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THE STRUCTURE OF LIGHTNING FLASHES HF-UHF: SEPTEMBER 12, 1975, ATLANTA, GEORGIA

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AUGUST 1976

GSFC

GODDARD SPACE FLIGHT CENTER

GREENBELT, MARYLAND

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ABSTRACT

Simultaneous measurement of sferics at 3, 30, 139, and 295 MHz have been made during thunderstorms near Atlanta, Georgia. Wideband electronics and an analogue tape recorder permitted continuous records of the radiation from lightning to be obtained with about 300 kHz of bandwidth. The data to be reported here were obtained during the passage of a cold front across the test area on September 12, 1975. Flashing rate, burst rate and the structure of of individual flashed were recorded.

The record of a typical flash, strongly suggestive of a cloud-to-ground discharge, begins with a sudden burst of closely spaced pulses whose temporal structure is typical of the stepped leader. This burst ends in a large pulse suggestive of a first return stroke; and the remainder of the flash is made up of a sequence of pulses of varying amplitude separated by quiet periods of the order of milliseconds. The shape of these pulses as well as the temporal structure suggest that the first few large pulses are return strokes. Other discharges begin with widely spaced discrete pulses and resemble the preceding discharge less the leader and return stroke phase. The radiation exhibits a similar structure, at each of the frequencies monitored.

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THE STRUCTURE OF LIGHTNING FLASHES HF-UHF:

SEPTEMBER 12, 1975, ATLANTA, GEORGIA

I. INTRODUCTION

During the summer storm season, 1975, a series of experiments were performed near Atlanta, Georgia, to study radiation from lightning in the HF-UHF frequency band. These experiments were part of a GSFC program to study the potential for using the RF emissions from lightning as an aid in the monitoring of severe storms, in particular, tornadoes.

Initial field experiments in the GSFC program were performed during the storm season, 1975. This consisted of flight experiments in the mid-western tornado belt from mid-March to early June, 1975, flights at NASA/KSC during late June and early July, 1975, and ground-based experiments near Atlanta, Georgia from August through early October, 1975. A great quantity of data was collected and is currently being reduced. It is the purpose of this report to present some examples of the signals radiated from lightning as collected on September 12, 1975 during the Georgia experiments.

The ground-based experiments were performed for NASA by the Georgia Institute of Technology at their Cobb County test site, a semi-rural location about 26 km from the GIT campus. During these experiments simultaneous measurement of lightning radiation was made at four frequencies: 3, 30, 139, and 295 MHz. At the lower two frequencies measurements were made only at vertical polarization whereas at the upper two frequencies, 139 and 295 MHz, measurements were made at both horizontal and vertical polarization. The sferics channels consisted of relatively standard radio receivers and antennas plus assorted attenuators and filters with each channel being designed for 300 kHz of video bandwidth. The details of the system are given in Appendix A.

Also included in the experiment, in addition to the sferics channels, were a measure of lightning activity, in the form of a count of burst rate, and a wideband system to monitor electric field changes. Two burst rate counters were used, one provided by W. Taylor of NOAA and similar to the system that he has been using to detect tornadoes (Taylor, 1971), and another designed by the Georgia Institute of Technology and also used by them as part of a research program in tornado detection (Greneker et al., 1976); however, on September 12 data is available only for the GIT instrument. The wideband system was provided by the University of Arizona and is based on the system they have used to study return strokes wave forms in Florida and Arizona thunderstorms (Krider and Radda, 1975).

All data was recorded on an instrumentation tape recorder (Ampex PR 2200) capable, at its fastest recording speed, of about 12 minutes of continuous recording and about 300 kHz of bandwidth.

II. STORM HISTORY: RADAR OBSERVATIONS

On September 12, 1975 a line of thunderstorms moved across the test site during the late afternoon. The front moved toward the SE with thunderstorm activity in the vicinity of the experiment site between 1600-1700 EDT. Sferics were monitored during the period of about 1530-1730 EDT.

Two weather radars supported the experiment, data on individual cell structure (location and cloud top height) in the vicinity of the test site was provided by a radar on the GIT campus in Atlanta, Georgia, while the large scale weather patterns were monitored by the NWS weather radar at Athens, Georgia which provided coverage up to either a 250 mile or 125 mile range. (Atlanta is approximately 60 miles west and slightly south of Athens. The test site is about 70 miles west of Athens.) Examples of weather radar observations during this period from the NWS radar are shown in Figures 1-9. The first figure (Figure 1) is an example of a clear day observation and is included here to illustrate the ground clutter pattern for this radar and the location of the test site. The "X" to the west of the origin marks the approximate location of the sferics test site and the "O" marks the approximate location of downtown Atlanta. The concentric circles represent a difference in radial distance of 25 miles. The images to the north between 25 and 75 miles from Athens are ground clutter and are present in all of the figures to follow. Figures 2-9 were made on September 12 by the NWS radar and illustrate the evolution of the storm front as it passed through the Atlanta area. Notice that as the front began to move across the test area the thunderstorm cells coalesced to form a solid radar return (Figures 2-6) and this storm then moved SE of Atlanta and began to dissipate (Figures 7-9).

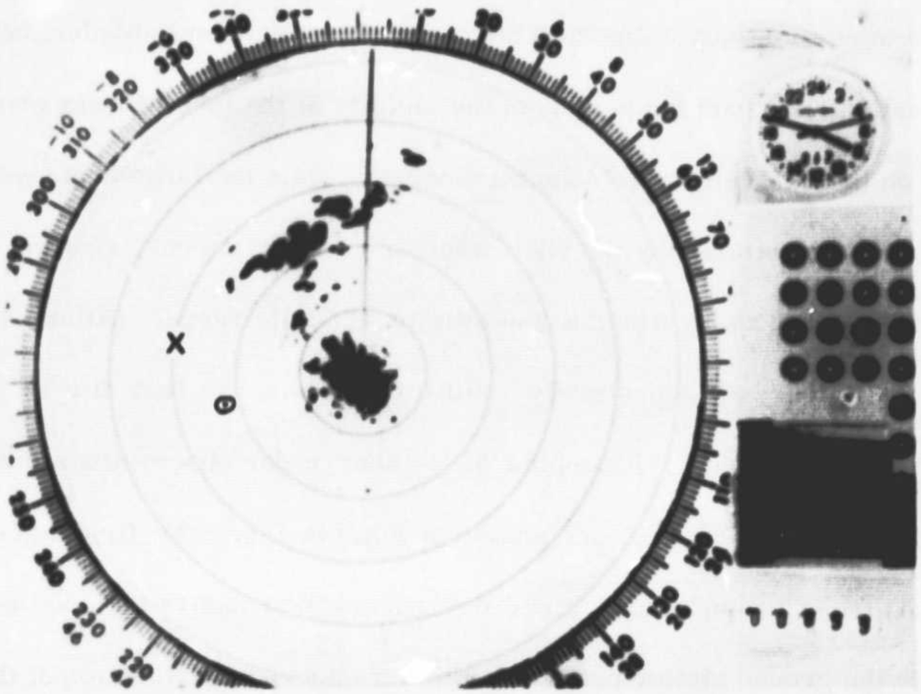

Figure 1. Ground Clutter Pattern, NWS Radar at Athens, Georgia, 25 Mile Range Contours Shown

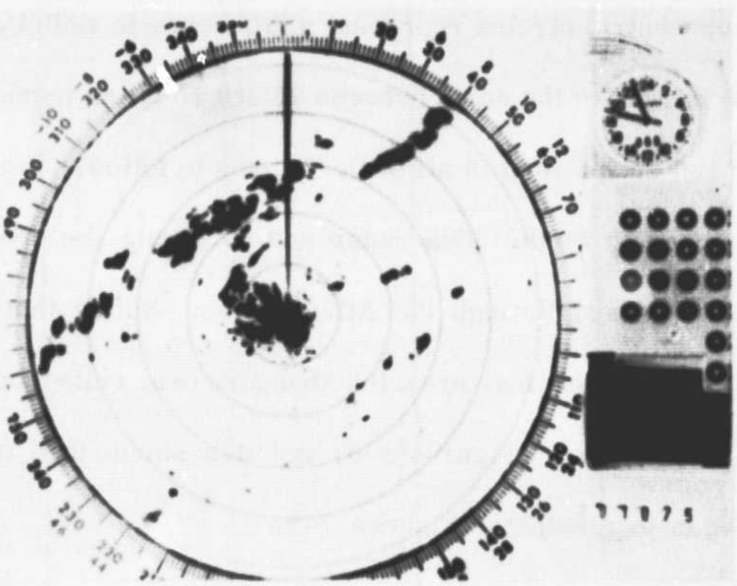

Figure 2. NWS Radar, Athens, Ga., September 12, 1975 at 2455 EDT, 25 Mile Range Contours

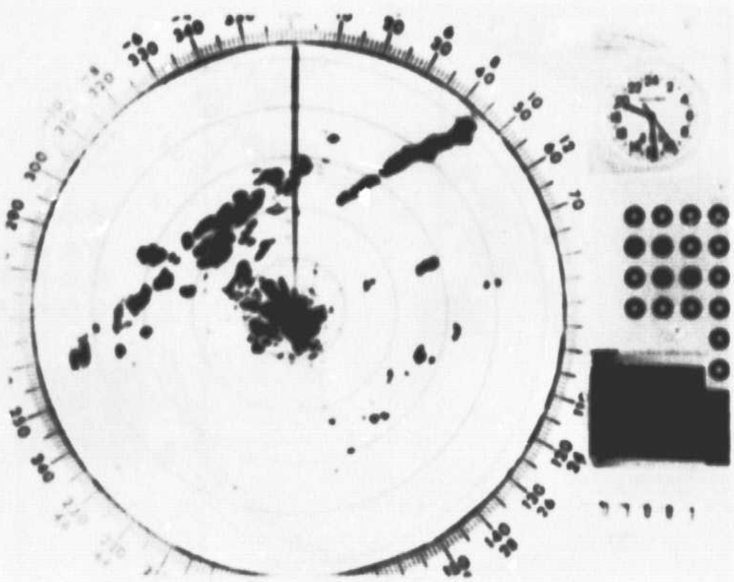

Figure 3. NWS Radar, Athens, Ga., September 12, 1975 at 1530 EDT, 25 Mile Range Contours

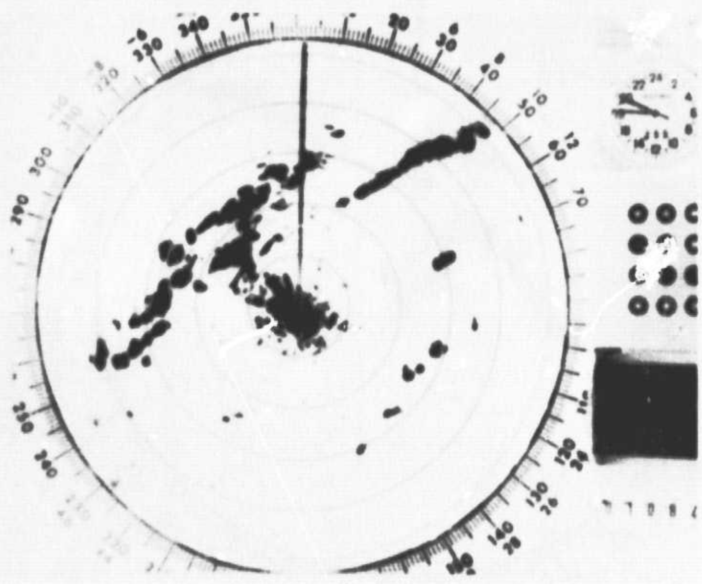

Figure 4. NWS Radar, Athens, Ga., September 12, 1975 at 1545 EDT, 25 Mile Range Contours

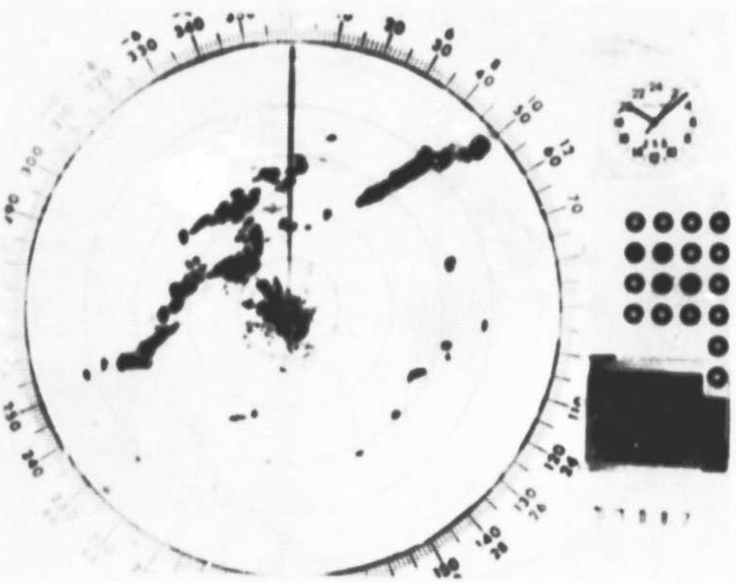

Figure 5. NWS Radar, Athens, Ga., September 12, 1975 at 1607 EDT, 25 Mile Range Contours

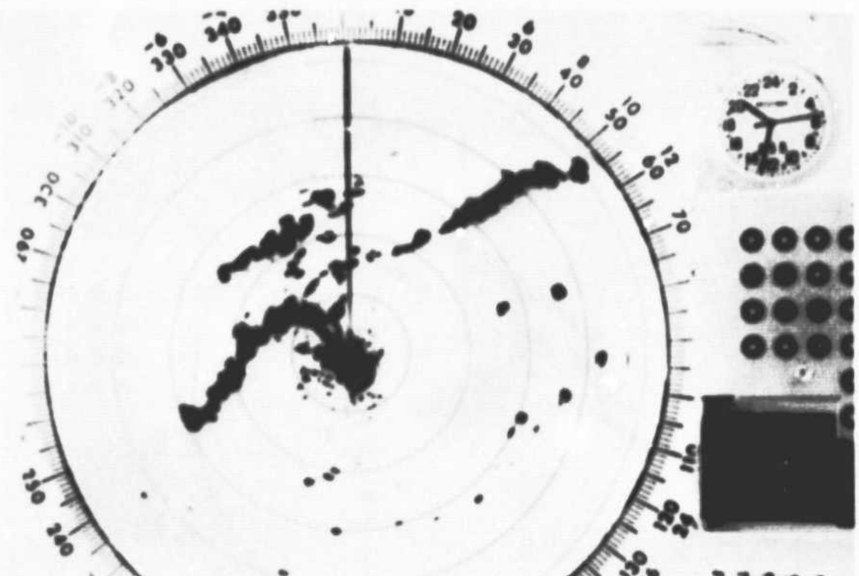

Figure 6. NWS Radar, Athens, Ga., September 12, 1975 at 1632 EDT, 25 Mile Range Contours

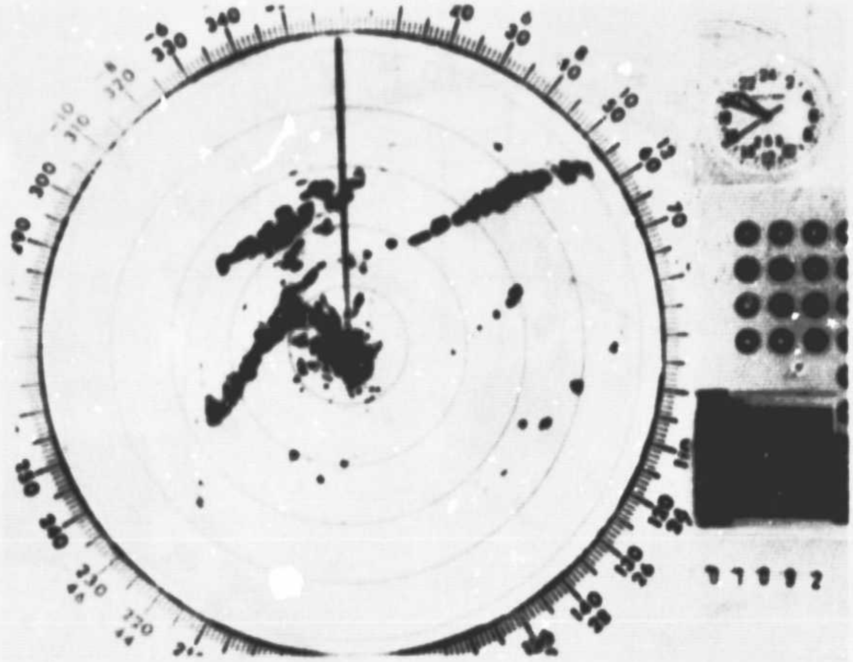

Figure 7. NWS Radar, Athens, Ga., September 12, 1975 at 1650 EDT, 25 Mile Range Contours

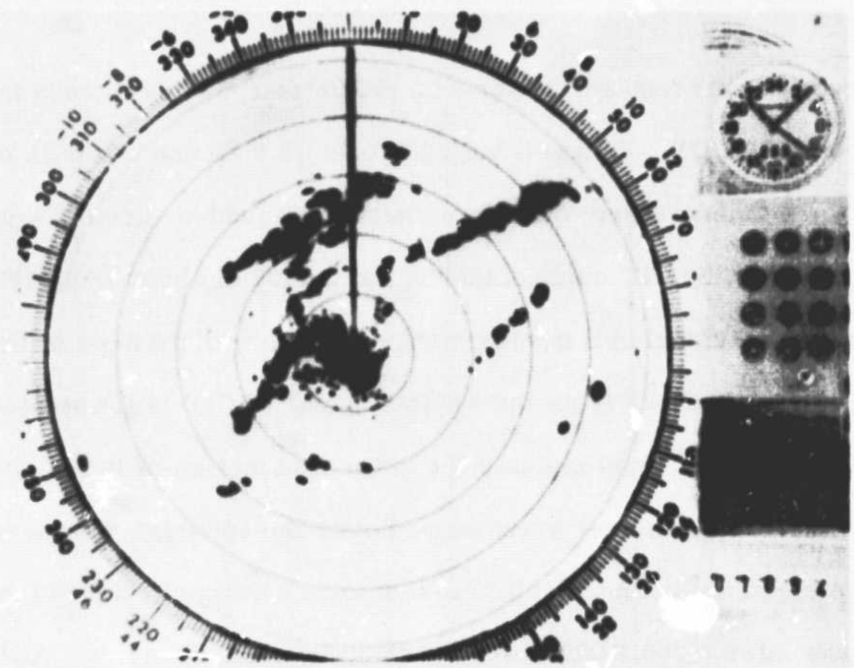

Figure 8. NWS Radar, Athens, Ga., September 12, 1975 at 1707 EDT, 25 Mile Range Contours

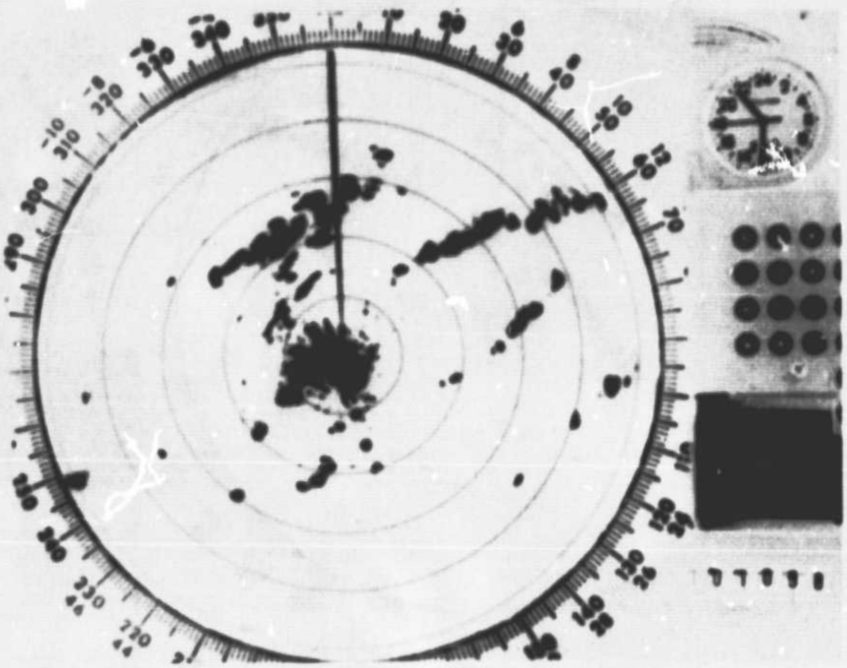

Figure 9. NWS Radar, Athens, Ga., September 12, 1975 at 1730 EDT, 25 Mile Range Contours

Observers at the test site reported a storm cell moving across the test site at about 1550 EDT. This cell built to about 29 k ft. and began to decay (1600 EDT). A thunderstorm with "considerable" cloud-to-ground lightning was reported over the GIT campus during the period of about 1615-1630 EDT. A summary of individual cell development in the immediate area of the test site and based on observations from the weather radar at GIT is illustrated in Figure 10. The dotted lines indicate the estimated motion of individual cells. Notice, in particular, the cell which moved over the campus: It was apparently quite active electrically and resulted in temporary outage of the GIT radar. This cell was later (1706 EDT) observed at 29 k ft. and decaying. Additional details are given in the observers log reproduced here as Appendix B.

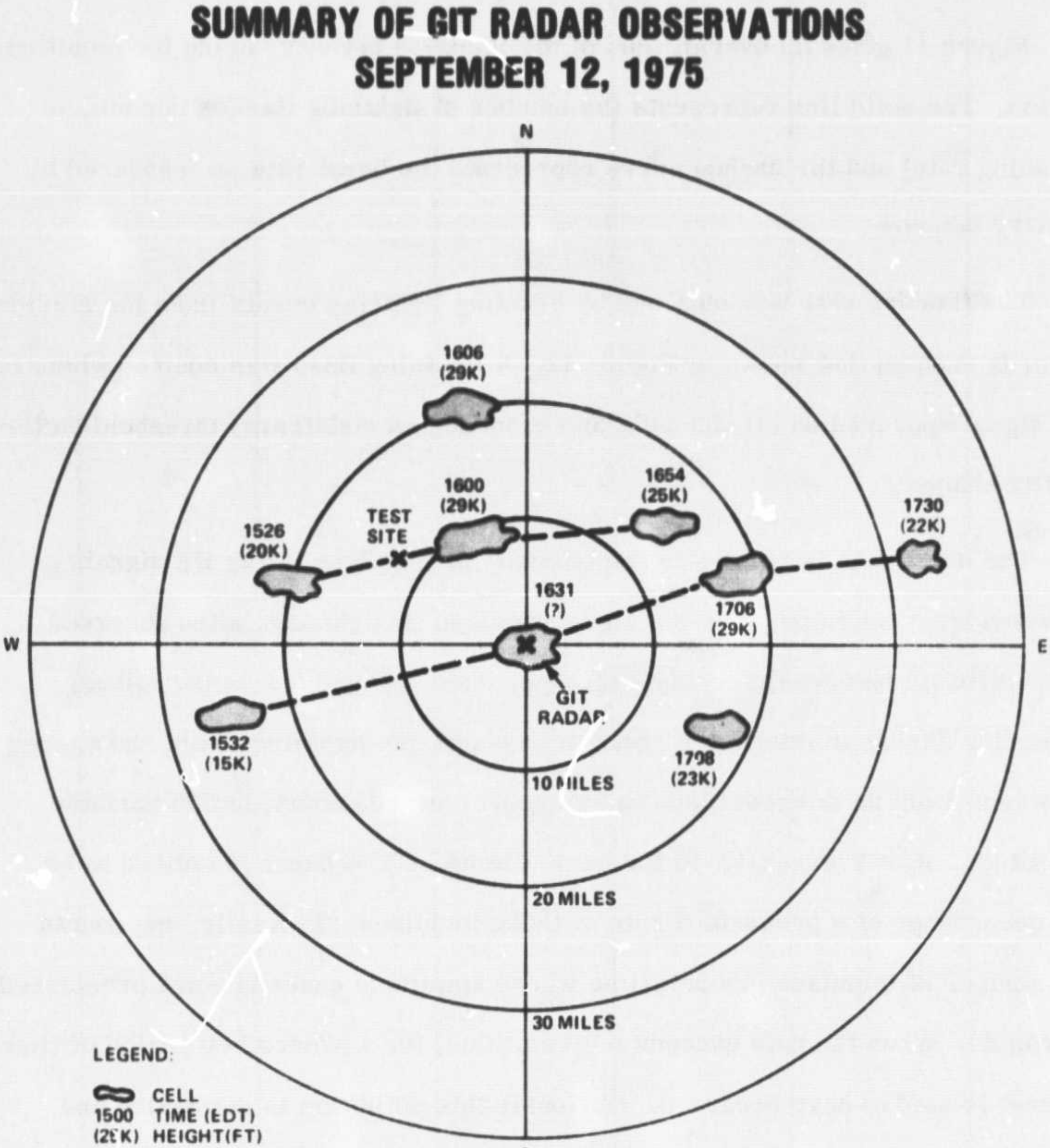

Figure 10. Summary of the Georgia Institute of Technology Radar Observations: September 12, 1975

III. ELECTRICAL ACTIVITY

A. Summary

Figure 11 gives an overall idea of the lightning activity during the monitoring period. The solid line represents the number of lightning flashes per minute (flashing rate) and the dashed curve represents the burst rate as measured by the GIT detector.

The flashing rate was obtained by counting lightning events from the sferics records such as that shown in Figure 12. A lightning flash was counted whenever the signal appeared on all channels and exceeded an (arbitrary) threshold on the 3 MHz channel.

The burst rate is related to the intensity of impulses in the RF signals radiated from lightning. The RF signal radiated by lightning, when observed with sufficient bandwidth, consists of a sequence of impulses (noise spikes) occurring during an interval of about 1/2 second per lightning flash, and spaced anywhere from 25 microseconds to many milliseconds apart, and of variable amplitude. (See Figures 13-16 for some examples.) A burst is defined to be the occurrence of a prescribed rate of these impulses. Typically, one counts the number of impulses per unit time whose amplitude exceeds some prescribed threshold. When the rate exceeds a given value, for a prescribed period of time, a burst is said to have occurred. Obviously this definition is subjective and what two investigators call bursts may be quite different depending on such things as the thresholds, integration time, and even frequency and bandwidth of their respective systems.

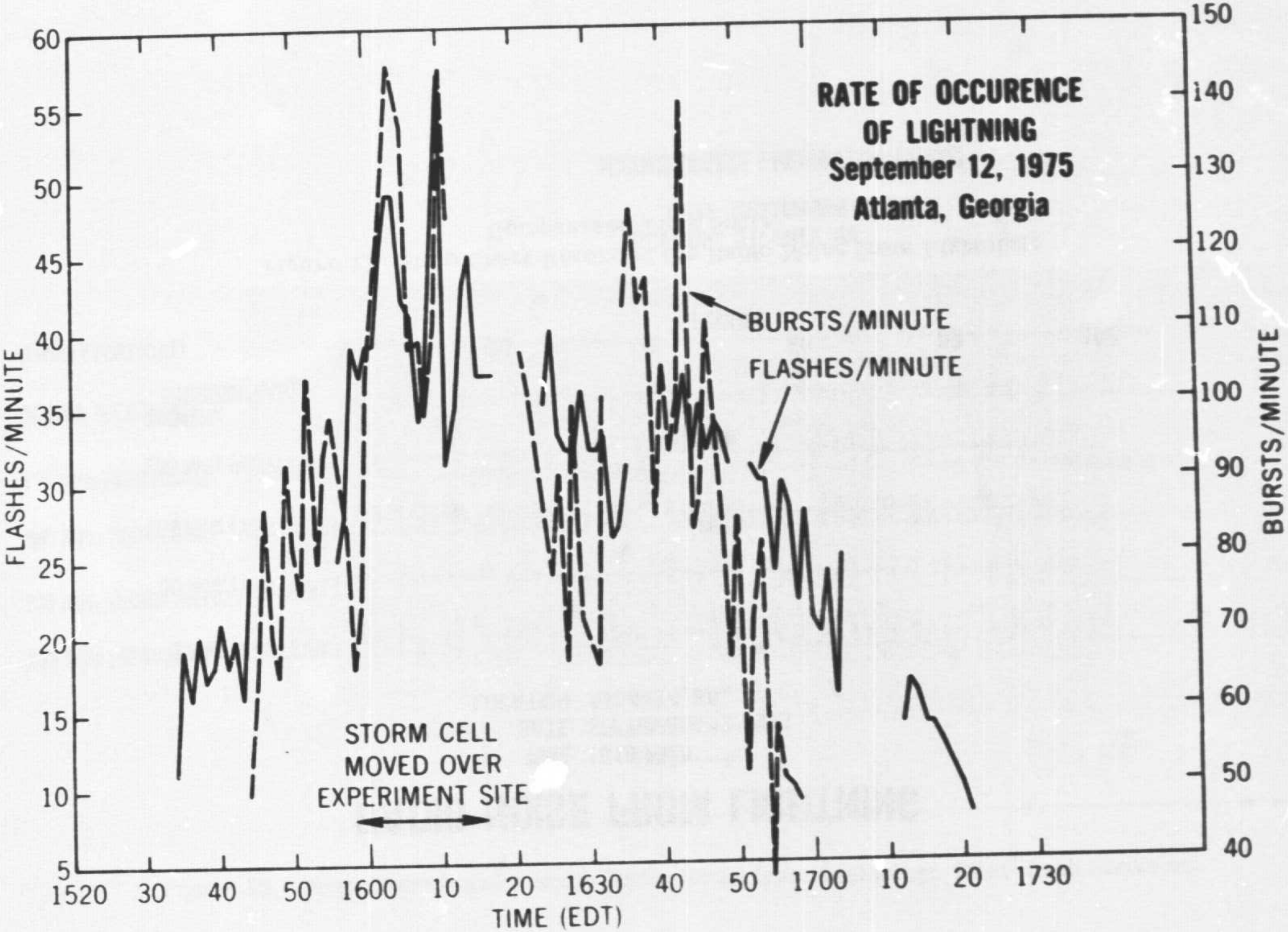

Figure 11. Rate of Occurrence of Lightning Flashes: September 12, 1975, Atlanta, Ga.

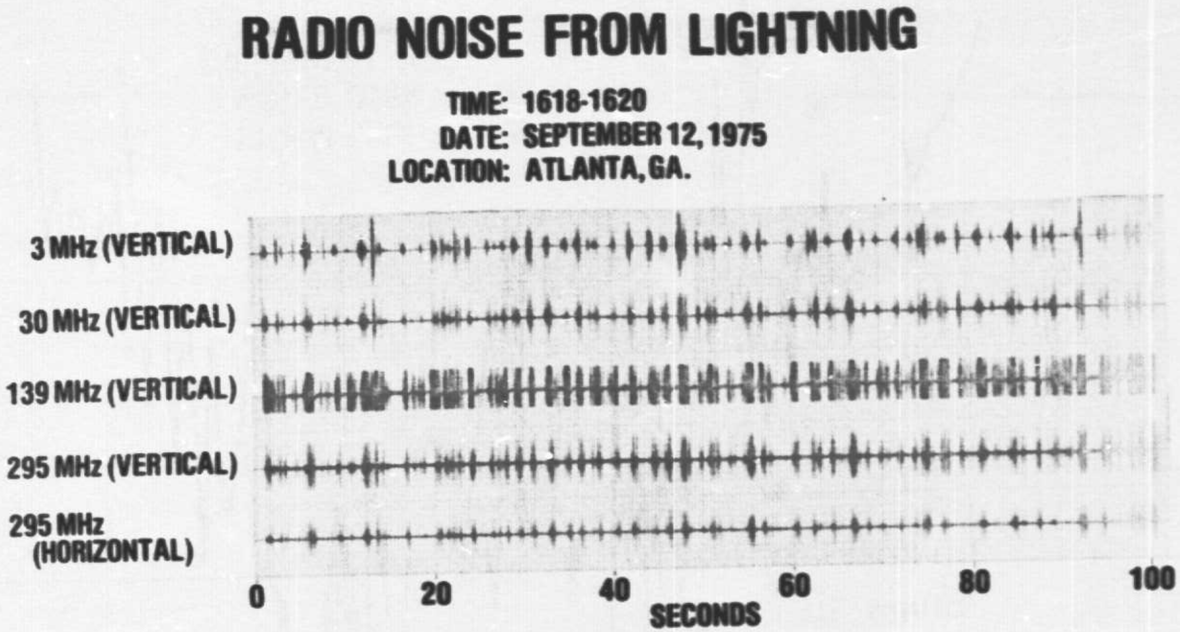

Figure 12. Strip Chart Record of the Radio Noise from Lightning: Compressed Time Scale

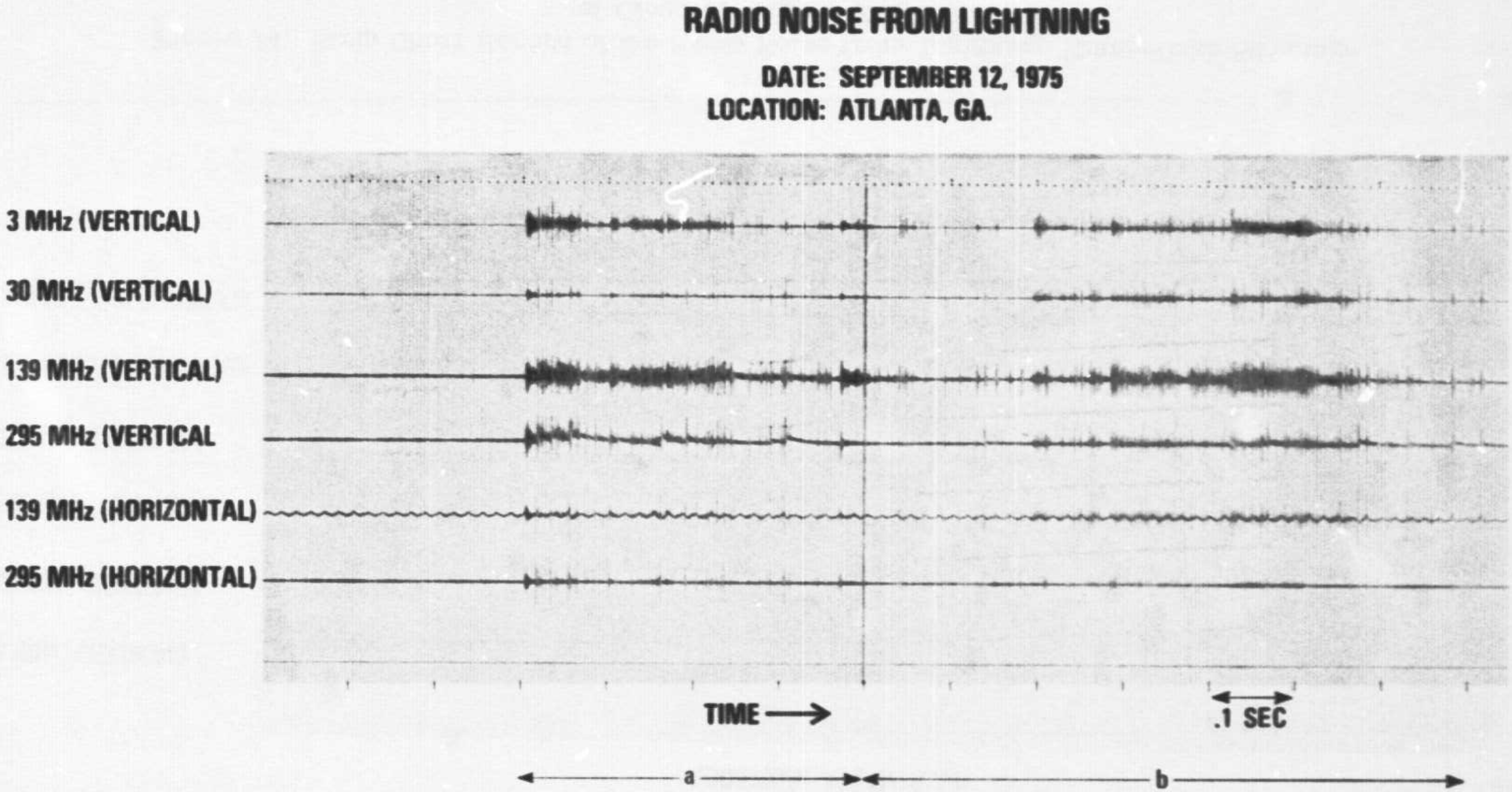

Figure 13. Strip Chart Record of the Radio Noise from Lightning: Inter-flash Structure

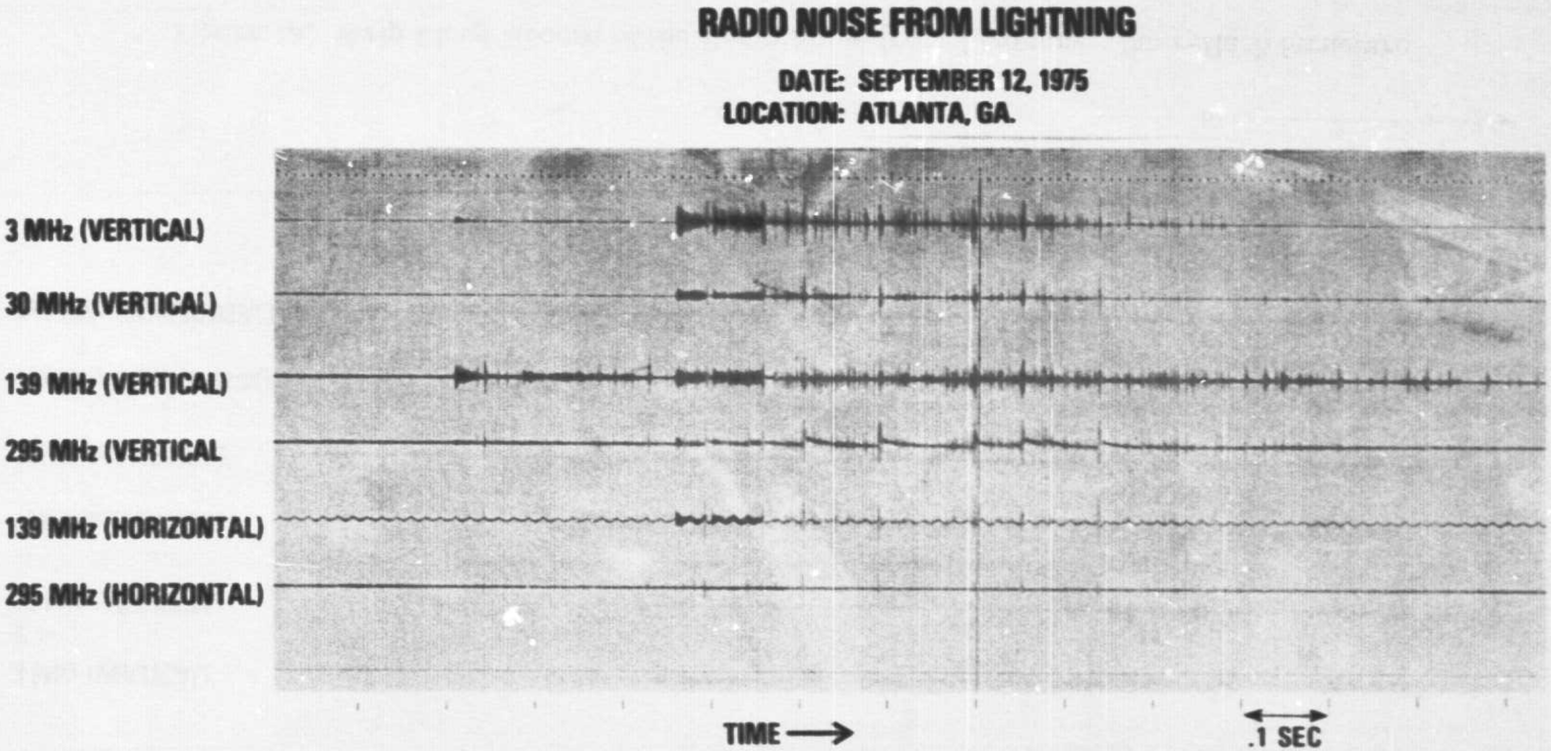

Figure 14. Strip Chart Record of the Radio Noise from Lightning: Inter-flash Structure of Cloud-to-Ground Flash

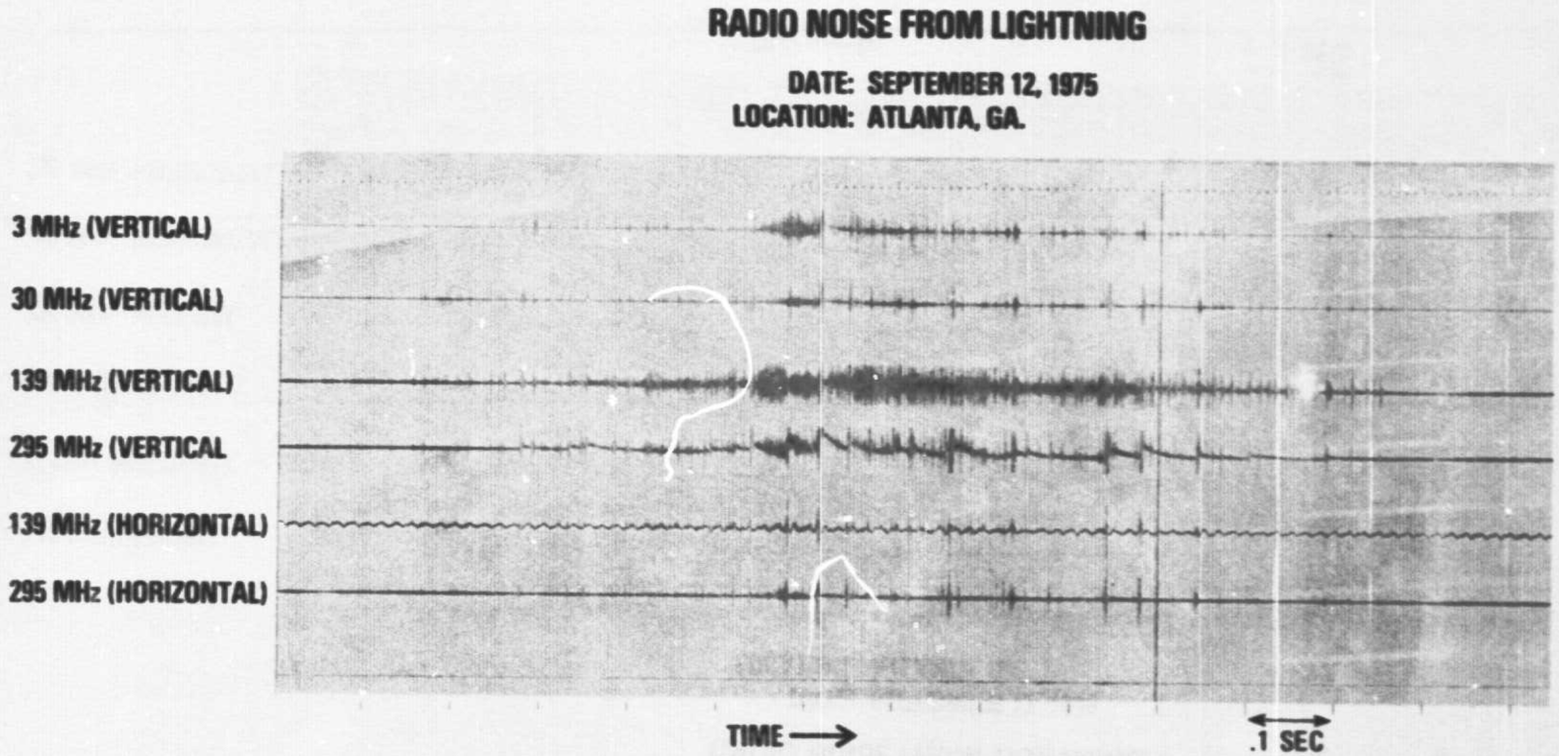

Figure 15. Strip Chart Record of the Radio Noise from Lightning: Inter-flash Structure of Cloud-to-Cloud Flash

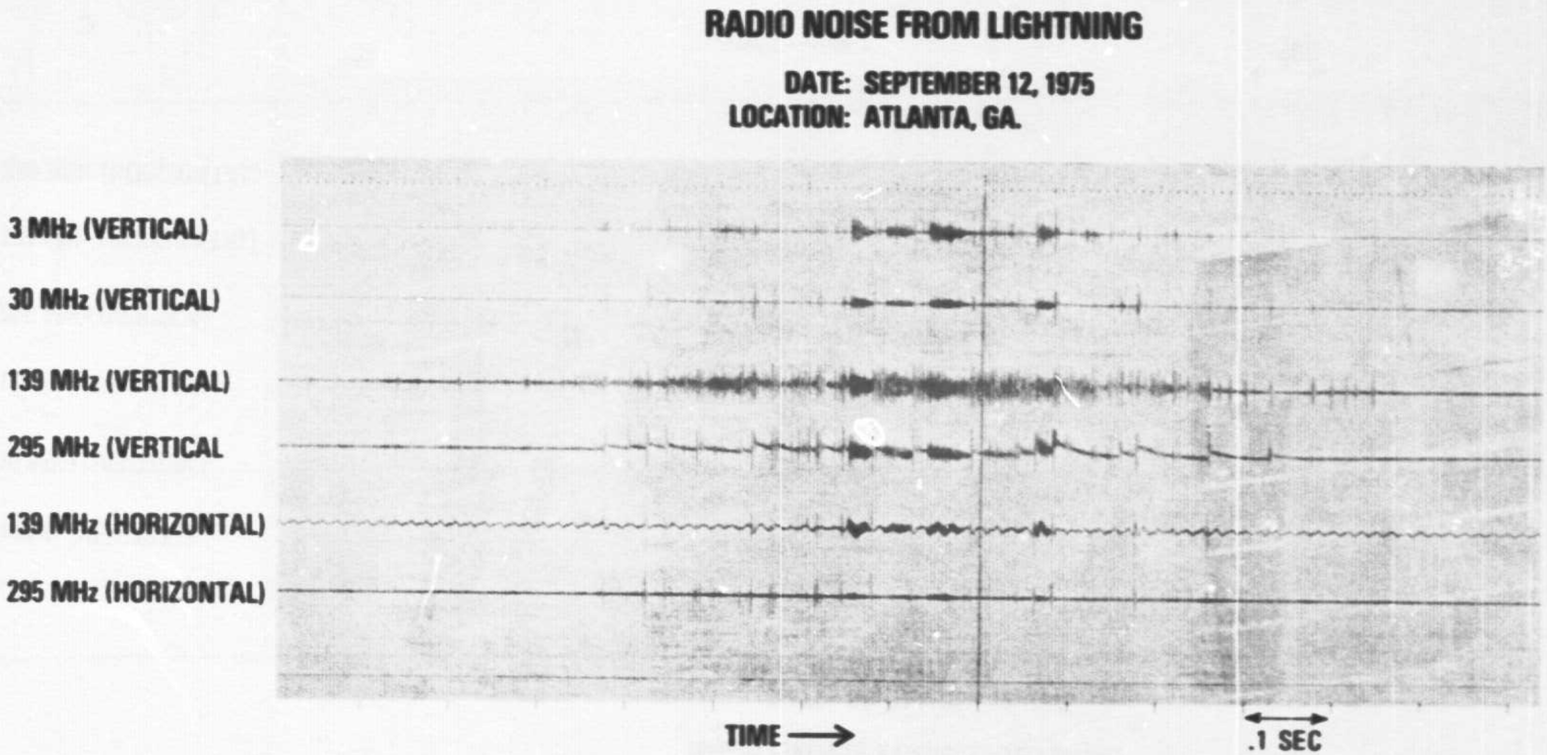

Figure 16. Strip Chart Record of the Radio Noise from Lightning: Inter-flash Structure of a Mixed Flash

It is burst rate which Taylor has used to distinguish tornadoes from the other manner of severe weather (Taylor, 1973 and 1975). It is interesting to note that he uses a burst rate in excess of 30 per minute to identify tornadoes. No tornadoes occurred on September 12 even though the GIT count is significantly higher. (The GIT system has a number of counting "ranges". Only the "mid-range" data is shown in Figure 13.) The relationship of burst rate to flashing rate is of importance in the study of tornado detection using RF techniques. Of course, theoretically burst rate and flashing rate are not necessarily proportional, however for the cases shown in Figure 12 (non-tornadic) there appears to be a great deal of correlation.

B. Structure of Individual Flashes

Examples of the data recorded on the sferics channels are presented in Figures 12-16. These figures were obtained by reproducing the signal on the analog tapes directly into a multichannel strip chart recorder. Charts with various degrees of (temporal) resolution were obtained by controlling the chart speed. For example, Figure 12 was obtained with relatively slow chart speed whereas Figure 13 was recorded at high chart speed. No attempt has been made to calibrate the signal amplitude on the chart recorder or relate it to that on the tape; rather, the amplitude of the signal on each channel of the chart recorder was chosen for optimum display (i.e., filling the space allocated). Consequently, comparison of signal levels in Figures 12-16 is not meaningful. Also, it is to be noted that the chart recorder, even when run at fast paper speed (50 cm/sec was the maximum speed available) is a relatively narrowband device. Consequently impulses detected by the sferics system ring when reproduced in the chart recorder, and appear with both positive and negative excursion.

Figure 12 is an example in compressed form of the signals received by the sferics system. A segment of approximately two minutes of data is shown which was recorded at about 1620 EDT on September 12. Each horizontal line corresponds to one channel (frequency) in the sferics system; and each dark vertical line is a lightning flash. Occasional interference due to RF communications or noise is generally apparent when viewed at higher resolution because its temporal structure and frequency dependence are different than that of the lightning. Figure 12 is reasonably typical of the data recorded. Notice the good correlation as a function of frequency and polarization of the lightning events.

Figure 13 shows a single lightning flash on an expanded scale. About one second of data is shown, with the tick marks at the bottom scale added to indicate .1 second intervals. Notice the discrete impulse-like structure of the lightning event, and also notice that there is a great deal of similarity in the structure as a function of frequency and polarization. This particular case was chosen as a first example of a lightning flash because it exhibits both of two characteristic patterns which appear in the data. Notice, for example, the activity on the left half of the figure (labelled "a"). It has a very well defined sudden beginning. This beginning pattern continues for a short period of time (a few milliseconds) and then ends in a large pulse. There follows a period of large pulses separated by (relatively) quiet times and then a gradual increase in spacing and decrease in intensity of the individual large impulses. This type of flash has been examined in detail from digital records of the data which show that the initial phase consists of individual impulses whose spacing and total duration is indicative of the stepped leader phase in cloud-to-ground lightning flashes. Furthermore, the first few large strokes have a spacing consistent with a first and subsequent return stroke in a cloud-to-ground flash (Uman, 1969). Also in many flashes the wideband system indicates signals at these first few large pulses which have a shape strongly suggestive of return strokes.

In contrast, the structure on the right-hand side of Figure 13 (indicated by "b") shows no well marked beginning or sudden crashing. Rather it starts with a series of widely spaced impulses which gradually build in amplitude, become most frequent toward the center of the flash and then decay away.

The data taken during the September 12 storm suggest the division of lightning events into flashes which exhibit the characteristics of either side "a" or side "b" of Figure 13. For example, Figure 14 is typical of a flash with characteristics of side "a", and Figure 15 is typical of a flash with characteristics of side "b". This same dicotomy has been reported in the literature by Kitagawa and Brook (Kitagawa and Brook, 1960) and later by Mackerras (Mackerras, 1968) on the basis of records of electric field changes made at frequencies lower than employed here, and by Kreielsheimer and Lodge-Osborn (Kreielsheimer and Lodge-Osborn, 1972) on the basis of the interval between impulses. Kitagawa and Brook concluded that the initial portions of the waveforms were so characteristic of cloud-to-ground flashes (feature "a") or cloud-to-cloud flashes (feature "b") that just the initial phase of a lightning flash could be used to classify it as cloud-to-ground or cloud-to-cloud. Although no reliable visual identification could be made in the September 12 experiment as to whether the lightning reached ground or not, the available evidence suggests that features "b" are cloud-to-ground strokes and in this sense support the observations of Kitagawa and Brook and others. Identification as to the type of flash is planned for future experiments.

Not all flashes fall in category "a" or "b." Some, such as shown in Figure 16, seem to be mixed. This may be because of temporal overlap in the occurrence of two distinct flashes (probably the case in Figure 13) or possibly the result of a flash beginning with a cloud phase and then having a stepped leader phase. Figure 16 may be an example of this type of mixed flash.

CONCLUSIONS

Work is presently being performed to obtain a quantitative description of lightning flashes such as those described above. The analog tapes are being digitized and analyses are being made of the spectral shape and statistics of pulse amplitude and spacing. Some very preliminary results indicate that the time between flashes is Poisson — which is what one would expect if the source of the radiation is many statistically independent radiators — and it is hoped that a quantitative description of lightning to compare with the work of such investigators as Kosarev et al. (1970), Kreielsheimer and Lodge-Osborn (1972) and Aiya (1962) will be available soon. Obtaining a reasonable characterization of the statistical structure of lightning is the first step in obtaining a quantitative correlation between lightning and the nature of the parent severe storm cell.

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APPENDIX A

DESCRIPTION OF THE SFERICS DATA SYSTEM

The recording system consists of a sferics monitoring system with wide bandwidth channels at 3, 30, 139, and 295 MHz, and also systems for the monitoring of electric field changes and for measuring burst rate. The 3 and 30 MHz frequencies in the sferics system are nominal, the actual frequencies being selectable but close to these values. Normally, two burst rate counters were employed for the ground based experiments, one provided by W. Taylor of NOAA and similar to the system employed by him to monitor tornadoes (Taylor, 1971) and a second system designed by GIT and also being studied by them for potential tornado detection. (However, for the September 12, 1975 tests only data from the GIT burst rate counter was available.) The system for measuring electric field changes was provided by the University of Arizona and is similar to the wideband system used by them to study the signals radiated from lightning in Florida and Arizona thunderstorms (Krider and Radda, 1975). The emphasis in this Appendix will be on describing the sferics recording elements in the overall monitoring system.

The sferics portion of this system consisted of eight data channels (two for each frequency). The functional block diagram for each channel is shown in Figure 17. The elements in this diagram are described below.

Linear (vertical & horizontal) antennas were used to receive the sferics data. Each channel (3, 30, 139, and 295 MHz) was recorded using a vertically polarized antenna. These were quarter wave length monopoles at all frequencies

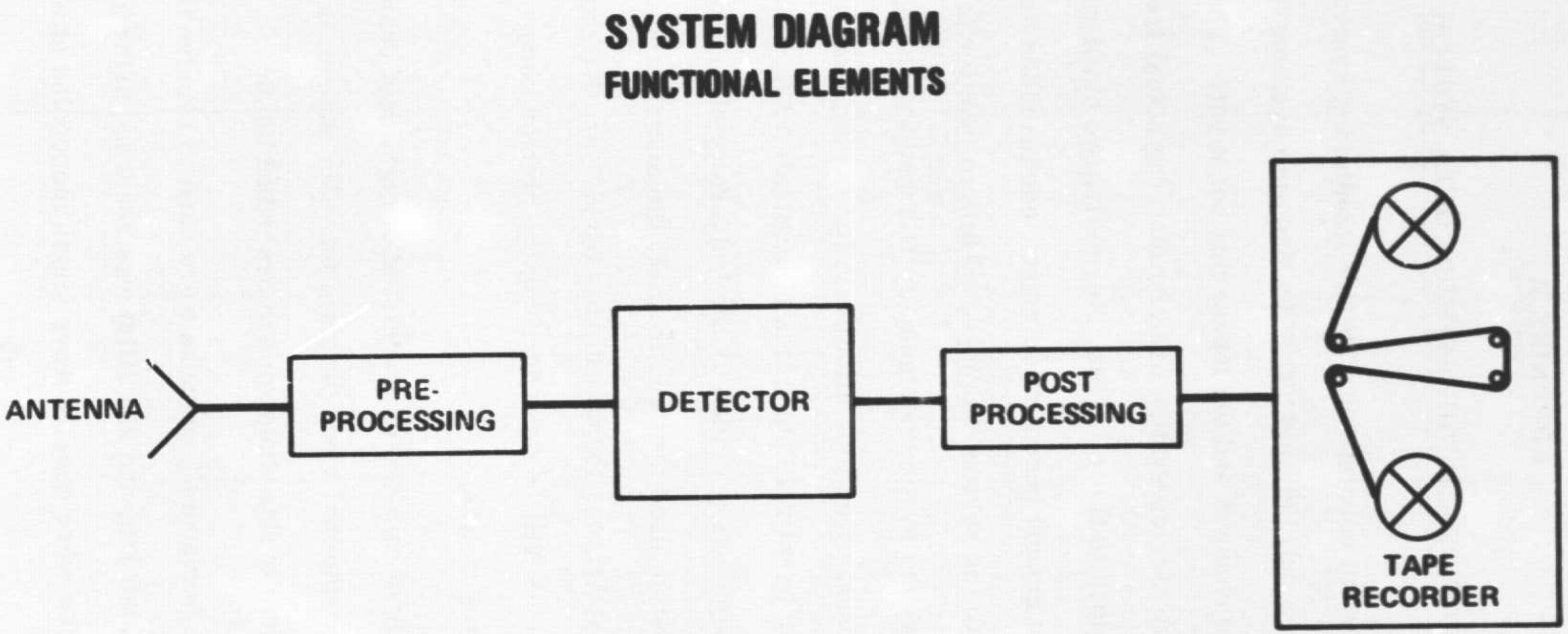

Figure 17. Block Diagram of the Sferics Data System by Functional Element

except 3 MHz in which case a base loaded monopole was used. The monopoles were mounted on top of the monitoring van (which housed the tape recorder, receivers, and associated electronics) and are shown in Figure 18. In addition, recording at horizontal polarization was provided at 139 and 295 MHz. For this purpose resonant (half-wave) dipoles were employed and were mounted on the block house roof (Figure 19). The wideband system for monitoring electric field changes ("lightning stroke detector") uses a flat plate antenna which was mounted on top of the monitoring van and is visible in Figure 18. A 1.5 meter stub (at 3.16 MHz) which is normally used with Taylor s detector is also visible in Figure 19. The antennas used for each channel are summarized in Table I.

Table I

Antennas Employed

Frequency	Antenna
Lower HF (3 MHz: vertical pol.)	Base loaded monopole*
Upper HF (30 MHz: vertical pol.)	Resonant quarter wavelength monopole*
139 MHz (vertical, pol.)	Resonant quarter wavelength monopole*
139 MHz (horizontal, pol.)	Resonant dipole**
295 MHz H (vertical pol.)	Resonant quarter wavelength monopole*
295 MHz (horizontal, pol.)	Respmamt resonant dipole**
Taylor's burst rate counter (3.16 MHz)	1.5 m stub**
Lightning stroke detector	Flat plate**
GIT burst rate counter (2.88 MHz)	Monopole*

*Mounted on block house roof

**Mounted on Roof of Van

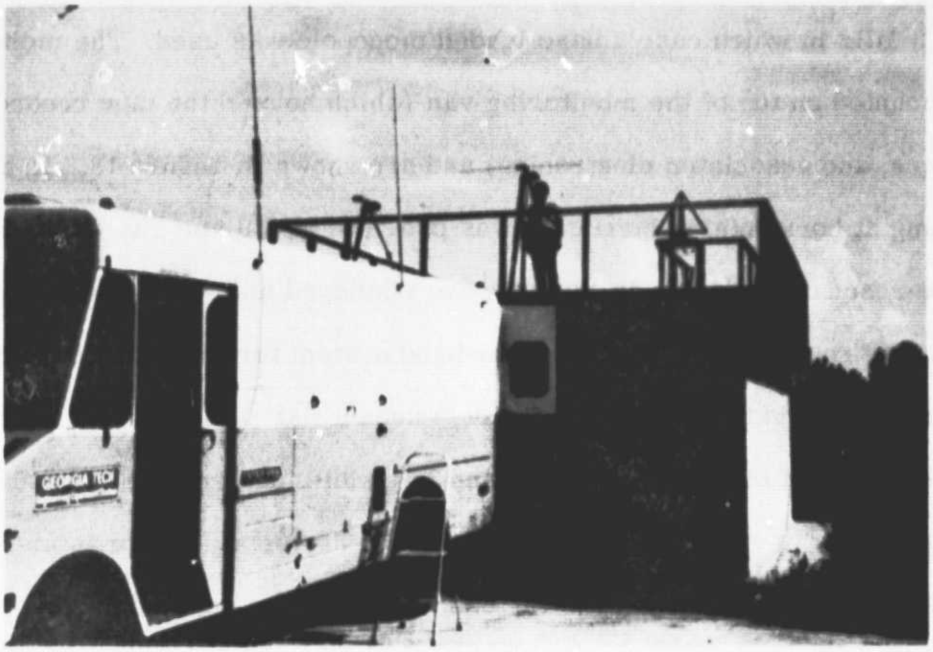

Figure 18. Ground Based Monitoring Configuration Showing Antenna Placements on the Monitoring Van

Figure 19. Ground Based Monitoring Configuration Showing Antenna Placements on the Block House Roof

The detectors are connected to the antennas through a preprocessing stage which consists of preamplifiers for the HF channels (3 and 30 MHz) and RF attenuators for the VHF-UHF channels (139 and 295 MHz). Diplexing circuitry is also included in the preprocessing stage for use in the aircraft experiments where antennas must be shared, but this was not necessary for the ground experiments. No RF attenuation was employed for the September 12 experiment.

The detectors consist of, at HF, two units specially designed by GIT for sferics work and adapted to this program, and at the higher frequencies of commercially available Watkins-Johnson receivers. The Watkins-Johnson receivers used at 139 MHz were WJ-977 receivers and at 295 MHz were WJ-8730 receivers (with WJ-9062 tuning heads). All receivers were operated with an IF bandwidth of 3 MHz without AGC. The GIT receivers are tuned radio frequency (TRF) receivers developed at GIT especially for sferics reception. A block diagram of these receivers is shown in Figure 20. The receivers employ bandpass filtering prior to the RF gain stages with a selectable center frequency which determines the operating frequency of the receiver. The unit designed for 30 MHz operation had five bandpass filters allowing selection at center frequencies of 31.2, 33.5, 35.5, 37.5, and 39.5 MHz. The unit designed to operate at the lower HF had three selectable bandpass filters with center frequencies at 2.2, 3.2, and 4.2 MHz. Each filter had a nominal bandwidth of 600 kHz. The RF step attenuators which preceed the filters cover a 120 dB range in steps of 10 dB and are designed to prevent overload. They are operated manually and can be set on the basis of the signal level meter indication.

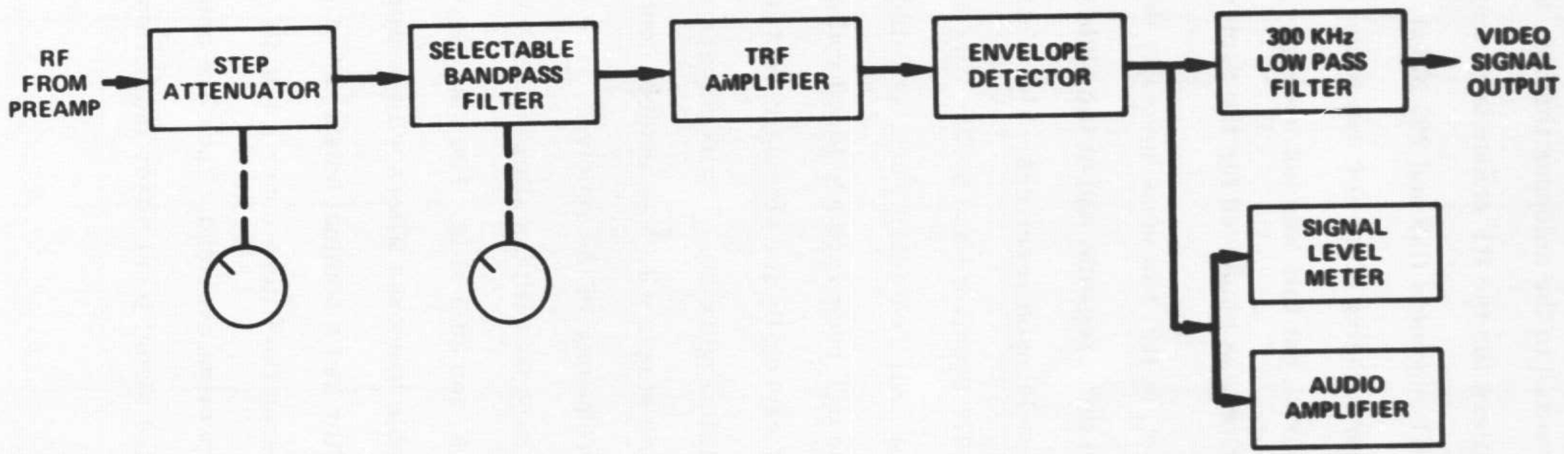

Figure 20. Block Diagram by Functional Element of the GIT TRF High Frequency Receiver

The post processing stage of the sferics system consists of linear amplifiers for all channels and for the HF channels, additional log amplifiers. The dynamic range of the linear amplifiers was about 50 dB and about 65 dB for the log amplifiers. The nominal voltage out of the post processor was adjusted to 2 volts (peak-to-peak) to accommodate the tape recorder.

The tape recorder employed was an Ampex PR-2200 with 14 channels of record/reproduce capability. The nominal bandwidth at a record speed of 60 ips is 300 Hz to 300 kHz on direct record and DC to 40 kHz on FM record (using wideband Group I electronics). At 60 ips about 12 minutes of continuous recording was available. The recording procedure was to alternate record speed between 60 ips and 30 ips to achieve a compromise between bandwidth and length of uninterrupted record time.

APPENDIX B

OBSERVER'S LOG

DATE: 9/12/75

RADAR LOCATION: GIT Campus

OBSERVERS: B. J. Wilson
H. N. Jenkins

TEST LOCATION: GIT Cobb County Test Site

HF Channel Frequency: 3.2 MHz and 39.5 MHz

WEATHER SUMMARY

In early September 1975, meteorological conditions in North Georgia changed from a high-pressure, fair weather pattern to a low-pressure, cold front activity during the period 10-12 September 1975 when sferics monitoring was performed.

A weak cold front moved through North Georgia on September 10 and 11, but was followed on September 12 by a strong fast-moving cold front with associated severe weather in the form of discernible squall lines containing embedded thunderstorm cells.

Sferics activity on the 10th and 11th was very light as cell build-up did not greatly exceed the freezing level for extended periods of time. However, precipitation was heavy.

The September 12th test data pertain primarily to a severe thunderstorm cell which formed near the test site, matured, and moved to the East as a portion of an extended squall line. This line did not dissipate until it was some 100 miles from the test site.

OBSERVATIONS (TIMES ARE EDT)

1300-1500

Radar reports numerous cells began to form and build in a line from SW through W to North at a distance of 20-40 mi. No cell heights above 21K.

1500

Visual observations at test site disclosed cumulus congestus in all quadrants but heavy cumulonimbus—with thunder—to southwest. Definite indication of extended line of cells SW/W/NW/N from test site and building.

1533

Sferics monitoring and data collection began due to approaching cell from SW with thunder and heavy sferics activity. Radar reported a large cell SW of test site building and moving rapidly.

1545

Rain beginning at test site. Cumulonimbus south/west/north; very close. All DF strobes to SW quadrant.

1547

DF strobes NW, W, SW. TS very close with thunder.

1550

TS moving across site from SW to NE. Radar estimates height as 20K ft. and building.

1555

Roll cloud moved across site.

1557

Heavy rain at site. DF strobes over entire scope. No cloud-to-ground lightning observed.

1560

DF strobes to NE/N. TS moved east. Cumulonimbus NE through SE.

1602

Radar reports cell over test site peaked out at 29K about 3 mi east of site and was largest cell within range of radar.

1615

Heavy TS with considerable cloud-to-ground (CLG) at Georgia Tech. Radar out-of-service due to heavy CLG. Cumulonimbus N/E/S. DF strobes NE, E, SE.

1630

TS line from east-to-south over GIT and downtown Atlanta. Heavy CLG.

1635

Line moved to east Atlanta. CLG.

1640

Thunder still heard at site from SE. DF strobes 70°, 80°, 100°, 110°, 140°, 170°.

1705

DF strobes 80°-140°. Cumulonimbus E and SE. No thunder heard at site.

1720

Sferic level dropping rapidly. TS very distant East. Radar shows line east of Atlanta and dissipating.