THE WAVEFORM RECORDER OF ATMOSPHERICS RADIATED FROM SHORT DISTANCE ORIGIN

By

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Abstract.

An apparatus has been designed to record the waveforms of atmospherics, the sources of which are distributed roughly within the range 0–100km. from the observing station. The apparatus is capable of recording the waveform of an atmospheric simultaneously in three ways. These give the 2m-sec. single time sweep waveform representing fine structures, the 20m-sec. single sweep waveform showing general features, each of which is photographed on the respective frame of 35 mm. film, and the waveform representing the whole structure of field variation and being recorded on 16 mm. cine film running continuously. Another recorder registering the highest peak voltage appearing in the duration of the individual atmospheric is attached to the apparatus to monitor the operation of the apparatus. In the present paper the construction and the performance of the apparatus are described in detail.

I. Introduction

For studying the lightning discharge mechanisms it is indispensable to perform the simultaneous observation of both optical and electromagnetic phenomena produced by a lightning discharge from as wide a stand point as possible. Among various types of records the results obtained from the analysis of atmospheric waveforms are verv important to investigate the mechanism of radiation of electro-magnetic disturbances from lightning discharges especially in the higher frequency range of lightning frequency spectrum. In order to obtain the available information for this purpose the waveforms of received atmospherics should be least affected by the propagation conditions between their sources and the observing station, such as those of reflection by ionosphere. The apparatus reported in the present paper has been constructed to satisfy these requirements, and can be chiefly used for recording the atmospheric waveforms propagating the distances roughly in the range 0-100 km. The apparatus also makes it possible to carry out the simultaneous measurement of lightning discharge in co-operation with other apparatuses for lightning observation, such as a rotating camera and an electro-static field meter.

The main part of the apparatus having been constructed by the present authors is based on the similar idea to that of the previous work made in our Institute. (1) The apparatus has been constructed and improved through the experiences of the past five summer observations of thunderstorms. Although there are many points remaining to be improved in details, the operation of the apparatus has shown that on the whole it is quite satisfactory as a recorder of atmospheric waveforms radiated from nearby lightning discharges. Fig. 1. shows the front view of the main part of the apparatus.

Some results obtained from the analysis of atmospheric waveforms recorded by the apparatus have already been reported in several of our previous papers. [2]

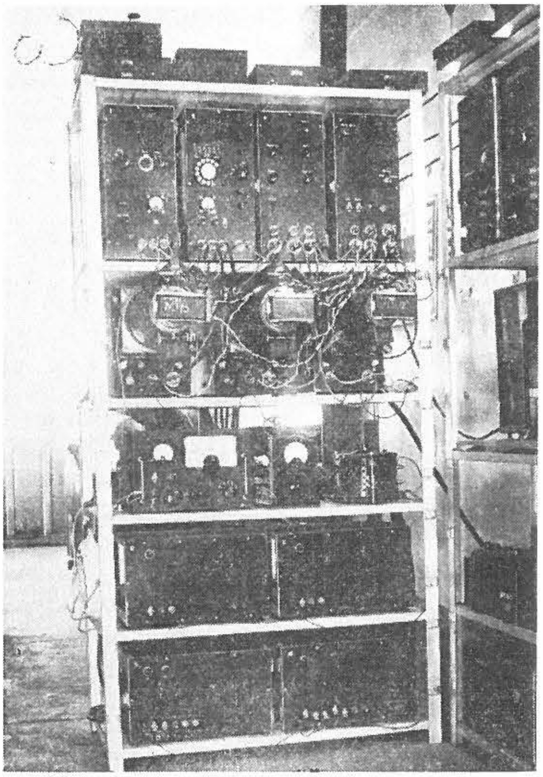


Fig. 1. Front view of the main part of the apparatus.

II. Construction

The construction of the apparatus for recording the atmospheric waveforms is shown in the schematical block diagram of Fig. 2. The volage variation being induced on the receiving antenna and proportional to the electric field variation at the station is amplified through the amplifiers having wide band frequency characteristics and then is led to two cathode ray tubes, each of which is provided with a single linear time sweep circuit each having a different speed. The high frequency component of the same atmospheric is simultaneously picked up by the second antenna and is led to a high frequency amplifier, a tuning frequency of which can be singled out from the three values 0.1, 1 and 10 Mc/s. The output from the amplifier is employed to obtain a trigger pulse, which produces a bright spot on each C. R. T. screen and sweeps it to form time axis. The sweeping times of each C. R. T. are 2 and 20m-sec. respectively. The image appearing on each fluorescent screen of C. R. T. is photographed on the respective frame of 35mm. film, which is rolled up by a manual operation after the disappearance of the image. The simultaneous recording of a lightning discharge by these two methods

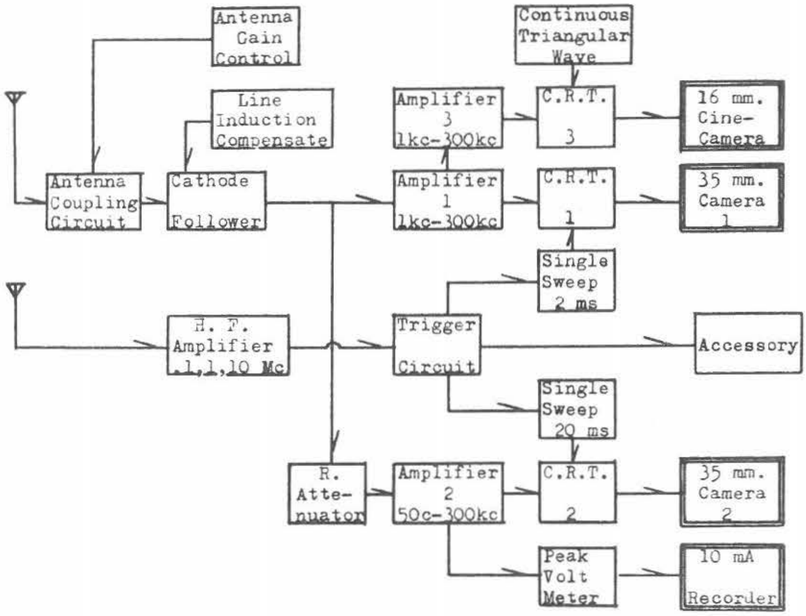


Fig. 2. Block diagram of construction.

is an indispensable means to analyse the fine structure of the beginning part and the general feature of the same atmospheric waveform at the same time.

Besides these two C. R. T. the third ontput of the wide band amplifier is led to another C. R. T. It has a continuous time base having triangular waveform and the image of atmospheric waveform appearing on the screen can be continuously recorded on 16mm. cine film running perpendicularly to the time axis. The recording of waveforms by means of the third C. R. T. is usually carried out on the occasion of thunderstorms occurring in the vicinity of the station. Although the continuous method of recording the waveforms demands a large consumption of long film in a short time, it is superior to the trigger method in the following respects; the records of the continuous method are not influenced by the effect of triggering which necessarily cuts off the beginning of the recorded waveform even if only a little, and it can record the waveform from beginning to end of a lightning discharge, even when the discharge has the time duration of no less than one second.

In addition to these three methods of recording the fourth output is led to a peak voltmeter circuit. The highest peak value involved in one series of waveform is continuously registered by the recording ammeter. The incessant operation of this unit gives a useful clue to fit the amplification of the apparatus to suit for obtaining the fair records of waveforms, to foresee the storm activity, and to obtain statistical data concerning the peak values of field variations produced by lightning discharges at different distances from the station.

III. Antenna system and pre-amplifier circuit

The receiving antenna is a vertical type and is about 4 meters high.

It carries a metal ball of diameter 10 cm. on its top to prevent the possible point discharge from the top of the antenna subjected to strong atmospheric electro-static field. It is placed in an open atmosphere apart from the main part of the apparatus arranged in an operating room. The atmospheric signal received on the antenna is transferred into a low impedance circuit by means of a cathode follower and the output from it is led to the main amplifiers through a long co-axial cable. These systems are shown in Fig. 3.

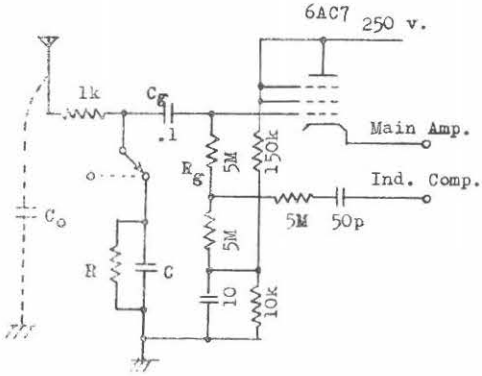


Fig. 3. Pre-amplifier circuit.

The characteristic impedance of the vertical antenna must be capacitive, so long as the frequency spectrum of the atmospherics concerned is lying in the range so low frequencies that the wavelengths of the received signals are much longer than the effective height of the antenna. The equivalent capacity of the present antenna is chosen to have the value 40 pF. The antenna is connected to one of the earthed condensers through a small series resistance inserted between them to make the antenna circuit aperiodic. The effective capacities of the earthed condenser systems are about 0.0004, 0.0012, 0.004, 0.012, 0.04 and 0.12 μF. respecpectively, so that the antenna gains for coupling can be varied roughly from -20 to -70 db. in 10 db. steps. Because the response of frequency of the antenna coupling system in the low side is determined by the discharge time constant of the earthed capacity, the resistances in parallel with these capacities must be altered together with the condensers, so that each product CR of the respective element of C-R couplers is kept at constant value of 4×10^{-3} sec.* throughout the operation of antenna gain selection. The selection of antenna gain can be performed from the operating room by means of a relay system composed of a rotary switch and a dial available for the automatic telephone exchange.

The maximum allowable signal input to the control grid of the top cathode follower is about 30 v. in p-p value and the maximum receivable field strength is about 5×10^{4} v/m., if the effective height of the antenna is assumed to be 2 metres. This maximum value of the measurable field is just the same magnitude as the electro-static field value observed in one of the most violent thunderstorms in our country.[(3)]

The voltage induced by the power lines to the antenna, a troublesome objection for recording the fair waveforms especially at high gain, is compensated only in amplitude and phase of its fundamental component, but the effects of higher harmonics are usually not very important for thunderstorm observations.

IV. Main amplifier circuit

It is evident that the amplifler for recording the waveforms must

* Exactly, $(C+C_o)\, R.R_g/(R+R_g)$ must be kept constant, if $C_gR_g \gg CR$ (See Fig.3.)

have a wide band frequency response, since the atmospherics from short distance origins have a very wide range frequency spectrum. However, the expansion of band-width beyond a certain limit is difficult and may be impractical. The lowest side of the frequency response is limited by the discharge time constant of antenna coupling circuit and the highest side of it is limited not only by its charge time constant that depends on the natural frequency of the system composed of antenna and series resistance, but also by the fact that the spot brightness on the screen of adopted C. R. T. cannot be made strong enough to be recorded on the photographic film, if the velocity of the time sweep is faster than 10^4 cm/sec. or more.

Amplifiers of the two channels are both of similar C-R connections, and the differences are that the resistance attenuator (10 db. $\times$ 3) is provided at the top of the second channel and that one of the coupling constants of the first channel is selected to have a small value in order to emphasize the radiation field component of the waveform. The records obtained by the first channel having faster time base are available for analysing the fine structure of radiation field component, and those by the second channel having slower sweep are useful to study the static field component, which varies its intensity at a slow rate and generally has much larger intensity than that of the radiation component, if the storm is occurring near to the station. In the first channel the minimum of the time constant is selected to 2×10^{-4} sec. and in the second it is selected to 10^{-1} sec. These amplifier circuits are shown in Fig. 4. and their characteristics of the frequency response including antenna system are illustrated in Fig. 5. They show flat characters from 50 c/sec. to 300 kc/sec. and from 1kc/sec. to 300 kc/sec. respectively.

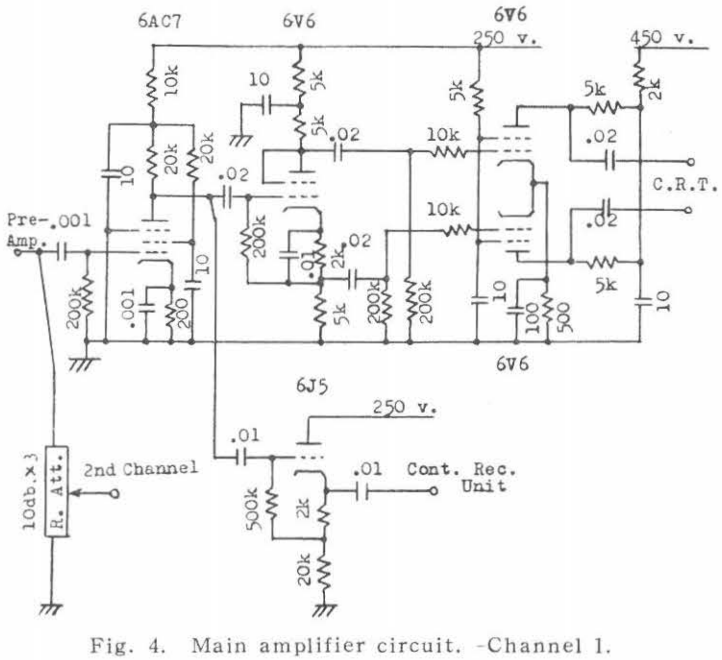


Fig. 4. Main amplifier circuit. -Channel 1.

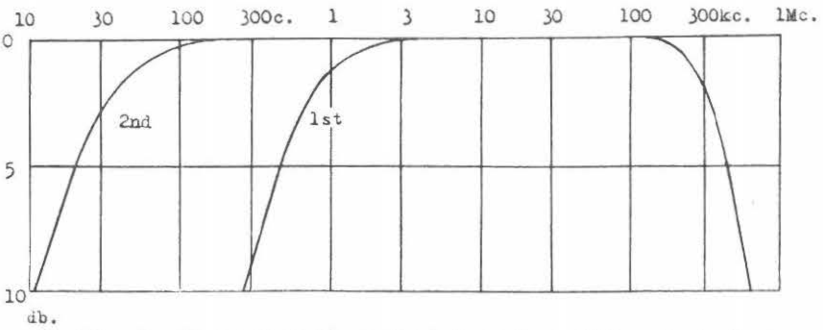


Fig. 5. Frequency characteristics of amplifiers including antenna coupling system.

The gain of each amplifier including the top cathode follower is about 50 db. and its push-pull last stage has maximum undistorted output of 400 v. in p-p value. Each of these outputs is applied to a pair of vertical deflection plates of the respective C. R. T. As the deflecton factor of the used C. R. T. is 25 v/cm., the deflection of the image appearing on the screen of diameter 12 cm. is sufficiently linear and the input voltage of the amplifier system required for the full deflection is 1 v. in p-p value.

The over-all amplifications of the apparatus including the antenna coupling system are $+30\sim-20$db. in the first channel and $+30\sim-50$ db. in the second one. These values correspond to the field strengths of recorded atmospherics of $5\sim1.5\times10^3$ v/m. and to that of $5\sim5\times10^4$ v/m. respectively for full deflections. According to our observational experiences, the apparatus provided with these advantages is sufficient to record the waveforms of atmospherics radiated from lightning discharges within a few hundred kilometers from the station.

V. Time sweep circuit and recording system.

1. High frequency amplifier and trigger circuit.

It seems that the trigger action of the time base caused by the high frequency component of the recorded atmospheric plays an important role especially when the slow static component predominates over the rapid one and is preceded by the rapidly changing field due to predischarge, such as the first leader stroke of a lightning discharge to ground. The high frequency amplifler adopted in the trigger channel is of a super-heterodyne type similar to a typical radio receiver, and its tuning frequency can be adjusted to any one value selected from the three frequencies, 0.1, 1 and 10 Mc/sec. As the band-width of I.F. amplifier is 10 kc/sec., the delay time required to form a trigger pulse is an order of magnitude of 10^{-4} sec. Therefore it is impossible to avoid the initial part of a waveform being always cut off from the record by the amount no less than the delay time of this order of magnitude. By selecting the trigger frequency, one would be able to determine the predominant frequency component in a certain type of the radiation field variation and also to record some selected types of waveforms.

The positive output sufficiently amplified after detection is applied to the grid of a triode being in a cut-off state and then the trigger pulse with a constant size is formed by this triode.

2. Suppression circuit.

Under the conditions of thunderstorms a lightning discharge frequently covers the duration of about a second, therefore the sweep is often repeatedly triggered on one frame of recording film no less than several times, provided that the length of the adopted sweeping time is less than several tens of milli-second at the longest. This overlapping of the waveforms makes it very difficult to analyse them, hence the suppression of triggering is required to prevent these difficulties. The succeeding trigger action is set into rest for a certain period after an action has started, and the trigger pulses appearing in such a pause period set to about a second in length produce nothing. The circuit and the behavior of the action at each point are shown in Fig. 6.

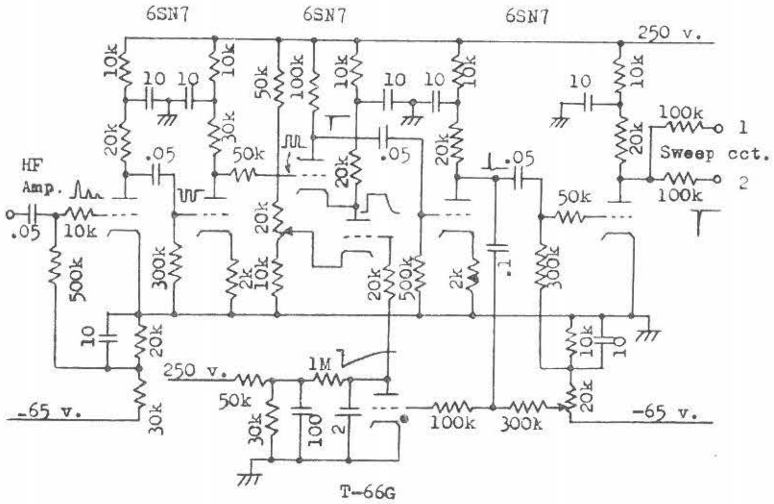


Fig. 6. Trigger and supression circuit.

3. Time sweep circuit.

The cathode ray beam is suppressed until an atmospheric to be received arrives at the antenna in order to keep the photographic film from fogging due to the luminosity of the spot on the C. R. T. screen. As soon as an atmospheric being fit for high frequency triggering is received, the trigger action sets in and C. R. beam liberated delineates a waveform of this atmospheric on the screen of C. R. T. The operation of brilliance control is performed by a positive rectangular pulse having the same duration as the time sweep, and applied to the grid of C. R. T. The rectangular pulse is formed by means of a so-called one shot multivibrator which is started by a negative trigger pulse from the suppressor. The rectangular pulse also generates a single saw tooth wave to sweep the linear time base on the screen of C. R. T. Its time width or the sweeping time is determined by the product of CR denoted in Fig. 7. showing the circuit.

As described in Section II, the time sweep circuits are composed of two channels in parallel and their arrangements are different only in the values of CR and in the coupling constants. The sweeping time of the present apparatus are 2 and 20 m-sec. respectively.

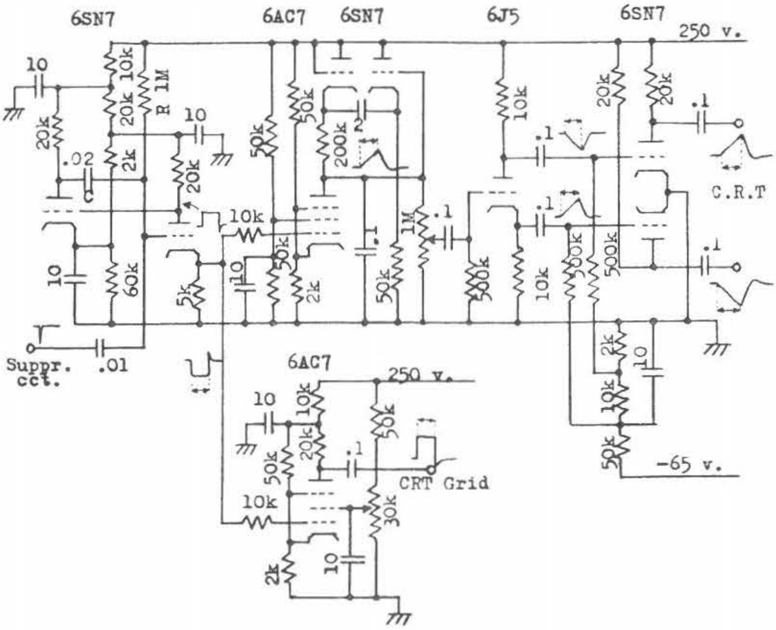


Fig. 7. Time sweep circuit. Channel 1.

4. Recording system.

To each C. R. T. is attached the respective camera hood, which makes it unnecessary to arrange the apparatus in a dark room for photographing. On the upper side of each hood is provided an eyehole to monitor the behavior of C. R. beam, and inside each hood there is an electro-magnetic shutter, which is usually open and is automatically closed after the disappearance of a waveform. The shutter prevents the recording of multiple sweeps in co-operation with the action of suppression circuit for triggering. The photographic film being used to record waveforms is 35 mm. negative film, and the frame exchange of the camera is performed by the operator's hand. One charge of 35 mm. film having 5 feet length includes 52 frames of waveforms.

VI. Continuously recording system.

From half-way of the wide band amplification of the first channel the third output is led to the third C. R. T. through the third amplifier similar to that of the first channel. Time base of the third C. R. T. is composed of a continuous isosceles triangular wave generated with C-R oscillator of transitron type shown in Fig. 8. The frequency of the oscillator is singled out from 50, 100 and 200 c/sec. and the corresponding time durations required to sweep one-way is 10, 5 and 2.5 m-sec. respectively. In order to record the images on the fluorescent screen continuously the 16 mm. cine film is perpendicularly driven to the direction of the time base at a speed selected from 6, 9, 12 and 18 cm/sec., and the film of 100 feet length wound on one reel is consumed in less than 3 min. at the highest speed. Fig. 9 (C) illustrates an example of the record obtained by the third C. R. T., and the mark at the upper left-hand side indicates the trigger time corresponding to the beginning of the waveform illustrated in Fig. 9 (A) and (B), which are photographed in the respective frames of 35 mm. film and represent the same atmospheric as the continuous record.

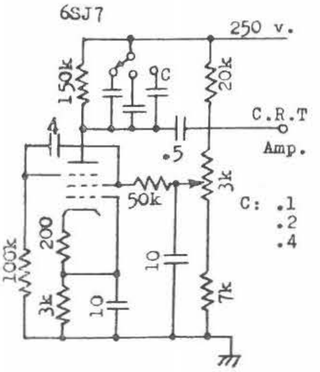
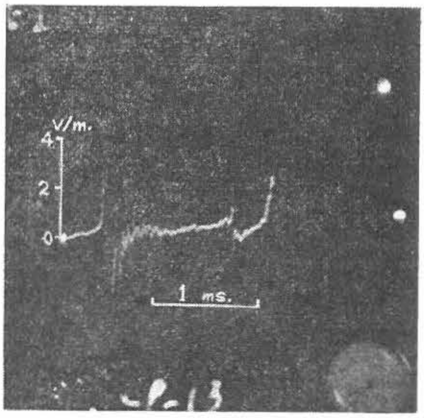
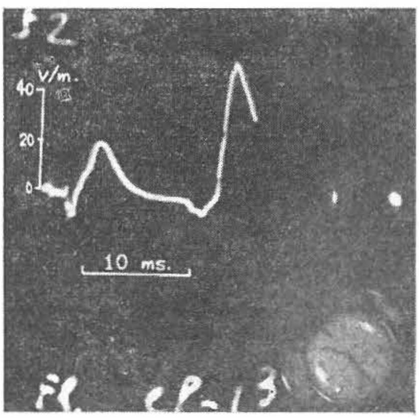


Fig. 8. Triangular wave oscillator.

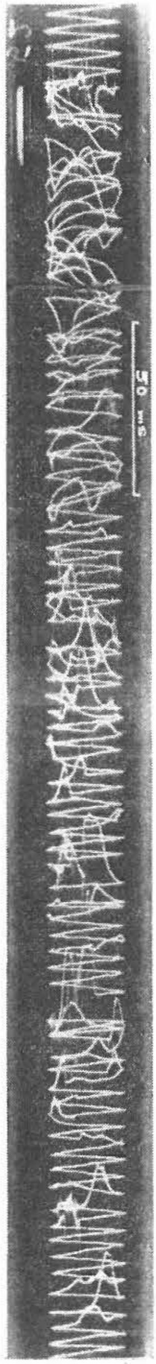
Fig. 9. Three simultaneous record of the same atmospheric.



(A) 2 m-sec. sweep.



(B) 20 m-sec. sweep.



(C) continuous record.

VII. Peak voltmeter circuit.

Since several-tenths of a second is neceasary to swing the writing pen of a recording ammeter out of the zero position, it is evident that even a single pulse with very short time width must be lengthened to the order of magnitude of a second. Considering the characteristics of amplifiers of C. R. T. systems the time response character of this unit must be about a few micro-seconds even at the greatest. The construction of this unit is shown in Fig. 10. The values of the time constants C_1R_1 and C_2R_2 have been determined to satisfy this demand. C_1 must be small enough to be charged up to the peak voltage of the incident pulse through the output impedance of cathode follower and the internal resistance of diode rectifier in very short time of the order of a few micro-seconds. The value of C_2R_2 must be large enough to swing the recorder pen out of zero position. Therefore R_1 and R_2 must be as high as possible within the limit of stability of the circuit. C_3 andR_3 is inserted

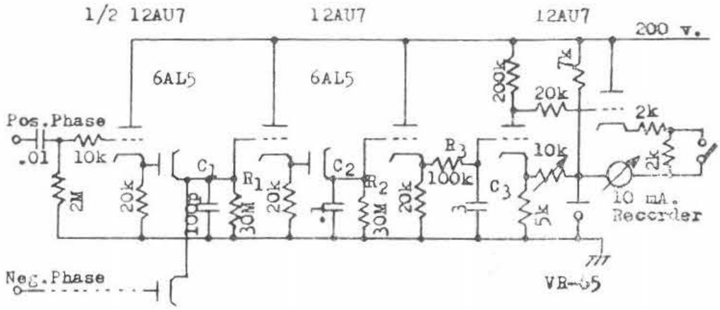


Fig. 10. Peak voltmeter circuit.

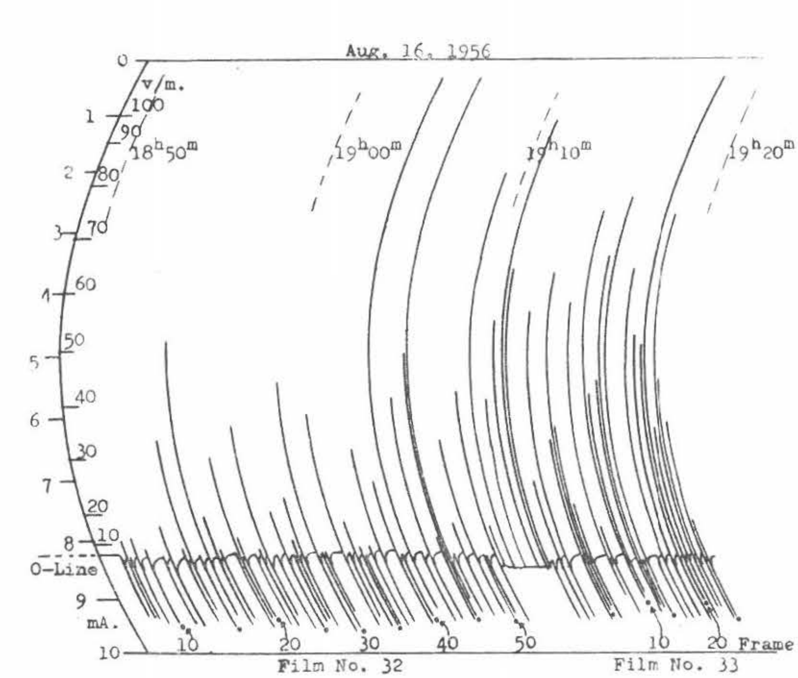


Fig. 11. An example of peak voltmeter record.

for the protection of ballistic movement of the pen. When the relay switch S illustrated in the circuit diagram in Fig. 10. is automatically closed, the mark indicating the frame number of the waveform record is registered in the opposite side of zero line. An example of the record is shown in Fig. 11.

VIII. Accessory unit.

The automatic actions performed by means of several relays of various types in the accessony unit are as follows.

When the trigger pulse is led into the unit from the suppressor:

(1) Both electro-magnetic shutters in the respective hoods being initially open to photograph the waveform are closed about a second after the trigger action and prevents double exposures. In the shuttering time lag period of a second the operator can photograph the mark on the frame of the waveform record. This mark indicates the corresponding relation to the records of other apparatuses registering the same lightning discharge, and is shown as a round spot at the upper right-hand corner in Fig. 9. (A).

(2) A strobotron inside of each hood is lighted at the moment of time sweeping and a watch placed beside each strobotron is photographed together with the waveform on a frame of 35 mm. film. Thus the accurate time of the waveform coccurrence is registered on every frame of records. This is illustrated by the respective watches in Fig. 9. (A) and (B).

(3) A neon-lamp mounted on upper side of the hood of C. R. T. of the continuously recording system is lighted at the same time and is photographed on the left-hand side of the continuous waveform record. This makes it possible to identify the equivalence of the continuous record to the waveform record on each frame. This is shown as a linear mark at the upper left-hand corner of the continuous record in Fig. 9. (C).

(4) The relay switch in the peak voltmeter circuit operates the recording pen, after the swing out of the pen has nearly been recovered, and it registers the mark, indicating the corresponding relation to the waveform on each frame, to the opposite side of the zero line. The mark is illustrated by each downwards directed line from the zero level in Fig. 11.

(5) A bell rings and informs the operator of the fact that the waveform has been photographed.

(6) A pilot lamp for monitoring is put out.

When the operator manually pulls each camera by the respective triggering chain to exchange the photographed frame for a new one:

(7) A relay switch attached to the camera nob is immediatetly turned to "on" and the circuit recovers the original state.

(8) The shutter in each hood opens.

(9) The pilot lamp described in (6) is lighted and it instructs the operator that the system is in a waiting state for the arrival of the next atmospheric.

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