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Propagation studies at Ku-band over an earth-space path at Kolkata

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Propagation measurements at Ku-band over an earth-space path have been carried out at Kolkata (22°34′ N, 88°29′ E) by receiving a signal at 11.172 GHz from the satellite NSS-6 (geostationary at 95°E). The amplitudes of the co-polar signal and the cross-polar component have been monitored along with the measurements of rain rate and drop size distribution by an optical raingauge and a Joss-type disdrometer, respectively. Three phenomena studied with the experimental data are rain attenuation, depolarization and scintillation. The rain attenuation observed experimentally tallies well with the values obtained from the point rain rate using a simple attenuation model, if the rain rate is low (less than 20 mm/h). The depolarization, indicated by an enhancement of the cross-polar component of the signal, is well correlated with the rain attenuation. The presence of large rain drops is found to have a more dominant role in determining the extent of depolarization than affecting the co-polar attenuation. The scintillation observations associated with the rain events indicate that the standard deviation of fast fluctuations increases with rain attenuation following a power-law.

Keywords: Earth-space propagation, Ku-band, Rain attenuation, Depolarization, Scintillation

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1 Introduction

A fast growth in new satellite services, such as, VSAT for internet access, LAN interconnection, multimedia applications, has caused an ever increasing demand of bandwidth pushing up the frequency for satellite communications and leading to more complex systems involving the frequency re-use scheme with cross-polarized channels. However, these systems are vulnerable to propagation effects which become increasingly significant as the frequency goes up. Already, a number of Ka-band satellite systems for both fixed and mobile communications have become operational which need an extensive data base and accurate propagation model to decide on the fade margin of satellite link and to implement different fade mitigation techniques. The propagation measurements at frequencies above 10 GHz have been carried out fairly extensively in the temperate climatic region where most of the developed countries are located. However, the scenario in the tropical region is not as encouraging since the data coverage for this region is, so far, inadequate, particularly in view of the fact that this region has much more complex and varying climatic behaviour compared to the temperate region. In the Indian region, the propagation data over the earth-space paths are very inadequate[1,2] which may be a matter of concern, as in the near future the Indian satellites will carry Ku- and Ka-band transponders to provide a variety of services. In this paper, some of the results of propagation measurements carried out at the Institute of Radio Physics and Electronics, University of Calcutta, are presented and discussed.

2 Experimental measurements

The Ku-band signal at 11.172 GHz transmitted from the satellite NSS-6 (geostationary at longitude 95°E) has been received to carry out propagation measurements over an earth-space path over Kolkata (22°34′ N, 88°29′ E). The elevation of the satellite signal is about 63°. The satellite signal is a TV broadcast signal with low fade margin (~20 dB). The clear-air separation between the co-polar and cross-polar channels is about 18 dB. The amplitudes of the co-polar signal (horizontal polarization) and the cross-polar component (vertical polarization) transferred from the horizontal component, have been recorded. The calibration of the satellite signal of both co-polar and cross-polar component has been done using a Ku-band signal generator and a rotary vane attenuator. At the site of the satellite receiver, an optical raingauge and an impact-type of disdrometer have been operated

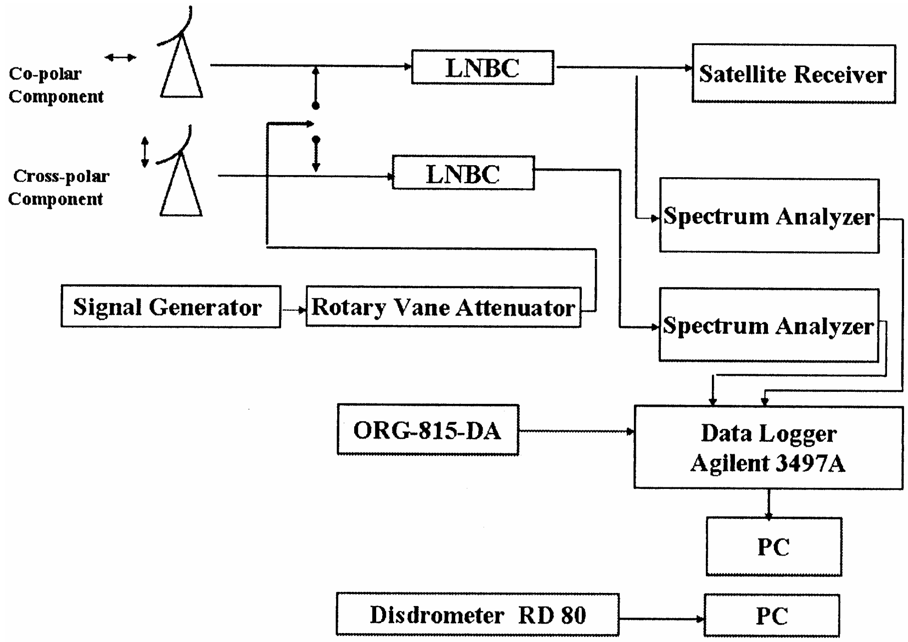

Fig. 1–Experimental set-up for propagation measurements at Ku-band over an earth-space path

to measure the rain rate with an integration of 10 sec and rain drop size distributions (DSD) with an integration time of 1 min. Figure 1 gives the experimental arrangement used for the present study.

3 Rain attenuation studies

The rain attenuation at Ku-band has been studied recording the satellite signal strength along with the rain rate measurements. Figure 2 shows a sample record of simultaneous measurements of attenuation and rain rate. There is a very good correlation between the attenuation of the satellite signal and the rain rate recorded by the optical raingauge. Figure 3 gives the cumulative distributions of the occurrence of Ku-band attenuation over the present earth-space path obtained with the experimental data and with the ITU-R model[3]. It is found that the ITU-R models underestimate the occurrences of rain attenuation at Kolkata.

An effort has been made to estimate the instantaneous attenuation over the earth-space path from the measurement of point rain rate using a rain attenuation model. The reliability of attenuation estimate depends on having a dependable model of the horizontal extension of rain cell and the effective rain height. Several models are available for these parameters which need to be tested for the present locations. For the present study, the Simple Attenuation Model (SAM)[4] has been used to estimate

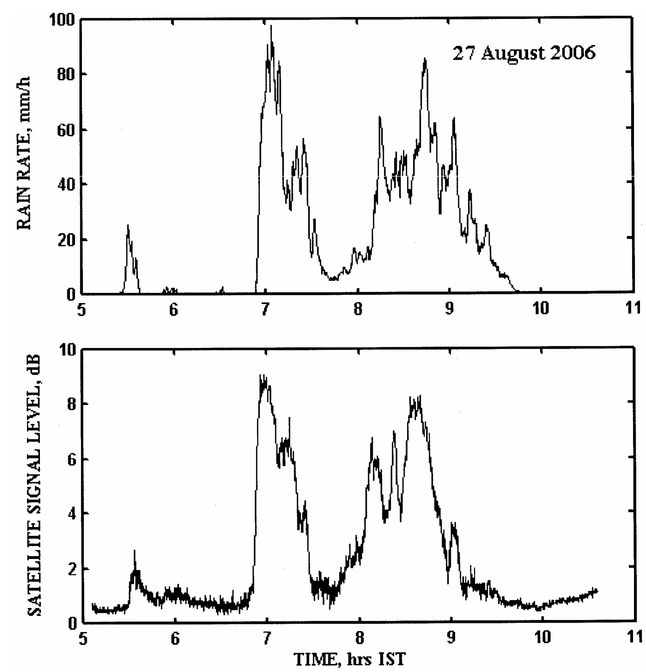

Fig. 2–Typical variation of Ku-band signal level during a rain event

the rain attenuation $A(R_o)$ over the earth-space path from point rain rate (R_o) measurements as given by

$$A(R_0) = kR_0^{\alpha}\, L_s \qquad \text{dB},\ R_0 < 10\ \text{mm h}^{-1}$$

$$A(R_0) = kR_0^{\alpha}\left[\frac{1\text{-}\exp[a\Gamma\ \ln(R_0/10)\ L_s\ \cos\theta\,]}{\alpha\Gamma \ln(R_0/10)\cos\theta}\right] \text{d B},\ R_0{}^{3} \geq 10\ \text{mm h}^{-1} \qquad \ldots (1)$$

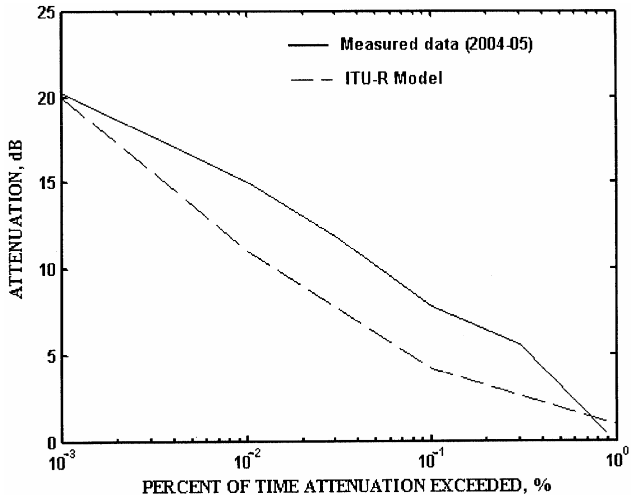

Fig. 3–Cumulative distributions Ku-band attenuation over an earth-space path for Kolkata obtained experimentally during June 2004-June 2005 and from ITU-R models

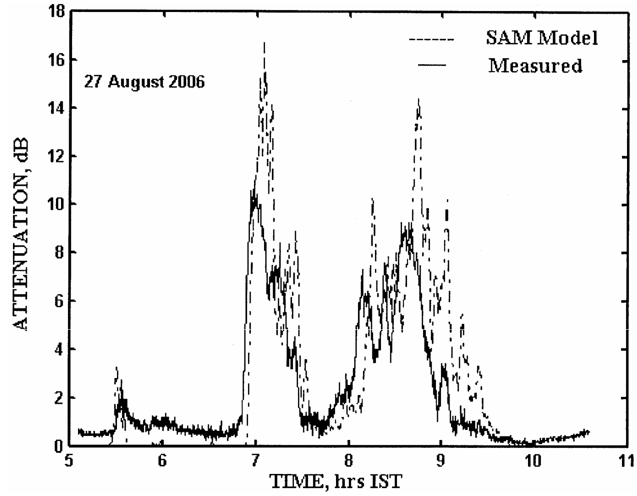

Fig. 4–Comparison between measured attenuation and SAM model generated values during a rain event

where L_s is the slant path length, θ the elevation angle, Γ the rain rate decay parameter, and k and α are the constants that relate the specific attenuation and the rain rate [$\gamma(R) = kR^{\alpha}$] and obtained from the ITU-R model[5]. The value of Γ was taken to be equal to 1/14 in the SAM model.

Figure 4 gives a typical comparison between the model-generated and the measured attenuation during a rain event. At low rain rates the discrepancies between the two values are not significant as the values are themselves small and the low rain rates prevail over a large area as in the case of stratiform rains. However, the discrepancy becomes significant when the rain rates are large (above 30 mm/h) and the corresponding rain cell size is small. Hence the same value of Γ does not hold good as the rain rate decay is faster and should depend on the rain rate itself. Also, sharp changes in the rain rate are not always reflected in the measured attenuations indicating that such changes occur locally and not over the entire satellite path.

4 Depolarization

The depolarization of satellite signal is caused by the anisotropy of the propagation medium contributed by rain, ice and turbulence in the atmosphere. The depolarization during rain has been studied in this paper which is mainly caused by the oblateness of raindrops. The manifestation of depolarization in the received signal is an enhancement of the cross-polar component. Usually, the depolarization is assessed in terms of degradation of cross-polar discrimination (XPD) which is measured from the signal variation in the co-polar and cross-polar channel during a rain event. The degradation is estimated by adding the attenuation of co-polar signal to the enhancement in the cross-polar channel. Figure 5 shows a typical variation of Ku-band satellite signal in the co-polar and cross-polar channels along with time evolution of DSD during a rain event as observed at Kolkata. The co-polar and cross-polar components are highly correlated during the rain event indicating that the depolarization is mainly caused by the raindrops. Relative to the co-polar attenuation, the cross-polar component was larger at the first peak than that at the second peak of the variation. Some large drops of diameter 3-4 mm were recorded by the disdrometer during the first peak which caused an enhancement of the cross-polar signal more prominently than affecting the co-polar attenuation. At the second peak, the number of drops of all sizes increased, causing an increase in the attenuation as well as in the cross-polar signal level. During the later phase of the event, the cross-polar signal continued to have a value greater than 1 dB, even if the attenuation became very small (around 0.5 dB). This is also caused by the presence of large drops of sizes ~ 3 mm which are responsible for noticeable depolarization, but not causing significant attenuation. This indicates that the presence of large drops, with prominent oblateness, has a greater impact on the cross-polar component than on the co-polar one. At tropical locations the rain events are associated with different types of precipitation (convective and stratiform) and DSD can be significantly different for similar rain rates even during a single rain event, which may cause different XPD degradations for identical co-polar attenuations. The XPD is usually modelled in terms of co-polar attenuation[6]. The XPD degradation obtained for the present event compares well with that obtained from the ITU-R model[7].

5 Scintillation

Scintillations are caused by the irregularities in refractive index structures due to turbulences in the atmosphere. In the present study, scintillations characterized by fast fluctuations of satellite signal level have been considered in association with rain attenuation. A strong correlation of scintillations is obtained with rain events. Scintillations are superposed on the variation of signal due to rain attenuation. The scintillation and rain attenuation occur at two different time scales, the scintillation being characterized by fast fluctuation, whereas the rain attenuation exhibiting slower fluctuations due to large scale variations of atmospheric refractive index effected by fluctuations in rain rate. The relation between the two events was studied for a satellite signal at Ka-band[8].

In this paper, a case study has been made to indicate the relationship between rain attenuation and scintillation with the Ku-band satellite signal. Figure 6 gives a typical record of scintillation event in association with rain attenuation. Figure 7 gives the power spectrum of the signal variation shown in Fig. 6. The slope of the spectrum is –20 dB/decade up to frequencies in the range 0.02-0.03 Hz that can be identified with rain attenuation[9], beyond which the scintillation effect dominates which is characterized by a slower slope. To indicate a relationship between the intensity of scintillation and the rain attenuation,

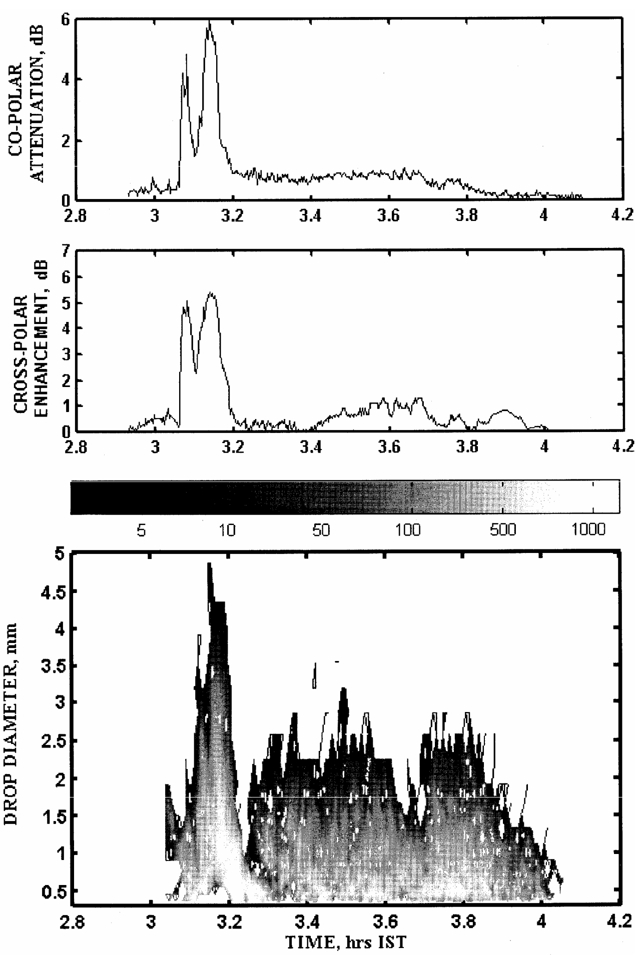

Fig. 5–Temporal variation of the co-polar and cross-polar component of Ku-band satellite signal and drop size distribution during a rain event

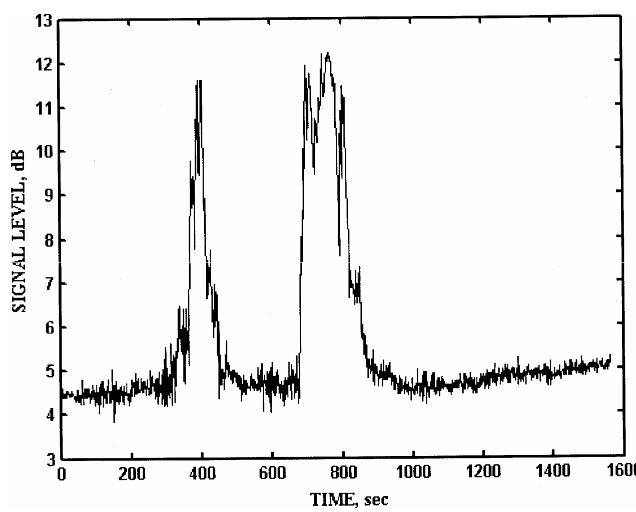

Fig. 6–Typical scintillation of Ku-band satellite signal event associated with rain attenuation.

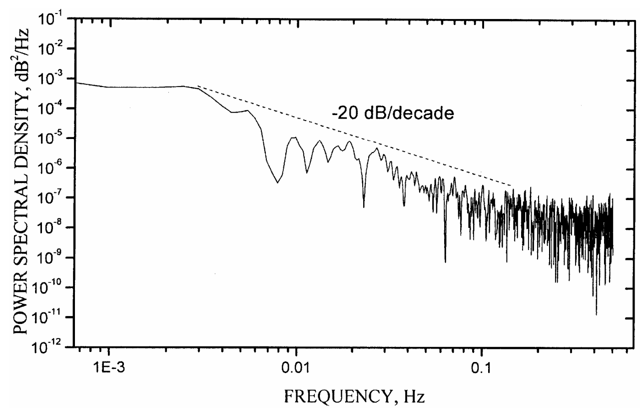

Fig. 7–Power spectral density of signal fluctuation shown in Fig. 6

the signal fluctuations caused by refractivity irregularities are separated from the combined effect using a high-pass filter with cut-off frequency 0.25 Hz. The filtered signal fluctuations, occurring due to scintillation, are shown in Fig. 8. The standard deviation of signal fluctuations over a time interval of 90 sec at successive time points are obtained against the moving average values of attenuations, the result of which is plotted in Fig. 9. A power-law curve has been fitted to the data, as indicated by a straight line in Fig. 9. It indicates that the thin-layer turbulence layer model is applicable to the present data which can be caused by clouds in raining conditions[9]. A long-term data will reveal the different regimes of turbulence along the earth-space paths during different types of rain over a tropical location.

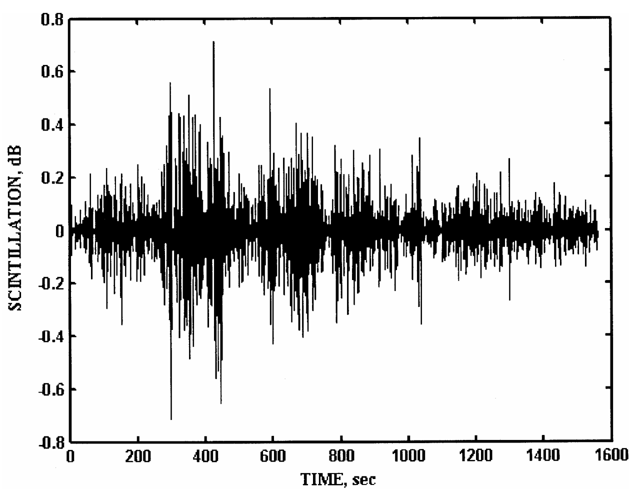

Fig. 8–High-pass filtered time series of scintillation of signal shown in Fig. 6

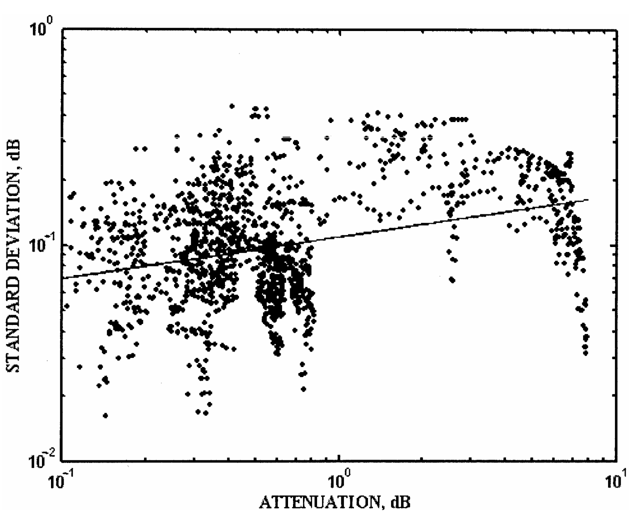

Fig. 9–Variation standard deviation of scintillation against attenuation obtained during the rain event shown Fig. 6. [The solid line is the fitted curve to the data indicating a power-law relationship between the two variables.]

6 Conclusions

In this paper, some features of propagation phenomena observed with a Ku-band signal over an earth-space path are presented. The rain attenuation can reasonably be well predicted from the point measurements of rain rate at low rain rates (< 20 mm/h). The depolarization caused by raindrops is a major concern for a frequency re-use system using cross-polarized signals. The degradation of XPD with respect to the clear air value can be obtained with a simple experimental arrangement that monitors the co-polar and cross-polar component of a plane polarized signal. It is observed that the presence of large drops causes an increased depolarization for identical co-polar attenuations. The scintillation phenomena associated with rain events are often observed at the present location. The standard deviation of fast fluctuations caused by the small scale irregularities of refractive index shows an increase with the rain attenuation, and, in a case study, a fitted power-law relation indicates that the thin-layer turbulence model is applicable to scintillation of satellite signal at Ku-band.

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