VHF RADIATION FROM GROUND DISCHARGES*

Masumi TAKAGI

It is well known that the lightning discharges, especially the leader stage of ground strokes, are accompanied by intense electromagnetic radiations in high frequeucy range. Brook and Kitagawa (1964) have pointed out that the dart leader radiation above 400 MHz ceases for 50 to 150 μsec before the start of return stroke and that the return stroke radiation above 400 MHz is entirely absent or appears with a time delay of 60 to 100 μsec after the start of return process. The present paper is to report the existence of several types of radiation from ground discharges in VHF region in addition to the Brook-Kitagawa type. Analysis is based upon the simultaneous records of electric field change in the frequency range 1 to 900 KHz and of radiations at 60, 150 and 420 MHz. Time coincidence between the records attains the accuracy to about 5 μsec. In general the radiation at a higher frequency is observed as if it had a shorter time duration than that at a lower frequency, because the sensitivity of receiver is insufficient to compensate radiation frequency spectral power, which is roughly in inverse proportion to the square of frequency (Takagi and Takeuti, 1963). However, the radiation patterns recorded at the three freqencies at the same time are found to be essentially similar with each other, although the slight difference found between them is mainly due to the difference in sensitivity of the receivers, and directivity and polarization of the antennas used, where the effect of polarization seems to be the most important in spite of very limited data fully to discuss it.

From the view point of occurrence time of VHF radiation, the radiation can be classified into three types, the occurrence rates of which are shown in Table 1 along with the modeled patterns of them.

Type 1 involves the radiation which has a relation to the dart leader process. The radiation begins at a moment 100 to 1000 μsec prior to the return stroke. As to the ending time of radiation, the maximum of the distribution almost coincides with the onset of return process (Fig. 4), though one-third of the data classified into this type finish their activity earlier than 50 μsec before the onset of return stroke as reported by Brook and Kitagawa (1964). On the other hand, for one-third of the data thes radiation continues to cover even the whole return process without any noticeable alteration

* Partial revision of the short paper presented at the Fourth International Conference on the Universal Aspects of Atmospheric Electricity held in Tokyo, May 1968.

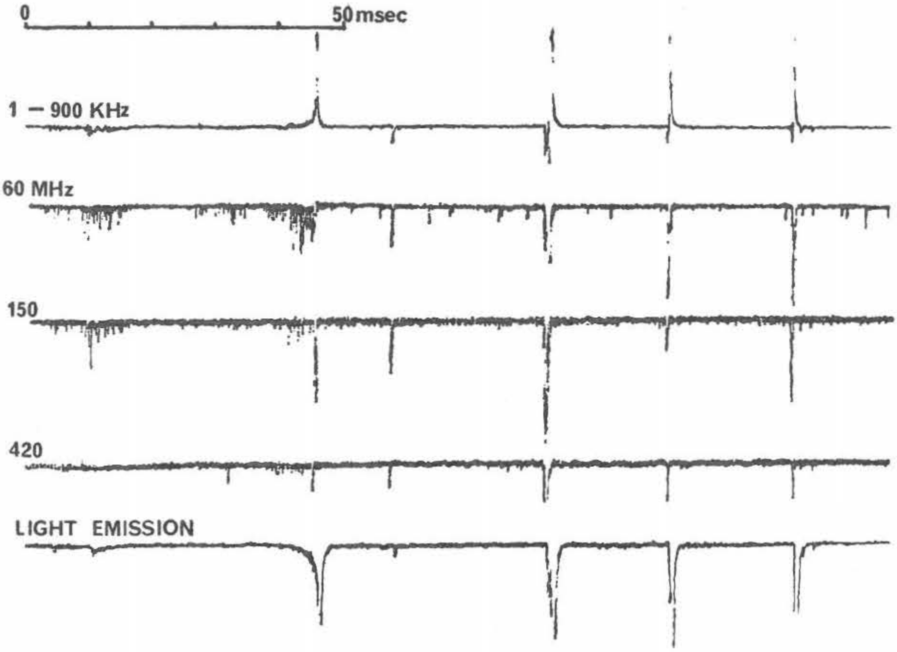


Fig. 1. Slow display of electric field change, radiations at three frequencies and light emission. The figure includes from the stepped leader process followed by the first return stroke through the fourth return stroke.

at the time of leader-return transition. Almost all the stepped leaders show intermittent pulsive VHF radiations, which correspond to each of step streamers and are not so intensive as involved in type 1 on a very fast display (Compare Fig. 2 with Fig. 3.).

Type 2 is concerned with the radiation which appears only after the return process has already started. In this case the radiation from the leader processes is absent or unusually weak. The radiation starts between 5 and 500 μsec after the onset of return stroke. It is noted that two distinct peaks are found on the distribution curve of starting time of it (Upper right histogram in Fig. 5). The first group, which has a peak at 10 μsec after the onset and distributes in the range up to 30 μsec, corresponds to the radiation from the return stroke stem progressing upward with a very high velocity. The second group, which has another peak at 50 μsec, originates in the discharge process diffusing into a thundercloud. The radiation continues for 40 to 300 μsec, and thereafter it comes out a comparatively long radiation pause, which has initially been found by Malan (1958). As seen in Table 1 and Fig. 5, there is a tendency that the principal source of the radiation in a ground discharge moves from the return stroke stem to the discharge processes taking place within a cloud as the order of stroke is increased.

Type 3 is a complex type. The radiation is composed of two parts isolated by some quiet period. The earlier part sets on in the leader process and the later part in the return process. The properties of the two parts are very similar to Type 1 and Type 2 respectively.

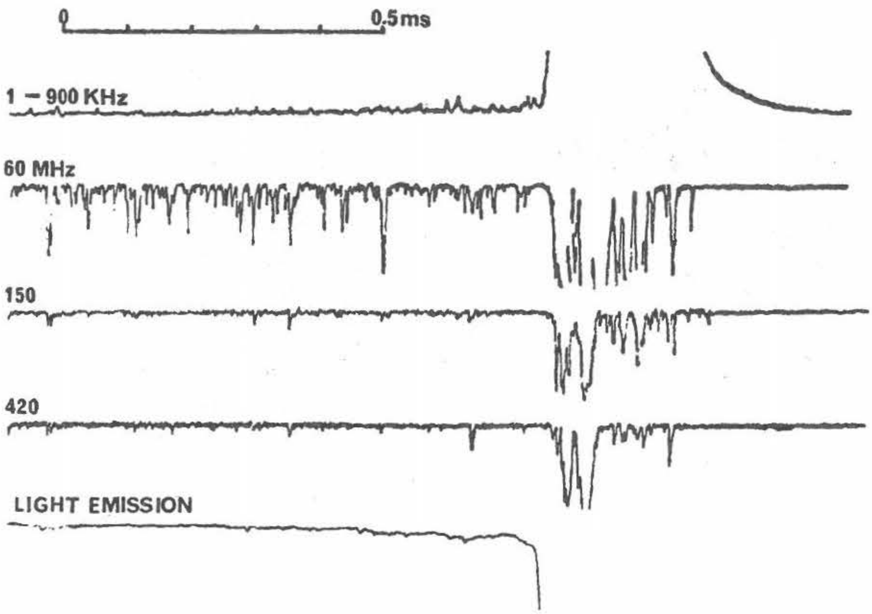


Fig. 2. Fast display of the first ground stroke of the same flash as shown in Fig. 1.

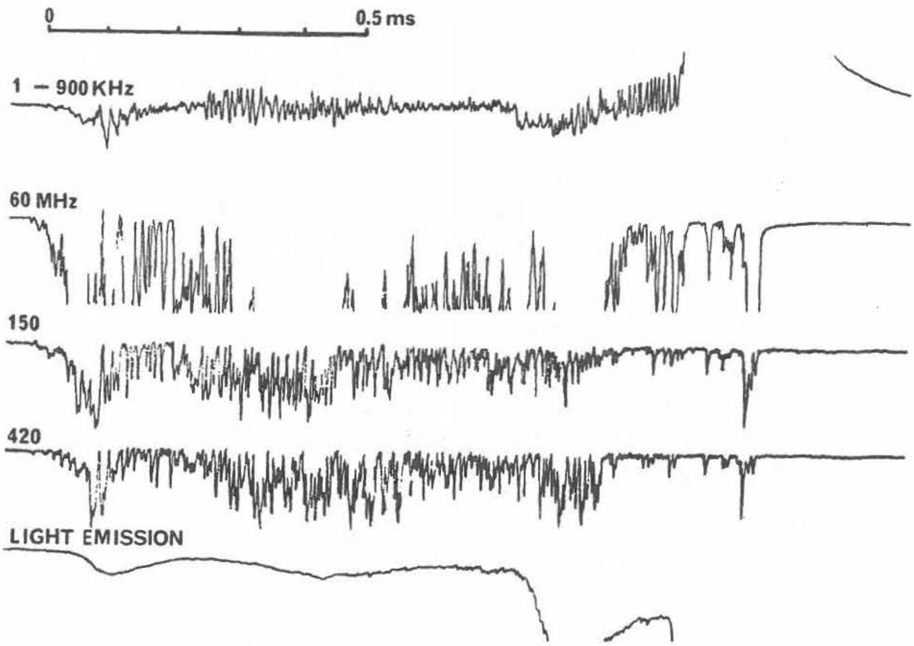


Fig. 3. Fast display of the second ground stroke of the same flash as shown in Fig. 1. Much more intense radiation accompanies dart leader process rather than return stroke.

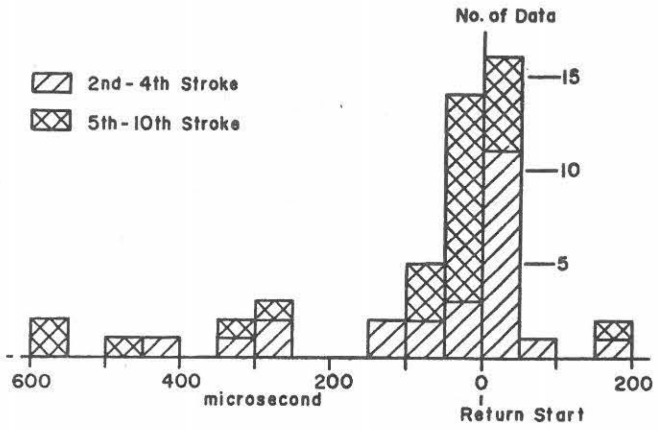


Fig. 4. Distribution of end-time of dart leader type radiation at 60 MHz (Types 1 and 3). Left-hand and right-hand sides of 0 respectively mean the time before and after the return stroke starts from the ground.

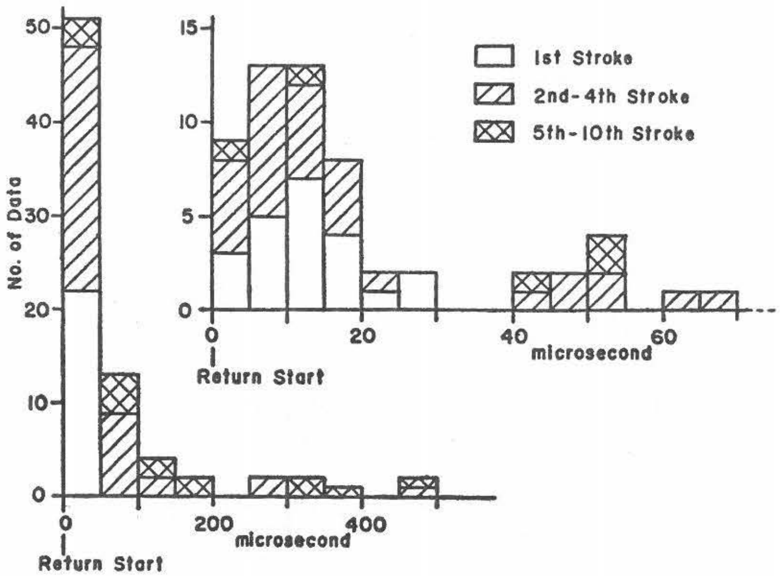
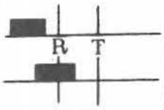
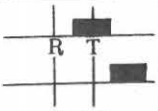
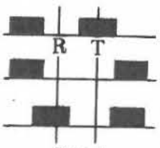


Fig. 5. Distribution of start-time of return type radiation at 60 MHz (Types 2 and 3). Upper-right figure shows the detailed distribution of start-time smaller than 70 μsec, where most of data are included.

Table. 1. Occurrence percentage of the three types.

Frequency		60 MHz				150 MHz				420 MHz			
Stroke order		1	2-4	5-10	Total	1	2-4	5-10	Total	1	2-4	5-10	Total
Type	Pattern*												
1		4	6	34	14	0	14	37	16	0	22	9	14
		0	9	8	6	0	8	0	4	0	8	9	6
	Total	4	15	42	20	0	22	37	20	0	30	18	20
2		92	43	0	43	90	53	0	49	69	30	0	33
		0	0	4	1	10	0	16	7	31	22	64	33
	Total	92	43	4	44	100	53	16	56	100	52	64	66
3		4	6	8	6	0	5	10	5	0	0	0	0
		0	17	35	18	0	17	32	16	0	18	18	14
		0	19	11	12	0	3	5	3	0	0	0	0
	Total	4	42	54	36	0	25	47	24	0	18	18	14
Number of data		23	47	26	96	20	36	19	75	13	27	11	51
Number of data of no-radiation		0	0	2	2	3	11	9	23	10	20	17	47

* ▬ : VHF radiation

R : onset of return stroke

T : 30 μsec after R

A remarkable change is found in the occurrence rate of the types with respect to the stroke order. As the stroke order goes up, the radiation from the return stroke stem becomes weaker than that from the leader stroke and from the diffusive discharge process inside a thundercloud. This seems to suggest that the higher is the order, the deeper develops the discharge path into the cloud, thus the more complicated will become the streamer process, which acts as an after-effect of return process and prepares for the next intra-stroke process.

Acknowledgement——This work was done during my stay at New Mexico Institute of Mining and Technology. I am deeply indebted to Prof. M. Brook for his valuable suggestions and discussions.

References

Brook, M. and N. Kitagawa : Radiation from Lightning Discharges in the Frequency Range 400 to 1000 Mc/s, J. Geophys. Res., **69**, 2431-2434 (1964)

Malan, D. J. : Radiation from Lightning Discharges and Its Relation to the Discharge Process, Recent Advances in Atmospheric Electricity, Pergamon Press, 557-563 (1958)

Takagi, M. and T. Takeuti : Atmospherics Radiation from Lightning Discharges, Proc. Res. Inst. Atmospherics, Nagoya Univ., **10**, 1-11 (1963)