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Title: An Introduction to Electromagnetic Pulse (EMP)

Author(s): Eric M. Nelson

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Abstract

After describing the potential danger from EMP, the different types of EMP are described. Components of a high-altitude EMP code are listed.

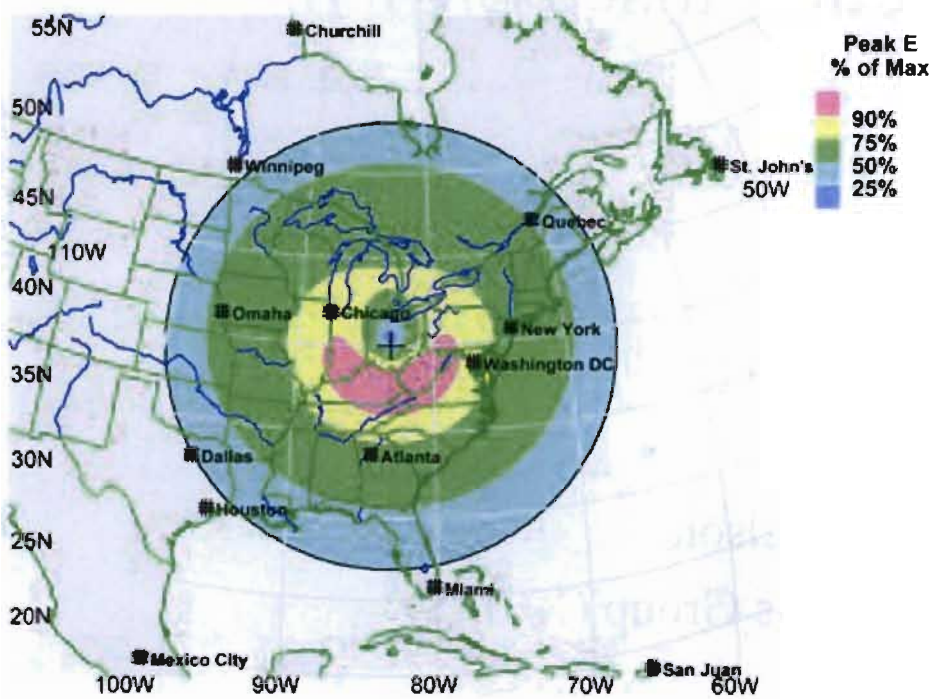
An Introduction to Electromagnetic Pulse (EMP)

5 July 2011

Eric M. Nelson
Verification & Analysis Group (XCP-8)

Why do we care about EMP?

Our critical infrastructure has become very interdependent and much more vulnerable to disruptions, particularly from an EMP attack.



EMP from a single high-altitude nuclear burst could upset and damage enough equipment…

to cause a cascading series of failures in electric power, communication, fuel/energy, transportation, food, water, banking and emergency services infrastructures…

that brings civilization as we know it to a halt.

The EMP Commission's reports have some more details.

EMP is one effect from a nuclear explosion. It arises from the nuclear explosion's gamma ray output.

Radiative outputs.

- Thermal x-ray radiation.
- Debris kinetic energy.
- Neutrons.
- Gamma rays.

Effects.

- Shock and/or blast.
- Thermal radiation (light and heat).
- Residual radiation and fallout.
- Atmospheric ionization.
- Electromagnetic pulse (EMP).

Starfish Prime event observed from Honolulu, 8 July 1962.

See Glasstone & Dolan *The Effects of Nuclear Weapons* (1977) for more details.

We distinguish types of EMP that arise from distinct physical phenomena.

Far from the burst, where equipment experiences just radiating electromagnetic fields.

Physics depends on burst altitude.

- Surface (or near-surface) burst
  - ground asymmetry EMP (GAEMP)
  - urban
- Atmospheric burst
  - a few km to ~30 km height
- High-altitude burst
  - above ~30 km height
  - geomagnetic EMP (GEMP)
  - also called HEMP
- Space/exoatmospheric

Near the burst, where equipment experiences even more.

- Source region EMP (SREMP)
  - a non-radiating (radial) electromagnetic field
- System generated EMP (SGEMP)
  - electromagnetic fields generated by gamma rays interacting inside equipment

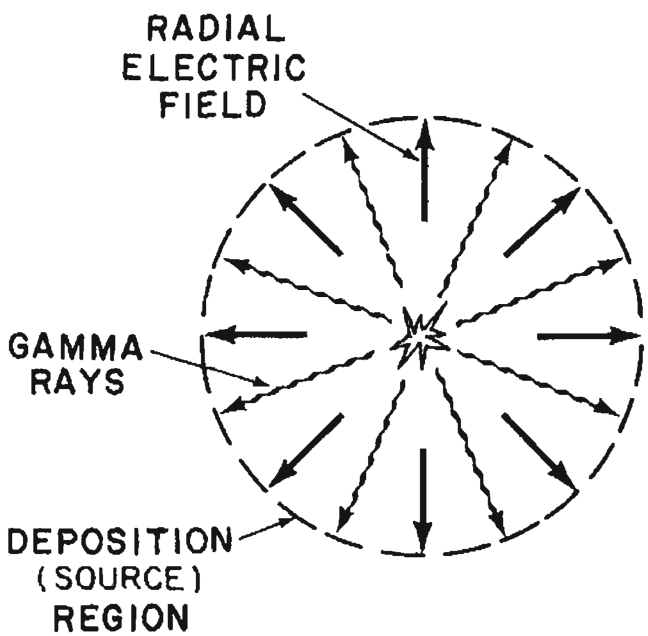
The electromagnetic pulse is often split into three components.

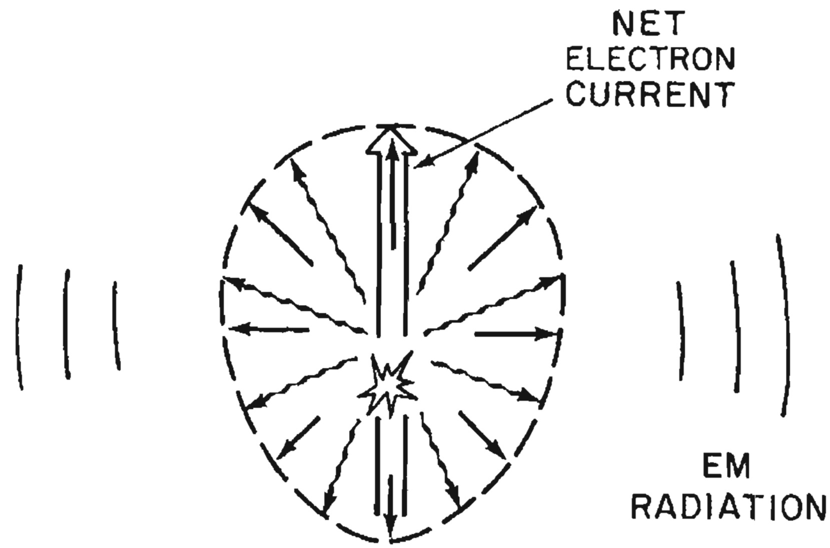
- The first component, E1, comes from prompt gammas, lasts ~1 μs, and can have a very fast (~ ns) rise time.
  - Electric field amplitude in the 10s of kV/m.
  - This is the electromagnetic "shock" that disrupts and damages electronic equipment.
- The second component, E2, comes from scattered and delayed gammas out to ~1 sec. It is slower and somewhat lower amplitude.
  - Akin to a lightning strike, which we already protect against.
  - But will that protection survive the E1 pulse?
- The third component, E3, comes from the plasma debris displacing the geomagnetic field. Lasts from 10s to 100s of seconds.
  - Akin to a really bad geomagnetic storm.
  - Couples well to electric transmission lines.

Gamma rays Compton scatter off electrons in air.
The Compton electron current drives electromagnetic fields.

In a homogeneous atmosphere there would only be a radial electric field that does not radiate. Just SREMP for a few gamma mean free paths.

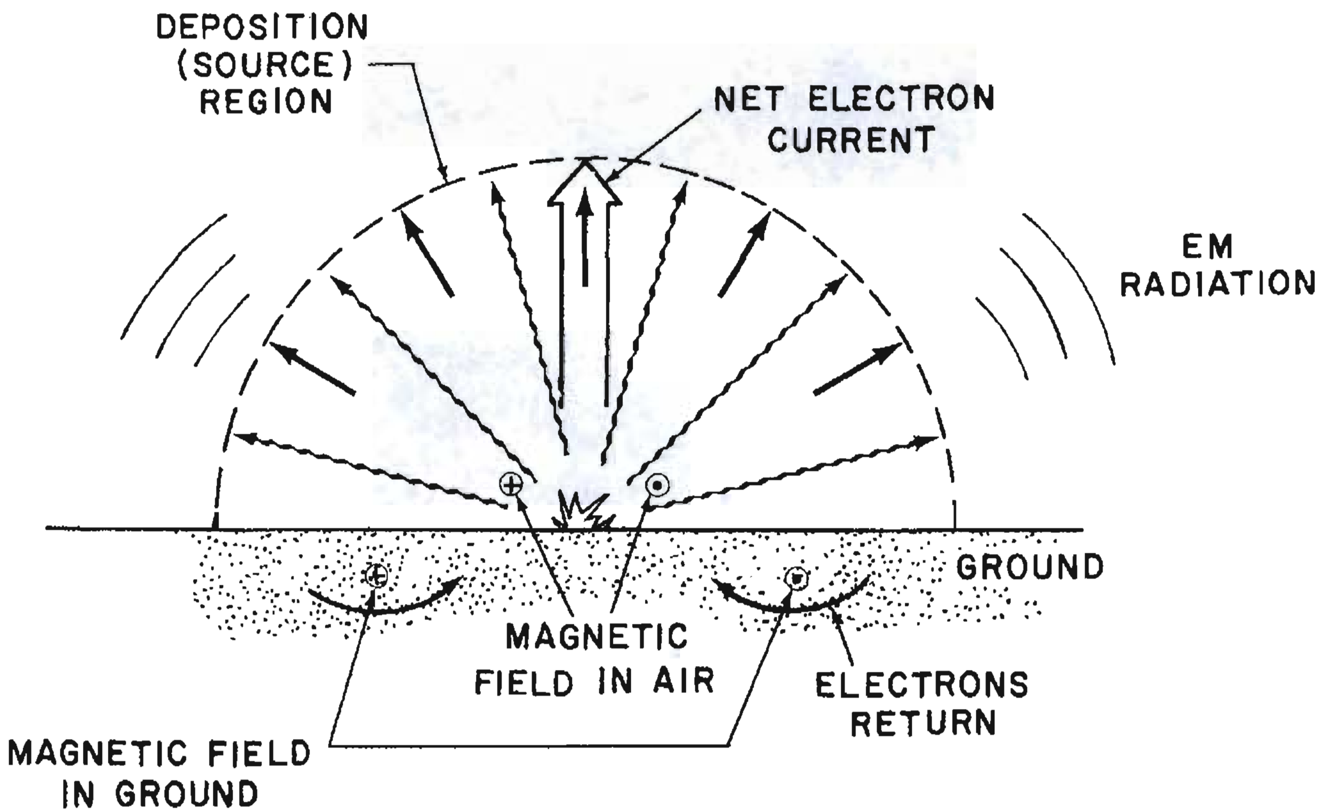
Slight variation of atmosphere with height introduces asymmetry in the mostly radial electric field, yielding a modest radiating electromagnetic pulse from an atmospheric burst.





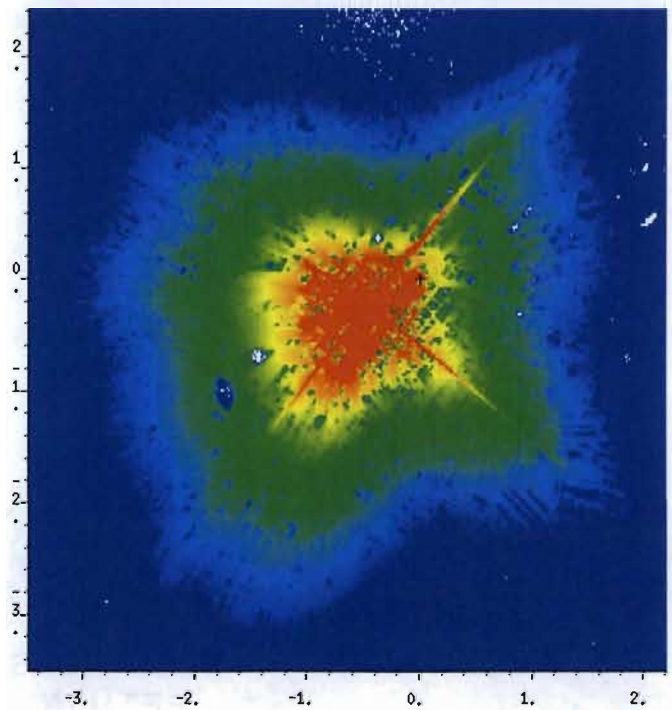
The Compton electron current is very asymmetric in a surface burst, producing a much larger electromagnetic pulse.

And the ground return current with magnetic diffusion into the ground produces notable late time electromagnetic fields.



A burst in an urban environment would be even more asymmetric.

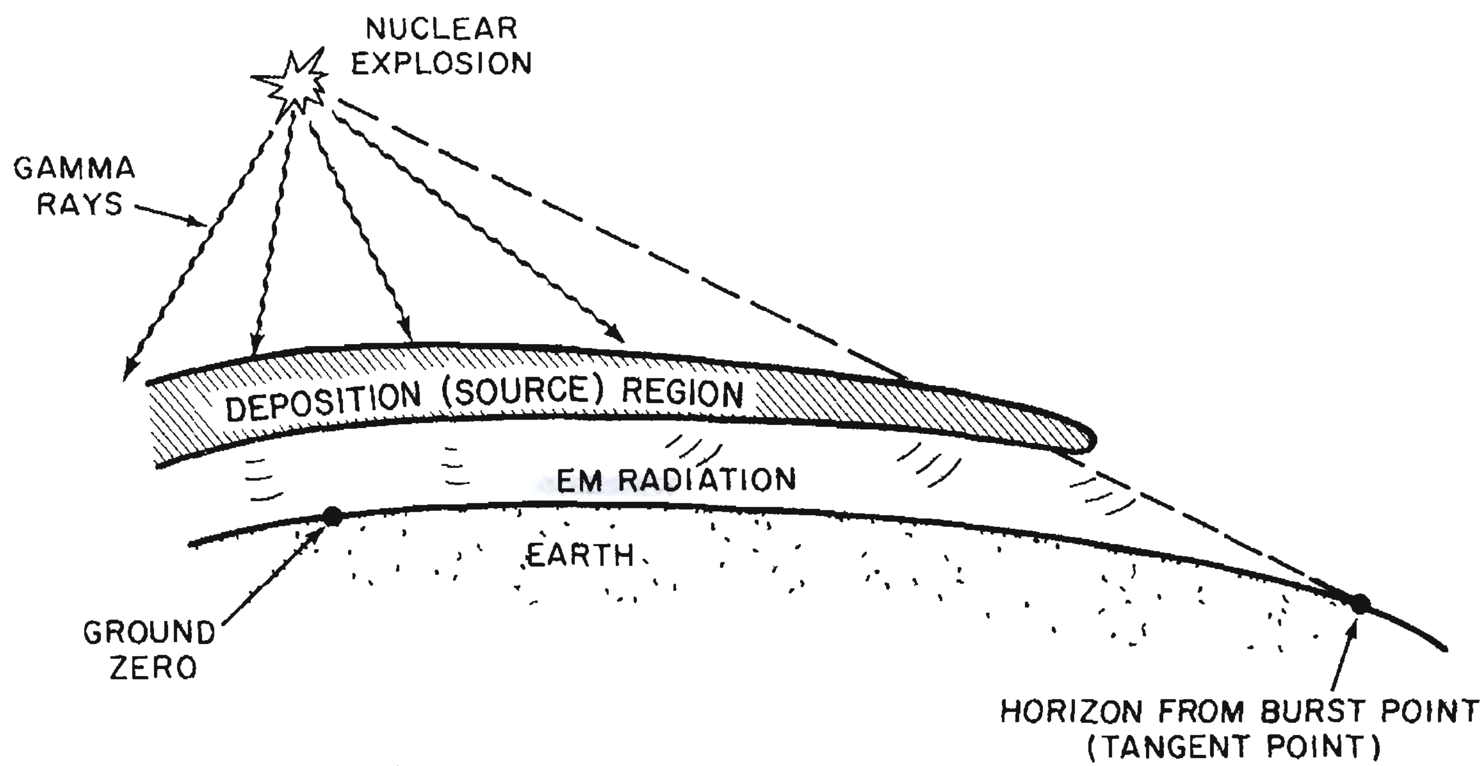
plan view of gamma ray flux



The geomagnetic field provides the asymmetry in a high altitude burst.

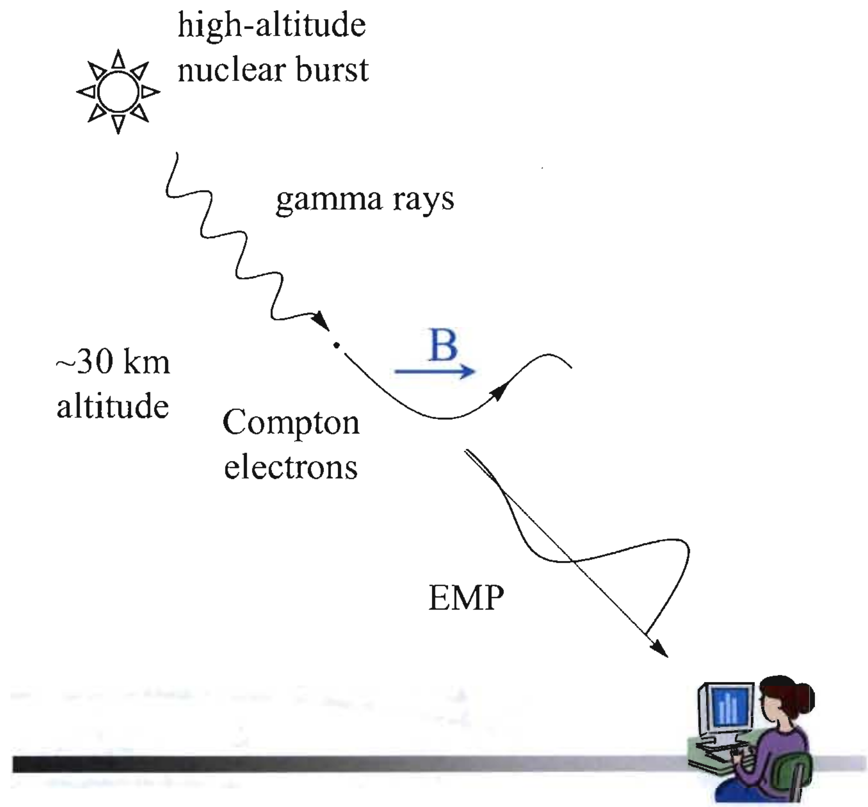
Gamma rays first have to propagate down to the sensible atmosphere.

The geomagnetic field turns radial Compton electron current to a transverse radiating Compton electron current.



What is geomagnetic electromagnetic pulse (GEMP)?

- Gamma rays from a high-altitude nuclear burst
- Compton scatter off electrons in air
- producing Compton electrons moving (mostly) radially outward
- that turn in Earth's geomagnetic field
- producing a pulse of transverse electric current
- that radiates electromagnetically in phase radially outward
- producing a large and fast-rising electromagnetic wave, the electromagnetic pulse.



Huh? My computer just died! Darn it! Guess I'll have to call computer support again. Hey! Why isn't my phone working? Geez, what's wrong with this place??? I'm going to lunch! *And then the power goes out…*

Physical phenomena modeled in a high-altitude EMP code.

- Gamma ray transport in air
  - compton scattering and pair-production
  - buildup of scattered gammas
- Compton electron generation and transport
  - multiple scattering, energy loss due to ionization
  - geomagnetic field
  - self field (the generated EMP acting back on the compton electrons)
- Air conductivity (secondary electron generation)
  - ionization by compton electrons
  - ionization/breakdown by electric field
- Electromagnetic fields
  - Compton current J and conduction current σE
  - radial electric field E_r
  - incoming and outgoing transverse electromagnetic waves ($G_{1,2}$ and $F_{1,2}$)