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Technical Note - TN18

Selection of pulse simulators for HEMP / NEMP tests

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1. Phenomenology

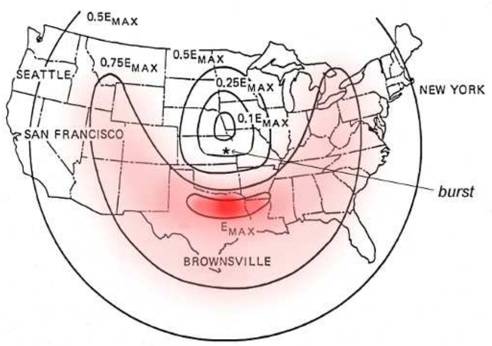
1.1 Introduction

During the explosion of an atomic bomb, an electromagnetic field is radiated, especially if the burst happens in a very high altitude (HEMP). The physical mechanism is very complex and is mainly due to the Compton effect. When the downward directed gamma rays encounter the upper regions of the atmosphere, they begin to interact with the molecules of the atmosphere. The dominant interaction is Compton scattering, in which the energy of a gamma ray is partially transferred to an electron of an air molecule. The electron then begins travelling in approximately the same direction as the gamma ray. The electrons rotate spirally around the Earth's geomagnetic field lines producing transient transverse currents which induce a radiating magnetic field. At a certain distance from the source, the pulsed magnetic field becomes a plane wave. That means that electric and magnetic fields are both present. The wave impedance is 377 ohm (= ratio between the electric and magnetic field). Both components of the electromagnetic field are perpendicular to the wave propagation.

1.2 Amplitude of the field

Depending on the altitude of the explosion, on the type of bomb and on the position of the electronic equipment on the Earth, the amplitude varies. The amplitude of the generated electromagnetic field is maximum if the direction of the radiation of the bomb is perpendicular to the geomagnetic field. Then the amplitude on earth then depends on the distance from the observer to the burst.

An example is given for a burst produced over the middle of the USA with an height of burst (HOB) of 500 km. The maximum peak electric field occurs just south of surface zero and can be as high as 50 kV/m.



Amplitude of the electromagnetic field on the Earth

1.3 Polarisation of the field

The polarisation of the field is complex to determine. As a simplified rule, the direction of propagation is radially outward from the burst point, and the direction of the electric field is normal to both the direction of propagation and the geomagnetic field at the observer's location. By introducing this on a burst happening 500 km high over the centre of the USA, the amplitude of the vertical and of the horizontal polarisation are separately shown on the next figures.

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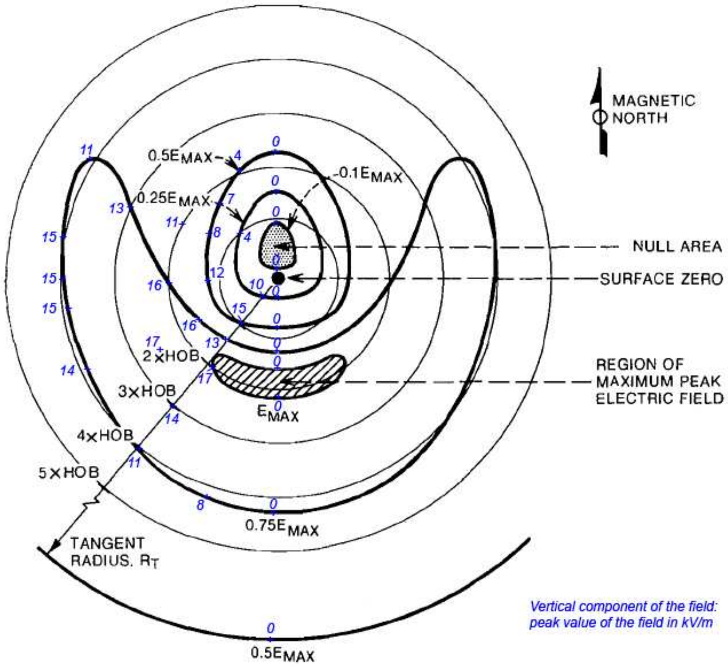
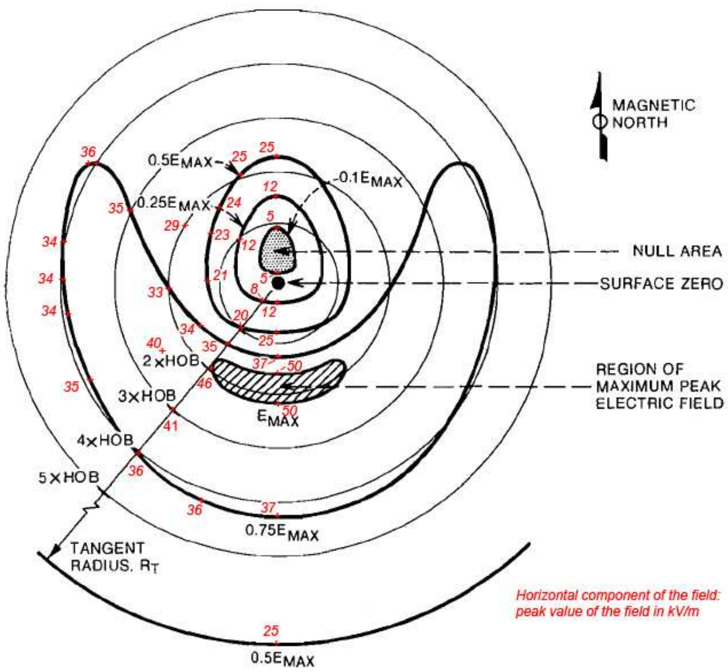


Vertical polarisation



Horizontal polarisation

This clearly demonstrates that the horizontal component of the field is more present on the Earth's surface than the vertical polarisation. The maximum peak value of the vertical field is only 17 kV/m and the zones where this component is high are small. The maximum peak value of the horizontal field is 50 kV/m and the areas where the amplitude is above 25 kV/m are predominant.

2. Test simulators

2.1 Environment and simulators

The environment to be simulated is dependant on the EUT and can be categorised in 2 types [1]:

1) aerospace systems are concerned by free field electromagnetic pulses;
2) ground or sea systems: the transient wave is more complicated due to the addition of the incident and the reflected waves.

To simulate these environments, different EMP simulators are possible:

1) radiating simulators
2) bounded wave (or guided wave) simulators
3) hybrid (or HPD) simulators.

2.2 Radiating simulators

This type of test installation is adapted for simulation of free electromagnetic fields but also for ground or sea systems. The test area can be very large but the homogeneity of the field is low. The size of the antenna must be very large to achieve low frequency content of the radiated transient. Last disadvantage: the efficiency of this type of simulator is low (ratio field / voltage of the generator). The polarisation is mainly vertical.

Example of radiating simulator (conical)

2.3 Bounded wave simulators

The bounded wave simulators are also named guided wave simulators. They consist of a HV pulse generator connected to a transmission line ended by a distributed resistance. The mode of the wave guided under the line is TEM (transverse electromagnetic). The polarisation is vertical. Different designs of the line are possible and a GTEM can also be used as a field generating structure. The bounded wave simulators have a good efficiency.

Bounded wave simulator

2.4 Hybrid simulators

The name of hybrid comes from the property of this type of simulator to produce both reactive ("static") and radiating field. At low frequencies, quasi-static form of the field is applicable and the current flowing in the whole structure creates the field under and around the line. In high frequency the early time transient achieving the tested equipment is radiated by the part of the antenna placed in the vicinity of the generator. The polarisation of the field is mainly horizontal.

Hybrid simulator

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3. Test simulators comparison

A simple comparison between the different simulators is given below.

Specification	*radiating*	*bounded wave*	*hybrid*
Polarisation of the electric field	mainly vertical	vertical	mainly horizontal
Homogeneity of the field	fair to good	good	fair
Waveform	distorted (depends on the length of the antenna)	good	distorted (depends on the nature of the soil)
Influence of the ground	none (if a metallic ground plane is present)	none (metallic ground plane)	yes (the waveform depends on the nature of the soil)
Efficiency[1]	low (depends on the EUT's position)	good	fair
Disturbance radiated in the vicinity	very high	fair to high	high
Maintenance costs	fair	fair	high
Sensitivity to weather conditions	moderate	moderate	high
Lifetime	good	good	fair
Complexity (price)	high	fair	very high

[1] : *ratio: amplitude of the field / voltage of the generator*

In addition to this basic comparison, the type of equipment to test can also be selection criteria. A system mainly containing a wiring laid vertically will obviously be more sensitive to vertical electromagnetic fields than horizontal ones due to a better coupling between the field and the conductors. This is the same for a horizontal devices placed in an horizontal field. As an example, if most of the devices to be tested are flat and horizontal, a test simulator producing a vertical field like the bounded wave system is not a good choice.

The selection of the test system is finally a compromise taking into account the "natural" environment, the technical advantages / disadvantages, the price and maintenance costs and the type of device to test.

Reference:

[1]: A brief survey of available EMP simulators, D. V. Giri, 1986.

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