EMP – Facts & some Myths

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For on-line papers on this subject

www.ece.unm.edu/summa/notes

1 April 2025

HAEMP – E1 , E2 and E3

The evolution of the risetime in E1-HEMP standards has been traced and described in Giri and Prather 2013 IEEE EMC Special Issue

One can categorize the three HEMP environment time frames as:

E1 ~ first 1 μs (early time)

E2 ~ 1 μs to 1 s (intermediate times)

E3 ~ 1 s to 1000's of s (late time)

the times above are retarded times , starting at the instant of arrival at observer location.

- **In the context of the E1 waveform, unclassified standards outlined in form the basis for developing the specifications in the procurement of E-1 HEMP simulators.**

The relationship between the standards and specifications is also documented.

D. V. Giri and W. D. Prather, "High-Altitude Electromagnetic Pulse (HEMP) Risetime Evolution of Technology and Standards exclusively for E1 Environment", Special Issue on High-Altitude Electromagnetic Pulse (HEMP), volume 55, Number 3, June 2013, pp 484-491

Simple view of E1 Phenomenology

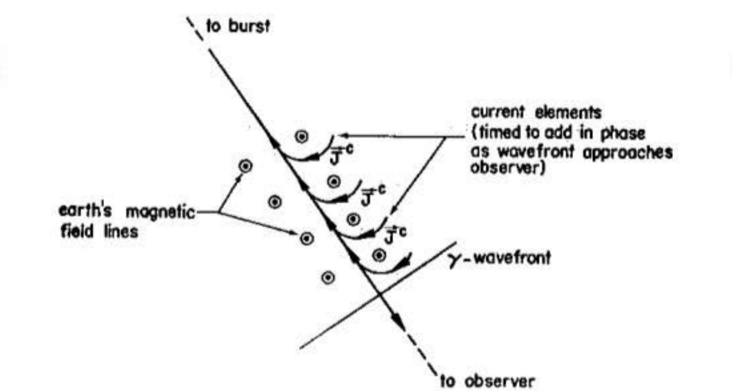


Fig. 5. Diagram indicating the current elements due to geomagnetic turning and how they add in-phase to give a large outgoing wave.

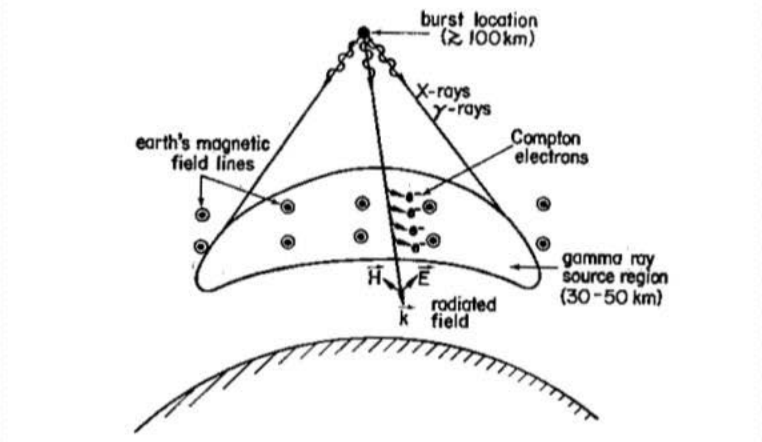
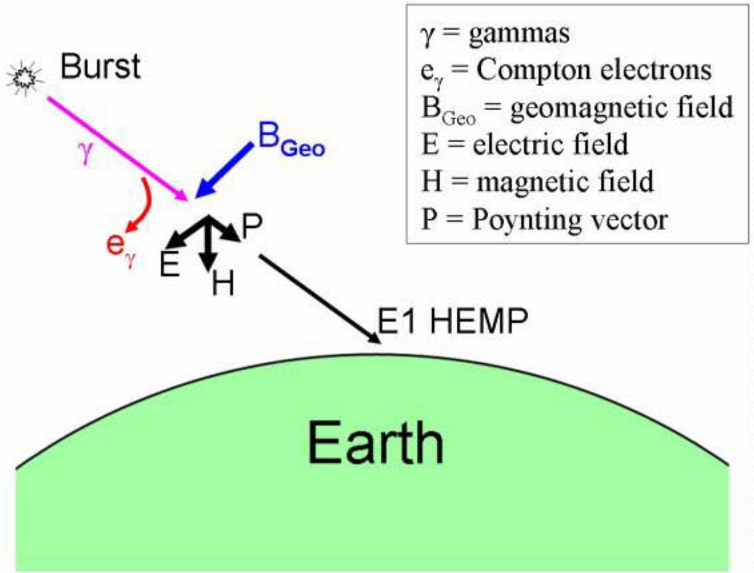
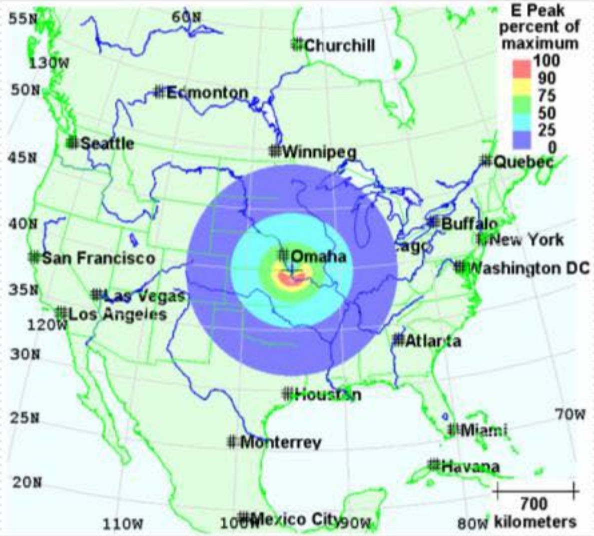


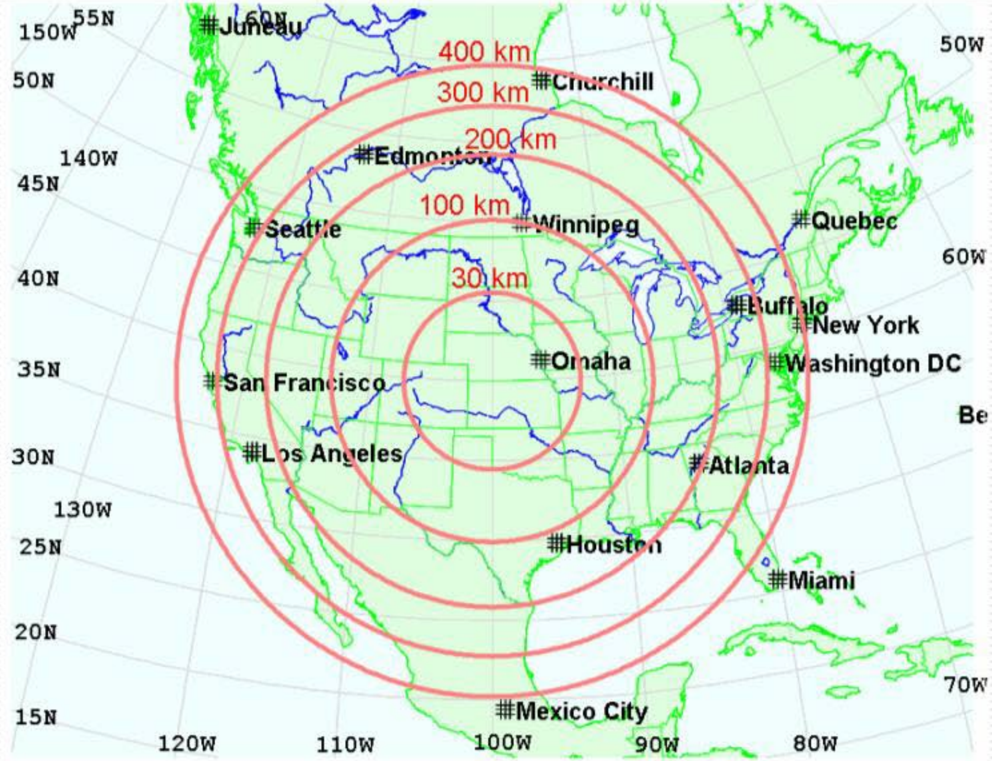
Fig. 4. Schematic representation of high-altitude EMP generation.



EMP Interaction, Principles, Techniques and Reference Data, K. S. H. Lee Editor, December 1980

“Smile Diagram” HoB = 75 km
Exposed area for varying HoB





Ref: Metatech reports cited in slides 32 and 33

Production of E1

- Gamma radiation from the nuclear detonation ionizes air atoms in the upper atmosphere.

- Compton effect and the resulting current is called the "Compton current".

- The Earth's magnetic field deflects the electron flow at a right angle to the field. This interaction produces a very large, but very brief, electromagnetic pulse over the affected area

- The correct mechanism was finally identified by Conrad Longmire of Los Alamos National Laboratory in 1963.

Production of E2

The E2 is generated by scattered gamma rays and inelastic gammas produced by neutrons.

This E2 component is an "intermediate time" pulse that lasts from about 1 microsecond to 1 second after the explosion.

E2 has many similarities to lightning, although lightning-induced E2 may be considerably larger than a nuclear E2.

Because of the similarities and the widespread use of lightning protection technology, E2 is generally considered to be the easiest to protect against.

The Problem is E2 follows E1 and E2 protective devices may be damaged already!

Production of E3

The E3 component is very different from E1 and E2.

E3 is a very slow pulse, lasting tens to hundreds of seconds.
mV/m for a long time – affecting long lines

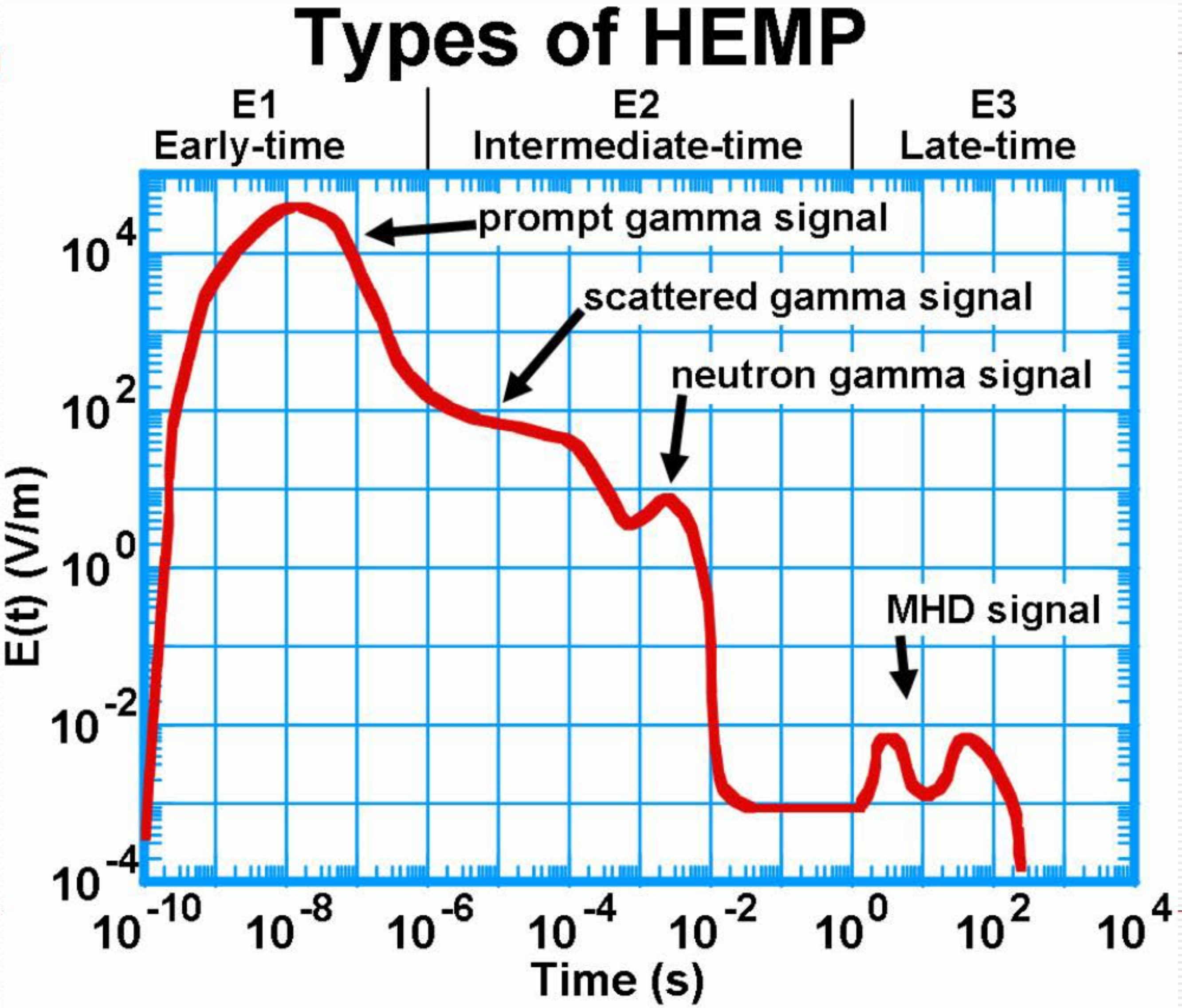
It is caused by the nuclear detonation's temporary distortion of the Earth's magnetic field.

The E3 component has similarities to a geomagnetic storm caused by a solar flare

Like a geomagnetic storm, E3 can produce geomagnetic ally induced currents in long electrical conductors, damaging components such as power line transformers

E1, E2 and E3 on one chart

This is a Magnitude plot **E3 has negative portions**

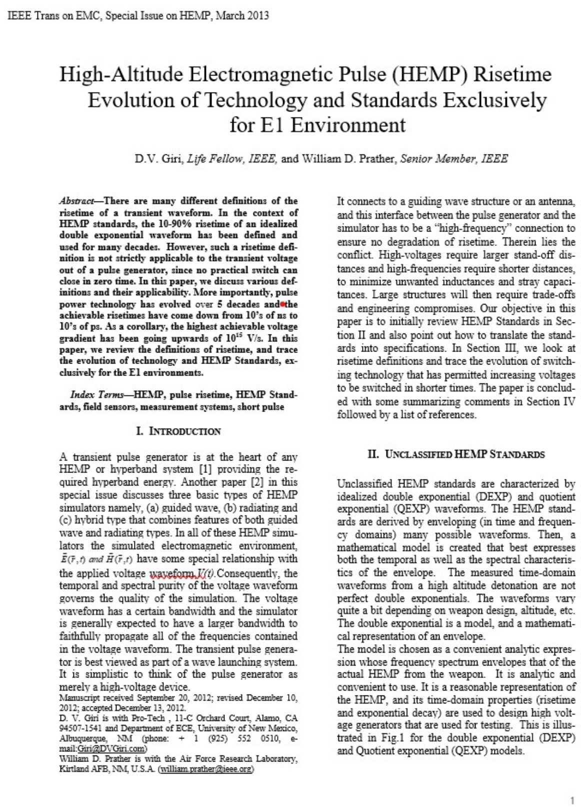


Parameters of Unclassified HEMP Standards (NOTE: IEC 77C [6] is same as DEXP in Baum [5])

	Bell Labs (1960s)	Baum (1992)		IEC-77C (1993)	Leuthäuser (1994)	VG95371-10 (1995)	IEC 61000-2-9 (1996)
		DEXP	QEXP				
Parameter	DEXP			DEXP	QEXP	DEXP	DEXP
Reference	[4]	[5]		[6]	[7]	[8]	[9]
$t_{10\%-90\%}$	4.6 ns	2.5 ns	2.4 ns	2.5 ns	1.9 ns	0.9 ns	2.5 ns
Peak Field E_0	50 kV/m	50 kV/m	50 kV/m	50 kV/m	60 kV/m	65 kV/m	50 kV/m
FWHM	184 ns	~23 ns	~24 ns	23 ns	23.8 ns	24.1 ns	23 ns
constant	1.05	1.3	1.114	1.3	1.08	1.085	1.3
a (1/sec)	$4x10^6$	$4x10^7$	$1.6x10^9$	$4x10^7$	$2.20x10^9$	$3.22x10^7$	$4x10^7$
b (1/sec)	$4.76x10^8$	$6x10^8$	$3.7x10^7$	$6x10^8$	$3.24x10^7$	$2.07x10^9$	$6x10^8$
Energy Density (J/m^2)	0.891	0.114	0.107	0.114	0.167	0.196	0.114

The references in this page can be found in Giri-Prather paper cited on Slide 2

Time Domain Plots of the unclassified civilian HEMP E1 standards



IEEE Trans on EMC, Special Issue on HEMP, March 2013

High-Altitude Electromagnetic Pulse (HEMP) Risetime Evolution of Technology and Standards Exclusively for E1 Environment

D.V. Giri, *Life Fellow, IEEE,* and William D. Prather, *Senior Member, IEEE*

***Abstract*—There are many different definitions of the risetime of a transient waveform. In the context of HEMP standards, the 10-90% risetime of an idealized double exponential waveform has been defined and used for many decades. However, such a risetime definition is not strictly applicable to the transient voltage out of a pulse generator, since no practical switch can close in zero time. In this paper, we discuss various definitions and their applicability. More importantly, pulse power technology has evolved over 5 decades and the achievable risetimes have come down from 10's of ns to 10's of ps. As a corollary, the highest achievable voltage gradient has been going upwards of 10^{15} V/s. In this paper, we review the definitions of risetime, and trace the evolution of technology and HEMP Standards, exclusively for the E1 environments.**

***Index Terms*—HEMP, pulse risetime, HEMP Standards, field sensors, measurement systems, short pulse**

I. Introduction

A transient pulse generator is at the heart of any HEMP or hyperband system [1] providing the required hyperband energy. Another paper [2] in this special issue discusses three basic types of HEMP simulators namely, (a) guided wave, (b) radiating and (c) hybrid type that combines features of both guided wave and radiating types. In all of these HEMP simulators the simulated electromagnetic environment, $\bar{E}(\bar{r},t)$ *and* $\bar{H}(\bar{r},t)$ have some special relationship with the applied voltage waveform $V(t)$. Consequently, the temporal and spectral purity of the voltage waveform governs the quality of the simulation. The voltage waveform has a certain bandwidth and the simulator is generally expected to have a larger bandwidth to faithfully propagate all of the frequencies contained in the voltage waveform. The transient pulse generator is best viewed as part of a wave launching system. It is simplistic to think of the pulse generator as merely a high-voltage device.

Manuscript received September 20, 2012; revised December 10, 2012; accepted December 13, 2012.

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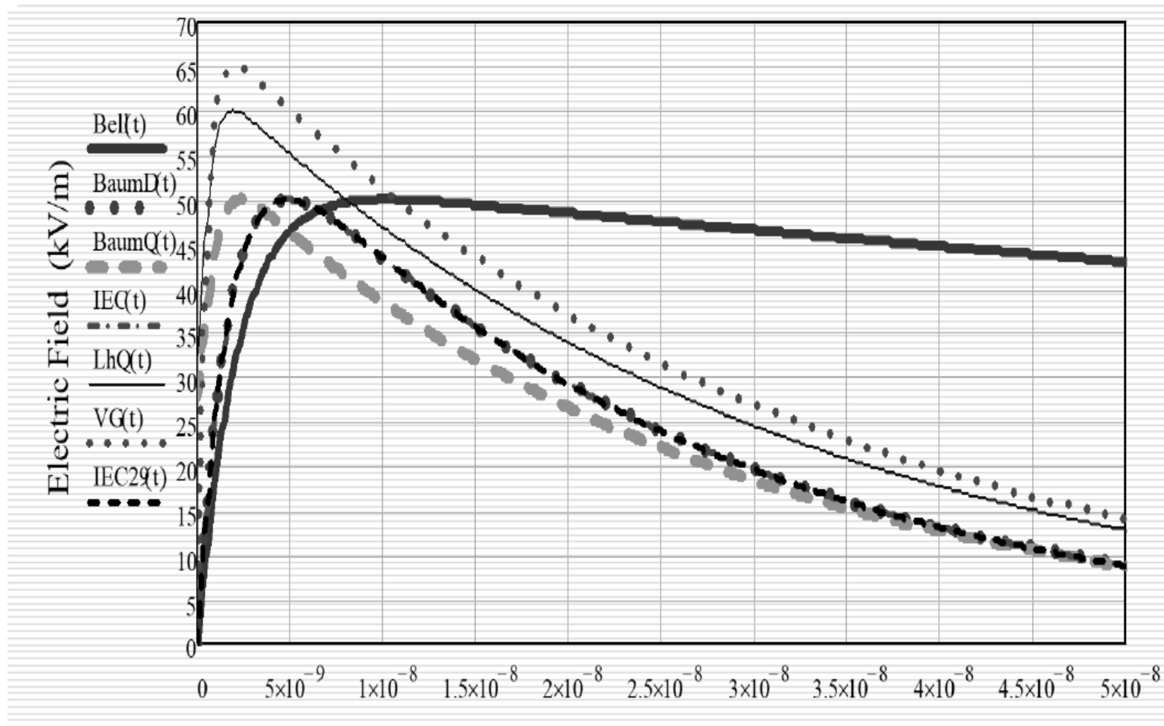
William D. Prather is with the Air Force Research Laboratory, Kirtland AFB, NM, U.S.A. (william.prather@ieee.org)

It connects to a guiding wave structure or an antenna, and this interface between the pulse generator and the simulator has to be a "high-frequency" connection to ensure no degradation of risetime. Therein lies the conflict. High-voltages require larger stand-off distances and high-frequencies require shorter distances, to minimize unwanted inductances and stray capacitances. Large structures will then require trade-offs and engineering compromises. Our objective in this paper is to initially review HEMP Standards in Section II and also point out how to translate the standards into specifications. In Section III, we look at risetime definitions and trace the evolution of switching technology that has permitted increasing voltages to be switched in shorter times. The paper is concluded with some summarizing comments in Section IV followed by a list of references.

II. Unclassified HEMP Standards

Unclassified HEMP standards are characterized by idealized double exponential (DEXP) and quotient exponential (QEXP) waveforms. The HEMP standards are derived by enveloping (in time and frequency domains) many possible waveforms. Then, a mathematical model is created that best expresses both the temporal as well as the spectral characteristics of the envelope. The measured time-domain waveforms from a high altitude detonation are not perfect double exponentials. The waveforms vary quite a bit depending on weapon design, altitude, etc. The double exponential is a model, and a mathematical representation of an envelope.
The model is chosen as a convenient analytic expression whose frequency spectrum envelopes that of the actual HEMP from the weapon. It is analytic and convenient to use. It is a reasonable representation of the HEMP, and its time-domain properties (risetime and exponential decay) are used to design high voltage generators that are used for testing. This is illustrated in Fig.1 for the double exponential (DEXP) and Quotient exponential (QEXP) models.



THEORETICAL NOTES

Note 363

October 1992

A COMPLETE EMP ENVIRONMENT GENERATED BY HIGH-ALTITUDE NUCLEAR BURSTS

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Appelsgarten 2, 5350 Euskirchen (Germany)

ABSTRACT

Very few papers are available in the open literature on high-altitude nuclear EMP fields offering detailed quantitative results for the whole variety of weapon related input parameters (i.e. gamma yield, energy and pulse shape) and scenario oriented quantities (i.e. height of burst, observer location with regard to Ground Zero).

The EXEMP code developed by the author is extensively employed for systematic variation of the above mentioned parameters. The code is self-consistent, i.e. solves the equation of motion of the Compton electrons in the presence of EMP generated collective electric and magnetic fields. The basic approximation is still the high-frequency or outgoing-wave approximation of the Maxwell equations in retarded time which are thus reduced to ordinary differential equations.

Equations of motion of Compton electrons, electron density rate equations and Maxwell equations are solved numerically by means of a fourth order Runge-Kutta algorithm. The influence of the various input parameters on the incident electromagnetic fields will be extensively discussed, including 'smile-face' diagrams and plots showing pulse width, power per unit area and polarization dependent on observer location.

Computations in the form of Figures from this reference are reproduced in the next 6 slides.

E field v. Gamma Yield

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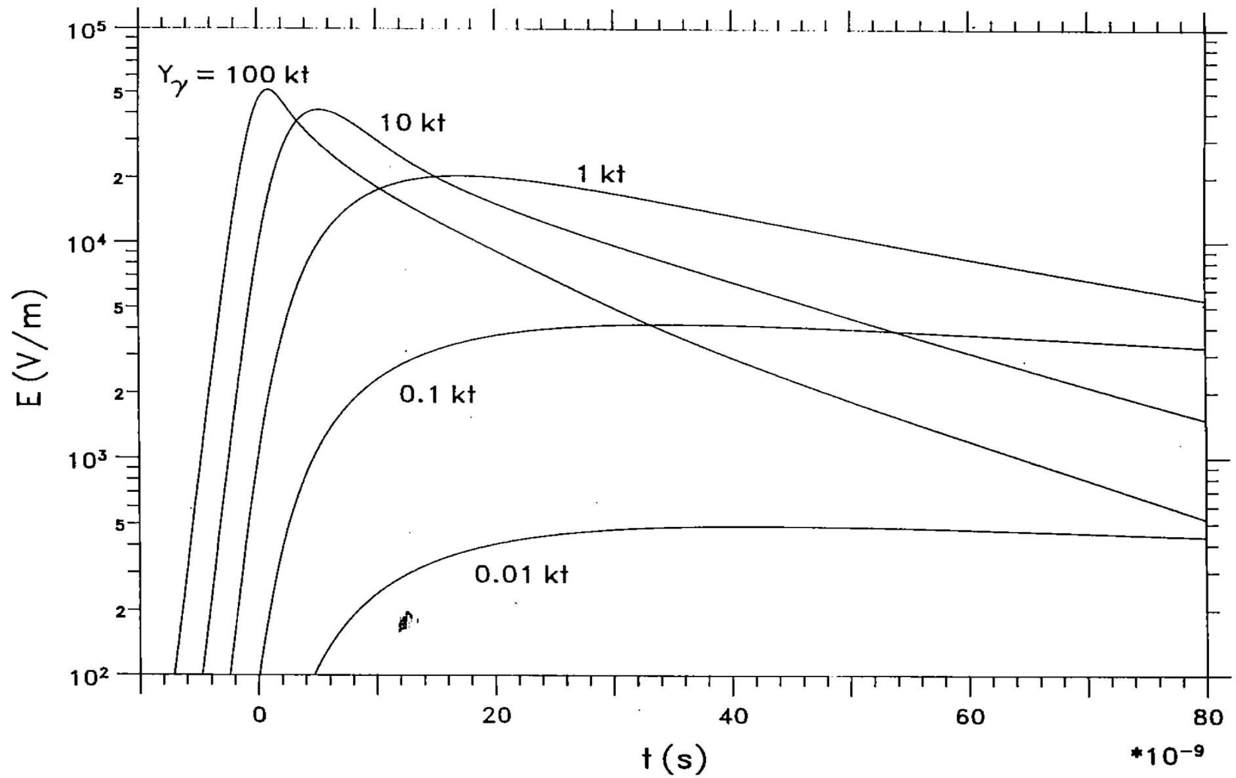


Fig. 1	Variation of total electric field with gamma yield

E field v. Height of Burst (HoB)

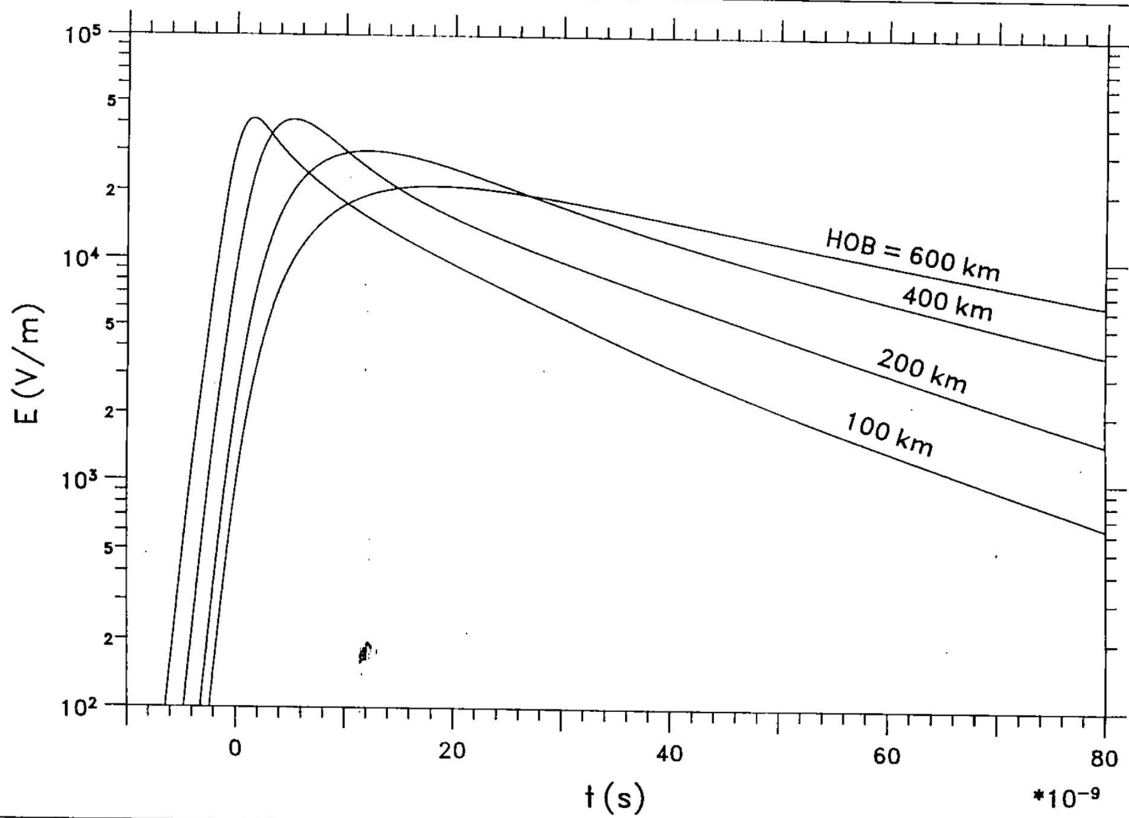


Fig. 2	Variation of total electric field with height of burst

E field v. Yield Energy

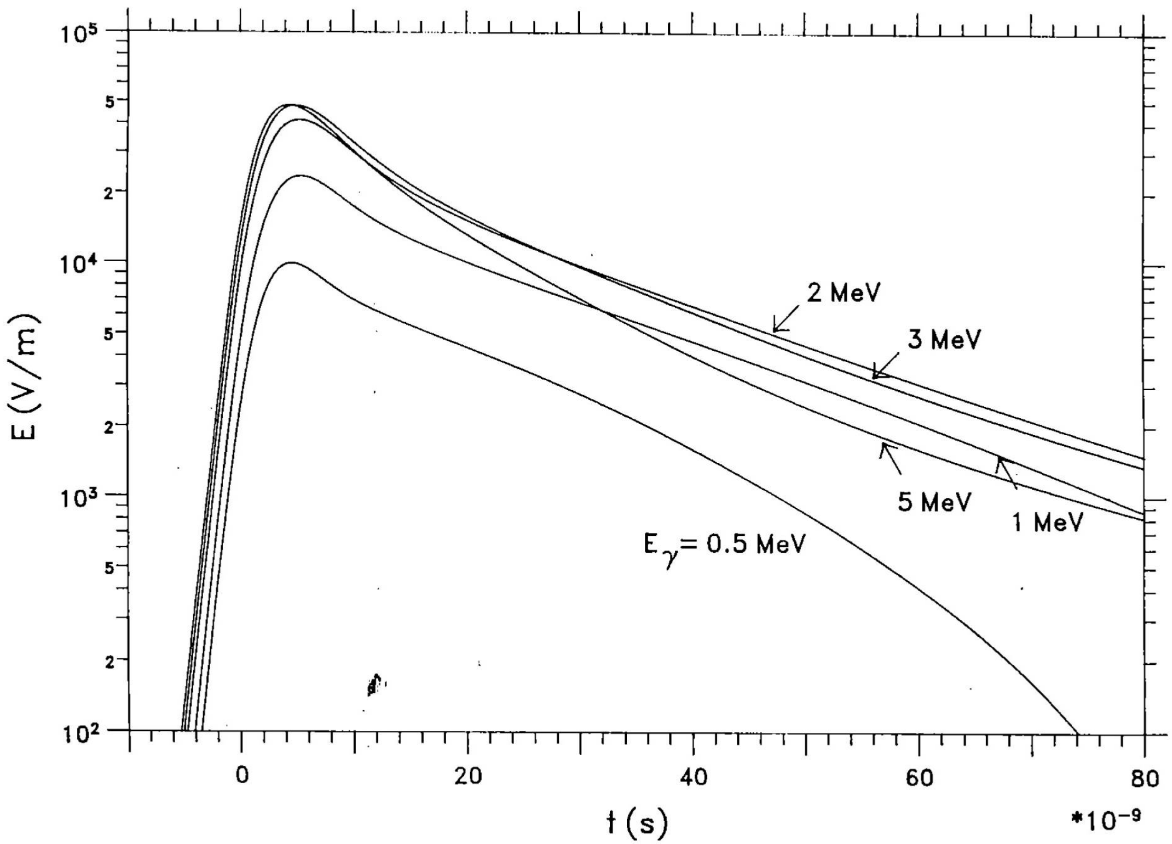


Fig. 3 | Total electric field for various energies of source gammas

E field v. Gamma pulse risetime

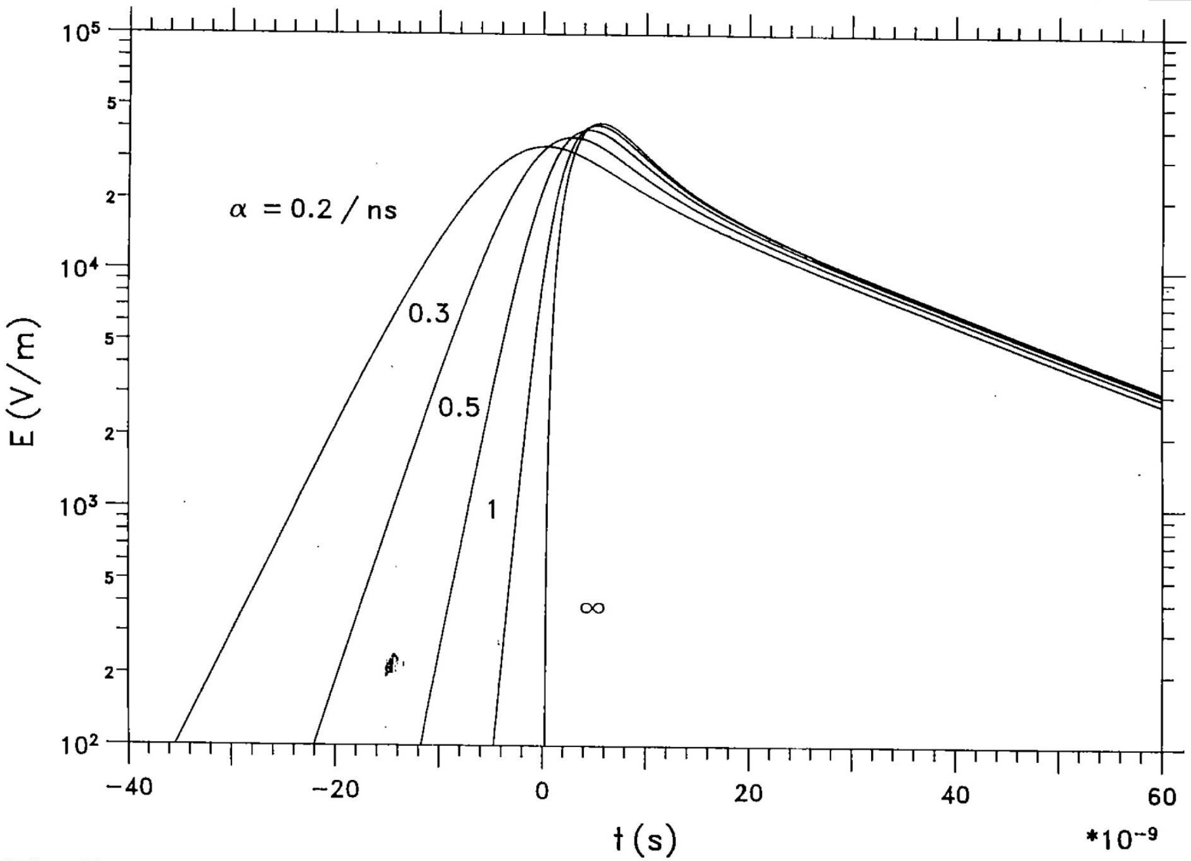


Fig. 4	Total electric field (field magnitude) for various gamma pulse rise times 1/Alpha

E field v. Gamma Pulse decay times

28

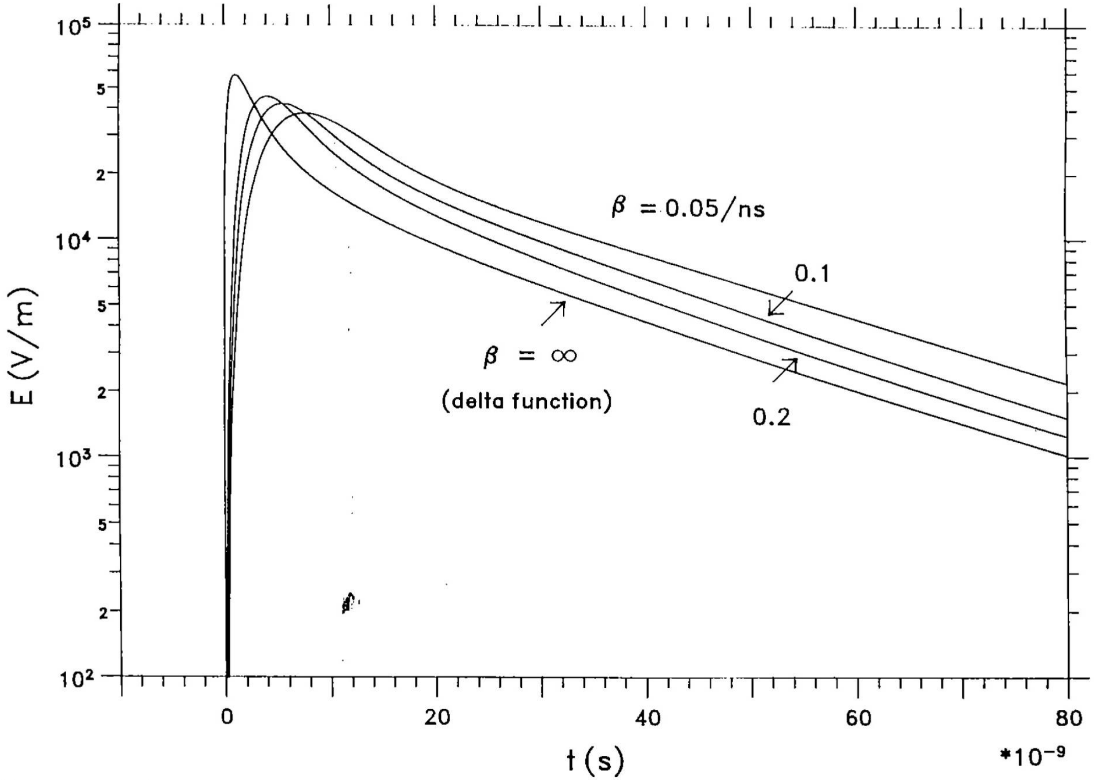
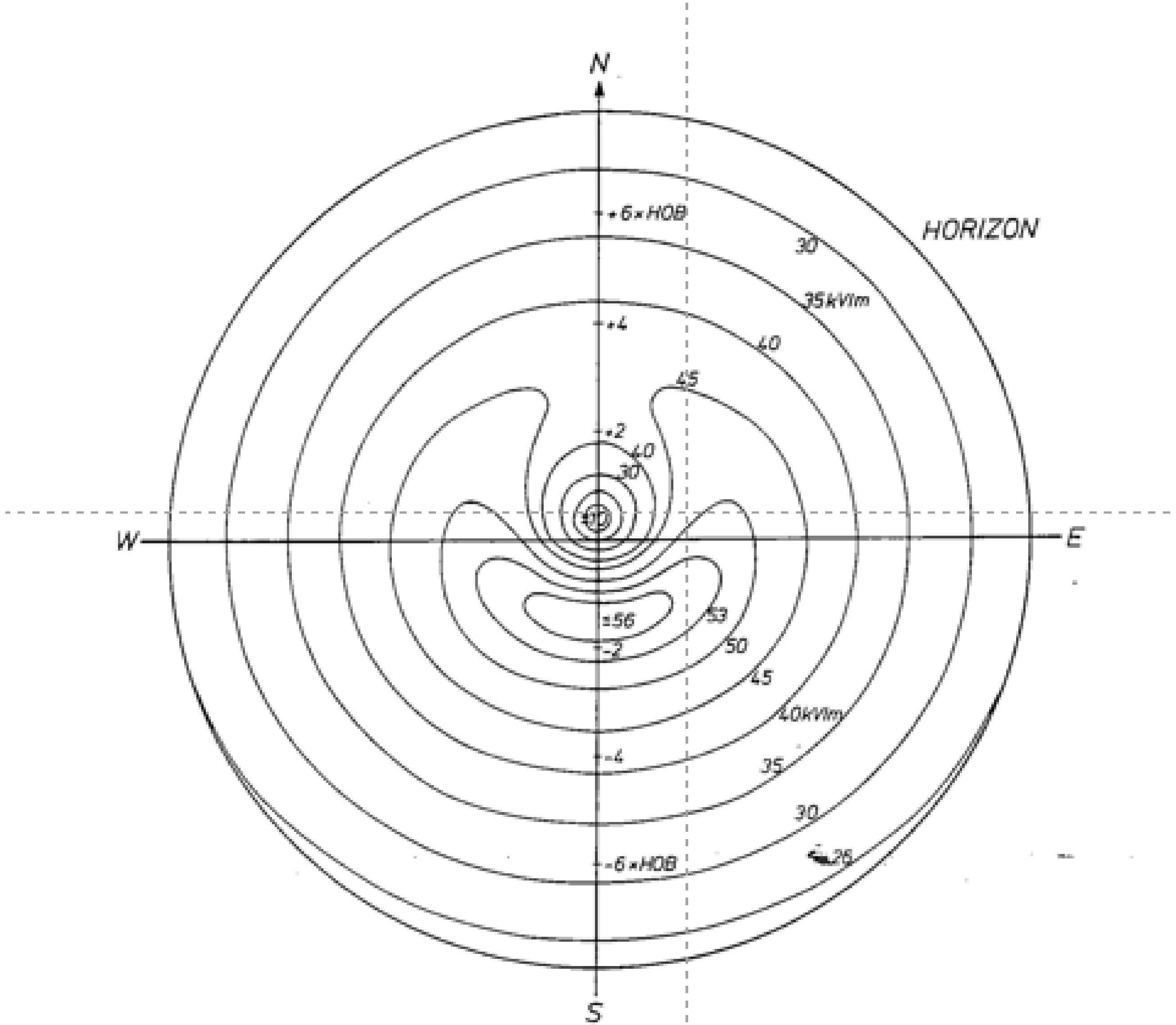


Fig. 5	Total electric field for various gamma pulse decay times 1/Beta

Contour Plot of Peak E field



General requirements for LLPMs. HEMP protection provided by LLPMs shall consist of linear and nonlinear transient suppression/attenuation devices or dielectric isolation techniques, as required to satisfy the performance requirements. When prescribed pulses (see table III) are injected at the long-line terminal of an LLPM, the norms of the residual response stresses at the intrasite cable terminal shall not exceed the maximums (see table IV) for the applicable class of LLPM[5]. Additionally, the LLPM shall be designed to withstand a sufficient number of test pulses at the prescribed current without damage or unacceptable performance degradation to accommodate life-cycle testing.

Power line LLPM requirements. A Norton source with a 2,500-A short-circuit current, ≤ 20-ns risetime and 500-550-ns FWHM, and ≥ 60-Ω source impedance, connected to the long-line terminal of a power line LLPM, shall produce a residual response stress at the intrasite cable terminal no greater than 250 A and shall not cause unacceptable LLPM damage or performance degradation[5].

A Norton source with a 250-A short-circuit current, ≤ 1.5-μs risetime and 3-5-ms FWHM, and ≥ 10-Ω source impedance, connected to the long-line terminal of a power line LLPM, shall not cause unacceptable LLPM damage or performance degradation[5].

A Norton source with a 1,000-A short-circuit current, ≤ 0.2-s risetime and 20-25-s FWHM, and ≥ 5-Ω source impedance, connected to the long-line terminal of a power line LLPM, shall produce a residual response stress at the intrasite cable terminal no greater than 10 A and shall not cause unacceptable LLPM damage or performance degradation[5].

Page 42 of MIL-STD-125-2

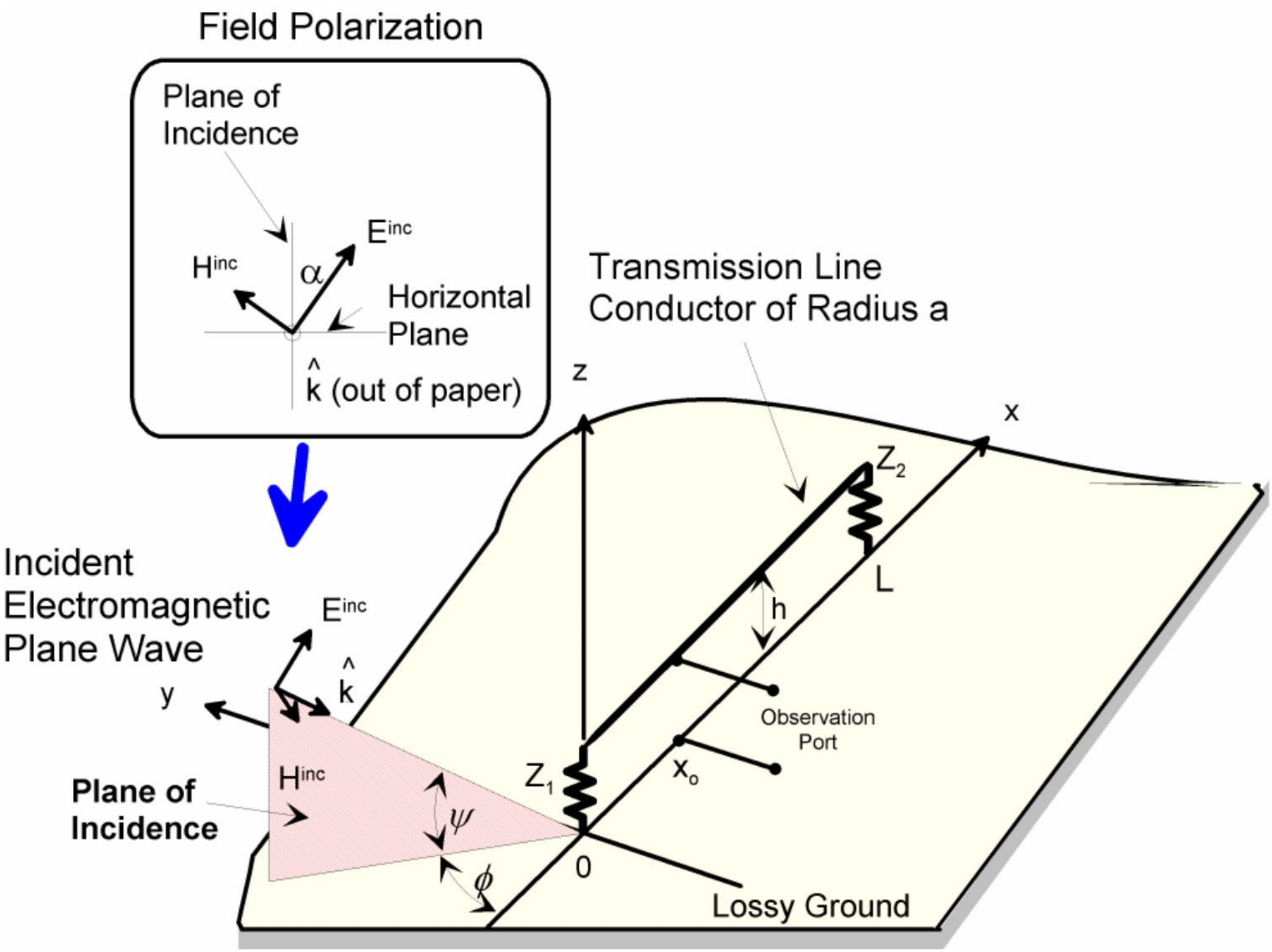
TABLE III. Norton source parameters, waveforms, and acceptance test loads for LLPM injection specifications.

20 ns

Class of LLPM/ Type of Injection[1]	Peak Short-Circuit Current (A)	Source Impedance (ohms)	Risetime (s)	FWHM (s)	Acceptance Test Resistance (ohms)
Power line LLPMs					
Short pulse common mode[2]	5,000	≥ 60	$\leq 2\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}	Not applicable
Short pulse wire-to-ground[3]	2,500	≥ 60	$\leq 2\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}	2
Intermediate pulse common mode[2]	250	≥ 10	$\leq 1.5\times10^{-6}$	3×10^{-3} - 5×10^{-3}	Not applicable
Intermediate pulse wire-to-ground[3]	250	≥ 10	$\leq 1.5\times10^{-6}$	3×10^{-3} - 5×10^{-3}	50
Long pulse common mode[2]	[4] 1,000	≥ 5	≤ 0.2	[4] 20-25	Not applicable
Long pulse wire-to-ground[3]	[4] 1,000	≥ 5	≤ 0.2	[4] 20-25	50
Control/signal/data line LLPMs					
Short pulse common mode[2]	5,000	≥ 60	$\leq 2\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}	Not applicable
Short pulse wire-to-ground[3]	[5] 5,000/$\sqrt{N}$ or 500	≥ 60	$\leq 2\times10^{-8}$	5×10^{-7} - 5.5×10^{-7}	50
Intermediate pulse common mode[2]	250	≥ 10	$\leq 1.5\times10^{-6}$	3×10^{-3} - 5×10^{-3}	Not applicable
Intermediate pulse wire-to-ground[3]	250	≥ 10	$\leq 1.5\times10^{-6}$	3×10^{-3} - 5×10^{-3}	50
Long pulse common mode[2]	[4] 1,000	≥ 5	≤ 0.2	[4] 20-25	Not applicable
Long pulse wire-to-ground[3]	[4] 1,000	≥ 5	≤ 0.2	[4] 20-25	50

Short, Intermediate and Long-term pulse in the above refers to E1, E2 and E3 respectively

Problem Definition
E1 pulse Incident on a Overhead wire



- ✓ We have a MathCAD routine

- ✓ Where one can input
    - a) the E1 Waveform,
    - b) overhead wire parameters and
    - c) the ground properties.

- ✓ The routine computes the induced current and voltages on the overhead wire

- ✓ This code is demonstrated in the next few slides

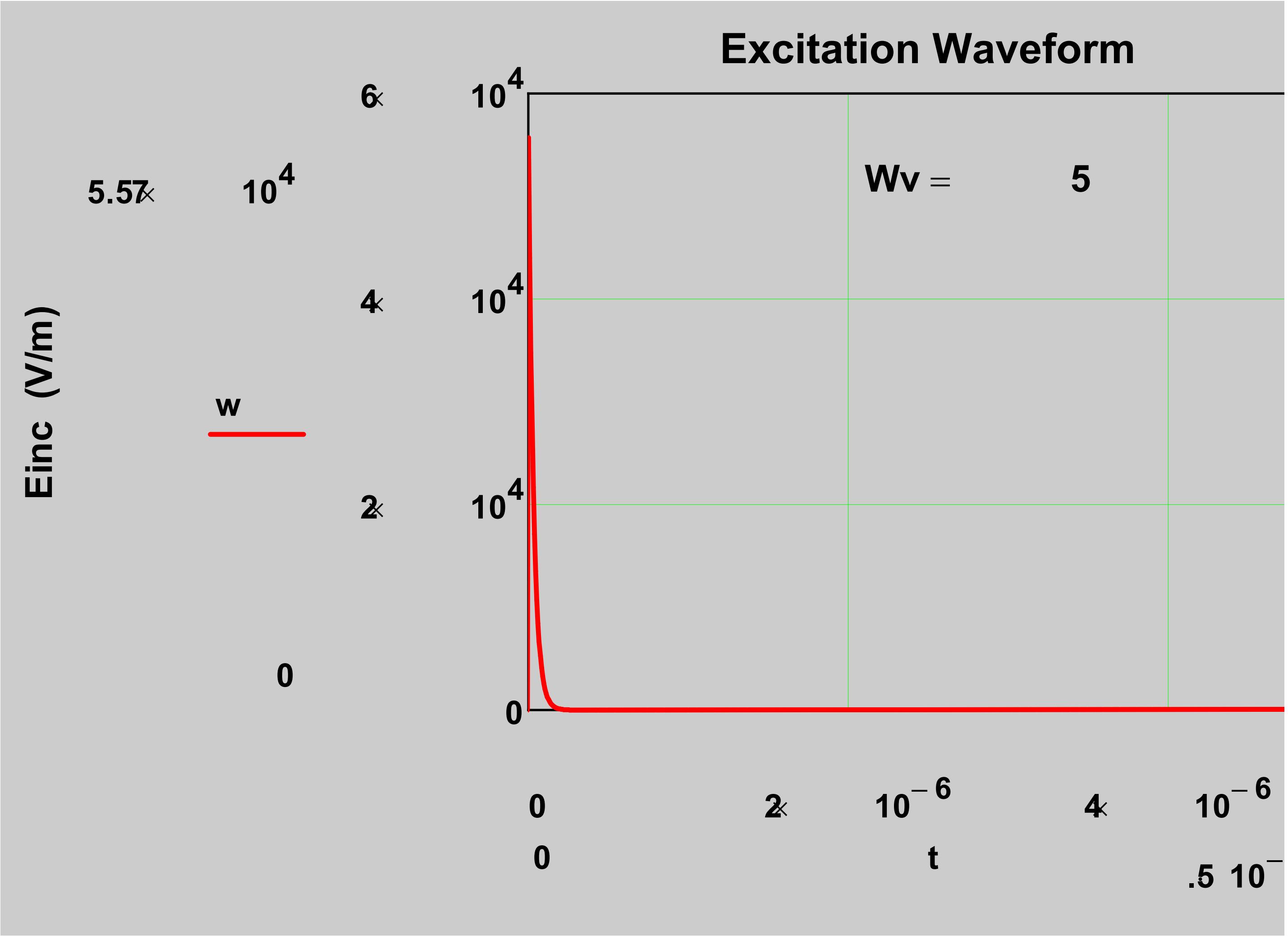
Select any one of the 6 Unclassified E1 Waveform . This includes the fast VG Waveform

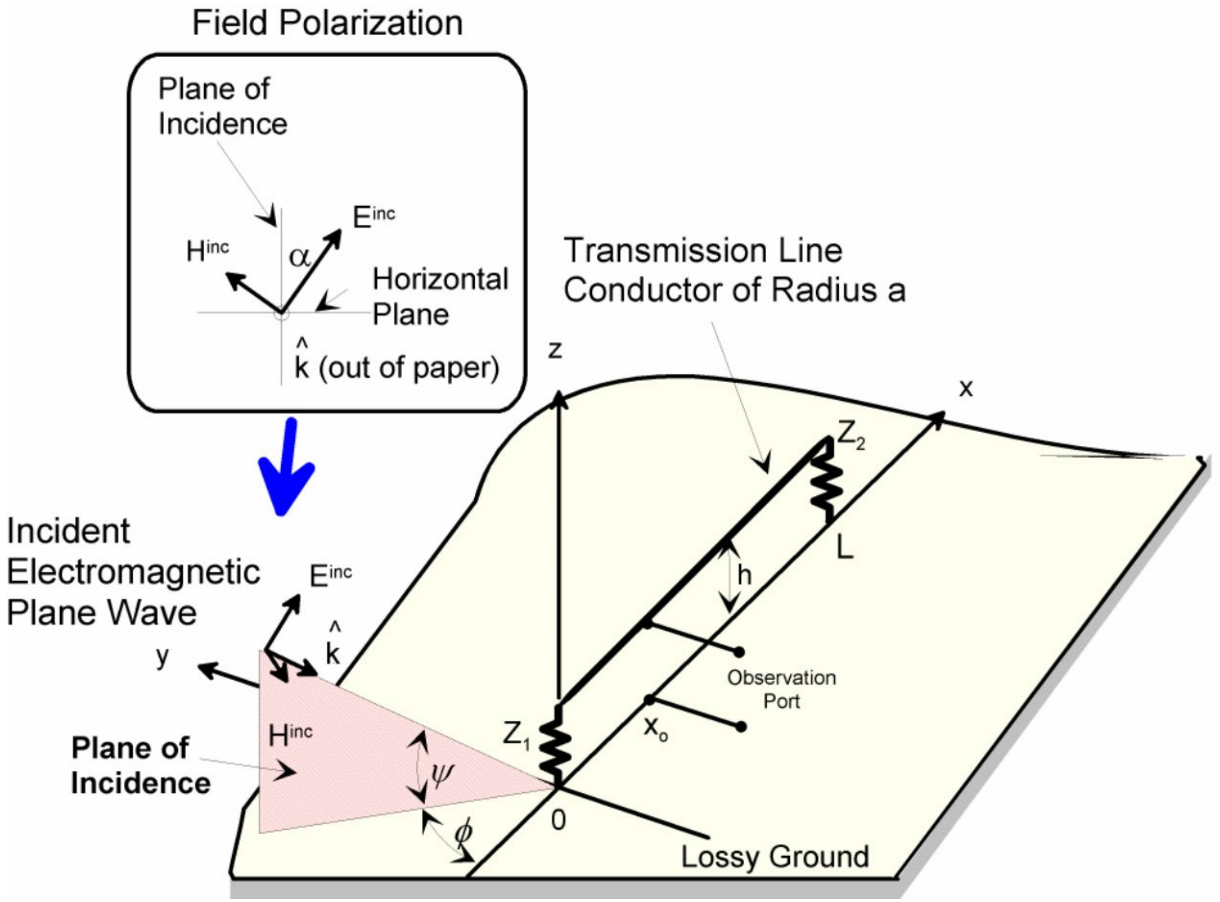
Bell Laboratory Waveform (DEXP)	$Eo_1 := 50000$	$G_1 := 1.05$	$\alpha_1 := 4 \cdot 10^6$	$\beta_1 := 4.76 \cdot 10^8$
Baum #1(DEXP)	$Eo_2 := 50000$	$G_2 := 1.3$	$\alpha_2 := 4 \cdot 10^7$	$\beta_2 := 6 \cdot 10^8$
Baum #2 (QEXP)	$Eo_3 := 50000$	$G_3 := 1.114$	$\alpha_3 := 1.6 \cdot 10^9$	$\beta_3 := 3.7 \cdot 10^7$
Leuthauser (QEXP)	$Eo_4 := 60000$	$G_4 := 1.08$	$\alpha_4 := 2.20 \cdot 10^9$	$\beta_4 := 3.24 \cdot 10^7$
VG95371-10 (DEXP)	$Eo_5 := 65000$	$G_5 := 1.085$	$\alpha_5 := 3.22 \cdot 10^7$	$\beta_5 := 2.07 \cdot 10^9$
IEC 6100-2-9 (DEXP)	$Eo_6 := 50000$	$G_6 := 1.3$	$\alpha_6 := 4 \cdot 10^7$	$\beta_6 := 6 \cdot 10^8$

$$\mathbf{DEXP}(t, E, \Gamma, \alpha, \beta) := \left| \begin{array}{l} \rho \leftarrow 0 \quad \text{if} \quad t < ts \\ \rho \leftarrow E \cdot \Gamma \cdot \left[e^{-\alpha \cdot (t - ts)} - e^{-[\beta \cdot (t - ts)]} \right] \quad \text{otherwise} \\ \rho \end{array} \right.$$

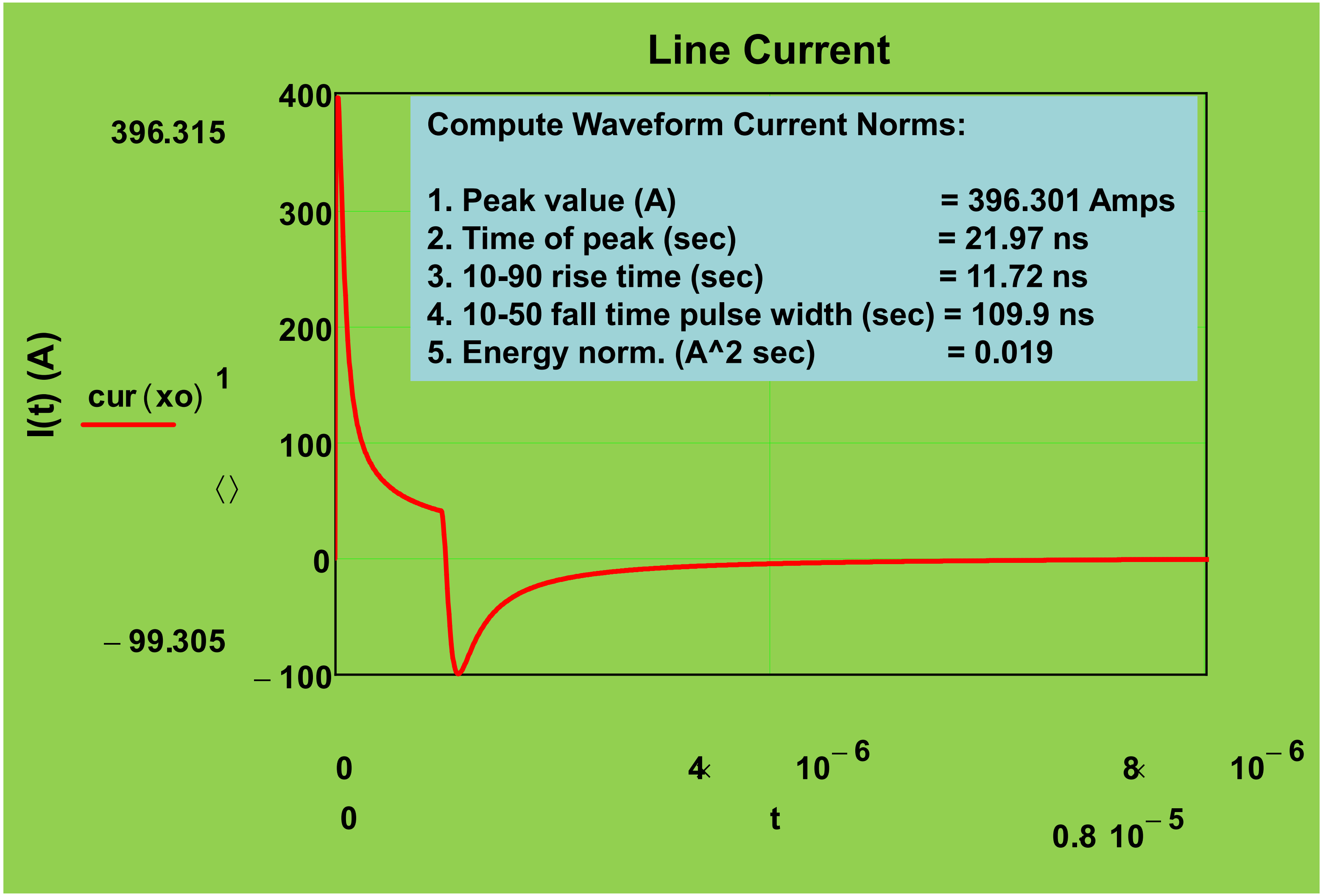
$$\mathbf{QEXP}(t, E, \Gamma, \alpha, \beta) := E \cdot \Gamma \cdot \frac{e^{-\beta \cdot (t - ts)}}{e^{-(\alpha + \beta) \cdot (t - ts)} + 1}$$

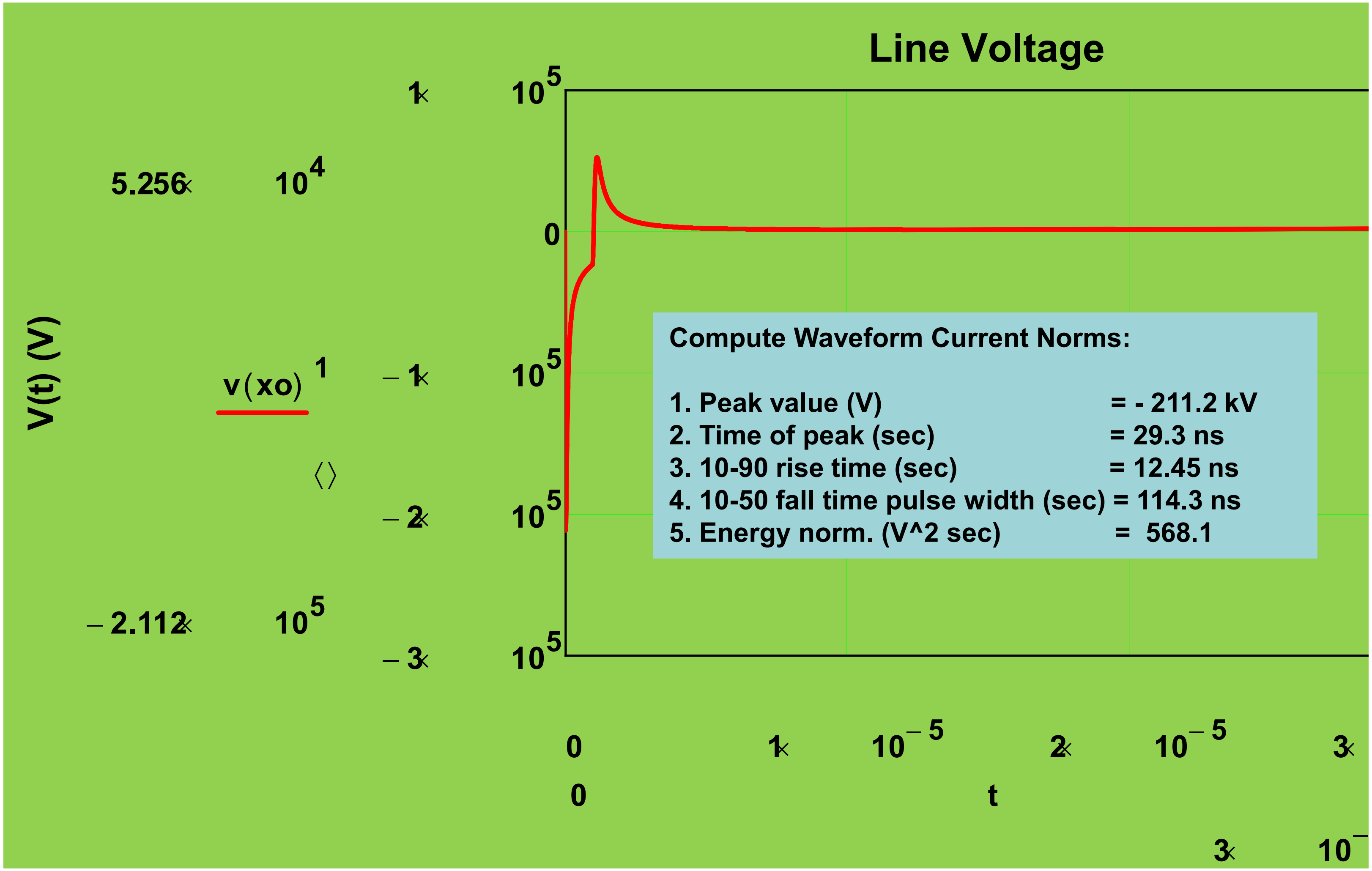
Example Calculation : Wv = 5 VG 95371-10 E1 Waveform
peak = 65 kV/m. Risetime = 0.9 ns FWHM = 24.1 ns





Wire parameters	**Incident field angles**	**Earth parameters**
Length of wire = 1000m	ψ = 45 deg	conductivity = 0.01 mho/m
Height = 3 m	ϕ = 0 deg	dielectric constant = 10
Radius = 1 mm	α = 0 deg	

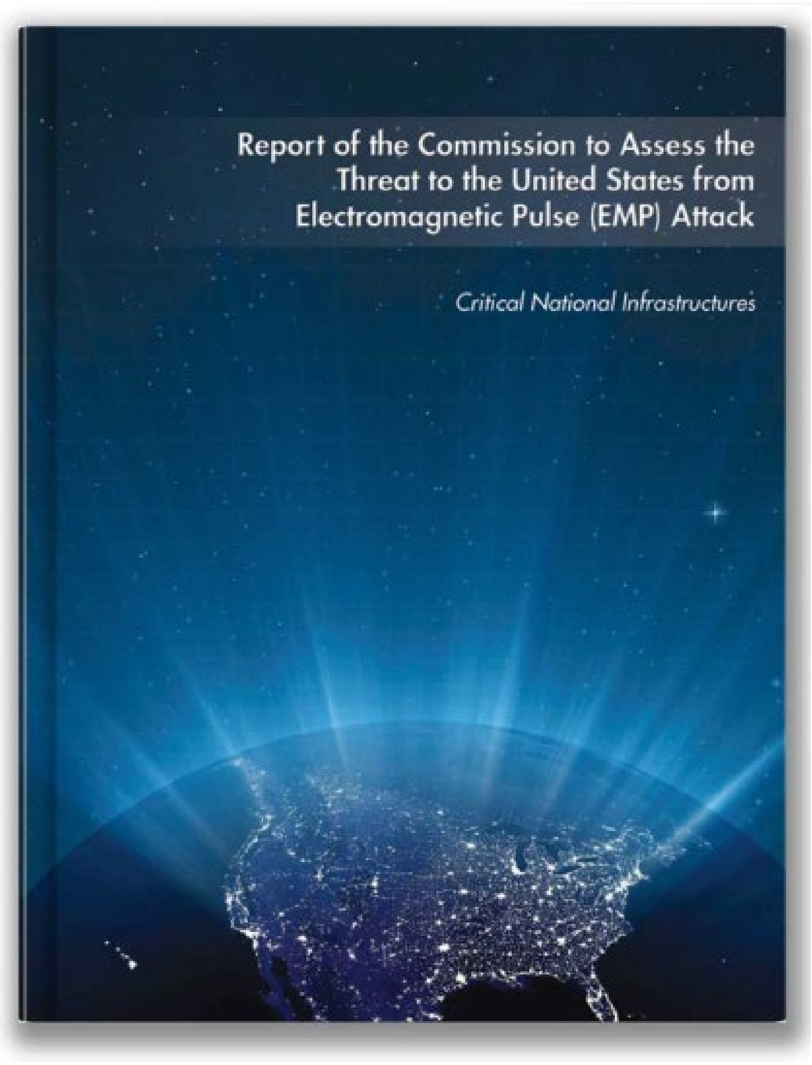

Line Current
Compute Waveform Current Norms:
1. Peak value (A) = 396.301 Amps
2. Time of peak (sec) = 21.97 ns
3. 10-90 rise time (sec) = 11.72 ns
4. 10-50 fall time pulse width (sec) = 109.9 ns
5. Energy norm. (A^2 sec) = 0.019
396.315
I(t) (A)
cur (xo) 1
⟨⟩
– 99.305
400
300
200
100
0
– 100
0
4× 10^– 6
8× 10^– 6
0
t
0.8 10^– 5


Line Voltage
V(t) (V)
v(xo)
t
Compute Waveform Current Norms:
1. Peak value (V) = - 211.2 kV
2. Time of peak (sec) = 29.3 ns
3. 10-90 rise time (sec) = 12.45 ns
4. 10-50 fall time pulse width (sec) = 114.3 ns
5. Energy norm. (V^2 sec) = 568.1

Summarizing Remarks on EMP Environments and Coupling to Power lines

- ✓ We see that for E1 risetime of 0.9 ns, the risetime of the induced current and voltage can be ~ 20 ns.
- ✓ There is no simple formula for the risetime of the induced current or voltage, if we know the risetime of the incident E1 waveform.
- ✓ Many factors influence induced current parameters, such as
  wire parameter (length, height and radius)
  incident field parameters , angles and polarization
  lossy earth parameters.
- ✓ We have seen an induced current as high as 800 Amps and risetime of 15 ns etc., Too many parametric variation and a detailed study may be performed.

EMP Commission – U.S. Congressional Committee Report available at: http://www.empcommission.org/docs/A2473-EMP_Commission-7MB.pdf



Commission Members :

Dr. John S. Foster, Jr.
Mr. Earl Gjelde
Dr. William R. Graham (Chairman)*
Dr. Robert J. Hermann
Mr. Henry (Hank)
M. Kluepfel
Gen Richard L. Lawson, USAF (Ret.)
Dr. Gordon K. Soper
Dr. Lowell L. Wood, Jr.
Dr. Joan B. Woodard April 2008

- Dr. Graham wrote a Foreword to Dave Giri's latest book published in 2020.

A System of Systems

Power System is the most critical Infrastructure Element

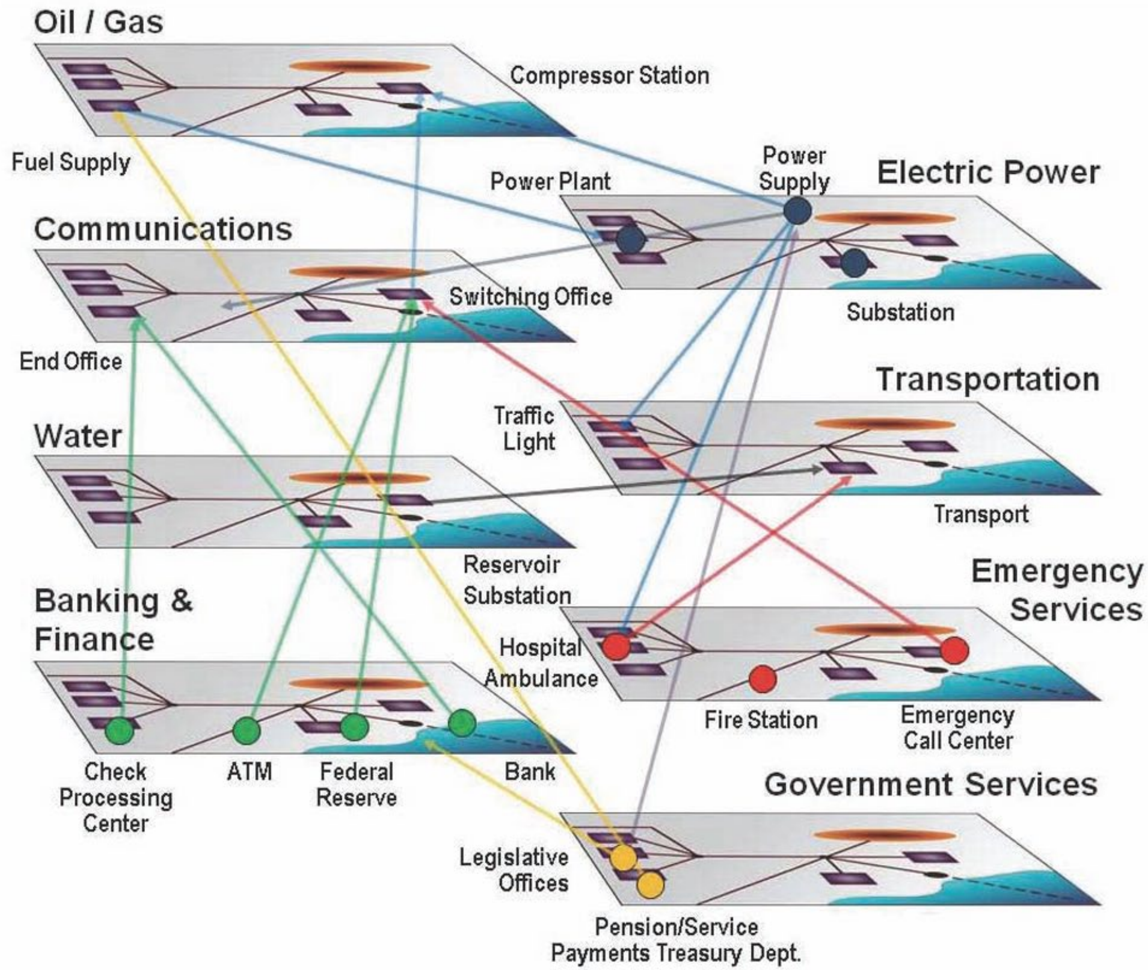


Figure 1-7. A Conceptual Illustration of the Interconnectedness of Elements Contained Within Each Critical Infrastructure. *Some connections are not shown (diagram provided courtesy of Sandia National Laboratory)*.

Ref:Reproduced from EMP Commission report

Section 1 of Presidential Executive Order from 2019

Section 1 states
By the authority vested in me as President by the Constitution and the laws of the United States of America, it is hereby ordered as follows:

Section 1. Purpose. An electromagnetic pulse (EMP) has the potential to disrupt, degrade, and damage technology and critical infrastructure systems. Human-made or naturally occurring EMPs can affect large geographic areas, disrupting elements critical to the Nation’s security and economic prosperity, and could adversely affect global commerce and stability. The Federal Government must foster sustainable, efficient, and cost-effective approaches to improving the Nation’s resilience to the effects of EMPs.

https://trumpwhitehouse.archives.gov/presidential-actions/executive-order-coordinating-national-resilience-electromagnetic-pulses/

Some quotes from EMP Commission Report

“ A single EMP attack may seriously degrade or shut down a large part of the electric power grid in the geographic area of EMP exposure effectively instantaneously. There is also a possibility of functional collapse of grids beyond the exposed area, as electrical effects propagate from one region to another. “

“A key issue for the Commission in assessing the impact of such a disruption to the Nation’s electrical system was not only the unprecedented widespread nature of the outage (e.g., the cascading effects from even one or two relatively small weapons exploded in optimum location in space at present would almost certainly shut down an entire interconnected electrical power system, perhaps affecting as much as 70 percent or possibly more of the United States, all in an instant) but more significantly widespread damage may well adversely impact the time to recover and thus have a potentially catastrophic impact.”

Relevant Reports (1)

Metatech

Meta-R-319

Geomagnetic Storms and Their Impacts on the U.S. Power Grid

John Kappenman

Metatech Corporation
358 S. Fairview Ave., Suite E
Goleta, CA 93117

January 2010

Prepared for

Oak Ridge National Laboratory
Attn: Dr. Ben McConnell
1 Bethel Valley Road
P.O. Box 2008
Oak Ridge, Tennessee 37831
Subcontract 6400009137

Metatech

Meta-R-320

The Early-Time (E1) High-Altitude Electromagnetic Pulse (HEMP) and Its Impact on the U.S. Power Grid

Edward Savage
James Gilbert
William Radasky

Metatech Corporation
358 S. Fairview Ave., Suite E
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January 2010

Prepared for

Oak Ridge National Laboratory
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Metatech

Meta-R-321

The Late-Time (E3) High-Altitude Electromagnetic Pulse (HEMP) and Its Impact on the U.S. Power Grid

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Relevant Reports (2)

Metatech

Meta-R-322

Low-Frequency Protection Concepts for the Electric Power Grid: Geomagnetically Induced Current (GIC) and E3 HEMP Mitigation

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Metatech

Meta-R-323

Intentional Electromagnetic Interference (IEMI) and Its Impact on the U.S. Power Grid

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High-Frequency Protection Concepts for the Electric Power Grid

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Notable EPRI Reports (1)

1. High-Altitude Electromagnetic Pulse and the Bulk Power System: Potential Impacts and Mitigation Strategies (April 2019) –
This comprehensive study examines the potential effects of a high-altitude nuclear detonation on the bulk power system, analyzing the combined impacts of E1, E2, and E3 EMP components and exploring mitigation options.

2. Assessment and Mitigation of High-Altitude Electromagnetic Pulse (HEMP) Impacts on Electric Distribution Systems (July 2021) –
This report provides technical guidance and tools for assessing and mitigating the potential impacts of HEMP on distribution systems, aiming to enhance system resilience.

3. EPRI EMP Testing and Design Support Applications (2019) –
This document outlines EPRI's capabilities in EMP testing and design support, highlighting their experience in power systems and high-frequency electromagnetics analysis to develop effective mitigation solutions for the electric utility industry.

Notable EPRI Reports (2)

4. Collaboration with Industry and Government –

"EPRI works with utilities, the U.S. Department of Energy (DOE), and the Department of Defense (DOD) to improve EMP preparedness and response planning."

5. Balanced Risk Assessment –

"Unlike some more alarmist perspectives, EPRI tends to Take a measured view of EMP threats. They highlight that while EMPs could cause disruptions, the likelihood of complete grid collapse is low if utilities implement reasonable protective measure."

EMP Facts (1)

1. EMP is real and can be generated by nuclear weapons or artificially.

• Solar storms (geomagnetic storms) and nuclear detonations can cause EMP effects.

2. Non-nuclear EMP (NNEMP) weapons exist

- **EMP can disrupt electronic devices and power grids.**

• Strong EMPs can induce currents in electrical circuits, damaging transformers, power lines, and electronic components.

• Sensitive microelectronics are more vulnerable than older, analog technology.

3. A nuclear EMP (NEMP) has three phases (E1, E2, E3).

• E1: Instant, high-intensity pulse that affects small electronics.

• E2: Similar to lightning, but less severe.

• E3: Long-lasting, low-frequency pulse that affects power grids.

EMP Facts (2)

4. EMP protection exists.

• Faraday cages can block EMP effects.

• Military and some government infrastructure have hardened electronics against EMP threats.

5. Solar EMP events have happened before.

• The 1859 Carrington Event was a powerful geomagnetic storm that damaged telegraph systems.

• Smaller events in 1989 and 2003 caused blackouts.

EMP Myths (1)

1. “An EMP will instantly send society back to the Stone Age.”

• While a strong EMP could cause severe damage, recovery would depend on the scale, preparedness, and location.

• Critical infrastructure in some countries is already hardened against EMP threats.

2. “EMP will make all cars stop working.”

• Most modern cars have some level of shielding, and tests have shown that while some may stall, many will still function.

• Older, non-computerized cars are even less affected.

EMP Myths (2)

3. "A small EMP device can knock out an entire city."

• Portable EMP weapons exist but have a limited range and cannot disable an entire power grid.

• Large-scale damage requires high-altitude nuclear detonation or a geomagnetic storm.

4. "EMP is like a lightning strike."

• While both involve electromagnetic energy, an EMP is much faster and more widespread.

5. "Only nuclear weapons can generate EMPs."

• Non-nuclear EMP weapons and solar storms can also generate powerful electromagnetic pulses