Table 2-1. Important features of EMP environments*

Type	Features	Systems impact
HEMP	Large extent, high amplitude, broad frequency band, plane wave	Most widely specified threat
Surface-burst		
Source region	Large amplitude, limited extent includes varying conductivity, currents	Important for systems which are hard to other nuclear effects
Radiated region	Large amplitude varies inversely with distance	Can supersede HEMP if vertical orientation or low freqs. important
Air-burst		
Source region	Similar to surface-burst	See surface burst
Radiated region	Amplitude less than HEMP	Superseded by HEMP
SGEMP	Very high amplitude and fast rise time	Important for exoatmospheric systems
MHD-EMP	Very low frequency, low amplitude, large extent	May affect long-land or submarine cables

*Source: ref 2-1, DNA EMP Course Study Guide, draft prepared for Defense Nuclear Agency (The BDM Corp., April 1983), p I-51.

Table 2-2. EMP waveform summary*

Type	Peak amplitude	Timeframe
HEMP	50 kV/m	Few nanosec to 200 nanosec
Surface-burst		
Source region	1 MV/m	Few nanosec to 1 microsec
	10 kV/m	1 microsec to 0.1 sec
Radiated region	10 kV/m	1 microsec to 100 microsec
Air-burst		
Source region	Similar to surface-burst	
Radiated region	300 V/m at 5 km, typical (highly dependent on HOB	10 nanosec to 5 microsec
SGEMP	100 kV/m	Few nanosec to 100 nanosec
MHD-EMP	30 V/km	0.1 sec to 100 sec

*Source: ref 2-1, DNA EMP Course Study Guide, draft prepared for Defense Nuclear Agency (The BDM Corp., April 1983), p I-49.

Table 2-3. Response thresholds*

Equipment	Lead**	Upset level, p-p*** (A)	Damage level, p-p (A)	Max. stress level, p-p (A)
Primary frequency supply (PFS-2A)	-24 V	0.4	--+	-9
A5 channel bank (solid state modem)	-24 V	80	--	150
	input	--	150	150
	gain	--	75	75
Multiplex				
WELMX-1 (tube)	130 V	0.07	--	1
WELMX-2 (solid-state)	-24 V	0.02	60	60
WEMMX-1 (tube)	130 V	2	--	2
WEMMX-2 (solid-state)	-24 V	--	--	50
Wireline entrance link, 3A (amplifier)	-24 V1	1	--	35
100-A protection switch (switching unit)	+24 V	0.2	--	0.9
TM-1 radio-27 V	--	25	25	
L4 cable system				
Trigger A equalizer	-24 V	8	--	110
Protection switch	-24 V	16	--	110
WE TD3 radio	dc power input	50	--	--
WE TH3 radio	dc power input	60	--	--
Farinon FM 2000 radio	dc power input	208	240	--
Lenkurt 778A2 radio	dc power input	35	--	--
Collins MW608D radio	dc power input	50`	--	--

*Source: ref 2-4, Prototype HEMP Design Practice Handbook, prepared for Defense Communications Agency (IRT Corp., Contract No. DCA 100-77-C-0040, May 1978).
**Point where induced current was measured.
***Induced peak-to-peak (damped sinusoid) on indicated lead.
+Data not measured.

Table 2-4. Typical EMP transients and equipment thresholds--
EMP threat level*

Point of entry	Waveform	Voltage	Current	Impedance (ohms)
A.C. power lines,	DE**	2 MV	4 kA	500
telephone cables (above-ground)	DE	2 MV	4 kA	500
External antennas	2-30 MHz DS**	60 kV	1.2 kA	50
Video COAX lines (inner conductor)	1-5 MHz DS5	5 kV	71 A	70
Telephone cable (submarine sheath)	DE	60 kV	1.2 kA	50

*Source: ref 2-1, DNA EMP Course Study Guide, draft prepared for Defense Nuclear Agency (The BDM Corp., April 1983), p VI-37.
**DE = double exponential; DS = damped sinusoid.

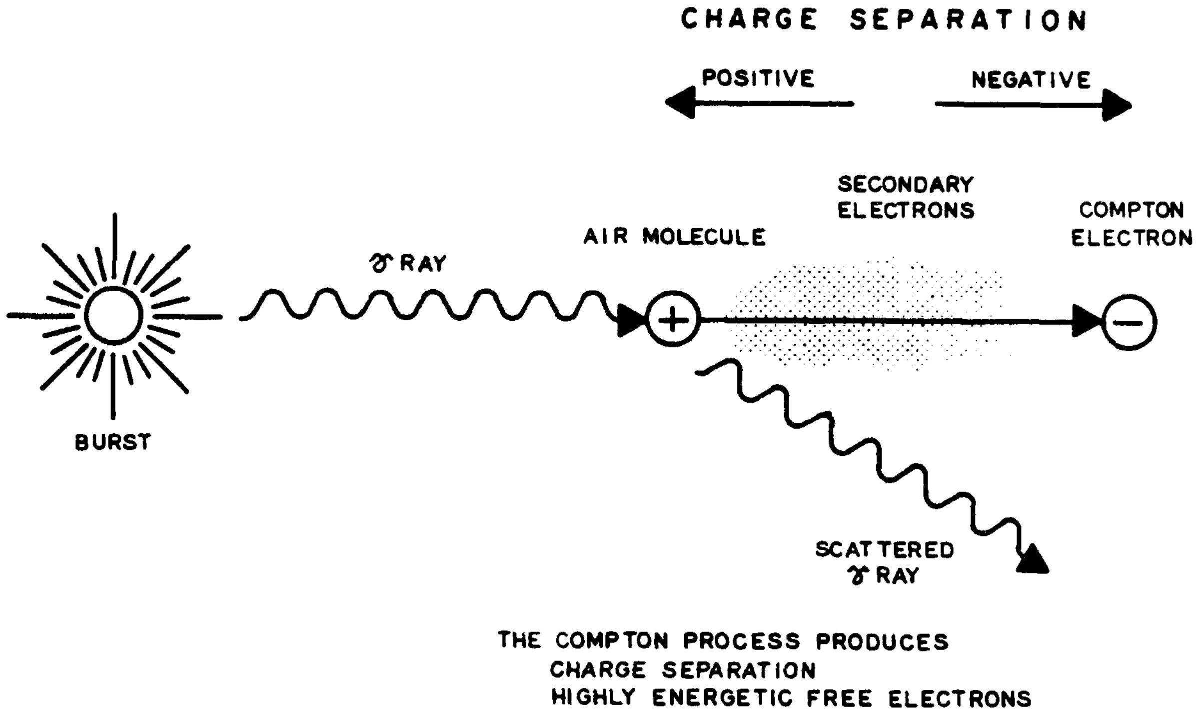

Figure 2-1. The Compton process. (Source: ref 2-1)

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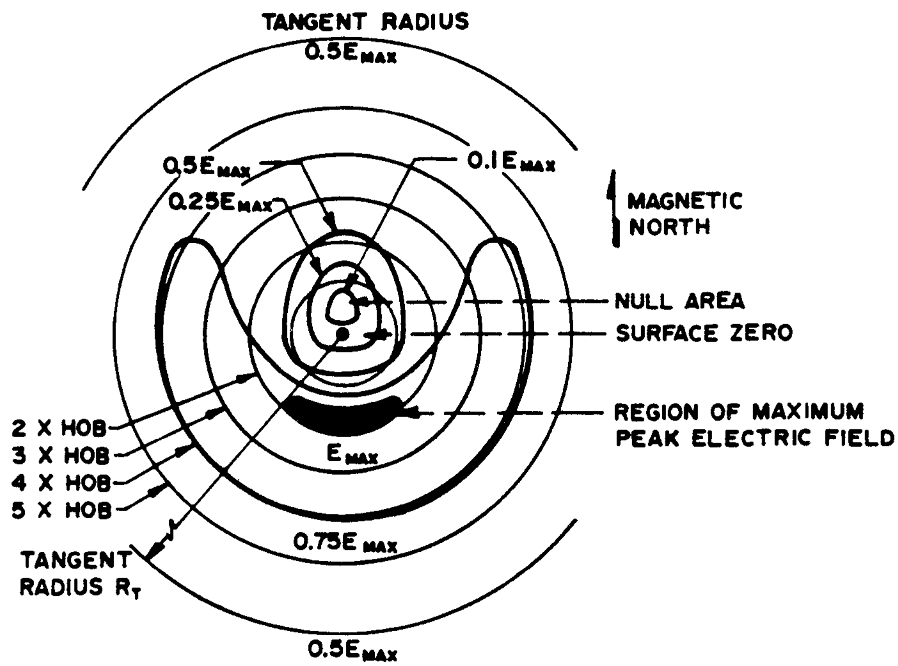


Figure 2-3. Variations in high-altitude EMP peak electric field strength as a function of direction and distance from surface zero. (Source: ref 2-1)

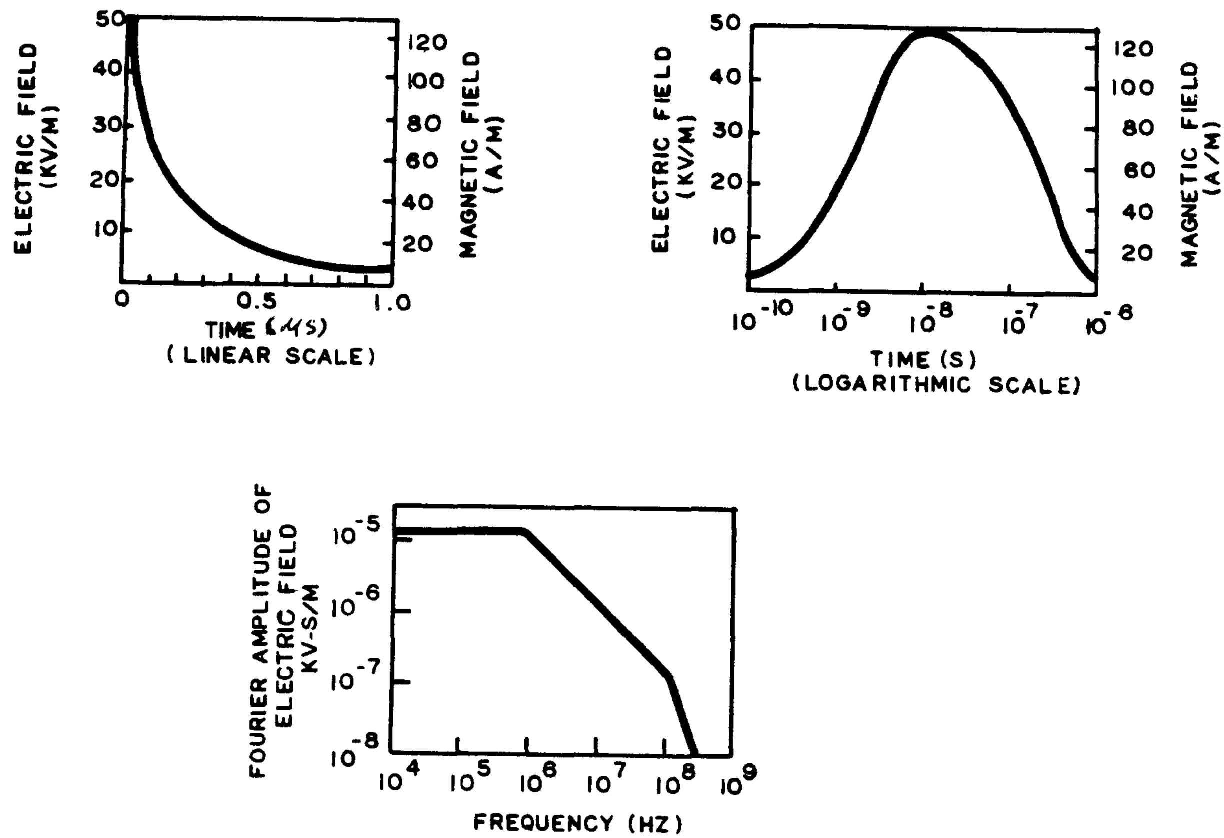


Figure 2-4. HEMP waveform. (Source: ref 2-1)

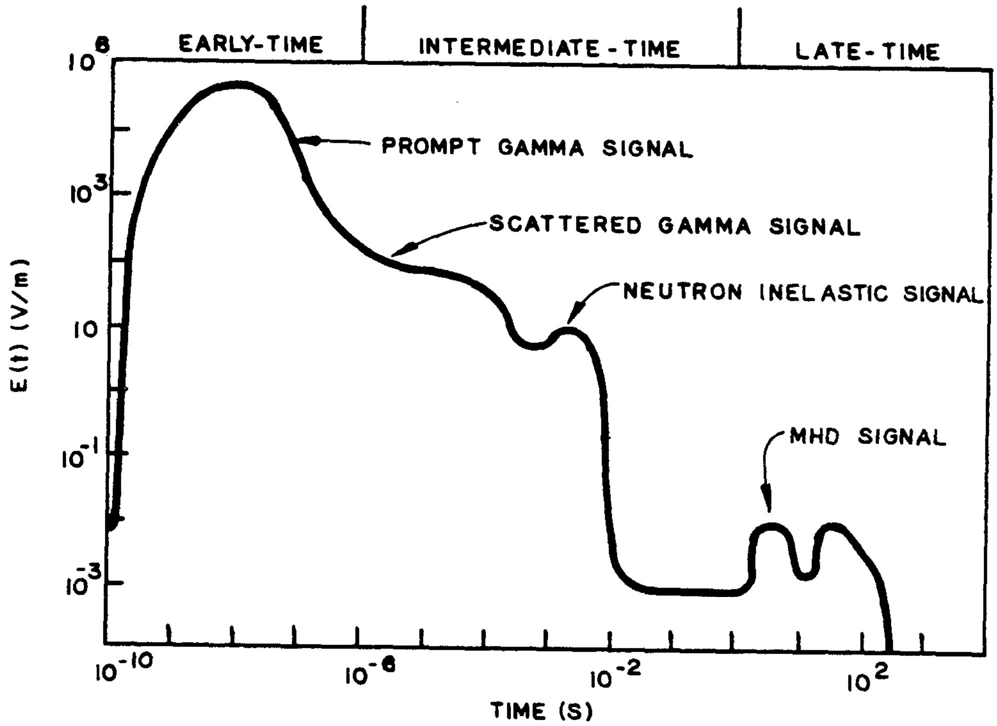


Figure 2-5. Qualitative time domain example of HEMP. (Source: ref 2-1)

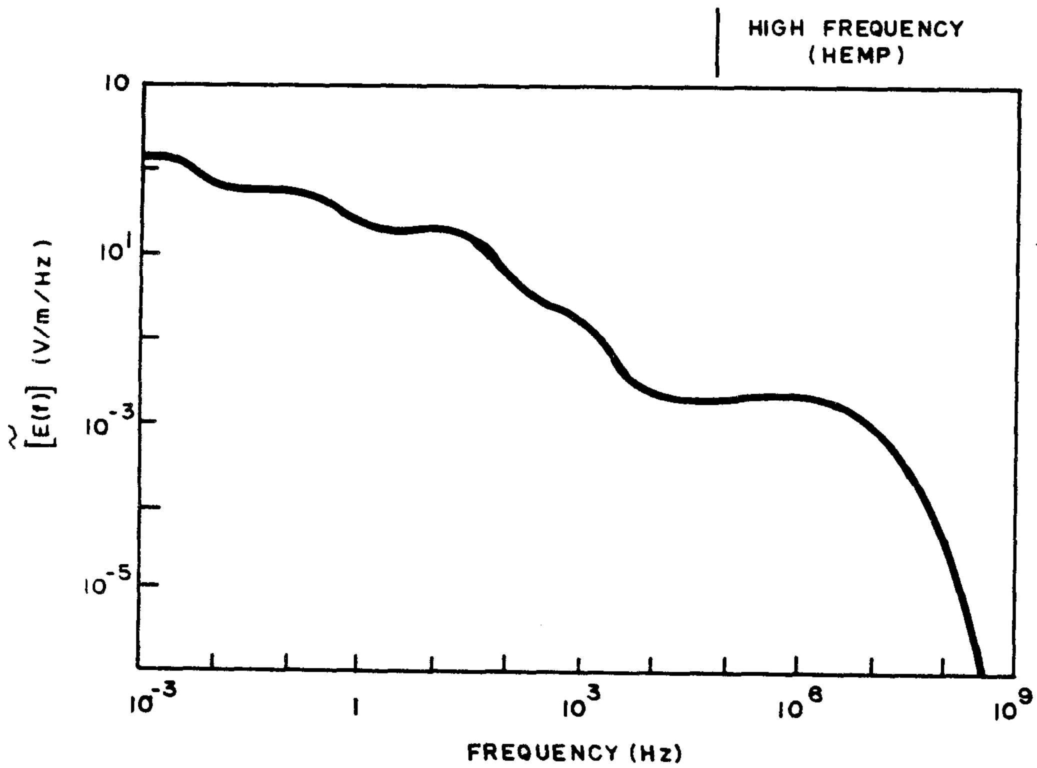


Figure 2-6. Qualitative frequency domain example of HEMP. (Source: ref 2-1)

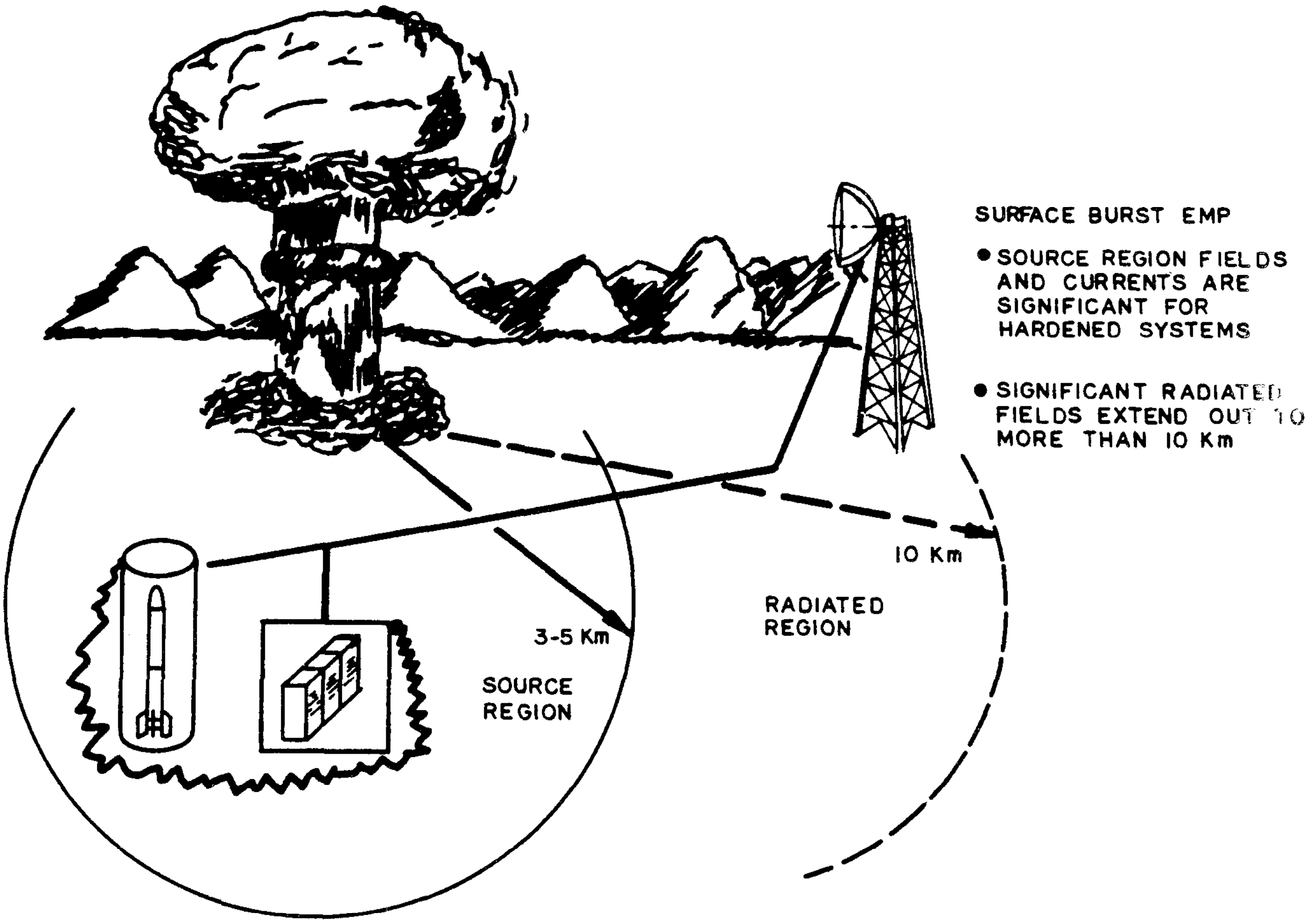


Figure 2-7. Surface-burst EMP showing source region and radiated region. (Source: ref 2-1)

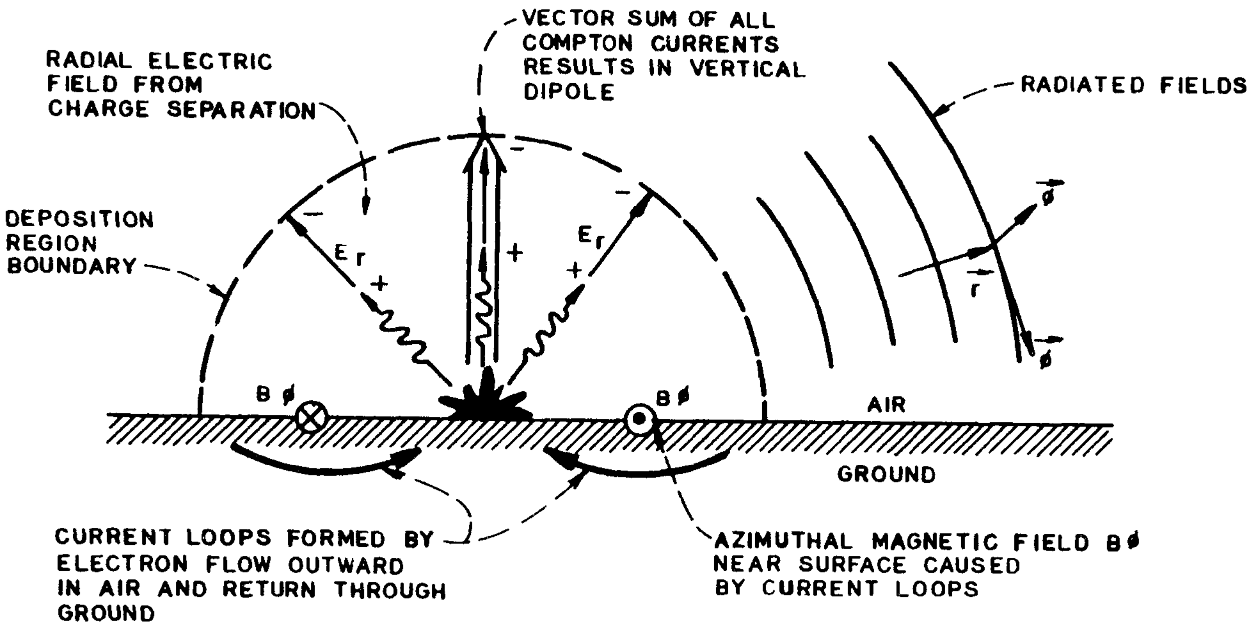
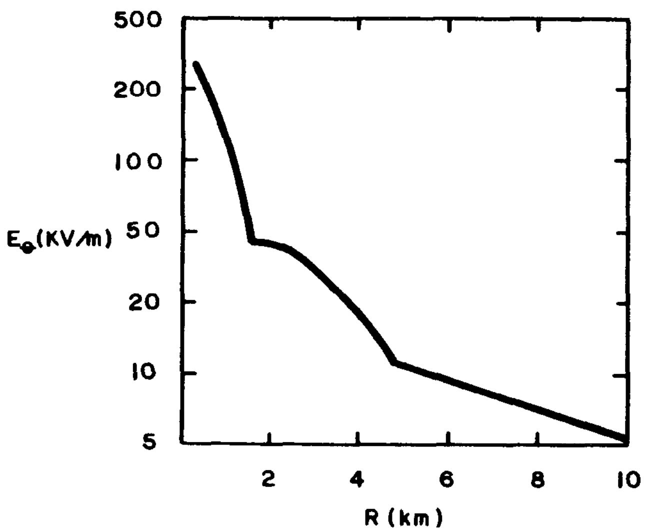


Figure 2-8. Overview of surface-burst EMP. (Source: ref 2-1)



- AMPLITUDE TYPICALLY LESS THAN H_2)IP OUTSIDE SOURCE REGION
- AMPLITUDE VARIES INVERSELY WITH RANGE OUTSIDE SOURCE REGION
- NO STANDARD WAVEFORM
- SYSTEM IMPACT MAY SUPERSEDE HEMP DUE TO
  - HIGH LOW-FREQUENCY CONTENT (BELOW 100 kHz)
  - VERTICAL E-FIELD ORIENTATION

Figure 2-9. Radiated vertical electric field--large surface burst. (Source: ref 2-1)

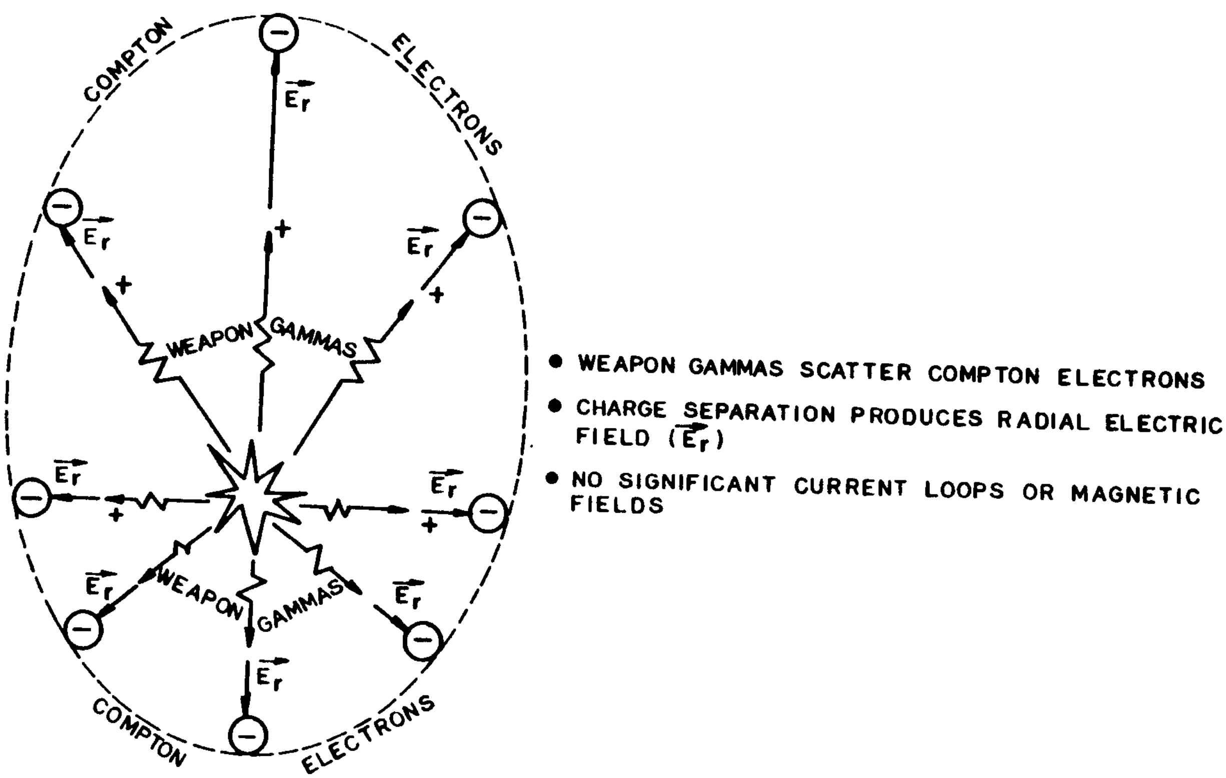


Figure 2-10. Air-burst EMP--source region.

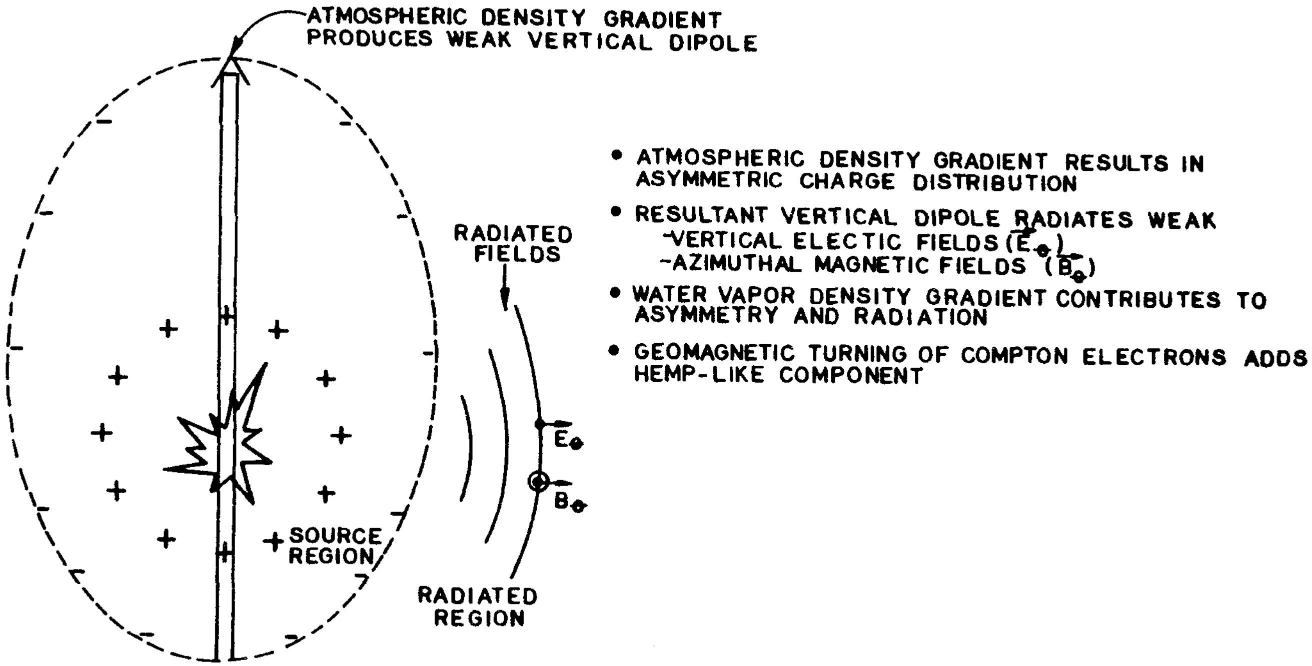


Figure 2-11. Air-burst EMP--radiated region. (Source: ref 2-1)

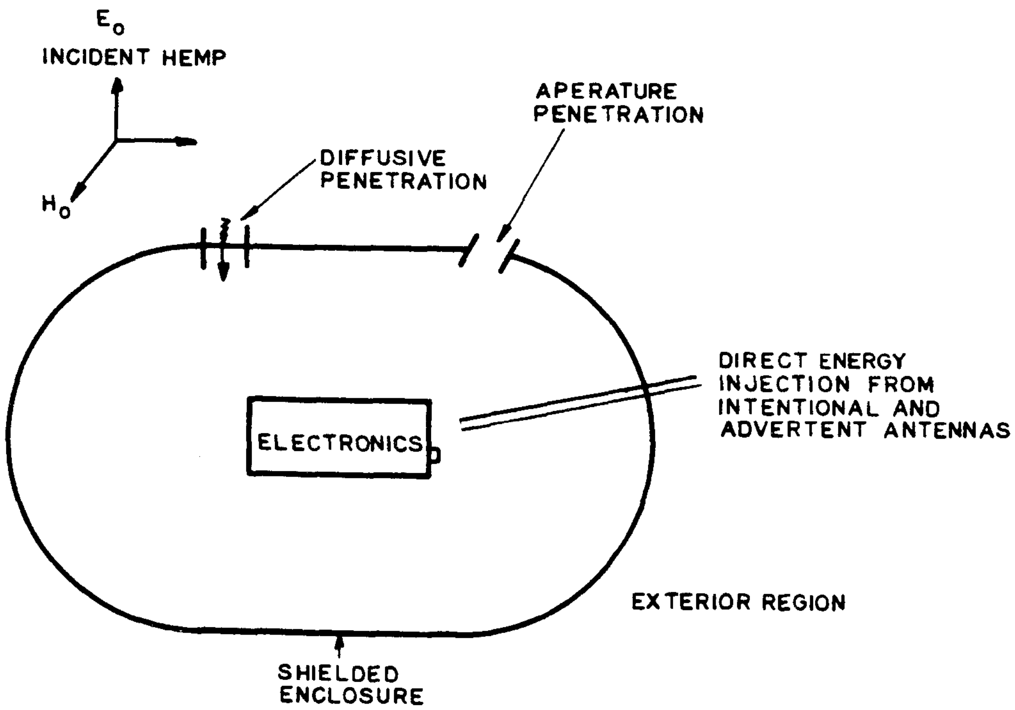


Figure 2-12. Three modes of penetration and coupling into shielded enclosures. (Source: ref 2-4)

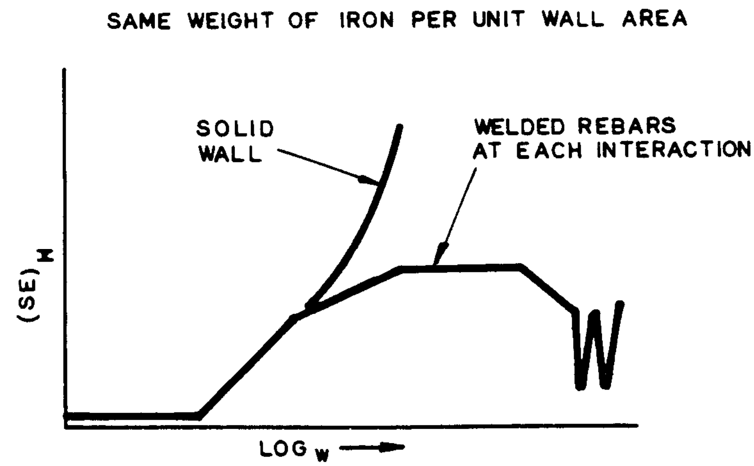


Figure 2-13. Magnetic shielding effectiveness of an enclosure with solid walls and an enclosure with rebar. (Source: ref 2-5)

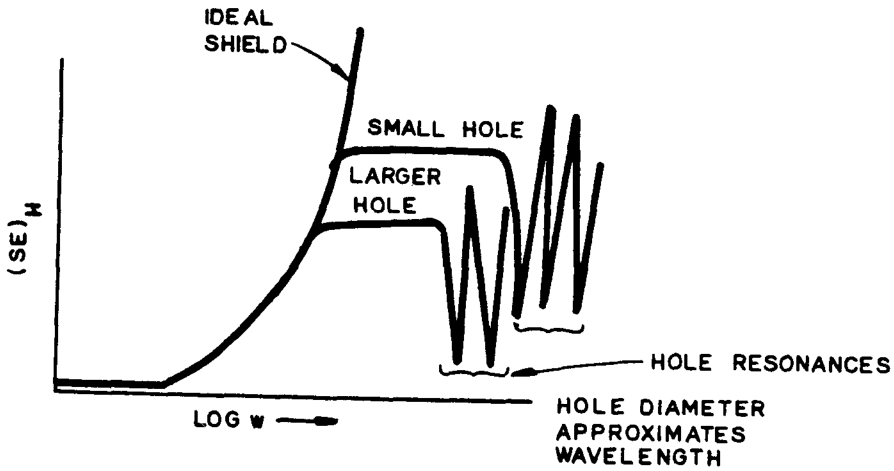


Figure 2-14. Magnetic shielding effectiveness of an ideal enclosure and an enclosure with openings. (Source: ref 2-5)

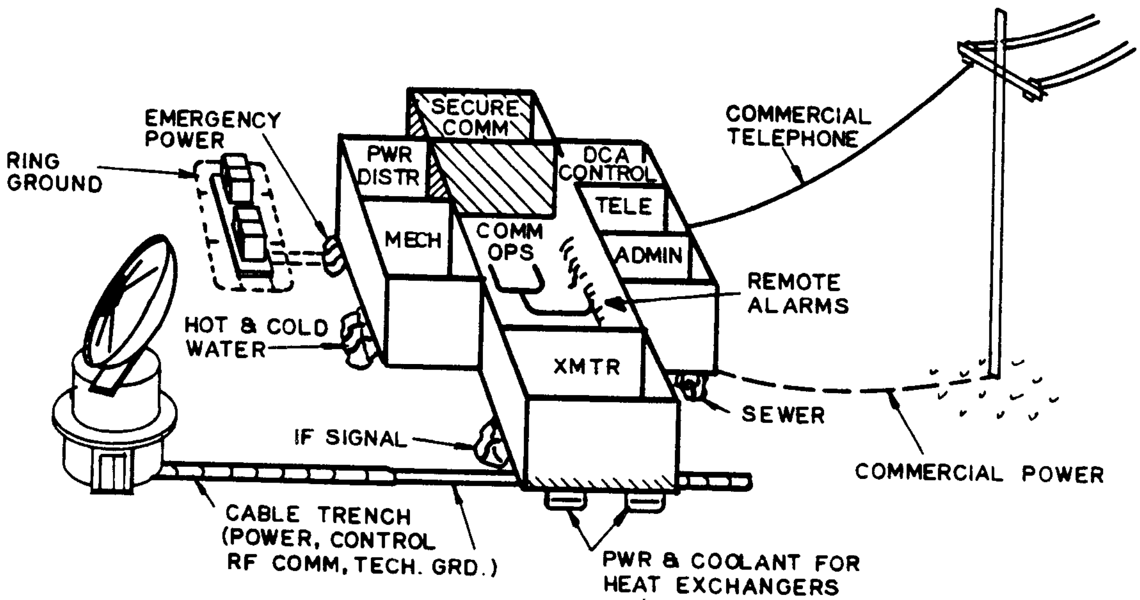


Figure 2-15. Ground-based facilities--unintentional antennas. (Source: ref 2-1)

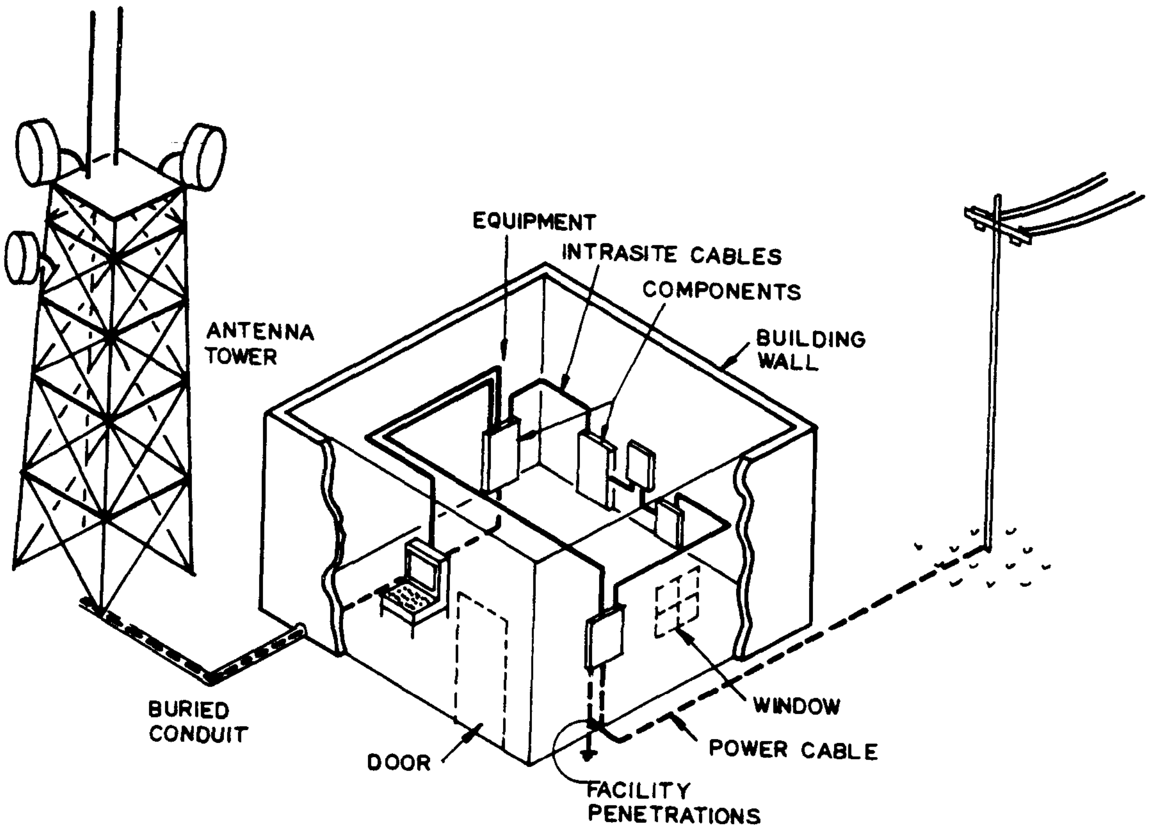


Figure 2-16. EMP coupling to facility penetrations. (Source: ref 2-1)

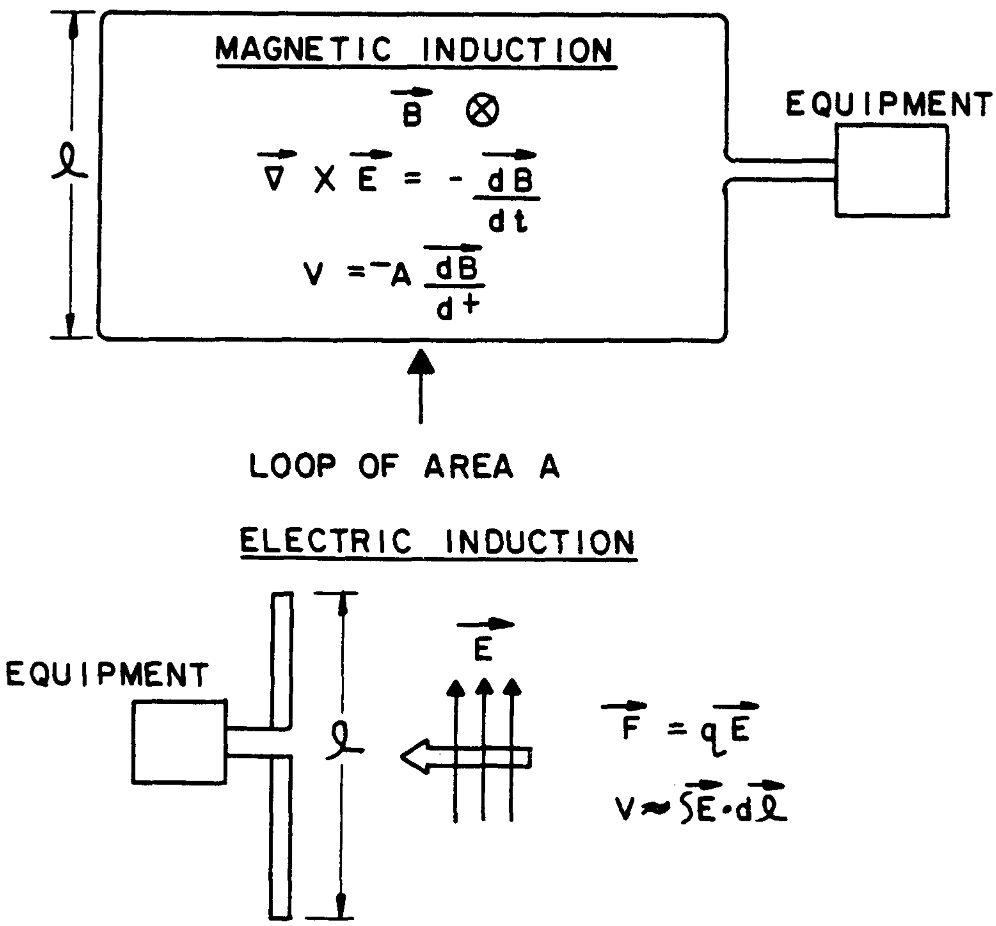


Figure 2-17. Two mechanisms by which EMP couples to conductors. (Source: ref 2-1)

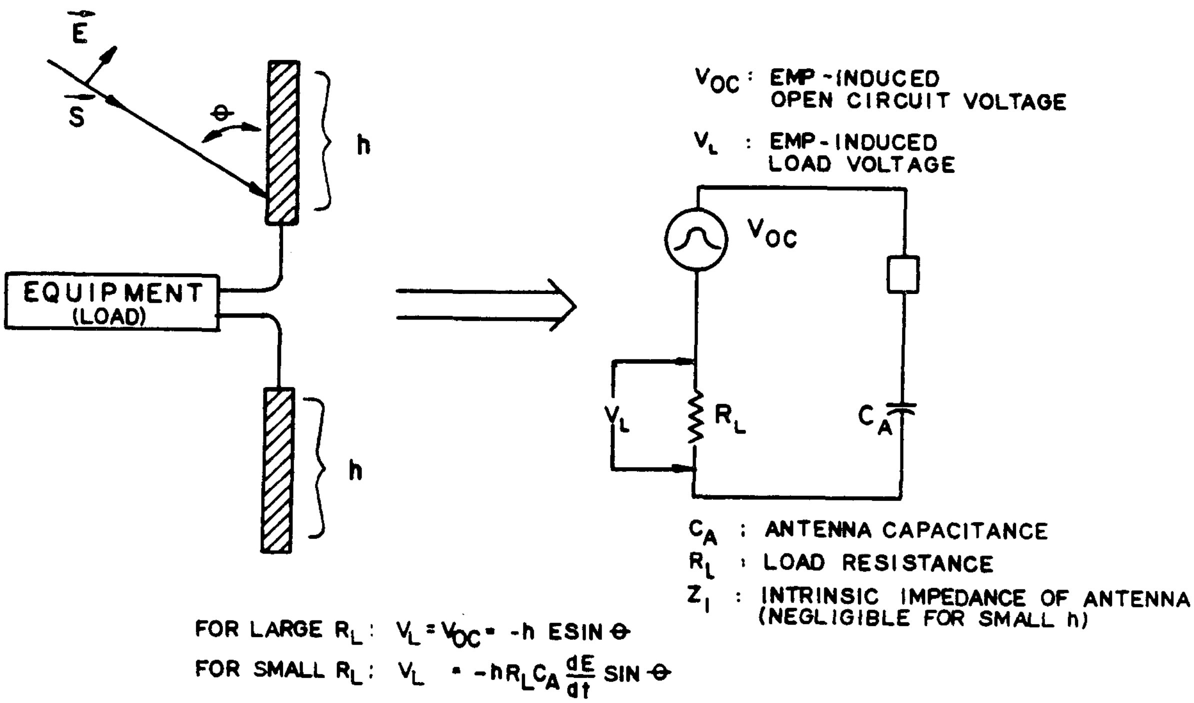


Figure 2-18. Equivalent circuit for a small electric dipole.
(Source: ref 2-1)

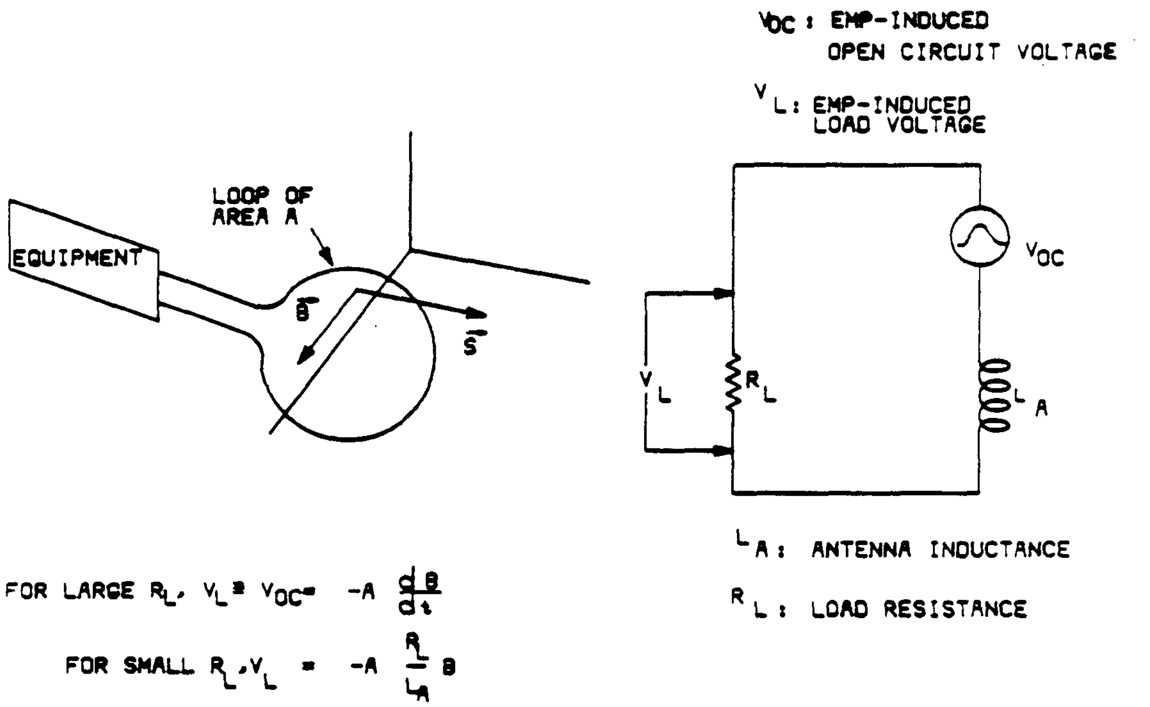


Figure 2-19. Equivalent circuit for a small loop (magnetic dipole).
(Source: ref 2-1)

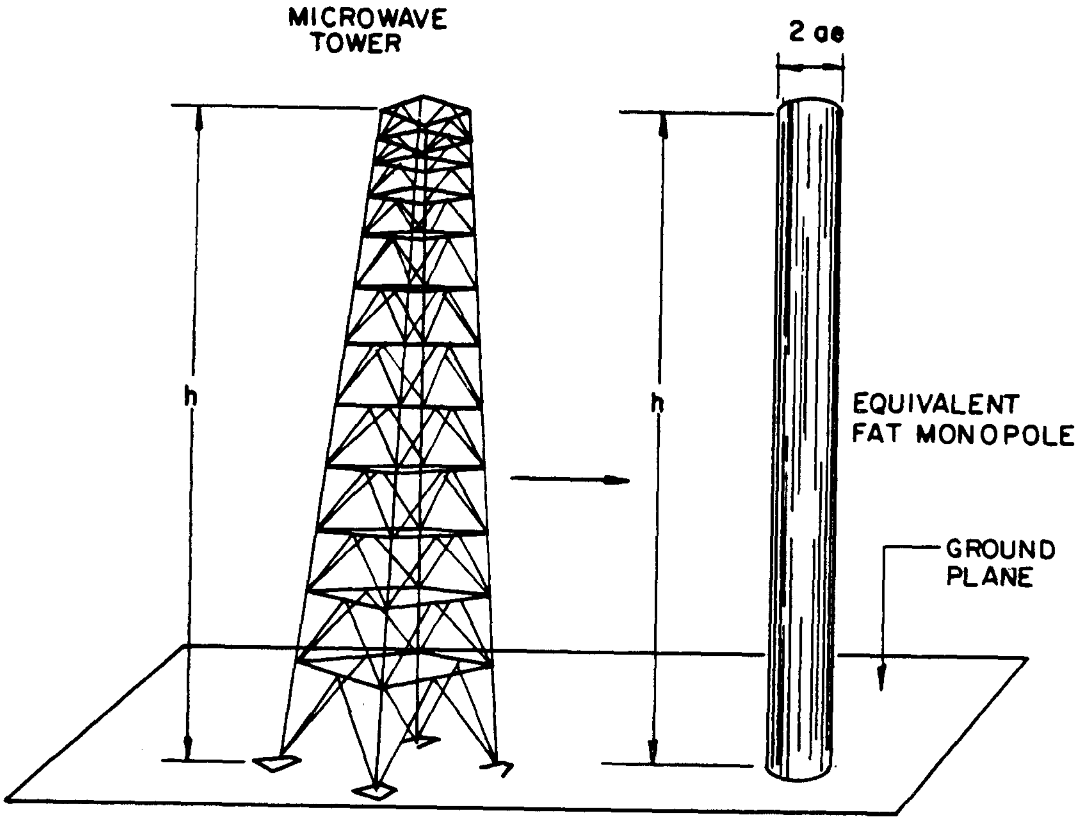
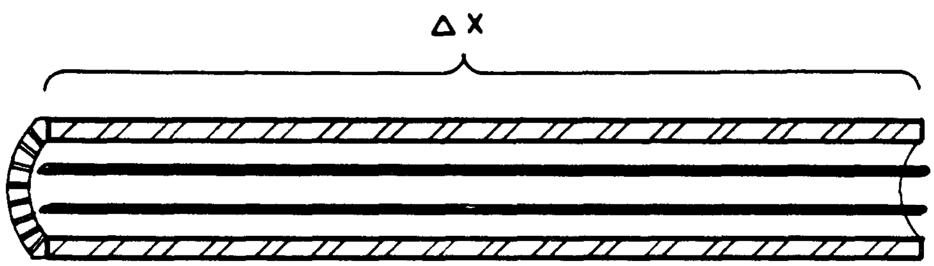


Figure 2-20. Modeling example--microwave tower and equivalent fat cylindrical monopole. (Source: ref 2-1)



$$\Delta V = I_S Z_T \Delta X$$

ΔV = VOLTAGE DROP ON CENTER CONDUCTOR OF CABLE OF LENGTH ΔX

I_S = SHEATH CURRENT

Z_T = TRANSFER IMPEDANCE PER UNIT LENGTH

ΔX = INCREMENTAL LENGTH

Figure 2-21. Shielded cables and transfer impedance. (Source: ref 2-1)

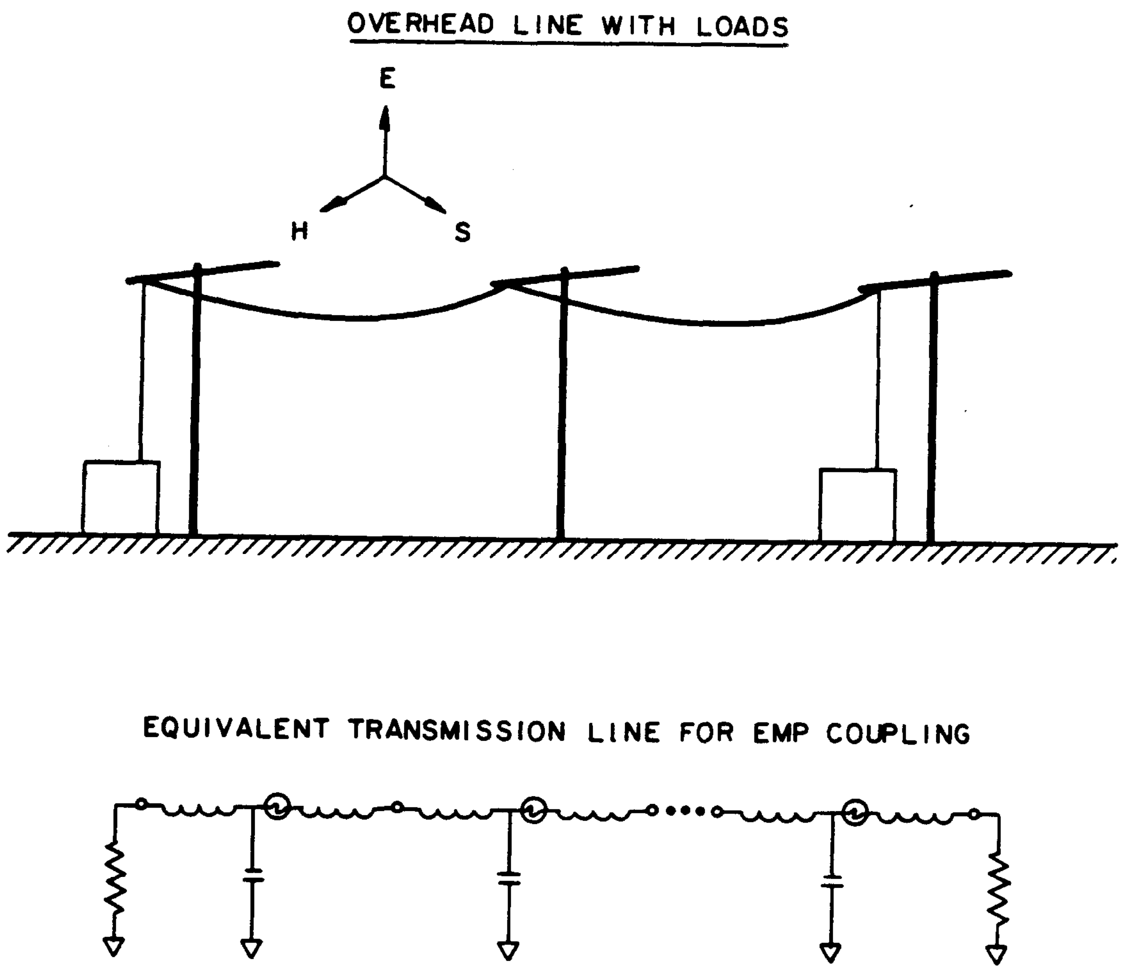


Figure 2-22. Transmission line coupling. (Source: ref 2-1)

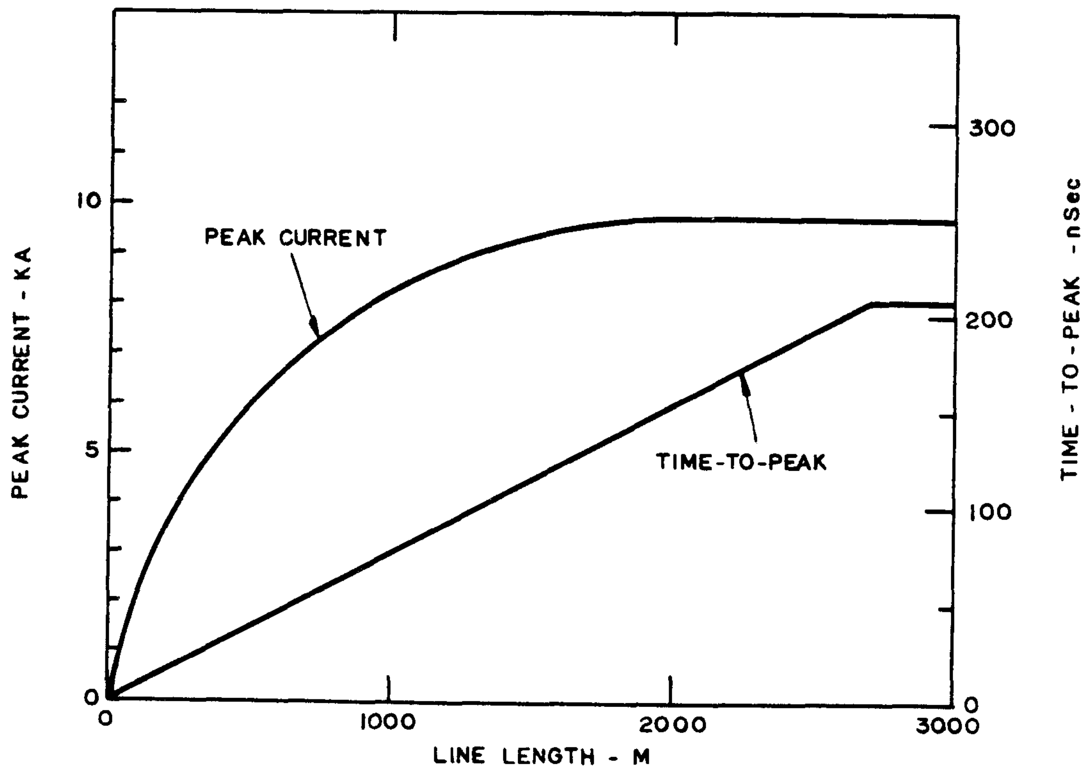


Figure 2-23. Aerial conductors: effect of conductor length. (Source: ref 2-1)

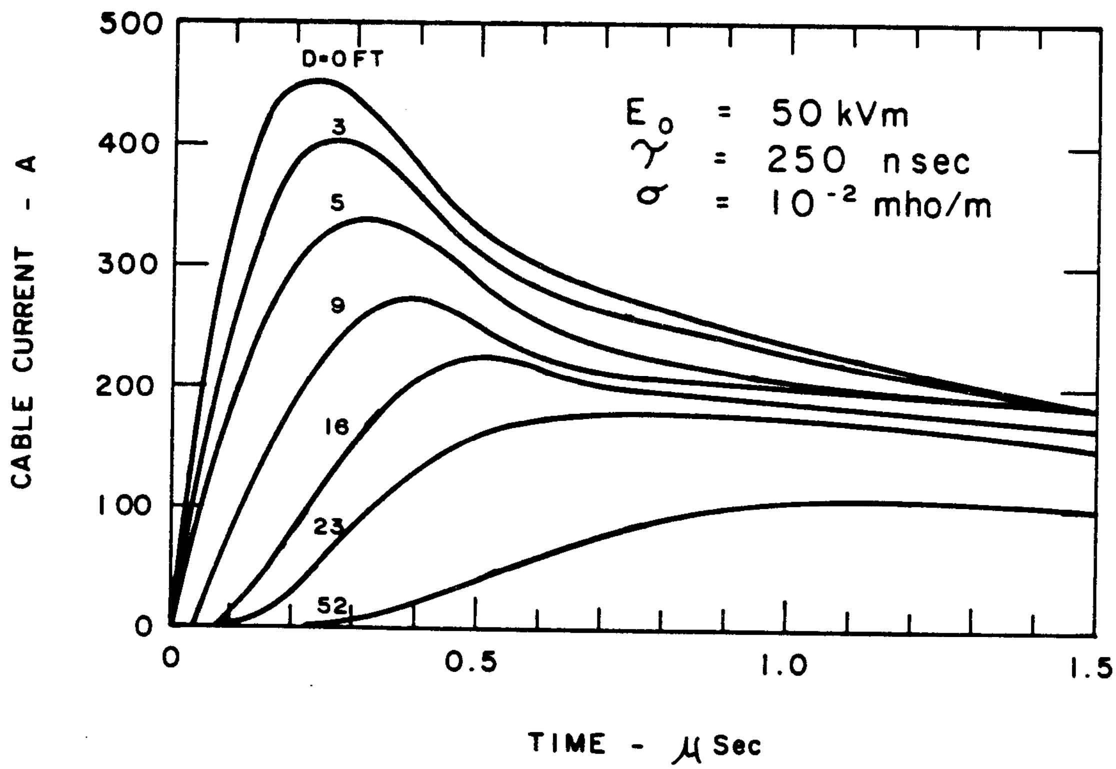


Figure 2-24. Buried conductors: effect of burial depth. (Source: ref 2-1)

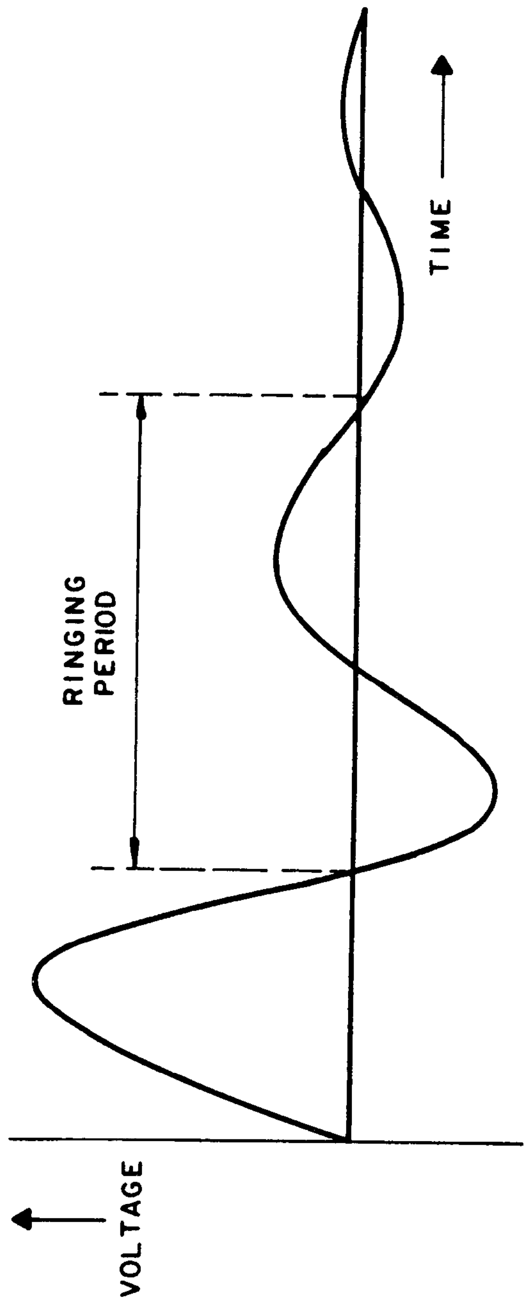


Figure 2-25. Ringing.

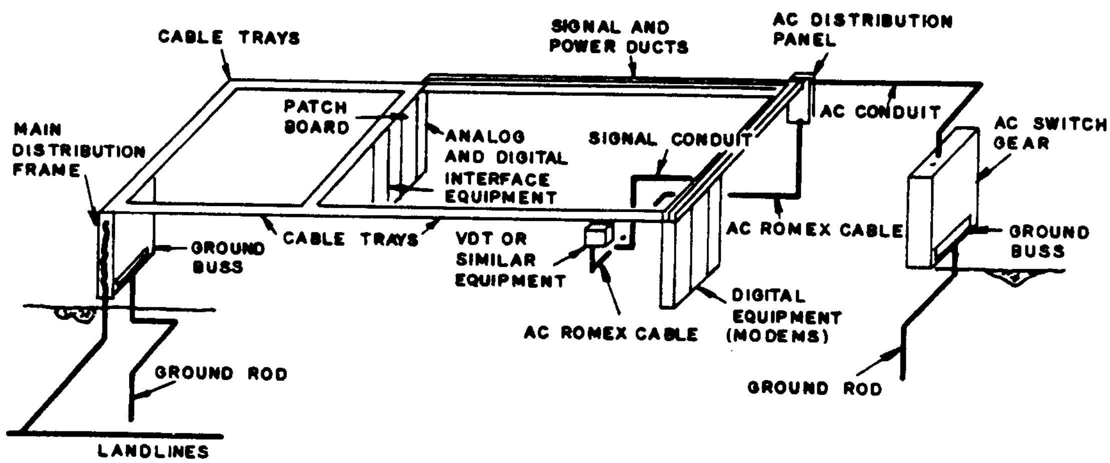


Figure 2-26. Typical internal signal cable distribution diagram.
(Source: ref 2-1)

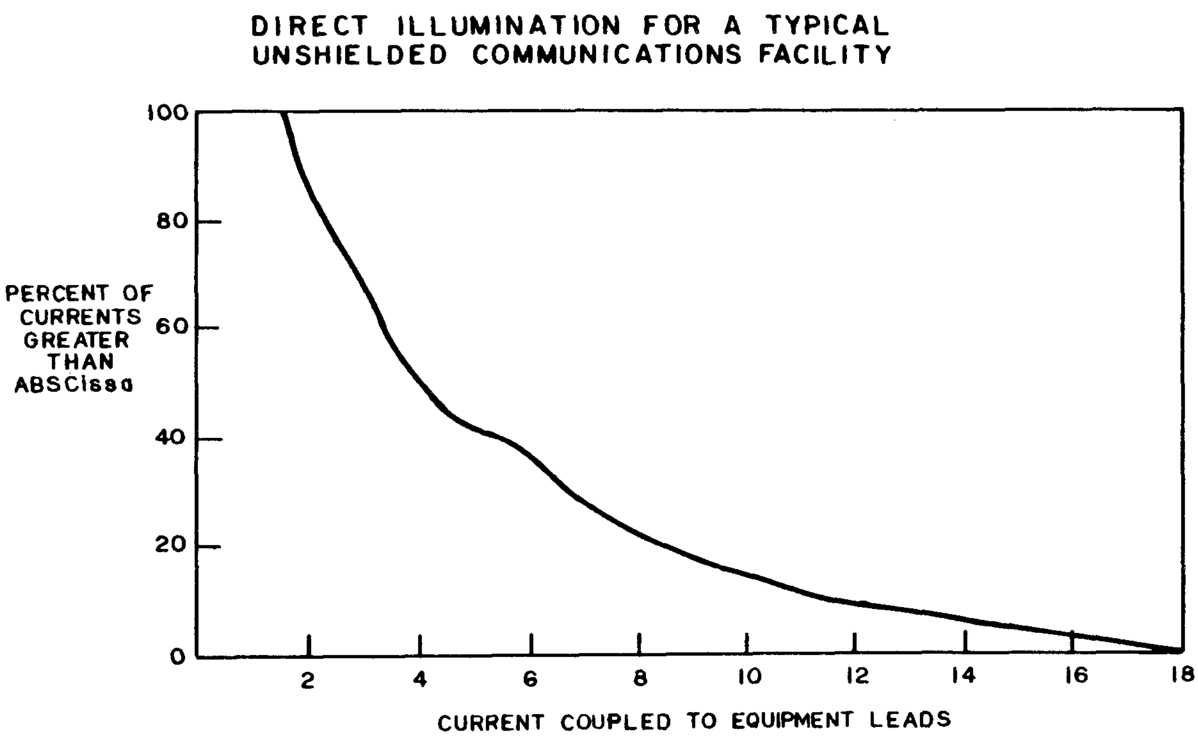


Figure 2-27. Intrasite cables. (Source: ref 2-1)

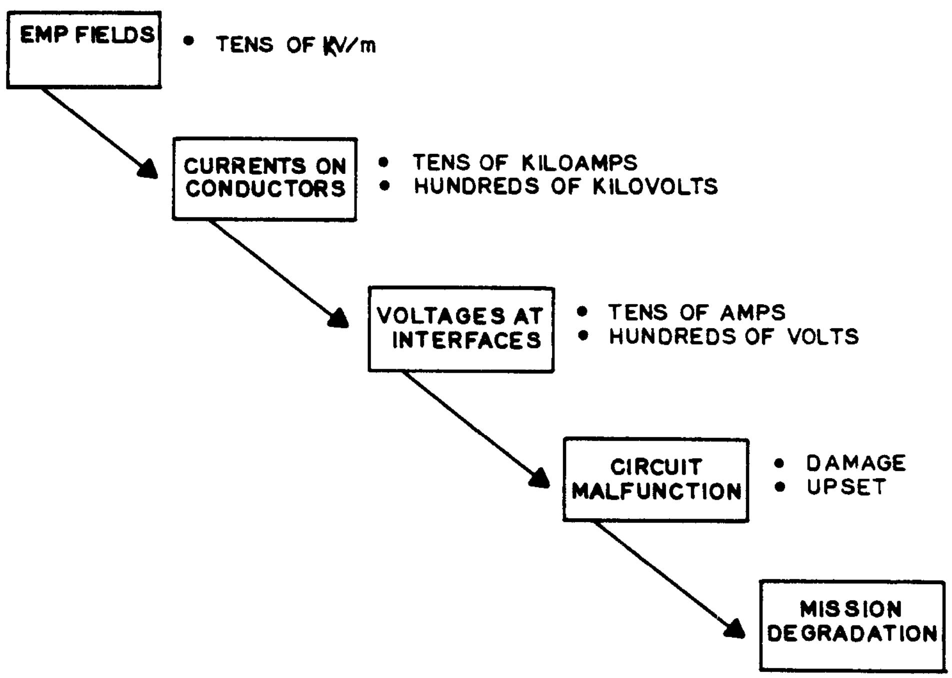


Figure 2-28. EMP system interaction. (Source: ref 2-1)

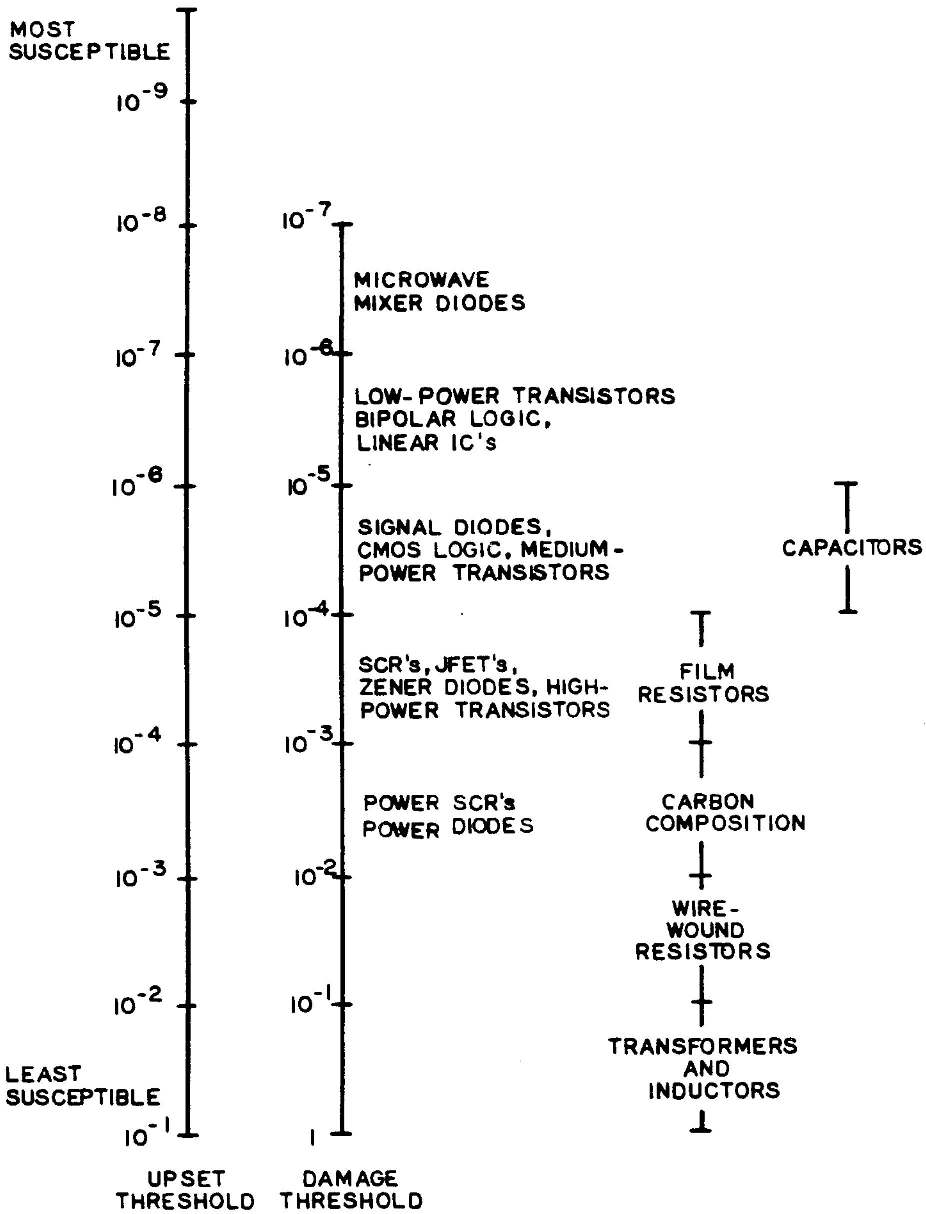


Figure 2-29. Energy level ranges, in joules, that damage various components. (Source: ref 2-4)

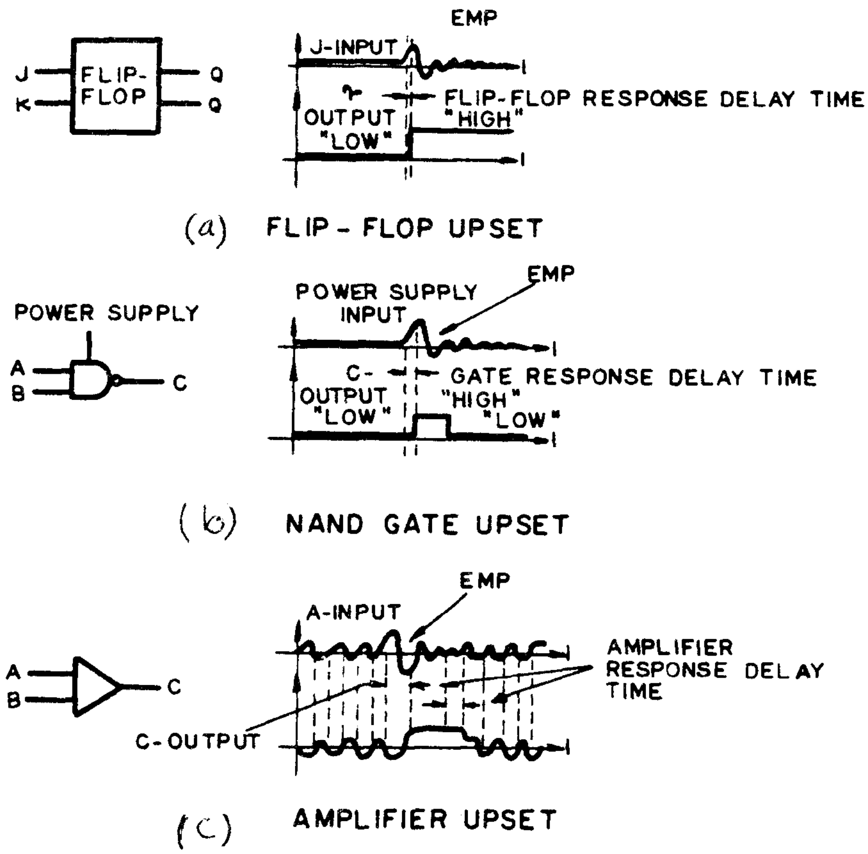


Figure 2-30. Examples of transient upset. (Source: ref 2-4)

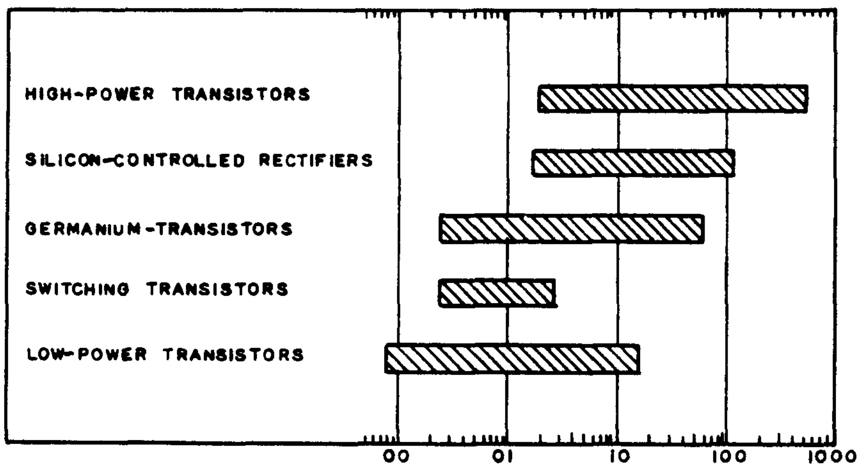


Figure 2-31. Range of pulse power damage constants for representative transistors.
(Source: ref 2-5)

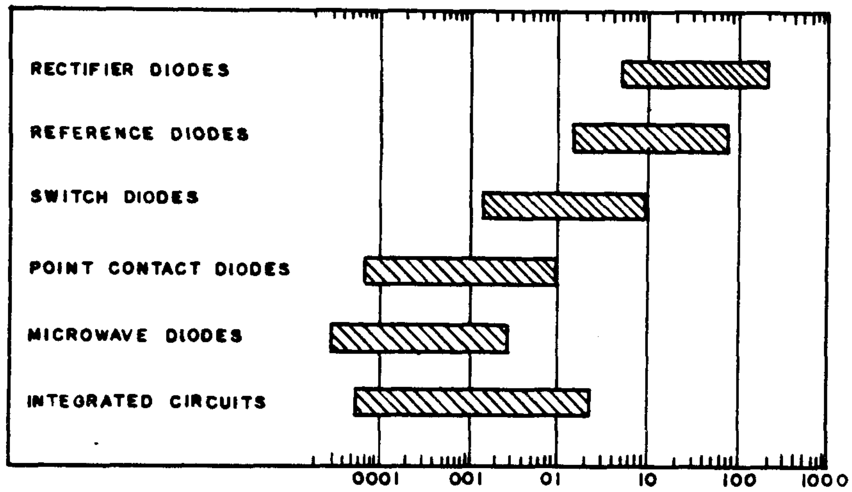


Figure 2-32. Range of pulse power damage constants for representative semiconductors. (Source: ref 2-5)