THE WAVEFORM OF ATMOSPHERICS IN THE DAYTIME AND AT NIGHT

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I. Introduction

It was 1940-1944 when the author [1] made observation of the waveform of atmospherics for the first time and defined leader stroke type, return streamer type, multiple stroke type, cloud discharge type and reflection echo type, and made some remarks on them. After the World War he spent time for a while in improving measuring apparata, and in 1950 he started again the observation of waveform, strictly synchronized with direction finding at 3 points in Japan, and published occasionally fragmental papers [2] [3] concerning the waveform of atmospherics.

In the meantime many valuable studies were made by Schonland, Budden, Chapman, Hepburn, Pierce, Horner, Clark, Carton, Bowe, Rivault, Haubert, Helliwell, Kessler, Norinder and many others, and there is every indication that the study proceeds on from qualitative to quantitative, from general to special, from phenomenal to intrinsic, and yet at present there are many different observations depending on research workers.

Prior to going into more detailed study, the author intends to summarize here in this paper his recent study on the waveform and to give some interpretation of it for the purpose of making clear the general features of the waveform observed in the Far East.

II. Experimental Details.

The apparatus consists essentially of an antenna connected through a wide-band amplifier to a cathode-ray tube, together with a trigger device designed to select individual waveforms. A vertical conductor of 10m in length is employed as the antenna. The amplifier is of conventional resistance capacity coupled design with a band-width (to 3 db. points) from 25 c/s to 400 kc/s. The gain is variable from 50 to 80 db.

Mains pick-up from adjacent power lines is reduced by injecting a voltage of suitable amplitude and phase; a tuned filter circuit is provided, whereby, if necessary, signals at 17.442 kc/s of Yosami Station can be greatly reduced.

In 1940 [1] the presentation of the waveforms upon the oscilloscope was made by a linear time-base deflected horizontally from left to right and another, with period an integral multiple of that of the horizontal sweep, applied to one of the vertical deflector magnets. The amplifier output was connected to the deflector plate deflecting vertically.

In the recent observation this vertical deflection was replaced by a vertical movement of film at the speed of 10 mm/sec., and, to avoid overlapping, the spot brilliancy is kept low for 1 sec. after every exposure for waveform image. Horizontal sweep time can be varied among 1, 2, 5 and 10 ms. Normally the brilliance is low, but it is increased, by the arrival of an atmospheric exceeeding a pre-set amplitude, to a level suitable for photographic recording. Triggering occurs at the left end point and starts horizontal sweep with sufficient brilliance.

Photographic recordings are obtained using an f/1.9 camera and 16 mm SP-Fuji film. Whenever a waveform is recorded, a special signal goes to the annexed direction finder to light the neon lamp on the one side of the oscilloscope to keep synchronization with the waveform recorder. At every second another signal, coming from a standard clock, controlled by Japanese Standard Waves, lights another neon lamp on the other side of oscilloscope of the wave-form recorder and the direction finder.

The direction finder consists of a set of shielded crossed frame antennae, a vertical antenna, and receiving sets connected independently to every antenna by shielded cables. The receiving sets adopt straight amplification system tuned to 10 kc/s with a band-width 300 c/s, and the gain is variable between 75 to 120 db.

To locate the position of source at a distance greater than 5,000 km, one of three direction finders distributed over Japan, the one in Toyokawa, indicates the sense by wiping out a small part of brilliant line near the center of the oscilloscope, using appropriately the output of the receiving set for vertical antenna. The photographhic recordings are also obtained using the same camera as in the wave recorder, but the film speed can be varied from 5 to 20 mm/sec. The observation was made in accordance with the following time table where Japanese Standard Time (JST) is employed and the sweep time is 1.9 ms for 10-13min. and 5.4 ms for 20-23 min. at every hour.

0010—0013	0020—0023
0910—0913	0920—0923
1210—1213	1220—1223
1510—1513	1520—1523
2110—2113	2120—2123

III. Classified Results of Observation and Interpretation

3.1. Wavefrorm in the Daytime.

3.1.1. The stepped leader stroke type, the partial discharge within cloud type and the successive discharges among clouds type.

These three types of waveform are recorded in the daytime as at night from distances less than 3,000 km along oversea paths and less than 2,000 km overland. Their frequency range, calculated from pulse intervals 30-90 μs, is about 10-30 kc/s. These figures are quite well coincident with our observation in the neighbourhood of lightning flashes in summer, accompanied by the measurements with other means of investigation. Followings are some examples of this category, explained in detail with recorded photos.

Fig. 1 is the waveform No. 83, 18 June 1955, 1220 JST; C.R.D.F. fix $D \cong 3,000$ km; sweep 5.4 ms; origin on the sea east of Mindanao Island, the Philippines. On the beginning of sweep a β type stepped leader stroke type waveform is seen. Its pulse interval is 91 μs. corresponding to 11 kc/s and duration 1.5 ms. After a pose of 1.51 ms a return streamer type follows.

Fig. 2 is the waveform No. 85, 18 June 1955, 1220 JST; C. R. D. F. fix forms a triangle whose centre is D = 2,200 km, farthest point D = 3,100km and the nearest D = 1,800 km, sweep 5.4 ms; origin on the sea southwest of Formosa. On the beginning of sweep a α type stepped leader stroke type waveform is seen. Its pulse interval is 83 μs corresponding to 12 kc/s and its duration 2.22 ms. A return streamer type follows immediately after leader stroke type.

Fig. 3 is the waveform No. 9, 18 June 1955, 1210 JST; C. R. D. F. fix D = 2,000 km; sweep 1.9 ms; origin in Manchuria. A β type stepped leader stroke type waveform fills the whole sweep space. Its pulse interval is 46 μs corresponding to 22 kc/s. No return streamer type follows.

Fig. 4 is the waveform No. 29, 20 June 1955, 1210 JST; C. R. D. F. fix D $\cong$ 1,000 km; sweep 1.9 ms; origin middle of Korea. A stepped leader stroke type waveform fills the whole sweep space. Its pulse interval is 33 μs corresponding to 30 kc/s. No return streamer type follows. It may be emitted from partial discharges within cloud or from successive discharges among many clouds. In accordance with our results obtained in the neighbourhood of lightning discharge in summer, the extent of pulse intervals in these three categories is almost the same. In short distances three types are discriminated by the results of other means such as field meters, rotating cameras, waveform recorders of different sweep time simultaneously used. For a very distant one there is no way of discrimination but to judge from general features.

3.1.2. The return streamer type.

3.1.2. A. The largest amplitude at the second or third peak.

This type of waveform is recorded in the daytime as at night from distances less than 2,000 km. It has a very smooth damped waveform as compared with the one at night, corresponding to Rivault's type III[7] or Pierce's quasi-sinusoidal type[6]. It has neither appreciable superposed higher frequency components nor split peaks.

Fig. 5 is the waveform No. 82, 18 June 1955, 0910 JST; C. R. D. F. fix D $\cong$ 1,000 km; sweep 1.9 ms; origin in the Ryûkyû Islands. This is a very smooth damped waveform among which the second peak has the largest amplitude and can easily be followed to the seventh peak. The auth or named this "return streamer type"[1] and it corresponds to Rivault's type III[7]. The peak interval between first and second is 90.5 μs corresponding to 11 kc/s. Intervals increase gradually and reach 180 μs or 5.5 kc/s at the one between fifth and sixth. Amplitudes decrease as intervals increase.

Fig. 6 is the waveform No. 45, 18 June 1955, 1510 JST; C. R. D. F. fix D = 1,700 km; sweep 1.9 ms; origin in Manchuria. In general the secondor third peak has the largest amplitude, but in this rather rare example the largest amplitude is found at the fourth peak. Comared with the former examle, the waveform is not so smooth as that in Fig. 5. The interval between the first and second peaks is 60.5 μs corresponding to 16.5 kc/s. The interval does not increase appreciably till the sixth peak, while at the seventh the amplitude decreases suddenly and the following interval increases to 121 μs or 8.3 kc/s.

3.1.2. B. The largest amplitude at the first peak.

This kind of waveform is generally regular smooth damped waves free from superposed harmonics or higher frequency components, and its smoothness is the characteristic of the daytime waveforms, influenced very little by the reflected space waves on the ionosphere. It is considered that the waves proceed along the conducting surface of the earth and generate appropriately the static field component, the induction field component and the radiation field component depending on the distance propagated. For the waveforms received at nearer distances the mechanism of lightning discharge influences greatly. This category of waveform is recorded from distances 1,000-5,000 km or more, and in general many peaks are appreciable due to lower attenuation along oversea paths. The mean peak interval between the first and the second is 170-60 μs corresponding to about 6-17 kc/s. Statistically frequency range of the initial peak seems to depend somewhat on distance, i.e. for D $\cong$ 1,000 km 6-7 kc/s, D $\cong$ 3,000 km 7-11 kc/s, D $\cong$ 5,000 km 7-10 kc/s.

Fig. 7 is the waveform No. 69, 18 June 1955, 1510 JST; C.R.D.F. fix D = 1,200 km; sweep 1.9 ms; origin in the Ryûkyû Islands. This is a very smooth typical damped waveform in this category. The first to fourth peaks are easily appreciable. The amplitudes decrease very rapidly and at the same time the intervals between peaks increase. The interval between the first and second peaks is 90.5 μs corresponding to 11 kc/s, and that between the fourth and the fifth is 199 μs or 5.0 kc/s. The fourth valley and the fifth peak are split, and the higher order peaks can not be seen.

Fig. 8 is the waveform No. 12, 20 June 1955, 1310 JST; C.R.D.F. fix D $\cong$ 1,800 km; sweep 1.9 ms; origin in Manchuria. This waveform is not so smooth as in Fig. 7. The amplitude decreases very rapidly from the first peak to the fourth and can not be discernible thereafter. The interval between the first and second peaks is 141 μs corresponding to 7.1 kc/s, and that between the fourth and fifth peaks 329 μs or 3.0 kc/s.

Fig. 9 is the waveform No. 7, 18 June 1955, 1210 JST; C.R.D.F. fix D = 2,000 km; sweep 1.9 ms; origin on the sea south-west of Formosa. Regular smooth and slowly damped waveform is recorded till the fifth peak after which it becomes irregular. The peak interval between the first and the second is 77 μs corresponding to 13 kc/s, and that between the fifth and the sixth 142 μs or 7 kc/s. The peak intervals increase very slowly and the amplitudes attenuate also very slowly. The waveform irregularity after the sixth peak is considered to be due to interference of downcoming space waves.

Fig. 10 is the waveform No. 68, 16 June 1955, 0910 JST; C.R.D.F fix D $>$5,000 km; sweep 1.9 ms; origin in Deccan, India. The very smooth damped wave is recorded till the fourth peak. The peak interval between the first and the second is 79 μs corresponding to 12.7 kc/s, and that between the fifth and the sixth 210 μs or 4.8 kc/s. The amplitude decreases suddenly from the second to the third, and the period makes corresponding increase.

Fig. 11 is the waveform No. 45, 22 June 1955, 1210 JST; C.R.D.F. fix D $>$5,000 km; sweep 1.9 ms; origin in Deccan, India. A regular very slowly decreasing damped wave is recorded, and despite a very long distance we can follow to the eighth or ninth peak favoured by oversea paths. The peak interval between the first and the second is 111 μs corresponding to 9 kc/s, and that between the fourth and the fifth 185 μs or 5.4 kc/s.

3.1.3. Multiple stroke type.

This group of waveforms is emitted from multiple lightning strokes which pass several times almost the same discharge channel, and consequently similar waveforms are recorded at the same time repeatedly. Correspondence of this type to multiple strokes is ascertained by direction finding in the distance and by rotating camera in the neighbourhood. The following are some examples belonging to this category.

Fig. 12 is the waveform No. 85, 20 June 1955, 0910 JST; C.R.D.F. fix D = 1,000 km; sweep 1.9 ms; origin in Korea. At the beginning of sweep and at 1.21 ms point two similar wave trains of peculiar style are recorded.

Fig. 13 is the waveform No. 12, 22 June 1955, 1210 JST; C.R.D.F. fix D = 2,000 km; sweep 1.9 ms; origin in Manchuria. At first glance the figure is complex, but at 226 μs and 632 μs points on the sweep two similar wave trains are recorded. In Fig. 13 the waveform No. 48 is recorded at the same time and place. At the beginning and at 1.14 ms point two similar simple pulsive waveforms are recorded. In both No. 12 and No. 48 the amplitude of the first wave trains is a little larger than the second.

Fig. 14 is the waveform No. 29, 18 June 1955, 0910 JST; C.R.D.F. fix D = 2,800 km; sweep 1.9 ms; origin on the sea south of Luzon Island, the Philippines. At the beginning and at 750 μs point two similar wave trains are recorded quite clearly.

Fig. 15 is the waveform No. 27, 18 June 1955, 0920 JST; C.R.D.F fix D = 3,200 km; sweep 5.4 ms; origin on the sea east of Mindanao Island, the Philippines. There are many similar wave trains of which the first is not clear, the second is at 635 μs, the third at 1430 μs, the fourth at 3020 μs, the fifth at 4100 μs points. These have similar waveforms between which exist some small waveforms of another kinds.

Fig. 16 is the waveform No. 52, 18 June 1955, 0910 JST; C.R.D.F. fix D = 540 km; sweep 5.4 ms; origin in the strait between Kyûshû and Shikoku. There are about five groups of waveform among which the first at the beginning and the third at 623 μs points have similar waveforms and both of them belong to this category.

3.1.4. Slow tail type.

This type is observed mainly at night and little in the daytime. Therefore only some examples will be given here with some remarks, and the detailed study will be postponed to section 3.2.3.

Eig. 17 is the waveform No. 53, 18 June 1955, 1220 JST; C.R.D.F. fix D ≅ 2,000 km; sweep 5.4 ms; origin in Manchuria. At the beginning of sweep a high frequency component of 10.3 kc/s is found and a slow tail component follows it. The period of the slow tail calculated from the interval between peaks is 1.8ms corresponding to 345 c/s. The difference of starting points between two components is attributed by Appleton and Chapman[8] to the dispersion of group velocity.

Fig. 18 is the waveform No. 47, 18 June 1955, 1510 JST; C.R.D.F. fix D ≅ 1,700 km; sweep 1.9 ms; origin in the outfall of the Hwang Ho. At the beginning of sweep a high frequency component of 11.6 kc/s is recorded and a slow tail component follows it. The latter has a rather aperiodic form whose quasi-period is 1.04 ms corresponding to 960 c/s.

3.2. Waveform at Night.

3.2.1. The stepped leader stroke type, the partial discharge within cloud type and the successive discharges among clouds type.

These types of waveforms are also recorded at night from distances 1,000 - 5,000 km or more, favoured by the good propagation conditions, and its frequency range is 10-30 kc/s quite the same as that in the daytime, but the frequency range of waves arriving from distances more than 3,000 km is 10-15 kc/s. Concerning other features of these types, the description mentioned in section 3.1.1. will be applied here too. The followings are examples belonging to these categories.

Fig. 19 is the waveform No. 70, 18 June 1955, 2110 JST; C.R.D.F fix D = 1,500 km; sweep 1.9 ms; origin in Manchuria. The mean pulse interval is 38 μs corresponding to 26 kc/s. Taking only larger pulses, the interval is 90 μs or 11 kc/s. This waveform seems to belong to the α type stepped leader stroke type, but the following return streamer type is missing due perhaps to short sweep time.

Fig. 20 is the waveform No. 4, 18 June 1955, 0010 JST; C.R.D.F. fix D = 1,600 km; sweep 1.9 ms; origin in Manchuria. The mean pulse interval is 46 μs corresponding to 22 kc/s, belonging to the α type stepped leader stroke type.

Fig. 21 is the waveform No. 29, 18 June 1955, 0010 JST; C.R.D.F. fix D = 1,300 km; sweep 1.9 ms; origin in the outfall of the Yangtze Kiang. The mean pulse interval is 41 μs corresponding to 24.2 kc/s. At the beginning several large amplitudes are recorded, but they decrease soon to the normal and indicate that they belong to the α type stepped leader stroke type. The return streamer type seems to follow them, but its main part is lacking in the figure.

Fig, 22 is the waveform No. 42, 19 June 1955, 2110 JST; C.R.D.F fix D ≅ 2,000 km; sweep 1.9 ms; origin in Manchuria. The mean pulse interval is 42.3 μs corresponding to 24 kc/s. This may be considered to belong to any of three types, the α type stepped leader stroke type, the partial discharge within cloud type or the successive discharges among clouds type. The larger pulses are recorded remarkably at the beginning.

Fig. 23 is the waveform No. 38, 22 June 1955, 2110 JST; C.R.D.F, fix D ≅ 2,000 km; sweep 1.9 ms, origin on the sea southeast of Formosa. The mean pulse interval is 60 μs corresponding to 16.7 kc/s. It belongs to successive discharge among clouds type.

Fig. 24 is the waveform No. 24, 18 June 1955, 0010 JST; C.R.D.F. fix D = 3,600 km; sweep 1.9 ms; origin in mountain districts of Burma. The mean pulse interval is 63.5 μs corresponding to 15.7 kc/s, and the pulse interval of larger one is 120-130 μs or about 8 kc/s. This waveform seems to belong to the successive discharges among clouds type.

Fig. 25 is the waveform No. 47, 20 June 1955, 0010 JST; C. R. D. F. fix D >5,000 km; origin in the Ceylon districts. The mean pulse interval is 87 μs corresponding to 11.5 kc/s. This waveform seems to belong to the successive discharges among clouds type.

3.2.2. Return streamer type.

Within the distance of 3,000 km, this type of waveform at night is in general not so smooth as the one in the daytime. There are often some waveforms where it is not easily determined whether they belong to the return streamer type or to the reflection echo type. There are many cases where the waveform seems at a glance to belong to the reflection echo type, but, in examining in detail, it belongs to Rivault's Type V, in other words, we can find neither reasonable value of reflection height nor distance concident with C. R. D. F. fix. Among waves recorded from distances more than 3,000 km, there are very smooth damped waveforms like those in the daytime as well as split peak waveforms at times superposed with harmonics or higher frequencies that characterize waveforms at night. Some of them seem often to belong to the reflection echo type by appearance, but there are almost none to be analysed as the reflection echo type. One may, therefore, deduce that the reflection echo type is found only in a distance less than 3,000 km.

Fig. 26 is the waveform No. 10, 22 June 1955, 2110 JST; C. R. D. F. fix D = 900 km; sweep 1.9 ms; origin on the sea west of Kyûshû Island. This is a comparatively smooth damped waveform, and as the peak order proceeds, the period prolongs gradually and from the fourth peak superposed higher frequency components are noticed. The peak interval between the first and the second is 183 μs corresponding to 5.5 kc/s. Apparently it may be considered as the reflection echo type, and, on consulting the calculating chart(6), the reflection height of 60 km and the distance of 700 km are obtained, but both of these values are not approvable.

Fig. 27 is the waveform No. 60, 18 June 1955, 2110 JST; C. R. D. F. fix D = 830 km; sweep 1.9 ms; origin on the sea west of Kyûshû Island. Apparently it seems to belong to the reflection echo type, and, on consulting the calculating chart(6), the reflection height of 70 km and the distance of 800 km are found within the maximum error of 25 μs, but at this time of the day there are no disturdances on the sun and the earth magnetism, and therefore the reflection height of 70 km is rather too abnormal to be admitted.

Fig. 28 is the waveform No. 43, 19 June 1955, 2110 JST; C. R. D. F. fix D > 5,000 km; sweep 1.9 ms; origin in Afghanistan. It is a fairly smooth damped waveform, and the peak interval between the first and the second is 91.5 μs corresponding to 10.9 kc/s. The amplitude decreases rapidly.

Fig. 29 is the waveform No. 33, 22 June 1955, 2110 JST; C. R. D. F. fix D > 5,000 km; sweep 1.9 ms; origin in Deccan, India. It is a very smooth and slowly attenuated damped wave, and belongs to rather lower frequency range. The peak interval between the first and the second is 130 μs corresponding to 7.7 kc/s, and that between the sixth and the seventh is 256 μs or 3.9 kc/s. From the fifth the peak is split into two and at the seventh the order of magnitude of split peaks is reversed. The splitting is considered to be developed from the interference of reflected space waves.

3.2.3. Slow tail type.

This type is recorded mainly at night and was noticed at first by Appleton and Chapman [8] (1937), Watson-Watt, Herd and Lutkin [12] (1937), and studied in detail by Hepburn and Pierce [13] (1953). In our observation some are aperiodic waveforms and othersq uasi-sinsoidal. The quasi-period is 400-700 c/s, and it is observed in the distance 1,000-5,000 km or more along oversea paths. Although in general higher frequency components precede this type on the record, the starting time difference does not depend on the distance, and the experimental formula by Hepburn and Pierce [13] does not always apply to every case. The amplitude of this type is relatively large even in the long distance, and so it is difficult to consider it static field travelled. After all it has not yet been studied exhaustively. There are at present agreements and disagreements depending on observers, and in order to draw final conclusions future study is expected.

The long train type is very often recorded accompanied by this type, but it has been studied already in detail by Pierce [9]. No special new event worthy of mention has been found since then, therefore the description of this type is omitted here.

Fig. 30 is the waveform No. 52, 20 June 1955, 0020 JST; C.R.D.F. fix D = 1,450 km; sweep 5.4 ms; origin in the Ryûkû Islands. At the beginning the high frequency component is recorded and the slow tail type follows it. The waveform No. 59, observed at the same time and place, shows similar features. Both No. 52 and No. 59 have the mean period of high frequency component 125 μs corresponding to 8 kc/s, and that of the slow tail, which was evaluated from the interval between peak and valley, 1.51 ms or 660 c/s. The starting time difference between the high frequency component and the slow tail is 670 μs in No. 52 and 880 μs in No. 59.

Fig. 31 is the waveform No. 18, 16 June 1955, 2120 JST; C.R.D.F. fix D $\cong$ 2,000 km; sweep 5.4 ms; origin in Formosa districts. At the beginnig of sweep a high frequency component, whose mean period is 106 μs corresponding to 9.4 kc/s, is recorded and a slow tail type follows at 825 μs point on the sweep. The quasi-period of the slow tail is 1.75 ms or 570 c/s evaluated from the interval between peak and valley.

Fig. 32 is the waveform No. 6, 16 June 1955, 2120 JST; C.R.D.F. fix D $\cong$ 3,300 km; sweep 5.4 ms; origin in the Philippines. At the beginning of sweep a high frequency component, whose mean period is 79 μs corresponding to 12.6 kc/s, is recorded and a slow tail type appears after it at 349 μs point on the sweep. The quasi-period of the latter is 1.43 ms or 700 c/s.

Fig. 33 is the waveform No. 23, 19 June 1955, 2120 JST; C.R.D.F. fix D = 4,000 km; sweep 5.4 ms; origin in Borneo. At two points on the slow tail type, whose quasi-period is 2.71 ms corresponding to 368 c/s, high frequency components are recorded independently. These start wherever the slow tails begin the low frequency cycles. The mean frequency of high frequency components is 126 μs or 7.9 kc/s. In the present example there is no indication of time difference of start between the two types.

Fig. 34 is the waveform No. 31, 22 June 1955, 2120 JST: C. R. D. F. fix D = 3,300 km; sweep 5.4 ms; origin on the sea northeast of Borneo. A slow tail type is recorded with superposed high frequency components. There is no indication of starting time difference between two types. The quasi-period of the slow tail is 1.53 ms, evaluated from the interval between peak and valley, corresponding to 655 c/s and the mean period of high frequency components 136 μs or 7.4 kc/s.

Fig. 35 is the waveform No. 24, 20 June 1955, 0020 JST; C. R. D. F. fix D > 5,000 km; sweep 5.4 ms; origin in Deccan, India. A smooth damped waveform, whose mean period is 105 μs corresponding to 9.5 kc/s, is recorded at the beginning of sweep and behind it at 944 μs point appears a slow tail type, whose quasi-period is 1.57 ms or 640 c/s, calculated from the interval between two peaks.

Fig. 36 is the waveform No. 29, 16 June 1955, 2110 JST; C. R. D. F. fix D ≅ 2,500 km; sweep 1.9 ms; origin on the sea east of Luzon, the Philippines. Examples described above are all recorded by sweep time 5.4 ms to show the general feature which is important in this type. This example is chosen to show the detailed construction, adopting sweep time 1.9 ms. At the beginning a reflection echo type is recorded. By using its negative pulses, the reflection height and the distance are evaluated to 90 km and 2,300 km respectively from the calculating chart. [6] The slow tail form begins at 204 μs point on the sweep and its quasi-period is 1.57 ms corresponding to 640 c/s derived from the interval between peak and valley.

3.2.4. The reflection echo type.

This type, corresponding to Rivault's type IV, is considered to consist of ground waves and space waves which are reflected between the earth and the ionosphere where the reflection is assumed to be done upon the geometric optical principle at the surface independent of incident angle. The ideal form, where the coincidence with the calculating chart [6] is perfect to find the reflection height and the distance, is not found so frequently but if we admit the maximum deviation 25 μs and the mean deviation less than 10 μs, use positive or negative pulse series according to their clearness, and adopt clearer pulses of higher order in case the ground and primary space wave pulses are complex, we can obtain a good deel of this type within the distances of 3,000 km. The reflection height 80-90 km and fairly well coincidence with C. R. D. F. fix are generally found. When the distance exceeds 3,000 km, neither the reasonable value of reflection height nor the coincidence with C. R. D. F. are obtained, and really in many cases the evaluation with the calculating chart fails to be applied. In the routine work, location of origin by the results of C. R. D. F. involves difficulties and expense in maintaining three stations continuously, and it is desirable to find any possible means to determine at one station by using simultaneously C. R. D. F. and waveform recorder, but for the present it was found possible only in the distances less than 3,000 km in favourable ionospheric and other propagation conditions at night. The followings are examples of this type.

Fig. 37 is the waveform No. 31, 22 June 1955, 2110 JST; C. R. D. F. fix is found a triangle whose centre is D = 700 km, the farthest point 1,260 km and the nearest 380 km; sweep 1.9 ms; origin on the north-west of Kyûshû Island. In consulting the calculating chart [6], the reflection height and the distance are found 85 km and 1,000 km (mean deviation 5.5 μs, max. 25 μs) or 80 km and 900 km (mean deviation 5.2 μs, max. 25 μs) respectively. Considering the distance and deviation, 80 km height group is adopted.

Fig. 38 is the waveform No. 3, 18 June 1955, 0010 JST; C. R. D. F. fix D = 1,070 km; sweep 1.9 ms; origin on the south-west of Kyûshû Island. As the negative pulse series is clearly defined, the reflection height and the distance are evaluated by this series to 85 km and 1,270 km (mean deviation 6 μs, max. 25 μs) or 80 km and 1,130 km (mean deviation 5 μs, max. 20 μs) respectively. Considering the distance and mean deviation, 80 km height group is adopted.

Fig. 39 is the waveform No. 54, 16 June 1955, 2110 JST; C. R. D. F. fix is found a triangle whose centre is D = 2,300 km, the farthest point 3,000 km and the nearest 2,000 km; sweep 1.9 ms; origin on the sea east of Luzon Island, the Philippines. Though the positive pulse series indicates irregularity at the beginning, from the third clearly defined pulses are found. In consulting the calculating chart, all four pulses coincide exactly with the chart, and the reflection height and the distance are evaluated to 90 km and 2,200 km or 85 km and 1,950 km. Examining the distance, 90 km height group is adopted.

Fig. 40 is the waveform No. 16, 18 June 1955, 0010 JST; C. R. D. F. fix D = 1,500 km; sweep 1.9 ms; origin in Manchuria. Somewhat disturbed as it is, the reflection height and the distance are calculated at 90 km and 1,580 km (mean deviation 5.2 μs, max. 25 μs) respectively by careful investigation.

Fig. 41 is the waveform No. 33, 18 June 1955, 0010 JST; C. R. D. F. fix is found a triangle whose centre is D = 3,200 km, the farthest point 3,500 km and the nearest 2,800 km; sweep 1.9 ms; origin in Mindanao, the Philippines. In consulting the calculating chart, the reflection height and the distance evaluated to 90 km and 2,050 km respectively in perfect coincidence of five points. Though the distance calculated is too small compared with C. R. D. F. fix, there is no way but to adopt it and to examine the accuracy of C. R. D. F., because there are many cases where we can not find coincidence of the data obtained from waveforms with the calculating chart, but in this case coincidence is perfect and the reflection height reasonable.

Fig. 42 is the waveforms No. 27, 18 June 1955, 2110 JST; C. R. D. F. fix is found a triangle whose centre is D = 1,800 km, the farthest point 3,200 km and the nearest 1,380 km; sweep 1.9 ms; origin on the sea north of Formosa. Though the beginning of the wave train is not clear and consequently the ground pulse can not be traced, from the first space wave pulse to the sixth are clearly defined from which the reflection height and the distance are evaluated to 90 km and 1,600 km (mean deviation 6.1 μs, max. 25 μs) respectively. These are obtained by positive pulses, while almost the same by the negative.

Fig. 43 is the waveform No. 40, 20 June 1955, 0010 JST; C. R. D. F. fix

D > 5,000 km; sweep 1.9 ms; origin in Ceylon Island. At first glance it appears to be the reflection echo type, but it is the return streamer type. In consulting the calculating chart, there is no coincidence except to shift the first pulse to the sixth space wave pulse on the chart. In this way we may obtain the reflection height and the distance 90 km and 3,700 km, but we can not find the reason why the first five pulses disappear, and consequently we can not admit this waveform to be the reflection echo type. As return streamer type, the peak interval between the first and the second is 185 μs corresponding to 5.4 kc/s. Similar cases are found very often in distances more than 3,000 km, especially over 4,000-5,000 km.

Fig. 44 is the waveform No. 63, 20 June 1955, 0010 JST; C.R.D.F. fix is found triangle whose centre is D = 3,000 km, the farthest point 3,700 km, the nearest 2,400 km. It is clear that the initial part fails a little. By taking the first negative pulse for the second sky pulse, the reflection height and the distance are found 90 km and 2,800 km respectively with perfect coincidence with the chart. This is very likely the limiting example of the reflection echo type for distance over which no reasonable values are obtained both for distance and reflection height.

Fig. 45 is the waveform No. 22, 18 June 1955, 2110 JST; C.R.D.F. fix is found a triangle whose centre is D = 1,260 km, the farthest point 1,500 km and the nearest 1,160 km. According to the positive pulse series, the reflection height and the distance are calculated at 85 km and 1,200 km (mean deviation 14.2 μs, max. 30 μs) respectively.

IV. Conclusion.

In the temperate zone it is possible to consider the waveforms arriving from a source located by the direction finding made simultaneously with the waveform recording at three stations over Japan. In the tropical zone there are too many lightning discharges in the neighbourhood of the observatory to discriminate one from the others, but our research institute and the other two stations chosen for direction finding are all in the calm district free from lightning flashes. The waveform of atmospherics depends remarkably upon the propagation conditions, and consequently the clear difference is observed between the waveform in the daytime and the one at night.

The main waveform in the daytime consists of (1) the stepped leader stroke type, the partial discharge within cloud type and the successive discharges among clouds type, (2) the return streamer type, (3) the multiple stroke type, while the slow tail type and the reflection echo type are generally found at night, few in the daytime.

(1) corresponds to Rivault's type I and are recorded from distances less than 2,000 km along overland paths and less than 3,000 km along oversea. The main frequency range is 10-30 kc/s, removing the pulsive superposed higher frequency components with small amplitude. Sometimes the return streamer type follows immediately after stepped leader type, and often does not; even in the latter case α and β types are generally discernible as Schonland described[(11)], and the general features (pulse intervals, durations and so on) of three types in (1) are quite similar to those observed at short distances 10-100 km.

(2) corresponding to Rivault's type III, consists of (2a) the waveform whose largest amplitude is found at the second peak or the third and (2b) the one whose largest amplitude at the beginning of the train. These are all very smooth damped waves of which (2a) is recorded from distances less than 2,000 km and (2b) from distances 1,000-5,000 km or more, i. e. from everywhere. Occurrence of (2b) is more numerous than that of (2a), and the frequency range of (2b) is 6-17 kc/s on the average. Describing more in detail, 6-7 kc/s are found at about 1,000 km distance, 7-11 kc/s at about 3,000 km and 7-10 kc/s at about 5,000 km.

(3) is observed in distances less than 3,000 km, and consists of more than two similar waveforms coming from the same origin, and is considered developed from multiple strokes, comparing with the time interval and duration observed in the neighbourhood of lightning flashes electrically and optically. This type is found only in the daytime, and not observed at night due to disturbances from the interference of sky waves.

The main waveform at night consists of (4) the stepped leader stroke type, the partial discharge within cloud type and the successive discharges among clouds type, (5) the return streamer type, (6) the slow tail type and (7) the reflection echo type.

(4) are observed almost the same way as in the daytime and the frequency range is 10-30 kc/s, but favoured by good propagation conditions, they are recorded from long distances even more than 5,000 km along oversea paths as well as overland. Those coming from origins more than 3,000 km distant have in general the frequency range of 10-15 kc/s.

(5) is not so smooth as in the daytime in the distance less than 3,000 km. Sometimes the peak or valley of the wave is split or superposed with pulsations of higher frequencies. It corresponds in general to Rivault's type III, but sometimes in appearance it is difficult to discriminate from the reflection echo type; even in the latter case, in examining carefully, it is found to be the return streamer type corresponding to Rivault's type V. This fact is found by unreasonable value of reflection height, remarkable difference from C. R. D. F. fix, no coincidence with the calculating chart [6] and so on. In other words, at night it is rather difficult to find a clear return streamer type within a distance less than 3,000 km; while the smooth damped waveform like that of the daytime is easily found in longer distances as 3,000-5,000 km or more. Even the latter is often taken as the reflection echo type by mistake, but, in examining with precaution, we can find it to be (5), and we may conclude that the reflection echo type is not recorded from distances more than 3,000 km at night.

(6) is at times observed even in the daytime, but it is generally the type at night. It is recorded from everywhere or from distances 1,000-5,000 km or more. The frequency observed is 400-700 c/s, average in the neighbourhood of 600 c/s, and follows very often the higher frequency types such as the return streamer type or the reflection echo type, but the difference of arriving time from higher frquency type is more or less indeterminate, and does not always depend on distances travelled as Pierce and Hepburn calculated [13]. The amplitude of (6) is often very large compared with long travelling distances, and contains lower

frequency components than Appleton observed; therefore more extensive study is required before a final conclusion will be derived.

(7) is recorded at times from distances about 1,000 km in the daytime[10], but in general it is observed at night in distances less than 3,000 km, and corresponds to Rivault's type IV. Assuming the space wave components reflected between the earth and the ionosphere where the reflection is assumed to be done upon the geometric optical principle at the surface independent of incident angles, the reflection height and the distance of sources are evaluated by this type. In this paper the mean deviation between records and the calculating chart[6] less than 10 μs and the max. deviation 25 μs are admitted for determination of the reflection height and the distance. A perfectly clear coincidence between the records and the chart is found relatively seldom but in order to make easier the evaluation selection was made to take positive or negative pulse series according to the clearness of waveform, and reasonable judgement was made to determine the order of sky pulses in case the initial part of wave train was complex. Thus the reflection height was found 80-90 km and the distance evaluated from the waveforms coincides fairly well with that of C.R.D.F. fix. Location of source at one station is expected at distances less than 3,000 km at night under favourable ionospheric and other propagation conditions.

V. Acknowledgements.

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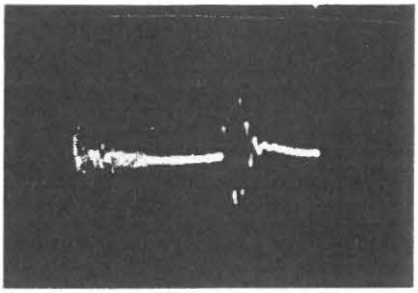
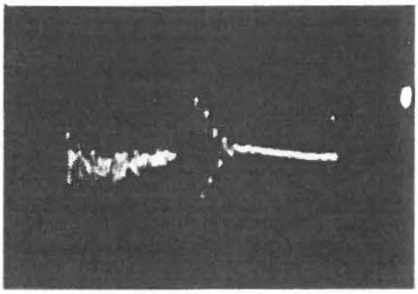


Fig. 1



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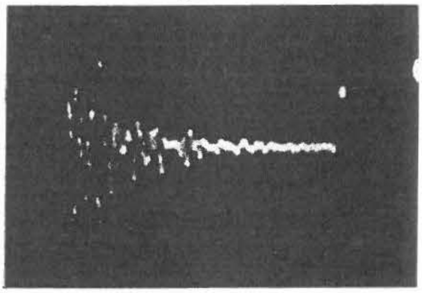

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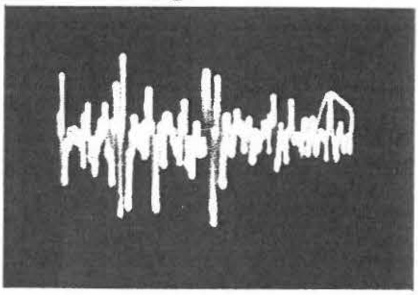

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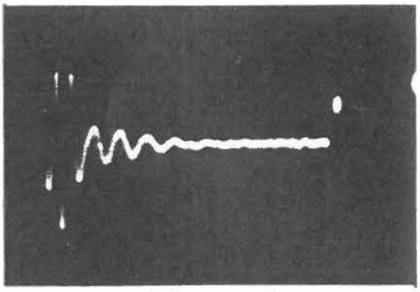

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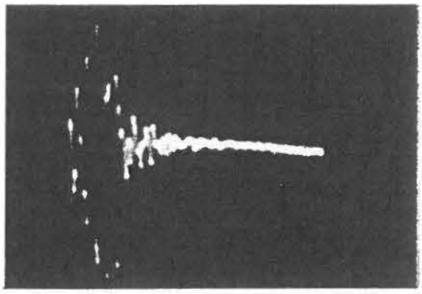

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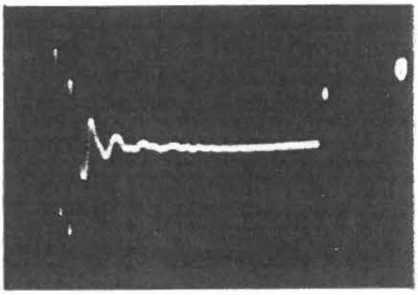

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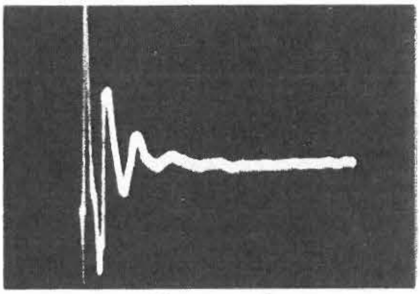

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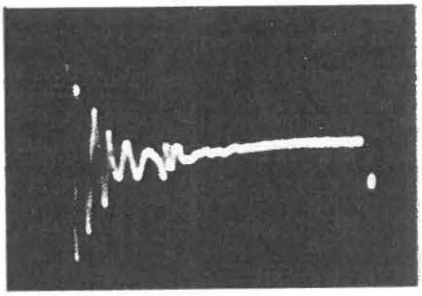

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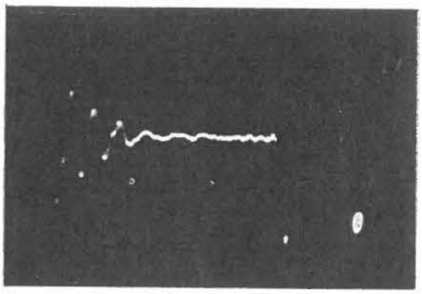

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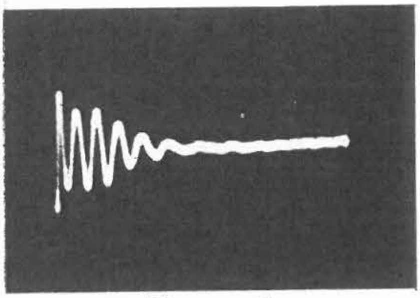

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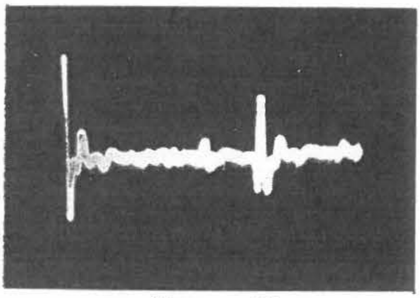

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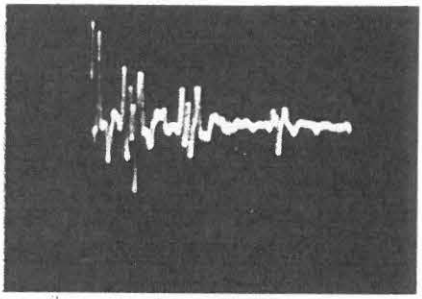

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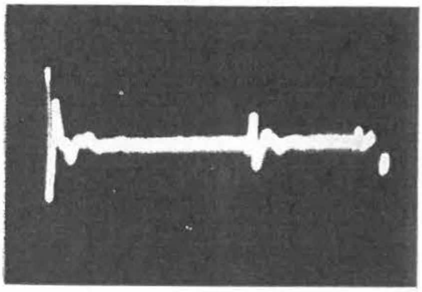

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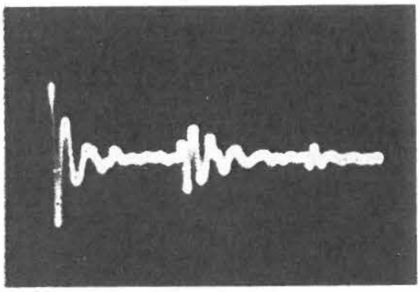

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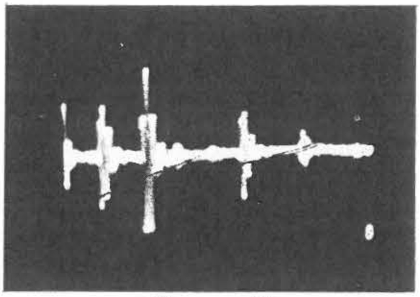

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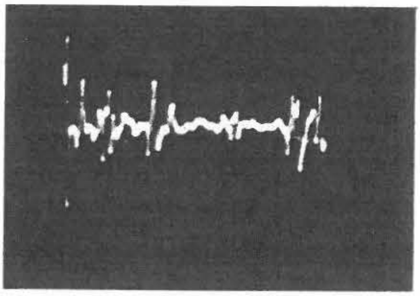

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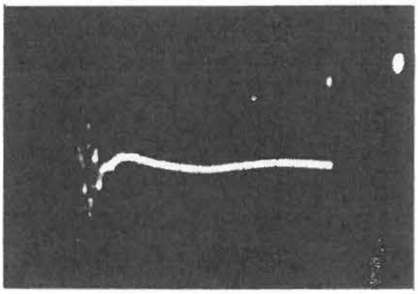

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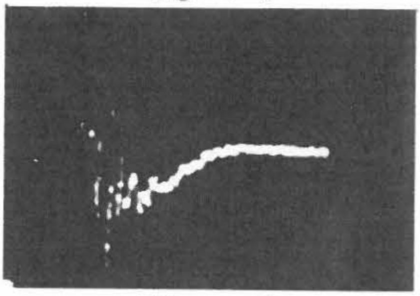

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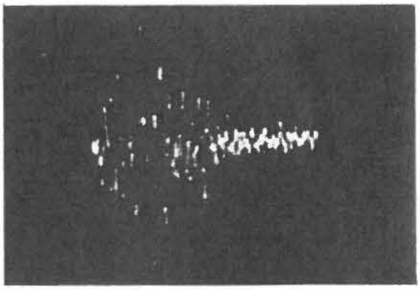

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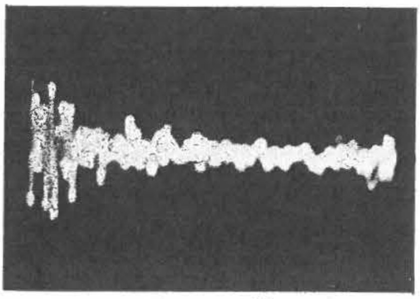

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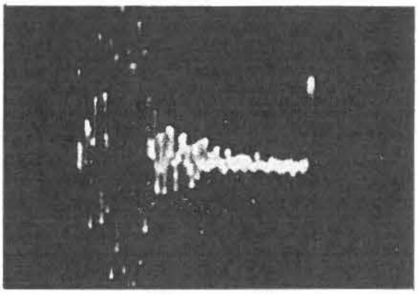

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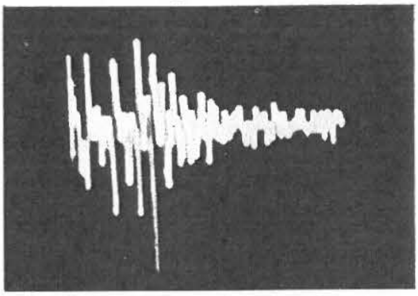

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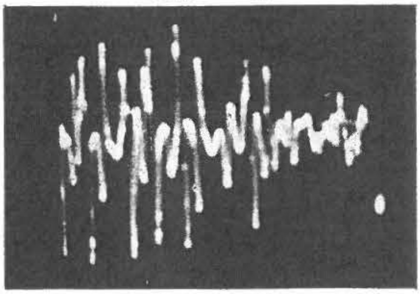

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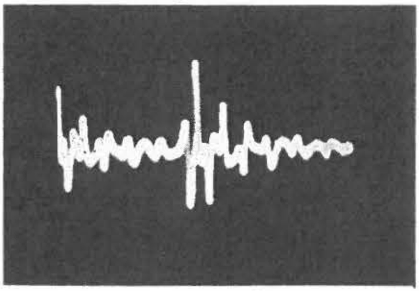

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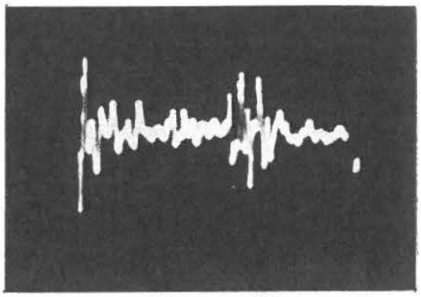

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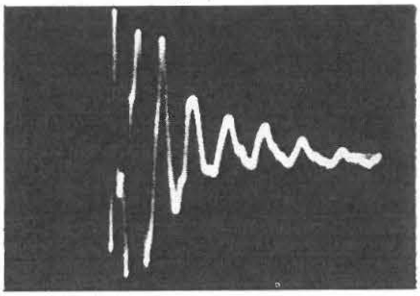

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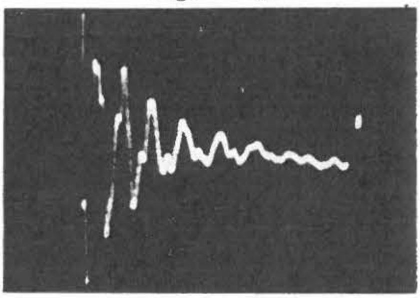

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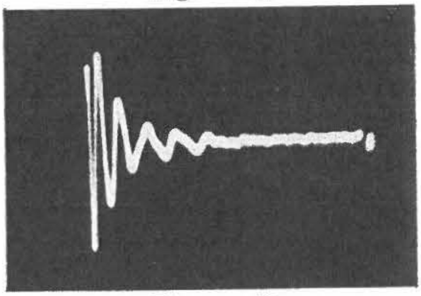

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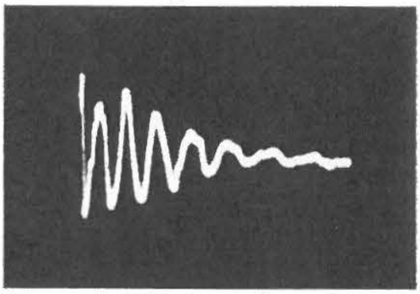

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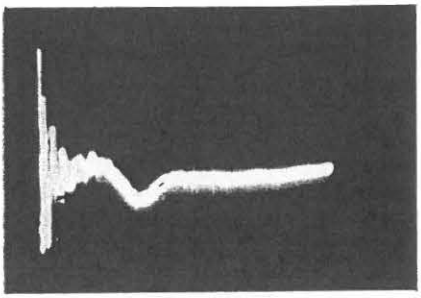

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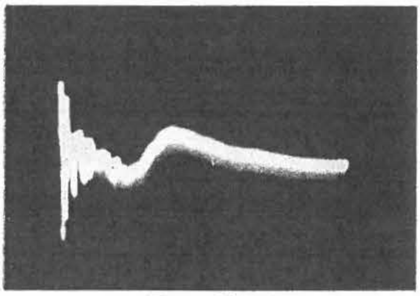

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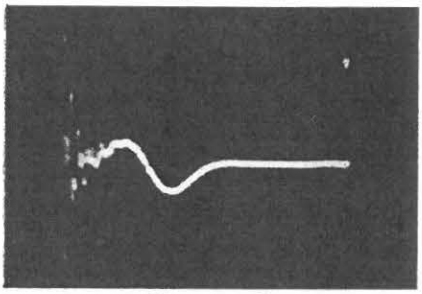

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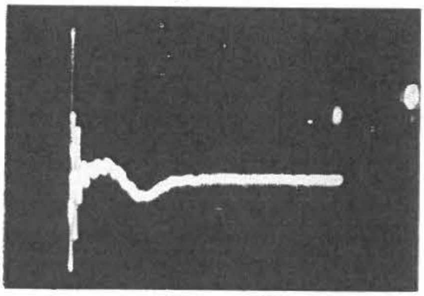

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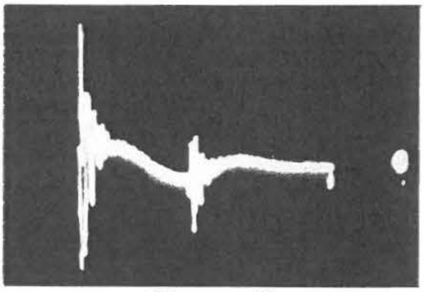

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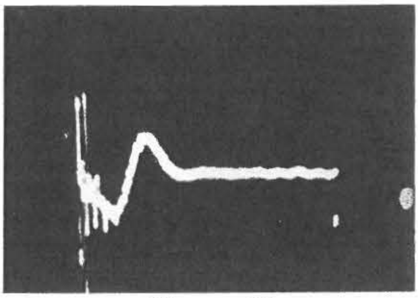

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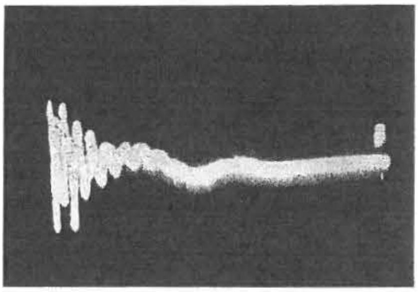

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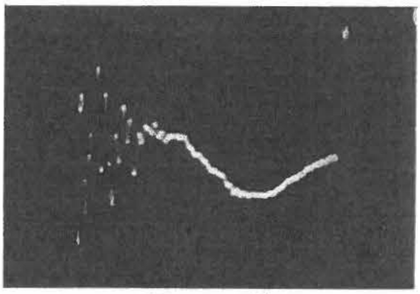

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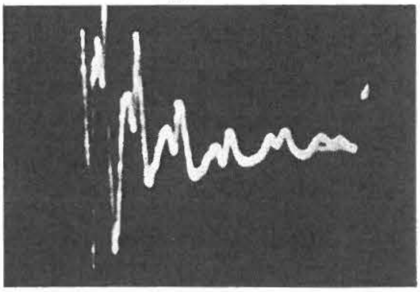

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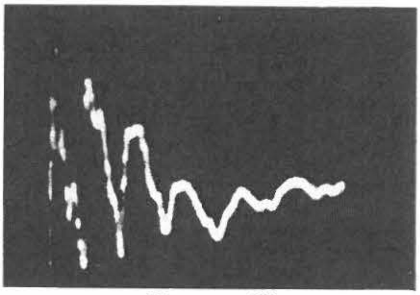

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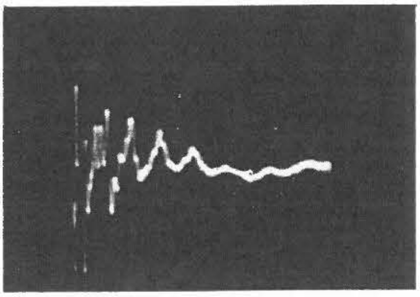
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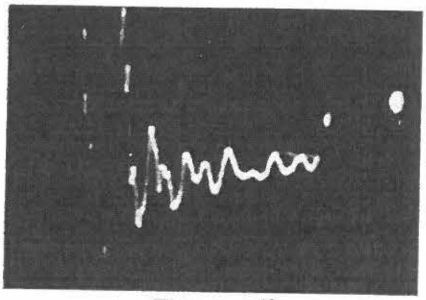
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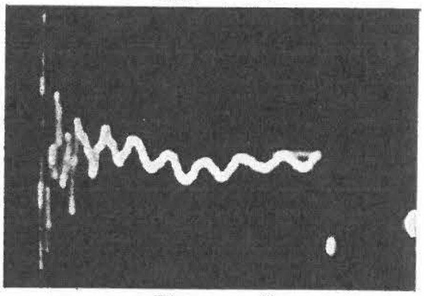
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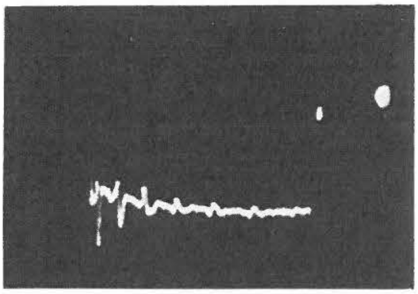
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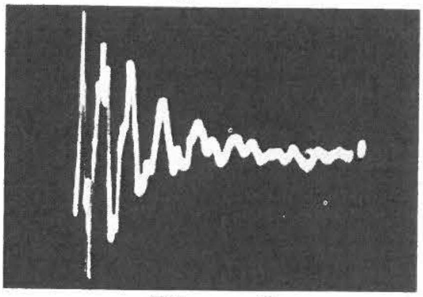
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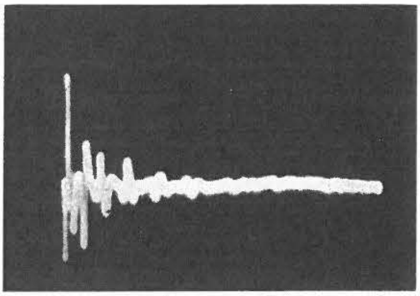
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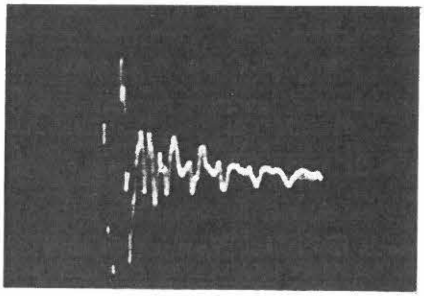
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