Commander, Operational Test and Evaluation Force

Modeling and Simulation of EHF SATCOM Low Probability of Intercept (LPI) and Anti-jam (AJ) Characteristics

14 September 2004

Outline

- **Test and Evaluation (T&E) of Navy EHF SATCOM Program (NESP) LPI and AJ requirements**
- **John Hopkins Applied Physics Laboratory (JHU APL) LPI conceptual model**
- **JHU APL AJ conceptual model**
- **Verification, validation, and accreditation (VV&A) process**

Communication Threats: Jamming and Interception

T&E of NESP AJ and LPI Requirements

- ***LPI requirement:*** ***Demonstrate a circular equivalent vulnerability radius (CEVR) of a specified distance at a given data rate for a given message size for ships and flagships. Probability of detection (PD) and probability of false alarm (PFA) are specified when the terminal antenna's elevation angle to the satellite is greater than a specified number of degrees. A specified optimum airborne interceptor altitude, a specified gain to thermal noise power density ratio (G/T), and an objective G/T are assumed.***

T&E of NESP AJ and LPI requirements (continued)

- ***AJ requirement:*** ***Achieve specified data rates for 3' ship, 4.5' ship, 6' shore, and 10' shore antennas against a tactical aircraft jammer with a given effective isotropic radiated power (EIRP) at specified altitude and stand-off distances.***

- ***Both requirements are considered to be measures of effectiveness for the Survivability Critical Operational Issues (COIs) in two NESP test phases (OT-IIID and OT-IIIF) and the MILSTAR Multi-service Operational Test and Evaluation MOT&E.***

T&E of NESP AJ and LPI requirements (continued)

- ***COMOPTEVFOR requested Naval Security Group Command (NSGC) perform a Signal Susceptibility and Vulnerability Assessment (SSVA) to provide the information needed to resolve the AJ and LPI aspects of the Survivability COIs.***

- ***NESP Program Office (PEO C4I & Space PMW-170) and Naval Undersea Warfare Command (NUWC) funded JHU APL to support NSGC's SSVA with modeling and simulation.***
  - ***PMW-170: $701K***
  - ***NUWC: $395K***

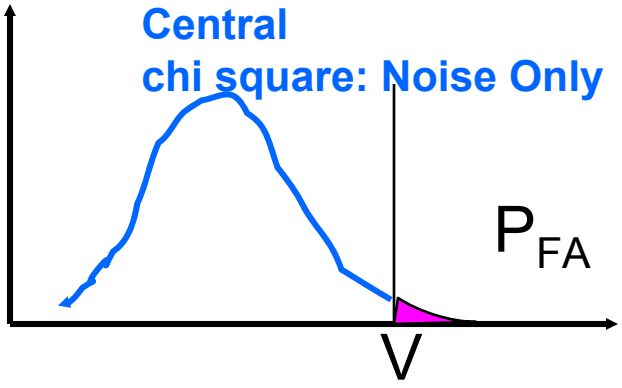
T&E of NESP AJ and LPI requirements (continued)

- ***PMW-170 provided COTF with $240K to support accreditation of the M&S.***
  - ***$40K for JASA administrative review of V&V package.***
  - ***$200K for Massachusetts Institute of Technology Lincoln Labs (MIT LL) independent peer review.***

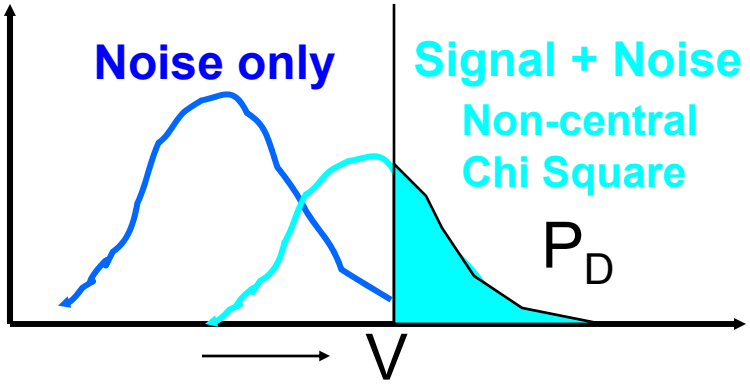
- ***NESP M&S working group membership:***
  - ***OSD DOT&E***
  - ***COTF***
  - ***NSGC***
  - ***PEO (C4I & Space) PMW-170***
  - ***JHU APL***
  - ***NUWC***
  - ***MIT LL (since JAN 04)***

LPI Analysis: JHU APL's Methodology

1. Given Prob. of false alarm P_{FA}, find energy detector threshold V.

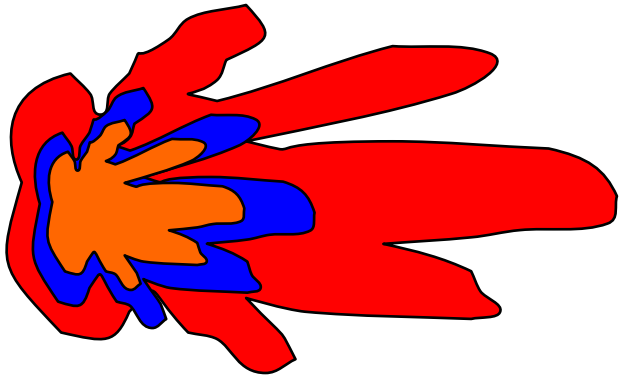


2. Given V and a geometric location, calculate Prob. of detection P_D.



PDF changed based on geometry
$\Rightarrow$ PDF changed due to different $(P_r/N_0)_{rcvd}$

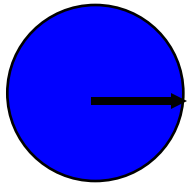
3. Form P_D contours and calculate CEVR



P_D =1%

P_D =10%

P_D =50%



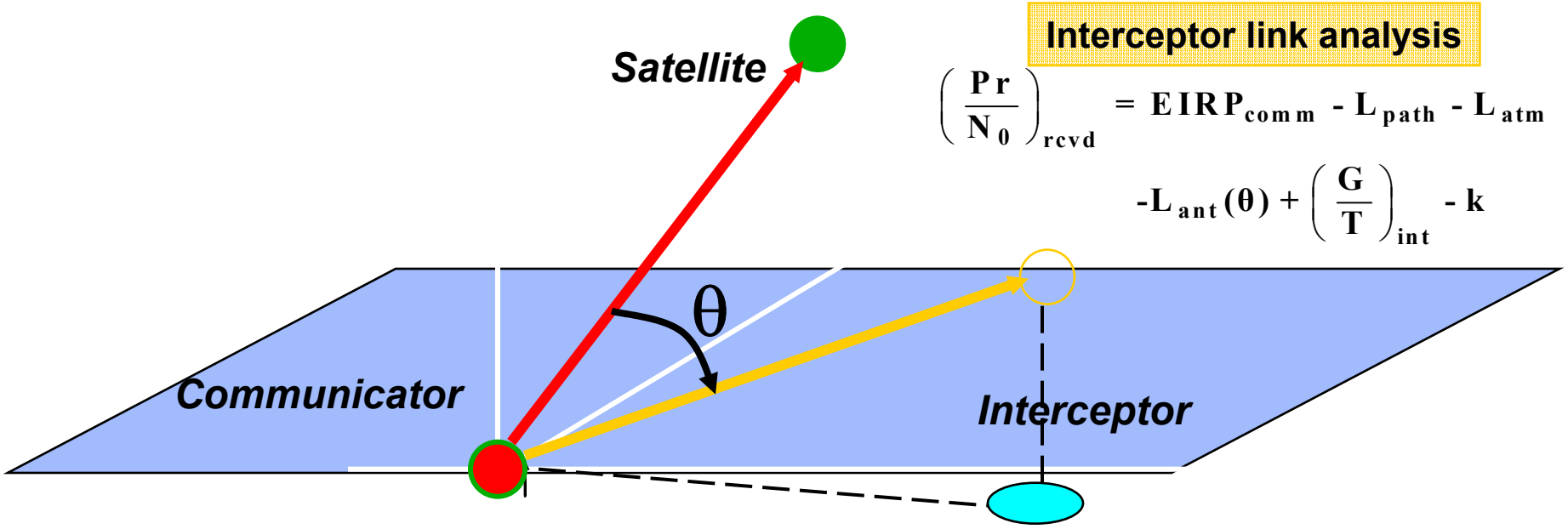
CEVR for P_D=10%

LPI Geometric Effect

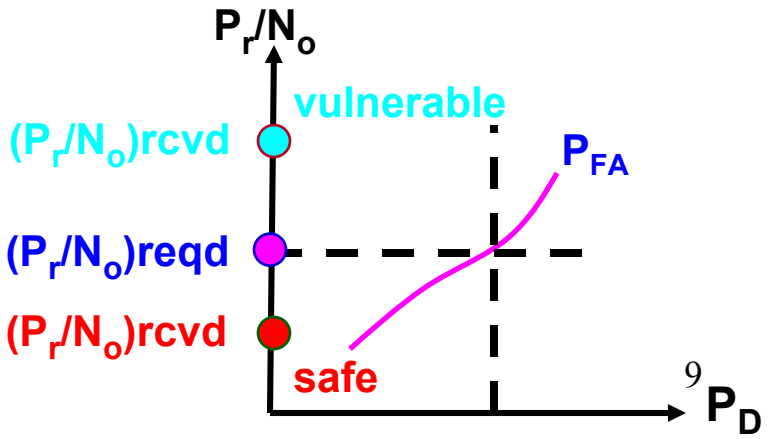
Interceptor link analysis

$$\left(\frac{Pr}{N_0}\right)_{rcvd} = EIRP_{comm} - L_{path} - L_{atm}$$

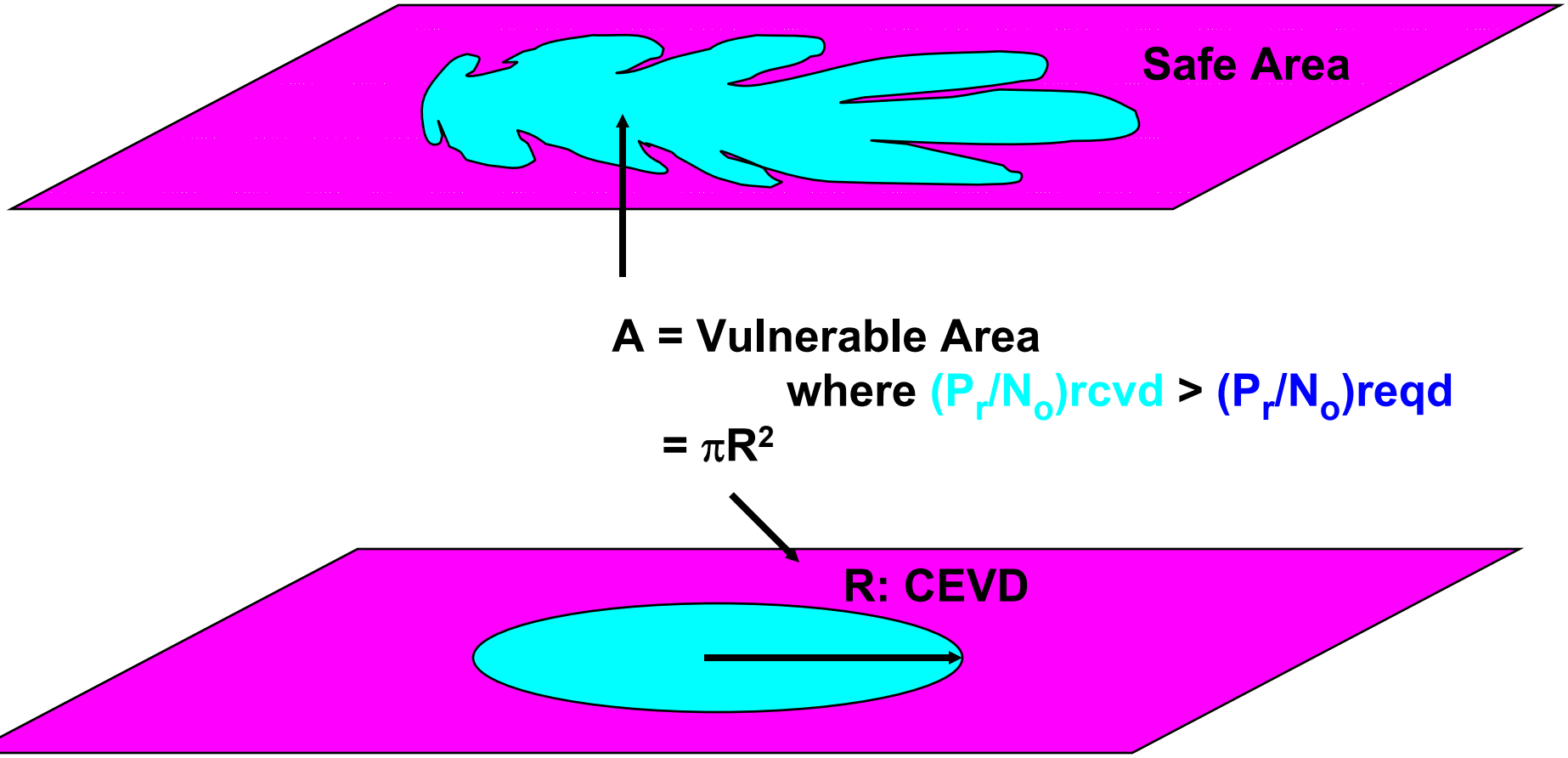
$$-L_{ant}(\theta) + \left(\frac{G}{T}\right)_{int} - k$$



For each location, compare (P_r/N_o)rcvd and (P_r/N_o)reqd

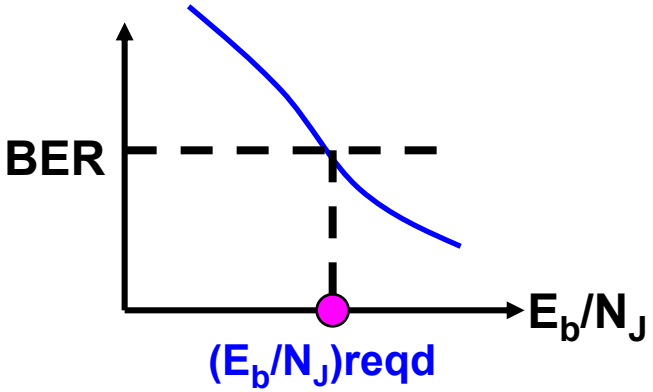


Circular Equivalent Vulnerable Distance (CEVD)

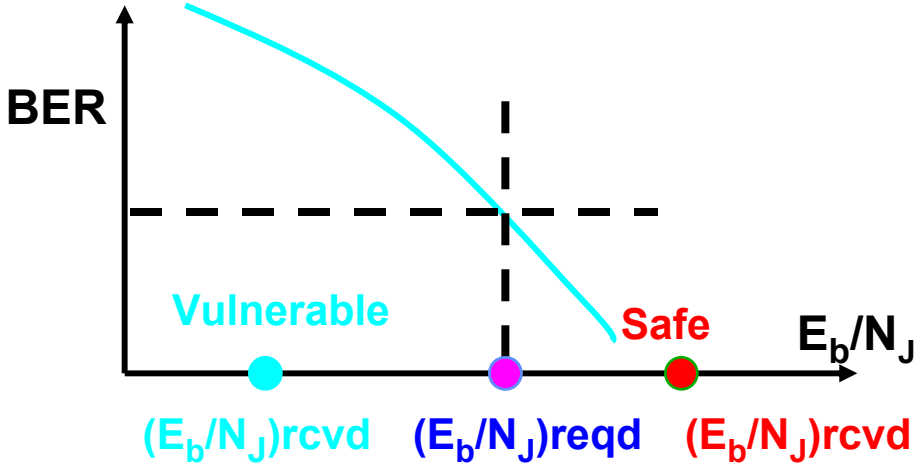


AJ Analysis: JHU APL's Methodology

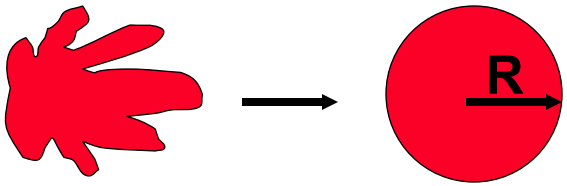
Step 1: Comm. system characterization
Obtain (E_b/N_J)reqd value via simulation



Step 2: Geometric effect
Obtain (E_b/N_J)rcvd by link analysis for a location



Step 3: Performance measure
Compute CESD by comparing (E_b/N_J)reqd and (E_b/N_J)rcvd



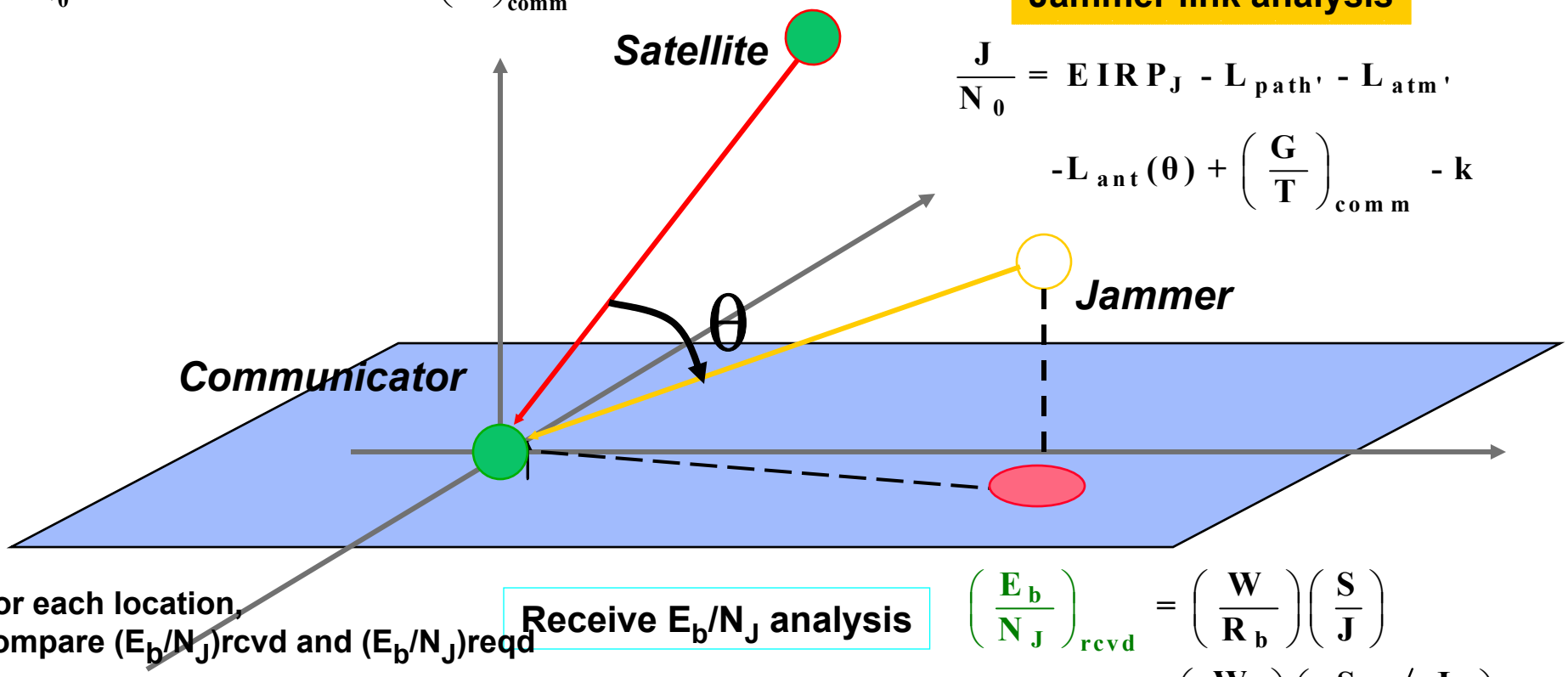
AJ Geometric Effect

Communicator link analysis

$$\frac{S}{N_0} = EIRP_{sat} - L_{path} - L_{atm} + \left(\frac{G}{T}\right)_{comm} - k$$

Jammer link analysis

$$\frac{J}{N_0} = EIRP_J - L_{path'} - L_{atm'} - L_{ant}(\theta) + \left(\frac{G}{T}\right)_{comm} - k$$

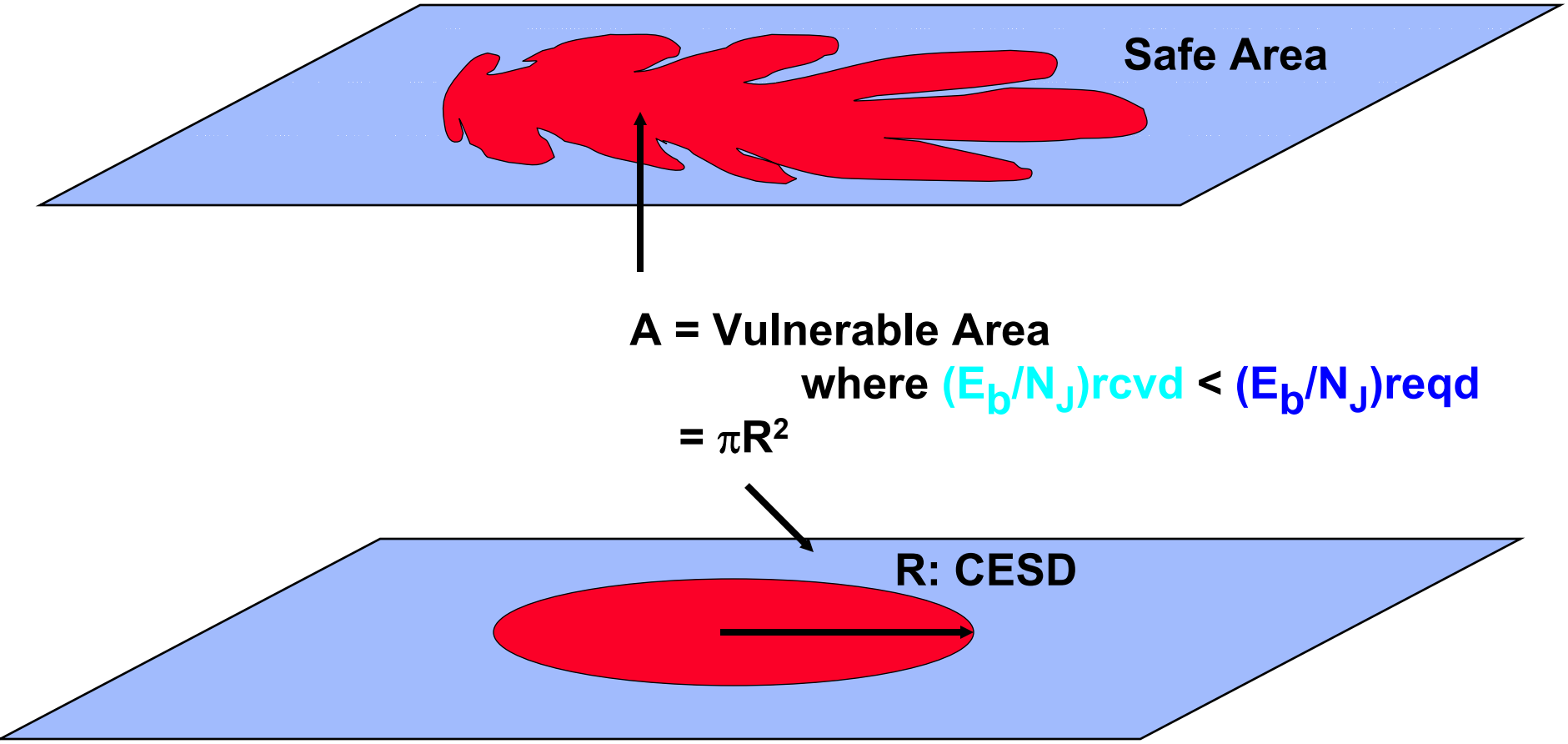


For each location, compare $(E_b/N_J)_{rcvd}$ and $(E_b/N_J)_{reqd}$

Receive E_b/N_J analysis

$$\left(\frac{E_b}{N_J}\right)_{rcvd} = \left(\frac{W}{R_b}\right)\left(\frac{S}{J}\right) = \left(\frac{W}{R_b}\right)\left(\frac{S}{N_0} \Big/ \frac{J}{N_0}\right)$$

Circular Equivalent Standoff Distance (CESD)



VV&A Policy Compliance

- ***References:***
  - ***COTFINST 5000.1, Use of Modeling and Simulation (M&S) in Operational Testing, of 05 Sep 95.***
  - ***Undated draft copy of COTFINST 5000.1A, Use of Modeling and Simulation (M&S) in Operational Testing.***
  - ***COTF Policy and Information Notice (PIN) 99-01, COMOPTEVFOR Modeling and Simulation Accreditation Documentation, of 13 May 99.***
  - ***COTF notice, Accreditation of modeling and Simulation in Support of Operational Test and Evaluation, of 29 Apr 98.***
  - ***SECNAVINST 5200.40, Verification, Validation, and Accreditation (VV&A) of Models and Simulations, of 19 Apr 99.***

Requirements and Clarity of Use

- ***System requirements in the ORD were defined early enough but M&S intended use statement was not formalized until the V&V process was nearly complete.***

- ***Level of detail and clarity of the requirements presented to the those involved in the M&S VV&A process was at an operational level consistent with the applicable ORD, system CONOPS, and STAR.***

- ***STAR lacked sufficient detail on threat systems.***

- ***No significant requirements changes made during development.***

Configuration Management (CM) and Documentation

- ***CM was not instituted until late in the process but was in place prior to conducting the simulation runs used to resolve OT&E COIs.***

- ***Documents produced as a part of V&V:***
  - ***Verification report***
  - ***Validation report***
  - ***Configuration management plan***

- ***Documentation generated is a valid artifact for those who may be interested in use of the models and simulation.***

Verification and Validation (V&V)

- ***Data V&V***
  - ***Lack of information available to account for variation in antenna patterns due to different platforms, geometry, and system configurations.***
  - ***Sufficient data available to validate when you consider the small variations attributed to lack of antenna pattern information when compared to the relatively larger/wider system performance margins.***
- ***System V&V***
  - ***Lack of information available to account for variation in antenna patterns due to different platforms, geometry, and system(s) configurations.***

Scheduling and Tracking

- ***Very little scrutiny applied to track the VV&A until very near the end of the process.***
- ***The overall tacking effort was not even moderately successful.***
- ***The VV&A process has taken much longer than expected. In all three of the completed test events originally requiring AJ and LPI M&S, the applicable COI remains unresolved. In one case, the accreditation will not occur for more than two years since the test event was conducted.***

Accreditation Process

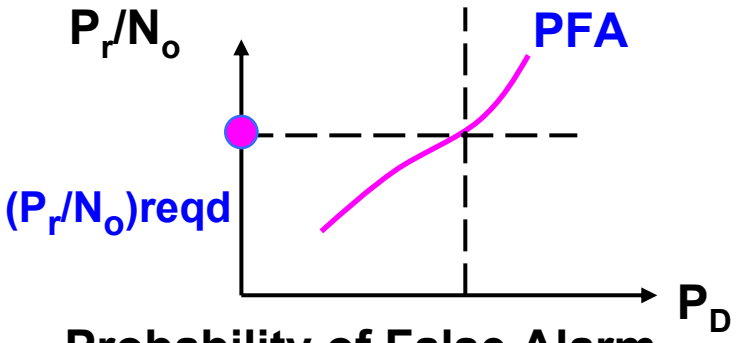
- ***Insufficient training.***
  - ***One hour in basic OTD course.***
  - ***No specialized training.***
  - ***No continuing training.***
- ***Inadequate organic support.***
  - ***Must rely on contract(s) with external organization(s).***
- ***Outdated instruction.***
  - ***COMOPTEVFORINST 5000.1 of 05 Sep 95***
- ***Not clear why COTF accreditation required for an SSVA conducted by NSGC.***

Back-up Slides

Questions?

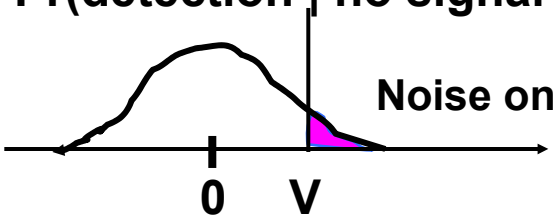
LPI Performance Measure: Required P_r/N_o for Interceptor

Detectability: Defined by P_r/N_o required by the interceptor with given detection quality P_D and P_{FA}



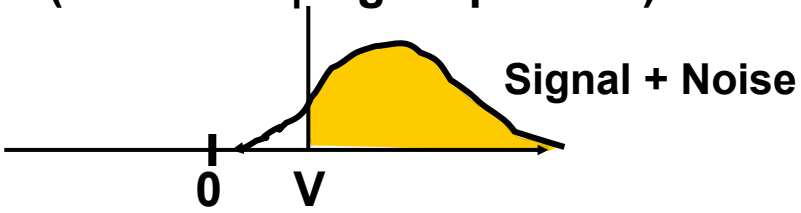
Probability of False Alarm

P_{FA}=Pr(detection | no signal present)



Probability of detection

P_D=Pr(detection | signal present)



Implicit system parameters

Communicator waveform design

- Total bandwidth
- Hop frequency spacing
- Hop duration
- Message duration

Interceptor design

- Energy threshold values
- Fraction of band listened
- Number of energy detectors
- Filter bandwidth

CEVR Evaluation

$$\text{CEVR} = \sqrt{\sum Area\{(P_r/N_0)_{rcvd} > (P_r/N_0)_{reqd}\}/\pi}$$

$$= f\,((P_r/N_0)_{reqd}, (P_r/N_0)_{rcvd})$$

$$= f\,((P_r/N_0)_{reqd}, G_T(\theta)) \text{ given Link Parameters}$$

$(P_r/N_0)_{reqd}$ = Interceptor performance

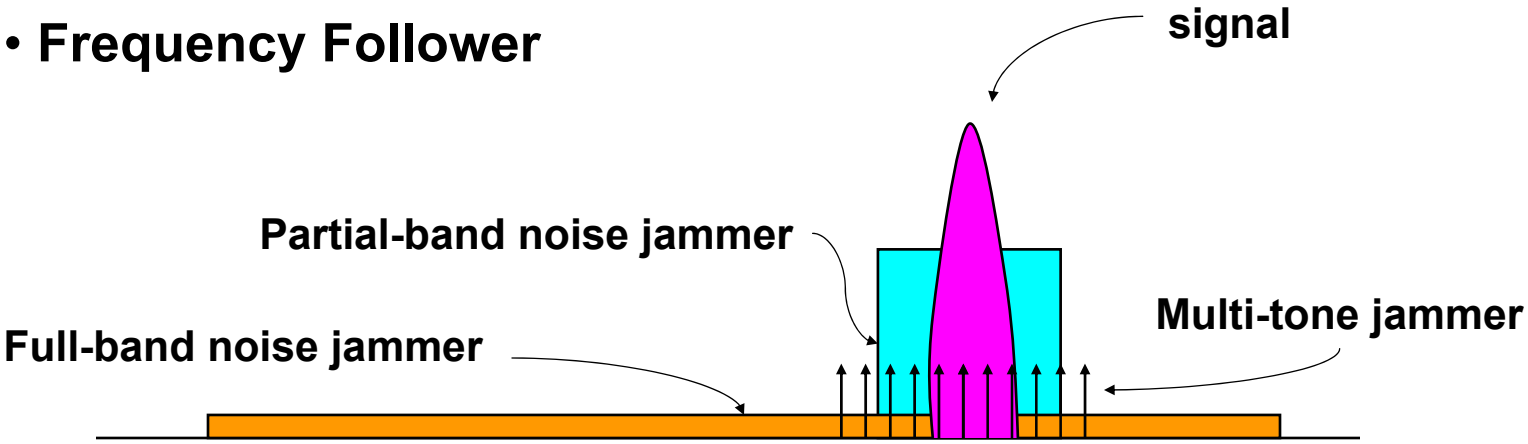
$G_T(\theta)$ = Terminal Tx antenna pattern

Link Parameters:

Terminal EIRP, Path Loss, Atmospheric Loss, Interceptor G/T, etc.

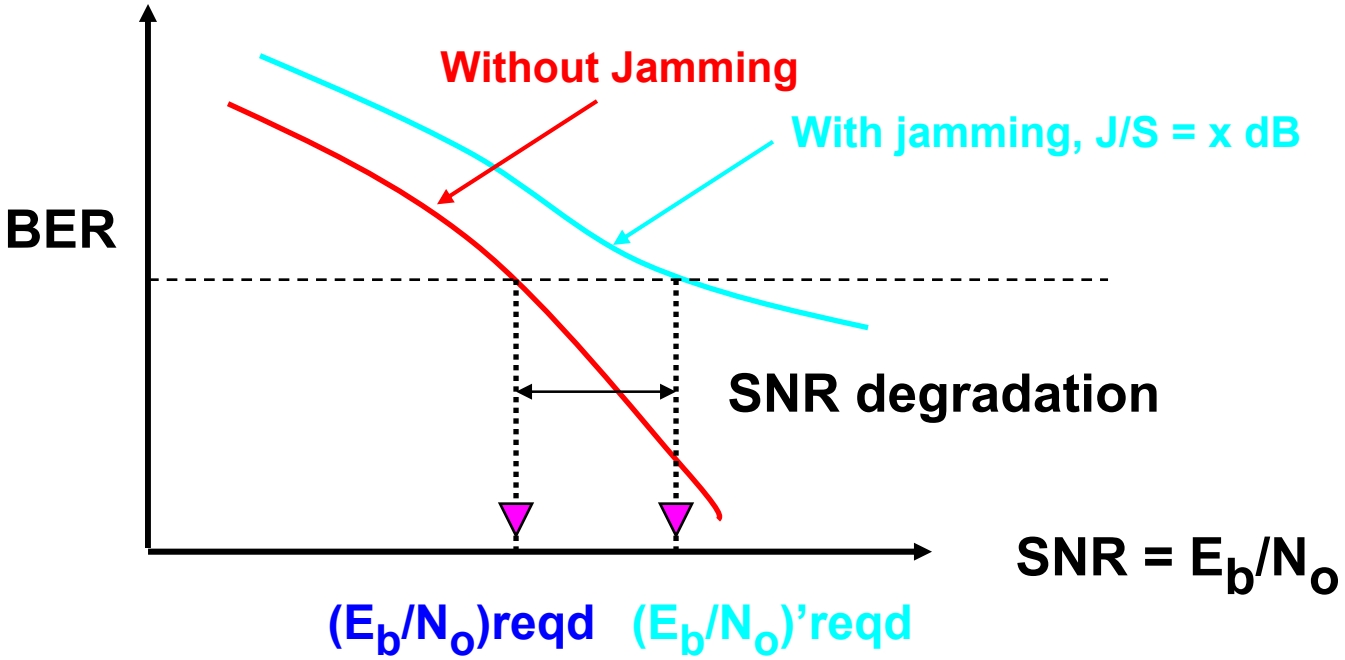
Jammer Type

- Full-band noise jammer (dumb jammer)
- Partial-band noise jammer
- Multi-tone jammer
- Pulse jammer
- Frequency Follower



Jamming Effect

- Given a BER, the communicator requires (E_b/N_o)reqd
- With jamming (J/S=x dB), the communicator requires larger (E_b/N_o)'reqd
- To ensure the comm. quality, the communicator needs to increase Tx power

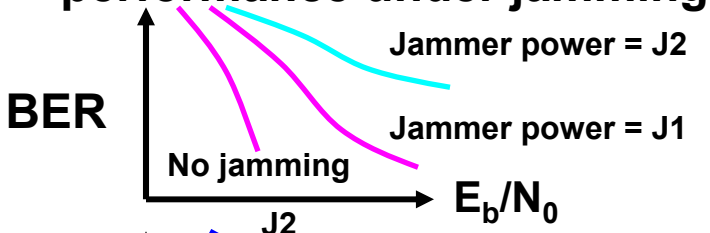


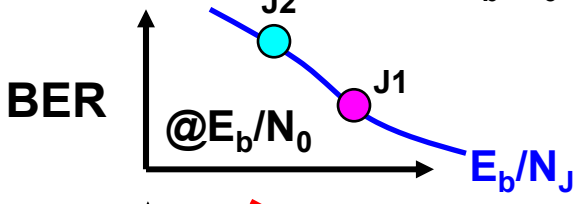
AJ Performance Measure: E_b/N_J for communicator

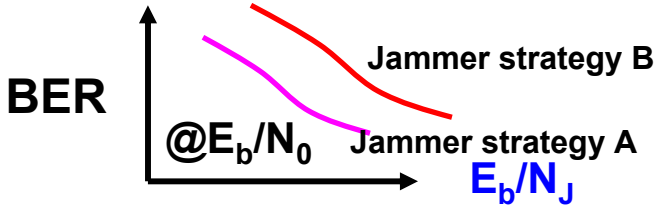
- E_b/N_J is Signal-to-Interference Ratio (SIR). $E_b/N_J=(W/R_b)(S/J)$
- E_b/N_J in jamming is equivalent to E_b/N_o in noise only environment

$$\frac{\text{Receive Signal Power}}{\text{Composite Noise Density}} = \frac{P_r}{N_0 + N_J} = \begin{cases} R_b \dfrac{E_b}{N_0} & if\ N_J = 0 \\ R_b \dfrac{E_b}{N_J} & if\ N_J >> N_0 \end{cases}$$

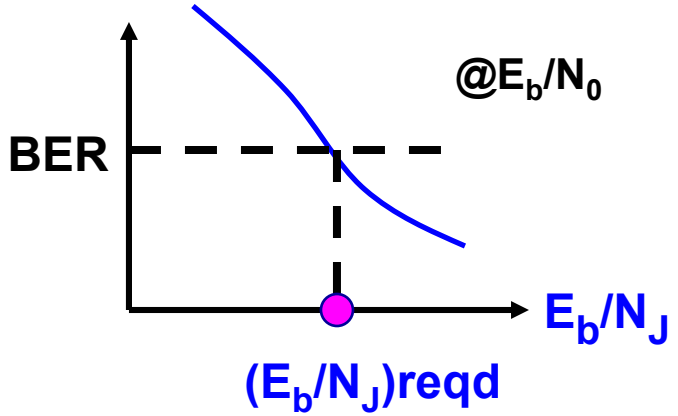
- E_b/N_J simplifies performance comparison and quantifies the system performance under jamming







- Goal: To find E_b/N_J required for a given communication quality under a given jamming strategy



CESD Evaluation

$$CESD = \sqrt{\sum Area\{(E_b/N_J)_{rcvd} < (E_b/N_J)_{reqd}\}/\pi}$$

$$= f\,((E_b/N_J)_{reqd}, (E_b/N_J)_{rcvd})$$

$$= f\,((E_b/N_J)_{reqd}, G_R(\theta))$$ given Link Parameters

$(E_b/N_J)_{reqd}$ = Terminal performance under jamming

$G_R(\theta)$ = Terminal Rx antenna pattern

Link Parameters:

Satellite EIRP, Path Loss, Atmospheric Loss, Terminal G/T,

Jammer EIRP, Path Loss, Atmospheric Loss, etc.