MEDIUM WAVE OBLIQUE PROPAGATION - ANOTHER VIEW

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1. INTRODUCTION

Lankford [1984] derived the critical frequency formulae for transverse and longitudinal propagation and computed numerical solutions for low wave elevation angles with typical and minimal nighttime mid-latitude ionospheric electron densities. The paper notes that longitudinal propagation (i.e. along magnetic field lines) is not consistent with low wave angle propagation at mid-latitudes, thereby leaving quasi-transverse propagation as the major mode for determining oblique wave critical frequencies of the ionospheric regions.

Appendix I interpreted the numerical results as they apply to Medium Frequency propagation at mid-latitudes and concluded (in part) that:

a) In the early evening hours, the best long distance MF propagation will be near the top of the BCB band where F_O (ordinary wave, F-region) propagation is possible and a larger low band segment (say 600-1100 khz) where F_X (extraordinary wave, F region) propagation is possible.

b) In the early morning hours (local midnight and later) the entire BCB is hypothetically open for F_O , F_X , and combined F_O and F_X propagation.

For the case of European and/or Asian reception from North America, the Appendix hypothesized that the signals are propagated by both the E-region (at higher latitudes) and the F-region (at mid-latitudes), due to the higher ionization levels at high latitudes. For North-South paths (e.g., Latin America or Down Under), the Appendix hypothesized that an E-/F- region mix might occur due to the variation in the gyrofrequency in the lower latitudes.

The Appendix also discussed ionospheric absorption, the effects of geomagnetic activity, and concludes by briefly covering other potential modes of propagation, including ordinary E-region modes.

My purpose in this article is not to discuss the main body of the paper, which I have not evaluated mathematically, but seems to be technically correct for the assumptions for which it was derived; however, I do disagree with the interpretations provided in the Appendix, and wish to discuss my own interpretations more fully in the balance of this article.

Seaver [1978] presented a discussion of Medium Wave propagation, including the nighttime E-region critical frequency for oblique "ordinary" waves. This article provides additional information to support the hypothesis that nearly all nighttime long-distance Medium Wave propagation occurs via refraction in the E-region of the ionosphere.

2. ORDINARY VS. EXTRAORDINARY WAVES

When radio waves encounter the ionosphere, they split into two components, called the "ordinary" and "extraordinary" waves. They follow different paths and incur different ionospheric losses. The total wave energy is shared between the two waves in a ratio which depends upon the angle between the direction of the wave and the Earth's magnetic field vector. Olver et al. [1971] gives the equations for the losses due to this "polarization coupling" that occurs each time a wave enters and leaves the ionosphere. Only on East-West paths at equatorial latitudes does the "ordinary" wave suffer a large polarization loss. On the other hand, the "extraordinary" wave polarization loss is greater than the "ordinary" wave polarization loss, except for East-West paths at equatorial latitudes. For instance, at 60 degrees geomagnetic latitude (which is about 30 degrees latitude in North America), the "ordinary" wave has a polarization loss of about 1 dB, while the "extraordinary" wave suffers a loss of 7 dB.

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The ionospheric absorption experienced by the "extraordinary" wave is infinite at the gyrofrequency, and greater than that experienced by the "ordinary" wave at frequencies above and below the gyrofrequency, according to Knight [1975] and others.

The conclusions that one can draw from the Olver [1971] and Knight [1975] papers is that the "extraordinary" wave mode is not a viable candidate for long-distance nighttime Medium Frequency propagation, especially for high and mid-latitude propagation paths below the gyrofrequency. Consequently, Lankford's [1984] hypothesis that the F-region is responsible for Medium Frequency propagation in the frequency range of 600-1100 khz, via the "extraordinary" mode, is not validated.

3. IONOSPHERIC ELECTRON DENSITY

The Lankford [1984] paper uses an E-region critical frequency of 300 khz (measured with a vertical ionogram) as representative of a minimal nighttime E-region mid-latitude ionosphere, and a 550 khz critical frequency for a typical E-region ionosphere. A review of the literature indicates that the minimal nighttime ionosphere may occur only in low-sunspot years and at times of low geomagnetic activity in mid-latitudes, as Lankford stated.

The E-region is a dynamic field composed of molecules, ions and free electrons. Solar radiation causes ionization to occur during daytime hours, with the number of electrons peaking near noon. The electron density continues to fall off after sunset, reaching a minimum near midnight (see Knight [1972] for typical values). This minimum electron density may be as low as 1000 electrons/cu.cm in sunspot minimum years, but typically is 3000-5000 electrons/cu.cm. near midnight, and significantly higher near sunset.

Figure 1 shows the variation of "ordinary" wave oblique propagation critical frequency as a function of ray elevation angle and E-region electron density, from Seaver [1978]. This figure shows good correlation with Lankford's [1984] "ordinary" transverse wave oblique critical frequency data (since 300 khz vertical corresponds to about 1100 electrons/cu.cm. and 550 khz vertical corresponds to about 3750 electrons/cu.cm.). The figure shows that for an E-region electron density of 1000 electron/cu.cm and a wave incident at or below 5 degrees, the critical frequency will be above 1500 khz, thereby effectively blanketing the Medium Frequency band for "ordinary" wave propagation.

The conclusion that one can draw from this information is that the minimal electron density occurs only rarely at midnight, and that the E-region electron density at sunset is significantly greater than it is at midnight. There is sufficient E-region ionization to refract low angle medium waves, even when the minimal electron density exists. Only on occasions when the minimal electron density occurs will "ordinary" waves on the higher BCB frequencies (above 1200 khz) and at high elevation angles pass through the E-region and be refracted by the F-region. Consequently, Lankford's [1984] hypothesis that the entire BCB is open in the early morning hours for F-region propagation via the "ordinary" wave, the "extraordinary" wave, or a combination of the two modes, is not valid.

4. ELEVATION ANGLE

Lankford [1984] uses 5 and 10 degree wave elevation angles to provide examples and to support his hypothesis that the F-region is mainly responsible for propagating mid-latitude Medium Frequency signals. Data in Knight [1975] and others indicate that one-hop paths at elevation angles down to 0 degrees and multi-hop paths down to 1-5 degrees are the predominant mode of Medium Frequency long-distance propagation via the E-region "ordinary" wave.

The prevalent model (i.e. Knight [1975] and others) of E-region refraction of Medium Frequency "ordinary" waves results in a maximum one-hop distance of about 2200 km (1360 statute miles). This is consistent with my own DX experience wherein stations

within 2200 km are much stronger and consistent (i.e. less fading minute-by-minute, and with less day-to-day variation in signal strength) than are stations at distances greater than 2200 km. My "one-hop" clear-channel stations in Southern California include KBOI-670, WBAP-820, KOA-850, KRVN-880, KOMO-1000, KTWO-1030, KSL-1160, WOAI=1200, KOMA-1520, and XERF-1570. These stations are always in during the evening hours at relatively high signal strengths. On the other hand, my "greater than one-hop" stations, including CBK-540, WSM-650, XERPM-660, XEX-730, KOB-770, WCCO-830, Belize-834, WHAS-840, WWL-870, WLS-890, WHO-1040 and XEB-1220, are often at relatively low signal strengths; there are times when the "two-hop" path signals are equal to the "one-hop" path signals on adjacent frequencies, but these occasions are relatively few. Auroral absorption may account for some of the variability for the more northern paths. The "two-hop" path signals also experience more frequent fading rates, which would be consistent with the prevalent theory.

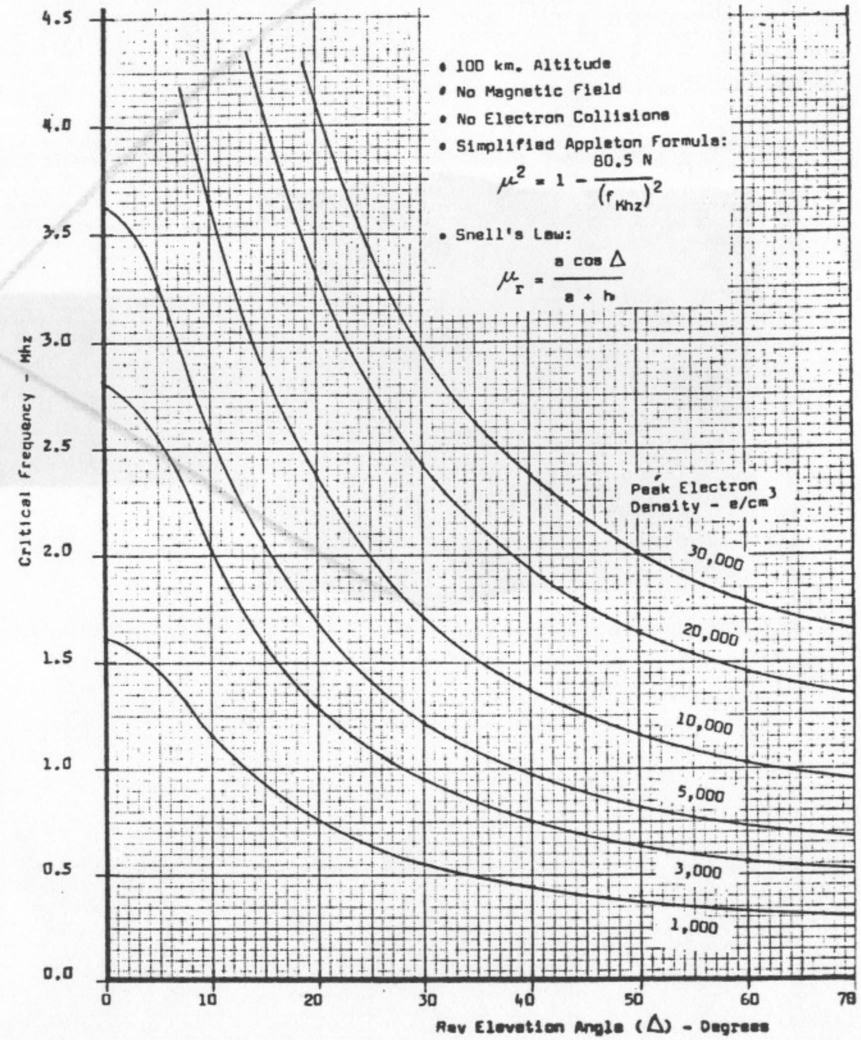

FIGURE 1. OBLIQUE RADIO WAVE E-REGION CRITICAL FREQUENCIES

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The argument put forward by some DXers concerning low elevation angle paths (say, less than 5 degrees) is that ground attenuation reduces the field strength significantly. This is true, but the extra ground attenuation loss for a low angle wave is usually less than the extra ionospheric and ground reflection losses suffered by a higher elevation angle wave with more hops. Knight [1975] provides data to calculate the various path losses. The ground attenuation loss is mainly a function of ground conductivity, elevation angle and frequency. For a 1 degree elevation angle, the sea water loss is only 2 dB, for good ground conductivity (10 mS/m) the loss is about 10 dB, and for poor ground conductivity (1 mS/m) the loss is about 20 dB. For a 5 degree angle, the losses are 0 db (sea water), 5 dB (10 mS/m), and 10 dB (1 mS/m).

To illustrate this difference, Figures 2 and 3 show the field strength analysis for the path San Antonio (WOAI-1200) to Chula Vista on a night with minimal E-region ionization for one-hop and two-hop paths, respectively. The field strength analysis is based on the Knight [1975] methods of analysis. Figure 2 shows that the one-hop path has a 1.5 degree elevation angle and results in an estimated field strength of 43 dB. For the two-hop path of Figure 3, the elevation angle is 9.1 degrees and the estimated field strength is 33 dB. The 10 dB difference in signal strengths means that the one-hop path will dominate and should provide a stable signal. Indeed, WOAI-1200 is received at an estimated 40-45 dB in Chula Vista on an average early morning.

5. IONOSPHERIC ABSORPTION

Lankford [1984] states "accurate theories of absorption exist only for vertical incidence and frequencies above 2 mhz". I disagree with this statement; the generalized magneto-ionic theory of Sen and Wyller [1960] provides the best available theory and includes the effects of the Earth's magnetic field and electron collisions on both ionospheric refraction and ionospheric absorption. When the actual electron density profile of the ionosphere is modelled in a ray-tracing computer program (e.g. Jones and Stephenson [1975]), medium and short wave path ionospheric absorption can be calculated accurately.

Knight [1975] provides ionospheric absorption losses for a model "mean" nighttime ionosphere in the range of 3 to 12 dB (decreasing as frequency increases and lower on North-South paths); this data was derived from ray-tracing computations. I have also run the Jones and Stephenson [1975] ray-tracing program with different model ionospheres to investigate the effects of the electron density profile on ionospheric absorption. My results indicated that ionospheric absorption is very dependent on the level and reflectivity of the electron density profile. For instance, raising the "mean" electron density profile only 5 km reduced the absorption significantly. The absorption was also significantly reduced if the electron density was more reflective, i.e. if the electron density gradient was increased (this includes sporadic E layers which have a very high gradient). The conclusion that one can draw from this information is that ionospheric absorption is highly variable due to the day-to-day and hour-by-hour variations in the E-region of the ionosphere.

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******  MEDIUM WAVE PROPAGATION ANALYSIS BY THE KNIGHT WAVE-HOP METHOD  ******
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* RECEIVER LOCATION: Chula Vista CA              117.15 W. LONG.  32.72 N. LAT.
* GROUND COND'Y     10.00 MS/M
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* TRANSMITTER LOCATION: San Antonio TX            98.50 W. LONG.  29.42 N. LAT.
* FREQUENCY           1.2000 MHZ        * EFFECTIVE RAD. POWER    50.00 KW
* GROUND COND'Y        10.00 MS/M       * ANTENNA HEIGHT        0.250  W'LENGTH
------------------------------------------------------------------------
* UNIFORM IONOSPHERE CHARACTERISTICS    * MAX E-REGION E-DENSITY  1000  E/CM3
* E-REGION VIRT. HT      90.0  KM       * F-REGION VIRT. HT     250.0  KM
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* PATH GREAT CIRCLE DISTANCE      1125.2  STAT MILES =   1810.9 KM
* GREAT CIRCLE BEARING  96.72  DEG CLOCKWISE OF NORTH
*  1  E  REGION REFRACTIONS             *  0  GROUND REFLECTIONS
* AVG. ELEVATION ANGLE    1.56  DEG     * AVERAGE HOP LENGTH      1810.9  KM
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****   MEDIUM WAVE FIELD STRENGTH ANALYSIS BY THE KNIGHT WAVE-HOP METHOD   ***
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	LONG. (DEG W)	LAT. (DEG N)	DIP LAT. (DEG N)	MAG ANGLE (DEG)	COND'Y (MS/M)	LOSS (DB)
TX GROUND	98.50	29.42			10.0	11.77
TX POLARIZATION	107.66	31.41	59.21	272.40		1.53
IONOSPHERIC ABS.	107.66	31.41	59.21	272.40		5.93
RX POLARIZATION	107.66	31.41	59.21	272.40		1.53
RX GROUND	117.15	32.72			10.0	11.77

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* RADIATED POWER GAIN     16.99   DB    * TOTAL POLARIZATION LOSS    3.06   DB
* UNATT. FIELD STRENGTH   50.29   DB    * TOTAL IONOSPHERIC LOSS     5.93   DB
* CONVERGENCE GAIN         8.34   DB    * TOTAL GROUND REFL. LOSS    0.00   DB
* TX ANTENNA HT CORR.      0.40   DB    * TOTAL TERM. GROUND LOSS   23.55   DB
* FIELD STR. (NO LOSSES)  76.01   DB    * TOTAL PATH LOSSES         32.54   DB
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* ESTIMATED FIELD STRENGTH FOR RADIATED POWER =   43.48    DB
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FIGURE 2. MEDIUM WAVE FIELD STRENGTH ANALYSIS - WOAI-1200 KHZ TO CHULA VISTA, ONE-HOP PATH.

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******  MEDIUM WAVE PROPAGATION ANALYSIS BY THE KNIGHT WAVE-HOP METHOD  ******
************************************************************************
* RECEIVER LOCATION: Chula Vista CA              117.15 W. LONG.  32.72 N. LAT.
* GROUND COND'Y     10.00 MS/M
------------------------------------------------------------------------
* TRANSMITTER LOCATION: San Antonio TX            98.50 W. LONG.  29.42 N. LAT.
* FREQUENCY           1.2000 MHZ        * EFFECTIVE RAD. POWER    50.00 KW
* GROUND COND'Y        10.00 MS/M       * ANTENNA HEIGHT        0.250  W'LENGTH
------------------------------------------------------------------------
* UNIFORM IONOSPHERE CHARACTERISTICS    * MAX E-REGION E-DENSITY  1000  E/CM3
* E-REGION VIRT. HT      90.0  KM       * F-REGION VIRT. HT     250.0  KM
------------------------------------------------------------------------
* PATH GREAT CIRCLE DISTANCE      1125.2  STAT MILES =   1810.9 KM
* GREAT CIRCLE BEARING  96.72  DEG CLOCKWISE OF NORTH
*  2  E  REGION REFRACTIONS             *  1  GROUND REFLECTIONS
* AVG. ELEVATION ANGLE    9.13  DEG     * AVERAGE HOP LENGTH       905.5  KM
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****   MEDIUM WAVE FIELD STRENGTH ANALYSIS BY THE KNIGHT WAVE-HOP METHOD   ***
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	LONG. (DEG W)	LAT. (DEG N)	DIP LAT. (DEG N)	MAG ANGLE (DEG)	COND'Y (MS/M)	LOSS (DB)
TX GROUND	98.50	29.42			10.0	3.32
TX POLARIZATION	103.03	30.49	59.24	275.80		1.53
IONOSPHERIC ABS.	103.03	30.49	59.24	275.80		6.81
GROUND REFLECTION	107.66	31.41	59.21	272.40	3.0	13.43
IONOSPHERIC ABS.	112.37	32.15	59.02	268.98		6.83
RX POLARIZATION	112.37	32.15	59.02	268.98		1.54
RX GROUND	117.15	32.72			10.0	3.32

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* RADIATED POWER GAIN     16.99   DB    * TOTAL POLARIZATION LOSS    3.07   DB
* UNATT. FIELD STRENGTH   50.16   DB    * TOTAL IONOSPHERIC LOSS    13.64   DB
* CONVERGENCE GAIN         2.46   DB    * TOTAL GROUND REFL. LOSS   13.43   DB
* TX ANTENNA HT CORR.      0.32   DB    * TOTAL TERM. GROUND LOSS    6.63   DB
* FIELD STR. (NO LOSSES)  69.92   DB    * TOTAL PATH LOSSES         36.77   DB
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* ESTIMATED FIELD STRENGTH FOR RADIATED POWER =   33.15    DB
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FIGURE 3. MEDIUM WAVE FIELD STRENGTH ANALYSIS - WOAI-1200 KHZ TO CHULA VISTA, TWO HOP PATH.

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My own hypothesis is that "great" DX conditions at mid- and low latitudes occur when the E-region of the ionosphere is raised above the "mean" and/or is more reflective. With such conditions, the absorption on one or more hops is reduced (perhaps even zero) and the signal strength of both strong and weak signals are enhanced, either generally or from one particular geographic region. However, there may be other factors that "enhance" long distance Medium Frequency signals, such as M-type paths (where a wave gets trapped between the E and F regions over much of the path) and chordal paths (where the wave does not suffer a ground reflection loss, due to magnetic field effects or an ionospheric tilt).

Nelson [1971] described the effects of the Earth's auroral zone on high-latitude paths. In the auroral zone, the precipitation of energetic particles into the D-region of the ionosphere results in more ionization and hence higher electron densities at altitudes down to 60 km. These high electron densities cause very high ionospheric absorption that greatly reduces the signal strength of waves passing through the zone. DXers in the northern latitudes frequently experience "auroral" conditions wherein northern stations have low signal strengths due to the auroral absorption effects, thereby allowing southern stations to be heard.

The auroral zone is actually an oval with a width of 10-15 degrees latitude, centered on the magnetic pole, that rotates diurnally, with the most southward extent near local midnight due to the effects of the solar wind on the Earth's geomagnetic field. The easiest way to visualize this is to consider a thick "curtain" hanging down to about 60 km altitude; within the "curtain" there are high electron densities. The auroral oval migrates toward the equator during periods of higher geomagnetic activity and toward the magnetic pole during periods of lower geomagnetic activity. The southward extent of the auroral oval seems to control the reception of high latitude European stations in Eastern North America and the reception of high latitude Asian stations in Western North America. This occurs as a result of the sharp increase in electron density at low altitudes as the radio wave enters the auroral oval, resulting in high absorption.

However, under some conditions, reception of high latitude stations may occur through the "doughnut hole" in the auroral oval. In this case, the radio waves are propagated through the auroral zone, passing beneath the auroral oval "curtain", and refracting from the ionosphere within the "doughnut hole". This mode is thought to be responsible for reception of European stations in Northwest North America and Asian stations in Northeast North America.

6. CONCLUSIONS

The conclusions drawn in this article concerning Medium Frequency oblique propagation include:

a) The "ordinary" ray is the primary mode by which medium waves propagate, since the "extraordinary" wave is greatly attenuated by polarization loss and absorption. The exception is East-West paths at equatorial latitudes.

b) The E-region of the nighttime ionosphere contains sufficient electrons to refract low elevation angle (5 degrees or less) "ordinary" Medium Frequency waves back to Earth. Only when the E-region electron density is extremely low, the wave BCB frequency is relatively high, and/or the elevation angle of the wave is relatively high will the "ordinary" wave pass through the E-region and be refracted from the F-region.

c) Assuming E-region refraction of "ordinary" waves, the maximum one-hop distance is about 2200 km, and the observations of this DXer confirm this. For multi-hop paths, a rule-of-thumb of about 1000 statute miles (about 1600 km) per hop is reasonable.

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d) Ionospheric absorption can be highly variable, and cases of very low absorption are probably the cause of enhanced signal strengths. Very high absorption of radio waves in the auroral zone effectively prevents some reception of high latitude European and Asian stations in North America.

e) It is possible to compute ray paths and ionospheric absorption of Medium Frequency radio waves using sophisticated computer programs. These methods depend on an accurate representation of the Earth's magnetic field, electron collision rates, and ionospheric electron density profiles to result in accurate results.

f) It is possible to compute average field strengths of radio waves using relatively simple computer programs that account for all of the losses and gains for the ray path. Knight [1975] and PoKempner [1980] provide methods to do these calculations.

7. CLOSURE

In the above sections, I mentioned some of the research I've carried out using the Jones and Stephenson [1975] ray-tracing computer program and the average Field Strength prediction program based on Knight [1975]. I hope to write articles in the future on the results obtained using these two programs. Some of this research has been presented at the NRC/Los Angeles (1980) and IRCA/Seattle (1983) conventions.

It is worthwhile noting that every article, report or book that I've read that describes Medium Frequency propagation states that the nighttime E-region is the primary mode of long-distance medium wave reception. It is interesting that only DXers have hypothesized that the F-region is the primary mode for Medium Frequency propagation.

8. REFERENCES

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