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
- 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

- **Total Duration**
- **Effective Duration**
- **Amplitude**

- **Rise Time** = 0
- **Decay Time** = 0

**Normal Operating Voltage**

**Zero Voltage Axis** - typically the ground plane
Inverse Square Law

Distance from Center

1 unit

2 units

Double the Distance Means 1/4th the Strength
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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 products 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 Lightning

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

- E1: Early Time
  - Prompt Gamma Signal
  - Scattered Gamma Signal
  - Neutron Gamma Signal

- E2: Intermediate Time
- E3: Late Time
  - MHD Signal

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

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Environment (V/m - rms)</th>
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<tbody>
<tr>
<td></td>
<td>Peak</td>
</tr>
<tr>
<td>10k-150M</td>
<td>200</td>
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<tr>
<td>150M-225M</td>
<td>3,120</td>
</tr>
<tr>
<td>225M-400M</td>
<td>2,830</td>
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<tr>
<td>400M-700M</td>
<td>4,000</td>
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<tr>
<td>700M-790M</td>
<td>3,500</td>
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<tr>
<td>790M-1000M</td>
<td>3,500</td>
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<tr>
<td>1G-2G</td>
<td>5,670</td>
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<tr>
<td>2G-2.7G</td>
<td>21,270</td>
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<tr>
<td>2.7G-3.6G</td>
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<tr>
<td>3.6G-4G</td>
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<td>4G-5.4G</td>
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<td>5.4G-5.9G</td>
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<td>5.9G-6G</td>
<td>15,000</td>
</tr>
<tr>
<td>6G-7.9G</td>
<td>12,650</td>
</tr>
<tr>
<td>7.9G-8G</td>
<td>12,650</td>
</tr>
<tr>
<td>8G-14G</td>
<td>21,270</td>
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<tr>
<td>14G-18G</td>
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<tr>
<td>18G-40G</td>
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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
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 Affected by an Electromagnetic Pulse, by Height of Burst

Predict EMP Impact Analysis

Figure 2. Illustrative EMP Effects – Fast Pulse
Texas is Semi-Isolated in One Key Area.
Some Much for Nukes...

Conventionally Pumped EMP

- 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

Fig. 1 Typical Electromagnetic Pulse Shapes

- Nuclear EMP Transient
- Lightning Stroke
- Flux Compression Generator

(normalised amplitude vs. time [usec])
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.”
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--

\[
E(t) = \frac{kE_{pk}e^{a(t-t_s)}}{1+e(a+b)(t-t_s)} \text{ (kV/m)}
\]

(eq 2-2)

where \( E_{pk} = 50 \text{ kV/m} \) (peak electric field in kilovolts per meter); \( k = 1.2 \) (a normalization constant); \( a = 5 \times 10^8 \) 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"

- 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

- Least Susceptible
  - Motors
  - Transformers
  - Inductors
  - Relays
  - Wire Wound Resistors
  - EMI Filters
  - Carbon Resistors
- Medium Power
  - Paper/Polyester Film Capacitors
  - Film Resistors
  - Ceramic/Mylar Capacitors
- Most Susceptible
  - Tantalum Capacitors
- Upset Threshold
  - TTL Logic
  - DTL Logic
  - MOS Logic
- Damage Threshold
  - Low Power Switching Diodes
  - TTL Logic, Linear ICs
  - MOS Logic
- Low Power
  - Mixers
  - Diodes

(Watts @ 1μs)
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

<table>
<thead>
<tr>
<th>TTL-Technology</th>
<th>CMOS-Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>High Speed (HC)</td>
</tr>
<tr>
<td>Schottky (S)</td>
<td>High Speed TTL-compatible (HCT)</td>
</tr>
<tr>
<td>Low Power Schottky (LS)</td>
<td>Advanced (AC)</td>
</tr>
<tr>
<td>Advanced Schottky (AS)</td>
<td>Advanced TTL-compatible (ACT)</td>
</tr>
<tr>
<td>Advanced Low Power Schottky (ALS)</td>
<td></td>
</tr>
<tr>
<td>Fairchild Advanced Schottky (FAST)</td>
<td></td>
</tr>
</tbody>
</table>

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

- Lightning pulse discussion http://www.weighing-systems.com/TechnologyCentre/Lightning1.pdf
- Lightning Decision Tree http://www.lightningsafety.com/nlsi_pls/decision_tree_people.html
- Spectrum impacts: From NX6R’s presentation www.metersinc.org/library/EMP.ppt which cites:
- Linked Infrastructures, Large EMP Event data http://www.empcommission.org/docs/A2473-EMP_Commission-7MB.pdf