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Detection of Surface-Burst EMP in the Presence of Cloud-to-Ground Lightning

Carl E. Baum
University of New Mexico
Department of Electrical and Computer Engineering
Albuquerque New Mexico 87131

Abstract

This paper addresses the problem of the detection of the surface-burst nuclear electromagnetic pulse (EMP). Cloud-to-ground lightning must be discriminated against. Also one would like to avoid false indications from high-altitude EMP and cloud-to-cloud lightning.

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1. Introduction

Let us now consider detecting the nuclear electromagnetic pulse (EMP) from a distant surface burst. As in the case of the high-altitude EMP we would like to reliably discriminate this from the lightning environment [2]. While there are some similarities in the two cases, there also important differences.

In the present case, let us also consider how to locate the surface burst. This will involve measurements of both electric and magnetic fields at two (or more) sensor stations.

2. EMP from Surface Bursts

The EMP radiated from a surface burst is quite different from that radiated by an exoatmospheric (high altitude) burst. Figure 2.1 illustrates the basics of the surface burst EMP. More details are given in [3, 4].

The essential thing to note is that the source current corresponds at early time to a radial current oriented radially inward toward the detoniation point (Compton electrons moving radially outward). As such the outer portions of the source region (a few km radius) are initially charged negative and the electiric field near the ground surface is positive (upward).

The amplitude of the electric field near the edge of the source region is a few times 10^4 V/m with a fast rise time (10 ns or so). However, the outward propagating field propagates as a surface wave near the earth, losing high frequencies as it goes along.

A minor phenomenon concerns the cancellation of the fair-weather field by the conducting source region. This field is of the order a negative 100 V/m (pointing downward). This should not cause problems when compared to the much larger source-region EMP fields.

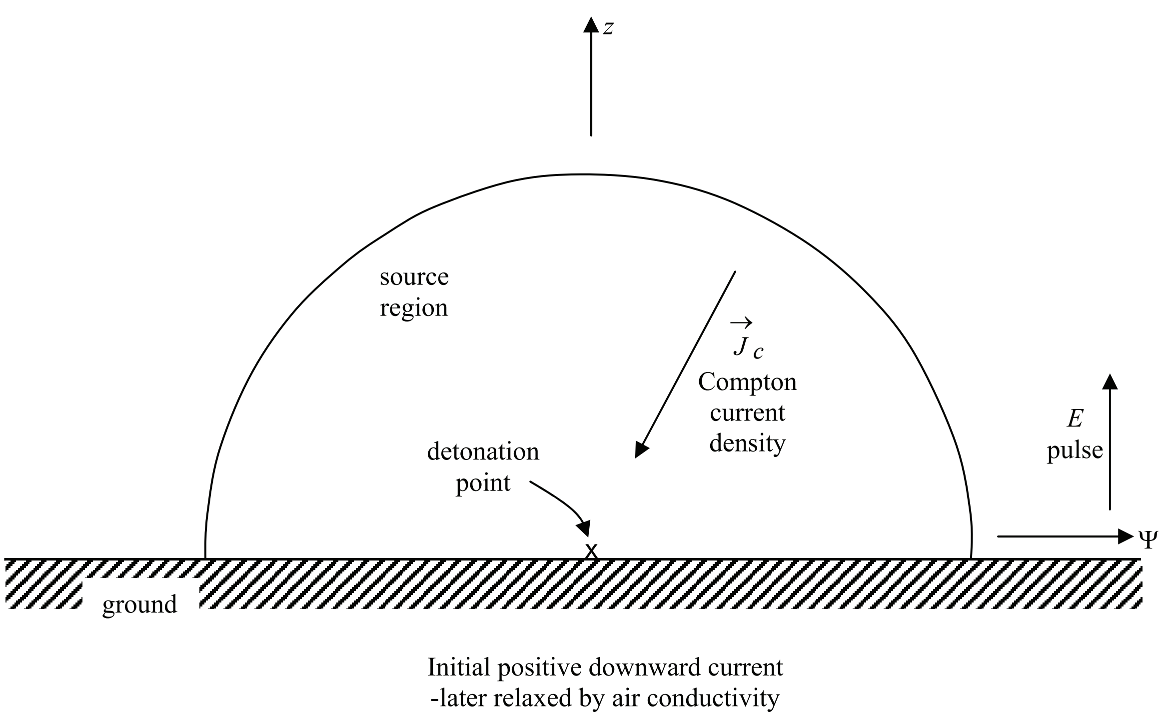


Fig 2.1 Surface-Burst EMP.

3. Fields from Cloud-to-Ground Lightning

For comparison let us consider the electromagnetic fields radiated by cloud-to-ground lightning, in particular the large return-stroke fields. Figure 3.1 shows the typical case of negative charge from a cloud being lowered to ground.

The return stroke begins near the ground surface and propagates up the lightning channel towards the cloud. Note that the current I is positive upwards, opposite to the ground-burst EMP case. As such the radiated electric field near the ground is initially negative. Its magnitude can be estimated as

$$\begin{aligned} E &\simeq \frac{\mu_0}{4\pi r}\eta c I \\ &\simeq \frac{3\times 10^6}{r}\eta \ \text{ for } I \simeq 100\ KA \end{aligned} \tag{3.1}$$

where η is of order of magnitude one based on various factors involved in the return-stroke initiation [7]. A typical case would have

$$\begin{aligned} r &\simeq 2\ km \quad , \quad \eta \simeq 1 \\ E &\simeq 1.5\ kV/m \end{aligned} \tag{3.2}$$

for comparison to the EMP at the edge of the source region. This is smaller than the surface-burst EMP at this radius (as discussed in the previous section) by about an order of magnitude. However, this field falls off with distance, so one would need an estimate of distance to the lightning or EMP source to use this as a discriminant [8].

The obvious discriminant between surface-burst EMP and negative cloud-to-ground lightning is then the opposite polarities of the two.

This brings up the problem of positive cloud-to-ground lightning. The polarity is the same as for surface-burst EMP. In this case one may use the relative amplitudes as a discriminant. This requires range information. Unfortunately, such positive lightning is not as well understood as negative lightning [6 (ch. 11)]. Perhaps the detector (to be discussed in the next section) can also be used to more reliably estimate both lightning cases. The actual experimental responses could be used for setting EMP discriminant levels.

Let us briefly mention cloud-to-cloud lightning. This generally gives fields arriving at our detector from some elevation above the ground. Without going into detail one can look at the lower currents, and the elevation angle of the fields above the ground.

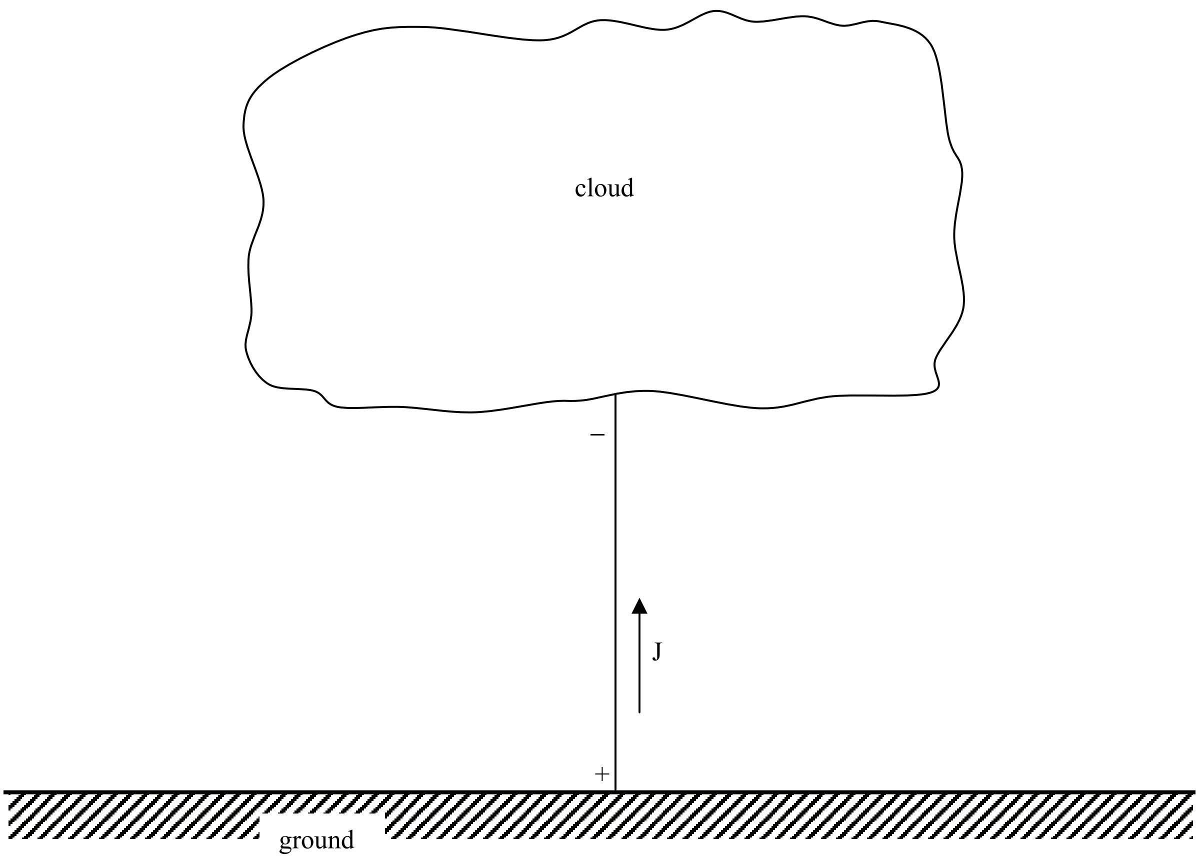


Fig. 3.1 Cloud-to-Ground Lightning Return Stroke (Negative).

4. General Sensor Concept

Based on the foregoing discussion we can envision a sensor concept something like that in Fig. 4.1. As discussed in [1, 2] we first establish a good local ground plane, peripherally connected to the earth.

As illustrated in Fig .4.1, we have a single D-dot and multiple (N) B-dot sensors. The B-dot loops are based on a conducting plate (disk) parallel to the ground plane with a central connection to the ground plane via a conducting tube (outer conductor of a coax). The B-dot signals are picked off by a conductor (coax inner conductor) extended from a coax which passes through the ground plane. This coax shield is peripherally bonded to the ground plane as it passes through the ground plane. There are *N* such pickoff positions uniformly spaced at an angle of

$$\phi_1 = \frac{2\pi}{N} \tag{4.1}$$

around the periphery of the disk.

The *N* B-dot signals are measured below the ground plane. The largest B-dot signal magneitude can be observed at some diametrically opposite pairs given by ϕ_n and $\phi_n \pm \pi$. If the signal is from a ground burst EMP the early signal has a positive electric field (D-dot) with a positive B-dot in a direction

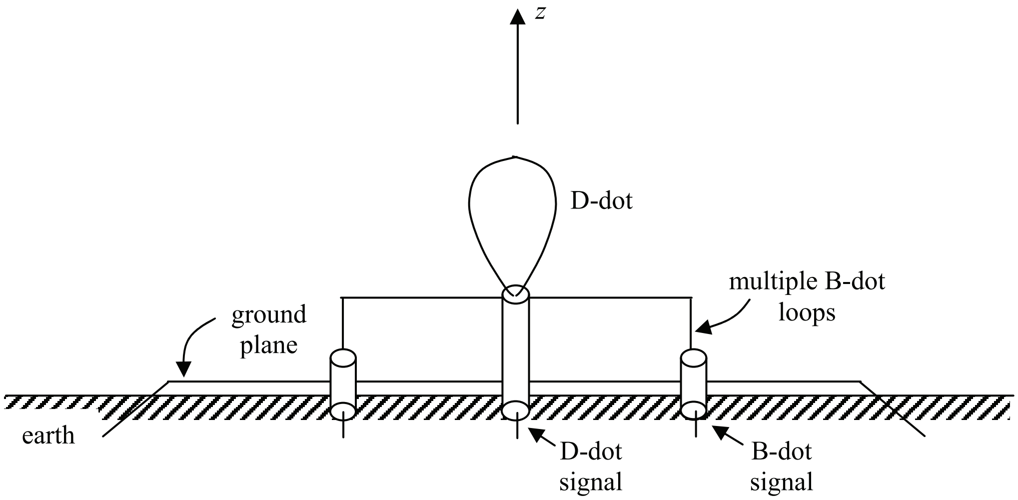
$$\vec{1}_b = \vec{1}_r \times \vec{1}_z \tag{4.2}$$

where $-\vec{1}_r$ is the direction *to the source*. This determines ϕ_n with the signal from $\phi_n \pm \pi$ being initially negative. A more accurate determination of $\vec{1}_b$ can also be made by fitting all the early peak signals by a function like $\cos(\phi_n - \phi_b)$, especially if *N* is small. For large *N*, one can take the smallest positive and negative signals at adjacent ϕ_m and ϕ_{m+1}, interpolate the zero between them, and rotate by $\pi/2$ (90°) to more accurately estimate the B-dot direction.

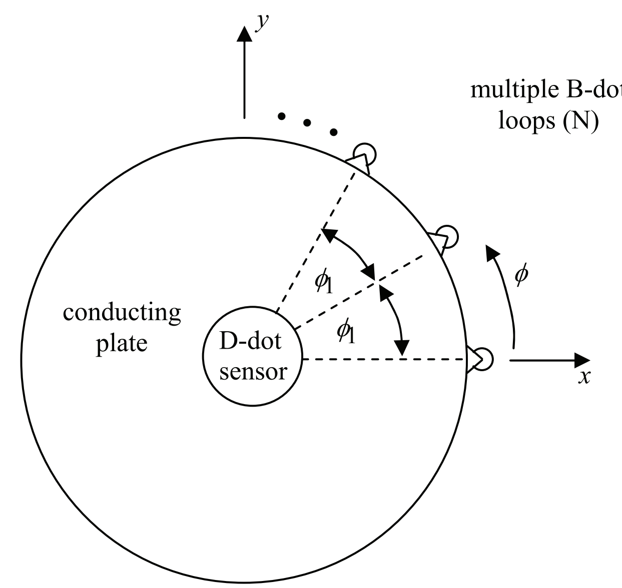
Now look at the same signal as recorded by the D-dot sensor. This should correspond to a positive vertical D-dot (giving a negative signal below the ground plane). If it is positive then we have the direction to the source as

$$-\vec{1}_r = -\vec{1}_z \times \vec{1}_b \tag{4.3}$$

(from $-\vec{E} \times \vec{H}$). Various body-of-revolution shapes are possible for the D-dot sensor, including the asymptotic conical dipole (ACD) [5].



A. Side view



B. Top view (different scale)

Fig 4.1 Surface-Burst EMP Detector

On the other hand, if the D-dot signal is negative we have negative, cloud-to-ground lightning. Then we can use this signal as a lightning locator. The polarity of B-dot is also reversed, giving the same $-\vec{E}\times\vec{H}$ direction.

If the D-dot signal is positive we may also have positive cloud-to-ground lightning. In that case we may need to rely on the expected lower signal amplitude compared to ground-burst EMP for a given range to the source.

We can also compare E-dot to cB-dot. For a wave propagating parallel to the ground the early-time signals will have approximately the same amplitude. If the wave arrives from some $\theta < \pi/2(90^\circ)$ (where θ is the angle from the positive z axis) then this would have E-dot smaller than CB-dot [2]. Such a case would correspond to cloud-to-cloud (or intracloud) lightning, or to high-altitude (or air-burst) EMP.

Another possibility involves the use of two sensor stations. This can triangulate the source location by the use of the two measured directions from the sensor. By this technique one can estimate the distance to the source. This, in turn, is used in the discrimination to infer relative source strengths as part of the discrimination scheme based on the previous discussion.

5. Concluding Remarks

Discriminating surface-burst EMP is not as easy as discriminating high-altitude EMP. The propagation over the earth distorts the waveform and makes it harder to discriminate from cloud-to-ground lightning. Fortunately, polarity helps some, as does field amplitudes at a given range.

There is also the problem of EMP and lightning arriving from above the earth surface. This can be circumvented by measuring the polar angle of arrival.

When not in use as an EMP detector, such measurement stations could be used as lightning detectors. Based on the foregoing, one could discriminate between positive, negative, and cloud-to-cloud (or intracloud) lightning.

References

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