# MILLIMETER AND OPTICAL WAVE PROPAGATION UNDER SNOW AND OTHER CONDITIONS

J. Awaka*, E. Kawai*, T. Ihara**, K. Kitamura*, Y. Echizen'ya***, and K. Okamoto*

* Communications Research Laboratory (CRL), Nukui-kita-machi 4-2-1, Koganei, Tokyo 184, Japan
** Kashima Branch, CRL, Kashima, Ibaraki 314, Japan
*** Akita Observatory, CRL, Tegata, Akita 010, Japan

## 1. INTRODUCTION

Several authors have published propagation characteristics of millimeter and optical waves under rain and fog conditions [1,2]. However, very little simultaneous propagation data of millimeter and optical waves under snow conditions have been published. It is important to obtain these data under snow condition for the development of communications and sensing systems using these wavelengths. Hence, the Communications Research Laboratory (CRL) made simultaneous measurements of wave intensities at 80 GHz and 350 THz on a 1.4 km range in Akita, Japan, where a great deal of snow falls in winter.

## 2. EXPERIMENTAL SYSTEM

Fig. 1 illustrates the experimental system. Both transmitters and receivers were installed on the tops of buildings. Rainfall rate and other meteorological data were obtained at the receiving site. One minute sample data were stored in a cassette data recorder, and the data were analyzed later by a mainframe computer.

## 3. EXPERIMENTAL RESULTS

The data analyzed here were obtained in the warm season from June 1986 to October 1986 and in the winter season from December 1987 to March 1988.

Fig. 2 shows data of a typical snowfall event. The figure clearly shows that the optical wave suffers very large attenuation by snowfall, whereas, the millimeter wave is attenuated very little.

Fig. 3 shows the scatter diagram of optical wave attenuation vs. millimeter wave attenuation. The data points in the figure can be divided into groups according to their causes. In the case of rain, the millimeter wave attenuation is about twice as large as the optical wave attenuation. In the case of snow and mist, the millimeter wave shows little attenuation whereas the optical wave suffers very large attenuation. In the case of sleet or wet snow, the data points in Fig. 3 show large scatter depending on the wetness of snow.

The snow attenuation of the optical wave shown in Figs. 2 and 3 is at most about 20 dB, which is well within the dynamic range of the measuring system. This value of attenuation seems to be too small, contradicting to our observation that heavy snowfall completely shut out the visibility of the light source to the naked eye. This apparent contradiction can be explained by the contribution of external light scattered by snow.

If the above explanation is true, the effect of external light must be strong in the day and weak at night. To check this idea, optical data of the entire snowfall event were examined for diurnal variations of the optical wave strength. Fig. 4 shows the number of samples whose measured optical wave attenuation by snowfall is greater than specified values as a function of time of day. Fig. 4 clearly indicates that the measured attenuation exceeding 20 dB occurs only in the nighttime. This arises because the effect of external light scattered by snow is weak in the nighttime. In the daytime, however, the external light scattered by snow is strong and the external light scattered into the receiving system causes the measured optical wave attenuation to appear small. Since the external light is just noise, the true snow attenuation of optical signal must exceed that shown in Figs. 2 - 5.

Fig. 5 shows the cumulative distribution of millimeter wave attenuation and that of optical wave attenuation. The cumulative distributions are based on the whole data set of both wavelengths which were simultaneously measured during the period indicated at the beginning of this section. For a large percentage of the time, the millimeter wave has the advantage of smaller attenuation than the optical wave.

Fig. 5 also shows the cumulative distribution of attenuation when a frequency diversity operation is assumed to be made by switching between the optical wave channel and the millimeter wave channel. The curve for the diversity operation in Fig. 5 can be easily understood from the scatter plot of data shown in Fig.3. A large attenuation in the case of diversity operation occurs when both the millimeter and optical waves suffer large attenuations, which condition is satisfied mainly by rain events. Since the optical wave attenuation by rain is about half that of the millimeter wave, the diversity system would choose the optical channel in the case of rain. Hence, at small percentages of time, the value of the diversity curve is about a half of that of the millimeter wave because both curves are dominated by rain events in the region of small percentages of time. At large percentages of time, however, the diversity system would choose the millimeter wave channel in order to avoid a very large attenuation of the optical wave caused by snow and fog (in our case mist). Hence, the diversity curve almost coincides with the millimeter wave curve at large percentages of time. Fig. 5 confirms the usefulness of a frequency diversity system consisting of an optical channel and a millimeter wave channel [3, 4] even when the case of snowfall is included.

## 4. CONCLUSIONS

The advantage of the use of millimeter waves over the use of optical waves in the case of snowfall has been demonstrated. If, however, a frequency diversity operation is used, the combination of both millimeter waves and optical waves will provide us with very reliable communication systems for nearly all weather conditions.

## REFERENCES

1] T. Manabe et al., National Convention of IEICE, Japan, 561, 1987.
2] C. Gibbins and M. G. Pike, ICAP 87, York, IEE Conf. Publ. #274, part 2, pp.50-53, 1987.
3] M. Hata et al., Proc. of ISAP 85, Kyoto, pp.1079-1102, 1985.
4] Public announcement of patent application, #2203, Japan, 1971.

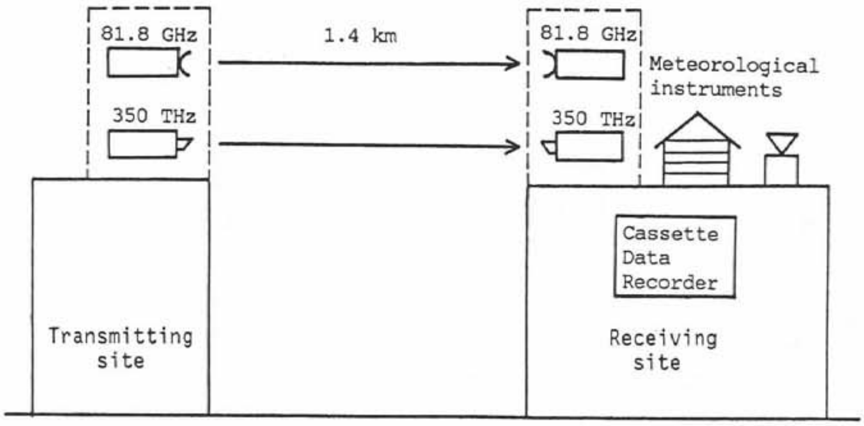


Fig. 1 Experimental System

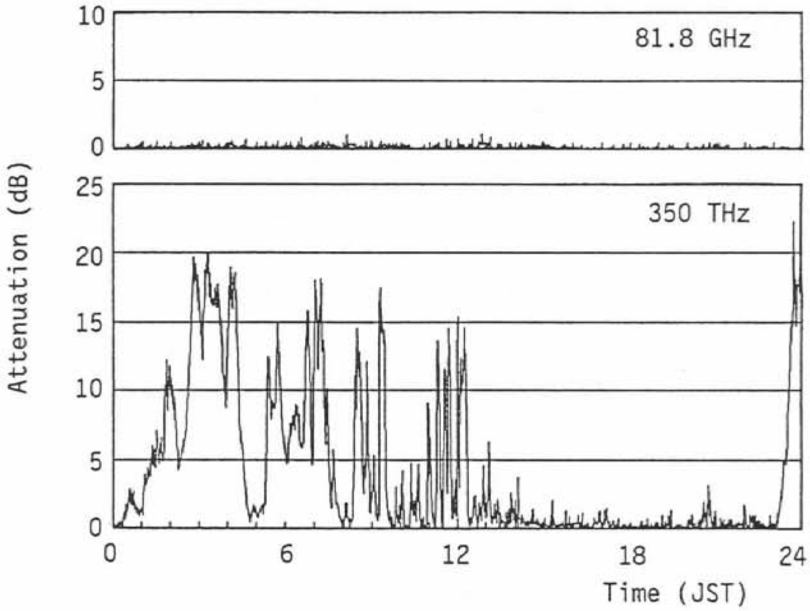


Fig. 2 Example of a snow event

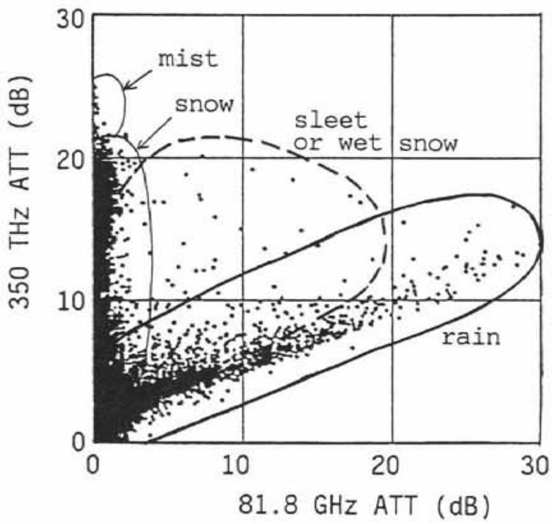


Fig.3 Scatter plot of optical versus millimeter wave attenuation

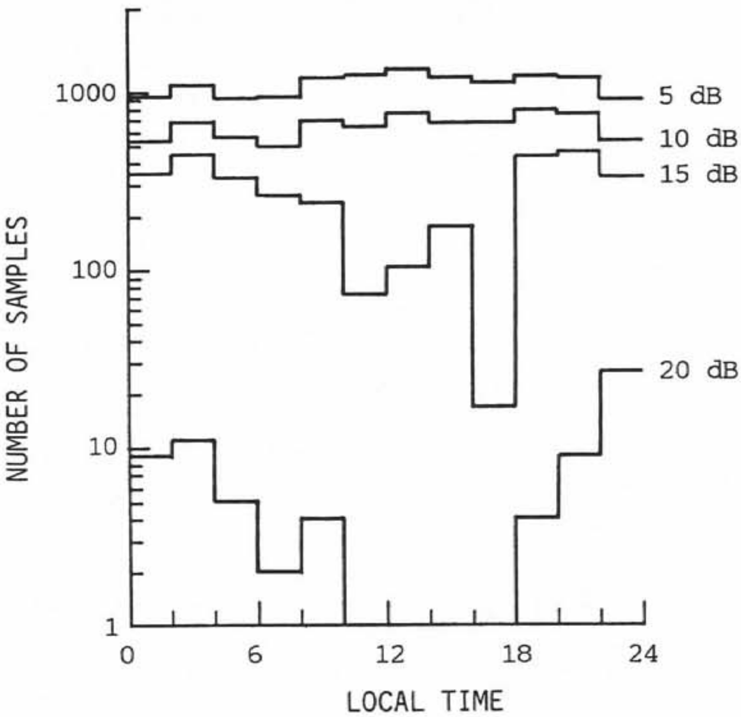


Fig. 4 Diurnal variation of measured optical wave attenuation due to snowfall

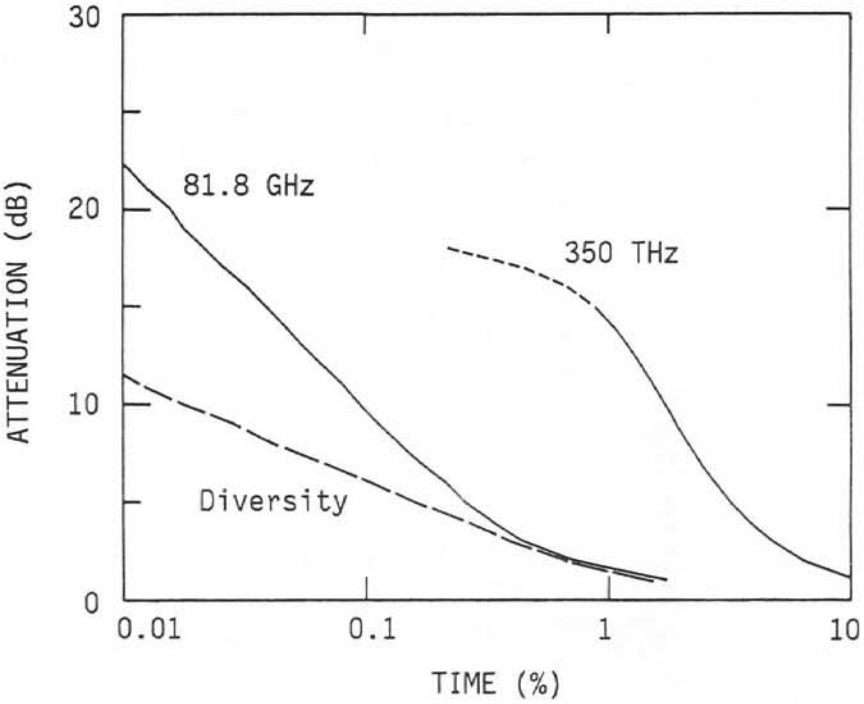


Fig. 5 Cumulative distributions