

DIURNAL AND SEASONAL VARIATIONS OF SATELLITE SCINTILLATION

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Master of Arts

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By

John David Martin

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APPROVAL SHEET

This thesis is submitted in partial fulfillment of  
the requirements for the degree of  
Master of Arts

*John D. Martin*  
\_\_\_\_\_  
Author

Approved, May 1963

*James D. Lawrence, Jr.*  
\_\_\_\_\_  
James D. Lawrence, Jr.

*John L. McKnight*  
\_\_\_\_\_  
John L. McKnight

*D. E. McLennan*  
\_\_\_\_\_  
Donald E. McLennan

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## ABSTRACT

Time versus signal amplitude strip charts of artificial earth satellites have been examined in order to investigate the diurnal, seasonal, latitude, and height variations of ionospheric irregularities responsible for disturbances of radio waves. The data indicate that the fluctuations or "scintillations" caused by the irregularities are predominately night-time phenomena. The seasonal study shows that the maximum scintillation activity appears to be centered about the autumnal equinox; the minimum activity, centered about the vernal equinox. The latitude variation study shows that during periods of strong scintillation activity, the scintillation depth is strongly dependent on latitude; the maximum depth occurring at high latitudes and the minimum depth at the observer's latitude. The variation of scintillation depth with height of emitter shows that maximum scintillation activity occurs at heights of 500 - 550 km. The depth then decreases steadily to heights of 1550 km.

The results of the diurnal and seasonal studies agree with the results of other workers. The height variation study does not conform with any present theory. A theory for latitude variation has not been proposed.

DIURNAL AND SEASONAL VARIATIONS  
OF SATELLITE SCINTILLATION

## INTRODUCTION

Among the early workers in radio astronomy were Hey, Parsons, and Phillips.<sup>1</sup> In 1946 they detected short-period irregular fluctuations in the signal strength of the noise power at 5 meters wave length in the direction of Cygnus A. They concluded that these fluctuations or "scintillations" were due to variations in the emission power of the source, and that these scintillations might prove particularly relevant in explaining the origin of cosmic radiation at radio frequencies. Bolton and Stanley,<sup>2</sup> and Ryle and Smith<sup>3</sup> established the existence of intense sources of radio frequency radiation from the constellations of Cygnus and Cassiopeia. They too thought that irregular fluctuations noticed on recordings of signal strength versus time were inherent in the sources themselves.

In 1949 Little and Lovell<sup>4</sup> at Jodrell Bank made a series of interesting observations. Using two receiving stations spaced 210 km apart they observed simultaneously radio frequency signals of wave length 3.7 meters from Cygnus. At the same time they observed Cassiopeia at Cambridge and Jodrell Bank at Cheshire. The results were that at both sites they generally saw fluctuations or failed to see such fluctuations on a given night. Only about 10% of the time did they notice a discrepancy between stations. There was, however, no significant correlation between the records. It was noticed in general, however, that the mechanism causing

the disturbances in signal received from either Cygnus or Cassiopeia was responsible for the disturbances in the other. Little and Lovell conducted another experiment with stations spaced closer together in an attempt to establish the amount of correlation over short distances. At 100 meters separation they saw complete correlation, and at 3.9 km fairly good correlation. As a result it was concluded that the mechanism probably lies in the earth's atmosphere or ionosphere rather than in interstellar space as had been proposed by earlier workers. They went further to suggest that localized clouds of electrons in the F region may cause changes in the refractive index of the ionosphere and consequently produce scintillation.

Smith<sup>5</sup> on 3.7 meter wave length saw no correlation of fluctuations when two stations were spaced greater than 20 km. At Cambridge on 3.7 m and 6.7 m there was found to be good correlation between rapid fluctuations. This might be explained by a mechanism in the earth's atmosphere due to local changes in index of refraction.

A summary of observation and theory of radio star scintillation is given by Booker.<sup>6</sup> The most significant conclusions of his paper are: (1) an increase of scintillation is observed with an increase in zenith angle, (2) a midnight maximum is observed by all workers and in Australia a weak midday maximum is observed, (3) observers in the northern hemisphere report little seasonal variation, and (4) there is a good correlation between the occurrence of radio

star scintillation and spread F reflections.

With the launching of the first artificial earth satellite in 1957, more comprehensive studies could be made on the irregularities in the ionosphere responsible for scintillation. Slee<sup>7</sup> observing the 108 Mc/s radio signal from the satellite 1958 Alpha during the months of February and March, 1958 concluded that the region of the ionosphere causing scintillation was below 350 km because at the satellite's perigee of 350 km there was no marked decrease in scintillation. He concluded that the regular variations of signal strength of the satellite were produced by the physical rotation of the satellite. Other workers have shown that rotation of the plane of polarization is produced by both (1) the anisotropic ionosphere through which the satellite signal is propagated and (2) rotation of the satellite. Kent<sup>8</sup> at Cambridge (52°N, 0°) has studied the 40 Mc/s transmission of 1957 Alpha. He observed very little scintillation for satellites south of Cambridge, and generally observed scintillation at lower latitudes to the west than to the east of Cambridge. He concluded that the irregularities responsible for scintillation (1) generally occur north of 50° N latitude, (2) are aligned along the magnetic rather than geographic meridians, (3) occur at heights above 250 km, and (4) that they are about 1 km in size. In addition Kent concluded that the irregularities responsible for satellite scintillation were probably responsible for radio-star scintillation and spread-F echoes.

Yeh and Swenson<sup>9</sup> at Urbana, Illinois, ( $40^{\circ}$  N,  $88^{\circ}$  W) have observed the 40 Mc/s transmission of 1957 Alpha and the 20 Mc/s transmission of 1958 Delta II. Their results indicate that scintillation is predominately a night time effect and generally occurs above  $40^{\circ}$  N latitude, but they observed no distinct latitude dependence during the day.

Mawdsley<sup>10</sup> suggested that (1) on the basis of star scintillation data one would expect the irregularities to be elongated along the earth's magnetic field lines (Spencer<sup>11</sup>), and (2) the scattering efficiency of the irregularity depends upon the angle between the direction of propagation and the direction of elongation of the irregularity, the efficiency being a minimum when the direction of propagation is along the direction of elongation. On the basis of these suggestions, he concluded that a higher incidence of scintillation should be observed to the north and west of Cambridge, and that the irregularities do not necessarily disappear south of Cambridge.

Singleton and Lynch<sup>12</sup> at Brisbane, Australia ( $27.5^{\circ}$  S,  $152.9^{\circ}$  E) recorded signals from the transmissions of 1959 Iota 1 at 20 Mc/s from July to September, 1960. From a study of their scintillation data they concluded that the scintillation activity (1) has a Gaussian distribution of amplitude, (2) is predominately a night time effect with a maximum shortly after local midnight, and (3) increases noticeably with zenith angle above  $50^{\circ}$ .

The theoretical aspects of the propagation of spherical

waves through a medium containing anisotropic random irregularities have been treated by Yeh.<sup>13</sup> He applies first order perturbation theory to the propagation of radio transmissions from satellites through the ionosphere. In contrast to the work by Singleton and Lynch, Yeh suggests that the scintillation index should be relatively insensitive to the zenith angle of the satellite position for temperate latitudes. In addition Yeh shows that the scintillations (phase and logarithmic amplitude) depend upon the height of the satellite above a slab containing the irregularities.

In a very recent paper by Briggs and Parkin<sup>14</sup> at the University of Adelaide, the variation of satellite scintillation with zenith angle is thoroughly discussed. Briggs and Parkin flatly disagree with Mawdsley's suggestions (mentioned earlier). They suggest that the maximum scintillation index will be observed when the signal from a satellite is propagated parallel to the axis of symmetry of the irregularities assuming an ellipsoidal configuration and not normal to the axis as suggested by Mawdsley. Their theory suggests that the amplitude scintillation index depends upon the ratio of the scattered power to the unscattered power which according to them is a maximum when the direction of propagation is parallel to the axis of symmetry.

### The Ionosphere

A number of ionized regions above the earth's surface form the ionosphere. These regions are responsible for

disturbances to radio waves from extraterrestrial sources mainly because of the presence of free electrons. The regions are arranged approximately in horizontally stratified layers. They do not have sharp boundaries and their heights above the earth are not rigorously defined. The lower limit of the ionosphere is generally considered to be at an altitude of 50 km and the upper limit about 500 km although this figure is not well agreed upon. The regions or layers are identified by the letters D, E, and F and differ in their origin and influence on radio waves. Figure 1 is a plot of height (km) above the earth's surface versus electron density (electrons/cc) of the average daytime ionosphere for the year 1962. The Seddon two-frequency radio-propagation experiment<sup>15</sup> demonstrated that in the lower ionosphere, the electron density increases monotonically with altitude, and thus the various regions are not well defined.

Until the advent of artificial earth satellites, radio stars were the only sources available for studies of the ionosphere above the  $F_2$  peak. Very few radio stars emit signals which can be observed without very elaborate equipment: thus, only certain portions of the ionosphere could be studied because of the limited apparent motion of the stars. The ionosphere above the  $F_2$  peak is not accessible to the classical ground-based ionosondes. Now it is possible to measure the disturbances to radio signals as functions of the various position parameters of the satellite in addition to measuring ionization radiation, electron density, and ion composition for all regions of the ionosphere.

# AVERAGE DAYTIME IONOSPHERE

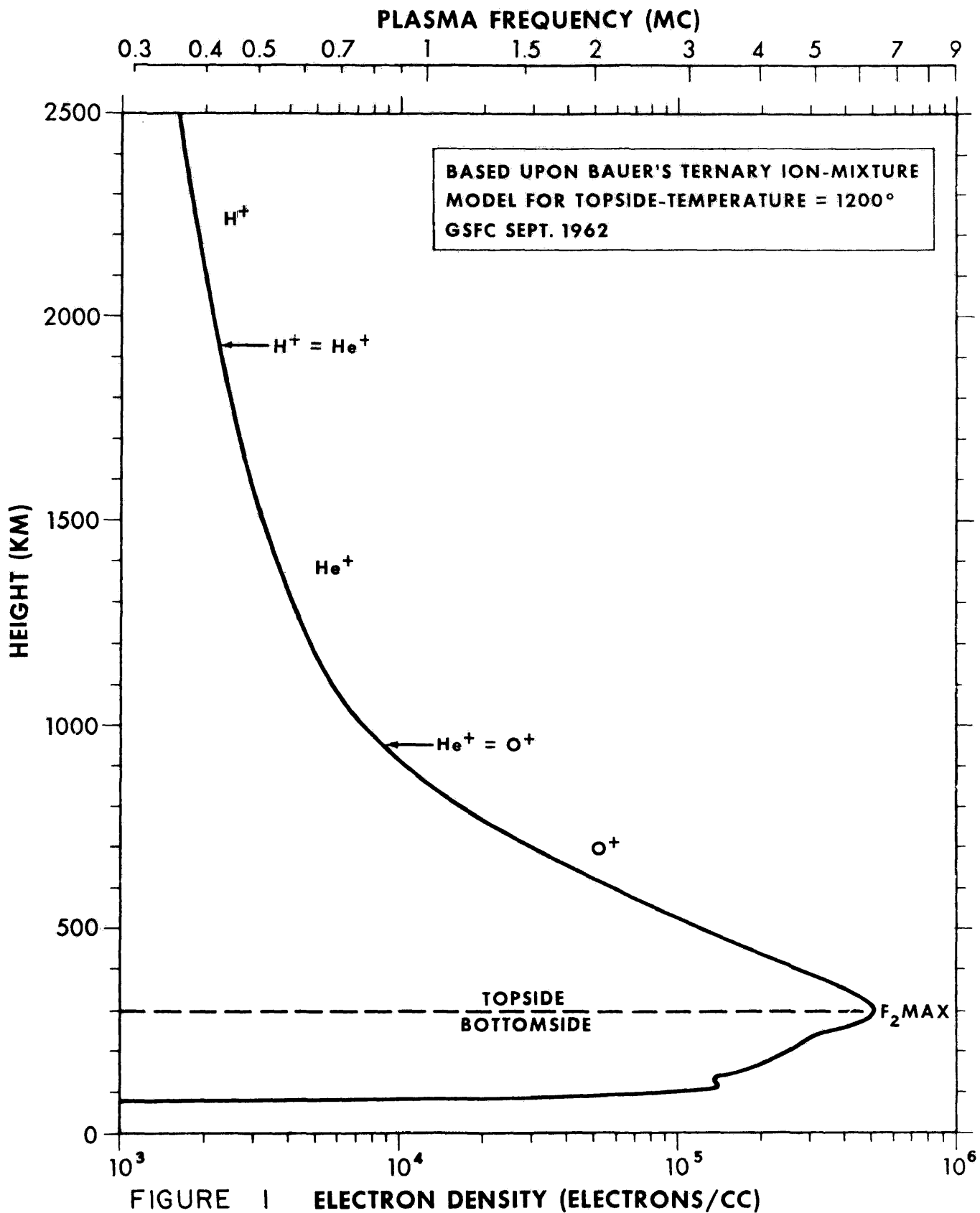


FIGURE 1 ELECTRON DENSITY (ELECTRONS/CC)

## D Region

The lowest of the ionospheric regions is the D region situated between approximately 50 and 85 km. It exists during the daylight hours only and merges into the E region at sunset. Aiken<sup>16</sup> has suggested that the major portion of the D region is created in an interval of about 30 minutes at sunrise.

Nicolet and Aikin<sup>17</sup> have done the most detailed theoretical analysis of D region formation although the complete mechanisms responsible for the formation are not fully known. They have concluded that:

- (1) cosmic radiation is the primary ionizing agent at altitudes up to 70 km;
- (2) "in the 70-85 km region, assuming a NO recombination coefficient of  $3 \times 10^{-9} \text{ cm}^3 \text{ sec}^{-1}$ , a nitric oxide abundance of only  $10^{-10}$  of the total neutral concentration is required to make X-rays (2-8A) unimportant to the formation of the D region under quiet solar conditions;
- (3) negative ions are unimportant above 70 km;
- (4) the ionization at altitudes between 85 and 100 km (base of the E region) is the result of X-rays (30-100 A) and ultraviolet radiation (Lyman B and Lyman continuum)."<sup>15</sup>

When the solar activity is high, the D region is characterized by increased ionization with associated electromagnetic wave attenuation strong enough to produce solar blackouts. Simultaneously with the appearance of solar

flares, large scale fluctuations in the D region cause sudden ionospheric disturbances (S.I.D.) and polar cap absorptions (P.C.A.) at auroral latitudes.<sup>15</sup>

### E Region

The next region in the ionosphere is located approximately between 85 and 140 km and is called the E region. The predominant ionizing sources of the E region for quiet solar conditions at mid-latitudes are solar ultraviolet radiation (Lyman B and the Lyman continuum) and X-ray radiations ( $\lambda > 10 \text{ \AA}$ ). The remainder of the ionizing sources are thought to be: (1) general ionization of air by soft X-rays<sup>18</sup> and (2) photoionization of  $O_2$  by solar radiation in the wavelength region between 800 and 1026  $\text{\AA}$ .<sup>19</sup> The ions formed in the greatest abundance in the E region are  $N_2^+$ ,  $O_2^+$ ,  $O^+$ .

The maximum ionization density is of the order of  $10^5$  electrons/cm<sup>3</sup>, but this varies in the course of the sunspot cycle.<sup>20</sup> At night the density is lower by two orders of magnitude. Until recently, neither rocket-borne experiments nor ground-based ionosondes were sensitive enough to measure accurately the density of the night-time E region. Now with low energy plasma probes in space flight studies the diurnal characteristics of the E region can be investigated.

### Sporadic E

At times ionosondes reveal, besides the well-recognized E, F<sub>1</sub> and F<sub>2</sub> regions, distributions of intense ionization

close to the height of the E region. Because of their random occurrence these are known as sporadic E. Smith<sup>21</sup> defines sporadic E as a "...comparatively strong and protracted transmission (several minutes to several hours) 'returned' from the E region of the ionosphere by some mechanism other than the normal reflection process from the daytime regular E layer."

The more probable energy sources of sporadic E are: solar corpuscles (thought to trigger the unstable upper atmosphere in the auroral zones), meteors, thunderstorms, winds and turbulence, and ionospheric currents. The structure of the sporadic E region is not at all well known. The three models which have been proposed are: (1) "a thin horizontal layer of high electron density embedded in the regular E layer,"<sup>21</sup> (2) a steep gradient in the upper or lower part of the E layer, and (3) blobs of ionization of high or low electron densities embedded in the surrounding medium.

### F Region

The F region is taken to be the region of the ionosphere above 140 km. Bourdeau<sup>15</sup> states that the upper limit is generally taken to occur where  $O^+$  ceases to be the predominant ion. The primary sources of ionization in the F region at mid-latitudes for quiet solar conditions are believed to be solar ultraviolet and X-ray radiations.

During the daytime there are two peaks of ionization in the F region. The lower of these, the  $F_1$  peak, occurs at a height of about 160 km with an electron density of

$2.5 \times 10^5$  electrons/cm<sup>3</sup> at noon at sunspot minimum. At night the F<sub>1</sub> peak merges with the F<sub>2</sub> peak.

For mid-and-high latitudes the F<sub>2</sub> peak occurs at a height of about 250 km with an electron density on the order of  $5 \times 10^5$  electrons/cm<sup>3</sup> at noon on magnetically quiet days. At night the F<sub>2</sub> peak, combined with the F<sub>1</sub> peak, rises to about 350 km. The F<sub>2</sub> region is subject to many anomalies, and is affected by tidal influences (solar and lunar), as well as by the conditions associated with magnetic storms. One such anomaly occurs at the equator where the F<sub>2</sub> peak is about 350 km at noon and about 300 km at midnight, and where as at mid-and high-latitudes, as mentioned above, the F<sub>2</sub> peak rises at night.<sup>22</sup> Most F region fluctuations appear to be associated with magnetic activity.

At certain times ionosonde returns are diffuse and broad near the critical penetration frequencies of the F region, indicating that this region is anisotropic; that is, it contains randomly distributed "blobs" of electron densities differing from their surroundings. This phenomenon is known as spread F and, with reasonable certainty, the inhomogeneities associated with spread F, the steep ionization gradient at night of the undersurface of the F region, and magnetic disturbances at mid-to high-latitudes, are the main causes of radio-star and satellite scintillations.

Above the F<sub>2</sub> peak the electron density decreases with a practically constant logarithmic slope for several hundred kilometers. This region is not too accessible to ordinary ground based pulse techniques. With the use of artificial

satellites, including especially the "top side" sounding satellites, a better understanding of the composition and behavior of the upper ionosphere is expected to be achieved.

### The Experiment

The purpose of this experiment is to attempt to gain a better understanding of the properties of the ionosphere. For example, good investigations of diurnal, seasonal, and latitude variations of the ionospheric irregularities have not been published. Also of interest is the effectiveness of the irregularities in producing disturbances on extraterrestrial radio signals as functions of the height of the emitter and its zenith angle (along the observer's magnetic meridian) measured from the observer on the surface of the earth. This experiment limits the extraterrestrial sources to artificial earth satellites. In particular the satellites observed were Transit IV-A (1961 Omicron 1) and three Russian satellites of the Cosmos series. The observing or receiving station is located near Williamsburg, Virginia (longitude  $76^{\circ} 45'$  W, latitude  $37^{\circ} 17'$  N).

Five hundred and nine (509) records of Transit IV-A and one hundred and forty-nine (149) records of the Cosmos satellites have been observed from January, 1962 through February, 1963. These records have been examined for irregular fading (due to the randomly distributed irregularities in the ionosphere) imposed on the regular fading due to the rotation of the plane of polarization of the propagated signal and the rotation of the satellite. The irregular fading has random amplitudes and fading rates and is termed

"Scintillation." Throughout this experiment the term "satellite scintillation" refers to the irregular fading observed on time versus amplitude traces of recorded satellite signals.

## EQUIPMENT

### 1961 Omicron 1 - Transit IV A

The 1961 Omicron payload was launched into orbit with a Thor-Able Star rocket on June 29, 1961 by the Applied Physics Laboratory of the Johns Hopkins University. The payload was the first to consist of three satellites; the principal one, Transit IV A, carried the first nuclear device ever rocketed into orbit. Attached on top of Transit IV A were two scientific satellites: 40 pound Injun and the 55 pound Greb. The two smaller satellites separated from Transit IV A but failed to separate from each other.

The 16 sided Transit IV A has a flat bottom and top, is 43 inches in diameter, and is 31 inches high. Its nuclear power device is fueled with plutonium 238 and produces three watts of power.<sup>23</sup> Transit IV A is equipped with four radio transmitters; two powered by the nuclear device, two by solar cells located on the surface of the satellite. Two of the radios transmit on 54 Mc/s with a radiated power of 150 mw; the other two transmit on 324 Mc/s with an estimated power of 80 mw.<sup>24</sup> "The 54 Mc/s doppler signal is phase modulated by approximately 35° with a ring type modulator."<sup>25</sup>

The initial orbit parameters of Transit IV A were: nodal period - 103.7 minutes, inclination - 67.00 degrees, perigee altitude - 858.8 km, apogee altitude - 1002.1 km.<sup>26</sup>

The memory readout system of Transit IV A provides

a new and more precise time standard available over the entire surface of the earth. It is more accurate than the time signals transmitted by WWV of the National Bureau of Standards, since WWV transmissions are subject to variations in reception time because of refraction due to fluctuations of the ionosphere.

#### Russian Satellites

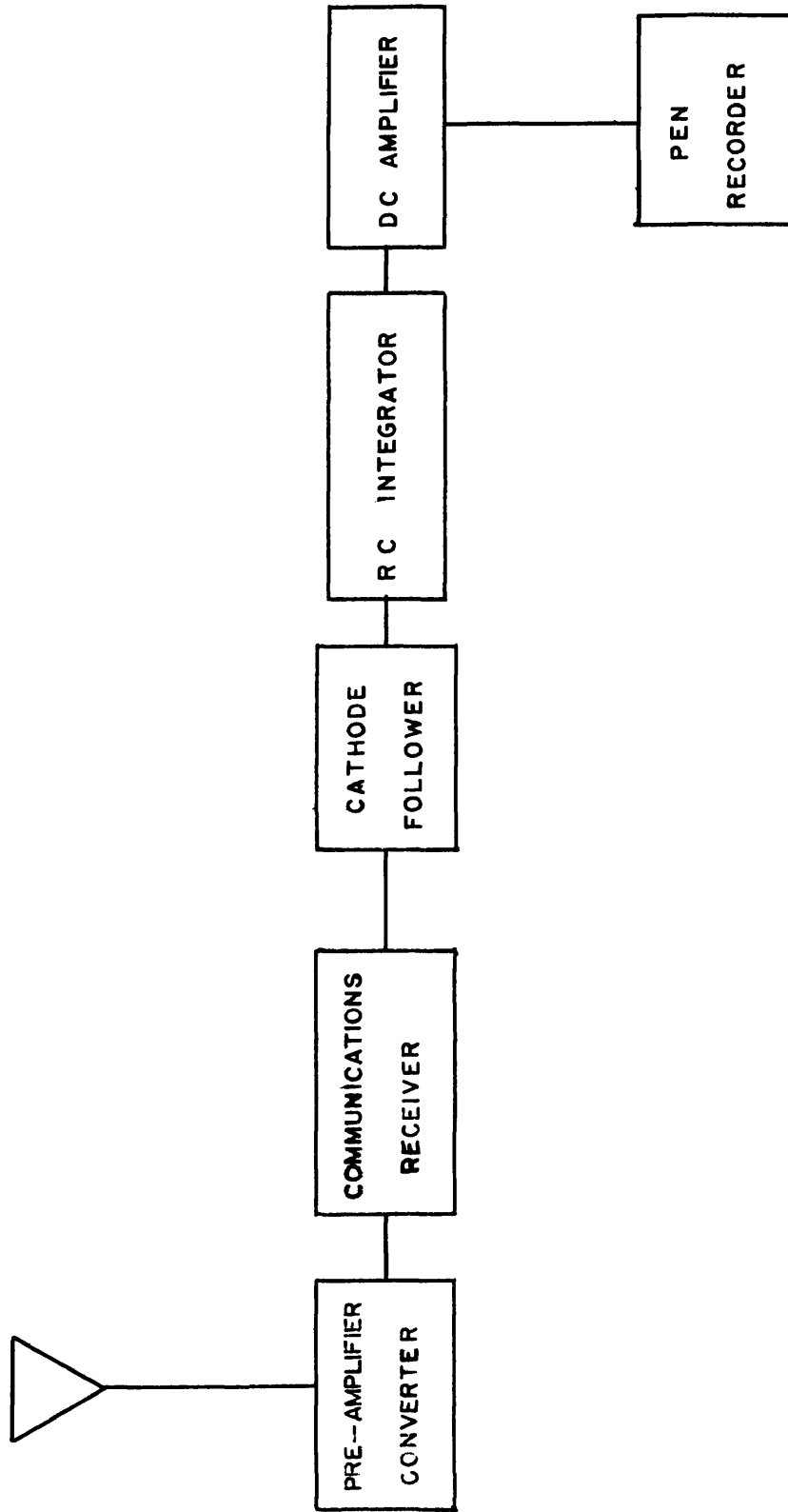
In addition to Transit IV A, three Russian satellites, transmitting on approximately 20 Mc/s, have been used in this problem: 1962 Theta 1 - Cosmos I, 1962 Iota 1 - Cosmos II, and 1962 Upsilon 1 - Cosmos V. Of course, the specifications on these satellites have not been made available. The initial orbit parameters are listed in Appendix I.

#### Receiving and Recording Equipment

The signal transmitted from a satellite is received by a half-wave folded dipole antenna and is then sent to a Tapetone converter. There the signal is preamplified and converted to 14.4 Mc/s which in turn is sent to a Collins 51J-4 receiver. The signal is taken out at the detector, sent to a cathode-follower, integrated, D C amplified, and then recorded by a Brush pen recorder. Figure 2 is a block diagram of the satellite receiving and recording equipment and a more descriptive account of the individual components follows:

#### Antennas

The antennas used for satellite tracking are half-wave folded dipoles constructed of 300 ohm, heavy duty twin lead (Amphenol 214-185). The calculation of the proper length



BLOCK DIAGRAM OF RECEIVING EQUIPMENT

FIGURE 2

of a dipole is as follows. The half-wave length ( $\frac{\lambda_e}{2}$ ) of a signal transmitted in free space is:

$$\left( \frac{\lambda_e}{2} \right) = \frac{ck}{2f}$$

$$\left( \frac{\lambda_e}{2} \right) (\text{feet}) = \frac{492k}{f(\text{Mc})}$$

where k is the "end correction" (k = 0.95). The velocity factor for 300 ohm twin lead is taken to be 0.84, thus the half-wave length ( $\frac{\lambda}{2}$ ) in the twin lead is:

$$\left( \frac{\lambda}{2} \right) = 0.84 \left( \frac{\lambda_e}{2} \right).$$

The difference in the length of the dipole for free space and that for the twin lead, 0.16 ( $\frac{\lambda_e}{2}$ ), is corrected for by adding a heavy copper wire of length half the difference to each end of the twin lead.

The use of a half-wave length balun, see Figure 3, is employed to produce a 4-to-1 step-down in impedance. This permits the use of a 73 ohm transmission line (RG - 59/U) to connect the antenna with the next stage of the receiving equipment. The balun is made with RG - 59/U coaxial cable with a velocity factor of 0.66.

The antennas are connected to glass insulators which in turn are connected to 1/4 inch nylon ropes. The ropes are fed through pulleys (to facilitate changing antennas) mounted on aluminum masts 27 feet high. Placing the antennas at this height reduces the effect of obstructions on the ground. The ground plane is not known nor has an artificial ground plane been constructed. This system of antennas has the advantages of being easily and inexpensively constructed.

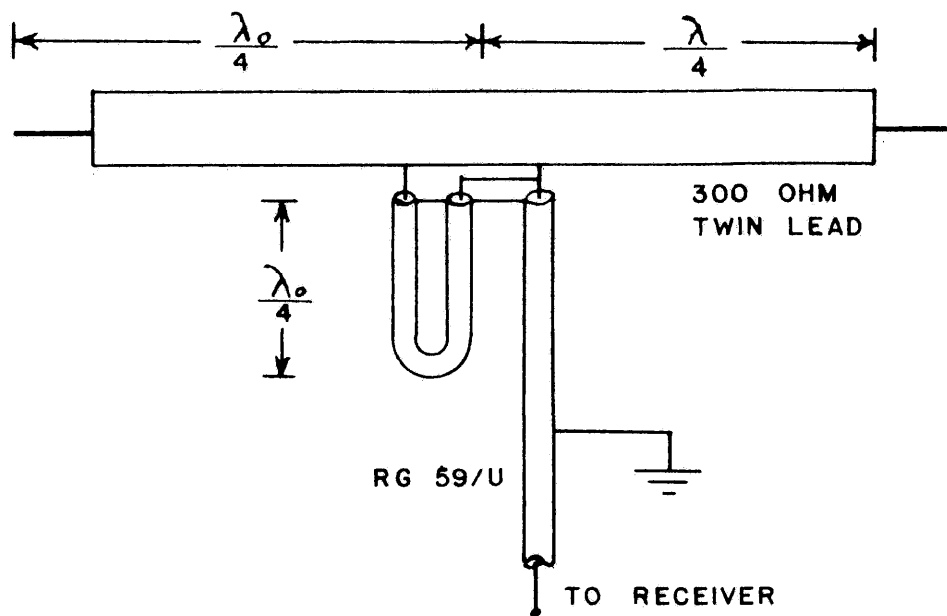


FIGURE 3 RECEIVING ANTENNA

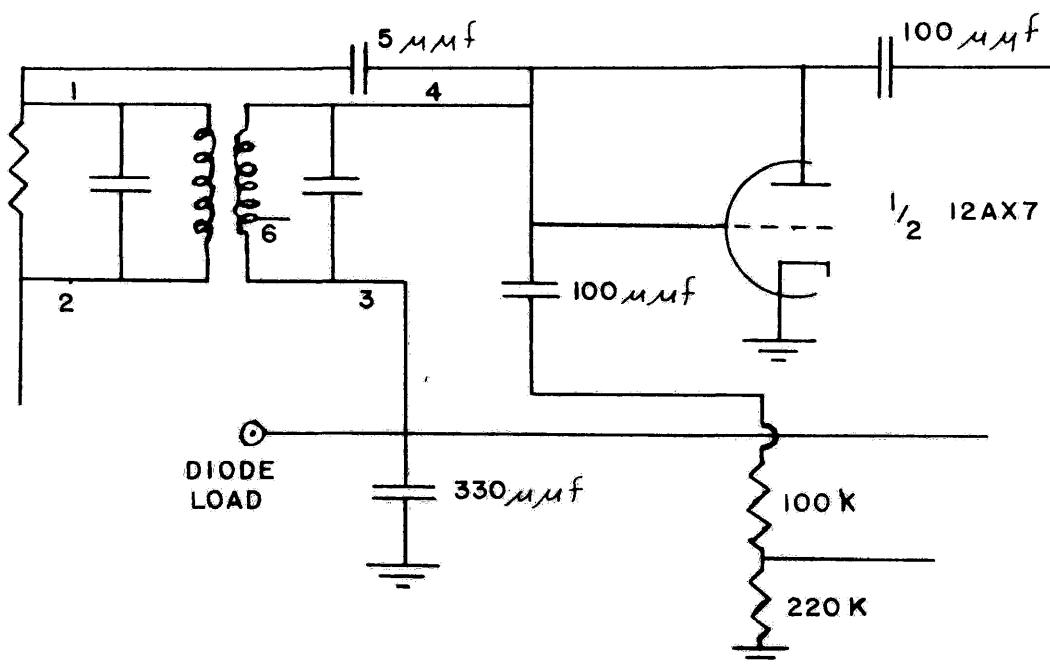


FIGURE 4 COLLINS 51J-4 OUTPUT LOCATION

The antennas, along with the other receiving and recording equipment are located in an open, flat field a few miles west of Williamsburg. One pair of antenna masts are situated so that one antenna is aligned along the north-south direction while the other is aligned along the east-west direction in such a way that they intersect at their midpoints. A similar pair of antennas is located a short distance from the first. The system of two mutually perpendicular antennas provides a means of examining the rotation of the plane of polarization of satellite signal.

#### Converter

A Tapetone TC-54 converter was used to convert the 54 Mc/s satellite signal to an intermediate frequency of 14.4 Mc/s. In the case of the Russian satellites a Tapetone TC-20 was employed. In either case the tube line up is a pair of 6BQ7A tubes as a cascode RF amplifier, followed by a 6CB6 mixer stage. The local oscillator is crystal-controlled, using a 12AT7. The TC-54 converter has a power gain of 44 db and a noise figure of 3.2 db.

#### Receiver

The two Collins 51J-4 Radio Communications Receivers, employed in this experiment, are complete coverage superheterodyne receivers capable of AM and CW reception in the frequency range of 0.5 to 30.5 Mc/s. The tuning spectrum makes use of single, dual, and triple conversion. Three stages of intermediate frequency amplification and a crystal filter produce the desired degree of selectivity.

A low impedance AVC, a good noise limiter, two stages of audio amplification, and a 100 kc frequency spotter or calibrator are featured in the receiver.

In the frequency range of interest, approximately 14.4 Mc/s, dual conversion is used. The signal frequency is beat against the high frequency oscillator output to produce a variable i-f of 2.5 to 1.5 Mc/s. This in turn is combined in the second mixer with the variable frequency oscillator output to produce the 500-kc fixed i-f. For the reception of a satellite signal frequency of 54 Mc/s, a 3.1 kc mechanical filter was incorporated, which would pass a band of frequencies approximately 3 kc wide centered on 500 kc. A 1.4 kc filter was used for a 20 Mc/s satellite signal.

The satellite signal is taken from the Diode Load test point in the detector circuit, (see Figure 4). The detector consists of one half of a 12AX7 dual triode, used as a diode, with rectification taking place between the plate and cathode. The grid is connected to the plate.

#### Cathode Follower and Integrator

The signal from the diode load test point of the receiver is fed to a cathode follower consisting of one-half of a 12AX7. This arrangement presents a constant impedance to the test point (detector output) regardless of the recorder time constant. For a year 90 volt batteries were used to supply voltage to the plate and cathode of the cathode follower. These proved to be unsatisfactory since they were both expensive and ineffective.

in supplying a constant voltage for a considerable length of time. As a result a simple power supply was built to eliminate the batteries. A circuit diagram of the power supply is presented in Appendix II. The cathode follower has a voltage gain of about one and a maximum output of about 2.0 volts.<sup>27</sup>

The signal is then integrated in order to prevent amplification of frequencies higher than the linear response of the D.C. amplifier in the recording system. In order to preserve the amplitude and phase of the signal to within five percent, the RC integrator time constant must be less than  $1/16$  of the minimum period of fluctuation:<sup>28</sup>

$$RC < T/16.$$

The circuit of the cathode follower and integrator is given in Figure 5:

#### Recording Equipment

The recording system employs a Brush D.C. Amplifier Model RD 5211 03 in conjunction with a four channel Brush Oscillograph Model 2641 00. The integrated satellite signal is fed into the D.C. amplifier which provides sensitivity steps of .01, .02, .05, .1, .2, .5, 1, 2, 5, and 10 volts per chart line (mm) on the oscillograph (pen recorder). This permits a full scale measurement range of d.c. amplification from 0.4 volt to 400 volts. The pen recorder has a d.c. sensitivity of 1.5 volts per mm from the chart center. The recorded peak to peak amplitude

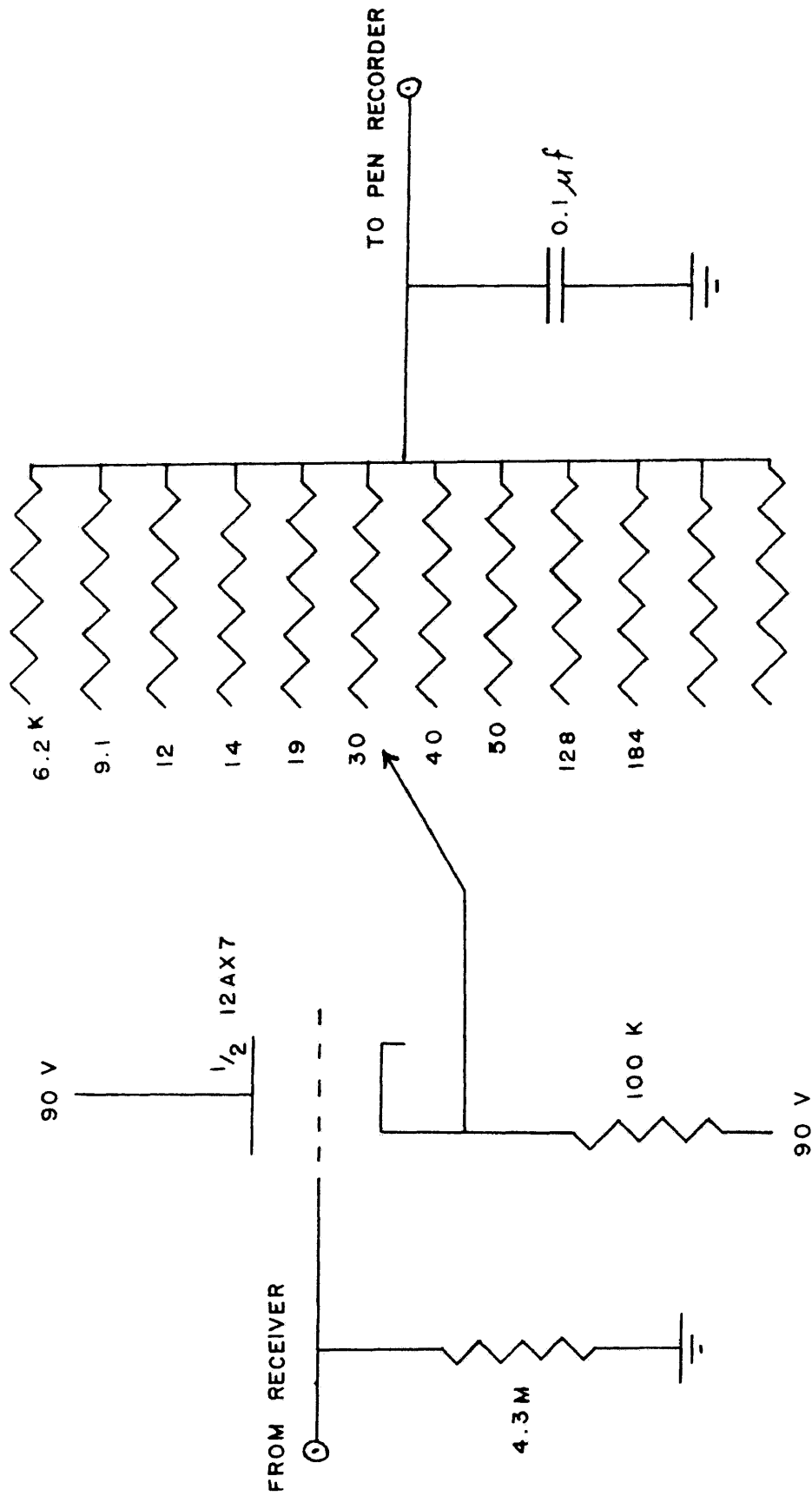


FIGURE 5 CATHODE FOLLOWER AND INTEGRATOR

of a constant voltage sine wave will be within  $\pm \frac{1}{2}$  chart line (mm) of nominal 40 lines from d.c. to 10 cps or within  $\pm 1$  chart line (mm) of a nominal 10 lines from d.c. to 100 cps. The maximum amplitude at 100 cps is 10 lines; at 40 cps, 40 lines. The chart speed is regulated by a direct drive, synchronous motor which provides the following standard speeds: 1, 2, 5, 10, 25, 50, 125, and 250 mm per second.

#### Auxiliary Equipment

A Specific Products Model SR-7R Receiver, specifically built for receiving radio transmissions from the National Bureau of Standards station WWV, provided accurate time marks necessary for determining precise satellite positions. The WWV transmissions were recorded on one channel of the Brush oscillograph simultaneously with the recording of a satellite transit.

## PROCEDURE

### Data Acquisition

Prediction bulletins supplied by Goddard Space Flight Center provide the means of determining the time when a particular artificial satellite will be within tracking range of the observing station. The observer then can arrive at the station in advance of the predicted time in order to "warm-up" and calibrate the receiving and recording equipment. A few minutes before the prescribed time the observer begins slowly varying the main tuning control (of the Collins 51J-4) through the frequency range centered about the known satellite frequency. When the satellite transmission is received, the signal is nulled with the BFO on; the BFO is turned off and the recorder is switched on.

The signal is kept at less than full scale by means of the d.c. amplifier gain control. The changes in gain, however, are minimized in order to facilitate in the analysis of the record. During the satellite transit, as mentioned earlier, one channel of the recorder is used for the recording of WWV time signals. Except in rare cases the chart speed was 10 mm/sec.

### Data Analysis

Before proceeding into the analysis of a satellite record, a description is given of the trace of a satellite signal as recorded on a time versus amplitude strip chart.

The recordings of the signal show two distinct kinds of fading. One is a slow regular fading with clear maxima and minima produced by: (1) the physical rotation of the satellite which changes the relative positioning of the satellite antennas with respect to the receiving antennas and (2) the rotation of the plane of polarization (termed Faraday rotation) of the emitted signal as it is propagated through the ionosphere. Faraday rotation is discussed in the section to follow.

The second kind of fading is a fast irregular fading which varies in both amplitude and period depending upon the irregularities in the ionosphere through which the signal is propagated. This type of fading is referred to as scintillation of signal and will be further discussed under the topic of Scintillation Indices.

#### Faraday Rotation

The ionosphere, because it is a magnetic-ionic medium, is doubly refractive. Thus an initially linearly polarized radio wave emitted from a satellite and propagated through the ionosphere is equivalent to two components (the ordinary and extraordinary waves). They are, in general, elliptically polarized with opposite senses of rotation, and travel with different velocities. In examining the behavior of the two components, one generally considers two cases: (1) the longitudinal case in which the direction of propagation is parallel to the earth's magnetic field and (2) the transverse case in which the direction of

propagation is perpendicular to the field. The Faraday effect for the cases of quasi-longitudinal and quasi-transverse propagation are treated by Daniels and Bauer.<sup>29</sup>

In the longitudinal case, if the wave frequency is sufficiently greater than the collision frequency of the ionospheric electrons, the major axes of the two ellipses are mutually perpendicular. Also, if the wave frequency is much greater than the gyro-magnetic and plasma frequencies, the ellipses become circles, and the resultant of the two circularly polarized waves is linearly polarized. However, because the two components have different phase velocities, the plane of polarization of the resultant gradually rotates as the wave progresses through the ionosphere. This phenomenon is known as the ionospheric Faraday effect.

In the transverse case the two elliptical components degenerate into linearly polarized waves, one component always remaining parallel to the magnetic field and the other one perpendicular thereto. However, because the components travel with different velocities, the resultant gradually changes along the path from a linearly polarized wave to an elliptically polarized one, and finally to one which is circularly polarized. Then the sequence is reversed and the wave changes back to a linearly polarized one. Now, however, the plane of polarization of the resultant is perpendicular to the original direction. Each time that the resultant passes through the cycle described, there is a 90°-rotation of the linearly polarized resultant.<sup>29</sup>

Continuous rotation of the plane of polarization occurs when the ordinary and extraordinary waves are doppler shifted. In nearly all cases the quasi-longitudinal case applies. The requirement for this condition is:

$$\frac{\omega_H}{2} \sin \theta \tan \theta \ll \frac{\omega^2 - \omega_N^2}{\omega}$$

where

$\omega$  = angular frequency of transmitted wave

$\omega_H$  = angular gyromagnetic frequency

$\omega_N$  = angular plasma frequency

$\Theta$  = angle between the direction of propagation and the field.

The angle of rotation (due to the Faraday effect) under this condition is:

$$\phi = \frac{e^3}{2\pi m^2 c^2 f^2} \int_0^R B N \cos \Theta dr$$

where

$e$  = electronic charge (esu)

$m$  = electronic mass (gm)

$f$  = frequency of transmitted signal

$B$  = earth's magnetic field (gauss)

$N$  = electron density ( $\text{cm}^{-3}$ )

$R$  = length of path through ionosphere

The top two samples of satellite records in Figure 6 show the effects of Faraday rotation on a signal received by folded dipole antennas.

In the case of Transit IV A the period of the rotation of the satellite is about 600 seconds; thus it is not considered an important factor in the analysis of the satellite record.

#### Scintillation Indices

The severity of the scintillation depth observed in an interval of a satellite record is denoted by visually assigning a "scintillation index" to that interval. One of a set of scintillation indices ranging from 0.0 to 2.0

in half-integral steps denotes the severity ranging from no scintillation to violent scintillation. The intervals of ten seconds are marked off on each satellite record using the WWV time signal as the reference. The various indices used are modifications of the indices used by Yeh and Swenson<sup>9</sup> and are discussed below. Two samples<sup>25</sup> of each index, shown in Figure 6, were simultaneously recorded on adjacent channels of the signal received on two mutually perpendicular antennas. The samples are taken from records of the 54 Mc/s transmissions from Transit IV A.

#### 0.0 Index

This index is assigned to an interval when no scintillation is evident. The uppermost pair of records in Figure 6 exhibits only the smooth sinusoidal fading due to the Faraday effect. The very slow fading produced by the physical rotation of the satellite is not evident in this short section of record.

#### 0.5 Index

In many cases regular sinusoidal fading is clearly evident but irregular fluctuations amounting to less than 50 percent of the maximum signal strength are imposed on it. This type of fading is assigned an index of 0.5. The second pair of samples show this index, and it is noted that the correlation of individual irregularities between the two records is good.

#### 1.0 Index

This index, samples of which are shown in the third pair, is similar to that of the previous one except that

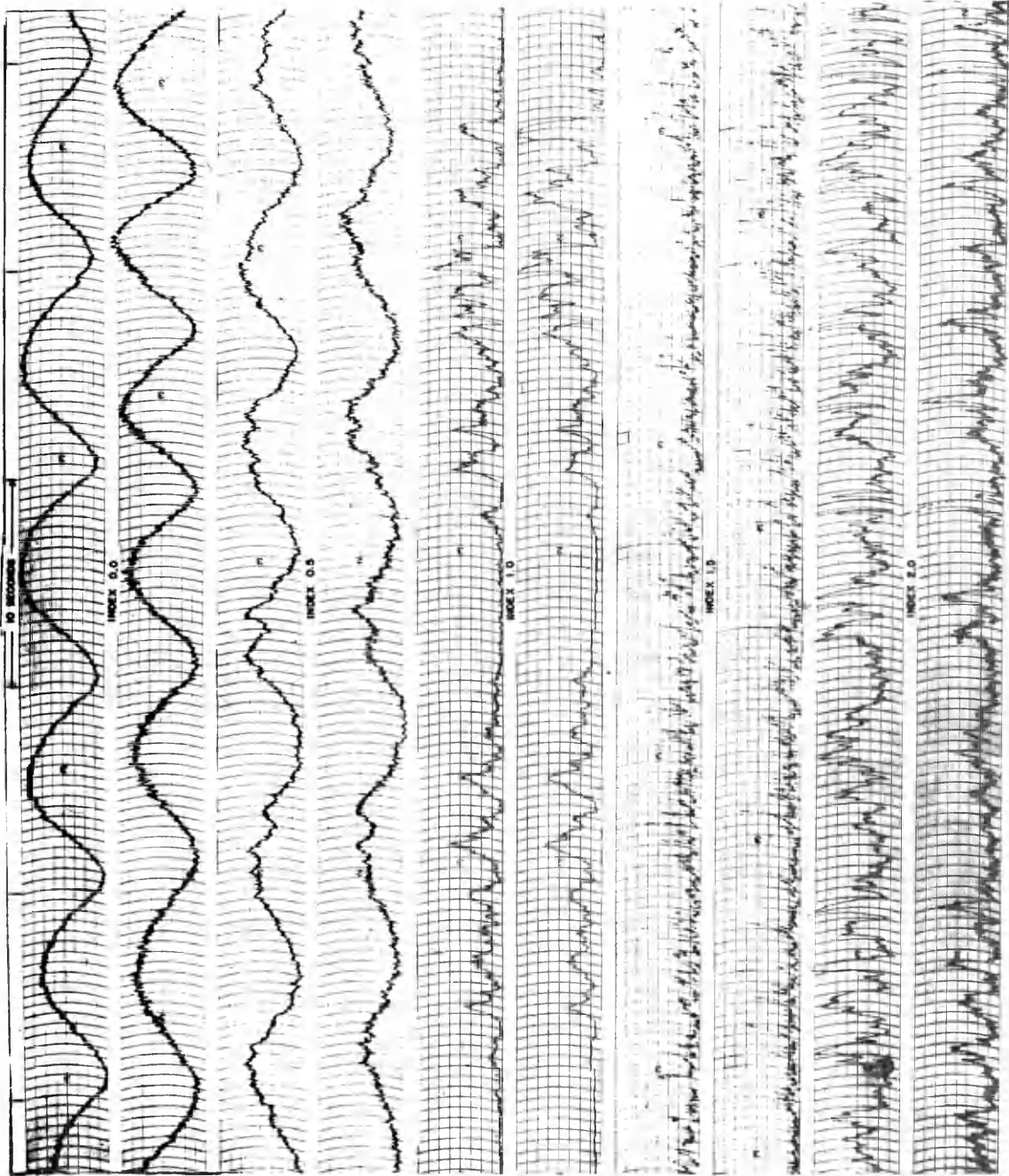


FIGURE 6 SCINTILLATION INDICES - TRANSIT IV-A

in this case the scintillations are more violent; their amplitudes are greater than 50 per cent of the maximum signal strength. The sinusoidal fading is evident and again there is good correlation between channels.

### 1.5 Index

The fourth set of records exhibit scintillation which is generally characteristic of irregularities "seen" near the horizon when the satellite is at low elevation angles. The signal is weak and irregular but bursts of regular fading are not uncommon. No Faraday rotation is evident. The samples were not recorded simultaneously in this case.

### 2.0 Index

This index is reserved for those cases when the signal is strong and the scintillation is so violent that the Faraday period is completely "washed out." This is assumed to be characteristic of a highly disturbed ionosphere. The scintillation is invariably of large amplitude and usually occurs at a rapid rate. The last pair of records show samples of the index 2.0.

This method of assigning indices is thought to present a fairly good picture of the ionospheric structure responsible for disturbances to radio waves from extraterrestrial sources. Since the indices were assigned visually, the interpretations of each experimenter play an important part in the analysis. Care has been taken to minimize discrepancies arising from such a procedure. In most instances the author assigned indices to the records. In a few cases indices were assigned by an assistant, but in each instance

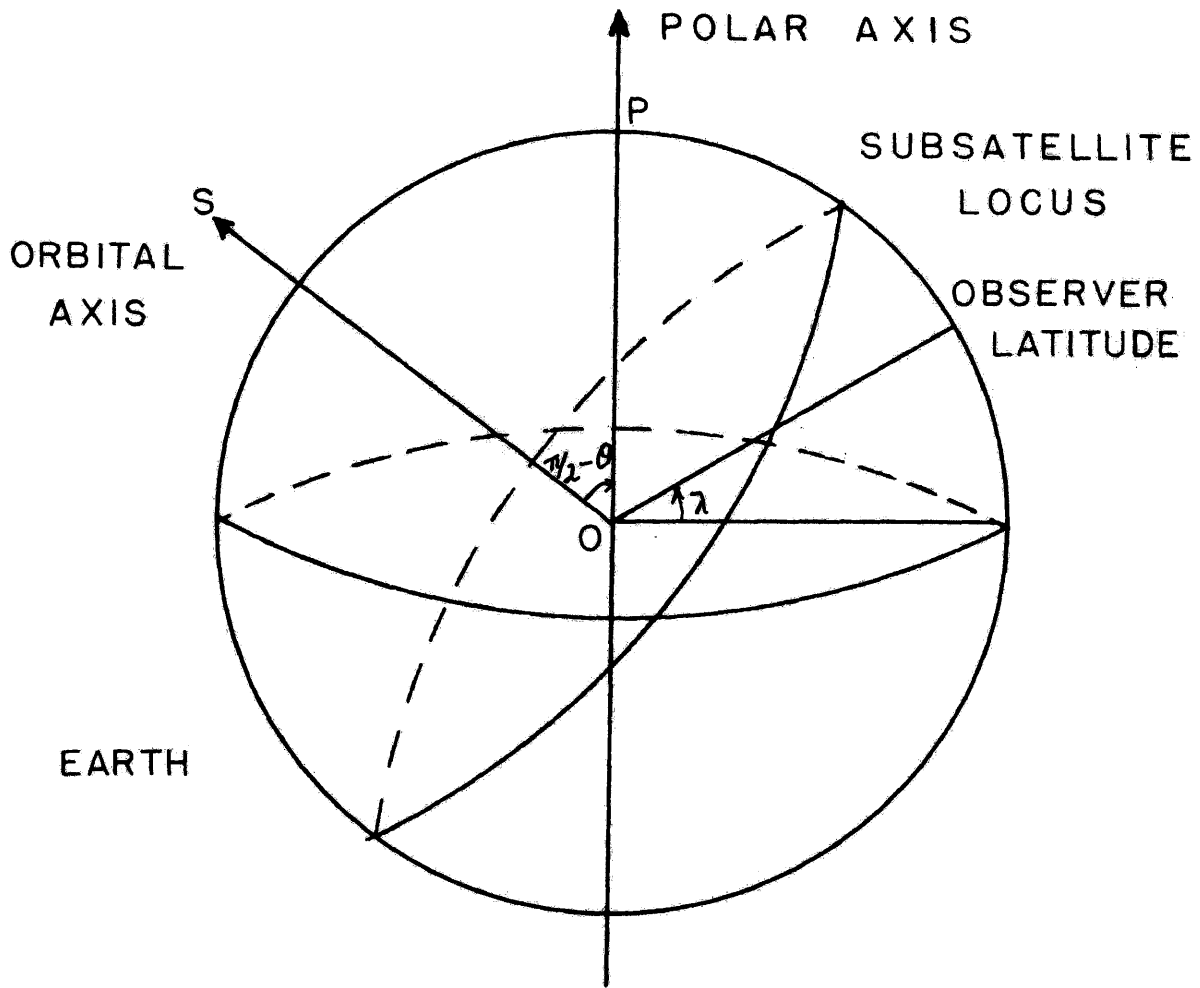
the records were checked by the author.

### Satellite Orbits

After the satellite record has been assigned scintillation indices, the next step is to determine position parameters of the satellite (with respect to the receiving station) for each minute of observation. The time interval (one minute) was arbitrarily chosen and proved to be adequate and convenient. Before proceeding into this, a short discussion of the nature of satellite orbits is in order.

To a first approximation the orbit of a small satellite in the earth's gravitational field is found to have the Keplerian form of an ellipse with one focus at the center of the earth, and whose plane and major axis are fixed in space. The square of the orbital period of the satellite varies as the cube of the major axis of the orbit. In order to keep the drag force sufficiently small, the minimum altitude of the satellite above the earth must be about 100 miles. This gives rise to a minimum practical period of about 90 minutes.

If the latitude of the observer on the earth is less than the inclination of the orbital axis to the polar axis, the observer will pass through the plane of the satellite orbit twice each sidereal day due to the earth's rotation. The geometry of the satellite-observer relationship is shown in Figure 7, OP is the polar axis, OS is the orbit axis at inclination  $\varphi$ ,  $\lambda$  is the latitude of the observer. The plane of the orbit precesses about the polar axis at



SATELLITE — OBSERVER RELATIONSHIP

FIGURE 7

a rate of about 3-4 degrees per day so that it crosses the observer's longitude about 12-15 minutes earlier each day.<sup>30</sup> If the inclination of the plane of the orbit is greater than the latitude of the observer, there are on the average four transits per day which are well within the tracking range (1000 miles) of the receiving station.

The sub-satellite locus shown in Figure 7 is defined by the curve formed by the intersection of the plane of the orbit and the earth's surface. The points at which the sub-satellite locus (sub-orbital plot) crosses the earth's equator are called nodes. The ascending nodes are those for which the satellite crosses the equator traveling in a northerly direction. The nodal period of the satellite is then the time required by the satellite to pass over two successive ascending nodes. The nodal period for a typical satellite is between 90-100 minutes.

#### Map Overlay Method<sup>31</sup>

In connection with the satellite position parameters, use is made of a large Miller cylindrical projection of the earth. On this have been drawn "aquisition circles"; each circle being the locus of points equidistant from Williamsburg on the surface of the earth. The concentric circles, drawn at intervals of 150 miles, extend outward to a distance of 2100 miles. On an acetate overlay of the same size as the Miller projection a sub-orbital plot is drawn. The method involves plotting a longitude versus latitude curve from data provided in the prediction bulletins for the satellite of interest. In practice only the northern hemisphere

portion of the sub-orbital plot is drawn as the satellite is not observed below the equator. Minute intervals beginning with  $t = 0$  at the ascending node are marked on the acetate plot from a time versus latitude graph again obtainable from the prediction bulletins. Thus a particular time (measured in minutes after equator crossing) on the sub-orbital plot represents the instant when the satellite will be directly above that point. In the case of Transit IV A, whose orbit is relatively stable, one overlay can be used for a month before the trajectory changes appreciably. The azimuth angle and distance corresponding to each minute on the sub-orbital plot can be found by inspection using the map overlay method. The latitude, elevation angle, slant range, and height of the satellite, minute by minute, can be found by the reduction of the orbital data to graphical form.

The procedure described in the preceding pages permits one to examine the average scintillation index for a number of satellite transits as a function of various position parameters. This enables one to investigate the distribution, relative intensities, diurnal and seasonal variations of the ionospheric irregularities responsible for disturbances to radio transmissions.

## EXPERIMENTAL RESULTS

Five hundred and nine (509) transits of earth satellite 1961 Omicron 1 (Transit IV A) were recorded at Williamsburg, Virginia from September, 1961 to February, 1963. In addition the following number of transits of the Russian satellites were recorded from March to August, 1962: 1962 Theta 1 - 22, 1962 Iota 1 - 7, 1962 Upsilon 1 - 120. A scintillation index was assigned (by visual inspection) to every ten second interval; for every minute the position parameters, height, azimuth, elevation, slant range, and latitude were calculated. By interpolation, one could determine the position of a satellite for shorter intervals. Diurnal, seasonal, latitude, and height effects on the depth of satellite scintillation are examined in the sections to follow.

### Diurnal Variation

The diurnal variation of satellite scintillation has been examined from January, 1962 through the middle of February, 1963. The scintillation observed on the 54 Mc/s transmissions of Transit IV A has been averaged over one hour intervals throughout the twenty-four hour day. A histogram of such an average, which is also averaged over all elevations, azimuths, and months of the year, is shown in Figure 8. The maximum scintillation occurs between 1900 hours and 0400 hours local time with the peak being between 0100 - 0200 hours, indicating that satellite scintillation

ALL ELEVATION ANGLES

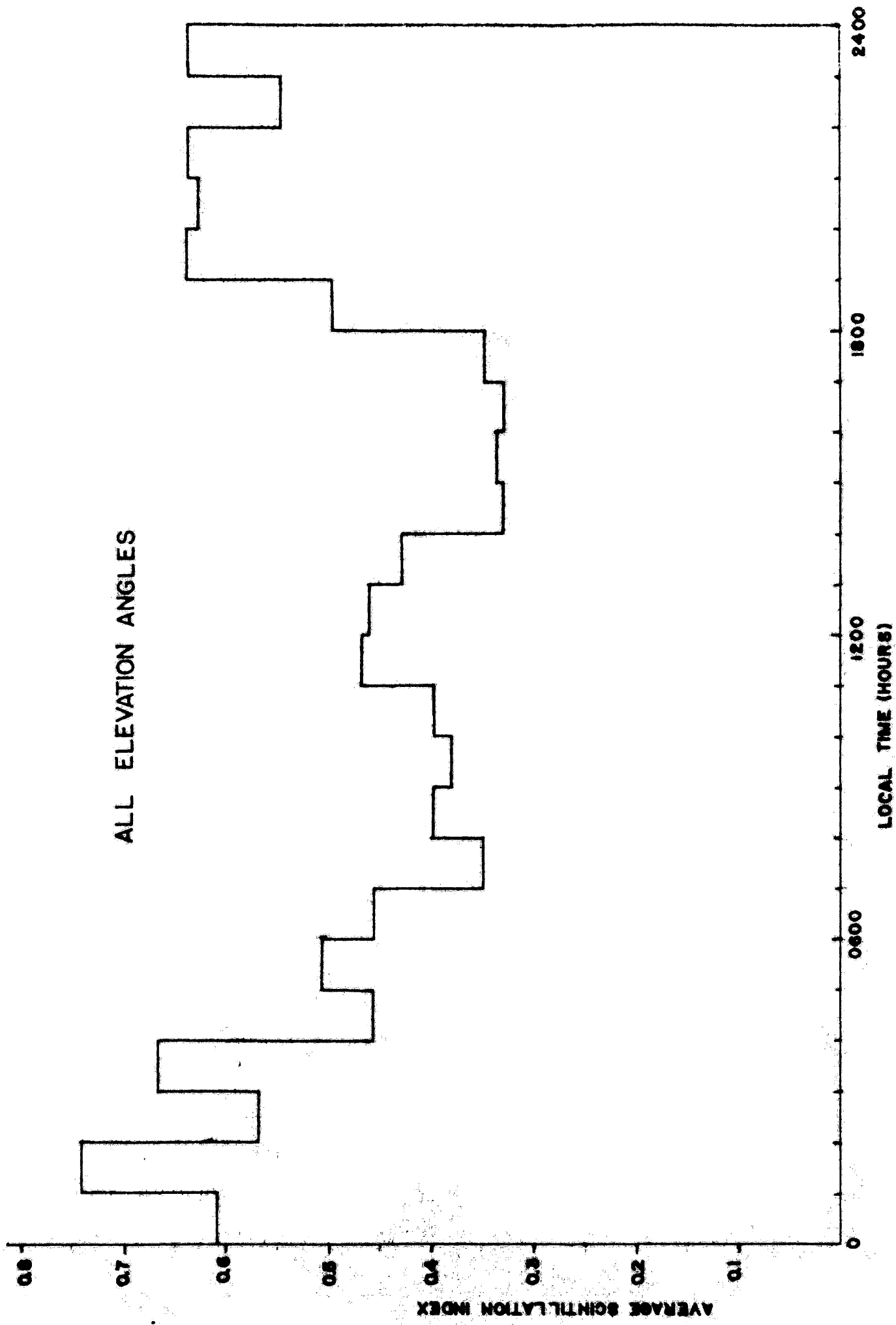


FIGURE 8 - AVERAGE SCINTILLATION INDEX VERSUS TIME

activity (like radio star scintillation activity) is predominantly a night-time phenomenon. The occurrence of the maximum scintillation depth shortly after midnight is in good agreement with the results of most workers.<sup>9,12</sup> In addition a secondary maximum is evident at midday which is in agreement with results (from radio star scintillation) obtained in Canada and Australia but not in England or the United States. Yeh and Swenson,<sup>9</sup> observing the 20 Mc/s signals from 1958 Delta 2, noticed a weak midday maximum during certain seasons. A minimum scintillation depth is evident between 1400-1700 hours.

Alexander<sup>25</sup> observed a sharp increase in scintillation depth at elevation angles below  $20^{\circ}$ . This prompted a diurnal study of satellite scintillation for elevation angles above  $20^{\circ}$  and a diurnal study for elevation angles below  $20^{\circ}$ . Histograms of the results of these studies are shown in Figures 9 and 10. In both cases the maximum is obvious shortly after midnight; however, there is little evidence of a midday maximum for elevation angles greater than  $20^{\circ}$  in contrast to the distinct midday maximum for angles less than  $20^{\circ}$ .

#### Seasonal Variation

The diurnal variation of satellite scintillation, averaged over a year's data, has been discussed. In order to do a seasonal study of the same data, three month intervals centered on the solstices and equinoctial points were chosen and the data were re-compiled. The data were averaged over two hour intervals to provide better statistics.

ELEVATION ANGLES ABOVE 20°

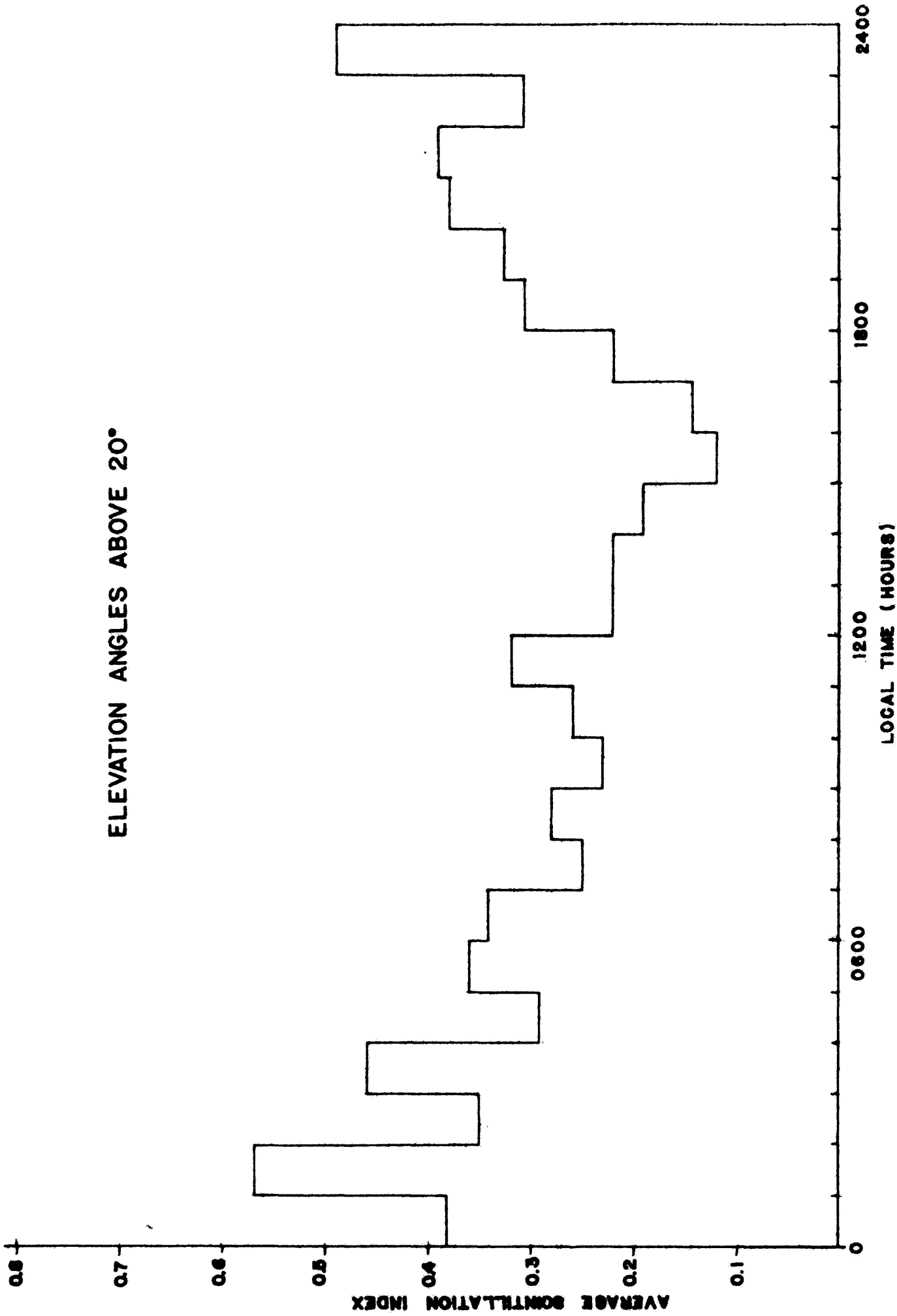


FIGURE 9 - AVERAGE SCINTILLATION INDEX VERSUS TIME

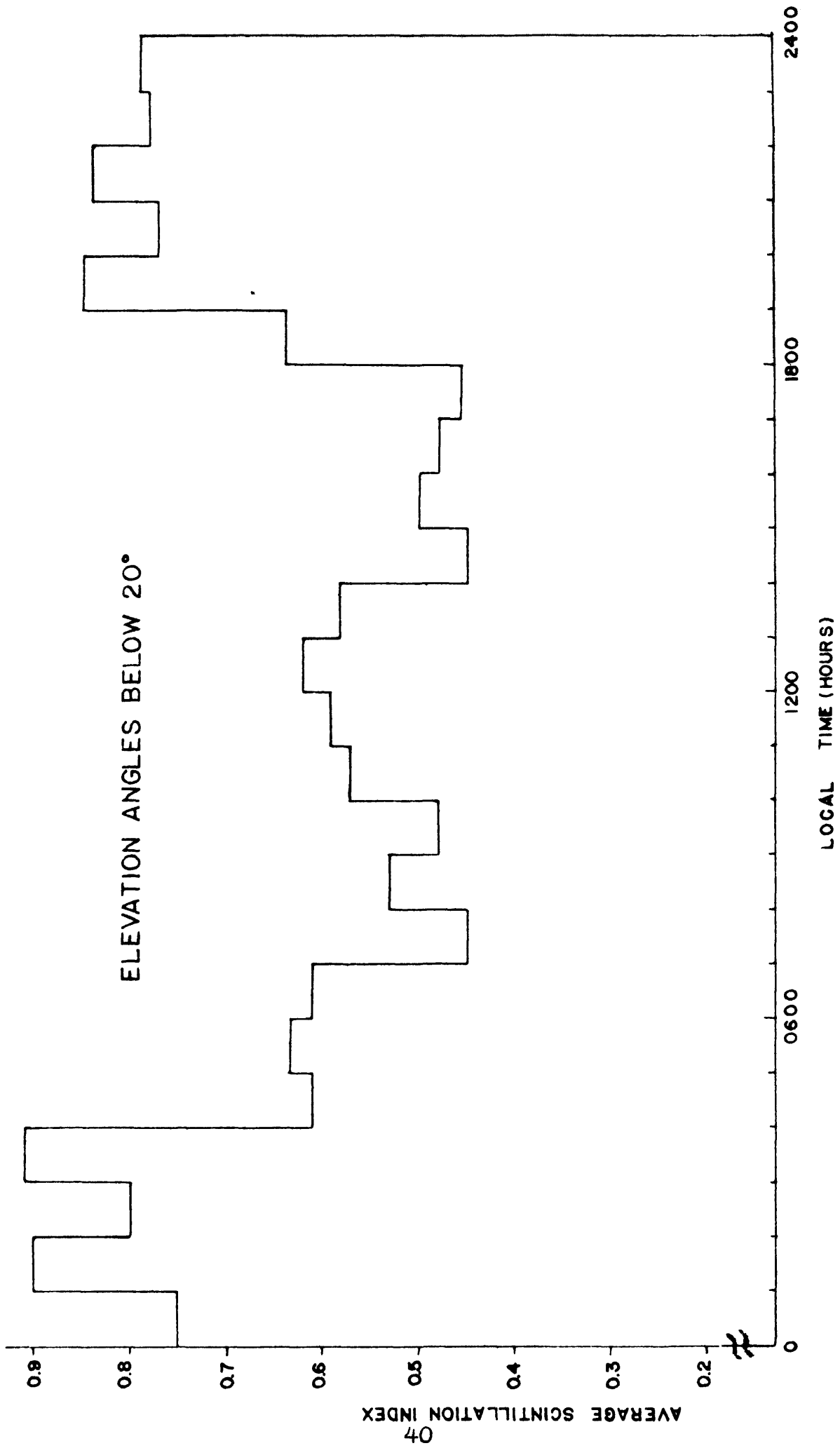


FIGURE 10 - AVERAGE SCINTILLATION INDEX VERSUS TIME

Figures 11 A and 11 B show the results. The data indicate that the scintillation depth is weakest during the period centered about the vernal equinox (February 1 - April 31) and strongest during the period centered about the autumnal equinox (August 1 - October 31). Both the winter and summer solstices show essentially the same characteristics. The midday maximum is most clearly evident during the three month periods centered on the solstices. The midnight maximum varies from 2200 to 0200, but shows no regular progression from one season to the next.

Yeh and Swenson<sup>9</sup> have performed a seasonal study similar to that described above; however, they presented their data in a different manner. They plotted percentage of scintillation index rather than average index versus time of the day. Little correlation is noticed other than a maximum centered about local midnight, between the two sets of data.

The data indicate that scintillation activity is connected with the solar cycle; however, the precise mechanism is not understood.

#### Latitude Study

In order to determine the variation of satellite scintillation activity with geographical latitude of the satellite, histograms have been computed of the average scintillation index versus latitude for each hour of the day. In addition computations were made only for elevation angles greater than  $20^{\circ}$  in order to exclude an elevation effect. These histograms represent observations made continuously

FEB. 1 - APRIL 30, 1962

MAY 1 - JULY 31, 1962

ALL ELEVATION ANGLES

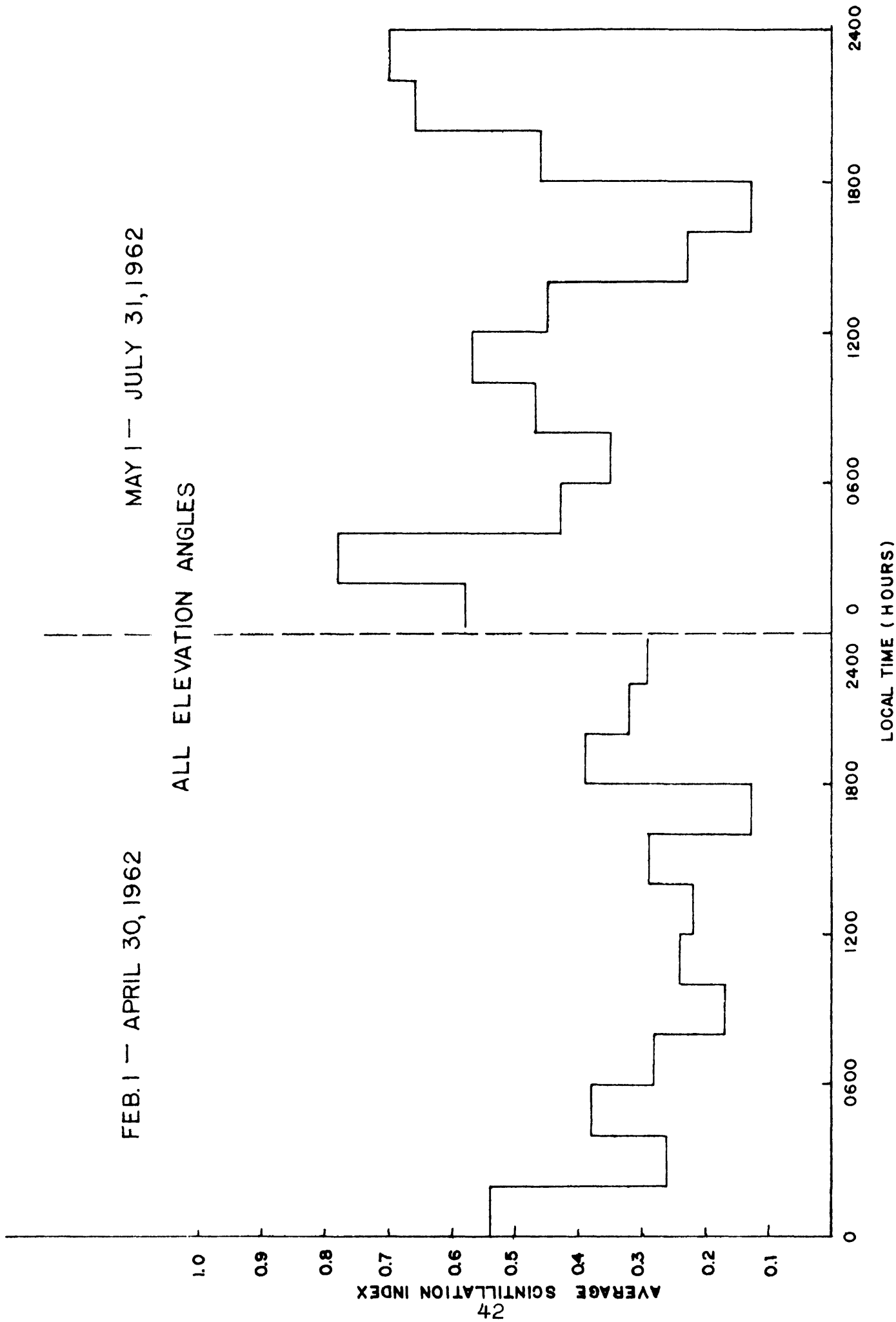


FIGURE IIA - DIURNAL AND SEASONAL VARIATIONS OF AVERAGE SCINTILLATION INDEX

AUG. 1 - OCT. 31, 1962

NOV. 1 - JAN. 31, 1963

ALL ELEVATION ANGLES

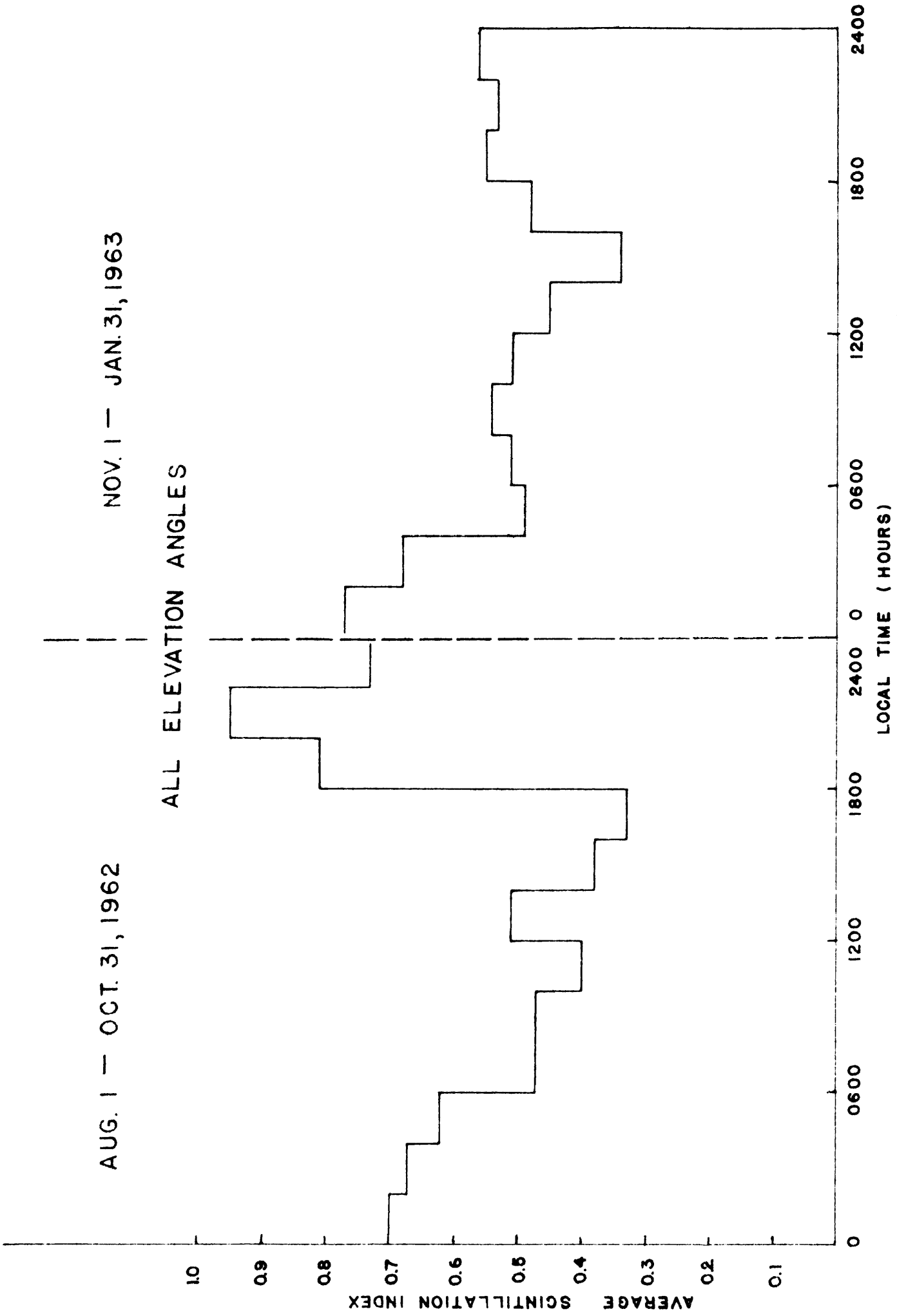


FIGURE 11B - DIURNAL AND SEASONAL VARIATIONS OF AVERAGE SCINTILLATION INDEX

over 12 months of records of Transit IV A and are given in Figure 12 A through Figure 12 H.

The scale of the abscissa represents the latitude of the satellite; however, it may be more meaningful to know the latitude of the region in the ionosphere through which the signal is propagated. The scale at the upper left in Figure 12 A correlates the latitude of the satellite to the latitude of a portion of the ionosphere at a height of 300 km. For example, when the satellite is at the latitude of  $20^{\circ}$  N, the portion of the ionosphere (at 300 km) through which the signal is propagated is  $26.6^{\circ}$  N.

The data indicate that during the periods of the day when the scintillation activity is relatively weak, there appears to be no significant latitude variation. On the other hand during periods of relatively high activity, a latitude variation is clearly evident. Further, the latitude variation increases markedly as one approaches either the midnight or midday maximum. During periods of significant activity the latitude curves show a minimum of activity at the latitude of the observing station ( $37^{\circ}$  N) with significant increase in activity when the satellite moves to more northern or southern latitudes. The scintillation activity is much higher at northern latitudes than in southern latitudes.

As the satellite moves southward the angle between the direction of propagation and the field lines decreases until at latitudes just south of the observing station the angle is zero. As the satellite continues southward the

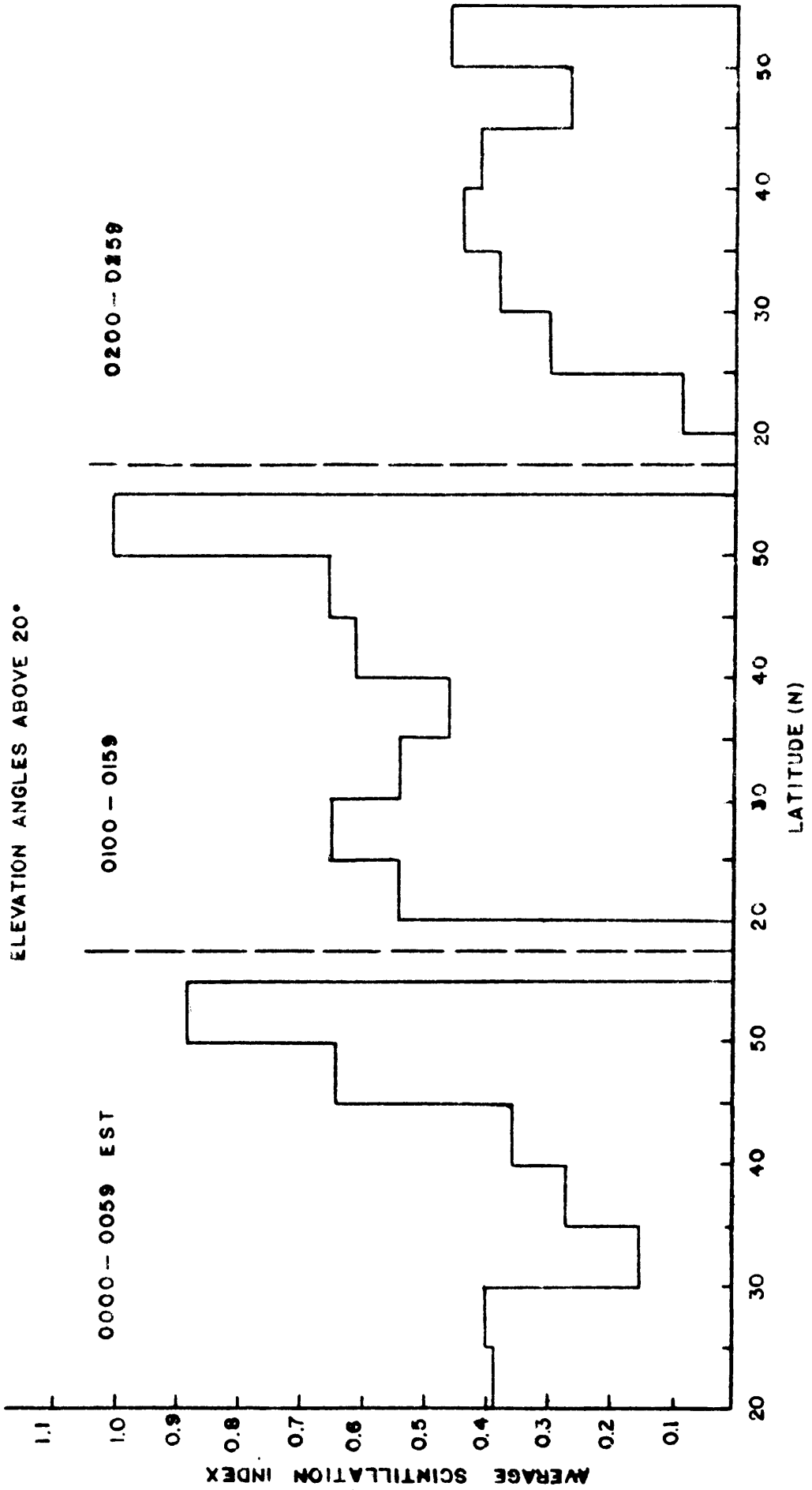
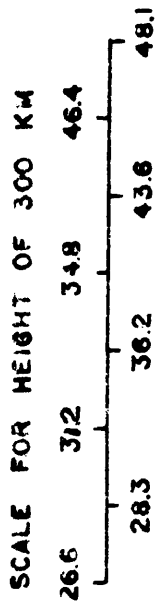


FIGURE 12A - DIURNAL VARIATION OF LATITUDE EFFECT

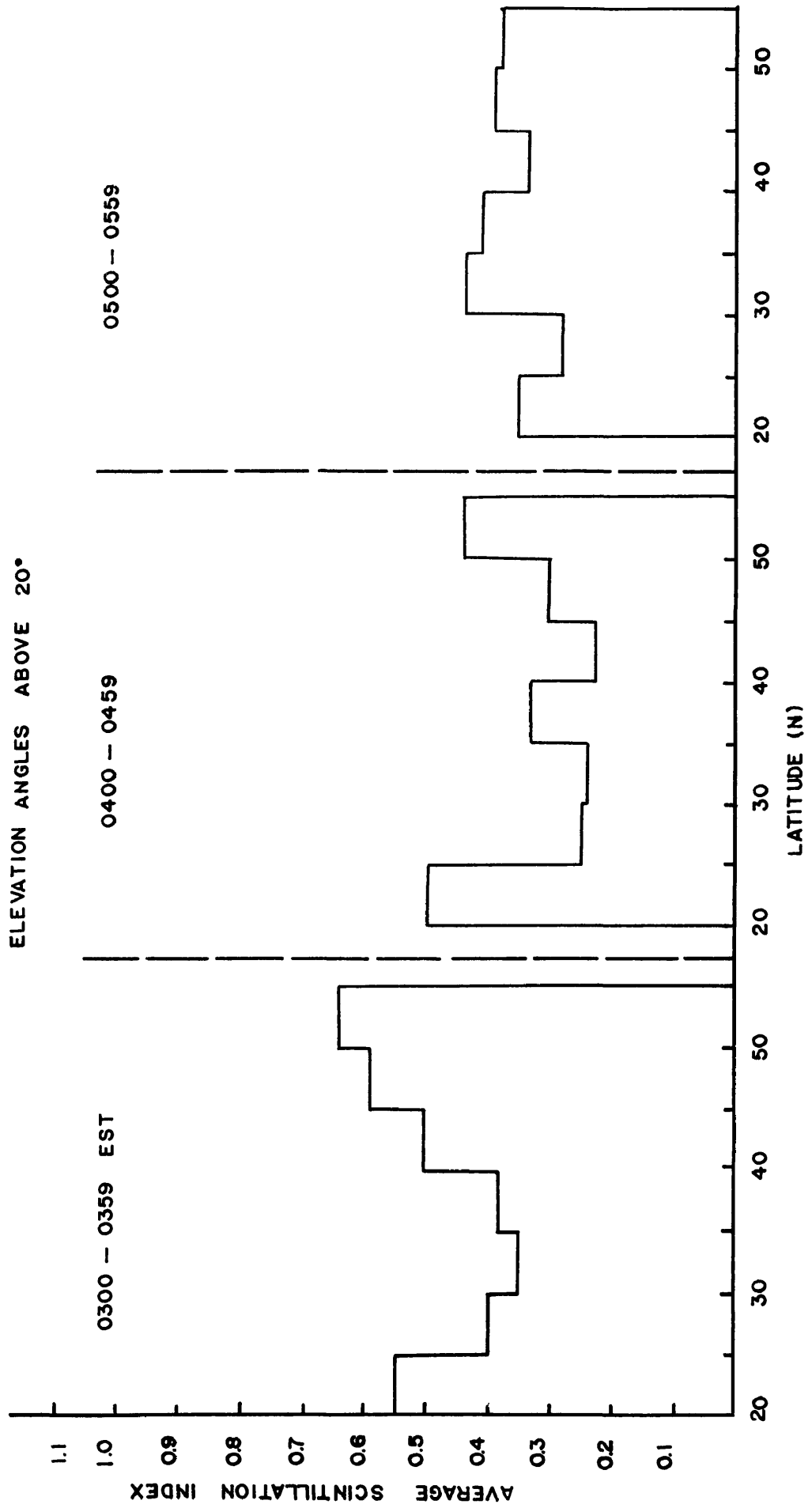


FIGURE 12B-- DIURNAL VARIATION OF LATITUDE EFFECT

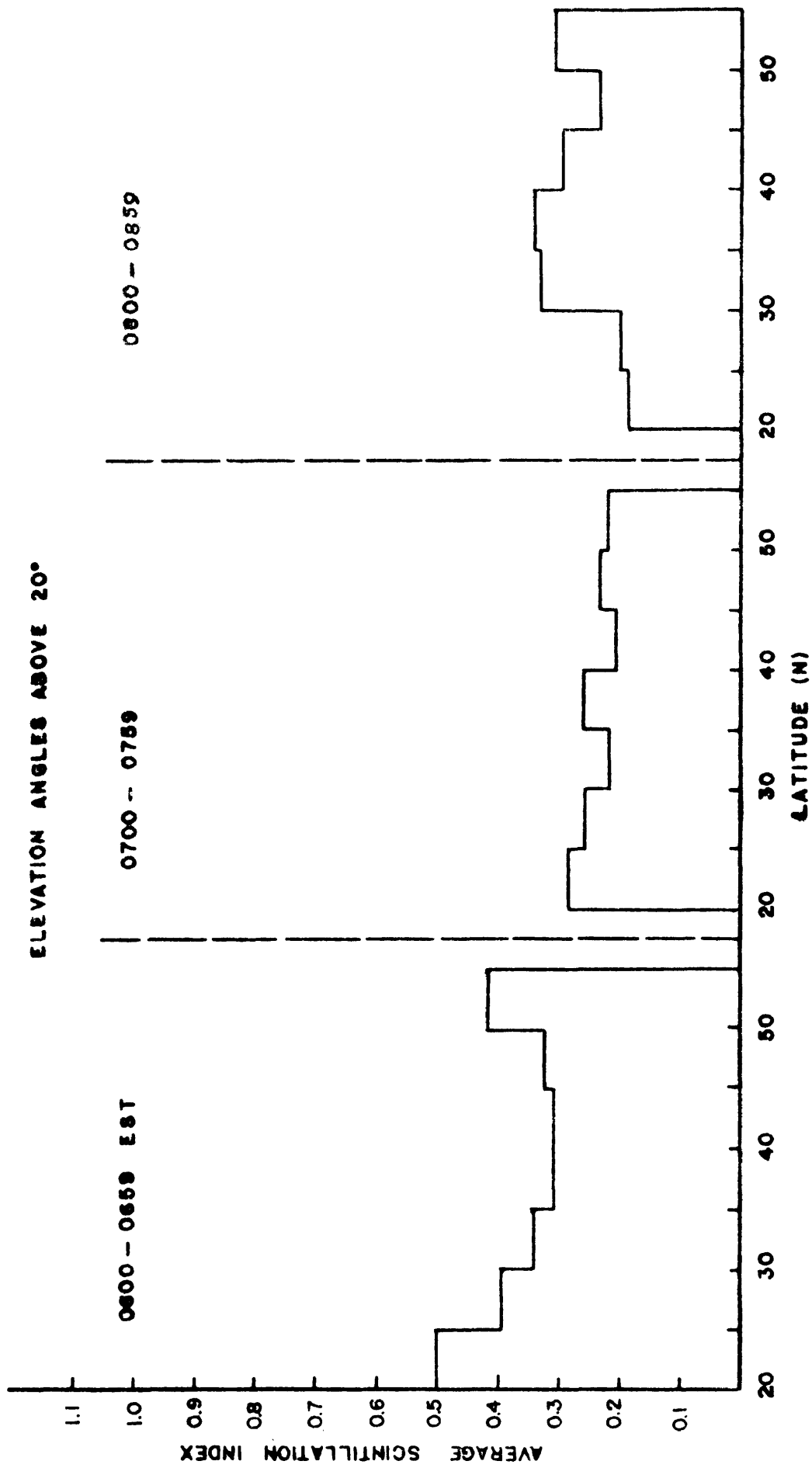


FIGURE 12C-- DIURNAL VARIATION OF LATITUDE EFFECT

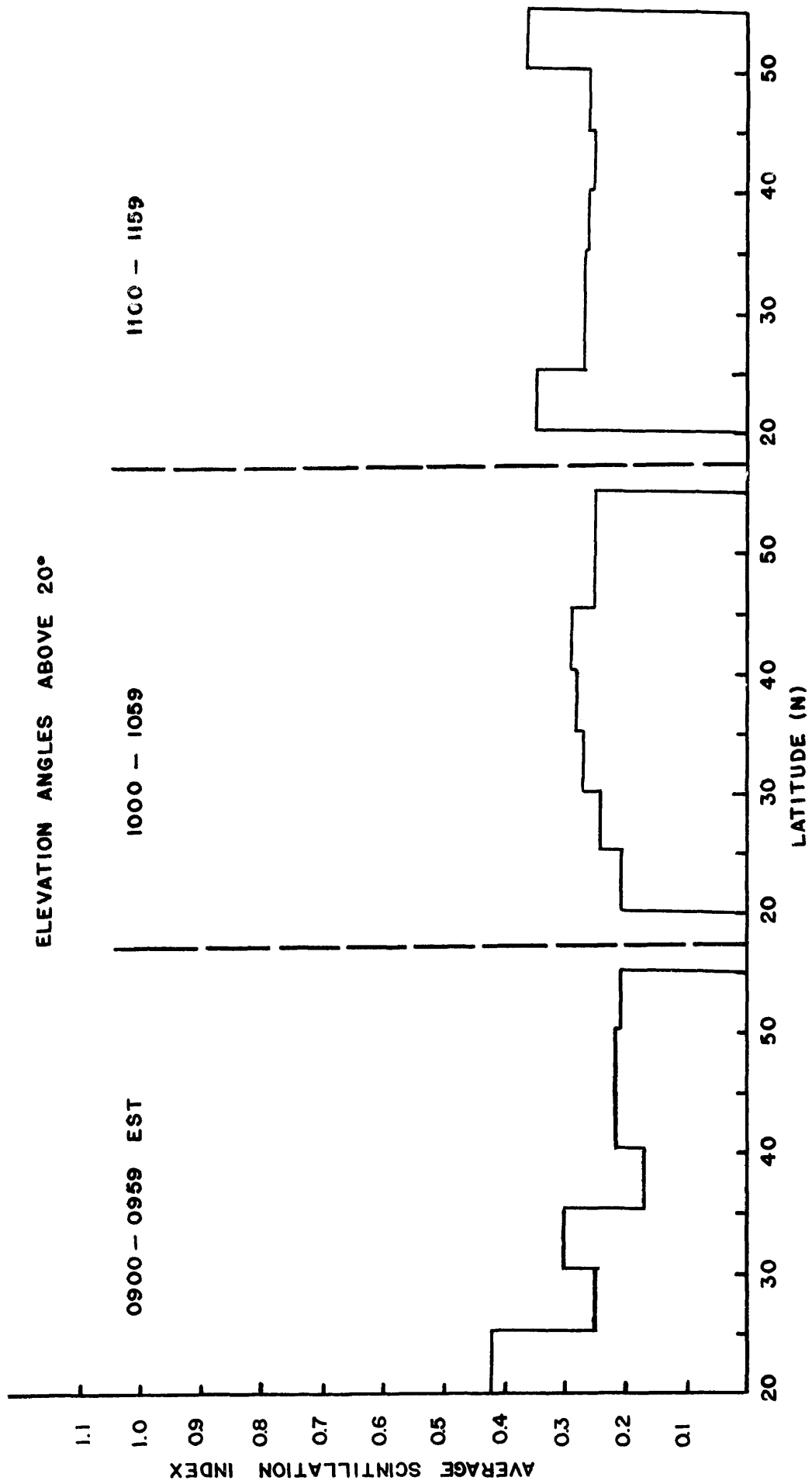
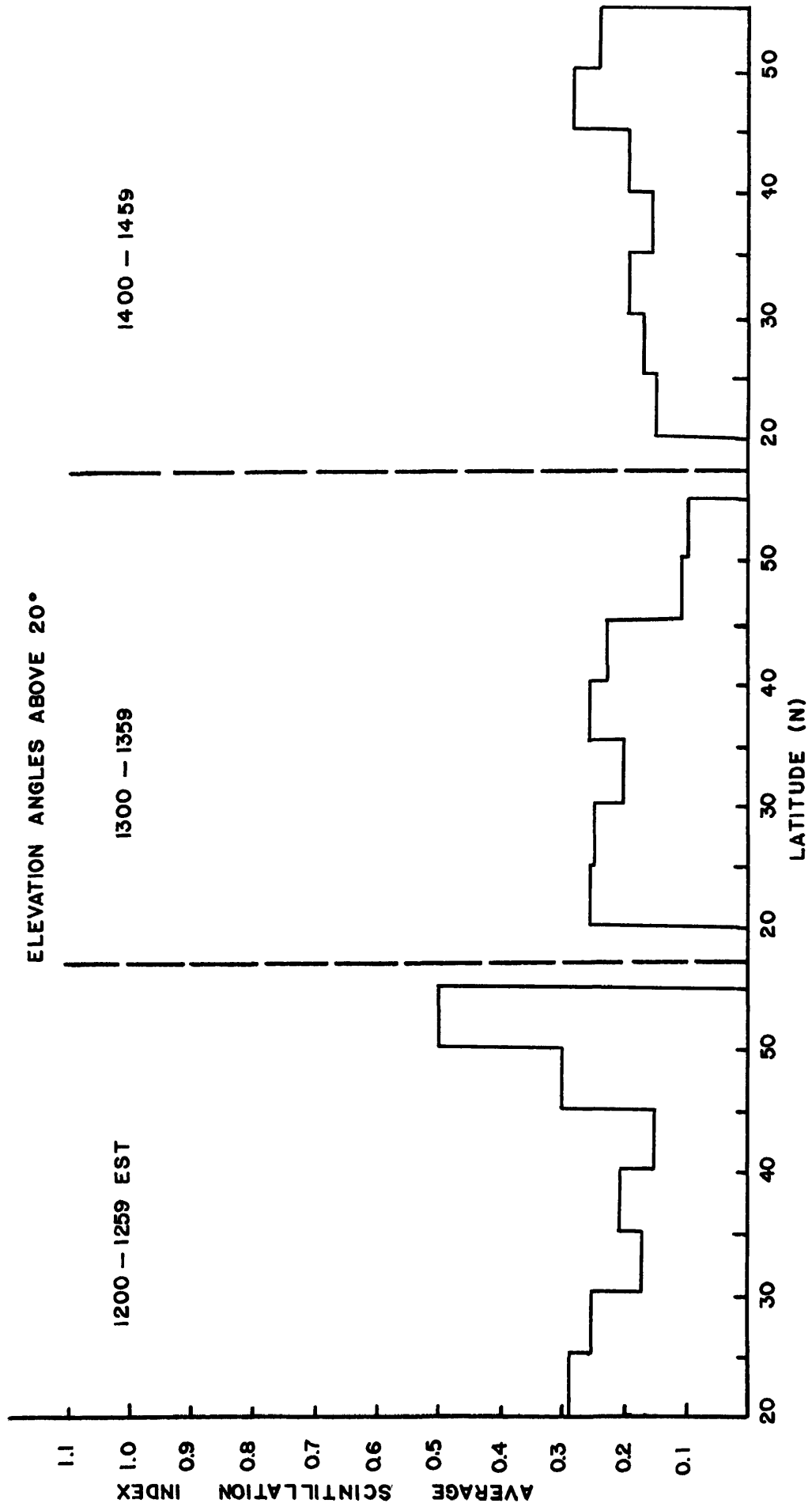


FIGURE 12D-- DIURNAL VARIATION OF LATITUDE EFFECT



**FIGURE 12E - DIURNAL VARIATION OF LATITUDE EFFECT**

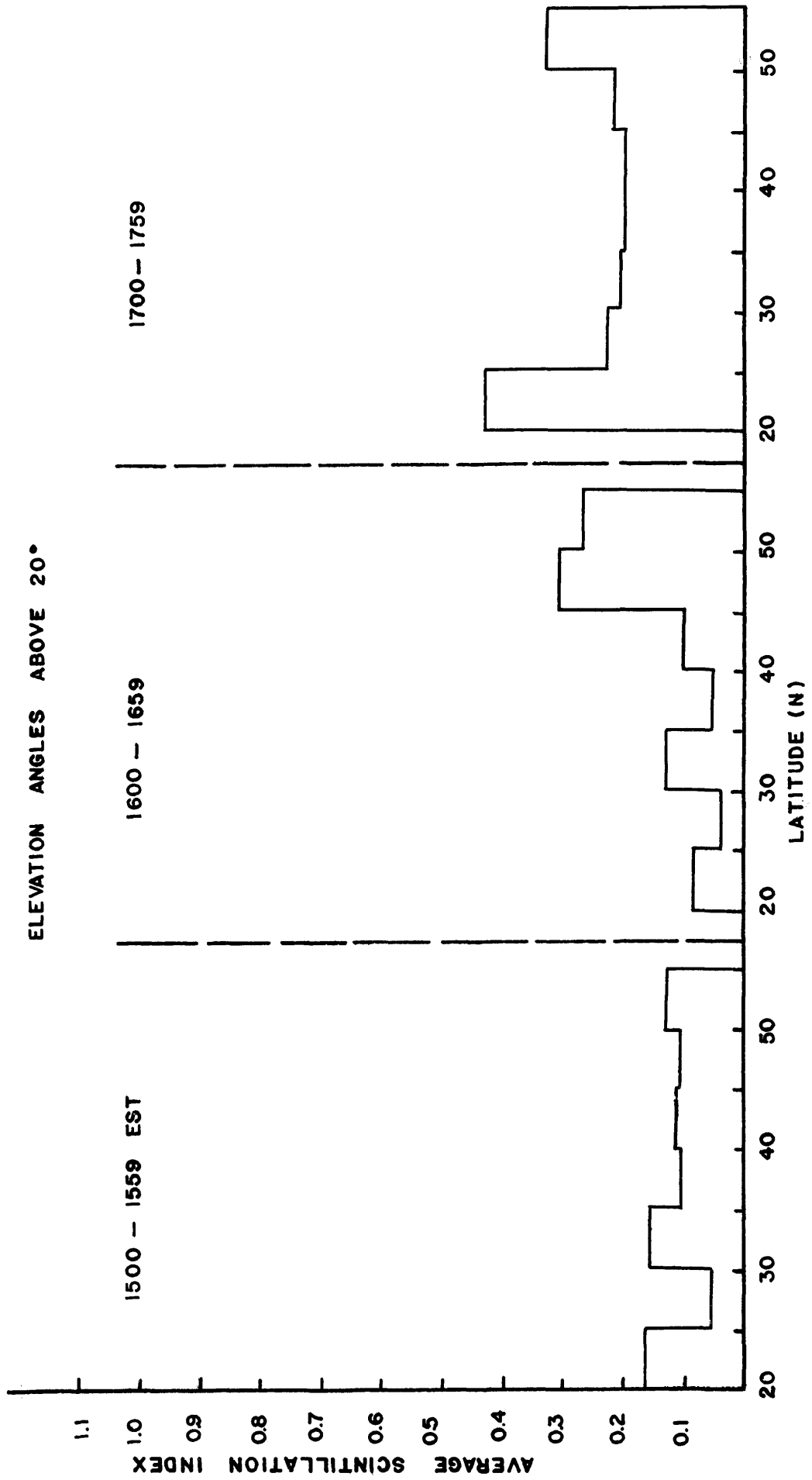


FIGURE 12F - DIURNAL VARIATION OF LATITUDE EFFECT

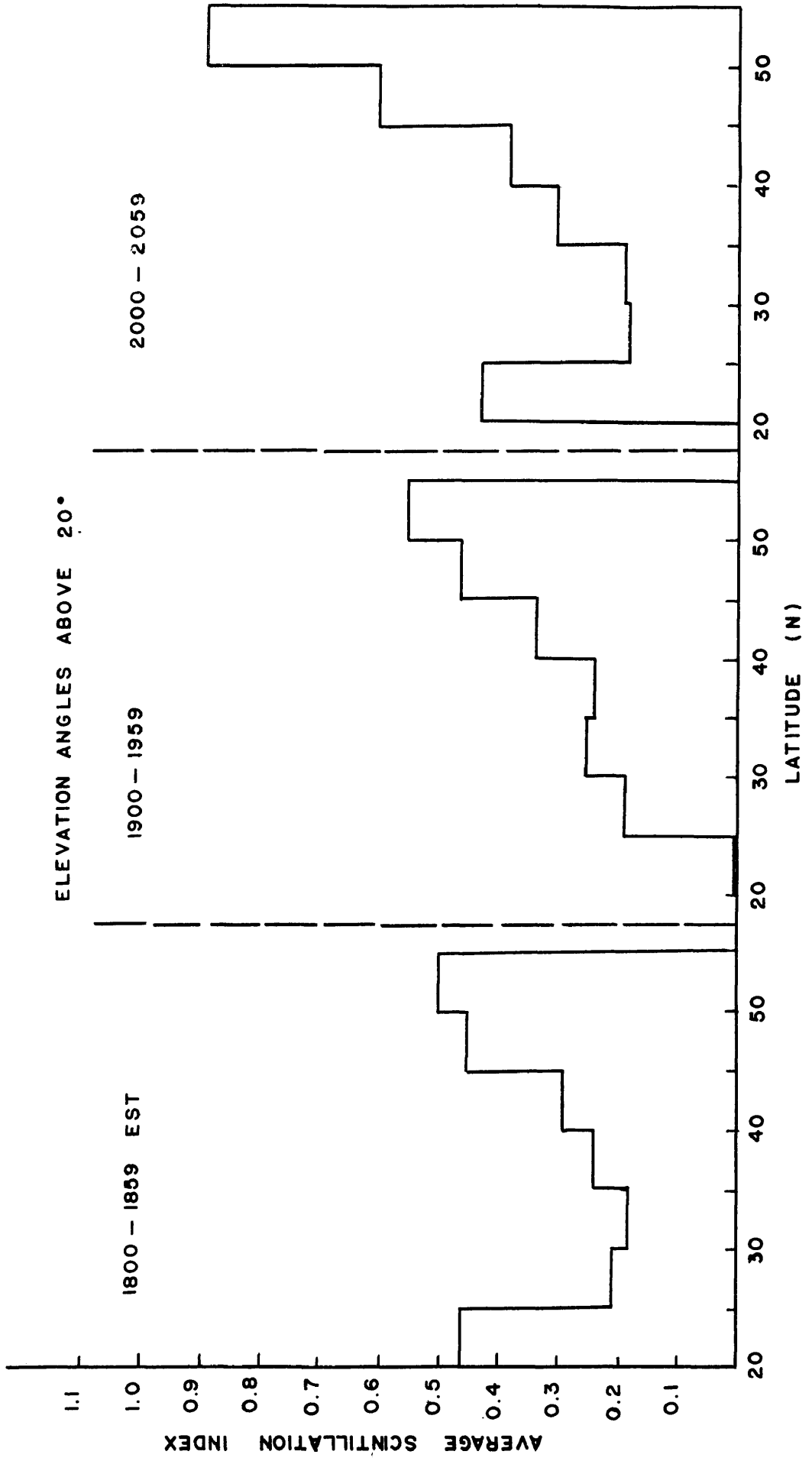


FIGURE 12G -- DIURNAL VARIATION OF LATITUDE EFFECT

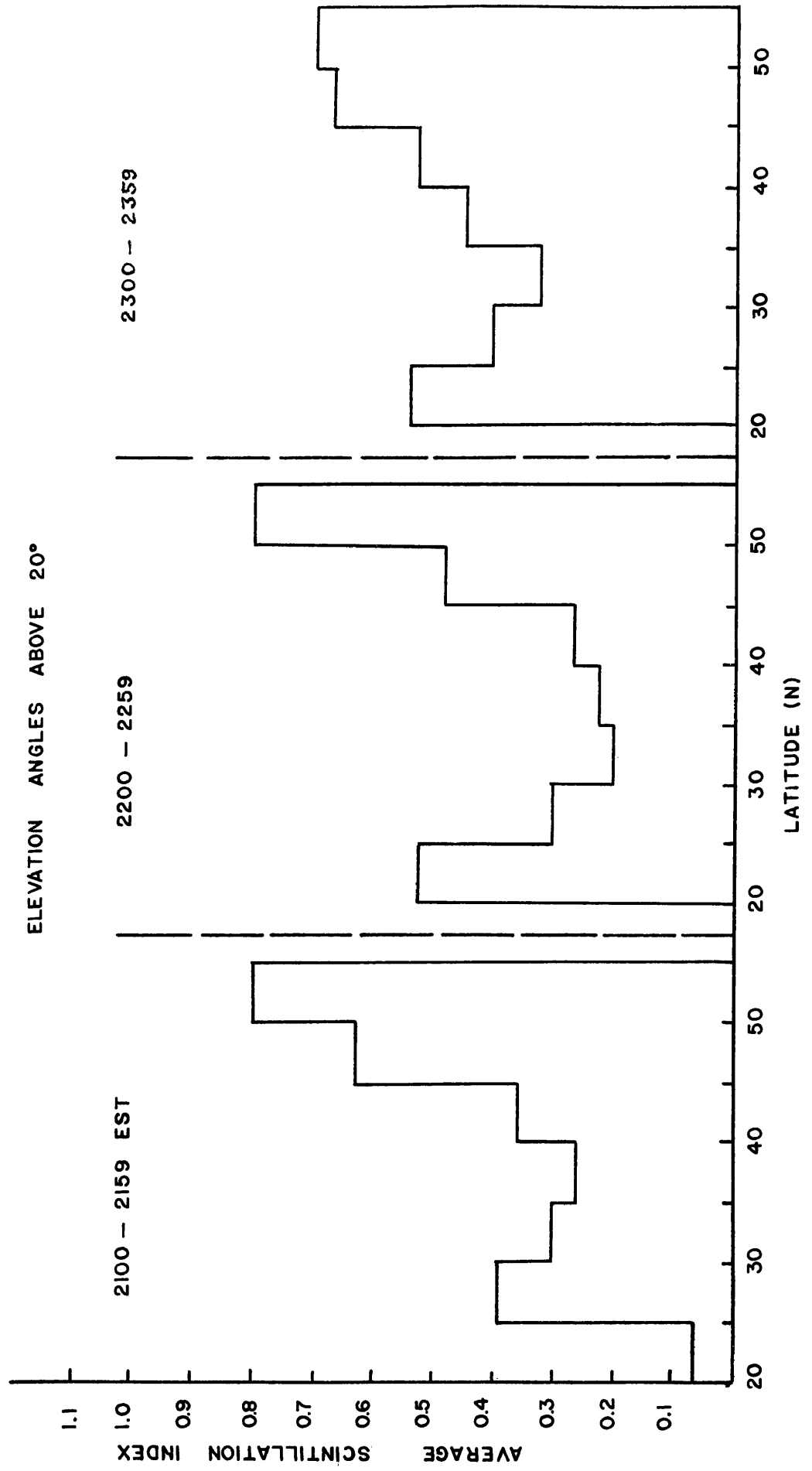


FIGURE 12H-- DIURNAL VARIATION OF LATITUDE EFFECT

angle increases but never becomes as large as when the satellite was far north of the observing station. The nighttime latitude data closely follow this angular dependence suggesting that perhaps maximum scintillation occurs when the signal is propagated perpendicular to the field lines as suggested by Mawdsley.<sup>10</sup>

Briggs and Parkin<sup>14</sup> suggest that the maximum scintillation activity should occur when the direction of propagation is directed "end on" through the blob. The magnetic dip angle at Williamsburg is nearly  $70^\circ$  so that at satellite latitudes near the receiving station ( $35^\circ - 40^\circ$ ), one would expect to observe maximum activity if the theory of Briggs and Parkin is correct. The data, however, show a distinct minimum is present for the latitude of the observing station when there is substantial scintillation activity.

If the irregularities have an appreciable vertical distribution, then the scintillation activity will depend on the path length through the ionosphere. One would then expect the latitude of variation to be essentially symmetrical about the latitude of the observing station (where the activity should be minimal). If one further considers (1) that the magnetic field lines converge as the latitude increases to the magnetic pole (the electron density gradient may be considerably increased due to the higher density of irregularities) and (2) the effect of auroral activity on the presence of irregularities (maximum auroral activity occurs at about  $65^\circ\text{N}$ ), then one would expect to observe greater scintillation activity to the north than to the south.

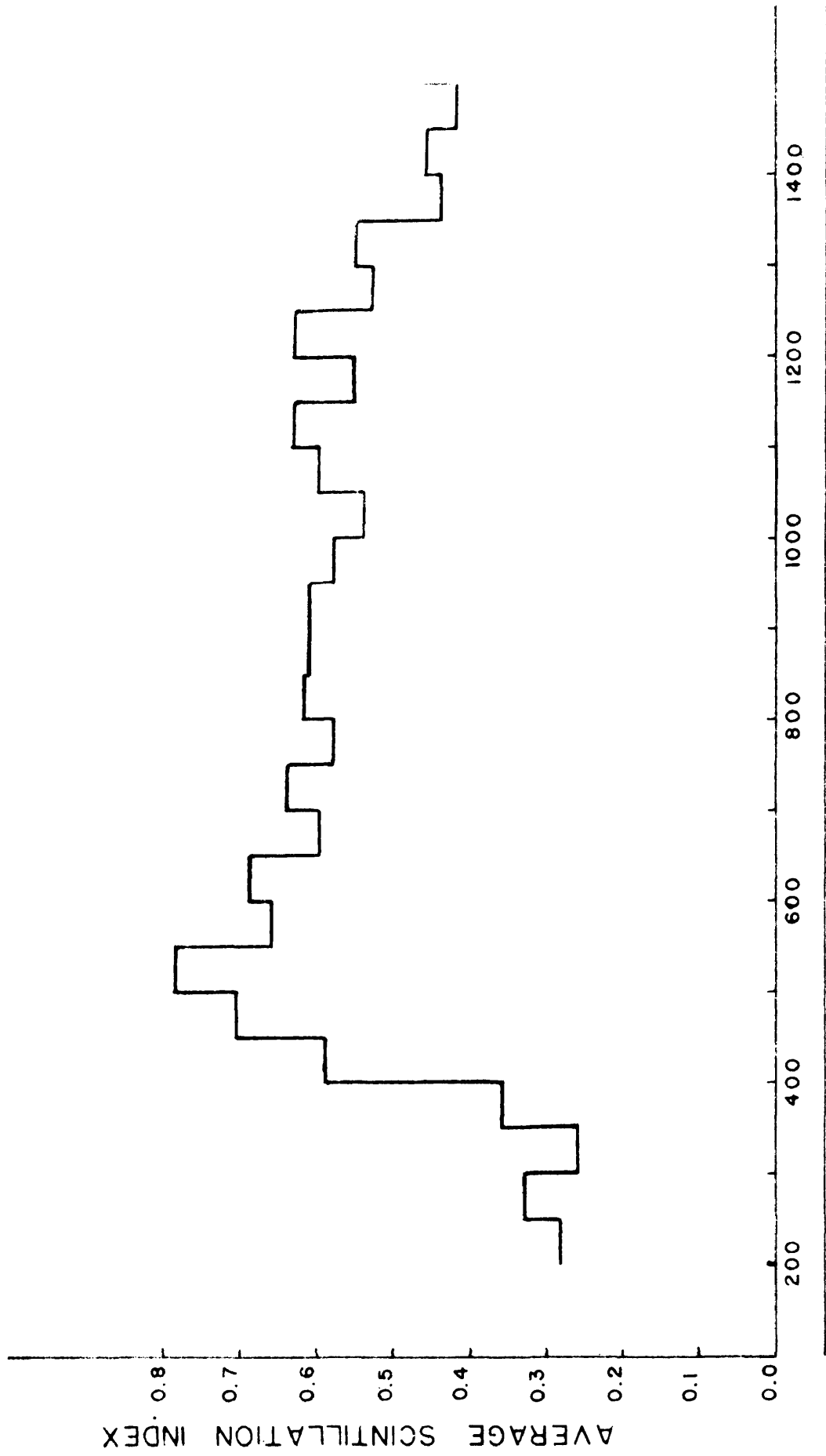
It is likely that various effects contribute to the results presented in the latitude study. The only conclusion that can be made is that the effect proposed by Briggs and Parkin is not evident.

#### Variation of Scintillation Depth with Height of Satellite

From March to August, 1962, the 20 Mc/s transmissions of three Russian satellites were recorded for 149 transits. Each of these satellites because of the high eccentricity of the orbit, provided an excellent opportunity for an average scintillation index versus height study. The altitudes accessible to this study ranged from 200 to 1550 km. The results, shown in Figure 13, are rather surprising. Notice particularly the steady decrease in depth of the scintillation above 550 km.

Apparently there are irregularities in the ionosphere responsible for satellite scintillation as low as 200 km. There is disagreement between workers as to the height of the lower boundary. Slee,<sup>7</sup> observing the 108 Mc/s transmissions of 1958 Alpha, noticed that at the perigee of the satellite of 350 km there was no marked decrease in scintillation. He concluded that the irregularities must, therefore, lie below 350 km. On the other hand DeBarber,<sup>32</sup> using phase scintillation techniques, suggested a height range of 300 - 600 km.

The 149 transits were predominately daytime passes and thus it is not likely that there is a diurnal effect imposed on the data. The data were reaveraged for only the daytime transits; the maximum scintillation and the decrease



HEIGHT (KM)

FIGURE 13 AVERAGE SCINTILLATION INDEX VERSUS HEIGHT FOR  
COSMOS 1, 11, V

in activity above 550 km were each slightly more pronounced. Since the majority of the data were obtained using 1962 Theta 1 (observed for the months of June, July, and August, 1962), one would not expect a seasonal effect to be apparent. Any zenith angle, azimuth angle, or latitude dependence should be at a minimum. This is due to the sufficiently rapid rate of the precession of the perihelion which would enable any such effects to be averaged out over a sufficient amount of data.

Perhaps one way to explain the results as shown in Figure 13 would be to examine the effects that the ionospheric irregularities impose on an initially spherical wave transmitted from a satellite as a function of the satellite's height. Yeh<sup>13</sup> has theoretically treated the case of the propagation of spherical waves through a medium containing anisotropic random irregularities and has applied this to the propagation of radio transmissions from satellites through the ionosphere. His work suggests that the amplitude scintillation index varies monotonically as a function of the height. Thus Yeh's model does not explain the data.

In another attempt to explain the data, the following scheme was employed. Briggs and Parkin<sup>14</sup> assume that amplitude fluctuations develop by a diffraction process as the wave propagates in the free space below the ionosphere. They have used the results of Mercier<sup>33</sup> to determine a scintillation depth for satellite scintillation as a function

of height:

$$S = \sqrt{2} \phi_0 \left[ 1 + \frac{\pi^2 r_0^4}{2 \lambda^2} \left( \frac{z_1 + z_2}{z_1 z_2} \right)^2 \right]^{-1/2}$$

Where  $\phi_0$  is the root mean square phase deviation,  $r_0$  is the distance at which the correlation function of electron density falls to  $1/e$  measured along the minor axis of the blob assuming an ellipsoidal configuration,  $\lambda$  is the wavelength of the satellite signal,  $z_1$  and  $z_2$  are the distances from the observer to the layer of irregularities and from the layer to the satellite, respectively (see Figure 14). If either  $z_1$  or  $z_2$  is zero, i.e. the irregularities are very close to the satellite or observer, then only phase scintillation is produced. According to Briggs and Parkin, one should expect maximum scintillation when  $z_1 = z_2$ , since under this condition the irregularities are most effective for producing amplitude scintillation.

To make use of the theory of Briggs and Parkin in an attempt to explain the maximum between 500-550 km, a method was devised to display the data (Figure 13) in terms of the slant range. In order to do this an arbitrary zenith angle of  $70^\circ$  was selected, see Figure 14. With  $\theta = 70^\circ$ , a plot was made of a normalized scintillation index versus slant range and the results are shown in Figure 15. The scintillation index was normalized in a manner presumably similar to that of Singleton, Lynch, and Thomas.<sup>34</sup> The scintillation index for the  $1/2$ -min. interval containing the time when the satellite was at a zenith angle of  $70^\circ$  was divided

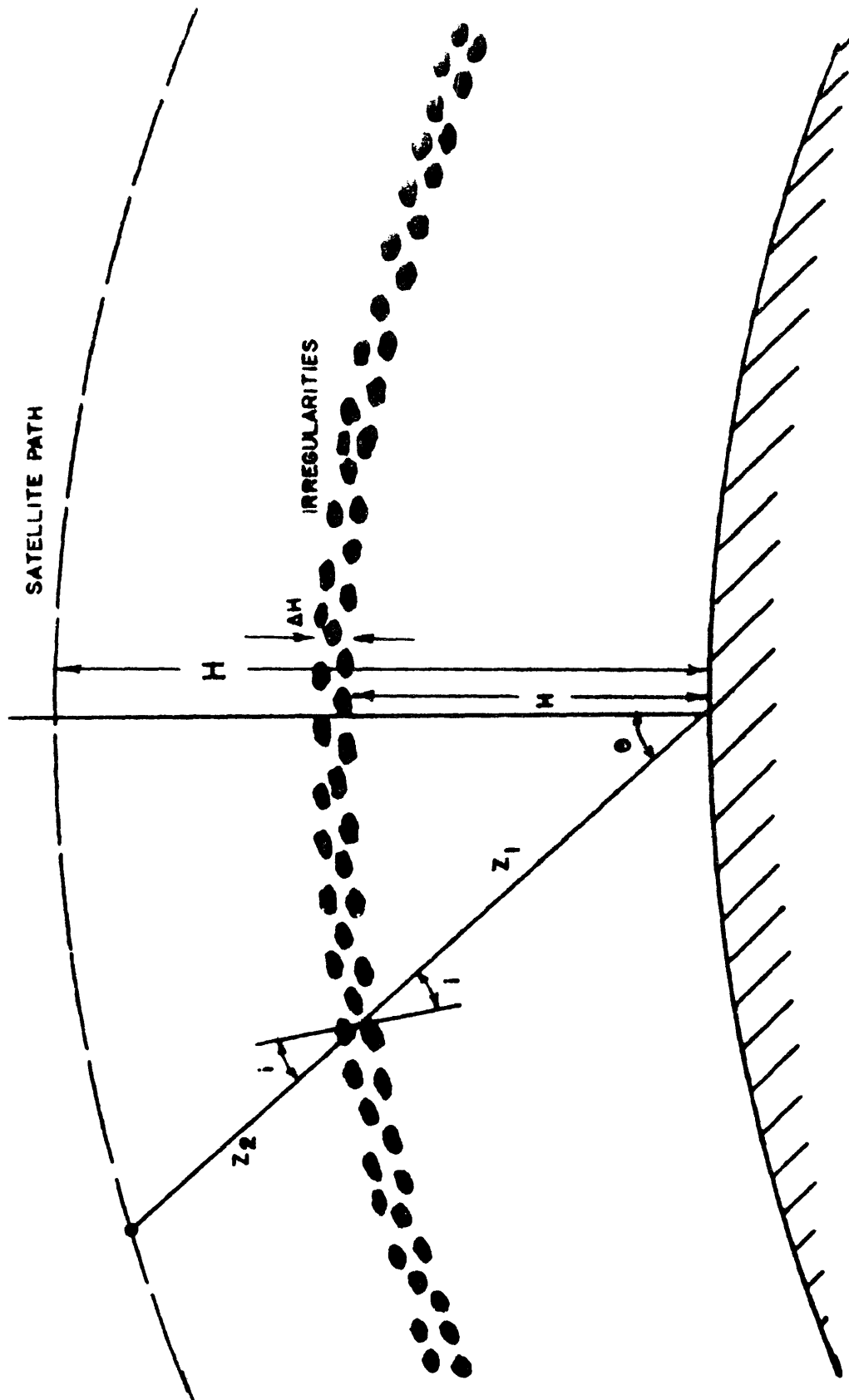


FIGURE 14 - ZENITH ANGLE - SLANT RANGE GEOMETRY

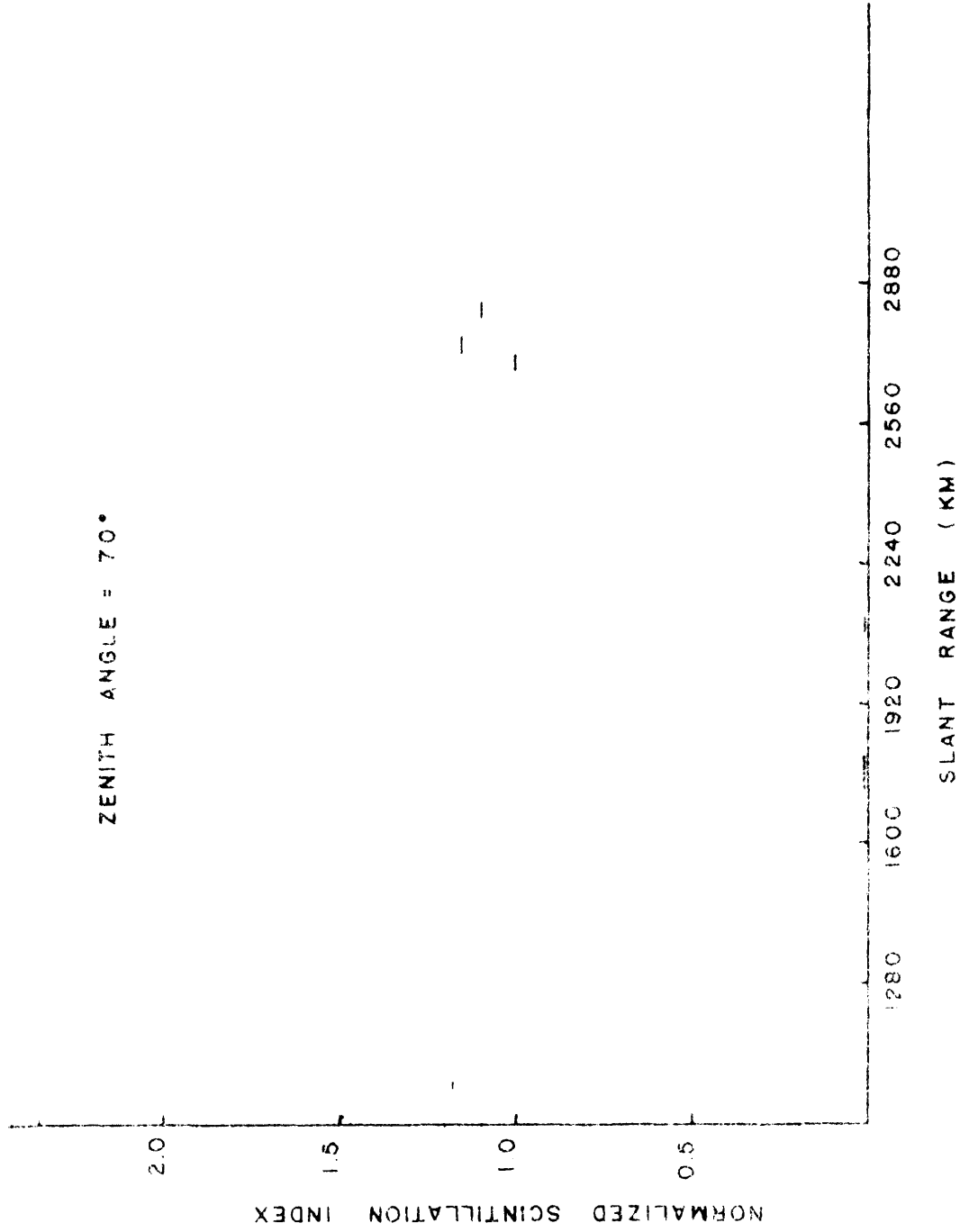


FIGURE 15 NORMALIZED SCINTILLATION INDEX VERSUS SLANT RANGE

by the average scintillation index for the entire transit. This should remove the diurnal and seasonal variations of scintillation activity.

While the statistics leave something to be desired, no conclusive evidence of a scintillation maximum at a particular slant range has been found. This method has been applied to several zenith angles; however, none of the plots appeared to suggest a slant range for which the average scintillation was clearly a maximum.

Neither Yeh's nor Briggs and Parkin's theory explains the results of the height study shown in Figure 13. At the time of this writing no theoretical explanation of the data exists.

## CONCLUSIONS

The results of the various studies of satellite scintillation suggest certain properties which appear to be characteristic of the ionospheric irregularities responsible for scintillation. The diurnal variation study suggests that satellite scintillation activity (like radio star scintillation activity) is predominately a night-time phenomenon, which is in agreement with the results of practically all workers. In addition a secondary maximum at midday is in agreement with the results of workers in Australia and Canada, but in disagreement with the results of workers in England and the United States.

The seasonal variation study indicates that the scintillation depth is weakest during the period centered about the vernal equinox and strongest during the period centered about the autumnal equinox. All periods show a maximum in scintillation activity centered about local midnight; the periods centered about the solstices show a distinct secondary maximum centered about midday. The midnight maximum varies from 2200 to 0200, but shows no regular progression from season to season.

In order to perform a latitude variation study that would be substantially free of elevation effects, the data used in the previous studies were averaged for elevation angles greater than  $20^{\circ}$ . In addition the study was divided into one hour intervals to investigate the diurnal effects

of the latitude variation with emphasis on the variations at the more northern latitudes. During those times of day when the scintillation activity was minimal no appreciable latitude variation was noticed; however, during times of increased scintillation activity there is clearly evident a latitude variation. During these times a minimum is noticed at the latitude of the observing station ( $37^{\circ}\text{N}$ ) and a higher scintillation activity to the north than to the south. These results support the theory suggested by Mawdsley; however, the convergence of the magnetic field lines and auroral activity may also influence satellite scintillation in a similar manner.

A significant increase in scintillation depth is noticed for latitudes greater than  $45^{\circ}$ . This corresponds to a latitude of  $43.6^{\circ}$  for a height of 300 km above the earth.

The study of variation of scintillation depth with height of a satellite shows rather surprising results. There are apparently irregularities responsible for satellite scintillation in the ionosphere at heights down to at least 200 km. The scintillation depth increases rapidly for heights up to 500 km then decreases steadily out to 1550 km. The theories of Yeh and Briggs and Parkin were investigated in order to explain the data; however, neither theory supported the results of the study. As of this writing no theoretical treatment has been found to explain the data.

In all probability satellite scintillation is caused by a composition of various ionospheric phenomena and to completely isolate one aspect of the problem is probably not possible. One study that might reveal a better understanding of the ionospheric behavior is that of the sunrise-sunset effect on satellite scintillation. Perhaps ionization in the D or E region during these periods may significantly contribute to the observed scintillation. In order to do a study of sunrise-sunset effects, the time of sunrise and sunset has to be known for all latitudes, for all heights of the ionosphere, and for all days of the year. The compilation of these parameters has been begun.

In addition a phase scintillation study and a Faraday rotation study are under way in order to attempt to answer problems concerning the height of the irregularities and the distribution of the integrated electron density.

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## APPENDIX I

The orbit parameters of the three Russian satellites are listed:

	nodical period (minutes)	inclination (degrees)	perigee (km)	apogee (km)
Cosmos	98.25	48.93	214	870
Cosmos I	101.7	48.94	209	1035
Cosmos V	102.73	49.13	203	1155

APPENDIX II

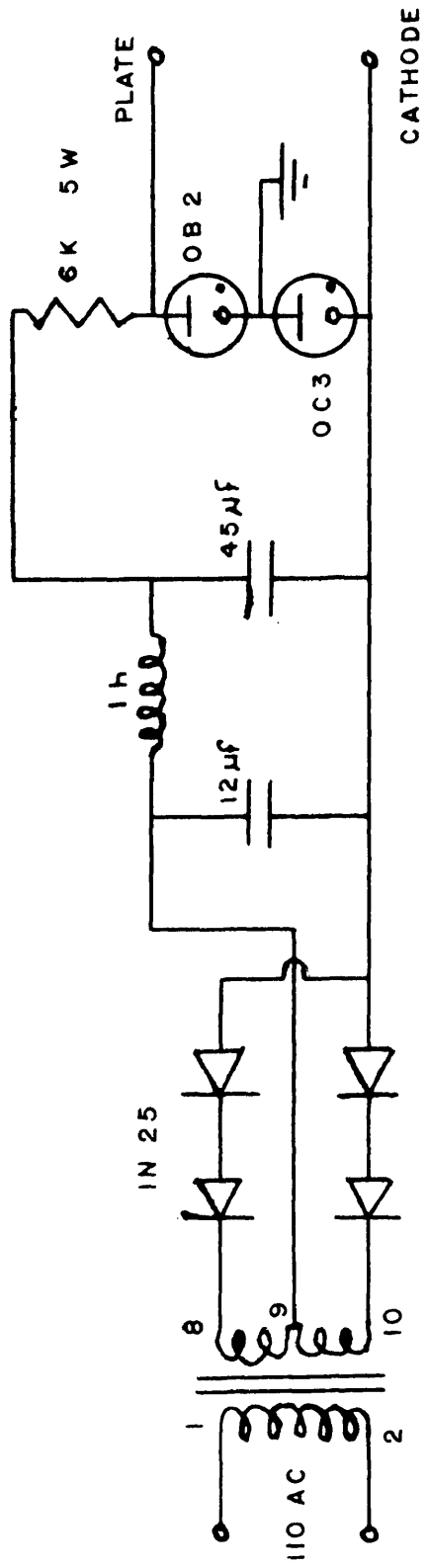


FIGURE 16 POWER SUPPLY

VITA

John David Martin

Born in Chicago, Illinois, November 8, 1939. Graduated from George Washington High School in Alexandria, Virginia, June 1957; B.S. in physics, Virginia Military Institute, June 1961. Served with the United States Army Engineer Geodesy, Intelligence and Mapping Research and Development Agency, Fort Belvoir, Virginia, summer of 1961. Entered the College of William and Mary as a M.A. candidate in physics, September 1961.