EMP and Precedents: Got a Pulse?

A discussion of Pulse Transients. Lightning and EMP

~ ac7x

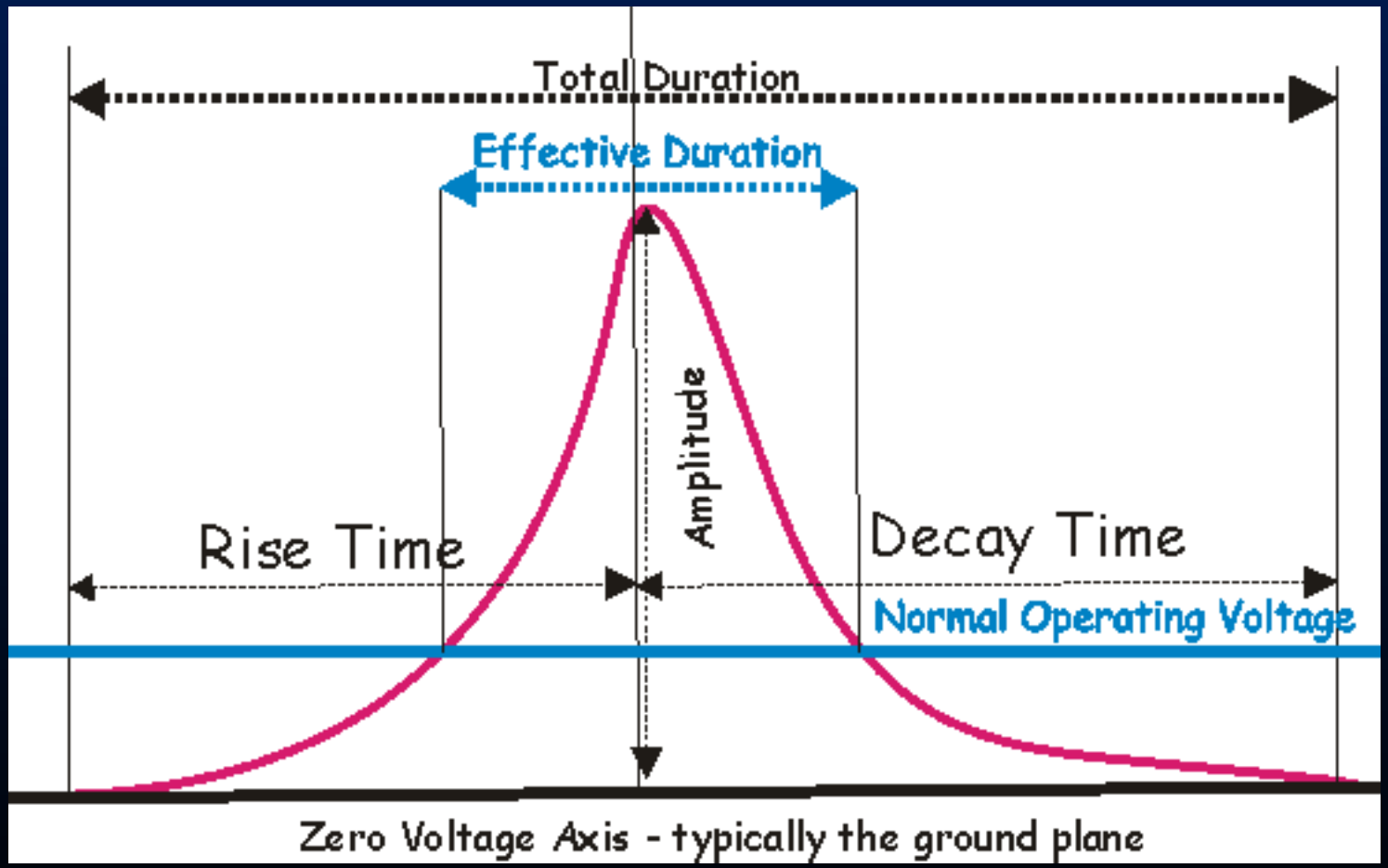
Agenda

- Technical Review
- Discussion of Threats
- More on EMP devices
- Buying and installing protection

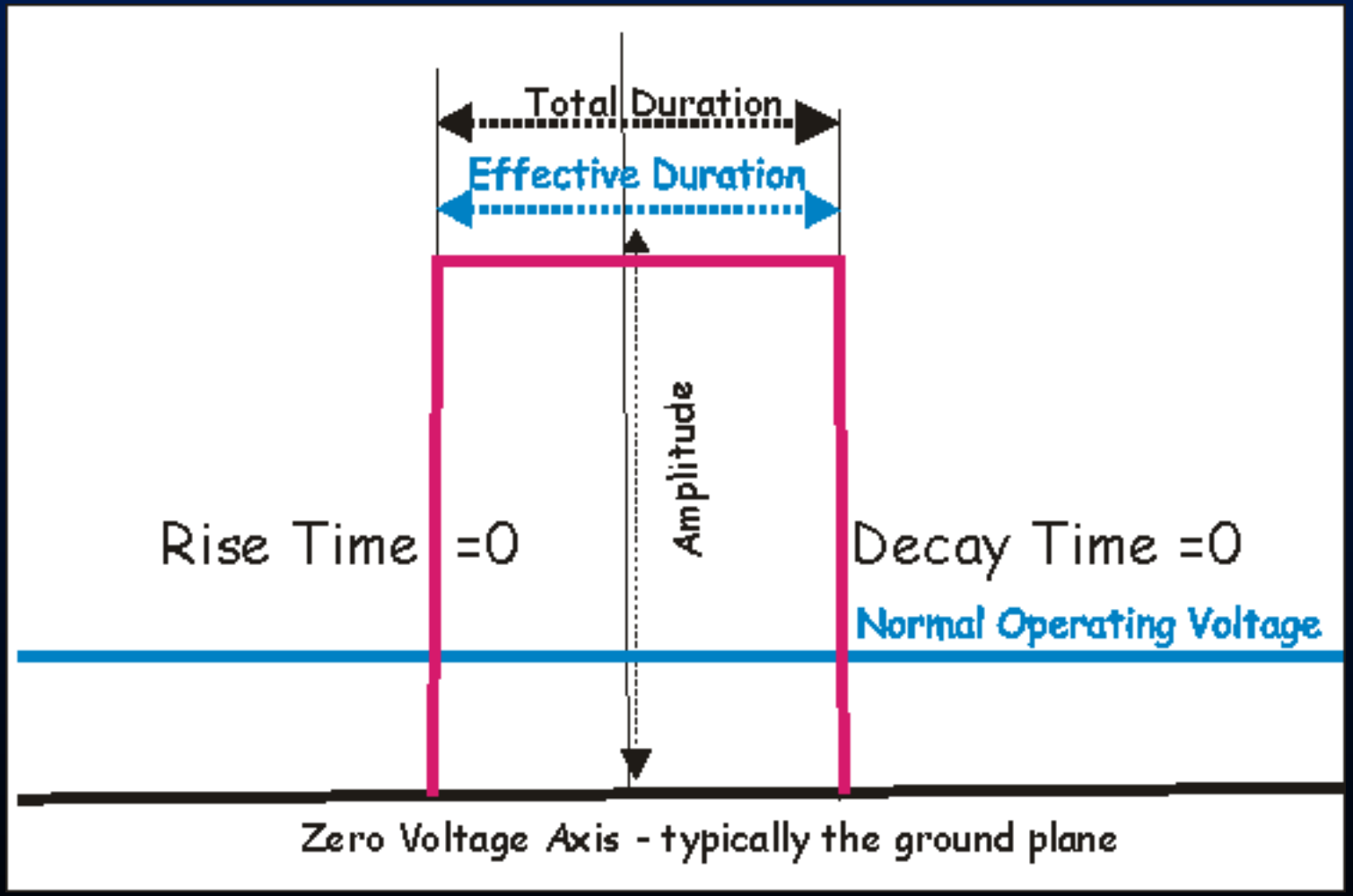
Boring Technical Review Part

- Terminology: what's what: (boring stuff 1st)
  - A "Pulse" is generally a maximum excursion on one side of a voltage zero axis
  - Has "Amplitude" (e.g. highest voltage on an instantaneous basis)
  - Also has "Duration" (e.g. the pulse width)
  - Peak *Amplitude* times *Duration* approximates *pulse power* – does not compensate for shape
  - "Shape" is determined by rise and decay times.

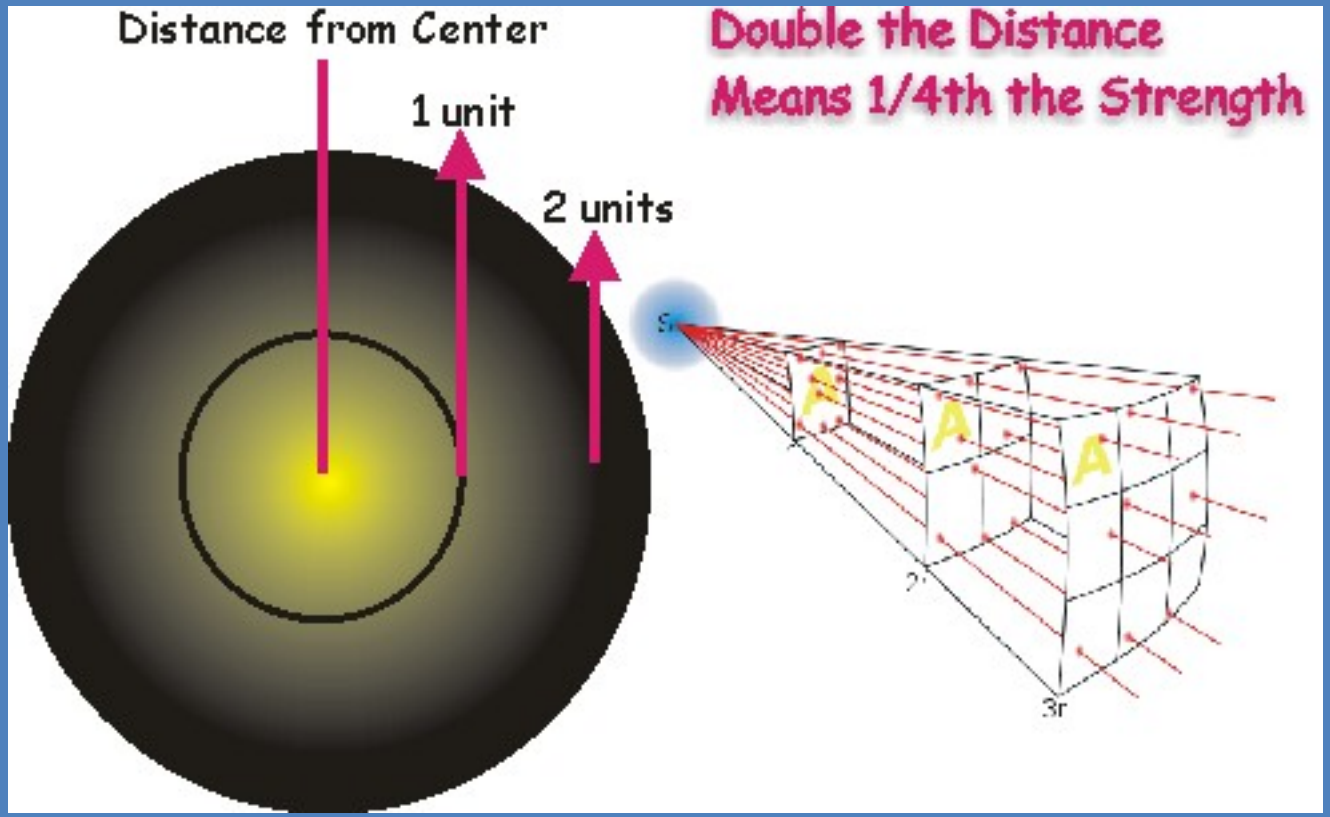
Pulse 101 – the Visual



Or -- for a Square Wave



Inverse Square Law



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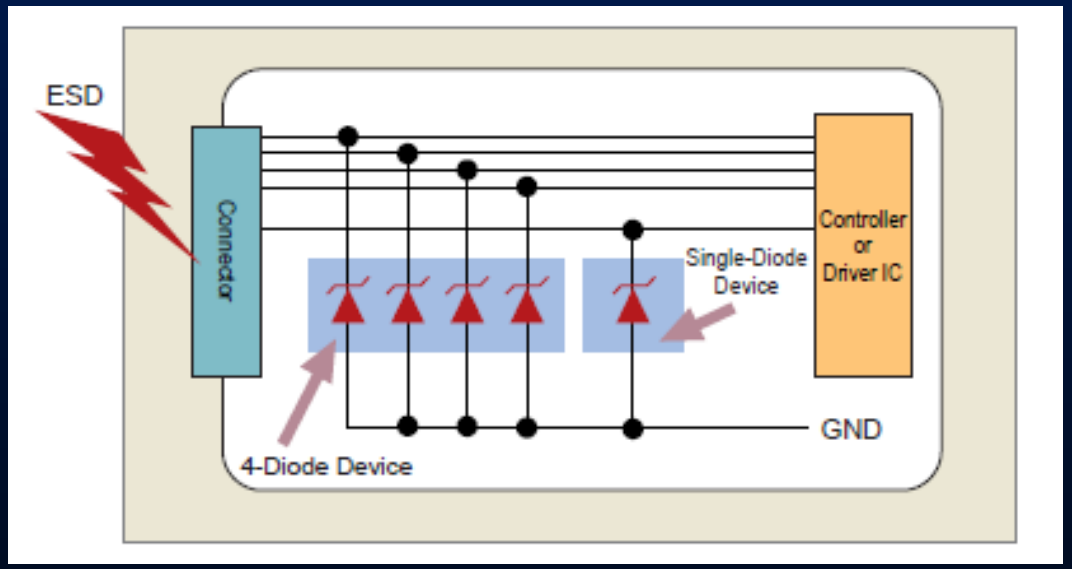
- More on EMP impacts
- Buying and Installing EMP Protection

Pulse Threats to Ham Radio

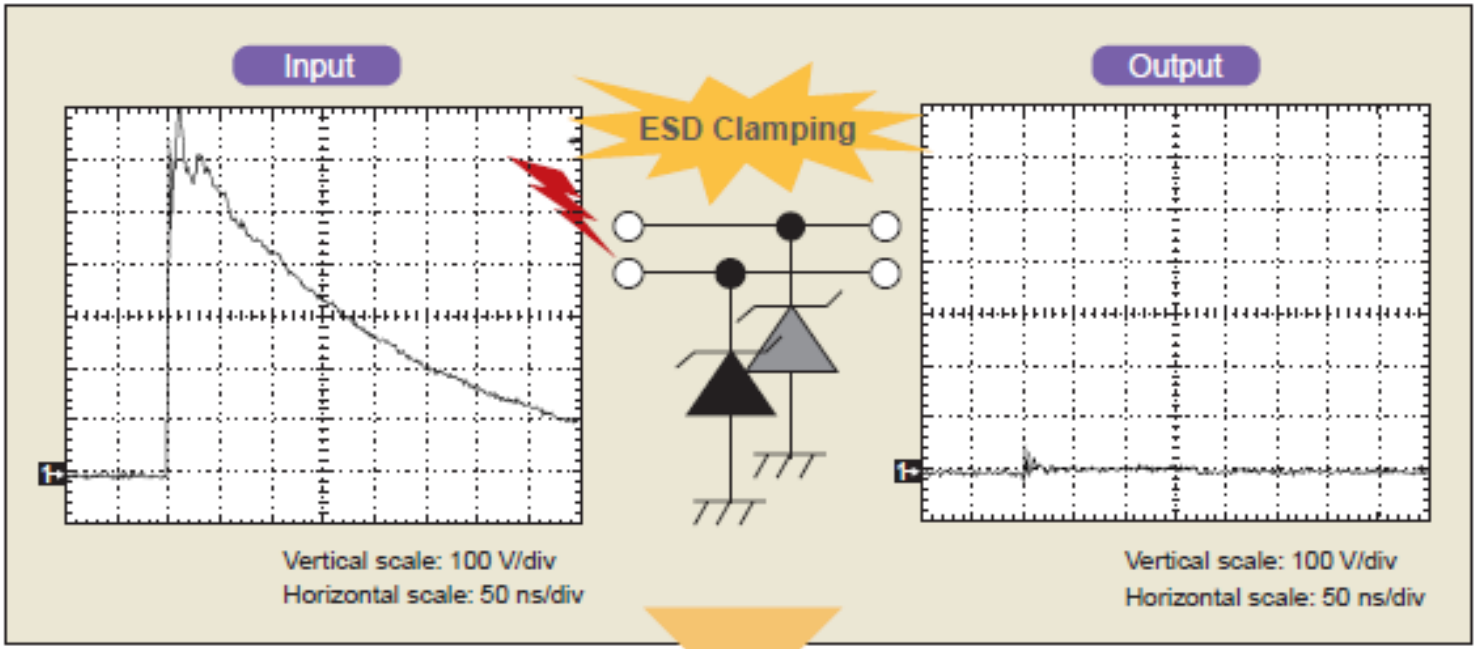
- Body Electrostatic Discharge
- Lightning
- EMP
  - Three major sources:
    - Solar Coronal Mass Ejection driven
    - EMP Weapons
    - HEMP Attack

Body ESD Protection



- Toshiba and other ESD protection makers offer product designed to protect sensitive low level inputs

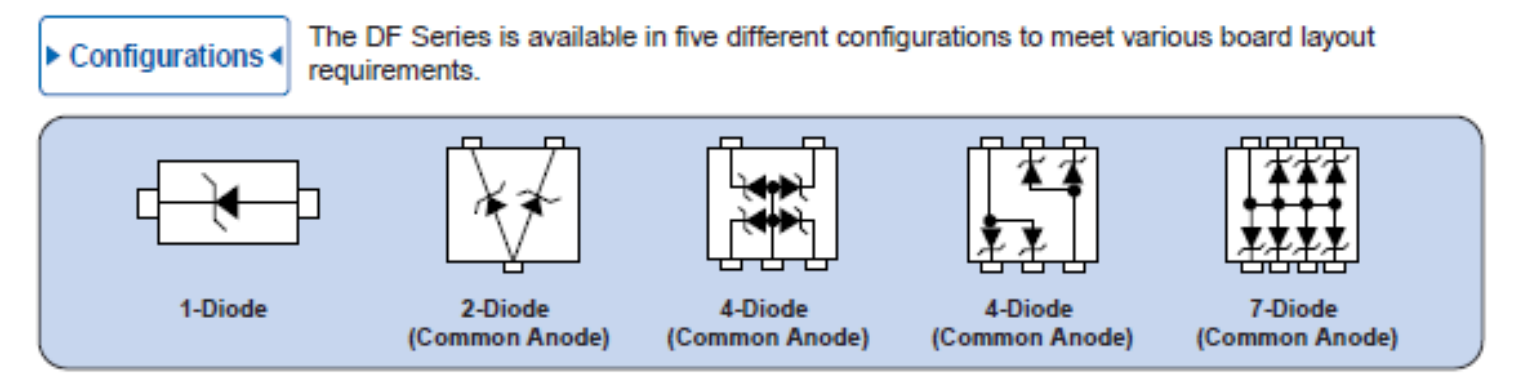
Sample of ESD Clamping Action



Toshiba's ESD-protection diodes are specifically designed for suppression of ESD-induced transients to protect against system malfunction and/or damage to ESD-sensitive ICs.

ESD & Transient Units

- TVS – Transient Voltage Suppressor
- Remember: Band (Cathode) goes away from ground! In multiple device packages, anodes



Is ESD a NON-ISSUE for Hams?

NO! It's *really something to think about!*

- Well, OK, non-issue in tube-type gear
- Small issues in discrete large signal devices
- Moderate issue in very small signal devices
- All easily addressed in component selection and wearing ESD protection

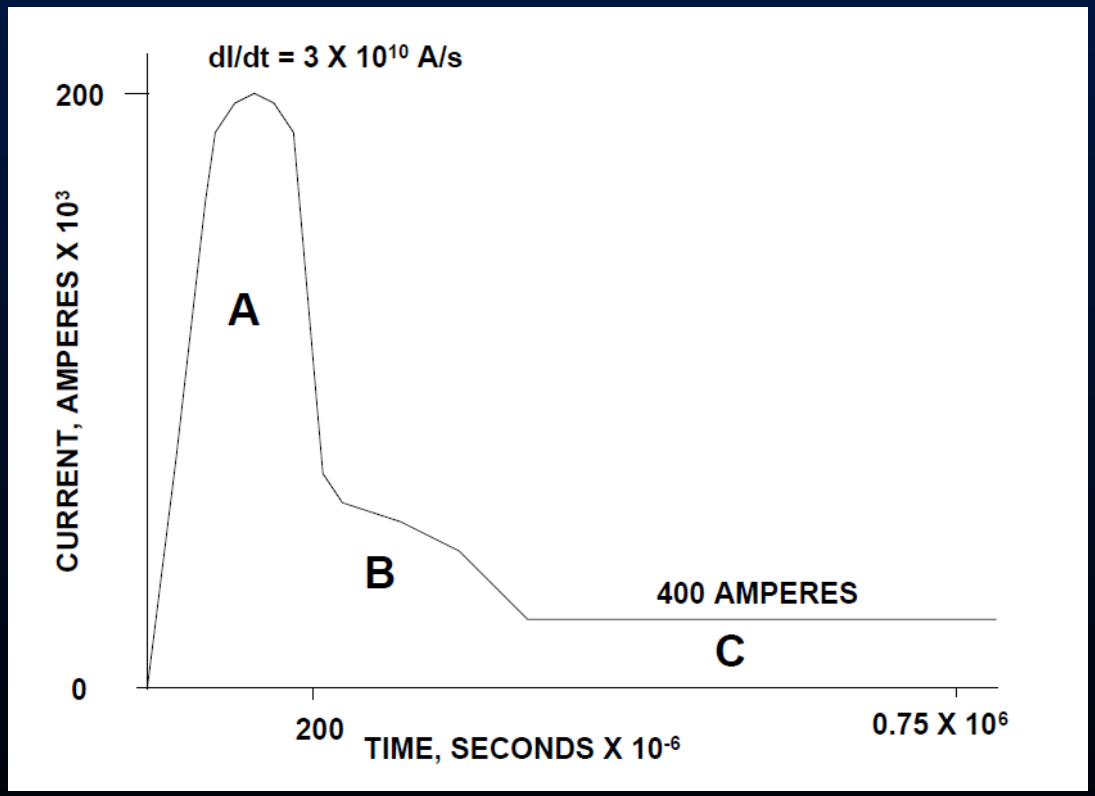
Basic ESD Protection

- Non-static bench mat About $20 on eBay

(I use cut piece of cardboard)

Lightning Pulses

- Think of lightning as an *EMP Lite* kind of pulse



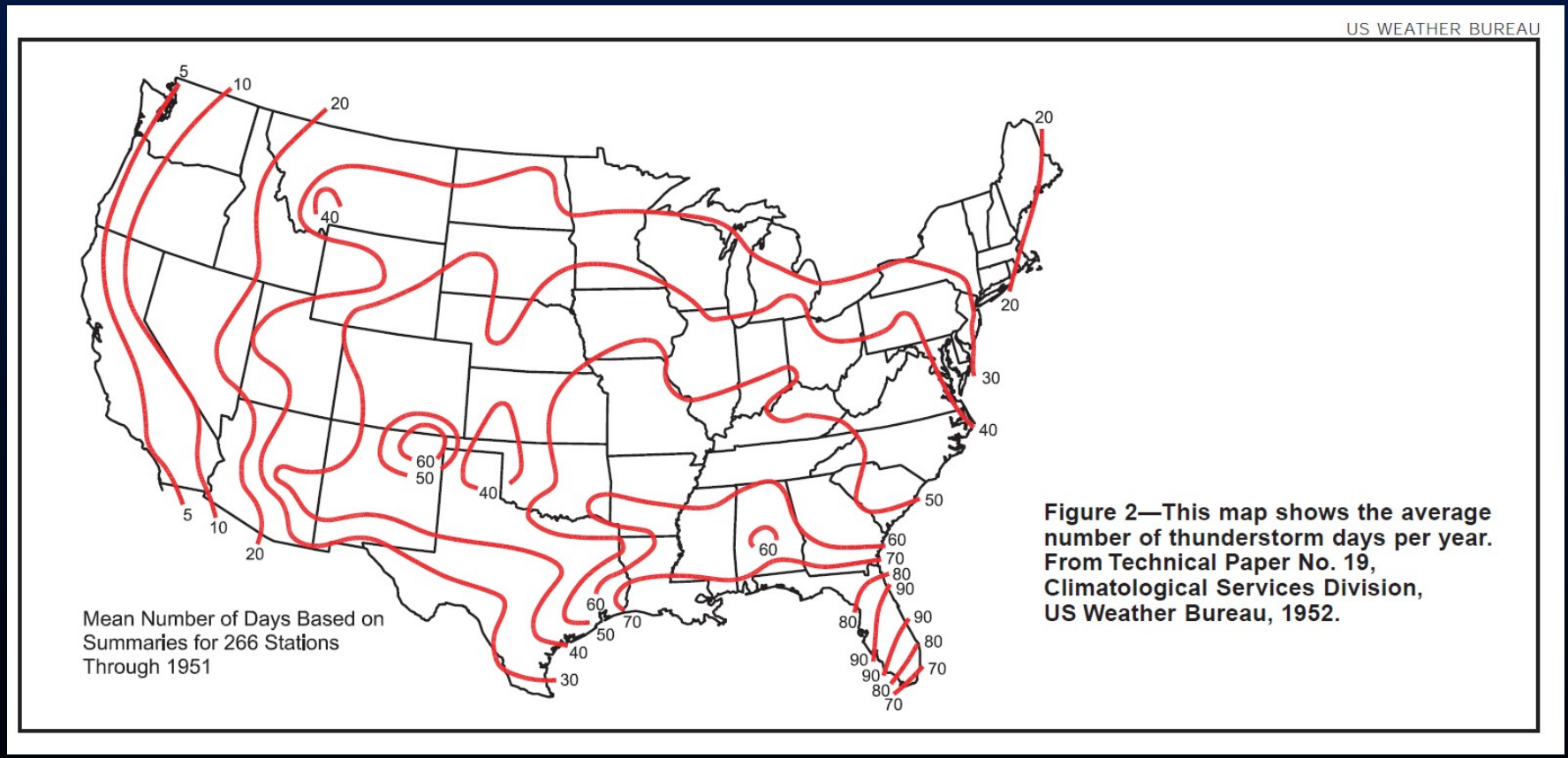
Component A is the high-current pulse. It is a direct current transient that has been recorded to reach up to 260,000 amperes and last for a duration of up to 200 microseconds.
Component B is a transition phase on the order of several thousand amperes.
Component C is a continuing current of approximately 300-500 amperes that lasts up to .75 second.

Lightning as Pulses

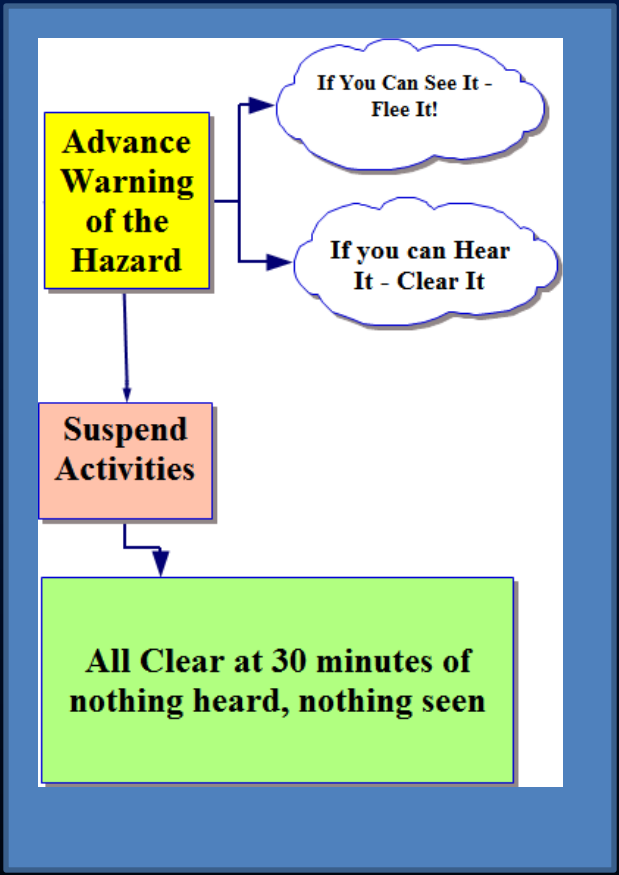
- Obeys the Inverse Square Law
- Propagates well below the MUF
- Worse in summertime (thunderstorm season)
- Lower frequencies are more impacted (e.g. 75 and 160 meters are more impacted than 40)
- Three layers to the threat: Personal Safety, Station Equipment, Operating Impacts
- Lightning is VERY SIMILAR TO EMP IN SOME REGARDS!!!

Risk Assessment

June 2002 QST has a great article on lightning risks and a dandy chart which shows we get 50-60 thunderstorms per year



Lightning Personal Safety



National Lightning Institute has a decision tree that answers the question “When can I play with my ham rig again?

Sometimes it takes a while till the threat is clear of the area but it’s a decision you don’t want to make wrong even once…

Station Equipment Safety

- Keep lightning out of the shack
- See ARRL Handbook for all kinds of ways to do that.
- Own lots of ground rods.
  - Two for shack and three at base of tower
  - Ham radio ground and the NEC are sometimes at odds
- Use good lightning protectors and ‘big as your thumb wiring
- Have an antenna disconnect switch on your Tuner or ahead of rig.

Antenna HAAT Matters to

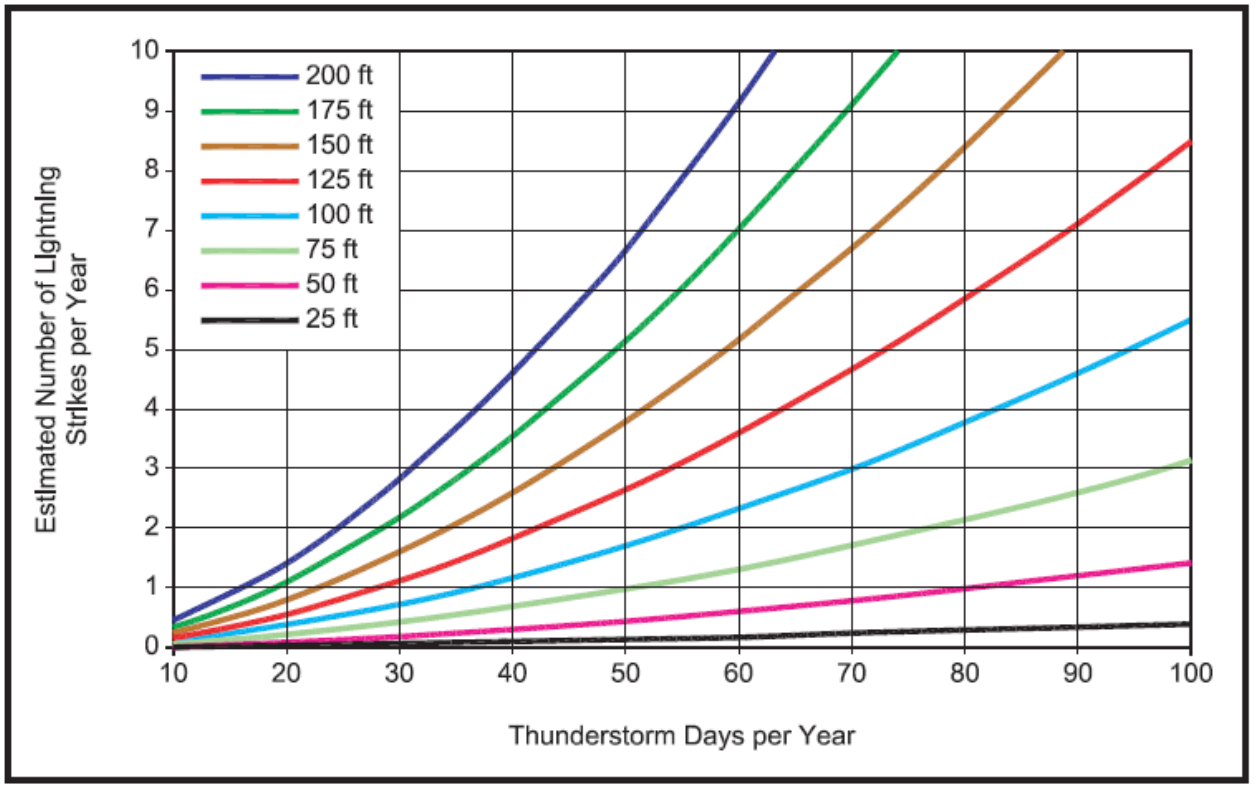


Figure 3—Estimated number of lightning strikes per year based on the number of thunderstorm days in your area and the height of your antenna. Based on information from *Living with Lightning*, Seminar Notes #ECP-826B Version F, GE Mobile Radio Technical Training, © GE 1985.

EMP Basics

- Stands for Electro-Magnetic Pulse
- Three main flavors
  - HEMP (High-altitude EMP device, nuclear)
  - Conventionally pumped devices
  - Solar-effects driven
- Planning framework:

  " Lightning in the back yard "

The Physics of EMP

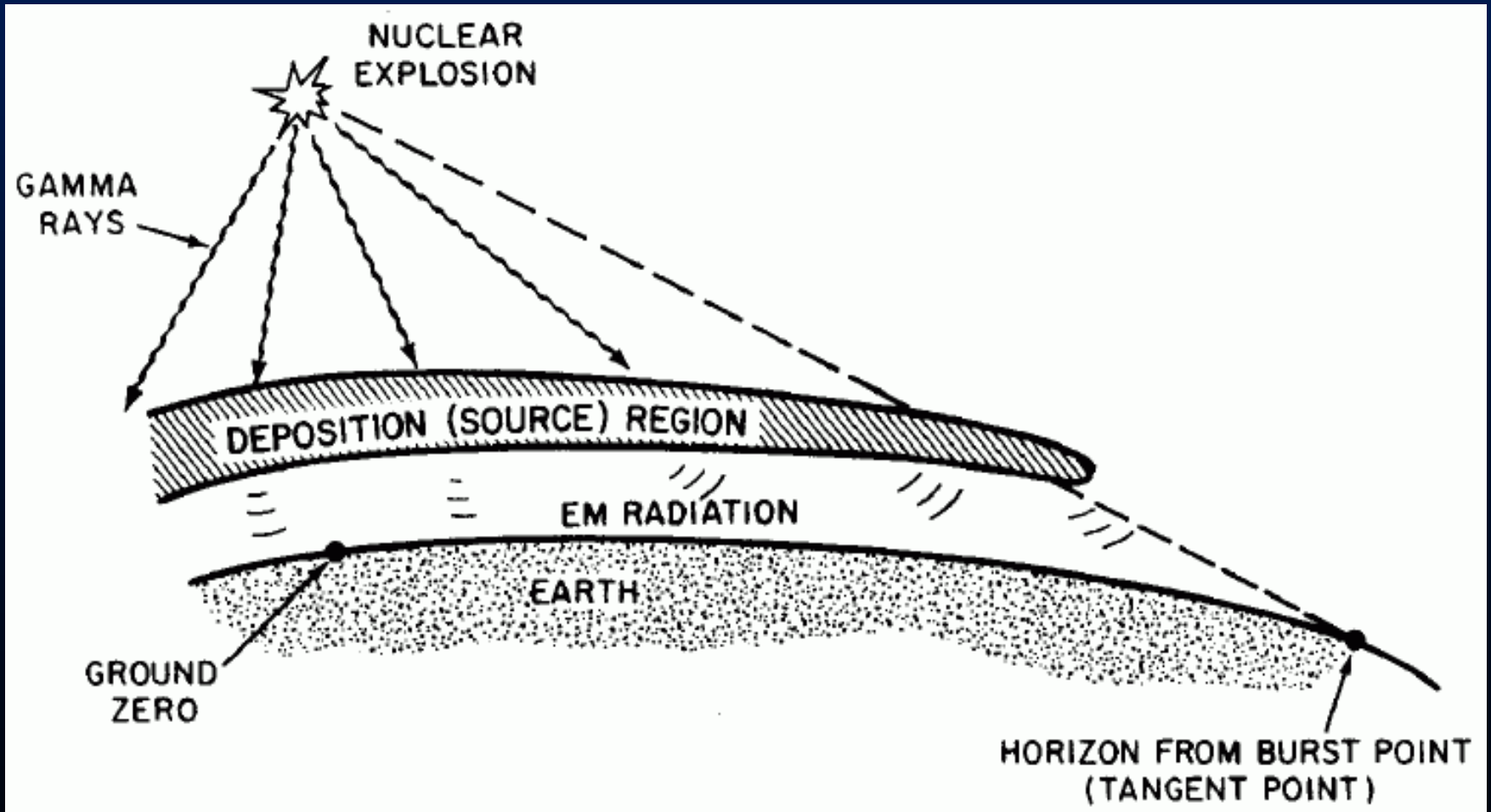
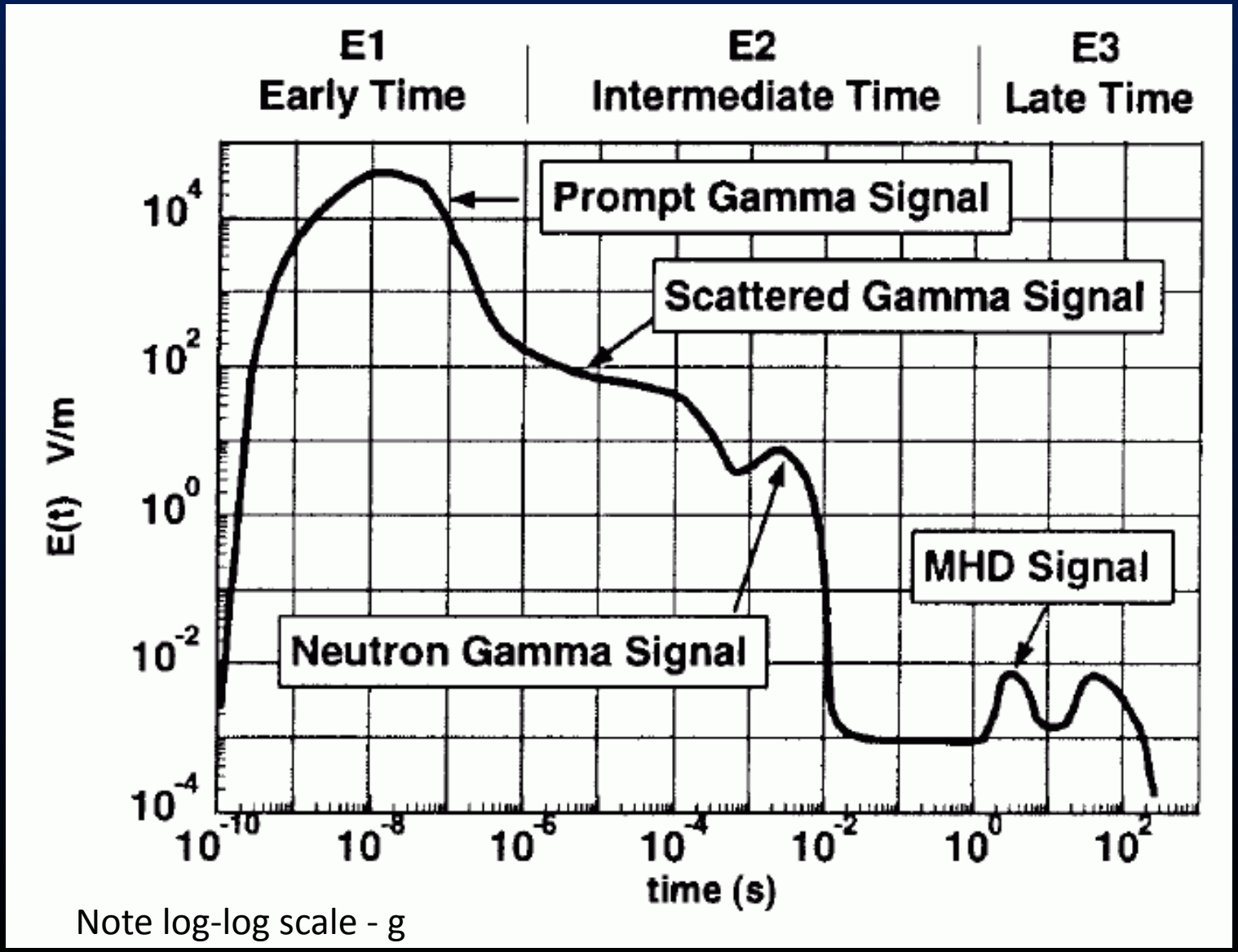


Figure 11.13. Schematic representation of the EMP in a high-altitude burst. (The extent of the deposition region varies with the altitude and the yield of the explosion.)

Three Parts of the EMP Waveform



Note log-log scale - g

MIL-STD-464

(EME= Electromagnetic Compatibility – which we all know, right?

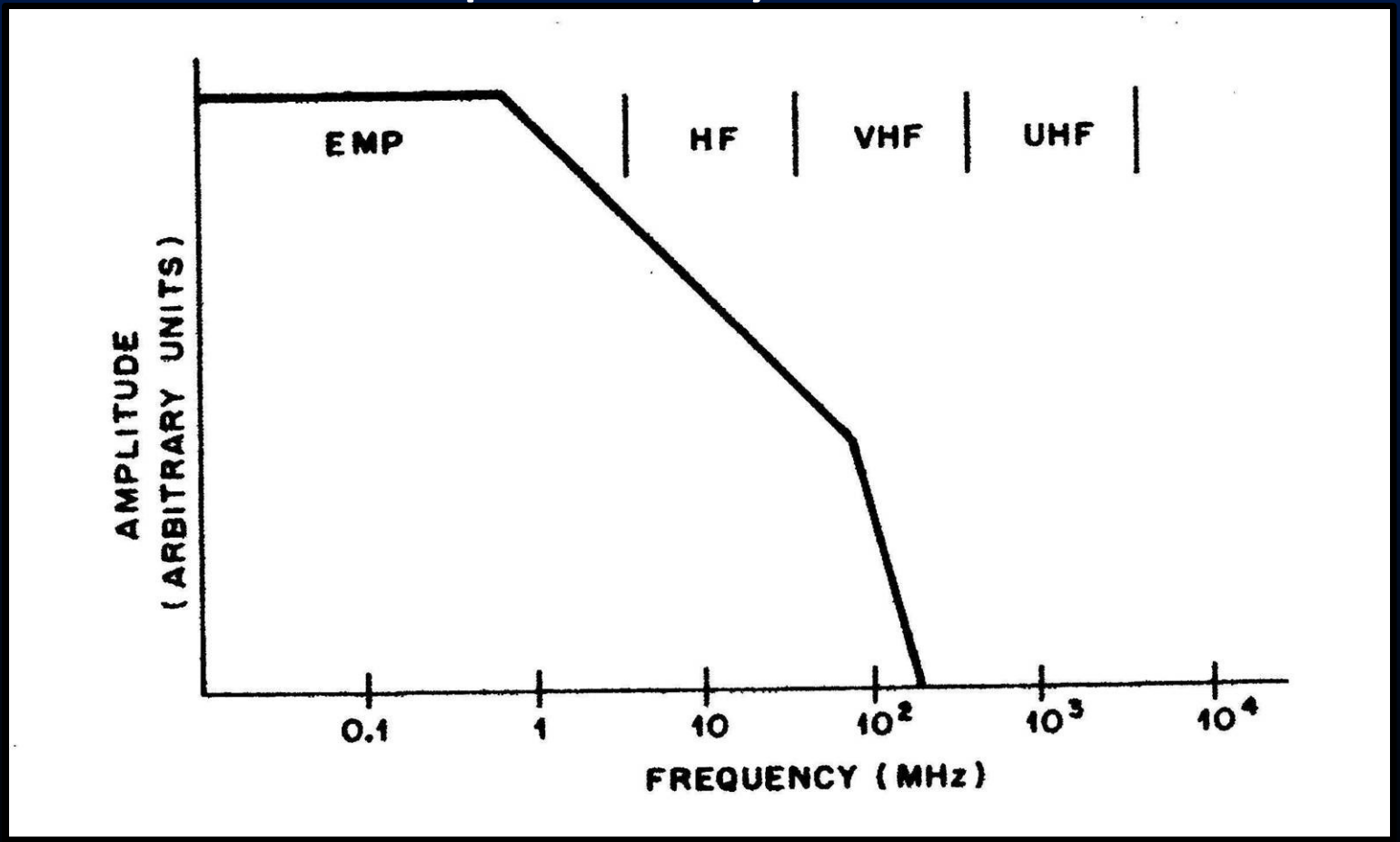
MIL-STD-464

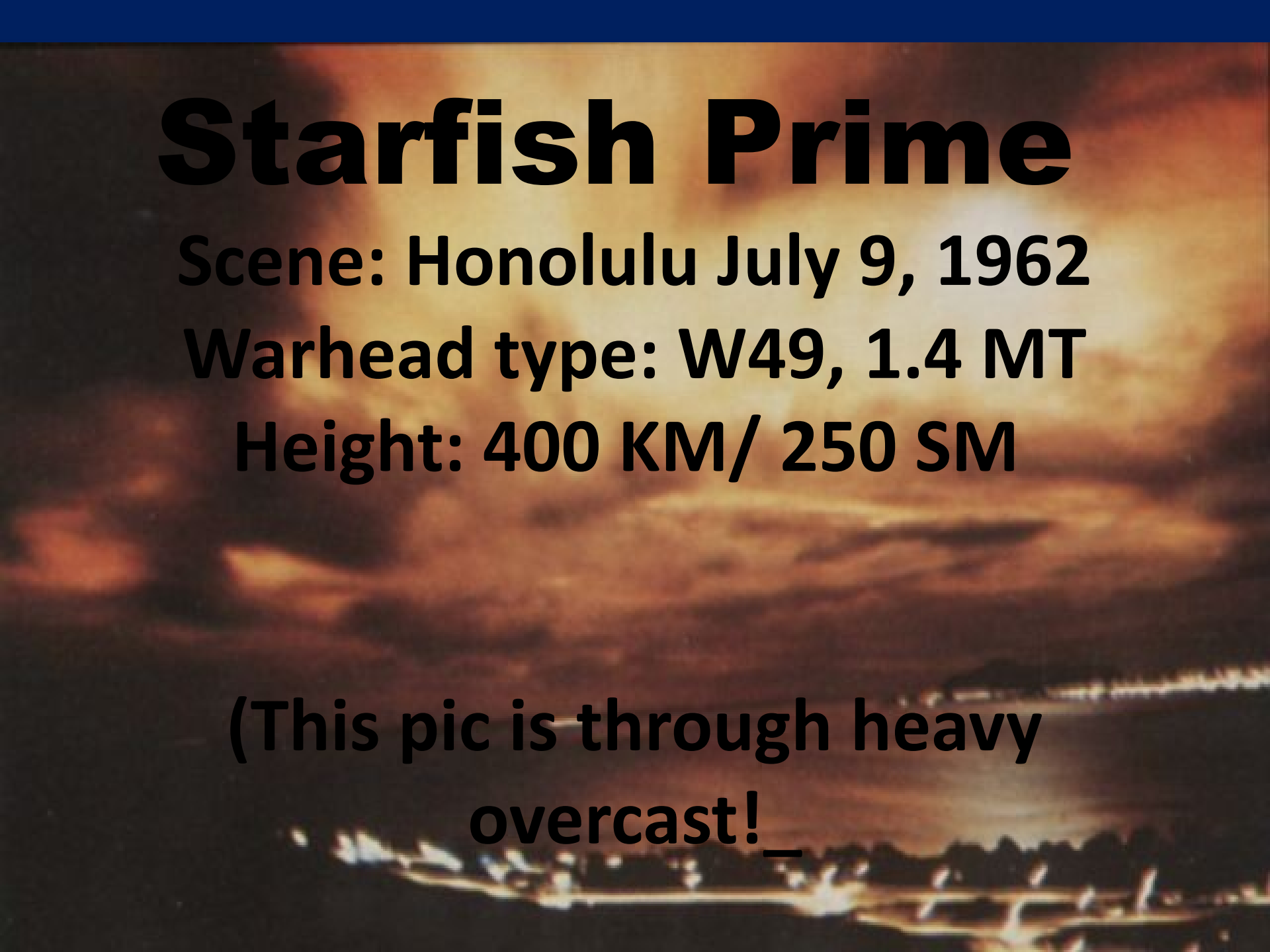
TABLE IA. External EME for systems capable of shipboard operations (including topside equipment and aircraft operating from ships) and ordnance

Frequency (Hz)	Environment (V/m - rms)	
	Peak	Average
10k-150M	200	200
150M-225M	3,120	270
225M-400M	2,830	240
400M-700M	4,000	750
700M-790M	3,500	240
790M-1000M	3,500	610
1G-2G	5,670	1,000
2G-2.7G	21,270	850
2.7G-3.6G	27,460	1,230
3.6G-4G	21,270	850
4G-5.4G	15,000	610
5.4G-5.9G	15,000	1,230
5.9G-6G	15,000	610
6G-7.9G	12,650	670
7.9G-8G	12,650	810
8G-14G	21,270	1,270
14G-18G	21,270	614
18G-40G	5,000	750

Spectrum Impacts

- Two-meter impacts may be a lot less than HF!




Starfish Prime
Scene: Honolulu July 9, 1962
Warhead type: W49, 1.4 MT
Height: 400 KM/ 250 SM
(This pic is through heavy overcast!_

Starfish Prime Impacts

- Unexpectedly large pulse
- Knocked out 300 street lights in Hawaii
- Some Telco microwave damage (Kauai link microwave link was shut down by it)

- “While some of the energetic beta particles followed the Earth's magnetic field and illuminated the sky, other high-energy electrons became trapped and formed radiation belts around the earth. There was much uncertainty and debate about the composition, magnitude and potential adverse effects from this trapped radiation after the detonation. The weaponeers became quite worried when three satellites in low earth orbit were disabled. These man-made radiation belts eventually crippled one-third of all satellites in low earth orbit. Seven satellites failed over the months following the test as radiation damaged their solar arrays or electronics, including the first commercial relay communication satellite ever, Telstar”

Large EMP Impacts
Scenario: 10 MT over Lake Superior

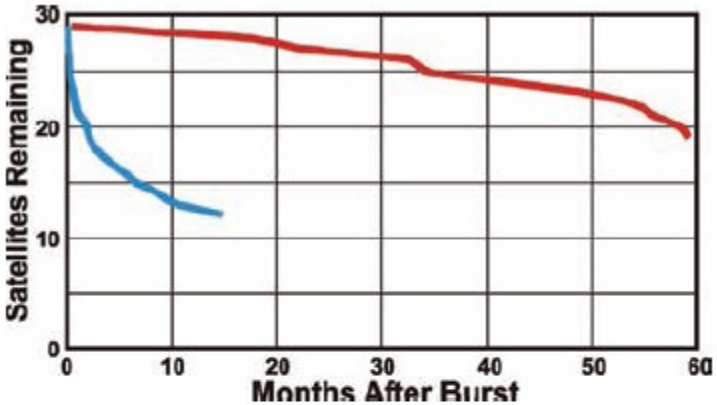


Figure 10-6 . Satellites remaining after a 10 MT burst over Lake Superior

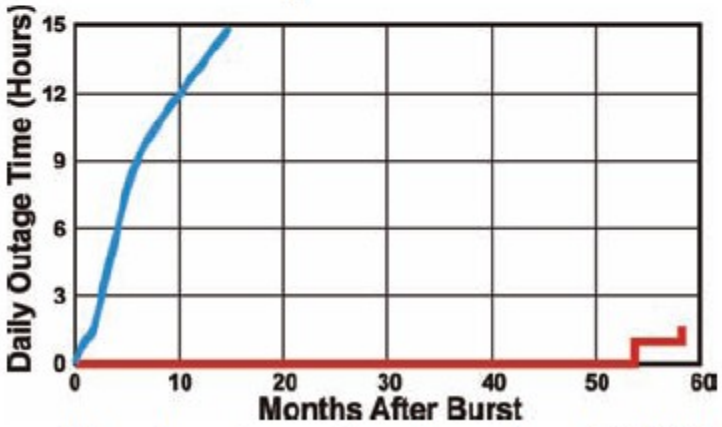


Figure 10-7. Satellite ground-based receiver outage time after a 10 MT burst over Lake Superior

Linked Infrastructure Impacts

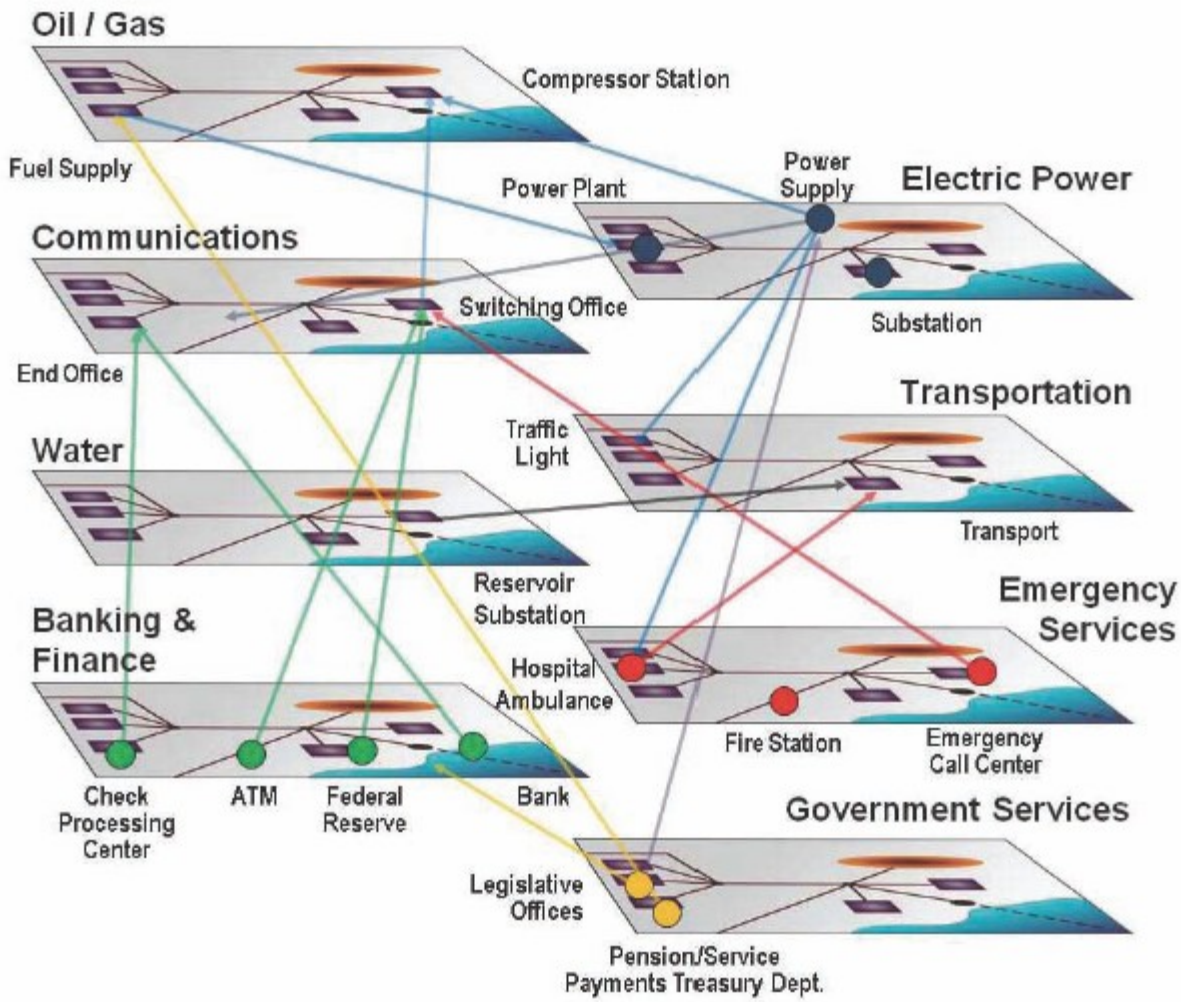
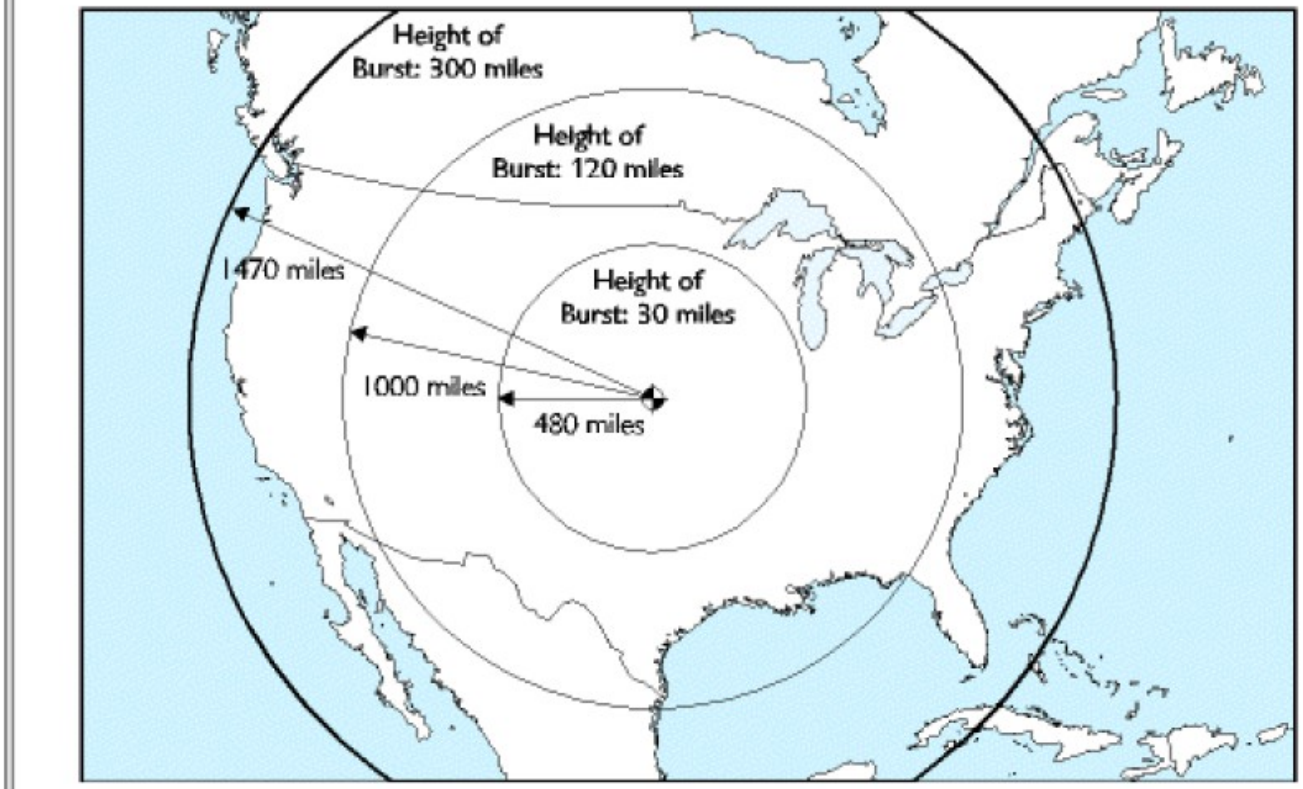


Figure 1-7. A Conceptual Illustration of the Interconnectedness of Elements Contained Within Each Critical Infrastructure. *Some connections are not shown (diagram provided courtesy of Sandia National Laboratory).*

EMP Height of Burst/Area Impact

Figure 1. Estimated Area Affected by High-Altitude EMP



Area Effected by an Electromagnetic Pulse, by Height of Burst

Source: Gary Smith, "Electromagnetic Pulse Threats," testimony before the House National Security Committee, July 16, 1997.

Predict EMP Impact Analysis

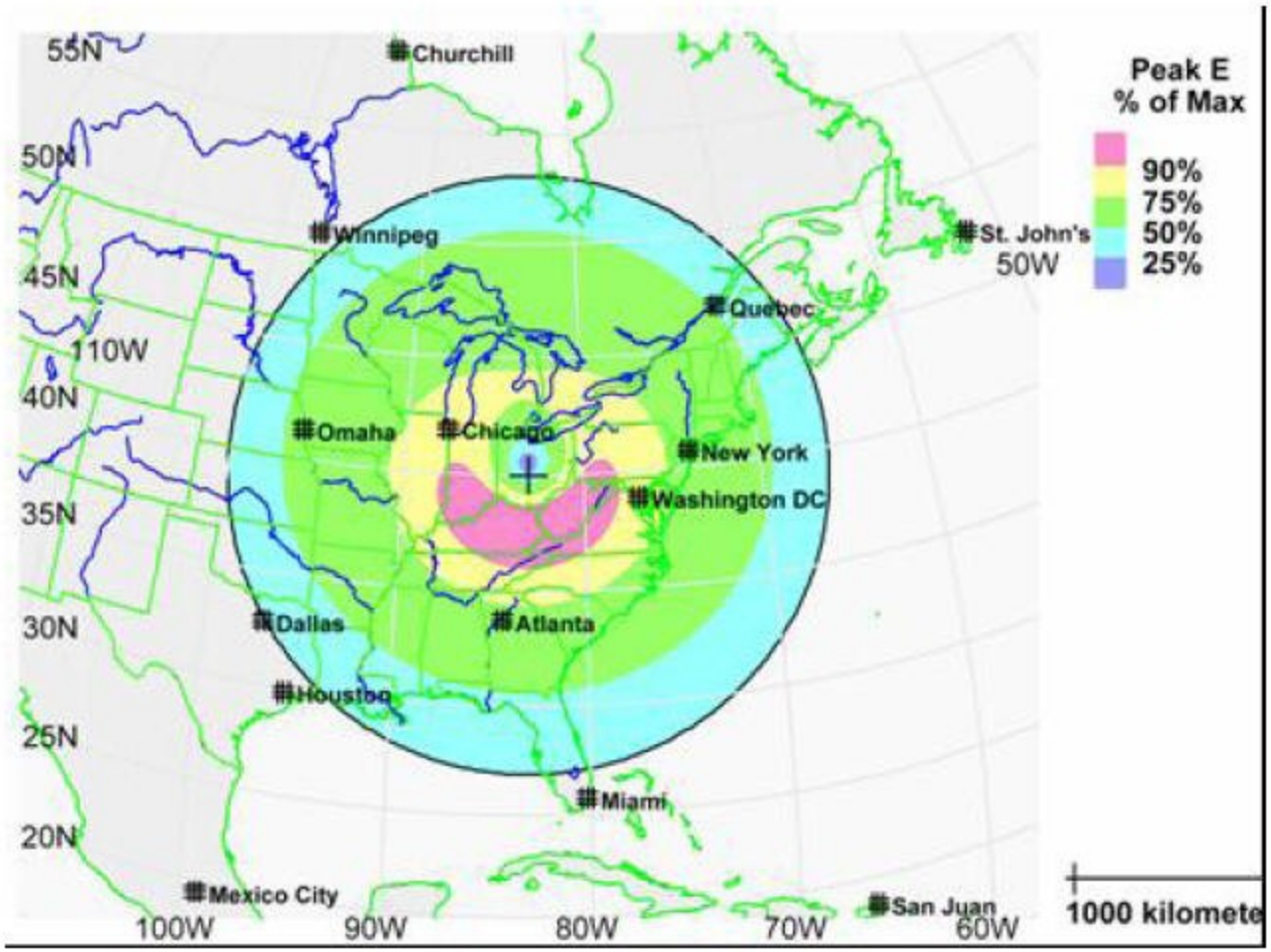


Figure 2. Illustrative EMP Effects – Fast Pulse

Texas is Semi-Isolated in One Key

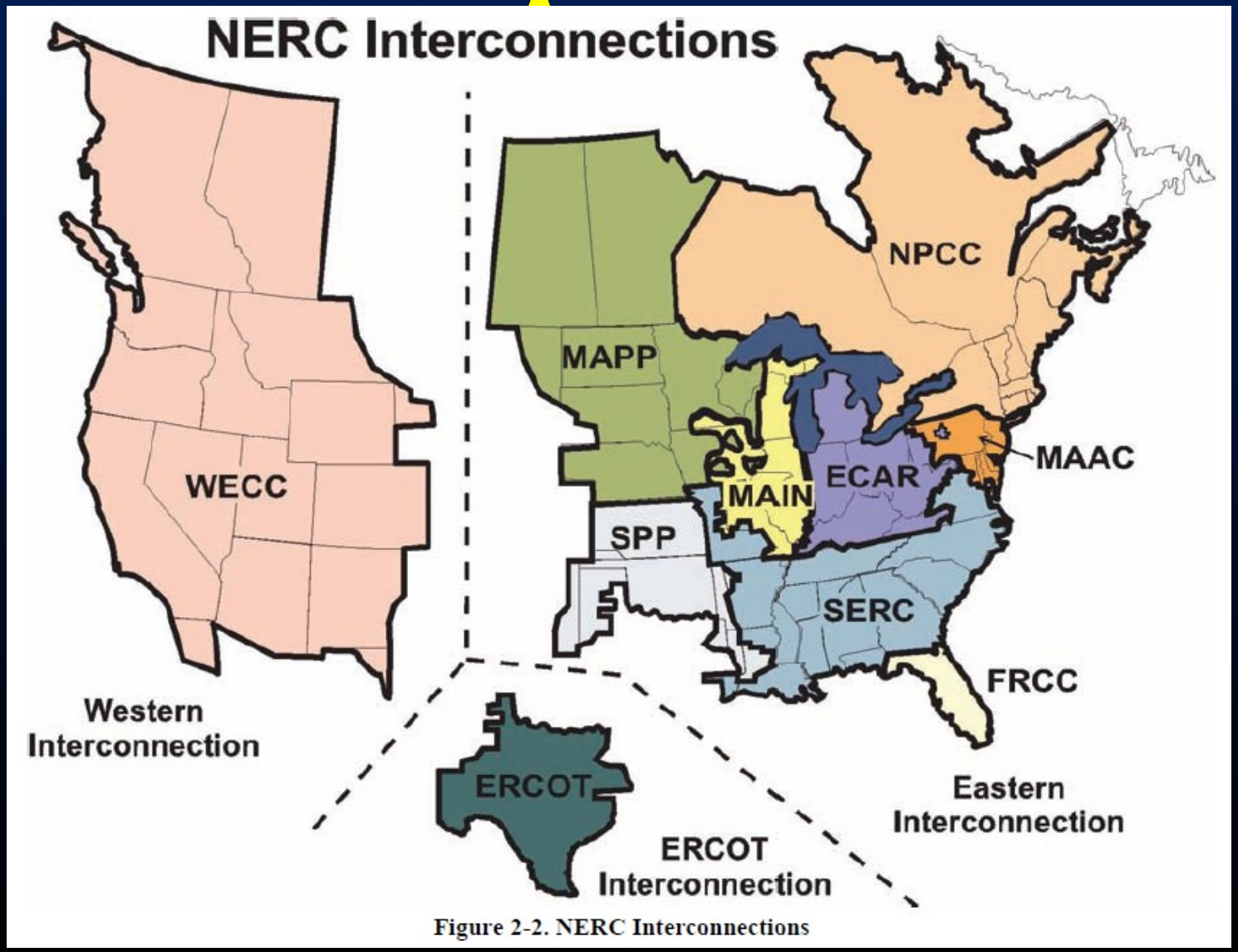


Figure 2-2. NERC Interconnections

Some Much for Nukes…

Conventionally Pumped EMP

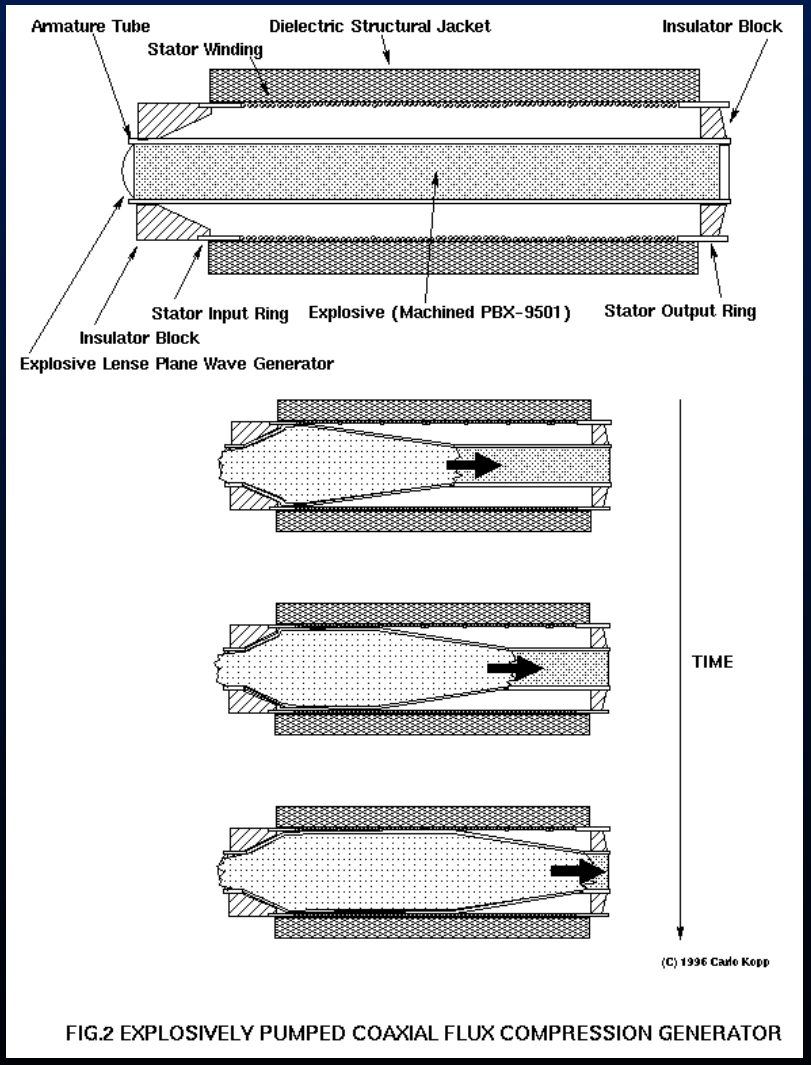


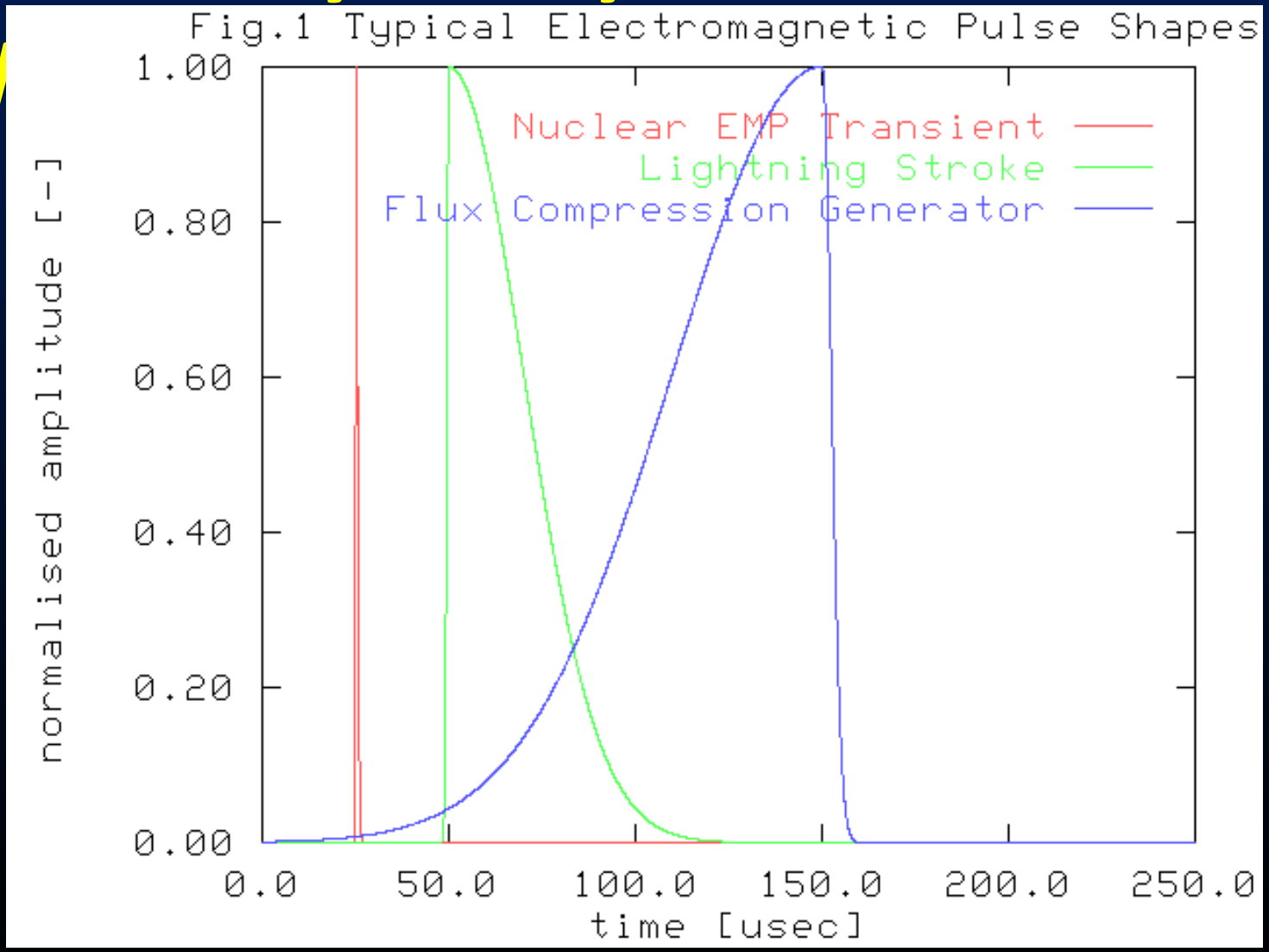
FIG.2 EXPLOSIVELY PUMPED COAXIAL FLUX COMPRESSION GENERATOR

- Windings around a core, some explosives and someone who doesn't like America and what do you have?
- Rewatch opening of "Oceans 11" and "Matrix Revolutions"

Twice as fast as Lightning…

Nitty-Gritty Device

W

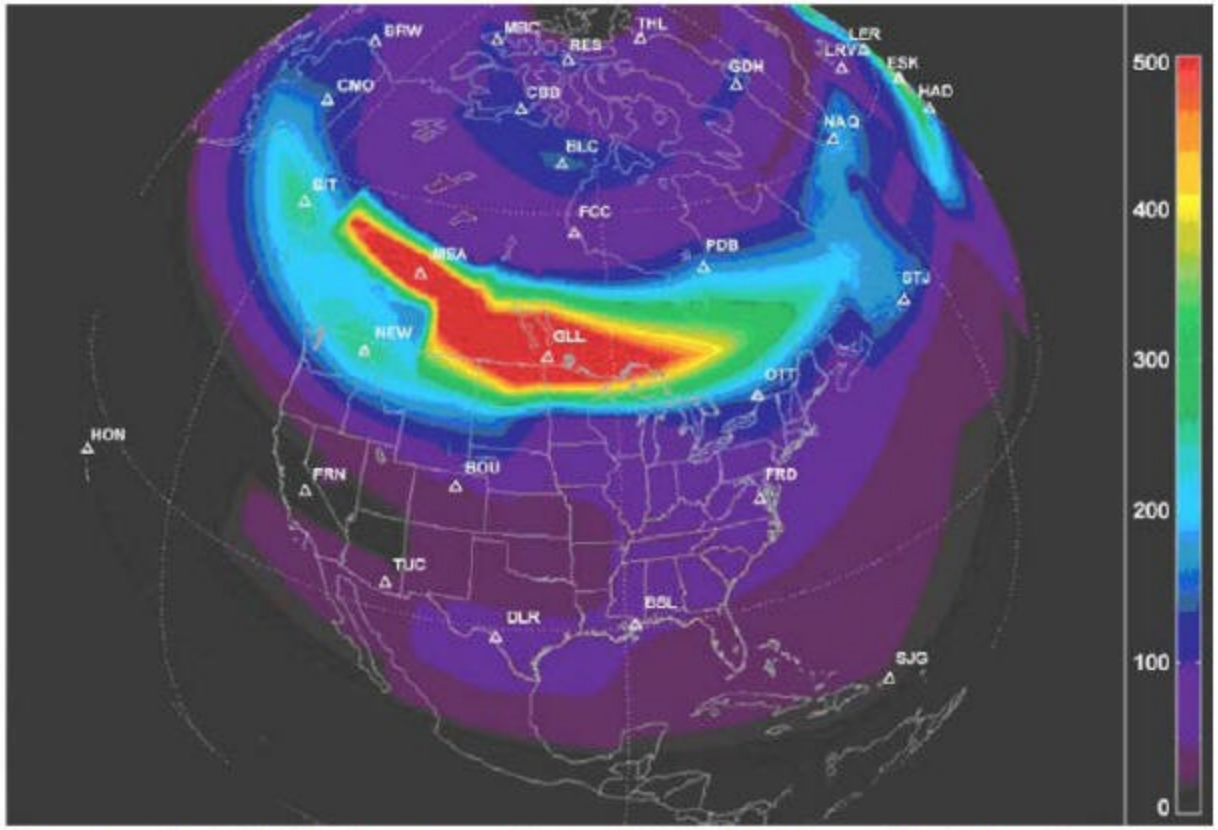


Solar EMP Event (Carrington)

- Called the “Carrington Event” Sept. 1-2, 1859
- Telegraph systems all over North America and Europe failed. Some sparks started fires.
- Associated with large solar flares
- More recent events: 1920, 1960
- Large flares are more likely at – and just after – solar maxima

Not Exactly GREAT DX'ing Conditions…

Severe Earth-Directed CME 1989



Geomagnetic field disturbance conditions, dB/dt (nT/min) over North America at time 7:45 UT on March 13, 1989

Source: Metatech Corporation, Applied Power Solutions

Figure 5. Extent of 1989 Geomagnetic Storm

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Buying Transient Protection

"When using these TVSs,
the most important parameters are
identified as the Rated Working Peak
Voltage or Rated Standoff Voltage
(VWM), the Peak Pulse Power
Dissipation (PPP), Peak Impulse Current
(IPP), and Clamping Voltage (VC)."

The *REAL* Design Issue is what???

"50kV in (5) Nanoseconds"

From some 'gray literature'…

- " MIL-STD-2169, a classified document, apparently provides detailed information about the EMP threat wave forms. For all of us (including me!) without access to classified documents like that one, an unclassified version of the EMP threat wave form has been released, and it describes a 50kV potential which develops in literally just nanoseconds.
- This is important because:

-- 50 kV is a very high voltage, more than enough to zap sensitive unprotected electronic devices

-- a few nanosecond rise time is so fast that most conventional surge suppressing technologies (aimed at much slower-building pulses, such as lightning), typically wouldn't have time to react

- It is also worth noting that besides the prompt ("E1") high voltage threat, there's also a longer duration wide area magneto-hydrodynamic ("E3") component which is also important."

EMP: How High to Be How Big?

d. Electric field. A commonly used unclassified time waveform of a HEMP electric field E(t) in free space can be approximated by the analytical expression--

$$E(t) = \frac{kE_{pk} e^{a(t-t_s)}}{1+e^{(a+b)(t-t_s)}} \quad . \text{ (kV/m)} \qquad \text{(eq 2-2)}$$

where E_{pk} = 50 kV/m (peak electric field in kilovolts per meter; k = 1.2 (a normalization constant); a = 5 x 10^8 per second (exponential decay rate); t_s = 10^{-8} seconds (a time shift parameter); and t is the time of interest (in seconds). This waveform is often called a "double exponential." Figure 2-4 is a graphic representation of the HEMP waveform; the frequency content of the HEMP pulse also is depicted in figure 2-4. This waveform rises from 0.1 to 0.9 times its peak amplitude in about 5 nanoseconds (t_r), and decays to one-half its peak amplitude in about 200 nanoseconds ($t_{1/2}$) (fig 2-4). The upper left curve shows this waveform plotted on a linear time scale. The upper right curve shows a logarithmic time scale that distorts the pulse shape but gives the risetime more clearly. The Fourier transform of this transient electric field is given by--

Wait!!! Too much math, not enough beer!

Selection and Decoding TVS Diodes

The AC7X Simplified Design Criteria…

"Buy the *fastest* protection you can, consistent with economic sanity"

Line No.	Supplier Number Customer Part No. Description	Quantity Ordered
1	863-1.5KE18AG 12V ON Semi TVS Diodes - Transient Vol US HTS: 8541.10.0050 ECCN:EAR99	15
2	863-1.5KE36AG 24V ON Semi TVS Diodes - Transient Vol US HTS: 8541.10.0050 ECCN:EAR99	10
3	511-1.5KE47A 41VPNLS ST TVS Diodes - Transient Voltage US HTS: 8541.10.0080 ECCN:EAR99	25

- Mouser.com is 'small order & ham-friendly'
- The 5KE##AG series shows *standoff voltage.*

Installation of TVS Diodes

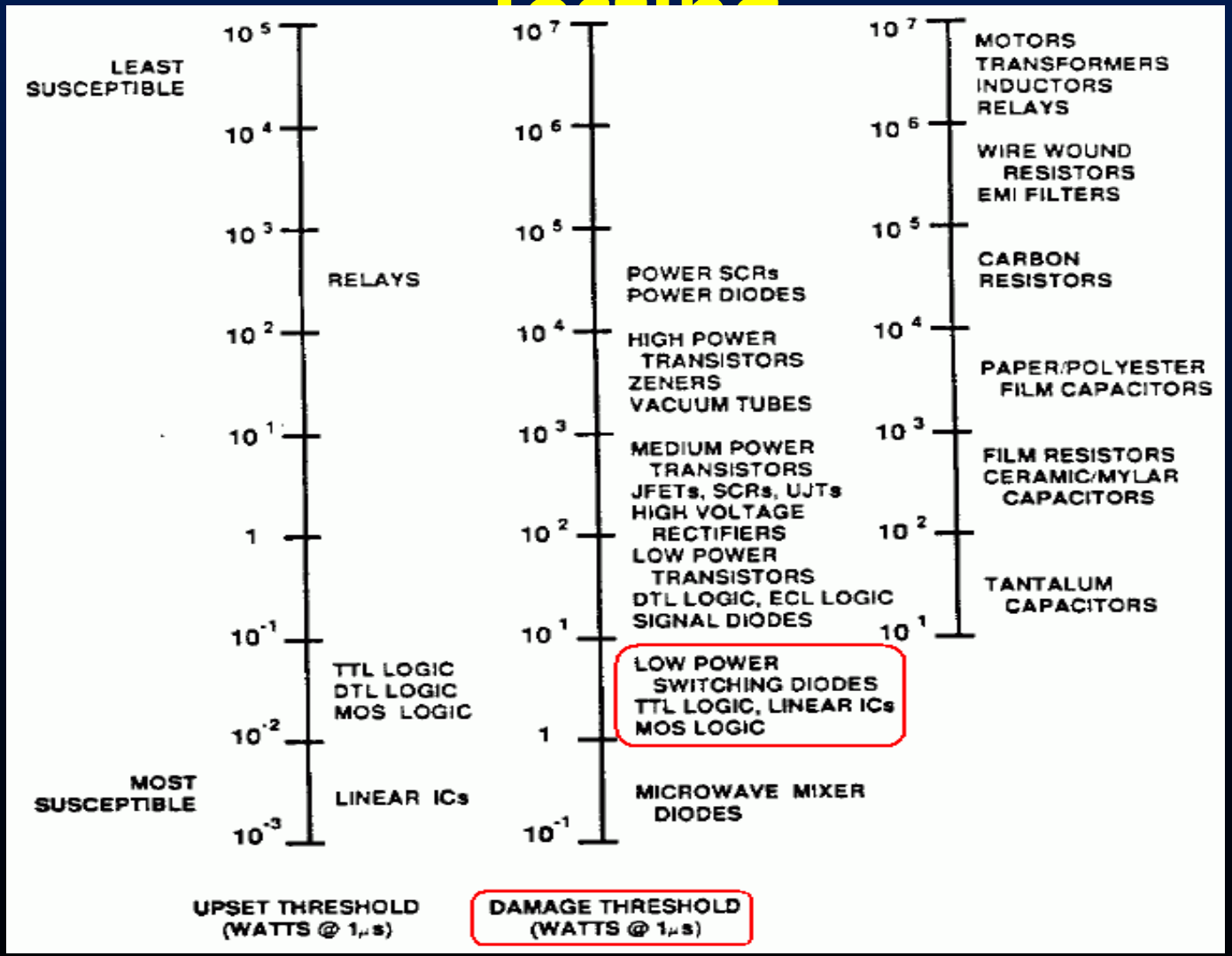
- On ‘car side’ of the +12V line (car side of ignition switch) *and* on the battery + to gnd. On these I’m planning to install the 18V standoffs.
- On 24 volt energy system, planning the 36V standoffs to protect the output of the charge controllers and the input of the grid-tied inverters
- On the solar panel side, using the 47V standoffs because panels will go as high as 38-39 V volts open-circuit, no load, full sun

Faraday Cages and More

- Small gasoline or diesel gensets may be semi-immune if disconnected.
- Grounded metal sheds are a start
- Metal garbage cans with metal lids are good.
- Disconnected radios and surge strips may be a good investment

- …the alternative is…..

Comprehensive Breakdown Testing



At the Device Level

"The investigation of the susceptibility of logic devices built in ten different semiconductor technologies to EMP and UWB pulses has shown, that CMOS devices first gets reversible breakdowns and at much higher field amplitudes non reversible destructions occur. The destruction thresholds of TTL and CMOS devices are similar but TTL devices always gets non reversible destructions."

BFR and DFR

- Analysis of components in EMP and other pulse stress tests differentiates between
  - BREAKDOWN FAILURE RATE (BFR)
  - DESTRUCTION FAILURE RATE (DRF)
- A device reset will recover a device level failure from BFR (think of it as ‘static lockup’) but in Destruction Failure Rate analysis, the underlying junction is kaput

BFR/ DFR Testing Results

Table 1. Tested Technologies

TTL-Technology					
Standard	Schottky (S)	Low Power Schottky (LS)	Advanced Schottky (AS)	Advanced Low Power Schottky (ALS)	Fairchild Advanced Schottky (FAST)
CMOS-Technology					
High Speed (HC)	High Speed TTL-compatibel (HCT)	Advanced (AC)	Advanced TTL-compatibel (ACT)		

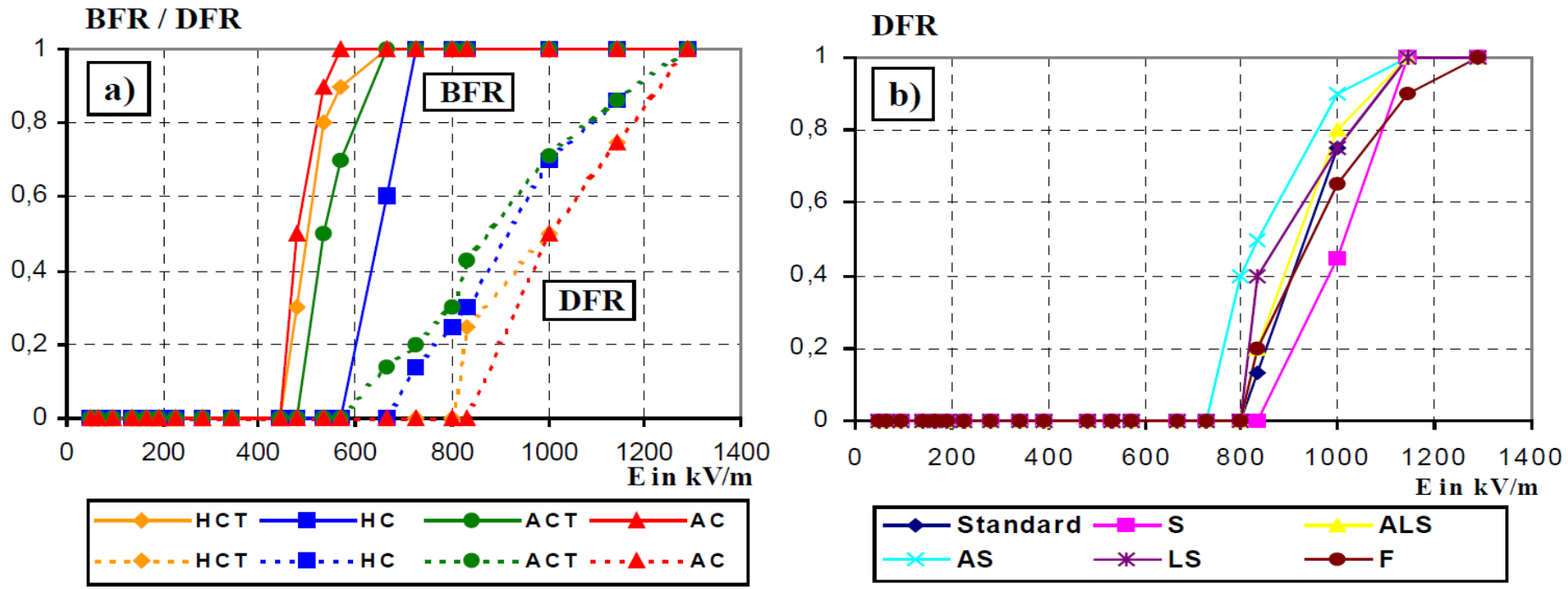


Fig. 5. Breakdown (BFR) and Destruction Failure Rate (DFR) of CMOS (a) and TTL (b) Inverter Devices

Some Simple “Best Practices”

- ESD: Tube gear, ESD Mat, wrist grounding
- Thunderstorms:
  - Good Lightning Protection
  - Keep Towers lowered if crank-up
  - Disconnect all antennas
  - Good lightning protection outside
- EMP:
  - Disconnect mics, keys (long wire leads are bad)
  - Short antenna inputs, disconnect DC power leads
  - TVS in the 12V supply line if it must remain connected
  - Spare rig(s) in metal garbage can
  - Know in advance about ‘high risk windows’ like Nov 8-12.

TVS EMP Protection is a Gamble

- If there ever was an EMP attack, rise time and proximity are the major concerns.
- Rise times of reported 1.5 to 5 nanoseconds rise times are hard to beat with off-the-shelf (public) components; 50 nanoseconds is a piece of cake.
- Best insurance: Rig in a metal garbage can, vehicles in metal closed buildings with metal screened (grounded) windows.
- Oh…and lots of beer and good walking shoes in case we all get it wrong…

Questions? Discussion?

Thank you!

References

- ESD graphics & discussion: http://www.semicon.toshiba.co.jp/docs/catalog/en/BEE0037_catalog.pdf
- Lightning pulse discussion http://www.weighing-systems.com/TechnologyCentre/Lightning1.pdf
- Lightning risk assessment: http://www.arrl.org/files/file/Technology/tis/info/pdf/0206056.pdf
- Lightning Decision Tree http://www.lightningsafety.com/nlsi_pls/decision_tree_people.html
- Physics of EMP http://www.princeton.edu/~globsec/publications/effects/effects11.pdf
- 3-Part EMP Waveform http://www.tscm.com/MIL-STD-464.pdf
- MIL-STD-464: http://www.tscm.com/MIL-STD-464.pdf
- Spectrum impacts: From NX6R's presentation *www.metersinc.org/library/**EMP.ppt*** which cites:
- Bodson, Dennis W4PWF "Electromagnetic Pulse and the Radio Amateur" ***QST***
  Parts 1-4: August, September, October, November 1986
  condensed from "Electromagnetic Pulse/Transient Threat Testing of Protection Devices for Amateur/Military Affiliate Radio System Equipment"
  National Communication Systems Report ***NCS TIB 85-10***
- Starfish Prime Impacts http://en.wikipedia.org/wiki/Starfish_Prime
- Linked Infrastructures, Large EMP Event data http://www.empcommission.org/docs/A2473-EMP_Commission-7MB.pdf
  Height of Burst to Impact Area chart http://www.fas.org/sgp/crs/natsec/RL32544.pdf
- Conventionally pumped EMP devices http://www.globalsecurity.org/military/library/report/1996/apjemp.htm
- "50kV in Nanoseconds": http://*darkwing.uoregon.edu/~joe/infragard-2009/infragard-eugene-2009.**ppt***
- ***How High, How Big? http://www.fas.org/nuke/intro/nuke/emp/c-2body.pdf***
- ***BFR/DFR Testing: http://www.columbiassacrifice.com/techdocs/Susceptibility_to_EMP&UWB.pdf***