A Comparison of CW Field Intensity and Backscatter Delay*

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***Summary*—Determination of failure and recovery times from backscatter records at 15 mc on a 2700-km path was done with good agreement. Certain disturbed days gave anomalous scatter records. Rapid changes in these records were compared with motion of ionospheric irregularities, rates being of the same order of magnitude.**

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I. Objective

EXPERIMENTS by various investigators have indicated that one prominent group in most observed scatter-echo patterns should be ground-scatter propagated via F_2 layer[1,2,3,4,5,6] because of focus effects at the edge of the skip distance.[7] The objective of this experiment was to study the relationship of backscatter to skip phenomena by comparing the field intensity of the 15,000-kc WWV signals received at the White Sands Proving Ground, New Mexico, with the recorded delay times for the backscatter received at Sterling, Virginia from a pulse transmitter operating at approximately 15,000 kc.

II. Equipment

The White Sands receiving station was equipped with a conventional field-intensity recorder. Calibrations were made in terms of microvolts input to the receiver. The transmitter at Sterling, Virginia had a 500-kw peak power output of 40-μsec pulses 25 times per second.

The directional antenna for the pulse transmitter, with characteristics similar to those of the antenna in footnote reference 2, was oriented at an azimuth of 263 degrees from true north. The receiver was a communications type modified for pulse reception, and a Loran indicator was used to display A-scope patterns for single-frame photography. In later stages of the work a range-time recorder was used. The receiving antenna was a sloping vee adjacent to the transmitting antenna and oriented in the same direction. A precise oscillator and frequency divider unit supplied trigger pulses to the transmitter as well as trigger pulses and marker pulses to the range-time recorder.

III. Description of Range-Time Back-Scatter Records

Fig. 1 is an illustration of a typical range-time record. The abscissas represent time in GCT running from left to right, and the ordinates represent delay in milliseconds. (This figure and other photographs were retouched, where necessary, for reproduction.)

On a normal day, such as that represented in Fig. 1 (if one can distinguish a trace which is normal from among the great variety of patterns which are obtained on the range-time records over a period), there is a fairly dense line running along the time axis at the delay time associated with the F_2-layer skip distance. In the early evening this line starts increasing in delay time and runs out as the skip distance increases. Usually this distance increases to a point where the echoes are too weak to record, being limited by low-angle antenna response. A normal ground-scatter return is frequently seen to be composed of a group of separate echoes which start up, change in range, and die out while overlapping echoes at slightly different ranges do the same thing. Possible reasons for this type of structure are discussed under 6 below.

At dawn, the F_2 ground scatter returns with rapidly diminishing range, but is mixed with a great deal of close-in scatter which may possibly be caused by stratification in the E region at the time of regular ionization increase. Later, these complex echoes disappear, perhaps because of increased ionospheric absorption, and leave the ground-scatter echoes at the regular F_2 skip distance, except under certain disturbed conditions where the F_1 layer may control propagation.

Fig. 2 illustrates a normal day with strong, steady, nearby echoes, which remain at about the same delay as the ground-scatter echo propagated via F_2 increases in delay with increase of skip distance. This effect seems to be caused by the presence of strong sporadic-E ionization. Figs. 3 and 4 are two very dissimilar records for disturbed days. They are discussed in further detail under 6 below.

IV. Method of Extracting the Data

Backscatter records of the general type of Figs. 1 through 4 for spring, summer, and late fall of 1950, and in some cases A-scope records, were examined and the

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† U. S. Department of Commerce, National Bureau of Standards, Washington 25, D. C.

[1] A. H. Benner, "Predicting maximum usable frequency from long distance scatter," Proc. I.R.E., vol. 37, p. 44; January, 1949.

[2] W. L. Hartsfield, S. M. Ostrow, and R. Silberstein, "Back scatter observations by the central radio propagation laboratory—August, 1947 to March, 1948," *Jour. Res. Nat. Bur. Stand.*, vol. 44, pp. 199–214; February, 1950.

[3] W. Dieminger, "The scattering of radio waves," *Proc. Phys. Soc.* (London), vol. 64, pt. 2, no. 374B, pp. 142–158; February, 1951.

[4] A. M. Peterson, "The mechanism of F-layer Propagated backscatter echoes," *Jour. Geophys. Res.*, vol. 56, pp. 221–237; June; 1951.

[5] W. G. Abel and L. C. Edwards, "The source of long distance back scatter," Proc. I.R.E., vol. 39, pp. 1538–1541; December, 1951.

[6] O. G. Villard and A. M. Peterson, "Instantaneous prediction of radio transmission paths," *QST*, vol. 36, pp. 11–20; March, 1952.

[7] T. L. Eckersley, "Studies in radio transmission," *Jour. IEE* (London), vol. 71, no. 429, pp. 405–459; September, 1932.

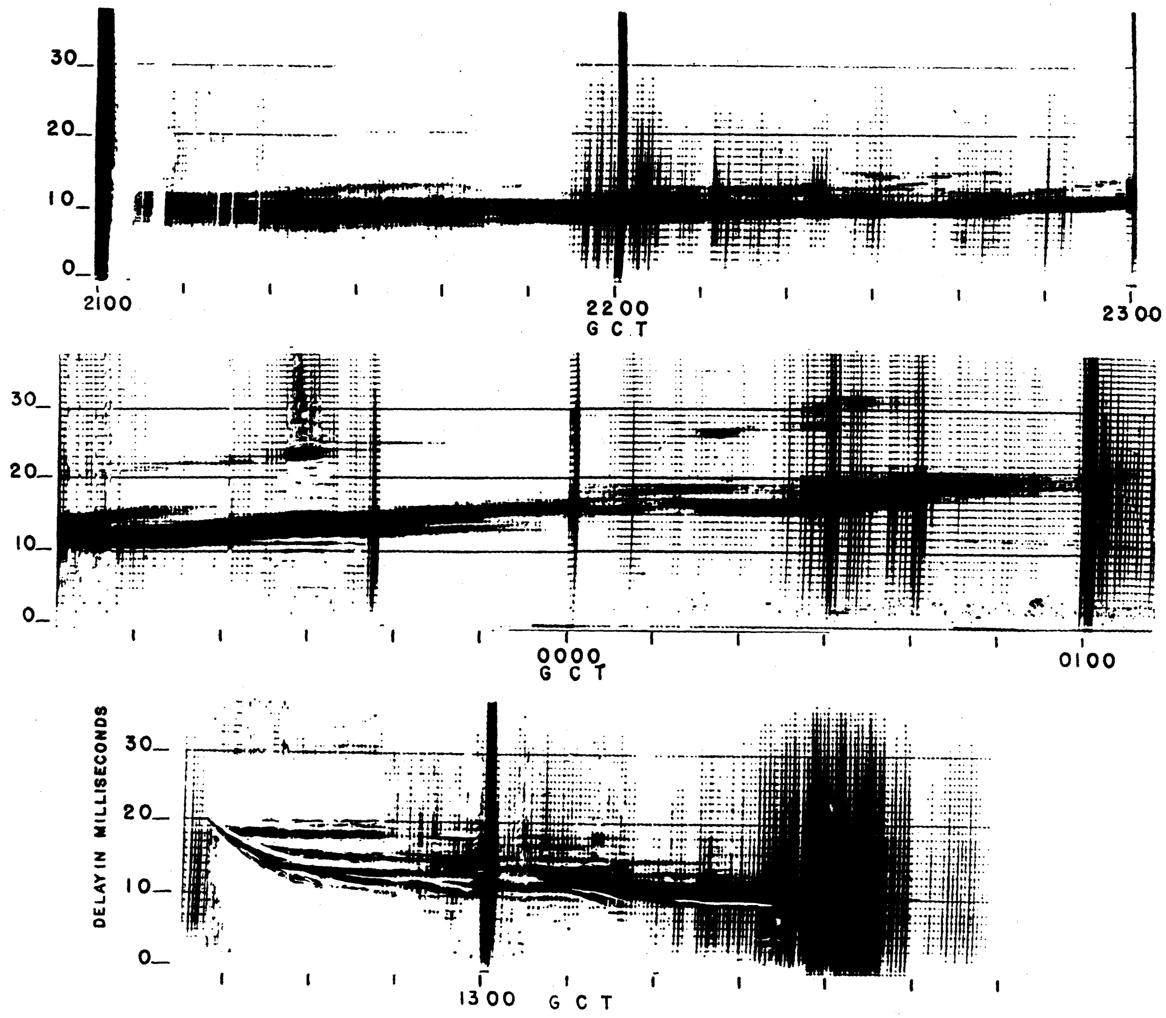

Fig. 1—Normal day record. December 4–5, 1950.

delay times in milliseconds between the transmitted pulse and the earliest peak of energy in the F_2-propagated ground-scatter group were plotted against Greenwich Civil Time. In some ambiguous cases traces at different ranges were plotted simultaneously.

The field-intensity record for the same day as that of a given scatter record was examined and, using the same time scale, a smoothed curve of the corresponding field intensity in decibels above 1-μv input to the receiver was plotted, so that it was possible to compare field intensity of the WWV 15,000-kc signals at White Sands, New Mexico, and the pulse delay times recorded at Sterling, Virginia. On each graph are placed two ionospheric disturbance figures, the Washington I figure and the North Atlantic Q figure (disturbance criteria in use by the National Bureau of Standards) for the periods covered, for qualitative evaluation of propagation conditions. Fig. 5 is a set of such plots.

In the experimental comparison of backscatter and point-to-point field-intensity records, the degree of complexity of the field-intensity records was such that it was difficult to establish the exact time of path failure and path recovery consistently from record to record. Therefore, a specific characteristic of the field-intensity record had to be defined as indicative of the start of path failure and the end of path recovery. The complexities appeared to be a result of ionospheric irregularities,[8,9] which cause different rates of failure and sometimes temporary partial recovery during a failure period. Almost all of the records exhibited a period of increased field intensity because of the focus at the edge of the skip distance just prior to an initial sudden sharp drop.[9,10] It was the start of the initial sharp drop which was taken as the start of path failure and compared with the scatter records, since it was deemed that partial recoveries did not represent a pure mode and often not a great-circle mode. The end of a sharp rise was treated in the same manner with regard to path recovery. Furthermore, the length of time after the initial drop that these modes could be observed was highly variable, being a

[8] E. N. Bramley and W. Ross, "Measurement of the direction of arrival of short radio waves reflected at the ionosphere," *Proc. Royal Soc. A*, vol. 207, pp. 251–267; June 22, 1951.

[9] R. Silberstein, "Interpretation of High-Frequency C-W Field Intensity Records with the Aid of Simultaneous Pulse Data," NBS Report No. 1085; July 27, 1951. Also to appear in Proc. I.R.E., vol. 40, pp. 974–976; August, 1952.

[10] E. V. Appleton and W. J. G. Beynon, "The application of ionospheric data to radio communication problems:" Part II, *Proc. Phys. Soc.* (London), vol. 59, p. 58; 1947.

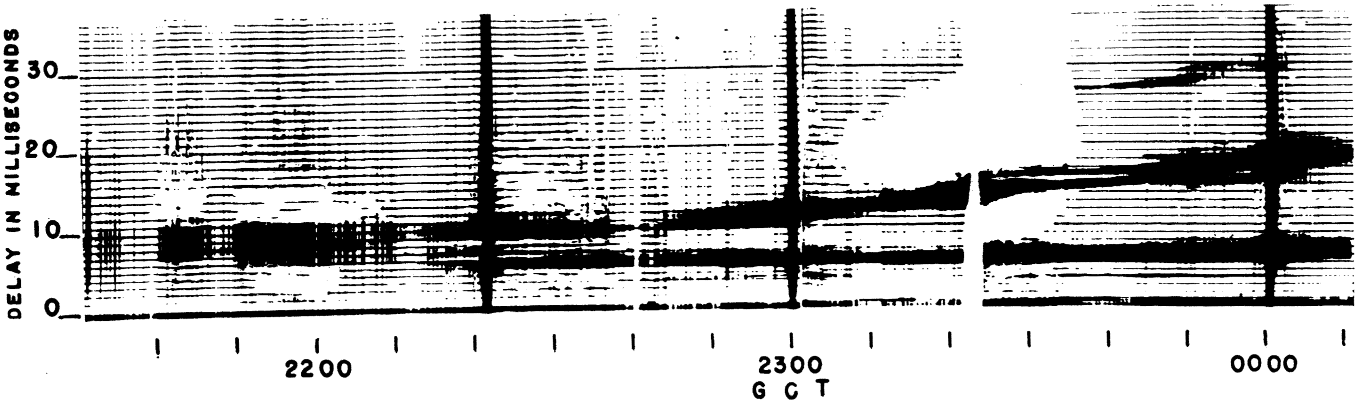

Fig. 2—Normal day record with close-in reflections. December 28, 1950.

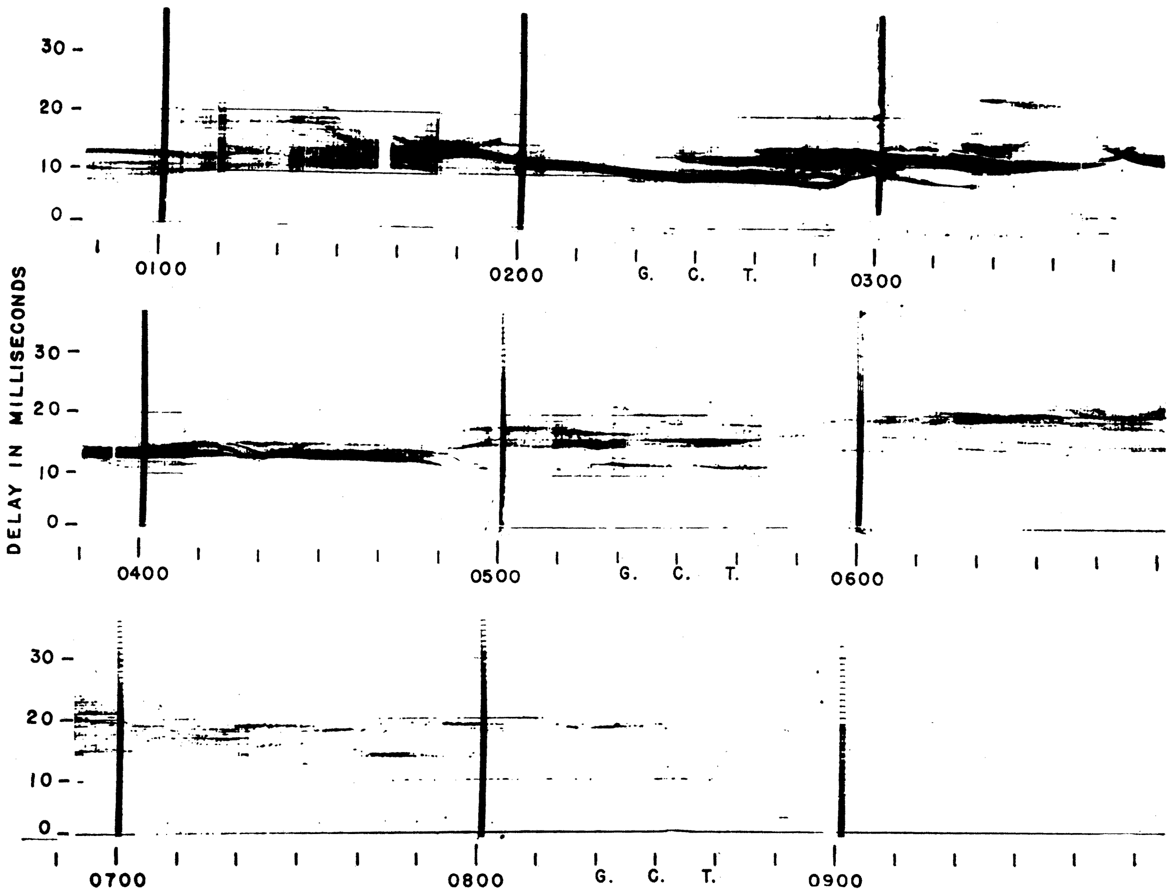

Fig. 3—Disturbed day record. June 30, 1950.

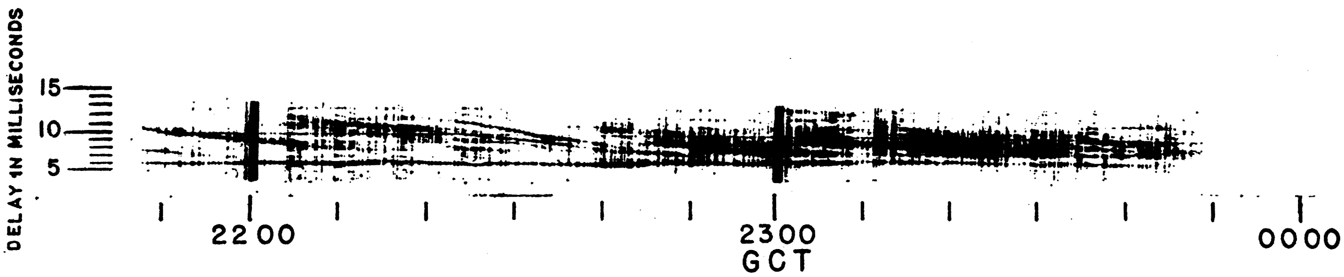

Fig. 4—Record near start of disturbance. November 22, 1950.

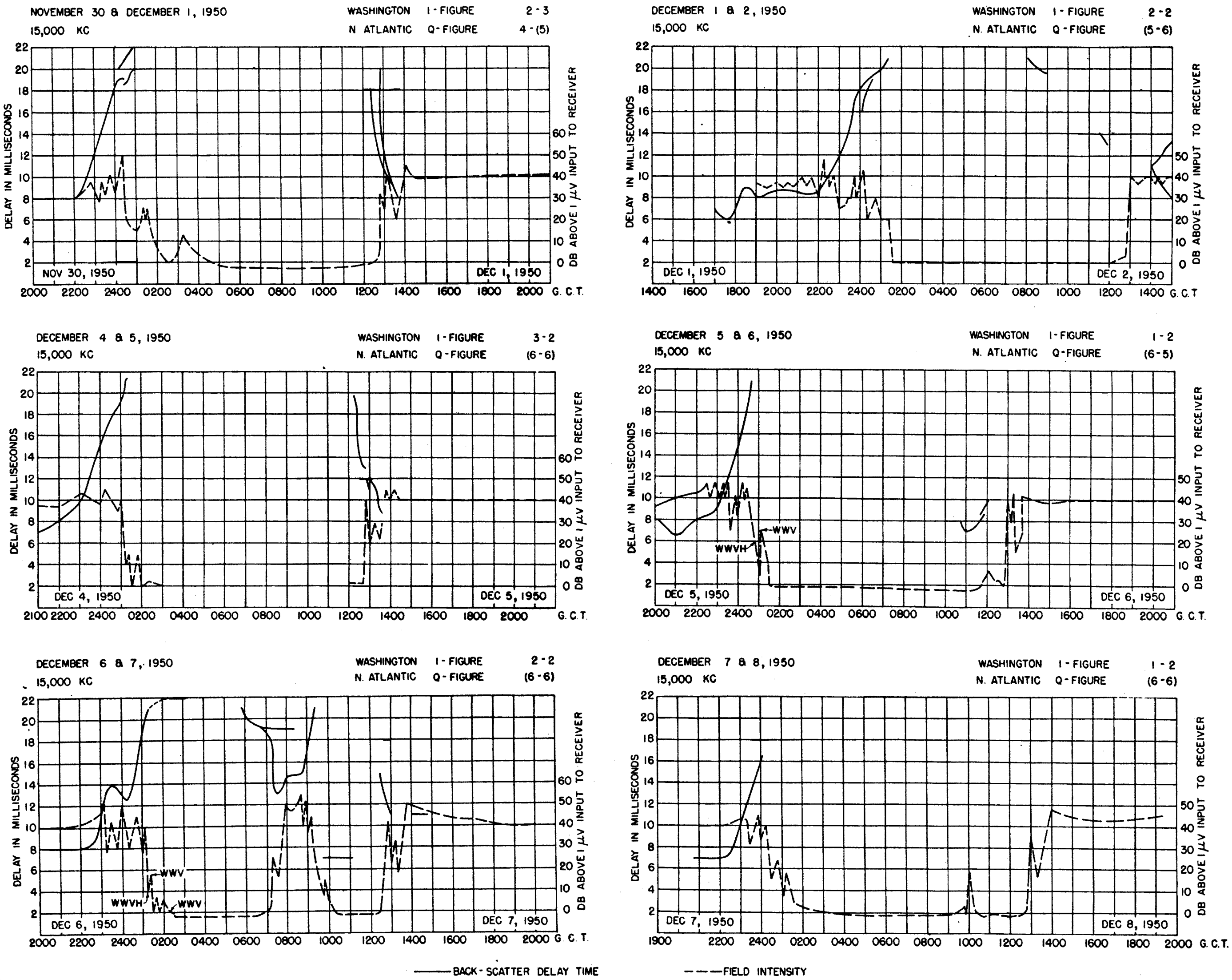

Fig. 5—Simultaneous plots of field intensity of WWV. Recorded in New Mexico and Sterling, Va. Backscatter delay times.

function of such diversified factors as ionospheric turbulence and the noise level at the receiver.[9]

Throughout the text, the time of the start of path failure and the time of the end of the path recovery are referred to, for the sake of brevity, as the time of path failure or failure time, and the time of path recovery, or recovery time.

Identification of which group of scatter constituted ground scatter propagated via F_2 layer required some knowledge of day-to-day conditions over the path and an appreciation of what other types of scatter might exist. For the distance and frequency involved, the identification was fairly easy at the time of path failure except on disturbed days, such as that of Fig. 3, and on certain anomalous records. "Short-scatter" echoes directly from the E layer, and ground scatter propagated by sporadic-E ionization, when visible, occurred at very much smaller delay times. At the time of path recovery, identification was frequently uncertain, partially because of the existence of many short-distance echoes.

In analyzing the data, average values of virtua heights at the times of path failure and recovery were assumed for the summer (spring and summer) and winter (late fall) group. This assumption was based upon values obtained by scaling Washington and White Sands vertical-incidence ionosphere records with a 2,700-km transmission curve for each day of the experiment, using records on which this transmission curve, for a 15-mc operating frequency, fell tangent to the h'-f curve. The final round figures were 400 km for summer and 300 for winter, corresponding to delay times of 19.3 msec and 18.8 msec, respectively, for ground scatter at 2,700 km. These delay values were used on the scatter records to estimate the times of path failure and recovery for comparison with the times of day when failure and recovery of the recorded WWV signal occurred. Again, the times of failure and recovery of this signal were applied to the scatter record to obtain delay times which yielded apparent skip distance, for comparison with the true distance.

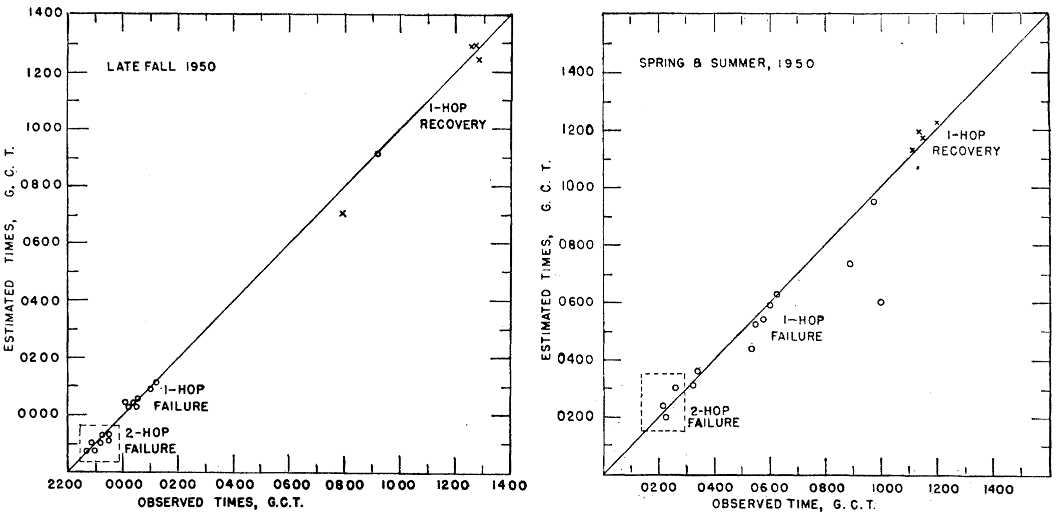

Fig. 6—Comparison of estimated and observed failure and recovery times.

V. Results

Fig. 6 shows plots of observed versus estimated path failure and recovery times scaled from figures like Fig. 5, one group being spring and summer, and one, late fall. Both 45-degree lines are loci of points of perfect agreement.

In the spring and summer group most of the errors were within 20 minutes, but May 10, June 16, and June 21 had large errors. The 4-hour error of June 21 was partly due to the difficulty of defining a failure time because of the slow decay of the signal. However, if interference had been less, it is possible that scatter peaks would have been observed at close enough range to account for propagation. The other errors may have been caused by lack of detailed information on the scatter records because of the presence of interference.

In the late-fall group the largest error was 15 minutes. The apparent improvement over the summer results was due to the rapid rate of change of skip distance under winter conditions.

Skip distances were estimated at the observed time of path failure by using the delay times and the assumed virtual heights. Errors are within about 12 per cent for the summer group and 8 per cent for the winter group, the rms errors being 5.7 per cent and 3.4 per cent, respectively.

The variation of estimated time of path failure with assumed virtual height was calculated for May 12. Changes of height of ± 50 km produce only small changes in the estimated failure time (6 or 7 minutes). These are typical results for the summer type of record since the rate of change of delay time with time of day is typical. Discrepancies would be smaller for winter conditions because of the greater rate of change, showing that the larger errors of estimating are not produced by erroneous height choices.

The change of estimated skip distance with change of assumed virtual height was also calculated for that day. Changes of the assumed virtual height of ± 50 km made changes in the estimated skip distance of less than 2 per cent, and for a typical winter day the error would have been still smaller because of the lower assumed virtual height.

Because of interference contaminating most of the records, only four sunrise path recoveries appear on Fig. 6 for spring and summer, and only three for late fall. They appear to have the same order of magnitude of error as the failures. However, the complexity of recovery periods at shorter delay times is such as to make interpretation of shorter skip distances than the one used here rather difficult.

Two-hop failure times are plotted on Fig. 6 for reasons of general interest, and surprisingly good results are obtained.

It is also desirable to point out that literal application of a simple rule of scaling the strongest peak seen, or of scaling the first peak, may lead to completely erroneous results in cases where close-in scatter groups representing ground-scatter propagated via E or direct E-layer short scatter are seen. On days such as are represented by the range-time record of Fig. 2 the echoes at about 4 or 5 msec might be regarded as one-hop ground scatter propagated by F_2, and the echoes at about 11-msec two-hop of the same type of propagation, and indeed on the A-scope both echoes would have similar characteristics, with equal possibility of either one being the stronger. It is only by watching trends as time progresses that one can see that the second group moves out with the F_2 skip distance and the first does not change much, identifying it with the next most likely source of short- or long-scatter reflections, the E-layer. In all cases where it is desired to determine F_2 skip distance, it is necessary to distinguish, by experience, which group is the ground-scatter group propagated via F_2.

Although there is apparent good agreement between the estimated failure and recovery times and observed failure and recovery times on most undisturbed days, it does not follow that signals will not be detectable and even usable for many hours outside the periods bounded by the estimated times of recovery and failure of transmission. It will be recalled that the start of path failure was defined as the start of the initial sharp drop after skip focus. Although this drop for this path is usually of the order of 20 to 40 db, and usually very rapid, there are times when it is not at all rapid; it is usually followed by one or more temporary partial signal recoveries, and the time at which the signal is last heard may be hours later. Listening observations made during field-intensity recording of WWV at White Sands on November 30, and December 1, 1950 showed that WWV could be detected at least 1 hour and 42 minutes on the first day and 2 hours and 25 minutes on the second day, after the defined start of path failure.

VI. Structure of Scatter Echoes on Range-Time Records

The frequent appearance of ground-scatter echoes as a number of close, but separated, echoes with the behavior described under Section 3 above suggests the fact that some things on the ground are better scatterers than others. Dieminger[8] believes that specific objects play an important part. The frequent appearance of cusps on the records suggested a mechanism whereby different regions of an irregular ionosphere pick up and lose the same or different objects as the ionization change causes the skip range to change.

It was first thought that if everything in the region just beyond skip distance were contributing equally to the echoes insofar as their scattering efficiency was concerned cusps could not appear since, if the ionization changed, echoes would come in at about the same strength from the new skip distance and any one part of a range-time record would be just as uniform and just as dense along a line marking the skip distance as any other part. However, such cusps could well exist without the help of specific good scatterers on the ground.

A possible explanation of cusps and discontinuities in the range-time records without the requirement of specific good scatterers is an ionosphere with irregularities in it many miles long, with velocity components in various directions. If the area became smaller, it would reach a critical size that would no longer produce a trace on the backscatter record. In general, changes in the tilt, ion density, ion distribution, and size of these areas should cause the backscatter echoes to vary in range and at times become too weak to record.

It should be noted that ionospheric irregularities and turbulence cause anomalies in the field-intensity records as well. One possible source of error due to nongreat-circle transmission may exist if an omnidirectional antenna such as that of WWV is used for transmitting. It is possible for the receiver to receive a signal reflected from an area not in the beam of the pulse transmitter and produce a field-intensity recording after the backscatter has exceeded the delay time corresponding to the skip distance for the region in which the receiver is located. However, appreciable discrepancies in time of failure of this type require very large horizontal gradients (tilts) in regions off the great circle path.

Fig. 3 for June 30, 1950 is, for a fairly disturbed day, one with an ionosphere character figure of 5. Near the beginning of the record, wisps coming downward represent echoes with rapidly decreasing range, the rapid changes terminating at a closer range. Thus, one of these traces has a delay time of 18.0 msec at 0128 GCT and 14.0 msec ten minutes later. Assuming the cause to be a change of skip distance, the change was found to be equivalent to a 41.2-per cent increase of ion density in 10 minutes, the rate of change being of the same order as that of a sunrise period. The apparent skip distance moved in under these circumstances at a rate of 3,600 km per hour. Other traces seen on the June 30 record are very baffling but not too unusual.

Fig. 4 for November 22, 1950, taken near the beginning of an ionospheric disturbance, shows a whole series of wisps representing echoes starting at about 12-msec delay, decreasing rapidly in range, and dying out just ahead of a steady, solid short-distance echo running along at about 6- or 7-msec delay. Since the rates of ionization change assumed for these disturbances seem so fantastic, one is led to speculate upon the possibility that the traces represent real changes of range of reflecting areas, particularly since on a night like that of June 30 the field intensity of WWV received at White Sands did not recover when the scatter delay times diminished. Direct reflections from fast-moving waves of sharp density gradient somewhere in the ionosphere might account for the heavy black traces which change range over about an hour and sometimes cross one another in range.

A possible explanation of the very fast-moving traces with receding range is the entry of corpuscular matter into the ionosphere from great heights, producing scattering regions which would reflect energy as they came down through the whole ionosphere. The phenomenon would correlate with that noted at vertical incidence by Wells, Watts, and George,[11] where discontinuities were seen to travel down the h'-f curve during an ionospheric disturbance. The rates of travel noticed by these observers, 1 to 2 km per second, agree very well with the 3,600-km per hour noted above. The slower-moving traces have velocities of the order of 200–300 km per hour, suggesting Meek's observations of fast-moving scattering regions in the E and F_2 layer at high latitudes.[12] The rates of travel are similar to the velocities of irregularities in F_2 noted by Munro[13] and others.[14] The F_2 scattering regions are apparently identical with Dieminger's G-scatter,[8] associated with auroral disturbances. It is significant that such scattering regions are unofficially reported for temperate zone stations in the United States about a half a dozen times a year, so that

[11] H. W. Wells, J. M. Watts, and D. E. George, "Detection of rapidly moving ionospheric clouds," *Phys. Rev.*, vol. 69, p. 540; 1946.

[12] J. H. Meek, "Sporadic ionization at high latitudes," *Jour. Geophys. Res.*, vol. 54, p. 339; December, 1949.

[13] G. H. Munro, "Travelling disturbances in the ionosphere," *Proc. Roy. Soc. A*, vol. 202, p. 208; July, 1950.

[14] "Winds and turbulence in the upper atmosphere," *Nature*, vol. 167, pp. 626–628; April 21, 1951.

it is reasonable to assume that records like that of Fig. 3 are a manifestation of the motion of such regions over the western part of the United States during an ionospheric disturbance.

VII. Conclusions

As a result of comparison of backscatter and field-intensity records obtained for transmissions over a 2,700-km path on 15 mc, during several months of the year, the following is concluded for such a frequency and path:

1. An echo group nearly always appears which is identified with the ground at the one-hop F_2-layer skip-distance range. The group follows the skip distance throughout 14 hours, being close in during the day and far out at night, and changes its range suddenly when the skip distance changes suddenly.

2. It is possible to determine approximate F_2-layer skip distance over a path by measuring the delay time to the leading edge of the ground-scatter group. However, this can be done only at a fixed location where average ionosphere heights for the path can be estimated and where the normal pattern which the scatter echoes follow is well known, so that abnormal close-in echoes coming from abnormal ionization regions in the E layer and echoes coming from regions excited by side lobes from the antenna can be recognized.

3. The simple technique of measuring the delay time to the first peak of an echo group, or to the strongest echo peak of a group, may result in completely erroneous results if the spurious echoes mentioned above are not recognized and discarded.

4. On ionospherically disturbed days, and a few other anomalous days, positive identification of the F_2-propagated ground-scatter echo may be difficult or impossible. However, close study of records taken daily on a continuous basis at one location should do much to reduce the number of doubtful records.

5. The range beyond which a signal is usable can generally be determined with fair accuracy.

6. The range within which no signal can be received cannot be determined because propagation by nongreat-circle and scatter modes at lower intensity than normal (particularly after the first major signal drop corresponding to the start of path failure, but also before the first major signal rise corresponding to the end of path recovery) may persist for many minutes or hours.

7. The times during which a signal at a given range is usable may be determined with fair accuracy when the rate of change of skip distance with time is rapid, as in the case of late fall, winter, and early spring conditions.

8. The times during which a signal from a given range may be detected (whether usable or not) cannot be determined reliably, even when the rate of change of skip distance is rapid, because of the considerations of 7 above.

9. Examination of a variety of experimental records indicates that backscatter data, because of the striking difference in the day-to-day records and their sensitivity to disturbed conditions, may provide an indicator of ionospheric disturbances which is even better than the direction-finder technique at present employed in disturbance forecasting. Tracking of these disturbances by use of a rotary beam antenna also seems possible.

Coaxial Transmission-Line Filters*

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***Summary*—Microwave filters based upon coaxial structures are not difficult to construct, and for wide-band applications they have an advantage over cavity types in that the terminal matching problems are more easily met. For narrow-band work the cavity is superior because of its higher Q. A tentative analysis of coaxial transmission-line band-pass filters is given and experimental work in support of the analytical results is included. A TE-mode high-pass filter is discussed and experimental data presented.**

Introduction

IT HAS been shown[1] that a band-pass filter may be constructed by introducing a number of equispaced short-circuiting elements into a coaxial transmission line. The transmission which occurs past such a group of shunt obstacles may be of the dominant TEM mode, or it may be of the TE type. TE transmission is found when the conducting shunt obstacles in a given obstacle group are arranged so that the electric field of the TE mode considered has a distribution such that no impressed electric field impinges upon the shunt obstacles. This kind of transmission has been adequately demonstrated[1] by the simple expedient of providing rotatable shunt obstacles in a band-pass coaxial transmission-line filter. When TE transmission occurs, the rotation of successive shunt-obstacle groups will cause the electric field from one group to be intercepted by the next with a high resultant attenuation. If the shunt obstacle groups are lined up, TE transmission may go on undisturbed and the structure will be a high-pass one. TEM transmission, on the other hand, is based upon the reactive behavior of the shunt obstacles and not upon the "fitting" of the electric field between the conductors

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[1] D. E. Mode, "Spurious modes in coaxial transmission-line filters," Proc. I.R.E., vol. 38, pp. 176–180; February, 1950.