

REPORT 304-3*

FADING CHARACTERISTICS FOR SOUND BROADCASTING IN THE TROPICAL ZONE

(Question 45/10, Study Programme 45B/10)

(1956-1959-1963-1978-1986-1990)

1. Introduction

The fluctuations of the received signal in time, space and frequency which occur as random short-period variations, irregular long-period variations and more or less regular variations, are collectively described as "fading". To plan sound broadcasting services, it is necessary to have precise information on the types and characteristics of fading that may be expected to be encountered in the received signal.

2. Types of fading

Fading may be caused by various effects of ionospheric phenomena. Depending on the cause, the different types of fading, in general, may fall into the following principal classes.

2.1 Interference fading

Interference fading results from interference between two or more waves which travel by different paths to arrive at the receiving point. This type of fading may be caused by:

- interference between sky wave and ground wave;
- interference between multiple reflected sky waves;
- interference between the two oppositely polarized magneto-ionic components – the ordinary and the extraordinary waves;
- interference between various wavelets diffractively scattered from different scattering centres, caused by the steady horizontal drift of the irregularities present in the ionosphere or by their random movement or both.

Interference fading may last for a period of a fraction of a second to a few seconds, during which time the resultant field intensity may vary over wide limits.

2.2 Polarization fading

Polarization fading occurs as a result of changes in the direction of polarization of the downcoming wave, relative to the orientation of the receiving antenna, due to random fluctuations in the electron density along the path of propagation.

Like interference fading, polarization fading also lasts for a period of a fraction of a second to a few seconds.

- The attention of Study Group 6 is drawn to this Report.

2.3 *Absorption fading*

Absorption fading is caused by variation in the absorption of radiowave propagated through the ionosphere due to changes in the densities of ionization and it usually lasts longer and sometimes may last even longer than one hour.

2.4 *Skip fading*

Skip fading may be observed at receiving locations near the skip distance at about sunrise and sunset, when, because of the instability of ionization density of ionosphere, MUF for a transmission path may oscillate around the actual frequency. The amplitude of the received signal may fall abruptly when the skip distance crosses over the receiving point and may suddenly increase with the decrease in the skip distance, thus causing fading.

2.5 *Selective fading*

In general, fading is faster at high frequencies than at low frequencies, because for given movement in the ionosphere, there is a greater phase-shift on the shorter wavelengths either on reflection or on scattering from irregularities. Sometimes on a modulated carrier, the frequency components in the sidebands fade differently and independently, giving rise to distortion of the modulation envelope. This is called "selective fading".

In general, all the above types of fading are encountered in the Tropical Zone. However, some special types of fading observed only in the Tropical Zone and at low magnetic latitudes are discussed in § 4.

3. *Character of fading*

The terms "severity" and "rapidity" of fading refer to the characteristics of the variation of the amplitude of the received signal.

3.1 *Severity of fading*

Severity or depth of fading is measured by the amplitude distribution or probability distribution function.

3.1.1 *Analysis of severity of fading*

In a fading curve, i.e. the variation in the received signal versus time, if R is the amplitude of the downcoming wave at any instant t , and dR represents a slight change in R in the time interval $(t + dt)$, the probability of finding the amplitude between the limits R and $(R + dR)$ is $P(R) dR$, $P(R)$ being the probability density function of R .

Probability density functions, computed analytically to describe the envelope of a fading signal, differ in form and depend upon the mechanism of fading of the received signal. Depending upon the amplitude and phase of the signals which form the resultant descending wave, the amplitude distributions normally observed conform in general to the following three standard statistical curves:

- Rayleigh distribution,
- normal or Gaussian distribution,
- log-normal distribution.

3.1.1.1 *Rayleigh distribution*

If the downcoming wave consists of a large number of waves scattered from the irregularities and moving in a random manner, the resultant amplitude of the signal at any instant will be the vector sum of the scattered waves each having a random phase. The probability distribution of the resultant amplitude R of the envelope will then be represented by a Rayleigh distribution.

$$P(R) = (R/\psi) \exp(-R^2/2\psi) \quad (1)$$

where,

R : amplitude at any instant,

ψ : density in the power spectrum and a parameter related to the average value $\bar{R}$, the r.m.s. value R_0 and the most probable value R_m as follows:

$$\bar{R} = \sqrt{\pi\psi/2}, R_0 = \sqrt{2\psi}, R_m = \sqrt{\psi}$$

It is sometimes convenient to evaluate ψ from the plot of $\log [P(R)/R]$ as a function of R^2 . The corresponding log plot is a straight line, the slope of which is $\psi/2$ and the intercept $\log (1/\psi)$.

Fig. 1(a) shows the Rayleigh type of probability density function of amplitude R , and Fig. 1(b), shows the corresponding plot of $\log [P(R)/R]$ against R^2 .

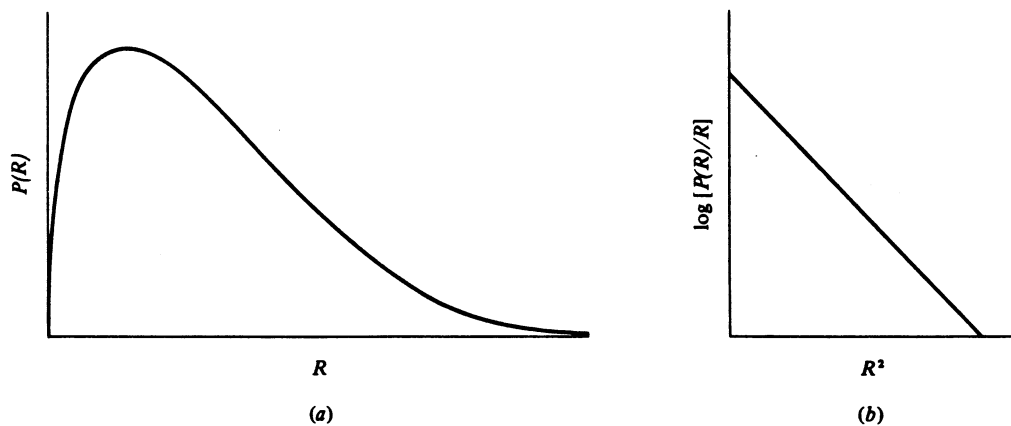


FIGURE 1

3.1.1.2 Normal or Gaussian distribution

The normal distribution is represented by:

$$P(R) = \left(1/\sigma \sqrt{2\pi}\right) \exp \left[-\frac{1}{2} \left(\frac{R - R_M}{\sigma} \right)^2 \right] \quad (2)$$

where σ is the standard deviation in Gaussian distribution and R_M is the median value of R .

The normal distribution is usually observed when the downcoming wave consists of a random component and a steady component because of specular reflection in the ionosphere. The contribution due to the specular component is of a considerable amount in comparison with the random one.

Fig. 2 shows the probability density function following a normal or Gaussian distribution:

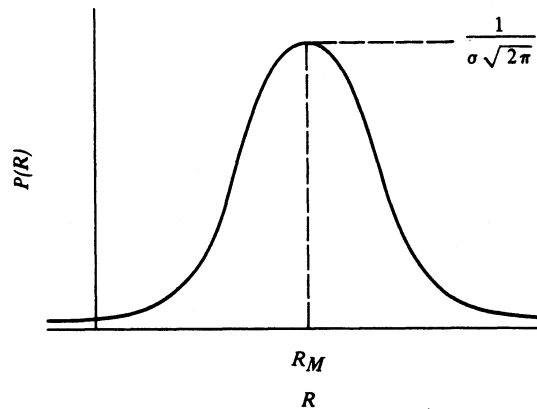


FIGURE 2

3.1.1.3 Log-normal distribution

The amplitude density function of fading records representing a log-normal distribution is given by:

$$P(x) = (1/\sigma_x \sqrt{2\pi}) \exp(-x^2/2\sigma_x^2) \quad (3)$$

where,

$$x = 20 \log(R/R_M)$$

R_M is the median value of the amplitude R . In this case the field strength measured logarithmically is distributed normally. Fig. 3 gives a typical log-normal distribution curve.

3.1.1.4 A general formula for intensity distribution

For a general form of fading, the signal at the receiving point may be assumed to be composed of a steady sinusoidal component and a random fluctuating component. This leads to a probability density function described by several workers [Nakagami, 1943; McNicol, 1949; Nakagami, 1960].

In this case, following work of Rice [1944-1945], the probability density of the resultant amplitude Q of the envelope may be expressed as:

$$P(Q) = (Q/\psi) \exp[(-Q^2 + B^2)/2\psi] I_0(QB/\psi) \quad (4)$$

where,

I_0 : is the Bessel function of zero order and imaginary argument;

B : is the amplitude of the steady signal;

ψ : is related to the amplitude of the random fluctuating component in the following manner:

$$\psi = R_0^2/2 \text{ or } R_m^2$$

where,

R_0 : is the r.m.s. value;

R_m : is the most probable value of the random component.

In general $\overline{Q^2} = B^2 + 2\psi$.

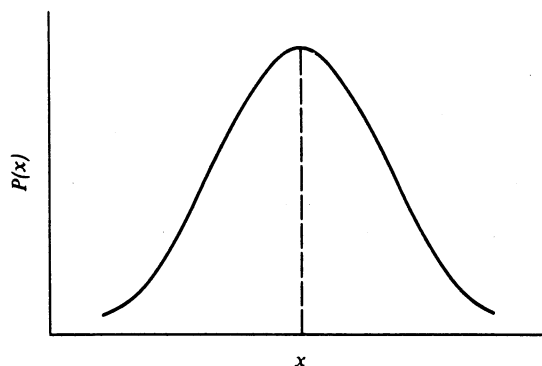


FIGURE 3

Fig. 4 describes the general behaviour of $P(Q)$ in terms of b , where $b = B/\sqrt{\psi}$, a ratio of the amplitude of the steady signal and the most probable value of the random signal.

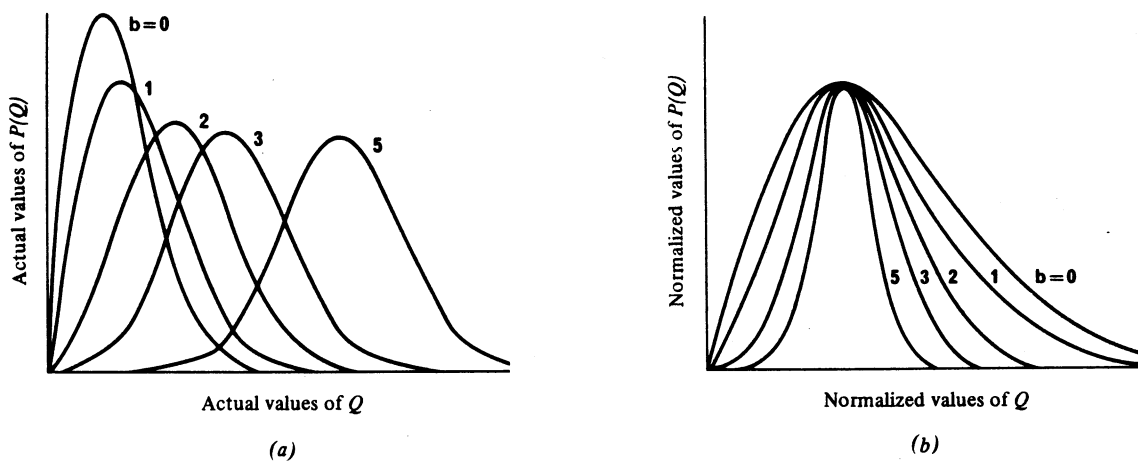


FIGURE 4 – Probability densities of the amplitude Q of a steady signal plus a random signal

(a) Actual curves

(b) Normalized curves

If $b < 1$, then equation (4) reduces to:

$$P(Q) \approx (2Q/R_0^2) \exp(-Q^2/R_0^2) \quad (5)$$

which approximates to a Rayleigh distribution.

If $b > 3$,

$$P(Q) \approx (1/\sqrt{2\pi\psi}) \times \sqrt{Q/B} \times \exp [-(Q-B)^2/2\psi] \quad (6)$$

The distribution is Gaussian, with a standard deviation of $\sqrt{\psi}$.

McNicol [1949] has shown that (6) can be rewritten in the form:

$$P(Q) = (1/\sqrt{2\pi\psi}) \times \exp [-(Q-Q_m)^2/2\psi] \quad (7)$$

within an accuracy of 1%;

where,

$$Q_m = \sqrt{\psi(b^2 + 1)}$$

A plot of $\log P(Q)$ as a function of $(Q - Q_m)^2$ gives a straight line, the slope of which is $1/2\psi$ as shown in Fig. 5. Knowing ψ and Q_m (from the distribution curve) one can evaluate b , which represents the relative proportion between the steady and the random signals in the received wave.

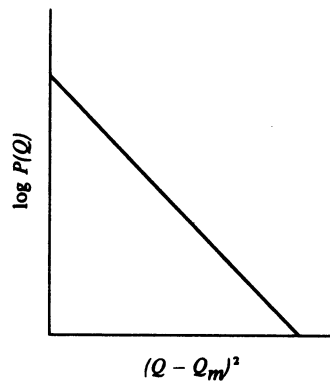


FIGURE 5

In addition to the above probability density functions, another distribution, “ m -type” may also occasionally be encountered.

The functional form of the m -distribution by Nakagami [1960] as:

$$P(R) = \frac{2m^m R^{2m-1}}{\Gamma(m) \Omega^m} \exp -(m/\Omega) R^2 \quad (8)$$

where, $\Omega = \overline{R^2}$ (time average of R^2)

and

$$m = (\overline{R^2})^2 / (\overline{R^4} - \overline{R^2}^2) \geq 0.5$$

always, that is the inverse of the normalized variance of R^2 .

Fig. 6 shows an m -type amplitude distribution.

Quantitative estimates of the severity of fading which can be obtained from the statistical distributions of the received signal are dealt with in § 5.