Method for Evaluating Solid-State Marine Radar Interference in Magnetron Marine Radars

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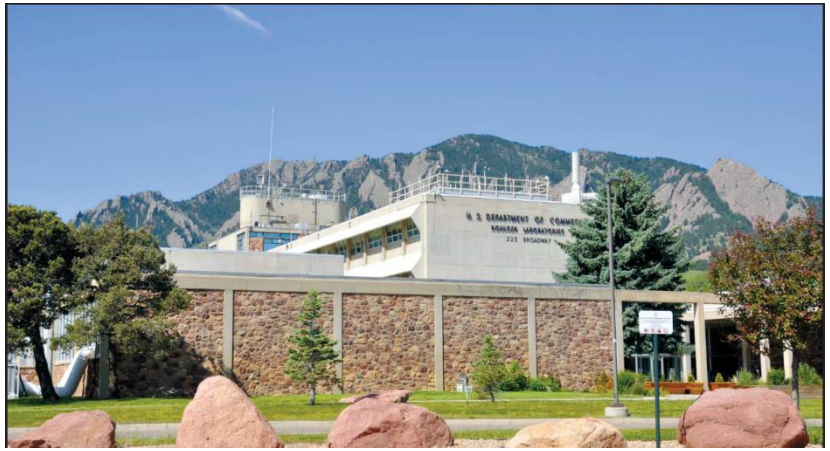
April 24, 2019

Institute for Telecommunication Sciences

- NTIA's research and engineering laboratory
- Supports NTIA policy formation
- Solves other Federal agency telecommunication problems

This work was originally funded by the U.S. Coast Guard Spectrum Management Telecommunications Policy Division



U.S. Dept. of Commerce Boulder Lab

ITS

Spectrum Sharing Viability

- What frequency and distance separations are needed to prevent harmful interference????

- Determined by:

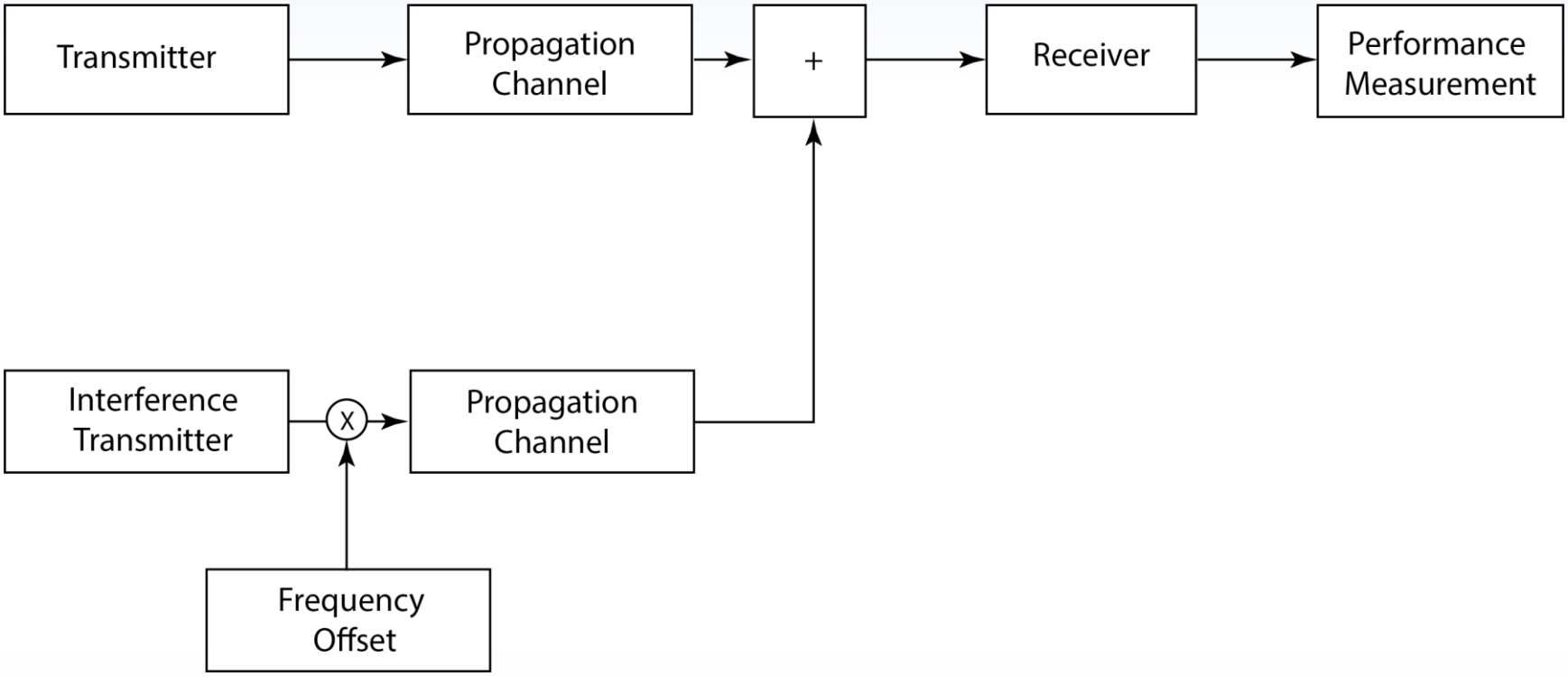
  Interference Protection Criteria , I_{ipc} vs. Δf

  Radio Wave Propagation Models, I vs. Δd

- I_{ipc} obtained with combination of Δf and Δd

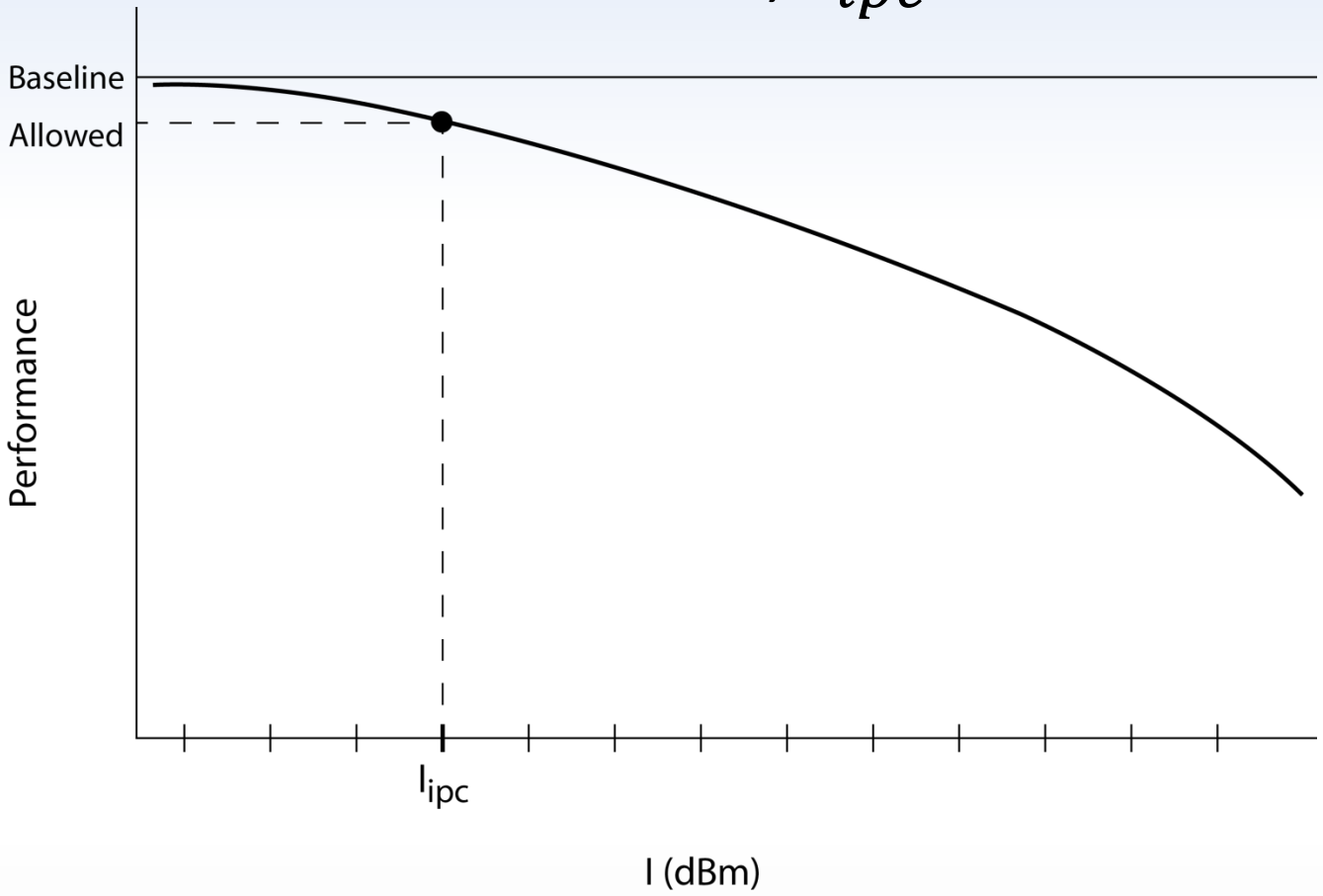
IPC 101

Test Fixture



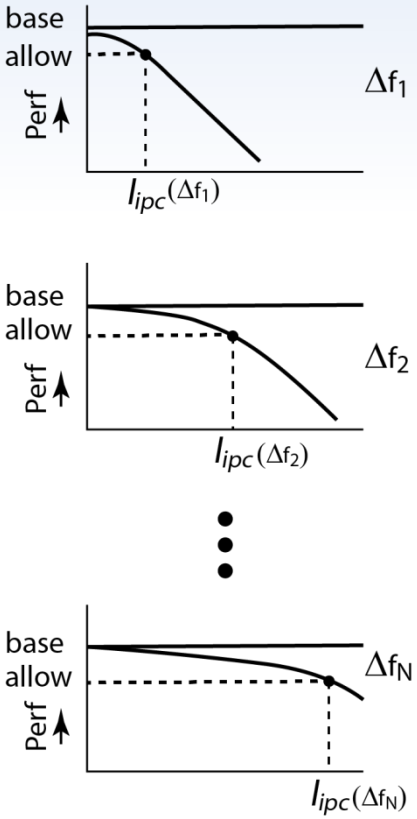
IPC 101

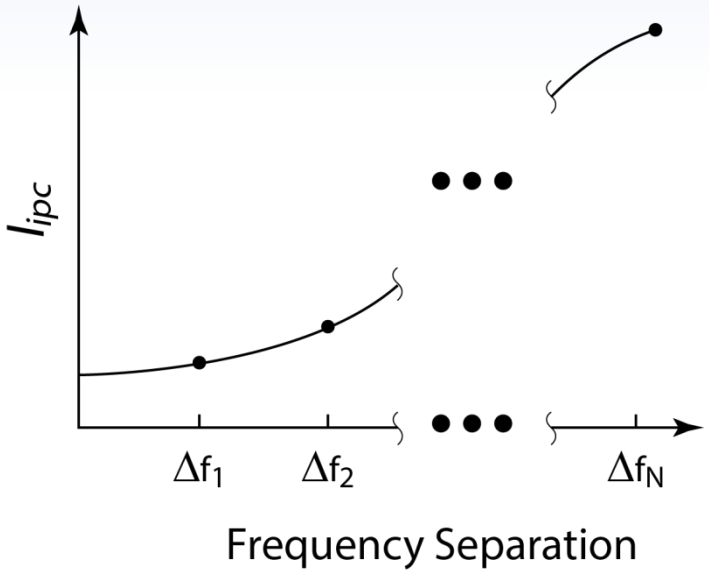
Test Result, I_{ipc}



IPC 101

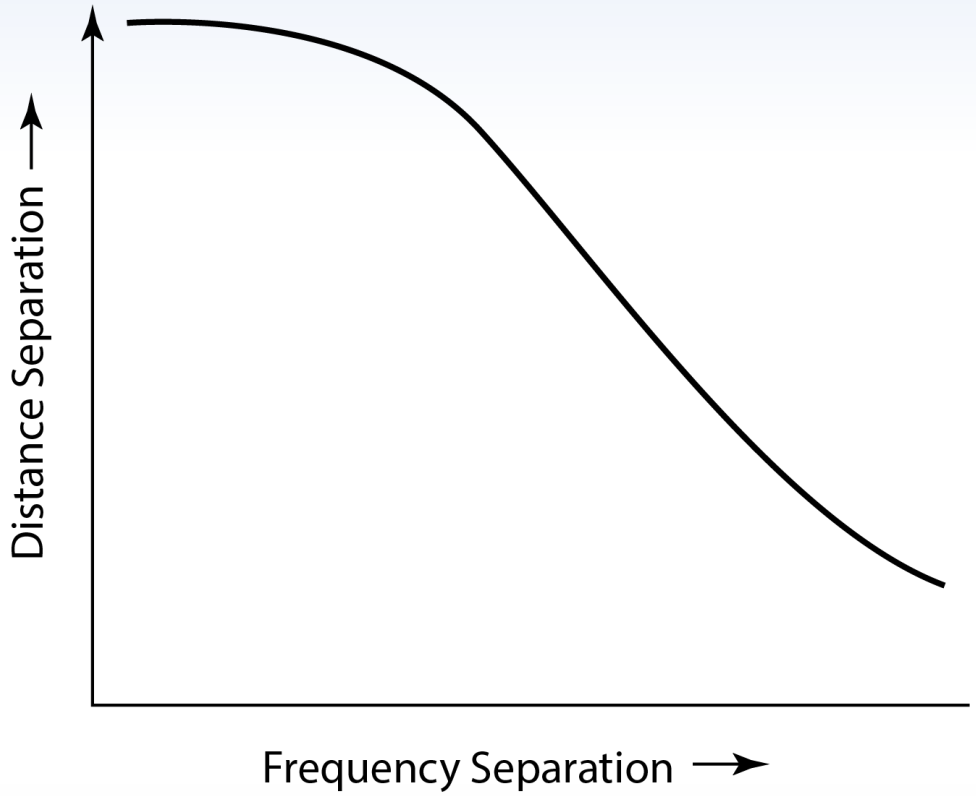
I_{ipc} @ Δf_n → I_{ipc} vs. Δf





IPC 101

Δd needed for $I_{ipc}(\Delta f)$

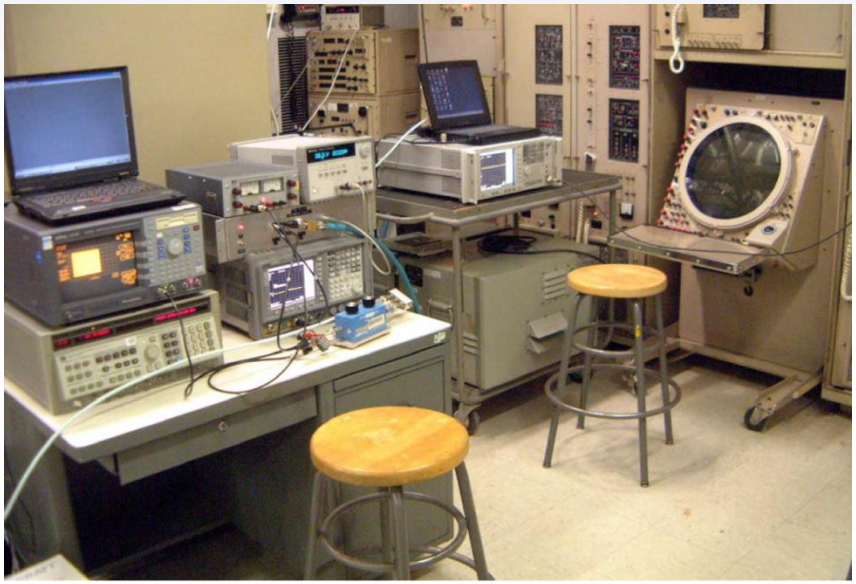


Problem

IPC typically derived from field or laboratory measurements

Equipment unavailable

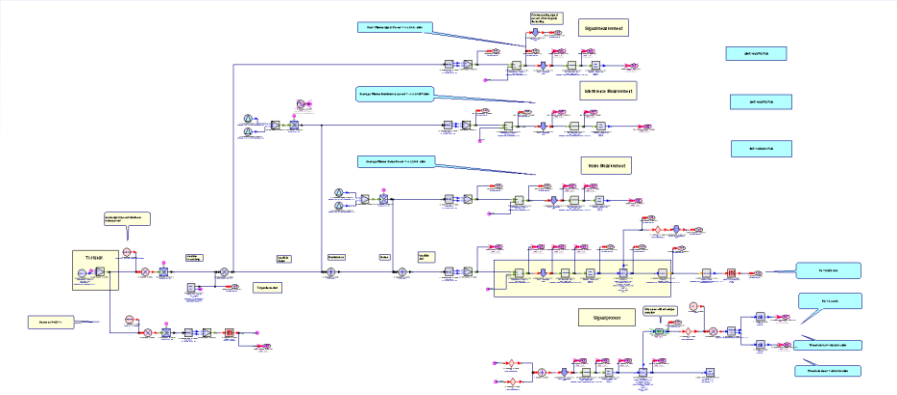
(U.S. Navy photo by Will Tyndall released)

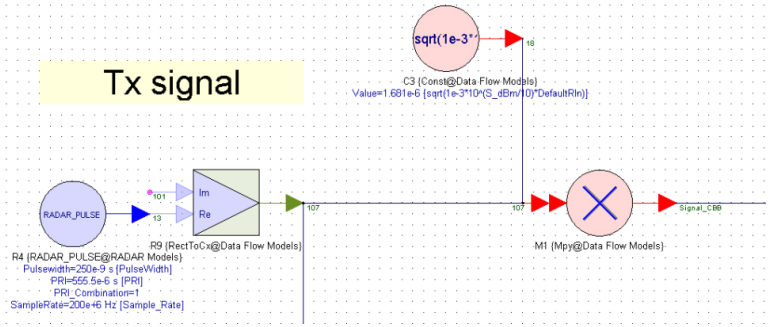


Signals and performance metrics difficult to access

Solution

IPC from software simulation





- Always available
- Accessible signals
- Accessible metrics
- Repeatable

Approach

- Emulate previous IPC measurements with software simulation
- Compare measurement results to simulation results

George Heilmeirer

Solid-state Radar Interference in Magnetron Radars

INTERNATIONAL MARITIME ORGANIZATION

JOINT IMO/ITU EXPERTS GROUP ON MARITIME RADIOCOMMUNICATION MATTERS
11th meeting
Agenda item 6

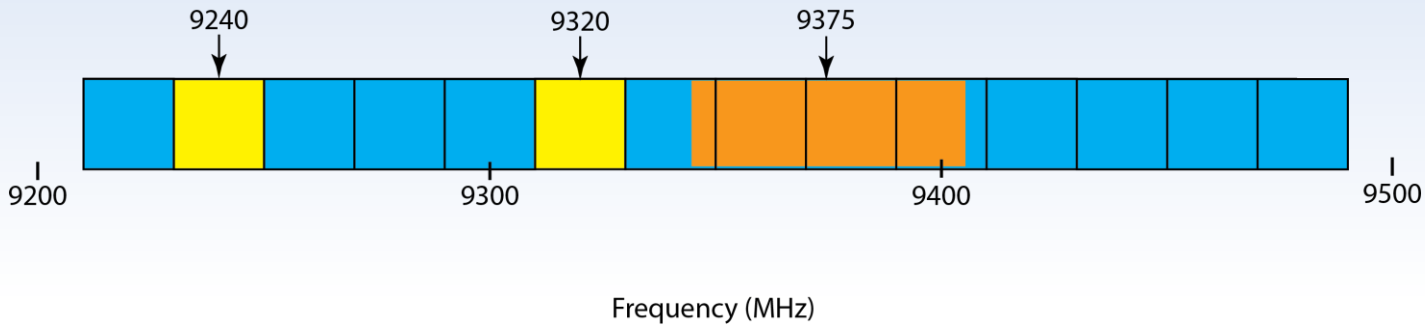
"Observed Interference on Marine Radar"

Los Angeles – Long Beach port

Field Test

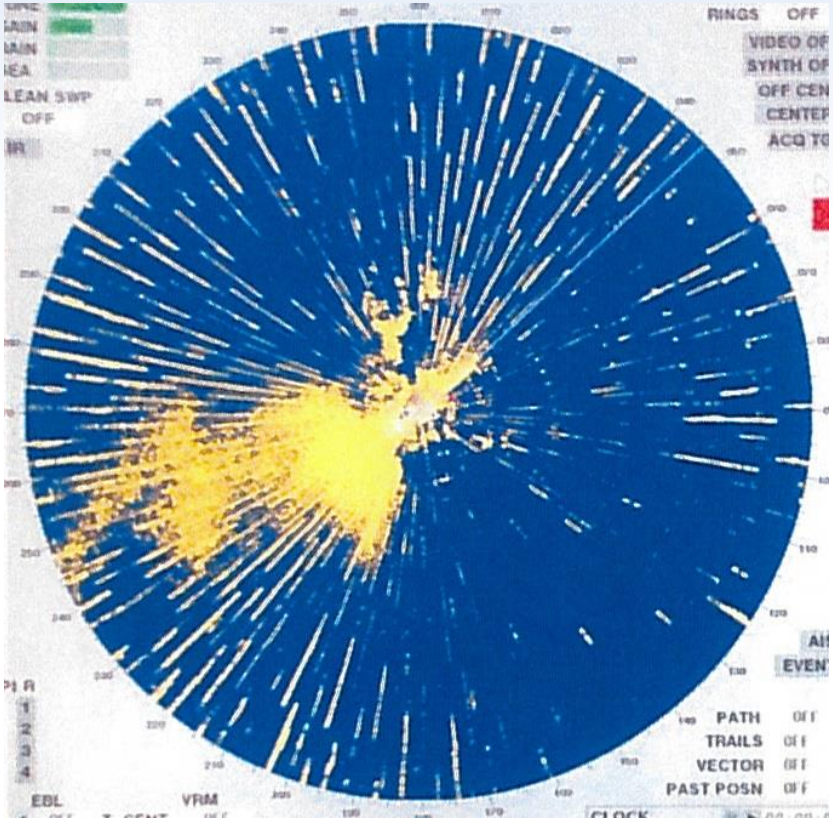
- Two ships in calm harbor waters
- “Capella” equipped with M-MR
- “Atair” equipped with SS-MR
- Evidence presented with 4 PPI photos

Field Test Radio Spectrum



- Orange: 60 MHz M-MR channel @ 9375 MHz
- Yellow: 20 MHz SS-MR channels
  - 55 MHz offset @ 9320 MHz
  - 135 MHz offset @ 9240 MHz

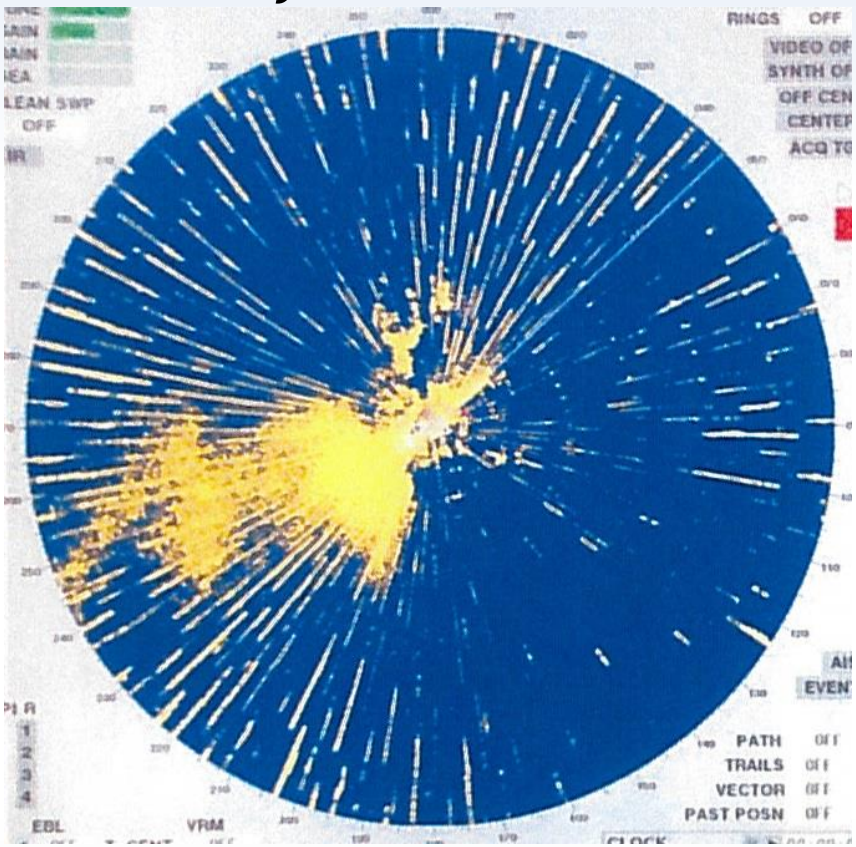
Reference Observation



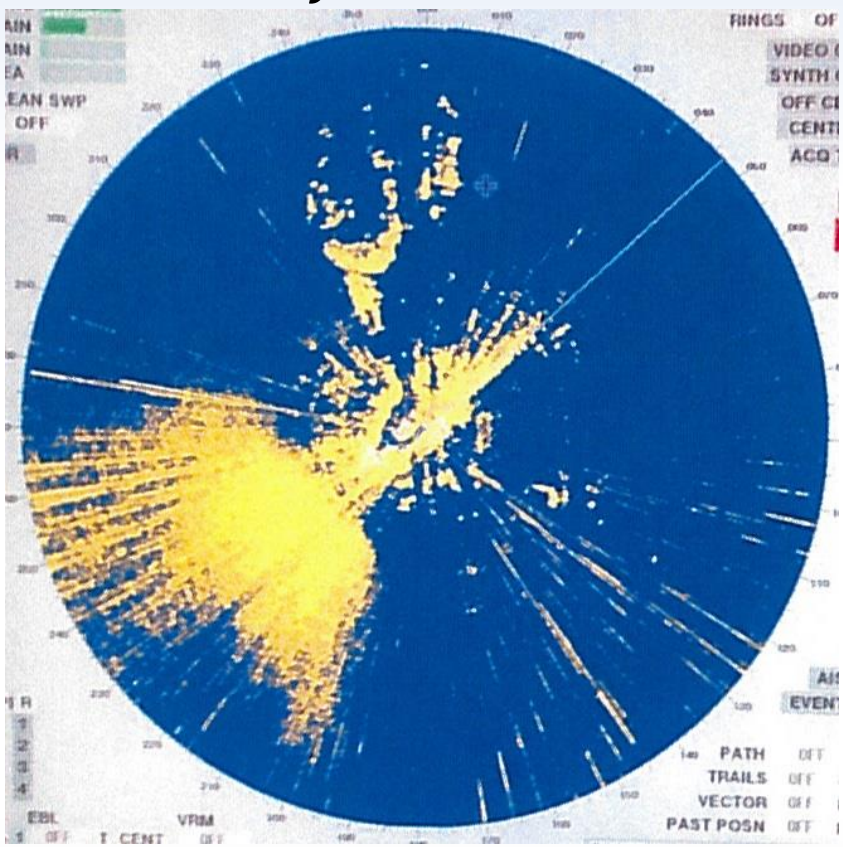
- 55 MHz Frequency Separation
- IR Off
- 0.34 NM Distance Separation
- Radial strobes are SS-MR interference
- Diffuse rain target

Effect of Frequency Separation

55 MHz Δf, Reference

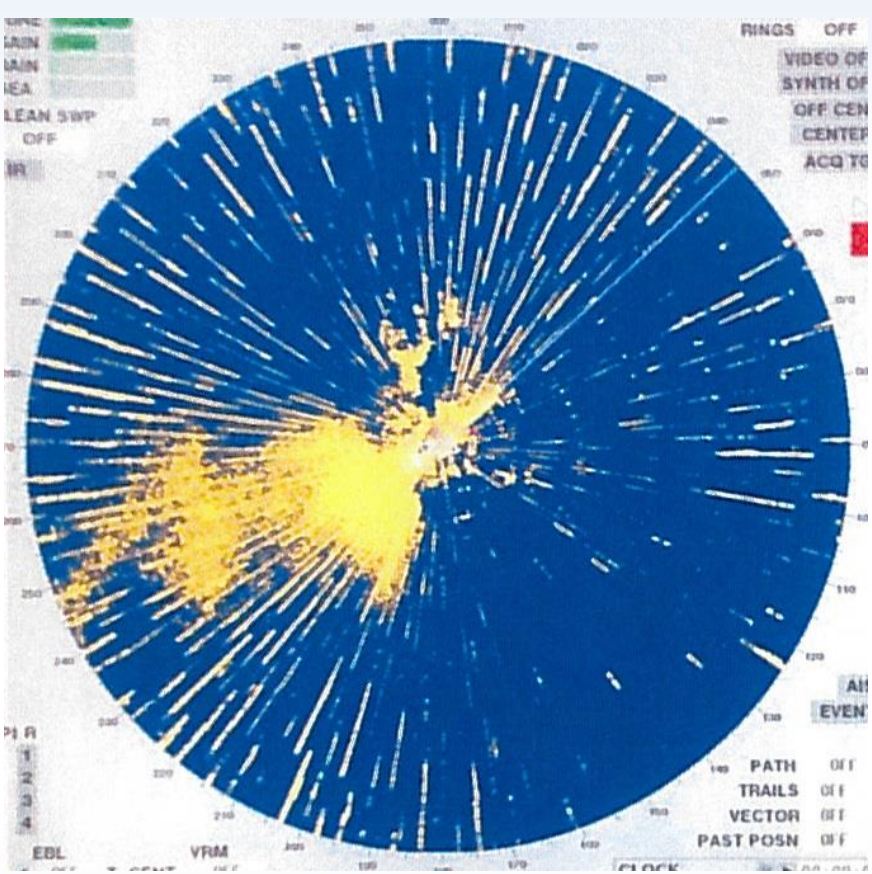


135 MHz Δf

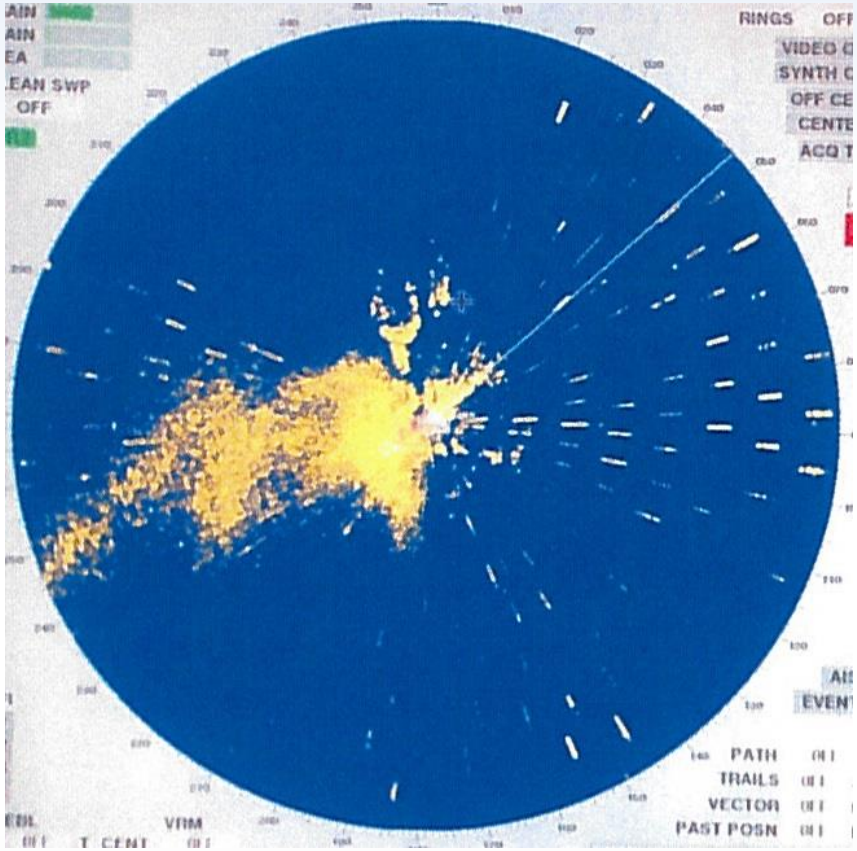


Effect of Interference Rejection

IR Off, Reference

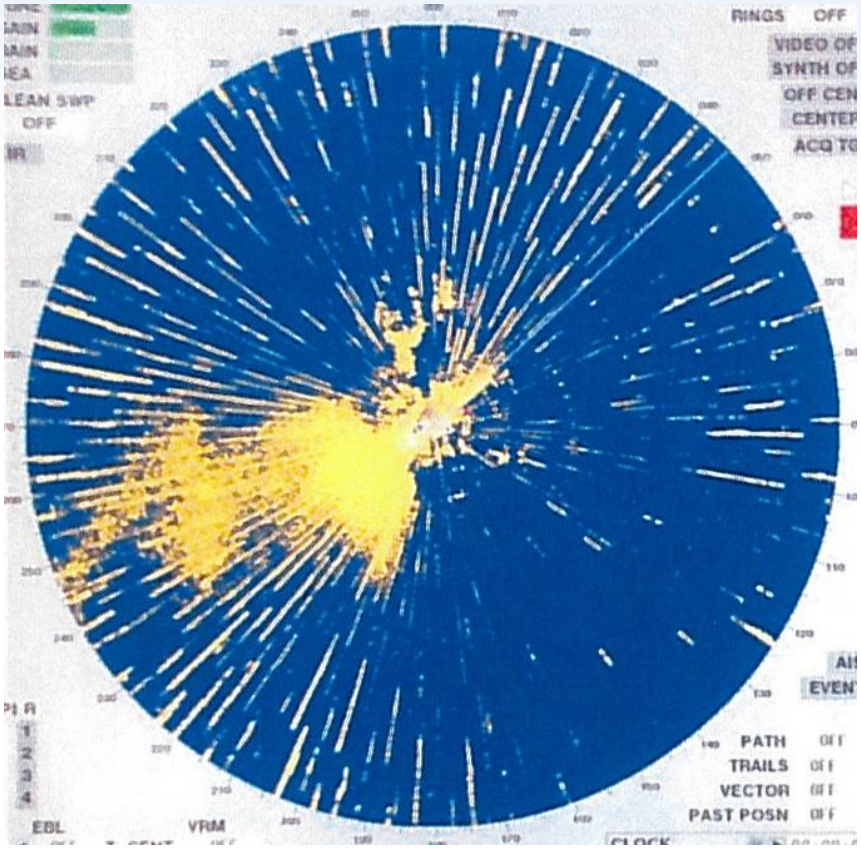


IR On

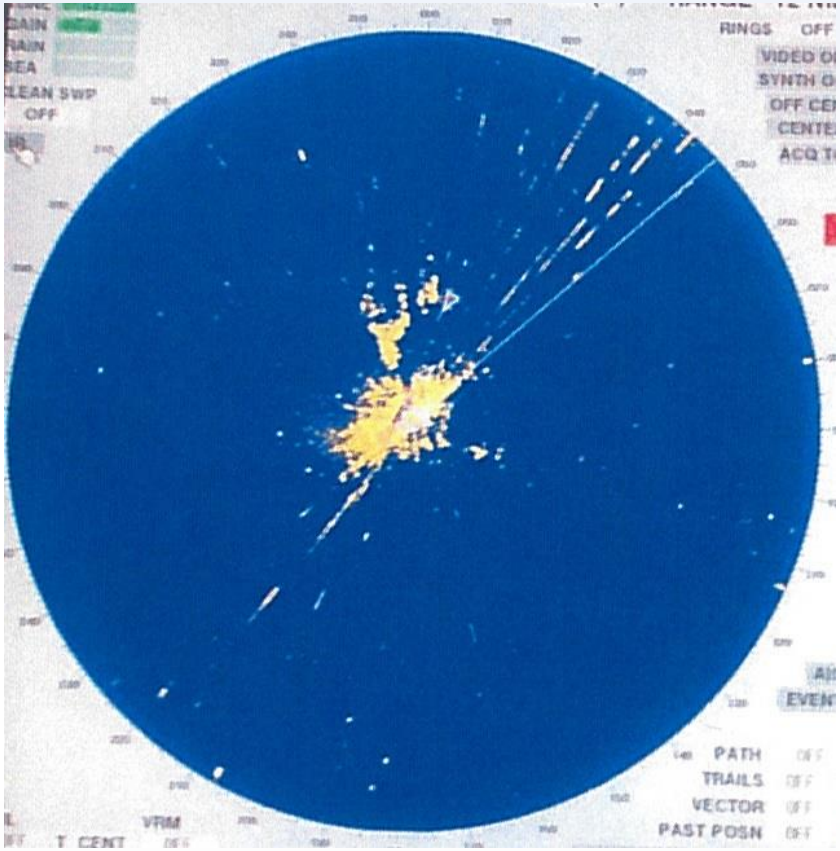


Effect of Distance Separation

0.34 NM, Reference



2.0 NM



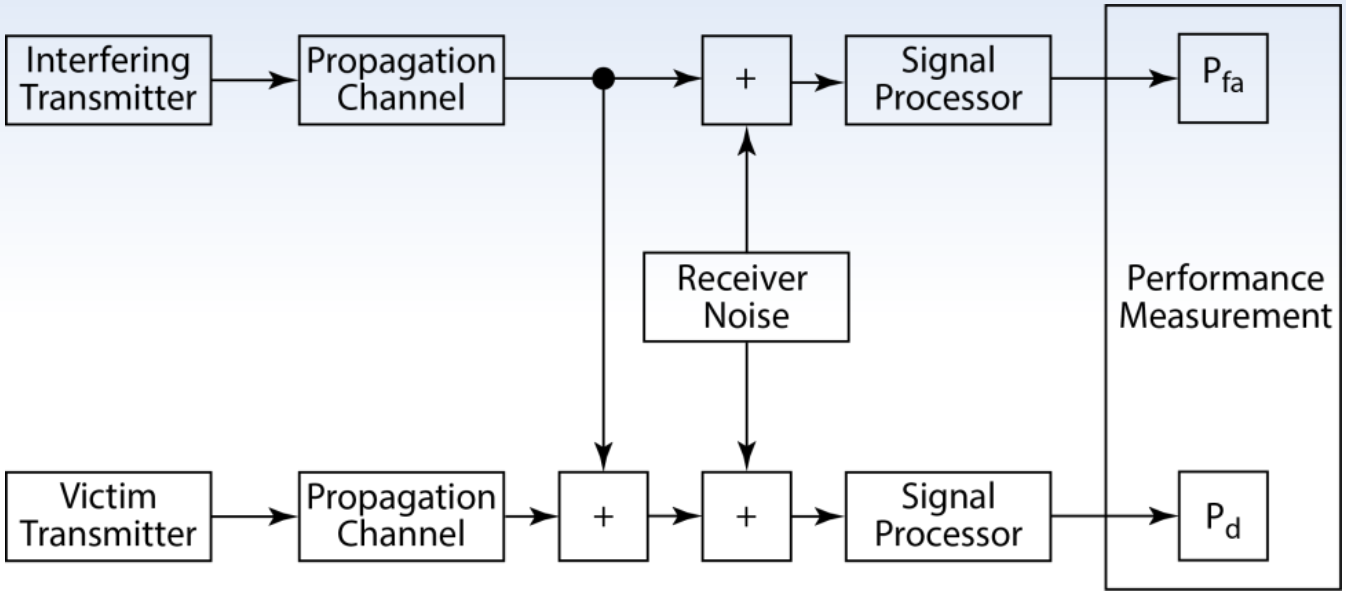
Field Test Caveats

- M-MR signal processing not documented
  - i.e. STC, FTC, Tracking, Scan-to-Scan correlation
- SS-MR waveform not documented
- No way to know whether the SS-MR is the only interferer
- Bottom line: Field test is anecdotal

Simulation and Analysis Method

1. Establish baseline performance (Pfa/Pd) without interfering signal
2. Measure performance with increasing amounts of interfering signal power
3. Determine IPC
4. Determine MSD analytically using link budget

IPC Simulation



- Pfa measured in top path
- Pd measured in bottom path

Separation Distance Analysis

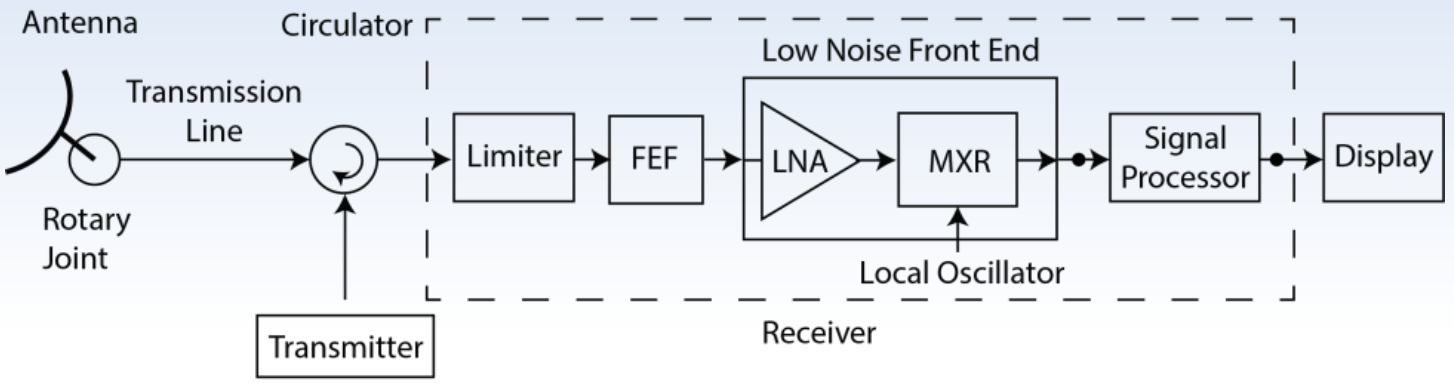
Path loss required:

$$L_p = I_t + G_m(\%) - INR_{ipc} - N\ (dB)$$

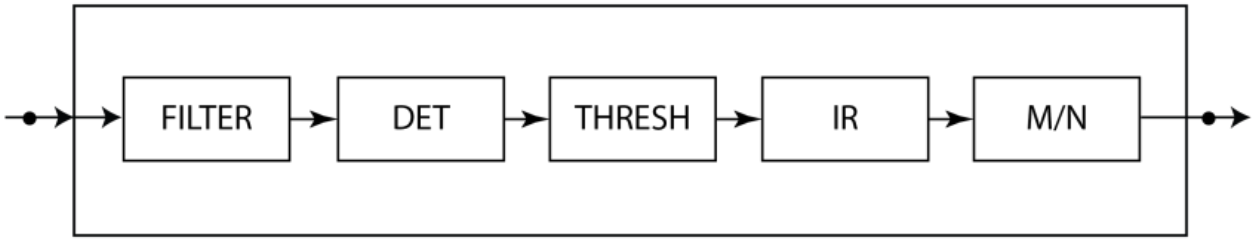
Minimum Separation Distance:

$$\text{MSD} = \sqrt{l_p}\,\frac{\lambda}{4\pi}\ \text{(linear)}$$

M-MR



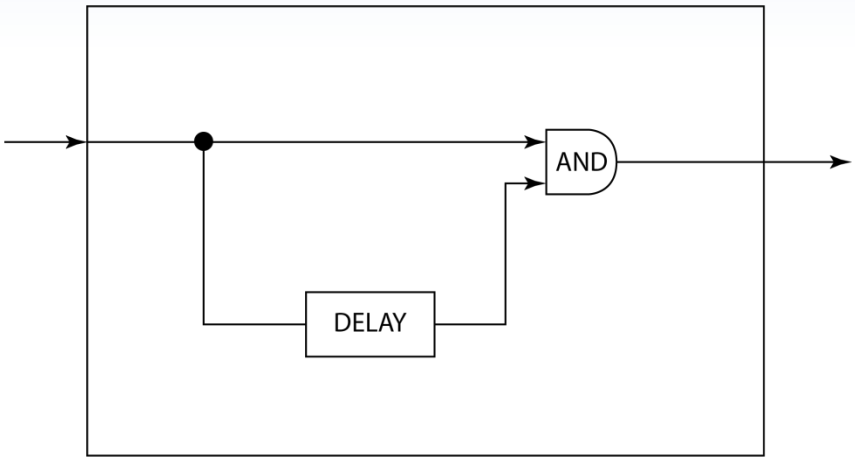
(a) Radar System



(b) Signal Processor

Double threshold detection

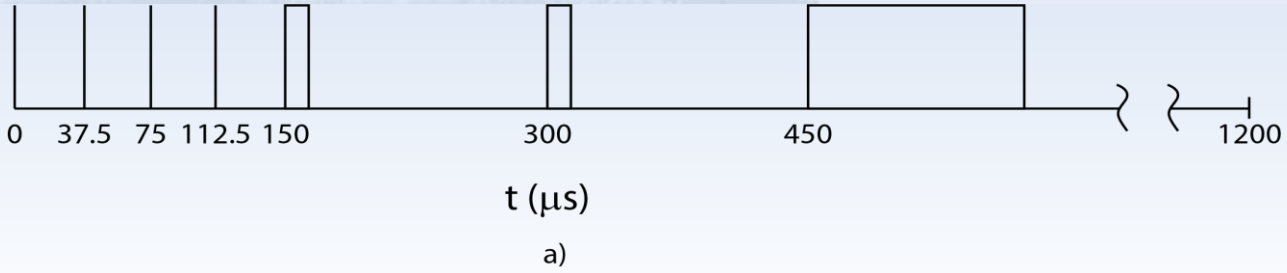
M-MR Interference Rejection (IR)



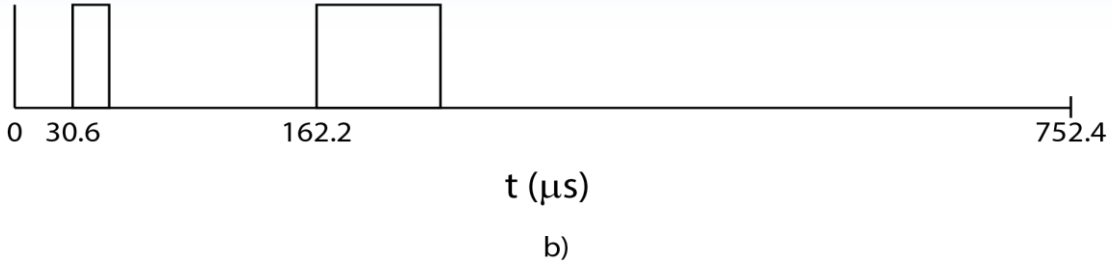
- Delay set to own radar PRI
- Own radar generates ones at output
- Other radar (with different PRI) generates zeros at output

SS-MR Pulsed NLFM Waveforms

Nelander

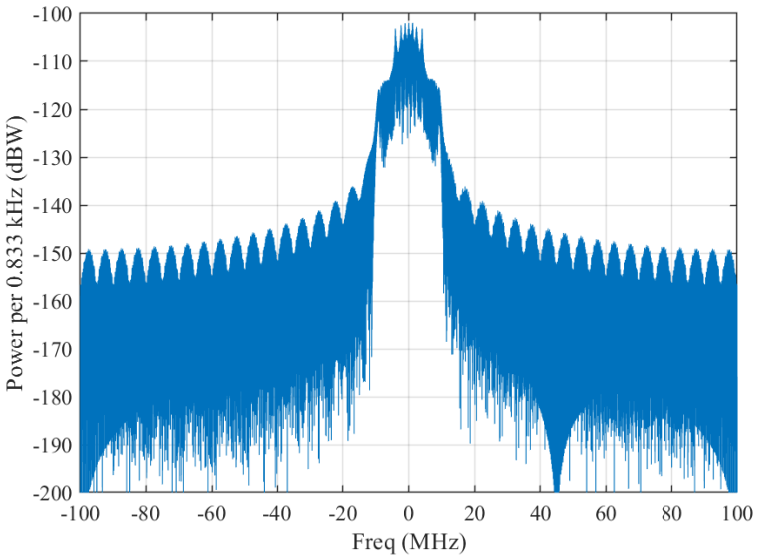


Harmon

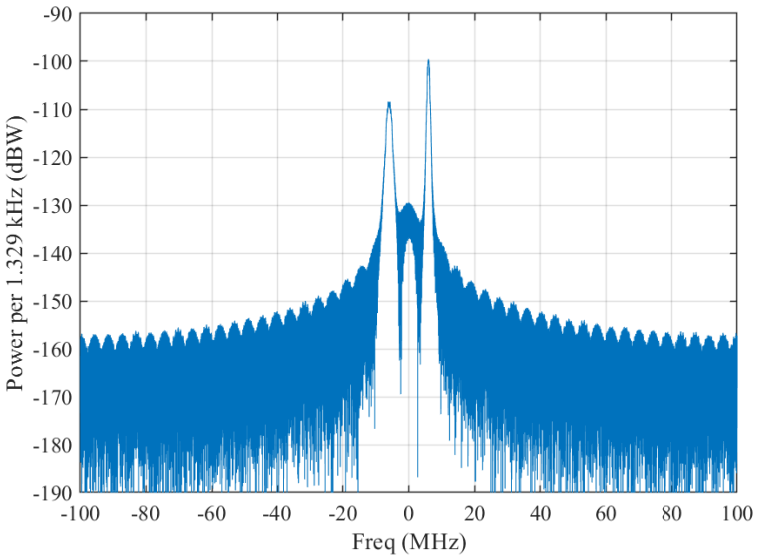


Signal for all ranges in one composite PRI

SS-MR Pulsed NLFM PSD



Nelander

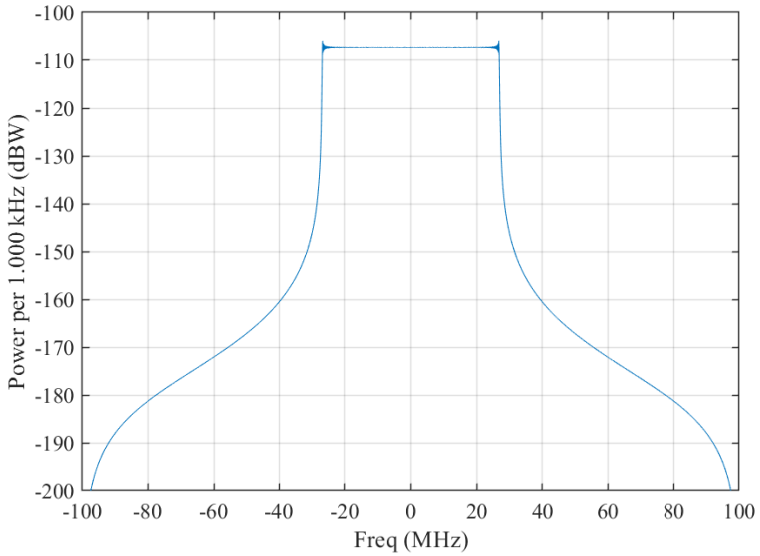


Harmon

SS-MR FMCW PSD

Range	Bandwidth (MHz)
Short	54
Medium	27
Long	13.5

Must switch between ranges

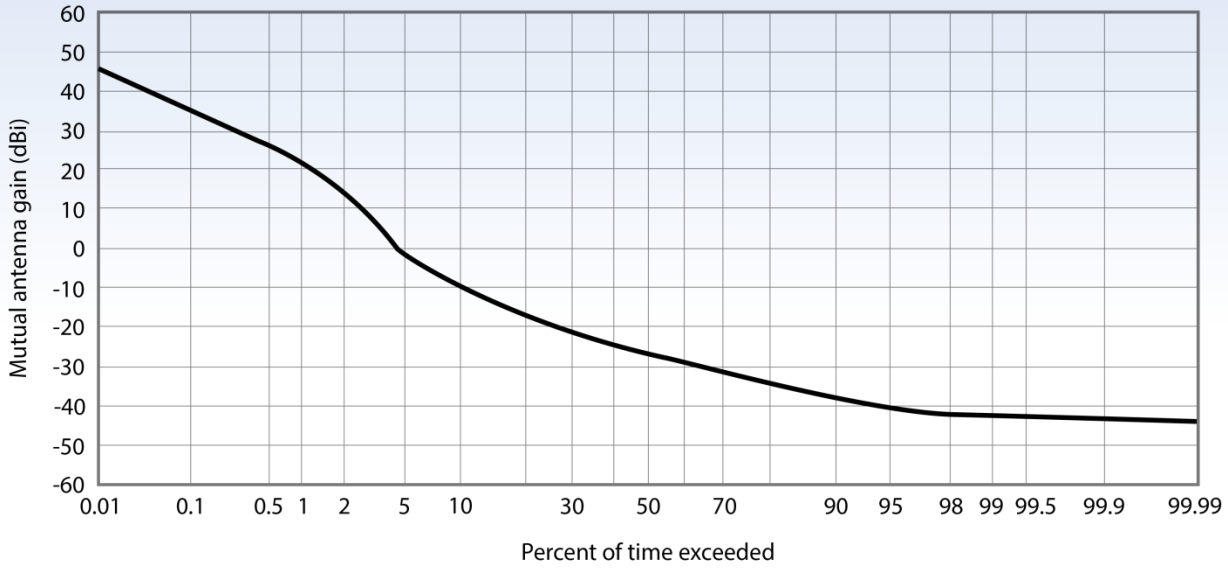


Short range FMCW PSD

Antennas

Parameter	Value
Type	Slotted array
Frequency	9000 MHz
Length	1.2 m (4 feet)
Az. Beam width	2.0 deg.
El. Beam width	25.0 deg.
Main lobe gain	27.0 dBi
First side lobe gain	1.0 dBi

Mutual Antenna Gain, $G_m(\%)$



Type	% of Time	Mutual Gain (dBi)
Max ML/SBL	0.5	28
Max SBL/SBL	5.0	2
Median	50.0	-25

Scope

- 3 SS-MR interfering waveforms
- 3 M-MR ranges (short, medium, and long)
- Interference rejection (disabled/enabled)
- Two frequency separations (55 and 135 MHz)
- 3x3x2x2 = 36 cases!

Results

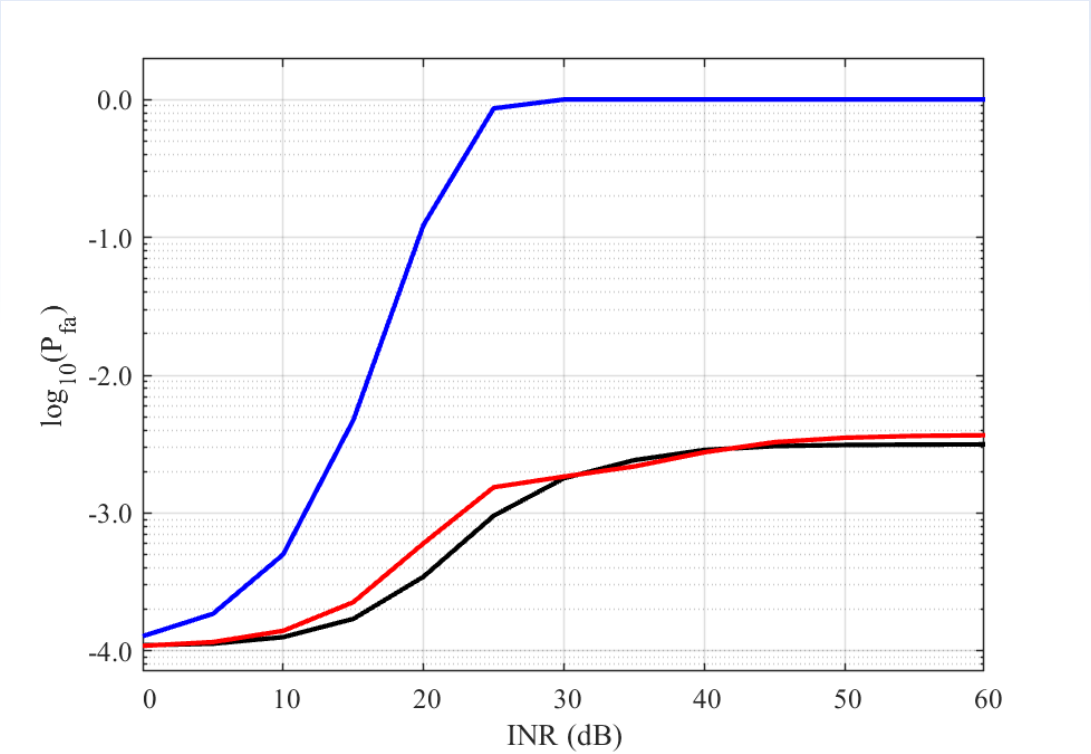
Negligible interference with:

- M-MR medium and long range operation
- M-MR IR enabled
- 135 MHz offset

Interference effects found with:

- Short range, 55 MHz offset, IR disabled

Short range, 55 MHz, IR disabled



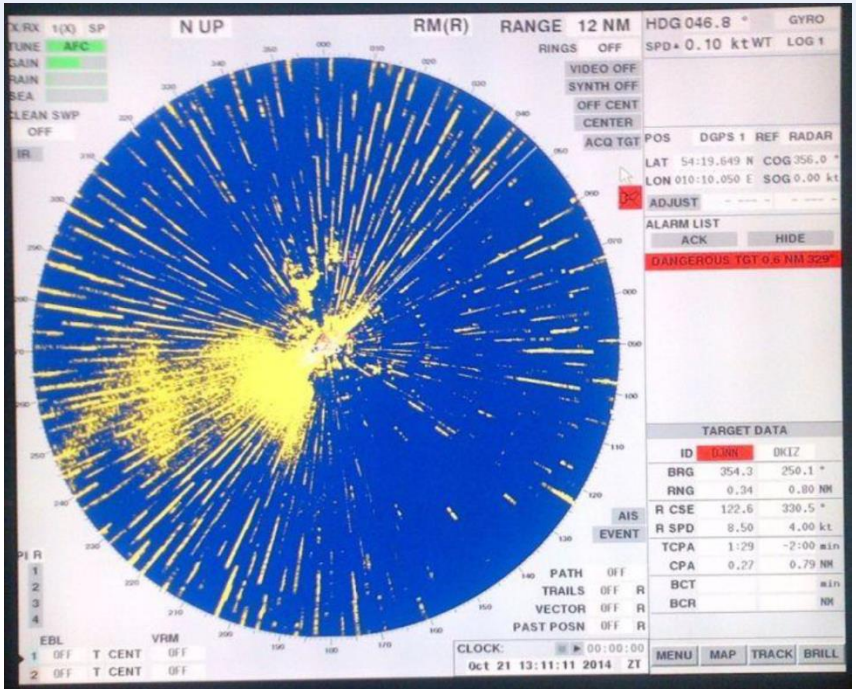
Black-Pulsed NLFM (Nelander), Red-Pulsed NLFM (Harmon) , Blue-FMCW

Short range, 55 MHz, IR disabled

SS-MR Signal	IPC (dB)	MSD (NM)		
		% of time exceeded		
		50.0%	5.0%	0.5%
Pulsed FM (Nelander)	10	0.69	15.47	308.64
Pulsed FM (Harman)	5	0.73	16.39	327.02
FMCW	0	0.22	4.89	97.60

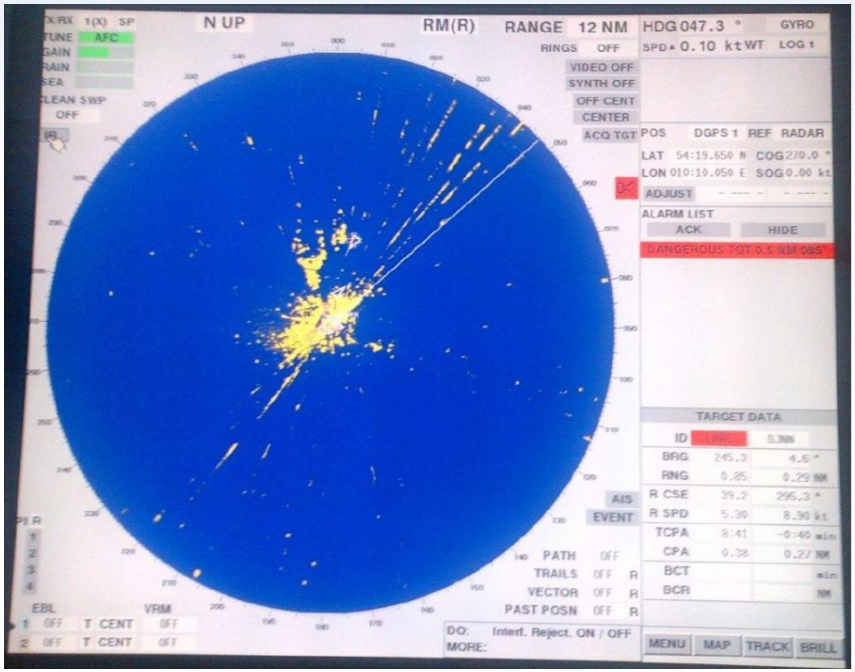
Comparison at 0.34 NM

SS-MR	INR (dB)		
	% of time exceeded		
	50%	5%	0.5%
Pulse FM (Nelander)	16.2	43.2	69.2
Pulsed FM (Harmon)	11.7	38.7	64.7
FMCW	-3.8	23.2	49.2



Comparison at 2.0 NM

SS-MR	INR (dB)		
	% of time exceeded		
	50%	5%	0.5%
Pulse FM (Nelander)	0.8	27.8	53.8
Pulsed FM (Harmon)	-3.7	23.3	49.3
FMCW	-19.2	7.8	33.8



Conclusions

- Assuming PPI interference:

1) occurs when INR exceeds IPC
2) increases with % of time exceeded

- Then

1) Comparisons show encouraging agreement
2) Software simulation is a promising tool

Future Work

- Use multiple SS-MR interferers
- Verify simulation results in laboratory
- Use more SS-MR waveforms
- Use more IR methods
- Add SS-MR non-linear amplification effects
- Determine minimum frequency separations