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COSMIC CYCLES AND RADIO TRANSMISSION

BY

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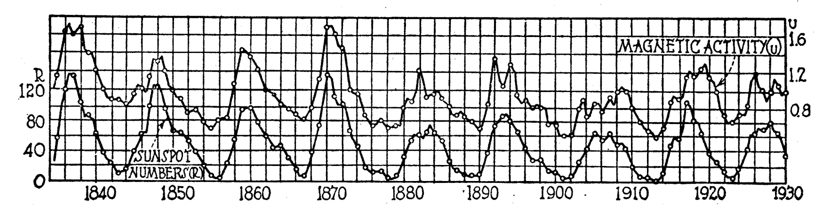
Everyone connected with radio transmission knows that there are certain times when communication is superior and other times when it is much inferior. Listeners to broadcast programs are aware of the fact that conditions change from time to time in the behavior of receiving conditions quite beyond the control of the receiving set. Variations in the amount of static and periods of fading often exhibit themselves at longer and shorter intervals depending upon conditions in the upper atmosphere that are receiving an increasing amount of study. Investigations extending over a decade or more leave little doubt in the minds of scientists who have probed these problems that there are cosmic effects taking place in the ionosphere through which radio waves are propagated. The study of these cosmic effects, the cycles which they undergo, and the ultimate causes, is a new and coming field in science which is likely to be of greatest importance not only from the scientific standpoint but from the point of view of the whole radio and communication industry.



Curve of sun-spot numbers and earth's magnetic activity.
"Reproduced from 'Earth, Radio and The Stars' by H. T. Stetson. McGraw, Hill Book Company, Inc."
Figure 1

The most obvious periodic change in the conditions affecting radio wave communication is that produced by the successive passing of daylight and darkness as the earth rotates upon its axis. Certain high frequencies invariably give better performance by day than by night. The region of the radio spectrum known as the broadcast band shows better performance in darkness than in daylight. The increase in the range of broadcasting stations is very noticeable a few hours after sundown. Even so, this diurnal cycle does not perform the same day after day but is subject first of all to wide variations due to seasonal effects of cosmic origin. The changing declination of the sun due to the combination of the earth's orbital motion and the inclination of the axis of rotation to the plane of its orbit is, of course, directly responsible for the inequality of daytime and darkness during the summer and winter seasons. The radio operator who knows his communication range must be provided with charts giving available ranges for different frequencies at different seasons of the year. Since the sun is the principal source of ionization of the earth's atmosphere that makes radio wave propagation possible, we can see that anything which influences the quantity, duration, or character of solar radiation must inevitably produce corresponding results in the radio business.

The results of studies carried on in the last decade indicate that the well known solar cycle of approximately 11 1/4 years' duration has its counterpart in radio wave propagation. As will be shown later, quantitative measurements of field intensities appear to show that during periods of marked solar activity such as is generally indicated by the appearance of large numbers of sunspots, the seasonal effect is more than counteracted. When one, therefore, endeavors to search out the cause of behavior of cosmic cycles he is at the same time anticipating the prediction of long range forecasting of conditions in the ionosphere upon which radio communication depends.

When asked if astronomical bodies other than the sun produce any effect upon radio communication lines, it already appears safe to answer this question in the affirmative. There is, for example, what appears to be direct evidence that the moon as well as the sun has an effect on the ionosphere. The same appears to be true of meteoric showers. Whether or not the planets can have any effect directly on the electrical condition of the earth's atmosphere or indirectly through causing disturbances in the solar atmosphere which in turn affects the ionizing power of solar radiation must be for the moment left open for question.

To approach the problem of the possible effect of cosmic cycles upon changing conditions in the conductivity of the earth's upper atmosphere from which radio waves are returned, it is well to examine various known sources of atmospheric ionization excluding those of terrestrial origin such as radio activity in the earth's crust. Skellett of the Bell Telephone Company has conveniently summarized extra terrestrial sources of ionization in the following table.[1]

Sources of Ionization	Energy Received by the Earth, Ergs per Square Centimeter per Second
Ultra-violet light from the sun	28.35
Meteors during meteoric shower (a.m.) up to	2.4
Ultra-violet light from the stars (approximate) . .	0.014
Cosmic rays	0.00031
Meteors - average normal day: a.m.	0.00024
p.m.	0.00012
Ultra-violet light from the full moon	0.000044

An examination of this table indicates that the ultra-violet light of the sun is by far the principal ionization agent to be considered; amounting to 28.35 ergs per square centimeter per second. Skellett estimates that meteors during the dates of particular showers take second place. It is perhaps a bit surprising to see the low value of the energy available for ionization that can be attributed to the high penetrative radiation of which we have heard so much, commonly called cosmic rays. It should also be noted that the lowest value of all in the table is attributed to the ultra-violet light from the full moon. This is important to keep in mind in connection with any explanation for a lunar effect on radio communication of which more will be said.

If we view a cross section of the earth's atmosphere from its surface out, some 10 kilometers must be allowed for the troposphere with which classical meteorology is concerned. Above this troposphere lies the isothermal region with a temperature of -55°C. Here the stratosphere begins. Judging from the latest scientific results of Stevens and Anderson in Explorer II, it appears that in the lower regions of the stratosphere we encounter the beginnings of the ozone level. Spectroscopic observations of sunlight at Captain Steven's record altitude of 72,395 feet above sea level indicated that at this altitude some 25 per cent of the total amount of ozone was below the observers.[2] From this level up, therefore, the amount of ozone must show considerable increase probably extending to the altitude of the ionized layers. From 50 to 80 kilometers the ionization of the atmosphere appears to be sufficient to reflect very long waves and to this region has been ascribed the D-layer. From 80 to 120 kilometers we arrive at an electron density great enough to turn back waves of broadcast frequency. The mean height of this E-layer, commonly referred to as the Kennelly-Heaviside layer in honor of our American and English engineers, will vary with the change from day to night conditions and from season to season, as well as with the solar cycle or any other cause that may affect the population or density of its electron or ionic content.

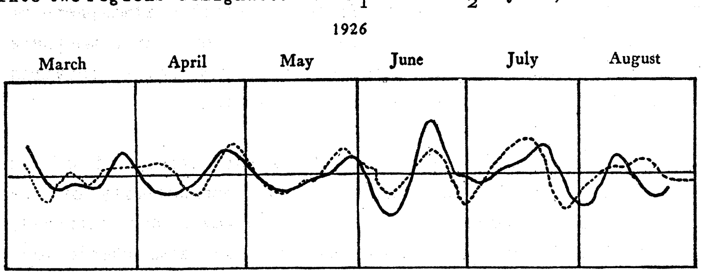
From 200 kilometers upward we arrive at the region of the ionosphere to which Appleton earlier called attention, the one that is often designated as the F-layer. Since high frequency waves turned back from the F-layer suffer polarization with consequent double refraction, this F-layer is for convenience split into two regions designated the F_1 and the F_2 layers, one of which turns back the ordinary and the other the extraordinary wave resulting from the double refraction.

Any cosmic phenomena, therefore, which cyclicly change the degree of ionization or the electron density will affect the success of the transmission of radio waves which depend upon the momentary constitution of the ionosphere. The radio, therefore, gives us a new tool for exploring the upper atmosphere to the height of 200 or 300 kilometers.

Two different methods may be employed for getting information concerning ionic variations. One of these is the direct reflection method such as has been used by Appleton and others in England and at the United States Bureau of Standards, Cruft Laboratory, and elsewhere in the United States. The elapsed time from the time of emission of a radio impulse and its subsequent reception at an adjacent point is recorded on the oscillograph and gives a measure of the virtual height from which the transmitted wave is reflected or turned back to earth. These virtual heights are, of course, calculated on the assumption that the radio wave is propagated with the velocity of light and cannot be taken as direct height on account of some uncertainty as to the variation of velocity with the conditions encountered. However, these virtual heights which vary widely from day to night show a definite seasonal trend as the degree of ionization at the respective levels from which known frequencies are reflected change with the duration and intensity of sunlight on the upper atmosphere.

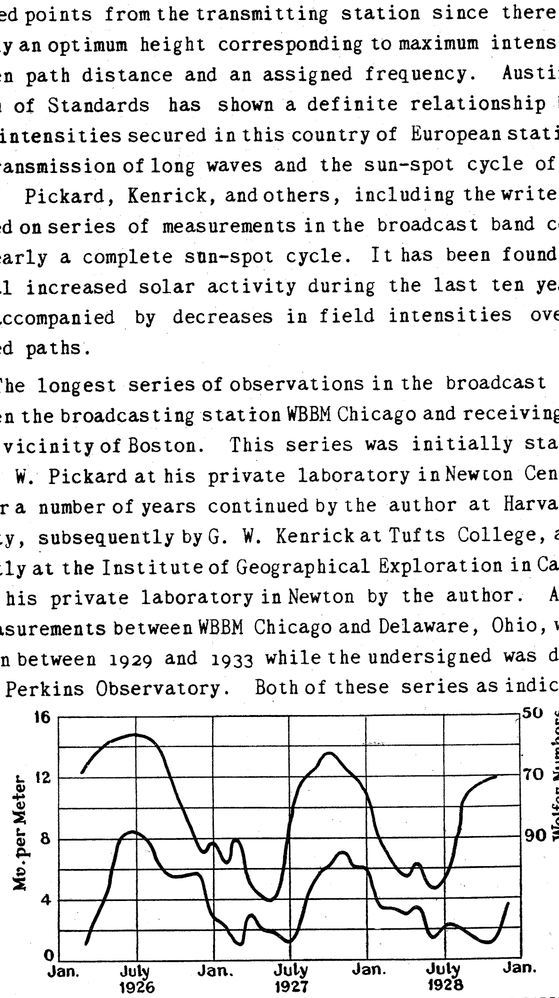
Another method of utilizing radio for obtaining variations in layer heights is through the measurement of field intensities at fixed points from the transmitting station since there is presumably an optimum height corresponding to maximum intensity for a given path distance and an assigned frequency. Austin at the Bureau of Standards has shown a definite relationship between field intensities secured in this country of European stations for the transmission of long waves and the sun-spot cycle of 11 1/2 years. Pickard, Kenrick, and others, including the writer, have carried on series of measurements in the broadcast band covering now nearly a complete sun-spot cycle. It has been found that in general increased solar activity during the last ten years has been accompanied by decreases in field intensities over prescribed paths.

The longest series of observations in the broadcast band is between the broadcasting station WBBM Chicago and receiving points in the vicinity of Boston. This series was initially started by Mr. G. W. Pickard at his private laboratory in Newton Center and was for a number of years continued by the author at Harvard University, subsequently by G. W. Kenrick at Tufts College, and more recently at the Institute of Geographical Exploration in Cambridge and in his private laboratory in Newton by the author. A series of measurements between WBBM Chicago and Delaware, Ohio, was carried on between 1929 and 1933 while the undersigned was director of the Perkins Observatory. Both of these series as indicated in



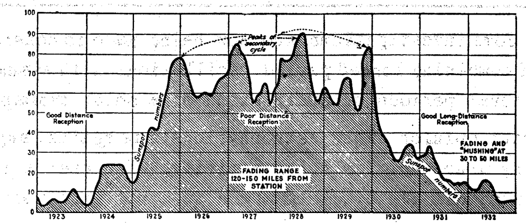
CURVE SHOWING CORRELATION OF SUN-SPOTS WITH RADIO RECEPTION
DOTTED CURVE, THE INVERSE OF SUN-SPOT NUMBERS; FULL CURVE, RELATIVE INTENSITY OF RADIO RECEPTION ON TRANSATLANTIC, SOUTH AMERICAN AND CONTINENTAL RECEPTION.

Figure 2



UPPER CURVE SHOWS INVERTED SUN-SPOT NUMBERS. LOWER CURVE RADIO INTENSITY MEASUREMENTS.

Figure 3



Curve of sun-spot numbers of the last solar cycle showing effect upon radio reception.

Figure 4

the graph have shown cyclical fluctuations that appear to reflect the degree of solar activity as measured by the number of sun-spots.

It has been found in the Chicago - Delaware series that if the sun-spot numbers are restricted to the central zone, corresponding to the position of spots near the sun-earth line, a somewhat closer correspondence is found between the graph of radio field intensities and solar activity than when spots for the whole disc of the sun have been included. This would appear to indicate that variations in the ultra-violet light are not alone responsible for the radio effects. While reception from a distance of several hundred miles appears to vary inversely in its field strength as compared with sun-spot numbers, the quality of reception at points nearby a broadcasting station may behave contrarily. This is usually explained on the grounds of interference between the sky wave and the ground wave. At times of sun-spot minima with a consequent ascent of the Kennelly-Heaviside layer, it may happen that the sky wave is reflected so well that it interferes at intervals with the ground wave at distances within 50 miles of the sending station, thus seriously hampering good reception. With the lowering of the Kennelly-Heaviside layer accompanying increasing solar activity, the sky wave ceases to interfere as effectively with the ground wave, thus we may actually get better reception within local areas at times of sun-spot maxima than at times of sun-spot minima.

In the case of distance reception, on the other hand, the lower Kennelly-Heaviside layer is less conducive to long distance transmission in the broadcast band, and even nighttime conditions at times of great solar activity simulate the usual effects of daytime reception in the broadcast band. It seems highly desirable that more of the relatively inexpensive equipment for measuring field intensities be established at strategic points throughout the country if we are to obtain more complete data for studying cosmic effects upon transmission in the broadcast band of the radio spectrum.

There is room for a difference in opinion concerning the exact mechanism whereby sun-spots produce changes in the ionization of the reflecting layers. The author has discussed at length in another place[3] the relative merits of the hypotheses of ultra-violet flares accompanying the formation of the spots and the theory that the spots themselves are centers of electronic or some kind of corpuscular emission from the sun-spot centers. Observations made during times of total solar eclipses show the immediate screening effect of the sun's ultra violet radiation in reducing the degree of ionization at a given height or the effective change in the Kennelly-Heaviside layer accompanying the optical shadow as the moon passes in front of the sun. Conflicting results give some evidence for a theory of ionization by corpuscular radiation advanced by Chapman. Evidence concerning this has likewise been discussed at length elsewhere. It would appear not improbable that superimposed upon the effects of ultra-violet radiation which may or may not be locally increased with the formation of sun-spot zones there is still room for a corpuscular hypothesis which is used so effectively by Stormer in brilliant studies of auroral forms.

The recent coincidences of eruptions in the sun observed at the Mount Wilson Observatory with time of complete fade-outs of transoceanic reception noted by Dellinger[4] is at least corroborating evidence for an intimate relationship between particular events on the sun and prompt response in the ionosphere. That the period of fade-outs has in many instances indicated intervals of 54-days or approximately twice the synodic period of solar rotation at the equator is especially puzzling and so far without explanation. It is most urgent that those engaged in radio operations and especially those in charge of continuous operations should cooperate with the Bureau of Standards in expediting reports of all such fade-outs whether it be suspected as a world-wide event or not. With the continued acquisition of information as to these periods of remarkable change in communication characteristics, it will be possible to more readily correlate corresponding solar events.

The relatively definite cycle of solar activity makes it possible to make general predictions concerning radio transmission. It is interesting to note that, as exhibited in the curve, many secondary fluctuations in the sun-spot numbers are reflected in the performance of radio reception. A period of fifteen months pointed out by the writer[5] has many times shown its counterpart in the curve of field intensities. The reason for the fifteen-month period in solar fluctuations or even for the 11 1/2-year period in sun-spot activity is not yet known. When we have obtained some evidence for the fundamental cause of these solar fluctuations, we shall have gone a long way to a more accurate prediction of the cosmic conditions affecting the radio industry. Meanwhile, it is perhaps worthwhile to reflect upon such hypotheses as have been considered as a possible basis of the fluctuations in the solar cycle.

Numerous attempts have been made from time to time to account for periodicities in the appearance of sun-spots on the basis of the various planetary periods. The sidereal period of Jupiter most nearly approximates that of the fundamental cycle in solar activity. Jupiter's period, however, is 12 years and not the mean sun-spot period of 11.25 years. The sun-spot period, however, is far from constant as in certain instances the interval between maxima has been as little as 8 years and in one case as long as 17 years. An exhaustive examination by E. W. Brown[6] made 36 years ago suggested at that time that a combination of the period of Jupiter with that of Saturn (29 1/2 years) showed a correlation with the sun-spot period. Later, however, discrepancies cast doubt in the same author's mind upon the validity of these earlier conclusions. One difficulty with all planetary theories for explaining the appearance of sun-spots is that the tidal action of the planets is too small to appear to be significant in causing eruptions in the solar atmosphere on gravitational grounds. If one were to suppose, however, that the planets are at different electrical potentials, then there is perhaps a fresh basis for attack on the sun-spot theory from the planetary viewpoint.

As has been pointed out by the writer[5], the fifteen-month secondary period in solar activity coincides very closely with the combined periods of Mercury (88 days) and that of Venus (225 days). If electric charges on the planets exist, it is not easy to separate their effect from the gravitational effect since both would follow the inverse square law. There are only a few thinkable instances where planetary perturbations would make it possible to differentiate an assigned value for gravitational mass from a similar value confused with a possible effect due to electro-static charges. Some investigations are now being made to consider the results of combining forced period oscillations with assumed values of natural periods of oscillation of a solar atmosphere.

Current opinion among astrophysicists is against any planetary theory to account for solar activity. Preference is being given to periodic disturbances in the internal structure of the sun that presumably give rise to disturbances in the outer atmosphere thus producing the sun-spots. Application of the hydrodynamic principles to the formation of solar vortices by Bjerknes(7) have yielded some plausible explanations for the formation of sun-spots at the extremities of tubular disturbances extending below the surface of the solar photosphere. No explanation, however, on such grounds has been forthcoming for eleven-year periodicity. Bjerknes shows, on the basis of his deductions, how spots may be expected to migrate in latitude as the cycle progresses.

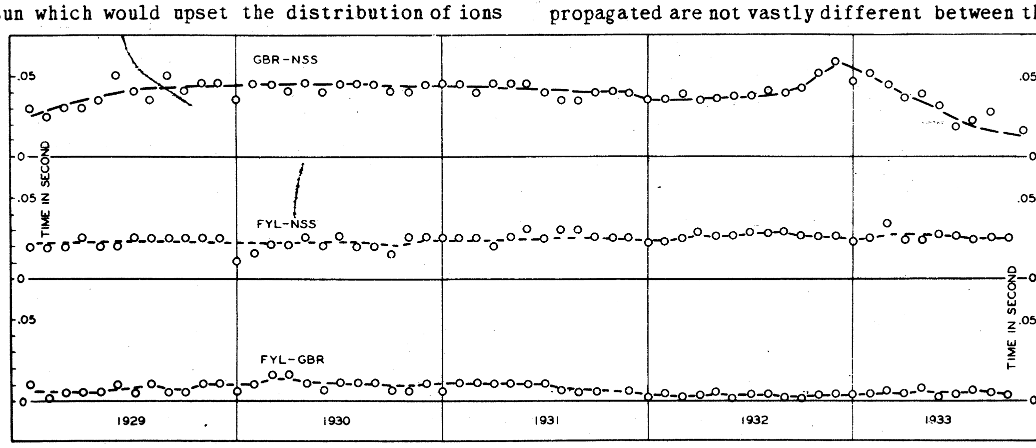
Notable correspondences between the occurrence of sun-spots and the disturbances in the earth's magnetic field have been on record for more than a century. Investigations in the performance of radio communication in recent years have shown disturbances concomitant with magnetic storms. Many radio engineers, therefore, have supposed that investigation of cycles in radio transmission with cycles in terrestrial magnetic activity is a more profitable field for exploration than the correlation of radio phenomena with solar activity. It is the opinion of the author, however, that solar disturbances are the primary cause for both magnetic variations and radio disturbances. Since any variations in the sources of ionization of the upper atmosphere of the earth would affect the ionic and electronic density of the ionosphere, it is easy to see that the electrical currents due to the rotation of the ionosphere would correspondingly vary. The current set up by motion of and in the ionosphere would immediately be reflected in changes in the magnetism induced in the earth by such variations. If we were to regard the ideal case of an ionosphere in equilibrium rotating with the earth, then the electric current produced by the motion of the electronic shell would induce magnetism in the earth symmetrical about the geographical poles. The compass needle at any given moment, therefore, would point in the direction determined by the resultant of the permanent magnetic field of the earth, whose axis lies in the direction of the earth's magnetic poles, and the field due to the induced magnetism determined by the geographical poles.

Any cosmic effects which would change the degree of this ionospheric shell would, therefore, vary the component due to the induced magnetism. In this way a well known diurnal change in the declination of the compass can be explained since the degree of ionization in the upper atmosphere is different for the illuminated and unilluminated halves of the globe. Any sudden disturbances on the sun which would upset the distribution of ions in the ionosphere might, therefore, be expected to be accompanied with corresponding disturbances in the earth's magnetism.

Herein also would appear to lie an explanation for a lunar period in terrestrial magnetic variations as has been previously hinted. In our quantitative studies of radio reception which show so unmistakably the effects of solar activity, considerable evidence exists for a lunar tide in the ionosphere. If such tides that correlate with the moon actually exist, the changed distribution of electrons with the position of the moon should result in variations in the magnetism induced in the earth, hence the lunar cycle in both magnetic activity and radio field intensities. Curves of field intensities both between Chicago and Boston, and Chicago and Delaware, Ohio, show systematic changes with the hour angle of the moon.

Through the courtesy of Professor Mimno of the Cruft Laboratory at Harvard University it has been possible to examine the percentage of reflection of waves of 3492.5 kilocycles frequencies from the E-layer and as has been reported(8) from about 10,000 hours of observations included in the material examined, there was an increase in the percentage of the time of reflection from the E-layer from 12 to 22 per cent as the moon passed from conjunction with the sun to a position a little past full. Even making allowances for a suspected seasonal correction there remained an 8 per cent increase of reflections in the E-layer as the difference between the hour angle of the sun and the moon increased from 0 hours to 14 hours. A corresponding decrease in the percentage of reflections accompanied the change in hour angle differences from 14 hours to 24 hours. We may summarize this by saying that near full moon there is a tendency for an increase in ionic density on the night half of the earth's atmosphere thus favoring increased numbers of reflections from the E-layer. At new moon, on the other hand, any effect which the moon may have, has probably been lost in the solar effect on the daily half of the earth's atmosphere. Whether the lunar effect on the ionic or electronic density at a given level is due to gravitational or other sources has not yet been determined.

Perhaps one of the most striking results from our investigations of variabilities in radio transmission is the apparent variation of time elapsed in the propagation of waves utilized for the intercomparison of time signals between observatories on either side of the Atlantic.(9) After making all reasonable allowances for variations in lag, the actual computed times indicate 100 per cent variation in the effective velocity of the 17 kilocycle waves between 1929 and 1934 over the Annapolis - Rugby path. Similar but less drastic variations occur from intercomparisons between Annapolis and Bordeaux, and Bordeaux and Rugby. While the assumed great circle routes over which the waves are propagated are not vastly different between the United States and



MONTHLY MEAN VALUES OF APPARENT TIME OF PROPOGATION OF 17-KILOCYCLE TRANS-ATLANTIC TIME-SIGNAL

Figure 5

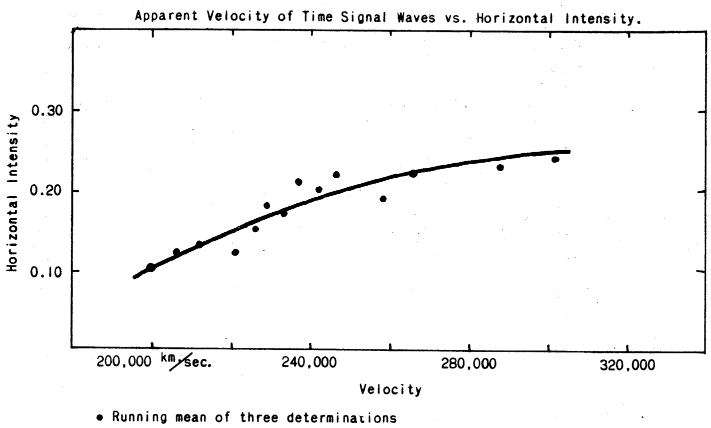


Figure 6

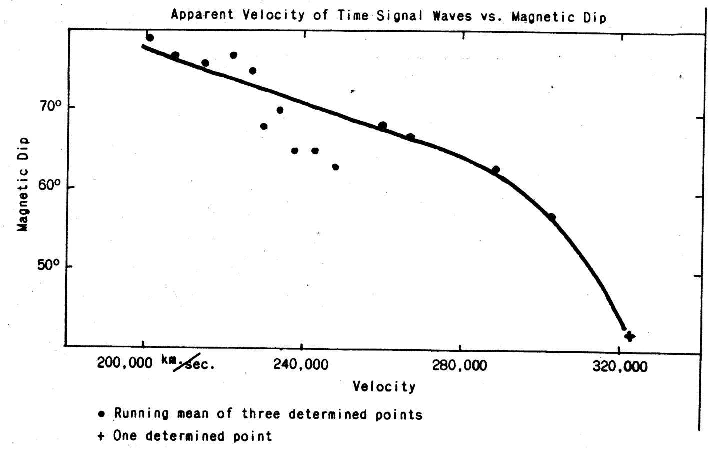


Figure 7

France, as compared with England, the more northern route may be subject to greater irregularities on account of its higher mean magnetic latitude. This has led to a careful study of all available material which might show a relationship between the effective velocity of time signal waves and the routes over which they are presumably propagated.

From a study of some 20 different inter-observatory comparisons distributed throughout the world the mean effective velocity of propagation shows a striking correlation with the value of the horizontal intensity of the earth's magnetic field$^{(H)}$. The calculated velocities have been found to range from less than 200,000 km. per second for a value of 0.08 to a velocity of 300,000 per second, approximately that of light, for values of H exceeding 0.20. A corresponding study of propagation velocities and the values of magnetic dip give consistent results, the highest velocity of 300,000 km. per second corresponding to a dip of 61° and the lowest velocity that of 200,000 km. for a dip of 83°. The relationship between the apparent velocities and both H and dip are represented in the accompanying graphs. The scattering of individual points is probably due chiefly to the fact that the great circle route between the points intercompared in many cases does not correspond to the actual path pursued by the radio wave.

From the foregoing discussion, it appears that the relation of cosmic phenomena to radio communication is to become a subject of increasing importance. That definite cycles in certain cosmic phenomena such as solar activity, the period of solar rotation, and the period of the moon's revolution about the earth, exert their effects upon the characteristics of radio communication appears to be established upon reasonable evidence. As we are able to discover the underlying cause of these cycles in cosmic phenomena we may actually hope in the future to predict with some degree of accuracy the performance of radio communication over various paths at various frequencies through coming years. Difficulties now encountered in communication, due to cosmic causes, may be overcome through cyclical changes in assigned frequencies when a more thorough understanding of cosmic phenomena shall make evident the cure for the present maladies.

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