T58-3-1

ON THEORIES, EXTRAORDINARY WAVES AND ELEVATION ANGLES IN MEDIUM WAVE PROPAGATION

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1. INTRODUCTION

Lankford [1984b] contends that it is impossible for one scientific theory to refute another without some experimental evidence which agrees with one theory and disagrees with the other. He states that, since Seaver [1984] did not present any such experimental evidence, Lankford's theory has not been refuted.

My Webster's New Collegiate Dictionary defines the terms "theory" and "hypothesis" as follows:

Theory - A plausible or scientifically acceptable general principle or body of principles offered to explain phenomena.

Hypothesis - A tentative assumption made in order to draw out and test the logical or empirical consequences of a theory.

There are other definitions in other dictionaries, but I consider the above to be reasonable. Within this context, I believe that the "theories" that Lankford [1984b] attributes to himself and myself are really "hypotheses" and in my article I was careful to call them such.

The "Theory" of radio wave propagation that I believe in is the Magnetoionic Theory. It was initially developed by Sir Edward Appleton in the 1920's. Davies [1965] and other books present the derivation of the theory and the complete equations. The equations relate the complex refractive index of the ionosphere to the electron density, Earth's magnetic field characteristics, and to the electron collision rate at a given point in space and time. The equations can be integrated with distance to determine the ray path and the ionospheric absorption of radio waves at Medium Wave and Short Wave frequencies.

Sen and Wyller[1960] formulated the Generalized Magnetoionic Theory, which accounted for several factors that were oversimplified in the classical Appleton theory. Both theories account for the presence of the "ordinary" and "extraordinary" waves which occur when a wave enters the ionosphere.

Experimental data in the form of ionograms have verified the validity and application of the theories. Computer programs have been developed that calculate the ray path and absorption characteristics, assuming representative ionospheric electron densities, a model of the Earth's magnetic field, and an effective electron collision rate (e.g. Jones and Stephenson [1975]).

Since the Booker quartic equations, upon which Lankford [1984a] has chosen to base his studies, are derived from the classical Appleton Magnetoionic Equation, it is evident that Lankford also accepts the basic Theory extant in radio wave propagation. Therefore, Lankford and I seem to agree on the "theory" involved; the difference in opinion is on the "hypotheses" concerning Medium Wave propagation.

Based on medium wave field strength measurements gathered over many years, primarily by the CCIR (International Radio Consultative Committee, which includes the FCC and the BBC), and on the Magnetoionic theory, Knight [1975] has developed a model for Medium Wave field strength prediction. This was published in the 16 July 1984 DX News so that Medium Wave DXers can read a definitive work on Medium Wave propagation. It is clear that the hypotheses in Seaver [1984] agree with the Knight [1975] model, while Lankford's [1984a, 1984b] hypotheses do not agree entirely with the Knight [1975] model.

It is evident that Lankford has chosen to test the Magnetoionic theory and to try to investigate the extraordinary wave aspects of the theory and then to apply it to the study of Medium Wave propagation. However, Lankford [1984a] has not taken account of the influence of absorption at the reflection point (resulting in Equation (24) of Lankford [1984a] in his work). This assumption greatly simplifies the calculation of the critical

frequency at oblique elevation angles. It is my opinion that the inclusion of electron collisions (and therefore absorption) is necessary when considering medium wave propagation below the gyrofrequency, especially when critical E-region frequencies are being determined.

Lankford's [1984b] comments on Seaver [1984] dwell on two major themes; these are:

a) The existence of the "extraordinary" wave mode and its potential for oblique medium wave propagation

b) The elevation angle at which long distance medium wave signals arrive.

The basic difference of opinion, as I see it, is that Lankford does not believe that low angle "ordinary" waves refracted from the E region are viable. He believes that higher angle "extraordinary" waves at low (e.g. below 1100 khz) Medium Wave frequencies and "ordinary" waves at higher Medium Wave frequencies refracted from either the E- or the F region are responsible for long distance propagation. On the other hand, I believe that the "extraordinary" wave suffers high polarization coupling and absorption losses and is therefore weaker than the low angle "ordinary" wave, which is propagated over the entire Medium Wave frequency band via the E-region.

The following sections discuss Lankford's [1984b] comments in greater detail.

2. "EXTRAORDINARY" WAVES

There is certainly no "myth" about the extraordinary wave insofar as the Magnetoionic theory or my own beliefs are concerned. It's presence on the many available ionograms confirms the theory itself. That Appleton may have erred in the derivation of the values of the gyrofrequency or in the polarization equation (as pointed out by Lankford [1984b]) is not really germane to the discussion; those errors have long been corrected and the theory is unchallenged in radiophysics circles.

However, seeing "strong extraordinary traces" on vertical ionograms (quasi-longitudinal propagation along magnetic field lines in mid- and high latitudes) and hypothesizing that strong traces exist for oblique extraordinary quasi-transverse waves (nearly across magnetic field lines at mid- and high latitudes) is illogical - it's an "apples and oranges" situation.

The only "experimental" data of real value that Lankford [1984b] offers is the oblique incidence ionograms of Fenwick and Barry [1966]. Unfortunately, I don't have a copy of that paper. However, I do have a representation of the two oblique incidence ionograms from Lankford [1980] in Lankford's own hand, reproduced in Figures 1 and 2 (but without Lankford's notations).

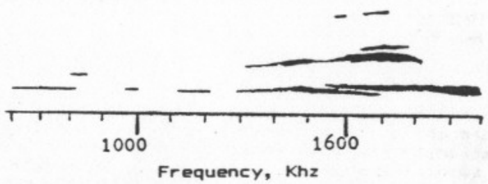


FIGURE 1.
(June 22, 1965, 0934 GMT)

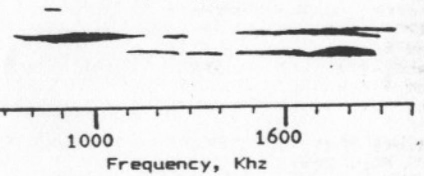


FIGURE 2.
(June 23, 1965, 0830 GMT)

This data was taken over a path from Stanford CA to Lubbock TX, a distance of about 2000 km, on two successive nights in 1965.

Figure 1 shows a trace from about 600 khz to about 2000 khz at one level, and a trace from about 1300 khz to 1800 khz at a second level, with some other traces of short extent. The lower trace has some breaks in it

T58-3-2

that may represent interference from local stations or short-term fade-outs at the instant the ionogram was taken. Fenwick and Barry apparently believe that these two major traces are one and two-hop "ordinary" traces showing refraction from the E-region. I agree with that conclusion. Lankford [1984b] does not indicate his belief on this ionogram one way or another. There do not appear to be any characteristic "extraordinary" wave traces on the ionogram of Figure 1.

Figure 2 shows a trace from about 1100 khz to 1900 khz at one level, and a trace from about 700 khz to 2000 khz at a second level, with one short trace at a third level. The two lower traces have some breaks. Fenwick and Barry apparently believe that the two major traces are one and two-hop "ordinary" traces showing refraction from the E-region. I agree with that conclusion. As Lankford [1984b] notes, the bottom trace starts at about 1100 khz; based on this, he hypothesizes that the second trace is an "extraordinary" wave trace below 1100 khz as the "only reasonable explanation".

I have another "reasonable explanation", totally consistent with the magnetoionic theory and my own hypothesis:

> "The lower trace starts at about 1100 khz because the E-region of the ionosphere was low enough to prevent the one-hop ordinary wave from being received over the distance below 1100 khz. Above 1100 khz, the one-hop wave was refracted from a slightly higher altitude that made reception possible."

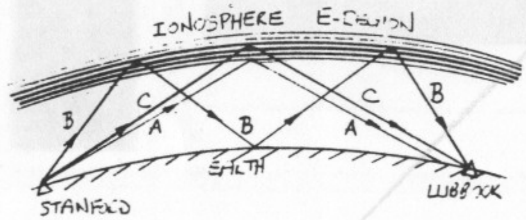
Figure 3 illustrates this situation. Curve A is a low frequency (e.g. 1000 khz) single-hop path that falls short of the Stanford to Lubbock distance with a zero degree elevation angle. Curve B is the two-hop path at this same frequency. Curve C is a higher frequency (e.g. 1200 khz) single-hop path at approximately a 1 degree elevation angle that is refracted from a higher altitude than curve A because it requires more electrons to be refracted back to Earth. Such a situation is probably quite common, especially in the early evening and in the summer months when there are more electrons produced in the E-region by solar illumination during the day.

FIGURE 3.

A. Low frequency, one hop, zero degrees.

B. Low frequency, two hops, 8 degrees

C. High frequency, one hop, 1 degree.



It is possible that a one-hop "extraordinary" wave could be received. What would an "extraordinary" wave trace look like on an ionogram? It should steadily increase in altitude (since it would be refracted from the 150-200 km altitude of the ionosphere) and should get gradually weaker due to the increasing absorption as it nears the gyrofrequency, disappearing between 1200-1500 khz due to very high absorption near the gyrofrequency. The second trace on Figure 2 extends across the frequency range (with some breaks) and is at nearly constant altitude, slightly increasing with increasing frequency. This would be characteristic of a two-hop "ordinary" wave trace, rather than a one-hop "extraordinary" trace.

I believe that my hypothesis, stated above, is more reasonable than is Lankford's hypothesis that the lower portion of the second trace is an "extraordinary" mode trace. If my hypothesis is correct (and it agrees with that of the researchers Fenwick and Barry), then Lankford has no apparent experimental data showing oblique "extraordinary" wave traces to support his hypothesis.

In summary, I do recognize that the extraordinary mode is possible, and that it will penetrate the E-region below the gyrofrequency. However, I believe that the polarization coupling loss, which is significantly greater for the extraordinary wave than for the ordinary wave, the high absorption loss of the extraordinary wave near the gyrofrequency, and the variability of the gyrofrequency over the Earth effectively precludes reception of the extraordinary mode on long-distance paths. I agree with the statement in Knight [1982]:

T58

> "At the gyromagnetic frequency, the extraordinary wave of the magneto-ionic theory is so greatly attenuated that it makes a negligible contribution to the received signal; furthermore the attenuation exhibits a broad maximum centred on the gyromagnetic frequency. As a consequence, the extraordinary wave can be disregarded for all practical purposes within the medium-frequency broadcasting band (approximately 550 to 1600 khz)."

3. ELEVATION ANGLES

The published data that Lankford [1984b] quotes concerning arrival angles of radio waves is for short wave frequencies. To take average arrival angles at short wave frequencies and to extrapolate the data to Medium Wave frequencies would not, in my opinion, be a valid use of the scientific method. A good statistician can make numbers tell whatever story he wants told! For instance, an "average" arrival angle for the stations I might receive over a certain frequency range (for example, the BCB) might well result in a 5-10 degree angle (since most of the frequencies are covered by stations within 1200 km or 750 miles) with a few down to 1 degree.

Short wave stations may have average angles in the range of 5-10 degrees for several reasons, such as:

a) Short wave antennas are usually targeted (using antenna height and directional patterns) for specific regions of the world, often within 3000 km or less, resulting in optimum elevation angles of 5-10 degrees.

b) The ground attenuation of low elevation angle waves increases significantly as the wave frequency is increased.

c) The E-region of the ionosphere can cut off very low elevation angle waves, but permits waves at higher elevation angles to pass through at short wave frequencies. This is especially true on multi-hop paths since the E-region peak electron density can vary widely over a long path.

d) The F-region of the ionosphere is not nearly as "spherical" as the E-region; on long paths, the short wave rays can be refracted from much different altitudes on each hop and can be deflected from a great circle path by ionospheric tilts, bulges and troughs in the F-region electron density along the ray path.

Lankford [1984b] quotes the Wilkins and Kift [1957] arrival angle data for a Ceylon to England path at 16 mhz and states the average angle was about 7 degrees, with 30% of the measurements below 5 degrees. Over this path, which is about 8600 km in length, and assuming a 300 km F-region virtual height, I estimate that a two-hop path would have an arrival angle of -2 degrees, a three-hop path would have an angle of 5 degrees, and a four-hop path would have an angle of 10 degrees. The average 7 degree angle quoted is very consistent with these estimates.

One piece of published evidence of low arrival angle Medium Wave propagation is provided in the oblique incidence ionograms of Fenwick and Barry [1966]. If, as Fenwick and Barry suggest (and I agree with), the traces are one and two-hop "ordinary" E-region modes, then the one-hop trace should have an angle in the 0-2 degree range (depending on frequency).

Other evidence can be found in the DX bulletins where thousands of receptions are reported each year, including paths over 10,000 km. What is required is a systematic study of field strengths of regularly heard stations, and then to correlate the average field strengths observed with the average field strengths estimated using the Knight [1975] wave-hop method, the CCIR-1978 method (described in PoKempner [1980]), etc. I have done some of the field strength observation work over the last five years and plan to write an article presenting the data and the field strength estimations for correlation.

All of the accepted methods of estimating field strength (e.g. Knight [1975]) indicate that one-hop "ordinary" wave paths at elevation angles down to 0 degrees and multi-hop paths in the range of 1-5 degrees are the predominant mode of Medium Frequency long-distance propagation via the

T58-3-3

T58

E-region. Lankford has not presented any firm experimental or theoretical data to refute the accepted methods - he has only hypothesized higher elevation angles, in tandem with his "extraordinary" mode hypothesis, based on data of questionable applicability.

4. CLOSURE

This article has addressed the two major themes that were the basis of Lankford's [1984b] critique of Seaver [1984], namely "extraordinary" wave traces and the elevation angle of oblique waves at Medium Wave frequencies. The Fenwick and Barry [1966] oblique incidence ionograms support the Seaver [1984] hypothesis that "ordinary" waves refracted from the E-region are the major propagation mode throughout the Medium Wave frequency band. If this hypothesis is correct (and it matches the accepted methods of Knight [1975] and others), then Lankford has no published data to support his hypothesis.

I ask the question:

"If the recognized authorities in radio broadcasting accept the Knight model (as indicated in PoKempner [1980]), then why don't Lankford and Stanbury accept it?"

Who would you believe? The broadcasting authorities and radiophysicists on one hand, or two DXers with little physics background on the other? I choose the former with no reservations whatsoever.

5. REFERENCES

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ERRATA

One error of substance found its way into Seaver [1984] on page 27 in the bottom paragraph: The listing of KOB-770 in the two-hop path listing should be in one-hop path listing. KOB-770 is definitely a one-hop path from Chula Vista and not a two-hop path as listed. My thanks to C.M. Stanbury II for pointing this out.