE
         JR Z,XMSG3 ;ERROR
         POP BC
         POP HL
         RET
;
;=CLOSE: CLOSES WRITE FILE
;/INPUT: (DE)= FCB
;/OUTPUT:FILE PUT TO DIRECTORY
;/REGS USED DE,AF
CLOSE:   PUSH HL
         PUSH DE
         PUSH BC
         LD C,16 ;CLOSE
         CALL ENTRY
         INC A
         JR Z,XMSG4
         POP BC
         POP DE
         POP HL
         RET
;
;=READ:GETS 128 BYTE RECORD
;/INPUT: (DE)=FCB
;/OUTPUT: NEXT 128 BYTES AT DMA
    ;Z =NORMAL READ
    ;NZ = PAST END OF FILE
READ:    PUSH HL
         PUSH DE
         PUSH BC
         LD C,20 ;READ
         CALL ENTRY
         CP 2 ;ERROR?
         JR Z,XMSG5
         POP BC
         POP DE
         POP HL
         OR A ;NZ=EOF,Z=NORMAL
         RET
;
;=WRITE:PUTS 128 BYTES TO DISC
;/INPUT:128 BYTE RECORD IN DMA BUFFER
;/     (DE) = FCB
;/OUTPUT:NONE
;/REGS USED DE,AF
WRITE:   PUSH HL
         PUSH DE
         PUSH BC
         LD C,21 ;WRITE
         CALL ENTRY
```

```
        OR A
        JR NZ,XMSG4
        POP BC
        POP DE
        POP HL
        RET
;
;=ERASE: REMOVES FILE FROM DIRECTORY
    ;NON EXISTANT FILE IS ACCEPTABLE
;/INPUT: (DE)= FCB
;/OUTPUT: NONE
;/REGS USED DE,AF
ERASE:  PUSH HL
        PUSH DE
        PUSH BC
        LD C,19
        CALL ENTRY
        POP BC
        POP DE
        POP HL
        RET
;
;ERROR ROUTINES LOAD MESSAGE TO HL
;DD LOADS SUBSEQUENT MESSAGES TO IX
XMSG1:  LD HL,MSG1
        DEFB 0DDH ;IGNORE NEXT
XMSG2:  LD HL,MSG2
        DEFB 0DDH
XMSG3:  LD HL,MSG3
        DEFB 0DDH
XMSG4:  LD HL,MSG4
        DEFB 0DDH
XMSG5:  LD HL,MSG5
        EX DE,HL ;HL->MSG
        LD C,9 ;PRINT
        CALL ENTRY
        LD DE,XCRLF ;NEWLINE
        LD C,9 ;WRITE IT
        CALL ENTRY
;
;=RETCPM: RESTORES CP/M STACK,EXITS
RETCPM: LD SP,(OLDSP)
        RET
;
;=NEWSTK:GETS NEW STACK,SAVES CP/M
;     STACK POINTER
;/OUTPUT:CP/M SP AT (OLDSP)
    ;SP = STACK
NEWSTK: EX (SP),HL;RET ADDRESS TO HL
        LD (STACK-2),HL;TO NEW STACK
        LD HL,2;FOR CALL
        ADD HL,SP
        LD (OLDSP),HL
        POP HL;GET HL
        LD SP,STACK-2
        RET
```

```
;
MSG1:    DEFM 'WRITE FILE EXISTS$'
MSG2:    DEFM 'NO DIRECTORY SPACE$'
MSG3:    DEFM 'I CANNOT FIND READFILE$'
MSG4:    DEFM 'WRITE ERROR$'
MSG5:    DEFM 'READ ERROR$'
XCRLF:   DEFB 0DH,0AH,24H ;CR,LF,$
;
OLDSP:   DEFS 2 ;STORE CPM SP HERE
;
         DEFS 100H ;STACK AREA
STACK:   DEFW 0;INITIAL SP ADDR
;=CPM CONSOLE INPUT/OUTPUT PACKAGE
;/CLASS 1
;/DESCRIPTION:
    ;IPCHAR:GETS A KEYBOARD CHARACTER
    ;IPLIN: GETS A KEYBOARD LINE
    ;OPCHAR:PUTS A CHARACTER TO VDU
    ;OPMSG: O/PS A MESSAGE IN (HL)
    ;OPTHIS:O/PS MESSAGE FOLLOWING CALL
    ;OPCRLF:O/PS LF,CR (NEWLINE)
;/ACTION: SEE INDIVIDUAL ROUTINES
    ;ALL REGISTERS SAVED
;/NO SUBROUTINE DEPENDANCE
;/INPUT SEE INDIVIDUAL ROUTINES
;/OUTPUT SEE INDIVIDUAL ROUTINES
;/STACK USE 10 MAXIMUM
;/LENGTH
;/PROCESSOR Z80
;
;=IPCHAR: GETS KEYBOARD CHARACTER TO A
;/INPUT NONE
;/OUTPUT A CONTAINS CHARACTER
IPCHAR: PUSH BC
        PUSH DE
        PUSH HL
        LD C,1  ;CPM KBD CALL
        CALL ENTRY ;CPM CALL
        POP HL
        POP DE
        POP BC
        RET
;
;=IPLIN GETS LINE TO TBUF
;/INPUT NONE
;/OUTPUT (HL)=LAST CHAR (EXCEPT CR)
  ;(DE)=1ST CHAR,A=NO. CHARACTERS
IPLIN:  PUSH BC
        LD DE,TBUF;BUFFER START
        LD C,10;CP/M BUFFERED READ CODE
        LD A,80 ;MAX ALLOWED CHARACTERS
        LD (DE),A
        PUSH DE ;SAVE BUFFER
```

```
         CALL ENTRY ;GET LINE
         POP HL ;GET BUFFER
         INC HL ;(HL)=NO. CHARACTERS
         LD A,(HL) ;A=NO. CHARACTERS
         LD C,A
         LD B,0 ;BC=NO. CHARACTERS
         LD D,H
         LD E,L ;HL=DE=BUFFER+1
         ADD HL,BC ;(HL)=LAST CHARACTER
         INC DE ;(DE)=1ST CHARACTER
         POP BC ;RSTORE BC
         RET
;
;=OPCHAR:OUTPUTS CHARACTER IN A TO VDU
;/INPUT: CHARACTER IN A
;/OUTPUT:NONE
OPCHAR:  PUSH AF
         PUSH BC
         PUSH DE
         PUSH HL
         LD C,2 ;CP/M CHAR O/P CODE
         LD E,A ;CHARACTER IN E
         CALL ENTRY
         POP HL
         POP DE
         POP BC
         POP AF
         RET
;
;=OPMSG: OUTPUTS MESAGE IN (HL)
   ;'$' TERMINATES MESSAGE
   ;'@' IS TRANSLATED TO NEWLINE
;/INPUT MESSAGE AT (HL)
;/OUTPUT (HL)=LAST MESSAGE CHARACTER+1
OPMSG:   PUSH AF
OPM1:    LD A,(HL)
         INC HL;NEXT CHARACTER
         CP '@'
         CALL Z,OPCRLF;'@'=NEW LINE
         JR Z,OPM1 ;LOOP FOR CHARS
OPM2:    CP '$' ;END MESSAGE?
         JR Z,OPM3 ;EXIT IF '$'
         CALL OPCHAR
         JR OPM1 ;LOOP FOR CHARS
OPM3:    POP AF
         RET
;
;=OPTHIS:SENDS MESSAGE FOLLOWING CALL
```

```
    ;'@' TRANSLATED TO CR,LF
    ;'$' TERMINATES
;/INPUT MESSAGE FOLLOWS CALL
;/OUTPUT NONE
OPTHIS: EX (SP),HL ;HL=MESSAGE,SAVE HL
        CALL OPMSG ;SEND MESSAGE
        EX (SP),HL ;RESTORE HL,RETURN
        RET
;
;=OPCRLF:SENDE NEWLINE
;/INPUT NONE
;/OUTPUT NONE
OPCRLF: PUSH AF
        LD A,CR
        CALL OPCHAR
        LD A,LF
        CALL OPCHAR
        POP AF
        RET
CR      EQU 0DH
LF      EQU 0AH
;
        DEFS 8
BUFFER: NOP
BUFF2   EQU BUFFER+4096
        END
```

ANALHIS

```
10 CLEAR 15
20 GRAPH 1:GRAPH 0
30 CALL"RESOLUTION",0,2
40 DIM N(1000),C(1000),R(100)
50 FOR J=49 TO 57
60 LET A$="FRDA"+CHR$(J)
70 GOSUB 140
80 NEXT J
90 FOR J=48 TO 57
100 LET A$="FRDA1"+CHR$(J)
110 GOSUB 140
120 NEXT J
130 GOTO 700
140 PRINT A$
150 IF LOOKUP(A$)=0 THEN 690
160 OPEN #10,A$
170 ON EOF GOTO 240
180 LET I=0
190 INPUT #10,A
200 LET N(I)=A
210 I=I+1
220 IF I=768 GOTO 240
230 GOTO 190
240 I=0
250 N(I)=N(I)+255*N(I+256)+255*255*N(I+256+256)
260 CALL"FILL",I,0,I+2 ,N(I)/5,1
270 XL=0:XH=318:XY=0:XI=10
280 YL=0:YH=191:YX=0:YI=10:TI=2
290 I=I+1
300 IF I=256 GOTO 320
310 GOTO 250
320 S=0
330 S1=0
340 FOR I=0 TO 255
350 S=S+N(I)
360 S1=S1+I*N(I)
370 NEXT I
380 M=S1/S
390 C(0)=(N(0)/S)*100
400 FOR I=0 TO 255
410 K=I+1
420 C(K)=C(I)+(N(K)/S)*100
430 IF C(I)<=1 AND C(I+1)>=1 THEN R(1)=(I-422)/3.7
431 IF R(1)=0 THEN R(1)=-114.054
440 IF C(I)<=5 AND C(I+1)>=5 THEN R(5)=(I-422)/3.7
441 IF R(5)=0 THEN R(5)=-114.054
450 IF C(I)<=10 AND C(I+1)>=10 THEN R(10)=(I-422)/3.7
451 IF R(10)=0 THEN R(10)=-114.054
460 IF C(I)<=50 AND C(I+1)>=50 THEN R(50)=(I-422)/3.7
470 IF C(I)<=90 AND C(I+1)>=90 THEN R(90)=(I-422)/3.7
480 IF C(I)<=95 AND C(I+1)>=95 THEN R(95)=(I-422)/3.7
490 IF C(I)<=99 AND C(I+1)>=99 THEN R(99)=(I-422)/3.7
500 CALL "PLOT",I,C(K),3
510 NEXT I
```

```
520 PRINT "R(99)     R(95)     R(90)     R(50)     R(10)     R(5)     R(1)"
530 PRINT R(1),R(5),R(10),R(50),R(90),R(95),R(99)
540 PRINT "R(50)-R(10)=";R(90)-R(50)
550 PRINT "R(90)-R(50)=";R(50)-R(10)
551 PRINT "R(50)-R(5)=";R(95)-R(50)
552 PRINT "R(95)-R(50)=";R(50)-R(5)
553 PRINT "R(50)-R(1)=";R(99)-R(50)
554 PRINT "R(99)-R(50)=";R(50)-R(1)
560 M=(M-422)/3.7
570 VAR=0
580 FOR I=0 TO 255
590 W=(((I-422)/3.7)-M)^2
600 W=W*N(I)
610 VAR=VAR+W
620 NEXT I
630 PRINT "VARIANCE=";VAR/S
635 IF ((VAR/S)-31)<0 THEN 650
640 PRINT "S=";SQR((VAR/S)-31)
650 PRINT "*****************************************************
660 GOSUB 710
670 CALL"RESOLUTION",0,2
680 RETURN
690 PRINT "FILE DOES NOT EXIST"
700 END
710 CALL"PLOT",XL,XY,3
720 CALL"LINE",XH,XY
730 FOR X=XL TO XH STEP XI
740 CALL"PLOT",X,XY-TI,3
750 CALL"LINE",X,XY+TI
760 NEXT X
770 CALL "PLOT",YX,YL,3
780 CALL"LINE",YX,YH
790 FOR Y=YL TO YH STEP YI
800 CALL"PLOT",YX-TI,Y,3
810 CALL"LINE",YX+TI,Y
820 NEXT Y
830 RETURN
```

APPENDIX B

EFFECT OF TRAFFIC ON THE RECEIVED SIGNAL

APPENDIX B

EFFECT OF TRAFFIC ON THE RECEIVED SIGNAL

When the mobile is stationary the variation due to multipath effects does not exist in the same manner as when the vehicle is moving. However, with the other moving vehicles and objects, the scattering path will vary with time and hence the signal strength will also vary.

Six sets of measurements, three at 900 MHz and three at 441 MHz were conducted with the mobile stationary in Liverpool city centre. The measurements were taken alternatively to eliminate any chance of prejudice. These measurements were taken at a distance of 1.5 km from the base transmitter and around 5.00 pm to guarantee a good flow of traffic. Each measurement lasted for 2 minutes.

The variation of signal strength with time at 900 MHz is shown in Fig. B.1, fades of 15 dB depth are apparent. This is relatively large compared with fades of 40 dB depth when the mobile is in motion.

The cumulative probability distribution measured over 60,000 samples was plotted in Figs. B.2 and B.3. The distribution is shown to be Weibull. At 900 MHz the slope of the line changes for each measurement, with some approaching a Rayleigh distribution, but at 441 MHz the slope of the lines remains constant, with slight variation in the median value. This can be explained by the fact that the variation of signal strength when the mobile is stationary depends on several factors. If the contribution from moving scatterers is only a small fraction of the total signal received, then only small variations in signal strength would be expected. However if the received signal strength is weak, then more variations would be expected.

In the same experiment, signal strength at 900 MHz would be expected to be less than signal strength at 441 MHz. This might explain the sensitivity of received signal to moving scatterers at 900 MHz. However, more measurements are needed to confirm the above statement.

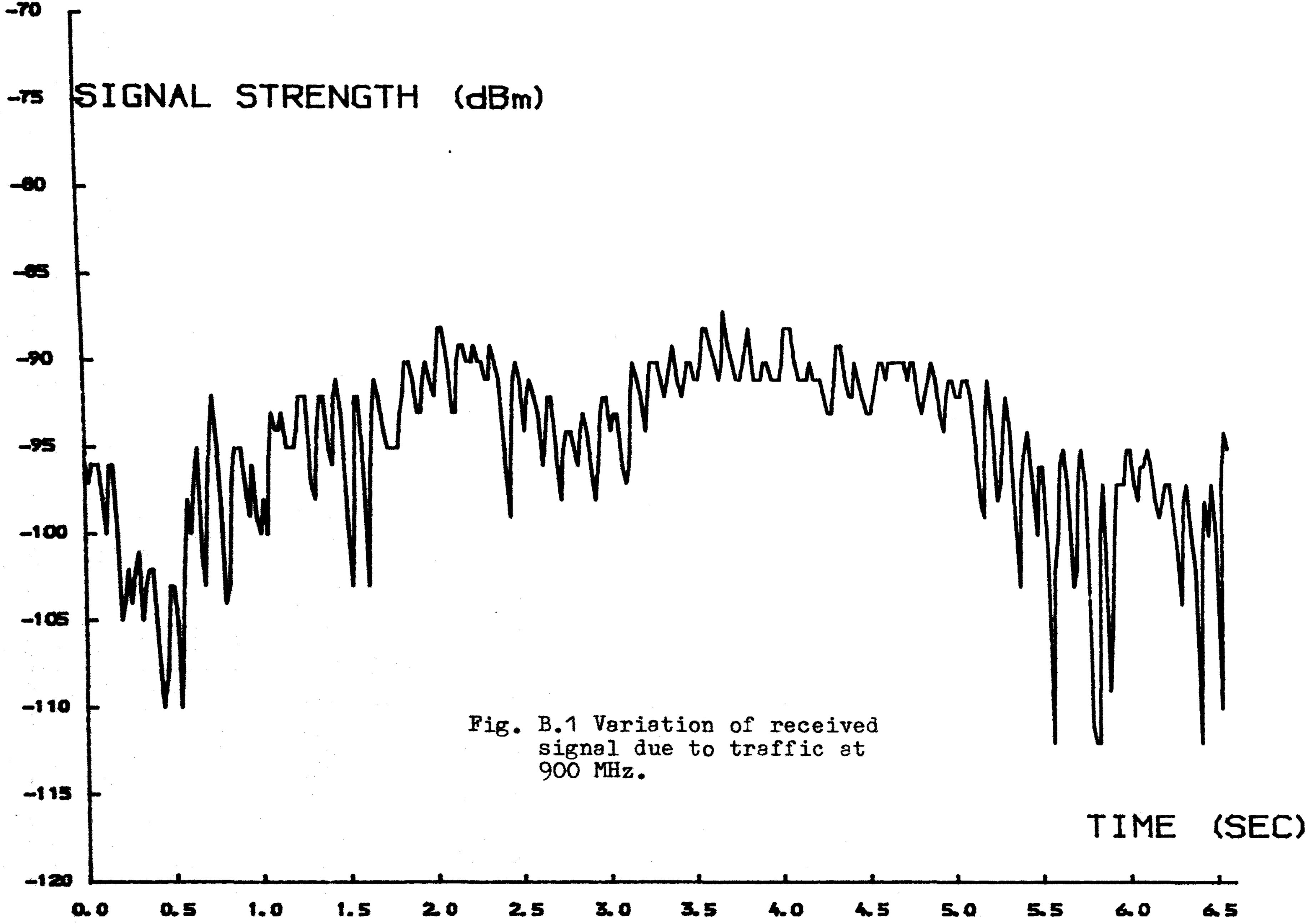

Fig. B.1 Variation of received signal due to traffic at 900 MHz.

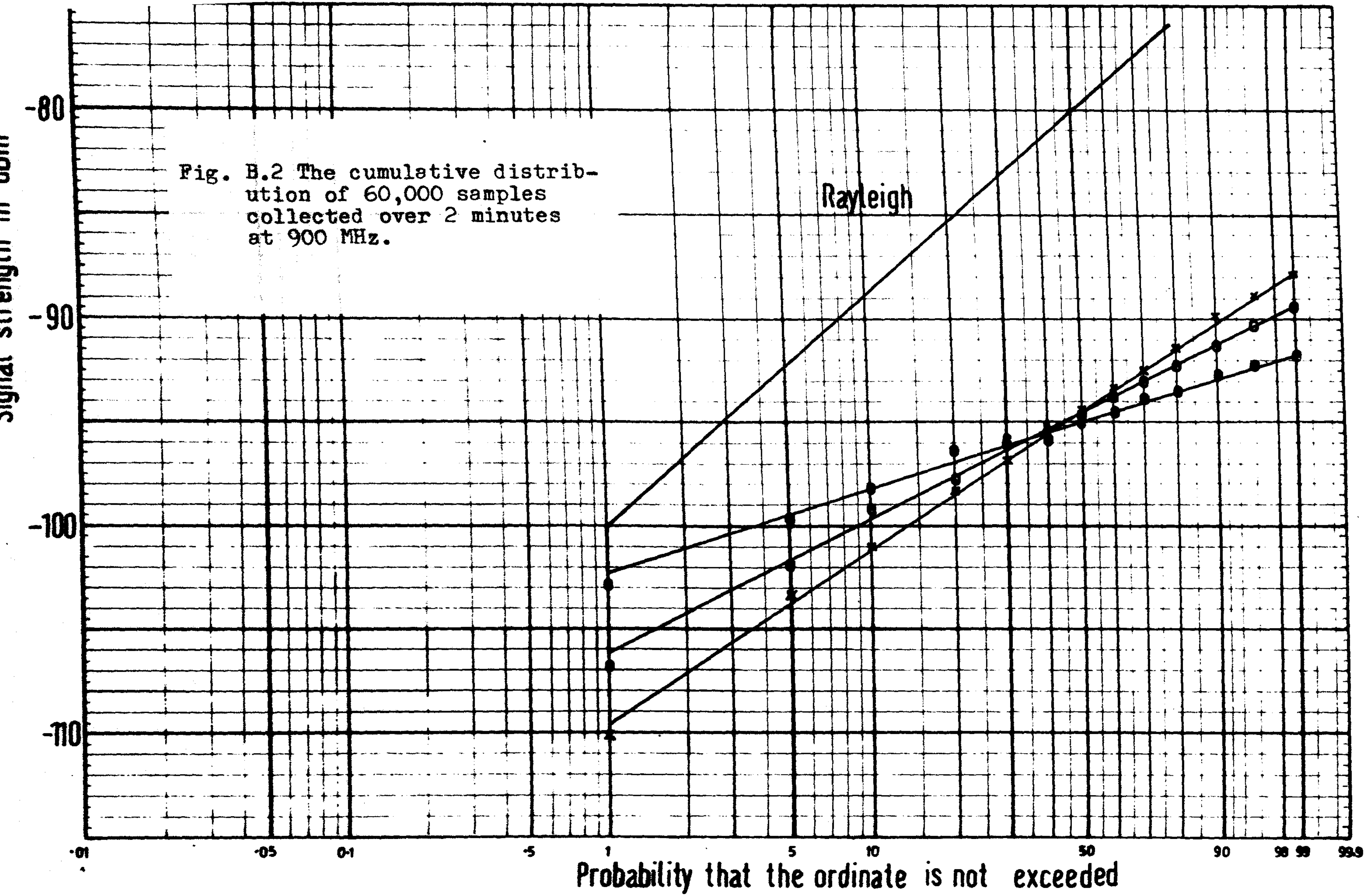

Fig. B.2 The cumulative distribution of 60,000 samples collected over 2 minutes at 900 MHz.

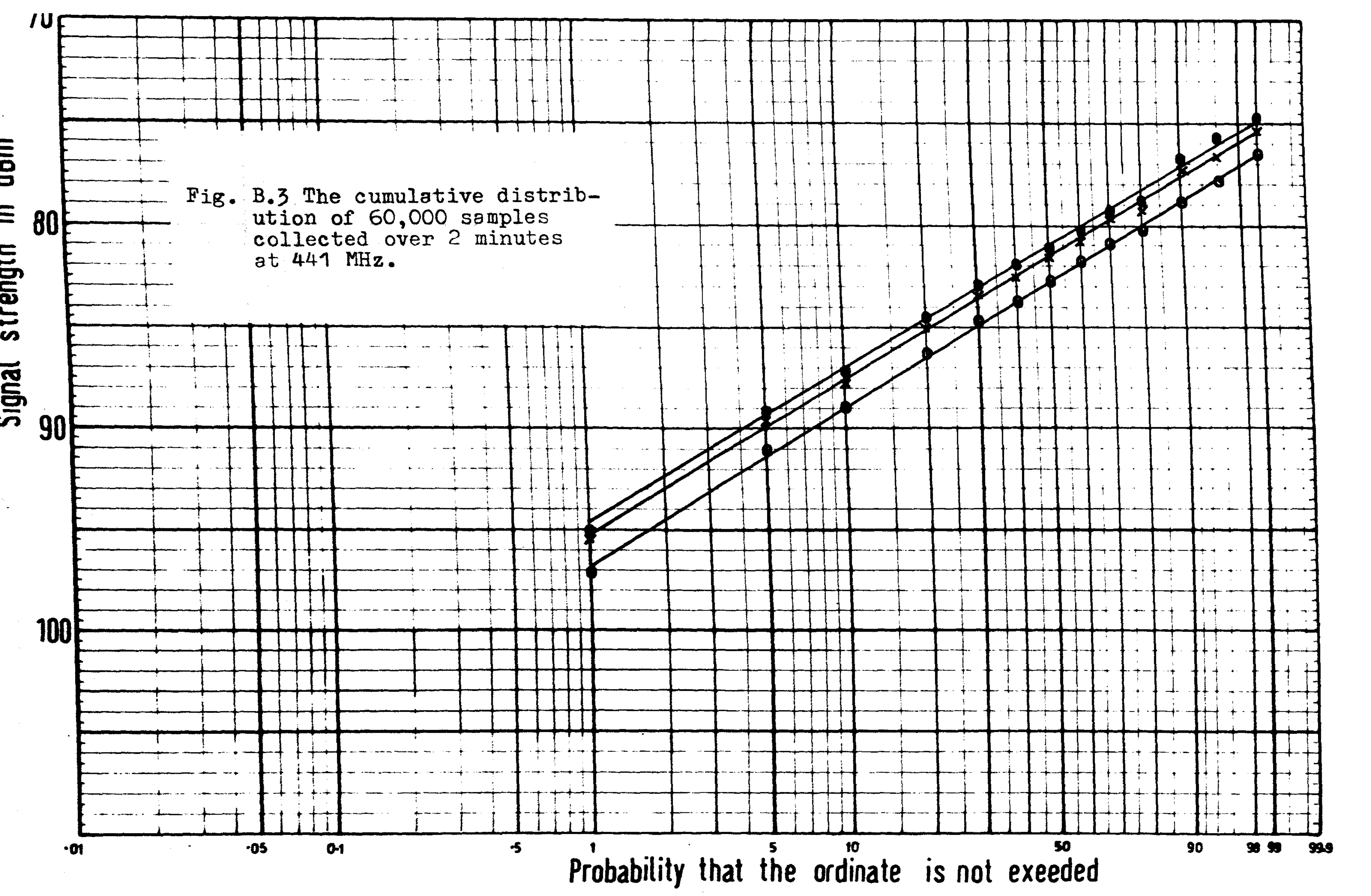

Fig. B.3 The cumulative distribution of 60,000 samples collected over 2 minutes at 441 MHz.