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.

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

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.

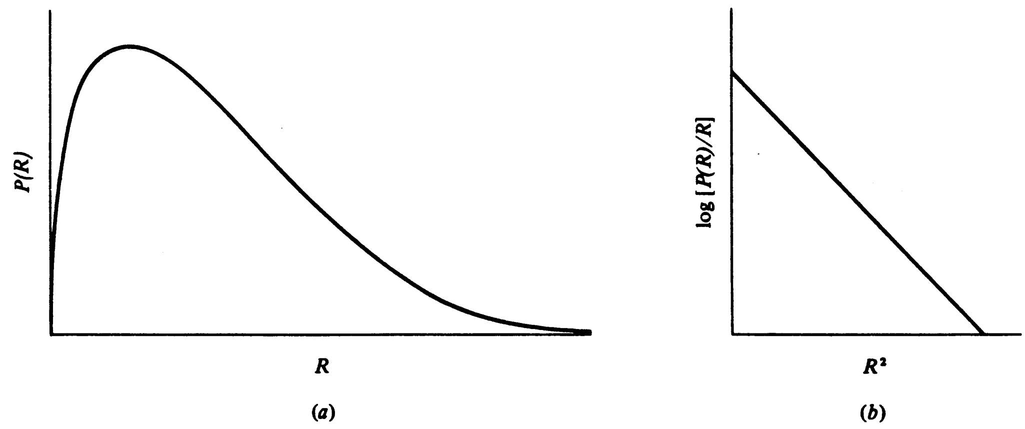

FIGURE 1

3.1.1.2 *Normal or Gaussian distribution*

The normal distribution is represented by:

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

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:

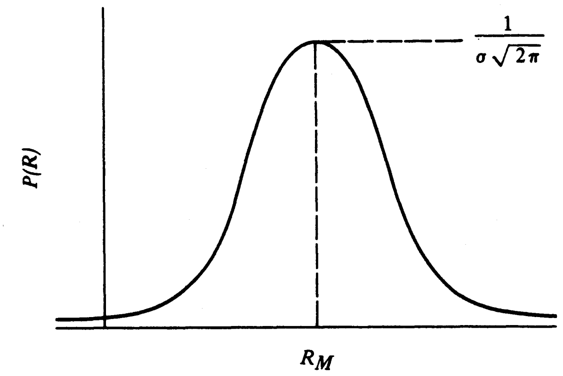

FIGURE 2

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

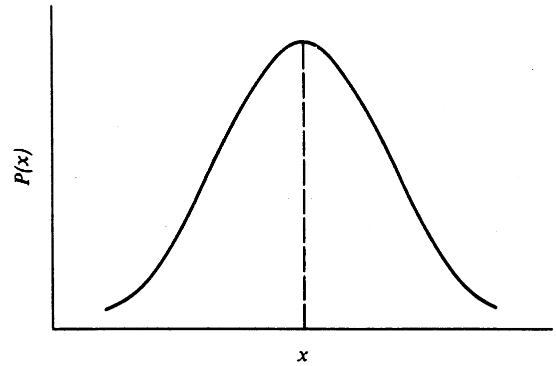

FIGURE 3

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.

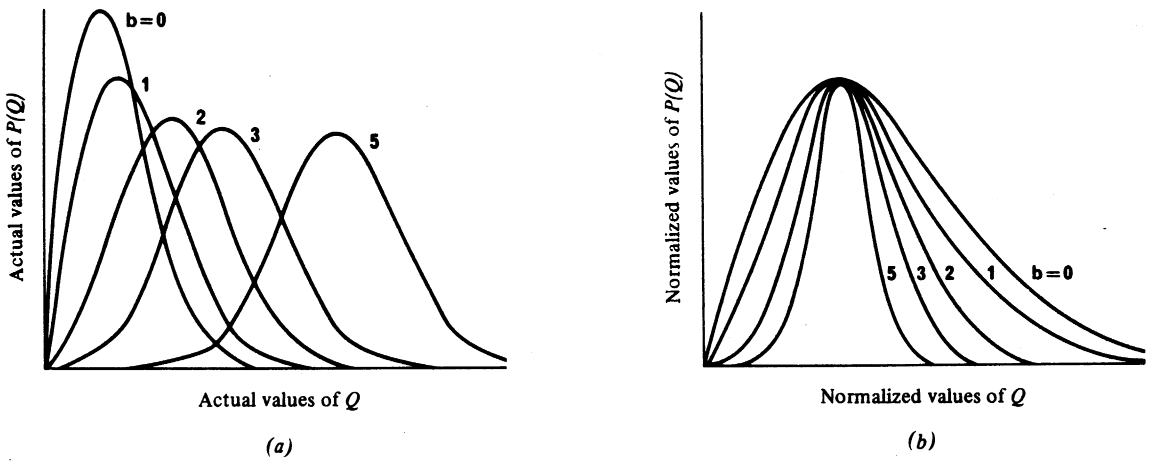

FIGURE 4 – *Probability densities of the amplitude Q of a steady signal plus a random signal*

(a) Actual curves

(b) Normalized curves

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

$$P(Q) \approx (2Q/R_0^2)\exp(-Q^2/R_0^2) \tag{5}$$

which approximates to a Rayleigh distribution.

If $b > 3$,

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

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

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

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

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 $\frac{1}{2}\psi$ 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.

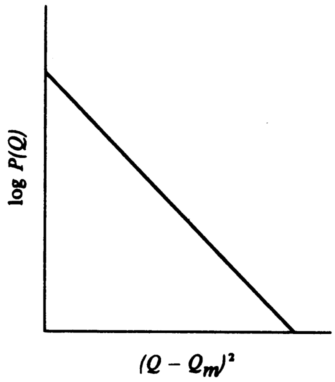

FIGURE 5

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:

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

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

and

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

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.

3.1.2 *Experimentally observed amplitude distribution*

Measurements on fading on transmissions in several areas in the Tropical Zone at different times of the day and at various distances from the transmitters have been reported in CCIR documents.

FIGURE 6

The fading records obtained at Barbados, Trinidad, Ghana, Singapore and Johannesburg by the Administration of the United Kingdom [CCIR 1959b; 1962b] agree fairly closely with the Rayleigh type of distribution for ranges between 0 and 350 km. However, for ranges exceeding 350 km, considerable departure from a Rayleigh type of distribution has been observed.

Measurements on the fading of CW transmissions at oblique incidence on 4.7, 9 and 15 MHz bands and on pulsed transmissions on the equivalent vertical incidence frequency were carried out by All India Radio. The distributions observed from the analysis of the fading curves were found to be Rayleigh, normal or log-normal [CCIR, 1959a].

Apart from the usually observed distribution of fading signal i.e. Rayleigh, normal or log-normal, *m*-type probability distribution was also reported in India [Das Gupta and Vij, 1960; Khastagir *et al.*, 1968; Srivastava *et al.*, 1972].

3.2 *Rapidity of fading*

The rapidity or speed of fading can be characterized in different ways [Fürth and MacDonald, 1947; McNicol, 1949; Booker *et al.*, 1950; Rice, 1958]. The various forms, characterizing the rapidity of fading, are discussed below.

3.2.1 *Analysis of rapidity of fading*

An important statistical property of the instant-to-instant variation of amplitude is given by the autocorrelation function. The rapidity or the speed of fading can be described in terms of the time auto-correlation function of the amplitude or in terms of the power spectrum of fading, which is the Fourier transform of the auto-correlation function.

If $A(t)$ represents the amplitude as a function of time, such that the average value is constant over the interval t to $t + \tau$, then the auto-correlation function $\rho(\tau)$ is defined by:

$$\rho(\tau) = \frac{1}{\tau} \int_{t}^{t+\tau} A(t) \cdot A(t+\tau) \cdot \mathrm{d}t \qquad (9)$$

If f represents the fading frequency and $F(f)$ is the Fourier transform of $A(t)$, i.e.

$$F(f) = \frac{1}{2\pi} \int_{-\infty}^{\infty} A(t) \cdot \exp(-i\omega t)\, dt$$

then the power spectrum $W(f)$ of the fading signal is given by $W(f) = |F(f)|^2$ which is proportional to $\int \rho(\tau) \exp(-i\omega\tau) d\tau$, the Fourier transform of $\rho(\tau)$.

Hence the frequency spectrum of the fading signal may be obtained with the aid of the auto-correlation function. The width of the fading power spectrum is related to the speed of fading.

Assuming that fading is produced by diffractive scattering from a large number of ionospheric irregularities and the scattered wavelets, having random amplitudes and phases, combined at the ground to give a resultant signal at any instant; [Booker *et al.*, 1950] have shown that the auto-correlation function $\rho R(\tau)$ of the amplitude R of the received fluctuating signal is proportional to:

$$\exp\left[(-16\pi^2 v_0^2 \tau^2)/\lambda^2\right] \tag{10}$$

where v_0 is the r.m.s. velocity of the irregularities in the line of sight.

The auto-correlation function falls to e^{-1} after a time $\tau = \lambda/4\pi v_0$ which can conveniently be called "fading time", since it will, on the average, represent the time which must elapse before the received signal has altered appreciably.

For oblique incidence,

$$\rho R(\tau) = \text{const.} \exp\left[(-16\pi^2 v_0^2\, \tau^2 \cos^2\varphi)/\lambda^2\right] \tag{11}$$

where φ is the angle of incidence of the radiowave to the ionosphere.

Whenever fading is random, the amplitude distribution is Rayleigh type and the auto-correlogram is a smooth curve having an exponential decrease. If however, the fading is not absolutely random, but has a tendency towards periodicity, the auto-correlogram will show a number of maxima and minima. The corresponding amplitude distribution is often a Gaussian curve [CCIR, 1959a].

Figs. 7(*a*) and 7(*b*) show the auto-correlograms for two types of fading curves.

Other forms used for characterizing the rapidity of fading do not represent as complete a description of fading as auto-correlation functions, but nevertheless they also provide useful information concerning fading rates, as discussed below.

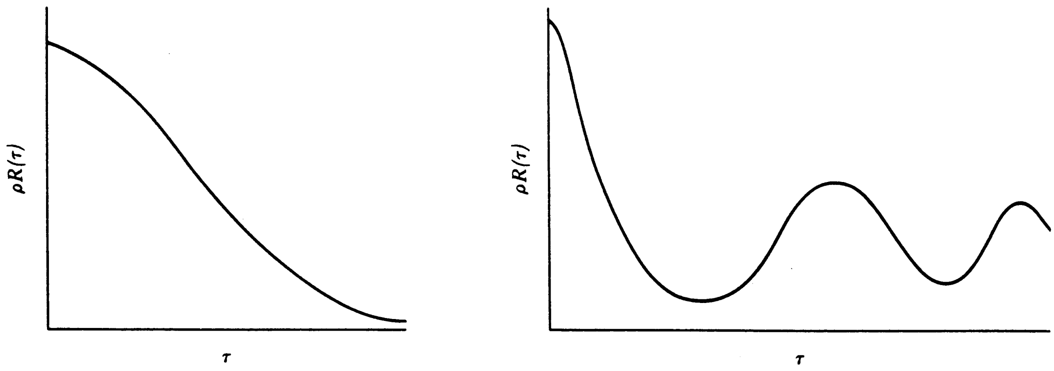

FIGURE 7

(a) Auto-correlogram for a Rayleigh type of fading

(b) Auto-correlogram for Gaussian type of fading

Following the work of [Fürth and MacDonald, 1947] on noise, speed of fading may be obtained by analysing successive differences of amplitudes of signals in the fading curve. They have shown from an extension of Rice's theory on random noise that, in the case of Rayleigh amplitude distribution, the probability distribution of v_τ, the successive difference between two amplitudes ($R_2 - R_1$) within a small interval of time τ, is given by:

$$\rho v_\tau \mathrm{d} v_\tau = (1/\pi) \exp(-x^2) \, \mathrm{d}x \qquad (12)$$

where,

$$x = v_\tau / (2\pi\sigma\tau\sqrt{2\psi})$$

and the power spectrum is Gaussian with standard deviation σ.

The power spectrum $W(f)$ is given by:

$$W(f) = (\psi/\sigma\sqrt{2\pi}) \exp[-(f - f_0)^2/2\sigma^2] \qquad (13)$$

where $\psi = \int_0^\infty W(f) \, \mathrm{d}f$ is the total energy in the power spectrum.

A similar expression may be derived in the case of a randomly fading signal. In that case, f_0 is the incident wave frequency and f is the Doppler shifted frequency of the reflected wave from the moving irregularities.

The average value of $| v_\tau |$ is defined by:

$$|\bar{v}_\tau| = 2 \int_{-\infty}^{\infty} v_\tau \cdot \rho v_\tau \cdot \mathrm{d} v_\tau$$

From (12) and (13) above, we get:

$$| \bar{v}_\tau | = 2 \sqrt{2\pi\psi} \cdot \sigma\tau$$

$$| \bar{v}_\tau / \tau | = \sqrt{2\pi\psi} \cdot 2\sigma$$

$| \bar{v}_\tau / \tau |$ is called the "speed of fading".

A simple form of defining fading rate is the number of positive crossings per unit time through any specified level. The number of maxima, N, of the amplitude of the received signal envelope per unit time may be used as a measure of the rapidity of fading. Rice has shown that if σ is the standard deviation of the power spectrum of the received signal, then $N = 2.52\sigma$.

The rapidity of fading may also be calculated from the derivative of the amplitude of the received signal and is given by $|\,d\overline{R}/dt\,|/\overline{R}$, where R is the instantaneous amplitude of the received signal.

3.2.2 *Some measured values of fading rates*

A few typical values of the fading rate measured in the Tropical Zone are given below:

In [CCIR, 1959a], India reported a fading rate of 11.9 fades per minute on an average, while the fading rate in general is observed to vary between 4 and 16 per minute.

Average fading frequency taken on 2.3 MHz in the E-region during daytime and night-time was found to be 10.96 cycles/min (0.183 Hz) and 14.002 cycles/min (0.233 Hz). In the case of F2 region, average fading frequency taken on 5.6 MHz during daytime and night-time was observed to be 11.22 cycles/min (0.187 Hz) and 8.37 cycles/min (0.14 Hz) respectively [Rao and Rao, 1967].

Increased rate of fading is observed almost throughout the Tropical Zone after sunset. The Administration of the United Kingdom reported this phenomenon through [CCIR, 1959b]. Typical value of the rapidity of fading is 10 Hz at 15 MHz [Davies and Barghausen, 1967]. Rapid fading rates up to 15 Hz were noticed by [McNamara, 1971].

The fading rate of signals reflected from the Es layer is found to be more than that from the normal E or F region. Rates of 0.2 to 5 Hz are typical [Rastogi *et al.*, 1966; Skinner and Wright, 1962].

[Skinner and Wright, 1962] found that, for the equatorial q-type Es, the fading rates are of the order of 4 Hz and the fading rate increases almost linearly with increasing wave frequency. For the blanketing type of Es, fading rates are much smaller than those of the q-type Es and are of the order of 0.8 Hz.

Observations in India at Thumba on the magnetic equator have shown that the speed of fading of the radiowaves reflected from the Es layer, has a strong diurnal variation, being very rapid in the early morning and evening hours and very slow at midday [Rastogi *et al.*, 1966].

4. Features of fading specially encountered in the Tropical Zone

Fading of signals in the tropical regions at low geomagnetic latitudes has some special characteristics due to:

- a particular type of sporadic E layer associated with the equatorial electrojet, which is a regular daytime occurrence;
- irregularities present in the night-time F layer, often mentioned as spread F.

4.1 *Fading due to sporadic E*

Fading observed during daytime in the equatorial zone is very often attributed to sporadic E. An analysis carried out by All India Radio [CCIR, 1962a] shows that sporadic E is one of the causes of the day-to-day fluctuations of signals.

4.1.1 *The characteristics of sporadic E in the Tropical Zone*

In the Tropical Zone, depending on the latitude, two types of sporadic E are usually prevalent:

- temperate zone sporadic E;
- equatorial zone sporadic E.

Temperate zone sporadic E observed at middle latitudes is predominantly a summer-time phenomenon occurring both by day and night and more intensely by day. In a narrow zone near the magnetic equator (± 6° magnetic dip), a special type of highly transparent sporadic E called equatorial sporadic E or Es-q appears regularly during daytime [Matsushita, 1962; Knecht and McDuffie, 1962]. It is observed that there is a narrower zone right at the dip equator, where the blanketing type of sporadic E is usually absent [Knecht and McDuffie, 1962; Cohen *et al.*, 1962].

But [Oyinloye, 1971] suggests that blanketing Es would sometimes occur over the dip and geomagnetic equator.

4.1.2 *Observed effects on fading due to sporadic E*

The fading characteristics of radiowaves reflected from Es layers studied by different workers indicate different results.

Some of the characteristics of echoes from the two principal daytime types of Es at Ibadan (Geomag. Lat. 10.6° N), Nigeria, have been investigated by means of vertical incidence pulsed transmissions in the frequency range 4 to 8 MHz. It has been observed that for the higher frequencies in the frequency range 4.3 to 8.5 MHz, the signal reflected from q-type Es is almost randomly phased with Rayleigh amplitude distribution, whereas at the lower frequencies near 4.5 MHz, amplitude distribution follows Rice function. Rayleigh type amplitude distribution is observed from the fading records at 5.7 and 7.5 MHz from the blanketing type of Es observed at midday at Ibadan [Skinner and Wright, 1962].

It is observed at Tirupati (Geomag. Lat. 3°45′ N) in India, that at times well before ground sunrise, the amplitude distribution of the echoes from sporadic E fitted most closely with the Rayleigh function, whereas just before ground sunrise and during the day, the amplitude distribution followed Gaussian or Nakagami-Rice functions [Venkateswarlu and Ramu, 1964]. However, observation at Thumba, situated at the magnetic equator, has shown that the probability distribution of the amplitude of signal strength does not fit with the theoretical Rayleigh or Gaussian distribution [Rastogi *et al.*, 1966]. Analysis of fading records at Calcutta (Geomag. Lat. 12.3° N) shows that the statistical distributions of amplitude are both Rayleigh and Nakagami-Rice types at noon, whereas during morning, evening and early night, other types of amplitude distribution – very often double-peaked or m-type have been observed [Ganguly and Samanta, 1967].

§ 3.2.2 may be referred to for the fading rates on high frequency signals reflected from the Es region.

4.2 *Fading due to F-region irregularities (flutter fading)*

A peculiar type of very rapid fading has been observed in the equatorial region after sunset. This is called flutter fading, the cause of which is attributed to F-region irregularities commonly known as spread F.

4.2.1 *Characteristics of F-region irregularities of spread F in the Tropical Zone*

In the equatorial zone after sunset, irregularities develop in the F-region ionization inside a belt extending approximately between geomagnetic latitudes of 30° N and 30° S. Its occurrence is high within ± 20° geomagnetic latitude. It is seen that just after local sunset the F-region over the equatorial belt exhibits a marked increase in height and seems to break up progressively into patchy regions or irregularities in patches, generally known as spread F [Lyon *et al.*, 1961]. The characteristics of equatorial spread F have been studied by many workers in the past few years [Osborne, 1952; Bhargava, 1958; Shimazaki, 1959; Lyon *et al.*, 1960; Rangaswamy and Kapasi, 1963; Krishnamurthy, 1966; Rao, B.C.N., 1966; King, 1970; Davies, 1972; Bowman, 1975; Röttger, 1976]. The main features are as follows:

The presence of the irregularities in the F region is manifested by echoes whose range has been spread in the ionograms and they are classified as either range spread or frequency spread echoes. The range spread echo which is due to equatorial type spread F observed after sunset is seen to influence HF propagation. The irregularities are known to be magnetically field-aligned [Cohen and Bowles, 1961]. Recent observations have shown that both large-scale, non-field-aligned irregularities and small-scale field-aligned irregularities coexist in the F layer, when spread F is observed in the ionograms at equatorial latitudes [Bates, 1971; Cole and McNamara, 1975; Röttger, 1976].

The diurnal variation of range spread F is controlled by the sunset and the range spread F irregularities are seen normally after sunset and before midnight.

The seasonal variations show maxima of range spread F at the equinoxes. A longitudinal anomaly is seen in this case. Significant differences exist between the Far Eastern and American Equatorial region in the seasonal behaviour of spread F [Singleton, 1960].

The range spread F occurrence is positively correlated with sunspot number and indicates a negative correlation with magnetic activity [Huang, 1970].

Various workers have observed the same characteristics of range spread F as for equatorial flutter fading. Their observations are discussed in the next section.

4.2.2 *Experimental observations on flutter fading due to spread F in the Tropical Zone*

Flutter fading has been observed in India on All India Radio shortwave regional broadcast transmissions, ever since they were introduced in 1938. It was found that while flutter fading was very intense and annoying on shortwave transmissions from AIR Madras (Geomag. Lat. 3°05′ N) and Radio Ceylon, (Geomag. lat. 3°38′ S), it was considerably less on SW transmissions from AIR Bombay (Geomag. lat. 10°00′ N) and almost absent on transmissions from AIR Delhi (Geomag. lat. 19°11′ N). This indicates that flutter occurs nearer the geomagnetic equator. [Subba Rao and Somayajulu, 1949] called attention to the occurrence of equatorial flutter fading while studying field-strength variations of broadcasting stations of AIR in the 41 and 60 metre bands at Waltair in India. [Osborne, 1952] mentioned intolerable fading of ionospheric reflections at nearly vertical incidence associated with HF broadcast transmissions near the magnetic equator. [Yeh and Villard, 1958] have also described a high frequency fluctuation (up to 40 Hz) of signals observed at Stanford on BBC transmissions in the 9 and 21 MHz bands from Singapore, propagated on paths crossing the equator. They termed this phenomenon as "Doppler Fading". During the month of August 1957 they noticed this fading almost daily in the case of Singapore, but only sporadically from the transmissions in the same frequency range from Australia to Peking and to Buenos Aires. [Humby, 1959] reported similar behaviour of transequatorial Admiralty circuits from England to Colombo and England to Singapore during the period 1947 to 1958. [Chaman Lal, 1960] also reported rapid type of fading which is seen to be particularly pronounced in equatorial Southern India at Madras, Tiruchirapalli and Trivandrum. A rather similar observation was published by [Bennington, 1960] on the reception of United Kingdom transmissions in Johannesburg (South Africa) and Singapore during the period 1954 to 1958. Sunset fading effect on flutter fading has been investigated in Ghana since 1958. [Koster, 1963] gave a detailed analysis of the flutter fading observed on BBC (15.07 MHz) broadcasts to West Africa and Accra and on a broadcast signal locally originating from Accra on 5 MHz at Kumasi (270 km north-west of Accra). [Davies and Barghausen, 1967] recorded the effects of equatorial spread F on 5 paths in Africa near the magnetic equator, and observed flutter fading on the equatorial path. [McNamara, 1971] observed the evening type transequatorial propagation with deep flutter fading of the order of 5 to 15 Hz on the circuits between Okinawa and Yamagawa (Japan) and Townsville (Australia). The results of a study of night-time records of the field strength of radio signals on 11.8 MHz transmitted from Colombo and received at Ahmedabad indicate the presence of flutter fading [Chippa and Patel, 1973]. [Cole and McNamara, 1975] enumerated the effect of spread F on equatorial propagation. [Röttger, 1976] also observed flutter fading on transequatorial circuits between Lindau (Federal Republic of Germany) and Tsumeb (Republic of South Africa).

4.2.3 *Characteristics of flutter fading*

Based on the above observations, the characteristics of flutter fading are summarized below.

4.2.3.1 *Geographical extent*

Equatorial flutter fading appears to be most serious within a geographical area between ± 20° geomagnetic latitude. Both the north-south circuits and east-west circuits are affected by this flutter fading.

4.2.3.2 *The diurnal variation of flutter fading*

Flutter fading is normally observed only between evening and midnight, starting almost always around sunset and continuing for three to four hours thereafter. It is found to be most intense within two hours of local sunset at the point where the propagation path crosses the magnetic equator. The time of start is quite well-defined and sudden, but the time of disappearance is rather gradual. The fades are very deep and the signal is almost completely drowned into noise, even though the mean signal strength remains high [Koster, 1963].

4.2.3.3 *Seasonal variation of flutter fading*

Seasonally, the phenomenon of post sunset flutter fading has been observed to be more pronounced during equinoctial months as compared to the other seasons of the year. It has been noted that definite maximum occurs during the two equinoctial periods well after the true equinox. The autumnal equinox shows significantly more flutter fading than the vernal equinox. The comparatively rapid falling-off of the phenomenon as the sunspot cycle approaches minimum is also observed [Koster, 1963].

4.2.3.4 *Solar-cycle-dependence of flutter fading*

Observations of [Osborne, 1951, 1952; Humby, 1959; Koster, 1963] tend to confirm that there is a positive correlation between mean sunspot number and amount of flutter fading. Equatorial flutter fading is most serious during sunspot maximum and becomes almost negligible during periods of sunspot minimum.

4.2.3.5 *Fading rates at various frequencies*

The observed fading rates are different for different wave frequencies. [Koster, 1963] analyzed fading on signals received in Ghana from London at frequencies approximately 7, 12, 15 and 21 MHz and concluded that the flutter fading rate was directly proportional to the wave-frequency. [Chaman Lal, 1960] also remarked that flutter increased with increase in operational frequency. Observations by [Cohen and Bowles, 1961] had shown that the effects of spread F on signals over transequatorial paths varied with frequency. [Davies and Barghausen, 1967] observed that the fading rate varied over a wide range, but a value of 10 fades per second was typical at a frequency of 15 MHz. A comparison of fading rates of signals at 10.1 and 20.2 MHz, observed over the same path from Monrovia to Accra, showed that the fading rates at 10 MHz were five to seven times faster than those at 20 MHz. This is, however, contrary to the observations of Koster and Chaman Lal, as mentioned above. [McNamara, 1971] observed the evening type transequatorial propagation (TEP) which had a high correlation with spread F with fading rates up to 15 Hz. Fading rates of transequatorial HF signals have been evaluated from observations on the paths Lindau to Rome and Tsumeb to Lindau which cross the equatorial zone of Africa [Carman *et al.*, 1974] and have been found to vary between 50 and 180 maxima per minute.

4.2.3.6 *Doppler fading*

Doppler fading of signals propagated on paths crossing the Equator noticed by [Yeh and Villard, 1958], has been observed by others also. [Calvert *et al.*, 1962], while measuring Doppler shifts of signals propagated from Tripoli to Accra, found that in the evening hours the spread in Doppler spectrum was of the order of 10 to 15 Hz. The systematic movement of a group of irregularities results in Doppler shift of the transmitted frequency up to 30 Hz at 20 MHz, while random motion of individual irregularities leads to Doppler spreading up to about 20 Hz [Bradley *et al.*, 1972]. [McNamara, 1975] also observed the evening type TEP with Doppler shift that sometimes exceed 40 Hz.

4.2.3.7 *Flutter fading and magnetic activity*

Flutter fading correlates negatively with magnetic activity [Wright *et al.*, 1956, Shimazaki, 1959; Briggs, 1965; Davies and Barghausen, 1966]. On quiet days flutter fading is noticed appreciably, whereas on magnetically disturbed days, flutter fading is absent [Chippa and Patel, 1973].

4.2.3.8 *Flutter fading and radio star scintillation*

In the equatorial region, observations of scintillation have been made at Accra in Ghana, at Ibadan in Nigeria and at Kodaikanal in South India. The temporal, seasonal, solar cycle and geomagnetic activity variations of scintillation have been found to be similar to spread F and flutter fading.

Wright *et al.* [1956] pointed out the high correlation between the occurrence of flutter fading and radiostar scintillation. This was further confirmed by [Koster, 1963]. Radiostar scintillation also correlates negatively with magnetic acitivity.

[Kent, 1961] who conducted scintillation observations utilizing satellite signals, obtained similar results on scintillation correlation with spread F. [Bhargava, 1964] at Kodaikanal also found the same diurnal and solar cycle variation of scintillation but the maximum rate of scintillation was found to occur several hours before the maximum of spread F.

4.2.4 *Effect of flutter fading on broadcasting*

From the standpoint of degradation in communication circuits, flutter fading is one of the most important factors. It affects the overall merit of broadcast programmes to a considerable extent. Bennington [1960] indicates that, in the audio spectrum, voice is still somewhat intelligible in presence of flutter, whereas music becomes very disagreeable and jarring to listeners.

4.2.5 *Other types of fading observed in the Tropical Zone*

Another peculiar type of fading has been observed in India on the shortwave broadcast transmission of All India Radio. This type of fading, which is characterized by sudden and violent fluctuations of the received signal intensity, has been designated as "surge fading". As compared with flutter fading, "surge fading" is slower but a deeper form of fading accompanied by severe distortion. This peculiar type of fading gives the impression of the signal being received in powerful surges.

4.2.5.1 *Characteristics of surge fading*

Surge fading is experienced at its worst after sunset. Seasonally, surge fading has been noted to be more pronounced during winter and the equinoctial months preceding winter. With surge fading, the signal varies over a wide range of amplitude with a recurrence rate of a few surges per minute. Surge fading may be due to phase interference or polarization changes of the received signal. The cause for this type of occurrence is not clearly known.

5. Fading allowances to be provided for planning broadcasting services in the Tropical Zone

Quantitative estimate of the fading range may be obtained from the statistical distribution of the signal, which can be characterized by indicating the levels exceeded for a number of specified time-percentages. The following Table I gives the levels for two time percentages derived theoretically from the distributions already discussed [Norton *et al.*, 1955].

TABLE I

Distribution	Level (dB) relative to median, exceeded for the following percentages of time	
	10%	90%
Rayleigh	5.21	– 8.18
Normal and log-normal (where σ is the standard deviation)	1.282 σ	– 1.282 σ

[CCIR, 1962a] serves as a preliminary basis for suggesting the values of fading allowances to be made for planning shortwave broadcasting services in the Tropical Zone. This document deals with two basic parameters associated with fading: the intensity fluctuation factor (IFF) and fading safety factor (FFS).

The intensity fluctuation factor, defined as the ratio (in dB) between the monthly median and the monthly lower decile values of the hourly-median field intensity, is considered to make allowance for day-to-day variations for 90% of the days. It is found that the values of IFF fluctuate widely between 1.0 dB and 15.4 dB, the overall average being 7.6 dB. The fading safety factor, defined as the ratio in (dB) between the median intensity of a received signal and the intensity exceeded 90% of the time, is estimated to make an allowance for instant-to-instant variation of the signal for 90% of time. The fading safety factor in summer varies from 2.4 to 27.0 dB, the most probable value being 11.2 dB and the corresponding figures for winter months are 1.6 to 14.4 and 7.0 dB respectively. The overall FSF is found to vary from 1.6 dB to 27.0 dB, the most probable value being 9.0 dB. The fading safety factor, calculated theoretically from the Rayleigh type of distribution which is predominant on short-term fading in the Tropical Zone, is 8.18 dB.

The overall fading allowance for planning may be obtained from the short-term and long-term fading allowance. Intensity fluctuation factor and fading safety factor, when referred to the received signal, take into account the variations of the wanted signal only. However, to arrive at the appropriate value of the fading allowance for planning any sound broadcasting service for a given service probability, it is important to take into account the character and variability of the interfering signal also. Considering this aspect, Recommendation 411 proposed certain values of fading allowance under three conditions of reception, as follows:

- radio frequency signal-to-interference ratio: 16 dB;
- wanted signal-to-atmospheric noise ratio: 17 dB;
- wanted signal-to-industrial noise ratio: 12 dB.

The above-recommended overall variability allowance must be made to ensure that the steady-state ratio is attained for 90% of the time.

There has not been any further documentation on this subject since the CCIR Recommendation 411 was adopted. However, it would appear that the due verification of this Recommendation for the Tropical Zone can be made only after further studies, especially, because it has been suggested that fading, referred to as instant-to-instant variations of field intensity, is more severe in the Tropical Zone than in the countries of the temperate zone [CCIR, 1962a].

Investigations in the USSR [CCIR, 1986-90] have shown that selective fading caused by multipath propagation of HF signals may give rise to distortions in the amplitude-frequency characteristic of the transmitted frequency spectrum. Additionally, with an envelope detector the occurrence of non-linear signal distortions is increased, and a deterioration in intelligibility occurs. The frequency at which the distortions occur and their duration are determined by the fading characteristics of the signal and their intensity is proportional to the signal modulation coefficient. Non-linear distortion may cause the level of the second harmonic of the signal to reach -12 dB with respect to the level of the sideband frequency.

Similar signal distortions may be observed in the case of the synchronized operation of two transmitters serving the same reception area even where no multipath propagation occurs.

6. Conclusion

In this Report, the nature, type and characteristics of fading encountered in the Tropical Zone have been discussed. Some of the special features of fading in the Tropical Zone for example flutter fading, surge fading and fading due to equatorial sporadic E, have also been described.

The fading records analysed by various workers in different parts of the Tropical Zone show different types of distribution such as, Rayleigh, normal, log-normal and *m*-type. An idea of the allowance for short-term and long-term fading may be obtained from the distribution curves.

Propagation in the equatorial belt is highly influenced by q-type sporadic E during daytime. The fading rate of the radiowave reflected from the Es layer is observed to be more than in case of normal E or F region.

Flutter fading is a typical evening time phenomenon and depends upon the geographical area, local time, season, sunspot number and magnetic activity. Equatorial flutter causes circuit degradation and affects the music transmission appreciably. Presence of irregularities in the lower part of F region appears to be the cause of flutter fading. Hence a shift to higher frequencies is recommended wherever possible in the HF band; at least to alleviate the deterioration of circuit performance in the presence of spread F. [Davies, 1972] provided a scheme of frequency usage, designed to minimize as far as possible, the adverse propagation effects of spread F.

"Surge" fading occurring in this zone reduces the satisfaction value of the programme considerably. This type of fading is slower but deeper in form accompanied by severe distortion. The causes that lead to surge fading are not yet firmly established. Since the information available at present is too meagre, further studies on surge fading appear to be necessary.

The fluctuations in the field strength which occur primarily in the HF broadcasting range due to interference and variations of absorption and polarization impair reception quality. These fading effects may be minimized by use of diversity systems. Depending upon the mechanism of propagation various diversity systems such as space diversity, frequency diversity and polarization diversity are in use. It may be mentioned that the use of space diversity or polarization diversity does not help much in reducing the degrading effects in reception when the fluctuation is very rapid (e.g. in "flutter" and "surge" fading). However, single-sideband reception may be used in minimizing the degrading effects of selective fading.

Sufficient data relating to the quantitative estimates of short-term and long-term fading in the Tropical Zone is not available. Further studies will have to be continued to arrive at specific values of fading allowances to be provided for planning sound broadcasting service. It would also be worthwhile to have detailed analysis of the fading characteristics on the types of fading especially those encountered in the Tropical Zone, and to make a study with a view to correlating the fading character and the fading allowance which should be provided to minimize annoyance to satisfactory listening.

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