Supporting Munitions Safety

Non-HERO Microwave Hazards to Munitions

IMEMTS 2019, Seville, Spain

Matt Ferran
TSO Munition Systems
m.ferran@msiac.nato.int

Christelle Collet
TSO Propulsion Technology
c.collet@msiac.nato.int

Contents

- The Military Electromagnetic Environment
- HERO
- EM Radiation Interaction with Matter
- Dielectric Properties of Energetic Materials
- Implications for Munition Systems
- Conclusions

Military RF Environment

Military RF Environment

- Actual RF EME encountered by munitions dependent on e.g.:
  - Operational environment
  - Platforms
  - Transmitter proximity
  - Etc.

- AECTP-250 – “NATO Worst Case EME”

Table-258-5: Worst-Case Operational EME Field Strength Levels

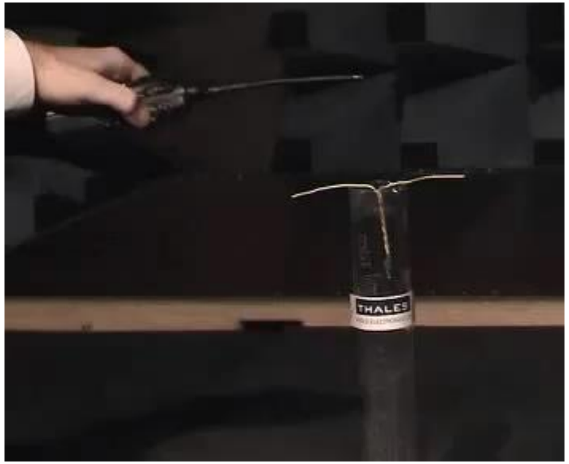
Frequency Range (MHz)			Average (V/m)	Peak (V/m)
0.01	-	2	200	200
2	-	30	200	200
30	-	150	200	200
150	-	225	200	200
225	-	400	200	1,500
400	-	700	270	1,860
700	-	790	240	1,500
790	-	1000	480	2,530
1000	-	2000	600	7,000
2000	-	2700	490	6,000
2700	-	3600	2,620*	21,050*
3600	-	4000	490	8,550
4000	-	5400	400	7,200
5400	-	5900	400	7,200
5900	-	6000	400	7,200
6000	-	7900	400	2,500
7900	-	8000	400	2,500
8000	-	8400	750	5,000
8400	-	8500	400	5,000
8500	-	11000	1,940	10,000
11000	-	14000	680	3,630
14000	-	18000	680	6,000
18000	-	40000	420	3,640
40000	-	45000	580	580

2.45GHz

Consideration of RF Hazards to Munitions

- HERO
  - EED firing lines act as an aerial
  - Sufficient energy to fire most EED can be picked up at substantially lower RF field strengths than experienced in service
  - Well understood

- Exposure of energetic materials to RF radiation?



Interaction of RF Radiation with Matter

- How does RF radiation interact with matter?
  - Dielectric Heating of non-metals
  - Not just water that is heated

- What about metals?
  - Penetration depth measured in µm
  - Reflect majority of incident microwaves
  - Cannot be heated significantly
  - Powdered metals absorb microwaves strongly – microwave sintering

Interaction of RF Radiation with Matter

- What factors influence RF heating?
  - Dielectric loss factor (ε”)
  - Temperature and frequency dependent

- Power absorbed / unit volume:

$$P = 2 \cdot \pi \cdot f \cdot \varepsilon''_{eff} \cdot \varepsilon_0 \cdot E^2_{rms}$$

- Rate of temperature increase:

$$\frac{\Delta T}{\Delta t} = \frac{2 \cdot \pi \cdot f \cdot \varepsilon''_{eff} \cdot \varepsilon_0 \cdot E^2_{rms}}{\rho \cdot c_p}$$

Material	ε” (@ 2.45GHz, ~20°C)
Water (0.5M NaCl)	67.0
Graphite	~12.5
Water (Distilled)	12.0
Ethyl Alcohol	6.5
Soda Lime Glass	1.2
PVC	0.016
Teflon	0.001

1. Gupta, M. and Leong, W.W., *Microwaves and Metals* (2007)
2. Hotta, M. et al., ISIJ International, Vol. 51 (2011), No. 11, pp. 1766-1772

Dielectric Properties of Energetic Materials

- Some reported values of ε" for energetic materials
- General observations:
  - ε" low for molecular explosives and formulations thereof
  - Very slight increase in PBXs – perhaps due to binder?
  - JA2 should absorb microwaves strongly – may be due to addition of graphite

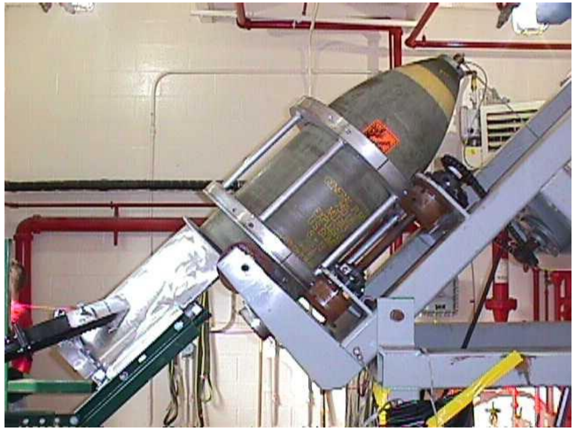
- Comprehensive body of knowledge does not exist

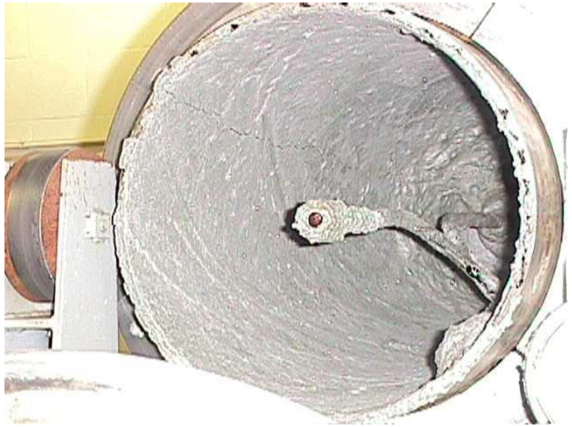
Material	ε" (@ 2.5GHz, ~20°C)
Comp. B	0.01
TNT	0.01
PETN	0.02
RDX	0.02
HMX	0.02
PBX-9404	0.03
Composite Propellant	0.27
JA2 Propellant	0.75

1. Duque, A.L.H et al., *Propellants, Explosives, Pyrotechnics*, Vol. 39, pp. 275-283, 2014
2. Barkley, S.J. et al., *52nd AIAA/SAE/ASEE Joint Propulsion Conference*, 2016
3. Howard, S.L. et al., *JANNAF Propulsion Meeting*, 1995

Microwave Heating of Energetic Materials

- Examples of heating to initiation in ~mins
- Examples of deliberate heating of EM
- No examples of EM exposure to AECTP-250 environment
- Estimate the microwave heating rate for in-service energetic materials using:
  - Equation for rate of temperature increase
  - Values for dielectric and physical properties taken from the literature
  - Average field strength values derived from AECTP-250





1. Hayes, R.W. and Crist, B.F., *Proceedings of the 19th JANNAF Safety and Environmental Protection Subcommittee Meeting,* 2002

Time to Heat by 100K (2.5GHz)

Explosive	ε"	E / $V.m^{-1}$	ρ / $kg.m^{-3}$	C_P / $J.kg^{-1}.K^{-1}$	Time to heat by 100K
Comp. B	0.01	490	1730	1065	153 hr
TNT	0.01	490	1590	1125	149 hr
PETN	0.02	490	1780	1090	80 hr
PBX-9404	0.03	490	1844	1130	58 hr
JA2	0.75	490	1500	1260	2 hr
JA2 @ 3GHz	0.5	2620	1500	1260	**5.5 min**

- Period of high intensity RF exposure generally insufficient for heating
  - Very short period of exposure; or
  - Administrative controls prevent exposure; or
  - Field strengths low by design or circumstance

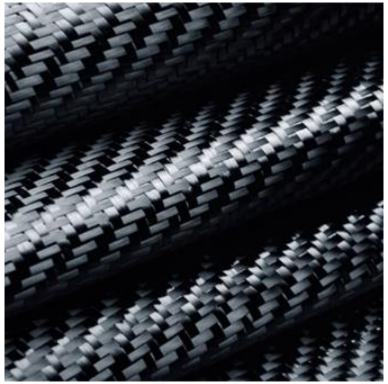
- Many munitions made from metal or have metal components
  - Warhead / rocket motor casings, logistic containers etc.
  - Microwave penetration depth in order of µm
  - Not perfect shielding – RF radiation can penetrate seams, ports, vents, nozzles etc.

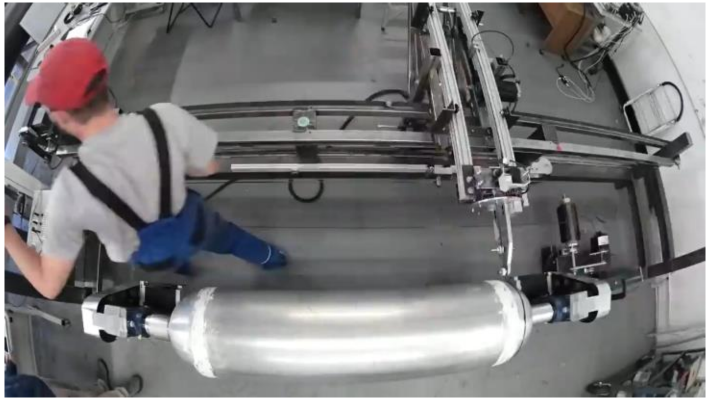
Composite Materials

- Increasingly used in munition systems, particularly rocket motor cases
- What are the dielectric properties?

Material	ε'' (@ 10 GHz)	Penetration Depth / mm
Kevlar Composite	0.45	23.0
Glass Composite	0.70	15.3
Carbon Composite	13.10	1.5

1. Zoughi, R. and Zonnefeld, B., *Review of Progress in Quantitative Nondestructive Evaluation*, 10B, pp. 1431-1436, 1991





- Assumptions regarding munition casing microwave protection may not be valid…

Known Incident

Known Incident

Conclusions

- Microwave heating of EM in munition systems is a credible hazard
  - Associated risk dependent on: EM ε”, munition system design, service EME
- Only a small amount of research on EM dielectric properties
  - Excludes formulations (for the most part), and temperature dependence
  - Molecular explosives appear to have low susceptibility – higher for composites, compositions containing carbon
- Munition system design may provide some protection
  - Composite materials allow microwave penetration and are susceptible to microwave heating

Conclusions (2)

- Under worst case conditions, EM can be heated to initiation in minutes
  - At least one recorded incident
- Assessment of munition susceptibility to microwave heating should be made prior to introduction into service. Scope of assessment proportional to likely risk:
  - Metal cased munitions containing molecular explosives subject to benign EME – basic assessment
  - Munitions without metal cases, containing microwave susceptible compositions, or subject to more severe EME – more extensive assessment