RADIO FREQUENCY DIRECTED ENERGY WEAPONS (RF DEWS) AND EFFECTS

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Outline

1. What Are High-Power RF/Microwave Directed Energy Weapons (HPM DEWs)?
2. How Are HPM Weapons Different Than High-Energy Lasers
3. What Can HPM DEWs do for the Warfighter?
4. How Are HPM DEWs Different From Traditional Electronic Warfare (EW) Jammers?
5. How Are HPM DEWs Similar to, but Different from Nuclear-Generated Electromagnetic Pulse (NEMP)?
6. How Does HPM Couple Into a Target?
7. What Types of Effects does It Cause?
8. How Do We Protect Our Systems Against HPM Pulses?
9. Summary

High-Power Radio Frequency/Microwave Directed Energy Weapons (HPM DEWs)

Also known as EM Weapons, RF Weapons, Non-Nuclear EM Pulse (NNEMP)

HPM DEWs Are Electromagnetic (EM) Sources That:

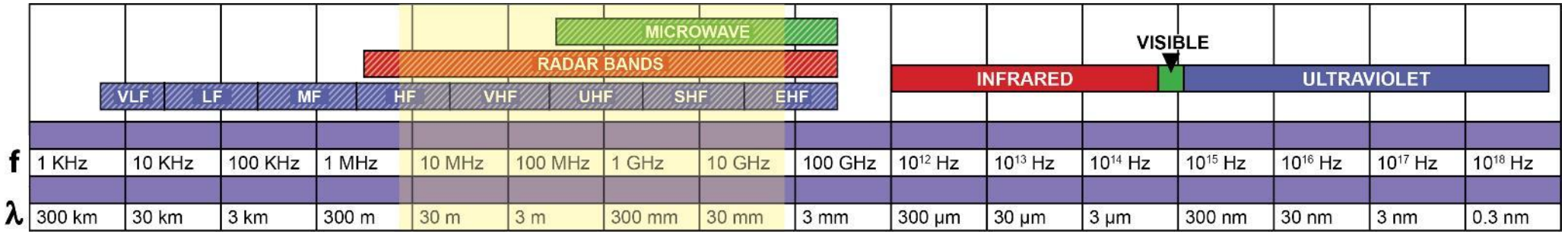
Generate and Direct Intense RF/Microwave Energy at an Electronic Target

- Have Peak Effective Radiated Power (ERP) of Greater Than 100 MW, or
- Radiated Energy of Greater Than 1 J per Pulse
- Range in Frequencies From HF/VHF/UHF to Millimeter Wave

Attack Targets With and/or Without Intentional RF Antennas/Receiver

Produce Persistent Effects That Last Longer Than the Beam Is On Target *(i.e., Temporary Electronic Upset and/or Damage)*

- "Unconventional Electronic Attack (UEA)"



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What Can HPM DEWs Do for the Warfighter?

1. Ability to **ENGAGE MULTIPLE TARGETS** at the "Speed of Light"
   (Instantaneous Fly-out No Lead Angle)
   However, Effect May Not Be Instantaneous Dwell Time Is Important

2. **PRODUCE "SCALABLE EFFECTS"** From Temporary to Permanent Based on Target and RF DE Range

3. **HAVE "VERY DEEP MAGAZINES"** — With Relatively Unlimited Number of "Low Cost Ammo (DE Pulses)"
   Reduces Logistics and Associated Cost

4. Provides **HIGH PROBABILITY OF HIT** Compared to KE (& Lasers)

5. Provides **PLAUSIBLE DENIABILITY**

6. **WORK AGAINST ELECTRONIC WEAPONS**, Sensors, and Communication Systems *(i.e., Force Multipliers)*

7. Operation & Maintenance **SIMILAR TO RADAR** Systems

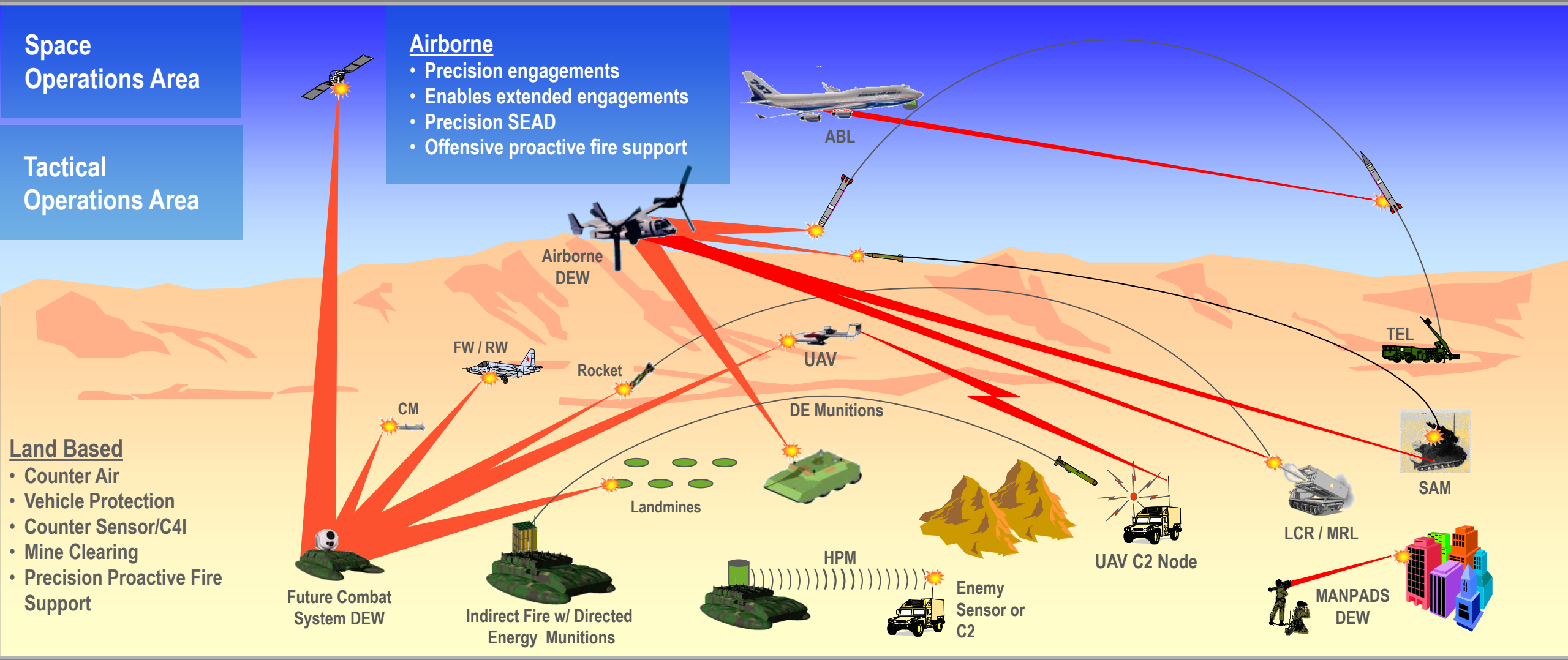
8. Typically **NON-LETHAL TO HUMANS**
   Millimeter Waves (mmW) Can Produce Temporary Pain, Crowd Control

9. RF Protection Is Easy Theoretically, but **MAY BE VERY DIFFICULT IN PRACTICE**

What Are Some Applications for Directed Energy Weapons?

Space Operations Area

Tactical Operations Area



Power/Energy Technology Has Been an Enabler for DEWs

2004

PHASE I – 2008

- Mission times extended up to 6X
- Rechargeable batteries charged 2 – 3X faster
- 10X increase in power for non-propulsion uses
- Aircraft, 500 kilowatt
- Enables dynamic armor

2008 *(Mid Term)*

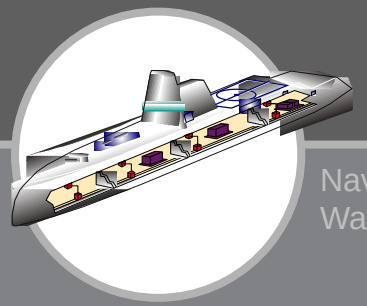
PHASE II – 2015

- Armor weight reduced up to 75%
- Ammunition weight reduced by 50%, volume by 67%
- Space payloads increased by 15%
- Fuel savings of 50% per ship
- Crew sizes reduced
- Reduced aircraft acquisition and maintenance costs
- Sorties per aircraft wing increased by 15%
- Aircraft, multi megawatt

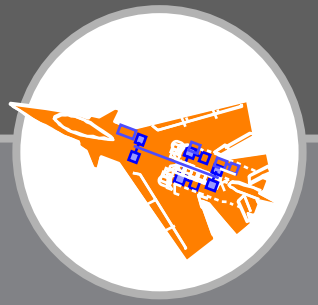
2020 *(Far Term)*

Land Warrior

Army Hybrid Electric Vehicle



Navy Electric Warship



Air Force/Navy More Electric Aircraft

Major Components of a HPM DEW

HPM DIRECTED ENERGY WEAPON | **RF PROPAGATION** | **TARGET SYSTEM**

Prime Power
- Electrical Generator
- Explosives

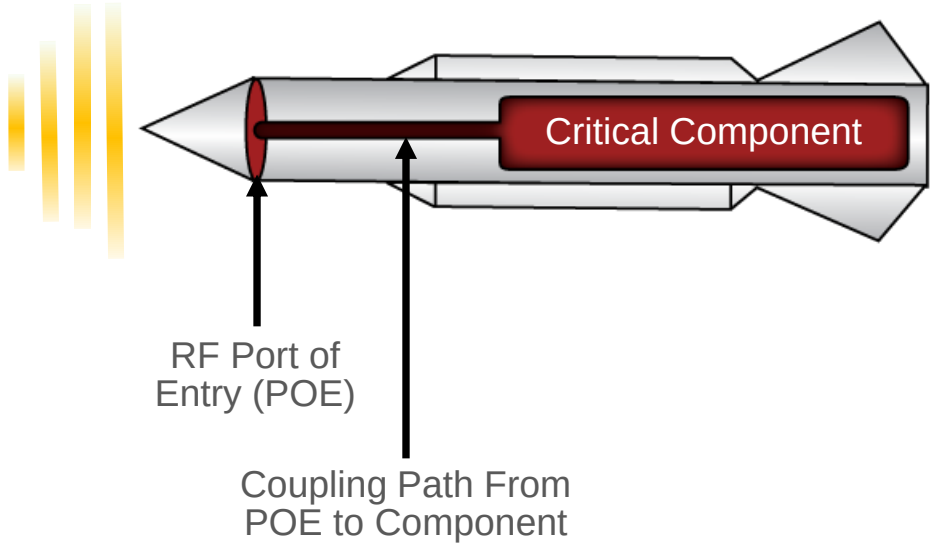
Pulse Power
- Capacitive
- Inductive PFN
- High Power Switches
  - Tubes
  - Solid State

RF Source
Pulsed CW (Narrowband <10% center frequency)
- Magnetron Tube
- Traveling Wave Tube (TWT) Amp
- Klystron Amp
- Gyrotron, et. al.

Transient Pulse (Wide Band: >25%f)
- Spark Gap
- Electronic Switches
- Ferrite Lines

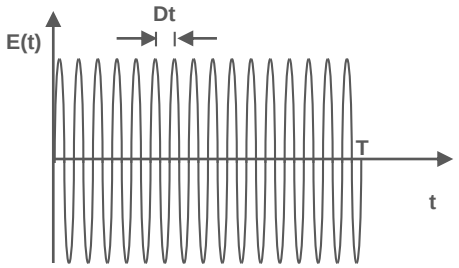
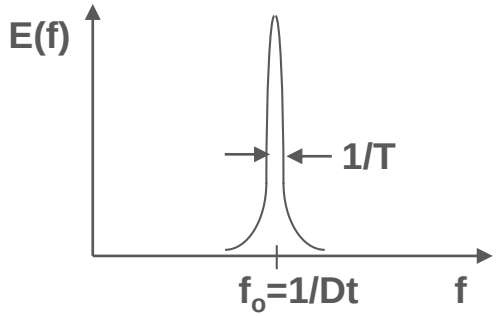
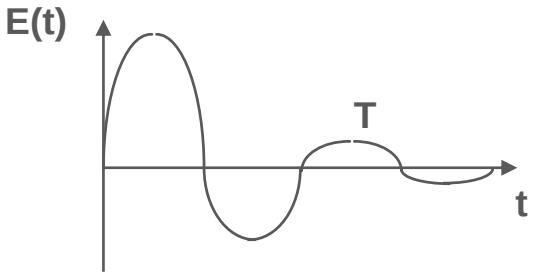
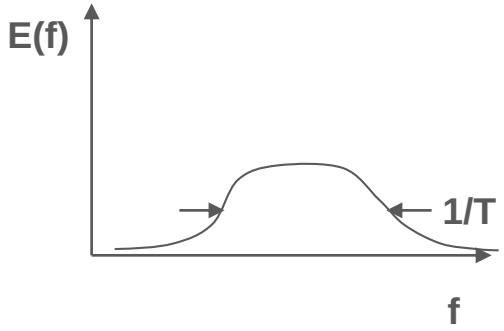
Antenna
Narrowband
- High-Power Apertures
- Higher Frequency
- High Gain/Directivity
- Well-Defined Pattern Off-bore Site

Wide Band
- Dipole/TEM Horn
- Lower Frequency
- Less Gain
- Less-defined Pattern

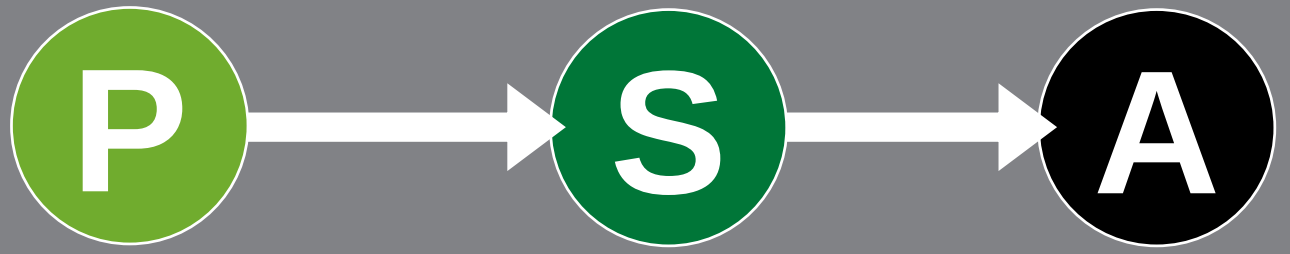


Types of HPM Sources

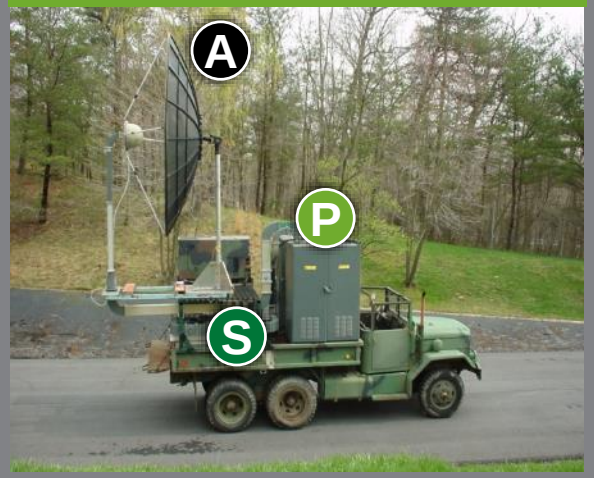
Narrowband delivers burnout punch while wideband can be repetitively pulsed at high rates for upset and disturbance since its pulses contain little energy

	Time Domain	Frequency Domain	Feature
Narrowband			Best for Maximizing Energy Per Pulse
Wideband			Best for Maximizing Peak Power Minimizes Intel Requirements Since Matching Source & System f_o Not Required.

Examples of HPM DEW Systems



Large-Truck-Mounted NB HPM Source



Small-Truck-Mounted NB HPM Source

Fixed UWB Source Impulse Radiating Antenna

Overview of Electron Warfare

ELECTRONIC WARFARE

ELECTRONIC ATTACK
Use of electronic energy, directed energy, or anti-radiation weapons to attach personnel, facilities, or equipment with the intent of degrading, neutralizing, or destroying enemy combat capability; considered a form of fires.

- Electromagnetic Jamming (e.g., Counter-RCIED, standoff jamming)
- Electromagnetic Deception
- Directed Energy
- Anti-Radiation Missile
- Expendables (e.g., Flares and Active Decoys)

ELECTRONIC PROTECTION
Actions taken to protect personnel, facilities, and equipment from any effects of friendly or enemy use of electromagnetic spectrum that degrade, neutralize, or destroy friendly combat capability.

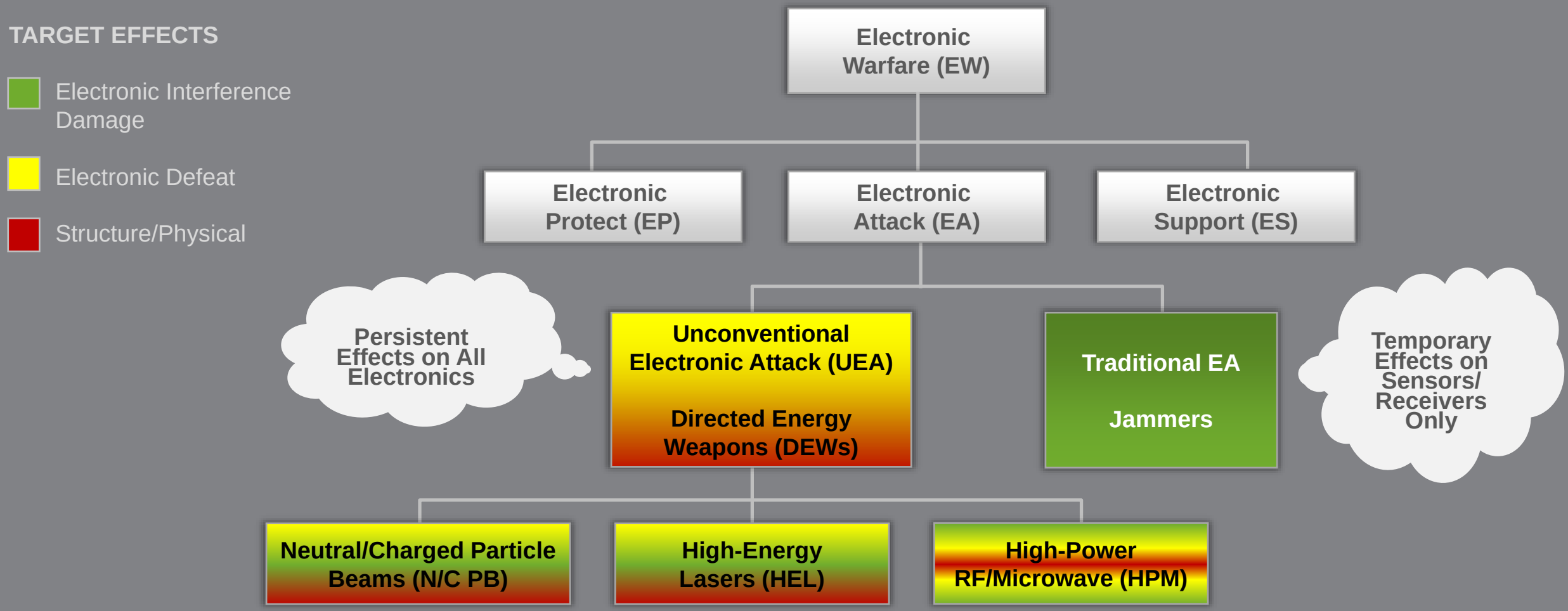
- Spectrum Management
- EM Hardening
- Emission Control

ELECTRONIC WARFARE SUPPORT
Actions tasked by, or under direct control of, an operational commander to search for, intercept, identify, and locate or localize sources of intentional and unintentional radiated electromagnetic energy for the purpose of immediate threat recognition, targeting, planning, and conduct of future operations.

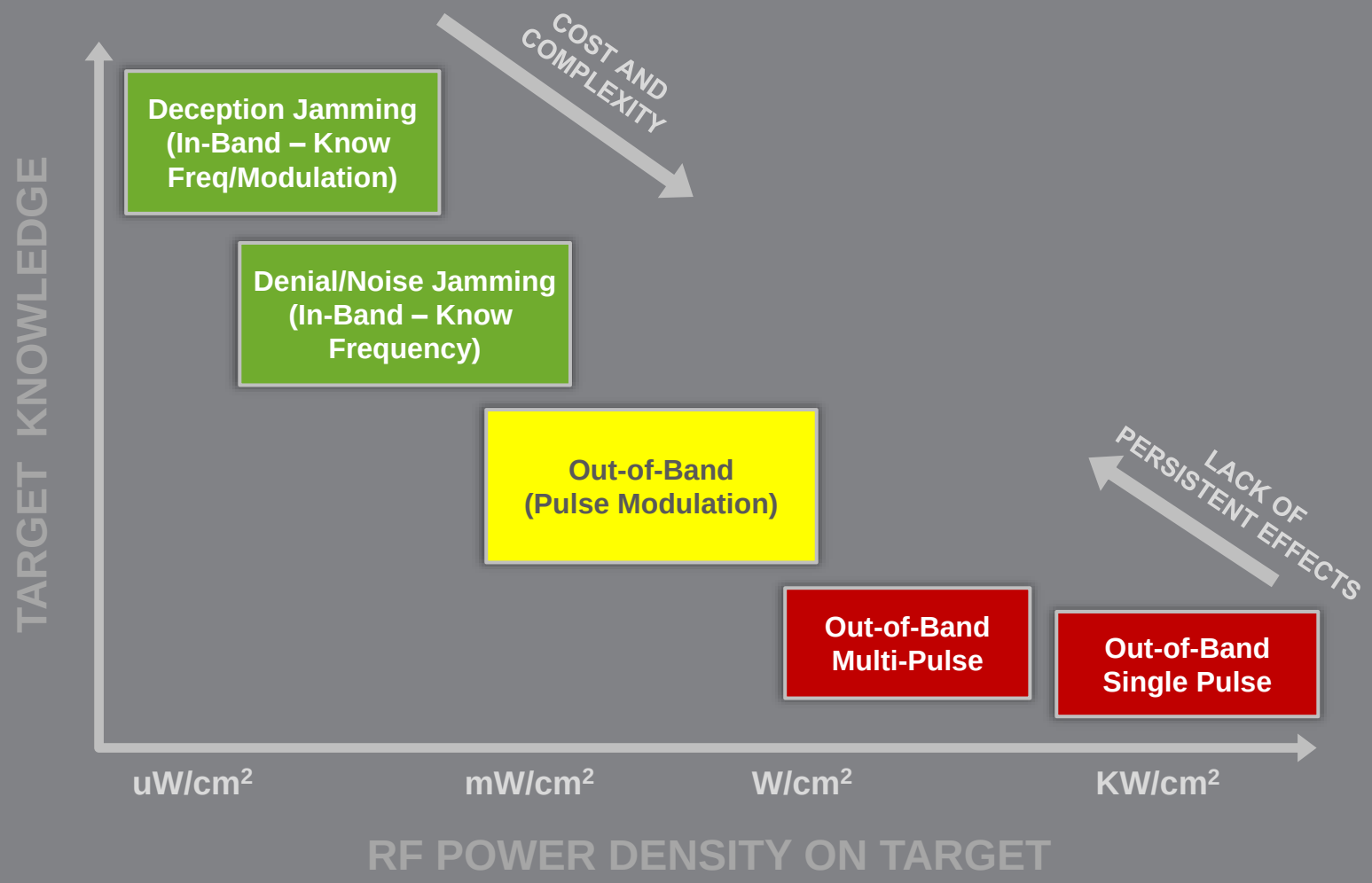
- Threat Warning
- Collection Supporting EW
- Direction Finding

RCIED *= Radio Controlled Improvised Explosive Device*
EW *= Electronic Warfare*
EM *= Electromagnetic*

HPM DEWs Provide Unconventional Electronic Attack (UEA)



Electronic Attack (EA) Traditional Jamming and HPM DEW



TARGET EFFECTS

- Temporary Interference
- Longer-Term Upset
- Permanent Damage

Jamming Generally Requires Less Power but Is Limited to Targets with RF Receivers and Produces Temporary Effects

HPM May Require Greater Power, but Can Attack Targets Without Receivers and Produce Long-term Effects ("Persistent Effects")

Electronic Attack

Traditional EA (Jammers) vs. UEA with RFDE

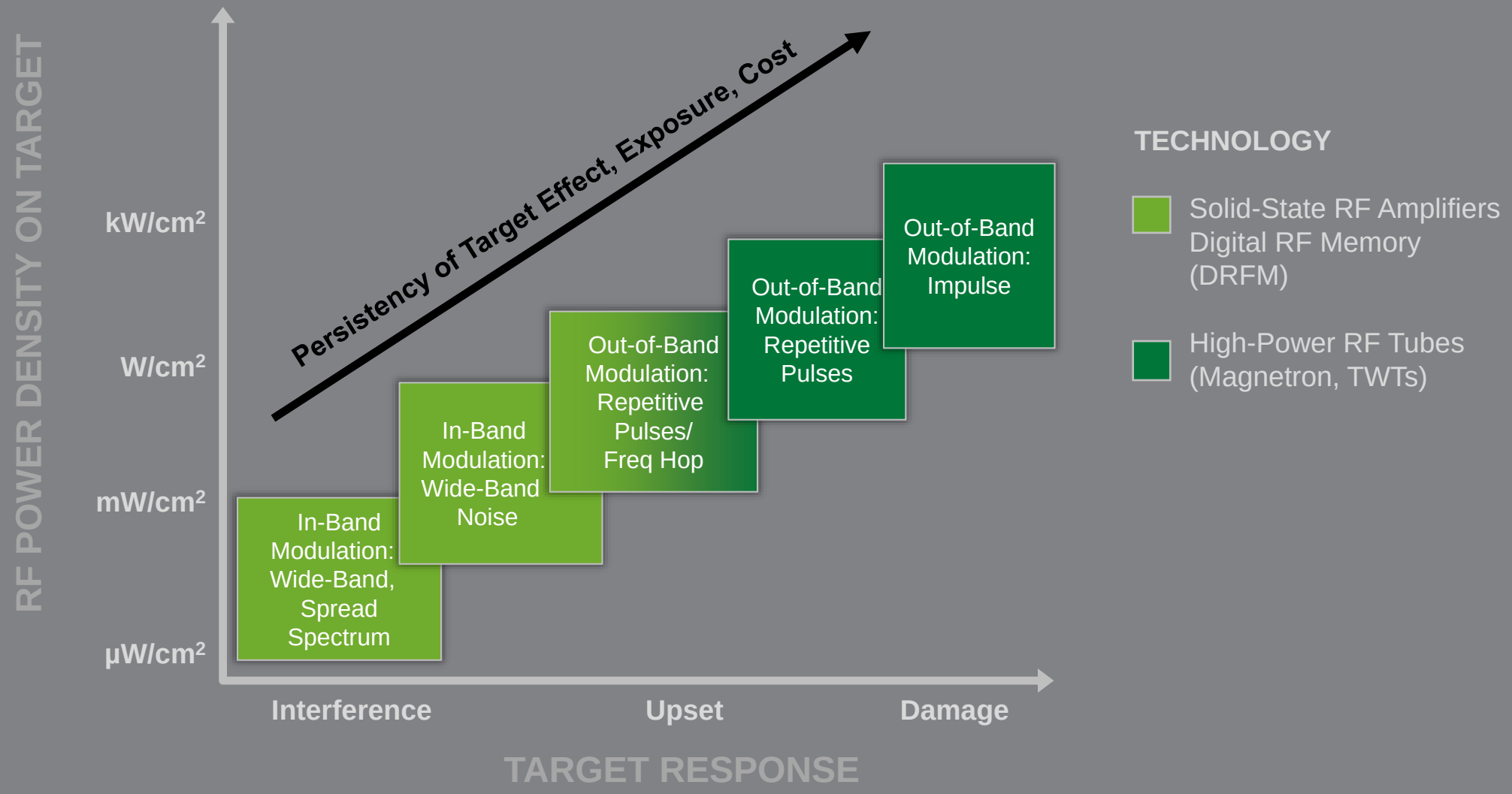
Traditional Electronic Warfare (EW) Jammers Generally:

- Require Targets With Intentional RF Antennas/Receivers
- Do Not Persist When the Jammer Beam Is Removed
- Require Significant Target Receiver Information (Frequency, Bandwidth, and Modulation)

Radio Frequency Directed Energy (RF DE):

- Can Attack Targets With and Without Intentional Receivers
- Can Produce Persistent Effects (Temporary Upset/Damage)
- Are Less Target-Specific and Require Less Information
- Generally Require Higher Power Transmitters/Antennas and Possibly Closer Ranges

Electronic Attack Technology



How Does HPM Differ From Nuclear-Generated EMP?

1. Nuclear-Generated Electromagnetic Pulse (NEMP) Is Single-Shot While HPM May Be Repetitively Pulsed

2. Frequency Regimes Differ So That Resonant Coupling of Energy Into a Target Occurs at Different Characteristic Lengths

	TYPICAL FREQUENCIES	CHARACTERISTIC LENGTH
Nuclear EMP	DC to 100 MHz	3 m or more
Wideband RF	~30 MHz to ~3 GHz	~10 cm to ~10 m
Narrowband HPM	~1 GHz and up	Up to 30 cm

How Does HPM Differ From Nuclear-Generated EMP?

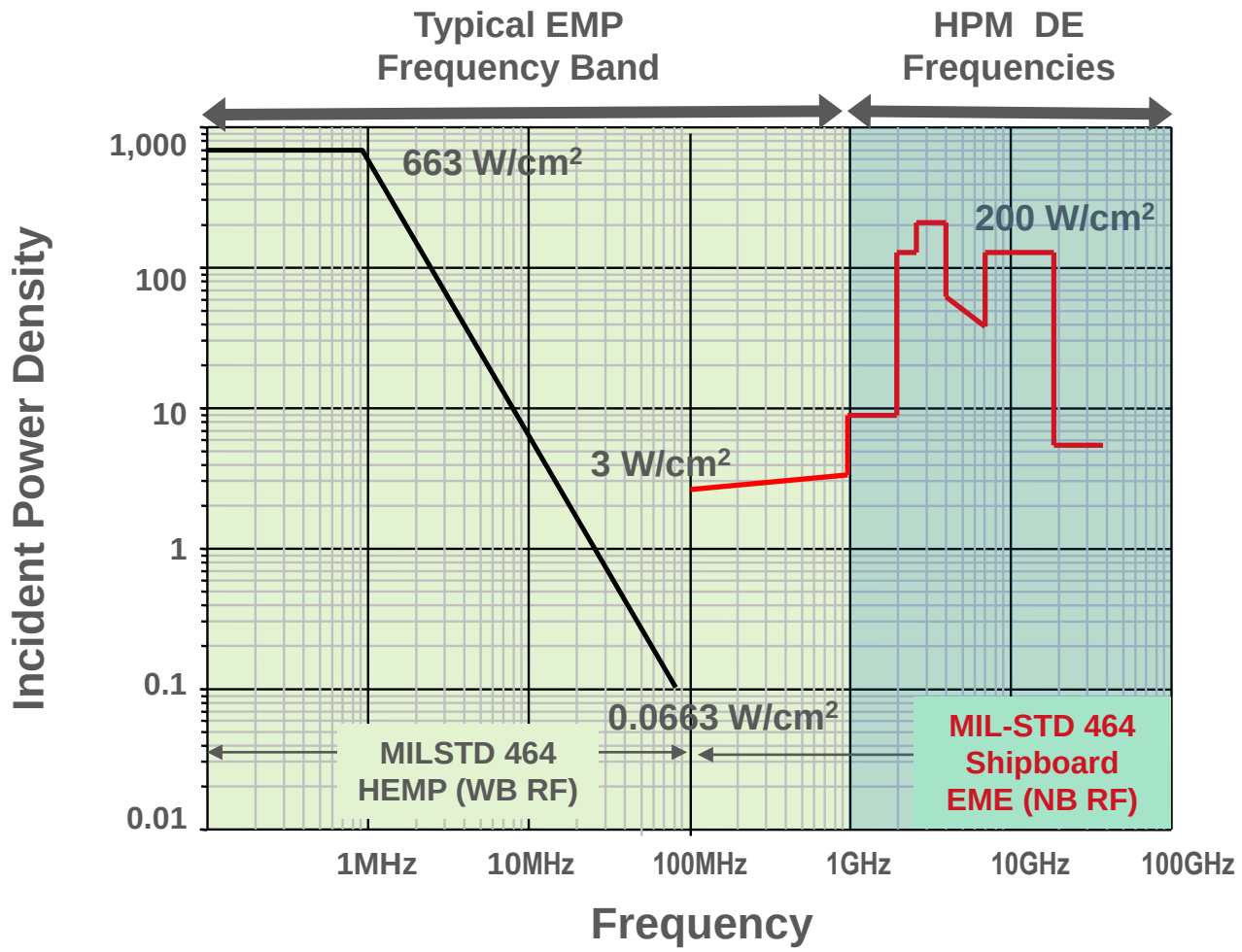
3 ASSESSMENT SIMILARITIES:

- Both Address Complex RF Coupling Into Targets and Require Numerous Variables to Describe Effect Levels
- Limited Facilities and Test Objects Sometimes Force Reliance on Low-Power Tests and Analysis

4 ASSESSMENT DIFFERENCES:

- The EMP Threat Is Usually an "Official Threat" So That Some Variables Are Constrained. There Is No Well-Defined HPM Threat; Numerous Parametric Excursions Are Required
- Systems Within a Given Class Are More Similar on EMP Length Scales
- Computer Models of Complex Systems Must Include More Detail for Narrowband HPM

Nuclear-Generated EM Pulse (EMP) vs. HPM DE

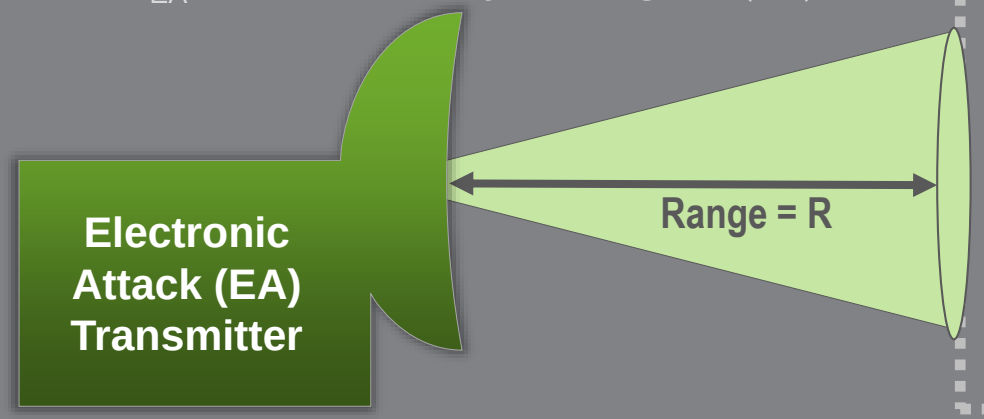


Reference: Military Standard 464 - DoD Interface Standard – Electromagnetic Environmental Effects Requirements for Systems, March 18, 1997

Electronic Attack Scenario and Key Parameters

Electronic Attack Source	Propagation	Target Effects
Transmitter Power (P) Frequency/Wavelength (f) / (λ) Antenna Gain (G) Pulse Duration/Width (τ) Pulse Rep Frequency [PRF] (F) Angle (θ, ϕ) Wave Polarization, p	Range (Space Loss) (R) Atmospheric Losses (La) *Losses Low for Lower Frequencies*	EA Power Received Electronic Effect Level (C)

S_{EA} = Power Density on Target = $(PG)/4\pi R^2$



EA Power at Electronics = $P_{EA} = (S_{EA} A_e)\ L$

ANTENNA

A_e = Effective Area = $\dfrac{\text{Gain } (\theta, \phi)\ (\lambda^2)\ p}{4\pi R^2}$

ENTRY PATH

Loss= L (f)

CRITICAL ELECTRONICS (EX. MIXER)

C= Component Failure Level (τ,F)

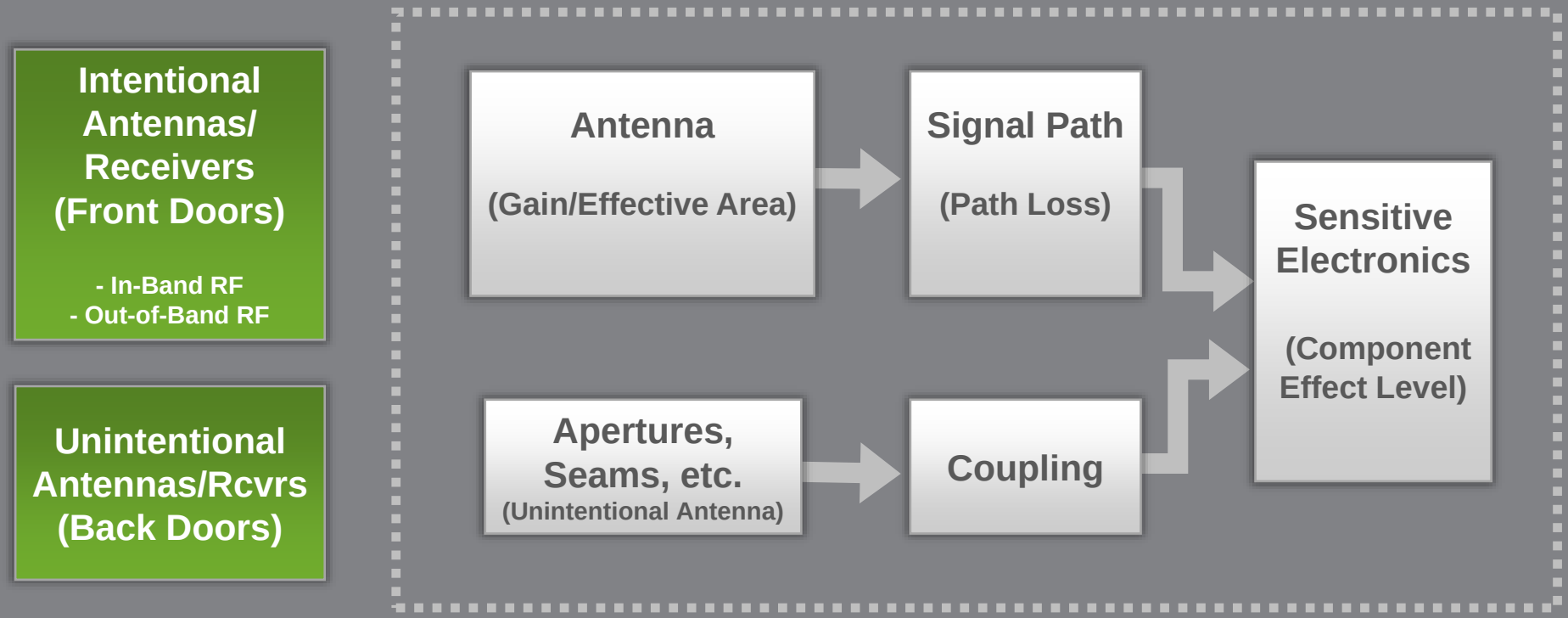
Desired Signal = $(P_{Normal})\ A_e L$

Difference Between Jamming and Persistent Effects Is:

Probability of Jamming: Probability {P_{EA} > Desired Signal}

Probability of RF DE Damage: Probability {P_{EA}>C} = Probability of {($S_{EA} A_e L$) > C}

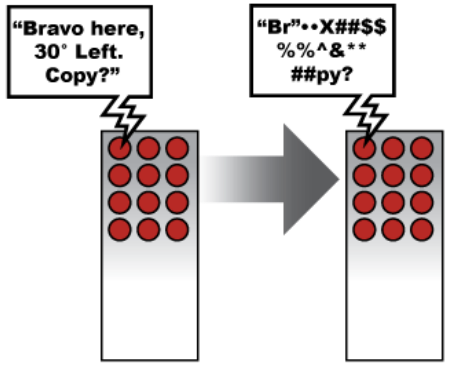
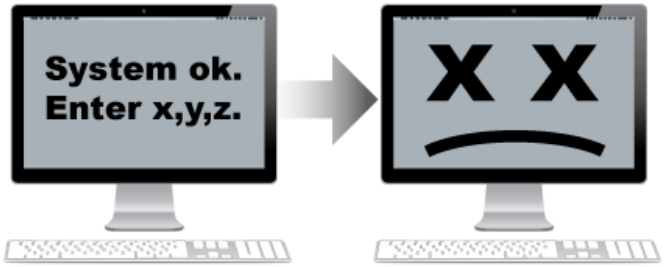
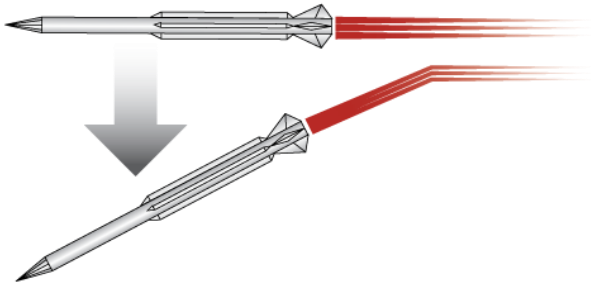
How Does HPM Couple Into Targets?



RF Energy Can Enter Target via Intentional Antennas [i.e.,"Front Doors"] or via Unintentional Antennas (i.e., Apertures, Cables, etc.) [i.e.,"Back Doors"]

HPM DEW Effects on Electronics

Effects Depends on HPM Source Power and Range

TEMPORARY INTERFERENCE System Recovers When Beam Removed (i.e., Jamming)	LONGER-TERM UPSET System Recovers After Reset	PERMANENT DAMAGE System Recovers ONLY After Repair/Replacement
		

Effects Are Statistical Quantities Expressed in Terms of Probability of Effect (i.e., Upset/Damage)

Types of HPM Effects Experiments

DIRECT INJECTION EXPERIMENTS

- Directly Couple Selected HPM Waveform Into Target
- Establish Upset & Damage Thresholds
- Evaluate Pulse Width and PRF Effectiveness
- Determine Optimum Frequency & Bandwidth for Selected Asset

FREE FIELD/CHAMBER EXPERIMENTS

- Radiate Target in RF Chamber or Outdoors
- Use HPM Source With Specified Parameters and Diagnostics
- Observe/measure Target Responses vs. Incident Energy

Target Effects and Down Time

RF DE can produce effects that range from interference to temporary disruption to damage of target electronics.

FAILURE MODE	POWER NEEDED	WAVESHAPE NEEDED	RECOVERY PROCESS	DOWN TIME
Interference or Analog Upset	Low	Repetitive Pulse or Continuous	Self-Recovery After Exposure Stops	Seconds
Digital Upset	Medium	Short Pulse Single or Repetitive	Operator Intervention	Minutes
Memory Corruption	Medium	Short Pulse Repetitive	Maintenance Intervention	Hours
Damage	High	Short Pulse (UWB) Longer Pulse (Narrow)	Maintenance Intervention	Days

GENERAL OBSERVATIONS

- Mission Impact of Failure Depends on When Exposure Occurs.
- Damage Mode Is Most Lethal but Is Hardest to Implement.
- Digital Upset or Memory Corruption Can Be Lethal and Is Easier to Implement.

RF DE Protection Guides

HPRF/M Hardening Design Guide for Systems

- HDL-CR-92-709-5, U.S. Army Research Laboratory (ARL), April 1992

DTRA/JAYCOR Has Produced JEM RF Code With Electronic Version of Hardening Design Guide [AFRL Is Now Model Manager]

- Estimates Voltage Induced vs. Component Strength

Military Systems:

- Army Hardening Demonstration on IFF (ARL)
- AF Hardening Demonstration F-16 and LANTIRN (AFRL/DE)

Commercial Systems

- Aircraft (e.g., CRDA with Boeing for Test Chamber)
- Computers

Summary

HPM DEW Provides Warfighter with:

- High Probability of Hit
- “Speed of Light” Engagements for Multiple Targets in Near-All-Weather Conditions
- Scalable Target Effects (Temporary to Permanent – Non-Lethal to Lethal)
- Relatively Low Cost Per Shot

HPM Provides Additional Electronic Attack/Warfare Capability

- Out-of-Band Attack on Targets With and Without Receivers
- Possibility to Attack Target Classes - Requires Little to No Target Information
- Long-Term to Permanent Effects (Damage)

Effects Levels Depend Upon HPM DE Source/Target Parameters

- Effect Levels Typically Measured Over Limited Parameter Space Due to Source Availability

Impact of Effects on Mission May Be Difficult to Determine

Protection/Countermeasures Technically Possible – May Not be Easy

- RF Protection Designed-In – 1 to 15% Total System Cost
- Retro-Fit Hardening – 20 to 90% of Total System Cost
  - “Pay Now or Pay Later”

QUESTIONS?

DSIAC Is Available for Advanced and/or Classified Training and Our Subject Matter Experts are Available to Answer Your Technical Questions and Support Contracted Analysis Tasks

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THANK YOU!