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In-House Report
October 1987

AIRBORNE MEASUREMENT OF LOW FREQUENCY ATMOSPHERIC NOISE ALFAN I

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John P. Turtle and Wayne I. Klemetti

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Atmospheric Noise
ALFAN I

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Essential airborne vlf/lf communication systems use long-wire transmitting antennas trailed behind high-flying aircraft. RF energy with a transverse magnetic polarization radiated by these antennas has been used in long-range communications. Recently, airborne systems have been upgraded and can receive transverse electric polarized waves. The range and connectivity of these communication systems are based on predictions from computer codes. Levels of atmospheric noise at aircraft altitude are predicted from models of lightning and ground-based measurements. Recent information on the amount of cloud-to-cloud lightning indicates the possibility that airborne noise level predictions may need to be revised. RADC Project ALFAN was devised to measure atmospheric noise from a balloon-borne antenna/receiver system. In this report, the system and first flight are described. Initial results are presented and discussed in terms of their possible implications for communication systems.

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Preface

The authors wish to thank Dr. A.C. Fraser-Smith and Mr. Paul McGill of the STARLAB at Stanford University for bringing the concept of a balloon-borne atmospheric noise receiver to a reality.

Appreciation is also expressed to Mr. Hans Laping and personnel of the Aerospace Instrumentation Division of AFGL for balloon instrumentation development and flight direction; Major Marvin Pershing and personnel from AFGL/Det 1 at Holloman AFB, N. Mex., for the perfect balloon flight operations; Mr. John Heckscher of the Ionospheric Physics Division at AFGL and Dr. Edward C. Field, Pacific Sierra Corp., for their valuable assistance in data interpretation.

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Airborne Measurement of Low Frequency Atmospheric Noise ALFAN I

1. INTRODUCTION

At very low and low frequencies (VLF/LF), electromagnetic waves propagate with relatively low attenuation in the waveguide bounded by the Earth's surface and the D-region of the ionosphere. In addition, propagation at these frequencies is known to be less prone to blackout during disturbed ionospheric conditions than at higher frequencies. Because of this, VLF and LF are extensively used in long range, survivable, military communication systems.

Conventional low-frequency systems use large, ground-based transmitter facilities with vertical antennas. These radiate energy with a transverse magnetic (TM) polarization. More recently, VLF/LF systems have been installed on aircraft using long trailing wire antennas.[1] During high speed flight, a significant portion of the antenna is horizontal and thus radiates energy with a transverse electric (TE) polarization.[2] As seen in Figure 1, the first order TM mode propagates with

(Received for Publication 13 October 1987)

1. Kossey, P.A., Lewis, E.A., and Field, E.C. (1982) Relative characteristics of TE/TM waves excited by airborne VLF/LF transmitters, in Medium, Long and Very Long Wave Propagation (at frequencies less than 3000 kHz), AGARD-CP-305, J.S. Belrose, Advisory Group for Aerospace Research and Development, NATO, ed., AD A113969, 305:19-1-19-10.

2. Lewis, E.A., and Harrison, R.P. (1975) Experimental Evidence of a Strong TE-Polarized Wave From an Airborne LF Transmitter, AFCRL-TR-75-0555, AD A019689.

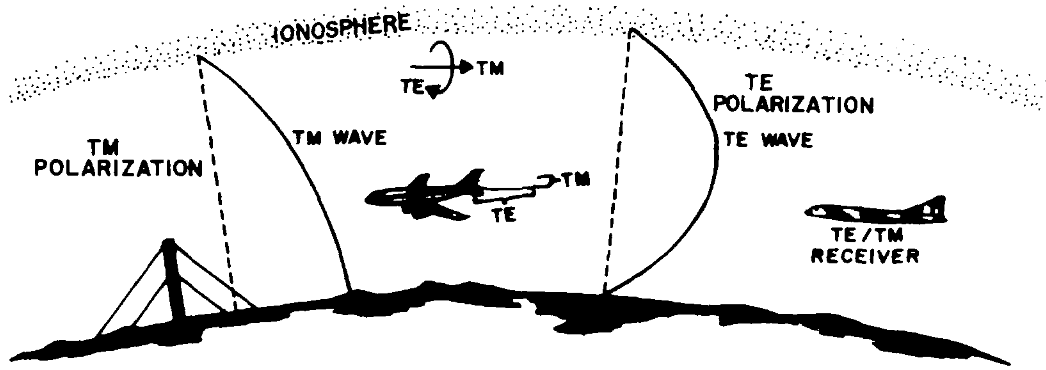

Figure 1. Transverse Magnetic (TM) and Transverse Electric (TE) Propagation (First-Order Mode)

a signal maximum on the ground and a minimum at the upper waveguide boundary, whereas the first-order TE mode propagates with a minimum at the waveguide boundaries and a maximum in the middle.[1] The TM mode is effective for ground-to-ground and air-to-ground communications, while the TE mode is useful for long-range air-to-air communications.[3] Because the conversion of energy from the TM to TE by the geomagnetic field is relatively inefficient, airborne TE communications are also less vulnerable to jamming from ground-based sources.

To utilize the advantages offered by the TE polarization, aircraft involved in military long-range survivable communications are being outfitted with polarization diversity receive capabilities. New receivers, such as the Miniature Receive Terminal (MRT) of the Minimum Essential Emergency Communication Network (MEECN), will be able to receive both polarizations, automatically using the best signal for essential communications.

The ratio of signal strengths to background atmospheric noise is critical to the coverage of communication systems. At VLF and LF, atmospheric noise is primarily caused by lightning. Extensive data exist on atmospheric noise at ground level. Based on these data, computer codes used in communication system planning and specification predict atmospheric noise strengths by propagating the noise from various sources to receiver locations. In these codes, it is assumed that the lightning source is vertical; thus, TE noise is predicted only from the conversion of TM by the effect of the geomagnetic field.

At present, predictions of atmospheric noise levels at aircraft altitudes rely on computer models based on ground-level measurements. Increasing information[4]

3. Hirst, G.C. (1975) U-2 investigations of a new mode for lf air-to-air communications, in Proc. AFSC 1975 Science and Engineering Symposium AFSC-TR-75-06 (Vol. 1), AD A021660.

4. Greifinger, C. (1985) Possible Importance of Horizontal Lightning Discharges as Sources of TE Noise at Elevated Terminals, R and D Associates, Marina Del Rey, Calif., DNA Report TR-85-386.

on the amount of inter-cloud and cloud-to-cloud lightning indicates that, at times, horizontal lightning may be a significant contributor to TE noise. TE noise from the combination of horizontal lightning sources and converted TM may be higher than predicted by codes presently used to specify coverage of airborne communication systems. Data on atmospheric noise measured from airborne receivers are required to evaluate the contribution of horizontal lightning sources.

2. PROJECT ALFAN (AIRBORNE LOW FREQUENCY ATMOSPHERIC NOISE)

In conjunction with the Defense Nuclear Agency and the ESD MEECN SPO, Project ALFAN was designed to determine levels of both TE and TM atmospheric noise using an airborne receiver supported by a free-floating balloon. Under RADC Contract F19628-84-K-0043, the Space, Telecommunications, and Radioscience Laboratory (STARLAB) at Stanford University developed a three-channel receiver with an octahedron-shaped antenna (shown in Figure 2) consisting of three orthogonal loop antennas 1.73 m on a side (2.44 m diagonal). The two vertical loops receive the horizontal magnetic field of the TM polarized wave and the horizontal loop antenna receives the vertical magnetic field of the TE polarized wave. Figure 3 shows a block diagram of the receiver. This receiver was integrated with a digital sampling system, a telemetry system for downlink data transmission, and an uplink, so that receiver functions could be changed by commands from the ground. A block diagram of the airborne and ground-based systems is shown in Figure 4. The specifications for the receiver and the data system are given in Table 1. As shown in Figure 2, the receiver, the control and telemetry systems, and the batteries were mounted on a horizontal "load-bar"; the antenna was suspended beneath the bar. The payload and antenna weighed about 850 lb. The flight configuration consisted of the payload instrumentation connected to a 60-ft-diameter recovery parachute that was, in turn, connected to a 335,000-ft^3 balloon. Balloon logistics and flight operations were conducted by the Aerospace Instrumentation Division of the Air Force Geophysics Laboratory.

3. FLIGHT

The first ALFAN flight took place on 4 August 1986. The balloon was launched at 0730 local time (1330 UT) from Roswell, New Mexico. It carried the payload to an altitude of 68,000 ft and floated at that altitude for about 5 hours. The flight was terminated at 1245 local time (1845 UT), and the payload parachuted to the ground in the vicinity of Alamogordo, New Mexico, approximately 75 miles west of the launch site. Figure 5 shows the balloon altitude during the flight, plotted as a function of time for the first 3-1/2 hr.

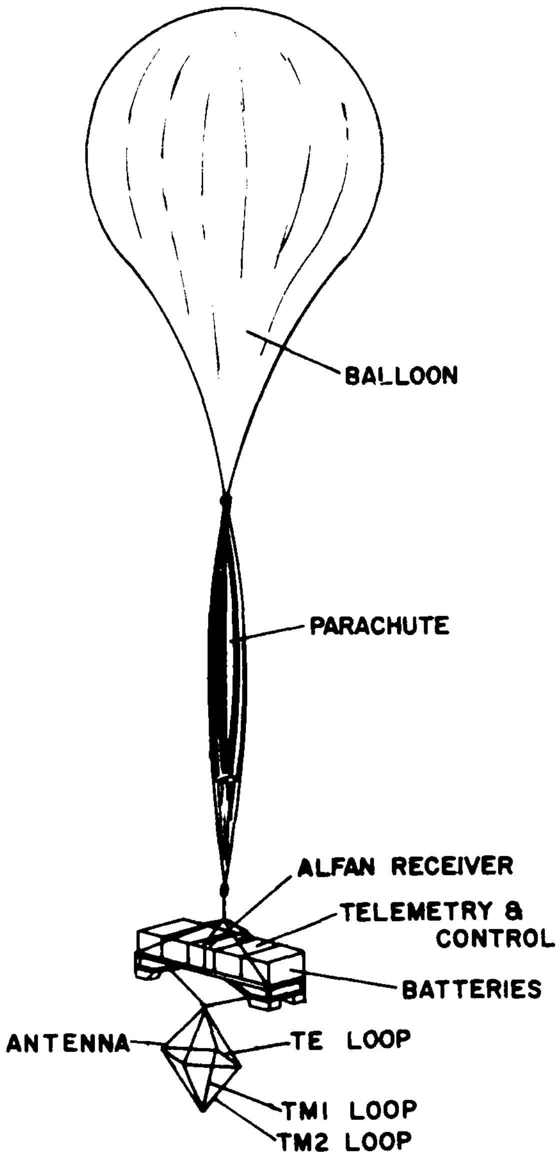

Figure 2. ALFAN Flight Configuration

The weather was clear in the vicinity of the launch site and remained so throughout the flight. Satellite photographs of cloud coverage as well as other meteorological records for the western half of the United States indicate that there was no thunderstorm activity within 300 to 400 miles of the balloon during the flight. The nearest activity was in central Texas and eastern Nebraska, particularly during the latter portions of the flight.

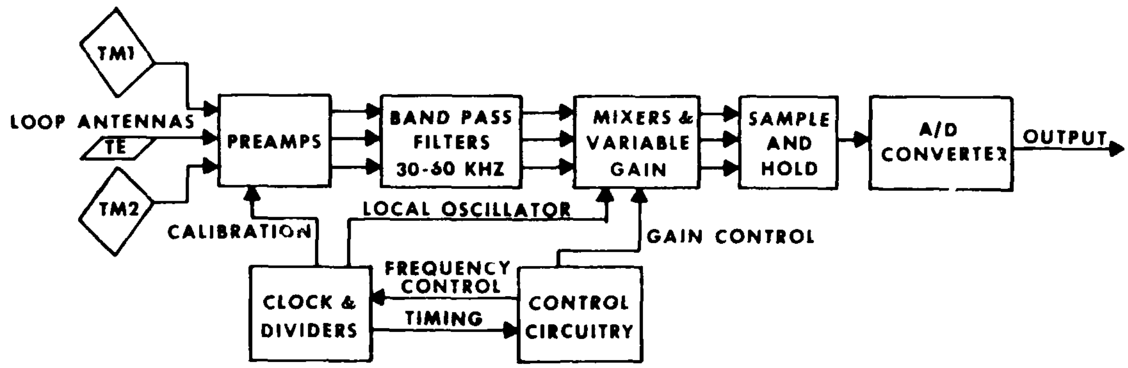

Figure 3. ALFAN Receiver Block Diagram

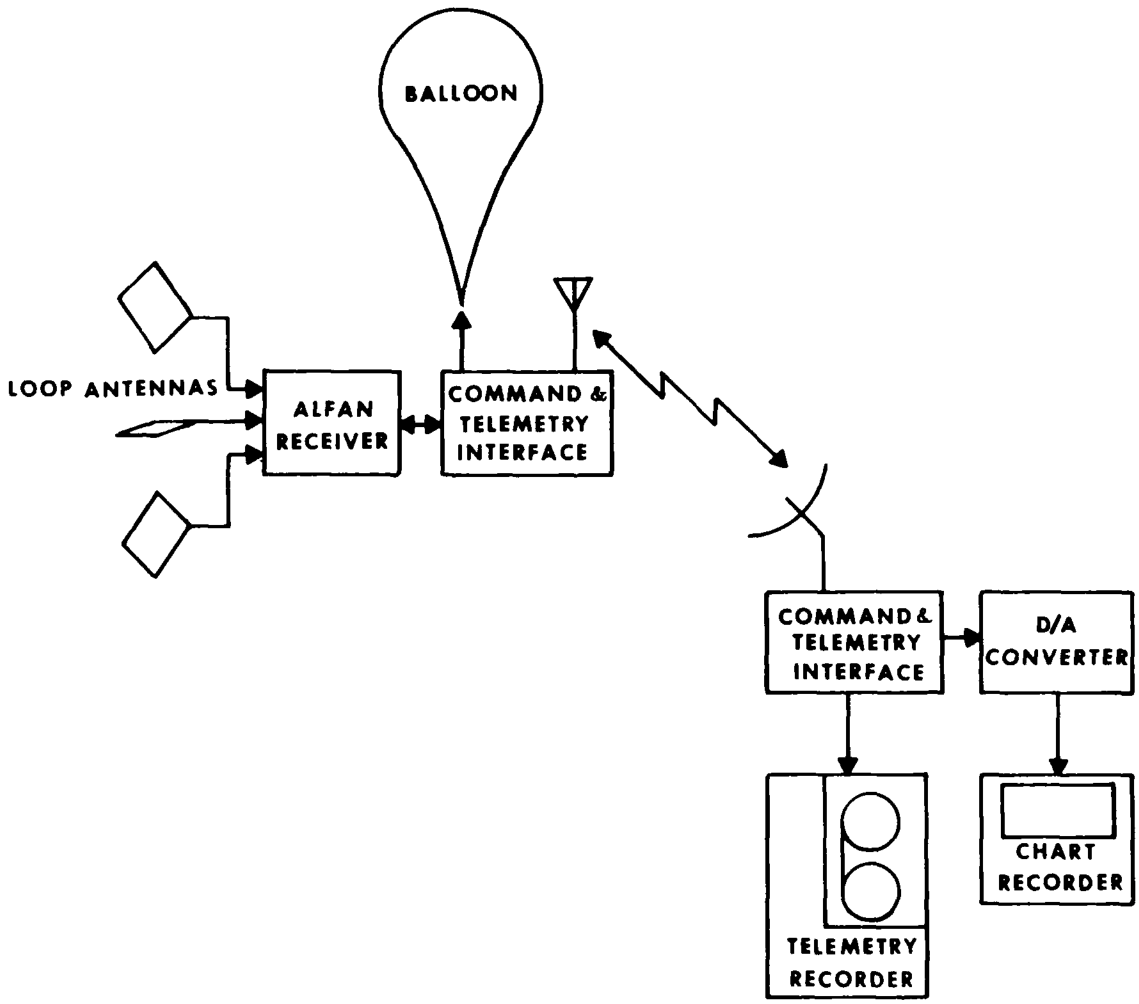

Figure 4. ALFAN Flight and Ground-Based Instrumentation

Table 1. Receiver Specifications

frequency range	30 - 60 kHz
bandwidth	1.5 kHz
remote tuning	100 Hz steps
antenna/preamp effective height	10 m
amplifier gain	0 dB, 20 dB, 40 dB, 60 dB
sampling rate	8 kHz
A/D conversion	12 bit
in flight calibration	1 mv/m RMS

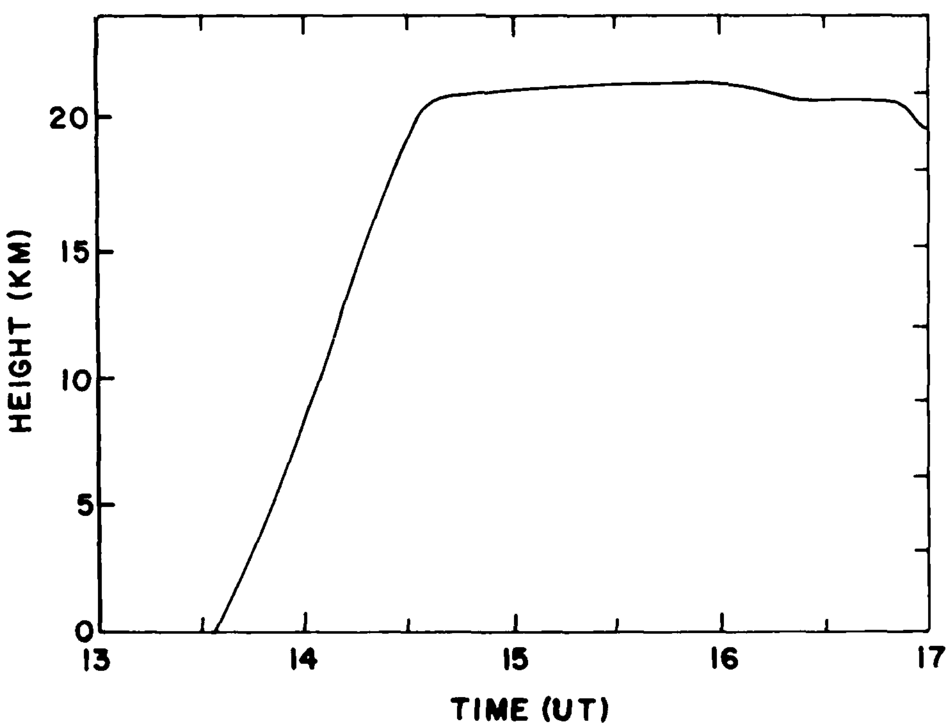

Figure 5. Balloon Altitude vs Time

4. DATA REDUCTION

The data recorded on high-speed PCM telemetry tapes were analyzed by both analog and digital processing techniques. Figure 6 gives a diagram of the steps involved in the reduction of the data from the flight.

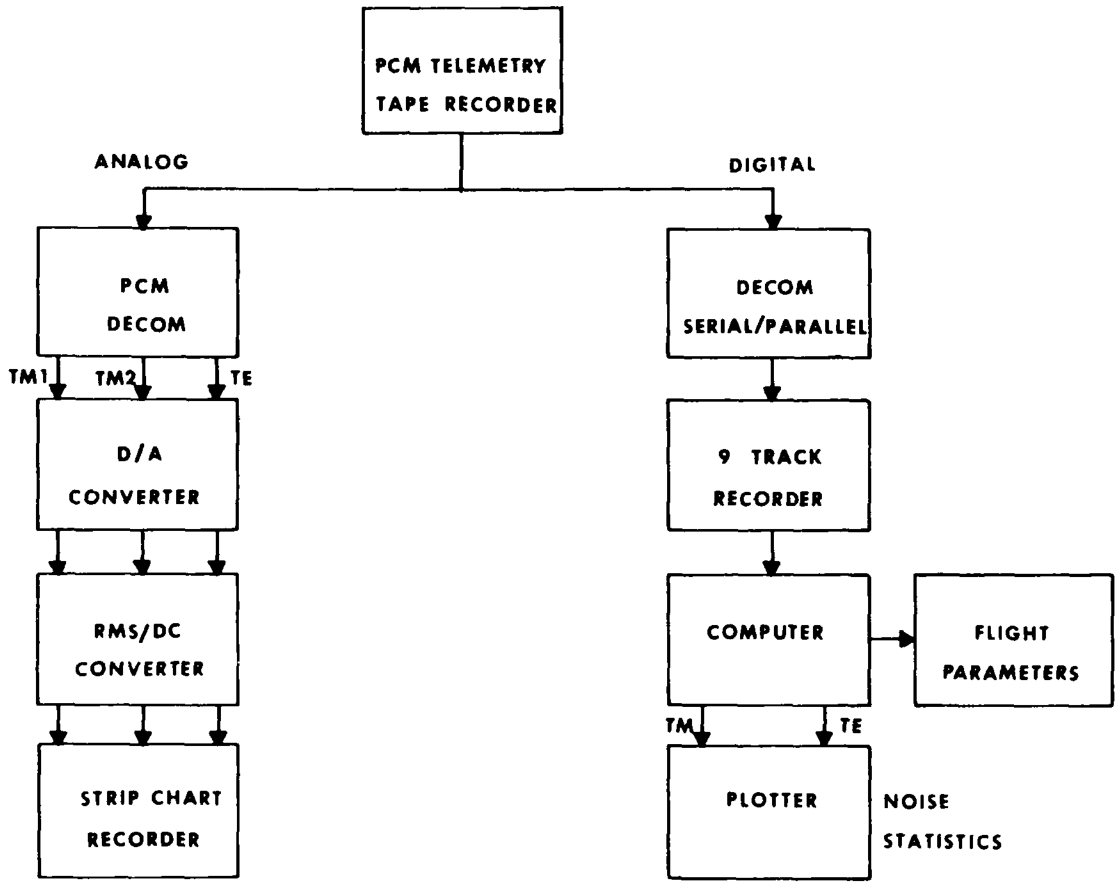

Figure 6. Data Analysis Flow Chart

4.1 Analog Processing Techniques

For direct analog analysis of the data, the tapes were read through a PCM decommutator to retrieve the data for the TE and the two TM receivers. After digital to analog conversion, the data passed through an RMS to DC converter. The output was recorded on a strip chart recorder, with one channel for each of the three receivers. Strip chart records were made of the signal data for the entire flight.

4.2 Digital Processing Techniques

For digital processing of the data, the telemetry tapes were first decommutated and converted from a serial to parallel format for computer processing. The data rate for the new digital tapes was the same as the sampling rate of the original data. From these tapes, computer plots of flight parameters including altitude and antenna azimuth orientation were obtained, along with plots of RMS signal levels for the three receivers.

5. DATA ANALYSIS

5.1 Analog Data Analysis—Ground-Based Transmitters

An important part of the data analysis was the determination of the antenna's attitude during the flight. Deviations of the TE loop antenna from horizontal, due to swinging, could result in contamination of the data with a component of TM signal. Although there was no direct means of determining whether the antenna was swinging, it can be inferred from the data. If the antenna were swinging, the TE data would show an oscillation resulting from varying amounts of TM contamination.

During the balloon ascent (about 1 hr), the receivers were alternately tuned between a ground-based transmitter (Silver Creek, 48.5 kHz) and atmospheric noise (42.5 kHz). The receivers were tuned to other ground-based transmitters after the balloon reached floating altitude. Figures 7 to 10 show the Silver Creek RMS signal received just before and after launch and at three altitudes: 8000 ft, 50,000 ft, and 68,000 ft (floating altitude). For each trace in Figures 7 to 10, the y-axis is linear receiver output voltage, and UT is plotted on the x-axis (about 4 minutes of data in each figure). The top trace, TE, is from the horizontal loop antenna and the lower two traces, TM1 and TM2, are from the two orthogonal vertical loop antennas. Because the TE signal was weaker than the two TM signals, the TE data was amplified by a factor of 5 before it was displayed on the strip chart recorder.

Before launch (Figure 7), the TE signal shows oscillations; the antenna was swinging slightly in the wind. Just after launch, the antenna was swinging wildly, as seen by the full-scale signal variations on the TE channel. The two TM signals are not affected by the swinging antenna. The more gradual variations seen in the TM channels are caused by the slow turning of the payload and antenna about the vertical axis. The figure-eight sensitivity pattern of the loops causes the TM signal levels to go from maximum to minimum as the antenna turns with respect to the azimuth direction of the ground-based transmitter. The signals from the orthogonal loop antennas are out of phase, the maximum of one coinciding with the

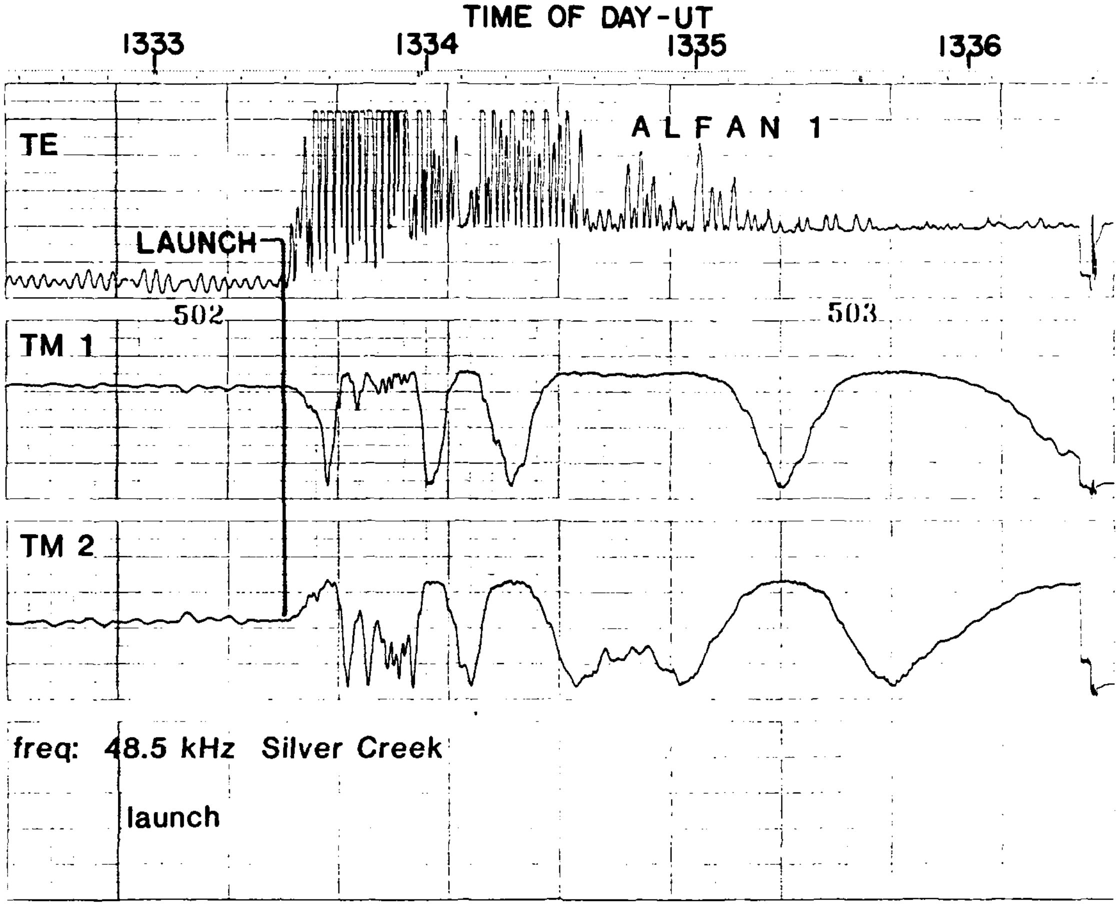

Figure 7. TE and TM Signals From Silver Creek lf Transmitter--at Launch

minimum of the other. The TE antenna, when horizontal, does not show effects of the turning.

Following the TE signal in Figures 7 to 9, it is evident that the antenna was swinging during the ascent part of the flight. The TE trace in each figure shows some degree of oscillation. However, in Figure 10, the TE trace shows no oscillations. These data were taken after the balloon had passed through the tropopause (at about 58,000 ft for this flight) and was floating in the stratosphere at about 68,000 ft. At float, the balloon is drifting horizontally at the same speed as the wind around it, there is little turbulence, and the payload and antenna are essentially motionless with respect to their surroundings.

Because the antenna was swinging during balloon ascent, the output of the TE loop was the vector sum of the true TE signal plus some varying amount of TM signal. The amplitude of the oscillation depends on the magnitude of the antenna swing, the direction of the swing with respect to that of the ground-based transmit-

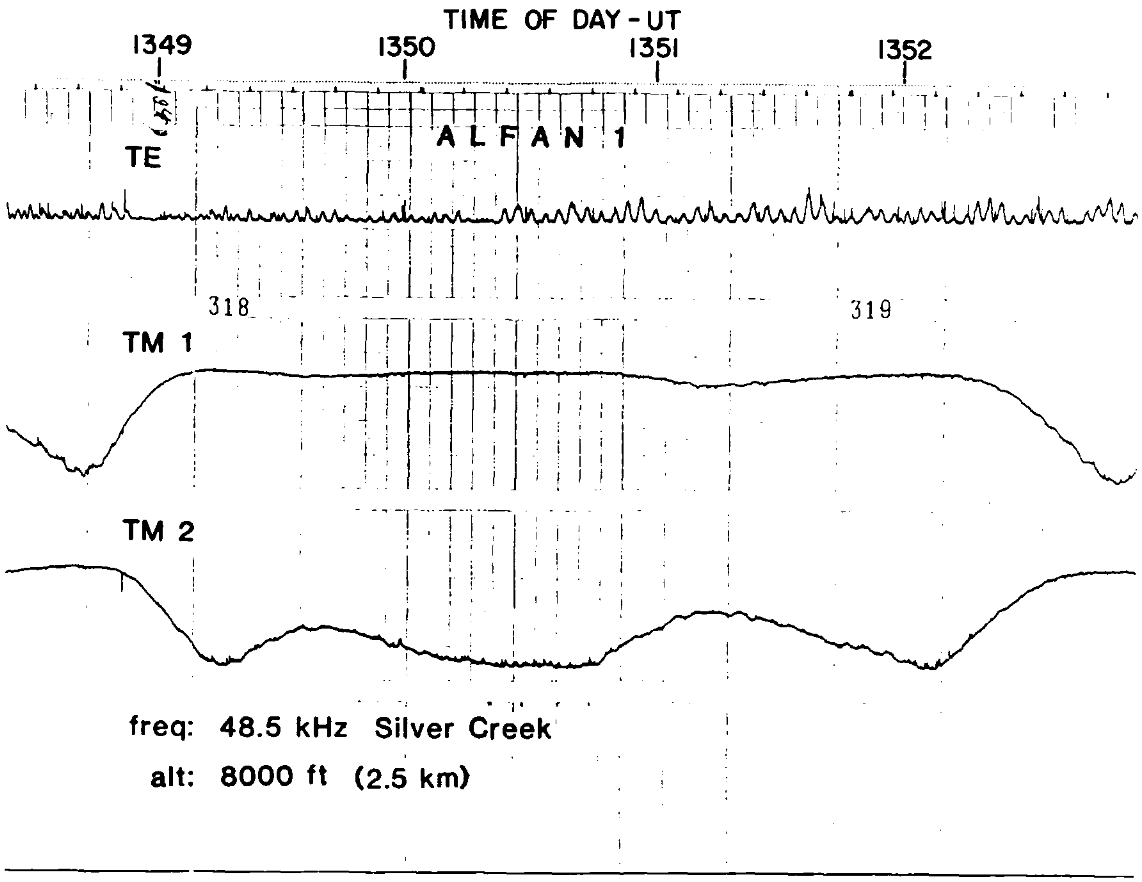

Figure 8. TE and TM Signals From Silver Creek lf Transmitter--at 8,000 ft

ter, and the phase relationship between the TE and TM signals. The true (uncontaminated) TE level evidently lies between the maximum and minimum of the oscillations. As mentioned earlier, the TE trace in Figures 7 to 10 has a gain factor of 5 compared to the TM traces; removing this gain difference would normalize the TE signal with respect to the TM signal, and the oscillations would be correspondingly smaller. In spite of the swinging antenna, it is clearly possible to identify the major TE and TM characteristics. Throughout the ascent, the TE and TM signals behave independently of each other; the TE signal shows an increase, and the TM shows a decrease. After floating altitude was reached, there was no evidence of any antenna motion, and the TE data are uncontaminated.

From the analog data processing, height profiles (Table 2) were obtained for the TM and TE signals from the Silver Creek transmitter. As is typical of first-order mode propagation (Figure 1), the TM signal starts out strong on the ground

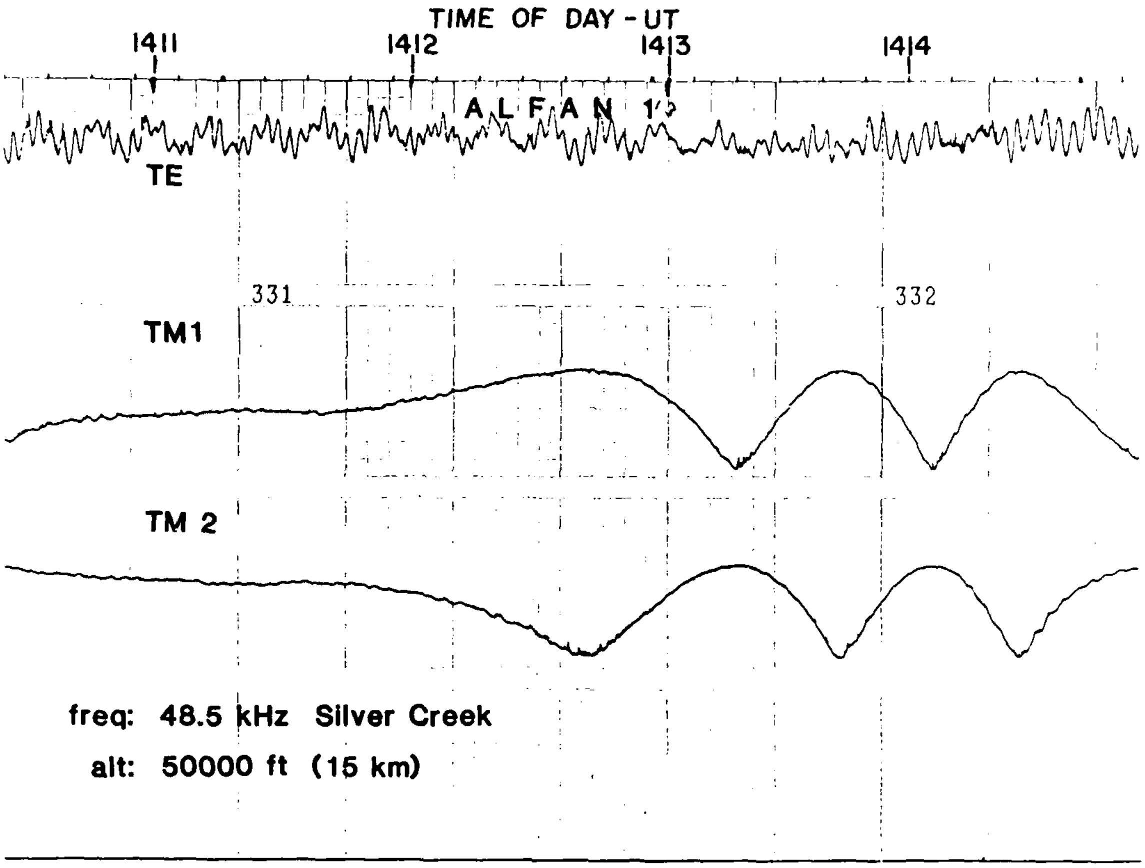

Figure 9. TE and TM Signals From Silver Creek LF Transmitter--at 50,000 ft

and decreases with altitude, whereas the TE signal is weak at ground level and increases with altitude.

The TE signal, between the measurements at ground and 3000 ft, shows a very large change. This change is seen in Figure 7 and appears to have occurred rather quickly after launch. The reason for some of this rapid change may, in part, be due to interference effects between the horizontal TE antenna and its image when within one or two loop diameters of the ground. After this initial increase, the TE signal shows a more gradual increase as the balloon rose to 68,000 ft.

At floating altitude, the signals from other ground transmitters were recorded. Table 3 shows the TE/TM signal ratio and propagation distance for the three transmitters monitored during the flight. Because of its impulsiveness and wide dynamic range, scaling of the noise data on the analog charts was not practical. Therefore, information on atmospheric noise came from the digital processing.

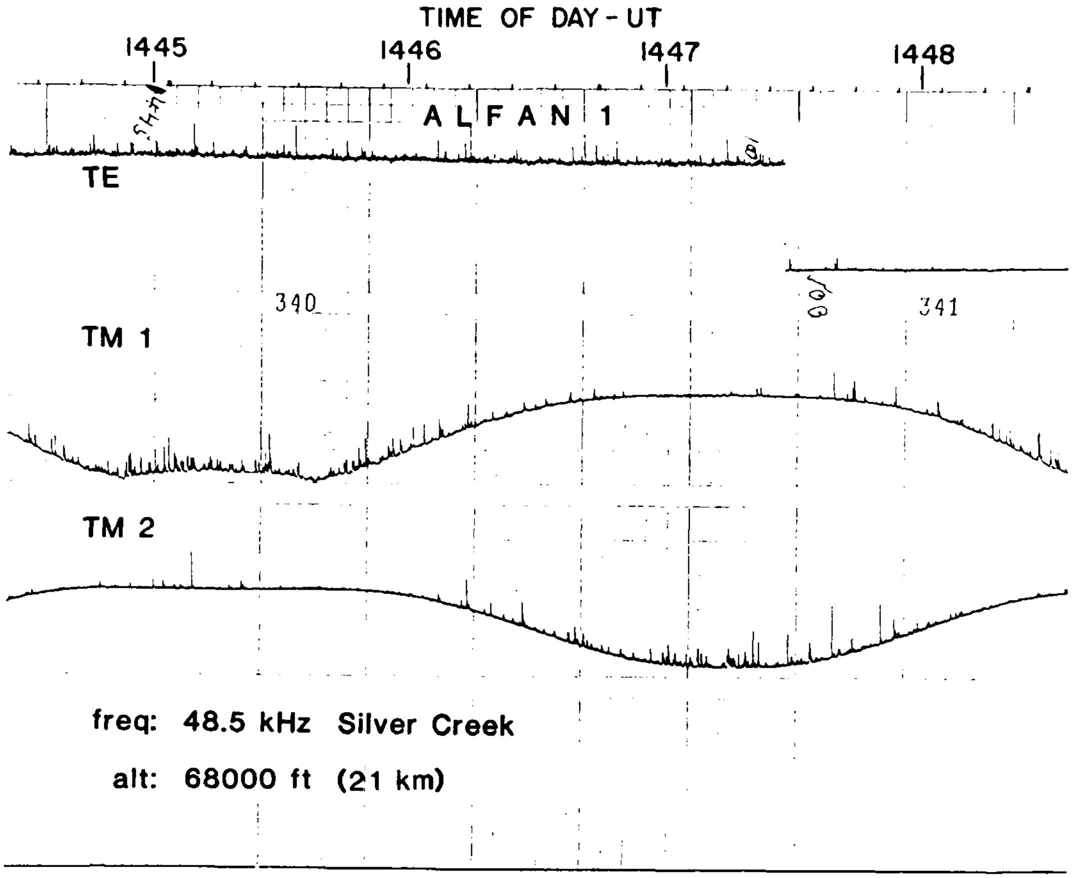

Figure 10. TE and TM Signals From Silver Creek LF Transmitter--at 68,000 ft, Floating Altitude

Table 2. Silver Creek, 48.5kHz, Signal vs Altitude (Amplitude in Relative Units)

Altitude (ft)	TM	TE	TE/TM ratio
0	350	4	-39 dB
3000	350	38	-19 dB
8000	330	44	-19 dB
50000	310	70	-13 dB
68000	270	77	-11 dB

Table 3. Ground-Based Transmitter TE/TM Ratio

Transmitter	Frequency	TE/TM	Distance
Hawes, Calif.	37.2 kHz	-3 dB	1125 km
Silver Creek, Nebr.	48.5 kHz	-11 dB	1125 km
Ft. Collins, Colo.	60.0 kHz	-17 dB	825 km

5.2 Digital Data Analysis—Atmospheric Noise at 42.5 kHz

As mentioned earlier, the analog outputs of the three receivers were sampled at a rate of 8.333 kHz and digitized with a 12-bit A/D converter. For this initial report, only RMS noise was calculated. Further analysis from this and other flights will yield noise statistics such as the Amplitude Probability Distribution (APD), the Time Probability Distribution (TPD), and the V(d) within the resolution of the data.

The horizontal loop is omnidirectional for TE signals. Thus, in order to compare TE noise levels with TM levels, an omnidirectional TM receive pattern was created by vector summing the signals from the two orthogonal TM loop antennas. For this report, the rms values of the TM and the TE signals were then calculated for each minute of the flight.

Figure 11 shows the computer processed RMS noise data for the first 3-1/2 hr of the flight for the combinted TM and the TE channel. The y-axis is linear in relative receiver output units, and the x-axis shows time in Universal Time (UT). (Balloon altitude was shown in Figure 5 using the same UT time scale on the x-axis.) The gaps in the data are times when the receiver was monitoring signals from the ground transmitters. As seen in Figure 11, the TM noise decreases somewhat, while the TE noise increases markedly. The ratio of the TE to TM noise levels in dB is plotted vs time in Figure 12, and, in Figure 13, this same ratio is plotted directly as a function of altitude.

Table 4 summarizes the TE and TM atmospheric noise data obtained during the flight.

6. DISCUSSION

This report is intended as a summary of the results of the first ALFAN balloon mission, a proof of concept flight to evaluate receiver capabilities and performance. The initial data presented here are the first measurement of atmos-

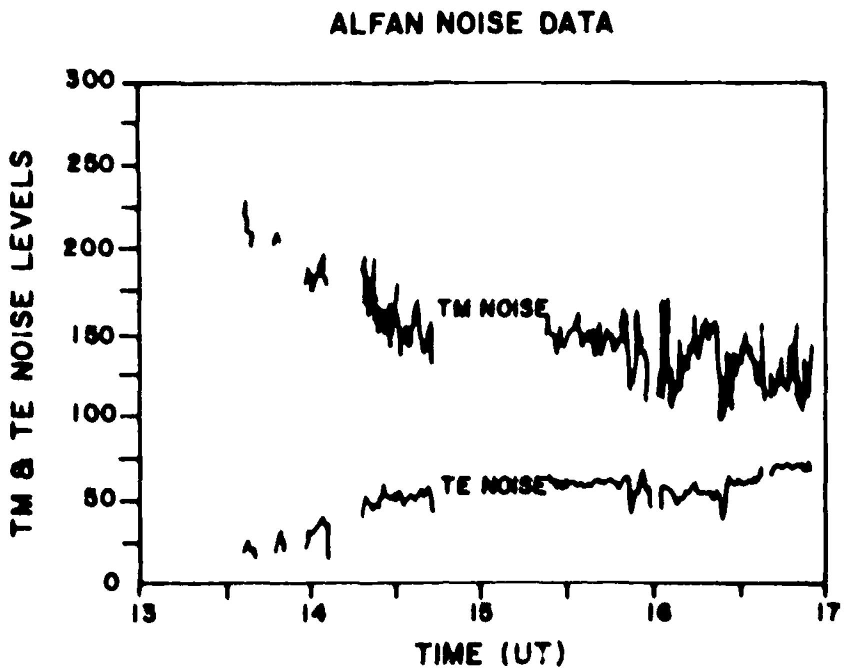

Figure 11. TE and TM Atmospheric Noise. RMS receiver output at 42.5kHz with 1.5kHz bandwidth

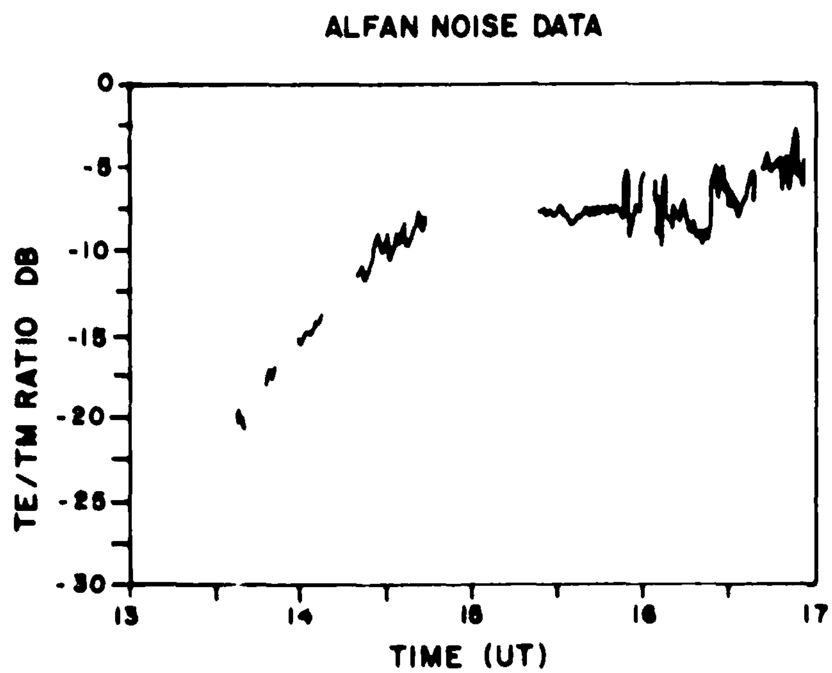

Figure 12. Ratio of TE to TM Atmospheric Noise During the Flight

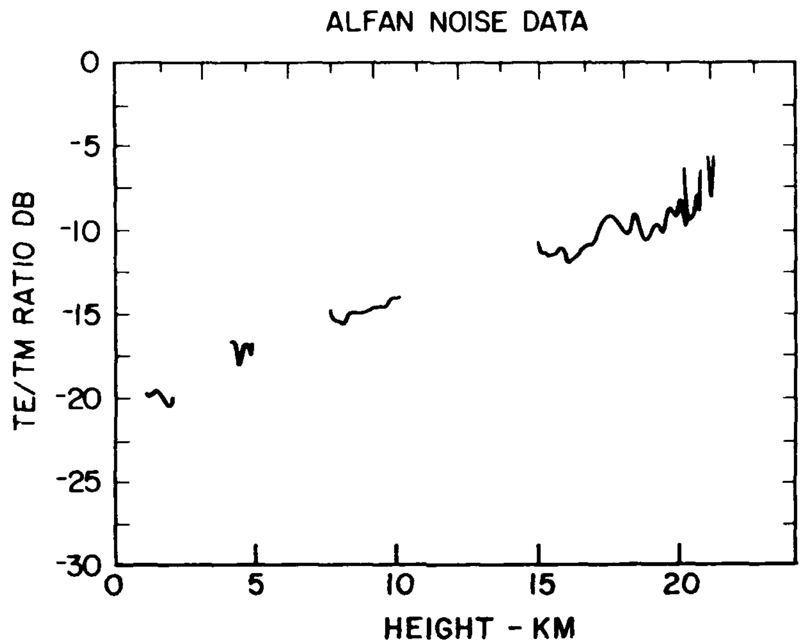

Figure 13. ALFAN Digital Data--TE to TM Noise Ratio vs Altitude

Table 4. TE/TM Noise Ratio vs Altitude

Altitude (ft)	TE	TM (RMS amplitude)	TE/TM (dB)
5000	20	210	-20.4
15000	28	203	-17.2
30000	32	184	-15.1
55000	46	170	-11.3
68000	55	145	-8.4

pheric noise for both the TE and TM polarizations from a "quiet" airborne platform.

The data from the measurements of the signals from the ground-based transmitters can be used to validate computer codes used for low-frequency propagation predictions. These transmitters have vertical antenna towers and thus radiate the TM polarization and no TE. The TE signals recorded during the balloon flight are a measurement of the conversion of TM to TE by the geomagnetic field. This is important in assessing the possibility that the converted signal from a strong ground transmitter could interfere with or jam TE mode transmissions.

The determination of the levels of atmospheric noise is the principal objective of the ALFAN project. The data (Figure 11) show that, as expected, the TE noise increases with altitude, while the TM decreases. Surprising, however, is the ratio of the TE to TM noise (Figures 12 and 13; Table 4). This ratio is as much as a factor of 2 larger than expected[1] at all altitudes. At least for this flight, the TE noise level appears to be relatively high. The flight took place during daylight hours, when conversion of TM to TE is expected to be low. A TE noise level higher than expected could mean that model predictions of the amount of daytime TM to TE conversion are too low or that there is a source of direct TE noise that must be taken into account.

It is inappropriate to draw general conclusions on TE and TM atmospheric noise levels based on the few data points from this first flight. Atmospheric noise is highly variable, and the TE noise recorded on ALFAN 1 may be sporadic. Future ALFAN flights are planned. Should they confirm the high level of TE noise, the implication for LF communications in the TE mode would be important.

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1. Kossey, P.A., Lewis, E.A., and Field, E.C. (1982) Relative characteristics of TE/TM waves excited by airborne VLF/LF transmitters, in Medium, Long and Very Long Wave Propagation (at frequencies less than 3000 kHz), AGARD-CP-305, J.S. Belrose, Advisory Group for Aerospace Research and Development, NATO, ed., AD A113969, 305:19-1 to 19-10.

2. Lewis, E.A., and Harrison, R.P. (1975) Experimental Evidence of a Strong TE-Polarized Wave From an Airborne LF Transmitter, AFCRL-TR-75-0555, AD A019689.

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