HIGH-POWER RADIO FREQUENCY/MICROWAVE (HPM) DIRECTED-ENERGY WEAPONS (DEWs) AND THEIR EFFECTS

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Defense Systems Information Analysis Center

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Outline

1. What Are HPM DEWs?
2. What Can HPM DEWs do for the Warfighter?
3. How Are HPM Weapons Different Than High-Energy Lasers?
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
10. Questions?

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

Also Known as Electromagnetic (EM) Weapons, Radio Frequency (RF) Weapons, Non-Nuclear EM Pulse, Electronic–Bombs (E-Bombs), Etc.

HPM DEWs Are EM Sources That:

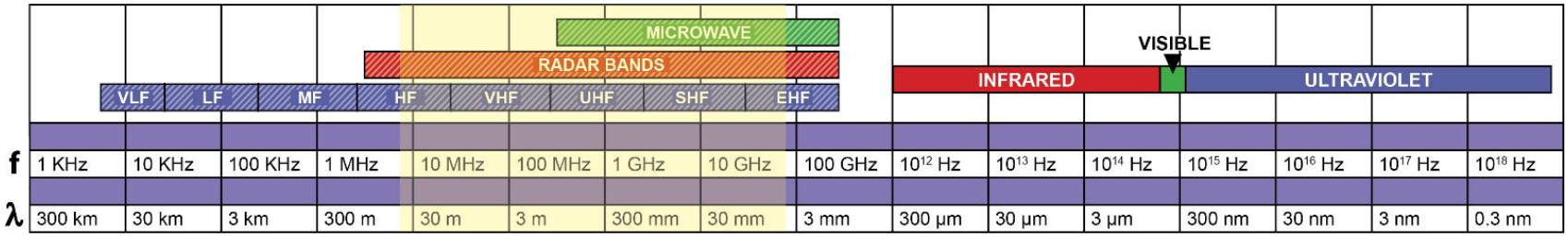
Generate and Direct Intense RF/ Microwave Energy at an Electronic Target

- Have Peak Effective Radiated Power of >100 MW or Radiated Energy >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)"



Major Components of an HPM DEW

HPM DEW | **RF PROPAGATION** | **TARGET SYSTEM**

Prime Power
- Electrical Generator
- Explosives

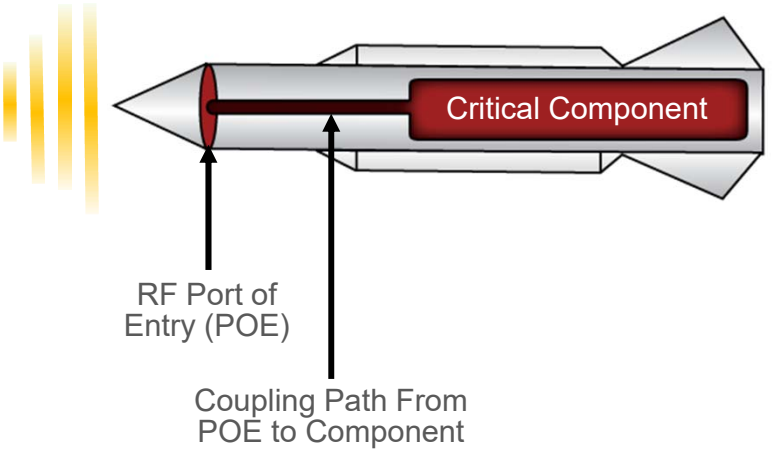
Pulse Power
- Capacitive
- Inductive (Pulse-Forming Network)
- High-Power Switches
  - o Tubes
  - o Solid State

RF Source
Pulsed Continuous Wave (Narrow Band [NB] <10% Center Frequency)
- Magnetron Tube
- Traveling Wave Tube (TWT) Amp
- Klystron Amp
- Gyrotron et al.

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

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

WB
- Dipole/Transverse EM Horn
- Lower Frequency
- Less Gain
- Less-Defined Pattern



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 Directed-Energy (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 Kinetic Energy Weapons and Lasers

5. Provides **PLAUSIBLE DENIABILITY.**

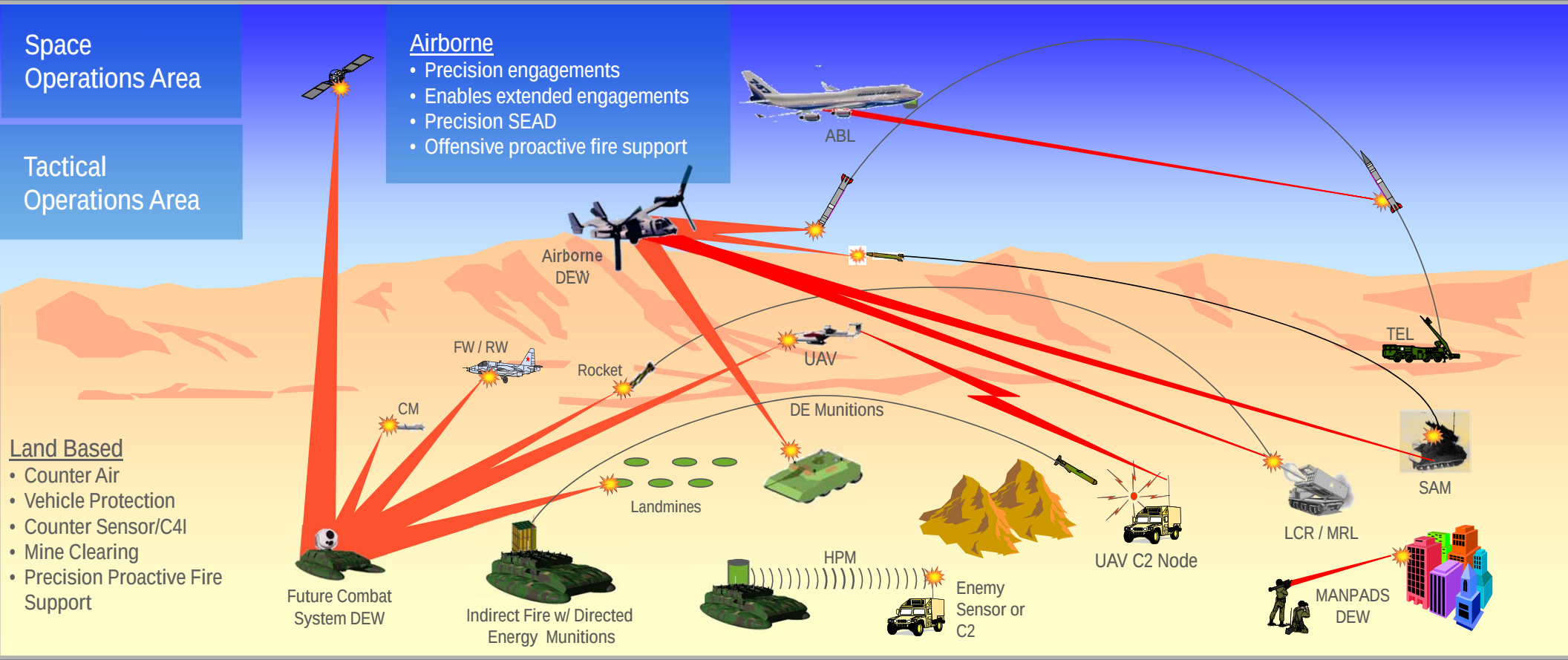
6. **WORK AGAINST ELECTRONIC WEAPONS**, Sensors, and Communication Systems *(i.e., Force Multipliers).*

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

8. Typically **NON-LETHAL TO HUMANS.**
   Millimeter Waves 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?



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
- Logistic fuels power the soldier
- 10X increase in power for non-propulsion uses
- Aircraft, 500 kW
- Enables dynamic armor

2008 *(Mid Term)*

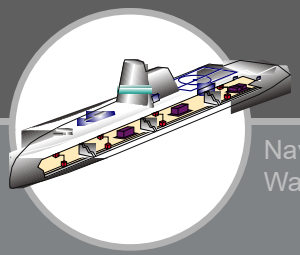
PHASE II – 2015

- 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

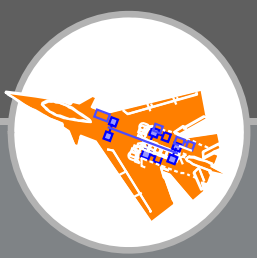
2020 *(Far Term)*

Land Warrior

Army Hybrid Electric Vehicle



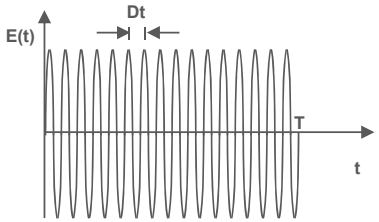
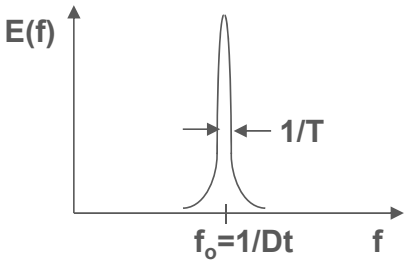
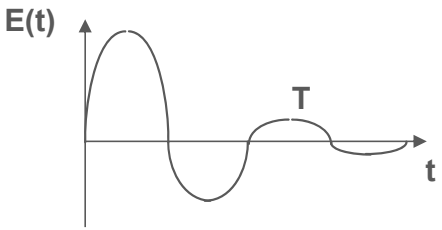
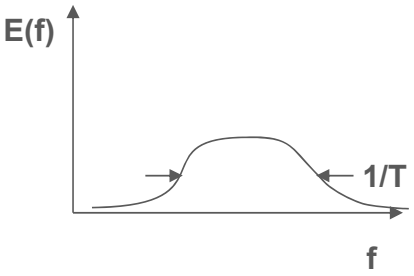
Navy Electric Warship



Air Force/Navy More Electric Aircraft

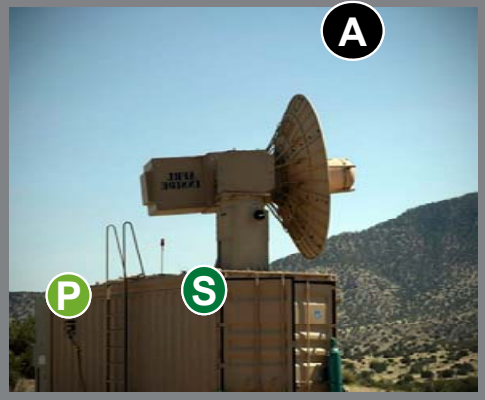
Types of HPM Sources

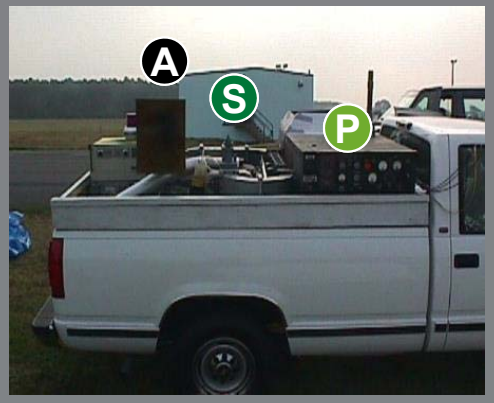
NB delivers burnout punch, while WB/ultra-wide band (UWB) can be repetitively pulsed at high rates for upset since its pulses contain little energy.

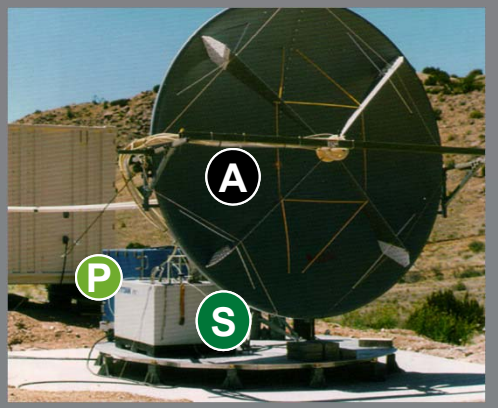
	Time Domain	Frequency Domain	Feature
Narrow Band			Best for Maximizing Energy per Pulse
Wide Band			Best for Maximizing Peak Power Minimizes Intel Requirements Since Matching Source and System f_o Are Not Required

Examples of HPM DEW Systems

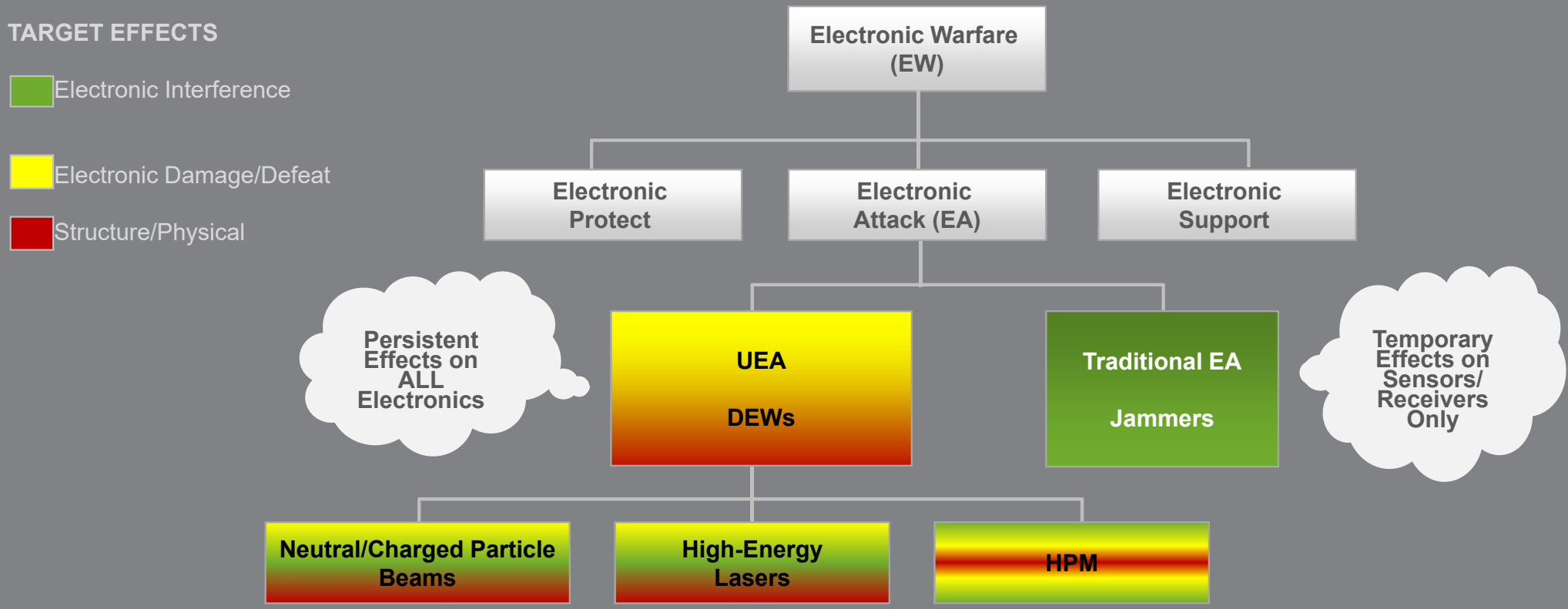
POWER SUPPLY	HPM SOURCE/ TRANSMITTER	ANTENNA/RADIATOR
U.S. Air Force (AF) Tactical High-Power Microwave Operational Responder (THOR)	Small-Truck-Mounted NB HPM Source	UWB Source With Impulse Radiating Antenna



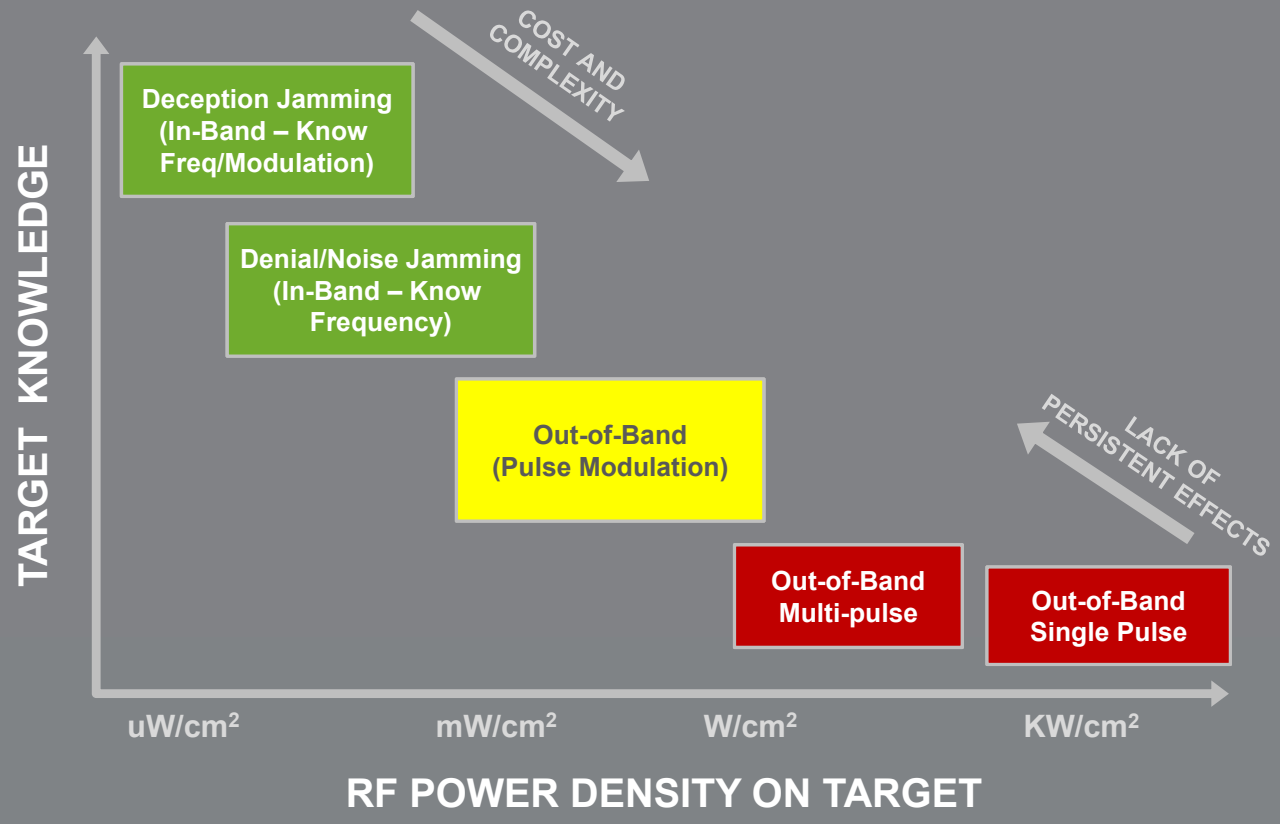




HPM DEWs Provide Unconventional Electronic Attack (UEA)



EA Traditional Jamming and HPM DEW



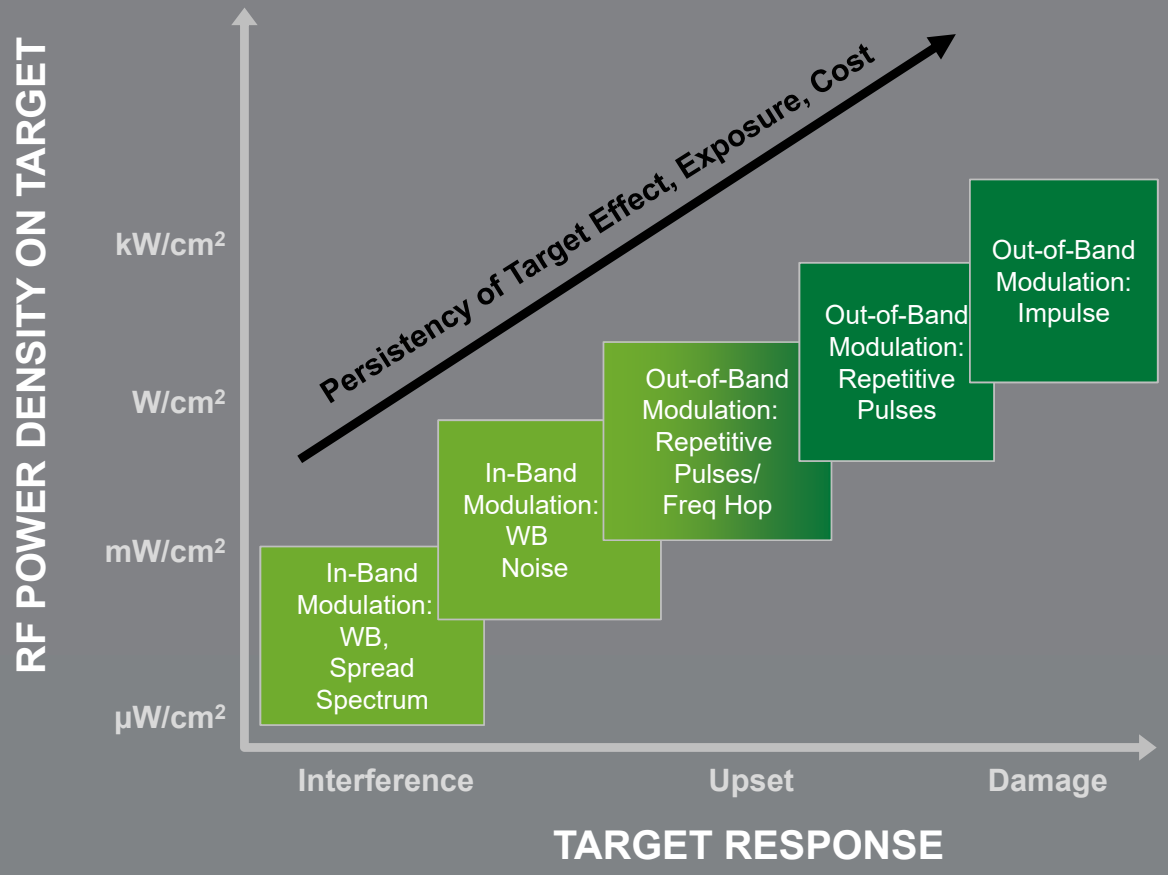
TARGET EFFECTS

- 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").

EA Technology



How Does HPM Differ From NEMP?

1. 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
NEMP	DC to 100 MHz	3 m or more
WB RF	~30 MHz to ~3 GHz	~10 cm to ~10 m
NB HPM	~1 GHz and up	Up to 30 cm

How Does HPM Differ From NEMP?

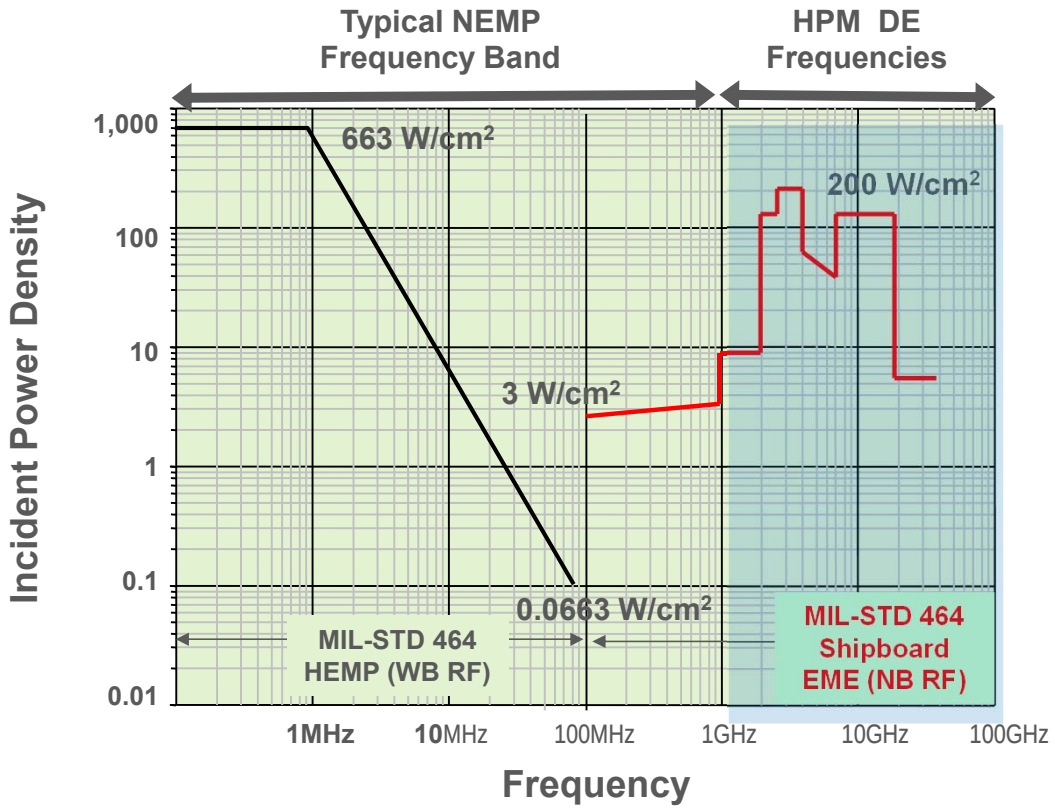
3 ASSESSMENT SIMILARITIES:

- 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:

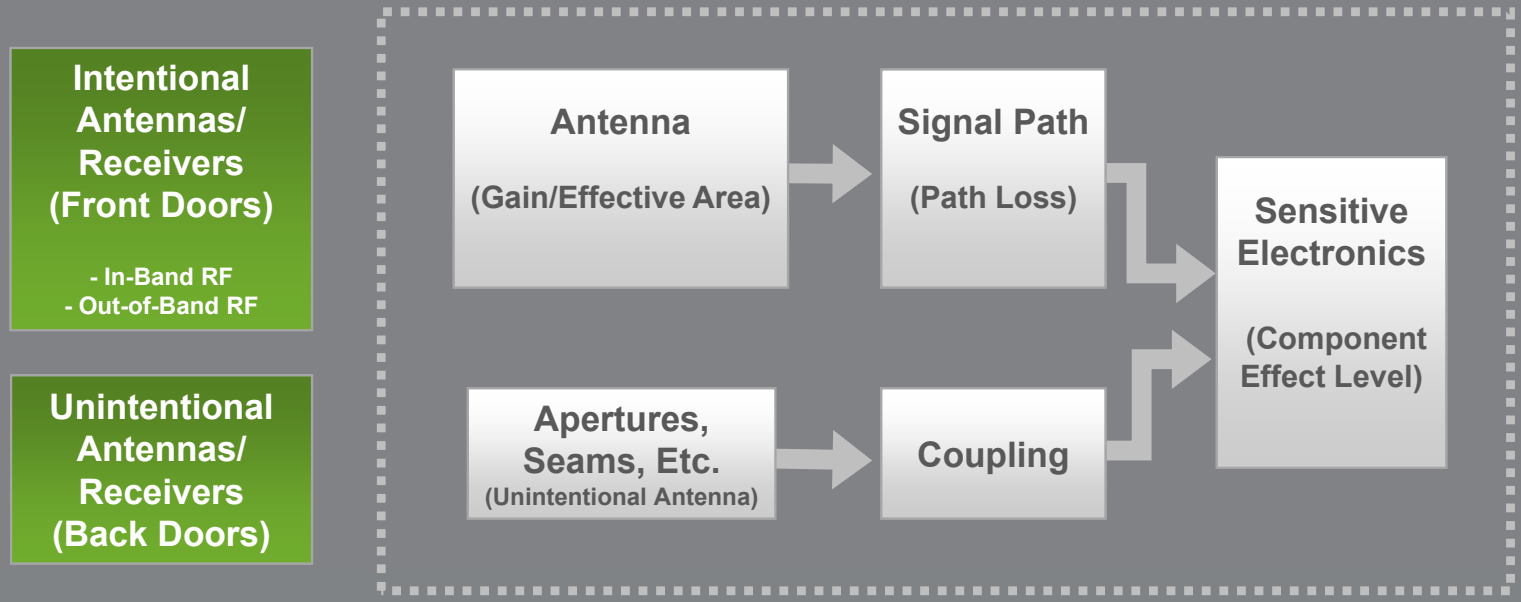
- The NEMP Threat Is Usually an "Official Threat" So That Some Variables Are Constrained. There Is No Well-Defined HPM Threat; Numerous Parametric Excursions Are Required.
- Systems Within a Given Class Are More Similar on NEMP Length Scales.
- Computer Models of Complex Systems Must Include More Detail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

NEMP vs. HPRF/M



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

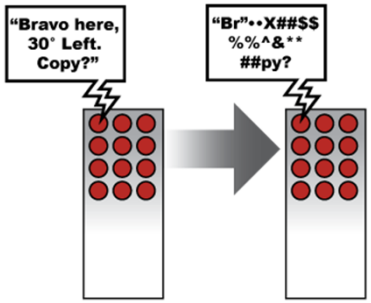
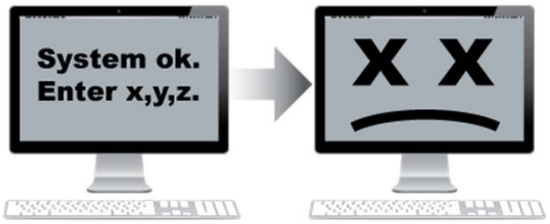
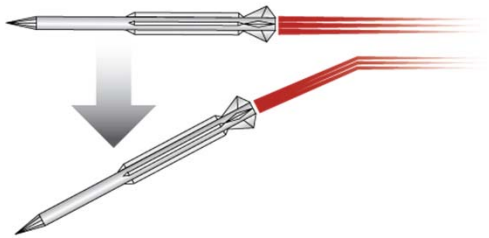
How Does HPM Couple Into Targets?



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 Is 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 and Damage Thresholds
- Evaluate Pulse Width and Pulse Rep Frequency (PRF) Effectiveness
- Determine Optimum Frequency and Bandwidth for Selected Asset

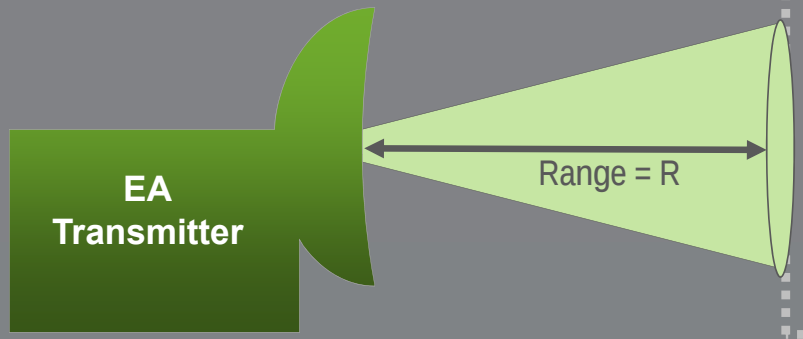
FREE-FIELD/CHAMBER EXPERIMENTS

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

Electronic Attack Scenario and Key Parameters

Electronic Attack Source	Propagation	Target Effects
Transmitter Power (P) Frequency/Wave Length (f) / (λ) Antenna Gain (G) Pulse Duration/Width (τ) 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 =
Gain (θ, ϕ) (λ^2) p
$4\pi R^2$

ENTRY PATH
Loss = L (f)

CRITICAL ELECTRONICS (e.g., 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}

Target Effects and Downtime

RF DE Can Produce Effects That Range From Interference to Temporary Disruption to Damage of Target Electronics.

FAILURE MODE	POWER NEEDED	WAVE SHAPE NEEDED	RECOVERY PROCESS	DOWNTIME
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 Hardest to Implement.
- Digital Upset or Memory Corruption Can Be Lethal and Is Easier to Implement.

High Power Radio Frequency/ Microwave 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 (AF Research Laboratory [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., Cooperative Research and Development Agreement with Boeing for Test Chamber)
- Computers

Summary

HPM DEW Provides Warfighters 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”