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Progress Report for the Period

1 December 1971 - 30 April 1972

Attenuation Studies at 35 GHz

by

Lai-iun Lo

Wolfhard Vogel

Contract No. NAS5-10387

Prepared by

Millimeter Wave Group
Electrical Engineering Research Laboratory
The University of Texas at Austin
Austin, Texas

for

Goddard Space Flight Center
Greenbelt, Maryland

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I. INTRODUCTION

This report presents the instrumentation and preliminary results of studies of attenuation of 35 GHz radio signals transmitted through the atmosphere. The purpose of this phase of the work is to provide information to supplement the ATS-5 downlink tests performed by GSFC/NASA. The period from 1 December 1971 through April 31, 1972 was chosen to correspond with the time interval appropriate to the topic to which this progress report is devoted. Any additional research in this area will be covered in the comprehensive final report due at the end of June.

Data on atmospheric losses at 35 GHz are being obtained by three methods as follows:

A. Sun tracker techniques

B. Sky temperature observations

C. Point-to-point transmissions

Details of each method are given later.

In addition supplemental information is being obtained as follows:

1. Three tipping bucket rain gauges are in use for obtaining rain and rain rate data.
2. A 95 GHz radiometer is used on the same mount with the 35 GHz radiometer in order to obtain information at higher frequencies. The 95 GHz studies are supported by the Air Force under Contract F33615-71-C-1203.

All of the observations covered by this report have been made at the Balcones Research Center of The University of Texas at Austin on the northern edge of Austin, Texas.

II. SUN TRACKER

The 35 GHz radiometer makes use of one of the 10 foot dish antennas acquired for the ATS-5 experiment. This parabola is mounted on a ballistic radar turret which is remotely controllable in azimuth and elevation in steps of about 1/18th of a degree. In order to track the sun without requiring a very stable foundation or knowledge of the axis errors, a closed loop feedback system which maximizes the output of the radiometer was designed and built. It changes antenna azimuth or elevation by one step in the direction of the movement of the sun. If the signal decreases, the antenna moves back to the previous position. The antenna is stepped once a second - a compromise between maximum azimuth speed of the sun at its highest elevation (77.5°), anticipated fastest path attenuation changes and the time response of the hydraulic servo. The maximization occurs alternately five times in azimuth and once in elevation. With these parameters the antenna can be moved with a speed always exceeding the speed of the sun. The lock-in range during rainstorms is essentially controlled by the dynamic range of the radiometric system.

III. 35 GHz RADIOMETER

The 35 GHz radiometer is of the Dicke type and consists of a superheterodyne receiver preceded by a motor-driven chopper which modulates the incoming signal and followed by a synchronous detector and chart recorder. The output voltage is shown both on the chart recorder and on a digital voltmeter. A print out is provided by a digital printer. Time data were also recorded.

Between the antenna and modulator, a waveguide switch was added to enable hot or cold load calibrations depending on whether attenuation or emission measurements were made. When the radiometer is used for attenuation measurement (sun tracking mode) the gas discharge type noise tube which has an excess noise ratio of 15.6 dB followed by a precision attenuator can be switched to the input port of the radiometer for calibration. On the opposite side of the switch from the noise tube a matched termination is connected which can be immersed in the liquid nitrogen (77°K) for the calibration of emission measurement temperatures (sky temperature mode).

When an observation is made with the radiometer, the signal which is received by the ten foot antenna with a half power beam width of 0.25° passes through the waveguide switch and is modulated by the motor-driven chopper at a frequency of 30 Hz. The modulated signal is then mixed with the local oscillator power at the balanced mixer. The output from the mixer goes to the IF preamplifier which has a center frequency of 60 MHz and a 3 dB bandwidth of 8 MHz. The radiometer front end and the preamplifier are embedded in a plywood box which is temperature controlled within a 0.5°C range. The box is mounted on an I-beam near the receiving antenna. The output of the preamplifier goes to the main amplifier located in a shelter twenty feet north of the radiometer. Also in the shelter are power supplies, control boards and recording equipment. The output from the detector stage of the main amplifier is detected in the lock-in amplifier and is both recorded on the chart and printed on the paper.

IV. 35 GHz LINE-OF-SIGHT PATH

The transmitter for the line-of-sight path is a battery powered Gunn diode which is mounted in the focus of a 4 foot paraboloid reflector and provides a transmitter power of 20 mw. The path over an open grassy field has a length of 660 m. The signal-to-noise ratio at the superheterodyne receiver for a clear atmosphere is at least 100 dB. The receiver is an 18 inch paraboloid reflector antenna. The local oscillator frequency is modulated to sweep the difference frequencies through the 30 MHz IF. The detected peak values are presented on a chart recorder with a dynamic range of about 20 dB resulting in the capability of measuring rain showers with intensities as high as 150 mm/hr. Both antennas are exposed to the outside weather conditions to avoid problems caused by wet radomes.

V. DATA ACQUISITION THEORY AND PROCEDURES

According to Kirchhoff's Law for a uniform medium in thermodynamic equilibrium, a good absorber is also a good emitter. Atmospheric gases and precipitation not only absorb but also emit electromagnetic energy, and this emission is often referred to as sky noise. Using Kirchhoff's Law and conservation of energy, one can derive the equation of radiative transfer which describes the radiation field in the atmosphere which can be measured with a microwave antenna. For a non-scattering atmosphere the amount of radiation received from the antenna when it is pointed at the source is:

$$T_A = T_A' e^{-\Gamma} + \int_0^\infty T(s)\,\alpha(s)\,e^{-\int_0^s \alpha(s')ds'}\,ds \qquad (1)$$

where T_A = effective antenna temperature, °K

T_A' = effective antenna temperature due to extraterrestrial sources with no interferring atmosphere, °K

Γ = total attenuation, nepers

$\alpha(s)$ = absorption coefficient at s, nepers per meter

The first term at the right side of the equation represents direct energy from the source being attenuated by the atmosphere, and the second term represents the noise radiated by the atmosphere.

In principle, there are two ways of measuring the atmospheric attenuation through the entire atmosphere:

1. Using the sun as a source, observations are made by measuring the extinction (Γ) of the source (T_A') by the atmosphere which is basically the first term on the right side of equation (1). The sun tracker, which was designed for this purpose has a dynamic range of 12 dB and a sensitivity of 1°K. It can follow the sun from a minimum elevation angle below 20°, which depends on the azimuth angle, up to an angle of 77.5°.

The positions of the sun and the number of air masses through the atmosphere from sunrise to sunset were calculated in five minute intervals from the sun ephemeris for the Austin area as a reference for locating the sun position at the beginning of the tracking and for correcting the attenuation to zenith attenuation at any elevation angle.

2. Under the assumption that the atmospheric attenuation is caused by absorption only, the sky temperature as measured by the radiometer can be converted to attenuation in decibels from the equation

$$\Gamma(\mathrm{dB}) = -10 \log \left(1 - \frac{T_e}{\overline{T}}\right) \quad (2)$$

where: T_e = measured sky temperature

$\overline{T}$ = mean temperature of the atmosphere averaged over the absorption path.

The relation of emission temperature vs attenuation as given by equation (2) limits the useful range of measurements to approximately 12 dB. Errors due to the uncertainty in T_e and $\overline{T}$ exist. The error due to an uncertainty of $\Delta T_e = 1°K$ is limited to 0.2 dB for attenuation losses of 10 dB but the error due to $\Delta\overline{T} = 10°K$ is 1.2 dB for the 10 dB loss level. This indicates that for accurate attenuation determination, the knowledge of mean path temperature is critical.

Before each measurement, the radiometers were allowed to warm up for at least one hour. Calibrations were performed before and after each data taking period and between the periods as needed. The precision attenuator which precedes the noise tube was preset to the level required to give the same output as obtained when tracking the sun without the interferring atmosphere. Additional attenuation was then added for calibration. Continuous ground level temperature and relative humidity were recorded simultaneously. Two tipping-bucket-type rain gauges were set near the radiometer and a third was located 2000 feet south of the site for comparison of rainfall rates and attenuation.

VI. DATA OBTAINED

A. Rainstorm of March 20, 1972

On March 20, 1972 measurements were made over the 660 meter path through a rain which totaled 0.45 inches in a 36 minute interval. The level of attenuation and the rain rate were determined at a number of different times during the storm. From these results the measured attenuation as a function of the rainfall rate was obtained.

The theoretical attenuation based on computer calculations for rain at 20°C assuming Laws and Parsons' drop size distributions is somewhat less than the measured values but the general correlation is good. The maximum measured attenuation was 17.4 dB/km for a maximum rain rate of 91 mm/hr.

No data were obtained with the radiometers during this rainstorm because its sudden onset did not permit sufficient warm up time.

B. Rain During April 26-28, 1972

A period of extended rain and rainshowers occurred on April 26 through 28, 1972 during which both sun tracking and sky temperature data were obtained.

The results of 50 minutes sun tracking were analyzed. Coordinates of the sun at 12:00 Noon were 72° elevation and 156° azimuth (north = 0°, south = 180°). At the start of the run, the meteorological conditions were characterized by a pause in measurable precipitation with 96 to 100% humidity and low dense clouds of large horizontal extent. During the first 25 minute interval the 35 GHz signal was attenuated between 0.1

and 1 dB compared to the clear day signal level, whereas the 92 GHz attenuation varied between 3 and 9.5 dB. The ratio of 92 to 35 GHz attenuation was rather high at that time, but decreased as the attenuations increased while heavier clouds move through the signal path. Considering that part of the attenuation was caused by water droplets, the Mie theory predicts a peak in the attenuation ratio of 12 to 1 for droplets of .4 mm diameter. When heavy clouds or rain attenuation exist the ratio will first rise and then reach a maximum as the drop sizes increase but will decrease with further increase in drop sizes associated with increased equivalent rain rates. This relationship is borne out by the measured data.

At the beginning of the sun tracking period the precipitation rate was 5 min/hr. As the rate increased the attenuation exceeded the dynamic ranges of both the 35 GHz and 92 GHz radiometers and the receiving mode for both radiometers was changed to sky temperature measurements.

Simultaneous records of the 35 GHz line-of-sight, the 35 GHz radiometer and the 92 GHz radiometer in the sky temperature modes were analyzed. There is no close correlation between the line-of-sight attenuation and the output of the radiometers. The maximum line-of-sight attenuation of 15 dB corresponds to a theoretical rain rate of about 40 mm/hr, whereas 30 mm/hr was measured. The reason for this might be a higher than average peak rain rate along portions of the path. Since at 35 GHz the attenuation is a measure of the average rain rate along the path the one rain gauge in use at this time may have measured less than the true average rate. During a ten minute period both radiometers were saturated. This means that attenuations in excess of about 12 dB would have occurred on ground-to-satellite links.