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Planned LMSS Propagation Experiment Using ACTS: Preliminary Antenna Pointing Results During Mobile Operations

John R. Rowland [+], Julius Goldhirsh[+], Wolfhard J. Vogel[#], Geoffrey W. Torrence [#]

[+]The Johns Hopkins University, Applied Physics Laboratory, Laurel, Maryland
[#]The University of Texas, Electrical Engineering Research Laboratory, Austin, Texas

Abstract – An overview and a status description of the planned LMSS mobile K band experiment with ACTS is presented. As a precursor to the ACTS mobile measurements at 20.185 GHz, measurements at 19.77 GHz employing the Olympus satellite were originally planned [Goldhirsh et al., 1990]. However, because of the demise of Olympus in June of 1991, the efforts described here are focused towards the ACTS measurements. In particular, we describe the design and testing results of a gyro controlled mobile-antenna pointing system. Prelimary pointing measurements during mobile operations indicate that the present system is suitable for measurements employing a 15 cm aperture (beamwidth $\approx 7°$) receiving antenna operating with ACTS in the high gain transponder mode. This should enable measurements with pattern losses smaller than ± 1 dB over more than 95% of the driving distance. Measurements with the present mount system employing a 60 cm aperture (beamwidth $\approx 1.7°$) results in pattern losses smaller than $\pm$ 3 dB for 70% of the driving distance. Acceptable propagation measurements may still be made with this sytem by employing developed software to flag out bad data points due to extreme pointing errors. The receiver system including associated computer control software has been designed and assembled. Plans are underway to integrate the antenna mount with the receiver on the University of Texas mobile receiving van, and repeat the pointing tests on highways employing a recently designed radome system.

1. Introduction

Since 1983, the authors have been involved in 11 experimental campaigns dealing with mobile satellite measurements at UHF and L band (see references). As a natural follow-on, mobile propagation measurements are important at K band in that they will provide information at a frequency where none exists. In particular, mobile communications and data transfer at K band will result in significantly larger bandwidths accomodating more users. As a consequence of employing higher gain antennas, larger fade margins will also be available to overcome precipitation and tree attenuation.

2. Link Margin Characteristics

The link parameters for the beacon and high gain transponder mode of ACTS for different receiver antenna sizes are tabulated in Table 1. Three antenna sizes are planned for the ACTS K band mobile campaigns; 61 cm (2'), 30.5 cm (1'), and 15.25 cm (6"). Repeat runs will be made for each of these antennas as these will provide information of the increased multipath

Table 1: Link Parameters for ACTS-K Band Mobile System

PARAMETER	BEACON			HIGH GAIN		
	Receiver Antenna Diameter (cm)					
	60	30	15	60	30	15
Satellite:						
Longitude (°W)	100					
Frequency (GHz)	20.185					
Polarization	Vertical					
Receiver:						
Latitude (°N)	39.25					
Longitude (°W)	77.0					
Elevation Angle (°)	38.7					
Azimuth Angle (°)	213.9					
Polarization	Horizontal					
Antenna Efficiencies	0.6					
Antenna Gains (dB)	40	34	28	40	34	28
Beamwidth (°)	1.7	3.4	6.8	1.7	3.4	6.8
Nominal System Temperature (K)	430					
Link Budget:						
EIRP (dBW)	20			50		
Free Space Loss (dB)	210.1					
Atmospheric Gas Loss (dB)	0.5					
Radome Loss (dB)	0.5					
Modulation Loss (dB)	3.0					
Mobile G/T (dB/K)	13.6	7.6	1.6	13.6	7.6	1.6
Signal Power (dBW)	-154.2	-160.2	-166.2	-124.2	-130.2	-136.2
Noise Power (dBW/Hz)	−202.2					
Carrier/Noise (per Hz)	48.0	42.0	36.0	78.0	72.0	66.0
Carrier/Noise (400 Hz)	22.0	16.0	10.0	52.0	46.0	40.0

contributions for various beamwidth sizes. Measurements employing transmissions from the ACTS beacons (20 dB e.i.r.p.) and the high gain transponder ($\approx$ 50 dB e.i.r.p.) are also planned. The latter mode will require a ground station to transmit to the satellite a cw signal which will be transponded down to the receiving van. Since planned experimental mobile runs are individually short, reserved time slots for this transmission of approximately 4 hours or less are required.

3. Gyro-Antenna Mount Tracking System

3.1 Block Diagram

In Figure 1 is a block diagram depicting the logic of the antenna mount control. The mount is an "elevation" over "azimuth" system. The antenna and vertical gyro (Block #2) are located on the elevation assembly and the azimuth gyro and flux gate compass (Block #1) are on the azimuth assembly. The synchro outputs represent the actual pointing direction of the antenna axis. A single output exists for the azimuth gyro (relative to magnetic north) and there are two outputs, pitch and roll, (relative to true vertical) for the vertical gyro.

The gyro outputs are fed into corresponding synchro/digital converters (Blocks #5, #7, #8) whose outputs are connected to a digital input/output (I/O) PC interface card (Block #10). The PC (Block #11) compares the azimuth, pitch, and roll angles of the mount with the respective "true values" and generates digital error signals for each which are in-turn fed back through the interface card (Block #10) to the azimuth (Block #6) and elevation (Block #9) mount control drivers. These drive the azimuth (Block #3) and elevation motors (Block #4) in such a direction as to reduce the error signal. Ultimately this feedback system results in a condition of zero pointing error and the antenna is pointed in the true direction.

3.2 Computer Control Features

If the differences between true and actual pointing in azimuth and elevation are each within 0.1°, no error signals are generated by the computer. This feature eliminates small angle hunting. More efficient tracking and further mitigation of hunting is achieved by controlling (via the PC) the speed of the elevation and azimuth mounts in the following manner: [1] For pointing errors greater than 2°, the slew rate is 10°/s. [2] For pointing errors between 1° and 2° the slew rate is 5°/s. [3] For pointing errors smaller than 1°, the slew rate is 2°/s. The above logic is software selectable and is based on the present PC (80286 processor with 12 MHz clock). The above conditions are expected to be modified for a planned faster computer system (80486 processor with a 33 MHz clock) and improved mount system having faster motor speeds.

4. Preliminary Mobile Tracking Tests

Several pointing tests were executed with the tracking antenna system during mobile operation. The objectives of these tests were to establish preliminary pointing accuracies of the designed tracking system during mobile operations and to establish requirements for

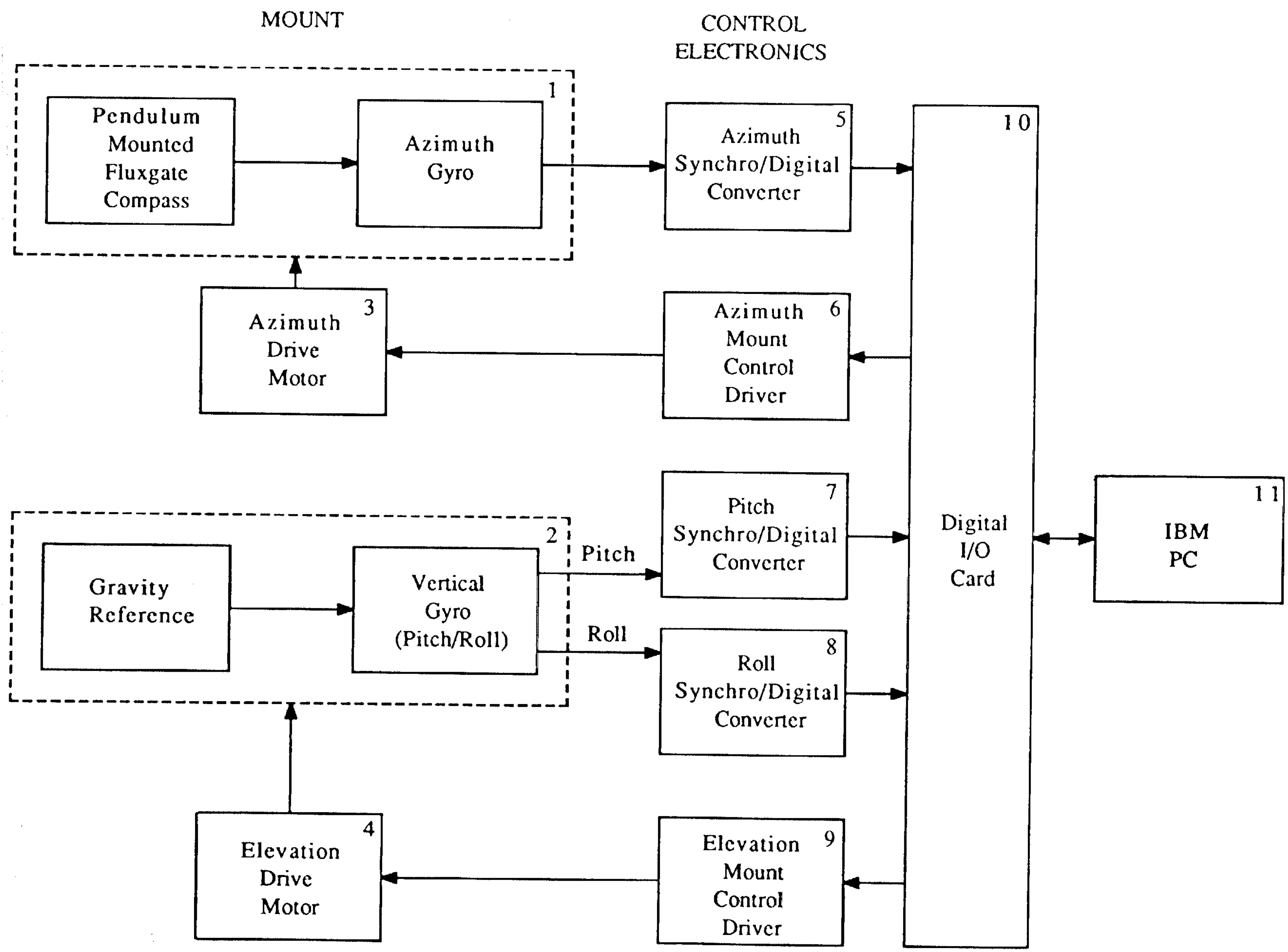

Figure 1: Block diagram of gyro-controlled antenna mount system to operate at K-Band.

improving the system. Since the radome was unavailable, all mobile tests were made within APL grounds at speeds smaller than 15 mph. The mount and controlling computer (and staff) were placed atop a pick-up truck and a sequence of runs were made along a relatively rough road having frequent sloping surfaces.

The mobile runs were made at fixed speeds (e.g., 0, 5, 10, and 15 mph) and included: [1] tracking the sun and [2] pointing towards the Olympus satellite. As these measurements were made prior to the demise of Olympus, ACTS pointing measurements were not made. The pointing results for the Olympus pointing are expected to be similar to those of ACTS. Prior to these runs, software was developed to operate with "Quickbasic" enabling the measurement of the actual pointing and true pointing angles, and subsequently the pointing errors for both the sun and satellite runs [Miller, 1991, Sterner, 1991a, 1991b, 1991c]. During the mobile runs, the mount azimuth and elevations were sampled at a 50 Hz rate. These positions were compared with the true values, and the mount pointing was updated (at this rate) following the logic described in Section 3 and Figure 1. The "actual" and "true" pointing angles were stored in computer memory at a selectable sampling rate and subsequently written into files.

In Figure 2 are cumulative distributions describing the percentage number of samples for which the pointing error is smaller than the abscissa values for repeated sun tracking runs. As mentioned, because no radome was available, these runs were made at slow speeds along an approximate one km road stretch. The sample sizes ranged between 100 to 200 at a sampling rate 1 to 10 seconds. The circular and bell shaped data points in Figure 2 represent the azimuth and elevation pointing error cases, respectively. The upper, middle, and bottom curves for azimuth and elevation represent zero vehicle speed, 5 mph, and 10 mph. In Figure 3 are shown a similar set of distributions describing the pointing errors for mobile-Olympus runs (azimuth of 111.6° and elevation of 15.9°). As mentioned, it is expected that pointing errors for mobile-ACTS run (azimuth of 213.9° and 38.7°) will give similar results.

We note that over approximately 98% of the driving distance, pointing errors are implied smaller than 2° for both the azimuth and elevation cases. These errors imply pattern losses of less than ± 1 dB employing a 15 cm aperture (≈ 7° beamwidth). Using the high gain transponder mode of ACTS with the 15 cm aperture will provide a nominal 40 dB carrier to noise ratio (Table 1). For the 60 cm aperture (2 ' dish), Figures 1 and 2 imply an approximate ± 3 dB pattern loss over approximately 70% of the driving distance. Even if the present mount system were used with ACTS (which it will not be), a software has been developed which flags receiver data for which the pointing errors are unacceptable. We note from the figures that an increase of the vehicle speed results in a monotonic increase of the pointing errors. This increase is due the combination of slow mount and computer speeds. As mentioned, plans are underway to correct both of these deficiencies.

5. Receiver and Data Acquisition

5.1 Block Diagram

We describe here the receiver system which, at this writing, has been designed, the

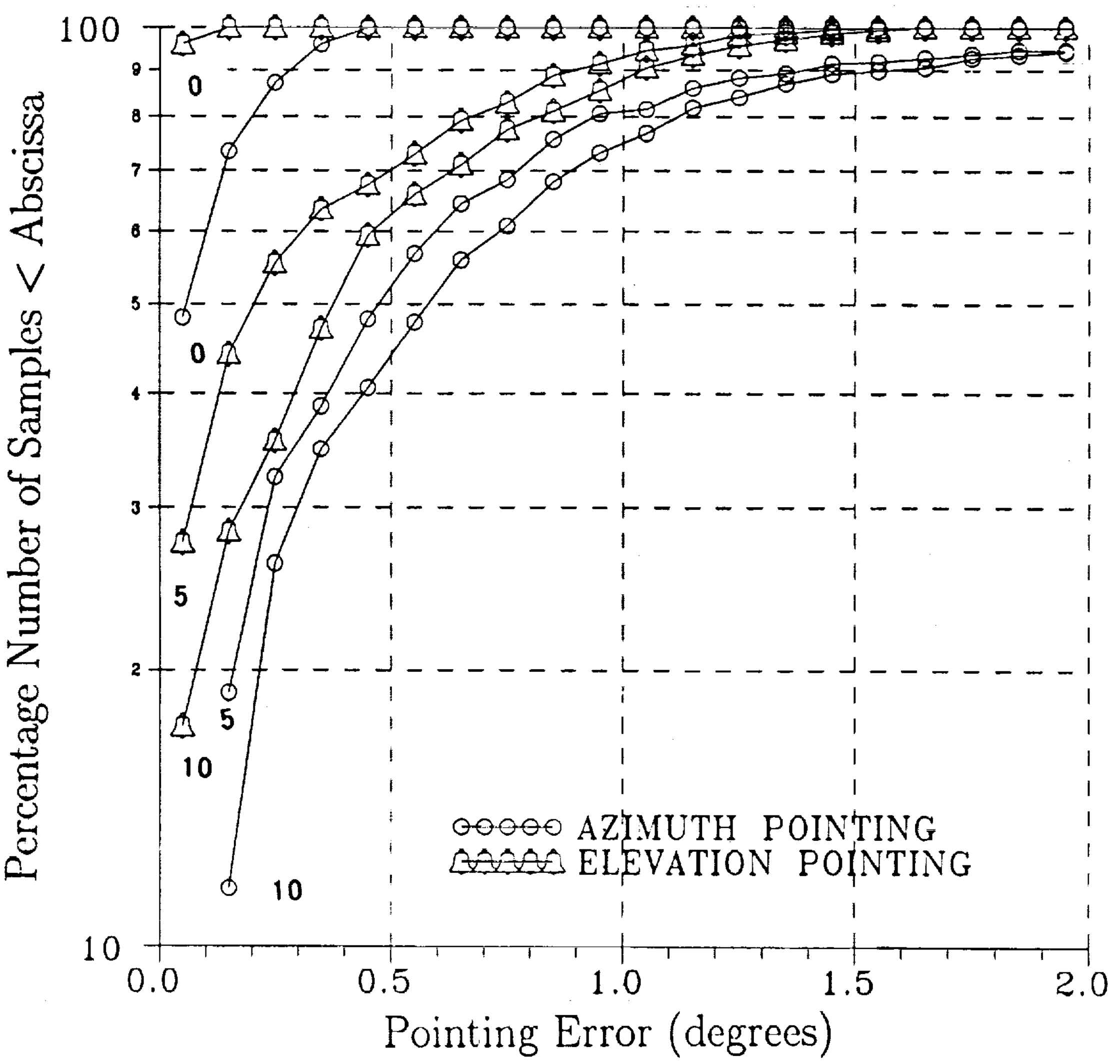

Figure 2: Cumulative distributions of pointing errors for mobile-sun-track runs for drive speeds of 0, 5, and 10 mph.

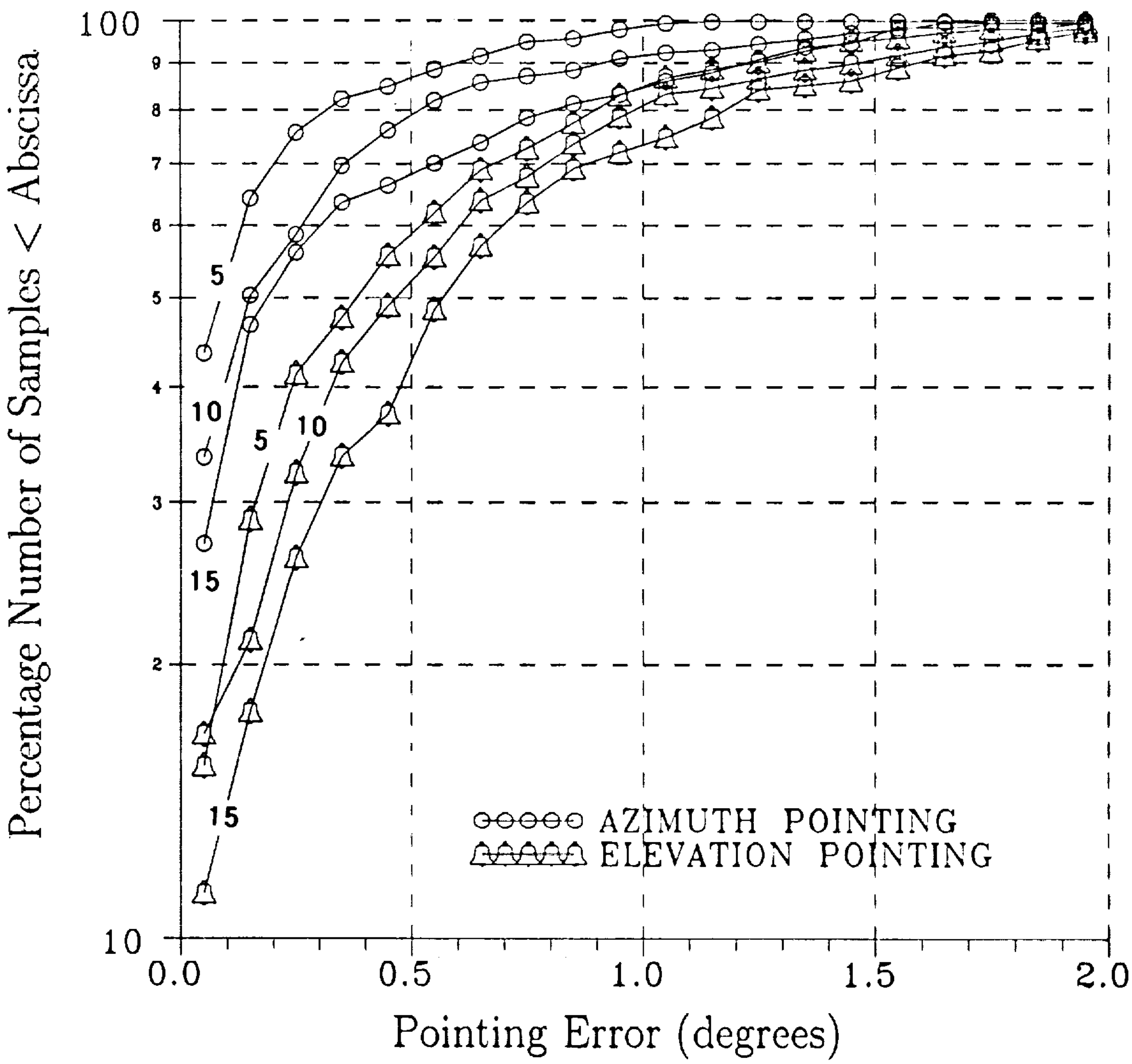

Figure 3: Cumulative distributions of pointing errors for mobile-Olympus runs at drive speeds of 5, 10, and 15 mph.

components integrated (with the exception of the mount system), and tested. With reference to Figure 4, the received signal enters the antenna-feed assembly (Block #1) and is then passed through a low noise amplifier mounted near the antenna (Block #2). The output signal is fed through a 1.7 to 2.2 GHz downconverter (Block #3). The amplified output signal from the low-noise converter is fed to a microwave spectrum analyzer (Block #4). Using a spectrum analyzer in the IF chain significantly enhances the functionality of the receiver by supplying built-in RF diagnostics, easy signal identification, and flexible receiver tuning. Once the correct signal has been acquired under computer control (Block #6) over the General Purpose Interface Bus (GPIB) interface, the spectrum analyzer mode is changed to non-sweeping and is centered at the desired beacon signal frequency. The 10 MHz IF output from the spectrum analyzer is converted to 10 kHz at the frequency tracking down-converter (Block #5). At that frequency, a filterbank comprised of eleven narrow filters has been implemented for the automatic frequency tracking function. The differential signal voltage from the two filter-channels straddling the center filter is used to tune an oscillator in the 10MHz to 10 KHz converter. On another path, the signal is quadrature detected, 500 Hz low-pass filtered, and fed to the data acquisition board in the PC (Block #6). The vehicle's speed will sensed (Block #7) and recorded once per second by the PC.

The antenna mount control system (Blocks #1, #8, #9, #10) is presently interfaced with a separate computer system (Block #10) which has an 80286 processor and 12 MHz clock). It is the intention to eliminate this system for further planned pointing tests and the ACTS experiment and to interface the mount control system with the existing receiver PC (Block #6) which has as 80486 processor and a clock speed of 33 MHz. This and planned mount improvements should improve the pointing accuracy allowing for more rapid updates.

5.2 Doppler Spread

For an omni-directional antenna, the maximum Doppler spread of a CW signal due to the range of relative motion in an environment filled with multipath scatterers is twice the speed divided by the wavelength. At 20 GHz, a maximum spread of 3.3 kHz results at 25 m/s speed ($\approx$ 55 mph). The receiving antenna does not couple into all directions, however, and therefore acts as a filter. With a high gain antenna practically all the power will be received from directions very close to the direction to the transmitter and the spread will be small. Although the transmitter frequency will be shifted by an amount proportional to the relative speed of the vehicle and the transmitter platform, the receiver AFC will be capable of tracking changes in this shift brought about by vehicle speed or direction variations.

6. System Integration with Van

The van to be used is the same in which eleven land-mobile measurement campaigns have been conducted. It is equipped with a shock-mounted standard equipment rack, a 115 vac primary power system, a video recorder and an electronic speed transducer. The video recorder captures the scene in front of the vehicle and the speed transducer enables a recording of the vehicle speed every second. The receiver data acquisition software, originally written in Microsoft Fortran, has been converted to a LabWindows/QuickBasic environment to take advantage of more modern and efficient software technology. As mentioned, the PC

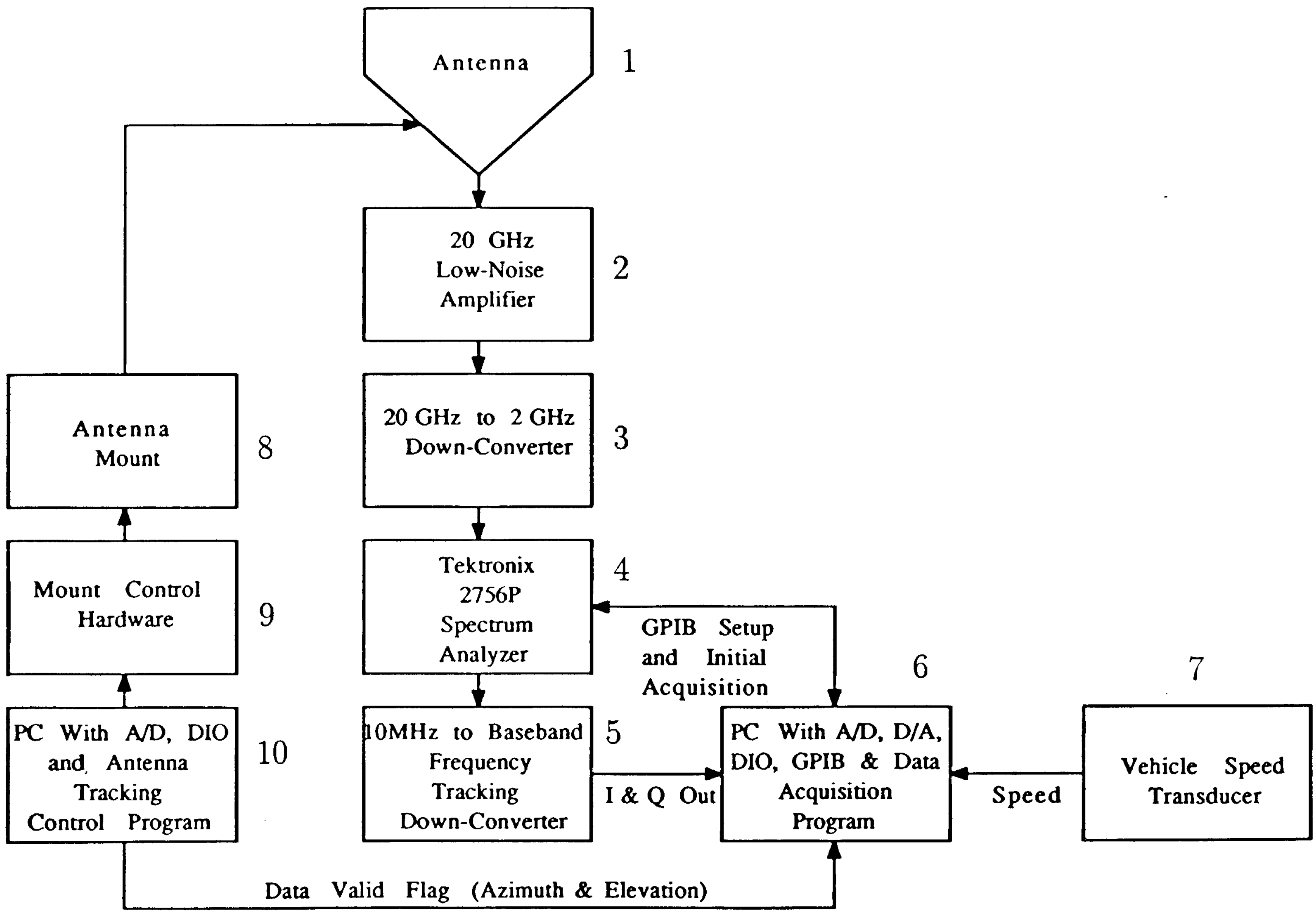

Figure 4: Block diagram of mobile K-band receiver system.

inside the van has a 80486 processor with a 33 MHz clock. It will serve the function of controlling both the receiver and the mount and will write data to 20 MHz Bernoulli Box disks. Plans are underway to integrate the mount-antenna control system with the van and its receiver system during the summer of 1991.

7. Planned Measurements

7.1 Pointing Measurements After System Integration with Van

As mentioned in Section 4, preliminary pointing measurements were executed using a slow speed computer system with the mount-antenna system having no radome placed atop an open truck. These preliminary measurements indicated the need for an improved mount system with faster motors and a higher speed computer; both changes of which are planned. In the meantime, the present antenna-mount control system will be integrated with the receiver and computer system within the van (described in Section 5.). A radome, which has already been designed and fabricated will be placed over the antenna-mount system atop the van and pointing measurements of the type described in Section 4 will be made using the integrated system on a highway traveling at normal speeds (e.g., 25 m/s).

7.2 LMSS Propagation Experiments with ACTS

Roadside tree propagation measurements will be instituted employing transmissions from the ACTS satellite for a system of roads in Central Maryland (Routes 295, 108 and 32). Under the NASA Propagation Program, attenuation measurements have been executed for this system of roads at 870 GHz and 1.5 GHz employing a helicopter and MARECS-B2 geostationary satellite as transmitter platforms [Goldhirsh and Vogel, 1991, 1989, 1987; Vogel and Goldhirsh, 1990]. It is planned to use the beacon measurements (20 dB e.i.r.p.) for making preliminary measurements and to follow these by repeat measurements with the high gain transponder (nominal 50 dB e.i.r.p.). The high gain measurements will enable the employment of a 15 cm antenna (6 inches) and result in a 40 dB carrier/noise at a 400 Hz bandwidth (Table 1). Since the beamwidth will be nominally 7° for the reduced aperture, minimal pattern losses are expected during tracking under mobile operation.

The analytical aspects will involve characterizing the fade distributions for the various road types, establishing the fade durations, combining the results with previous measurements at UHF and L band, and extending "frequency scaling" concepts from UHF to K Band. Analyses will be performed which are, in part, similar to those described by Vogel and Goldhirsh [1990], and Goldhirsh and Vogel [1991, 1989].

Some examples of propagation results to be derived for mobile-propagation experiments at K-band using ACTS are as follows: [1] cumulative fade distribution at 20 GHz due to roadside trees, [2] equi-probability cross polarization discrimination measurements, [3] cumulative fade distributions for different antenna size demonstrating the effects of enhanced multipath, [4] simulation of antenna diversity employing measured time-series fade data at K-Band, [5] equi-probability frequency scaling of cumulative fade distributions, [6] effects of foliage on cumulative fade distributions (measurements at different seasons), [7] fade reduction statistics versus side of road, [8] fades caused by individual trees (static case), and [9] possible extension of the empirical roadside shadowing model to include K-Band.

8. Summary and Conclusions

A first generation gyro-controlled antenna tracking system has been designed and has undergone preliminary mobile testing by tracking the sun and the Olympus satellite. Although these measurements were performed before the demise of Olympus, the pointing results for ACTS are believed to be approximately similar. These measurements indicate that the present system may be used as is with a 15 cm aperture antenna ($\approx 7°$ beamwidth) employing the high gain transponder mode of ACTS. Minimal pattern loss due to pointing errors will ensue (e.g., $< \pm 1$ dB) for this mode which should result in a carrier to noise ratio of approximately 40 dB. Beacon measurements employing the present system and the 60 cm antenna (1.7°) will experience enhanced pattern losses (e.g., $\pm$ 3 dB for 75% of the distance), although acceptable measurements may even be made with this system by generating *pointing error flags* and not using propagation data during pointing degraded periods.

Plans are presently underway to: [1] Integrate the present system with the receiving antenna, the van, and a radome, [2] Repeat mobile pointing measurements on highways with the integrated system, [3] Update the present mount sytem by interfacing higher speed mount motors and connecting the system to a higher speed computer system (80486 processor, 33 MHz clock). The possibility of further updating the system to receive the ACTS 27.5 GHz beacon during mobile operations is also being explored.

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