K/Ka-band Antenna for Broadband Aeronautical Mobile Application

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Introduction

The Jet Propulsion Laboratory (JPL) has recently begun the development of a Broadband Aeronautical Terminal (BAT) for duplex video satellite communications on commercial or business class aircraft. The BAT is designed for use with NASA's K/Ka-band Advanced Communications Technology Satellite (ACTS). The development of the aircraft antenna is a major portion of the overall BAT effort, and the current status of the development is discussed in this paper. The BAT system is broadband in the sense that it affords communication rates up to **384** Kbps, far in excess of that required for voice (5 Kbps).

The BAT development will provide the systems and technology groundwork for an eventual commercial K/Ka-band aeronautical satellite communication system. With industry/government partnerships, three main goals will be addressed by the BAT task: 1) develop, characterize and demonstrate the performance of an ACTS-based high data rate aeronautical communications system; 2) assess the performance of current video compression algorithms in an aeronautical satellite communication link; and 3) characterize the propagation effects of the K/Ka-band channel for aeronautical communications. The BAT will be developed and installed in the first aircraft in two years. Flight communications experiments will begin in Fall, 1995. The experiments will demonstrate duplex video communications between the aeronautical terminal in flight, anywhere above the continental United States, and a fixed ground station. Several different aircraft are planned to host the antenna installation, from a business class Saberliner (similar to a Lear jet) to a commercial class jumbo jet. A partnership between Rockwell International and JPL has been established, whereby Rockwell will provide an aircraft in return for participation in the communication experiments.

Antenna Development

The objective of the aeronautical antenna development is to obtain a satellite-tracking antenna which may readily be installed on a variety of aircraft and potentially suited for mass-production as a component of a commercial aeronautical mobile terminal in the future. To ensure that the antenna development is in line with future commercialization, the task was offered to US

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industry in the form of a contract with JPL. Electromagnetic Sciences, Inc., in Norcross, Georgia won the contract award. The aircraft antenna requirements and proposal are summarized below. A block diagram of the antenna system is presented in Figure 1; it shows that the antenna system consists of two assemblies: a main antenna assembly (MAA) that mounts to the fuselage, and a second assembly that mounts inside the cabin with the antenna support equipment (ASEA). The goal for the antenna radome size is seven inches height with a base diameter of less than twenty four inches. The weight of the main antenna assembly will not exceed 50 pounds.

The baseline design has dual, slotted-waveguide arrays. The area occupied by the receive and transmit apertures is a combined total of about fifty square inches. The transmit half-power beamwidth is approximately 5 deg, and the receive beamwidth is approximately 7 deg. The frequency bands of operation are a downlink (receive) of 19.2-20.2 GHz and an uplink (transmit) of 28.9 -30.0 GHz. Circular polarization is required for both bands, with axial ratios less than 2 dB. Meanderline polarizers will be placed in front of the slotted waveguide arrays to produce the circular polarization. ACTS has orthogonal, linear polarization, and the polarization mismatch will vary from 2.1-4.1 dB, depending on aircraft orientation.

The receive. system sensitivity is required to be no less than O dB/K (G/T). The antenna assembly contains a low-noise amplifier (LNA) which, along with the antenna, sets the system noise temperature, so the system G/T is determined by the antenna assembly. The receive directivity is expected to be about 29 dBi.

The transmit requirements are a minimum gain of 29 dBi while handling up to 50 Watts CW RF power. The transmit ERIP is a minimum of 46 dBW. The transmit RF power will be supplied by a traveling wave tube amplifier (TWTA). Isolation of the receive system (LNA) from the high power transmit signal is required to ensure not only that the amount of transmit carrier signal that couples into the receive signal path does not desensitize the LNA, but also to keep noise generated by the transmitter in the receive frequency band from reaching the LNA. An isolation factor of approximately 100 dB is required.

The sidelobe requirement is derived from a satellite system concept with 30 deg angular separation between adjacent satellites. (For the currently planned experiments there is only the one ACTS satellite in operation, so this requirement only symbolically represents the potential future commercialization of such a system.) The requirement is that sidelobes farther than 30 deg from boresight shall be more than 25 dB down from the beam peak.

The antenna system includes the capability and control for automatic (servo) tracking of a geostationary satellite, such as ACTS. A combination of open-loop, feed-forward, and closed-loop feedback tracking is planned. Only a small bandwidth (a fraction of a Hz) of closed-loop tracking information is used, sufficient to compensate for the errors that develop in the open-loop information. A Kalman filter will be used to properly weight all the open-loop input parameters. An 80486 microprocessor based system will be used to control the antenna. Co-boresight alignment and tracking accuracy are required to within a fraction of a beamwidth.

With beamwidths of about 5 deg, the antenna tracking accuracy must be better than about 0.5 deg. The antenna will provide satellite tracking 360 deg in azimuth and elevation angles from aircraft zenith to -5 deg. Airframe blockage will only slightly limit the satellite visibility.

Since the satellite is geostationary, inertial stabilization of the antenna can provide sufficient tracking accuracy for several minutes, until the aircraft has traveled so far that parallax becomes significant. As a result the tracking system primarily relies on pointing the antenna by compensating for changes in aircraft orientation.

Most of the pointing information is provided in an open-loop manner from one of several sources available within the aircraft. The potentially available sources are inertial sensors of aircraft orientation, analog heading and steering indicator signals from the cockpit, and Global Positioning System estimates of location and heading, any of which may be used to estimate the aircraft-to-satellite vector. The mechanism used to point the antenna in two dimensions is an elevation drive over an azimuth turntable.

Closed loop tracking with a loop bandwidth of less than 1 Hz provides sufficient compensation of pointing errors that develop in the open-loop (inertial) tracking system. A special beacon signal is relayed by the satellite to support closed-loop tracking. A low-rate mechanical dithering technique is used to provide the low-bandwidth pointing error estimate for both azimuth and elevation. The system design affords a nominal beacon signal to noise ratio (SNR) of more than 50 dBHz. This SNR affords the required closed-loop pointing accuracy.

For aerodynamic reasons a hemispherical shape is not selected for the radome. As a result the radome will cause refraction dependent on antenna pointing angle. Since the low bandwidth closed-loop tracking system may not quickly enough compensate for changes in the radome refraction angle due to changes in the aircraft orientation, the refraction effects of the radome will be fully characterized by measurement and incorporated into the Kalman filter open-loop portion of the tracking system. A B-sandwich, three-layer radome design is proposed because it is comparatively insensitive to the angle of incidence of the antenna beam -- compared to practical A-sandwich and C-sandwich alternatives. The radome will be equipped with lightning diverters. The front base of the radome will be equipped with a rain erosion boot to minimize the wear typical of fuselage protrusions on jet aircraft.

Conclusion

JPL is currently developing a K/Ka-band, satellite-tracking antenna system under contract for JPL's Broadband Aeronautical Terminal task to demonstrate full-duplex, compressed video communications from both business and commercial jumbo jet class aircraft. The aircraft antenna represents a major part of the development of the terminal, and the antenna system preliminary design has been summarized in this paper. The antenna is scheduled to be used for formal communication experiments in Fall 1995 with NASA's ACTS K/Ka-band satellite.

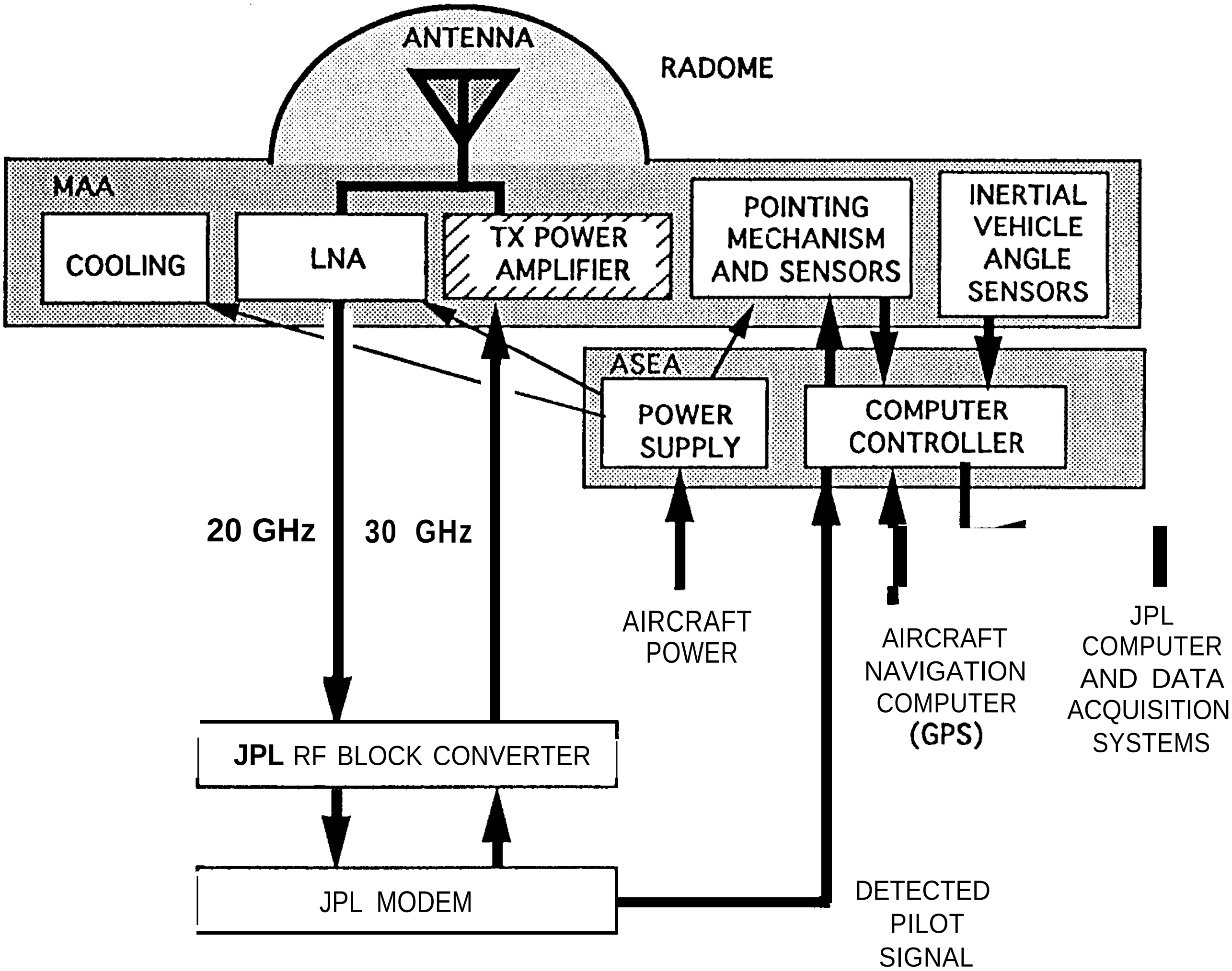

Figure 1. Block Diagram of Broadband Aeronautical Terminal Antenna System