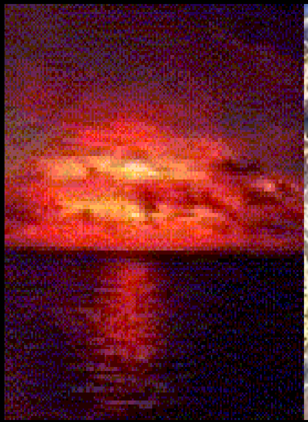

EMP Knots Untied: Common Misconceptions about EMP

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Common EMP Misconceptions

1. EMP will burn out every exposed electronic system
2. EMP effects will be very limited and only result in "nuisance" effects in critical infrastructure systems
   a) EMP will cause "upset" effects – not permanent damage
   b) These upset effects are not serious with easy recovery
3. Long-haul fiber optic lines are not vulnerable to EMP
4. To protect our critical national infrastructure would cost a large fraction of the GNP
5. Megaton class weapons are needed to cause any serious EMP effects – low yield "entry-level" weapons are not a concern
6. Only late-time EMP (E3), not E1 will damage electric power grid transformers
7. Ground burst EMP effects are limited to 2-5 km from a nuclear explosion where blast, thermal and radiation effects dominate.

Misconception: EMP will "fry" every exposed electronic system

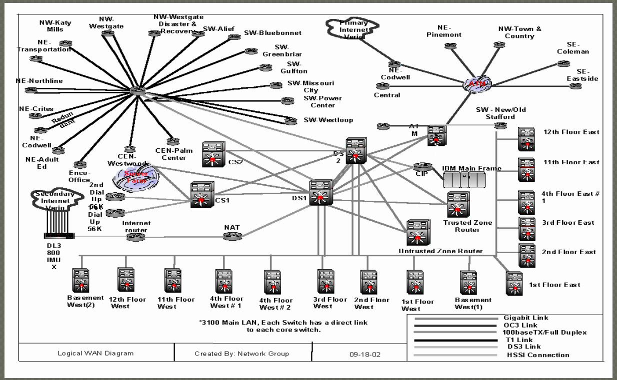
Based on a large EMP test data base we know:

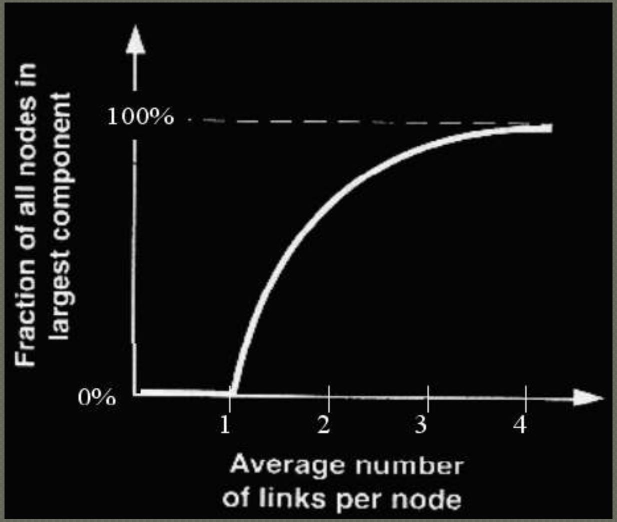
- Threat-level testing reveals that smaller, self-contained and self-powered (not connected into long line networks) systems such as vehicles, hand-held radios and unconnected portable generators often survive EMP
  - If there is an effect, it is more often temporary upset rather than component burnout
- Threat-level testing also reveals that systems connected to long lines are vulnerable to component damage
  - The longer the line, the higher the probability of EMP damage
  - Power grid and long-haul landline communication systems are vulnerable to component damage – with ubiquitous cascading effects to dependent systems
- EMP system failure predictions are highly unreliable – system testing is required to ascertain vulnerability
  - Uncertainties in coupling levels, coupling paths, and electronic box thresholds combine to produce orders of magnitude uncertainty
  - Experts often do not even identify the location of components actually affected.

Misconception: EMP effects will be very limited and cause only easily recoverable "nuisance" effects in critical infrastructure systems

Corollary misconception: EMP will cause only "upset" effects – not component burnout and these upset effects will be easily and quickly recoverable

- Although EMP does not affect every system, widespread failure of limited numbers of systems, because of the interconnectivity among affected and unaffected electronic systems, will cause large-scale cascading failures of critical infrastructure systems and system networks
  - Paul Erdos' "small world" network theory applies
- For unmanned systems, upset is tantamount to permanent damage in most cases – and may cause permanent damage due to control failures. Examples:
  - Lockup of long-haul communication repeaters
  - Upset of remote pipeline pressure control SCADA systems
  - Upset of generator controls in electric power plants
  - Upset of machine process controllers in manufacturing plants

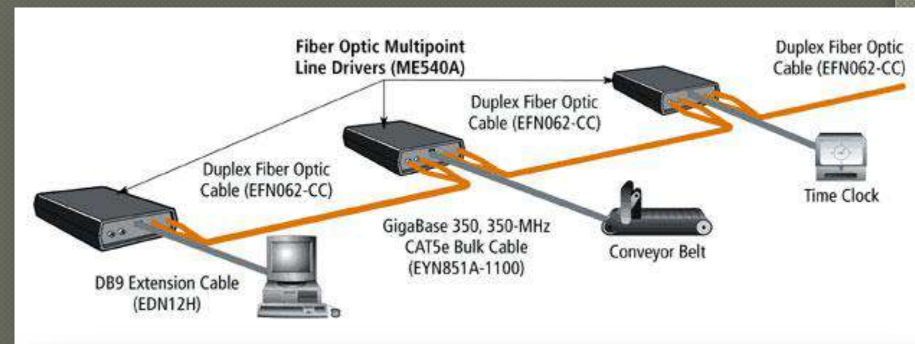


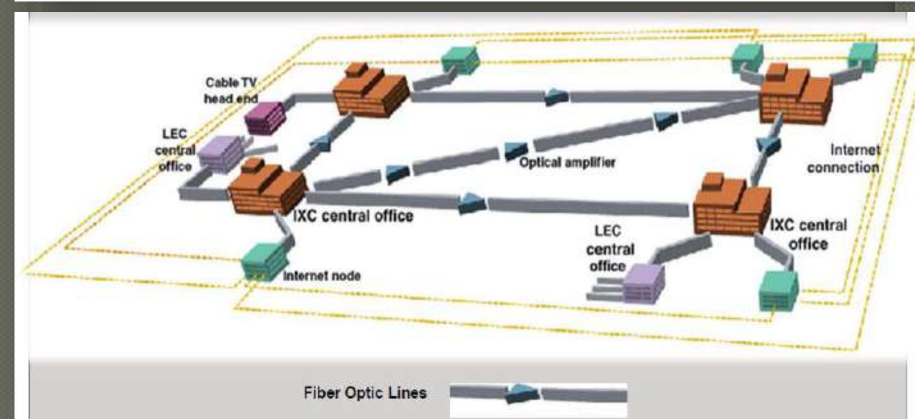


Erdos' "Small World" Theory Result

Misconception: Optical fiber networks are not susceptible to EMP effects

- In general they are <u>less</u> susceptible than metallic line networks, however …
  - Fiber optic line driver and receiver boxes are susceptible
  - Long-haul telecom and Internet optical fiber repeaters are susceptible
- On the plus side:
  Line drivers/receivers and repeaters are relatively easy to protect using shielding, aperture treatment, and power line filters





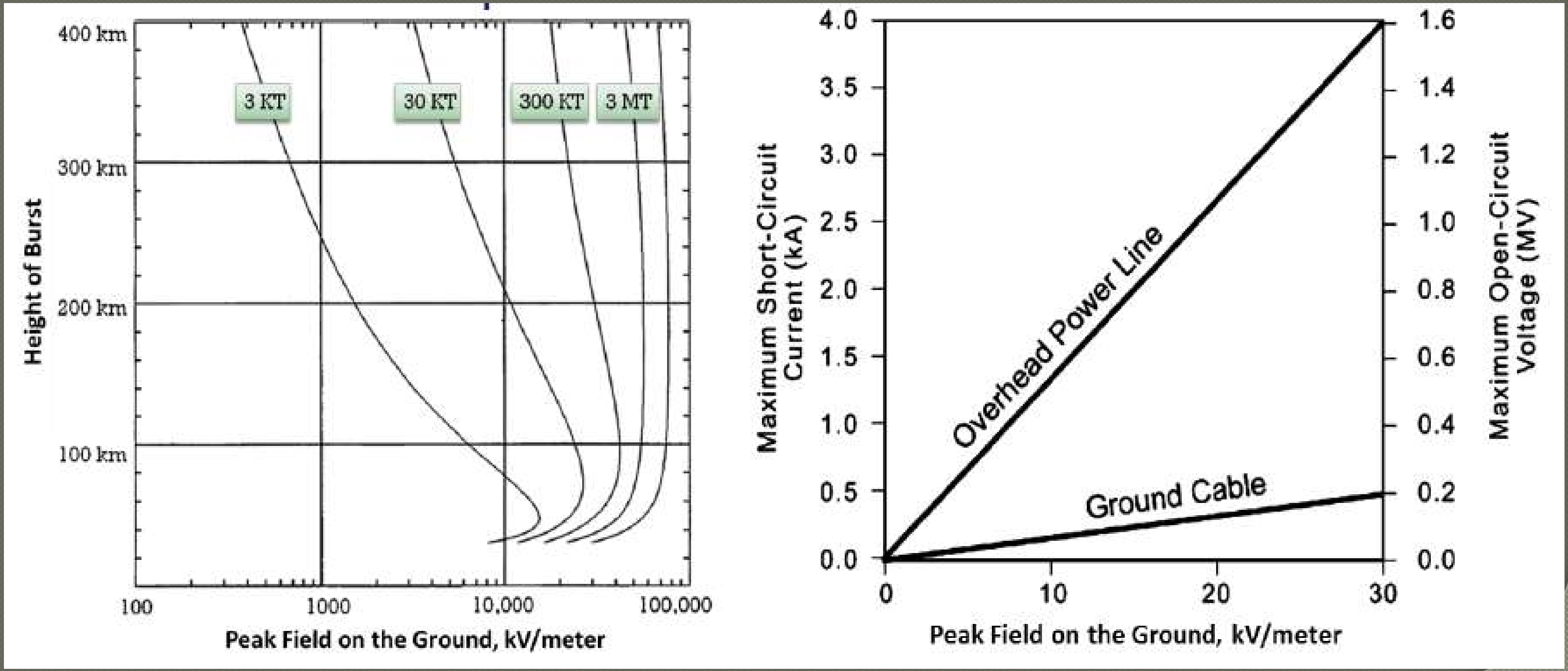
Misconception: To protect our critical national infra-structure would cost a large fraction of the U.S. GNP

- Of the 14 critical infrastructure sectors, EMP risk is highest for electric power grid and telecommunications networks – attention to these alone would bring major benefits to national resiliency
  - Most vulnerable due to organic long lines
  - Most necessary for operation and recovery of other infrastructure sectors

- Protection of electric power grid alone is worth pursuing
  - Bipolar: fails fast and hard over large regions
  - Most necessary for sustaining basic life services
- Protection of the components most difficult to replace buys valuable time
  - High voltage transformers and generators take months to replace – years if large numbers are damaged
  - HV transformer protection unit cost is estimated to be $250,000. Total number of susceptible units range from 300 – 3000 (further assessment required)
  - Generator protection costs still undetermined but likely in the same ballpark as transformers (further assessment required)
- Need for SCADA system protection moderated by availability of spares and relative ease of repair/replacement
- Protection costs for heavy-duty grid components are in the single digit billions of dollars – a small fraction of value of losses should they fail – amortizes to pennies.

Misconception: Megaton-class weapons are needed to cause any serious EMP effects – "entry-level" Kiloton-class weapons are not a concern

- Low yield weapons below 75 km altitude produce peak E1 fields comparable to large yield weapons
- 30 KT nuclear weapon above 100 km causes geomagnetic disturbances as large as solar superstorms but over smaller area
- Currents in 1000s of amperes induced by low yield weapons



Misconception: Only late-time EMP (E3), not E1, will damage electric power grid transformers

- ORNL E1 tests of 7.2 KV distribution transformers caused permanent damage to transformer windings in seven of the twenty units tested
- Failures were due to
  - Turn-to-turn flashover
  - Primary-to-secondary flashover
- Transformers with direct-mounted lightning overvoltage protection were not damaged
- Similar tests of HV transformers are needed

XFMR	Shots #@kV	Peak Voltage (kV)	Time to Peak (ns)	Surge Arrester	Notes	Result
ZS1						Pulser calibration
ZS2	1@400	264	618	No	(1)	T-T failure
ZS3	2@400	288	668	No	(2)	HV-LV failure
ZS4	2@400	280	600	No	(1)	L-L failure
ZS5	1@400	272	550	No	(2)	HV-LV failure
ZS6	2@400	290	643	No	(1)	No damage
ZV1	1@400	296	601	No	(1)	No damage
ZV2	1@400	304	592	No	(2)	HV-LV failure
ZV3	2@400	110	100	Yes	(3)	No damage
ZV4	2@500	110	100	Yes	(3)	No damage
ZV4	2@780	116	110	Yes	(3)	No damage
XV1	1@400	272	500	No	(2)	HV-LV failure
XV2	2@400	115	110	Yes	(3)	No damage
ZW1	2@400	292	552	No	(1)	No damage
ZW2	2@400	16	Oscillatory	No	(4)	No damage
ZW3	2@780	100	110	Yes	(3)	No damage
ZW4	2@1000	112	105	Yes	(3)	No damage
ZD1	2@400	120	550	No	(5)	No damage
ZD2	2@400	20	Oscillatory	No	(4)	No damage
ZE1	2@1000	95	100	Yes	(6)	No damage
ZE2	6@780	95	100	Yes	(6)	No damage

(1) External flashover on HV bushing; T-T failure denotes turn-to-turn failure; L-L failure denotes line-to-line failure
(2) No external flashover; HV-LV failure denotes a high-voltage winding flashover to the low-voltage winding
(3) Surge arrester operation and no external flashover
(4) Surge applied to the low-voltage bushings with no external flashover
(5) Surge applied common mode to both HV bushings with external flashover
(6) Surge applied common mode to both bushings, and both arresters operated