Interpretation of High-Frequency CW Field-Intensity Records with the Aid of Simultaneous Pulse Data*

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Summary—Several causes of changes in field intensity of cw signals are outlined and their identification by the use of pulses discussed. Results of comparisons of cw and pulse records are given for a winter-type record and a summer-type record and characteristics due to several of the listed causes are identified.

INTRODUCTION

An ionospherically propagated skywave from a distant point usually consists of a group of several waves, each with its own changing phase and amplitude characteristics, coming down at different angles to the horizontal. These waves and their ground-reflected components combine at the antenna to give a resultant voltage which is amplified and detected.

In a record of the field intensity of a continuous-wave signal in which more than one mode is present at any one time, it is not easy to tell what combinations are present. Identification of arriving modes by determination of their angles of arrival is difficult when several modes are present simultaneously; the resultant arriving wave does not have a plane phase front, does not provide uniform illumination of the antenna aperture, and undergoes violent time fluctuations of all its characteristics.[1]

With pulsed signals the delay differences between the various observed modes can be measured and correspondence obtained between them and the delay differences calculated for combinations of possible modes. Some ambiguities can still occur, but may often be resolved if enough is known about ionospheric conditions over the path.

It is possible to enumerate several different causes of field-intensity changes appearing on radio-field-intensity records, among which are

(a) focusing effects as conditions approach or recede from skip,
(b) failure and recovery due to ionospheric irregularities,
(c) interference between modes,
(d) interference within a mode,
(e) changes in absorption in or shielding by a lower layer,[2]
(f) antenna-pattern effects.

A study of simultaneously observed pulses transmitted over the same path and on about the same frequency should make it possible to identify effects such as those of (a) and (b) with a fair degree of certainty. It should also be possible to obtain an idea of what modes of propagation are present and thus identify a given depth and rate of fading with the modes responsible for it (c). The effect of (d) will probably always be present because of ionospheric roughness, but will show as a fast fading rate usually superimposed upon slow-fading cycles due to other causes.

The effects of (e), not considered in this work, should be identifiable by a very slow change in the intensity of one mode of a group on A-scope pulse records.

One effect under (f) is that of changing polarization or angle of arrival resulting in a change of pickup as determined by receiving-antenna characteristics. Angle-of-departure changes also result in changes in received field intensity because of the directional patterns of the antennas. The effects of (f) are not always identifiable without auxiliary polarization- and angle-of-arrival measuring equipment, but should be easy to demonstrate in certain cases, such as near the limit of one-hop transmission, where angles of departure for the lowest order mode are very small. In the case to be considered the path was fairly short so that the lowest order mode was not severely attenuated.

INSTRUMENTATION

The path of which a study was made was that from Beltsville, Md. to the White Sands Proving Ground, N. M., a distance of about 2,700 km. Continuous recordings were made at White Sands of the field strength of WWV 15 mc, the over-all time constant of the receiving and recording system being 18 seconds. Occasionally, simultaneous high-power pulse transmissions were made on a frequency between 15.00 and 15.09 mc from Sterling, Va. and received at White Sands on a loran-type indicator, pulse groups being photographed every minute during the failure and recovery period. The cw power at WWV was 9 kw into a half-wave vertical antenna and the peak power at Sterling was 700 kw into a rhombic antenna, a 40-microsecond pulse being used.

RESULTS

An examination was made of a number of field-strength records for the summer and late fall in conjunction with accompanying pulse records. With regard to the field-strength records, in general, there were large differences between individual days and between seasons. However, certain common characteristics were

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[1] F. W. Schott, "On the response of a directive antenna to incoherent radiation," PROC. I.R.E., vol. 39, p. 677; June, 1951.

[2] E. V. Appleton, W. J. G. Beynon, and W. R. Piggott, "Anomalous effects in ionospheric absorption," *Nature*, vol. 161, p. 968; June 19, 1948.

noted and made more readily identifiable by the use of pulses. The simpler records were those for late fall because of an absence of the F_1-layer and because the rate of change of ionization at the beginning and end of skip was very fast.

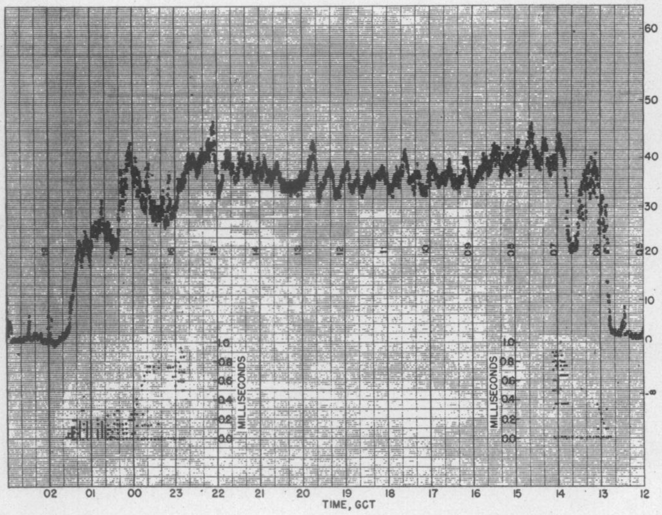
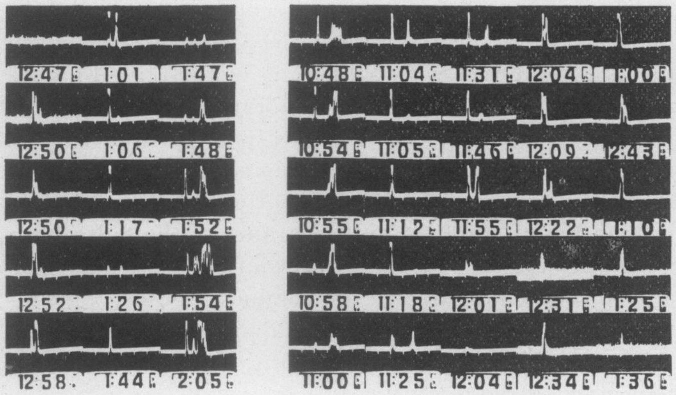


Fig. 1—Field Intensity of WWV, 15 mc, received at White Sands Proving Ground, N. M., with concurrent pulse delay times for an adjacent frequency arriving over almost the same path, December 1–2, 1950.

Fig. 1 shows a field-strength recording made on December 1, 1950 which illustrates a typical late fall or winter record. The time is Greenwich Civil Time and reads from right to left. Below the periods of rise and fall are superposed scalings of relative delay times of the various modes as shown by the pulse positions on the loran indicator. Zero delay is taken as the time of arrival of the first pulse, presumably propagated by the one-hop F_2-mode; occasional solid lines indicate groups of many peaks, or strong peaks with indefinite separation. Fig. 2 is a group of A-scope photographs of the pulse groups, the time here being GCT on a 12-hour basis.



Path recovery 1247 to 1405 GCT, December 1

Path failure 2248 GCT, December 1 to 0136 GCT, December 2

Fig. 2—Typical pulse patterns received at White Sands, December 1–2, 1950.

In Fig. 1 the field intensity of WWV is seen rising above the noise level at 1246. At 1247 a single dot on the record indicates a pulse seen in the noise. At 1250 two pulses are seen separated by about 0.1 millisecond. In the succeeding minutes there are usually two pulses separating in range as time increases. The first pulse is the one-hop f_2 low ray and the second pulse the one-hop f_2 high, or Pedersen, ray. The phenomenon of the low and high rays may be explained by the theory advanced by Appleton and Beynon[3] or by application of Smith's transmission curves to vertical-incidence ionospheric data.[4] A continuous photographic plot of echoes showing both low and high rays appears in a memorandum by Pierce.[5]

As the high ray increases in delay and dies out in intensity the cw signal increases in intensity, rising to about 20 db above the noise in the first 4 minutes and reaching a peak of about 35 db above the noise by 1310. This peak represents a focusing effect pointed out by Eckersley[6] and others.

After 1310 the field intensity drops about 20 db, with the high ray presumably delayed even more, and falls below the noise level. A minimum intensity of the cw field is reached at 1340 after a fall of about 15 db. Up to this time the cw signal is seen to fade at a rapid rate. It seems reasonable to say that these fades are partly caused by interference between waves propagated by different modes, such as the low and the high modes seen on the pulse record, (c), and partly because of the effect of interference within a single mode (d).[7]

At 1348 a pulse group is first seen at 0.65 millisecond spreading upward and downward as time progresses. This pulse group is most probably the start of two-hop propagation, the spread being due to the formation of low and high rays. Coincidentally, with its appearance the field-intensity curve rises to a maximum which it reaches within two or three minutes. The group of echoes starting and persisting at about 0.35 millisecond is possibly an M-type reflection.

The presence of waves coming via a two-hop mode along with those coming via one hop is identifiable directly on the field-intensity records by coarse fading cycles of duration of the order of 30 minutes.

These fading cycles are most probably caused by beats between the one- and two-hop modes due to

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[3] E. V. Appleton and W. J. G. Beynon, "The application of ionospheric data to radio communication problems," *Proc. Phys. Soc.* (London), vol. 52, pt. I, p. 518; July, 1940; vol. 59, pt. II, p. 58; January, 1947.

[4] N. Smith, "The relation of radio sky-wave transmission to ionospheric measurements," Proc. I.R.E., vol. 27, pp. 332–347; May, 1939.

[5] J. A. Pierce, "The frequency dependence of ionospheric maximum speeds," Cruft Laboratory, Harvard University, Technical Memorandum No. 4, Contract N50RI-76 Task Order No. 28, Office of Naval Research, May 5, 1949.

[6] T. L. Eckersley, "Studies in radio transmission," *Jour. IEE*, vol. 71, pp. 405–459; September, 1932.

[7] J. A. Ratcliffe, "Diffraction from the ionosphere and the fading of radio waves," *Nature*, vol. 162, p. 9; July, 1948.

changes in the relative path lengths for the two modes. The existence of swells in the F_2 region of the ionosphere of 5 to 30 minutes in length has been fairly well demonstrated by Ross[8] in lateral-deviation experiments with precision direction finders and by other experimenters in other ways.[9] Such swells, having greater effect in changing total path length for the relatively high-angle two-hop mode at its two reflecting regions than for the relatively low-angle one-hop mode at its one reflecting region, could well produce beats of the order of magnitude of 30 minutes. A characteristic beat-wave form has sharp spikes at the bottom and is rounded on top. The peaks appearing at the tops of the two-hop fading-pattern maxima in Fig. 1 are probably due to momentary maxima of the individual modes.

The middle of the day is characterized on the cw record by a slight drop of the average curve to a minimum at about noon over the path or around 1800 or 1900 GCT. No pulse patterns were available for the period.

At 2248 pulse delay times are recorded again with multiple 2-hop echo groups at delay times starting at 0.5 millisecond. By 2310 the last 2-hop pulse echo is seen at 0.75-millisecond delay. Sometimes a 2-hop focus effect is seen just before 2-hop failure, but does not appear on this record; ionospheric irregularities probably masked the effect. A build-up to one-hop focus now begins. A high ray is first seen at 2315 on the pulse plot. As the rays merge the focus field intensity rises, aided by the decrease in ionospheric absorption at the end of the day, the peak of focus being reached at about 0005. At 0031 the pulses observed were weakest, well merged, and had a scattered appearance. The field-intensity record at this point is at the end of a 15-db drop. A field-intensity rise beyond this point is followed by an apparent spreading of the pulse groups, indicating a partial recovery of propagation, such as would be caused by the appearance of another high-ionization area affording partial regular-layer propagation, perhaps because of motion of irregularities or because of pressure waves in the F_2-region. This field-intensity rise might also be caused by a drop of virtual height, resulting in a decrease of skip distance. Since the pulses appearing after this first failure were fairly clean but with an occasional appearance of a large number of modes, it is definite that the partial recovery is not a scatter mode. The peak of the partial recovery of WWV appears to be at 0045 although the signal was partially contaminated by the presence of fields from WWVH in Hawaii. Beginning at 0120 the signal makes a final rapid drop of 18 db to the noise level. The last pulse was seen at 0138 and WWV was last heard at 0144.

Fig. 3 is similar to Fig. 1 for a summer day, June 13–14, 1950. Pulse data were available for the failure period only.

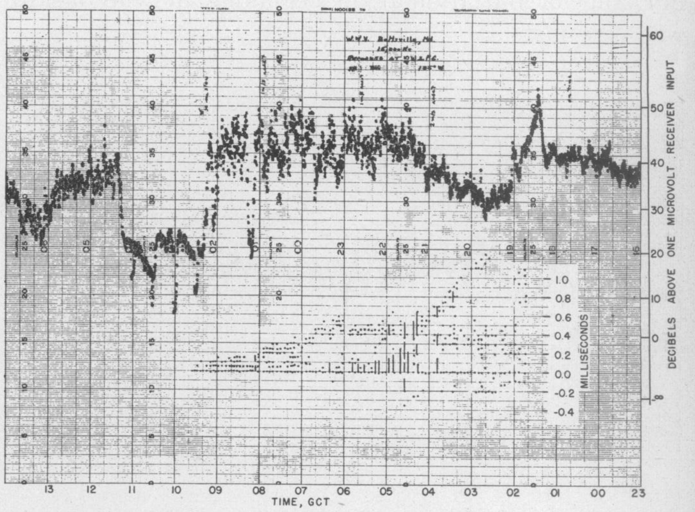

Fig. 3—Field intensity of WWV, 15 mc, received at White Sands Proving Ground, N.M., with concurrent pulse delay times for an adjacent frequency arriving over almost the same path, June 13–14, 1950.

The June 13–14 record is harder to interpret than that for December 1 because of the slower rates of change of ionization at path failure, general propagation characteristics approaching those for summertime ionospheric conditions. However, the pulse pattern shows the same general agreement with the cw pattern as was the case for the December record. The group of dots at a delay time of 0.9 to 1.1 milliseconds disappearing at 0200 appears to be the nose of the 3-hop curve. A sharp dip of 0812 agrees with a merging of the pulsed modes and probably represents a temporary path failure. An immediate recovery follows, corresponding to a spreading of the modes and a subsequent second failure corresponding to another decrease of delay time between pulse groups. The final disappearance of the pulses into the noise was at 0936, but the exact time of signal disappearance could not be determined because of contamination of the record by weak signals from WWVH in Hawaii, identifiable by interruptions on the hour and half hour.

Identification of the modes on the pulse patterns was accomplished in part by geometric calculations for the path length and reasonable ionospheric heights, and in part by considerations of the changes of the pulse patterns with time. In general, measured delay differences were smaller than expected, indicating lower effective ionospheric heights.

ACKNOWLEDGMENT

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[8] W. Ross, "Lateral Deviation of Radio Waves Reflected at the Ionosphere," Department of Scientific and Industrial Research, Radio Research Special Report No. 19, London; 1949.

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