MILLIMETER WAVE SPACE COMMUNICATIONS

WITH THE ATS-F SATELLITE

Louis J. Ippolito
NASA/Goddard Space Flight Center
Greenbelt, Maryland

Abstract

The first space communications system operating at millimeter wavelengths is planned for the sixth NASA Applications Technology Satellite (ATS-F), scheduled for launch in April of 1974. The ATS-F experiment is designed to provide engineering data on wideband space-to-earth transmissions at 20 GHz and 30 GHz as a function of meteorological conditions and modulation techniques. This paper describes the system design for both the spacecraft and ground station portions of the experiment and emphasizes the unique design characteristics of these relatively new and unexplored frequency bands.

Introduction

The first space communications system operating at millimeter wavelengths is planned for launch in April of 1974 on the sixth Applications Technology Satellite (ATS-F). The ATS-F Experiment is designed to provide engineering data on wideband space-to-earth transmissions at 20 GHz and 30 GHz as a function of meteorological conditions and modulation techniques.

The experiment is designed to provide wideband 1440 MHz propagation links and 40 Megabit communications links with simultaneous downlink operation at 20 GHz, 30 GHz, and 4 GHz for link comparisons.

The radio frequency bands below 10 GHz, which presently support virtually all terrestrial and space communications links, are rapidly becoming overcrowded. The communications demands of an expanding technology are requiring the systems designer to look to new frequency bands to support high data rate communications links. The frequency bands between 10 and 100 GHz, commonly called "millimeter waves," offer a promising area for reducing the crowding in the lower bands. A number of earth-space applications, including domestic distribution, data relay, wideband communications, navigation, and earth resources would benefit from the uncluttered spectrum and the high data rates possible with millimeter wave communications systems.

Propagation effects in the millimeter band can be more severe than in the lower bands, however, and reliable earth-space communications could be hindered, particularly during such heavy precipitation events as rain, hail, or wet snow. The ATS-F Experiment will measure the propagation characteristics of wideband 1440 MHz multitone propagation downlinks centered at 20 and 30 GHz and of communications downlinks operating simultaneously at 20 GHz, 30 GHz, and 4 GHz.

Experiment Objectives

The ATS-F Millimeter Wave Propagation Experiment (MWE) is designed to evaluate the propagation characteristics of space-to-earth links centered at 20 GHz and 30 GHz during measured meteorological conditions. The ATS-F MWE is the second NASA flight experiment for the evaluations of propagation effects above 10 GHz. The first experiment, launched on-board ATS-5, has been providing measurements at 15.3 GHz and 31.6 GHz since August 1969.[1,2]

The primary objectives of the ATS-F Millimeter Wave Experiment are described under three areas of investigation:

1. Propagation - provide the propagation characteristics of space-earth communication links operating at 20 GHz and 30 GHz under various meteorological conditions and modulation techniques.

2. Communications - provide engineering data on space-earth communications links operating at 20 GHz and 30 GHz under various meteorological conditions and modulation techniques.

3. Prediction - investigate techniques for predicting millimeter wave propagation effects from indirect means such as radiometric sky temperature, radar backscatter, etc., and establish a model for the millimeter wave channel under defined meteorological conditions.

Experiment Description

Three modes of operation are included in spacecraft hardware to provide the measurements needed to meet the experiment objectives:

The Multitone (MT) Mode consists of a combination of nine tones equally spaced out to ±720 MHz from the carrier. This mode provides the major parameters required under the first objective, namely carrier and sideband attenuation statistics, relative sideband phase statistics, coherence bandwidth, fade durations, fade depths, multiple station diversity statistics, outage times, etc.

The Communications (COM) Mode consists of a frequency translation transponder with the uplink supplied from the ATS transponder and "cross-strapped" to 20 GHz and/or 30 GHz downlinks. This mode provides the parameters required under the second objective, namely carrier-to-noise ratio, modulation index, etc., for analog modulation schemes and bit error rates, information rates, etc., for digital modulation techniques. The cross-strap capability will also allow a direct comparison of 20 GHz, 30 GHz, and 4 GHz transmissions through the same weather profile.

The Carrier Only (CW) Mode consists of a single downlink test signal at each frequency to provide attenuation measurements for additional locations and multistation diversity studies under the first objective, as well as prediction, correlation, and modeling studies under the third objective.

In addition, an extensive network of meteorological support data, including radiometric sky temperatures, rainfall rates, radar backscatter, etc., is required for the MT, COM, and CW modes to define the meteorological conditions required under the first and second objectives and to provide the tools for predicting and modeling under the third objective.

In the Multitone and CW modes, data is transmitted from the spacecraft at 20 GHz or 30 GHz, or both, to the Millimeter Wave Facility at Rosman, NC, and the data processing is completed at GSFC, Greenbelt, MD. In the Communications Mode, modulated data is transmitted up to the satellite at 6 GHz from Rosman, cross-strapped at IF in the satellite, and transmitted back down to Rosman at 4 GHz, and 20 GHz or 30 GHz or both. This mode will provide a direct correlation of communications link quality at three frequencies experiencing the same weather effects.

Two antenna beamwidths are available on the satellite: a narrow spot beam (2°) for communications tests and a continental coverage (6° X 9°) horn for more complete coverage during the Multitone tests.

The spacecraft transmitted power at either 20 GHz or 30 GHz is 2 watts, providing fade margins of greater than 60 db for CW propagation measurements during extremely severe weather events. The communications mode provides a 25 MHz bandwidth capability, and both analog and digital tests during weather events are planned.

The ground receiving system for the Millimeter Wave Experiment, located at Rosman, NC consists of a dual frequency cassegrain feed and RF front end mounted on a 15 ft. diameter parabolic reflector. The feed system provides conical scan autotrack or program track for a small minicomputer and permits simultaneous reception at 20 GHz and 30 GHz. A polarization rotation assembly permits remote alignment of ground antenna polarization with that of the linearly polarized satellite antennas. In the communications mode, transfer switches are used to bypass the radiometer and propagation channels for minimizing line losses. Uncooled non-degenerate parametric amplifiers are utilized at both frequencies to provide the low-noise front end characteristics required for communications mode operation.

Data Analysis and Evaluation

The data processing program for the MT and CW modes of operation consists of, 1) short term processing, which utilizes analog data recording and produces amplitude scintillation and time-frequency correlation studies and, 2) long term processing, which utilizes digitally recorded data to provide hourly and daily statistical output functions.

The short term program provides a detailed study of channel decorrelation effects and amplitude and phase scintillations which could hinder wideband communications at the two frequencies under investigation. The long term program provides automated outputs of probability density, cumulative distributions, fade periods, and covariance functions on an hourly or daily basis to evaluate outage time and link margins or operational earth-space systems.

The basic objective of the communications mode testing is to observe and evaluate the propagation effects of the earth's atmosphere, primarily caused by heavy fog and precipitation, on modulated signals transmitted during the weather occurance. To accomplish this, the experiment will be operated on a call basis, 24 hours a day, 7 days per week. That is, when precipitation is expected or observed, the communications links will be energized and monitored through the extent of the storm or until the required data has been obtained. Test runs for a number of modulation techniques, data rates, and durations are planned for as many weather events as possible during the 9 to 12 month period of satellite availability.

Both analog and digital modulation techniques will be utilized, and engineering data on carrier-to-noise, modulation index, error rate, and information rate will be developed as a function of meteorological conditions and modulation techniques. Bit error rates of 10^{-5} are attainable at rates up to 20 Mbps for the clear weather baseline link, with up to 40 Mbps rates available for detailed studies during weather effect periods.

The propagation and communications measurements obtained from the ATS-F Experiment will provide the engineering data necessary to characterize and optimize millimeter wave communications, which forms the basis for the next generation of operational space communications systems.

References

1. Ippolito, L. J. "Effects of Precipitation on 15. 3 and 31.65 GHz Earth-Space Transmissions with the ATS-V Satellite," Proceedings of the IEEE, Special Issue on Space Communications, February 1971.

2. Earth-Satellite Propagation Above 10 GHz, Papers from the 1972 Spring URSI Session on Experiments Utilizing the ATS-5 Satellite, NASA/GSFC Report X-751-72-208, May 1972.

3. Ippolito, L. J., "The ATS-F Millimeter Wave Propagation Experiment," NASA/GSFC Report X-751-71-460, October 1971.