Low-THz Wave Snow Attenuation

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***Abstract*—This paper assesses the attenuation through various intensities of snowfall experimentally at 300 GHz, and is characterized by measuring the ratio of the received power from the target through the snow precipitation and through the same path with no precipitation. Higher attenuation is measured at higher snowfall rate. Snow events are categorized as "dry snow" and "wet snow". The comparison between the measured attenuation through wet and dry snowfall shows larger attenuation is expected through wet snowfall compared to the same snowfall rate of dry snow. This study is fundamentally important to investigate the effect of adverse weather condition on Low-THz waves and to assess their feasibility for outdoor applications.**

Keywords— specific attenuation; snowfall; Low-THz wave

I. Introduction

A new research area of increasing operating frequency range of automotive sensors from microwave to Low-Terahertz (THz), frequency range of 0.1-1 THz, is attracting attention in recent years [1]. This increase in frequency introduces advantages such as better image resolution and smaller component sizes compared to current automotive sensors operating at 24 GHz and 77 GHz. To deploy Low-THz sensors in automotive and other outdoor applications, knowledge on Low-THz wave propagation through uncontrolled and harsh environments is crucial and is the main focus of this research. This study is started by investigating transmissivity through various contaminants (ice, leaves petroleum-based fuel, etc.) that cover the radome. The results of Low-THz wave propagation through two of the frequent contaminant for outdoor applications, water and sand, are presented in [2] and [3], respectively. Strong signal reduction is presented through a uniform layer of water at 150 GHz and 300 GHz in [2]. However, the measured transmissivity through distributed water droplets, which occur in practice due to the surface tension of water, shows lower transmission loss at the shorter wavelength, due to the distribution of gaps between droplets. The signal reduction through a uniform layer of sand with various particle sizes and moisture content is presented in [3]. The results indicate that the attenuation is not only influenced by the sand layer thickness and the moisture of the sand, but also by the size of sand granules, so that coarser particles lead to greater attenuation.

The effect of different forms of precipitation (drizzle, rain, snow, hail and etc.) on Low-THz wave propagation is another very important aspect of this research. A number of studies are devoted to characterizing experimentally and theoretically attenuation through rain in different frequency ranges [4]-[5]. However, the effect of snow precipitation on wave propagation is not well characterized. The impact of snowfall at 20.2 GHz over a period of two years in Ottawa is measured and presented in [6]. Cumulative distribution functions (CDFs) of snow attenuation show that the attenuation does not exceed more than 2 dB at this frequency. The specific attenuation at 666 THz is measured over the path of 71 m and presented in [7]. The results show attenuation of 100 dB/km for a snowfall rate of 10 mm/hr. The specific attenuation of larger than 2, 3 and 9 dB/km for snow mass concentration of 1 g/m^3 at 95 GHz, 140 GHz and 217 GHz, respectively, are presented in [8]. Measured specific attenuation through precipitation of wet snow at 140 GHz in [9] shows 5 dB/km versus equivalent rainfall rate of melted snow. They show 3 times greater attenuation by wet snow compared with the same rate of rain precipitation. This can be explained by lower fall velocity and larger size of snowflakes compared to raindrops. The effect of wet and dry snow on the wave propagation at about 200 THz is studied in [10] and significant difference (more than 20 dB) between specific attenuation of 4 mm/hr of wet and dry snow is shown.

In this paper, the measured specific attenuation for various snowfall rate at 300 GHz is presented. The snow storms are categorized as "wet snow" and "dry snow" and the difference between their measured attenuation is discussed.

II. Measurement Methodology

A. *Snow characterisation*

Snow is precipitation of aggregation of crystalized ice water which occurs in certain weather conditions. Snowflakes have an open structure with uneven surface and they are formed in various shapes: columnar, needle-like, dendritic crystal, etc. The sizes of snowflakes generally vary between 2 to 5 mm and their maximum size can reach up to 15 mm [11]. Snowflakes are large compared to the wavelength of this experiment (1 mm) and attenuation caused by snowflakes is expected to be more pronounced at shorter wavelengths.

Snowflake structure is a combination of air, ice and water. The ratio of this mixture depends on meteorological conditions and can be used to classify them into: dry, wet, watery etc. The fall velocity of dry snow is in the range of 1 to 1.5 m/s and the snowflake has higher fall velocity (in range of 5 to 6 m/s) as the snowflakes have higher water content [11].

B. Measurement setup

The measurement setup in this experiment consists of radar and disdrometer installations. Theis Clima Precipitation Monitor (disdrometer) is installed on the roof of the Department of Electronic, Electrical and Systems Engineering (EESE), in Birmingham, UK as a part of the experimental setup. The laser disdrometer can measure and detect different types of precipitation such as drizzle, rain, snow, hail and mixed precipitation. The instrument also provides the information on intensity of the precipitation and the size spectrum. The disdrometer is isolated to avoid perturbations from nearby obstacles on the measured snowfall rate.

A Stepped Frequency Radar (SFR) operating at frequency of approximately 300 GHz is developed by VivaTech in collaboration with the University of Birmingham [12]. The SFR sweeps frequency between 282 and 298 GHz; a bandwidth of 0.3 GHz is chosen in this experiment to avoid having an unnecessarily high range resolution. The characteristics of the radar are summarized in Table I.

TABLE I. 300 GHz RADAR PARAMETERS

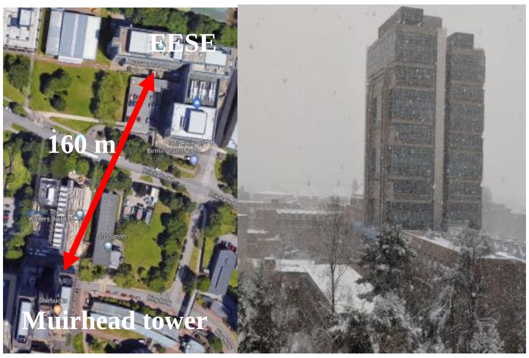
	300 GHz
Output power (dBm)	-17 dBm
Antenna beamwidth Azimuth	1.6°
Antenna beamwidth Elevation	1.2°
Frequency band	282-298 GHz
Antenna gain	39 dBi
Dynamic Range (dB)	35

The radar is in monostatic configuration and placed in the EESE department at an open window. The radar antennas are pointing to a nearby high rise building (Muirhead tower) which is used as a large RCS target in this experiment. The Muirhead tower is a 16-storey building with a height of approximately 195 m above mean sea level and the radar is placed approximately 160 m above mean sea level, on the 5th floor of the EESE building. The radar is placed approximately 25 m above the local ground level to render negligible any ground reflections or scattering due to the ground cover or low lying buildings, given the antenna elevation beamwidth quoted in Table I. Snow accumulation on the radome results in reducing transmissivity due to reflection from the interface between the radome and contaminant and also, absorption through the contaminant, as explained in [2] and [13]. To evaluate the attenuation caused solely by the snow precipitation, it is important to eliminate the effect of any contaminant accumulation on the radome. Therefore, the radar is set 0.5 m inside the open lab window and kept dry at all times with no radome present. This setup gives an unobstructed two-way path length of 320 m between the antennas and target with only snowfall across the antenna beams. Based on the antenna beam and the distance to the target, an area of about 3.3×4.5 m of the tower is covered by the antenna half-power beamwidth. The photos of the laser precipitation monitor and the radars are shown in Fig. 1. An aerial image showing location of the radar and the target and a photo of the target during the snow event on 8th December 2017 are shown in Fig. 2 (a) and (b), respectively.

The snow events occurred on the 8th, 10th and 11th of December 2017. The recorded snowfall by the disdrometer during the three snow events is shown in Fig. 3. The snow starts with rate of below 1 mm/hr and goes up to 10 mm/hr in day 1. The snowfall rate is bigger than 5 mm/hr and reaches 18 mm/hr in the first half of day 2. However, snowfall rate of less than 5 mm/hr is recorded for rest of day 2 and day 3. Light snow is defined as snowfall rate smaller than 1 mm/hr, moderate snowfall as range between 1 mm/hr and 2.5 mm/hr; and snowfall rate greater than 2.5 mm/hr is defined as heavy snow [14]. A total of 33 hours and 7 minutes of snowfall is recorded. Relative humidity exceeds 90% for the majority of the measurement duration, ranging from 90% to 97%. The temperature on day 1 (wet snow event) is above freezing and below freezing on days 2 and 3 (dry snow events). Table II presents the total recorder time (in minutes) and total snowfall (in mm/hr) in 468, 1162 and 357 min for days 1, 2 and 3, respectively.

(a) (b)

Figure 1. Measurement setup (a) laser precipitation monitor and (b) 300 GHz radar



(a) (b)

Figure 2. (a) An aerial image showing location of the radar and the target (b) photo of the target taken on 8th December 2017

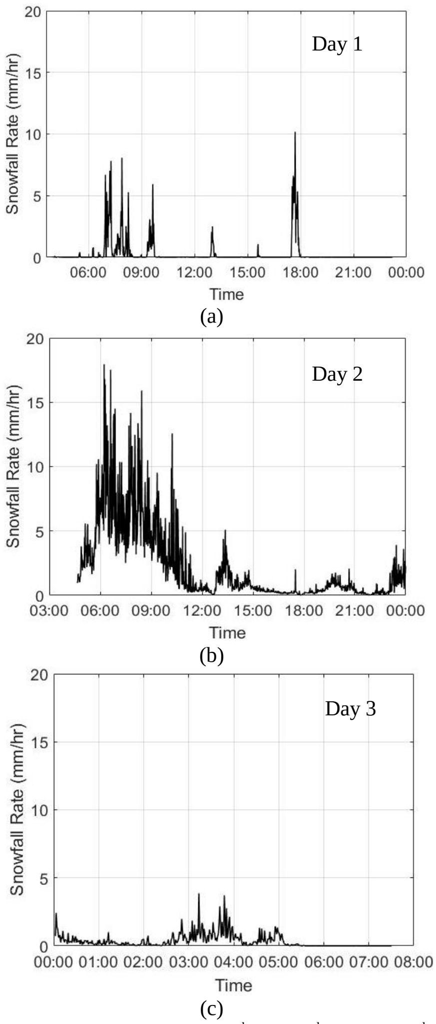


Figure 3. Measured snowfall rate on (a) 8th, (b) 10th and (c) 11th of December 2017

TABLE II. RECORDED SNOW EVENTS

Date	Type of snow	Total Time (min)	Total snowfall (mm/hr)
8th December	Wet	468	333
10th December	Dry	1162	25420
11th December	Dry	357	154

III. MEASUREMENTS AND DISCUSSION

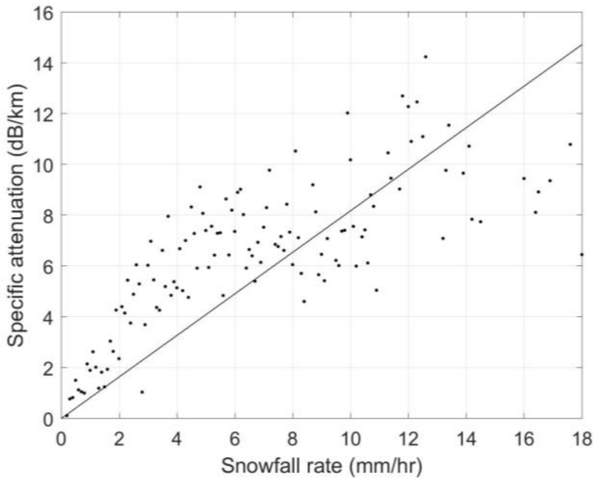
The characterization of wave attenuation through snow is complicated due to variable shape and permittivity of snowflakes, arising from differing water content in each snowflake. The attenuation through different snowfall rates is characterized by comparing the received power from the target through snow precipitation and through clear sky which we employ as a reference signal (no precipitation, just atmospheric gas absorption). The reference is recorded close to the snow events (before and after the event). As mentioned in the previous section, the humidity is not constant during the measurements. Variation in relative humidity will result in the change in the strength of the received power from the target at 300 GHz. The received power from the target reduced by approximately 3 dB when relative humidity changed from 90% to 97%. It is important to account for the effect of attenuation due to different relative humidity when measuring the attenuation caused by snowfall. Therefore, the received power is normalized with respect to the clear air relative humidity measured immediately adjacent to each snowfall event. An integration time of 1-minute is kept constant for the disdrometer and the radar. The 1-minute integration time is commonly adopted as a standard time interval in propagation studies in the literature.

The measured specific attenuation at 300 GHz through dry and wet snowfall are shown in Fig. 4 (a) and (b), respectively. Snowfall rates of up to 18 mm/hr were measured in dry snow events and up to 8 mm/hr for wet snow events. The solid line in Fig. 4 corresponds to a linear regression analysis. The general conclusion is that as snowfall rate increases the attenuation also increases for both wet and dry snow storms. The difference between measured specific attenuation through dry and wet snow shows that higher attenuation is expected for snowflakes with higher water content. The level of absorption in snow depends on different factors and one of the important factors is the level of the snowflakes' water content. The graph shows a wide spread of measured median specific attenuation, with corresponding standard deviations of 1.5 dB/km and 2.5 dB/km for dry and wet snowfall events, respectively. This spread of data is due to different sources of uncertainty. The most significant source of uncertainty is the limitted information on snow characterization. For example, the wind will result in errors in snowfall rate measurement. Also, accumulation of snow on the target will change the reflectivity of the target and this will introduce error in the measured results. Accurate information on snowflake properties such as, shape, size and water content, as well as the distribution of their orientation are all crucial to quantifying scattering and absorption by individual snowflakes.

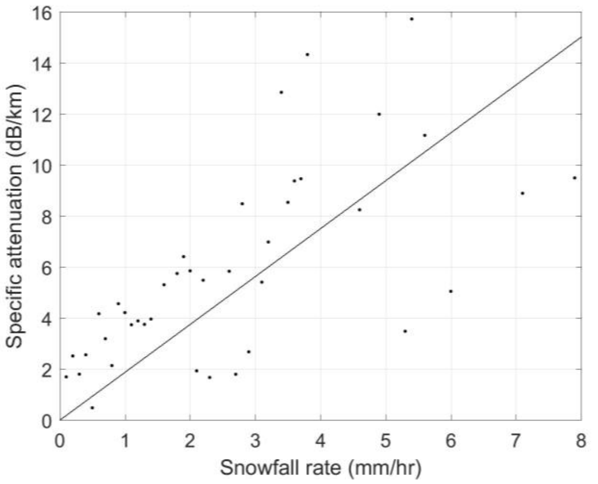
A preliminary study of absorption and scattering through snowflakes is more complex than water drops in rain. This is due to non-spherical and complicated geometrical structure of snowflakes, as well as their inhomogeneous dielectric properties. The model to calculate absorption and scattering through snowfall is done by using "equivalent sphere". There are three ways to produce equivalent spheres: spheres of same volume, same surface area and an aggregate of spheres with same volume and surface area ratio. The absorption is proportional to the volume and scattering is proportional to the surface area [15].

IV. CONCLUSION

Measurements of specific attenuation through wet and dry snow at 300 GHz versus various snowfall rates are presented and discussed in this paper. Measured results show that attenuation through snow is monotonically increasing with snowfall rate. The comparison between attenuation measurement through wet and dry snow shows that higher attenuation is expected for snow with higher water content. The spread of the measured results indicates the need for developing a detailed model of the joint distribution of snowflake size, shape and inhomogeneity. Developing a credible theoretical model is work in progress.



(a)



(b)

Figure 4. Measured specific attenuation at 300 GHz through (a) dry snow and (b) wet snow

V. ACKNOWLEDGEMENT

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