Instrumentation for the Remote Monitoring of Thunderstorm Activity

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ABSTRACT

The development and operation of two types of thunder detection and recording systems are described. Both operate remotely and make a permanent record of lightning and thunder. They were developed to obtain objective and more reliable thunder occurrence statistics, and to provide verification of thunderstorm development in convective cells. These systems are applicable to a variety of field experiments that involve data on thunderstorm activity. One device eliminates the need for audio recording and facilitates rapid data analysis.

1. Introduction

The number of reported *thunder days* in various parts of the United States has decreased by 5–20% over the last few decades (Changnon, 1973). Whether this decrease is due to actual climatic changes or to hampered observations is a subject of extreme interest. The chief trouble may be distraction of the observers by other responsibilities (such as forecasting) and by noisy working locations (airports and buildings with noisy air conditioning).

Thunder-day data have been used in a variety of important climatic studies (U. S. Weather Bureau, 1947) and in urban weather studies revealing that urban effects were potentially responsible for near-city increases in thunderstorm activity (Changnon, 1968; Huff and Changnon, 1973). A recent study of urban effects on precipitation was METROMEX, a field program centered at St. Louis to investigate possible urban effects on thunderstorm frequency (Changnon *et al.*, 1971).

For METROMEX, instruments were developed to obtain objective records of the lightning and thunder frequency at several sites. The data were desired for use in individual storm studies as well as to furnish thunder-day statistics. The thunder-day data from the 1971–73 period revealed an increase in thunder-day activity just east of St. Louis (Semonin and Changnon, 1974). Potentially, these data may also furnish new information on the audible distance of thunder under varying weather conditions.

Three tape thunder recorders, joined with lightning detectors, were built initially and used in 1971–72, but certain audio and analytical problems occurred which were resolved in the second design for three additional instruments used in 1973–74. Finally, a thunder detector that records both lightning and thunder on a strip chart was developed, and the prototype instrument was used in 1974.

The purpose of this paper is to describe the design and operation of the tape thunder recorders and the lightning and thunder detectors. These systems should be applicable to a variety of field experiments concerned with monitoring thunderstorm activity, and they offer a means for better thunder monitoring at our national weather stations, as well as at remote locales without observers.

2. Tape thunder recorders

The initial device recorded the sounds of thunder on tape, and was triggered by a lightning detector. The thunder recording system used a Crown recorder and a synchronous FM scheme with five channels on ¼-inch tape. Four channels recorded the modulated carrier, and one channel recorded the unmodulated carrier used on playback for synchronous detection. Four microphones were placed at the corners of a large rectangle (about 30 m×30 m) in hope that through geometric analyses, the direction of arrival of the thunder could be determined. The lightning detector triggered the thunder recording system and the recorder ran for 2 h. Each 10.5-inch reel could hold from 12–16 h of recording. Naturally, the storm would often cease well before the 2 h were up, and the analyst had to listen to long records without thunder. The quality of the sound was often poor. Also, the lightning detector would frequently trigger because of some spurious event (electrical noise), and the whole 2 h of tape recording would be blank.

The second recorder system corrected most of these problems. The recording is done with Norelco stereo cassette recorders so that the losses in fidelity of the FM process were removed. The recording cycle

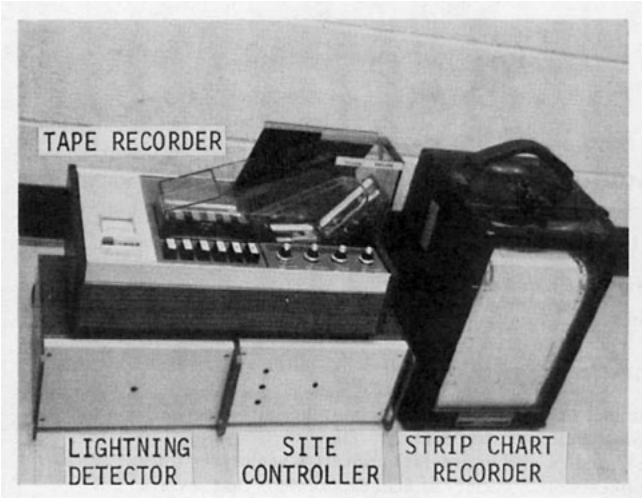

FIG. 1. Inside site installation.

length is set at 10 min to reduce tape wastage. As an accessory to the Norelco recorders, a recirculator allows the continuous recording of both sides of six cassettes without operator interference, which usually permits a week or more of operation between tape replacements. Since the recorders record only in stereo, the four-channel approach to determination of direction had to be abandoned. The indoor installation is shown in Fig. 1. Outdoors, three microphones are installed at three corners of a 10 m square.

When the lightning detector triggers this system, the recorder starts and continues to run for 10 min. During the first 5 min of this period, the two microphones forming a north-south line operate. During the second 5 min, the two microphones forming an east-west line operate. The one on the northwest corner is common to both 5 min intervals.

The microphones contain a ceramic cartridge (from a push-to-talk mike) with our own electronics. The cartridges, with a small breather hole punctured, have response down to 1 Hz or less, and beyond 12 KHz. This can be seen when the microphones are connected directly to playback equipment, but we have not had the ability to record to this low limit. The philosophy of the design is that the signal from the microphone should be high-level and low-impedance to have the capability of delivering adequate signals over extremely long lines. This is accomplished by preamplifier and driver stages mounted with the cartridge; connection to the recording equipment is through a 3-wire cable. The schematic of the design is shown in Fig. 2.

Waterproofing is accomplished by stretching a piece of plastic across the top end of the microphone to cover the cartridge. The electronics is sprayed with a clear enamel to protect it against moisture and the voltage-dropping resistors in the microphone body are purposely intended to provide warming heat for the microphone to help keep it dry. When mounted and in use, the microphone is covered by a terry cloth cube. The cover serves several functions, chiefly reduction of wind noise in the recordings. Ancillary benefits include shielding from direct raindrop impacts, and protection against birds that like to pick out the diaphragm. Fig. 3 shows a photograph of the installed microphone with and without cover. With appropriate protection against wind and rain, their survival rate is very good. The principal problem

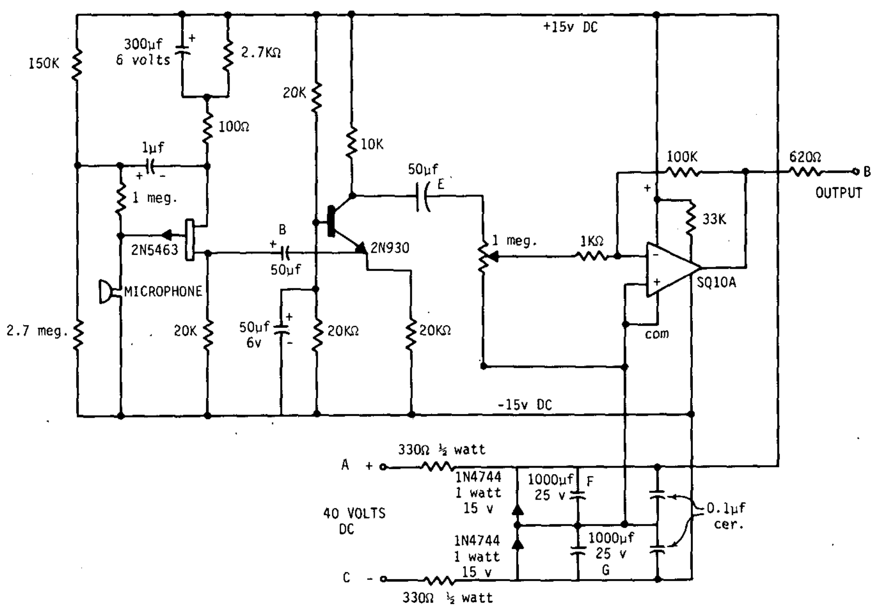

FIG. 2. Microphone schematic.

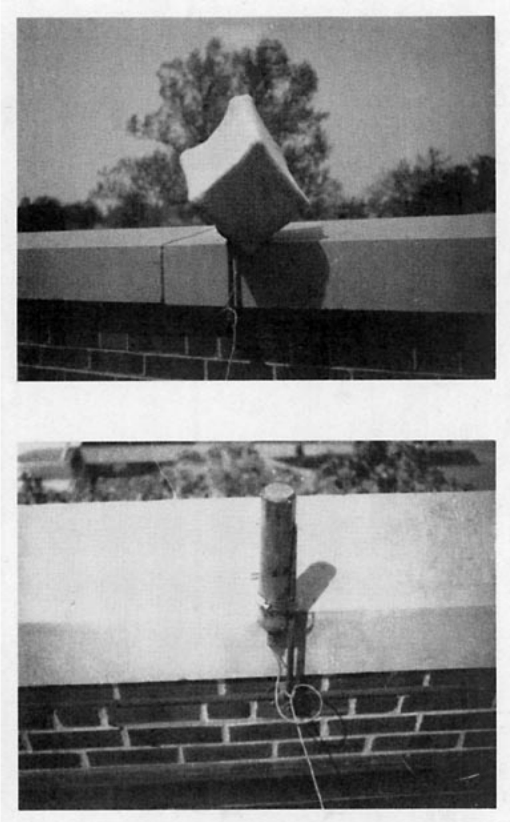

FIG. 3. Microphone installation.

has been failure of some of the electrolytic capacitors on hot summer days from overheating.

The site controller (Fig. 1) receives the signals from the lightning detector and microphones, and provides timing and control signals that appropriately start and stop the tape recorder. It provides for the automatic switching to the second pair of microphones, and delivers the marking signals to the strip-chart recorder. In addition, the site controller generates tones to be recorded on the tape, which help the auditor determine what events are occurring. The event tones are a long high tone at the beginning of each 10 min period, a long low tone when the microphone switchover occurs, and a short medium pitch tone that is sounded each time the lightning detector is triggered by a change in the electric field. The tones are recorded on the right-hand channel of the recorder and mixed together with the audio from the two microphones that are switched. The audio from the northwest microphone is recorded without adulteration onto the left-hand channel of the recorder.

The site controller performs a last, but extremely important, function. By mixing the control currents for the various relays, it drives a chart recorder and generates a strip chart, thus giving a complete history of when the recorder was and was not running, when lightning was detected, which pair of microphones was in use, and when power failed. By using a signal from the tape recorder, a large deflection is added that indicates when each cassette is ejected and a new one loaded. This record is invaluable in correlating lightning and thunder occurrences with real time, and serves as a handy index to the recordings. These charts are cut into 13-inch lengths and mounted, overlapped and bound in a computer printout folder. This is superior to leaving them in a roll, because they can be reviewed more quickly.

Each element of the system is packaged in an attractive chassis (see Fig. 1), which helped secure cooperation from owners of desired installation sites. For example, in one small town, we were able to install the equipment in a town hall that also serves as a small library.

The main analytical problem from the operation of six thunder recording sites in two summers (1973 and 1974) was the phenomenal amount of recordings that needed human auditing. We obtained about 500 h of tape each summer. The mass of data made the effort to further analyze it for more than just frequency of events (not direction) a difficult matter. Attempts to study direction of arrival or distance of travel (by using radar echo data) have been hampered by the fact that these were only secondary goals in the design. Thus, the utility of the data was reduced somewhat by both the mass and the quality of the data.

3. Lightning detector

The lightning detector employed was a device built for a previous experiment, adapted by the Illinois State Water Survey engineers from work by Pierce (1956). Essentially, this device detects the rather rapid changes in the atmospheric electric field caused by nearby lightning. Inasmuch as the detector is sensitive to small changes due to displacement currents, there is no need for a very close strike to provide an intense current. In its most sensitive setting, the device will detect some lightning as far as 30 km, well beyond the range of audible thunder (Byers and Braham, 1949).

The lightning detectors used in the first systems were constructed with vacuum tube technology. A solid state version was then designed with the use of discrete components. Presented here is the design of the latest version, built with integrated circuit timers, and of great simplicity compared with the earlier models. This device proved to be a reliable detector of lightning and the complete schematic is presented in Fig. 4.

The antenna for the lightning detector is merely an inverted coffee can with the preamplifier installed inside. The antenna is attached to a fiber glass rod which insulates it from the structure on which it is mounted. The preamplifier uses a tube but will sustain

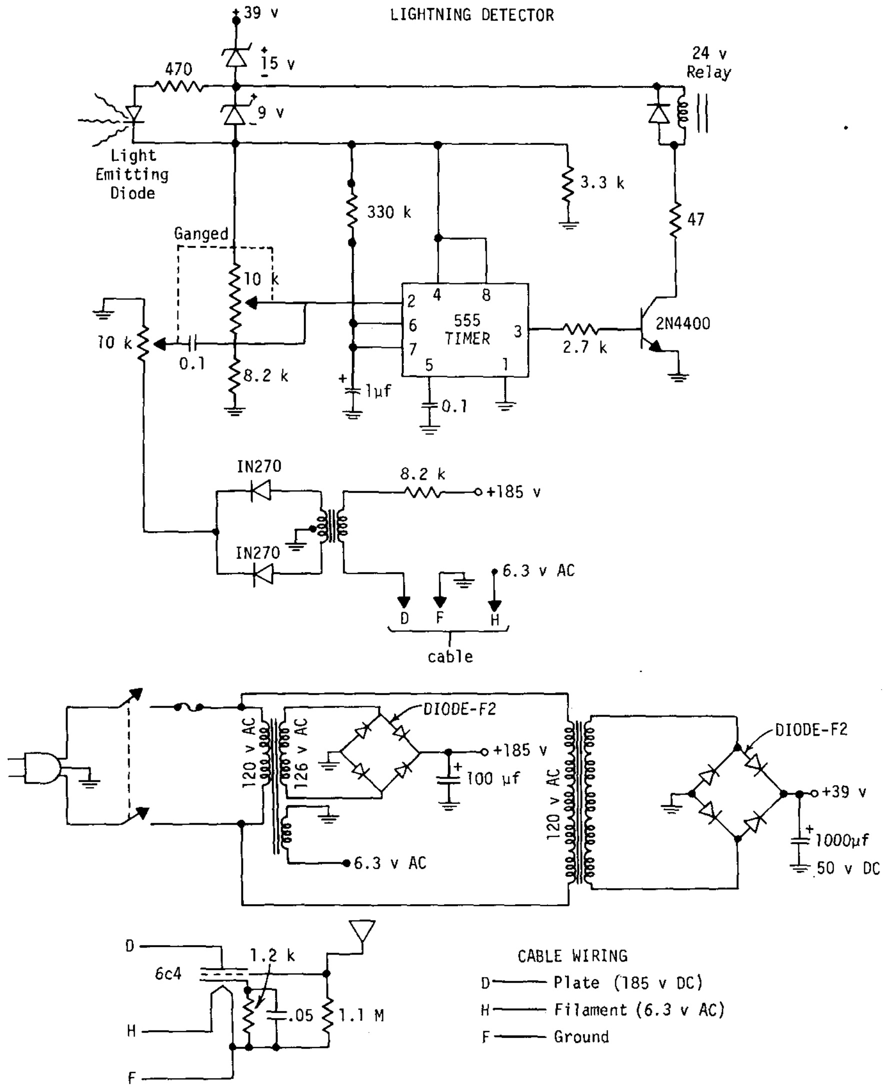

FIG. 4. Lightning detector schematic.

higher transient and steady-state voltages than most inexpensive transistors. Connection directly to the grid gives the antenna an extremely high impedance, and it quickly assumes a potential near that of the field in which it is placed. Fluctuations in grid voltage due to fluctuations in the field are reflected as changes in the plate voltage and current. These changes are coupled through a transformer into the trigger circuit of a 555 timer. The transformer rejects slow changes in the field and provides good transfer of the much faster changes caused by lightning discharges. The bridge rectifier in the trigger circuit provides for triggering either positive-going or negative-going transitions of the field voltage, thereby roughly doubling the number of lightning flashes to which the unit will respond. (There are conditions, however, in which even relatively nearby flashes will not cause a sufficient local field change to trigger the detector.) The timer fires for about 1 s, pulling in a relay in the present application, although other users could couple in other ways to the binary indication of the timer. The 1 s relay closure starts the timing cycle and records a tone on the tapes at each subsequent closure.

Sensitivity control is accomplished by a ganged-potentiometer arrangement coupling the bridge output with the timer trigger input. The timer contains a comparator as input, with an established threshold of one-third of the supply voltage. Any time the input goes below this value, the timer is fired. The sensitivity potentiometer does two things simultaneously to enhance the sensitivity: one gang of it moves the dc level at the trigger input down closer and closer to the threshold, and the other gang simultaneously removes attenuation from the transmitted pulses, so that even small individual pulses will trigger the device. This arrangement has proved very effective.

4. Thunder detector

Although the tape thunder recorders provided desired thunder-day data, analytical problems led to the design and building of a thunder detector for easier acquisition of thunder statistics. By monitoring the sound intensity after occurrence of lightning, the device determines the occurrence of thunder as it occurs. The strip chart then shows the occurrence of both lightning and thunder. This eliminates the need for a tape recording and thus for an auditor. The barrier to acceptance of the data from the device would be more traditional than technical—traditionally, a day was not a thunder day unless someone actually *heard* thunder (U. S. Dept. of Commerce, 1964).

A rather high correlation between the occurrence of lightning and the occurrence of thunder is expected. Nevertheless, cases have been observed of nearby lightning with no discernible thunder, as well as thunder with no apparent lightning. The detector will say "No Thunder" in either case.

The basic principle of the thunder detector (Fig. 5) is that thunder is usually closely preceded by lightning, and usually represents an increase in the audio level in the vicinity of the observer (the detector). The procedure is as follows: When no lightning has been detected for more than 15 s, the detector, in its rest state, continuously monitors the sound level and derives an average sound level in the form of a dc voltage. As soon as lightning is detected, by using the previously described technique, this average voltage is held by a portion of the circuitry, and the continuing average is carried on by another portion of the circuitry. The "held level" and the new level are compared electronically during the 15 s following the lightning. If the sound level increases for about 3 s during that time, the detector indicates thunder and records a mark on the strip chart. The system compensates somewhat for more distant thunder by the slow decay of the stored level. This thunder detector can be installed in a weighing bucket recording raingage with a second pen to record the thunder.

The rain and thunder data traces can be reduced at the same time, and, in conjunction with the rainfall data, the occurrence of thunder can be defined on a much finer scale than can be determined by any practical network of observers. The detection of thunder is a digital event at the output of the timer and could be easily multiplexed into automated or automatically transmitting weather stations, or it could be used in any digitally recording or transmitting weather station scheme.

The thunder detector was first tested in the laboratory by using recordings of thunder made during the field project and simulated lightning detection whenever a tone is heard. It proved to be highly successful in determining the presence of thunder,

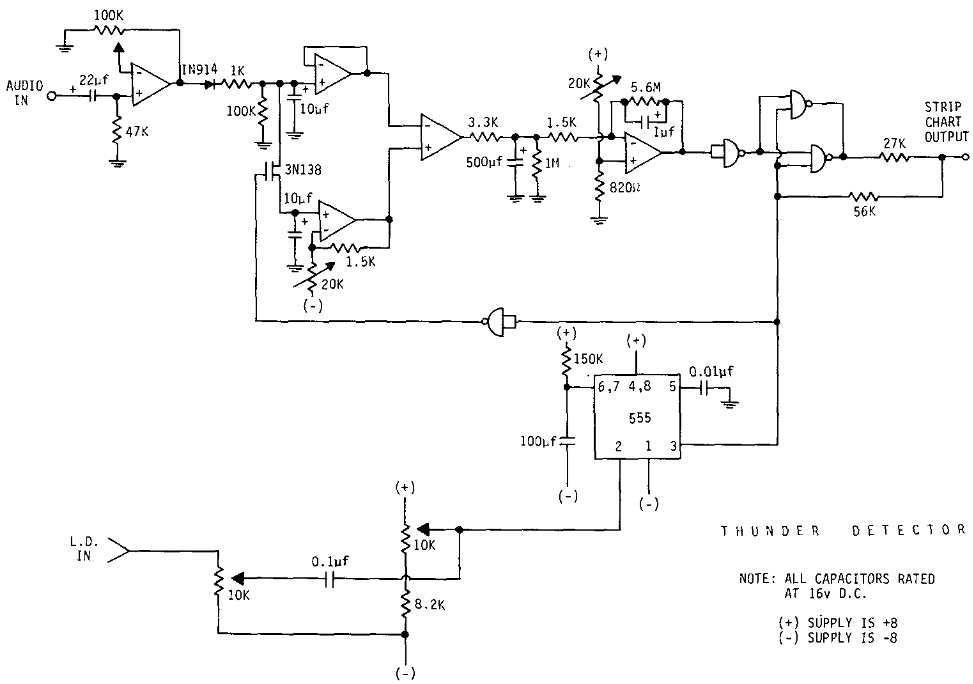

Fig. 5. Thunder detector schematic.

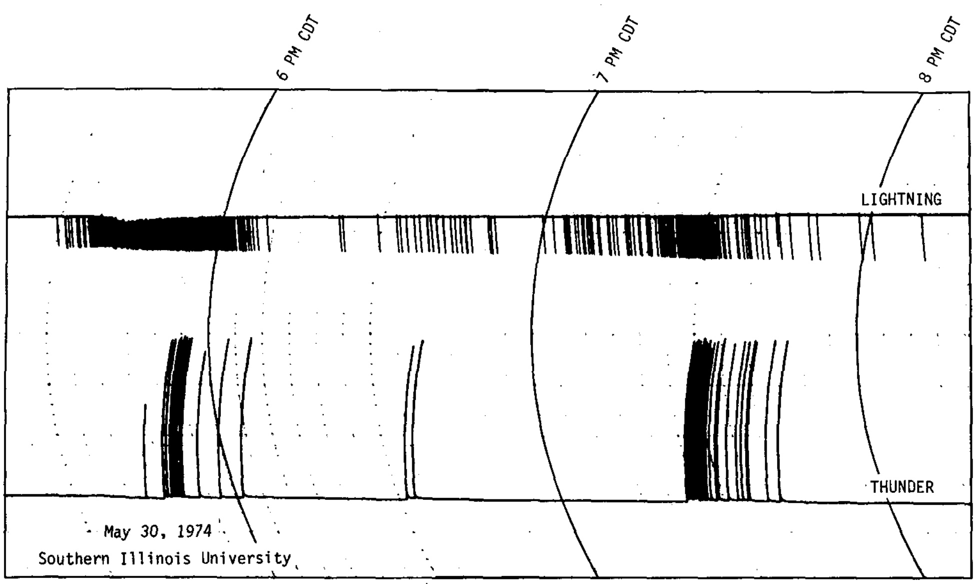

FIG. 6. Strip-chart record from thunder detector.

even in the midst of heavy rain and wind noises. The success rate on individual thunder peals is in excess of 90%.

In the summer of 1974, this prototype detector was installed at a METROMEX site. A portion of the strip chart is shown in Fig. 6. Except during periods of power failure or system failure, the data appear to be valid and totally consistent with recordings made at the site, with local observations, and with radar echo data.

5. Summary

Devices to objectively record thunder peals in 1970–71 were developed as part of a mesoscale project concerning urban modification of storms. The recorder system was designed to also furnish directional information by using an array of microphones. Certain audio problems were resolved in the design of a second, simpler system in 1972–73. Excessive analytical efforts were reduced by shortening the tape operational period and requiring lightning to trigger new periods. Finally, a thunder detector, an even simpler device, that records both lightning and thunder on a strip-chart recorder was developed. This device greatly reduces analytical time and problems, and could be particularly useful for remote stations.

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