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The Temporal Structure of RF Radiation from Lightning

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ABSTRACT

Radiation from lightning in the RF band from 3-300 MHz has been examined during experiments at the Kennedy Space Center (Florida) during the Thunderstorm Research International Project. Simultaneous measurements were made of the RF radiation from lightning together with records of fast and slow field changes. Continuous analogue recordings were made with a system having 300 kHz of bandwidth in the RF channels.

The temporal history of RF radiation of these frequencies consists of a sequence of discrete pulses. The data reveal a distinct pattern in the radiation which is independent of frequency and depends on the type of lightning flash: Cloud-to-ground flashes are characterized by an abrupt beginning associated with the stepped leader, whereas cloud-to-cloud flashes begin with a slower train of noise pulses more typical of the end of both types of flash. An exception to this pattern is cloud-to-ground flashes preceded by a breakdown phase, in which case the radiation begins like a cloud-to-cloud flash.

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INTRODUCTION

The RF radiation from lightning has been investigated by this author during the Thunderstorm Research International Project at several frequencies between 3 and 300 MHz using a wide bandwidth (300 kHz) system. The RF radiation in this frequency range consists of a sequence of irregularly spaced pulses of variable amplitude. However, if the pulse trains are examined on the time scale of the entire flash (for example, by playing the wide bandwidth data through a strip chart recorder at slow enough speed so that all events associated with a single flash can be viewed together) characteristic patterns emerge. In this format, cloud-to-ground and cloud-to-cloud flashes have characteristic and distinct patterns which are independent of frequency in the 3-300 MHz range monitored here. It is the purpose of this paper to present representative examples of the data together with simultaneously recorded slow electric field changes.

A dichotomy in the radiation from cloud and ground flashes has been reported at lower frequencies by Kitagawa and Brook (Kitagawa and Brook, 1960) and has been suggested as the basis for a possible technique for distinguishing flash type (Kitagawa and Brook, 1960; Krielshiemer and Lodge-Osborn, 1972). For the most part the difference between flash types is quite apparent in the RF data collected here; however, there are notable exceptions. In particular, cloud-to-ground flashes which start with a breakdown phase (Uman, 1969; Clarence and Malan, 1957) have an RF pattern which is initially that of a cloud-to-cloud flash. This pattern persists up to initiation of the stepped leader, after which the RF history is typical of a cloud-to-ground flash. Several examples are presented.

The RF patterns examined to date are essentially the same at the several frequencies monitored between 3 and 300 MHz. No quantitative studies have been completed yet; however, the frequency independence is quite clear from the examples. This is in contrast to reports in the literature of a dependence of the number of impulses on the frequency of observation (Pierce, 1977; Oetzel and Pierce, 1969). According to the literature the number of impulses should have peaked near 100 MHz and decreased noticeably by 300 MHz. Although the signal levels are significantly different between 3 and 300 MHz, no significant difference in structure was noticeable after adjusting the traces to account for this difference.

The data were obtained during experiments at the Kennedy Space Center during the Thunderstorm Research International Project (Pierce, 1976) during the summer, 1976. Figure 1 is a schematic of the experiment which was performed. Radiation at several RF frequencies between 3 and 300 MHz was received and recorded analogue on magnetic tape. In total, six different receivers were employed consisting of HF receivers at 3 and 300 MHz, which were designed by the Georgia Institute of Technology (Le Vine, et al., 1976), and VHF receivers at 139 and 295 MHz which were manufactured by Watkins-Johnson Inc. (Model WJ-997 at 139 MHz and Model WJ-8730 at 295 MHz). Vertical quarter-wave monopole antennas received vertically polarized signals at each frequency except 3 MHz, where a baseloaded monopole was used because of the long wavelength. Horizontally polarized signals were detected using resonant (half-wave) dipoles at 139 and 295 MHz. Each RF channel had a video bandwidth of 300 kHz, although a 3 MHz bandwidth could be obtained in the VHF channels by disconnecting filters.

The six RF outputs were recorded in parallel together with the output from a calibrated electric field measuring system which consisted of "fast" and "slow" field change detectors. The fast field change system monitored the electric field changes in the band from a few hundred Hz to a few MHz (Krider, 1977; Krider, et al., 1977); and since this region includes most of the energy in a typical return stroke, the waveforms out of such a system have the dominant shape of the radiated fields. The slow field change system monitors the quasi-static electric fields at the surface and consequently is an indicator of changes in charge distribution within the cloud. Sample data from the RF system and slow field change system will be presented here; examples of correlated RF radiation and fast field changes have been reported elsewhere (Le Vine and Krider, 1977; Krider, Weidman and Le Vine, 1978). (In the case of fast field changes, selected events were recorded at larger bandwidth by means of digital sample and hold devices

(Krider, et al., 1977). Two such devices were operated in parallel, simultaneously recording the signal from the fast field change system and one of the RF channels, and then the stored waveforms were displayed on an oscilloscope and photographed.)

All experiments were performed at the Kennedy Space Center from Universal Camera Site #12 which is located on a slight mound near the beach southeast of launch pad #39 and east of the VAB (Le Vine, 1978). The electric field systems were built by the University of Arizona and the RF electronics was provided by the Georgia Institute of Technology.

DATA

When one views the RF data for an entire flash, for example by displaying the signals recorded with the tape recorder on a strip chart, the flash appears as a sequence of impulses each of which correspond to radiation from individual events within the flash. In this format, cloud-to-ground and cloud-to-cloud flashes have characteristic and distinct patterns independent of frequency in the range of measurements made here. A schematic of typical patterns is shown in Figure 2.

Typically, a cloud-to-ground flash begins with a sudden crashing of closely spaced pulses which on close examination have characteristics of the stepped leader. This sudden beginning is followed by several large pulses which are generally, but not always, associated with return strokes. Smaller pulses fill the gaps between the large pulses making an early active phase of high pulse density. It is not uncommon in the data to see leader like pulses preceding some of the later large pulses. This may correspond to multiple channel flashes, a hypothesis which the 1977 experiment was designed to test. The flash ends in a stage of gradual decrease both in pulse amplitude and density.

In contrast, a cloud-to-cloud flash begins slowly, builds to an intense stage of closely spaced pulses, but generally not as intense as in the early stages of the cloud-to-ground flash, and then decays much as it began in a stage of gradually decreasing pulse amplitude and density. The decaying stage of cloud-to-cloud and cloud-to-ground flashes are quite similar. (Figure 2 suggests that the duration of cloud-to-cloud flashes is greater than that of cloud-to-ground flashes; however, this is an open issue requiring further investigation.)

Examples of typical data are shown in Figures 3-5. These examples were obtained by displaying the vertically polarized channels of RF data from the tape recorder on a strip chart. The effective bandwidth of the chart recorder is a few kilohertz, and since the pulses recorded on tape are typically significantly faster (300 kHz bandwidth), each pulse represents the impulse response of the chart recorder at the particular speed employed. Sample data are shown at 3, 30, 139, and 295 MHz together with the slow electric field changes. The amplitude of each RF trace has been adjusted arbitrarily to make the display clear. Consequently, only relative amplitude information along each trace is correctly displayed and amplitude comparisons between traces cannot be made. (For example the signal level at 3 MHz is roughly two orders of magnitude larger than at 295 MHz.) The vertical scale on all traces is linear.

The electric field change in Figure 3 is typical of a distant cloud-to-ground flash with 3 return strokes. Notice the characteristic sudden beginning of this flash, the following period of intense activity and then the decay. Notice, also, the frequency independence of this pattern: most events appear at all frequencies. Of course, quantitative statements regarding frequency dependence are complicated by relative sensitivity and bandwidth. For example, if the gain of one channel were increased significantly relative to that of others, events would appear at this frequency which did not appear at the others. Similarly, a channel with large bandwidth compared to that of the others could resolve several events where the other channels could only resolve the sum. If one assumes a causal relationship between events in the flash and radiation, then given equivalent bandwidth and sensitivity as in the examples presented here, one would expect frequency independence when monitoring a process as broadband as lightning.

Figure 4 is typical of the RF radiation from a cloud-to-cloud flash. The flash begins much like it ends, in a sequence of relatively widely spaced pulses. Notice in particular the absence of the intense beginning characteristic of the cloud-to-ground flash and (almost certainly) associated with the stepped leader. In contrast, the amplitude and pulse density of the cloud-to-cloud flash tends to build slowly to a period of high pulse density with frequent large pulses, and then decays. The decaying stage is similar to that of the cloud-to-ground flash. Notice also that the pattern is essentially independent of frequency.

Figures 3 and 4 are typical of data observed in Florida; however, all data do not fall into these two categories. An example of one such exception is shown in Figure 5. The PF pattern in Figure 5 from about 0.4 seconds to the end of the flash is that of a cloud-to-ground flash; however, the beginning at about 0.1 seconds is much more like that of a cloud-to-cloud flash. This is a recurring pattern. The associated slow E waveform has a characteristic pattern beginning with a shape typical of a cloud flash generally followed by a plateau region of little change and then ending in the rapid steps typical of a cloud-to-ground flash. (The slow E record in this particular example saturated the system, and the dashed portion of the curve represents a recreation based on a few data points near the beginning of the first return stroke.) Two additional examples are shown in Figure 6 in the case of initial upward motion of the slow E trace. In these examples RF radiation at only 30 and 139 MHz is shown to save space, the radiation at the other frequencies being substantially the same. The slow E pattern shown in Figures 5 and 6 is typical of the "breakdown" phase preceding those cloud-to-ground flashes which develop from clouds having a small positive charge at their base (Uman, 1969; Clarence and Malan, 1957). The breakdown phase is assumed to be the result of neutralization of this small positive charge prior to development of the channel to ground, and the different initial direction (up or down) of the slow field change (Figures 5 and 6) is what one would expect when comparing observations of close and distant lightning (Uman, 1969). Examples of cloud-to-ground flashes preceded by a breakdown phase were not uncommon in the data surveyed to date, although they were a small percentage of total flashes. The occurrence of such patterns obviously complicates the choice of an algorithm to distinguish between cloud-to-ground and cloud-to-cloud flashes on the basis of the initial portion of their RF signature.

CONCLUSIONS

The purpose of this paper has been to present representative RF histories of lightning. These have been presented in conjunction with simultaneously recorded slow electric field changes. The data suggest many interesting possibilities, including studies of flash duration, studies of pulse interval statistics within the flash, careful examination of the correlation of RF patterns with flash type as identified from slow electric field changes, a detailed examination of RF radiation during the breakdown phase, and more. Several of these activities are currently underway, and it is hoped that quantitative descriptions of the RF radiation from lightning in the HF-UHF range will be forthcoming soon.

ACKNOWLEDGMENT

This work would not have been possible without the leadership provided by E. P. Krider of the University of Arizona; nor without the careful engineering and field support of C. S. Wilson and B. J. Wilson of the Experiment Station of the Georgia Institute of Technology.

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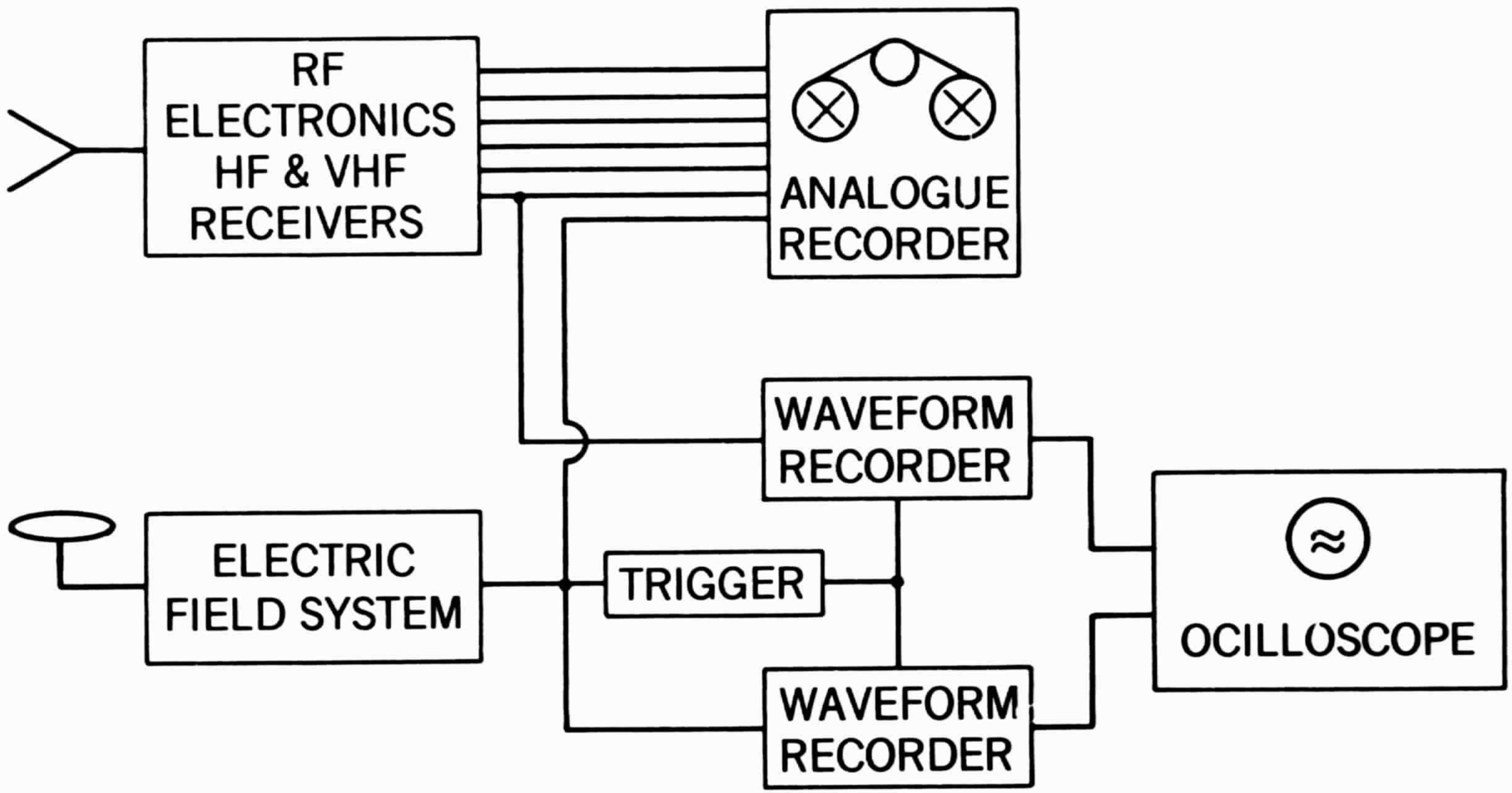

Figure 1. Block diagram of the experiment as performed during the summer, 1976 at the Kennedy Space Center, Florida.

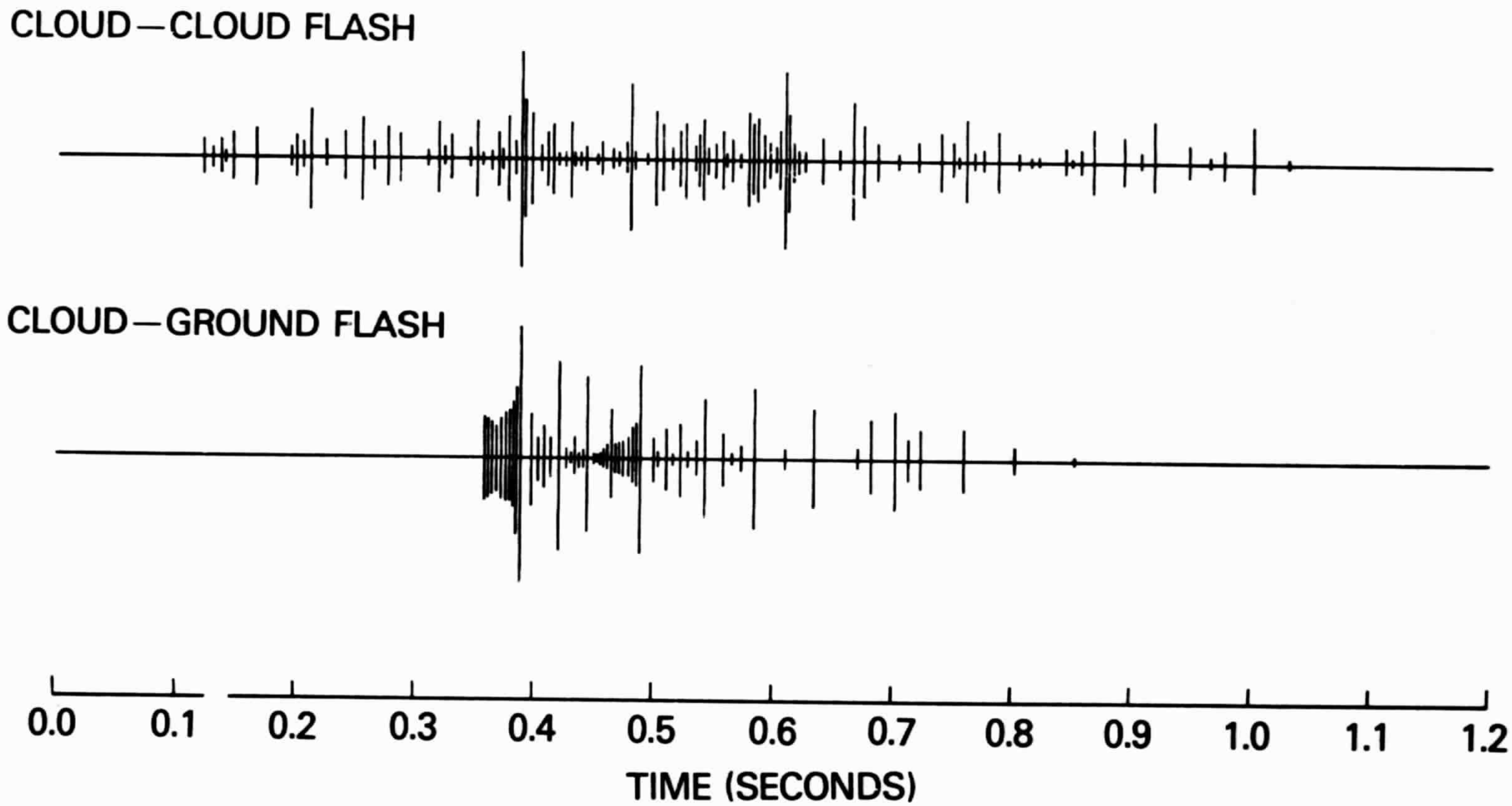

Figure 2. Typical structure of RF radiation from lightning.

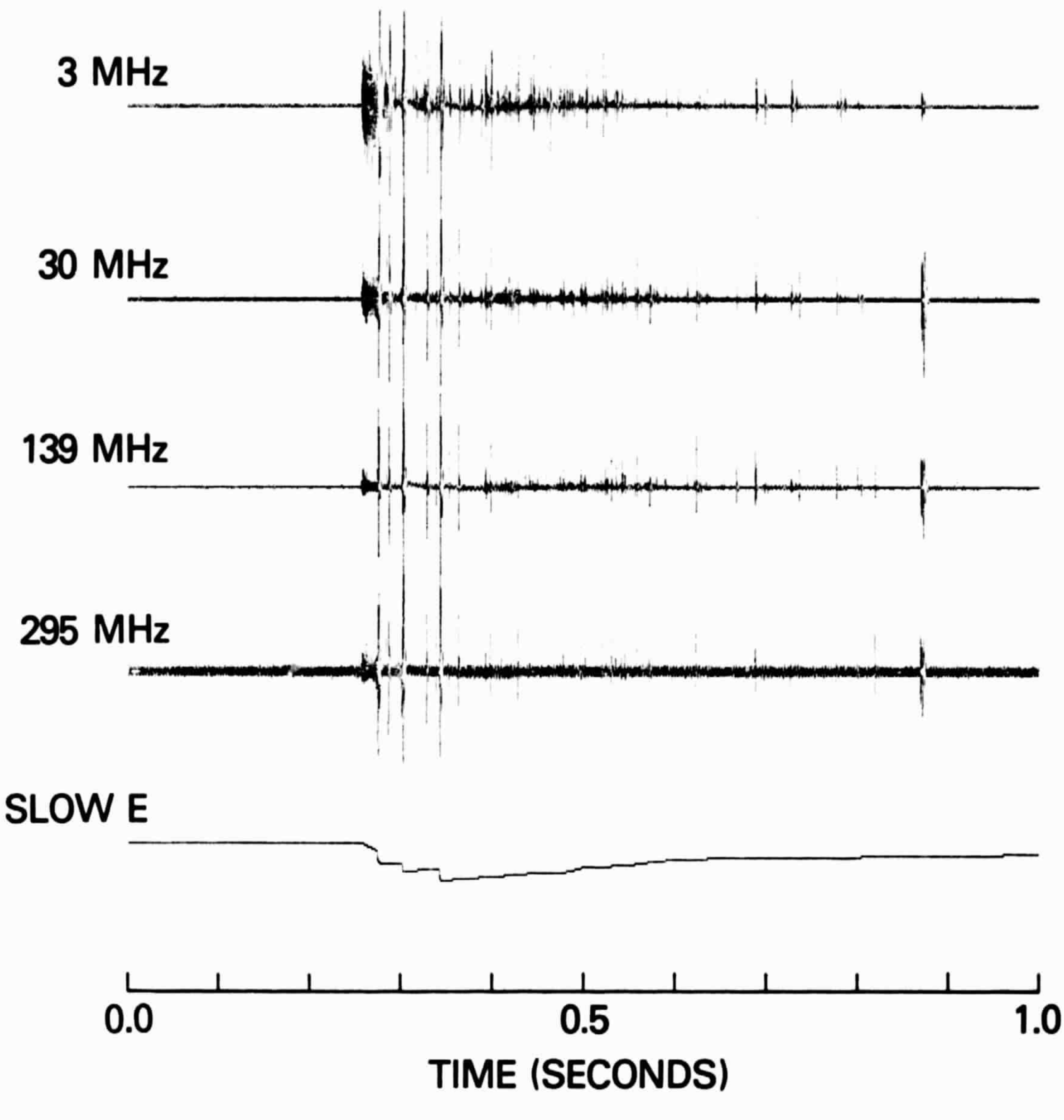

Figure 3. Example of RF radiation from a cloud-to-ground flash. All RF data are vertically polarized.

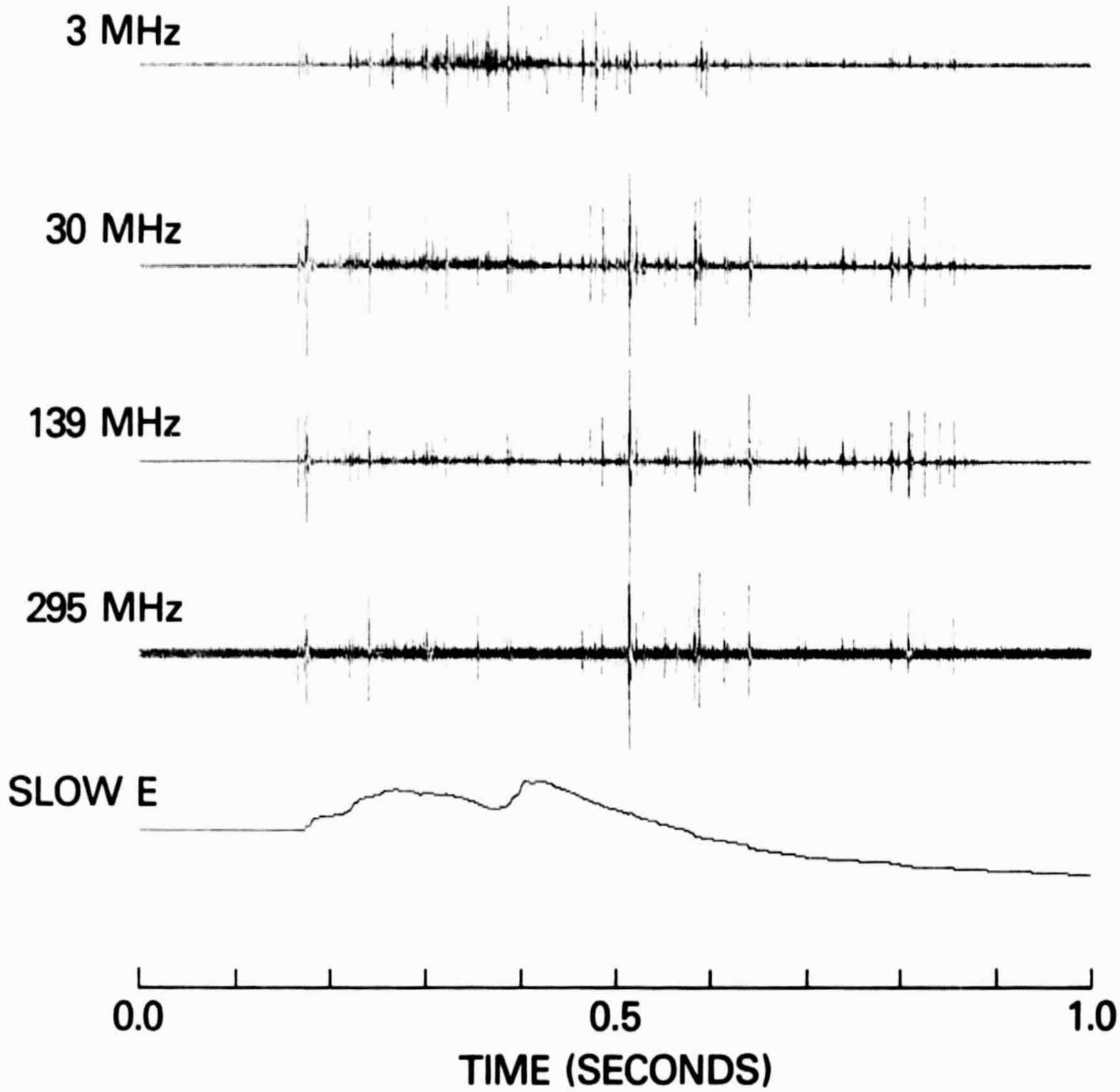

Figure 4. Example of RF radiation from a cloud-to-cloud flash. All RF data are vertically polarized.

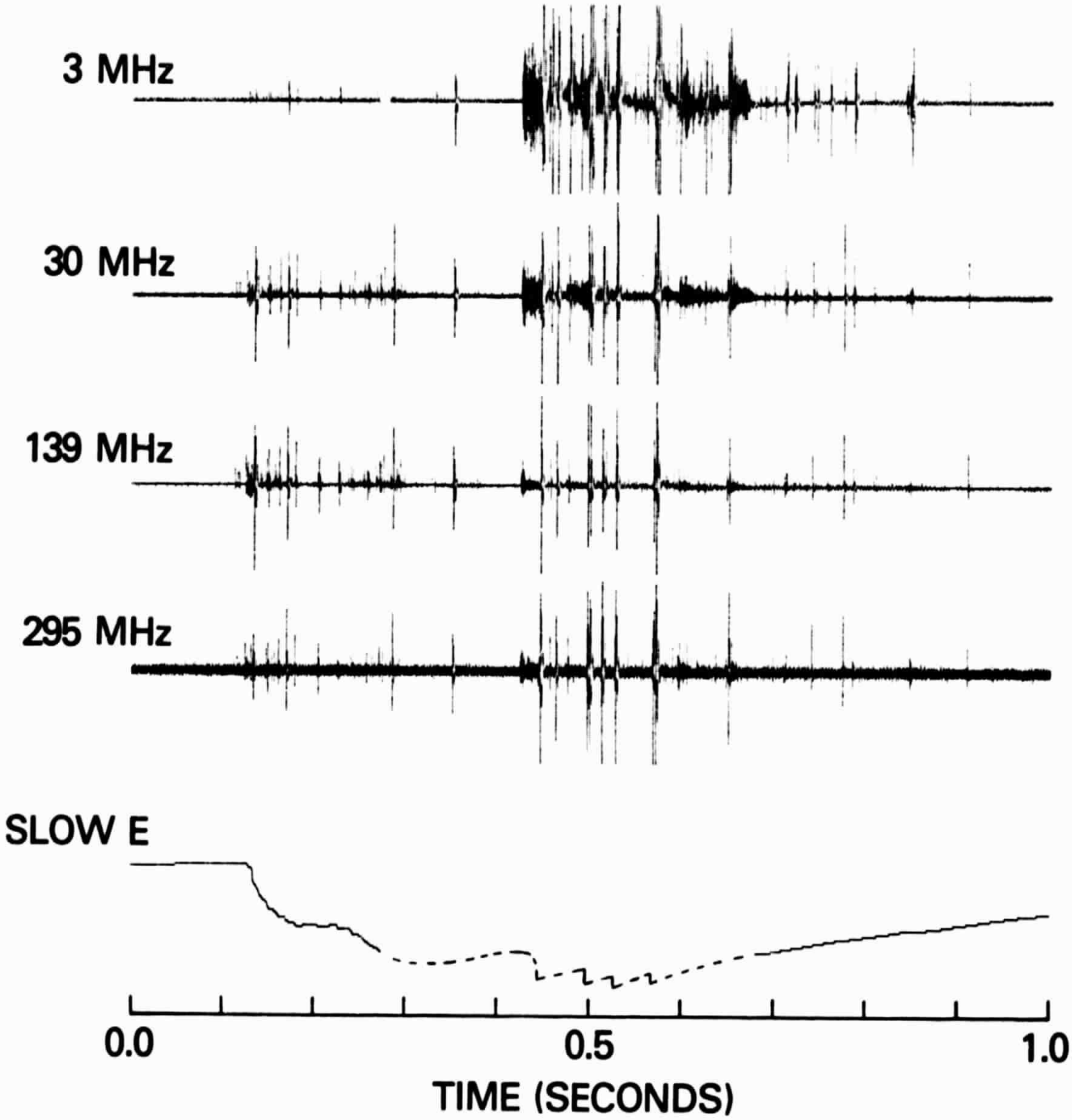

Figure 5. Example of a mixed flash. This is probably a cloud-to-ground flash in which the complete pre-stroke development ("Breakdown-Intermediate-Leader"; Clarence and Malan, 1957) is apparent.

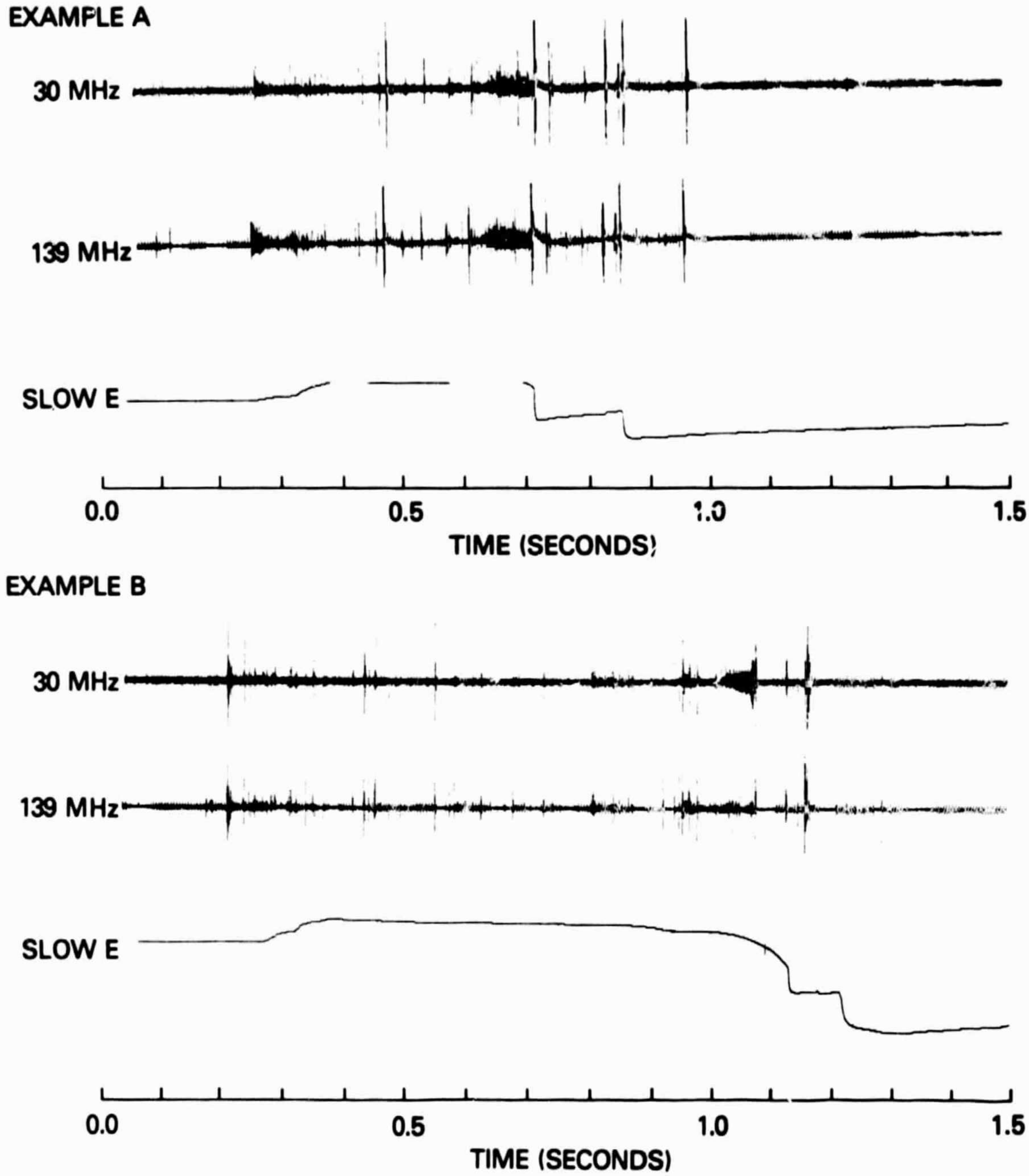

Figure 6. Examples of cloud-to-ground flashes preceded by cloud radiation, probably associated with the pre-stroke "breakdown" phase. Radiation at 3 and 295 MHz, not shown to conserve space, is essentially the same.

BIBLIOGRAPHIC DATA SHEET

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16. Abstract

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