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K-Band Mobile Propagation Measurements Using ACTS

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ABSTRACT

An overview of two planned propagation campaigns employing land-mobile scenarios with ACTS is presented. The campaigns will be undertaken through a joint effort involving The Johns Hopkins University, Applied Physics Laboratory (APL), The University of Texas at Austin, Electrical Engineering Research Laboratory (EERL), and the NASA Lewis Research Center (NASA LeRC). Propagation campaigns are planned in Central Maryland in November 1993 (elevation angle $\approx 40°$) and in Fairbanks, Alaska in June 1994 (elevation angle $\approx 8°$) employing a computer controlled antenna tracking system located atop a van containing a receiver/data acquisition system. The antenna will track (in azimuth) downlink transmissions at 19.914 GHz from ACTS during the mobile propagation measurements. The major objectives of the campaigns are to measure the fade and multipath effects of trees and terrain at 20 GHz for rural and suburban scenarios and to extend existing models which were previously validated at UHF to S-Band.

BACKGROUND

Since 1983, EERL and APL have undertaken 13 land-mobile propagation campaigns involving transmitter platforms located on stratospheric balloon, remotely piloted aircraft, helicopters, and geostationary satellites. An overview of the first eleven experiments and other results are presented in NASA Reference Publication 1274 [1]. The earlier experiments were performed at UHF (870 MHz) and the latter ones at UHF and/or L-Band (1.5 GHz). In particular, fading and multipath effects due to trees and terrain were determined for rural and suburban areas. These effects were examined in open fields, along tree lined highways, and in mountainous terrain. The results were expressed in terms of distributions of fading, fade and non-fade durations, and space diversity. The fade distributions, for example, provide information as to the percentage of distance travelled such that different attenuation margin levels are exceeded. Such information provides criteria for establishing design fade margins for different driving scenarios. Empirical models were developed from which one is able to calculate the fade distributions for roadside tree scenarios for elevation angles ranging from 20° to 60° and frequencies ranging from UHF to S-Band.

GENERAL OBJECTIVES OF PLANNED TESTS

The objective of the planned tests is to execute systematic propagation measurements at 20 GHz employing ACTS in Central Maryland and Fairbanks, Alaska. In Central Maryland the elevation angle is 39° and in Fairbanks, it is 8°. The rationale for making measurements in Central Maryland employing ACTS is to build on previous LMSS measurement experience and propagation results at UHF and L-Band [2, 3]. Measurements will be made along the same system of roads as previously examined. The Alaska campaign will enable exploration of fading effects for low angle measurements which include possible scintillations. Results at K-Band will represent a natural extension of previous ones at UHF and L-Band, where frequency scaling criteria will be explored at this new frequency and elevation angle. Empirical models developed and validated for UHF to S-Band will also be tested at K-Band [4].

GENERAL EXPERIMENTAL CONFIGURATION

We plan to provide a tone generator at 3.373 GHz at the input the High Burst Rate, Link Evaluation Terminal (HBR/LET) upconverter located at NASA LeRC. This will ultimately result in CW radiation at an uplink frequency of 29.634 GHz and downlink transmissions at frequency of 19.914 GHz. Transmissions at this latter frequency will be received by the mobile van located either in Central Maryland or Fairbanks Alaska. In Central Maryland, the east scan sector "Spot Beam 10" should provide a peak EIRP of at least 65 dBW. In Alaska we plan to use the steerable antenna which will provide an EIRP of approximately 55 dBW.

LINK PARAMETERS FOR THE LMSS CONFIGURATION

The link parameters are listed in Table 1 for both the Maryland and Alaska locations. A 15 cm diameter (≈7° beamwidth) receiving antenna is planned for use on the van. Assuming a 400 Hz receiver bandwidth, the carrier to noise ratios should be 58 dB in Maryland and 47 dB in Alaska. For an 10 dB carrier to noise ratio margin, fading effects covering 48 and 37 dB dynamic ranges are possible, respectively.

ANTENNA TRACKER SYSTEM

Shown in Figure 1 is a block diagram of the antenna tracker system. The antenna and the angular rate sensor (Block #1) rest on a rotary table driven by a step-motor system (Blocks #5-#7). When the vehicle under the rotary table turns, the rate sensor develops an output voltage proportional to the angular turn rate (i.e., $d\theta/dt$). This voltage is integrated (Block #2) giving another voltage signal proportional to the turning angle θ. This voltage signal is fed into a voltage-to-frequency converter (Block #4) (via a summing network (Block #3) to be described shortly) whose output gives a series of pulses at a frequency proportional to the turning angle. These pulses and a direction signal are, in turn, fed to the stepping motor driver (Block #5) such that the rotary table is driven in such a direction as to reduce the turning angle θ. When the error angle reduces to zero, no further pulses are injected into the stepping motor driver. If the rate sensor experienced no drift, the above tracking loop would keep the rotary table platform pointed in an approximate constant azimuth direction maintaining zero error angle.

Because the rate sensor has a slowly drifting offset voltage, the table would slowly rotate after about 30 seconds if no further controls were applied. An up/down counter (Block #8) and PC (Block #9) are used to derive the absolute table position with respect to a known reference position on the rotary table (employing a home-switch). The above mentioned drift offset is corrected approximately once per second by comparing the average table direction with the average direction from a flux-gate compass mounted to the vehicle (Block #10) creating an offset voltage which is interfaced with the PC (Block #9). The resultant offset angle signal established by the PC (Block #9) is fed via a D/A interface to the summing circuitry (Block #3). The offset compensates for the rate sensor drift and when added to the "apparent turning angle" (Block #2) gives the "true turning angle," θ. The PC will also contain software which mitigate fluxgate compass errors caused by magnetic anomalies due to the vehicle and roadside structures.

The elevation of the antenna is established by locating the vehicle on a horizontal surface and peaking the received signal radiated from the satellite. It is expected that for the planned roads to be traveled, the elevation angle changes should be within $\pm 2°$ of the nominal pointing angle. Since the beamwidth is approximately $\pm 3.5°$ relative to the pointing axis, a deviation of $\pm 2°$ in elevation results in a received power loss of ± 1 dB assuming a Gaussian beam pattern.

MOBILE RECEIVER SYSTEM

The mobile receiver system is depicted in Figure 2 and shows a microwave spectrum analyzer and frequency synthesizer at the heart of the RF system. Other main functional components are the aforementioned antenna tracker system, a low noise frequency downconverter, an intermediate frequency stage with automatic frequency control (AFC), and a PC based data acquisition system. Ancillary sensors give vehicle speed and direction.

The 19.914 GHz vertically polarized ACTS pilot signal is focused by the antenna into the waveguide feed of the RF front end. There the 19.7–20.2 GHz low noise amplifier (LNA) determines the noise temperature of the receiver (430 K). After amplification, the pilot signal is fed to the first mixer through a bandpass filter, which eliminates image sideband noise. The local oscillator is locked to the same high-stability frequency reference as the spectrum analyzer. The mixer output (1.7-2.2 GHz) is again amplified and fed to the IF system in the mobile van's interior. There the Tektronix 2756P spectrum analyzer in its non-sweeping mode is used as a tunable receiver with a 10 MHz IF output. Having a spectrum analyzer built into the receiver also affords convenient trouble shooting and signal acquisition. The 10 MHz signal is first converted to 455 kHz and finally to 10 kHz. At that frequency, a filter bank of 11 analog filters with 100 Hz spacing is used for AFC and keeps the satellite pilot signal centered in the receiver. The AFC has a 0.1 sec time constant. The 10 kHz signal is also fed to a quadrature detector, converted to base band, and low-pass filtered with a 200 Hz cutoff frequency. This results in a receiver noise bandwidth of 400 Hz. The in-phase and quadrature phase voltages are amplified and sampled by the PC based data acquisition system at a 1000 Hz rate. The resulting data are stored on the computer's hard disk, which has the capacity to hold over four hours of continuous data. The time, vehicle speed, and direction are stored once every second. The antenna pointing parameters are stored at a 5 Hz rate.

DOPPLER SHIFT CORRECTION

At a low elevation angle, the maximum Doppler shift will be about $\pm$ v/λ, where v is the vehicle speed and λ is the wavelength. At 20 GHz, a maximum shift of $\pm$ 2000 Hz is expected assuming a top speed of about 65 mph. The AFC voltage will be corrected by an amount depending on the vehicle speed, direction, and the satellite elevation angle. The correction signal will be calculated by the computer. This will ensure that the pilot signal always reappears within the ± 1000 Hz AFC capture range.

SAMPLING RATE AND BANDWIDTH

For L-Band measurements with azimuthally omni-directional antennas and low gain on the horizon, a signal bandwidth of 200 Hz was found to be sufficient to capture the dynamic behavior of the received signal amplitude and phase variations and provide enough fade margin while observing low power satellite beacons. As a rule of thumb, one should sample the standing wave field set up by the interference between the direct line-of-sight signal and the multipath components at an interval of about $\lambda/8$. This condition was satisfied at L-Band ($\lambda = 20$ cm) by the present system which achieved a spatial sampling interval of 2.5 cm at a speed of 55 mph. A similar argument can be made about signal variations due to shadowing by tree branches or utility poles. At 20 GHz ($\lambda = 1.5$ cm), an azimuthally omni-direction antenna should mandate proportionally wider bandwidths and higher sampling rates. Considering that the beamwidth of the antenna is relatively narrow ($\approx 7°$) however, the main Doppler effect is just a shift in frequency with limited spread. The AFC will compensate for the frequency shift. The current signal bandwidth of the receiver is about 200 Hz, but can easily be increased to 500 Hz if that proves necessary.

PLANNED CAMPAIGNS

As of this writing, the ACTS satellite is expected to become operational in October, 1993. The key periods and locations in which the campaigns will be executed are as follows:

1. **November, 1993 (Central Maryland):**
   Field measurements are planned in Central Maryland in November 1993. These measurements will be executed along a system of roads previously examined at UHF and L-Band where previous driving scenarios will be replicated [2, 3]. The system tests encompass fours hours per day during five contiguous days.

2. **June, 1994 (Fairbanks, Alaska):**
   Field measurements are planned in Fairbanks, Alaska during the early part of June. This month represents the most benign period for Alaska when trees are in full bloom. Four hours per day of measurements are planned during five contiguous days.

REFERENCES

[1] J. Goldhirsh and W. J. Vogel, "Propagation Effects for Land Mobile Satellite Systems: Overview of Experimental and Modeling Results," *NASA Reference Publication 1274*, February, 1992.
[2] J. Goldhirsh and W. J. Vogel, "Roadside Tree Attenuation Measurements at UHF for Land-Mobile Satellite Systems," *IEEE Trans. Antennas Propagat.*, vol. AP-35, pp. 589-596, May, 1987.
[3] J. Goldhirsh and W. J. Vogel, "Mobile Satellite System Fade Statistics for Shadowing and Multipath from Roadside Trees at UHF and L-band," *IEEE Trans. Antennas Propagat.* vol AP-37, no. 4, pp. 489-498, April, 1989.
[4] W. J. Vogel, J. Goldhirsh, and Y. Hase,"Land-Mobile-Satellite Fade Measurements in Australia," *Journal of Spacecraft and Rockets*, vol. 29, no. 1, pp. 123-128, January-February, 1992.

Table 1: Link parameters for the land-mobile ACTS configuration employing the microwave switch matrix mode and the steerable antenna.

PARAMETER	BOTH SITES	MARYLAND (Central)	ALASKA (Fairbanks)
Satellite:			
Longitude (°W)	100		
Downlink Frequency (GHz)	19.914		
Uplink Frequency (GHz)	29.634		
Polarization	Vertical		
Receiver Site Locations:			
Latitude (°)N		39.25	65.0
Longitude (°)W		77.0	147.7
Elevation (°)		38.7	7.9
Azimuth (°)		213.9	129.5
Receiver System Parameters			
Polarization	Vertical		
Antenna Efficiency	0.6		
Antenna Diameter (cm)	15		
Antenna Gain (dB)	28		
Beamwidth (°)	6.8		
System Temperature K (Nominal)	430		
Link Budget:			
EIRP (dBW)		65	56
Free Space Loss (dB)		−210.0	−210.6
Atmospheric Gas Loss (dB)		0.5	2.2
Radome Loss (dB)	0.5		
Mobile G/T (dB/K)	1.7		
Signal Power Received (dBW)		−118.0	−129.3
Noise Power (dBW/Hz)	−202.2		
Carrier/Noise (dB per Hz)		84.2	72.9
Carrier/Noise (dB; 400 Hz)		**58.2**	**46.9**

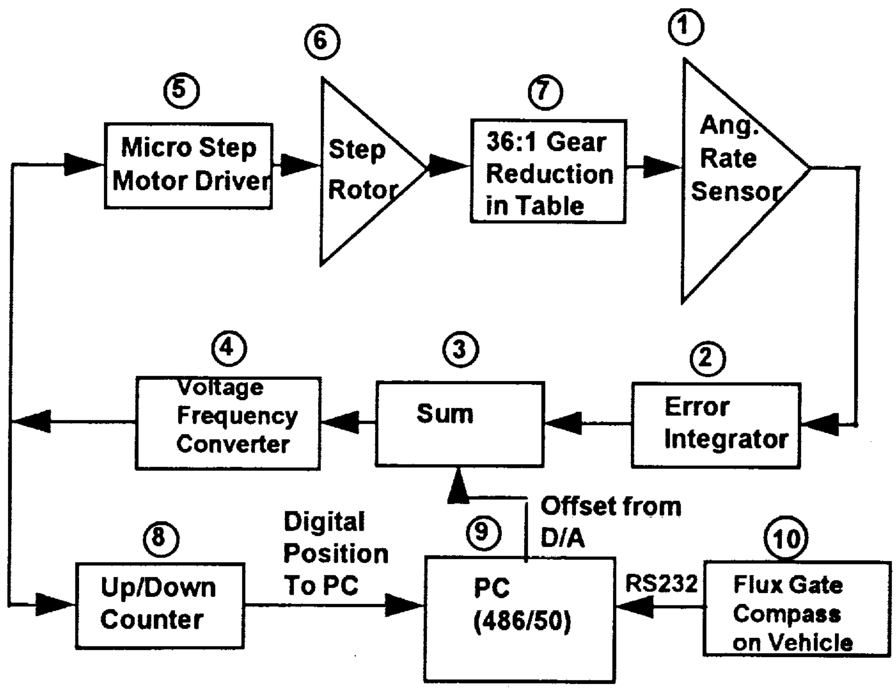

Figure 1: Block diagram of mobile antenna tracking system.

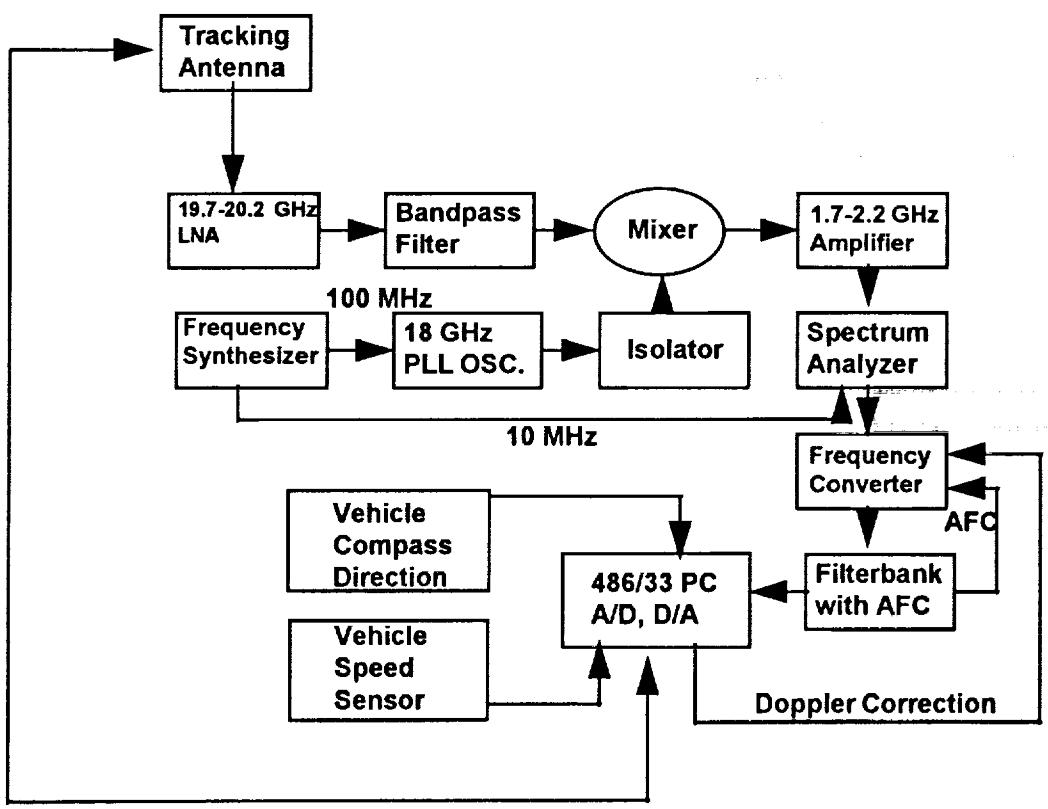

Figure 2: Block diagram of mobile receiver system.