# Analytical and Phase-Aware Probability of Intercept Modeling

These lab notes summarize the implementation and conceptual understanding of a Probability of Intercept (POI) simulation model for a wideband scanning receiver and a scanning radar emitter. The implementation combines analytical estimation with a time-domain counting simulation to understand how scanning synchronization, pulse structure, and timing alignment influence intercept probability.

## 1. System Concept Overview

The model represents a passive receiver operating between 1-18 GHz with an instantaneous bandwidth (IBW) of 1 GHz. The receiver sequentially scans the full band, dwelling in each 1 GHz segment for a configurable time before switching to the next. The transmitter emits pulses periodically while its beam scans across azimuth with a defined scan rate and beamwidth.

The central objective is to determine how many radar pulses are intercepted by the receiver over a simulation period, given the timing parameters of both systems.

## 2. Beam-On Modeling The radar is not always directed toward the receiver, thus, a beam-on probability is introduced to model the fraction of time the radar’s beam illuminates the receiver’s direction. This is given by:

P\_beam = T\_dwell\_tx / T\_scan\_tx

This ratio defines the time fraction where the radar beam is effectively on the receiver’s line of sight. If the radar is omnidirectional, the simulation can bypass this effect by setting omni = 1. The total number of pulses directed at the receiver is then:

N\_emit = N\_total \* P\_beam

## 3. Pulse–Dwell Overlap Modeling Intercept occurs only when a transmitted pulse overlaps with the receiver’s listening window in both time and frequency. The overlap probability models the chance that a radar pulse coincides with the receiver’s dwell period in the correct frequency bin:

P\_overlap = min((T\_dwell\_rx + T\_PW) / T\_cycle\_rx , 1)

This incorporates the pulse width (T\_PW) as an extension of the effective overlap window and accounts for the receiver’s dwell and switching timing.

## 4. Receiver Scan Cycle and Switching Compensation The receiver covers the entire 1-18 GHz band in discrete steps of 1 GHz IBW. Between each dwell, a finite switching delay is introduced to model the dead time during retuning. The total scan cycle is given by:

T\_cycle\_rx = N\_bins \* (T\_dwell\_rx + T\_switch\_rx)

This ensures the receiver’s frequency coverage and effective listening duty cycle accurately reflect the presence of switching intervals, which reduce total dwell availability per band.

## 5. Phase-Aware Pulse Counting Simulation Thee analytical section estimates expected probabilities, the time-domain simulation explicitly reconstructs the timing of both systems. It generates pulse start times for the radar and receiver listening windows for the target band, then checks for pulse window temporal overlap. Random phase offsets are introduced between the radar’s pulse repetition sequence and the receiver’s scanning cycle to represent asynchronous operation. Averaging over many random phase samples yields an expected intercept count independent of initial timing alignment.

## 6. Outputs and Interpretation The script outputs both analytical and simulation-based estimates of intercepted pulses: 1. Receiver configuration: number of bins and total scan cycle time. 2. Analytical POI: expected intercept probability and count. 3. Deterministic or phase-averaged simulation results showing realistic intercept counts. Together, these outputs illustrate the combined effect of scanning synchronization, beam dwell, frequency alignment, and receiver switching on intercept performance.