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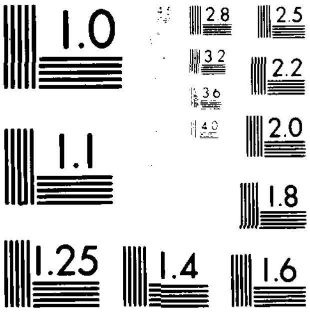

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**RADC-TR-81-235**
**In-House Report**
**August 1981**

# TM/TE POLARIZATION RATIOS IN A SAMPLE OF 30 kHz SFERICS RECEIVED AT ALTITUDES FROM 0 TO 70 km

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**ROME AIR DEVELOPMENT CENTER**
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A rocket-borne payload, carrying both vertical and horizontal magnetic dipole antennas and receiving instrumentation, was flown from Wallops Island, Virginia, to observe the Transverse Electric (TE) and Transverse Magnetic (TM) polarization components of individual sferics at 30 kHz. During the 2-1/2 min flight to apogee at 96 km, 293 individual sferics were observed. Upon applying corrections for difference in azimuthal antenna patterns, it was concluded that the TM noise fields were larger than the TE fields by about 15 dB near the ground, and approximately equal at 60 km.

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## Preface

The excellent support received from Mr. William Lord, Mr. Raymond Atkins, and the operational crews of NASA Wallops Flight Center, Wallops Island, Virginia is gratefully acknowledged. This work was supported jointly by RADC Project 4600 and by ESD/YSM under Project 616A.

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# TM/TE Polarization Ratios in a Sample of 30 kHz Sferics Received at Altitudes From 0 to 70 km

## 1. INTRODUCTION

Radio waves for Low Frequency (LF) communications are conventionally radiated from vertical antenna structures on the surface of the earth and, hence, the primary polarization is Transverse Magnetic (TM). Accordingly, most measurements of LF background noise have been made of the TM polarization. It has now become practical to radiate LF waves from long antenna-wires trailed behind high-altitude aircraft. Since these antennas tend to be more horizontal than vertical, the radiated fields tend to be predominantly in the Transverse Electric (TE) polarization. In view of the possibility of air-to-air communication using TE polarization, it is of interest to explore the noise environment in that polarization relative to that in the conventional TM. The ratio of TM to TE noise depends on the altitude of the receiving antenna, the altitude and orientation of the lightning strokes responsible for the noise bursts, as well as many other factors, so that direct experimental measurements are required over a range of altitudes, frequencies, times, seasons, and locations. To provide such information in a degree of completeness approaching that of noise-data for the earth's surface would be a large undertaking. This report presents data from a small noise-sample from one rocket flight from 0 to 96 km altitude with an ascent time of 165 sec.

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(Received for publication 12 August 1981)

The measurement of atmospheric noise with simple payloads presents problems in noise identification and, hence, also in credibility. For example, if the payload simply measured receiver output power, this might inadvertently include contributions from man-made transmissions as well as any radio noise generated by the rocket and its electrical equipment (see Section 4). To avoid this difficulty, the experiment was designed to detect and measure individual sferics, thus providing relatively reliable data for a limited sample. A much more sophisticated approach would have been required to provide equally reliable data on the numerous small sferics which constitute the quasi-continuous background noise from worldwide thunderstorm activity.

## 2. ROCKET FLIGHT OF 24 JULY 1979

On this date, at 1555 UT (1155 LT), a low frequency rocket payload was launched from the NASA Wallops Flight Center, Wallops Island, Virginia (Lat. 37.84°N, Long. 75.48°W) to measure the ratio of TM to TE signal strength for received individual sferic noise pulses. The 11-lb payload, carried by a Super ARCAS rocket, provided data across the entire low-frequency waveguide formed by the earth and the lower ionosphere. The rocket was launched at an azimuth of 100° and and elevation angle of 80° and penetrated the daytime ionosphere to a height well above the reflection level for low-frequency waves. Meteorological information indicated that there was thunderstorm activity in the eastern US at the time of launch, but the principal source of sferic noise was most likely in the Caribbean region. Since the area within 7000 km of Wallops Island was in daylight, it is probable in any case, that the sferics propagation paths were under daytime conditions with little polarization conversion.

## 3. INSTRUMENTATION

The rocket payload was designed with two separate receiving channels to measure the TE and TM components of an incident wave. The receiving antennas, shown in Figure 1, consist of 1/2 in.-diameter ferrite cores with 200 turns of No. 24 wire. Because of space limitations in the payload (diameter = 4 in.), the TM antenna uses two 3-in. horizontally mounted, ferrite cores with the turns connected in series; whereas the TE antenna, mounted vertically, has one continuous 10-in. length of ferrite. A fiber-glass nosecone covers the antennas during flight. The difference in physical length and sensitivity between the two antennas is accounted for in the laboratory calibration procedure in which the payload was placed in a

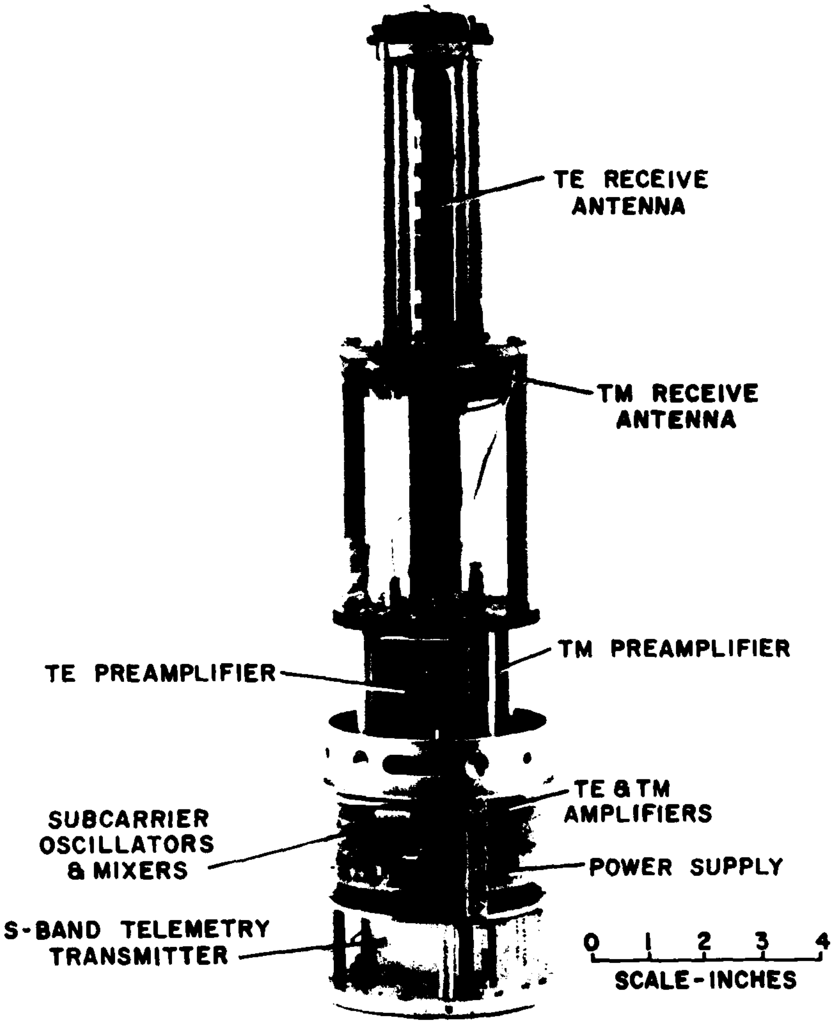

Figure 1. Payload, Showing Major Components

radio frequency magnetic field of known strength. Since the axis of the TE antenna was off-vertical by 10° inflight, the response to the vertical magnetic field of a sferic was less than the laboratory sensitivity by a factor of cos 10°, or 0.13 dB, and was the same for sferics from all azimuths. If the rocket axis had been vertical, the figure-of-eight pattern of the TM antenna would be swept around the horizon as the rocket spun at its 23 revolutions per second rate. With the rocket axis 10° off-vertical, the average effect may be illustrated by considering three cases: (a) The horizontal magnetic field of the sferic is perpendicular to the vertical plane containing the tilt axis, (b) The horizontal magnetic field is parallel to that vertical plane, and (c) The horizontal magnetic field is 45° from the plane. The geometric calculations for these cases do not warrant a description here, but it may be shown that the average antenna sensitivities in these cases are less than the maximum value by the factors 0.637, 0.627, and 0.632 respectively. The average value for the three cases is 0.632 or -3.99 dB. Thus in comparing the TM and TE antenna voltages, the former must be increased by an average 3.99 - 0.13 = 3.86 dB to correspond to the average TM/TE ratios of the radiation fields.

It is to be noted that with the 10° axis tilt, the TE antenna has a sin 10° or -15.2 dB response to TM waves propagating perpendicularly to the plane of the trajectory. The corresponding figure for an azimuthally uniform distribution of directions would be about -19 dB, and if the TM/TE ratio were much greater than 19 dB this simple instrumentation would not be capable of measuring it.

Figure 2 is a block diagram of the payload instrumentation. Each antenna is connected to a high-gain (10-60 kHz) amplifier which frequency modulates a separate sub-carrier oscillator. The two sub-carrier signals are then mixed together to form a composite signal which is telemetered to the ground through a 2-W, S-Band (2251.2 MHz) transmitter and its associated slot antenna.

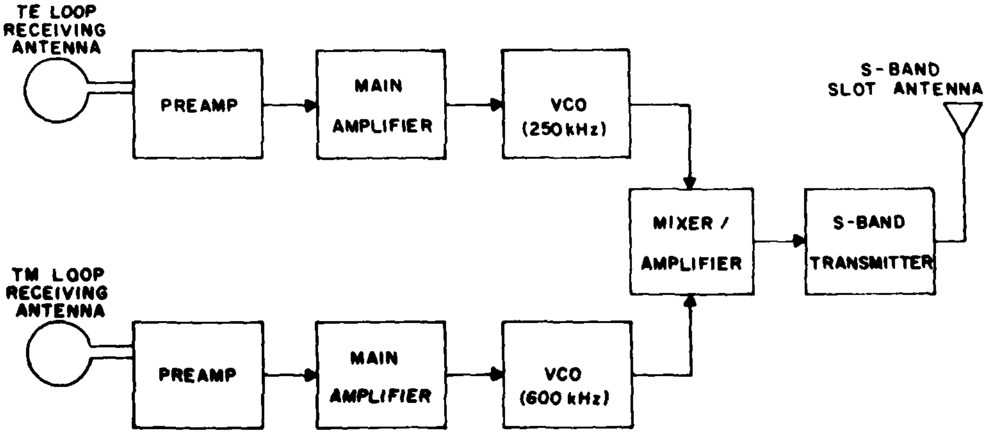

Figure 2. Block Diagram of TE and TM Channels in the Payload

The telemetry receiving system and associated ground-based instrumentation is shown in Figure 3. The telemetry tracking antenna has a gain of 39 dB at S-Band, providing adequate signal from the rocket payloads during the entire flight. The video output of the telemetry receiver is the original sub-carrier composite as transmitted from the rocket which is filtered and processed through FM discriminators to recover the original radio frequency noise in the TE and TM channels. These voltages are recorded on separate analog tracks with a HP3960 instrumentation recorder, preserving the original 10- to 60-kHz bandwidths. This allows post-flight processing to be done in different ways depending on the study requirements. For this particular study, noise at 30 kHz was selected by playing back the tape-recorded radio-frequency data through receivers (Singer NM-12) operating with 1500 Hz bandwidths. The IF output of each receiver was full-wave detected and run through a low-pass filter to a strip-chart recorder (Gould MK220) whose stylus deflection responding from DC to 40 Hz gave a comparison-measure of quasi-average amplitude spectral density.

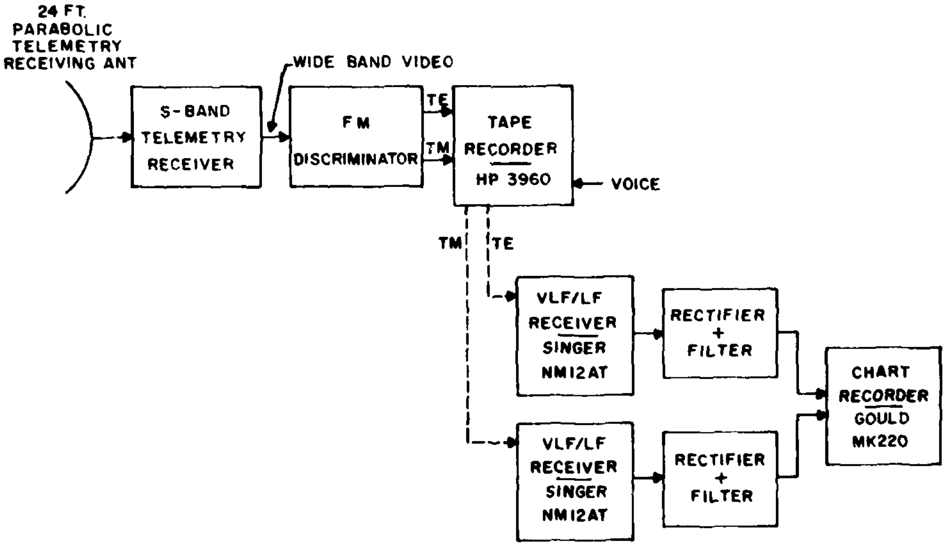

Figure 3. Block Diagram of Ground Equipment

## 4. TM/TE RATIOS

Strip-charts of the 30 kHz noise in the TM and TE channels are shown in Figure 4 which covers the entire time period from rocket-launch to entering the lower ionosphere at about 75-km altitude. In this display, large sferics appear as individual impulses. The TE trace shows a dense and increasing noise, particularly during the period from about 20 to 30 sec. Since this noise faded at about the time of rocket motor burnout, it was probably not due to sferics: a conclusion supported by oscilloscopic examination. Accordingly, this 10-sec portion of the data was excluded. For numerical analysis a faster chart speed was used. Figure 5 shows a typical 10-sec (40-50sec) sample of the fast chart. Coincident impulses in the TM and TE channels are readily identified, and these are assumed to have originated from the same lightning discharge. The relative amplitudes of TM and TE impulses were read manually and their ratios, converted to decibels, were averaged for the altitude ranges listed in Table 1.

The last column of the table gives the average values, including the 3.65 dB antenna response adjustment factor discussed in Section 3. For the first altitude range (0-2.3 km) the TM channel contained 46 impulses large enough to have their amplitudes read above the general background noise. Of these, only 30 had matching impulses in the TE channel which were large enough to measure. The remaining 16 were too small to measure so instead they were assigned upper bounds which means that the resulting TM/TE ratio (14.7 dB in this case) represents a lower bound. Since the actual ratio must have been larger, this is indicated by the > sign in the last column of the table. A similar situation occurred in the other altitude ranges up to 28 km. In the range 28 - 35 km there were 35 measurable impulses in the TE channel but only 34 in the TM channel. The one unmeasurable deflection in the TM channel was given an upper bound, resulting in an average for the interval which is too high; but probably only slightly so. A similar situation appeared in the altitude range of 49 - 63 km, while in the 35 - 49 range one member was unmeasurable in each channel so that the average ratio could be (slightly) larger or smaller. The ratios in Table 1 are shown graphically in Figure 6, which also shows an arbitrary curve which approximates the trend of the data points. Horizontal lines attached to the points in Figure 6 indicate directions corresponding to the < and > signs in Table 1. The length of these lines is proportional to the fraction of 'unmeasurable' sferics in each altitude range.

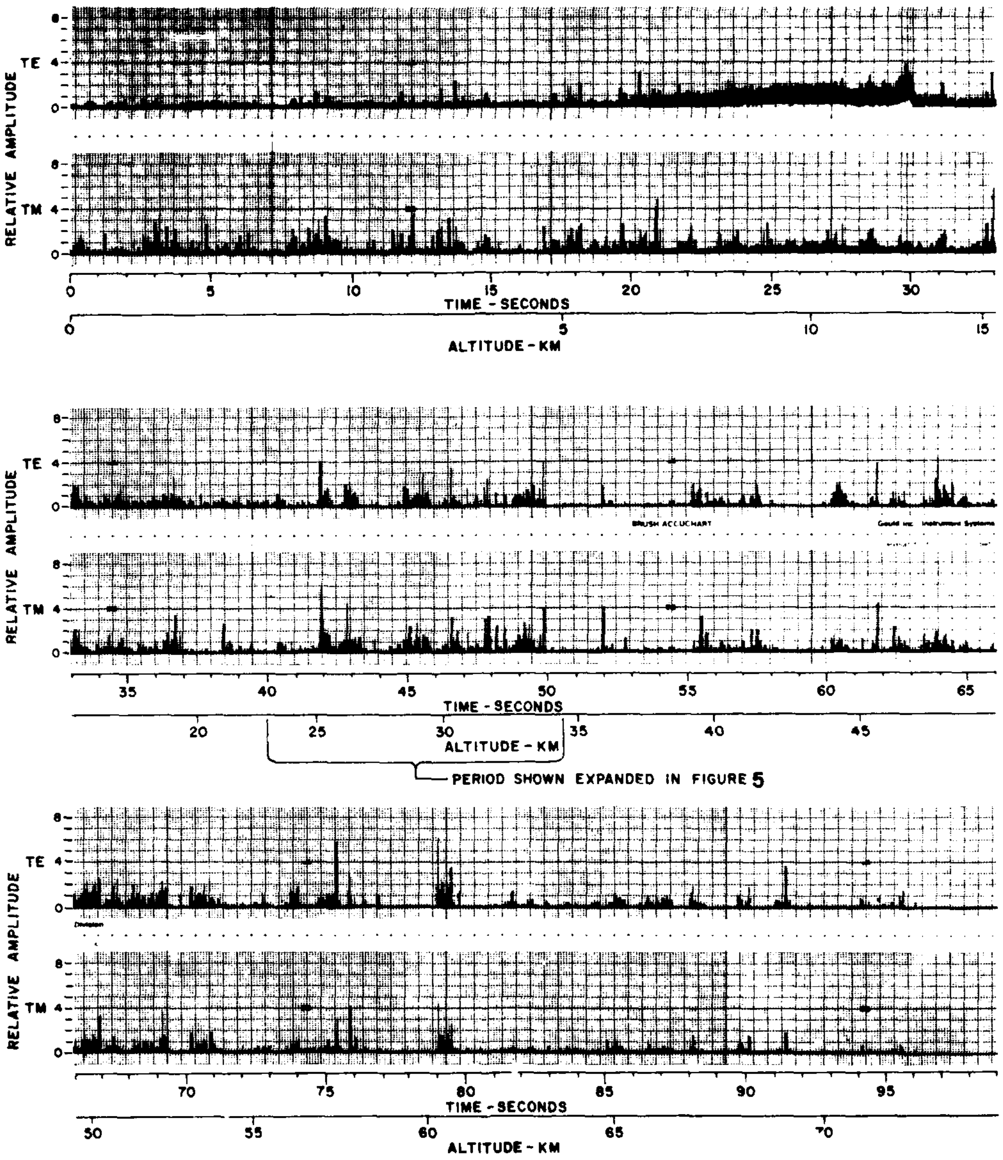

Figure 4. Slow-Speed Strip Chart of the Flight Data

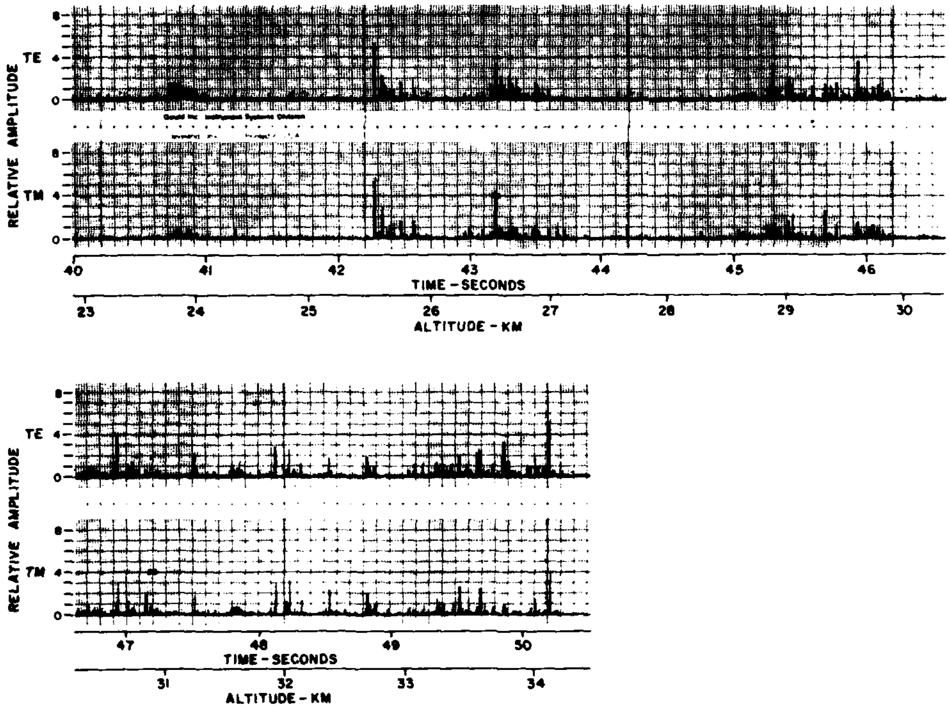

Figure 5. Portion of Fast-Speed Strip Chart Recording

Table 1. Data Summary

| Altitude Range (km) | TM Sferics | | TE Sferics | | Average Ratio (TM/TE) (dB) |
|---|---|---|---|---|---|
| | Measurable | Not Measurable | Measurable | Not Measurable | |
| 0 - 2.3 | 46 | 0 | 30 | 16 | > 14.8 |
| 2.3 - 7.0 | 35 | 0 | 29 | 6 | > 11.6 |
| 14 - 21 | 50 | 0 | 48 | 2 | > 7.4 |
| 21 - 28 | 33 | 0 | 30 | 3 | > 8.1 |
| 28 - 35 | 34 | 1 | 35 | 0 | < 5.2 |
| 35 - 49 | 29 | 1 | 29 | 1 | ≷ 2.8 |
| 49 - 63 | 38 | 1 | 39 | 0 | < -0.2 |
| 63 - 73 | 25 | 0 | 25 | 0 | -0.5 |

**Total Number of Sferics Pairs = 293**

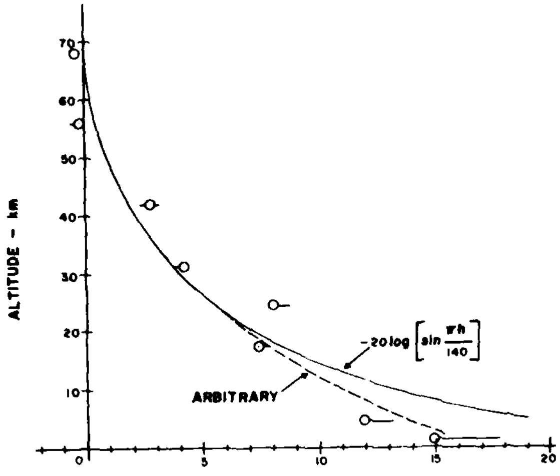

Figure 6. TM/TE Ratios From Table 1

## 5. DISCUSSION AND CONCLUSIONS

The data presented here represents only a very limited sample—a snapshot of the situation at one time and one place in the world. In this sample, the TM-polarized components of individual sferics were larger than the TE counterpart by about 15 dB near the ground, but were roughly equal around 60 km altitude. The data suggest that at low altitudes the ratio may be larger than 15 dB and may approach the estimated 19-dB limit of measurement imposed by the off-vertical tilt of the rocket axis (see Section 3).

If the simplest vertical profile of TM amplitude in a lossless earth-ionosphere waveguide is represented as being proportional to $\cos\pi h/140$ (where h is the altitude in kilometers) and if the simplest TE profile is represented by $\sin\pi h/70$, the ratio

$$\frac{TM}{TE} = K\frac{\cos\pi h/140}{\sin\pi h/70} = \frac{K}{2\sin\pi h/140} \qquad (1)$$

where K is a constant describing the relative amplitudes of the wave-patterns (K would depend on the orientation and altitude of the lightning currents and on the propagation distances). As a matter of interest, Eq. (1) is plotted in Figure 6 for the case K = 2 even though it represents a great over-simplification of the real situation and neglects any other modal patterns that might be present.

Propagation losses may cause the TE wave-patterns to attenuate with distance more rapidly than the TM patterns, although theoretical calculations[1,2] suggest that the difference is not great at 30-kHz frequency under normal daytime conditions. As mentioned in Section 1, the low-level background noise consists of many small sferics arriving over long propagation paths. To the extent that long-distance propagation might favor the TM polarization, it would be expected that the TM/TE ratio for the background noise might be even greater than for the large individual sferics which probably had shorter propagation paths. However, for nighttime propagation some of this TE advantage would be lost because of the "mixing" effects of polarization conversion in the ionosphere.

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1. Fields, F. (1976) Effects and Antenna Elevation and Inclination on VLF/LF Signal Structure, RADC-TR-76-375, AD A035510.
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