

# MOBILE SATCOM ANTENNA DEVELOPMENTS AND EXPERIMENTAL RESULTS OF LAND- AND AERONAUTICAL-MOBILE FIELD TRIALS

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## ABSTRACT

This paper discusses several mobile satcom antenna systems that the Jet Propulsion Laboratory (JPL) has developed and demonstrated during the last ten years for land- and aeronautical-mobile digital audio/data/video satellite communication "on the move." Presented herein are field trial results, including a live, nation-wide, educational television broadcast from a NASA research aircraft. Several U.S. patents have resulted from these efforts.

## INTRODUCTION

Chartered by NASA to develop and demonstrate enabling technologies for mobile satcom, JPL has focused three "waves" of effort on the advancement of mobile satcom vehicle antenna technology. For each "wave" several antennas were investigated as competing candidates to be developed for specific field trials. Those antenna systems which were fully developed for and used in field trials are discussed in this paper. In the latest wave of effort ('93-'95) JPL pushed into K/Ka-band aeronautical-mobile satcom at data rates up to T1. In a prior wave of effort ('89-'94) JPL pushed into land-mobile satcom at the K/Ka-band with data rates up to 112 Kbps. In the first wave of effort ('80-'89) JPL opened the doors of land-mobile satcom at UHF and L-band for data rates up to 5 Kbps. A description is given of four different antennas and of the various vehicle installations in which each has been demonstrated and evaluated. The unique technologies provided by each antenna are identified. Overviews of each antenna's RF and tracking system designs are presented. Field trial performance is discussed.

## AERONAUTICAL-MOBILE ANTENNA

Recently JPL developed a high-gain, aeronautical, tracking antenna as part of JPL's Broadband Aeronautical Terminal (BAT), for high speed video

and data communication via NASA's K/Ka-band ACT S satellite from a variety of aircraft. This antenna is shown in Figure 1. The external dimensions of the radome cover (not shown) are about 16 cm height and 60 cm base diameter.

**RF System.** The BAT antenna was developed by EMS Technologies, Inc., under contract with JPL, and consists of two side-by-side waveguide slot arrays, one for receive and one for transmit. The antenna provides a transmit gain of 30 dBi at 30 GHz and a receive sensitivity of 0 dB/K at 20 GHz. The beamwidth is about 3 deg. A polarizer mounted on the face of each array produces circular polarization from the slot's linear polarization. Hundreds of slot elements in each array are uniformly fed by binary tree power dividers in half-height waveguide. Separate waveguide azimuth and elevation rotary joints convey the transmit signal to the slot array with low loss. A low noise amplifier resides immediately behind the receive slot array. The unique technology utilized in the BAT antenna include a method of integrating the waveguide slot array and its waveguide feed network into a highly integrated, compact assembly.

**Tracking System.** The BAT tracking system utilizes 3-axis inertial stabilization of an elevation-over-azimuth antenna positioner. The BAT uses circular polarization to obviate the need for polarization tracking. The antenna incorporates a low-cost 3-axis inertial sensor to provide short-term stabilization to respond quickly to aircraft movement. The drift of the low-cost 3-axis sensors is canceled in the steady state by a unique algorithm which uses low bandwidth (1/2 Hz) aircraft navigational information and tow bandwidth (1/2 Hz) conical scanning of the antenna to provide closed-loop feedback tracking. The measured refraction effects of the radome on the radiated beam direction are compensated in a feed-forward manner within the tracking algorithm. The control system was implemented in a 486 CPU PC architecture in C language.

**Field Trials.** The BAT system has been installed in two different aircraft for two different field trials using the ACTS satellite, and during both trials the

antenna has performed flawlessly. For one trial the antenna was installed in a small, five seat business-class jet, and signal quality was evaluated while the jet was flown intentionally through various weather conditions, including thunderstorms. Another trial required that the BAT system be installed on a large military cargo jet converted by NASA for airborne high altitude astronomy research. A live educational television series, entitled "Live from the Stratosphere," was broadcast nationwide on PBS-TV from the research aircraft, via the BAT antenna. During both trials the tracking system kept the 3 deg antenna beam locked on to the satellite to within a fraction of a degree throughout all phases of flight, including takeoff and landing. More than ten hours of successful television coverage was provided, with only one outage (of only five seconds duration) due to the keyhole effect, when the satellite direction briefly passed very close to the antenna azimuth axis (zenith).

QA  
Tracking?

## LAND-MOBILE ANTENNAS

Throughout the '80's and '90's JPL has developed a succession of land-mobile satcom antennas. The most recent developments accommodate higher data rate applications using the greater spectrum availability of K/Ka-band. Original system studies and the early developments centered on digital voice communications at L-band, after an initial consideration of UHF.

### AMT Small Reflector

In the early 1990's JPL developed a K/Ka-band, low-profile, land-mobile, tracking, "small" reflector antenna as part of a mobile digital communications laboratory, called the ACTS Mobile Terminal (AMT), for high speed digital voice and data communication via ACTS from a variety of land vehicles. The antenna is shown in Figure 2. The external dimensions of the radome cover (not shown) are about 10 cm height and 23 cm base diameter.

**RF system.** The AMT antenna consists of a small reflector (about ten wavelengths in width), a dual frequency feed horn, orthomode junction, diplexer and rotary joint. The feed horn, orthomode junction and diplexer are integrated into a single waveguide assembly which adapts to the rotary joint in the center. Linear polarization is provided: K-band horizontal, and Ka-band vertical. The antenna provides a transmit gain of 23 dBi at 30

GHz and a receive sensitivity of -3 dB/K at 20 GHz. Its beamwidth is about 10 deg.

**Tracking system.** The AMT antenna utilizes a patented method of single-axis satellite tracking. (U.S. Patent No. 5,398,035) The antenna positioner provides only azimuth control, since the elevation beamwidth is made wide enough to accommodate the pitch and roll variations typical of land-mobile vehicles. A low cost, single axis inertial sensor that detects vehicle yaw turn rate provides the short term inertial stabilization information. A slow (2 Hz) sinusoidal mechanical dithering of the antenna azimuth direction produces a low bandwidth estimate of any resulting pointing error, which in turn provides the feedback signal for the tracking control system. The control system nullifies both the pointing error of the antenna and the drift of the low cost inertial sensor. The need for polarization tracking is obviated by the system design which accommodates the limited range of pitch and roll variation typical of standard paved roads. The tracking system was implemented in a VME 68030 CPU architecture as a real-time embedded controller with C and assembly software.

**Field Trials.** The AMT small reflector antenna has been installed in several vehicles and used to conduct several land-mobile communication field trials using the ACTS satellite. Initially the system was installed in a converted satellite news gathering van. Data collected during several trials while driving highways and city and residential streets have provided a full characterization of system performance. Tracking accuracy during mobile operation is well within a fraction of a degree. The tracking system handles signal outages of duration up to about 30 seconds well. The AMT system has also been installed in a military HMMWV vehicle to provide digital video teleconferencing during U.S. Army field exercises. The antenna tracking system performed flawlessly.

### MSAT Microstrip Yagi Array

In the 1980's JPL developed both mechanical and phased-array land-mobile tracking antennas along with a mobile digital communications laboratory, called the MSAT -X Terminal, for Inmarsat or AMSC class digital voice communications from a variety of land mobile vehicles.

**RF System.** A novel antenna concept, namely the mechanically steered microstrip Yagi array, was developed by JPL "to offer the advantages of low profile and low cost for the MSAT application using circular polarization at L-band. The concept was

patented in U.S. Patent No. 5,220,335. This antenna, as shown in Figure 3, consists mostly of parasitic reflector and director patches with only four active driven patches connected to yield an equivalent 16-element array aperture. The external dimensions of the radome cover are 4 cm height and 56 cm diameter. Because the parasitic elements are not physically connected to the power distributing circuitry, the complexity and RF loss of the power distributing circuit are dramatically reduced, resulting in improved antenna noise temperature and antenna gain.

The antenna has achieved 10 dBic of gain throughout the specified coverage region. The measured nominal G/T ratio is -12 dB/K. The antenna's beam pointing system has functioned flawlessly in several field tests which include the one with the Inmarsat satellite. The beamwidth is about 30 deg.

**Tracking System.** The satellite beam pointing system employs a monopulse azimuth tracking scheme augmented by an open-loop inertial angular yaw rate sensor. A monopulse rate of 1 kHz is used. No elevation tracking is needed because the wide elevation beam provides the complete elevation coverage. The tracking system was implemented with an Apple IIe computer as a real time embedded controller using 6502 assembly language.

**Field Trials.** The Microstrip Yagi has been used in several mobile field trials using Inmarsat satellites and has shown the best performance to cost ratio of all the MSAT antennas developed at JPL. Initial trials fitted the antenna on a Ford Econoline van that was driven along highways and city and residential streets. Antenna tracking performance was flawless, and outages of more than ten seconds duration were handled very well -- satellite lock was recovered immediately. These trials have included a public demonstration in Washington D.C. of Direct Broadcast Satellite Radio digital audio reception from the Ford Econoline van while driving the streets of D.C. for the Voice of America.

#### **MSAT Phased Array**

For the MSAT L-band mobile satellite communications, in order to demonstrate the low-profile and beam-agility capabilities of the mobile medium-gain antenna, a phased array was developed, under contract with JPL, by Teledyne Ryan Electronics. This antenna is shown in Figure 4.

**RF System.** The phased array was developed to meet the requirement of a minimum gain of 10 dB with circular polarization over the angular region of 20° to 60° above the horizon. The antenna, with a multilayer design, has 19 radiating elements arranged on triangular lattice to achieving wide angular beam scan. It employs a stripline crossed-slot radiating element. The phase shifter is a 3-bit switched-line type with 12 pin diodes. Its overall antenna size is 53 cm in diameter and 1.8 cm in thickness. The antenna beamwidth is about 30 deg.

**Tracking System.** After the satellite signal has been acquired, the antenna tracks the satellite by a closed-loop sequential lobing technique. Different lobing rates are used to decorrelate the azimuth and elevation pointing error estimates. A rate of 50 Hz is used for azimuth, and a rate of 1/2 Hz for elevation. In the event of a severe signal fade, an open-loop angular inertial yaw rate sensor provides sufficient inertial stabilization until the inertial sensor drift exceeds the antenna beamwidth, a period of about 10 sec. The tracking system was implemented as a custom real-time embedded 8096 microcontroller using C language.

**Field Trials.** The Teledyne phased array was used in a field trial in Australia with the ETS-V satellite. The antenna was installed in both a van and a sedan and driven between Sidney and Brisbane while communicating via satellite using digital compressed audio and data. The field trial helped the Australian AUSSAT organization evaluate the merits of mobile digital audio, and as a result AUSSAT switched to digital. Both the antenna beam pointing and speech transmission tests were successful. Nominal antenna G/T ratio was measured to be -15 dB/K. The measured minimum antenna gain is 9.2 dBic.

#### **CONCLUSION**

Several antenna developments for the field of mobile satellite communication on land and in the air have been described, along with the results of field trials during which the antennas were extensively evaluated.

#### **ACKNOWLEDGMENT**

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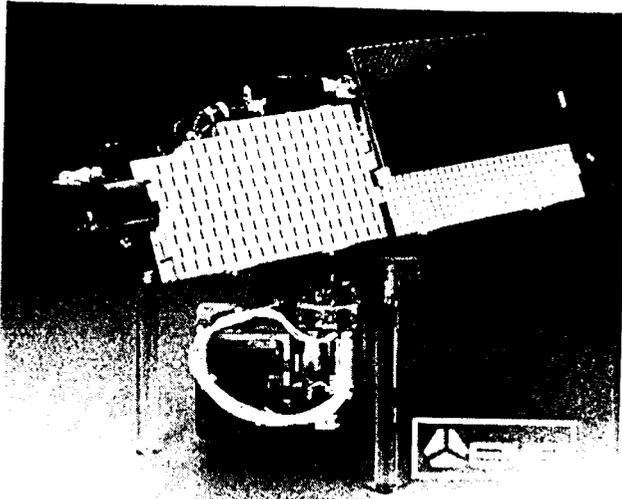


Figure 1. K/Ka-band Aeronautical Slot Array

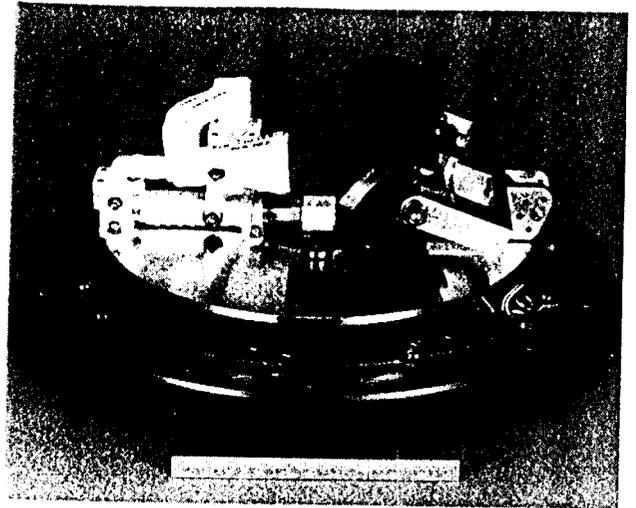


Figure 2, K/Ka-band Small Reflector

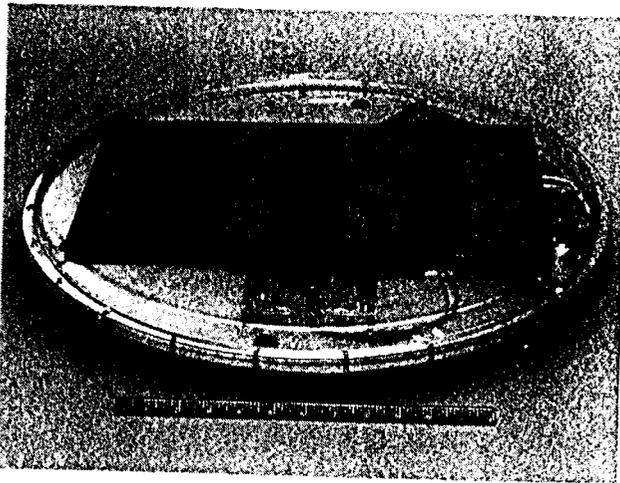


Figure 3. L-band Microstrip Yagi Array

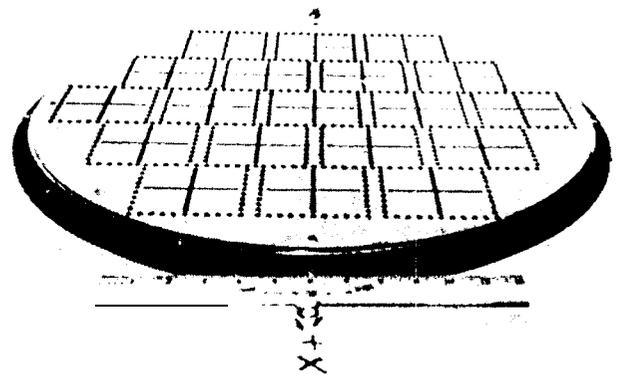


Figure 4. L-band Crossed-Slot Phased Array