Spectrum Sharing and Potential Interference to Radars

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Proposals for Spectrum Sharing with Radars

- Radar systems have historically been allocated in bands where they do not share spectrum with communication systems. But in recent years proposals have been made for communication systems to operate in radar bands. These include:
  - Radio local area networks (RLANS);
  - Various proposed new mobile radio systems (e.g., IMT-2000/Advanced);

→ **These proposals have raised the question: At what thresholds do various types of radio interference degrade the performance of radar receivers?**

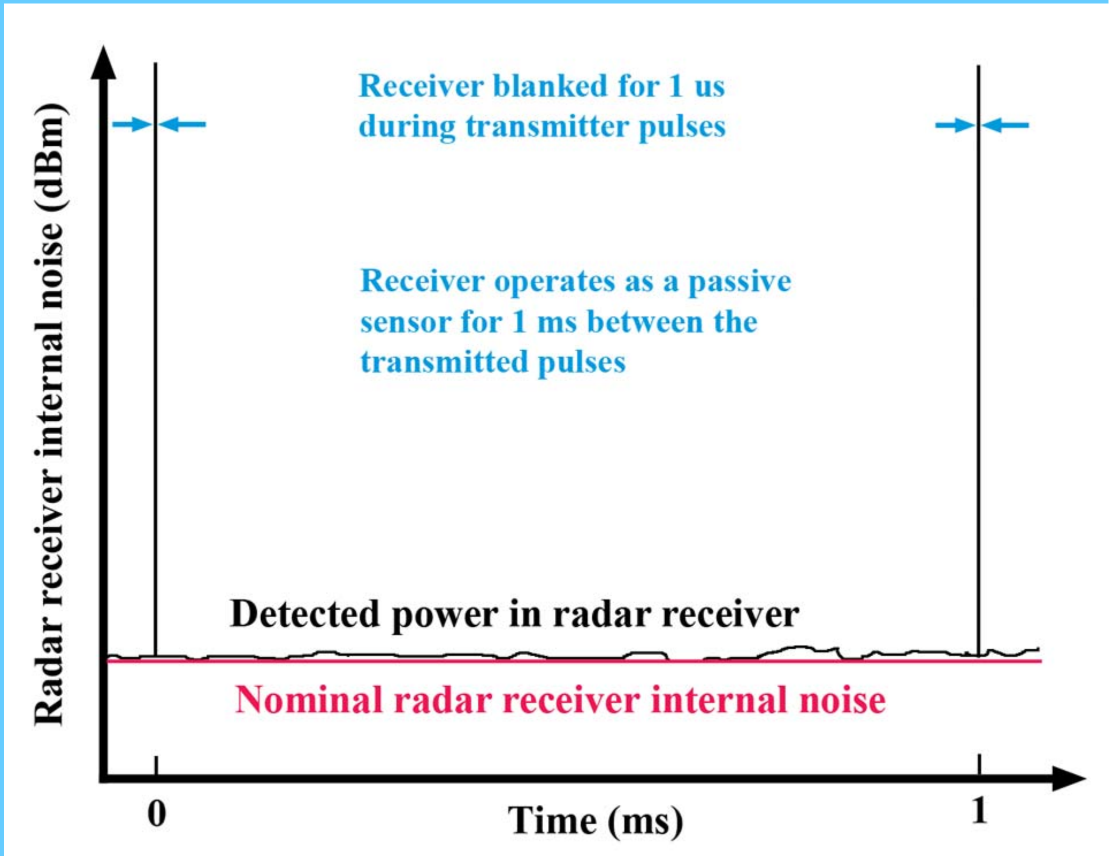
Basics of Microwave Radar Receivers

Microwave radars typically transmit pulses at an EIRP of more than 1 GW.

Typically (if there is any such thing for radar designs), radar pulses are 1 μs long and the listen time between pulses is 1 ms. So radars commonly have a duty cycle of 0.1% and they operate as passive sensors 99.9% of the time.

Between transmitted pulses, radars operate as if they were passive sensors: *their operational performance is limited by internal receiver noise*.

Any external factors that add to a radar receiver's internal noise level will tend to degrade the operational effectiveness of the radar.



A radar may transmit pulses at > 1 GW EIRP but will commonly operate as if it were a noise-limited passive sensor 99.9% of the time.

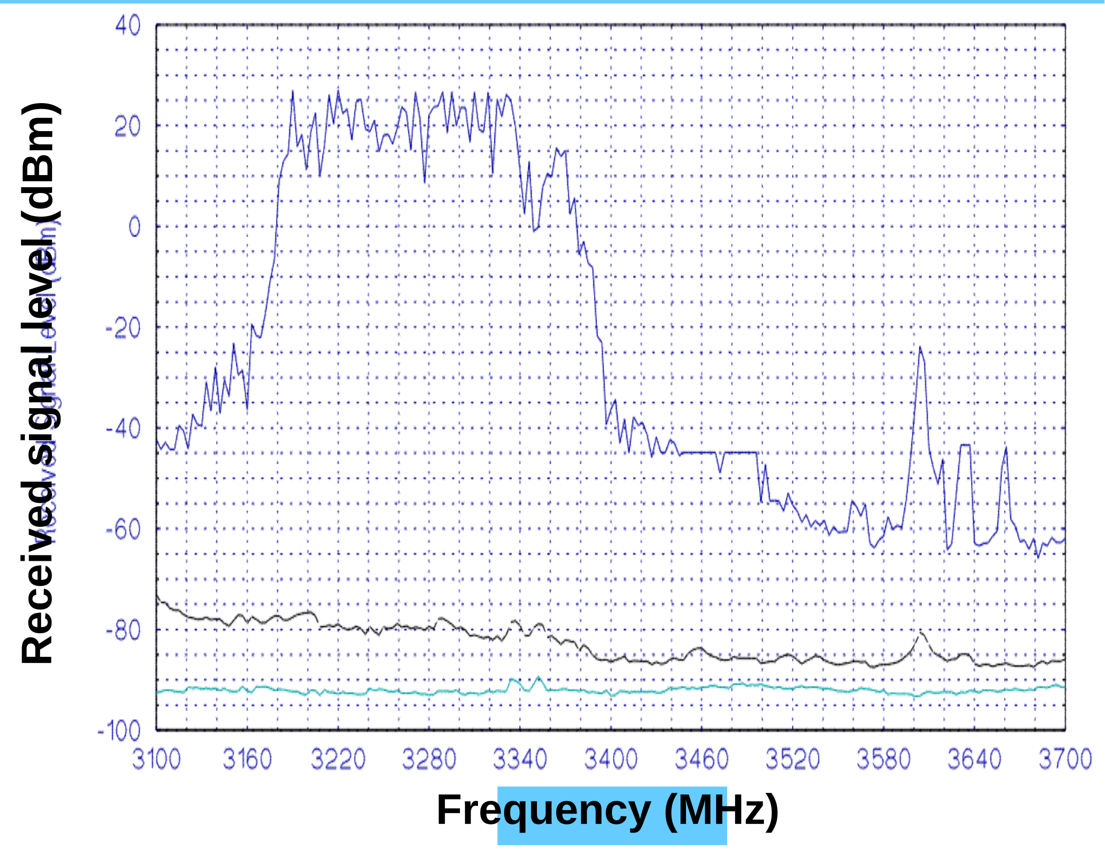
Do Radar Signals Really Fill Their Spectrum Allocations?

The low duty cycle of radar transmitters leads to a myth that they are “not using” most of their spectrum most of the time.

This myth is partly rooted in typically unsuccessful attempts to observe radar signals with conventional (and naïve) swept-spectrum measurements.

The reality is that radar signals do occupy the majority of their allocated spectrum bands most of the time…albeit often (not always) at about 0.1% duty cycle. NTIA spectrum survey reports support this conclusion.

Properly configured spectrum measurements do show allocations **are** filled by radar signals. But special stepped-frequency algorithms are needed to effectively reveal the signals.



Snapshot of some radar spectrum occupancy at San Diego, measured with NTIA stepped-frequency algorithm. See NTIA Report 97-334 for details.

NTIA Radar Interference Research Program

Spectrum sharing proposals may directly affect US Government radar systems. Therefore it is critical that technical parameters for sharing between radar receivers and non-radar systems be accurately quantified.

PROBLEM: A lack of quantitative data regarding thresholds at which various types of interference degrade performance of radar receiver systems.

Starting in 2001-2002, NTIA Office of Spectrum Management and NTIA Institute for Telecommunication Sciences undertook a joint effort to determine thresholds for interference to radar receivers.

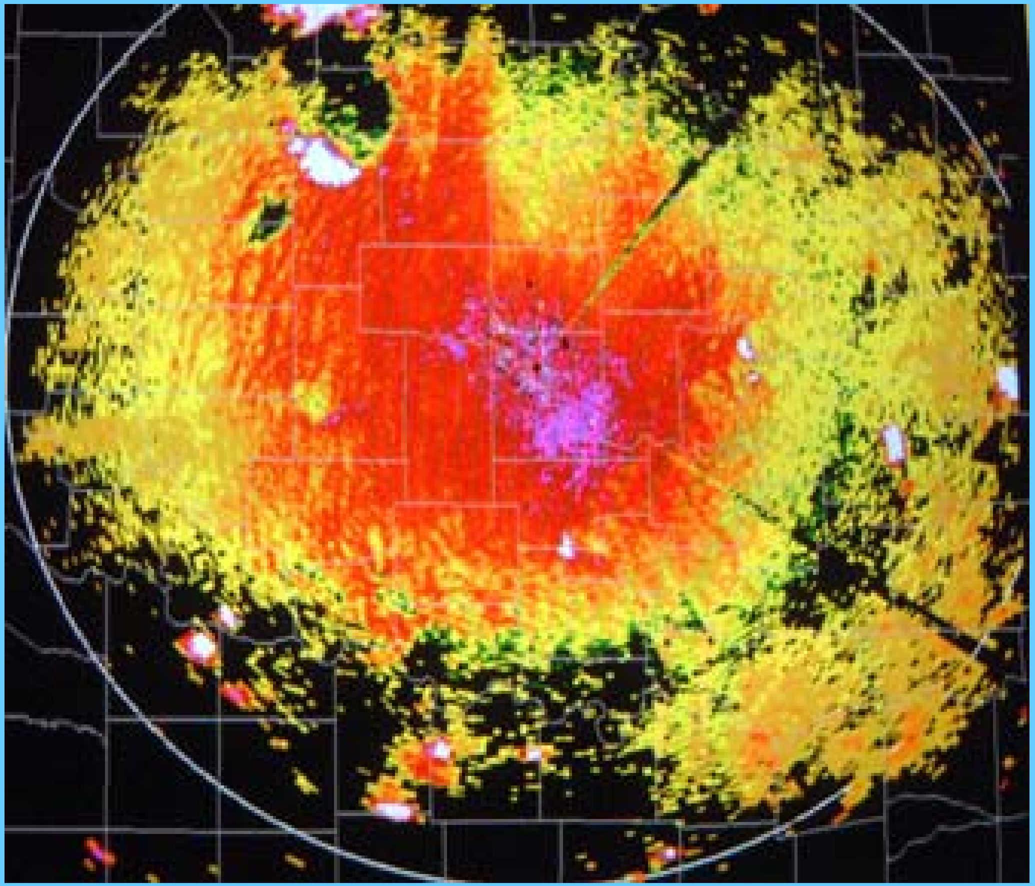
An example of a fixed, ground-based 3-GHz airport surveillance radar antenna.

Radar Interference Criterion: *I/N*

Communication receivers typically experience interference effects as a function of the ratio of the interference level to the level of the desired signal (*S/I* or *C/I*).

Radar receivers, in contrast, normally operate against their internally generated noise. They are **noise limited** and thus the critical interference level parameter is the ratio ***I/N*** within the radar receiver IF stage.

But what criterion (or criteria) should be used to determine **radar receiver performance** at a given *I/N* level?



Fixed ground-based weather surveillance radar display in the presence of strong interference from a digital data signal (*I/N* = +3 dB).

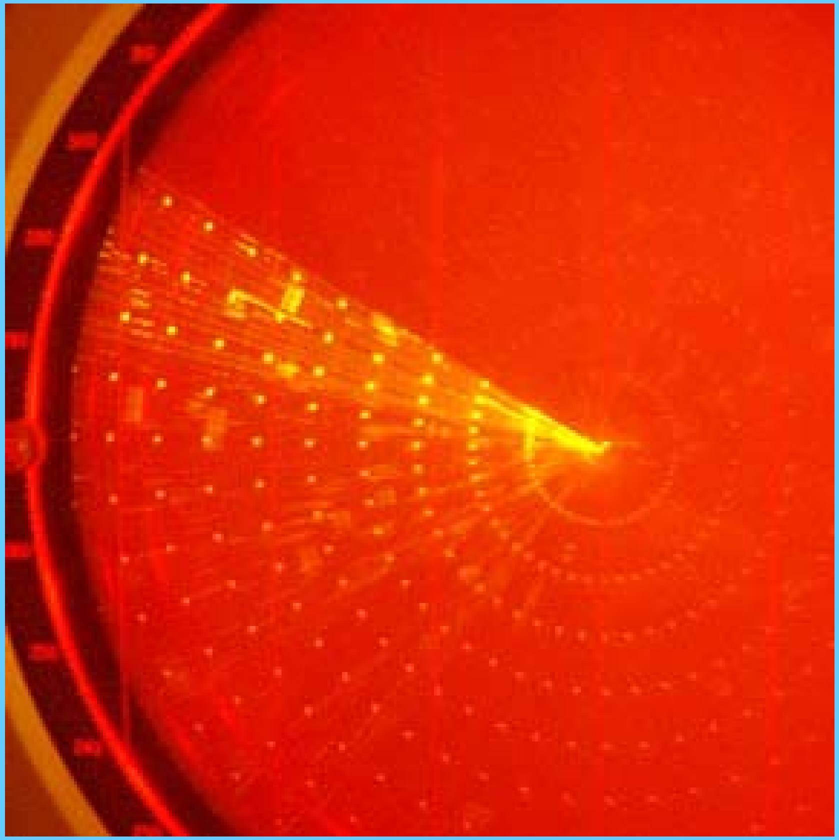
Radar Performance Criterion: Probability of Detection of Controlled Targets

OSM and ITS decided to assess radar performance on the basis of probability of detection (P_d) of desired targets as a function of interference level (I/N) in the radar IF stage.

Target levels would have to be controlled during measurements. Therefore synthetic targets would be generated and injected into the radar receivers along with interference.

Baseline (non-interference) P_d required that the targets be strong enough to be easily observed a high percentage of the time.

Decision was made to set baseline P_d of desired targets at **90%.** Then interference effects would be measured relative to that performance level.



Air surveillance radar ppi display with internally generated targets

Radar Interference Measurement Procedure

Although procedures varied slightly from radar to radar, the core procedure that NTIA (OSM and ITS) engineers used was:

1) Disconnect radar receiver and inject desired (controlled) targets at the RF stage so that they were handled the same way as regular returns.

2) Adjust synthetic target strength until P_d was as close as possible to 90%.

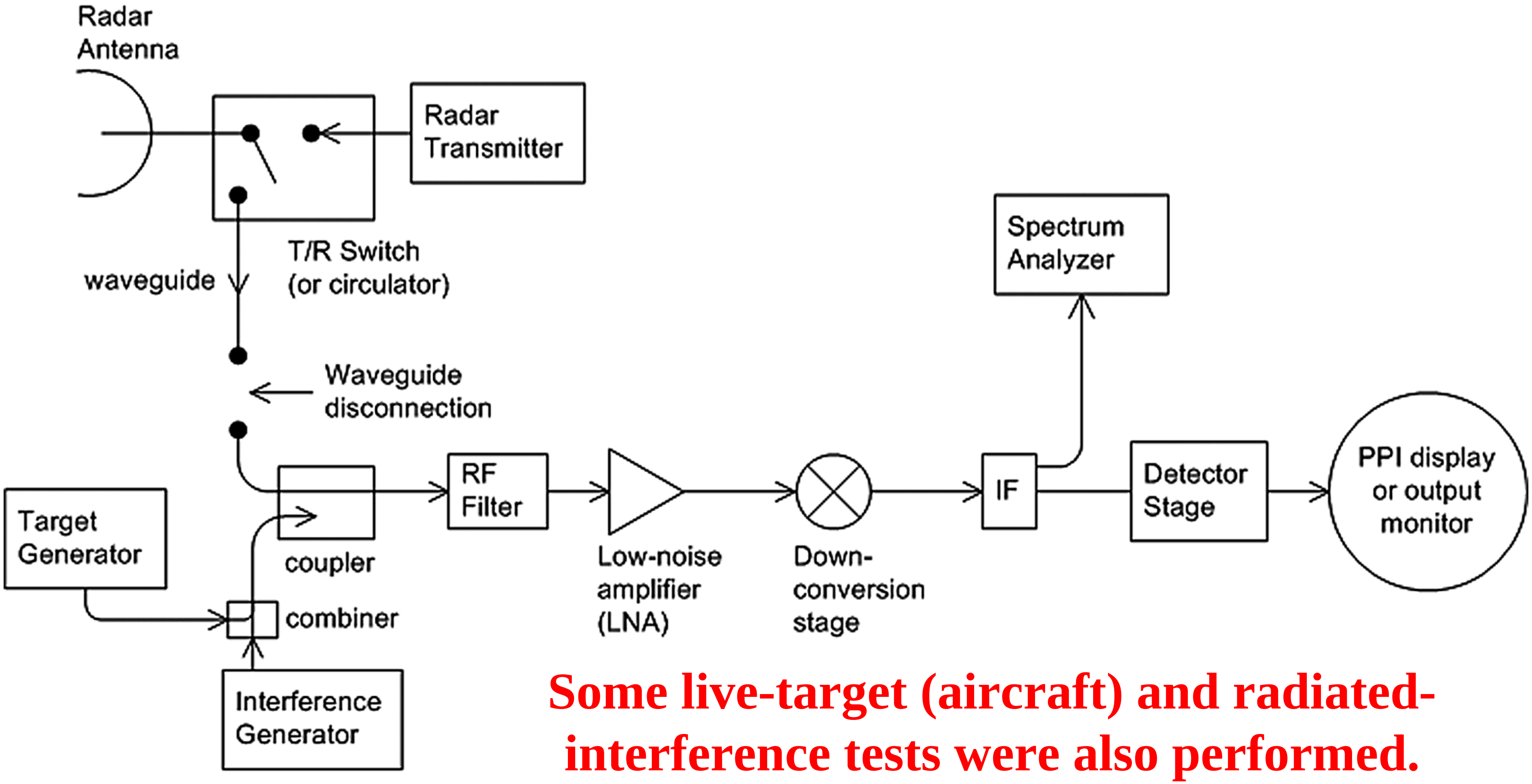
3) Inject interference signals at the radar RF stage. For each interference modulation, NTIA started at I/N = -12 dB, and successively raised the level to: -10 dB, -9 dB, -6 dB, -3 dB, 0 dB, +3 dB, +6 dB, Continuing to as much as +60 dB if necessary.

OSM engineer preparing a maritime radar for signal injection at Curtis Bay Coast Guard Station near Baltimore.

4) NTIA counted 200 desired injected targets to obtain P_d for each level of interference.

Interference types tested included: CW; CDMA; TDMA; BPSK; QPSK; OFDM; and UWB; and a variety of simulated radar pulses. Not all modulations were used on every radar.

Typical Radar Interference Testing Block Diagram



Some live-target (aircraft) and radiated-interference tests were also performed.

Typical Measurement Setup

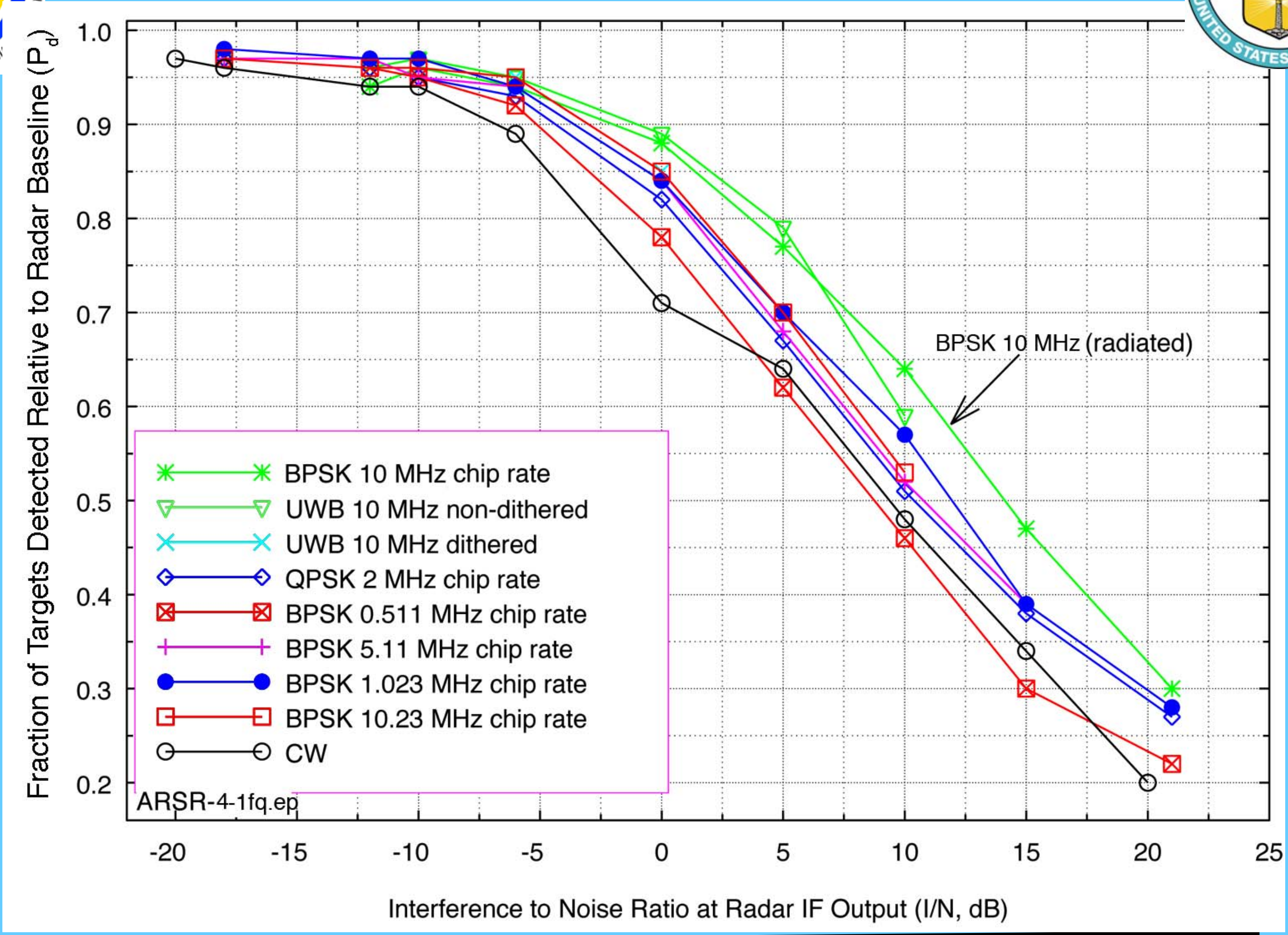
Long-range air route surveillance radar station with NTIA measurement hardware

Interference (*I/N*) Calibration

Radars Measured in 2002-2006

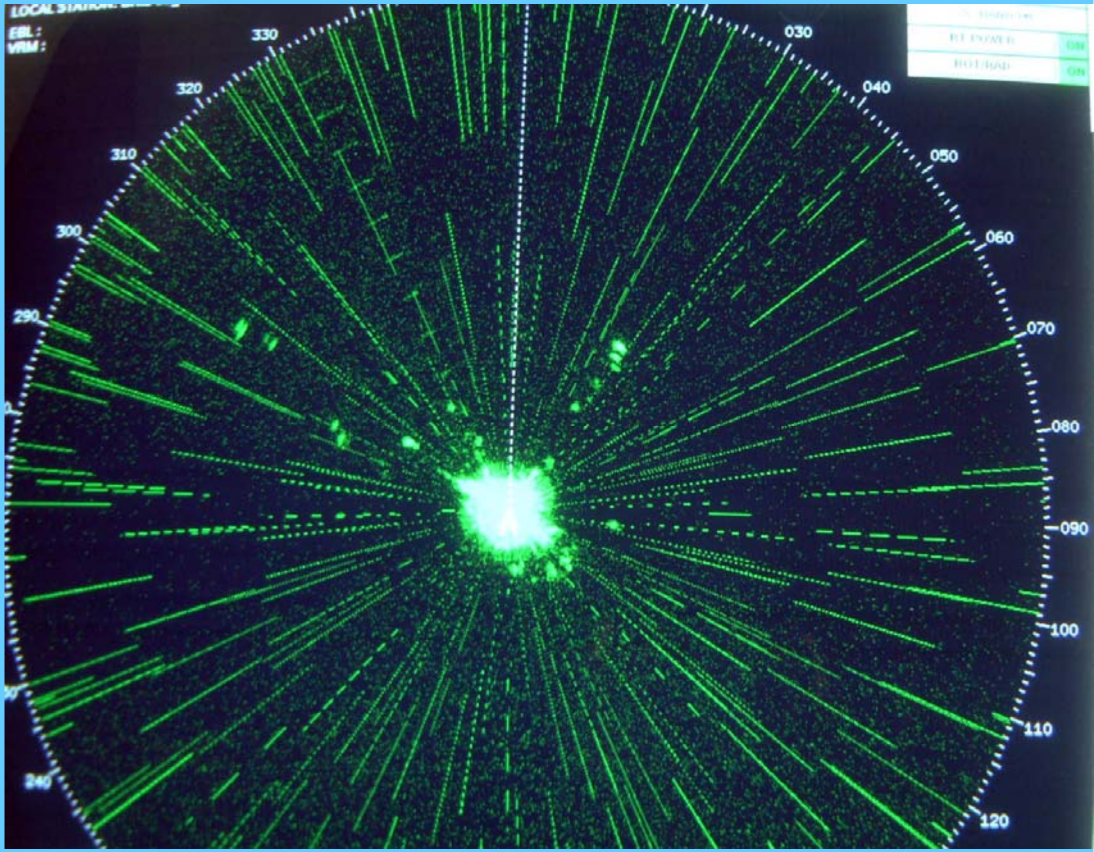
- Several maritime radars at 3 GHz and 9 GHz (in both the US and the UK);
- Two models of long range surveillance radar at 1.3 GHz;
- Airport surveillance radar at 3 GHz;
- Fixed ground-based weather surveillance radar at 3 GHz;
- Airborne weather surveillance radar at 9 GHz;
- Airport surface detection (ASDE) radar at 9 GHz;
- Precision approach radar (PAR) at 9 GHz.

Example of P_d Data Curves



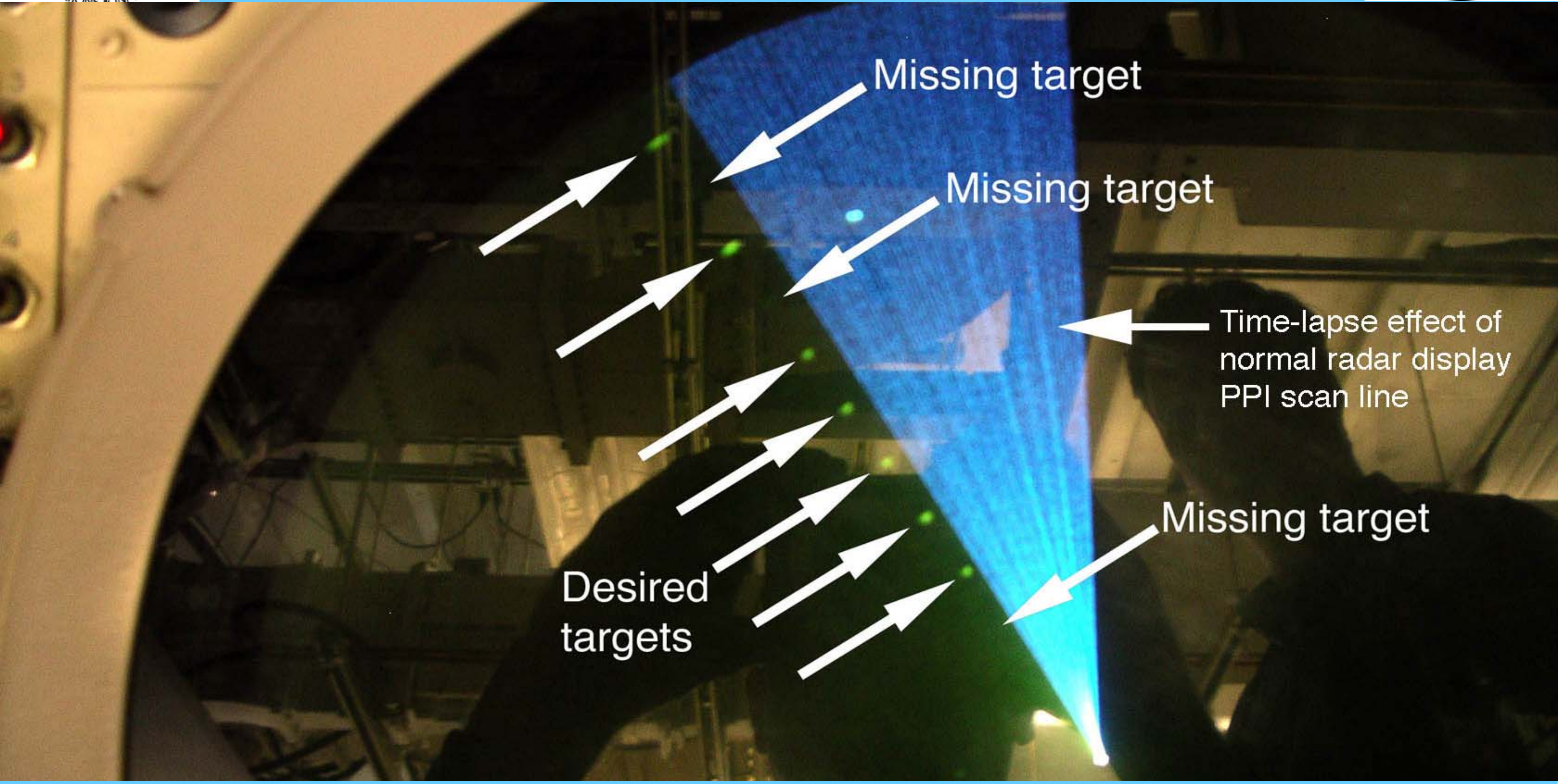
Can Target Losses be Translated into Range Reduction?

- Target losses are a function of interference duty cycle and *I/N* level.
- Target losses can occur at any time in the echo-listen period (and thus at **any** distance from a radar).
- **IF** all target cross sections were equal, interference levels **could** be equated with a decrease in radar range.
- **But** target cross sections vary enormously. So the concept of range loss is not very informative. Smaller targets may disappear closer-in while larger targets may be lost farther away.
- Can anyone decide which targets various radars can afford to lose, at which ranges?



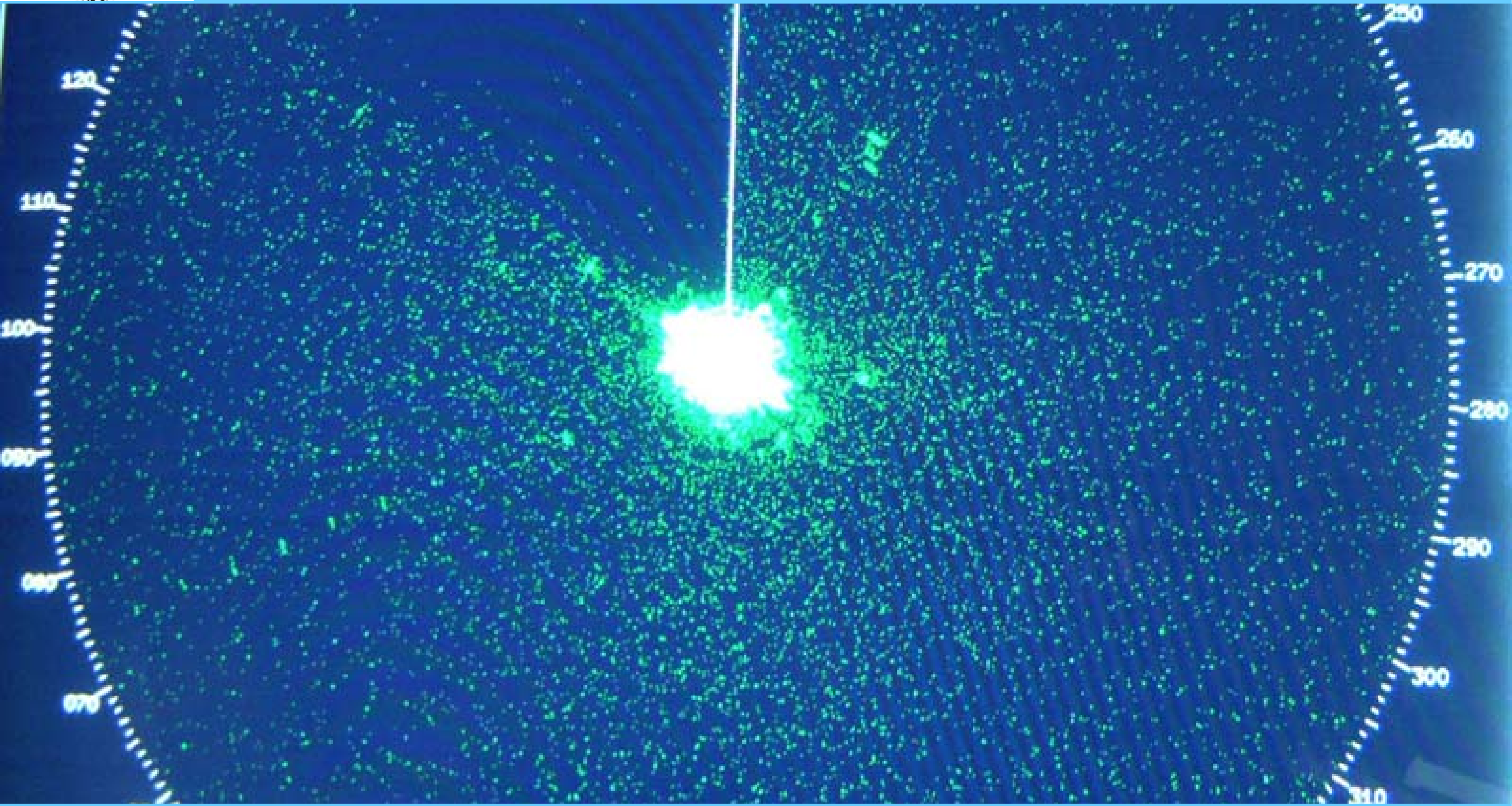
Interference effect of 1% duty cycle pulses at high *I/N*.

Example Target Loss at Low *I/N* Levels--Communication Signals



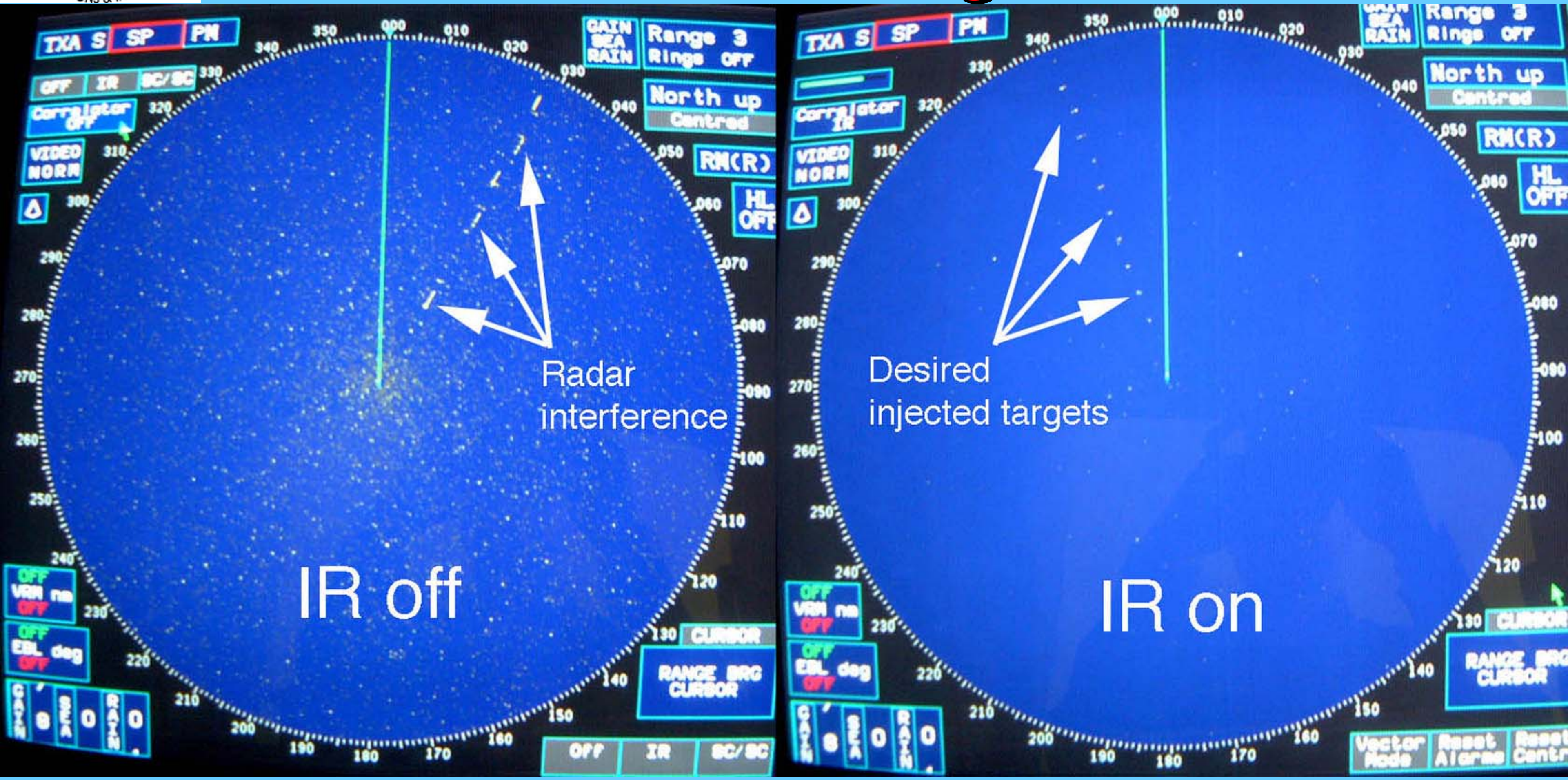
Target losses at low *I/N* levels are *insidious* because there are *no ancillary effects* to indicate that interference is occurring or that targets are being lost.

Example Target Loss at High *I/N* Levels--Communication Signals



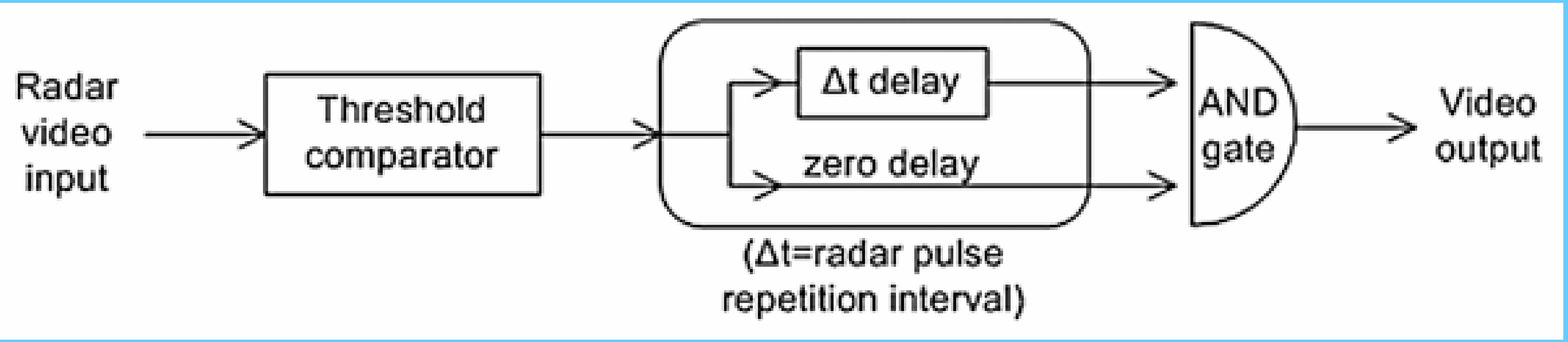
Example of QPSK interference at *I/N* = +2 dB.

Behavior at High *I/N* Levels from Other Radar Signals



Interference from other radars is effectively mitigated by interference rejection (IR) circuits at *I/N* levels as high as +30 dB to +60 dB. Next slide explains why…

Radar Interference Rejection (IR) Circuitry Performance Limits



Interference rejection (IR) circuits accept echo pulses that are time-coherent with the radar's own transmitted pulse repetition interval (PRI) and reject pulses that non-coherent with that PRI (or PRI's).

Empirical NTIA test results indicate that IR circuits are only effective against interference that has *less than* a duty cycle of 1-3%.

Summary of Results: Interference to Radars

These results are applicable to interference signals having duty cycles of more than 1-3%.

Lower duty cycle signals, as are characteristic of emissions from radars, have been tolerated in NTIA tests at *I/N* levels of +30 dB to +60 dB.

Radar Tested	*I/N* Threshold for Decreased P_d
Long Range Air Search Radiolocation Radar 1 (installation 1)	-9 dB
Long Range Air Search Radiolocation Radar 1 (installation 2)	-9 dB
Long Range Air Search Radiolocation Radar 2	-6 dB
Short Range Air Search Radionavigation Radar	-9 dB
Fixed Ground-Based Meteorological Radar	-9 dB*
Maritime Radionavigation Radar A	-7 dB
Maritime Radionavigation Radar B	-10 dB
Maritime Radionavigation Radar C	-6 dB to -9 dB
Maritime Radionavigation Radar D	-9 dB
Maritime Radionavigation Radar E	-6 dB
Maritime Radionavigation Radar F	-6 dB
Airborne Meteorological Radar	-6 to -2 dB

* -14 dB is the predicted threshold for an upgraded version of the fixed meteorological radar.

Summary of Results, continued

* **Interference at high duty cycles (above 1-3%), such as from most communication signals, typically causes target losses to begin at *I/N* levels between -10 dB to -6 dB, depending upon radar type.**

*** Interference at low duty cycles (less than 1-3%), such as from other radars, can often be sustained at *I/N* levels as high as +30 dB to +60 dB without degrading receiver performance.**

*** Target losses due to low levels of interference are *insidious* because no visible effects are associated with the interference. The targets simply fade away.**

*** Target losses can occur at *any* range. Losses do not just occur at the edge of radar coverage, but rather anywhere that the targets are close to radar receiver noise.**

Implications for Spectrum Sharing with Radars

* **To the extent that communication-type signals have duty cycles above 1-3%, *I/N* levels in radar receivers must be kept below -10 dB to -6 dB in any proposed spectrum sharing schemes.**

*** Although workability of dynamic frequency sharing (DFS) has been demonstrated in NTIA testing, *DFS is limited to the terms of ITU-R M.1652*. It is limited to WLANs against 5 GHz radars. DFS is meant to limit interference to radars to *I/N* levels below -6 dB.**

*** Extension of some sort of DFS to other bands and other radio technologies (e.g., IMT-2000 at 3 GHz), if ever attempted, will require the development of new sharing protocols to accommodate the unique characteristics of new mobile radio systems, etc., for the limits NTIA has measured. Unique characteristics of radars in non-5 GHz bands would need to be understood and accommodated as well.**

Further Reading

Details may be found in NTIA Report TR-06-444, which fully describes this work:

"Effects of RF Interference on Radar Receivers"

The report may be downloaded from:
www.its.bldrdoc.gov/pub/ntia-rpt/06-444/index.php

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