A short note on the variation of path loss in the atmosphere

Noraisyah Mohamed Shah, Jeremy E. Allnutt

Abstract

Diurnal variations of received satellite signal in Ka-band, and from co-located radiometer data were investigated using data collected from the propagation measurement campaign conducted by the National Aeronautics and Space Administration (NASA) Advanced Communications Technology Satellite (ACTS). The database contains a maximum of five consecutive years of data collected from seven sites in North America that were receiving signals from a geostationary satellite, using similar on-site equipment and data processing tools. The investigation emphasis is on simultaneous diurnal variation seen in the beacon attenuation as well as attenuation inferred from the co-located radiometer. Evidence showed that the diurnal variations observed on satellite beacon experiments are an atmospheric effect, unconnected with the satellite or the satellite motion. The spectral content of the beacon attenuation data as well as from attenuation inferred from the radiometer showed an element of a solar day periodicity with ‘side-bands’ of sidereal and anti-sidereal periodicities.

1. Introduction

The ACTS was launched by NASA in September 1993 with the objective of testing unproven Ka-band technology and applications (Davarian et al., 1997). The satellite was assigned geostationary position at 100° west longitude. Two types of propagation experiments were conducted: (1) long term experiments, designed to collect statistical data for propagation-model development and testing; and (2) shorter experiments, designed to explore mitigation techniques and special topics. Only data from the type (1) experiment were used and reported here. For the purpose of propagation measurements, the satellite was provided with two Ka-band frequency beacons, at 20.185 GHz (20.2 GHz for short) and 27.505 GHz (27.5 GHz for short). The 20.2 GHz beacon was also used for telemetry, but the 27.5 GHz beacon was unmodulated. The 20.2-GHz beacon can be vertically or horizontally polarized while the 27.5-GHz beacon is vertically polarized.

Seven sites in North America were selected to conduct continuous in situ measurements of the 20.2- and 27.5-GHz beacons using NASA-provided, identical, receive-only terminals, designed by Stutzman et al. (1993). The 1.2 m offset reflector and novel feed design was used to monitor both ACTS beacons at 20.2 and 27.5-GHz beacon is vertically polarized.
27.5 GHz as well as sky noise temperature at these two frequencies using total-power radiometers with 80 MHz bandwidth. The receiver equipment monitoring and calibration, as well as data-collection and first-level data preprocessing system were computer controlled (Crane et al., 1997). The satellite beacon and radiometer sky noise used the same antenna and feed. A single preprocessing program was used by the experimenters to provide for automatic calibration, generation of attenuation histograms, and data archival. The characteristics of the selected sites are summarized in Table 1. They span many rain-climate zones, with path elevation angles to the satellite varying from 8° to 52°.

At the terminal, the beacon and radiometer data were collected simultaneously and continuously at a rate of one sample per second. These data were combined with a time stamp, meteorological

Fig. 2. The dual plots of beacon and radiometer data for May 6th to 13th 1996 in Florida.

Fig. 3. Single-sided amplitude spectrum for the 20.2 GHz beacon attenuation in (a) Florida, (b) Colorado, (c) New Mexico, (d) Alaska, (e) British Columbia and (f) Oklahoma. The anti-sidereal and sidereal frequencies were indicated with a vertical solid line, shown from left to right, respectively. The solar cycle is marked by the vertical dotted line.
observations, and receiver status information and stored in daily output files. The raw daily data files were input to the preprocessing program, which performed the calibration functions, generated attenuation histograms and prepared 1-min average and standard deviation estimates for beacon signal level, beacon attenuation, radiometer-derived sky brightness temperature and radiometer-derived attenuation. Any scintillation effects were removed by the averaging process (Crane et al., 1996). The preprocessing program also extracted the meteorological, status, and calibration control information from the raw data files. The calibrated preprocessed data files are produced for public use.

The chart in Fig. 1 gives the percentage of the ratio between actual recorded data to total time for the ACTS propagation data collected in 5 years. The ratio is assessed according to month. High recorded data rate (above 90%) can be seen in all sites except in New Mexico, where available recorded data is below 80% for the month of July till December. There is also below 80% data from Florida in the month of October. The data from the site in Reston, Virginia has been excluded from the analysis here as it contains only four years’ worth of data.

2. Investigation and analysis

Fig. 2 shows selected one week-long samples of the beacon and radiometer attenuation signal variation during clear sky, taken from the 20.2 GHz beacon and radiometer data in Tampa, Florida. Diurnal variations observed on satellite beacon experiments, are often ascribed to changes in satellite antenna beam pointing due to a non-geostationary orbit or to diurnal heating effects on the satellite antenna. Radiometer data are used to establish an absolute reference level for beacon data, since they are not subject to spacecraft induced diurnal signal variations. The ACTS propagation terminal (APT) has a resolution of 0.01 dB with an accuracy of ± 0.1 dB. For the combined...
radiometer and beacon measurements systems, the typical root mean square attenuation measurement error was less than 0.3 dB for all sites except for British Columbia (Crane and Dissanayake, 1997). Radiometric inferred attenuation and beacon attenuation tended to track each other well at low path attenuation levels. When co-located with the beacon receiver, a radiometer provides a measure of the inferred attenuation of the signal that is obtained based on the noise temperature that is detected along the path. It is clear that solar heating effects are driving the diurnal variations observed in Fig. 2. Annual periodicity in the variation of the mean clear sky level was also observed and reported by Mohamed Shah and Allnutt (2012). This annual variation recorded almost a 3 dB peak to peak change from winter to summer in the Alaskan site. A 3 dB drop in signal quality during clear sky is significant for low margin systems operation. The average annual attenuation was estimated using the approximate method to estimate gaseous attenuation on slant path contained in the Annex 2 of the recommendation by the Radiocommunication Sector of International Telecommunication Union (2012) ITU-R 676-9, and is in agreement with the averages obtained from the recorded data. Similar evidence of diurnal, seasonal and annual variations in the clear sky levels at Ku-band was also reported from an experiment in Papua New Guinea (Pan et al., 2006). The observed signal variations were attributed to the atmosphere, and not due to changes in satellite beam pointing caused by orbital motion and/or variations in pointing due to diurnal heating effects on the satellite antenna.

A Fourier analysis was conducted on the beacon and radiometer attenuation data to further detect the periodicity of the variations that existed, and the results for the ACTS beacon attenuation data are shown in Figs. 3 and 4 for the 20.2 and 27.5 GHz frequency, respectively. The 1-min data were grouped into segment size of 2, 3 and 4 years’ worth of data, beginning with data collected in January. Within each group, the frequency spectrum was generated for each segment, and then the amplitude averaged to obtain one averaged amplitude spectrum. These averages were then plotted together with the frequency spectrum of all five years of data. The frequency spectrum for the radiometer inferred attenuation gave similar spectral lines as the beacon attenuation data. An example of the frequency spectrum for radiometer attenuation data obtained in Florida is given in Fig. 5.

A distinct spectral content can be seen in the vicinity of the frequency of one cycle per solar day. The ‘sidbands’ were found to correspond to a cycle per sidereal day, and a cycle per anti-sidereal day (Farley and Storey, 1954), to the right and left of a cycle per solar day, respectively. The characteristics of the three spectral components differ in all the sites. Comparing Fig. 3 to the spectrum of an amplitude modulated signal, Fig. 3(a) is a double sided amplitude spectrum. Fig. 3(b) an unmodulated amplitude spectrum and Fig. 3(c) and (d) a double-sided suppressed carrier amplitude spectrum. There appears to be a general trend of decreasing solar tidal effect as the climate becomes less warm and humid, but with an increase in the presence of the sidereal and anti-sidereal component. There seemed to be no specific pattern between the result in 20.2 and 27.5 GHz. However, the solar and sidereal peaks do not seem to increase or decrease concurrently. A pattern of decreasing solar peak and increasing sidereal peaks from 20 to 27 GHz can be seen for sites in Florida, Colorado and Alaska, but not in others. The gaseous absorption of the 20.2 GHz frequency is higher than the 27.5 GHz frequency during clear air for all six sites. As soon as it started to rain, the 27.5 GHz absorption was higher than the 20.2 GHz frequency. An example of the cumulative excess attenuation data at 20.2 and 27.5 GHz measured by beacon receivers is shown in Fig. 6 for Florida. This agrees with a similar investigation in (Thorn, 1984) which found the cumulative statistics of 30 GHz begins to be higher than the 20 GHz at 2% of the time and higher, on a 30 slant-path in the UK. It is speculated that the magnitude of the diurnal variation will increase with frequency, as does attenuation due to atmospheric gasses.

Changes in the mean clear sky level seen in these data are attributed to changes in the atmospheric parameters, and can be closely estimated by attenuation due to gaseous absorption.
Examination on the spectral content of the specific attenuation due to dry air ($\gamma_0$) and water vapor ($\gamma_\omega$) for each site showed that the water vapor absorption is the main contributor to the sidereal component, while the oxygen absorption produces a solar variation effect. Both $\gamma_0$ and $\gamma_\omega$ were estimated using the approximate method found in annex 2 of ITU-R 676-9 (2012) using meteorological value of each minute, in the ACTS database. The results for Florida for the frequency of 20.2 GHz were given in Fig. 7.

Solar and sidereal effects are well known phenomena in atmospheric physics, but they have been largely ignored in communication satellite research. It is interesting to note that the sidereal and anti-sidereal spectra required many years’ worth of data to become apparent.

3. Conclusion

Investigations of variations in clear sky level on a fixed satellite-ground path – essentially changes in transmission level in the absence of rain – gave evidence of the existence of diurnal variations as well as seasonal variations. Both solar and sidereal components could be seen in the satellite beacon and radiometer data. Investigations are continuing to identify the cause(s) of the dissimilarity seen in the spectrum content of the beacon attenuation data obtained in each site. If the diurnal variation of the mean clear sky is considered in determining link budget, a more accurate fade margin description can be made to establish performance and availability criteria. This would be advantageous to systems with very small aperture terminals, with limited link operating margins.

Acknowledgements

We would like to acknowledge NASA for permitting the use of the ACTS data in all the sites. We would also like to offer our special appreciation to Dr. Qing Wei Pan and Mr. Charles Tsui of the Manukau Institute of Technology in Auckland, New Zealand, for letting us use the DFT program they developed for the spectrum analysis. This research was produced as part of a doctoral program that is funded by University of Malaya.

References