CONTINUED PERFORMANCE OF THE WIDEBAND SATELLITE EXPERIMENT

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Final Report. 1 Jun 77–31 Jan 81

CONTRACT No DNA/301-77-C-0220

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**CONTINUED PERFORMANCE OF THE WIDEBAND SATELLITE EXPERIMENT**

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**Propagation Theory**  
**Radio Waves**  
**Scintillation**  
**Wideband Satellite**
SUMMARY

This report formally completes the active data-taking phase of the Wideband Satellite Program. The experiment has been an outstanding success, both in meeting its objectives and in revealing several new and unexpected aspects of the structure of naturally-occurring ionospheric irregularities.

The report summarizes the extensive data base that was accumulated and processed during the three years of operation of the Wideband satellite. The data base is itself a unique and invaluable resource, because the Wideband satellite is the only experiment that has permitted completely unambiguous multifrequency phase-and-amplitude scintillation measurements.

The report outlines, in two categories, the major accomplishments of the Wideband satellite experiment. The first category has to do with propagation theory and channel modeling, which is the basis for extrapolating the Wideband satellite results to the disturbed nuclear environment (Section I). In this area the Wideband satellite program has stimulated a number of refinements in the propagation theory (Section II). The second category is the structure and development of the naturally occurring ionospheric irregularities that cause the scintillations. Here several unexpected and important new results have emerged (Section III).

This report is primarily a survey of the direct and related work that has resulted from the Wideband Satellite Program. A bibliography of the numerous reports, papers, and complementary efforts up to the time this report was written are included.
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I INTRODUCTION

The Wideband Satellite Program formally started in 1968, when SRI International was awarded a contract to develop a satellite-borne, multifrequency, phase-coherent beacon for measuring the propagation characteristics of the transionospheric channel. Radar propagation effects were the dominant concern at the time. Of particular interest was the determination of the maximum bandwidth signals that the disturbed ionosphere could support. A comb of seven equally-spaced UHF frequencies covering a 70-MHz bandwidth was, therefore, incorporated into the beacon for coherence-bandwidth measurements.

From the outset of the project, a formal channel-modeling approach was pursued. The ionosphere, insofar as the transmission of radio waves is concerned, is a linear medium. Because of this property, all propagation effects can be characterized in terms of a time-varying transfer function $h(t; f)$. The spatial structure of the perturbed wavefield is implicitly contained in the transfer function. The concept is illustrated in Figure 1.

One applies the channel model in the following manner: If a signal

$$S_i(t) = \text{Re} \left[ v_i(t) \exp \left[ 2\pi f_c t \right] \right]$$  \hspace{1cm} (1)

is transmitted, the received signal, $S_o(t)$, admits a representation similar to Eq. (1) with $v_i(t)$ replaced by

$$v_o(t) = \int v_i(f) h(t; f + f_c) \exp \left[ 2\pi ft \right] df .$$  \hspace{1cm} (2)

In (2) $\hat{v}_i(f)$--the Fourier transform of $v_i(t)$--occupies a finite band of frequencies, $B$, such that $B/f_c \ll 1$. It is clear from (2) that if a sinusoidal signal for which $\hat{v}_i(f) = \delta(f)$ is transmitted, then the complex modulation imparted to $S_o(t)$ is $h(t; f_c)$. By using the phase-coherent
FIGURE 1  EQUIVALENT CHANNEL MODEL FOR IONOSPHERIC PROPAGATION EFFECTS
signal at S-band as a phase reference, the synchronously demodulated Wideband signal gives the complex signal \( v(t) = h(t; f_c) \), which is the most basic quantity that is used in analyzing fading channels [see for example, Schwartz, Benet, and Stein, *Communication Systems and Techniques*, Ch. 9 (McGraw-Hill Book Co., 1966); and Kennedy, *Fading Dispersive Communication Channels* (John Wiley and Sons, Inc., 1969)].

Because \( h(t; f) \) cannot be predicted in detail, a statistical characterization must be used, although for most engineering applications a complete statistical description is unnecessary. Indeed, under conditions of Rayleigh fading, only second-order temporal and frequency coherence measures need be specified. An appropriate measure of the perturbation level is first used to estimate the onset of Rayleigh fading. The application of such a channel model for evaluating the performance degradation in communication or navigation systems is illustrated in Figure 2.

In principle, the problem is amenable to complete mathematical treatment. To accommodate all the complexities of various systems, however, simulations are invariably used. To faithfully reproduce the statistics of \( h(t; f) \), the diffraction process itself must be modeled. It is obviously more efficient, however, to directly generate a Gaussian process that has the same temporal and frequency coherence as \( h(t; f) \). The diffraction theory then has to supply only the second-order coherence measures and their geometrical dependence.

The Wideband satellite data base is ideally suited for testing both propagation theory simulations and the alternative Gaussian implementation. In the course of fulfilling this objective, moreover, the Wideband satellite experiment has provided invaluable information on the occurrence and structure of the striations that cause the propagation disturbances.

In this final report, which concludes the active data-taking phase of the Wideband Satellite Program, we review the major accomplishments of the program. In Section II the data base, acquired during the three years of continuous operation of the Wideband satellite, is summarized. The data have all undergone preliminary and summary analysis and are
FIGURE 2  CHANNEL MODEL APPLICATION FOR COMMUNICATION AND NAVIGATION SYSTEMS
archived in a data library. This task is complete, and has provided a unique resource that can be productively utilized for many years to come.

In Section III, we review the accomplishments of the Wideband Satellite Program in the area of propagation theory and channel modeling. As noted in the Introduction, this effort was the major objective of the program. It has, moreover, resulted in a number of essentially new theoretical results concerning the propagation of radio waves in randomly irregular, power-law media.

In Section IV, we review the accomplishments of the Wideband Satellite Program in the area of irregularity occurrence, intensity, and structure. Here, as in the case of the propagation theory, a number of new and unexpected findings have developed. To provide a complete up-to-date summary, we have referenced the work performed under separate contracts, as well as new results that have emerged since the formal stop-work date for this contract.

In Section V, the operation of the DNA002 satellite beacon, up until its loss in August 1979 (caused by a boost-regulator circuit failure) is reviewed.
II THE WIDEBAND SATELLITE DATA BASE

The locations of the Wideband receiving stations are listed in Table 1. The Stanford station was moved to Kwajalein in October 1978 to provide data on the longitudinal variation of equatorial scintillation. Both the Poker Flat and the Kwajalein stations have three UHF phase-coherent remote antennas with a 900-m geomagnetic north-south baseline and a 300-m and a 600-m geomagnetic east-west baseline. The data accumulated during the active data-taking phase of the Wideband Satellite Program are summarized in Table 2.

For each pass, which provides ∼15 min of data, a maximum of 13 complex channels are sampled (at a 500-Hz rate) and digitally recorded on 9-track tape (at 1600 bpi). The first step in the routine data reduction is to detrend the S band, the L band, the two extreme and center UHF channels, the 900-m, 600-m, and 300-m spaced-receiver channels, and the VHF channel (9 of the 12 recorded channels). The detrend cutoff is 0.1 Hz (10 s) and the detrended intensity and phase data for these nine channels are recorded at a 100-Hz rate. A continuous phase trend is preserved, together with the signal intensity trend, at a 20-Hz rate.

The detrended data are then processed to extract phase-and-amplitude scintillation indices, space and frequency correlation coefficients, and the spectral characteristics of the VHF and center UHF scintillation data. Summary parameters are computed for every 20-s data segment and recorded, together with satellite location and propagation geometry, at E- and F-region reference altitudes. These summary parameters, together with the intensity-and-phase trends for each of the routinely detrended channels, are preserved on summary tapes. A detailed description of the detrend and summary data is presented in Appendix A.

The routine processing described above has been performed on all of the data listed in Table 2. The detrend and summary tapes for all data are cataloged and stored in a data library at SRI International. These
data have formed the basis for a number of scintillation morphology and propagation studies, which we shall describe in Sections III and IV. A more detailed discussion of the summary processing can be found in Fremouw et al. (1978).

In addition to the routine summary processing, several more elaborate data analysis procedures have been developed. To process the spaced receiver data, for example, all possible complex correlations among the four receivers must be computed. To accommodate this data load economically, an array processor was used. Preliminary results are described in Topical Report 1. Table 3 lists the passes that have been processed for spatial coherence studies.

For analysis of strong scatter effects, the L-band, the center UHF, and the VHF data from a selected subset of the most disturbed passes at Ancon and Kwajalein were detrended by using a 0.04 Hz (25 s) low-pass filter and a 250-Hz sample rate. Finally, the 7 UHF channels from the same data set have been separately detrended at 0.1 Hz for coherence bandwidth studies.

Selected subsets of the Poker Flat, Stanford, Kwajalein, and Ancon data have undergone a dual detrending procedure that separates the scintillation into fast and slow multiplicative components. This processing procedure was developed for analyzing the first-order signal statistics.

<table>
<thead>
<tr>
<th>Station</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Dip Latitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poker Flat, Alaska</td>
<td>65°7'N</td>
<td>147°29'W</td>
<td>65.4°N</td>
</tr>
<tr>
<td>Stanford, California</td>
<td>37°24'N</td>
<td>122°10'W</td>
<td>42.8°N</td>
</tr>
<tr>
<td>Ancon, Peru</td>
<td>11°46'S</td>
<td>77°9'W</td>
<td>0.4°N</td>
</tr>
<tr>
<td>Kwajalein, Marshall Islands</td>
<td>9°24'N</td>
<td>16°28'E</td>
<td>4.4°N</td>
</tr>
</tbody>
</table>
### Table 2

**SUMMARY OF WIDEBAND SATELLITE DATA BASE**

*May 1976 to August 1979*

**Poker Flat** (1140 Passes)

<table>
<thead>
<tr>
<th>Regular Weekly Operations</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>28 May 1976 to 25 May 1978</td>
<td></td>
</tr>
<tr>
<td>10 July 1978 to 2 February 1979</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intensive Campaign Operations</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>13 to 16 November 1976</td>
<td>~ 40 passes*</td>
</tr>
<tr>
<td>7 to 17 November 1977</td>
<td>~ 48 passes</td>
</tr>
<tr>
<td>28 February to 9 March 1978</td>
<td>~ 53 passes</td>
</tr>
<tr>
<td>28 November to 14 December 1978</td>
<td>~ 86 passes</td>
</tr>
<tr>
<td>27 January to 2 February 1979</td>
<td>~ 33 passes</td>
</tr>
</tbody>
</table>

**Ancon** (500 Passes)

<table>
<thead>
<tr>
<th>Regular Weekly Operations</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>26 May 1976 to 17 June 1976</td>
<td></td>
</tr>
<tr>
<td>8 July 1976 to 26 November 1977</td>
<td></td>
</tr>
<tr>
<td>28 December 1977 to 15 April 1978</td>
<td></td>
</tr>
<tr>
<td>19 September 1978 to 27 April 1979</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intensive Campaign Operations</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>8 March to 2 April 1977</td>
<td>~ 55 passes</td>
</tr>
<tr>
<td>28 February to 17 March 1978</td>
<td>~ 27 passes</td>
</tr>
</tbody>
</table>

**Kwajalein** (530 Passes)

<table>
<thead>
<tr>
<th>Regular Weekly Operations</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>13 October to 22 December 1976</td>
<td></td>
</tr>
<tr>
<td>5 January to 27 October 1977</td>
<td></td>
</tr>
<tr>
<td>29 March to 28 August 1978</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intensive Campaign Operations</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>17 August to 30 September 1977</td>
<td>~ 85 passes</td>
</tr>
<tr>
<td>28 July to 29 August 1978</td>
<td>~ 50 passes</td>
</tr>
<tr>
<td>10 June to 3 August 1979</td>
<td>~ 40 passes</td>
</tr>
</tbody>
</table>

**Stanford** (100 Passes)

<table>
<thead>
<tr>
<th>Regular Weekly Operations</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>26 May to 10 September 1976</td>
<td></td>
</tr>
<tr>
<td>(Site moved to Kwajalein October 1976)</td>
<td></td>
</tr>
</tbody>
</table>

*Remote station operated at Fort Yukon, Alaska 5 to 18 November 1977.*
### Table 3

**SPACED RECEIVER DATA ANALYSIS SUMMARY**

<table>
<thead>
<tr>
<th>Inclusive Dates</th>
<th>Passes</th>
<th>Books</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Poker Flat</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>February-July 1978</td>
<td>~ 180</td>
<td>50, 51, 52, 53*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Kwajalein</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>June-July 1977</td>
<td>~ 100</td>
<td>26, 49, 58</td>
</tr>
<tr>
<td>June-July 1978</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Detrended only.*
III PROPAGATION THEORY

A. First-Order Signal Statistics

The first-order statistics of radio-wave and light-wave scintillation have been the source of controversy since the first papers on the subject were published [see Rino (1980a)]. All attempts to rigorously justify either the log-normal or Gaussian models, including the Gaussian Rayleigh limit under conditions of strong scatter, have failed. The Wideband satellite data have consistently shown that scintillating signals are dominated by slow, trend-like phase variations even under conditions of strong scatter. The quadrature signal components are, therefore, never completely uncorrelated, as required by the Rayleigh and Rice models; moreover, the phase structure is not strictly Gaussian, as required by the log-normal model.

To accommodate the slow phase trends formally, Fremouw et al. (1976) postulated a multiplicative, two-component model. The most rapid complex signal scintillations are represented by a general Gaussian model. The slow-phase and associated amplitude variations are represented by a log-normal process. The partitioning, however, is somewhat arbitrary.

Fremouw et al. (1980) performed detailed tests of the two-component model, using Wideband satellite data. They showed that the most rapid scintillations can always be well represented by the general Gaussian model. The intermediate multiplicative component does not adhere so closely to the log-normal model. The best overall fits to the measured complex signal statistics were nonetheless obtained by using the two-component model. For intensity only, however, the Nakagami distribution (which includes the Rayleigh distribution as a special case) gives the best fit when tested against the two-component, general Gaussian, and log-normal models.
The two-component model has been used in both purely theoretical analysis [Johnson and Rino (1979)] and simulations [Scott and Knepp (1978)] of digital communications systems. Insofar as communication systems are concerned, the subtle departures of the signal statistics from the Gaussian model, in particular deviations from the Rayleigh limit, are unimportant. The slow trend-like phase variations, however, have important ramifications in the propagation theory.

B. Propagation Theory in Power-Law Environments

An early finding in the Wideband satellite data, also noted earlier in TRANSIT satellite differential phase data by Crane (1976), was that the value of the rms phase depends on the interval over which it is measured. This is easily understood in light of the fact that the phase spectral-density function has the power-law form

$$\varphi(f) \sim T f^{-p}$$  \hspace{1cm} (3)

where $f$ is temporal frequency, $T$ is the spectral-strength parameter, and $p$ is the spectral index.

For a data interval of length $\tau_c$, the spectrum is effectively truncated at a frequency $f_c \sim \tau_c^{-1}$. In the routine Wideband data analysis, a detrend filter is applied that removes all spectral components below $f_c$. In any case, as long as Eq. (3) applies for $f > f_c$, the rms phase can be calculated as

$$\sigma_{b\phi}^2 = 2 \int_{f_c}^\infty T f^{-p} df \hspace{1cm}$$

$$\hspace{1cm} = \frac{2T}{p-1} f_c^{p-1} = \frac{2T}{p-1} \tau_c^{p-1}$$  \hspace{1cm} (4)

For the routine Wideband summary analysis, $f_c$ was chosen to represent the approximate minimum frequency that makes a significant contribution to the corresponding intensity scintillation. It is important to note,
however, that $T$ and $p$ do not depend on how they are measured, and that they therefore constitute a completely unambiguous characterization of the average phase structure.

The ramifications of the power-law continuum of scale sizes that characterize the ionospheric irregularities have been developed in a series of papers and reports [Rino (1979a,b,c; Rino (1980b,c)]. The theoretical computations show that, in a power-law environment where the outer scale is much larger than the Fresnel radius, the diffraction effects are critically dependent on the power-law index $p$.

If $p < 3$, for example, the mutual coherence function can be characterized independent of the rms phase level. The intensity scintillation index $S_4$, moreover, converges to unity under conditions of strong scatter, which is a necessary (but not sufficient) condition for Rayleigh statistics. Indeed, under the same conditions, there is a simple relation between the intensity correlation function and the mutual coherence function. If $p > 3$, however, these simple relations break down.

It is fortunate, therefore, that the Wideband satellite data have consistently given spectral $p$ indices less than 3. The most recent results clearly show, as discussed in Section IV, that the spectral index varies systematically with changing perturbation strength.

The weak-scatter theory has been applied to the Wideband satellite data in Rino (1979a). We note that the angle dependence of the scintillation is particularly important for low orbiting satellites such as Wideband. The theory is developed in Rino and Fremouw (1977). The time structure of the scintillation as measured by Wideband is discussed in Rino and Owen (1980a). In particular, the strong-scatter dependence of the coherence time on the spectral index has been verified.

To analyze the spaced-receiver data, an elaborate analysis procedure was developed. With an appropriate angle-dependence theory, the method gives simultaneous estimates of the anisotropy and apparent drift of the diffraction pattern. The method and preliminary results are described in Rino and Livingston (1978). The results confirm the high
degree of the field-aligned anisotropy of the irregularities. There is, however, a second axis of elongation in the auroral zone (see Section IV).

The frequency coherence across the Wideband UHF comb of seven frequencies, spanning a 70-MHz bandwidth, has been analyzed and compared to theoretical predictions in Rino et al. (1980a). Good results are obtained when the signal is appropriately parameterized. The UHF comb has also been used to synthesize a narrow pulse and to measure the ionosphere-induced delay jitter. The results are in good agreement with model computations.

The Wideband satellite data, overall, are in excellent agreement with model computations that are based on a power-law phase screen with an outer scale dimension that is larger than the largest Fresnel radius of practical interest.

C. Channel Modeling

The Wideband satellite data have verified the accuracy of simple formulas that give a basic set of parameters for characterizing the average performance degradation in communication systems. These parameters include: (1) the intensity scintillation index $S_4$, which saturates near unity under strong scatter conditions, (2) the temporal coherence times for intensity, $T_\tau$, and the complex signal, $T_\nu$, and (3) a measure of the delay jitter induced by frequency decorrelation. Measures of angle-of-arrival jitter and Doppler spread are also available. A complete parameter specification has been described by Wittwer (1980).

The time structure of the intensity scintillation under conditions of both weak and strong scattering has been thoroughly analyzed by Rino and Owen (1980a). The coherence of the complex signal itself has not been directly measured. The coherence bandwidth formula and the delay-jitter estimate have been verified in Rino et al. (1980a). The analysis accommodates wave-front curvature as well as signal decorrelation along the propagation direction.

The overall characterization of average scintillation structure derived from the Wideband experiment completely validates the propagation
theory. One must, of course, have an appropriate characterization of the in-situ irregularity structure. A minimal characterization includes: (1) the effective turbulence level, (2) the power-law index, (3) the anisotropy of the irregularities, and (4) an effective height and thickness of an equivalent phase screen that reproduces the average signal structure. The propagation theory is therefore essentially complete.
IV IONOSPHERIC IRREGULARITY STRUCTURE AND OCCURRENCE

A. General Characteristics

The Wideband satellite phase scintillation data have consistently shown spectral indices \( p \) in Eq. (3) that are less than 3; moreover, the \( p \) index varies systematically with increasing perturbation strength. It has been found empirically that \( p \) follows a relationship of the form

\[
p = p_0 - \eta \log_{10} T
\]  

(5)

that \( p \) decreases as \( T \) increases. Because diffraction effects in the phase data should ultimately tend to cause the same effect, there was an initial reluctance to accept the result as genuinely reflecting the underlying irregularity structure.

In-situ data from the AE-E satellite, however, have shown exactly the same trend: for a one-dimensional in-situ spectral density function of the form \( T_1 f^{-p_1} \), \( p_1 \) admits a functional dependence on \( T_1 \) of the form given by Eq. (5) with the same \( \eta \) parameter [Livingston et al. (1980)]. This behavior has also been confirmed in rocket probe data from a recent DNA equatorial spread-F campaign [Rino et al. (1980b)]. Recall that \( p_1 = p - 1 \); thus, if \( p = 3 \), then \( p_1 = 2 \).

As a final confirmation of the varying spectral index, we have accommodated Eq. (5) in the propagation theory. In doing so, a considerable improvement in the theoretical fits to intensity-coherence time data was obtained [Rino and Owen (1980b)]. The frequency coherence data clearly show evidence of a systematically varying spectral index [Rino et al. (1980a)].

The varying spectral index was an unexpected finding that has important ramifications. It had generally been accepted that a convective instability (e.g., gradient drift or Rayleigh-Taylor) generates striations with steep gradients (see Ossakow, 1979). Such an environment...
would favor a $k^{-2}$ one-dimensional in-situ spectral density function which implies $p = 3$. Equatorial and auroral irregularities that occur naturally are clearly much more complex.

In light of recent data from the DNA Kwajalein rocket campaign (PLUMEX), we believe that the steep gradients are broken up by the large-scale flow fields that develop in the course of the dynamic evolution of the background plasma. In the case of equatorial spread F, it is the depletions associated with backscatter plumes that generate the flow field. Appropriate simulations have not yet been performed to verify this conjecture, and a considerable amount of work needs to be done to understand all the ramifications of these new results.

B. **High Latitude**

The general morphology of the occurrence and latitudinal distribution of the auroral-zone scintillation, measured by the Wideband satellite, is described in [Rino and Matthews (1980)]. The most conspicuous feature in the data is a pronounced localized scintillation enhancement that occurs at the point where the propagation path to the satellite lies within a L shell [Fremouw et al. (1977)]. The unique localization of the enhancement has been shown to be caused by sheet-like irregularities—that is, irregularities that have a high degree of spatial coherence along L shells as well as along the magnetic field.

Other experiments have identified the source region to be localized in a latitudinally narrow enhanced F region [Rino and Owen (1980c); Vickrey et al. (1980)]. This particular scintillation phenomenon has received considerable attention from theoreticians [Ossakow and Chaturvedi (1978); Chaturvedi and Ossakow (1979)]. Field-aligned currents can destabilize a region, that might otherwise be stable, to the ordinary gradient drift instability. Both the mechanism and sheet-like structure of the irregularities are being intensely studied. The structure of scintillation, associated with auroral arcs and other general features of high-latitude scintillation as observed by Wideband, are discussed in [Rino et al. (1977)].
C. **Equatorial**

The occurrence and distribution of equatorial scintillation, as observed at Kwajalein in the north Pacific and Ancon, Peru, are described in [Livingston (1980)]. The most intense scintillation occurs at stations located near the geomagnetic equator. The occurrence at any given station, however, exhibits a strong seasonal dependence. The active period at Ancon persists for approximately 8 months, centered on December. At Kwajalein, the active period has a similar duration, but it is centered on July. Other stations report a pronounced seasonal dependence [see for example, Basu et al. (1980)].

The interrelationships among all the various manifestations of equatorial spread F are currently a subject of considerable interest, particularly in light of the results that have emerged from the recent DNA PLUMEX experiments. An invaluable contribution to that experiment was made by the ALTAIR radar which mapped the coherent backscatter, as well as making incoherent scatter measurements. This effort was partially supported under the Wideband program [Tsunoda et al. (1978), Topical Report 1].

The general subject of the total electron content (TEC) structure and its association with scintillation has not been treated under this contract. Some of the unique equatorial structures are described in [Rino et al. (1977)]. Work on both auroral and equatorial TEC structures are, however, currently being pursued under a separate contract.
The design of the Wideband beacon dates back to the late 1960s. The experiment was originally designed (electrically and mechanically) to be compatible with the SAMSO P72-2 spacecraft built by the Rockwell Corporation. The P72-2 Satellite Program encountered many technical difficulties and scheduling delays before it finally suffered a launch failure in April 1975.

As part of the development program for the beacon, a prototype/spare flight beacon was constructed that was electrically and mechanically identical to the flight unit. With the launch failure of P72-2, discussions were held with DNA and SAMSO to determine what other, if any, launch opportunities existed. After many meetings, it was determined that one of the Navy spare TRANSIT spacecraft could be modified quickly and at a reasonable cost. Because the TRANSIT was designed to be launched on a Scout booster, the launch costs would be minimized.

In mid-1975, the Applied Physics Laboratory of John Hopkins University was awarded a contract to obtain a spare TRANSIT from the Navy, modify the spacecraft as necessary, and integrate the spare beacon for a launch on a Scout booster in 1976. This program was assigned the designation P76-5 by SAMSO. Two major modifications required by the TRANSIT spacecraft were (1) a new beacon antenna design, and (2) a boost regulator to raise the 10-VDC bus voltage to the 28 VDC required by the Wideband beacon. It is this boost regulator that most likely caused the recent failure of the Wideband satellite.

A major difference between the P72-2 and P76-5 program was the satellite orbit. Because the TRANSIT spacecraft carried only the Wideband experiment, the orbit could be optimized for that experiment. The satellite was launched into a precise noon-midnight, sun-synchronous orbit on 26 May 1976. The orbit was chosen to maximize the value of the data obtained; however, it is one of the worst possible orbits for the
hardware. Being in a noon-midnight orbit, the satellite passes through
the earth's shadow on each orbit. This shadow time varies with the time
of year, but averages about 35 minutes out of each 107-minute orbit.
This repetitive encountering of the earth's shadow led to the first satel-
pite power problem in June 1977.

A well known, but little understood, phenomena of nickel-cadmium
batteries is the effect known as a "memory." The normal discharge curve
for a ni-cad cell is a nearly constant voltage until the cell is com-
pletely discharged, followed by a sudden collapse in the terminal voltages.
When a cell has been subjected to repeated partial discharges of the same
magnitude, a memory develops within the cell. The discharge curve for a
cell with memory departs from the normal discharge curve when the cell
is repeatedly discharged below the depth previously reached. At that
point, the terminal voltage drops to a lower plateau, where it remains
until the cell is completely discharged. The lower bus voltage, result-
ing from the battery memory, caused the Wideband experiment to experience
its first Low-Voltage Sense-Function (LVSF) shutdown in June 1977.

The LVSF is a special circuit incorporated into the boost regulator
that was added to the original TRANSIT spacecraft. Its function is to
prevent a catastrophic complete battery discharge. The LVSF monitors
the buss voltage, and switches the boost regulator into a no-boost state
when the buss voltage drops below a predetermined value. This state
allows the batteries to recharge, while keeping the experiment "on" in
a low power, non-operational condition. As the ni-cad batteries on the
satellite developed their memory, the bus voltage dropped below the
LVSF switched "off" for the first time since the launch in 1976. Numer-
ous tests were run on the satellite to understand the problem and to
check the state of the batteries. It was determined that the battery
and solar cell capacity was as predicted, and most probably the battery
memory was causing the LVSF trips.

Because the earth was near the maximum distance from the sun during
this period, it was assumed (correctly) that the situation would improve
over the subsequent months. NAG was instructed to minimize both the
total number of Doppler passes taken each week, and to maximize the ratio of sunlight/shadow passes in an attempt to maintain the battery in a higher state of charge. In addition, the experiment was turned "off" for one orbit each day. This mode of operation was used successfully until May 1978.

The reduced solar input to the solar cells (increased earth-sun distance), coupled with the ever-degrading battery, caused the LVSF switch to trip with ever-increasing frequency. Further study of the problem led to the decision to send the LVSF disable command that toggles the relay that deactivates the LVSF circuitry, thus enabling the boost regulator to gain access to the extra energy stored in the battery, but available only at a lower voltage. Careful management of the various commands was necessary to prevent a complete discharge of the battery. An operating procedure was developed that required NAG to communicate with the satellite on a daily basis, sending appropriate Doppler transmitter on/off, experiment on/off, and LVSF enable/disable commands. This operating mode resulted in the experiment being turned on approximately 16 hours a day, Monday through Friday, and turned off the remainder of the time. That mode was used successfully until August 1979.

On a pass in which NAG was supposed to send commands to the satellite, no response from the spacecraft was obtained. On a subsequent pass over California, NAG was able to obtain telemetry information, although it was not of a quality to allow automatic data processing. Subsequent manual data analysis revealed that the bus voltage was about half of what it should have been, and that both the Doppler transmitter and the Wideband experiment were "on"—a condition that was never supposed to occur. Review of the command history revealed that no incorrect commands had been given, and that the spacecraft had responded correctly to all commands sent.

On several subsequent passes on several different days, commands were sent to turn the experiment "off"—all without result. This left the satellite in a condition that was certain to discharge the batteries completely. About a week later, while attempting to communicate with an operational TRANSIT satellite, NAG found the P76-5 satellite in a
normal condition with the Doppler transmitters "on" and the experiment in the low voltage condition. The experiment was commanded "on" and found to be operating properly. Tests conducted over the next few passes revealed that the batteries had degraded to the point that they could no longer provide adequate energy to get through the earth's shadow with the experiment turned "on." On a subsequent pass, the boost regulator failed to respond to a command to turn the experiment "on." It can only be concluded, therefore, that the LVSF portion of the boost regulator circuitry (or its associated command relay) failed, and caused the battery to be completely discharged, greatly reducing the battery capacity. It has also become impossible to reliably command the satellite.

It appears that further efforts to stretch the mission would be futile. The satellite has been left in a condition with the experiment in the low power (non-operational) mode with the Doppler transmitters "on." This provides the capability of Doppler tracking, telemetry decoding, and provides 150/400-MHz phase-coherent transmissions (without the normal TRANSIT modulation) for anyone who desires to receive them. Considering the fact that the original mission requirement was for a six months mission, with hopes for one year, the 3-1/2 years of continuous data gathering makes the Wideband experiment an extremely successful program.
REFERENCES


Appendix A

WIDEBAND MAGNETIC TAPE FORMATS

There are three levels of tapes in the Wideband library; raw tapes of unprocessed data, detrend tapes of data prepared for analysis, and summary tapes of accumulated signal statistics. The formats of each of these tapes is described here. All are 9-track 1600-bpi density.

Raw Tapes

As outlined in Section II, thirteen complex channels of data for a single satellite pass are included on each raw tape recorded in the field. The file format of these tapes is shown in Figure 3. In addition to the main data file, a short initial file includes calibration data for the A-D converter. The last two files on the tape are RF calibrations. One is recorded system/sky noise with the receiver unlocked; the second is a constant-level coherent calibration signal.

Each record of the raw tape includes 50 ms of data and is 742, 16-bit-words long. All words are in standard Hewlett-Packard binary integers. The contents of each record are shown in Table 4. At Ancon (with a single-spaced receiver baseline) and at Stanford (with none), other channels are duplicated into the channels allocated for spaced receivers. Note also that the header portion of each record is different for the ADC calibration records.

Detrend Tapes

Of the 13 complex channels on the raw tapes, up to nine are decimated to 100 Hz and processed onto detrend tapes. The nine processed channels are split, three to a file, as shown in Figure 4. The channel allocations in each file are given in Table 5. At Stanford, where only six channels are processed, File 3 is zero-length. The remaining two
*ON SOME TAPES, ALL FILE MARKS OTHER THAN DATA MAY BE MISSING. ON NORMAL TAPES
RECORDED BEFORE OCTOBER 1976, THE NOISE CALIBRATION FILE WILL BE MISSING.

FIGURE 3 WIDEBAND RAW TAPE FILE/RECORD STRUCTURE
**Table 4**

WIDEBAND RAW TAPE RECORD CONTENTS

The first 650 words of each 742-word record are data from the A/D input. The 650-word array is made up of 25 sequential groups of 26 words which are the sample values from the 13 pairs of channels in order. X-Y pairs are simultaneously sampled. Adjacent channels are samples 80 µs apart. The high-order 4 bits of each word is the channel number.

<table>
<thead>
<tr>
<th>Word</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
</tr>
<tr>
<td>2</td>
<td>X</td>
</tr>
<tr>
<td>3</td>
<td>X</td>
</tr>
<tr>
<td>4</td>
<td>X</td>
</tr>
<tr>
<td>5</td>
<td>X</td>
</tr>
<tr>
<td>6</td>
<td>X</td>
</tr>
<tr>
<td>7</td>
<td>X</td>
</tr>
<tr>
<td>8</td>
<td>X</td>
</tr>
<tr>
<td>9</td>
<td>X</td>
</tr>
<tr>
<td>10</td>
<td>X</td>
</tr>
<tr>
<td>11</td>
<td>X</td>
</tr>
<tr>
<td>12</td>
<td>X</td>
</tr>
<tr>
<td>13</td>
<td>X</td>
</tr>
<tr>
<td>14</td>
<td>X</td>
</tr>
<tr>
<td>15</td>
<td>X</td>
</tr>
<tr>
<td>16</td>
<td>X</td>
</tr>
<tr>
<td>17</td>
<td>X</td>
</tr>
<tr>
<td>18</td>
<td>X</td>
</tr>
<tr>
<td>19</td>
<td>X</td>
</tr>
<tr>
<td>20</td>
<td>X</td>
</tr>
<tr>
<td>21</td>
<td>X</td>
</tr>
<tr>
<td>22</td>
<td>X</td>
</tr>
<tr>
<td>23</td>
<td>X</td>
</tr>
<tr>
<td>24</td>
<td>X</td>
</tr>
<tr>
<td>25</td>
<td>X</td>
</tr>
<tr>
<td>26</td>
<td>X</td>
</tr>
<tr>
<td>27–650</td>
<td>Sequence of words 1 to 26 is repeated 25 times.</td>
</tr>
</tbody>
</table>

The remaining 92 words of each record is header information. For the data file, it contains the following information useful to outside users:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>651–659</td>
<td>N/A</td>
</tr>
<tr>
<td>660</td>
<td>Hour</td>
</tr>
<tr>
<td>661</td>
<td>Minute</td>
</tr>
<tr>
<td>662</td>
<td>Second</td>
</tr>
<tr>
<td>663</td>
<td>Packed fraction of second</td>
</tr>
<tr>
<td>664</td>
<td>N/A</td>
</tr>
<tr>
<td>665</td>
<td>Day of year (BCD from clock)</td>
</tr>
<tr>
<td>666</td>
<td>N/A</td>
</tr>
<tr>
<td>667</td>
<td>Azimuth position from antenna controller (θ_x at Poker Flat)</td>
</tr>
<tr>
<td>668</td>
<td>Elevation position from antenna controller (θ_y at Poker Flat)</td>
</tr>
<tr>
<td>669–674</td>
<td>N/A</td>
</tr>
<tr>
<td>675</td>
<td>Azimuth position command (θ_x at Poker Flat)</td>
</tr>
<tr>
<td>676–679</td>
<td>N/A</td>
</tr>
<tr>
<td>680</td>
<td>Elevation position command (θ_y at Poker Flat)</td>
</tr>
<tr>
<td>681–687</td>
<td>N/A</td>
</tr>
<tr>
<td>688–690</td>
<td>Blank</td>
</tr>
<tr>
<td>691–706</td>
<td>N/A</td>
</tr>
</tbody>
</table>

*X* = in-phase component, *Y* = phase quadrature component.
The header information for the first (ADC calibration) file is different. Those 8 records contain the following header data:

<table>
<thead>
<tr>
<th>Word</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>651-652</td>
<td>ADC calibration voltage applied (real word format)</td>
</tr>
<tr>
<td>653-660</td>
<td>N/A</td>
</tr>
<tr>
<td>681-700</td>
<td>ASCII data, second line of ephemeris message (20A2 format)*</td>
</tr>
<tr>
<td>701-742</td>
<td>N/A</td>
</tr>
</tbody>
</table>

*Only on records 1, 3, 5, and 7.
*FILE 3 IS ZERO-LENGTH FOR STANFORD TAPES.

FIGURE 4  WIDEBAND DETREND TAPE FILE STRUCTURE
files for each satellite pass are simply duplicates of the raw-tape RF calibration files. Usually three satellite passes, five files each, are included on a single tape.

Within each data file, the contents of each record are given in Table 6. Each record is 742 16-bit-words long, but includes a mixture of HP integrated real binary words. The first two records are copies of raw tape records 1 and 5, to carry over ADC calibration information. The remaining records (up to about 1600 of them) include 0.5 s of both rapidly and slowly varying detrend processing components, and header information.

Table 5
WIDEBAND DETREND TAPE
FILE/CHANNEL ALLOCATIONS

<table>
<thead>
<tr>
<th>File</th>
<th>Channel</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Poker Flat/Kwajalein</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>137.7</td>
<td>378.6</td>
<td>447.5</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2891.2</td>
<td>413.0</td>
<td>413.0 south</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1239.1</td>
<td>413.0 east</td>
<td>413.0 west</td>
<td></td>
</tr>
<tr>
<td>Ancon</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>137.67</td>
<td>378.6</td>
<td>447.5</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2891.2</td>
<td>413.0</td>
<td>413.0 east</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1239.1</td>
<td>390.1</td>
<td>436.0</td>
<td></td>
</tr>
<tr>
<td>Stanford</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>137.67</td>
<td>378.6</td>
<td>447.5</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2891.2</td>
<td>413.0</td>
<td>1239.1</td>
<td></td>
</tr>
<tr>
<td>Record</td>
<td>Word No.</td>
<td>Parameter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>--------</td>
<td>----------</td>
<td>-----------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1-742</td>
<td>Duplicate of raw tape record No. 1 (ADC ground)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1-742</td>
<td>Duplicate of raw tape record No. 5 (ADC constant voltage)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>Intensity Channel 1 Detrended signal, i.e., components &gt; 0.1 Hz, floating point words at 100 Hz rate;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Phase Channel 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Intensity Channel 2 intensity: relative units unity mean;</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Phase Channel 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Intensity Channel 3 phase (dispersive Doppler): radians, continuous</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>Phase Channel 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13-600</td>
<td></td>
<td>Repeat (50 times) of above sequence</td>
<td></td>
<td></td>
</tr>
<tr>
<td>601</td>
<td></td>
<td>Intensity Channel 1 Detrend reference signal, i.e., components &lt; 0.1 Hz, floating point words at 20 Hz rate;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>603</td>
<td></td>
<td>Phase Channel 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>605</td>
<td></td>
<td>Intensity Channel 2 intensity: scaled counts, 0 to (2048)^2;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>607</td>
<td></td>
<td>Phase Channel 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>609</td>
<td></td>
<td>Intensity Channel 3 phase (dispersive Doppler): radians, continuous</td>
<td></td>
<td></td>
</tr>
<tr>
<td>611</td>
<td></td>
<td>Phase Channel 3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>613-720</td>
<td></td>
<td>Repeat (10 times) of above sequence</td>
<td></td>
<td></td>
</tr>
<tr>
<td>721</td>
<td></td>
<td>Hour (integer)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>722</td>
<td></td>
<td>Minute (integer)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>723</td>
<td></td>
<td>Second (integer)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>724</td>
<td></td>
<td>Packed fraction of seconds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>725</td>
<td></td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>726</td>
<td></td>
<td>Day of year (BCD from clock)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>727</td>
<td></td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>728</td>
<td></td>
<td>Azimuth position from antenna controller (θ_x for Poker Flat)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>729</td>
<td></td>
<td>Elevation position from antenna controller (θ_y for Poker Flat)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>730</td>
<td></td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>731</td>
<td></td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>732</td>
<td></td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>733</td>
<td></td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>734</td>
<td></td>
<td>N/A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>735-742</td>
<td></td>
<td>Blank</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 through file mark</td>
<td></td>
<td>Repeat of record 3 format, each record corresponding to 0.5 seconds of data.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Summary Tapes

The summary tapes are a statistical condensation of the Wideband temporal data included on the detrend tapes. Unlike the raw and detrend binary tapes, the summaries are coded ASCII to simplify transfer to other computers.

Figure 5 shows the file and record structure of the summary tapes. Each tape starts with a file mark and contains data from 10 to 12 Wideband satellite passes, one file each. Each file, in time, starts with a header block four records long, followed by up to 45 data blocks. The formats of these records are outlined in Table 7, using the same notations used in Fremouw et al. [1978].
FIGURE 5 WIDEBAND SUMMARY TAPE FILE AND RECORD STRUCTURE
<table>
<thead>
<tr>
<th>Record</th>
<th>Format</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20A2</td>
<td>Station label</td>
</tr>
<tr>
<td>2</td>
<td>20A2</td>
<td>Blanks</td>
</tr>
<tr>
<td>3</td>
<td>3F10.4</td>
<td>Data detrend period (seconds, = 10 for Wideband)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Year modulo 100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Station number (1 = Poker Flat, 2 = Stanford, 3 = Ancon, 4 = Kwajalein)</td>
</tr>
<tr>
<td>4</td>
<td>2(13,412)</td>
<td>Day, Hour, Minute, Second, Millisecond</td>
</tr>
</tbody>
</table>

**20-SECOND SUMMARY BLOCKS (Up to 45 per Pass Following Header Section)**

<table>
<thead>
<tr>
<th>Record</th>
<th>Format</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>212,13,4E2</td>
<td>Current data point counter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total point counter in pass</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Day, Hour, Minute, Second, Millisecond</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Current time, center of 20-second segment</td>
</tr>
</tbody>
</table>

Note: Termination of the pass is indicated by all -1s in this record.

<table>
<thead>
<tr>
<th>Record</th>
<th>Format</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>212</td>
<td>Channel identifier</td>
</tr>
<tr>
<td></td>
<td></td>
<td>= 1, 137.6748</td>
</tr>
<tr>
<td></td>
<td></td>
<td>All stations</td>
</tr>
<tr>
<td>3</td>
<td>10F10.4</td>
<td>Intensity (relative)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sample 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Phase (rad)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sample 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intensity Phase</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sample 5</td>
</tr>
<tr>
<td>4</td>
<td>10F10.4</td>
<td>As record 3, samples 6-10</td>
</tr>
<tr>
<td>5</td>
<td>10F10.4</td>
<td>As record 3, samples 11-15</td>
</tr>
<tr>
<td>6</td>
<td>10F10.4</td>
<td>As record 3, samples 16-20</td>
</tr>
<tr>
<td>7</td>
<td>9F10.4</td>
<td>S4 intensity scintillation index</td>
</tr>
<tr>
<td></td>
<td></td>
<td>rms phase deviation (rad)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sample 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>VHF intensity and phase trends, i.e., components &lt; 0.1 Hz, 1 Hz sampling rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sample 2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Statistics for VHF intensity and phase scintillation components, i.e., &gt; 0.1 Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sample 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sample 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sample 5</td>
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</tbody>
</table>

Statistics for VHF intensity and phase scintillation components, i.e., > 0.1 Hz
Table 7 (Continued)

<table>
<thead>
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<th>Record</th>
<th>Format</th>
<th>Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>9F10.4</td>
<td>rms least-squares cubic fit to intensity spectrum, 0.2 to 5.0 Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spectral slope of intensity 0 to 5 Hz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Spectral strength of intensity (dB mks units)*</td>
</tr>
<tr>
<td>8</td>
<td>212</td>
<td>Channel identifier = 2, 413.0244 west, Poker Flat, Kwajalein</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Channel identifier = 3, 413.0244 east, Ancon</td>
</tr>
<tr>
<td>9-12</td>
<td>10F10.4</td>
<td>As records 3-6, trend components</td>
</tr>
<tr>
<td>13</td>
<td>9F10.4</td>
<td>As record 7, statistics</td>
</tr>
<tr>
<td>14</td>
<td>212</td>
<td>Channel identifier = 3, 413.0244 east, Poker Flat, Kwajalein</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Channel identifier = 5, 388.6057, Ancon</td>
</tr>
<tr>
<td>15-18</td>
<td>10F10.4</td>
<td>As records 3-6, trend components</td>
</tr>
<tr>
<td>19</td>
<td>9F10.4</td>
<td>As record 7, statistics</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>Channel identifier = 4, 413.0244 MHz south, Poker Flat, Kwajalein</td>
</tr>
<tr>
<td>21-24</td>
<td></td>
<td>Channel identifier = 6, 390.0786 MHz, Ancon</td>
</tr>
<tr>
<td>25</td>
<td></td>
<td>Channel identifier = 11, 447.4431 MHz, Stanford</td>
</tr>
<tr>
<td>26</td>
<td>212</td>
<td>Channel identifier = 5, 378.6057 MHz, Poker Flat, Kwajalein</td>
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<tr>
<td>27-30</td>
<td></td>
<td>Channel identifier = 8, 413.0244, Ancon</td>
</tr>
<tr>
<td>31</td>
<td></td>
<td>Channel identifier = 12, 1239.073, Stanford</td>
</tr>
<tr>
<td>32</td>
<td>212</td>
<td>Channel identifier = 8, 413.0255 MHz, Poker Flat, Kwajalein</td>
</tr>
<tr>
<td>33-36</td>
<td>10F10.4</td>
<td>Channel identifier = 10, 435.9702 MHz, Ancon</td>
</tr>
<tr>
<td>37</td>
<td>9F10.4</td>
<td>Channel identifier = 12, 1239.073 MHz, Stanford</td>
</tr>
<tr>
<td>38</td>
<td>212</td>
<td>Channel identifier = 11, 447.4431 MHz, Poker Flat, Kwajalein</td>
</tr>
<tr>
<td>39-42</td>
<td>10F10.4</td>
<td>Channel identifier = 12, 1239.073 MHz, All stations</td>
</tr>
<tr>
<td>43</td>
<td>9F10.4</td>
<td>Channel identifier = 12, 1239.073 MHz, Stanford</td>
</tr>
<tr>
<td>44</td>
<td>212</td>
<td>Channel identifier = 12, 1239.073 MHz, All stations</td>
</tr>
<tr>
<td>45-48</td>
<td>10F10.4</td>
<td>Channel identifier = 12, 1239.073 MHz, All stations</td>
</tr>
<tr>
<td>49</td>
<td>9F10.4</td>
<td>Channel identifier = 12, 1239.073 MHz, All stations</td>
</tr>
<tr>
<td>50</td>
<td>212</td>
<td>Channel identifier = 13, 2891.171 MHz, All stations</td>
</tr>
<tr>
<td>51-54</td>
<td>10F10.4</td>
<td>Channel identifier = 13, 2891.171 MHz, All stations</td>
</tr>
<tr>
<td>55</td>
<td>9F10.4</td>
<td>Channel identifier = 13, 2891.171 MHz, All stations</td>
</tr>
<tr>
<td>56</td>
<td>212</td>
<td>Satellite location identifier (= 20)</td>
</tr>
<tr>
<td>57</td>
<td>13F8.3</td>
<td>Azimuth angle, station to satellite (deg)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Elevation angle, station to satellite (deg)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Satellite latitude (deg, +N)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Satellite longitude (deg, ±E)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Satellite height (km)</td>
</tr>
</tbody>
</table>

*On early tapes, this parameter is the rms least-squares linear fit to the intensity spectrum 5 to 40 Hz.
Table 7 (Concluded)

<table>
<thead>
<tr>
<th>Record</th>
<th>Format</th>
<th>Parameter</th>
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<tbody>
<tr>
<td>58</td>
<td>212</td>
<td>E-region (110 km) penetration point identifier (= 21)</td>
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<tr>
<td></td>
<td></td>
<td>E-region (110 km) penetration point identifier (= 21)</td>
</tr>
<tr>
<td>59</td>
<td>13F8.3</td>
<td>Penetration point latitude (deg, +N)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Penetration point longitude (deg, +E)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Penetration point height (= 110 km)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Magnetic latitude (deg, +N)</td>
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<tr>
<td></td>
<td></td>
<td>L-shell</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dip angle (deg)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Magnetic azimuth (deg)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Zenith angle (deg)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Briggs-Furkin angle (deg)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reduced propagation range (km)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scan velocity, x component (km/s)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scan velocity, y component (km/s)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scan velocity, z component (km/s)</td>
</tr>
<tr>
<td>60</td>
<td>271</td>
<td>F-region (350 km) penetration point identifier (= 22)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>F-region (350 km) penetration point identifier (= 22)</td>
</tr>
<tr>
<td>61</td>
<td>13F8.3</td>
<td>As record 29, but for 350 km penetration altitude</td>
</tr>
</tbody>
</table>

Continued repeat of data block records 1-61 for up to 45 data blocks

Last record: 212,13,472  All -1s indicate end of pass
Appendix B

PUBLICATIONS RELATING TO WIDEBAND PROJECT

WIDEBAND SATELLITE (P76-5) PUBLICATIONS


WIDEBAND SATELLITE (P76-5) REPORTS


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ATTN: C3ISTCCS

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Atomic Energy
ATTN: Executive Assistant

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ATTN: C-650, G. Jones
3 cy ATTN: C-650, W. Heldig

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ATTN: B-10, J. Barna
ATTN: Code 480
ATTN: 101B
ATTN: Code 480, F. Dieter

Defense Communications Engineer Center
ATTN: Code R123
ATTN: Code R410, N. Jones

Defense Intelligence Agency
ATTN: DB-4C, E. O’Farrell
ATTN: HO-TR, J. Stewart
ATTN: DB, A. Wise
ATTN: DT-5
ATTN: DT-1B
ATTN: DC-7D, W. Wittig

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ATTN: STNA
ATTN: NATD
ATTN: NAFD
3 cy ATTN: RAAE
4 cy ATTN: TITL

Defense Technical Information Center
Cameron Station
12 cy ATTN: DD

Field Command
Defense Nuclear Agency
ATTN: FCPR

Field Command
Defense Nuclear Agency
Livermore Branch
ATTN: FCPR

Interservice Nuclear Weapons School
ATTN: TVT

Joint Chiefs of Staff
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ATTN: CJS, Evaluation Office

Joint Staff Tgt Planning Staff
ATTN: JLA
ATTN: JLTW-2

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Department of Defense
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WMCCS System Engineering Org
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U.S. Army Electronics R&D Command
ATTN: DELAS-EO, F. Miles

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Department of the Army
ATTN: ATC-0, W. Davies
ATTN: ATC-T, M. Capps

BMD Systems Command
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ATTN: DAMO-ROC

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U.S. Army Electronics R&D Command
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ATTN: DELHD-N-P
ATTN: DELHD-N-RB, R. Williams
ATTN: DELHD-I-TL, M. Uelner

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ATTN: CCC-CEC-CCO, W. Neudorff
ATTN: CCC-EMEO-PED, G. Lane

U.S. Army Communications Command
ATTN: CC-OPS-W, H. Wilson
ATTN: CC-OPS-W

U.S. Army Communications R&D Command
ATTN: DRDCO-COM-RY, W. Kesselman

U.S. Army Foreign Science & Tech Ctr
ATTN: DRXST-SO

U.S. Army Materiel Dev & Readiness Cmd
ATTN: DRCLDC, J. Bender

U.S. Army Missile Intelligence Agency
ATTN: J. Gamble
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U.S. Army Satellite Comm Agency
ATTN: Document Control

U.S. Army TRADOC Sys Analysis Actv
ATTN: ATAA-TDC
ATTN: ATAA-PL
ATTN: ATAA-TCC, F. Payan, Jr

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Naval Electronic Systems Command
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ATTN: PME-117-20
ATTN: PME-106-4, S. Kearney

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3cyATTN: Code 5324, W. Moler

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ATTN: Code 7500, B. Wald

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ATTN: OP 981N
ATTN: OP 941D

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ATTN: NSP-43
ATTN: NSP-2141
ATTN: NSP-2722, F. Wimberly

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ATTN: OPR, A. Stair
ATTN: PHP
ATTN: PHI, J. Buchau

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Air Force Systems Command
ATTN: SUL
ATTN: NTTC
ATTN: NTN

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ATTN: W. Hunt

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ATTN: L. Berry
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ATTN: M. Gantsweg
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ATTN: W. Wright
ATTN: C. Greifinger
ATTN: B. Gabbard
ATTN: R. Turco
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ATTN: E. Straker

Science Applications, Inc
ATTN: SZ

Science Applications, Inc
ATTN: J. Cockayne

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ATTN: A. Burns
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ATTN: R. Tsunoda
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ATTN: R. Leadabrand
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ATTN: G. Smith
ATTN: W. Jaye
ATTN: W. Chesnut
4 cy ATTN: B. Fair
4 cy ATTN: M. Cousins
4 cy ATTN: R. Livingston
10 cy ATTN: C. Rino

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