Wave Propagation at High Frequencies

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NO attempt at an explanation of high frequency propagation phenomena can be considered entirely acceptable unless it ties up in some way with already fairly well organized conceptions of the nature of propagation of low frequency waves.[1] I am unable to go into this matter more fully than to say that the most reasonable ideas that have been advanced by way of explaining propagation of low frequencies, assume a more or less gradually increasing state of ionization in the higher level of the earth's atmosphere. Heaviside in England and Kennelly in this country were the first to suggest the existence of an ionized region above the surface of the earth which might have an influence on the mechanism of propagation of radio waves. It can be shown by mathematical calculations that such ionized layers would be able to transmit an electromagnetic wave with higher velocity than it would have when traveling thru un-ionized space. If then we imagine a wave sent out from a vertical antenna, it is evident that many of the rays will strike such an over-head region at a more or less oblique angle, but instead of being sharply reflected, will be gradually bent over because the top of the wave travels more rapidly than the bottom.[2] Thus they will be bent back towards the earth. The earth itself has (from the reaction of the induced currents in the earth's surface at the base of the wave) an action tending to straighten the waves or keep them nearly perpendicular to the surface of that portion of the earth over which they travel. This gives a tendency for the wave to climb over and around obstacles, rather than to penetrate them or jump over them. Nevertheless, at certain frequencies certainly, pronounced jumping effects or shadows can be observed; in other words, the frequency plays an important part in phenomena of this sort. If any one is interested in getting a more complete summary of low frequency information, it can be found in the Proceedings of the Physical Society of London, volume 37, part 2, February 15, 1925.

Ionization in the Upper Air

A word as to possible causes of ionization in the earth's atmosphere and the nature of that ionization may not be out of place. Ionization must be thought of as the breaking up of neutral gas molecules into positive and negative constituents, the negative constituent being the light and very mobile electron and the positive constituent being the much heavier and more sluggish ion. Among the causes which produce ionization of the atmosphere, may be mentioned the ultra-violet light from the sun and direct bombardment of the outer layers of the earth's atmosphere by electrons thrown off from the sun—notably from sun spots. Excessive potential gradients produce perhaps violent movements of electrons and ions in connection with lightning strokes. Other electrical phenomena, such as possibly the aurora, could no doubt greatly augment the degree of ionization. This is because an electron under the influence of the strong potential gradients can move with a very high velocity and act upon a neutral ion when it hits it, like an explosive, jolting other electrons loose from the neutral particle.

De-Ionization

Another thing that must be kept in mind with regard to the general process of ionization is that it has a counter part in de-ionization. De-ionization may be thought of as a re-marriage which has taken place between the divorced electron and its positive mate. Of course, it may not re-marry the same mate, but in the social life of the electron that appears to make no essential difference. These positive and negative particles move rapidly about, often accidentally approaching close enough to each other so that their affinity for each other asserts itself and a reunion between the positive ion or at least some positive ion and some one of the electrons, takes place so that de-ionization or re-combination is constantly taking place. Now, if ionization has taken place in regions where the gas molecule population is very sparse, the divorced individuals may move about for a long while before they meet any of the opposite affinities; therefore ionization at very high levels of the earth's atmosphere is persistent and indeed in the very rare high levels, a considerable amount of ionization is probably present all the time. The ionization and conductivity however, probably does not rise indefinitely because this would be limited by the very sparsity of the electron population.

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1—The author refers to the lower radio frequencies.—Tech. Ed.

2—This is in accord with our comment on The Reinartz Theory of sharp reflection. See "Editor's Notes" p. 12 of *QST* for April, 1925. See also "Is There a Heaviside Layer?" page 33 *QST* for September, 1925.—Tech. Ed.

Wave-Energy Losses

For low frequency oscillations, namely, long waves, it would appear that energy can be lost or dissipated in only three ways.

First, some of the high angle rays will not be sufficiently refracted to ever bend down again to the earth but pass on out beyond the earth and their energy is lost in space.

Second, the ions and electrons would constitute a medium capable of absorption as the rays force them to move about and dissipate energy by collision.

Third, that portion of the wave which is earth-bound (and for very long waves, this means probably the major portion of the wave) suffers absorption from currents induced in the earth, owing to the fact that the earth's surface is *neither* a perfect dielectric nor a perfect conductor.

Absorption

For rarified regions where collisions are infrequent, the absorption must be very low. In order for a wave to exist in free space with its "feet off the earth," it is obvious that it must reach levels which are very high in comparison to the length of the wave. If now we consider the causes which affect ionization, we see that one principal cause, namely, sunlight, is removed at night, and therefore the ions will rapidly recombine after sun-down in the lower levels, but in the very high levels where the mean free paths of the electrons are large, which means that they can wander a long way without possibility of collision, the ionization will still be strong. Some of the wave energy will therefore reach high levels before it is turned over and brought back down to earth and when this happens, long distance signals of great intensity are produced because the region traversed has been mainly a non-absorbing medium. The lower levels have had their ions removed by re-combination and in the upper levels the ions are too far apart to collide readily. Of course, when the wave returns from the high altitude it probably fixes its feet on the earth again but we have sufficient evidence indicating that the night waves are far more complicated in structure when they arrive at the receiving station than those received by daylight.

Fading effects may be due to interference phenomena between earth-bound and reflected rays or to interference between reflected rays coming from different portions of a somewhat complicated upper ionized layer,[3] or it may be connected with rotation of the plane of polarization of the wave, which altho starting off essentially vertical from the transmitting antenna, may suffer a rotation somewhere along the route when that route is a high level route.[4] Evidently the reflecting or refracting layer is not at rest because of the rapidity with which fading effects alter. Moreover, conditions temporarily arise which will concentrate energy in some region at a great distance from the transmitter, thus giving rise to freak transmissions which we know are very common, especially in the 1500-KC. band. It is also well known that if the frequency is lower, the difference between night and day effects becomes less and less.[5] Freak transmissions are not as common on very low frequencies, also monthly and annual variations of the signal strength are of lesser magni-

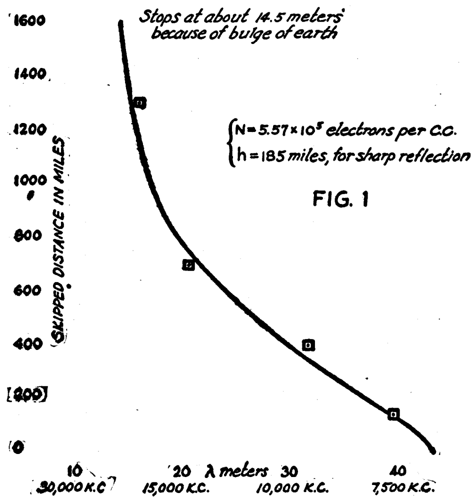


FIG. 1 THE "SKIPPED DISTANCE" from observation and calculation.

tude. It generally can be said that up to 2000 KC. the daylight range, with a given amount of antenna power, steadily falls off and the opportunities for freak transmissions are most numerous in the winter nights and are most numerous at the higher frequencies. This, then, is the general situation for frequencies lower than 2000 KC.; that is, for waves longer than 150 meters.

The experimental data and theoretical considerations which have led to this brief outline of the low frequency situation are too well established to be upset readily and any consideration of high frequency wave propagation must not disturb well tested older ideas as to the situation at low frequencies. However, the experiments with high frequency waves, described in the

3—See *QST* for Sept., 1923, pp. 25 and 26.—Tech. Ed.

4—*QST* will, within 6 months, present some results of an investigation of wave-front distortion. Preliminary notes will appear in the Experimenter's Section.—Tech. Ed.

5—The very uniform signals of LY and LPZ are perhaps the best illustrations.—Tech. Ed.

following pages, have brought to light new facts which cannot be explained by the low frequency theory in its present form. A new idea must be introduced into the theory in such a way as to leave it untouched in the low frequency range and yet to bring it into agreement with the high frequency facts. This new idea fortunately has already been suggested by Appleton in England and independently by Nichols and Schelling in this country, although they have not used it as we use it. The new idea consists in the recognition of the fact that the magnetic field of the earth influences the motion of the electrons in the atmosphere, and calculation shows that this influence is important for the propagation of high frequency waves and does not affect appreciably the low frequency waves. An appeal to this influence and to the well known laws of the reflection and refraction of waves has resulted in a theory which appears to fit the facts fairly well and which altho by no means complete, will at least, we hope, encourage theoretical and experimental work which will throw light on the subject.

The data upon which the theoretical considerations of this paper are based, has been gathered by the Radio Division of the Naval Research Laboratory with the assistance of the American Radio Relay League, and its co-workers in the foreign countries. Some data have also been collected from commercial companies at home and abroad.

The theoretical work has been very largely carried on by the Superintendent of the Heat and Light Division of the Naval Research Laboratory. A preliminary note bearing on the work has been sent to *Science* and a full treatment of the theory will be published in some scientific magazine, we hope within a few months. In presenting here the salient features of this work, it will be borne in mind that in estimating the data from hundreds of observations we have tried to keep to the method of general averages to which there will be unquestionably a good many individual exceptions[7].

The "Skipped Distance"

Perhaps the most striking fact which has come out of the studies of radio transmission at frequencies in excess of 2,000 KC. and particularly in excess of 4,000 KC., is the evident existence of a "skipped distance" combined with the fact that in many cases the signals at relatively great distances are much stronger than they are at relatively short distances.[8]

You will all recall how some of the earlier work in the 15,000 KC. band failed because the observers were not far enough away from the transmitter. Signals could be picked up 40 or 50 miles away, sometimes 100, after which they disappeared, and not until they were sought for at points many hundreds of miles distant, did we realize that we were getting anywhere with our transmissions. What actually happens with the 15,000 KC. wave is that the portion of the wave which follows the earth, is absorbed very rapidly and is so attenuated that it cannot be received at any great distance on the other hand, other components of the radiation with a higher angle upward are either reflected or refracted from the Heaviside layer and returned to the earth at a considerable distance from the transmitter. Mr. Reinartz has shown in his article in *QST* for July, 1925, how this might be possible in the case of reflection and altho we cannot agree with him as to the height of the reflected layer, nor as to the mechanism of reflection, his sketches in that paper will serve well enough to illustrate our points. This reflected or refracted component marks then the beginning of a region of good reception beyond the "skipped distance." In the case of a very high frequency, low powered transmitter, the actual missing region may be definitely determined but at somewhat lower frequencies—say in the neighborhood of 4,000 KC.—the effect is obscured (especially if the transmitter be of high power) by the persistence of the ground wave. Nevertheless by direct measurements and comparisons of signal strength at different distances, one can get a fairly good idea of the extent of what we will still call the skipped distance, even if it is partially filled in with energy from the ground wave.

Conditions even in daylight vary quite materially from summer to winter and indeed the skipped distance in the 15,000 KC. band is scarcely half in the heat of the summer months of what it is in the midwinter months. We have also confined our calculations for the present to conditions at midday, being fully aware of the fact that they merge gradually over, at either end of the day, into nocturnal conditions. Most reliable observations of the skipped distance were taken by Major J. O. Mauborgne, S. C., U. S. Army, on the U. S. S. ST. MIHIEL, enroute from New York to Panama. These observations, taken day by day, and in the spring of the year when conditions are fairly average, gave quite definitely the skipped distance between 19,000 and 7,500 KC. and permitted us to draw the curves shown in Fig. 1. This curve shows how the skipped distance increases as the frequency is raised, starting with 150 miles for 7500 KC. and increasing to 1400 miles for

6—For a brief general discussion of the Kennelly-Heaviside theory, the Eccles-Larmor theory and the Nichols-Schelling theory, see "Is There a Heaviside Layer?" page 33 *QST* for September, 1925—Tech. Ed.

7—A very important point which almost all amateur experimenters overlook. Much of the material submitted to *QST* is based on too few observations. Tech. Ed.

8—See p. 10 of *QST* for April, 1925.—Tech. Ed.

25,000 KC. It is necessary now to turn to certain theoretical considerations to see why there should be any skipped distance at all, understanding that there will not be an actual skip but only a region of weak signals if the transmitter is very powerful, and the frequency not very high.

The Causes of "Skipped Distance"

We have good reason to say that the change from what we have long been familiar with as normal radio conditions, to what we now recognize as high frequency conditions leading to extraordinary range of communication at low power, occurs at about 130 meters wavelength (2300 K.C.) If we realize that in the upper atmosphere the free electrons will be moving about with great rapidity, there is reason to suspect that they will execute spirals about the lines of the earth's magnetic field. When this phenomenon is considered quantitatively in connection with what is known as total internal reflection, we can derive some interesting results. Total internal reflection may be explained by analyzing what happens when a ray of light passes from a point in a medium of any given wave velocity towards the boundary surface of a second medium in which the ray would have a higher velocity. This occurs for instance, when a ray of light from a source under water becomes incident upon the surface which bounds water and air, as shown in Fig. 3. In general a small part of the ray is reflected and a large part of it emerges into the air, being bent away from the normal to the surface as it emerges, (Fig. 3B) but at a certain angle (known as the angle of total internal reflection). the portion of the ray which emerges falls parallel to the surface of the water (See Fig. 3C) and an infinitesimal increase beyond this angle causes this ray not to emerge at all, but to be refracted completely back into the water as shown at Fig. 3D. This only happens when the upper region is a region of high velocity but the angle at which this happens is related to the refractive index; that is to say it is a function of the ratio of the velocities in the two respctive media[9], therefor if we know the refractive index, we can calculate the angle of total internal reflection, or knowing the angle of total internal reflection, we can work back to the refractive index and can calculate the velocity in the upper region. From that, we can draw conclusions as to the number of electrons per cubic centimeter and say whether our results lead to a reasonable or to an unreasonable number. Here is where the advantage of knowing skipped distances at *different* frequencies comes in. Using them as base of a triangle, we will be able to construct a figure which represents (we think), what actually happens. Most important of all, we will be able to find out how far up the top of the wave reaches before it is turned back to the earth. We find that such calculations based on the curve of skipped distances, as a function of wavelength, all lead to a very reasonable assumption as to the number of electrons at the point where the wave turns over and we find the number to be 5.57 x 10^5 per cubic centimeter.

9—A discussion of this subject appears on p. 29 of *QST* for July, 1925. Our present Fig. 3 appears in that paper as Fig. 1.—Tech. Ed.

Some information as to the proper value of this number is at hand from other physical sources not connected with radio and this number appears to be entirely reasonable. The question now arises as to how the situation will be changed if instead of being sharply reflected as from a sheet of copper, the ray is gradually bent or refracted. We think we have proved that the effect is substantially the same quantitatively, but the height to which the ray penetrates will, in the case of refraction, depend somewhat upon the disposition of electrons with reference to height.

Reflection or Refraction?

Figure 4 shows the results of our calculations based on sharp reflection giving a height of reflecting layer 185 miles.

If we consider the electrons to increase in number gradually and in proportion to the height above the earth, the ray will

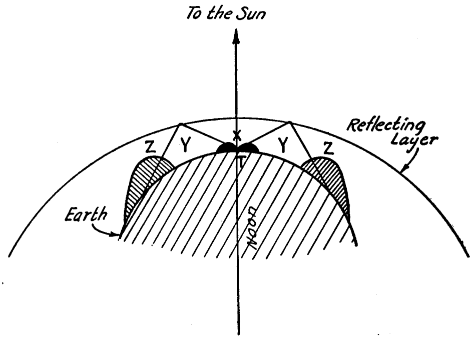


FIG. 4

FIG. 2 THE NATURE OF "SKIPPED DISTANCE" OR "DEAD BELT."

T—transmitting point.
T—Transmitting point.
X—Local signal due to earth-bound wave.
Y—Dead belt or "skipped distance."
Z—Region of reflected signal.
This figure appears as Fig. 4 on p. 11 of QST for April 1925 where it is discussed in detail.

be bent gradually as shown in Fig. 5 and the maximum height will be 92½ miles.

Figure 6 shows the situation if the electron density varies with the square of the height. Here the top of the wave rises 114 miles. Please remember these observations refer to average conditions. Finally Fig. 7 shows what may perhaps be more nearly the actual situation, namely; the electron density varying with the logarithm of the height. It will be seen that this height becomes a very near approximation to the height in the case of sharp reflection, the high point in the wave path comes to 183.6 miles. There is of course another way of looking at the thing, and that is to assume that the electrons do not begin to exist in any quantity until 20 or 30 miles up. This will

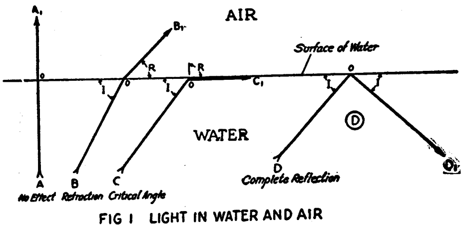


FIG. 3 REFRACTION AND REFLECTION.
This figure appears as Fig. 1 on p. 29 of QST for July 1925 where it is discussed in detail.

only raise the base line of the figure and leave the rest substantially the same.

We have not yet calculated the height of the Heaviside layer for nocturnal conditions, partly because we have insufficient data covering night and winter work but roughly speaking, the height of the layer will increase somewhat in proportion to the increase in skipped distance.

To make it clear just what all this has to do with communication on high frequencies, one must realize that all rays striking at an angle higher than the critical angle, will be very slightly reflected and those rays coming out parallel to the earth will be very heavily absorbed by the earth's surface and therefore it is the intermediate rays below the critical angle and yet considerably above the surface of the earth which do the work in long-distance, high frequency communication. If we could have rays reflected with a fair amount of energy from very steep angles, we could not possibly have a skipped distance. Such rays, however, pass out beyond the atmosphere as shown by example A in Fig. 3. It also turns out that the critical angle is a function of the frequency and that the higher the frequency, the flatter the angle; that is, the nearer to the earth's surface will the ray have to go out. This means for instance, that at about 20,700 KC., the ray in order to be properly reflected will have to leave so nearly horizontal that it will be very heavily absorbed by the earth. In addition the curvature of the earth will actually get into the way of it so that it cannot reach the layer with such an angle as to be reflected. According to this we are not likely to see very satisfactory communication over great distances on waves shorter than 10 meters we will say—that is, of higher frequencies than 30,000 KC. The only way that we can conceive of communication at higher frequencies being feasible over long ranges would be to have them started preferably in a beam from comparatively high altitude, so that they could come to the reflecting layer at a low angle without being absorbed by the the earth. This point will of course no doubt, be proved or disproved in the not very far distant future.

Seasonal Effects

The skipped distance in the summer night time is much greater than it is in the daytime and the skipped distance gradually increases towards midnight. This is what we normally expect. Altho the winter night skipped distance is not accurately known, it is very definitely known that the skipped distance is decidedly greater than it is during summer nights and this again seems reasonable because the ionization should be less in the winter time and therefore should not penetrate to so low a level because the periods of sunlight are shorter and the intensity of sunlight less. It is perhaps only fair to state here that with a single exception, our own observations and those reported to us by reliable observers from other parts of the world, clearly indicate the existence of this skipped distance.

Extreme Distances

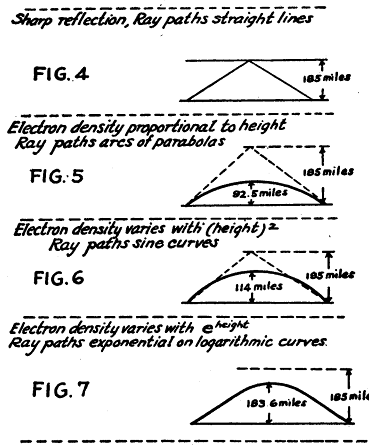
The problem becomes a little more difficult to handle for extremely long skips on account of the fact that we have to make allowance for the curvature of the earth in handling the theory. It remains now to consider what happens after the cone of rays included between the horizon and the critical angle starts out from the transmitter. It is our idea that the first few degrees from the horizontal upward are so close to the earth that they are very heavily absorbed and do not get out more than a few miles, the distance depending on the frequency, the higher frequencies being probably more heavily absorbed. There is left then a cone whose angular width is determined by the critical angle and a limiting angle closely horizontal which is probably in the neighborhood of 4 or 5 degrees. Now for very high frequencies, this cone is fairly small but for lower frequencies, say in the neighborhood of 3000 or 4000 KC., the cone is quite wide corresponding to the much shorter skipped distance. In the case of the wide cones, repeated reflection will result in plastering the effective energy for suitable reception over a wide annular region on the earth's surface in such a way that repeated reflections will mix up considerably with each other and there will be no region beyond the first skip which is entirely without signal energy.

For extremely high frequencies the cone is so narrow that a new possibility is brought out and that is, the possibility of blank spaces beyond the first zone of good reception, the contour of which and extent of which will depend on the height of the Heaviside layer and therefore upon the time of the year at which the observations are made and naturally upon the time of day. If, for instance, the Heaviside layer is very low down as appears to be the case during hot, summer months, and we operate with so high a frequency that only a narrow cone is available, we find, on tracing the path of the cone thru successive reflections from the Heaviside layer and the earth's surface, and making due allowance for the curvature, that it is quite possible to have missing regions occur between the successive reflection points on the surface of the earth.

We are unable to say definitely from our observations whether such additional skipped regions occur at great distance, but we are inclined to think that at high frequencies, they do occur during the summer. This is a point at which the American Radio Relay League can gather a great deal of extremely valuable information.

It is our opinion that in general at extremely distant points fading is neither so rapid nor so violent. It would seem that the rays of radiation can arrive by many different possible routes as the Heaviside layer is no doubt full of convolutions and variations and that these rays summing up at a very distant point tend to average conditions and somewhat reduce fading effects.

There is also no doubt at all, but what a station on the extremely opposite side of the earth from the transmitting station or even approximately on the other side will receive a remarkable concentration of signal. This has been beautifully exemplified in our reports from Johannesburg, South Africa on the transmissions from the USS Seattle. Mr. Sydney Pleass has forwarded voluminous reports on the Seattle when she was at Honolulu. It happens that Honolulu and Johannesburg are on exactly opposite sides of the world. There were two periods of the day when Mr. Pleass could make almost solid copy on signals from NRRL. One period was in the early morning (South African time) and the other period in the early evening (South African time). The moment the Seattle moved on towards Samoa, he found this impossible to do, altho at the same time, signals from our Naval Station in Honolulu continued to be received. This was in the 7500 KC. band. Mr. Pleass' observations taken in the early morning were no doubt taken on signals which arrived over the shortest route, namely the Atlantic Ocean. On the other hand, late afternoon signals arrived to him over the Indian Ocean. He also demonstrated quite clearly that it was possible to receive signals more than half way around the world. Some of these observations were taken at a time when for the signals to have traversed the short route, namely the Atlantic Ocean, they



All figures on basis of a maximum electron density of 5.57×10^5 per cubic C.m

would have had to cover nine hours of daylight which does not seem at all possible at 7500 KC. therefore they must have gone the other way around and arrived to him over the Indian Ocean which made the distance considerably more than one-half way around the world.

The Effect of Frequency

Too little is known of the relative absorption of high frequencies to do much more than speculate as to the role played by absorption but a few general conclusions can be drawn on the assumption that the absorption in the lower levels increases with frequency. We would expect higher absorption in the 15,000 KC. band than in the 7500 KC. band, whereas for daylight work between points separated by a distance greater than the skipped distance, the contrary seems to be the case. This can be understood if one realizes that the 7500 KC. transmission occupies a cone at higher angle so that a good many successive reflections have to be made in the 7500 KC. band before a wave finally arrives at its destination and since each reflection brings it down to the earth thru an absorbing region, it may lose considerable energy. On the other hand, the 15,000 KC. wave can get away at a low angle and still keep its feet clear of the earth, so to speak. Since it skips a much greater distance, it remains in the higher non-absorbing region for a greater portion of its transit than does the 7500 KC. We admit that we are not completely satisfied with this explanation but it does agree with the fact that for nocturnal transmission where the layer is very high, the 7500 KC. wave (which could then keep away from the earth for a longer distance) shows up very well in comparison with 15,000 KC. One thing, however, is absolutely certain and that is, that the absorption on 15,000 KC. is very much greater in the middle of the summer than it is in spring or fall to say nothing of the winter.

Very little work has been done during summer months from coast to coast in the 15,000 KC. band and we even have difficulty in mid-summer in reaching our station at Balboa, 1800 miles south of us when operating in the 15,000 KC. band. We believe this to be due to the fact that the skipped distance at that time of the year is scarcely half of what it is in the winter midday and therefore the wave has to go up and down several times before it gets across the Continent which very greatly weakens it.

Communication With Greenland

It is very remarkable that 15,000 KC. communication to and from the Navy-MacMillan Artic Expedition has been a *flat failure* altho the distance from Washington to Etah, Greenland, is only 2700 miles and from Chicago to Etah very nearly the same. Nevertheless communication has repeatedly been had (two-way) from Washington to Etah and from 9CXX at Cedar Rapids, Iowa, to Etah on the higher frequencies corresponding to waves of 19 meters and under. At the time of this writing nothing has been tried under 15 meters, and the communication is anything but perfect.

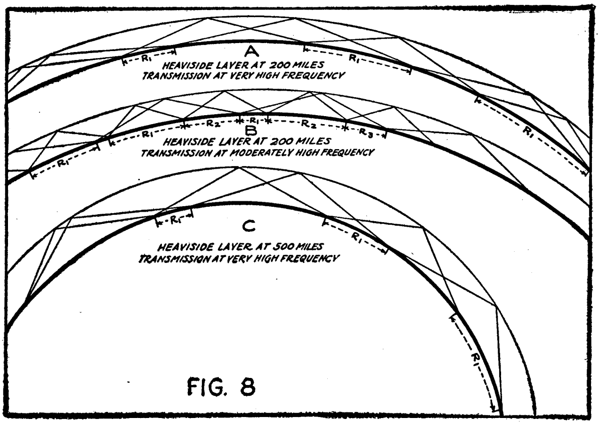


FIG. 8

In the Artic regions at this time of the year there is perpetual sunlight. The Heaviside layer therefor is very low indeed and daylight communication is exceptionally difficult. Communication at any time of the 24 hours with the MacMillan Expedition involves in the summer time the penetration of a considerable distance of daylight and twilight. Signals from WAP on 8240 KC., have been extremely satisfactory in Washington during the month of August, fairly satisfactory during the latter half of July, but extremely unsatisfactory prior to that time. We have consistently tried out during daylight hours at 9 A. M., noon, 2 P. M. and 3 P. M., 14,400 KC., 12,500 KC., and 17,000 KC., and the latter is the only frequency that has met with any marked success during daylight hours in spite of the fact that it is lowest powered of the three transmitters. This lends color to the idea of skipped distances beyond the first one. It is unfortunate that systematic tests on various frequencies cannot be arranged over the entire 24 hours.

It is perhaps interesting to note since the Navy Department started sending time signals for the benefit of the MacMillan Expedition from 2:55 to 3 A. M., followed by a broadcast of official and other messages, the Artic Expedition has reported practically 100% copy, strength 8. The signals it may be remarked, were sent at the special request of the Peary which stated the expedition was out of the range of all other time signals. This opens up a new and important field of activities for higher frequencies. It readily permits an international checking up of the signals on account of the extreme ranges which it is possible to cover.

Day and Night Effects

The success of the Peary in receiving these signals is interesting theoretically because an examination of the conditions will show that the signals are obliged to traverse 1200 miles of daylight at this time of the year. It has frequently been noticed that when a signal starts in the dark from far western points it can be received at Washington an hour or two after daylight, sometimes more. Such observations have been made on our stations in Samoa and Honolulu, on the U. S. S.

SEATTLE in Australian waters and on Australian and New Zealand amateurs. It is interesting to see that a somewhat similar effect holds for transmission to the northward. It can not be positively stated that this is a reversible condition because in communicating with these other points we have not used exactly the same frequency that they were using, but we have generally used a frequency at least of the same general value so that conditions would appear to be fairly reversible; that is, they would lose our signals at approximately the same time we lost theirs.

This data to my mind indicates that in the early morning hours the Heaviside layer is still fairly high up, permitting the signals in their successive reflections from the earth and from the air spending too much time in the immediate proximity of the air where they would be heavily absorbed.

If the skipped distance on high frequencies is shortened enough due to the Heaviside layer moving downward we have at least a reasonable explanation as to why the 15,000 KC signals in mid-summer are weaker than they are at other times. In line with this is the fact that in the spring when we could do Trans-Continental work in this band the signals were in general, stronger after dark, particularly west coast signals as received on the Atlantic coast. This condition held until after midnight at which time no doubt, the skipped distance became so great that the signals skipped over the east coast. Probably the strongest high frequency signals occur when the skip is extremely long and only one reflection; is necessary to reach the point in question. Nevertheless many other points further on can be reached if sufficient power is used, but the question remains to be definitely settled as to whether or not there are other missing regions further out.

Other Reflections

Considerable evidence crops up from time to time indicating other possible reflections at very low levels indeed. For instance, at points between 5 and 10 miles distant from NKF (Naval Research Laboratory)—very violent fading in the ratio of at least 20 to 1 can be observed at night on the 4200 KC. transmission from NKF. According to the theory herein presented the Heaviside layer at night is fairly high, probably several hundred miles even in mid-summer so that it is very difficult to imagine the reflected waves coming down to a point only 5 miles away and being strong enough to produce almost complete neutralization of the direct or ground wave at such short distances. It is particularly difficult therefore to understand this when we realize that the rays would have to be sent up almost vertically and could be reflected only with a small percentage of the energy which they have when they are reflected at or below the critical angle; nevertheless, something produces an interference phenomena which may perhaps even play a role in the broadcast band around 800 KC. Attempts have been made to correlate this effect with weather, particularly cloudiness, but without success. Even in the broadcast band[10], there is a small but easily measurable amount of fading even at points 5 or 10 miles distant from the broadcast stations when observations are taken at night, and in all cases this fading is accompanied by a blurring of the minimum and a distortion of the bearing as taken with a radio compass.

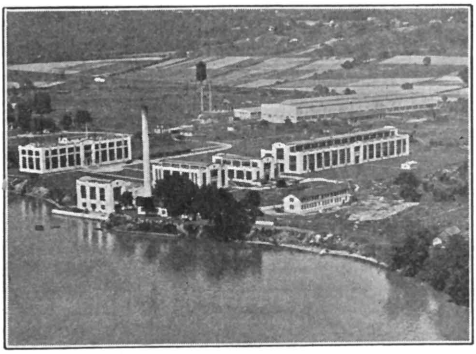
We have taken observations at the same points on fading of the 7200 KC. band and we find that the fading is not nearly so marked. Observations at 14,400 KC. show no fading at all either by day or night at such close distances. There may be therefore, some very low level ionization effect that is playing a part and that it also has a critical angle such that the higher frequencies are not reflected at a sufficiently steep angle to return to the earth within a few miles of the station, therefore the only thing that is heard a short distance from the station is the ground wave.

In order to illustrate the possible behavior of very high and moderately high frequencies according to the theory herein presented we have drawn figures (8) which represents three different cases, one for a 200-mile high Heaviside layer with transmission at very high frequencies; one for a 200-mile high layer with transmission at moderately high frequencies, and one for a 500-mile high layer with transmission at very high frequencies. For the sake of simplifying the drawings we have made them for the case of sharp reflection. Introducing the idea of refraction or gradually bending will make very little difference in the appearance of the figure and no difference in the final results, especially if one assumed a logarithmic variation of electron density with altitude.

For rays at very high frequencies, we have assumed the critical angle of 10° and have utilized all rays up to within 5° of the horizon. We have not used rays lower than 5° because we believe they will be absorbed and will be interfered with by the curvature of the earth. Thus a narrow cone going out from the transmitter is available for transmitting signals, radiation going out in other directions is dissipated in space or absorbed by the earth. If we follow the successive reflection of this cone of rays (Fig. 8A) we see that there is the possibility of a second skip or

10—200-600 meters.

lesser area than the first one and if we go on out with successive reflection alternatively at the Heaviside layer and the earth, the region of good reception becomes broader and broader and the skipped region diminishes until it finally disappears and regions appear in which there are overlapping rays from the transmitter arriving by very different routes. Now all of these different zones will be subject to some flickering due to movements in the Heaviside layer which are apparently much more violent at night than in the daytime. If we compare this figure with the one for the same very high frequency but for a much higher layer, namely 500



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miles, we see that the same sort of thing is again repeated (Fig. 8C) except that a lesser number of reflections are required to bring about the disappearance of the skipped regions. At the same time the first skip is much longer and the chance of reaching very remote points are greater because the rays spend less time traversing regions close to the earth.

Turning now to the figure for the 200-mile layer, with transmission at a moderately high frequency, (Fig. 8B) we see that we have to deal with a cone which is broader and more steeply inclined upward, the critical angle is nearer the vertical. We do not, however, dare to use rays quite so horizontal because these longer waves would have to rise somewhat more sharply than at very high frequencies in order to get clear of the earth and exist in free space. Nevertheless, the cone is wide on the whole and there is very little trace of even a second skipped distance and beyond the second there is none at all. There are, however, countless places where over-lapping rays occur coming by different routes, thus giving ample opportunity for inerferences which can produce fading. It is only necessary then to assume a certain amount of flickering and movement in the Heaviside layer to account for rapid variations in fading. It does not seem surprising that these should be more rapid and more violent at night than in the daytime because the night levels are high and the electrons having greater free paths, may readily vary their disposition and concentration. It is therefore of great importance that additional observations be accumulated which will determine the existence or non-existence of secondary skipped regions beyond the first one. A glance at the figures just presented will show that they must appear considerably beyond the first region. Some evidence of this nature we already have, but it is by no means conclusive. Incidentally it appears owing to the extreme ranges which are plainly possible with very high frequencies, it will be advisable wherever possible to use considerable power in the transmitters upon which these observations are to be made. However, with power of 500 watts and more in the antenna, very satisfactory results should be obtained and doubtless much valuable information will be furnished from records on transmitters having only a small fraction of that power.

In examination of Fig. 8B for the 200-mile layer and a moderately high frequency, shows that there is only a small trace of a skipped distance beyond the first one. A little flickering or irregularity of the layer would reduce the skipped distance to merely a region of very bad fading. We believe this region has been definitely observed. Beyond this point there is no portion of the earth's surface that does not receive at least one set of rays but as one gets further from the transmitter, one finds the region which receives only one set of rays being rapidly diminished in extent and at extreme distances all points will receive 3, 4 and even more sets of rays. This may account for greater steadiness and less fading as observed at very great distances. The diagram readily accounts for the fact that the fading may be materially different at various intermediate range positions. It must also be borne in mind that these diagrams represent a purely ideal case where the layer is of uniform height. Unfortunately we have not yet had time to complete diagrams. which would show the general trend of affairs with a layer of varying height such as one is bound to have on east and west transmission over great distances, part of which lie in sunlight and part in darkness. It seems that the only hope of getting extremely long ranges on frequencies higher than 25,000 KC., would be to take advantage of some peculiar layer formation that would permit traversing in the upper ranges. Even with north and south transmission there is no doubt considerable variation in the height of the layer as the strength of the ionizing agencies, particularly sunlight, would be a function from the latitude.

The diagrams do show, however, the general nature of the phenomena which we may expect to observe if these theoretical considerations are approximately correct.

Conclusion

In making this attempt to extend the theory of electromagnetic wave propagation to the region of high frequencies, we have tried throughout to avoid making use of erratic or freak observations and to base our ideas on normal and readily reproducible conditions. We have indeed undertaken this work with considerable reluctance because we could wish for still more systematic and more adequate information with respect to certain frequencies but we have been encouraged to put these ideas in the hands of our radio friends in the hope that we will at least have stimulated some speculation along these lines which may help the solution of this very interesting problem. Certainly we shall welcome criticisms and reports of data bearing on this work whether or not it tends to confirm what we have herein set down.

Experimenter's Section Notice

THE Report of the Experimenter's Section is omitted this month, pending consideration of the means for handling the future work of the Section.

Increasing *QST* work is making it more and more difficult for the Technical Staff to take care of the necessary experimental outlines, schedules and correspondence. Fortunately the enrollment records and the like are being kept up to date by our office assistant, Lawrence Flebeau, partly on his own time.

The Editorial Staff and the Executive Committee are studying the problem and hope to be able to report in the next issue of *QST* that it has been possible to gain the necessary time without unduly disturbing other headquarters activities.

Jenkins' Awards

THE judges in Mr. C. Francis Jenkins' contest for ideas for picture-telegraphy have awarded a prize of $50 to Mr. G. J. Shadick, of Regina, Sask., Canada, for a suggestion made in the first 60-day period. Mr. Shadick's winning suggestion was a very simple one—he proposed that instead of the complicated and messy pen-and-ink arrangement used for reproducing, a piece of carbon paper be wrapped around the white paper and a plain metal stylus be used for writing.

Certainly a very simple suggestion and a very easy way to earn $50! But no one had thought of it before, and that is the purpose of the contest—to bring forth ideas that have not occurred to the laboratorians working on this development. The contest continues, with prizes of $100, $50 and $25 awarded every sixty days. See page 18, May *QST*. It should be noted that the suggestions must deal with mediums and mechanism for transmission and or reproduction, and that they must be new and original suggestions.

Award of the first and third prizes in the first period has not yet been announced, pending some technical considerations, but Mr. Shadick's suggestion is typical. Mr. Jenkin's position in the matter is tha his laboratory is honestly soliciting amateur help and is willing to pay for it. Here is jack for the new bottles, fellows, for a little constructive thinking and experimenting.

A. R. R. L. Information Service Rules

1. Before writing, search your files of *QST*. The answer is probably there.
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3. Be reasonable in the number of questions you ask.
4. Put the questions in the following form:
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   - B. Make diagrams on separate sheets and fasten sheets together.
   - C. Number the questions and make paragraphs of each.
   - D. Print the name and address (NOT merely call letters).
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