RDECOM

A View of Simulation Conceptual Modeling

AMRDEC
STRENGTH THROUGH TECHNOLOGY

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

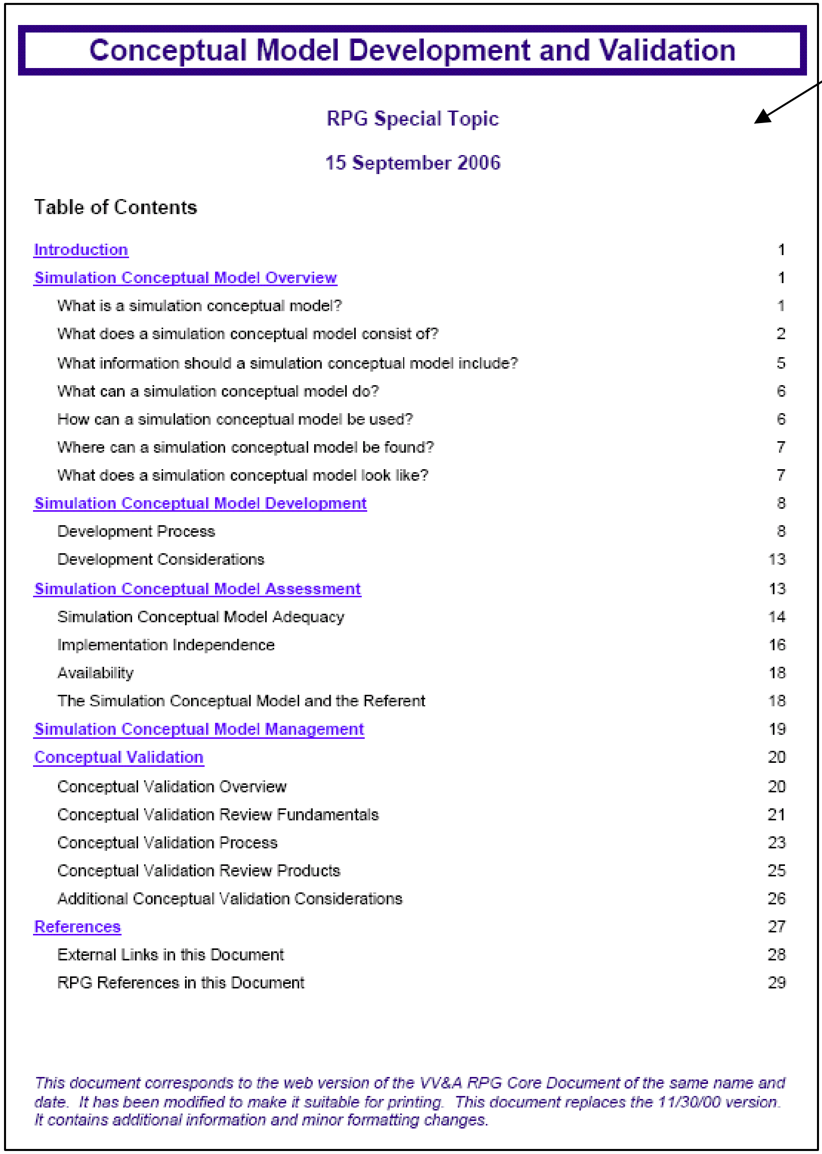
Presented by:

Charles Derrick

Aviation and Missile Research, Development and Engineering Center

Date: 10/22/07

Sources / Contributors



Conceptual Model Development and Validation

RPG Special Topic

15 September 2006

Table of Contents

This document corresponds to the web version of the VV&A RPG Core Document of the same name and date. It has been modified to make it suitable for printing. This document replaces the 11/30/00 version. It contains additional information and minor formatting changes.

http://vva.dmso.mil/

RPG

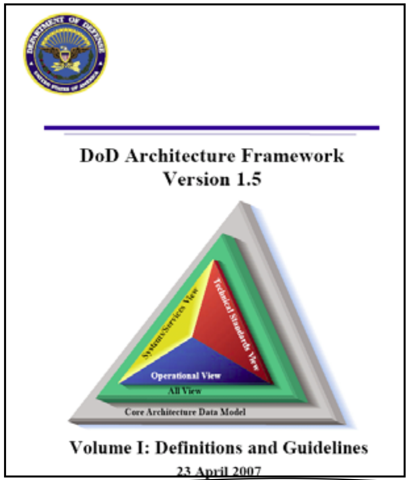
→ Templates

Dr. Surasak P. Hauger

Mr. Chris Burns

Mr. David Whitten

Personal Bias



DoD Architecture Framework
Version 1.5

Volume I: Definitions and Guidelines

23 April 2007

Volume II: Product Descriptions

Volume III: Architecture Data Description

V&V&A

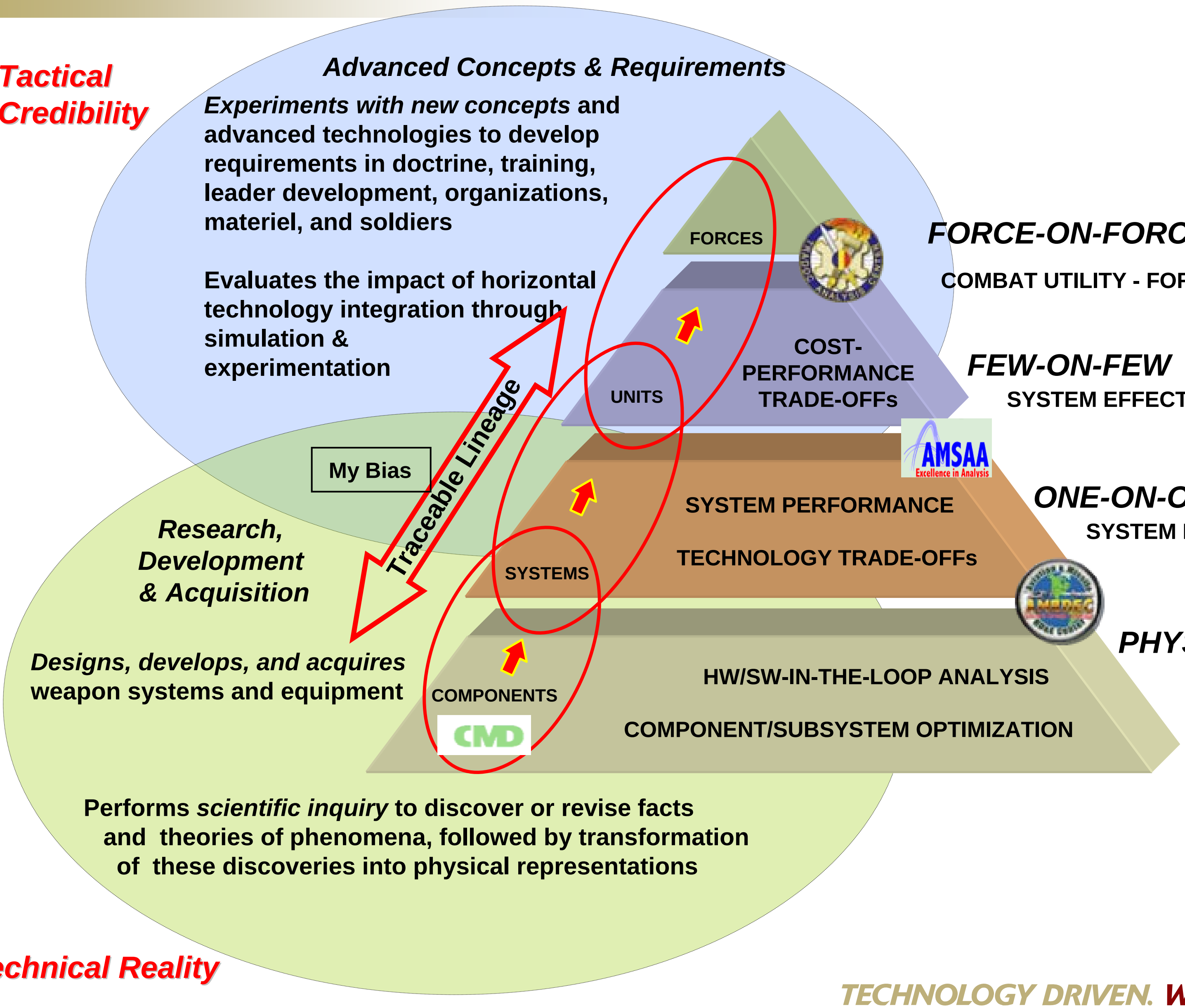
DMSO
Simone Youngblood
VV&A Technical Director

Conceptual Model

Adapted from work by Dr. Dale Pace of The Johns Hopkins University Applied Physics Lab sponsored by the Defense Modeling & Simulation Office

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

My Bias



Tactical Credibility

Advanced Concepts & Requirements

Experiments with new concepts **and advanced technologies to develop requirements in doctrine, training, leader development, organizations, materiel, and soldiers**

Evaluates the impact of horizontal technology integration through simulation & experimentation

My Bias

Traceable Lineage

Research, Development & Acquisition

Designs, develops, and acquires **weapon systems and equipment**

Performs *scientific inquiry* to discover or revise facts and theories of phenomena, followed by transformation of these discoveries into physical representations

Technical Reality

FORCES

UNITS

COST-PERFORMANCE TRADE-OFFs

SYSTEMS

SYSTEM PERFORMANCE

TECHNOLOGY TRADE-OFFs

COMPONENTS

HW/SW-IN-THE-LOOP ANALYSIS

COMPONENT/SUBSYSTEM OPTIMIZATION

FORCE-ON-FORCE

COMBAT UTILITY - FORCE EFFECTIVENESS

FEW-ON-FEW

SYSTEM EFFECTIVENESS

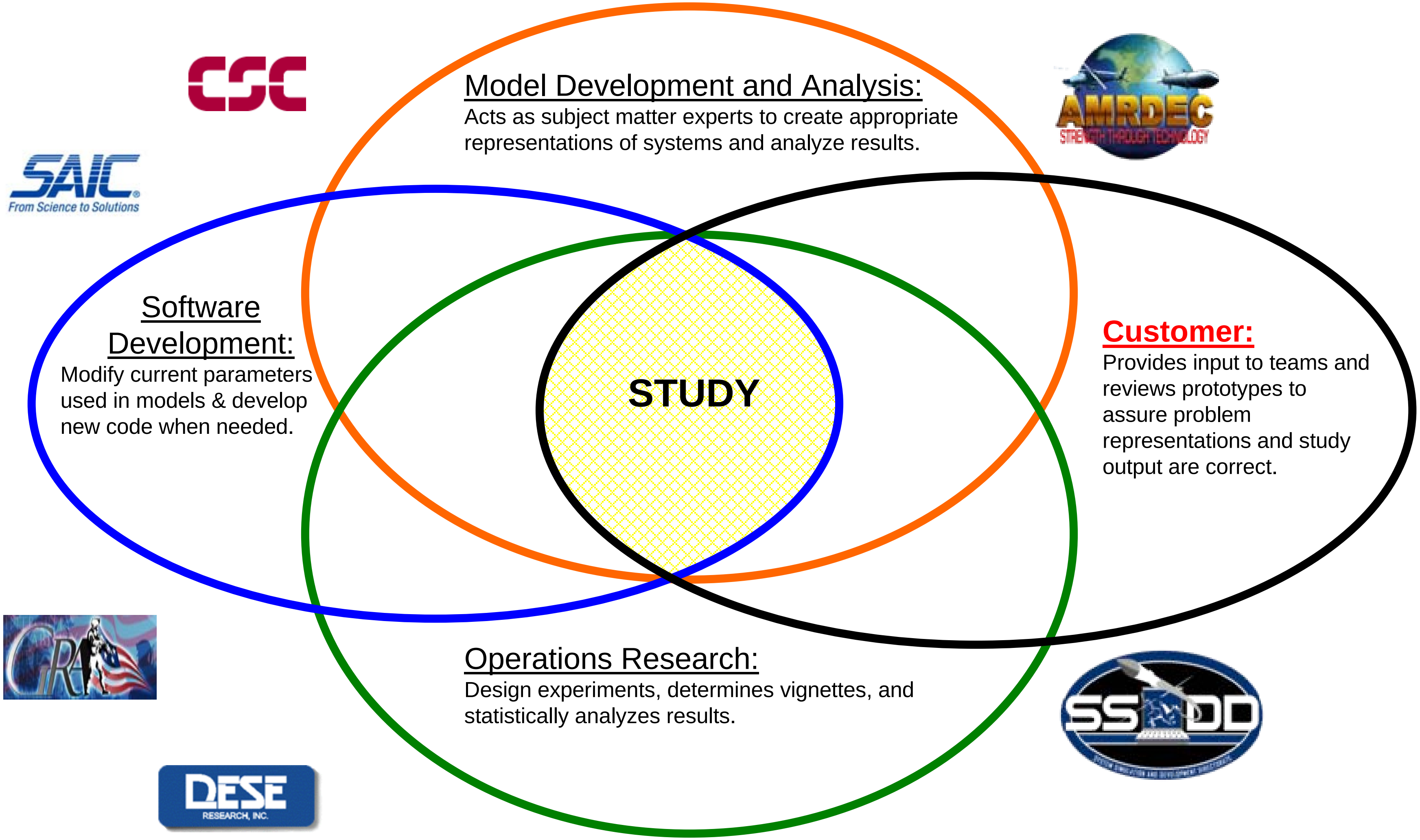
ONE-ON-ONE

SYSTEM PERFORMANCE

PHYSICS / ENGINEERING

SUBSYSTEM EFFECTS

IDEEAS Analysis Process



Model Development and Analysis:
Acts as subject matter experts to create appropriate representations of systems and analyze results.

Software Development:
Modify current parameters used in models & develop new code when needed.

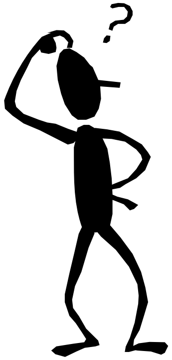
STUDY

Customer:
Provides input to teams and reviews prototypes to assure problem representations and study output are correct.

Operations Research:
Design experiments, determines vignettes, and statistically analyzes results.

Operationally Relevant? Achievable? Comparable? Measurable? Document.

Definition used by Simone Youngblood in her class at UAH



“The conceptual model is a simulation developer’s way of translating modeling requirements into a detailed design framework, from which the software, hardware, networks, and systems/equipment that will make up the simulation can be built, modified, or assembled.”

from SIW Paper 00F-SIW-019, “Simulation Conceptual Model Development Issues and Implications for Reuse of Simulation Components” by Dr. Dale Pace

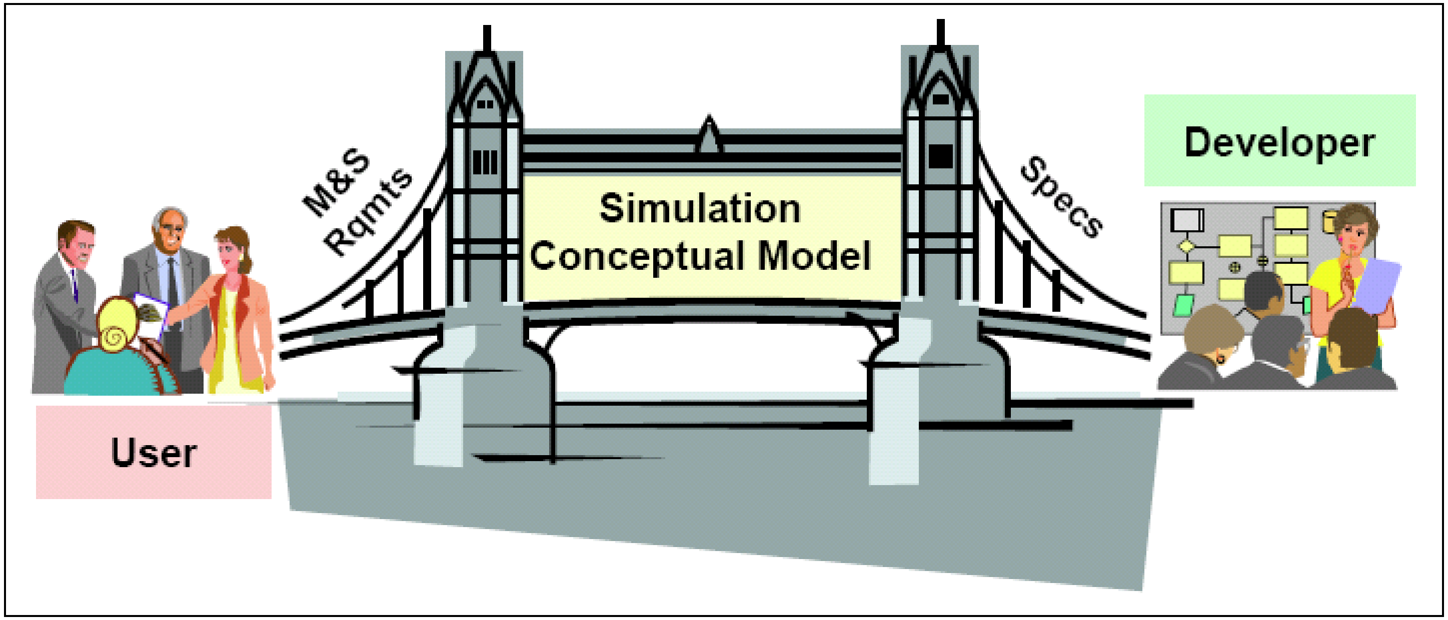
Online M&S Glossary

(DoD 5000.59-M)

- **Conceptual Model**
  "A statement of the content and internal representations which are the user's and developer's combined concept of the model. It includes logic and algorithms and explicitly recognizes assumptions and limitations."

  ***Reference*: "A Glossary of Modeling and Simulation Terms for Distributed Interactive Simulation (DIS)," August, 1995 Conceptual Model of the Mission Space (CMMS)**

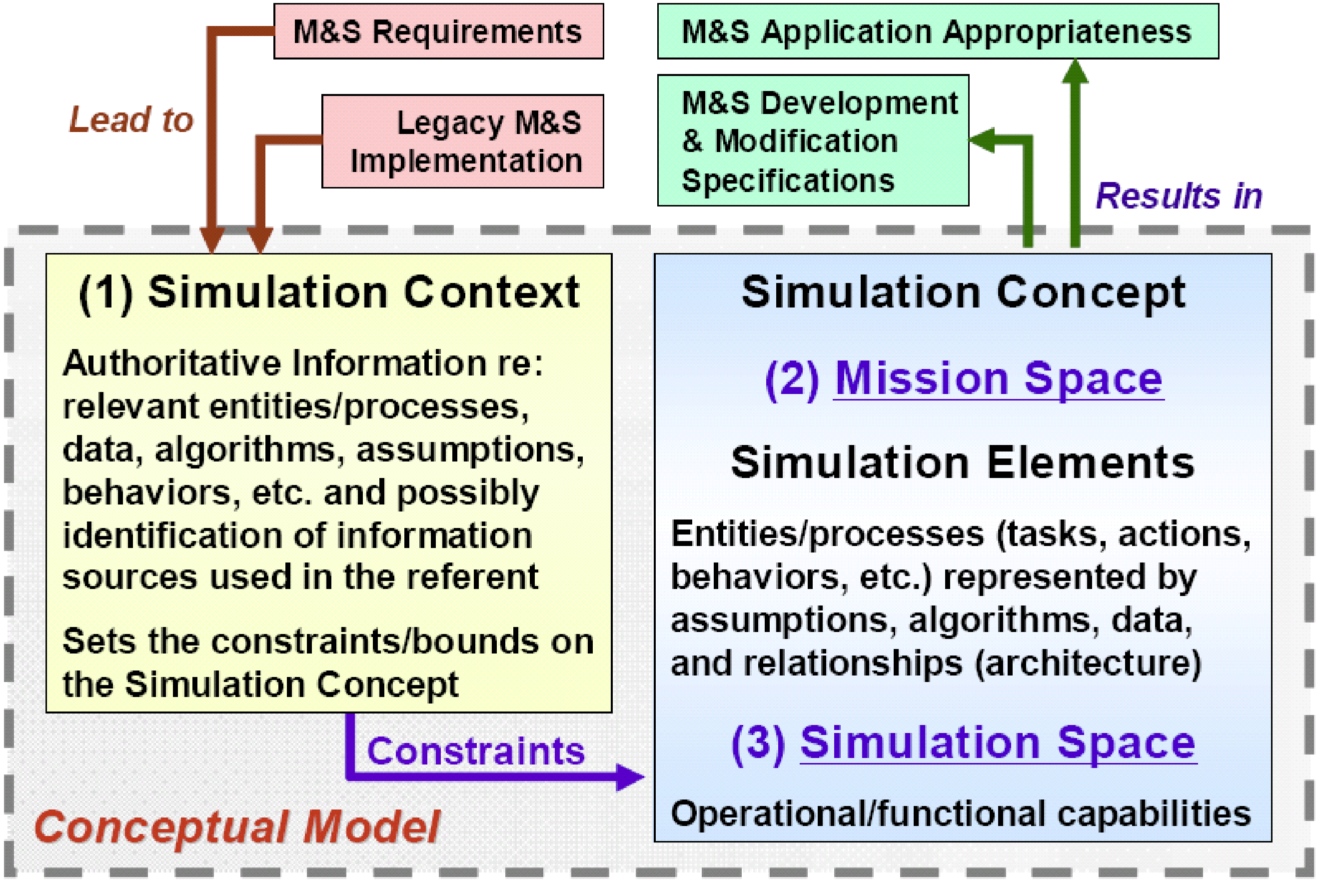
- **Conceptual Model of Mission Space (CMMS)**
  "First abstractions of the real world that serve as a frame of reference for simulation development by capturing the basic information about important entities involved in any mission and their key actions and interactions. They are simulation-neutral views of those entities, actions, and interactions occurring in the real world."



Simulation Conceptual Model: The Bridge Between Developer and User

From: Conceptual Model Development and Validation
RPG Special Topic
15 September 2006

Conceptual Model Components



M&S Requirements

Legacy M&S Implementation

Lead to

M&S Application Appropriateness

M&S Development & Modification Specifications

Results in

(1) Simulation Context

Authoritative Information re: relevant entities/processes, data, algorithms, assumptions, behaviors, etc. and possibly identification of information sources used in the referent

Sets the constraints/bounds on the Simulation Concept

Constraints

Simulation Concept

(2) Mission Space

Simulation Elements

Entities/processes (tasks, actions, behaviors, etc.) represented by assumptions, algorithms, data, and relationships (architecture)

(3) Simulation Space

Operational/functional capabilities

Conceptual Model

Note: Legacy simulation conceptual models focus on (2) Mission Space

From: Conceptual Model Development and Validation
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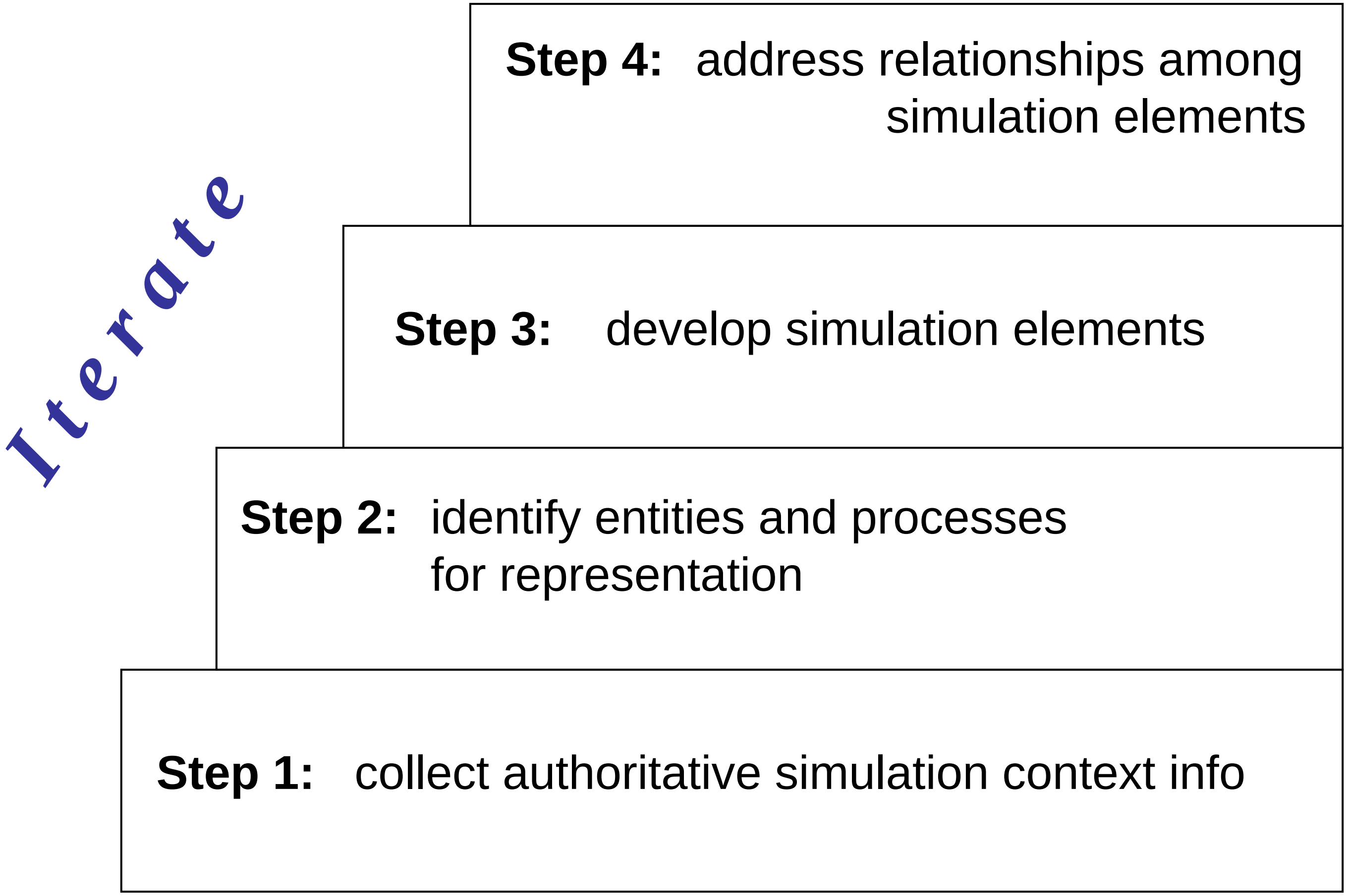
Steps in Conceptual Development



Iterate

Step 4: address relationships among simulation elements

Step 3: develop simulation elements

Step 2: identify entities and processes for representation

Step 1: collect authoritative simulation context info

Adapted from work by Dr. Dale Pace, sponsored by DMSO and briefed by Simone Youngblood in her UAH Class

Conceptual Model Documentation

- Conceptual Model Portion Identification
- Principal Simulation Developer POCs
- Requirements and Purpose
- Overview
- General Assumptions
- Identification of Possible States, Tasks, Actions, and Behaviors, Relationships and Interactions, Events, and Parameters and Factors for Entities and Processes being described
- Identification of Algorithms
- Simulation Development Plans
- Summary and Synopsis

Adapted from work by Dr. Dale Pace, sponsored by DMSO and briefed by Simone Youngblood in her UAH Class

Examples?

- I hope the following facilitates discussion on the application of conceptual modeling.
- These slides represent some “real-life” examples of our view in our application of conceptual modeling.
- Comments between the audience is encouraged.
- Non-attribution.

A Specific View of Conceptual Modeling

The three simple questions asked by Chris Burns to our team at the beginning of each effort:

“What are we modeling?”

“What is the purpose of the conceptual model?”

“Who is the target audience?”

Chris Burns is the lead computer scientist for IDEEAS – an engagement level constructive simulation

Our use of Conceptual Models?

- The type of model created is driven by what you are modeling
  - More information is required when complex specifics are involved
  - Software models are not sufficiently able to convey engineering details that are not directly related to the software design.
- Our Team uses:
  - <u>System Architecture Conceptual Models</u>
    - Domain description, components, and the communication flow
    - Purpose: Define the components involved and their intercommunication
    - Audience: Integrators, Network Engineers, Developers, Users
  - <u>Physics/Engineering Conceptual Models</u>
    - Inputs, outputs, algorithms
    - Purpose: Defines the mathematical representation of a system, including the inputs, algorithms, and outputs
    - Audience: Physicists, Engineers to Software Developers
  - <u>Software Conceptual Models</u>
    - Software centric design representation of the system
    - Purpose: Representation of the system from a software centric view, to convey operation, assumptions, and limitations
    - Audience: Software Developers to Physicists, Engineers

An Example

Radar Modeling for Analysis Utilizing IDEEAS

Surasak P. Hauger, Ph.D.

Science Applications International Corporation (SAIC)
Huntsville, AL 35805, USA

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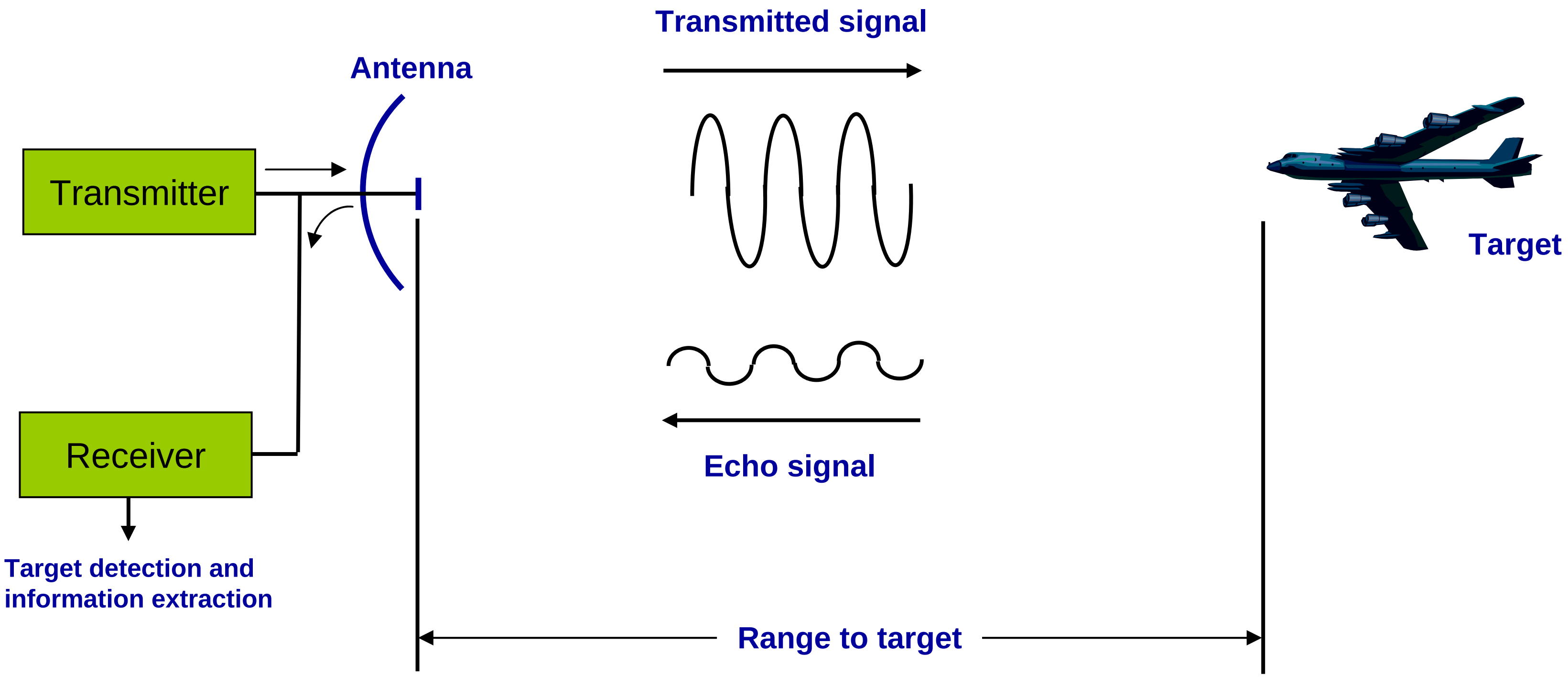
TPQ-37

LCMR

Presenting the process of radar modeling for analysis by utilizing the Interactive Distributed Engineering Evaluation and Analysis Simulation (IDEEAS).

RADAR → RAdio Detection and Ranging

Basic Principle of Radar



Transmitted signal

Antenna

Transmitter

Receiver

Target

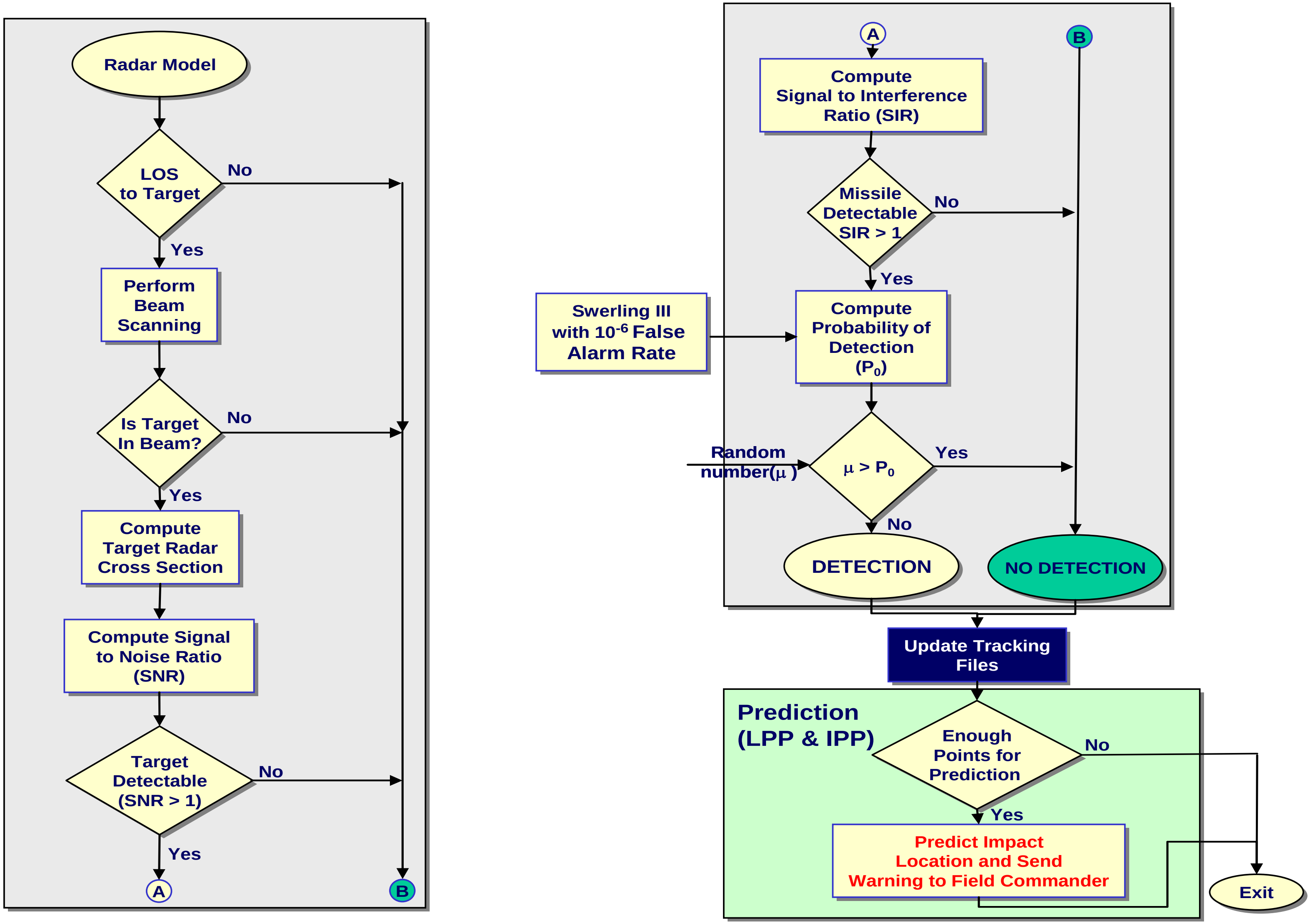
Echo signal

Target detection and information extraction

Range to target

Image derived from “Introduction to Radar Systems” by M. I. Skolnik.

Radar Flow Chart in IDEEAS



Radar Model

LOS to Target

No

Yes

Perform Beam Scanning

Is Target In Beam?

No

Yes

Compute Target Radar Cross Section

Compute Signal to Noise Ratio (SNR)

Target Detectable (SNR > 1)

No

Yes

A

B

A

B

Compute Signal to Interference Ratio (SIR)

Missile Detectable SIR > 1

No

Yes

Swerling III with 10^{-6} False Alarm Rate

Compute Probability of Detection (P_0)

Random number(μ)

$\mu > P_0$

Yes

No

DETECTION

NO DETECTION

Update Tracking Files

Prediction (LPP & IPP)

Enough Points for Prediction

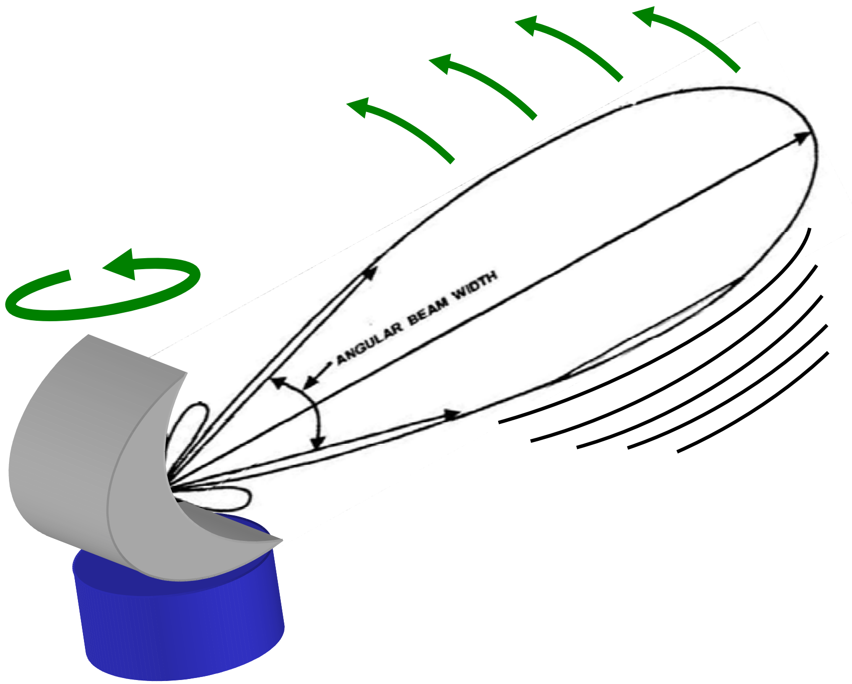
No

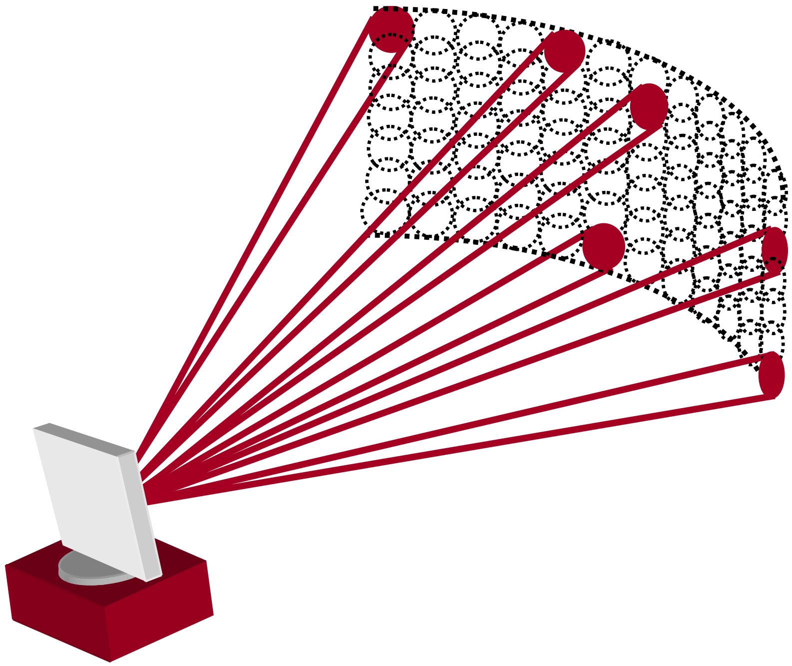
Yes

Predict Impact Location and Send Warning to Field Commander

Exit

Beam Scanning



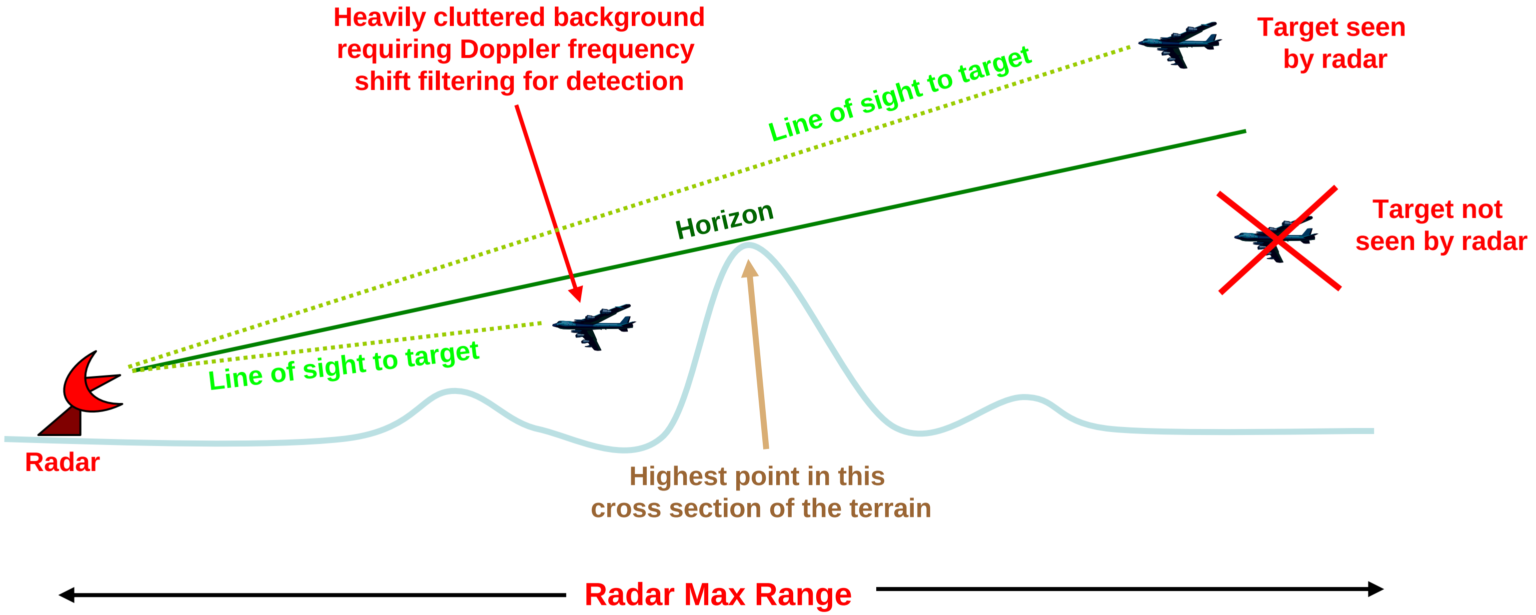


Mechanical Scanning Radar with rotating antenna panel

Phased Array Radar with fixed antenna panel where beams are moved electronically in any direction within a scanning limit

Scanning for Target

- Line of Sight from radar to target required within scanning limit of radar.
- Clutter can be minimized by only scanning the area above the horizon.
- Moving target in the heavily cluttered region can be detected by employing Doppler shift method.



Heavily cluttered background requiring Doppler frequency shift filtering for detection

Target seen by radar

Target not seen by radar

Highest point in this cross section of the terrain

Radar Max Range

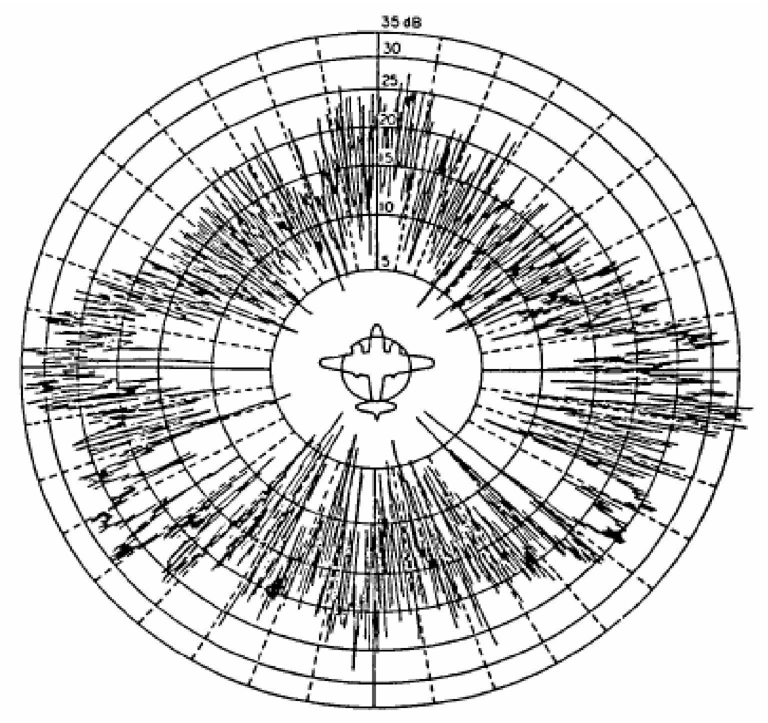
Radar Cross Section

- Radar Cross Section (RCS) is the property of a scattering object that represents the magnitude of the echo signal returned to the radar by the target

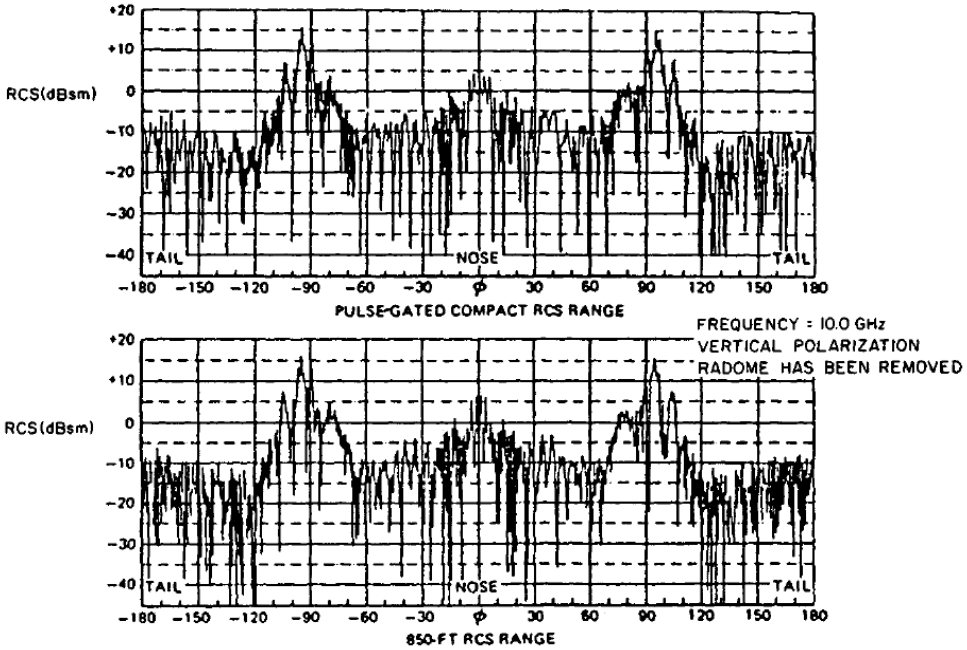
- Unit of RCS is m^2 or dBsm

- Even though its unit is m^2, the RCS may or may not correlate with the physical size or effective area of the object

Target Radar Cross Section

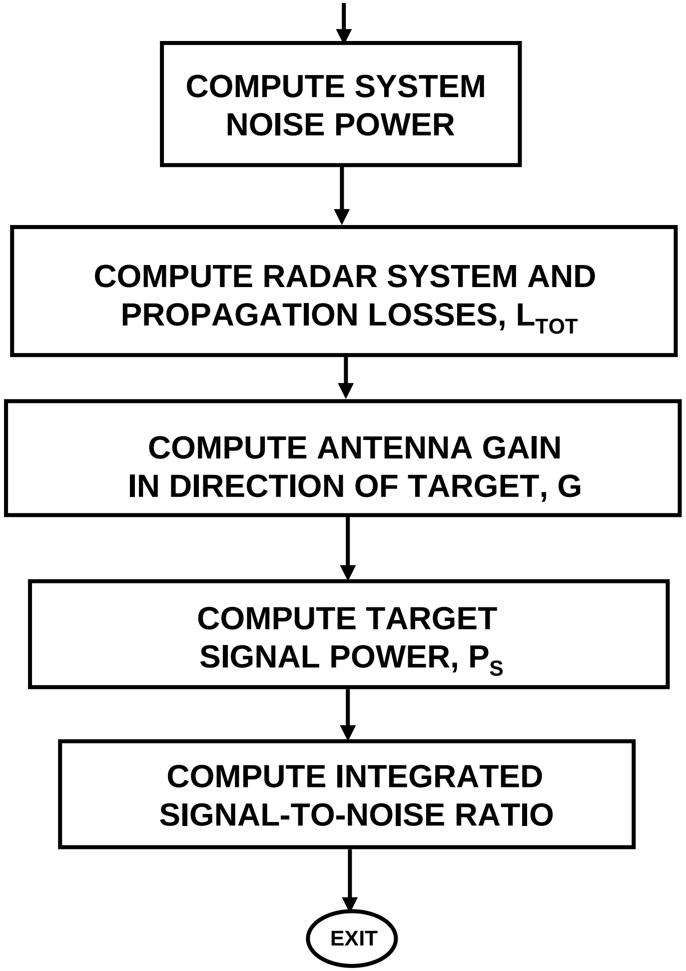


Measured RCS pattern of a B-26 bomber at 10-cm wavelength. (from “Introduction to Radar Systems” by Merrill I. Skolnik)



Measured RCS of a one-fifteenth scale model Boeing 737 commercial jetliner at 10 GHz and vertical polarization. (from “Introduction to Radar Systems” by Merrill I. Skolnik)

Signal to Noise Calculation



COMPUTE SYSTEM NOISE POWER

COMPUTE RADAR SYSTEM AND PROPAGATION LOSSES, L_{TOT}

COMPUTE ANTENNA GAIN IN DIRECTION OF TARGET, G

COMPUTE TARGET SIGNAL POWER, P_S

COMPUTE INTEGRATED SIGNAL-TO-NOISE RATIO

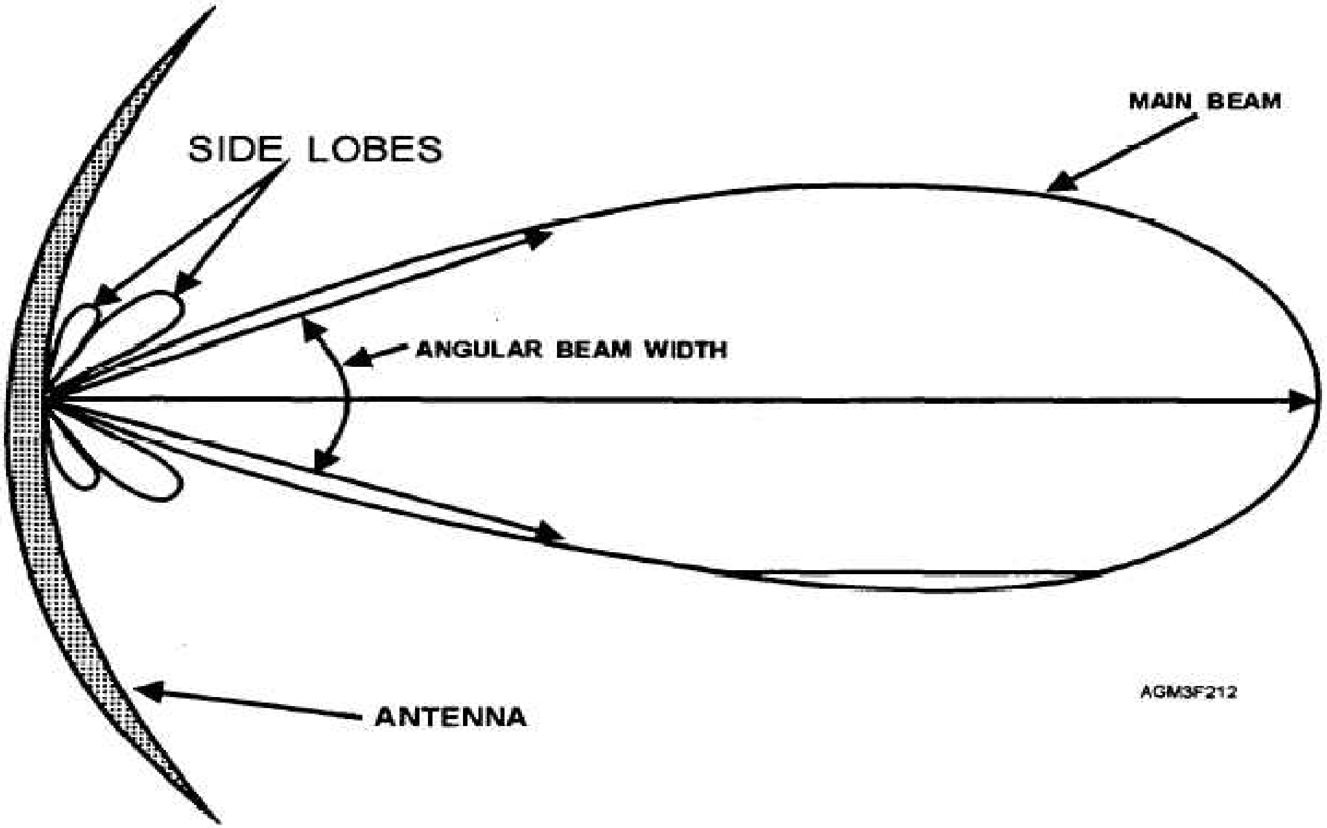
EXIT

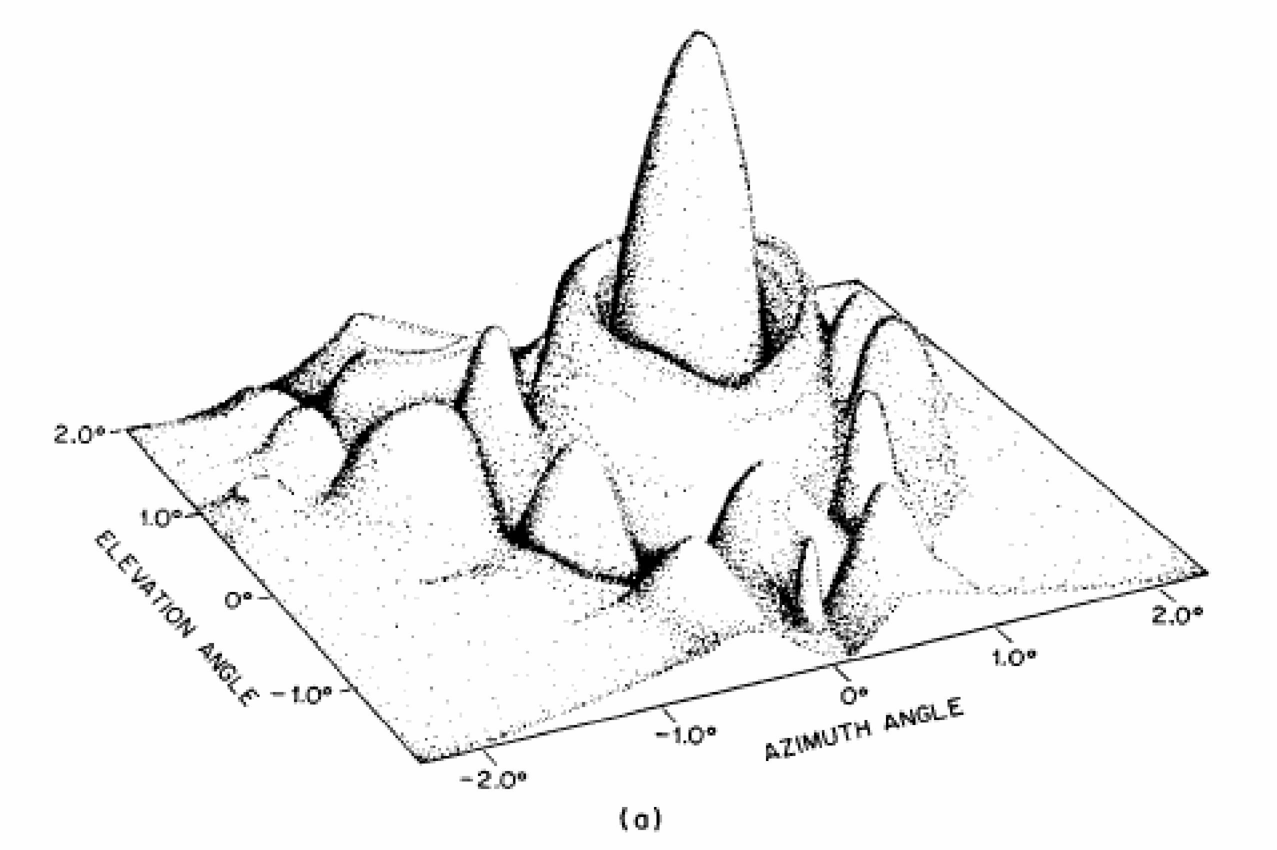
Noise Signal Level

$$P_n = \frac{kT_o N_F}{\tau}$$

P_n = Radar System noise power
k = Boltzmann's constant
T_o = System reference noise temperature (°K)
N_F = Receiver noise figure
τ = Radar pulse width

Antenna Beam and Gain Pattern

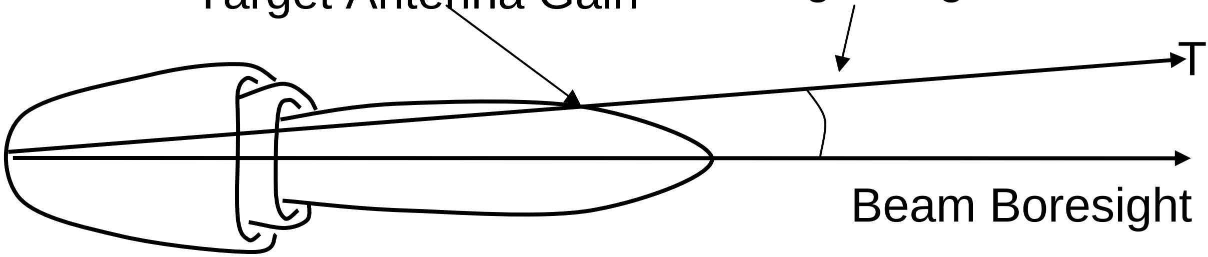




Example of 3-D Antenna Pattern

(from “Radar Handbook” edited by Merrill I. Skolnik)

Antenna Gain in the Direction of Target



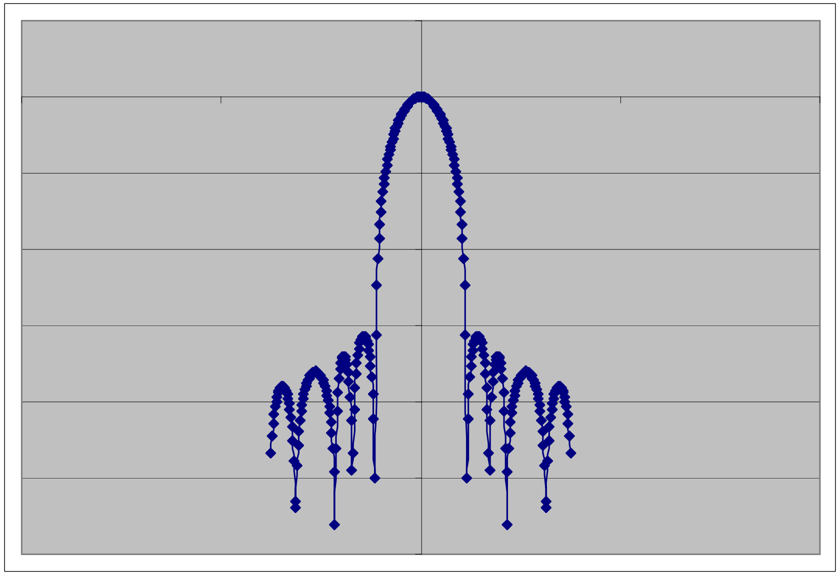
Target Antenna Gain

Target angle

Target

Beam Boresight (Look Angle)

Antenna Gain Pattern



Antenna gain representation within IDEEAS (note pattern characteristic is configurable through input)

Signal Power

Density of Radiated Power at Target Range

Reflection and Spreading on Return Path

Intercept Area of Receiving Antenna

System and Propagation Losses

$$P_s = \text{Signal Power} = \left(\frac{P_T G}{4\pi R^2}\right) \cdots \left(\frac{\sigma}{4\pi R^2}\right) \cdots \left(\frac{G\lambda^2}{4\pi}\right) \cdots \left(\frac{1}{L}\right)$$

$$P_s = \frac{P_T G^2 \lambda^2 \sigma}{(4\pi)^3 L R^4}$$

P_T = Peak Power transmitted
G = Antenna gain in direction of target
λ = Wavelength
σ = Radar Cross Section of target
L = Radar system and propagation losses
R = Range to target

Compute Integration Gain

Dwell – The time on target, and time it takes to scan the antenna beam over a beamwidth or some fraction of a beamwidth

Duty Cycle – A measure of the fraction of the time a radar is transmitting

Number of pulses during dwell time = Dwell×PRF ➔ Integration Gain

Leading to:

$$SNR = G_{INT}\left(\frac{P_S}{P_N}\right)$$

Signal to Noise Ratio

$$SNR = \frac{P_{pk} \, G_t \, N_{pulses} \, \tau_{pw} \, \sigma \, G_r \, \lambda^2}{(4\pi)^3 k T_o N_F L R^4}$$

Radar Range Equation

$$R = \sqrt[4]{\frac{P_{pk} \, G_t \, N_{pulses} \, \tau_{pw} \, \sigma \, G_r \, \lambda^2}{(4\pi)^3 k T_o N_F L (SNR)}}$$

Pulse Compression Simplified Concept

Energy content of long-duration, low-power pulse will be comparable to that of the short-duration, high-power pulse

$$\tau_1 \ll \tau_2 \text{ and } P_1 \gg P_2$$

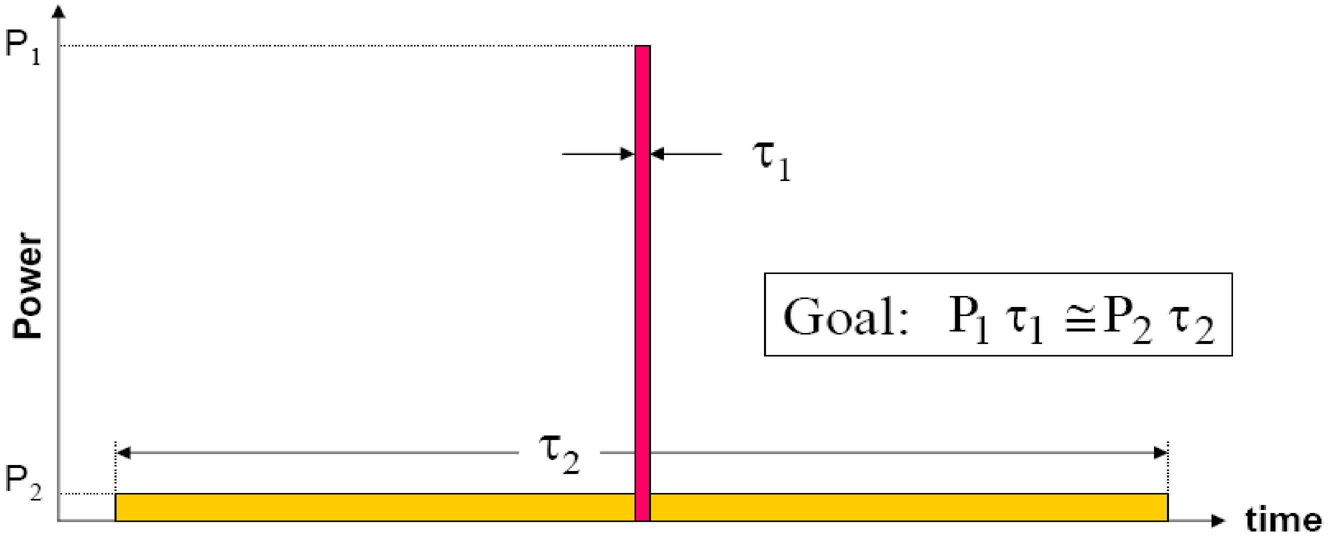
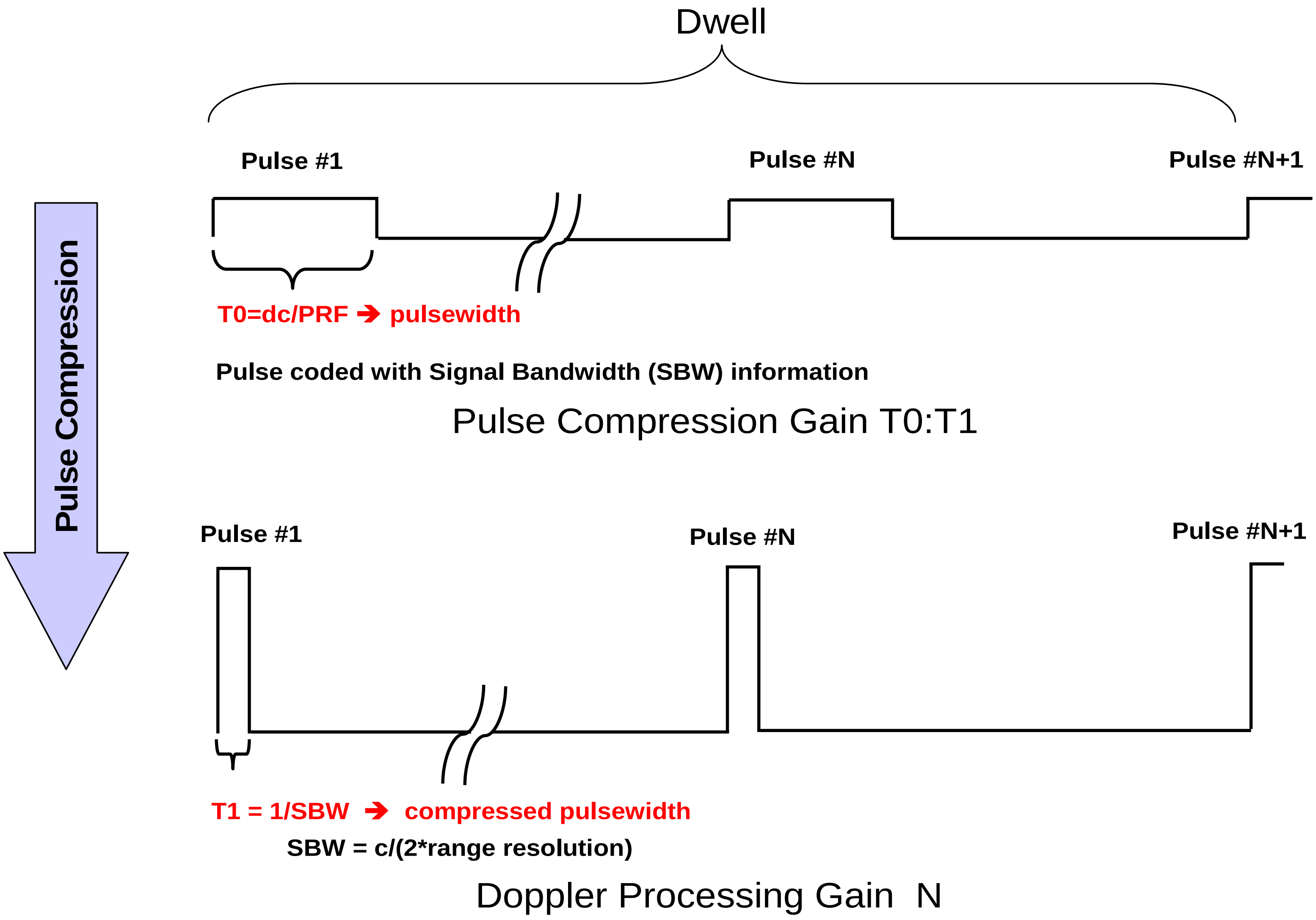


Image from Radar Pulse Compression by Chris Allen, June 17, 2004.

Pulse Compression



Dwell

Pulse #1 **Pulse #N** **Pulse #N+1**

T0=dc/PRF ➔ pulsewidth

Pulse coded with Signal Bandwidth (SBW) information

Pulse Compression Gain T0:T1

Pulse Compression

Pulse #1 **Pulse #N** **Pulse #N+1**

T1 = 1/SBW ➔ compressed pulsewidth

SBW = c/(2*range resolution)

Doppler Processing Gain N

Gain Calculation Through Pulse Compression

Signal Bandwidth (SBW) = c/(2.0*range resolution)

Compressed Pulsewidth = 1/SBW

Pulse Compression (PC) = Pulse Compression Gain
= Pulse Compression Ratio
= Pulsewidth * SBW

Number of Pulses (NP) = Integration Gain
= integer(dwell*PRF)

Processing Gain = 10.0*log(PC*NP)

Radar Equation with Pulse Compression

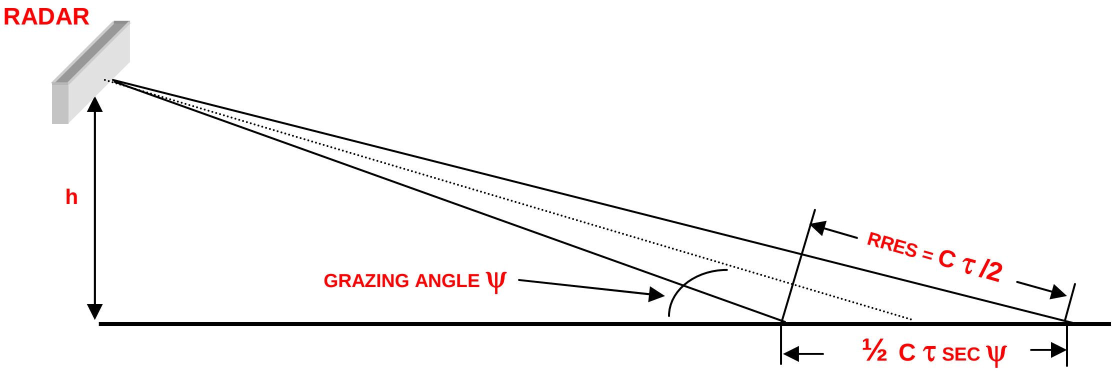
$$SNR = \frac{P_{pk}\, G_t\, N_{pulses}\, \tau_{comp}\, G_{pc}\, \sigma\, G_r\, \lambda^2}{(4\pi)^3\, k T_o N_F L R^4}$$

G_{pc} = Pulse compression Gain

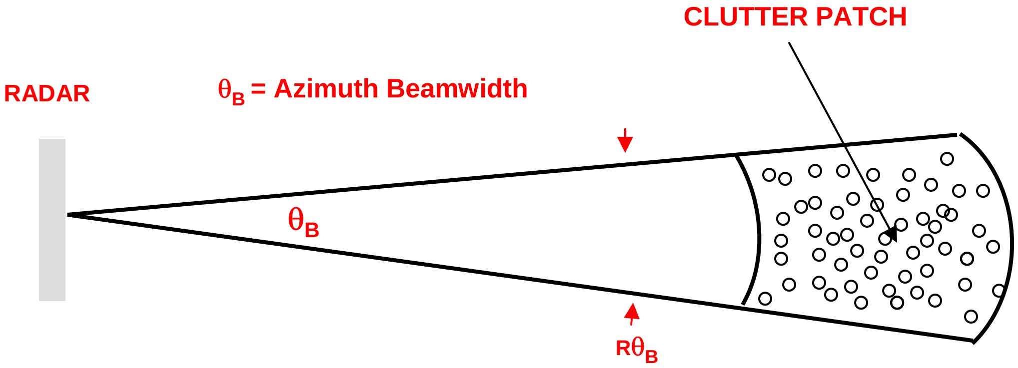
N_{pulses} = Number of pulses or integration gain

τ_{comp} = Compressed pulse width

GEOMETRY OF RADAR SURFACE CLUTTER



ELEVATION VIEW SHOWING THE EXTENT OF THE SURFACE ILLUMINATED BY THE RADAR PULSE



PLAN VIEW SHOWING THE ILLUMINATED CLUTTER PATCH (OR RESOLUTION CELL)
CONSISTING OF INDIVIDUAL, INDEPENDENT SCATTERERS.

Ground Clutter Signal Level

GROUND RETURN WITHIN TARGET RANGE GATE (P_c)

$$P_c = \sum_i P_{c_i}$$

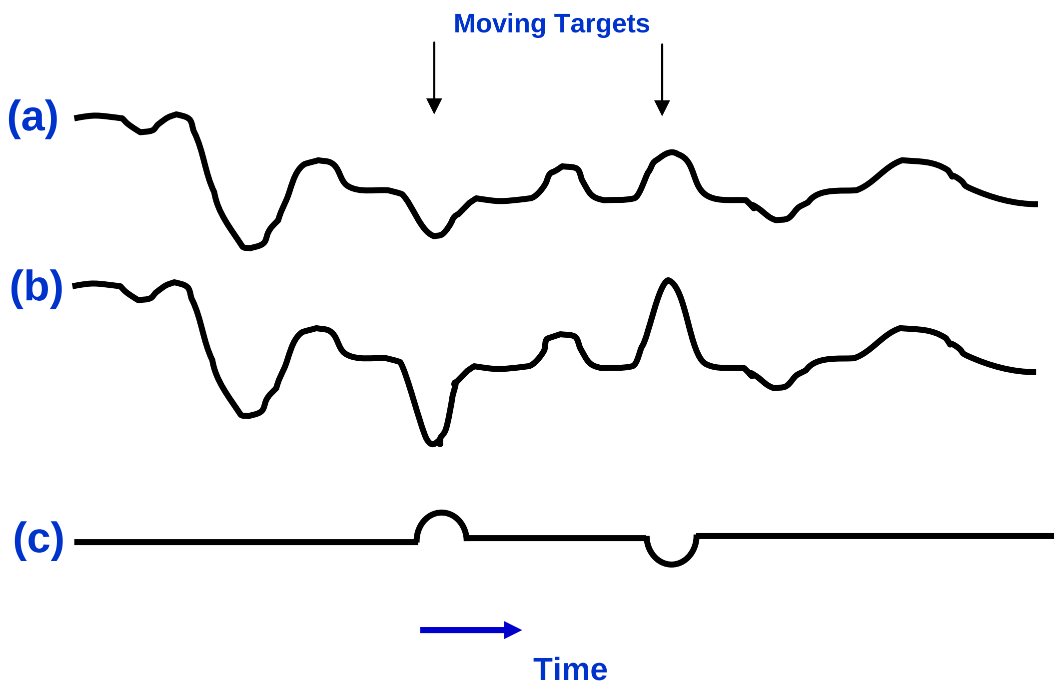
RADAR RECEIVED POWER FROM TERRAIN CELL (P_{c_i})

$$P_{c_i} = \frac{P_T G_i^2 \lambda^2 \sigma_i}{(4\pi)^3 L_i R_i^4}$$

Clutter to Noise Ratio

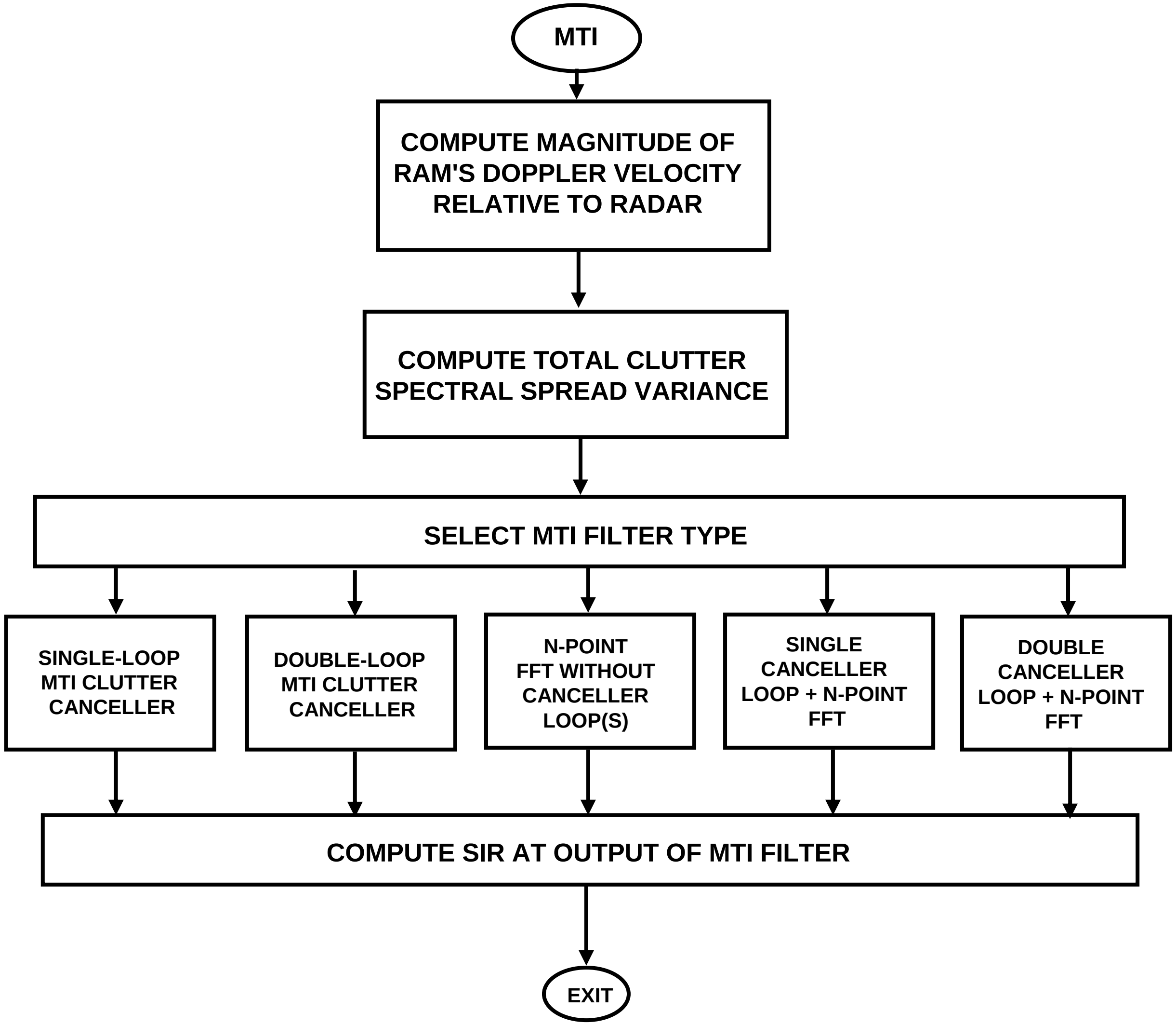
$$CNR = G_{INT}\left(\frac{P_c}{P_n}\right)$$

Detecting a Moving Target by MTI Radar



Two successive sweeps, (a) and (b), of MTI radar. When (b) is subtracted from (a), the result is (c) and echoes from stationary targets are canceled, leaving only moving targets (Image from “Introduction to Radar Systems” by Merrill I. Skolnik).

Moving Target Indicator (MTI)



MTI

COMPUTE MAGNITUDE OF RAM'S DOPPLER VELOCITY RELATIVE TO RADAR

COMPUTE TOTAL CLUTTER SPECTRAL SPREAD VARIANCE

SELECT MTI FILTER TYPE

- SINGLE-LOOP MTI CLUTTER CANCELLER
- DOUBLE-LOOP MTI CLUTTER CANCELLER
- N-POINT FFT WITHOUT CANCELLER LOOP(S)
- SINGLE CANCELLER LOOP + N-POINT FFT
- DOUBLE CANCELLER LOOP + N-POINT FFT

COMPUTE SIR AT OUTPUT OF MTI FILTER

EXIT

Signal to Interference Ratio

$$SNR = G_{INT}\left(\frac{P_s}{P_n}\right)$$

$$CNR = G_{INT}\left(\frac{P_c}{P_n}\right)$$

$$SIR = \frac{SNR}{(1 + CNR)}$$

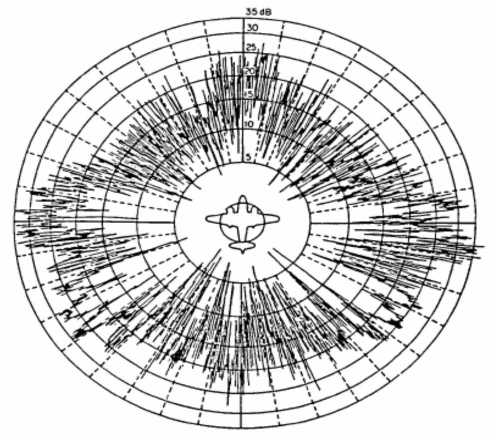
G_{INT} = Integration Gain

P_s = Target Signal Power

P_n = Radar System noise Power

P_c = Clutter Signal Power

RCS Fluctuation and Probability of Detection



Small change in viewing aspect of a radar target such as aircraft or ship can result in a major change in RCS.

The popular method for representing the fluctuation of targets are the four statistical models described by Peter Swerling.

For example, Swerling III model is used for calculating probability of detection.

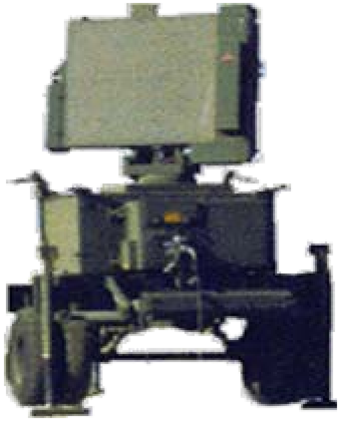
$$P = \left(\frac{1.0 + \left(\frac{T}{1.0 + \frac{SIR}{2.0}} \right) + \frac{2.0}{SIR}}{1.0 + \frac{2.0}{SIR}} \right) \times e^{\left(\frac{-T}{1.0 + \frac{SIR}{2.0}} \right)}$$

Swerling III ➔ APPLICABLE TO

- **SMALL, RIGID, STREAMLINED AIRCRAFT**
- **TARGETS CONSISTING OF ONE DOMINANT SCATTERER WITH MANY SMALLER SCATTERERS**

WHERE: T ➔ DETECTION THRESHOLD AND SIR ➔ SIGNAL TO INTERFERENCE RATIO

Measurement of Error, ΔR, ΔEL and ΔAZ



$$\delta_{R} = \frac{c\tau}{2\sqrt{2\frac{S}{N}}}$$

C = speed of light

τ = (compressed) pulse width

S / N = signal to noise ratio

$$\delta_{\theta} = \frac{\Theta_{3dB}}{\sqrt{2\frac{S}{N}}}$$

Θ_{3dB} = beam width at 3dB half power

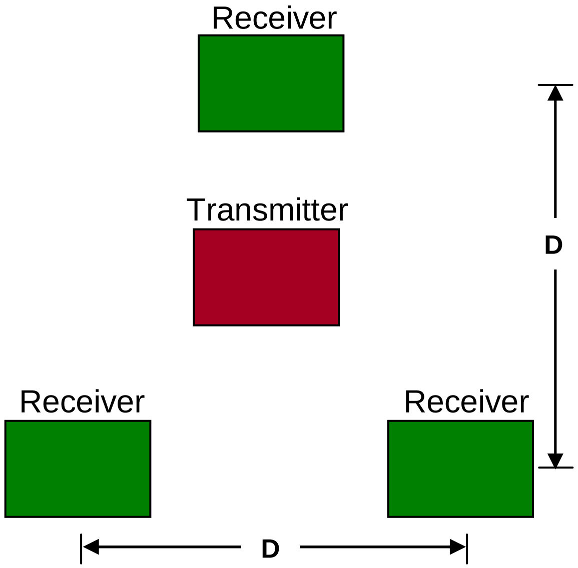
S / N = signal to noise ratio

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Measurement of Error ΔEL and ΔAZ Interferometer Base Radar

$$\delta_\theta = \frac{\lambda}{2\pi D\sqrt{\frac{S}{N}}}$$

λ = Wavelength
D = Distance between antennas
S/N = signal to noise ratio



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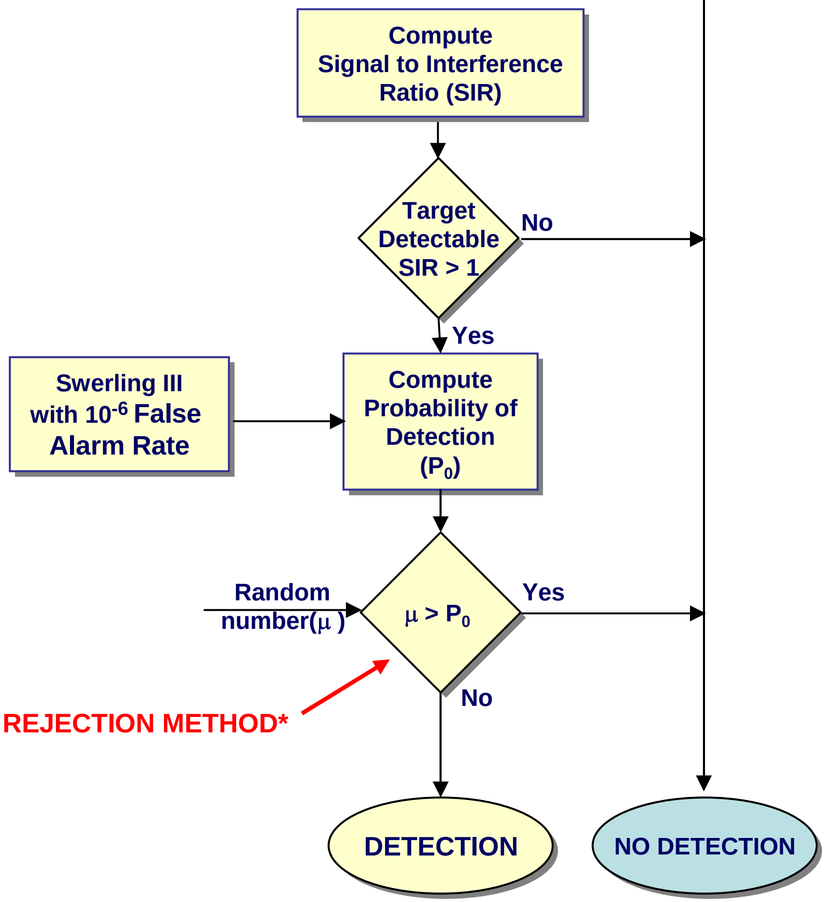
Random Sample in Modeling Radar Detection

SIMULATED DETECTION BASED ON SIR



Compute Signal to Interference Ratio (SIR)

Target Detectable SIR > 1

No

Yes

Swerling III with 10^{-6} False Alarm Rate

Compute Probability of Detection (P_0)

Random number(μ)

$\mu > P_0$

Yes

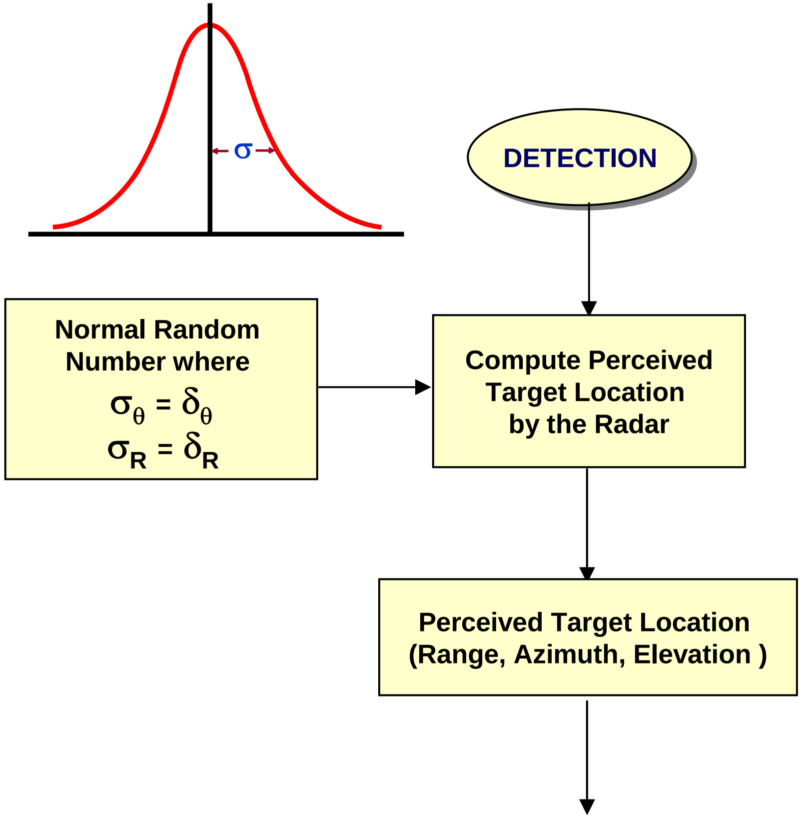
No

REJECTION METHOD*

DETECTION

NO DETECTION

SIMULATED PERCEIVED LOCATION AS SEEN BY RADAR



DETECTION

Normal Random Number where

$\sigma_\theta = \delta_\theta$

$\sigma_R = \delta_R$

Compute Perceived Target Location by the Radar

Perceived Target Location (Range, Azimuth, Elevation)

*The rejection method of generating random numbers drawn from particular distribution by rejecting those that fall outside the geometrical limits of the specific distribution.

Kalman Filter for Impact and Launch Point Prediction

- Kalman filter is an estimation technique that utilizes measurement information to predict the best estimate of the true state at each measurement point.

- It is a recursive procedure which processes one measurement at a time until all measurements have been processed.

- This “best” estimate is a mix of predicted state estimate and a measured state estimate.

Extended Kalman Filter

- Generally Kalman Filter estimation techniques require that there is a mathematically linear relationship between the system states and measurement.

- When Kalman filter is applied to a nonlinear estimation problem, such as the calculation for IPP and LPP, as applied to radar tracking of ballistic projectiles, it is called **Extended Kalman Filter**.

Extended Kalman Filter

Continuous-Discrete, Extended Kalman Filter Computation Sequence that is used for IPP and LPP can be summarized in the next page where:

x_o → **Initial condition, or the initial location estimate and the initial velocity estimate obtained from the radar tracking algorithm**

$[P]_o$ → **Initial value of state error covariance**

$f(x)$ → **System equation which is nonlinear system differential equations for ballistic projectiles motion (speed and acceleration in x, y and z direction)**

$[F]_k$ → $[\partial f/\partial x]$ = ***System differential equations*** → ***System Matrix***

$[\Phi]_k$ → $[I]_k + \Delta t[F]_k$ = ***Transition Matrix***

$h(x)$ → ***Measurement equation which is measurement position of ballistic projectiles.***

$[H]_k$ → $[\partial h/\partial x]$ = **Measurement matrix**

$[Q]_k$ → ***Uncertainty in the predicted state estimate (the same for all measurement intervals)***

$[R]_k$ → ***Measurement error covariance in spherical coordinates which needs to be transformed into equivalent covariance in rectangular coordinates for use in the Kalman filter***

$[P]_k$ → ***Predict error covariance***

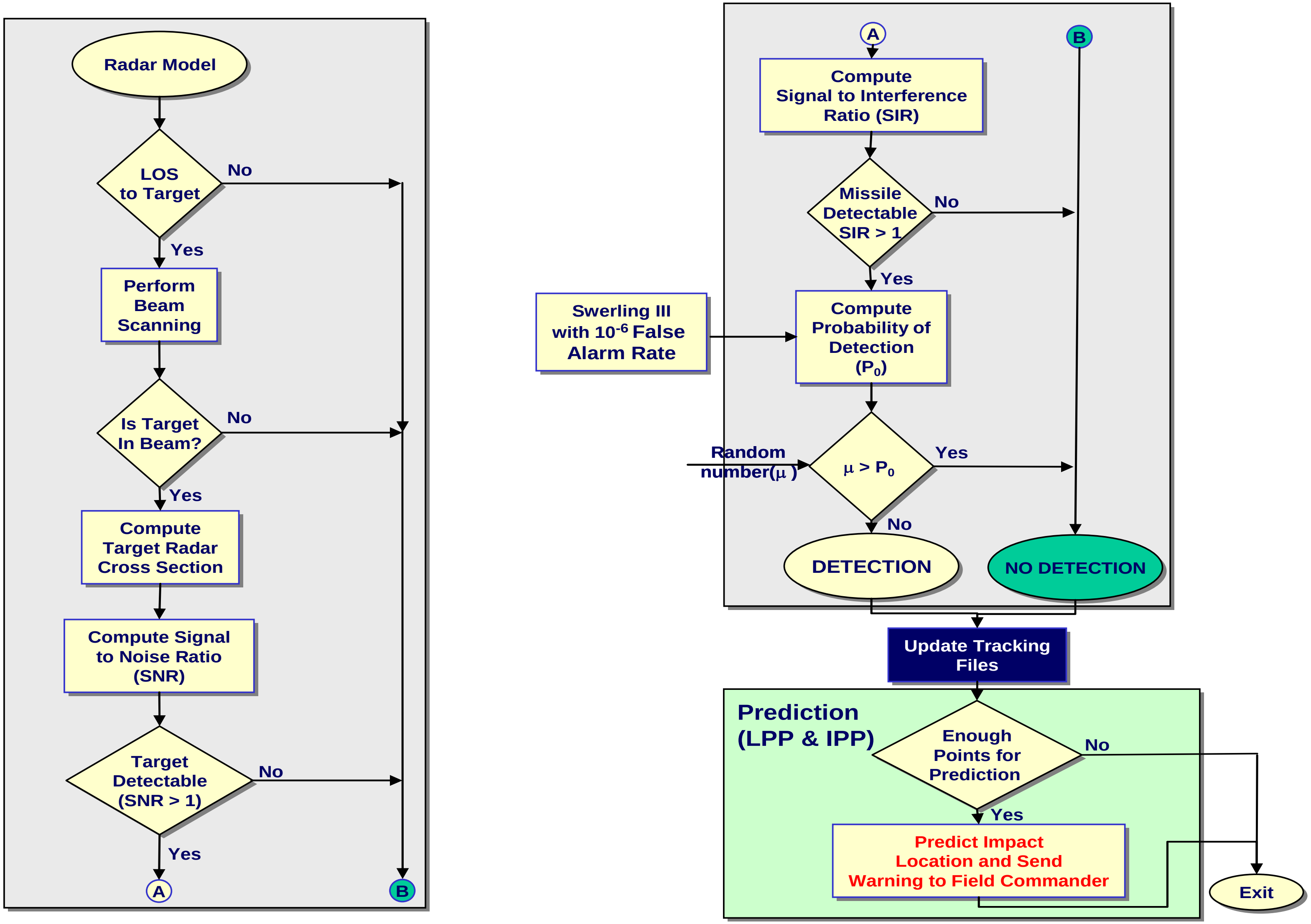
$[K]_k$ → ***Kalman Gains***

Extended Kalman Filter Computation Sequence

STEP	DESCRIPTION	EQUATIONS	FLOW
0	Initial Conditions	$\underline{\hat{x}}_o ; [P]_o$	↓
1	Inputs at each iteration	$[Q]_k ; [R]_k$	↓←←9
2	Predict state (example uses Euler integration)	$\underline{\tilde{x}}_k = \underline{\tilde{x}}_{k-1} + \underline{f}(\underline{\tilde{x}}_{k-1})\Delta t$	↓
3	Compute system matrix	$[F]_k = \left[\frac{\partial \underline{f}(\underline{x})}{\partial \underline{x}}\right]_{\underline{x}=\underline{\hat{x}}_k}$	↓
4	Compute measurement matrix	$[H]_k = \left[\frac{\partial \underline{h}(\underline{x})}{\partial \underline{x}}\right]_{\underline{x}=\underline{\tilde{x}}_k}$	↓
5	Compute error covariance transition matrix	$[\Phi]_k = [I] + \Delta t [F]_k$	↓
6	Predict error covariance	$[\tilde{P}]_k = [\Phi]_k [P]_{k-1} [\Phi]_k^T + [Q]_k$	↓
7	Compute Kalman Gains	$[K]_k = [\tilde{P}]_k [H]_k^T \left[[H]_k [\tilde{P}]_k [H]_k^T + [R]_k \right]^{-1}$	↓
8	Correct error covariance using gains	$[P]_k = \left[[I] - [K]_k [H]_k \right] [\tilde{P}]_k$	↓
9	Correct state estimate using current measurement and Kalman gains	$\underline{\hat{x}}_k = \underline{\tilde{x}}_k + [K]_k (\underline{z}_k - \underline{h}(\underline{\tilde{x}}_k))$	↓→→1

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

Radar Flow Chart in IDEEAS



Radar Model

LOS to Target

No

Yes

Perform Beam Scanning

Is Target In Beam?

No

Yes

Compute Target Radar Cross Section

Compute Signal to Noise Ratio (SNR)

Target Detectable (SNR > 1)

No

Yes

A

B

A

B

Compute Signal to Interference Ratio (SIR)

Missile Detectable SIR > 1

No

Yes

Swerling III with 10^{-6} False Alarm Rate

Compute Probability of Detection (P_0)

Random number(μ)

$\mu > P_0$

Yes

No

DETECTION

NO DETECTION

Update Tracking Files

Prediction (LPP & IPP)

Enough Points for Prediction

No

Yes

Predict Impact Location and Send Warning to Field Commander

Exit

Radar Model

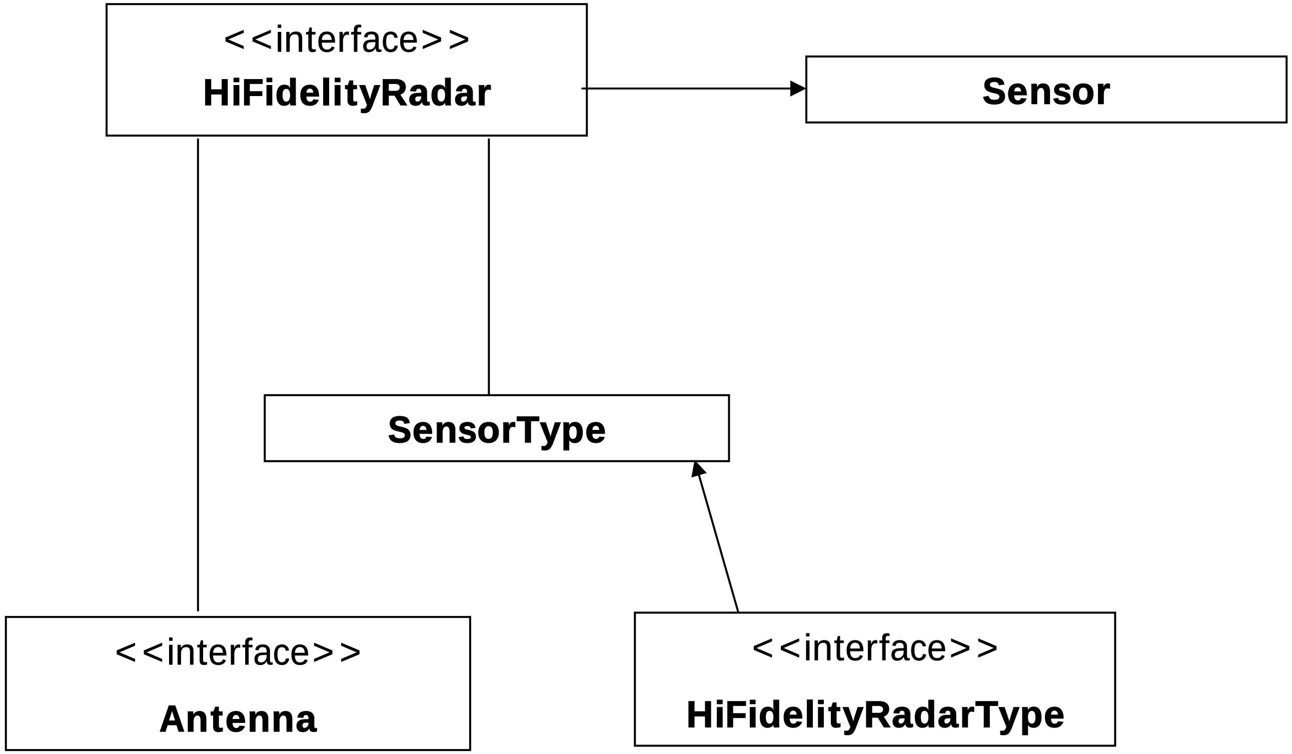
Description:

Conceptual software design document for our radar model.

CR Created: <this single CR that lead to the creation of the model >

CRs Related: <this is a list, to be constantly amended, for all CRs after the initial creation that touched this particular model in any way>

Class Diagram



<<interface>>
HiFidelityRadar

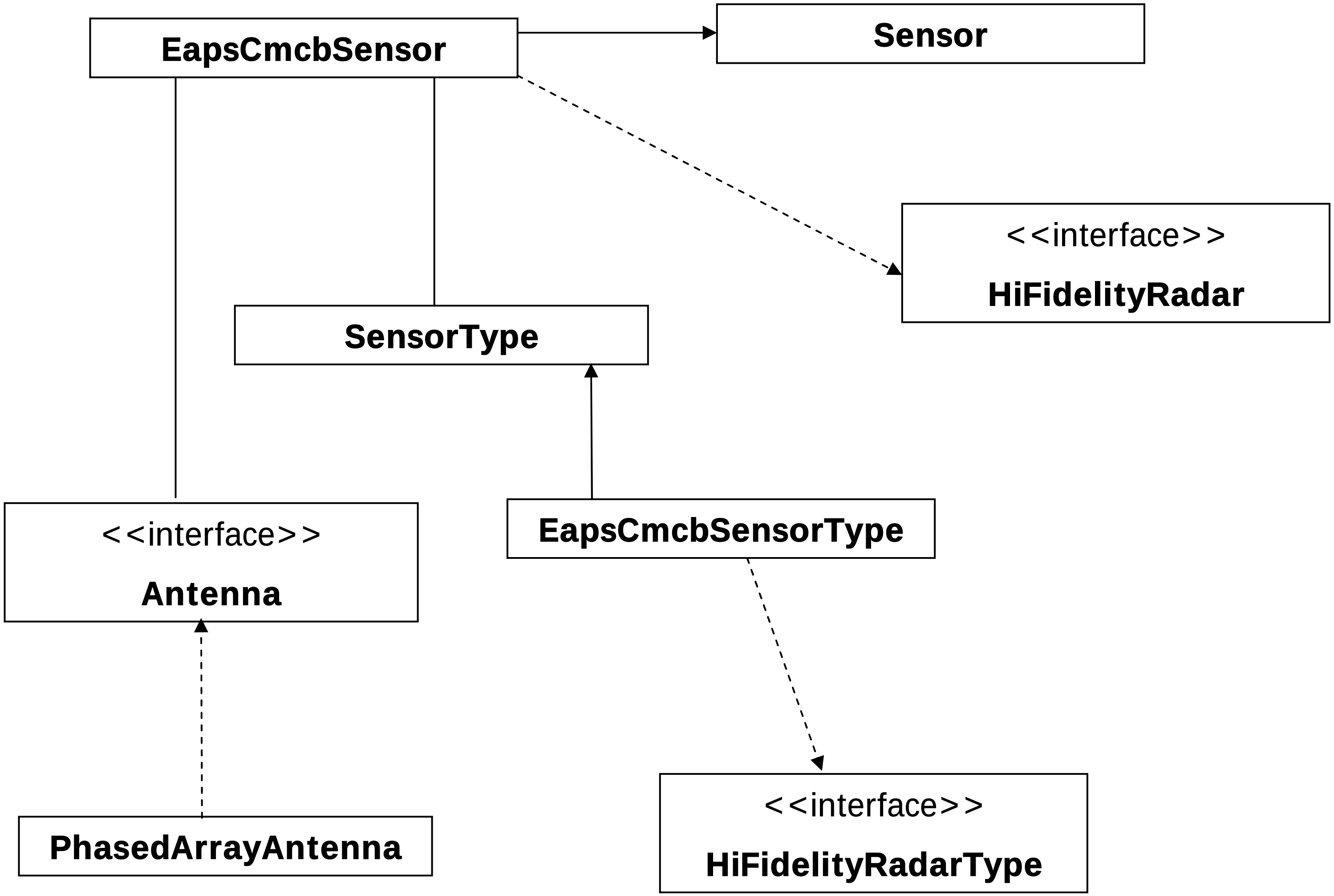
Sensor

SensorType

<<interface>>
Antenna

<<interface>>
HiFidelityRadarType

Class Diagram(more detailed)



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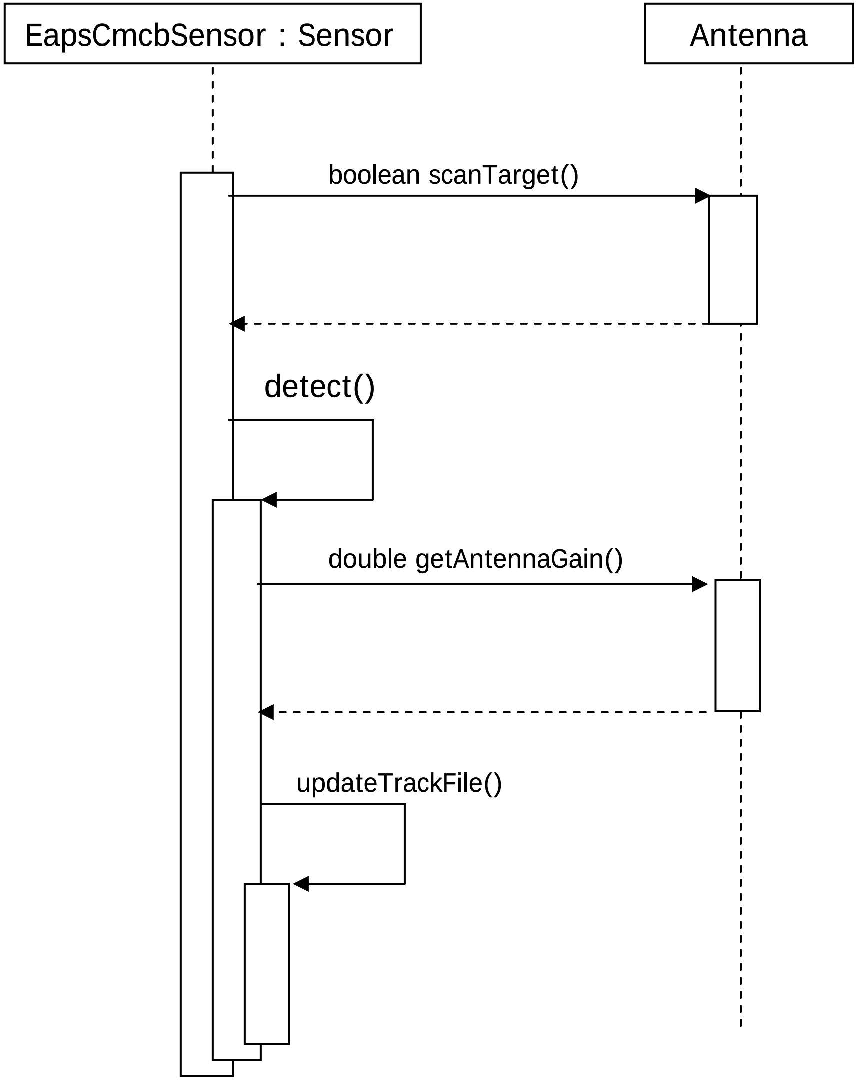
Sequence Diagram



TECHNOLOGY DRIVEN. **WARFIGHTER FOCUSED.**

Conclusion

- DMSO - RPG
  - Simone Youngblood's Brief
    - DoDAF
- Our team uses three "types" of Conceptual Models to communicate in a iterative, recursive manner from the "developer to user".
- In preparing for this brief, I found few people with a common definition of conceptual modeling; however, everyone possessed a common understanding of tailoring products and processes in order to achieve effective communication.