Radioclimatological effects on correlation bandwidth of transhorizon microwave communication link

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Information can be sent effectively if enough bandwidth is provided in troposscatter microwave communication link. Correlation bandwidth of a system is related to the path delays due to the rays travelling through the two extremes of the scattering volume. The radioclimatology influences severely the correlation bandwidth of the transhorizon microwave communication links. The correlation bandwidth problem is found to be more when the atmospheric stability is of low order. The problem of correlation bandwidth is less over the Indian coast and moderate over the northern plains while it is severe over the desert. It is also observed that depending upon the effective earth's radius factor, there is a critical antenna diameter for a given frequency beyond which the correlation bandwidth problem disappears essentially. The increase in transmissible bandwidth is directly proportional to the antenna gain degradation in a system. It is needed to compromise for optimizing the above two parameters for a system.

1 Introduction
The multichannel FM/FDM troposscatter systems require coherent bandwidth of several mega hertz. The usable bandwidth is affected by the uncorrelated fading which is always present on transhorizon links.

The correlation bandwidth problem in troposscatter systems is a consequence of the scattered combinations from widely separated structures in the common volume arriving at the receiver with considerable delay time. This obviously depends on the antenna beamwidth (gain) and path distance.

The radioclimatology of a region also plays a dominant role in bandwidth considerations as illustrated in this paper. The demand for increased channel capability in troposscatter systems encourages us to make extensive studies on correlation bandwidth. Different definitions of mathematical correlation functions are used in different techniques to estimate correlation bandwidth. The correlation bandwidth is defined as the frequency spacing at which the correlation coefficient of the signal envelopes falls to $e^{-1} = 0.4$.

In this paper, we present the estimates of correlation bandwidth deduced under varied meteorological conditions over India. The correlation bandwidth problem is found to be more when the atmospheric stability is low and during this period the intermodulation problems also become severe since for significant percentage of time the correlation coefficient values of the signal envelopes are of low order.

2 Meteorological conditions over India
One of the prime parameters is the effective earth's radius factor $(K)$ which determines the radio horizon distance for a given set of receiving and transmitting antenna heights and controls the height of common volume in the troposscatter propagation. It is important to have the knowledge about the distribution of $K$ over regions where correlation bandwidth studies are to be done. The parameter $K$ exclusively depends upon the refractivity gradient and is expressed as

$$K = \frac{1}{1 + 10^{-6} a \frac{\Delta N}{\Delta H}}$$

where $a$ is the earth's radius and $\Delta N/\Delta H$ is the refractivity gradient in N units/km.

A typical diagram of the distribution of $K$ observed during May at 0000 GMT corresponding to early morning local time is presented in Fig. 1. In the premonsoon months, March to May, the highest mean value of $K$ is of the order of 4.3 over the coastal stations. The large gradients of refractivity are responsible for such high values of $K$ over the coastal stations compared to the inland plains. Over the plains, the mean value of $K$ is found to vary be-
Fig. 1—Distribution of mean effective earth's radius factor ($K$) observed in May during 0000 GMT over the Indian subcontinent. The value is more over the coastal stations and low over the desert. High lapse rate of humidity and temperature inversion due to nocturnal cooling are responsible for the occurrence of large values of $K$ over the Indian coast.

between 1.4 and 2.2 during premonsoon months while it is 1.4 to 1.8 during winter season. Over the desert area, where the microwave propagation is considered to be substandard, the annual mean $K$ is of the order of 1.62. The probability distribution of $K$'s observed over desert, northern plains and coast are presented in Fig. 2. It is shown in Fig. 2 that at 50% probability level the values of $K$ are 1.45, 1.6 and 1.95 over desert, northern plains, and coast respectively.

The importance of $K$ in correlation bandwidth estimation stems from the fact that a large $K$ value brings the common volume drastically down and consequently the path lengths from the extremities of the common volume have a smaller difference. The reverse happens with very low $K$ values when the bandwidth decreases rapidly. The large diurnal variability in meteorological parameters, viz. surface refractivity, refractivity gradient, $K$-factor, etc. in tropical regions result in large correlation bandwidth fluctuations. Figure 3 presents the variation of the surface refractivity in 24 h.

A brief survey of relevant models of Rice$^3$ and Sunde$^2$ is given in Sections 3 and 4.

3 Rice model$^3$

The time fluctuations are not taken into account when the transmitter frequency changes rapidly. In such a situation envelope of the signal wave received at some distance changes because of change in frequency. The correlation coefficient ($\rho_c$) between the two envelopes under that condition is given by Rice$^3$ as

$$\rho_c = \exp \left[ - \frac{(2 \pi \sigma_c f^2)^2}{f^2} \right]$$

where $f$ is the frequency separation and $\sigma_c$ is the multipath spread based on a geometrical analysis using the antenna upper and lower rays.

The angle between the two extreme rays corresponds to the half-power beamwidth, and the multipath spread is presented by Kennedy$^1$

$$\sigma_c = \frac{d \alpha \theta}{4 e^{\sqrt{3}}}$$
where $d$ is the path length, $a$ the beamwidth, $\theta$ the scattering angle, and $c$ the velocity of electromagnetic wave in vacuum.

### 4 Sunde model

The variations of signal amplitude with time ($t$) and frequency ($u$) causes change in autocorrelation function of $U(u,t)$ and $V(u,t)$. $U(u,t)$ is one of the two components of the signal. These are related to changes in the structure of the scattering volume. The rate at which the changes take place depends on the velocity and directions of winds and on meteorological variation in terms of temperature, humidity and pressure. Under these conditions the autocorrelation function will vary with time and frequency. For frequency correlation function, let us consider the variations in two components ($U$ and $V$) of the signal with frequency, $u$ at time $t$. At a different time, a different variation in $U$ and $V$ with $u$ will occur. The form of $U$ and $V$ suggests that if $u$ is regarded as a time variable and $\Delta$ as a frequency variable, then $U(u)$ would be the variation in time owing to impulses of amplitudes impinging at time intervals on a flat low pass filter of bandwidth $\Delta$. The autocorrelation function of components $U$ and $V$ for a difference $\nu = \omega_2 - \omega_1$ in frequency is

$$
\psi(\nu) = \psi(0) \left( \frac{\sin \nu \Delta}{\nu \Delta} \right)
$$

where $f$ is the frequency of the filter, and $\psi(0)$ is the initial autocorrelation function.

The corresponding power spectrum of the variation in $U$ and $V$ with frequency $\delta$ as given by Sunde is

$$
W(\delta) = \frac{2}{\pi} \int_{0}^{\infty} \psi(\nu) \cos \nu \delta \, d\nu
$$

$$
= \psi(0) \quad \text{for} \quad 0 < \delta < \Delta
$$

$$
= 0 \quad \text{for} \quad \Delta < \delta
$$

For an autocorrelation function ($A$), the corresponding correlation coefficient is

$$
\rho_c = \left( \frac{\sin 2 \pi f \Delta}{2 \pi f \Delta} \right)^2
$$

where $\Delta$ is the maximum time departure from the mean transmission delay. The calculation of $\Delta$ is essentially a geometrical problem and it is given as

$$
\Delta = \frac{4 \theta^2}{16 c} \left[ \left( 1 + \frac{2a}{\theta} \right)^2 - 1 \right]
$$

with all quantities on the right defined as above.

### 5 Results

The effect of the atmospheric stability on correlation bandwidth has been studied by changing the values of $K$ which is a function of refractivity gradient. The results are presented in Fig. 4. It is seen that the frequency separation is around 1 MHz for 10 ft antenna dish diameter for $K$ equal to 0.1 and 4.5 MHz for $K$ equal to 1.33. But, when $K$ is equal to 0.1, it is seen that the correlation coefficient decreases very sharply. Fig. 4 also depicts that the correlation bandwidth problem is severe when the values of $K$ are 0.1 and 1.33, but it does not occur when the atmosphere is stable, i.e. refractivity gradient is more negative than $-70$ N units/km as the correlation function never falls to 0.4. The correlation bandwidth has been evaluated for different values of $K$ for 10 ft antenna dish diameter.

Figure 5 presents the results on correlation bandwidth for different antenna dish diameters under low atmospheric stability condition for troposcatter system. It is seen that the correlation bandwidth problem is severe when the antennas of smaller sizes are used. The correlation bandwidth is 4.5 MHz for 10 ft dish diameter while it is 7.2 MHz for 16 ft dish. But, the correlation coefficient never approaches to 0.4 when the dish diameter is > 40 ft. The received power ($P$) is proportional to the cube of beamwidth ($a$), i.e., $P \propto a^3$ (Refs 6 and 7). Though correlation bandwidth problem reduces considerably by using very big antennas, but the cost of the antennas and the complexity of installation also increase with the
increasing dish diameter. It is very important to optimize the correlation bandwidth and received power in terms of antenna size and its cost and transmitter power. The received power for different antenna sizes of a troposscatter link at 4.6 GHz is given in Table 1. There is not much improvement in received power beyond a certain size of antenna.

Figure 6 indicates the effect of path length on correlation bandwidth for troposscatter propagation. The correlation bandwidth problem decreases with distance. The study also reveals that over the Indian coastal regions, the problem of correlation bandwidth is less than over desert areas as the atmosphere is more stratified over coastal regions than over desert areas. The correlation bandwidth problem is maximum during monsoon and minimum during premonsoon and winter months.

6 Discussion

The objective of this paper is to demonstrate the necessity of taking the radioclimatology into consideration in designing troposscatter systems, especially in view of dependence of possible bandwidth on $K$. Merely increasing the antenna size does not significantly contribute to the gain of the system because of the dominance of aperature-to-medium coupling loss for very large antennas. However, appropriately large antenna systems are essential if the correlation bandwidth is to be large to handle the channel capacity. We have shown in this paper that depending upon $K$, there is a critical antenna diameter for a given frequency beyond which the correlation bandwidth problem essentially disappears.

It is also seen that the correlation bandwidth problem is not serious if a dish of diameter more than 40 ft is used during high atmospheric stability conditions, i.e., when the effective earth’s radius is very high. Thus, it is necessary to use large antenna systems to achieve adequate correlation bandwidth especially when subnormal refractivity gradients exit. Since the cost factor in large troposscatter antenna systems is very important so it is necessary to opti-
mize the antenna systems by taking into consideration the aperture to medium coupling loss factor which annuls the additional gain one would expect from very large dishes and also the correlation bandwidth requirements. Thus for high reliability systems, the diurnal variation morphology of the effective earth’s radius factor is a prerequisite for optimization. Such measurements should be conducted either by using a kytoon or a slow rising balloon at several points of local time in a day.

References
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