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OSU PARTICIPATION IN THE CTS COMMUNICATIONS
LINK CHARACTERIZATION EXPERIMENT

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This report summarizes the progress during the first fifteen months of Contract NAS5-22575 entitled "OSU Participation in the CTS Communications Link Characterization Experiment." This effort included the development and implementation of a four element self-phased array for propagation measurements utilizing the Communication Technology Satellite (CTS) 11.7 GHz downlink. The parameters of interest in measurements are: attenuation, amplitude scintillation, and angle-of-arrival variability.

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I. INTRODUCTION

This report summarizes the progress during the first fifteen months of Contract NAS5-22575 entitled "OSU Participation in the CTS Communications Link Characterization Experiment". This effort included the development and implementation of a four element self-phased array for propagation measurements utilizing the Communication Technology Satellite (CTS) 11.7 GHz downlink. The parameters of interest in these measurements are: attenuation, amplitude scintillation, and angle-of-arrival variability.

Also included in this effort were simultaneous scintillation measurements at 360 MHz, 2.075 GHz, and 30 GHz utilizing the Applied Technology Satellite 6 (ATS-6). The unique movement of ATS-6 during 1976 permitted extensive measurements of scintillation characteristics as a function of path elevation angle.

These efforts are part of a series of NASA funded grants and contracts which have included millimeter wavelength propagation experiments utilizing the ATS-5 and ATS-6 satellites as well as theoretical propagation studies and the development of a unique radar/radiometer capability. References 1 - 12 contain results derived through these earlier efforts.

II. CTS MEASUREMENTS

Development of a self-phased antenna array and receiving system for use with the CTS 11.7 GHz downlink was initiated in September, 1975. This system was to be used to measure angle-of-arrival fluctuations induced as a result of propagation through the troposphere as well as attenuation and amplitude scintillation characteristics. As a subsidiary result, the utility of a self-phased array for non-mechanical satellite tracking was to be demonstrated. The approach chosen to achieve these objectives was based on technology developed under an earlier, unrelated ElectroScience Laboratory research program[15]. Consequently, existing hardware including the necessary phase-lock-loop receivers were available for this application.

Design constraints and trade-off considerations between angular resolution and ambiguity led to the implementation of a four-element self-phased array. Each element of this array was a 0.6 m parabolic reflector having a left-hand circularly polarized focal point feed. The elements were spaced 1 meter apart in a square pattern (Fig. 1). The bandwidth of the receiving system was initially 180 Hz and has been narrowed to 80 Hz in order to improve angle-of-arrival resolution. This system, in its present form, provides angle-of-arrival resolution better than 0.05° in both the azimuth and elevation planes. A more complete description of this system along with preliminary samples of

Fig. 1. CTS 11.7 GHz self-phased array.

data were presented in References 13 and 16 and will not be repeated here.

The 11.7 GHz CTS beacon was first acquired by Ohio State University using this self-phased antenna array and receiving system on February 20, 1976. Over 1,600 hours of data were obtained prior to the eclipse shut-down of CTS which commenced on August 27, 1976. These data include digital samples of the amplitudes of the signals received by each element of the array, the array sum amplitude, the relative phases between the array element signals, and various VCXO voltages and system parameters; these data are recorded at a rate of 1/3 Hz at all times and at a rate of 10 Hz on demand.

Enhanced amplitude and angle-of-arrival scintillations have been observed in these measurements. The most significant of these occurrences have been associated with amplitude fading as a result of rainfall along the propagation path. Angle-of-arrival excursions well in excess of 0.1° have been observed on these occasions. Such excursions are certainly important in the context of large aperture antennas operating at frequencies above 10 GHz and having beamwidths of a few tenths of a degree or less.

These characteristics will be demonstrated by the following samples. Measurements of azimuth and elevation differential phase are presented here for three twenty-four hour periods. The means of the array coherent sum amplitude channel and the azimuth and elevation differential phases are plotted in Figs. 2-4. Maximum and minimum phase for each plot point interval are also shown; each interval represents 58 points (144 seconds) and the center line is the average taken over this interval. Figure 2 represents a day with no precipitation events. The twenty-four hour sinusoidal phase variation is a result of the diurnal motion of the satellite. Amplitude variations in mean on the order of 1 dB have been attributed to klystron instability which has subsequently been improved. Both azimuth and elevation differential phase measurements have maximum-to-minimum excursions on the order of ±10° (or ±.04° in angle-of-arrival). Note that the excursions are of the same magnitude above and below the mean. The non-symmetric behavior exhibited in the azimuth differential phase from hours 14 to 19 is a result of foldover in the differential phase detector characteristics.

Similar differential phase data ·e presented in Fig. 3 for a day containing a precipitation fade event at hour 17. Two points of interest are apparent. First, the maximum-to-minimum excursions in differential phase increase to ±20° (or ±.08° in angle-of-arrival) within the fade period and their magnitudes are well correlated with the fade depth. Second, the mean undergoes a slight positive shift in azimuth and a negative shift in elevation differential phase. This is most apparent when one observes the asymmetric behavior of the maximum-to-minimum excursions. There is not sufficient data available at the present time to determine whether this mean shift in differential phase is a propagation or equipment-related effect. If this behavior is interpreted

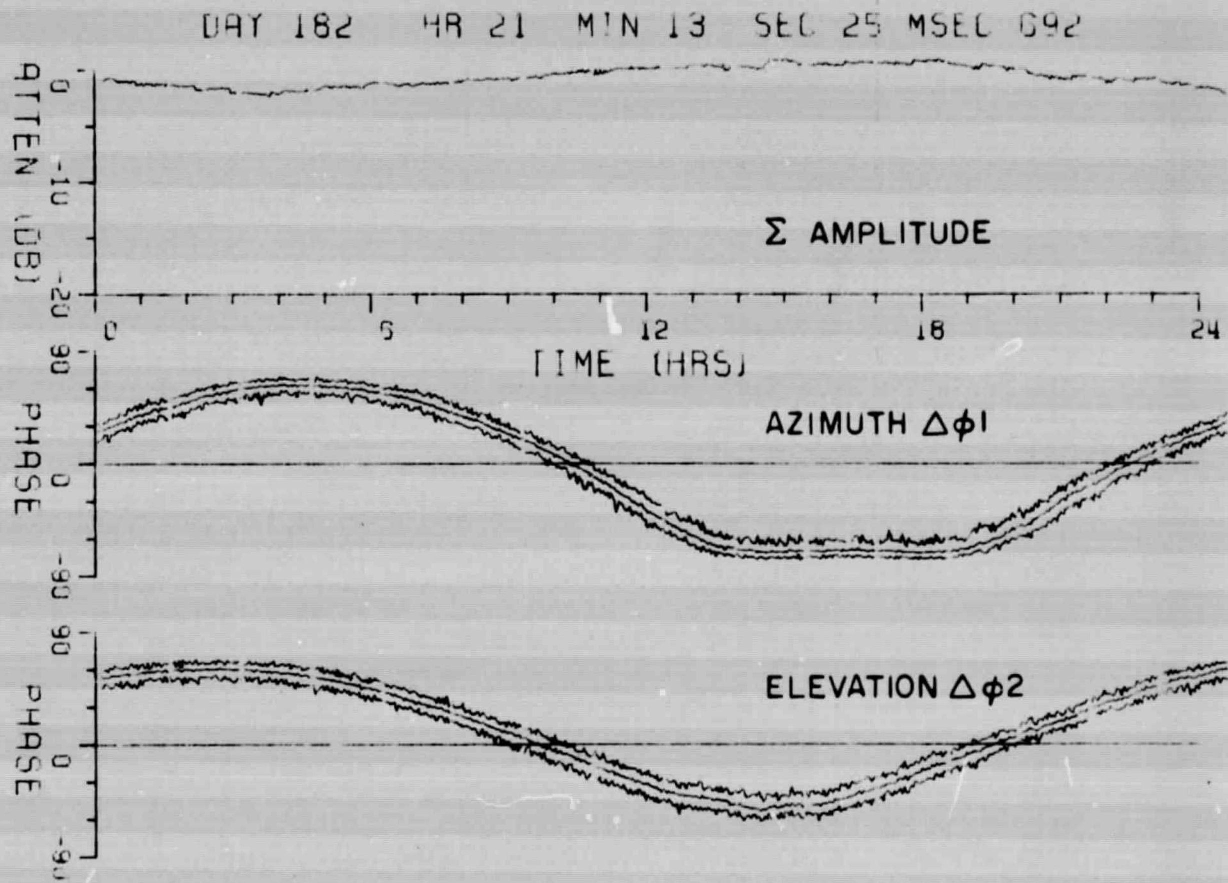

Fig. 2. Sum amplitude and angle-of-arrival excursion - day 182.

as a propagation effect, it would imply a bulk refractive effect associated with propagation through a precipitating region.

A third example is given in Fig. 4. Four distinct precipitation events occur between hours 6 and 10. Again, the differential phase excursion magnitudes are directly correlated with the fade depth and small mean shifts are observable.

The variances of these amplitude and differential phase data were also determined. Amplitude variance for a data interval of N samples, expressed in decibels, is defined:

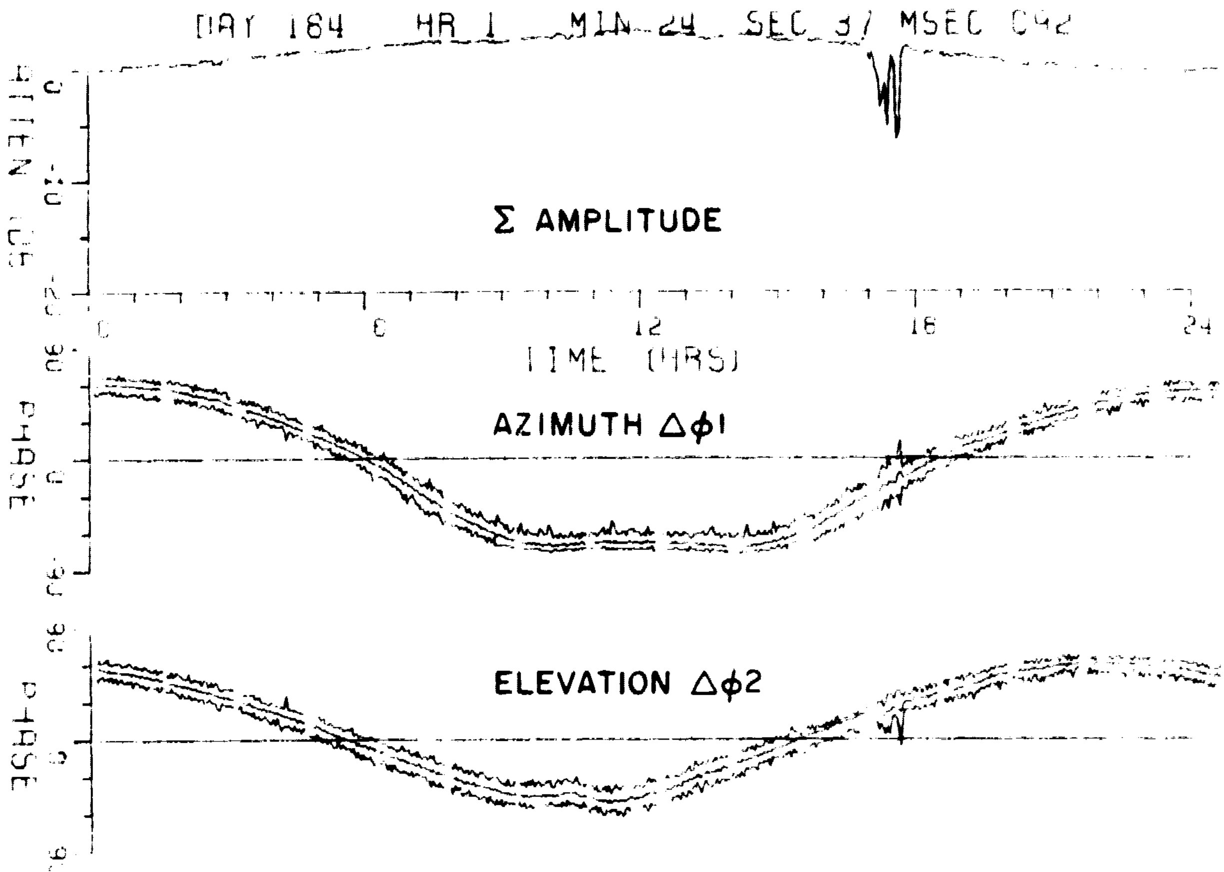

Fig. 3. Sum amplitude and angle-of-arrival excursion - day 184.

$$\text{(1)} \qquad \sigma_A^2 = 10 \log_{10} \frac{\sum_{i=1}^{N} [v_k(t_i) - \bar{v}]^2}{N\bar{v}_k^2}$$

where

$$\text{(2)} \qquad \bar{v} = \frac{\sum_{i=1}^{N} v_k(t_i)}{N}$$

and the v_k are the kth channel voltages samples at times t_i. Similarly, differential phase variance over the same interval is expressed in decibels as:

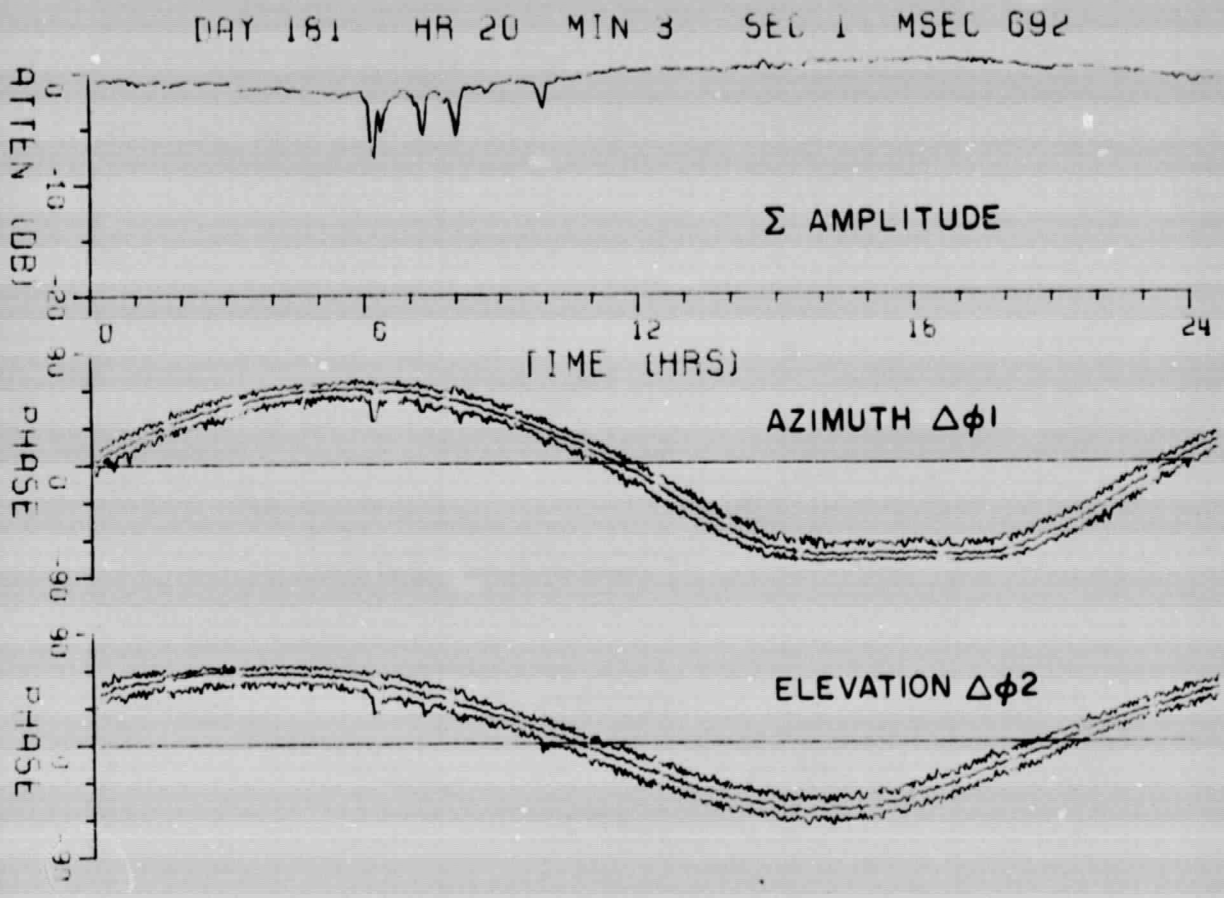

Fig. 4. Sum amplitude and angle-of-arrival excursion - day 181.

$$(3) \qquad \sigma_\phi^2 = 10 \log_{10} \frac{\sum_{i=1}^{N} [\phi_m(t_i) - \overline{\phi}]^2}{N\phi_o^2}$$

where

$$(4) \qquad \overline{\phi} = \frac{\sum_{i=1}^{N} \phi_m(t_i)}{N}$$

and ϕ_o is an arbitrary constant used to reference the decibel scale. $\overline{\phi}^2$ is not a suitable reference because differential phase is not a stationary process and the mean phase is arbitrary. The $\phi_m(t_i)$ are the mth channel calibrated differential phase measurements sampled at times t_i.

Figures 5 and 6 are plots of amplitude and differential phase variance versus time for the same fade events présented previously. Each variance point is calculated for a data interval of 32 samples (96 seconds) and $\phi_0 = 100°$ for both differential phase variance calculations. In both figures, there is significant correlation between fade depth, seen in the coherent sum amplitude channel, and both the amplitude and differential phase variances.

There are two points of interest demonstrated in Fig. 5 in addition to the correlation between fade depth and variance. First, although the onset of the precipitation event is evident in the sum amplitude channel at hour 5.5 on the time scale, the sum amplitude variance experiences an increase beginning at hour 3.5. One may speculate that such a phenomenon is attributable to cloud or frontal activity preceding the precipitation. Second, note that a more subtle change occurs in the differential phase variance beginning at about the same time. The azimuth variance gradually increases and the elevation variance decreases before the event. Hence, phase variance does not necessarily exhibit the same behavior as amplitude variance in the vicinity of a precipitation event.

The tracking performance of this self-phased antenna array and receiving system has been excellent. The system readily follows the diurnal motion of the satellite achieving maximum gain at all times. No tracking problems have been encountered using this technique.

The operation of this self-phased antenna array and receiving system is continuing and will proceed through 1977. The data processing will, of course, also continue with the generation of cumulative amplitude and phase statistics as well as the careful examination of individual events.

III. ATS-6 MEASUREMENTS

The return of ATS-6 from a synchronous position over India to a synchronous position over the United States provided a unique opportunity for the study of scintillation behavior as a function of elevation angle. The movement of the satellite was such that the change in the elevation angle of the propagation path was less than a degree per day; consequently, the change in satellite position during any hour was extremely small.

Three phase-lock-loop receiving systems were implemented at 360 MHz, 2.075 GHz, and 30 GHz for these measurements. The antennas for these systems were a 30 foot parabolic reflector fed by a Yagi at the focal point, a 30 foot parabolic reflector Cassegrainian fed by a horn, and a 15 foot parabolic reflector Cassegrainian fed by a horn, respectively. Using the ATS-6 satellite beacons at these frequencies, system margins of 35 dB, 48 dB, and 55 dB, respectively, were achieved. All three

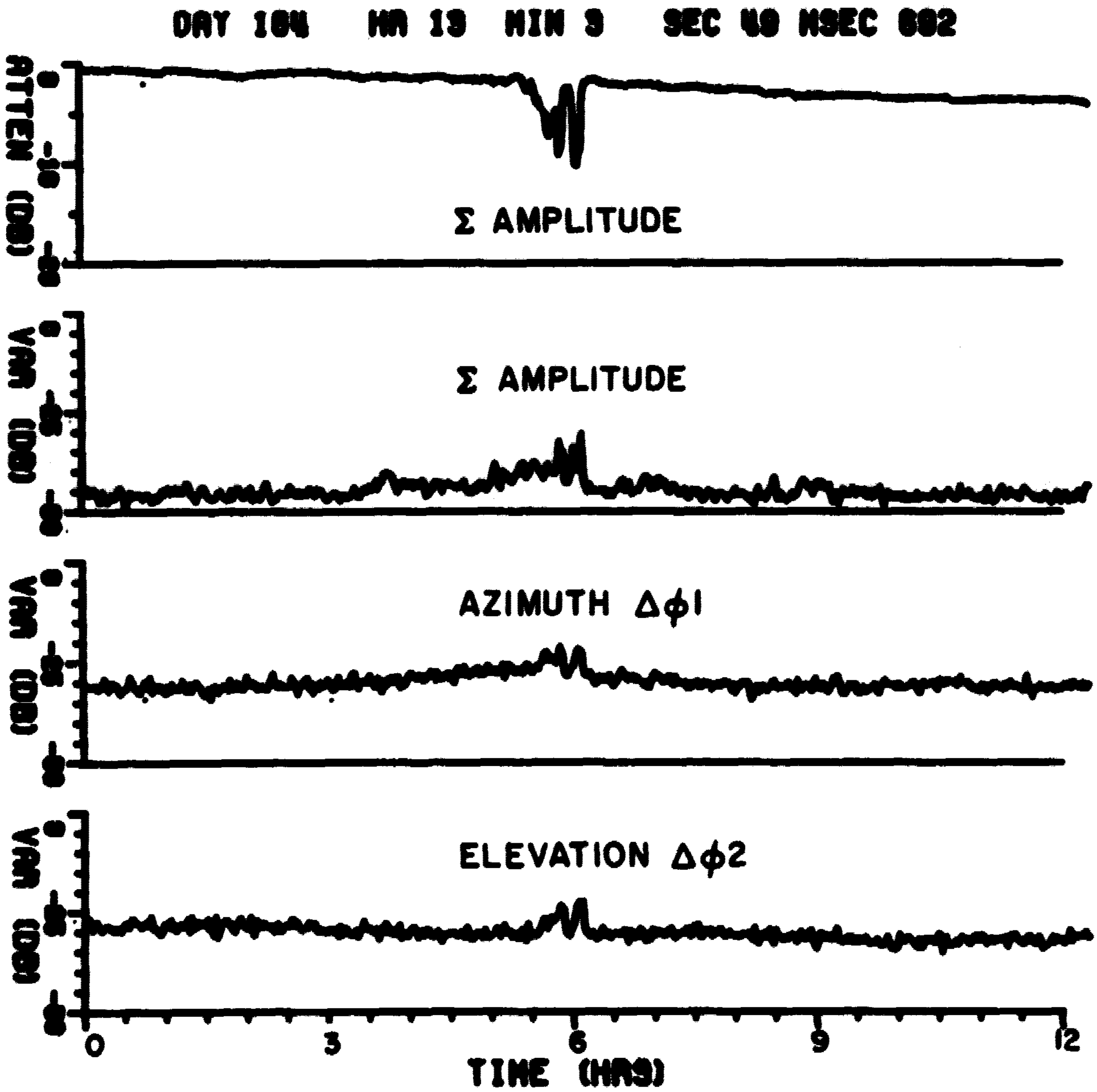

Fig. 5. Sum amplitude and variance of sum amplitude and angle-of-arrival - day 184.

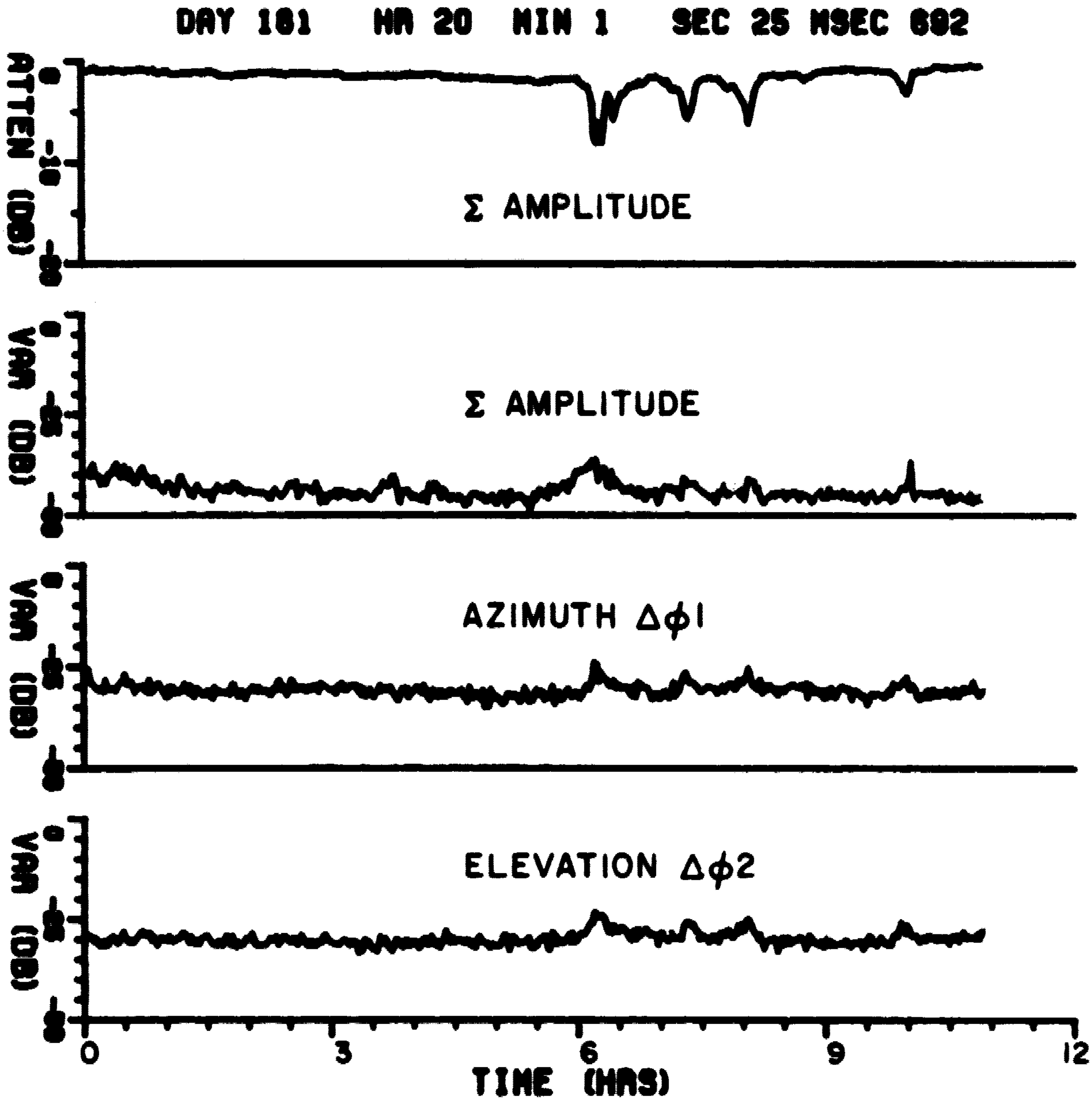

Fig. 6. Sum amplitude and variance of sum amplitude and angle-of-arrival - day 181.

received signal amplitudes were sampled at a rate of 10 Hz at all times and 200 Hz on demand; these samples were recorded digitally in real time.

Thirty data periods were recorded between August 29 and October 25; these periods corresponded to elevation angles ranging from -0.7° to 43.9° (uncorrected for refraction). A total of 84 hours 18 minutes and 59 seconds of data was recorded with 30 hours 20 minutes and 49 seconds of this time corresponding to measurements of all three beacon signals simultaneously. Data periods at 2.075 GHz were limited to durations of about one hour each due to satellite power allocation restrictions. Also, unfortunately, the 360 GHz data were contaminated by interference which makes these data suspect; nevertheless, a substantial amount of good 2.075 and 30 GHz data were obtained over the entire range of elevation angles.

Three samples of these raw data are presented in Figs. 7, 8 and 9. They correspond to elevation angles of 2.8°, 5.9°, and 22.3°, respectively. At the lower elevation angle the 30 GHz scintillations are observed to exceed 20 dB while the 2.075 GHz scintillations are on the order of 4 dB peak-to-peak. As the elevation angle is increased to 5.9° these peak-to-peak scintillation levels drop to about 9 and 3 dB, respectively. Finally, in the sample at 22.3° the scintillations have dropped to rather small values with the exception of the 30 GHz signal between the times of 10 and 25 minutes in the period shown. Here one notes enhanced scintillation of the type often observed when non-precipitating cumulus clouds cross the propagation path.

The processing of these data is progressing well and the preliminary results of this experiment will be presented at the URSI Commission F Open Symposium on Propagation in Non-Ionized Media[14].

IV. SUMMARY

A self-phased antenna array and receiving system was implemented to measure angle-of-arrival and amplitude statistics on the 11.7 GHz CTS beacon downlink. This system became operational on February 20, 1976, and operation is continuing at the present time. Enhanced angle-of-arrival as well as amplitude scintillations have been observed in conjunction with precipitation fade events. The utility of the self-phased array technique for non-mechanical tracking of synchronous satellites with small orbital perturbations has also been demonstrated.

An experiment involving simultaneous measurements of amplitude scintillations at 360 MHz, 2.075 GHz, and 30 GHz was performed during the return of ATS-6. Enhanced amplitude scintillations were observed at both 2.075 and 30 GHz in conjunction with the occurrence of non-precipitating cumulus clouds along the propgation path.

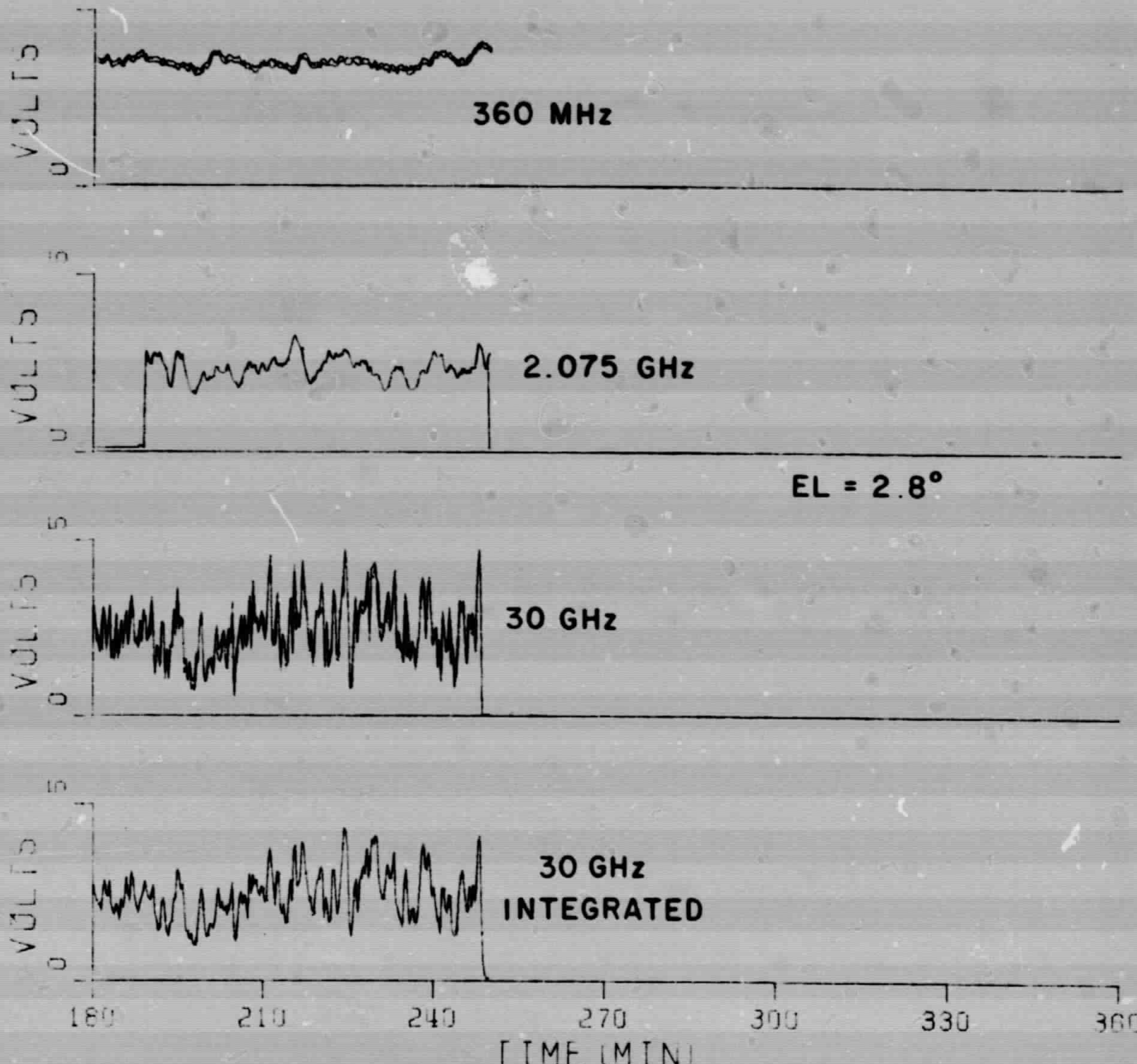

Fig. 7. ATS-6 beacon signals recorded on Day 246.

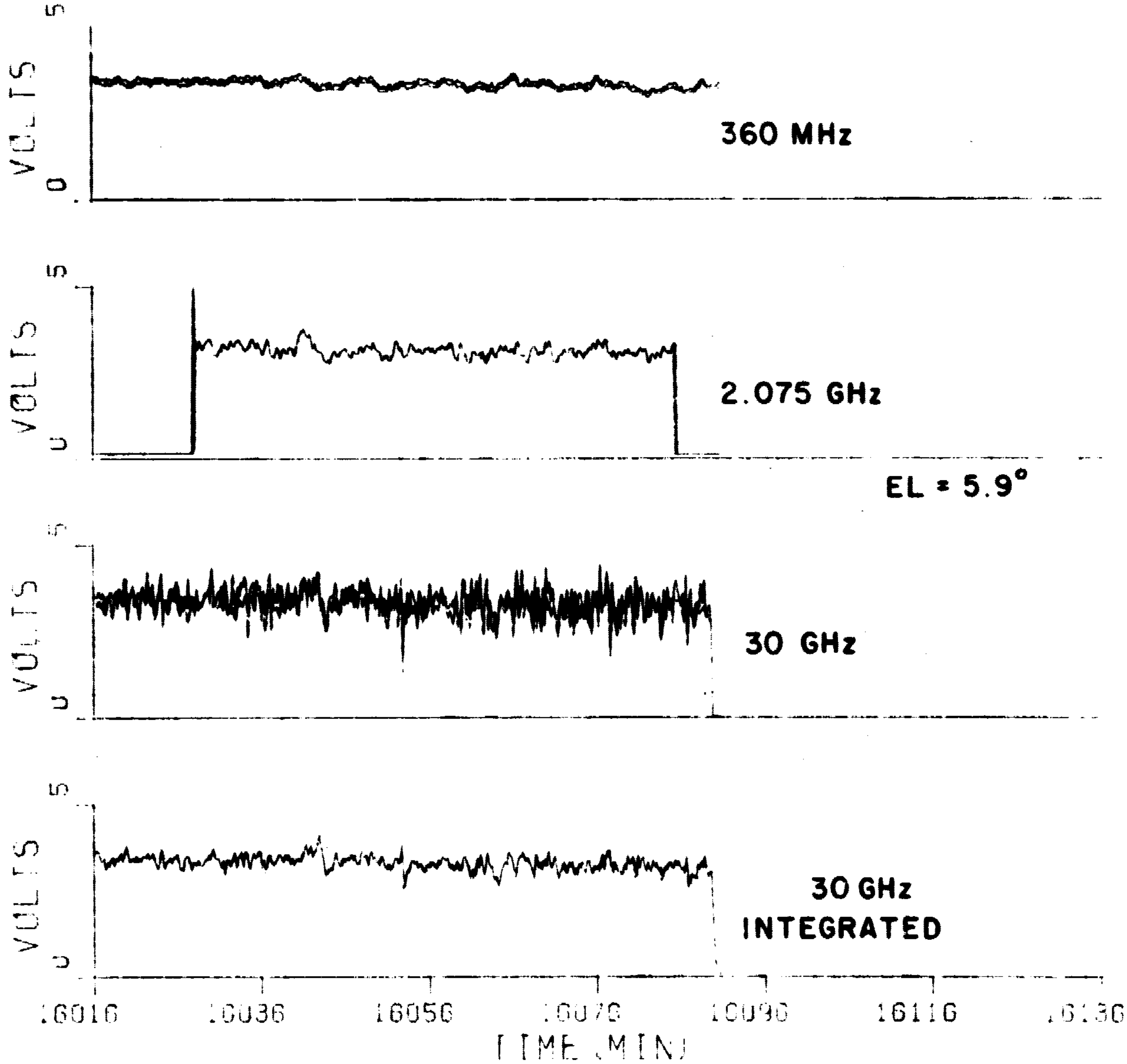

Fig. 8. ATS-6 beacon signals recorded on Day 248.

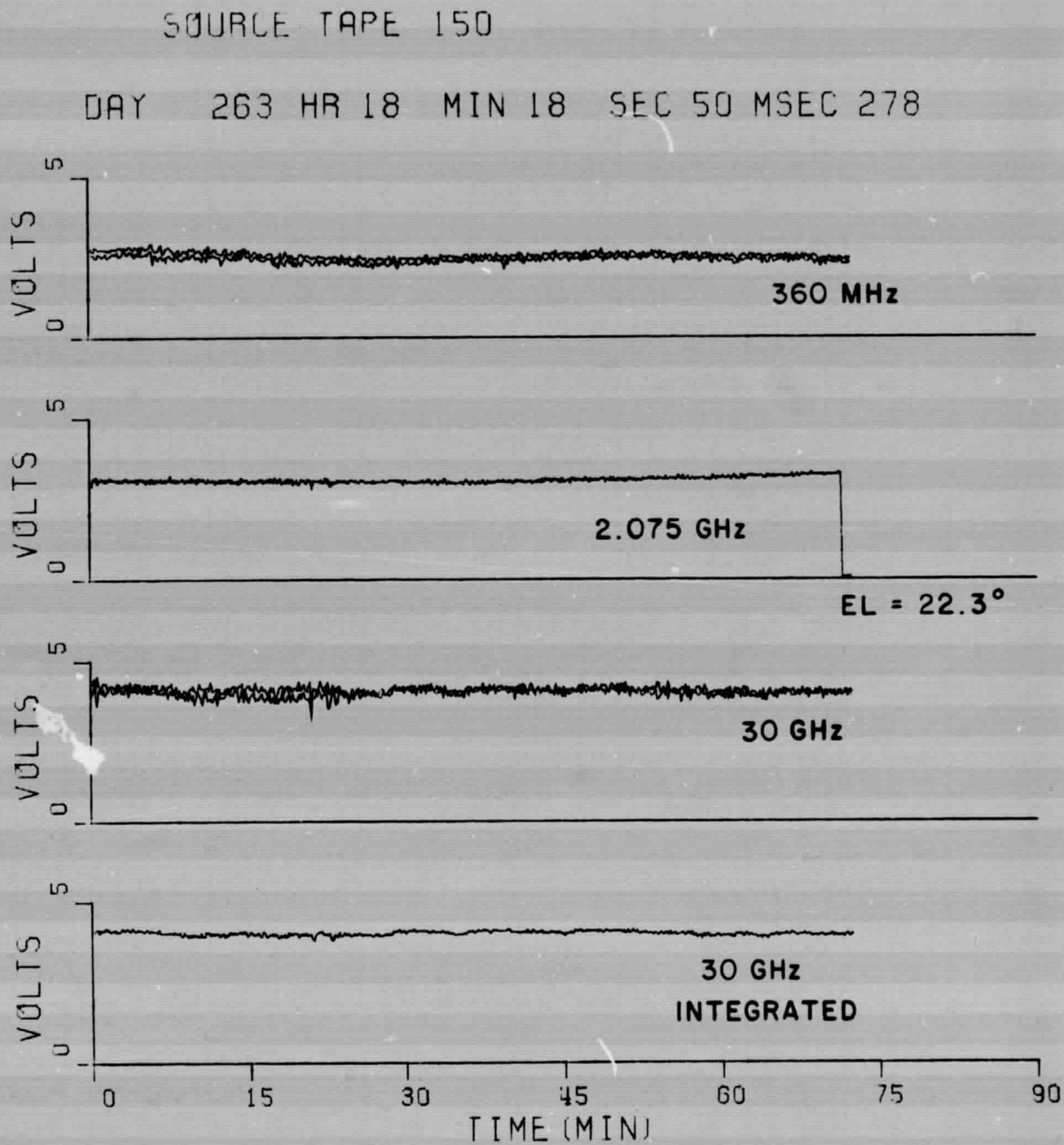

Fig. 9. ATS-6 beacon signals recorded on Day 263.

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