that minimization of the stray capacitance associated with the overlay is achieved only with decreased ambient protection due to the decrease in the overlay area.

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4-gc Transmission Degradation Due to Rain at the Andover, Maine, Satellite Station

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I. INTRODUCTION

The microwave link between a ground station and a communications satellite is normally very stable and essentially free from fading. Under conditions of rain or snow, however, the transmitted and received signals encounter extra attenuation and additional noise is introduced into the low-noise receiver on the ground. A good knowledge of such rain effects is important for the design of satellite ground stations which have to meet certain statistical requirements for transmission degradation. It is known that radome covered ground stations like Andover, suffer more degradation during rain than uncovered stations. Some analytical work has been done by D. Gibble[1] and B. C. Blevis[2] to determine the effects of a water layer on radomes. Their theoretical work has been supplemented by an experimental technique applicable at existing satellite ground stations and to be described in this brief report. It consists of measuring the reduction of the noise power received from the strong and stable radio star Cassiopeia A during periods of rain.

II. THE MEASURING TECHNIQUE

If the ground station antenna is pointed exactly at Cassiopeia A, the noise power received will be proportional to

$$T_{tot} = T_{SYS} + tT_A \tag{1}$$

where T_{SYS} = receiving system noise temperature referred to the input terminal of the low noise receiver (maser) if the antenna is pointed in the vicinity of the star but far enough away from it to make its contribution to the noise temperature negligible. T_{SYS} can be conveniently measured at the Andover station

T_A = temperature due to the radio star alone at the maser input under the assumption of zero loss in the transmission path (except for geometrical path loss)

t = power transmission coefficient due to the transmission path (atmosphere, rain, radome, waveguides) to the input of the maser.

Solving (1) for t we obtain:

$$t = \frac{T_{tot} - T_{SYS}}{T_A} = \frac{T_{SYS}}{T_A}\left(\frac{T_{tot}}{T_{SYS}} - 1\right). \tag{2}$$

Now we introduce $\Delta = T_{tot}/T_{SYS}$, a quantity which can be easily measured as a power ratio at the output of the receiver by moving the antenna on and off the radio star. Equation (2) becomes now:

$$t = (T_{SYS}/T_A)/(\Delta - 1). \tag{3}$$

A measurement during dry weather yields

$$t_o = (T_{SYS_o}/T_A)(\Delta_o - 1). \tag{4}$$

This allows the definition of an excess transmission coefficient

$$t_x = \frac{t}{t_o} = \frac{T_{SYS}}{T_{SYS_o}} \frac{\Delta - 1}{\Delta_o - 1} \tag{5}$$

giving the signal loss over the normal "dry" value. The degradation D of the signal-to-noise (SNR) ratio in the receiver is

$$D = \frac{\text{SNR}}{\text{SNR}_o} = \frac{t/T_{SYS}}{t_o/T_{SYS_o}} = t_x \frac{T_{SYS_o}}{T_{SYS}} = \frac{\Delta - 1}{\Delta_o - 1}. \tag{6}$$

Since rainfall occurs at rather unpredictable times, it was not feasible to drive the Andover antenna along the path of Cassiopeia A by computer tape. Instead, a computer printout was made available to the

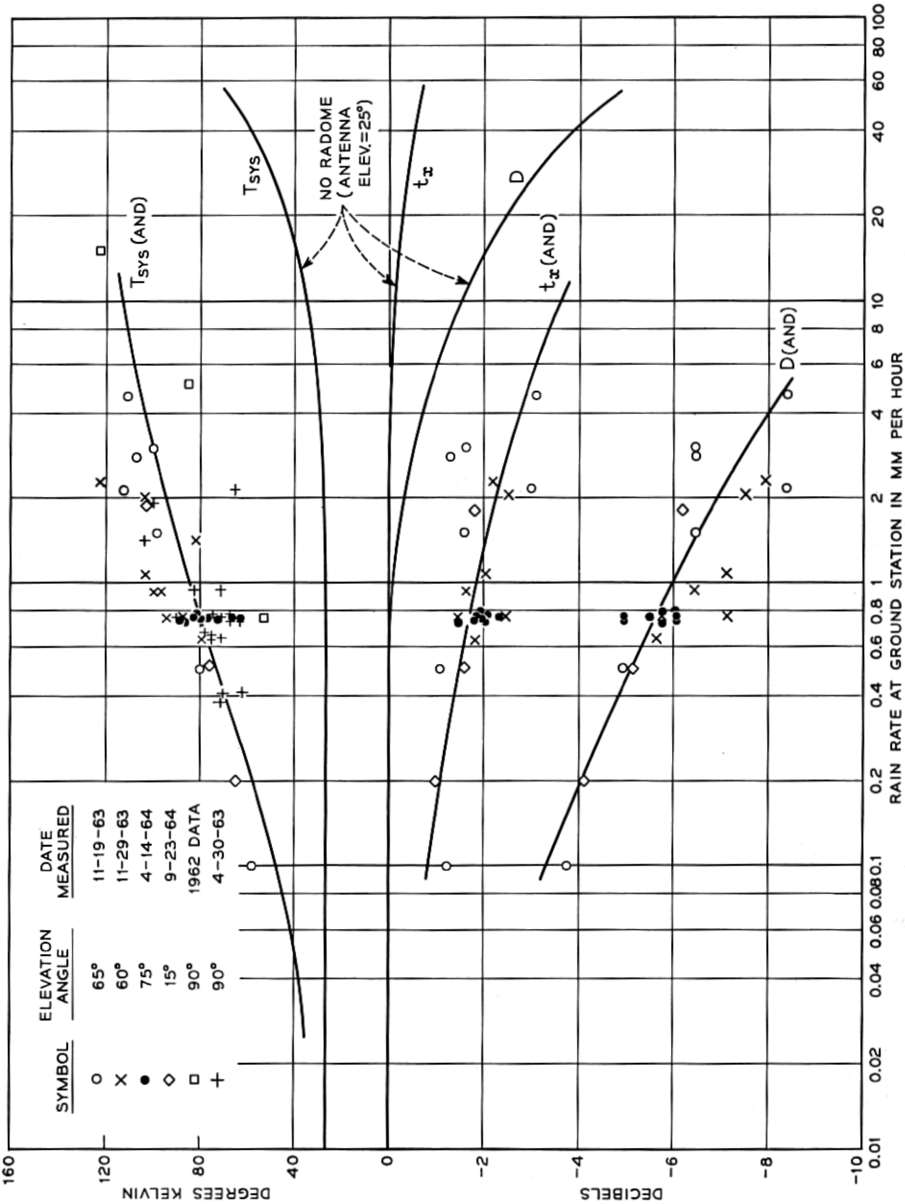

Fig. 1 — Transmission degradations caused by rain.

station operators in Andover containing the star's coordinates at intervals of 10 minutes for a period of several months. The antenna is then set manually to the calculated Cas A coordinates about 5 minutes ahead of time and the drift of the star through the antenna beam is observed on the IF power meter at the output of the receiver. The maximum noise level is recorded and the antenna is quickly swung away about 3° from the star. The noise power drop yields Δ. In addition, T_{SYS} is measured in this position. Measurements can be repeated every 10 minutes at any desired time since Cassiopeia A is always visible from Andover at elevation angles ranging from 13.3° to 76°. Equations (5) and (6) require the knowledge of T_{SYS_o} and Δ_o, two quantities which have to be measured on a dry day as a function of antenna elevation angle.

Measured values of T_{SYS}, t_x and D are plotted in a scatter diagram (Fig. 1) vs the rain rate existing at the Andover site. Because the transmission degradation is mainly due to the water layer on the radome, which is directly related to the local rain rate, a reasonable correlation is exhibited by the scatter plots. Since the radome is still wet, some transmission degradation is observed for about 30 minutes after the rain has stopped. Measurements taken during this period of time have been excluded from Fig. 1.

The measurements were made at the elevation angles of Cassiopeia A at the time of the rain, but the results do not seem to indicate any systematic dependence on elevation. This has been found before during measurements of T_{SYS} vs elevation during rain (see Fig. 16 of Ref. 3). It also checks with Gibble's theory which says that the thickness of the water layer on the radome is approximately the same everywhere.

As indicated by Fig. 1, the degradation in signal-to-noise ratio can be appreciable. Since it is the water layer and not the radome material which causes the degradation, results are expected to be similar with other materials. This assumes that water cannot penetrate the material and is preferably repelled by the radome surface. The inflated Andover radome, made of Hypalon coated Dacron fabric, has such desirable features. It is about 2-mm thick, the dielectric constant is 3.0, and the loss tangent 0.0155 under dry conditions.

III. ESTIMATED RESULTS FOR AN UNCOVERED ANTENNA

No measurements of the same nature are available for an uncovered antenna at Andover. It is important, however, to know the difference in the electrical characteristics of a covered and an uncovered antenna during rain. A simple model is proposed to estimate the rain characteristics of the uncovered antenna. It consists of a volume of rain with uniform rate of precipitation and temperature T_R and a constant ceiling, h, of 5 km, extending indefinitely in lateral direction. This model should give a pessimistic answer for the transmission degradation because: (1.) precipitation normally stops at an altitude of about 3 km in temperate zones and at about 1 km in tropical zones with a heavy nimbo-stratus cloud mass extending to about 3 km, Ref. 4, and (2.) the average rain rate over an extended area is normally below the rain rate measured (during rainfall) at a fixed point[5] (the satellite ground station). We further assume that the antenna is directed at a fixed elevation of 25° which corresponds to the angle at Andover when operating with the stationary satellite Early Bird. This model gives a path-length in rain of $l = h/\sin 25° = 5/0.4226 = 11.8$ km. Signal attenuations per km, α, for various rain rates and frequencies are given by S. D. Hathaway and H. W. Evans.[6] The attenuation in the 11.8-km long path can therefore be easily calculated at a frequency of 4 gc for various rain rates. The rain attenuation at 4 gc is entirely due to absorption except for very heavy rainfalls where about 1 per cent of the energy is scattered. Neglecting scattering entirely, the rain loss αl (in decibels) can be directly related to the extra noise temperature T_a picked up by the antenna of the ground station,

$$T_a = T_R(1 - t_x) \tag{7}$$

where

$$t_x = 10^{-\alpha l/10}. \tag{8}$$

It should be noted that no such simple relation exists between loss and noise temperature for the radome covered antenna because substantial scattering is provided by the wet radome.

The total noise temperature of the uncovered system at Andover would then be

$$T_{SYS} = T_{SYS_o} \text{ (at 25° elevation)} + T_a = 26°\text{K} + T_a \tag{9}$$

and the degradation becomes

$$D = \frac{\text{SNR}}{\text{SNR}_o} = t_x \frac{T_{SYS_o}(25°)}{T_{SYS}} = \frac{t_x}{1 + \dfrac{T_a}{26°\text{K}}}. \tag{10}$$

The three quantities t_x, T_{SYS} and D for the uncovered antenna are shown in Fig. 1 for comparison.

The curves show that a radome covered ground station antenna is affected considerably more by rain than an uncovered antenna.

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