Countermeasures Against Snow Accretion and Icing on Radomes

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Television broadcasting through an artificial satellite calls for a task of solving various problems of propagation of electromagnetic waves in snowy countries, where serious problems of attention is paied to removal of snow accreted on the surface of a radome covering a receiving aerial. Since the wavelengths of electromagnetic waves to be used in satellite broadcasting are extremely short, they are easily absorbed by liquid phase existing in wet snow. The rate of attenuation of a 24-GHz wave was measured as a function of thickness of a water film and found to be 18 dB/mm. One of the most convenient and economical devices to remove wet snow deposited on a radome surface was to rotate the radome at the rate of 100∼1400 r.p.m.. Meanwhile, brushing of the surface of a rotating radome was found effective in removal of rime deposits formed by freezing of supercooled water droplets thereon.

This paper contains some investigation results and countermeasures against snow and ice accretion on the surface of a radome covering a receiving aerial.

Effects of Snow Accretion on a Radome

Television broadcasting through an artificial satellite is being planned in various countries, using electromagnetic waves in the range of 10∼30 GHz. How to prevent antennas from snow accretion may become a serious problem in snowy districts, because the elevation of a receiving antenna aimed to a satellite resting above the equator should be set at a fairly high angle, e.g., 37° in Tokyo and 30° in Sapporo. Therefore, the upward facing surface of a parabolic antenna allows easy accumulation of snow, causing much attenuation of the intensity of the electromagnetic waves received by the antenna. One of the convenient ways to prevent the antenna from snow accretion is to cover it with a plastic dome composed of a low-dielectric loss material, so-called "radome". However, further problem may arise from how to prevent the surface of the radome from snow accretion.

Y. Asami et al. (1) investigated microwave propagation in 1958 in snowy districts in Japan, whereby showed that snow or rime deposited on antennas did not cause any significant trouble for the propagation of microwaves unless accreted snow or rime contained much free water in it. This suggests that, if wet snow accretes or deposited dry snow begins to melt on the surface of a radome, the energy of a microwave received by an antenna may be significantly reduced by the absorption of free water existing in snow. The purpose of this paper is to show the rate of attnuation of an electromagnetic wave ranged in 10∼30 GHz by absorption of the free water and to find a convenient and economical devise to remove snow or rime from the surface of a radome.

Absorption of a 24-GHz Wave by a Water Film on a Radome Surface

Michiya Suzuki, (2) Mitsuhiro Ono and Yasuo Nomura made in 1973 a simple experiment on the attenuation of an electromagnetic wave by absorption of a water film, using a 24-GHz wave (1.25 cm in wavelength), one of the waves to be used in satellite broadcasting in future. As shown in Figure 1, the 24-GHz wave was emitted perpendicularly against a plastic board (0.5 m × 0.5 m; 1 cm in thickness), where water was continuously flowed on its surface. A sensitive receiver was placed behind the board to measure the attenuation of the wave which passed the board. Since the surface of the plastic boad was hydrophobic, a sheet of gauze was stretched on the surface to maintain flowing water in a uniform thickness.

When the surface of the plastic board was dry, the attenuation of only 0.2 dB was observed. While water began to flow uniformly through the gauze, the attenuation increased as a function of the thickness of water film or the flow rate of water as shown in Figure 2, a, where a solid line indicates theoretical values of attenuation calculated by the formula given by Hippel (1961) on the assumption that numerical values of dielectric constant and loss factor of free water in the range of 24 GHz are 34 and 0.265, respectively. As seen in this

Figure 1 Block diagram to measure the attenuation of a 24-GHz wave by absorption of a water film
K: Transmitter of a 24-GHz wave
R: Sensitive receiver
SA: Absorber of an electromagnetic wave
SP: Plastic board (0.5 m × 0.5 m; thickness 1 cm)
W: Water flow on the surface of the plastic board

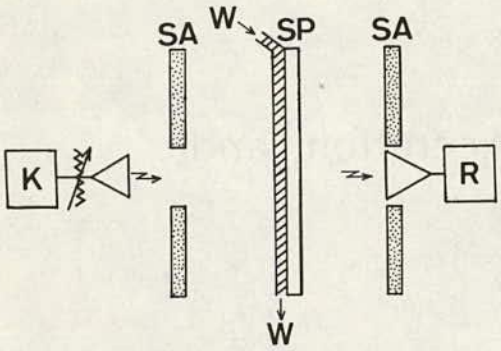
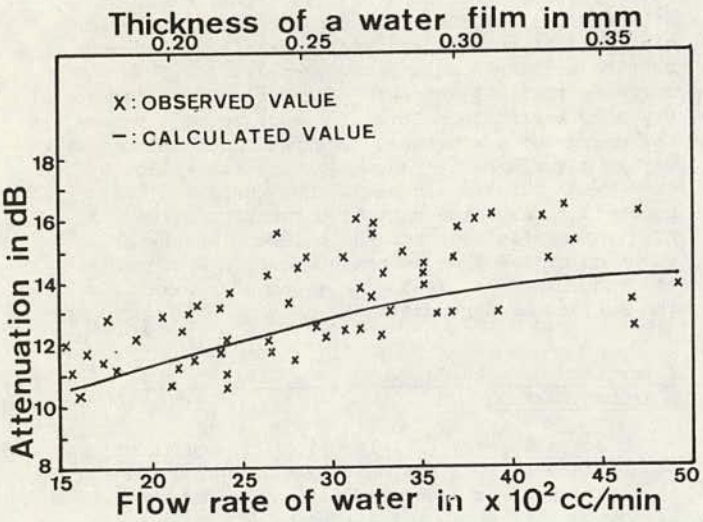


Figure 2 Attenuation factor vs. thickness of water film and flow rate of water



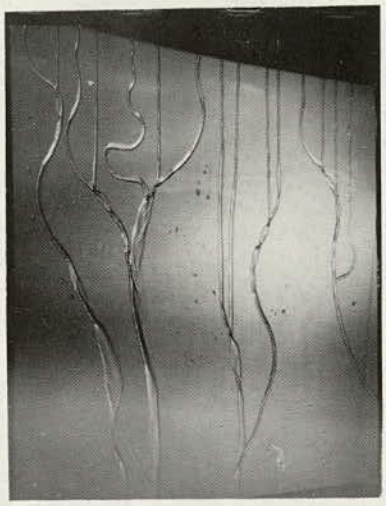
figure, the rate of attenuation of the 24-GHz wave by a water film found to be approximately 18 dB/mm.

It should be noted, however, that, when poured water flowed down in the form of strings, as shown in Figure 3, the attenuation depended upon the percentage of area screened by stringing water. This expermental result strongly suggests that wet snow deposited on the surface of a radome reduces significantly the intensity of an electromagnetic wave. In acuality, it has been reported (3) that wet snow deposited in thickness of about 0.33 m on a radome surface attenuated the intensity of a 11-GHz wave in value of 8.5 dB.

Shape of Snow Deposited on a Radome

In order to find a convenient and economical devise to remove snow accreted on a radome surface,

Figure 3 Stringing water flow on a radome surface



two types of radomes, i.e. cone- (or umbrella-) type radome and spherical radome were tested in our investigation. The typical shape of snow deposited on a radome placed in a natural snowfall is studied first.

a) Deposition of snow on a cone-type radome

A cone-type radome which consists of a fiber-reinforced plastic (F.R.P.), 3.3 m in diameter and 120° in the flair angle, was placed on the rooftop of a building of Yamagata University. The angle of elevation of the radome was set at 45°. Figure 4,a, shows a typical shape of deposition of wet snow on the surface of the radome. The thickness of the snow deposited was approximately 0.2 m at the upper part of the radome. When the air temperature approached 0°C, snow accreted on the lower part of the radome was removed by gravity. Figure 4,b, shows a photograph taken about 2 hours later than the previous picture. As the air temperature rose to +2.1°C, a large part of snow was dropped off, leaving a small amount of snow at the upper surface of the radome. However, melted water came out from the remaining snow and flowed down continuously on the surface of the radome, forming many strings. Many water droplets also adhered on the surface of the radome. Though the removal of snow by gravity was accerelated as the result of the rise of air temperature and radiation of the sunlight, the moistened radome surface have caused a significant attenuation of the electromagnetic wave.

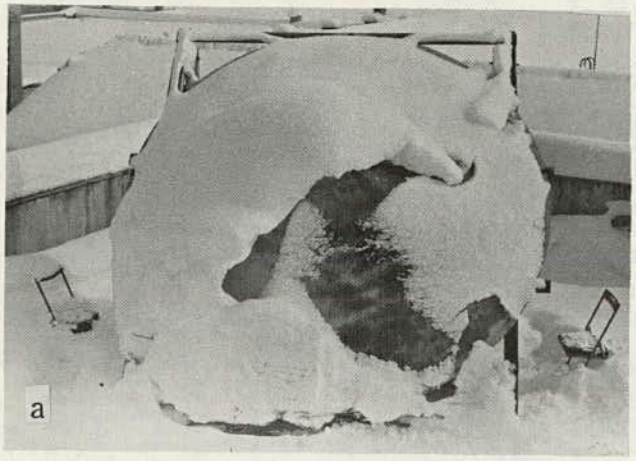
b) Deposition of snow on a spherical radome

Figure 5,a, shows a typical shape of deposition of snow on the surface of a spherical radome, 0.5 m in diameter. When the spherical radome was placed in a calmly precipitating snowfall, a cylindrical deposit was formed vertically on the hemisphere of the radome, as seen in this picture. However, when it was placed in a windy snowfall, snow accreted at both the windward and lee-side surfaces, as shown in Figure 5,b.

How to Remove Deposited Snow from a Radome Surface

Many studies have been made with a view to removing snow deposited on a radome surface. One of the most effective ways for de-icing and anti-icing is to heat the surface of the radome until deposited snow is completely removed by melting. Since the method of de-icing by heating consumes much energy

Figure 4 Shape of wet snow deposited on a cone-type radome (3 m in diameter; 120° in flair angle) Elevation angle : 48.2°
a) +1.5°C; 10h30m, Feb. 10, 1973
b) +2.1°C; 12h45m, Feb. 10, 1973



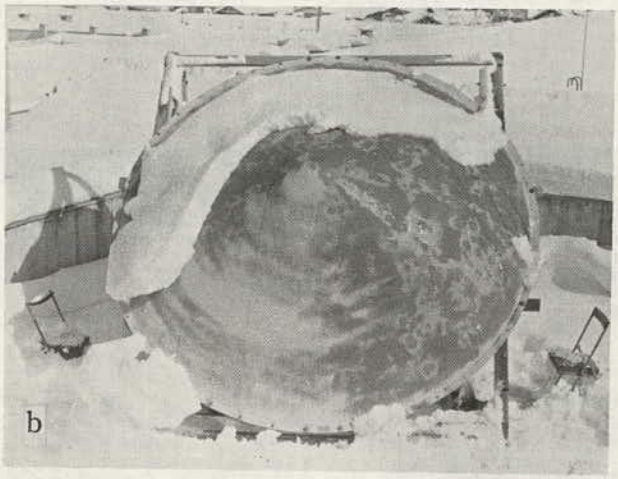
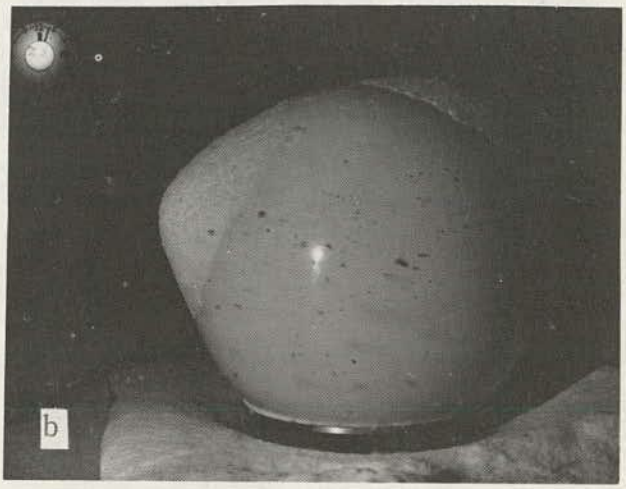


Figure 5 Shape of snow deposited on a spherical radome
a) Cylindrical deposit formed in a calm snowfall
b) Cone-shaped deposit formed at windward and lee-side of a sphere in a windy snowfall



depending on the amount of deposited snow and meteorological conditions, heating is far from satisfying the need for individual houses to keep their radomes free from snow accretion. The application of a chemical de-icer may also be too inconvenient to be used in residencial areas. Therefore, mechanical de-icing methods (4) were tested in our investigation.

a) De-icing by rotation of a radome

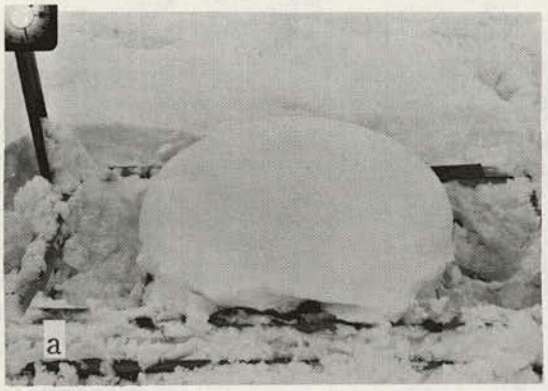
To remove snow deposited on a radome surface by action of centrifugal force, the radome was rotated around its principal axis at the rate of 100~1400 r.p.m.. Figure 6,a, shows the shape of snow deposited on a resting cone-type radome (before the application of rotation). Its elevation angle was 80°. When it began to rotate, a large part of snow was removed within 10 seconds. As seen in Figure 6, b, the rotation was continued for 60 seconds in a heavy snowfall, but no snow flakes were allowed to deposit on the surface of the radome except at the vertex of the cone where action of centrifugal force diminished.

Figure 7 shows the schematic diagram of an experimental apparatus used to rotate a spherical radome, 0.5 m in diameter and 2.4 kg in weight. Figure 8 shows the photograph of a spherical radome taken two hours after the application of rotation at the rate of 300 r.p.m. in a heavy snowfall. The air temperature was -2.5°C, but no snow was allowed to deposited on the surface of the radome except at the zenith of it. According to our experiments, de-icing by the rotation of the radome was successful for snow accretion occuring at the air temperatures above -3°C.

b) De-icing by brushing

The method of de-icing by rotation of a radome was effective for wet snow deposition, but it was not always successful for rime deposition created by freezing of supercooled water droplets. For removal of rime deposits, a brushing device was applied on the surface of a rotating radome. Figure 9 shows two types of brushes applied, while Figure 10 represents a typical brushing result for de-icing. When riming occurred at the wind velocity of 1.5 m/sec and the air temperature of -9°C, the brushing device was applied on the surface of a radome rotating at the rate of 500 r.p.m.. This

Figure 6 Removal of snow by rotation of a cone-type radome (0.8 m in diameter; the angle of elevation: 80°)
a) Before rotation
b) 60 seconds after rotation at 300 r.p.m.



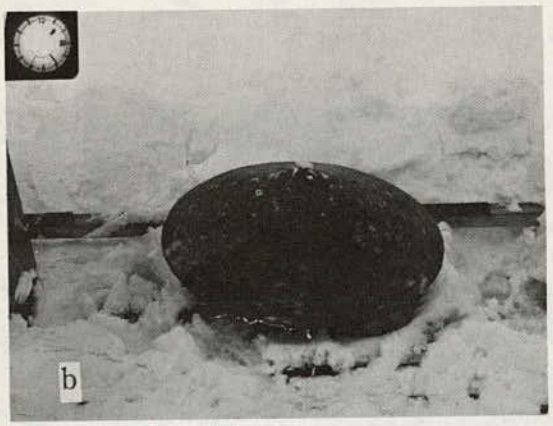


Figure 7 Schematic diagram of an experimental appratus to rotate spherical radome

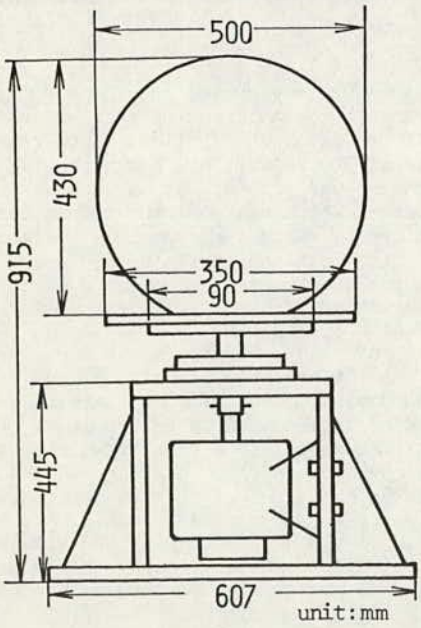


Figure 8 Result of removal from a spherical radome, the picture being taken 120 min. after application of rotation at -2.5°C

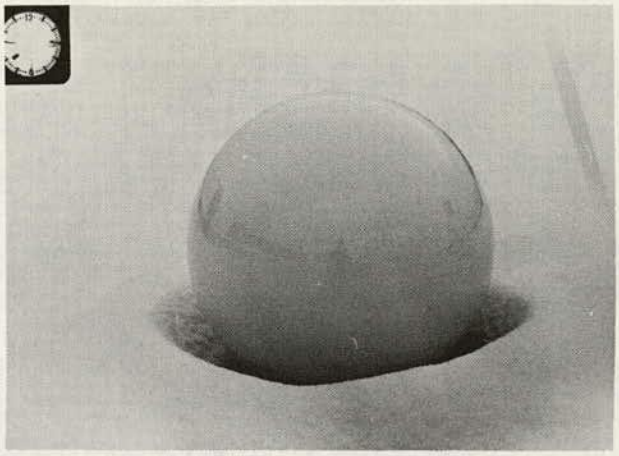
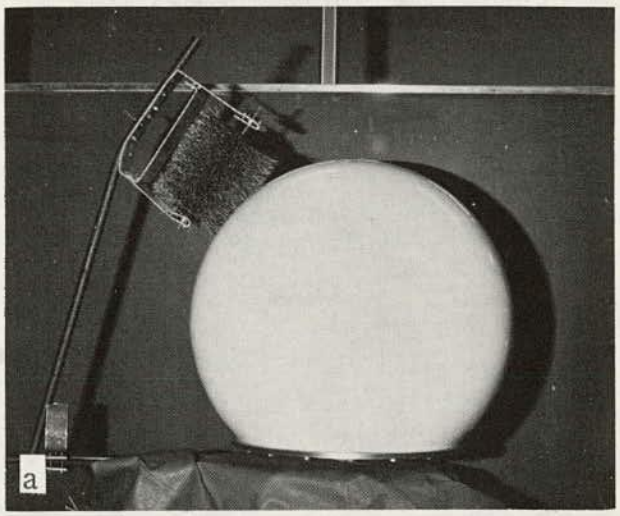


Figure 9 Two types of brushes applied on a radome surface
a) Brush is contacted on the surface
b) Brush can move on the surface like an automobil's wiper



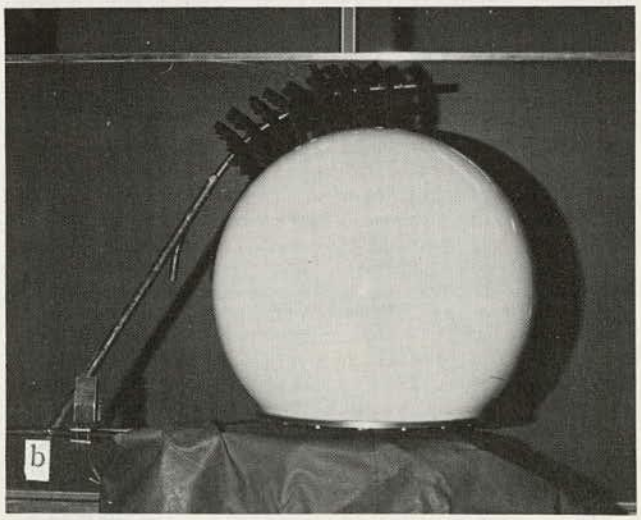
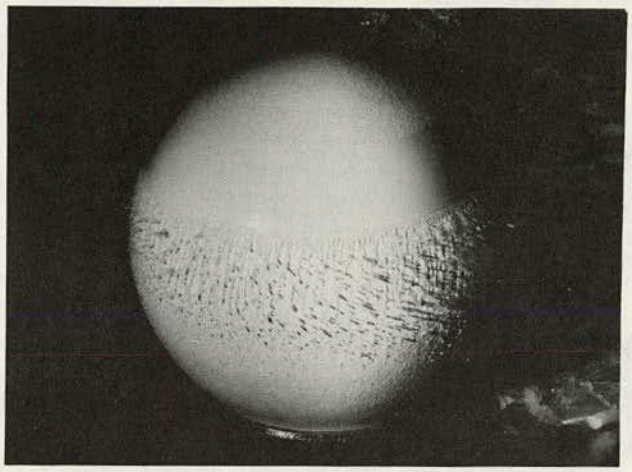


Figure 10 Typical brushing result of removal of rime from the surface of a rotating radome at -9.6°C

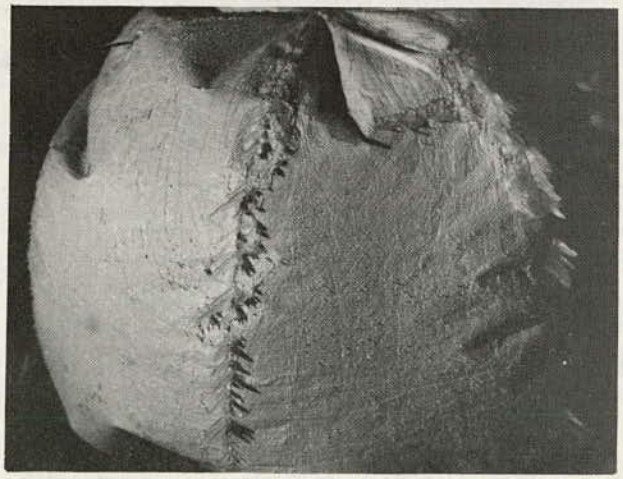


picture indicates that brushing is effective to remove rime deposits from the surface of rotating radome.

c) De-icing by inflation or fluttering of a soft plastic sheet covering a radome surface

It has been accepted that thick rime or ice deposited on the leading edge of an aircraft wing could be removed by inflation of a rubber sheet stretched on the surface of the leading edge. Following this idea, a simple test was made to remove ice deposited from surface of a radome. The surface of a spherical radome was loosely covered with a soft plastic sheet composed of a fine polyethylene net and laminate resin. After making ice deposits on the surface of the sheet by spraying water droplets at low temperature, an air gap between the sheet and the radome was periodically inflated by the aid of a blower. A large part of ice deposits were removed except ice fragments which had adhered along a seam of the sheet, as shown in Figure 11. The efficiency in removal of ice deposited on the surface of a soft plastic sheet could be increased by fluttering of the sheet by action of a natural wind and rotation of the radome.

Figure 11 De-icing by inflation of a soft plastic sheet covering a spherical radome



Concluding Remarks

It was shown by simple experiments that the intensity of a 24-GHz wave was attenuated by the absorption of a water film at the rate of 18 dB/mm. Therefore, snow or rime that accreted on the radome surface should be removed completely before the deposit begins to melt. Our investigations showed that the rotation of a radome was very successful to prevent the radome surface from snow accretion and that the application of an appropriate brush de-icer on the rotating radome surface was effective to remove rime deposits formed by freezing of supercooled water droplets at low air temperatures. A d.c. electric motor used to rotate a radome in our experiments required the electric power of about 100 watts for a spherical radome (0.5 m in diameter; 2.4 kg in weight) at 300 r.p.m. and about 26 watts for a cone-type radome (0.8 m in diameter; 2.1 kg in weight) at 300 r.p.m..

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