U. S. Department of Commerce
National Bureau of Standards

Research Paper RP2071
Volume 44, February 1950

Part of the Journal of Research of the National Bureau of Standards

Back-Scatter Observations by the Central Radio Propagation Laboratory—August 1947 to March 1948

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A high-power pulsing transmitter and a westwardly beamed antenna system were constructed, and emissions were made from Sterling, Virginia, on 13,660 kilocycles, for reception by USNEL and USAF cooperating groups. CRPL efforts were concentrated on the study of "back scatter" received near the transmitter.

In the controversial issue as to whether back scatter comes from the ground or the E region, it was believed that both types were identified, with ground scatter usually predominating, except in the case of long skip.

Aids to data interpretation were transponder echoes, reception logs and skip distance maps drawn from concurrent ionospheric data.

I. Introduction

1. Historical Background

It has been known for many years [1, 3, 6, 9] [1] that low-quality radio signals may be received when the receiving station is within the skip zone of the transmitting station. This phenomenon has been given the name "scatter".

When electromagnetic waves impinge upon clouds of ions, energy is scattered in all directions from the clouds. The intensity of the scattered energy is strongest in the original direction of propagation (forward scatter) and weakest in the opposite direction (back scatter). If the ionic clouds are randomly distributed, and of various densities, the scattered energy is quite weak, and the scattered signals fluctuate rapidly in phase and intensity. Scatter may also occur when the radio waves strike a rough surface, such as the ground or the sea.

Signals scattered back toward the transmitter are of low and fluttering intensity, telegraph signals being almost unreadable. They have an indefinite and varying direction of arrival, when the transmitting antenna is omni-directional; when the transmitting antenna is highly directional, they appear to come from some place along the beam remote from the transmitter.

[1] Figures in brackets indicate the literature references at the end of this paper.

Observations of back scatter using pulsed emissions from highly directive antennas indicated that weak irregular scatter echoes were arriving from the region where the beam penetrated the E layer, followed by stronger and more continuous scatter echoes with retardation times roughly equal to the equivalent path for single-hop F_2-layer transmission over a distance equal to the skip distance. Eckersley [3, 9] attributed both these effects to the same phenomenon, i. e., back scatter from ionic clouds in the E layer (see fig. 1) and called the first scatter group "short scatter" or "E scatter" and the second group "long scatter" or "F_2-E scattered". It was believed that, since the beam spreads with increasing distance, the more distant echoes appeared to have greater continuity than the simultaneously observed short-distance echoes only because more scattering sources are excited at any given time.

As a result of the work done by Eckersley and by K. W. Tremellen, a hypothesis of radio transmission known as the two-control-point theory was evolved by the latter. In this hypothesis it was assumed that the limiting condition for transmission over any path greater than one hop in length was for propagation to be possible at both ends of the path at angles of arrival and departure approaching grazing incidence, it being assumed that the long-scatter sources would assist in carrying sufficient useful energy across the intervening distance.

Other observers, including Jansky and Edwards [4] and W. R. Piggott, observed echoes that appeared to come from the ground, and concluded, contrary to Eckersley, that the ground was a major source of scatter.

In order to obtain more information on the origin and mechanism of back scatter, the Central Radio Propagation Laboratory decided to undertake oblique-incidence pulse experiments. In addition, high-power directional pulse transmissions from the CRPL Sterling, Va. field station had been requested for other experiments conducted by the U. S. Navy Electronics Laboratory, San Diego, Calif., and by a Boston University group at Alamogordo, N. Mex. Both these groups furnished valuable data for the back-scatter studies.

2. Equipment

A self-excited pulsing transmitter, figure 2, using a pair of 527 triodes in push-pull, was constructed for operation on 13,660 kc with peak pulse inputs as high as 770 kw. The operating frequency was in the middle of a "scientific, medical, and industrial" band. The pulse repetition rate was 25 per second and the pulse length 40 microseconds. The transmitting antenna was a rhombic with a calculated major lobe at an angle of 14° with the horizontal, oriented 263° from true north, as shown in figure 3.

The receiver was a commercial model modified for pulse reception. The receiving antenna, in later experiments, was a sloping vee directed toward the west.

The indicator was a conventional loran-type indicator. An Air Forces 0–15 recording camera was used to record the pulses. In operation the initial transmitter pulse was located at a convenient position on the sweep and readings taken from it as a reference. The movable pedestal was used to locate pulses for detailed observation on "fast sweep."

II. Miscellaneous Experimental Observations

1. General

The transmitter was operated during all or a portion of a selected 24-hr period on a number of days during the months covered by this report. On all runs visual observations were made of the received back-scatter as it appeared on the screen of the indicator, and the delay times were noted. Photographs of the received pulse patterns were taken at intervals. Scalings of the observed phenomena or of these photographs were made for many of the runs and the results plotted against time. Figures 4 through 9 are plots of such observations for six periods from August 1947 through March 1948, illustrating the diurnal variation of the delay times and their association with skip distance. A detailed study of the trends and anomalies illustrated on these graphs appears in section III of this report.

In the interpretation of some of the data, delay times of pulse groups were noted and, assuming reasonable virtual heights of the ionosphere layers, plausible modes of propagation were inferred, considering the radiation pattern of the transmitting antenna. The lack of precise knowledge of the ionosphere was less of a drawback than it would at first appear since usually, if one mode was chosen as reasonable, the next best would appear unreasonable in the light of probable ionosphere heights and angles of departure.

The curves of figure 10, relating delay times, distances, and virtual height of the ionosphere were used to determine distances from the observed delay times and assumed virtual heights. These curves were calculated from the geometry of a propagation path, assuming the "equivalence theorem," i. e., assuming, for oblique-incidence propagation, specular reflection from virtual heights observed at vertical incidence.

Figure 11 shows families of curves of constant angle of departure, the most nearly vertical of the two families on the figure, which were calculated using the same geometrical assumptions as were used for the curves of figure 10. These curves were used for determining probable angles of departure for given delay times and assumed virtual heights. Incidentally, the transmission curves (for different distances) of figure 11, were originally derived at this Bureau during World War II for obtaining oblique-incidence maximum usable frequencies from recorded vertical-incidence ionospheric data.

2. Usual Types of Observations

In general the echoes received along the delay-time axis were not discrete pulses, but groups of myriads of rapidly varying echoes peaking in intensity around one or more fairly well defined delay times. Each of these echoes faded in and out so rapidly that even a single camera exposure does not do justice to the picture. Besides, even the major peaks shifted in amplitude and delay. Figure 12 shows how a return group with a delay time from 8½ to about 16 msecs changed its configuration in as little as 45 sec, the six photographs having been made between the time of 0010+58″ and 0011+43″ GCT on November 21, 1947. Figure 13 shows such a back-scatter echo seen on August 27, 1947, with the fine-grain structure changes that occur in as little as 2 sec, made evident by displaying an echo group on the 2,500-microsecond sweep of the Loran indicator at 2-sec intervals.

Recording of pulses was beset with great difficulties caused by interference from stations on channels near or directly on the transmitter frequency. Figure 12, mentioned above, also shows the change of interference conditions in the 45-sec interval.

In addition to interference, reflections from airplanes and meteors were often noted. These were in the form of discrete pulses, to the extent of the resolution of the "slow sweep," in contrast to the scatter returns.

Often under night conditions over the path, pulse return groups corresponding to as many as four long hops were noted, assuming that the delay time is a measure of the skip distance to a scatter source. This would mean that back-scatter was being received at times from as far as the middle of the Pacific Ocean. It was often noted in the evening at Sterling that the delay between a second echo and a first echo was shorter than that between the transmitted pulse and the first echo. These observations may be explained by the fact that at these times the second hop was in daylight, as well as farther to the south, both conditions contributing to a shorter skip distance. Figure 14 for Feb. 16, 1948, at 0252 GCT shows three separate back-scatter groups. These echoes appear as plots in figure 8 at the appropriate time delay.

3. Direct F_2 Reflections

When the ordinary-wave critical frequency overhead is greater than the operating frequency, as occasionally happens during winter daylight hours, as shown in figure 6 at 1536 GCT, November 26, 1947, the ordinary-wave return shows a single intense clean pulse, in this case at 2.4-msec delay. Another weaker pulse at 3.4 msec corresponds to the extraordinary wave. The 2.4-msec delay corresponds to a virtual height of 370 km. It was actually noted that the virtual heights observed in this manner were of the order of 20 km higher than those noted simultaneously for the same frequency on the vertical-incidence ionosphere recorder operating in the same building. This seemed to indicate the fact that the highest lobe on the rhombic transmitting antenna, peaked at an angle less than 90°, caused the reflections to be observed from an angle slightly off the vertical. Two groups of pulses seen on the same sweep, beginning at 4.6 and 8.2 msec were examined for the delay times of 5.2 and 9.0 msec at about the center of each group. The 5.2-msec delay may correspond to scatter from the ground 475 km away propagated via the F_2 layer at a reasonable assumed virtual height of 300 km. The angle of departure for this would be 50°, corresponding to the middle of the second lobe of the rhombic antenna. The 9.0-msec delay may correspond to scatter from the ground 1,250 km away propagated via the F_2 layer at a virtual height of 220 km. The angle of departure for this would be 16°, near the peak of the lowest lobe. The virtual height of 220 km is reasonable for this case since at oblique incidence, with frequency constant, the virtual height decreases as the distance increases and approaches the minimum virtual height, which was of that order of magnitude in this case.

4. Persistent "Short Scatter"

An odd type of phenomenon, rather difficult to explain, was noted on the night of January 21–22, 1948, between 0500 and 0700 GCT. Very strong and persistent echoes were received at delays of the order of 2.6 msec along with longer-delayed echoes of much lower intensity as shown in figure 15, and in the plots of figure 7. From the delay time the only reasonable source of these echoes would be short scatter directly from the E layer at an angle of departure of 14°, right on the main lobe of the transmitting antenna, yet a more intermittent and weaker type of echo would have been expected for this case. The alternate solution would be ground scatter propagated via E layer from a source 310 km away, but not only did the angle of departure for this case fall in an antenna null but, in addition, E-layer ionization would probably not have been great enough to sustain a reflection at 13,660 kc/s. It is possible that the intense short distance reflections, because they were seldom seen, were associated with the sporadic-E type of ionization.

5. Sudden Increase of Skip

It was observed that at times of "fadeouts" of the scatter echoes, when the skip suddenly increased, observable in several of the plots as in figure 8, at 0650 GCT, echo groups always become indistinguishable long before the delay time, about 27.1 msec, for the theoretical 4,000-km limit of one-hop F_2 was reached. It may be concluded that the echoes became weaker than the noise and interference at the longer distances because the angles of departure were far below the maximum of the first lobe of the transmitting antenna.

A point of interest is the great speed with which the observed echoes change their delay times before and after the "fadeouts" just mentioned. Figure 9 for March 14, 1948, between 0530 GCT and 0645 GCT illustrates the point. The first echo visible after the fadeout was at 0610 GCT, and the first pulse peak of the group came at 22.3 msec delay. The delay time decreased almost uniformly to 0645 GCT, when it became 15.5 msec. The rate at which the delay time decreased was then 11.7 msec/hr, making the energy peak appear to approach the receiver at a speed of 1,750 km/hr if the velocity of propagation were assumed to remain constant at 3×10^5 km per second.

6. Sunrise Effects

Effects around sunrise over the path are rather complex, and data are very scarce because of interference and also because of a number of equipment failures that occurred around this time.

Study of the films indicated that all of the returns between 0845 and 1015 GCT shown at a delay of less than 12 msec on figure 5 for October 2, 1947, were really distant multihop echoes seen the second time around on the 40-msec sweep, since they were all weaker than the large groups plotted in the region of 22 ms. However, later short-distance groups after 1100 were strong enough to be considered as reflections from close-in sources. It is to be noted that these groups appear during the period when groups just beyond are moving closer and that they subsequently disappear. Similar effects are seen in figure 4 for August 27, 1947. The close-in groups at 1042 and 1103 appear to be from a short distance, and the single group at 1130 is ambiguous in appearance but may be a distant group moving in.

One possible source of the close-in scatter noted in the above two cases is the regular E or the E_2 layers as ionization increases greatly with sunrise. Such scatter, if weak, might disappear because of increased absorption later in the day. Another possible source of close-in echoes at sunrise would be specular reflections caused by a tilted layer or a combination of a tilted F_2 layer and the start of the E layer, forming a duct with an oblique top into which waves may go and be returned specularly. Reference [2] treats of this type of mechanism, which may be responsible for certain types of echoes and also gives a plausible explanation for the variation of the relative intensities of multiple echoes at near vertical incidence on the basis of specular reflections from irregularities in the ionosphere, which have a focusing and defocusing effect as they drift by.

Occasionally, visual observations of the indicator, around sunrise, showed that groups may be received corresponding to daytime skip, with long-distance echoes from the night-time regions seen simultaneously. This condition could prevail when the presunrise minimum of F_2-layer ionization was some distance to the west of Sterling.

III. Comparison of Results with Other Concurrent Observations: Sources of Scatter

1. General

Other concurrent observations with which test data were compared were:

a, Vertical-incidence ionosphere observations.
b, Arrival time of transponder pulses from Alamogordo, N. Mex.
c, Recordings of pulses from Sterling, Va., made by U. S. Navy Electronics Laboratory at San Diego, Calif. [11].

The variations of the delay times of CRPL back-scatter observations were compared with simultaneous vertical-incidence ionospheric observations at several stations in the United States.

Since only a very small percentage of the radiated energy is scattered backward from either the assumed ground or E-region scatter source, back scatter on 13,660 kc, even with the power and beaming used, is not easily detected except for scattering areas at approximately the skip distance from the transmitter. At or near the skip distance "high" and "low" waves traversing the ionosphere converge, forming a caustic, at which the transmitted energy is concentrated and, similarly, energy scattered at different angles of elevation from a scattering area is made to converge by the ionosphere, concentrating the reflected energy so that it is sufficient for detection [1, 7]. Consequently, if back scatter is from the ground, the delay time observed between the transmitted and back-scattered pulses should correspond roughly to the skip distance for that frequency at the point of reflection. If back scatter is from the E layer the delay time is less by the travel time along the oblique path between the E-layer scatter source and the ground scatter source in figure 1.

2. Skip-Distance Maps

In order to test these assumptions, F_2-layer skip-distance maps of the United States, for the frequency 13,660 kc were prepared from ionospheric data observed at Washington, White Sands, Baton Rouge, San Francisco, Boston, and Ottawa, for a number of hours during each day on which the pulse experiments were conducted. Such skip-distance contour maps were necessarily rather rough, since the observations at these six locations must be extrapolated to cover the entire country. The F_2-layer skip distance was derived by standard methods from the observed values of $f^{\circ}F_2$ and F_2-3000-muf reported by the ionosphere stations, and the map construction involved longitudinal extrapolation. Figure 16 for August 27, 1947, at 1100 GCT is typical of the F_2-layer skip-distance maps. The values of the contours are the skip distances in kilometers, for 13,660 kc, for one-hop transmission reflected at points on the contours.

It was assumed that the transmitting antenna beam width was 30°, centered on the direction of orientation, and that, in this sector, back scatter is observable for a given path length wherever the midpoint of path coincides with the skip-distance contour for that distance. Assuming the velocity of propagation to be 300 km/msec, and arbitrarily adopting an ionospheric reflection height of 300 km, the expected range of time delay between transmitted and back-scattered signal over the sector was derived from the range of values of skip distance for which back scatter was expected. The ground-scatter delay-time values derived from the skip-distance maps are plotted on figures 4 through 8, for comparison with the observed back-scatter delay-time values, solid circles being used to designate the shortest and longest delay time expected. For the shortest delay time the corresponding delay times for E-layer long-scatter from an assumed 110-km height were obtained from figure 17 and plotted as open circles. Arrows pointed vertically upward indicate skip greater than 4,000 km.

Each of the figures were examined to decide from the relative positions of the plotted returns whether or not scatter was from the ground or the E layer. Echoes from the ground over a range of skip distances would give a line of pulses on the indicator time axis, and the same could be true for the E layer but with the returns displaced by a time difference of the order of that between curves B and C of figure 17; it is obvious that if both types were present ambiguity would exist where the two lines of pulses overlapped. However, if only one or a few closely grouped peaks of ground scatter exist in a given case an analogous group for E-layer back scatter may also exist separately at the distance determined roughly by figure 17.

3. Transponder Results

The strongest supporting evidence indicating that the observed returns may often be ground scatter is presented in figure 6 of the run of November 25 to 26, 1947. In that experiment a transponder operated by Boston University personnel at Alamogordo, N. Mex., was synchronized on the strongest pulse of a group received from Sterling. It is seen on the plot between 0430 and 0607 GCT. As the skip moved out in that period the transponder arrival time changed relatively little, because it was dependent only upon the virtual height of the ionosphere. At 0445 the transponder return is seen split, apparently because of Pedersen ray effects (actually at some intervals more than two echoes were visible because of extraordinary wave). At 0607 it is last seen at a delay time of 18.9 msec (figs. 6 and 19). It is almost on top of the nearest back-scatter energy peak, so that it seems reasonable to conclude that that peak represented ground scatter from the equivalent distance for a single F_2 hop, since a reasonable F_2-layer virtual height would give approximately the same delay time. The transponder was turned off at that time because the pulses from Sterling were too weak for synchronizing. Since the transponder was adjusted manually to emit within less than 50 microseconds after reception of the Sterling pulse at Alamogordo, and since E-layer scatter would have appeared on the sweep about 4.6 msec earlier, the assumption that the back scatter in this case was from the ground seemed justified.

The predicted minimum skip distance for the assumed 30° sector as indicated by the lower solid black dot at 0600 in figure 6 falls right at the range at which the transponder was last seen. This, however, was not the skip distance for the exact azimuth of Alamogordo on the skip-distance map for that hour, the latter being greater than 4,000 km. Therefore, the agreement of the dots and the scatter and transponder ranges is not as good as it seems on first inspection. However, considering the limited number of points from which ionospheric data were obtained, these maps could easily be in error.

Good agreement was not obtained for the times of signal failure at Sterling and at Alamogordo. The transponder signal of only a few hundred watts peak power, was still fairly strong at Sterling, as shown by figure 6 when the Sterling pulses were reported as too weak for synchronizing at Alamogordo. This fact points to possibilities of differerence of antenna patterns of both transmitter and receiver at both ends, nonreciprocity in the ionosphere, and lateral deviation, all of which should be investigated further. The antennas at Alamogordo were not sharply beamed, making it possible for transponder returns to travel over a devious route after direct path failure. However, the presence of more interference at Alamogordo than at Sterling could have caused the discrepancy. It still seems to be true, in spite of discrepancies, that the peaks of the returned pulse groups particularly the one corresponding to the transponder position in figure 19 are ground scatter because no peaks were seen at the delay time which would be required for E-scatter for this path, which would be of the order of 4 or 5 msec earlier than the transponder pulses.

Subsequent transponder experiments up to a year past the period covered by this paper demonstrated that the delay time of the first major peak of the back scatter begins to exceed the delay time of the transponder as the latter fails, and that the reverse is true as the signal returns with sunrise over the path. These results indicate that the main body of the back scatter is, for the case under consideration, ground scatter. If E-layer back scatter is present under these conditions, it must be much weaker and hidden under the interference.

4. E-Layer Scatter Preceding Ground Scatter

Generalizing from the transponder results, it was assumed that returns showing only a few closely spaced pulse peaks were probably of the ground-scatter type. Similar groups with single peaks or small groups of pulse peaks falling the right amount earlier, as determined from figure 17, were judged to be ground scatter with E-region scatter ahead of them. This assumption was supported by the fact that occasionally very strong, discrete pulses of a few seconds duration, which appeared to be reflections from meteor trails, came from about the expected E-scatter region. These echoes seem to appear usually when there is no persistent scatter peak at the point in question, suggesting that possibly the back scatter from the E-region is not always present. Sometimes, however, they appear in other places, suggesting the desirability of an investigation of the possible overlap of delay times of E and ground-scatter returns because of finite beam width.

The type of echo pattern in which such earlier separated echo groups appear is noted in figure 5, for October 2, 1947, an ionospherically disturbed day, between 0845 and 1015, the separate returns falling at between 16- and 20-msec delay. It will be noted that most of these fall about 4 msec ahead of the first energy peak in the succeeding groups. The independently calculated F_2 return points (solid circles), and corresponding E points (open circles) fall a few milliseconds earlier, but the agreement is fairly good.

The earlier separated echo groups, assumed to be E scatter, were quite variable in amplitude with a tendency to disappear altogether, leaving a line of low-intensity echoes extending along the time axis to the major peaks. Figure 18 illustrates this fact when viewed in conjunction with the plotted returns in figure 5 for the period 0845 to 1015. The points concerned are on the upper trace in each frame of figure 18. The initial pulse is on the lower pedestal, and the little echo on the lower trace is probably 2-hop F_2. On the upper trace is seen a strong return preceded by a weaker echo that disappears into a line of very weak return pulses after a few seconds. Several echo groups at other hours on figure 5 seem to exhibit similar characteristics, notably those at 0545 and 0807.

Weak fleeting pulses at about the E-layer distance ahead of second multiple F_2 were sometimes noted on winter days when the ionosphere could sustain vertical-incidence F_2 reflections, suggesting the weak echoes shown by Eckersley in figure 21 of reference [3].

5. Agreement of San Diego Reception Results

Referring again to the October 2 observations, at 0530 on this day the Sterling emissions under observation at San Diego failed for several minutes. Reception then recovered and failed again at 0548, being intermittent to 0558. During this period, figure 5 shows a pulse peak in the neighborhood of 25.0 msec, which is the delay time for the 3,650-km path for ground scatter propagated via the F_2 layer at a height of 300 km. At 0545 there appears to be an F_2 echo after an E-echo group. At 0530 there is a first strong peak with echoes coming in for about 5 msec preceding. At this time the return is shown as one group, but the peaks at 22.3 and 22.9 msec could be associated with E-layer back scatter by comparison with the 0545 return. In fact the pictures taken in this period resemble those of figure 18, and the peaks at 22.3 and 22.9 msec are weak compared to the return at 25.0 msec. The calculated skip-distance chart for 0600 for the azimuth of San Diego was in exact agreement with the results at San Diego. This chart was one with regular contour lines, which seem to be more accurate than those for an irregular distribution of ionization where interpolation is difficult.

6. E-Layer Scatter Exclusive of Ground Scatter

A case that appears to exhibit E-layer scatter exclusive of ground scatter is that for January 21 to 22, between about 0400 and 0830, as seen on figure 7. In section II it was noted that the close-in returns appeared to be short scatter. The returns around 15 msec fall near the expected E-layer long-scatter delays. It is to be noted that the calculated F_2 skip for that period as shown by the position of the solid dots on figure 7 was long. This was corroborated by the record of reception of the Sterling pulses at San Diego, which reported reception weak between 0630 and 0730 and out completely between 0730 and 0946 with a "fade" commencing again at 1002. At the long distance, the E-scatter region is considerably closer than the ground-scatter region, and it would appear that the energy going to and from the ground is attenuated greatly by passing twice through the D and E layers so that one may conclude that the echoes seen at about 15 msec between 0400 and 0830 are solely E-layer returns. The assumption agrees with the observed loss of long distance returns as the F_2 skip moved out, as noted under section II, 5. There was a fair amount of sporadic-E ioni ation observed at Washington and some at Alamogordo during this period.

Echoes of the type discussed above are seen in figure 15, beginning at 2.4 msec for the E-layer short-scatter case and beginning at 13.0 msec for the E-layer long-scatter case.

7. Additional Considerations

It appears that often the strongest peaks may be due to back scatter from the ground, but that a continuous group of weak echoes preceding it in time may come from the E layer. The whole problem of just what the individual peaks are due to may be ambiguous in almost all cases where no concurrent supporting data are available, and in many cases where such data are obtainable. Among the many things that may cause these peaks are E-layer back scatter and scatter from ordinary ground, as well as from the sea and from large irregularities in the terrain. For a single hop in one direction, the low ray, ordinary wave, will always appear. There is also the possibility of ordinary-wave high ray (Pedersen ray), and low and high wave extraordinary. All four modes for one hop could conceivably, in the limiting case, become 4^{2n} modes for n hops of back scatter, although in practice conditions would never arise whereby all control points would propagate all modes. Besides, echoes returned by more than one hop become weaker as the number of reflections increases, so that many modes probably would not be visible.

Another source of ambiguity is the antenna radiation pattern. The transmitter beam width is only approximately allowed for in the analysis and minor lobes may cause reception of scattered energy from other sectors.

IV. Conclusions

As a result of the study of back-scatter echoes from a high-power pulse transmitter on a westward path from Sterling, Va., on a frequency of 13,660 kc between August 1947 and March 1948, certain conclusions were reached for the case studied.

Echo groups may often be seen containing peaks of energy scattered from the ground, which are stronger than peaks due to other sources. Echoes also appear, however, which are identifiable with E-layer long scatter. These are sometimes seen as weak, intermittent pips ahead of what appear to be ground-scatter pips and sometimes as a continuous line of weak pulses ahead of the main ground-scatter pulse. On occasions of long-distance F_2 skip, E-layer long scatter may appear without ground scatter being visible above the interference.

What is usually termed E-layer short scatter can be said with some certainty to be echoes from meteor trails. However, on rare occasions very strong clean and steady echoes have appeared at night at a distance which would indicate that they were direct reflections from intense clouds of sporadic E.

At sunrise, peculiar conditions arise that may in part be explained by the presence of long- and short-distance echoes when the pre-sunrise minimum of F_2-layer ionization is over the path and in part by back-scatter from the regular E or the E_2 layer before ionospheric absorption becomes large. Another possibility is a specular type of reflection from tilted layers.

Many ambiguous echoes are to be seen whose interpretation will require further study and experiment, considering ionospheric phenomena and antenna patterns.

The authors are indebted to G. F. Montgomery, who was responsible for the calculations of the rhombic antenna radiation pattern and the chart of sky-wave transmission delays. They are also grateful to W. Cullen Moore, of Boston University, through whose efforts the original transponder emissions were made from Alamogordo and to H. P. Gates of the U. S. Navy Electronics Laboratory, who furnished reception data from San Diego.

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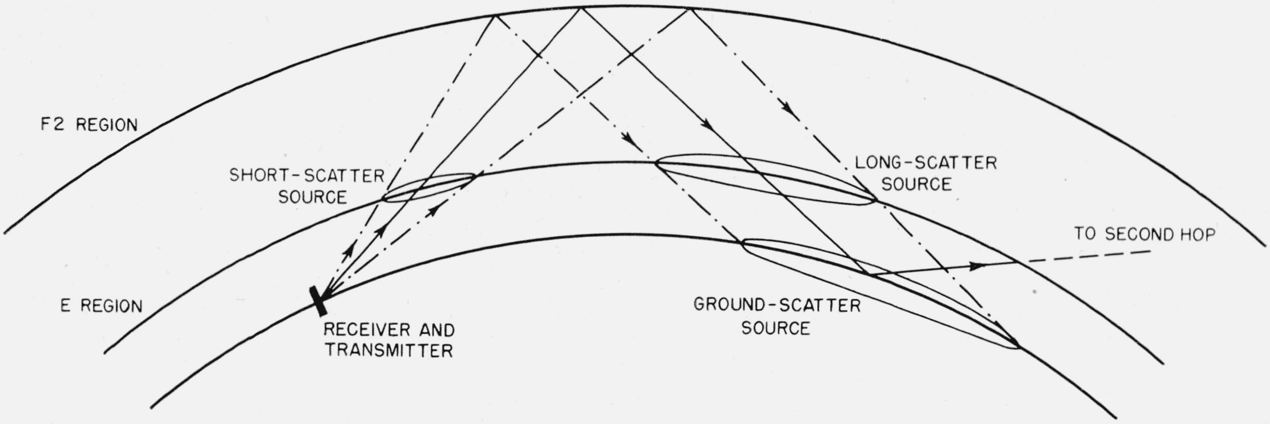


FIGURE 1. *Probable sources of scatter phenomena.*

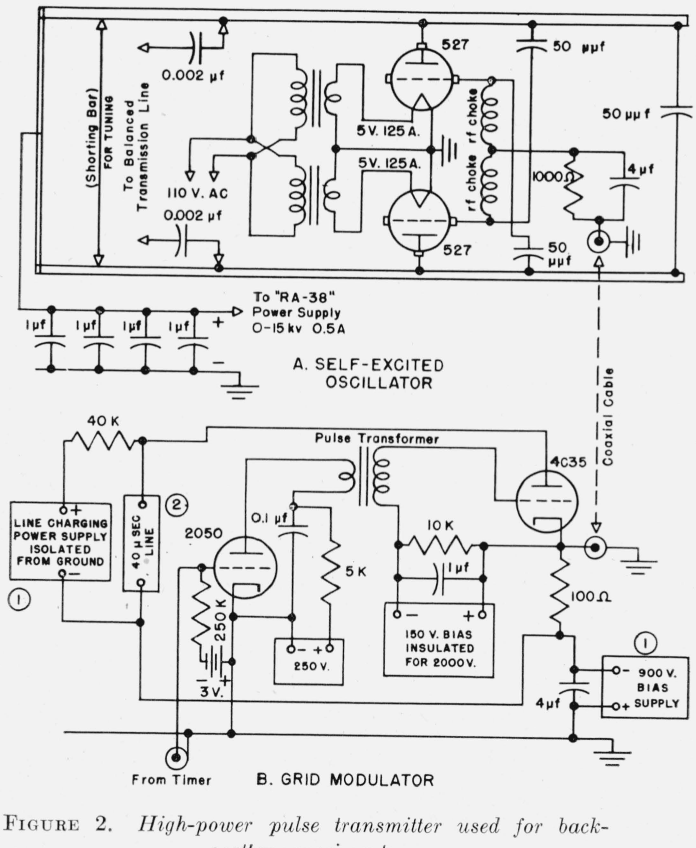
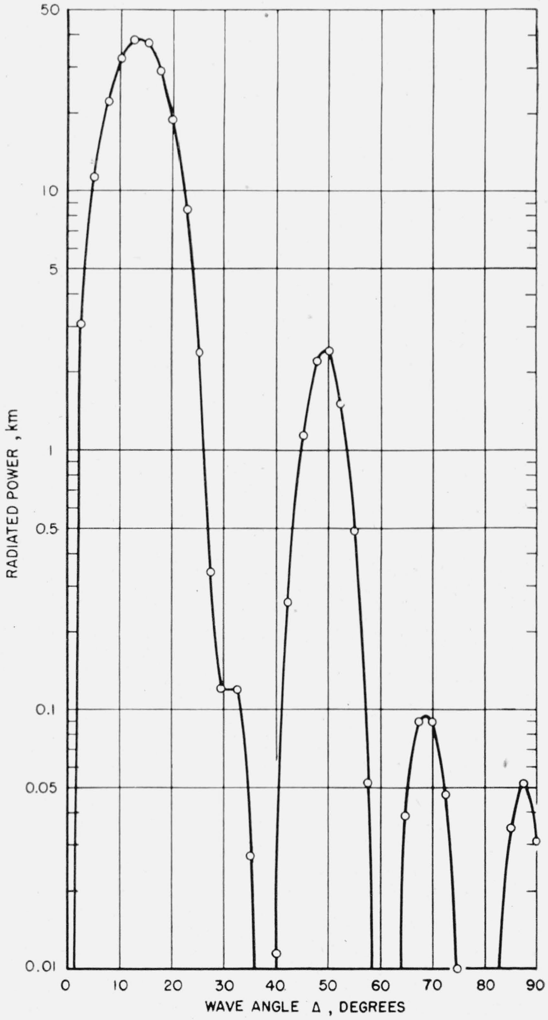


FIGURE 2. *High-power pulse transmitter used for back-scatter experiments.*

Bias-supply and line charging-supply voltages are varied for proper operating conditions. Line has 100-ohm characteristic impedance. A, Self-excited oscillator; B, grid modulator.

FIGURE 3. *Calculated vertical radiation pattern of rhombic antenna used in back-scatter experiments at zero azimuth.*

Data assumed in calculations: leg length, 262.5 ft; height, 75 ft; angle of tilt, 67°; frequency, 13.66 Mc/s. Ground constants: $\epsilon=10$; $\sigma=2\times10^{-14}$ emu. Radiated power at a particular wave angle is the power input to a lossless short vertical antenna over perfect ground, which will produce a zero elevation field intensity equal to the field intensity at the given angle produced by 1-kw input to the rhombic. The field intensity produced by 1-kw input to this reference vertical antenna is 186.3 millivolts/meter at 1 mile.



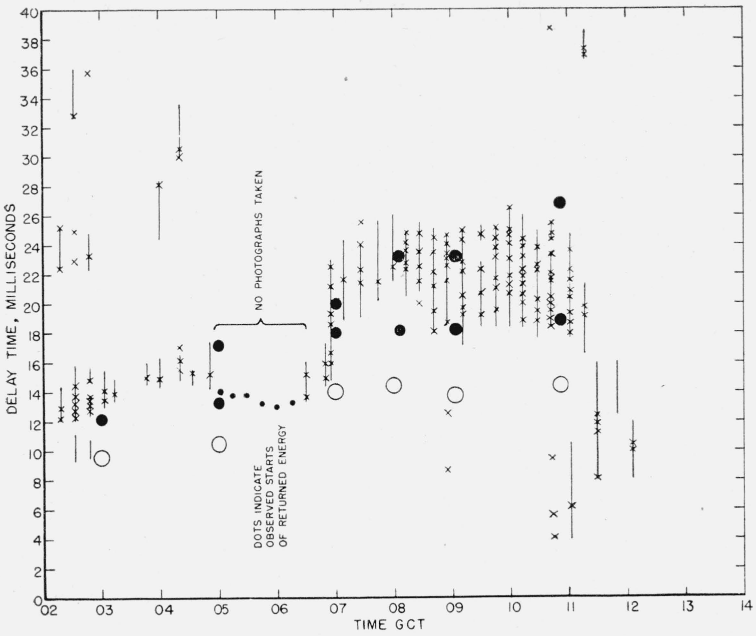


FIGURE 4. *Back-scatter observations on 13,660 kc at Sterling, Va.; 0200 GCT August 27, 1947 to 1200 GCT August 27, 1947.*

Crosses indicate amplitude peaks. Solid circles indicate shortest and longest of ground-scatter delay times derived at any time from F^2 skip-distance maps. Open circles indicate E-layer long scatter corresponding to shortest derived ground scatter delay time.

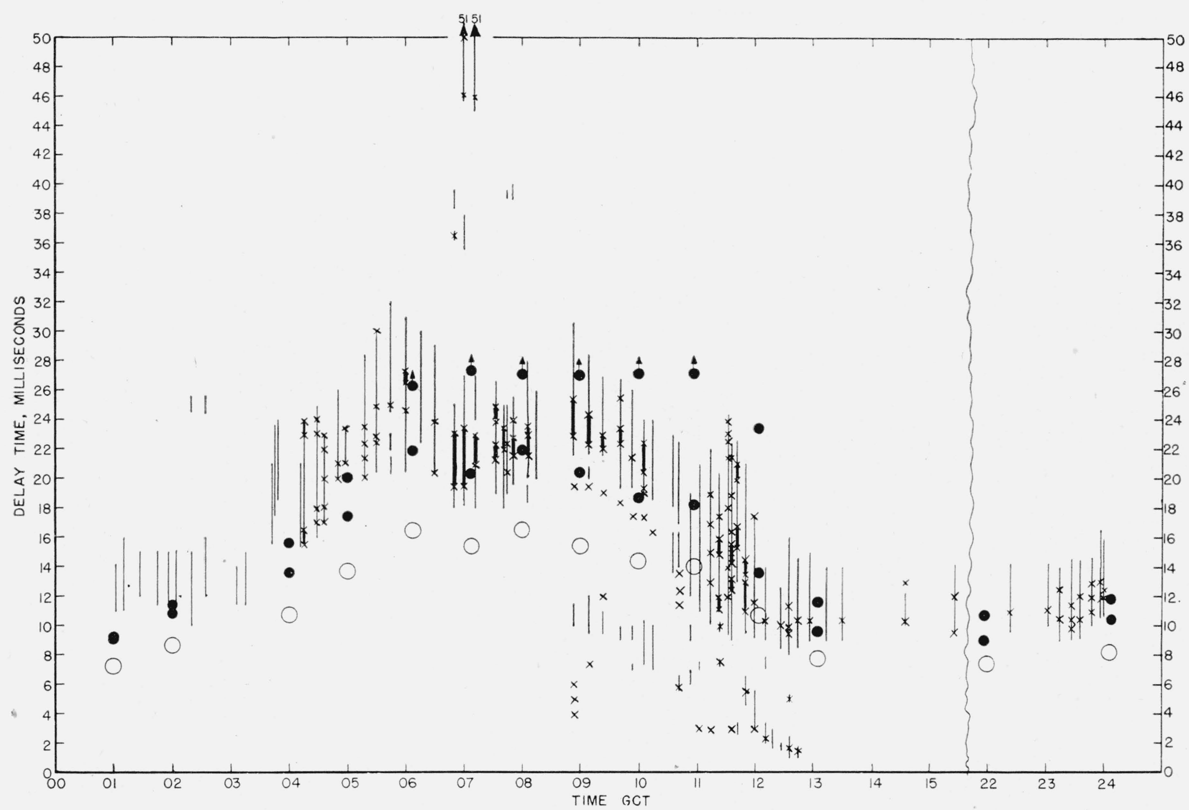


FIGURE 5. *Back-scatter observations on 13,660 kc at Sterling, Va.; 0100 to 2400 GCT, October 2, 1947.*

Crosses indicate amplitude peaks. Heavy line between crosses indicates high amplitude between peaks. Solid circles indicate shortest and longest of ground-scatter delay times derived at any time from F^2 skip-distance maps. Arrows pointed vertically upward indicate skip greater than 4,000 km. Open circles indicate E-layer long scatter corresponding to shortest derived ground-scatter delay time.

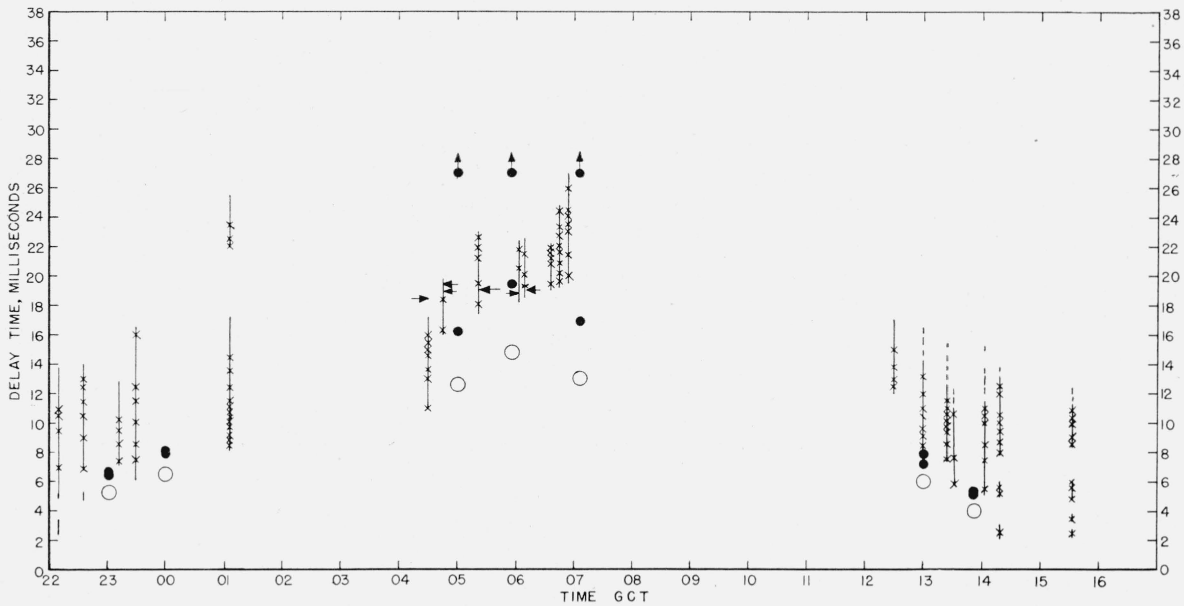


FIGURE 6. *Back-scatter observations on 13,660 kc at Sterling, Va., including reception of transponder located at Alamogordo, N. Mex.; 2200 GCT November 25, 1947 to 1500 GCT November 26, 1947.*

Crosses indicate amplitude peaks. Horizontal arrows indicate Alamogordo transponder returns. Solid circles indicate shortest and longest of ground-scatter delay times derived at any time from F^2 skip-distance maps. Arrows pointed vertically upward indicate skip greater than 4,000 km. Open circles indicate E-layer long scatter corresponding to shortest derived ground-scatter delay time.

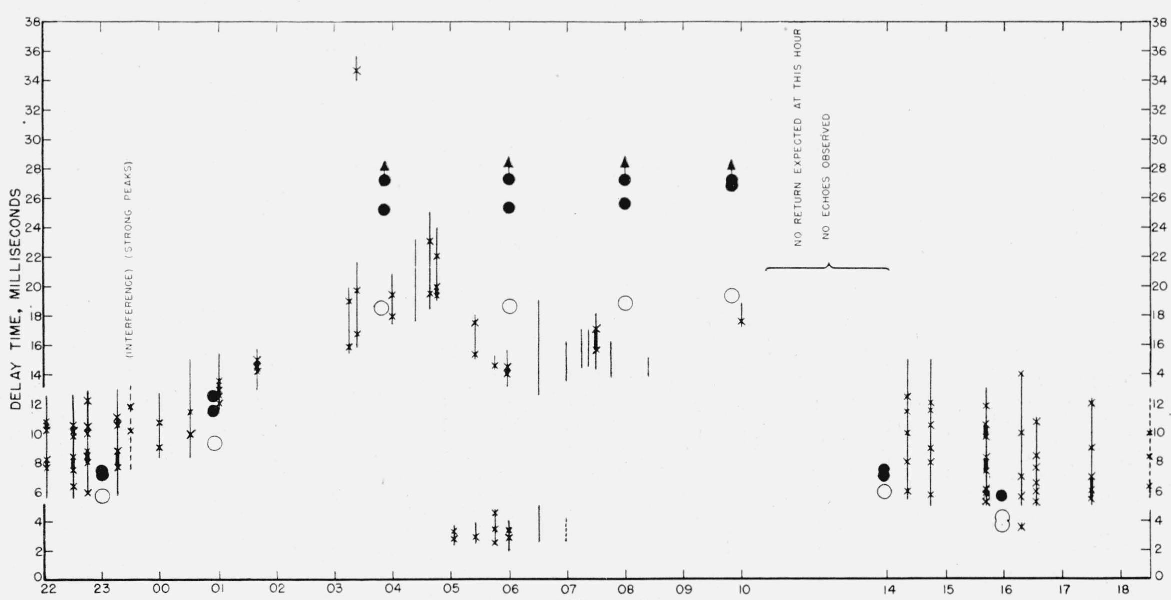


FIGURE 7. *Back-scatter observations on 13,660 kc at Sterling, Va.; 2200 GCT January 21, 1948 to 1830 GCT January 22, 1948.*

Crosses indicate amplitude peaks. Heavy line between crosses indicate high amplitude between peaks. Solid circles indicate shortest and longest of ground-scatter delay times derived at any time from F^2 skip-distance maps. Arrows pointed vertically upward indicate skip greater than 4,000 km. Open circles indicate E-layer long scatter corresponding to shortest derived ground scatter delay time.

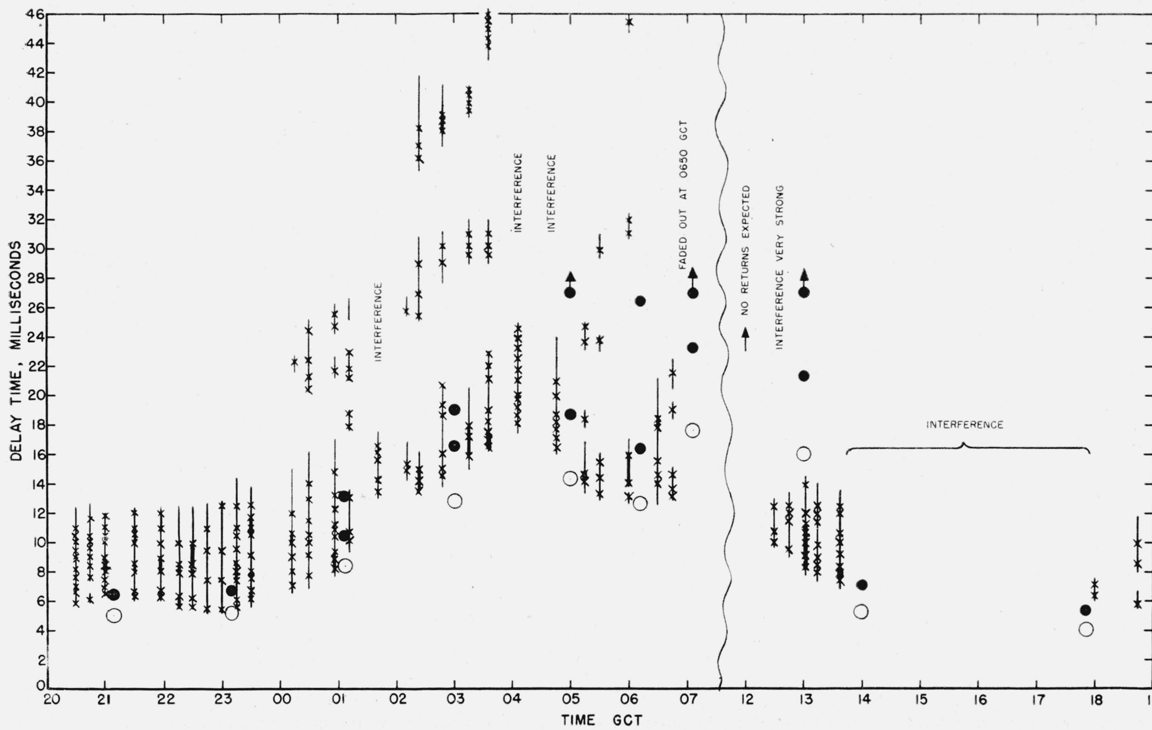


FIGURE 8. *Back-scatter observations on 13,660 kc at Sterling, Va.; 2000 GCT February 15, 1948 to 1900 GCT February 16, 1948.*

Crosses indicate amplitude peaks. Solid circles indicate shortest and longest of ground-scatter delay times derived at any time from F^2 skip-distance maps. Arrows pointed vertically upward indicate skip greater than 4,000 km. Open circles indicate *E*-layer long scatter corresponding to shortest derived ground scatter delay time.

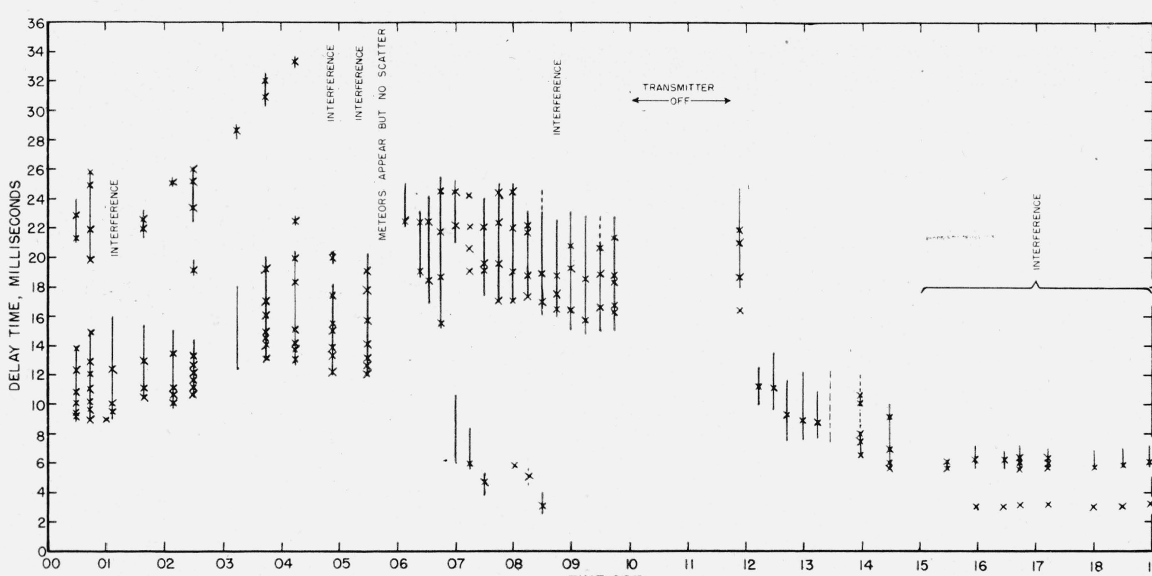


FIGURE 9. *Back-scatter observations on 13,660 kc at Sterling, Va.; 0000 GCT March 14, 1948 to 1900 GCT March 14, 1948.*

Crosses indicate amplitude peaks.

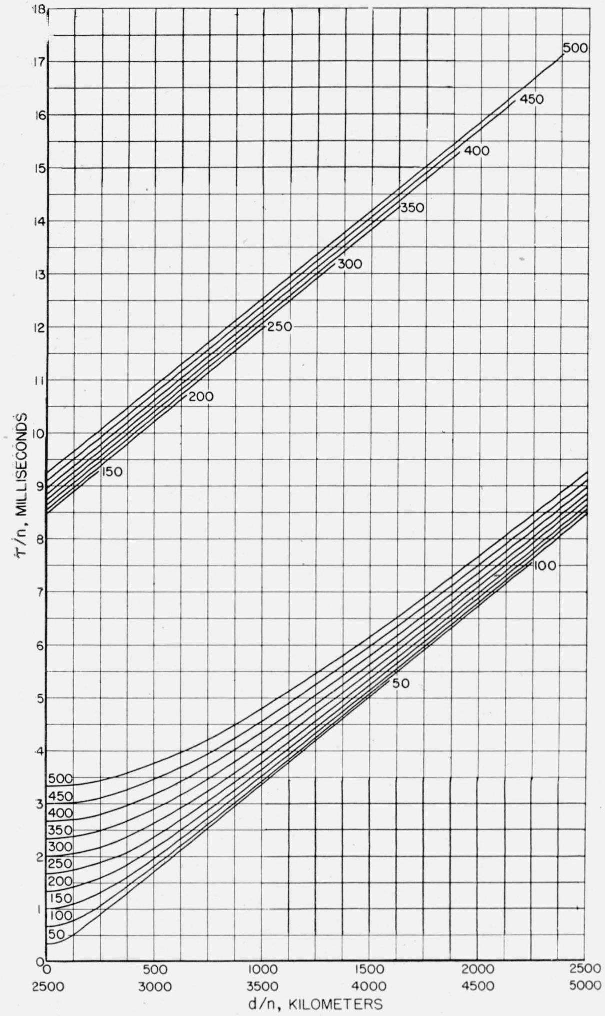


FIGURE 10. *Sky-wave transmission delays (geometrically calculated).*

τ is the total sky-wave delay; d is the total great circle range; n is the number of hops. Values on curves denote virtual heights in kilometers. Curves terminate at maximum range, zero wave angle. Assumed earth radius is 6,370 km.

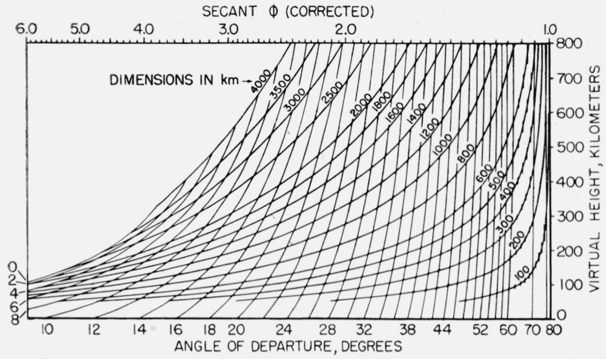


FIGURE 11. *Transmission curves showing vertical angles.*

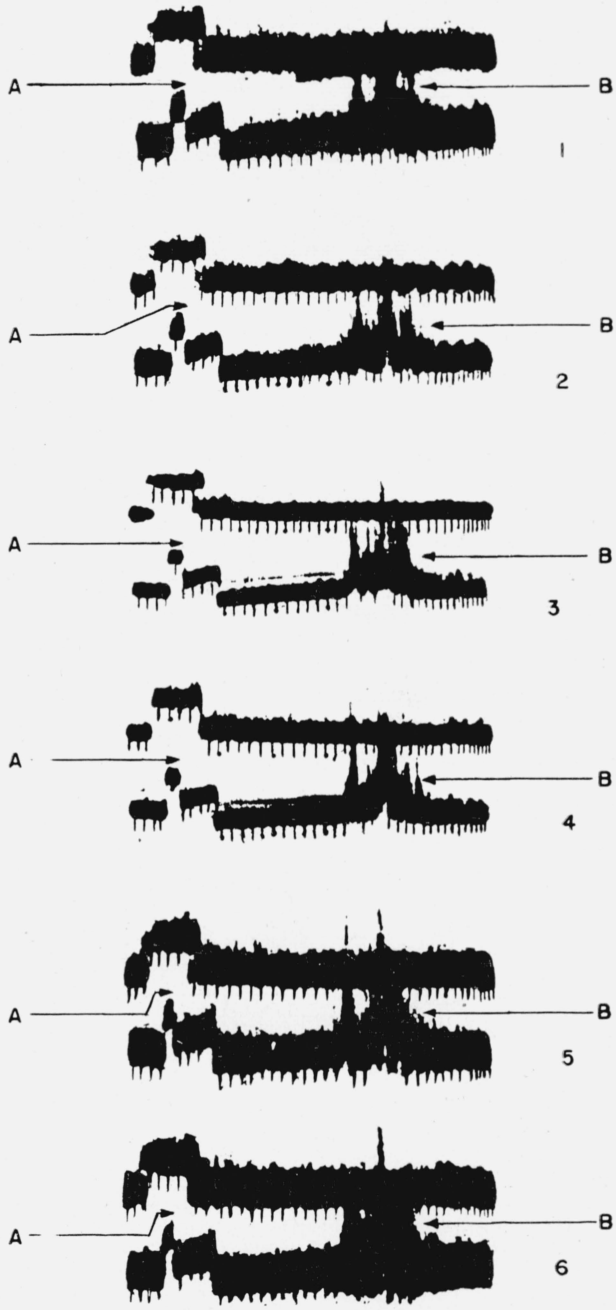


FIGURE 12. *Back-scatter echoes November 21, 1947 at 0010 GCT showing changes over a 45-sec interval.*

Initial pulse starts on pedestal on lower left. Time proceeds to extreme right, then to upper left and across to right, then down to lower left, total sweep being 40 msec. Each marker represents ½ msec, and every fifth marker is shorter than the rest. Frames 1 through 6 in time sequence. A, Transmitter pulse; B, first echo group.

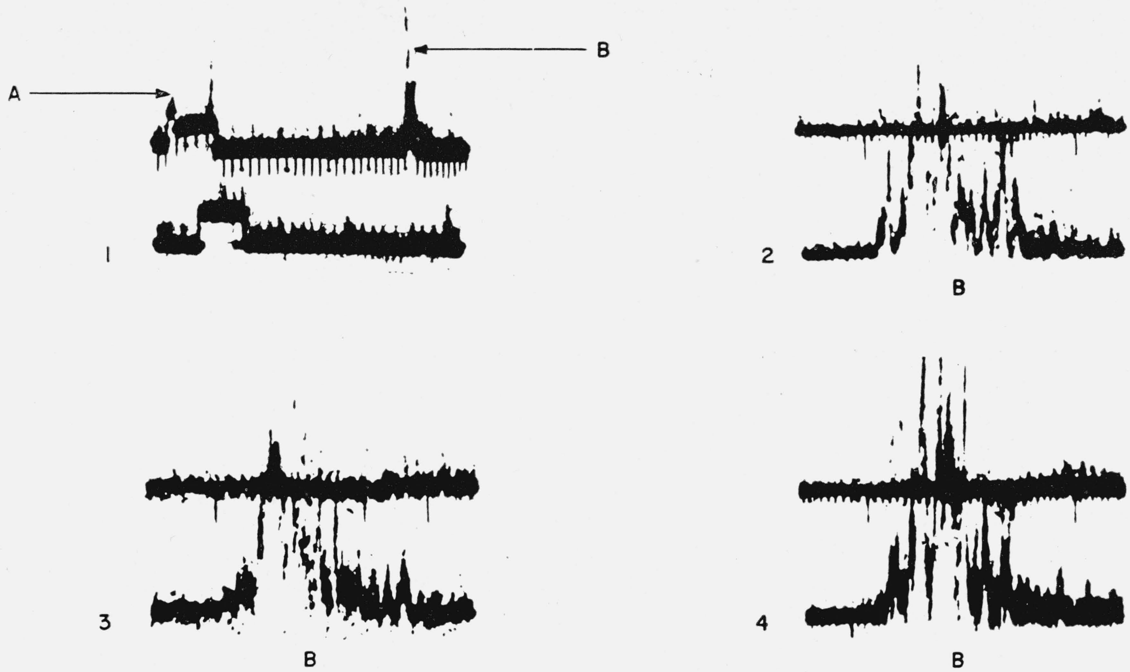


FIGURE 13. *Back-scatter echoes August 27, 1947. 1, slow sweep taken at 0314 GCT; frames 2, 3, and 4 taken a few minutes earlier at intervals of 2 sec on 2,500-µsec sweep.*

A, Transmitter pulse; B, first echo group.

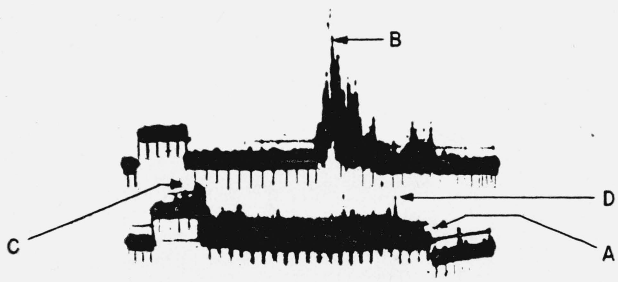


FIGURE 14. *Back-scatter echoes February 16, 1948, 0252 GCT, demonstrating presence of at least three echo groups.*

Initial pulse starts at lower right at break in base line. Time proceeds to extreme right, then to upper left and across to right, then down to lower left. First group is large double group on upper trace, second is partially on top of lower pedestal, third is just ahead of initial pulse. Pip to right of main pulse is probably a meteor. A, Transmitter pulse; B, first echo group; C, second echo group; D, third echo group.

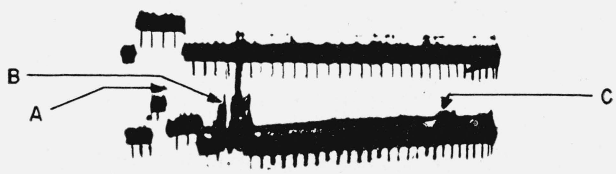


FIGURE 15. *Returns on January 22, 1948, at 0617 GCT showing close-in strong reflections beginning at 2.4 msec in addition to weaker long-distance reflections beginning at 13.0 msec.*

A, Transmitter pulse; B, close-in strong reflections; C, long-distance reflections.

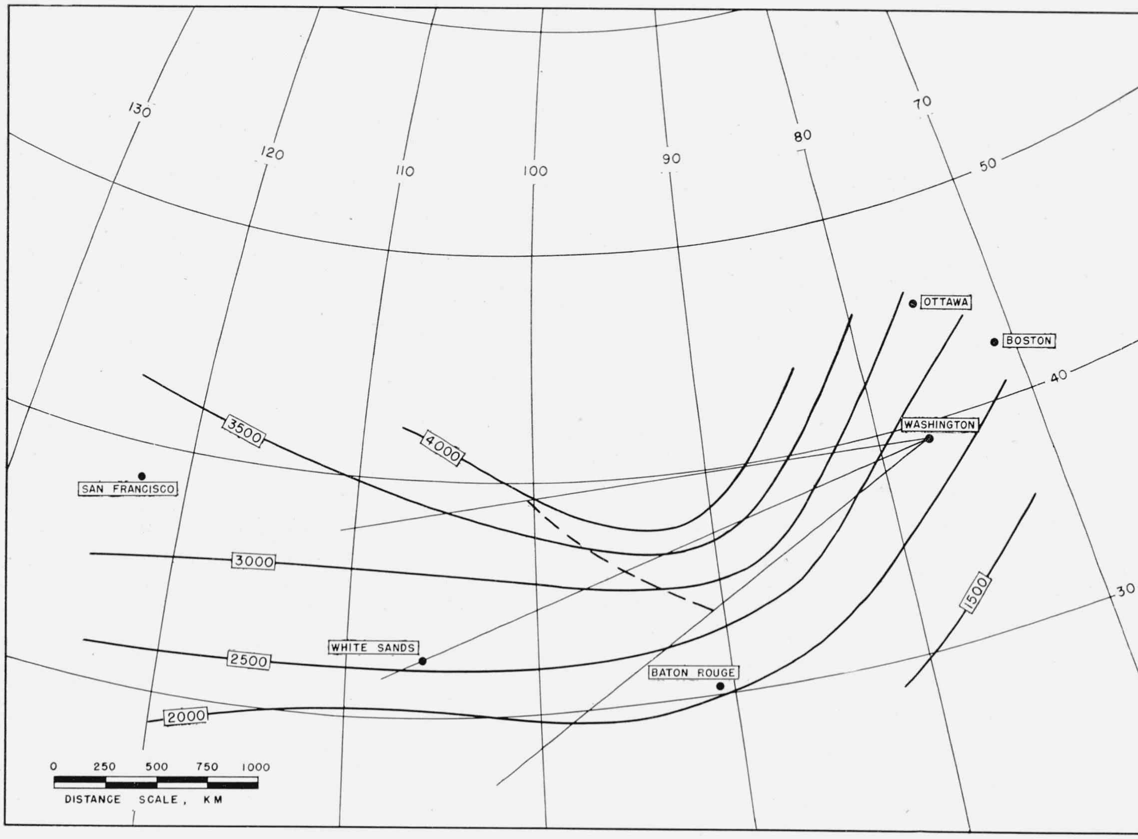


FIGURE 16. *Skip-distance contour map for 13,660 kc, 1100 GCT August 27, 1947.*

– – – –, Expected control points for back-scatter propagation via *F*2 layer.

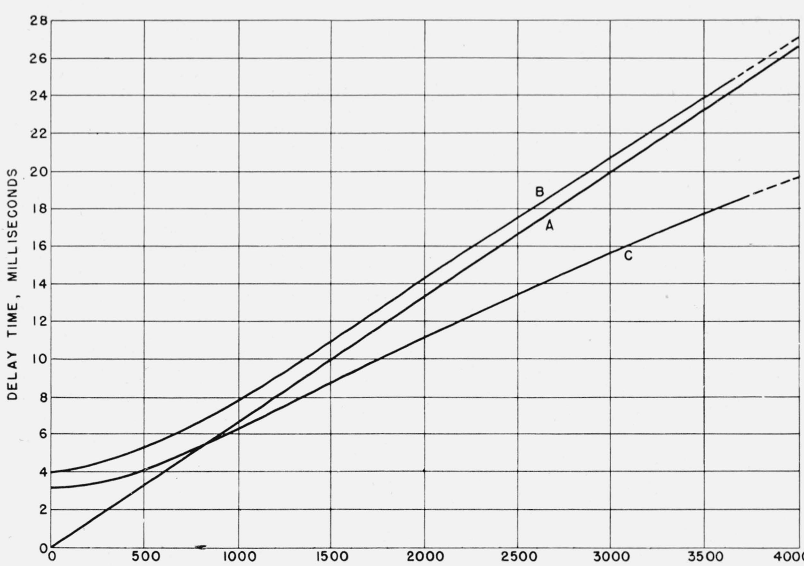


FIGURE 17. *Calculated echo delays assuming ground scatter and E-layer back scatter.*

A, Echo delay time, assuming ground-scatter and propagation along the earth's surface; B, echo delay time, assuming ground-scatter and 300-km virtual height of reflection; C, echo delay time, assuming back-scatter from *E* layer at 110-km virtual height and 300-km virtual height of reflection.

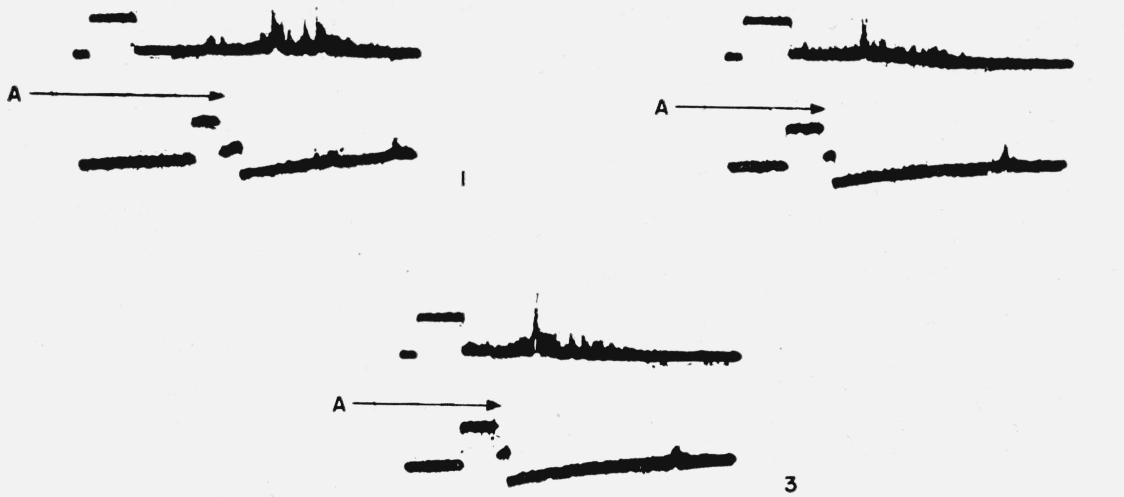


FIGURE 18. *Echoes on October 2, 1947 apparently showing E-layer back scatter ahead of ground scatter.*

Pulse and time sequence as in figure 4. Echoes under discussion are on upper trace. Small pip to right of lower trace is 2-hop. 1, "*E*-layer long scatter" ahead of assumed first-hop ground scatter at 0855+35 sec GCT. 2, "*E*-layer long scatter" weak, ahead of assumed first-hop ground scatter at 0923+17 sec GCT. 3, "*E*-layer long scatter" almost disappearing 2 sec later. A, Transmitter pulse.

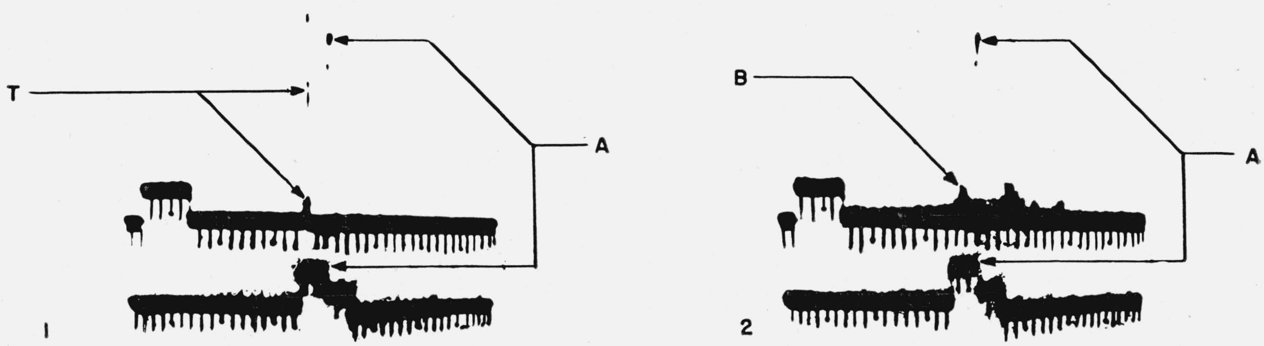


FIGURE 19. *Relative positions of transponder and back scatter when Sterling, Va., signal failed at Alamogordo.*

Initial pulse starts in middle of lower pedestal. Time proceeds as in figure 4. Point where initial pulse crosses top trace is approximately 20 msec. 1, Position of transponder last time definitely seen 0607 GCT (back scatter detuned). 2, Position of scatter group as seen 2 min later. A, transmitter pulse; B, first echo group; T, transponder.

WASHINGTON, July 25, 1949.