The Reception of Radio Echoes From Distant Ionospheric Irregularities

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For many years it has been generally known that strong, sharply defined radio echoes occasionally return to the sending station, or to points within the normal skip-zone, after having traversed a path which greatly exceeds the round trip distance to the *F* layer of the ionosphere. Previous investigators tentatively ascribed such effects to reflection from distant mountains or from concentrations of ions in the polar regions. Studies of numerous reflection patterns strongly indicate that the delayed echoes are returned from regions where there is marked curvature of the *F* layer. A region of this sort normally occurs at the edge of the sunlit zone and can turn back a ray which may have traveled many thousands of kilometers around the dark side of the earth. Small nighttime variations in the curvature of the *F* layer are of very common occurrence and are believed to explain several phenomena, including much long period, long distance fading. These variations are frequently of cyclic character and may tentatively be attributed to wave motion in the upper atmosphere.

Introduction

Continuous records of ionospheric layer heights frequently exhibit a phenomenon which may be described as a sudden variation in the number of multiple reflections returned from the *F* layer. A record may be obtained showing, say, three multiples which have intensities decreasing with increasing path length. After a time the second and third multiples will disappear, leaving a record typical of rather "weak" reflections. This condition may persist for fifteen or twenty minutes and be followed by a period of extremely "strong" reflections, when as many as eight or ten multiples are observed. Since the coefficient of reflection at the *F* layer, for the condition of total internal reflection, is always very nearly unity, it is necessary to explain this behavior in terms of large variation in the absorption of energy in the lower layers or to assume that the reflecting surface is not (approximately) concentric with the earth.

We find many records which exhibit little variation in the strength of the echoes over periods of hours before or after the occurrence of this phenomenon. Examination of such records leaves an impression that the bursts of multiples indicate an intensity far greater than normal, while the energy returned in the intervals between bursts is below that which we would expect. This fact can be explained on the assumption that a series of waves appears at times on the surface of the *F* layer. At a moment when the surface over the transmitting (and receiving) location is concave downwards, the transmitted energy is focused upon the receiver; and when the layer, at the point of reflection, is concave upwards the received energy is subnormal. It should be noted that, if the radius of curvature is considerably greater than the equivalent height of reflection, the focusing effect will become stronger as the total path length increases, thus partially offsetting the inverse distance effect. With a very moderate assumption of curvature, in fact, we may expect the sixth or eighth multiple reflection to be returned as strongly as, say, the third.

It will be noticed that the illustration of the

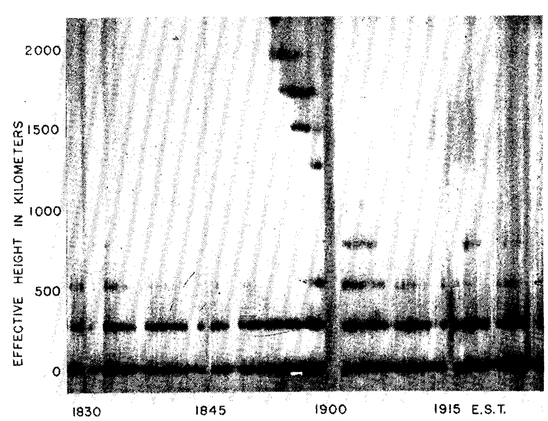

Fig. 1. "Staggered" multiple reflections from the *F* layer, recorded at 3.5 megacycles.

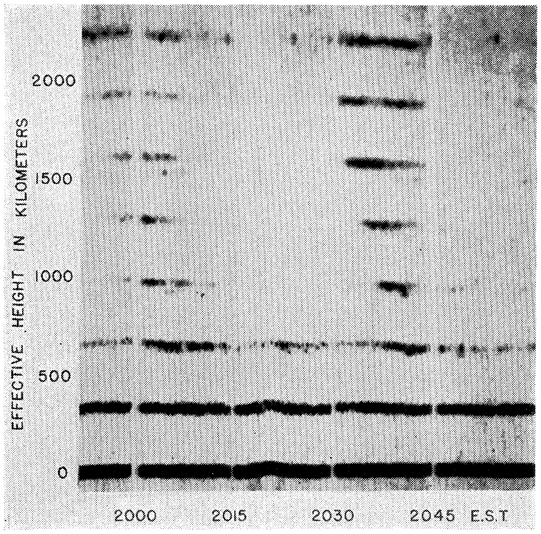

FIG. 2. Another example of "staggered" multiple reflections.

phenomenon shown in Fig. 1 exhibits a remarkable modification of the effects to be expected under the simple theory outlined above. It is characteristic, at least in the early evening, that the onset of one of these bursts of reflection is indicated by the appearance, in addition to the first two or three multiples, of two or three multiples of high order, such as the eighth and ninth. With the passage of a few minutes the highest multiples will disappear while those next below appear in sequence. Five or ten minutes after the onset of the high order reflections, we find that the entire sequence of multiple reflections has been run through in reverse order, leaving only the lowest (continuous) orders. An interesting modification of this pattern is shown in Fig. 2, where each multiple remains on the record until all have appeared, and shortly thereafter the abnormal multiples fade out simultaneously.

We can conceive of no disposition of low layer absorption which could cause the attenuation of certain multiple reflections while permitting those of higher order to return to the region near the transmitter. We must, therefore, see if our hypothesis of varying curvature of the surface of the equivalent reflector can explain the phenomenon. Unfortunately our knowledge of the geometry of such second-order curvature of the layer is indirect and inaccurate. We hope, however, to show that curvature of a type which may reasonably be expected to exist can explain records of the sort we have obtained, and to suggest possible effects of such curvatures upon communication circuits.

A Qualitative Explanation of the Phenomena

Figure 3 is a cross section of an equivalent reflector upon which we have indicated a number of ray paths. This diagram represents a condition we believe to exist and is shown in exaggerated form in order that we may trace a number of ray paths with a minimum of confusion. We have constructed this equivalent reflector by superimposing one wave-length of a cosine wave upon a plane, the cosine curve having a wave-length of 500 km and an amplitude of 5 km. Since this surface is large and at a small angle to the horizontal, we can always find a ray from the transmitter position O (which we have chosen to locate underneath a node of the curve) which is perpendicular to the reflector. This perpendicular, OA, represents the path of a ray which will be reflected directly to a receiver which shares the transmitter location. We can trace a very large number of rays which leave O at different angles to the vertical. These rays will be reflected back and forth between the earth and the layer and, in general, will not be returned to O. A few rays, however, will sooner or later strike a reflecting surface normally and will then be sent back along their outward courses and returned to O after having traversed the region between the earth and the layer a number of times. Consider, for instance, a ray which departs from O along the path OC_1, which happens in this case to be nearly vertical. This ray is reflected in sequence at C_1, C_2, C_3, and so on until it meets the earth normally at C_8. It is then returned exactly along its former path, reaching O where it can be recorded (if it be not too weak) as the eighth multiple reflection.

Figure 3 has been constructed so that we may use its nomenclature to discuss this problem qualitatively. Consider the rays which first reflect from the layer to the left of A, the point marked by the directly reflected ray. Some ray such as OB_1 will be reflected vertically downward to B_2 and then returned to O as the second multiple. Another ray, not shown, will, at its third reflection, meet the layer normally and become the third multiple. This will continue until some ray, such as OM_1, is lost because it has not been turned back towards O before escaping from under the curved region. We find, thus, that, if we examine in sequence all rays to the left of OA, among a multitude of rays which are lost to us are a few which are returned in order as the first, second, third multiples, and so on. This is exactly what we would find in the case of a plane reflector, except that in our case the intensity of the multiple reflections is decreased because of their repeated reflection from a convex surface.

For rays reflecting originally to the right of A the situation is changed in several respects. We have found above that the ray OC_1 returns finally as the eighth multiple. Similar tracing of the rays OD_1, OE_1, and OF_1 shows that they return, respectively, as the seventh, eighth, and sixth multiples. Other rays not shown are, of course, also returned. There is a limiting angle in this case, as in the other. Rays which leave O at too great an angle to the vertical will escape at the right-hand side of the diagram before being turned back. Such a ray is shown as ON_1. In general, the farther to the right the original ray is reflected, within the limit, the sooner it is likely to return because it cannot turn back until it has reached a negative slope to the right of O. At the same time the *probability* of its being returned to O is decreasing as its original angle to the vertical increases. Two factors operate to increase the intensities of multiple reflections returned to O. In general, these rays are being reflected from a concave surface and are consequently focused back, to some extent, upon O. The other reason is that a number of rays may be returned to O after having made the same number of traverses of the region between the earth and the layer; a condition which has no parallel in the case of a plane reflector. For example, the ray paths labeled C and F, in Fig. 3, each contribute to the 8th-order multiple reflection.

We may summarize this case by stating that the normal set of multiple reflections which we would expect from a plane reflector are now represented by the reflections from the left-hand part of the diagram, these being weaker than in the plane case, especially in the higher multiples. In addition to this set of reflections we have an entirely new family reflected from the right-hand side of Fig. 3. In this family the higher multiples are more probable and there are cases of several rays combining to form a single, intense reflection of a high order, as well as a general increase in intensity due to a focusing effect. There is a limit set by the geometry of the layer which operates in such a way that no multiples of *less* than a certain order can be present in this family. If the reflections from the layer shown in Fig. 3 were to be recorded with an instrument having a finite threshold sensitivity we might well expect to see a record showing the presence of the first, second, third, sixth, seventh, and eighth multiples only.

It is obvious that the sixth multiple (made up of OF_1, F_1F_2, etc.) in this case would have a total path length much greater than six times OA, while in the actual case path lengths for the higher orders do not differ by more than one or two percent from multiples of the layer height indicated by the first reflection. This means that the layer we have sketched is indeed an exaggerated example of any similar formation which may appear in the F region. The same conclusion follows from the fact that if the layer height varied by ten kilometers from point to point and minute to minute direct evidence of the height variations would be obvious. We must, therefore, restrict ourselves to postulation of the existence of ripples in the F layer of not more than one or two kilometers amplitude and consider that the phenomena of Fig. 3 are compressed into a lateral space of not more than fifty or a hundred, rather than five hundred, kilometers. Even with this restriction, however, it seems reasonable to

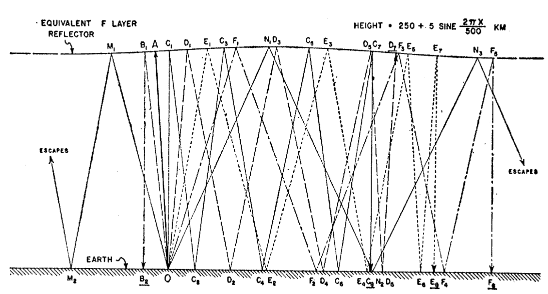

FIG. 3. A cross section of an assumed equivalent reflector showing a number of possible ray paths.

assume that this simple theory of a "dimple" in the layer can explain not only the observed variations in the number of multiple reflections, but also the fact that, from time to time, certain intermediate multiples are missing.

If we consider that a series of waves of this

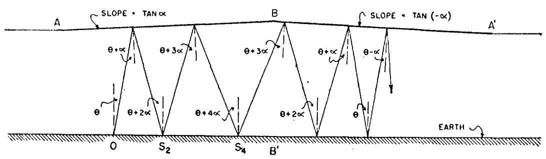

FIG. 4. A straight line approximation to the reflector of Fig. 3.

form roll across the surface of the F layer it is easy to see certain variations which are to be expected in the reflection pattern. When the transmitter is under the center of the part of the curve which is convex downwards, all the multiple reflections will be present in their normal order but with intensities which decrease more rapidly than the increase in the squares of their path lengths. When the layer is symmetrically concave towards the transmitter, all the multiples will be present but with increased intensities. At intermediate positions certain multiples may be returned with great intensities and other multiples of lower order may be forbidden or present only very weakly.

Reflections From a Layer of Symmetrical Triangular Form

This problem does not lend itself to mathematical treatment, and the complexities of a graphical solution for all possible layer curvatures and transmitter positions are insuperable. We can, however, reduce our dimple in the layer to the simple triangular form shown in Fig. 4 and draw some useful conclusions with the aid of the nomenclature we have indicated. We have given a region within which the layer has a slope of $\tan\alpha$ and, to the right, a similar zone where the slope is $\tan(-\alpha)$. From the transmitter at O, on the left-hand side of the diagram, a ray departs at an angle θ to the vertical. So long as this ray is being reflected between the part of the layer having a positive slope and the earth, its angle of incidence upon a reflector increases by α at each reflection. Similarly, when the ray is in the right-hand part of the diagram, the angle of incidence decreases by α at each reflection. Since the angle of incidence upon either the layer or the earth must be zero in order to have the ray return along its outward path it follows that θ must equal $n\alpha$ before a ray can be of interest to us, n being a positive or negative integer, or zero. This greatly limits the number of rays we must consider for any given extent and slope of the layer and any transmitter position, but it is still uncertain whether each of these possible rays will return to O, or, if so, after how many reflections.

If α is so small that we may take $\tan n\alpha = n\alpha$, it is easy to express the distance OS_2 as

$$s_2 = 2h(\theta+\alpha), \tag{1}$$

where h is the average height above ground of the points of reflection on the layer. This may be extended to:

$$s_n = n(\theta/\alpha + n/2)h\alpha, \tag{2}$$

where n is the number of times the ray has traversed the space between the earth and the layer, and θ and α are to be taken as positive for the departing ray shown in Fig. 4. This equation breaks down at the first reflection from a slope other than α, but with its aid a tabulation may be made showing the horizontal distance traversed by each of a family of rays leaving O at angles to the vertical of 0, $\pm\alpha$, $\pm 2\alpha$, etc. The distances from one point of reflection at the earth to the next of course decreases, after the rays pass under the region BA', in the same way that they had increased before.

It is easy, after these preparations, to trace each possible ray for a given set of values of h, α, the distances AB and BA', and for each of a number of transmitter positions. We find that, as O moves from A toward B, the first returning rays (as we examine those with θ positive in sequence) appear as high multiples. As O approaches B', the energy returning to O is contained in lower and lower multiples until, when O is at B', all multiples are present as though reflection were taking place from a plane surface. As O moves from B' toward the right, the procedure repeats itself in the reverse direction.

We have traced the rays corresponding to the case of a dimple 2 km deep and 200 km in total length in a layer at a height of 250 km. The results are exhibited in Fig. 5 where the solid lines represent reflections of rays which departed with θ positive, and the dotted lines the reflections for θ negative. Widened lines indicate cases where two or more rays return to make up a given multiple reflection.

A number of complex rays return as even higher multiples than those shown. These are the ones which depart with θ negative, reflect first at the left of O, then at the right, and finally return to O after very long delays. They are omitted from the figure because their long path length probably reduces their intensity to a value which we could not detect.

The Effects of Asymmetry

Figure 5 represents the reflection pattern we would expect to record if a triangular wave of this sort rolled over the transmitter. It differs from the most usual type of record chiefly in its symmetry. Occasionally, in the middle of the night, a pattern of this sort is observed, one being shown in rudimentary form at the left of Fig. 6. In general, however, the phenomenon is characteristic of the three or four hours after sunset, and at this time the right-hand part of Fig. 5 is absent. The most reasonable explanation of this asymmetry is that waves are superimposed upon

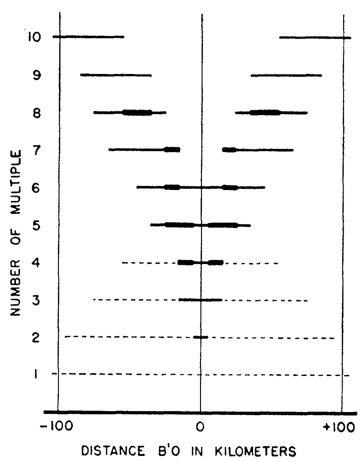

FIG. 5. A computed reflection pattern. The ordinate may be expressed in time to make this figure comparable with the experimental records.

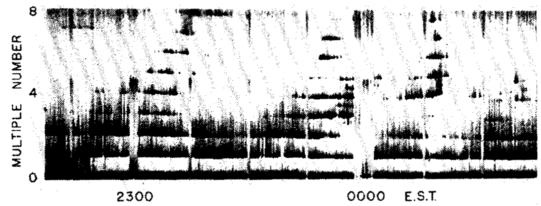

FIG. 6. An example of the variation of multiple reflections with time. The portion of the record centered at 2300 should be compared with Fig. 5.

a sloping layer. Examination of a number of records gives us an average increase in layer height (from west towards the east) of about one kilometer in a hundred, during the evening. If we superimpose the ripple of Fig. 4 upon this slope we find that the slope AB is only one-third of that between B and A'. The region BA' is now very effective in turning back rays which originated at the left of B, but rays which are traveling towards the left will, in general, escape. This asymmetry is shown in Fig. 7, which was drawn up under the same conditions as Fig. 5, except for the slope of -0.01 upon which the ripple was superimposed. The seventh, eighth, and ninth multiples appearing just to the right of O are part of a sort of second-order pattern most of which is contained in multiples higher than those shown. This part of the pattern is sensitive to small changes in the geometry of the layer and may be expected to be rudimentary in many cases. It is probable that, when it is present, it is blurred sufficiently to merge it with the primary pattern, the combination giving a record of the type of Fig. 2.

The Magnitude of Ripples in the F Layer

We have remarked that the amplitudes of ripples of this sort cannot be more than one or two kilometers, or the height variations would be directly measurable. Since this is the case, we expect that the phenomenon of the forbidden multiple reflections should be observed only when the receiver and transmitter are very close together. This is because some of the transmitted rays must pass laterally beyond the receiver and return to it, and this is impossible unless θ and α, in Fig. 4, are of the same order of magnitude. For transmission over distances comparable to the height of reflection, θ must be many times larger than any angle between the earth and the ionized layer could possibly be. This conclusion has been checked experimentally. The records reproduced in Figs. 1, 2, and 6 were made with the receiver within 250 meters of the transmitter, while simultaneous records were made at a distance of 240 kilometers and showed no indication of the phenomenon. As a check on the maximum slopes in the layer, the receiving equipment was removed to a location about four kilometers from the transmitter and operated there for about ten days. The records made at this distance exhibited the effects of *focusing* in the variation of the number of multiples, but the echelon formation of multiple reflections was present only in rudimentary form in one or two cases although the records made at 250 meters distance immediately before and after the removal indicated a number of occurrences nearly every day.

If we were to draw a circle through the points A, B, and A' in Fig. 4 we would find a radius of curvature of 2500 km, and this figure may well be increased to 4000 km to allow for the defocusing effect of the convex surface of the earth. It is easy to calculate the variations in intensity of a ray reflected between a cylindrical mirror and a plane reflector, as the number of multiple reflections increases. The results of such a calculation, for a layer height of 300 km and a radius of curvature of 4000 km, are shown in Fig. 8. Perfect reflection and no attenuation in the absorbing layers have been assumed, but the effect of attenuation may be simulated by giving the ordinates in the figure an arbitrary negative slope. Since a truly cylindrical curvature cannot be expected, it is probable that the cusps computed for the concave case are blurred out of existence so that the values fall more or less along a smooth curve which, for multiples beyond the second or third, varies inversely as the multiple number rather than as the square of that number. The most interesting conclusion from the figure is that we may expect the high multiples, such as the eighth or tenth, to vary as much as 20 db if the reflecting surface becomes alternately concave

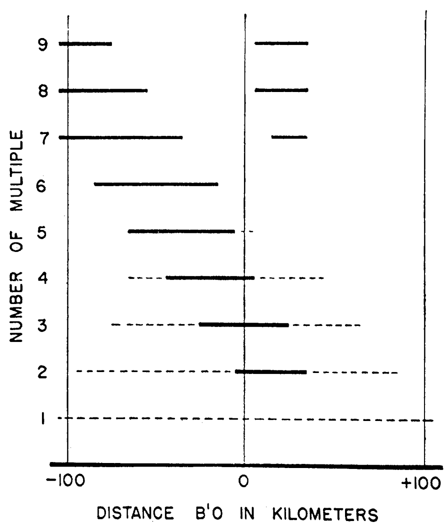

FIG. 7. The computed reflection pattern corresponding to the layer of Fig. 4 and the records of Figs. 1 and 2.

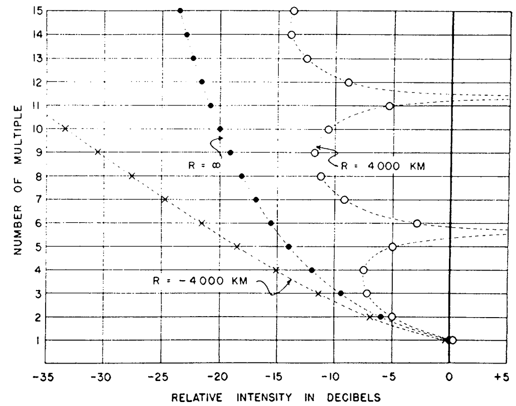

FIG. 8. The computed variation in intensity of a ray reflecting between a plane and a cylindrical mirror separated by 300 km.

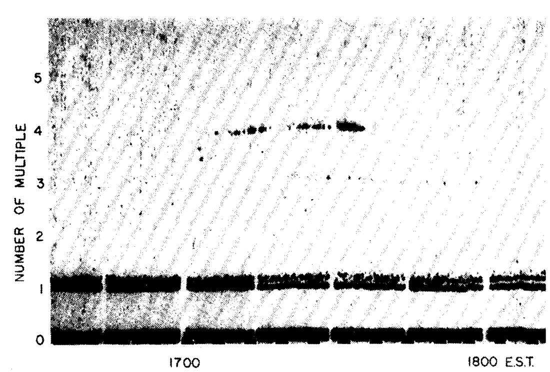

FIG. 9. A record showing the presence of a fourth multiple reflection which is stronger than either the second or the third.

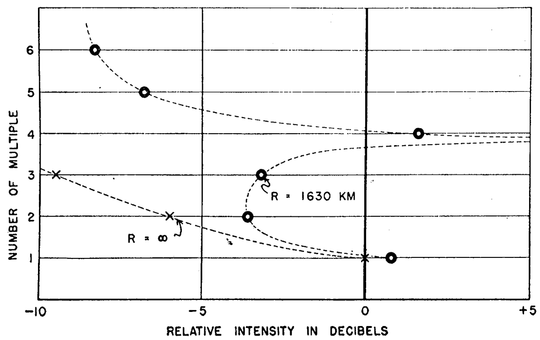

FIG. 10. The computed variation in relative intensity of several multiple reflections for a case where the curvature is large.

and convex. An effect of this magnitude would be caused by the passage of a sine wave, such as that shown in Fig. 3, having a wave-length of 200 km and an amplitude of 0.25 km.

Occasionally random curvatures of greater magnitude occur. The record corresponding to one of these is reproduced in Fig. 9 and, although made with the receiver sensitivity below normal, shows that the fourth multiple was, for a time, nearly as strong as the first, and that the second is absent while the third is represented by a very weak trace. The variations in intensity compare favorably with those computed for a cylindrical curvature having a radius of 1630 km which are exhibited in Fig. 10.

THE FADING OF LONG DISTANCE SIGNALS

It is obvious that the parts of this discussion dealing with phenomena which are detectable only in the special case of vertical incidence observations can have little importance in practical communication. They have, however, enabled us to postulate the frequent occurrence of significant changes in the curvature of the F layer. For communication over short distances these changes are unimportant, but when the total length of the transmission path approaches the radius of curvature they become very interesting. It is possible that much of the long period fading observed on long distance circuits may be a result of this effect. This type of fading occurs too slowly to be a result of polarization changes or interference between a number of rays. It seems to us that the hypothesis of varying attenuation in the absorbing strata may not explain the cases of slow fading observed at night and at high frequencies, while the mechanism we are suggesting is not, within limits, a function of frequency. An example of what may well be a focusing effect is shown in Fig. 11, which is a record of the field strength of a short wave broadcasting station operating on a frequency of about 12 megacycles at a distance from Cambridge of 5200 kilometers. The transmission begins at 0115 E.S.T., when the ionization density has fallen so low that only one ray path is effective. This is indicated by the absence of the rapid fading caused by the interference between several rays. The signal remains steady and pleasant to hear but with a smooth fading cycle

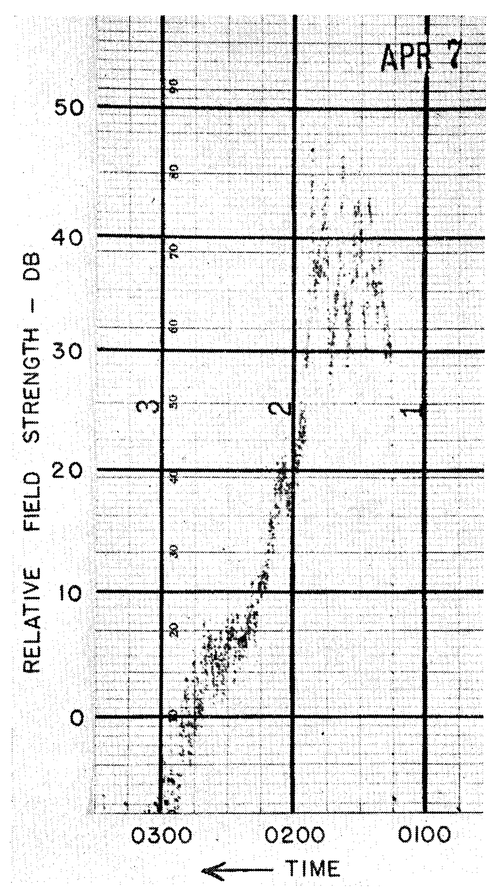

FIG. 11. A record of the field strength of a transatlantic short wave broadcasting station. Note that the time scale reads from right to left.

having a period of about ten minutes and a full amplitude of nearly 20 db. This lasts until about 0155 E.S.T. when the ionization density falls below the limiting value, the signal strength decreasing by 30 db in the next few minutes. It appears to us that this slow, cyclic fading without change in the general signal level is evidence of the focusing effect we have postulated.

An Hypothesis of Ripple Formation

Under the conditions obtaining in the F region in the evening of a magnetically quiet day, the equivalent height of reflection increases by about twelve or fourteen kilometers per megacycle in the region near three or four megacycles. This can be interpreted to mean that the density of ionization increases by about five percent for one kilometer increase in height. If, then, irregularities in height of this order of magnitude are to be explained by assuming that some non-uniform source of ionizing energy is operative, the *local*

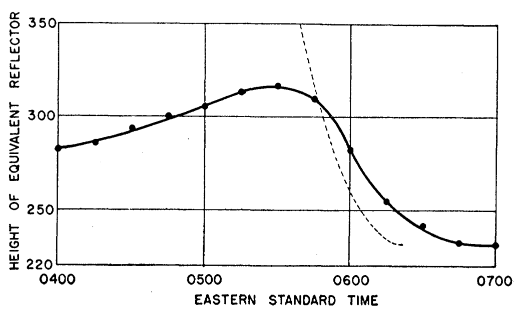

FIG. 12. The variation of F layer height with time in the sunrise period (3.5 megacycles; November, 1938).

variations in intensity of this source must be of the order of ten percent of the intensity which would maintain the ionization in equilibrium at a value of 10^5 electrons/cm^3. While such variations in incident energy are not impossible and are, in fact, smaller than variations which are known to affect the E region, it is improbable that the effect we are discussing is due to this cause. If the total ionization in part of the F region were changing in such a way as to cause variations in the equivalent height of reflection at a fixed frequency, the changes would give rise to phenomena of other types, such as cyclic variations in the critical frequency, which have not been reported.

We prefer to believe, therefore, that these effects are due to a temporary redistribution of the free electrons already existing in the lower part of the F region. The simplest mechanism which will cause such a redistribution is an atmospheric compressional wave. We have noted that our phenomenon occurs generally in the period immediately following sunset. This permits us to postulate a disturbance, set up by the cooling of the upper atmosphere at sundown, which is propagated in the direction opposite to that of the advancing shadow. It will be noted that this direction of propagation, together with the slope in the equivalent layer, is necessary to explain the observed asymmetry in our records.

It is difficult to estimate the velocity of propagation in the tenuous medium which exists at the height of the F region, where the mean free path is probably several kilometers and the temperature and pressure can only be guessed at, but it is obvious that waves can be set up whose length is large compared to the mean free path. Such waves would cause compressions and rarefactions of the free electrons in the F region in essentially the same ratio as in the atoms or molecules of gas if, as is unquestionably the case, the period of half-recombination is long compared to the period of the wave, and these changes in electron density would appear as changes in the height of the equivalent reflector.

We are not able to deduce the wave-lengths of these disturbances accurately, but they seem to be of the order of two or three hundred kilometers. The records which exhibit a definite cyclic character give a mean period of about 20 minutes, although it often varies between half and twice this figure. The velocity corresponding to these estimates is some six or eight hundred kilometers per hour or, say, 200 meters/second. This figure is of the magnitude of the velocity of sound and is, therefore, somewhat interesting. It is barely possible that a careful study of this phenomenon, involving simultaneous observations at two or more locations, might lead to a reasonably accurate figure for the velocity of sound at the 300-kilometer level.

Focusing of Echoes at Sunrise

In contemplating the effects of changes in curvature of the equivalent F layer reflector it is necessary to consider the curvatures associated with sunrise. This region is important because there is a large change in effective height in a horizontal distance of a few hundred kilometers, with correspondingly large curvatures, both convex and concave. Fig. 12 shows the average variation of equivalent height with time for a number of magnetically quiet days in November, 1938. The dotted line indicates the height at which the sun's rays strike the region after grazing an "opaque" sphere of 6600 km radius, and is shown here only because it is interesting to note that the layer height begins to fall before there is any directly incident ultraviolet radiation, indicating that diffusion is an important factor at these heights.

If we assume that there is no variation in electronic density with longitude (as distinguished from time) the heights of Fig. 12 may be plotted as a function of distance by use of the fact that sunrise, in these latitudes, advances at some 1200 km/hour. On this sort of graph radii of curvature may be measured which vary, in this average case, from infinity to about 5000 kilometers. If the curvature is somewhat greater than average we should immediately expect an increase in intensity of the echoes returned from the concave region exactly as in the case of the random curvatures discussed above. Under magnetically quiet conditions and when the frequency of observation is well below the critical frequency, this deduction is confirmed experimentally. An example of this sort of record is exhibited in Fig. 13, where the focusing of the fourth and fifth multiple reflections is clearly marked.

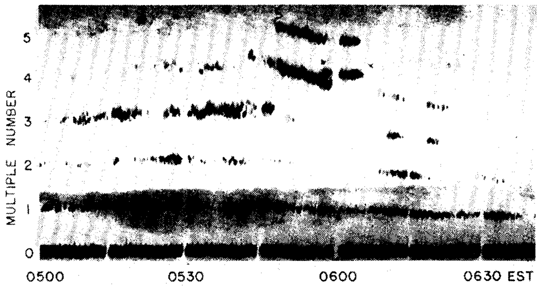

FIG. 13. A record showing the focusing of the fourth and fifth multiple reflections at sunrise (November, 1938).

THE RETURN OF LONG DELAY ECHOES

At this point we should emphasize the distinction between the sort of concavity in a layer which can cause the focusing of a beam of incident energy, and the effect of slope in a layer which can turn back a ray which has had a component of its path in the direction of the lower equivalent height. The latter effect is of especial importance in the sunrise zone. A ray which has been propagated along the dark side of the earth will, upon entering the sunrise zone, meet the reflecting layer and the earth at an angle of incidence which decreases with each reflection until it reaches zero, or until the ray passes on into a region in the sunlit zone where the layer is again concentric with the earth. If the angle of incidence is reduced to zero and if the horizontal component of the direction of the ray is perpendicular to the edge of the shadow, the ray will be returned toward the transmitter along a path similar to that followed on its way to the sunlit zone. This mechanism can be used to explain echo paths of long delay, such as some which have been ascribed to "G" layers.

In Fig. 14 we have shown the average F layer curvature in the sunrise zone deduced from Fig. 12, with the addition of a sporadic E layer. Between these layers we have indicated a ray which enters the region from the left and which finally meets a reflecting layer perpendicularly at

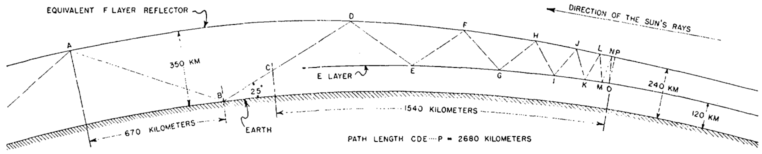

FIG. 14. A cross section of the ionosphere in the sunrise zone, showing the path of a ray which may be returned to the neighborhood of the transmitter.

P so that it will return along its outgoing path. This construction is intended to illustrate the mechanism of reflection of one echo of long delay which was observed, using a sweep-frequency technique, on November 7, 1938. This echo was delayed by almost exactly 0.1 second, corresponding to a total equivalent path of 30,000 km. The delay was not, within limits, a function of frequency, indicating that an explanation of its existence must be based upon the geometry of the reflecting surface rather than upon variations in ionic density. At the time of this record, which is not clear enough for reproduction here, the great circle distance from Cambridge to the point where a ray would meet the sunrise line perpendicularly was somewhat less than 12,000 kilometers. Thus, allowing for the vertical components of the ray path shown in Fig. 14, the reasonable assumption that the average velocity of propagation was slightly less than the velocity of light would enable us to explain this echo completely. The E layer ionization was assumed because the record showed a tendency towards a family of reflections differing in their "apparent height" by about fifty kilometers, which is approximately half the spacing between the two layers at the point where reflection occurred perpendicularly. A second ray, after following a path almost identical with that shown in Fig. 14, could be turned back (by making two successive reflections at the same angle of incidence) without having encountered either layer normally but having traversed the region between the layers once more (or less) than the ray shown in the figure. Thus a family of reflections having very long delays which differ by multiples of the time corresponding to the distance between the E and F layers could be returned to the transmitter. The (sporadic) E region ionization may have existed only in the sunrise zone, or may have extended a considerable distance along the path towards the transmitter. The latter assumption would help to explain the fact that the reflections were strong enough to be recorded, because propagation between the E and F regions should be subject to much less attenuation than propagation between the F region and the earth, where the ray would pass repeatedly through low level absorbing strata.

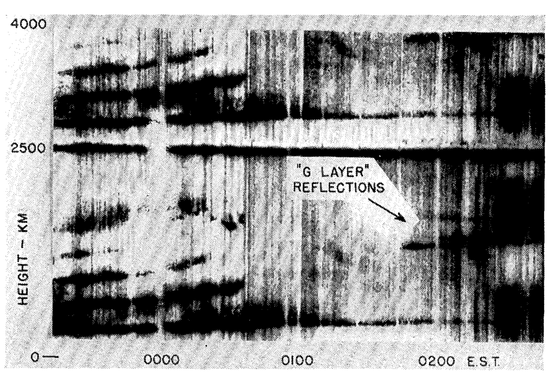

FIG. 15. A record showing, at the right, a group of G layer reflections. Note that the base line is below the bottom edge of the photograph, the lowest continuous trace being the first F layer reflection. Part of the pattern is repeated and normally the height scale would be repeated also.

Figure 15 is a reproduction of a record exhibiting an unusually uniform structure of "G layer" reflections which appeared at about 0200 E.S.T. at the end of April, 1934. Here the apparent "height" of the group is about 1500 km. Since the use of 60-cycle pulses causes the whole reflection pattern to be repeated with a period corresponding to 2500 km of effective height, the equivalent distance is 1500 plus a multiple of 2500 km. At this time the edge of the sunlit zone was about 3000 km north by east of Cambridge. Comparison of this pattern with Fig. 14 will indicate that the effective distance of the reflections was about 4000 km, the additional 1000 km being accounted for chiefly by the vertical components of the ray direction. The family of reflections referred to above is seen distinctly in this record, and their spacing is that to be expected if the height of reflection, at the point where the rays turned back, was about 220 km.

In conclusion, we should refer to a paper[1] which came to our attention after our oral presentation of this report. The authors of the paper concluded an attempt to explain certain complex echo patterns with the paragraph:

"However, we have to consider the other possibility put forward by one of us, that at times the ionized regions may be an undulatory

[1] G. R. Toshniwal, B. D. Pant, R. R. Bajpai and B. K. Verma, Proc. Nat. Acad. Sci. (India) **6**, 161–174 (1936).

surface with various ledges here and there. The presence of such a structure along with the possibility of arrival of echoes from angles other than the vertical can easily account for the complex echoes. If this view of the production of the complex echoes is accepted, we have to search for the agency which can cause such a structure of the ionosphere."

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Nuclear Isomerism in Selenium and Krypton

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A study has been made of the radioactive chain

$$Se^{83}\rightarrow Br^{83}\rightarrow Kr^{*83}.$$

The last member is an isomer of the stable krypton of mass 83. An isomeric pair $Se^{79\text{ or }81}$ has been found and the two genetically related nuclear isomers have been separated chemically. Kr^{83} and Br^{83} are produced by the fission of uranium and thorium as well as by the bombardment of selenium with deuterons and slow neutrons.

IN the course of an investigation of radioactive products of thorium and uranium fission, we observed a radioactive krypton growing out of a radioactive bromine with a period of 2.4 hours. This bromine period coincides with that assigned by Snell[1] to Br^{83}, which he found to be the product of the decay of Se^{83} produced by deuteron bombardment of selenium. He did not, however, observe radioactive krypton growing out of the bromine. We therefore repeated this deuteron bombardment of selenium and were able to extract from the products a radioactive isotope of krypton having the same period as the fission product, and emitting the same type of radiation. Since the radioactivities of selenium and bromine appeared rather complicated, we thought it desirable to go over the different points in detail.

The main results of our investigation are the identification of an excited state of the stable Kr^{83}, the identification and chemical separation of an isomeric pair in $Se^{79\text{ or }81}$, and confirmation of the identification of Se^{83}. Although discovered by Snell, there had been some uncertainty as to the true half-life of Se^{83}.

[1] A. H. Snell, Phys. Rev. **52**, 1007 (1937).

THE CHAIN $Se^{83}\rightarrow Br^{83}\rightarrow Kr^{*83}\rightarrow Kr^{83}$

We have produced Se^{83} by means of slow neutrons with the reaction Se^{82} (n,γ) Se^{83} and by deuterons with the reaction Se^{82} (d,p) Se^{83}. The latter reaction of course gives much more concentrated samples and has been used for all the chemical separations. In order to determine the period of Se^{83}, repeated extractions of Br^{83} are necessary to identify its parent in the complex of selenium activities. The Br^{83} can be recognized easily from the fact that it is the only bromine isotope giving rise to an active krypton.

In order to make repeated extractions of bromine, the bombarded selenium was converted to selenic acid free of the primary 34-hour bromine activity produced by the reaction Se^{82} $(d,2n)$ Br^{82}. Preliminary experiments with the more rapidly prepared selenious acid had shown serious difficulties as a result of the apparent impossibility of achieving a complete extraction of bromine from this material, so that the longer chemical preparation of selenic acid was found to be necessary. To the selenic acid solution we added periodically five milligrams each of potassium bromide and iodide, and precipitated them with silver sulphate solution. Decay curves of the bromine activities thus

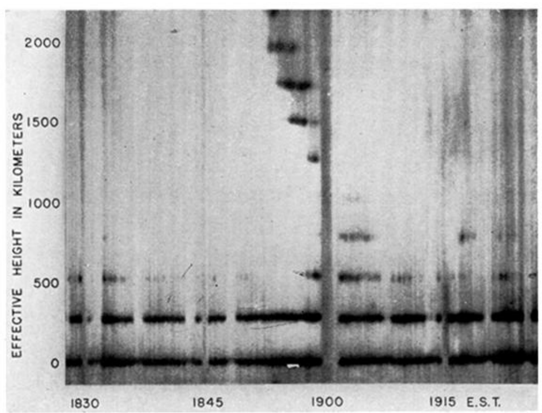

FIG. 1. "Staggered" multiple reflections from the *F* layer, recorded at 3.5 megacycles.

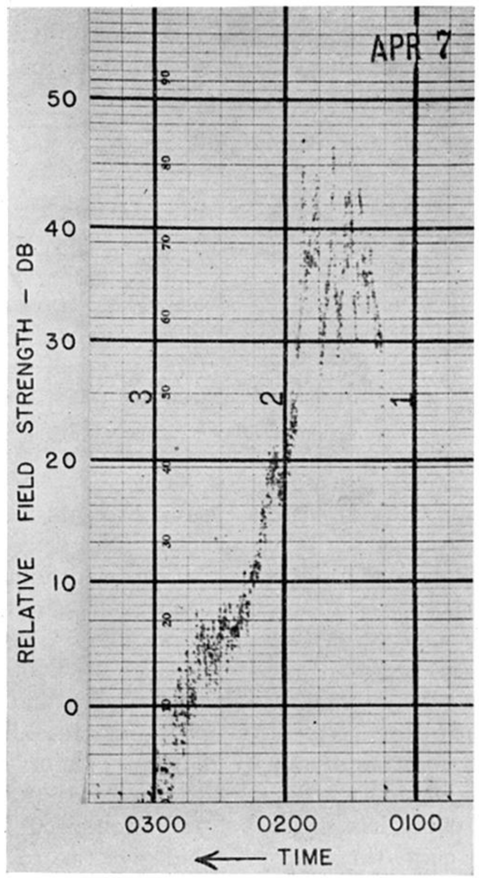

FIG. 11. A record of the field strength of a transatlantic short wave broadcasting station. Note that the time scale reads from right to left.

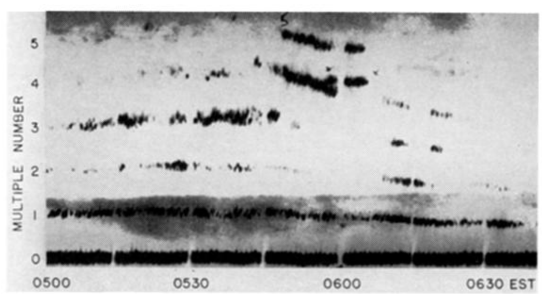

FIG. 13. A record showing the focusing of the fourth and fifth multiple reflections at sunrise (November, 1938).

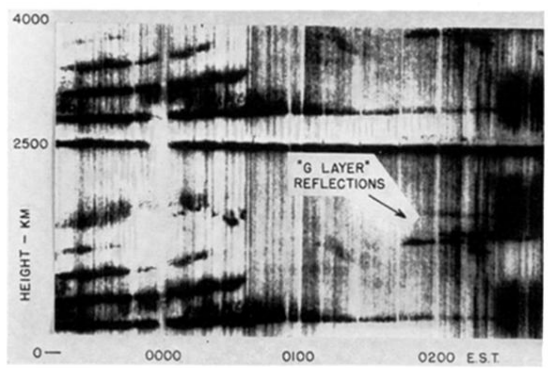

FIG. 15. A record showing, at the right, a group of G layer reflections. Note that the base line is below the bottom edge of the photograph, the lowest continuous trace being the first F layer reflection. Part of the pattern is repeated and normally the height scale would be repeated also.

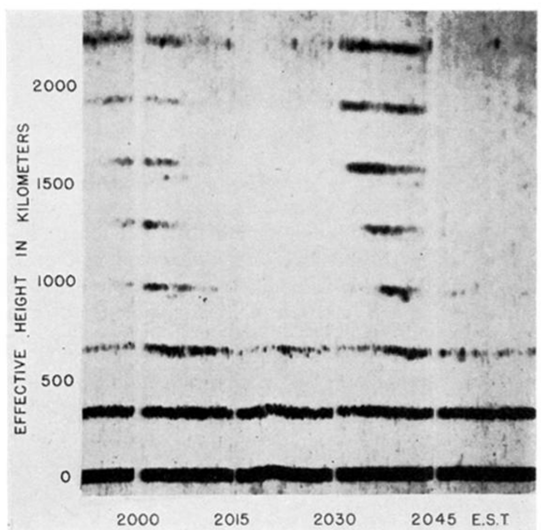

FIG. 2. Another example of "staggered" multiple reflections.

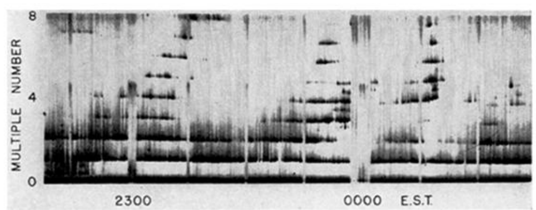

FIG. 6. An example of the variation of multiple reflections with time. The portion of the record centered at 2300 should be compared with Fig. 5.

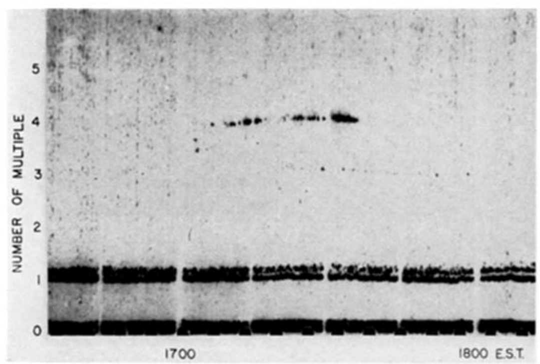

FIG. 9. A record showing the presence of a fourth multiple reflection which is stronger than either the second or the third.