Study to establish measurement parameters for testing radar bandsharing performance –summary of results

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A presentation to the Public Spectrum Safety Test Group

4th October 2007

Background

The spectrum allocated to public sector systems is often used for applications which provide security or safety of life. It is therefore essential, before allowing bandsharing, to determine the levels of interference which can be tolerated by existing systems without having any impact on their efficacy

This study aims to develop and refine, through the use of modelling techniques, a methodology to assess the potential impact of bandsharing technologies on the performance of S-band radars operating between 2.7GHz and 3.4GHz

If it can be demonstrated that S-band radar systems can continue to operate, with no perceived degradation in operational performance, in the presence of secondary technologies, then this spectrum range could be one of the first public spectrum bands to allow bandsharing

Programme overview

Work package 1 – Background research and parameter identification, propose outline test methodology

Work package 2 – Parameter and control conditions determined through modelling; bandsharing radar protection criteria established and methodology refined

WorkPackage 1

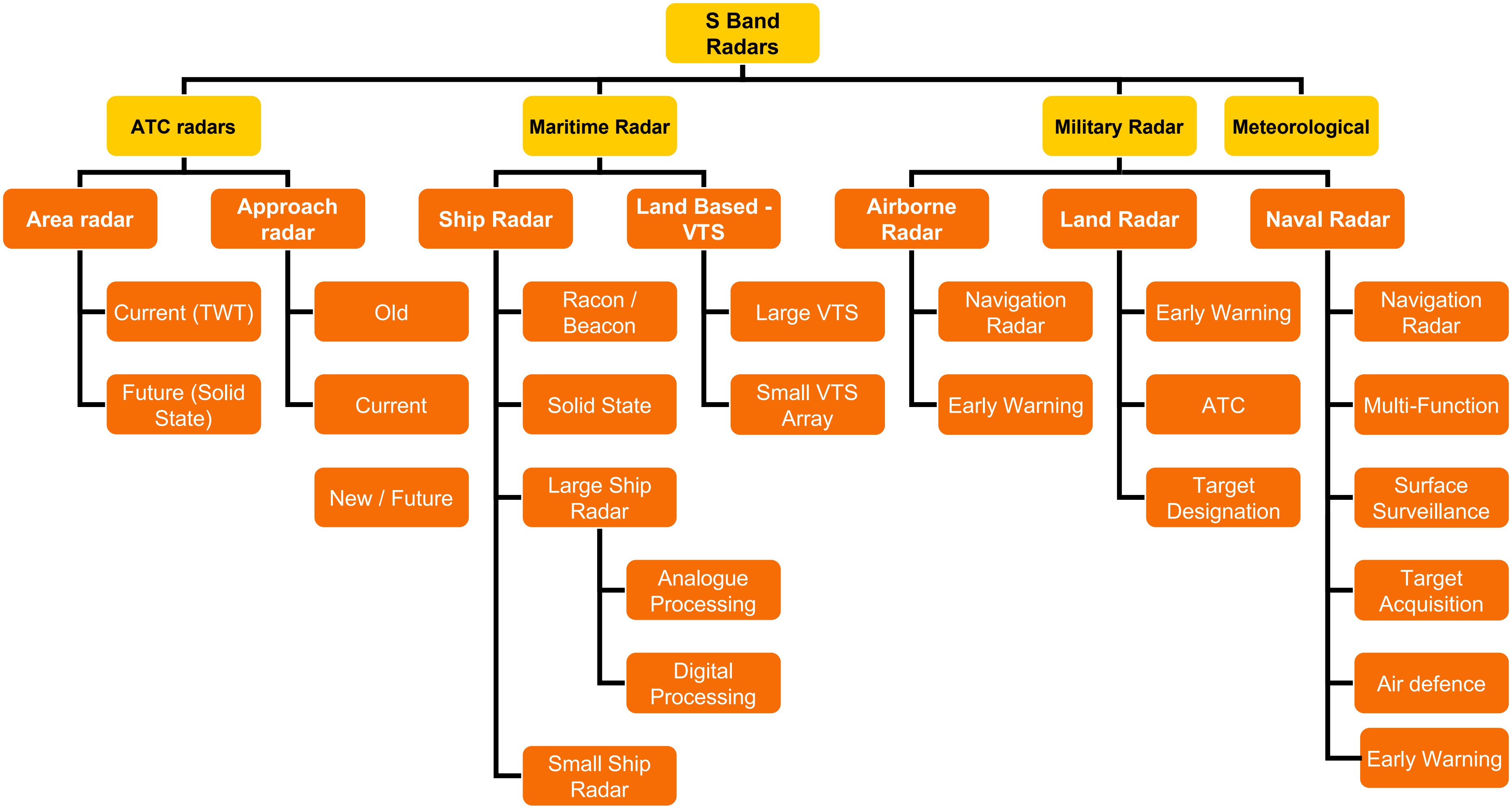
Collection of background supporting information

- Interviews with SMEs
- Literature survey
- Radar families and parameters used to establish radar performance
  - operational parameters
  - type approval
  - acceptance procedures

Identify candidate parameters for the protection criteria

- establish which measurement, or measurements, of radar performance could potentially be used as the parameters by which the ‘protection criteria’ are defined
- propose an initial test methodology for measuring radar protection criteria for subsequent trials of radars operating in the presence of sources of interference

Radar families



Outcome of literature review and SME interviews

Wide range of differing techniques in use to establish radar performance

Varying requirements and acceptance criteria used across the different families

Differing levels of automation and reliance on operator interpretation

Interference-to-noise ratio widely used in proposals to define protection levels, but

- large variation in protection levels from -6 dB to less than -12 dB have been proposed
- lack of consistent, scientific reasoning behind the proposed levels

Need protection criteria and test methodology which limit interference power levels to give no perceived operational degradation in radar performance

Candidate parameters for the protection criteria

- Probability of detection (Pd)
- Probability of false alarm (Pfa)
- Plot elevation accuracy
- Plot azimuth accuracy
- Plot range accuracy
- Plot Doppler accuracy
- Plot RCS accuracy
- Resolution
- Track initiation range
- Track accuracy (azimuth, elevation, range, velocity, acceleration)
- False track density
- Identification accuracy
- Rate of track breaks
- Track continuity
- Identification continuity

Initial proposed outline acceptance methodology for bandsharing technologies

Two stages of testing backed up by modelling

- Controlled ‘laboratory’ testing using a False Target Generator (FTG) against ‘primary’ parameter(s)
  - Testing carried out under conditions where the radar is most sensitive to interference
  - Defines protection levels for ‘worst case’ scenario
- ‘Field’ testing under representative operational conditions to validate ‘laboratory’ measurements
  - Under operational conditions the radar will, in general, be less sensitive to interference than the worst case laboratory scenario and we would not expect to observe degradation in performance at the protection level defined by the laboratory testing

Work Package 2 – Use of Modelling to Define Methodology for Testing Bandsharing Applications

- Validate, through theoretical modelling, which of the possible measurements of radar performance is the preferred parameter for use as the primary protection criterion
- Establish the 'worst case' control conditions required for accurate, repeatable measurement of this parameter in a controlled test environment
- Establish the maximum acceptable degradation in the chosen parameter and therefore the protection criteria for radar systems
- Determine, based on theoretical modelling, the maximum acceptable interference power levels (protection levels) at the radar antenna for any given interference source,
- Create a final methodology which will allow the findings of the modelling work to be verified in a controlled test environment and also in field trials, where the additional potential impact of human factors on perceived radar performance needs also to be validated

Choice of primary parameter

Want to minimise number of parameters

- reduced complexity, cost, time

Want a generic methodology and parameters that are applicable to all radar types

Probability of detection at a constant false alarm rate is considered most appropriate primary protection parameter

- Globally applicable
- Highly sensitive to interference
- Can define controlled, repeatable, measurements

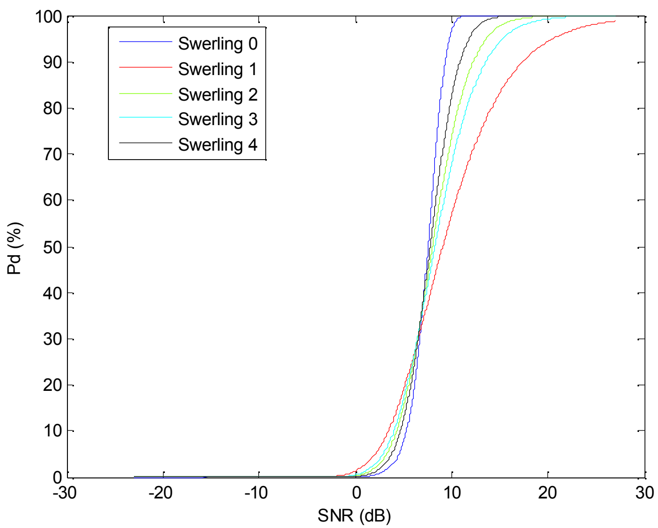
Other system specific parameters (including human factors) should also be measured to confirm these are not degraded at the interference level defined by the primary protection parameter criteria

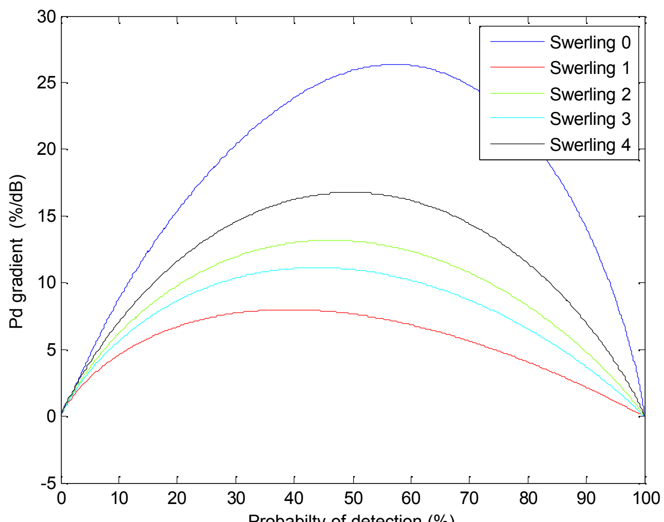
Protection criteria (measurement conditions and maximum acceptable degradation of the primary performance parameter)

No perceived degradation under operational conditions

Need to define the primary parameter measurement conditions which are most sensitive to interference ('worst case')

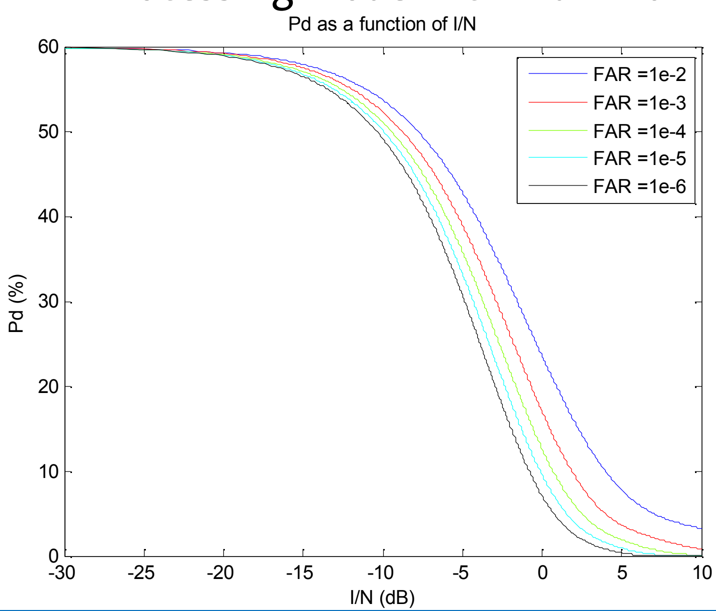
- Detailed modelling undertaken to determine optimum conditions using NEMESIS modelling suite (white noise model)

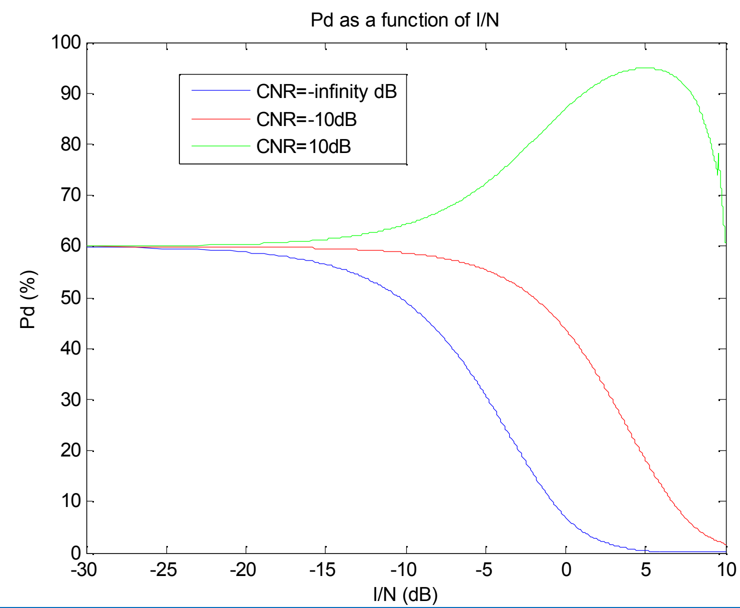




Most sensitive ('worst case') conditions for measurement of Pd

- Pd starting at 60% measured a constant false alarm rate
- Swerling 0 target
- No clutter
- No STC
- Processing mode with maximum number of bursts and lowest false alarm rate

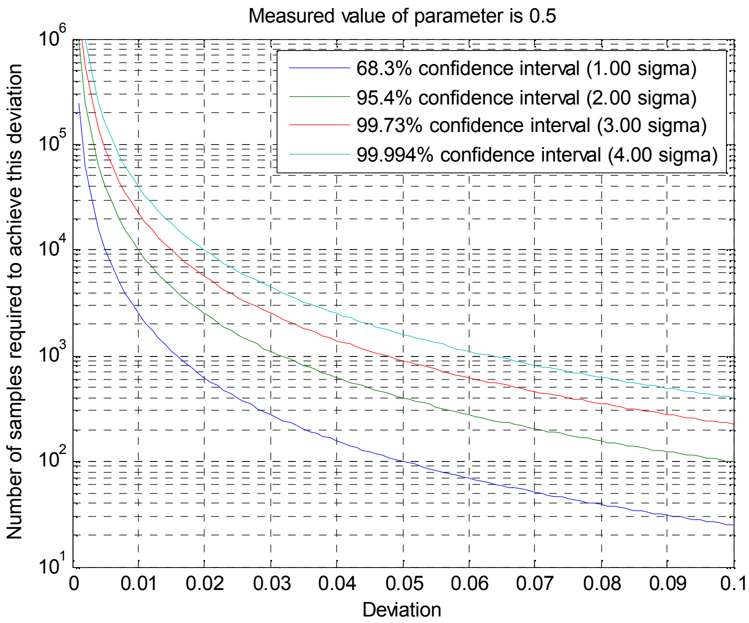




Maximum permissible degradation

- Statistical analysis to determine measurement limits under operational conditions
- Empirical evidence from existing trials and measurements and protection level recommendations

5% degradation in Pd is recommended maximum permissible degradation



Protection criteria are then;

- Pd 60% to 55% at a constant false alarm rate
- Swerling 0 target
- No clutter
- No STC
- Processing mode with maximum number of bursts and lowest false alarm rate

Protection levels (total aggregated interference allowable)

Can be defined in terms of power flux density per Hz (pfd/Hz) at radar antenna or interference-to-noise ratio within radar

NEMESIS used to predict protection levels for 16 different radar systems

- Uses Pd 60%-55% criteria and assumes white noise interference

Modelled radars

Military surveillance radars – 6 off

Marine navigation radars – 3 off

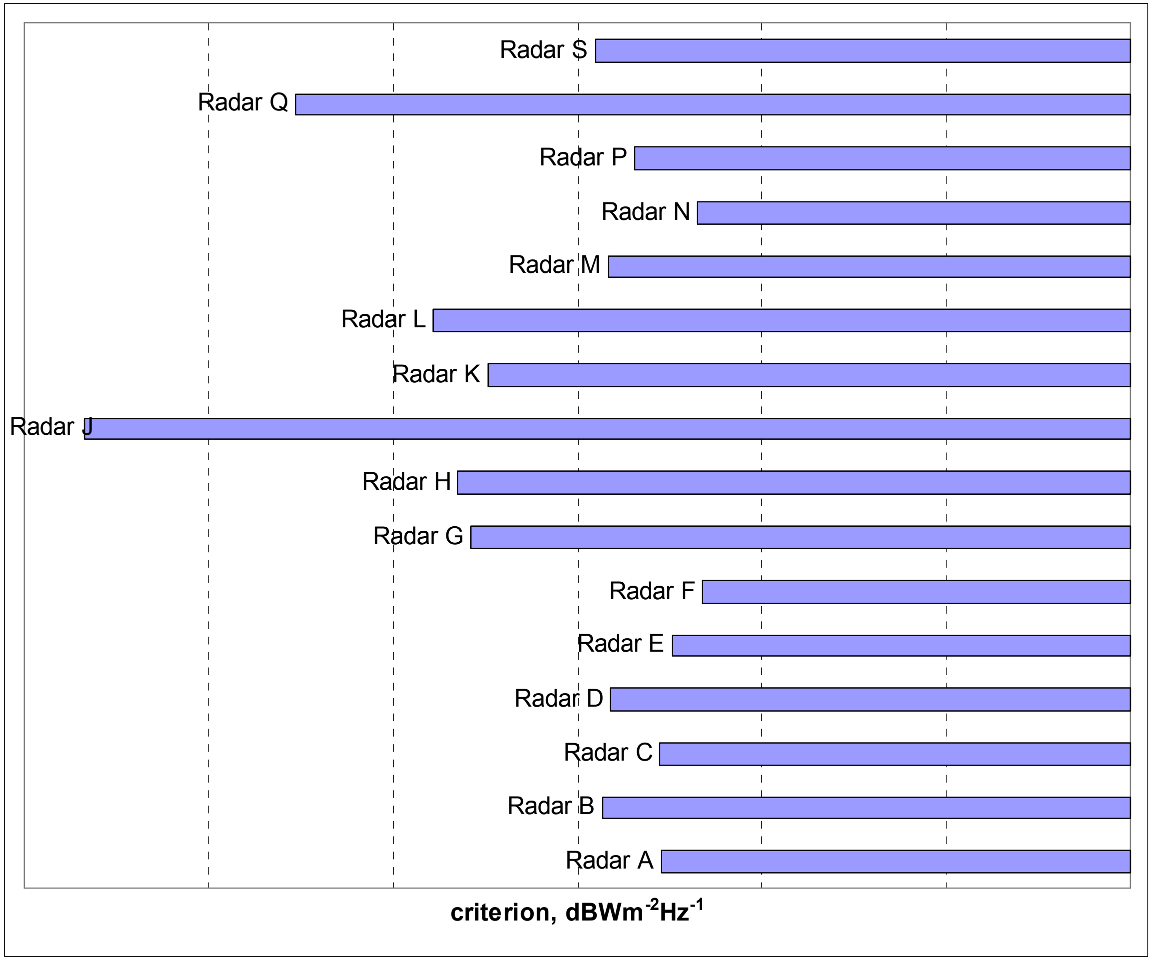
ATC radars – 3 off

VTS radars – 2 off

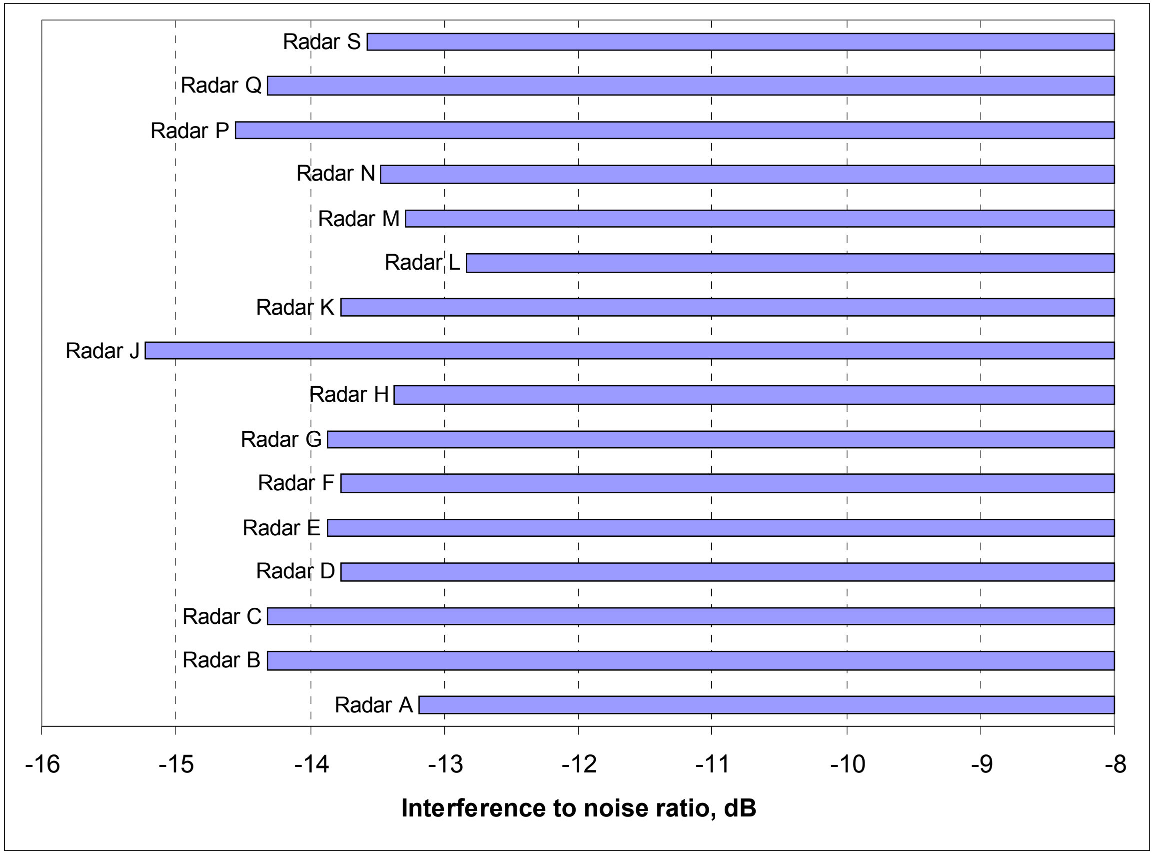
Meteorological radar – 1 off

“Baseline” S-band radar – 1 off

Modelled protection levels in terms of power flux density per Hz



Modelled protection levels in terms of interference to noise ratio

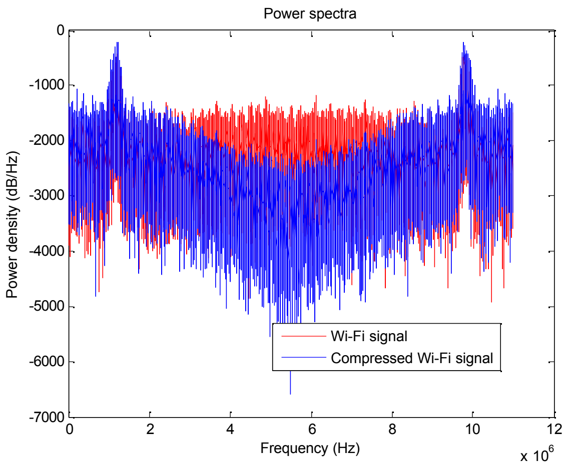


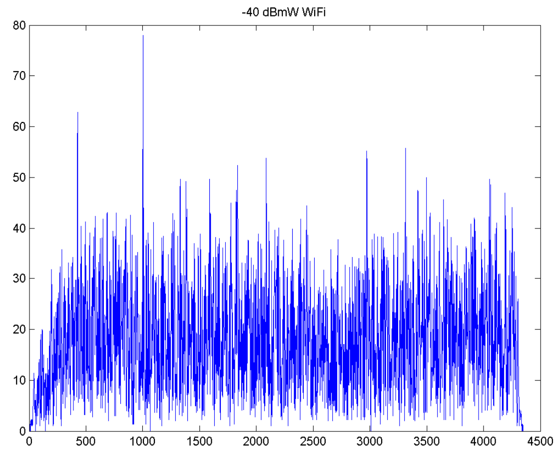
Modelled protection levels for specific interference waveforms

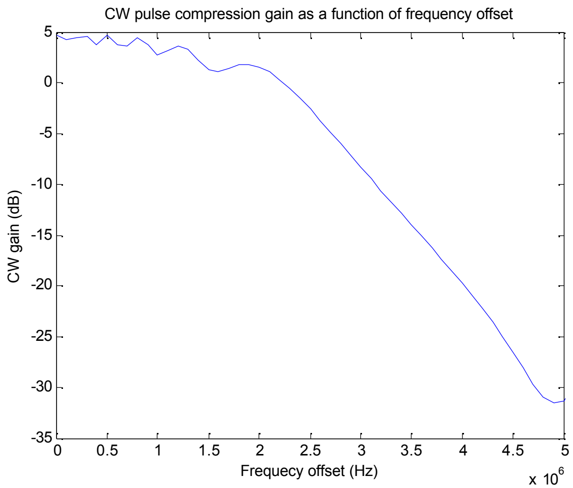
NEMESIS modelling assumed Gaussian white noise interference

PROGNOSIS I,Q baseband level modelling used to assess 3 specific interference waveforms on radar F

- Gaussian white noise
- Pure tone CW
- Recorded WiFi signal

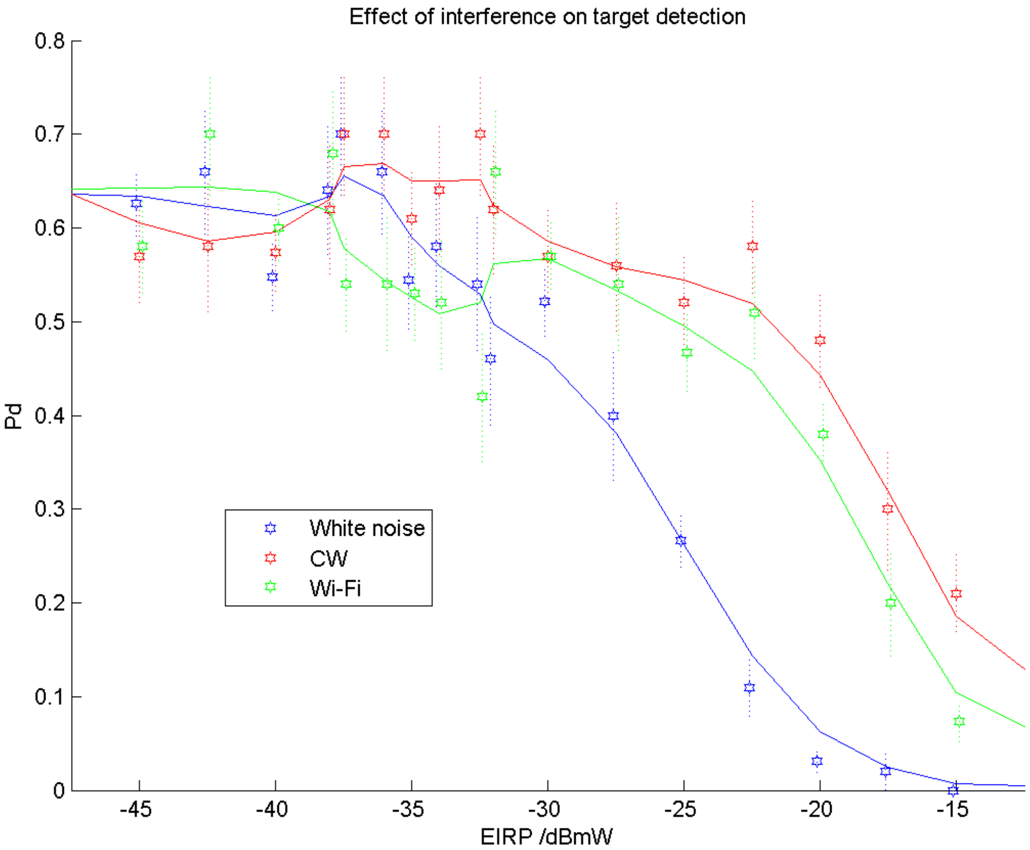






PROGNOSIS modelling of non-noise interference

- Modelling predicts that the CW and Wi-FI signals produce less degradation in performance than white noise
- Emphasises danger of defining a single interference to noise (I2N) value as a protection criterion – different waveforms will produce different levels of performance degradation for the same I2N
- This detailed level of modelling will be required if actual measurements cannot be carried out on all radars against prospective bandsharing technologies, as the actual waveforms employed will effect the protection levels



Generic radar protection methodology

Two stages of experiments

- Controlled ‘laboratory’ testing at the most sensitive (to interference) conditions for the radar
  - repeatable , highly accurate measurements
  - direct injection of FTG and interference
  - defines the protection levels
- ‘Field’ testing under operational conditions
  - compare performance with and without interference at the laboratory defined protection levels
  - verifies the lab measurements
  - assessment of human factors
  - ‘ensemble average’ measurements of multiple targets of opportunity
  - FTG field measurements
  - internal and external injection of interference

‘Laboratory’ test methodology recommendations

Pd measurements need sufficient samples (~2000) to achieve ~1% accuracy in Pd, equivalent to 1dB in interference power level

- Multiple false targets should be used to reduce measurement times
- Care needed to ensure these do not affect CFAR levels

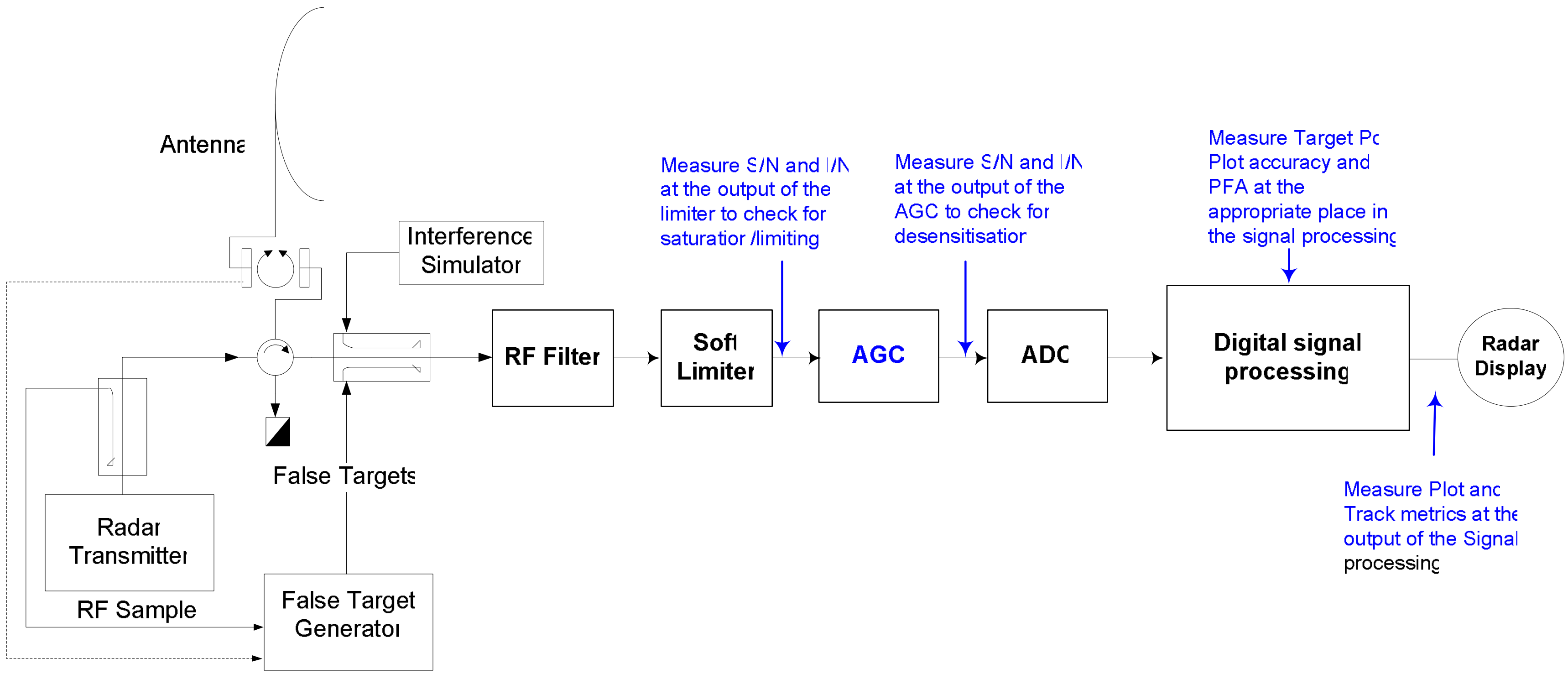
Aggregated interference effects should be simulated

- Spatial
- Temporal
- Spectral

pfd levels should be measured using bandwidth ~ radar instantaneous bandwidth

Where no automation is used for target detection then experiments should be repeated to take account of human factor variability

Proposed experimental configuration for assessment of primary protection criteria using direct injection of false target and interference signals



‘Field’ test methodology recommendations

Measurements carried out under representative operational conditions with and without interference at the protection level calculated from the ‘laboratory’ measurements

Asses other performance parameters according to ‘normal’ operational requirements for that radar type

Use both FTG and real targets

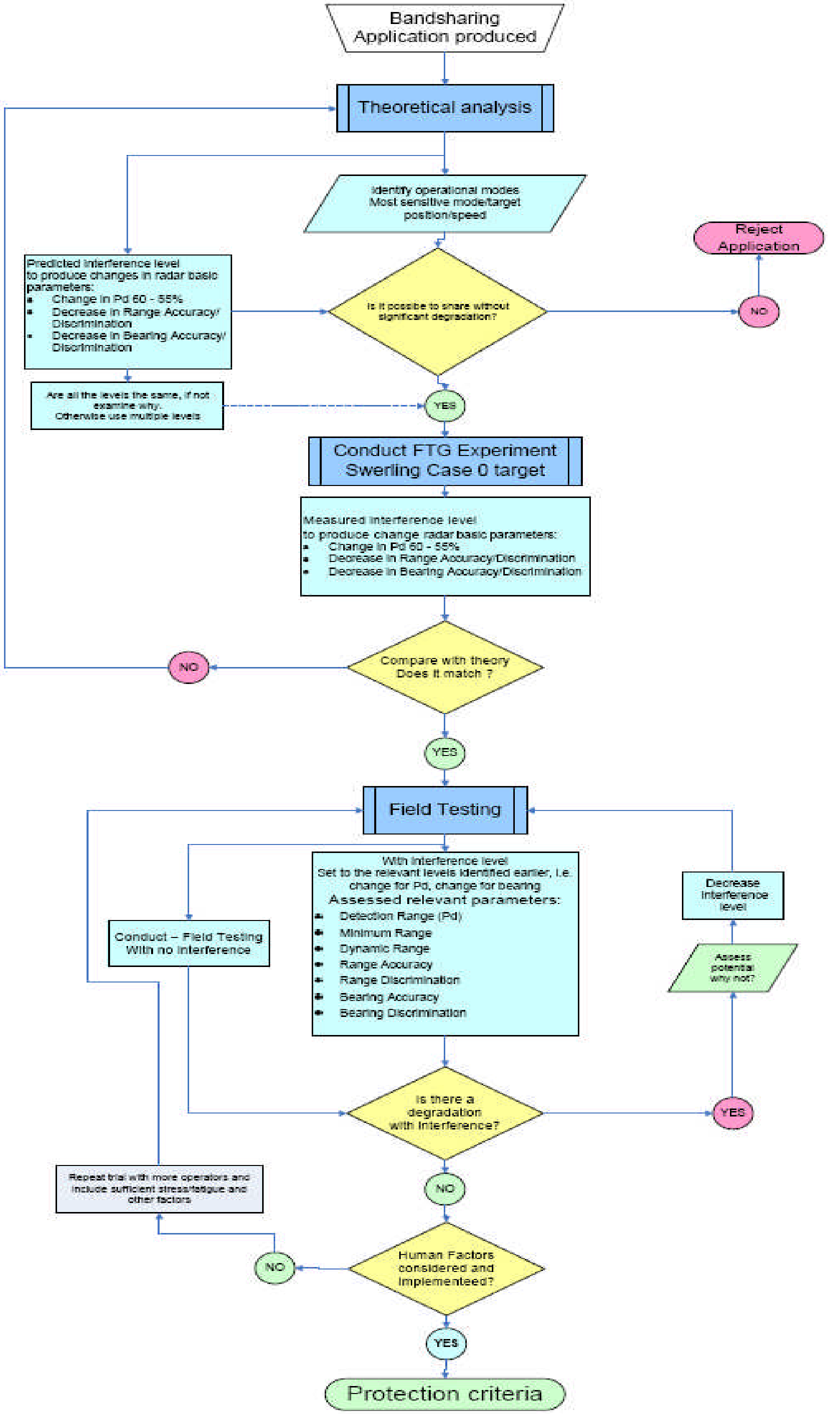
Use both external and internal noise injection

‘Ensemble average’ measurements of Pd and plot and track accuracies using targets of opportunity where secondary radar ground truth is available (>50000 samples is recommended for ATC radar to reduce target variability issues)

Human factors trials should be repeated using multiple operators under repeatable conditions

Ensure that environment and target set are not significantly changed from no-interference to with-interference measurements

Measurements should include background non-intentional interference levels


Bandsharing
Application produced
Theoretical analysis
Identify operational modes
Most sensitive mode/target
position/speed
Predicted interference level
to produce changes in radar basic
parameters:
Change in Pd 60 - 55%
Decrease in Range Accuracy/
Discrimination
Decrease in Bearing Accuracy/
Discrimination
Is it possibe to share without
significant degradation?
NO
Reject
Application
Are all the levels the same, if not
examine why.
Otherwise use multiple levels
YES
Conduct FTG Experiment
Swerling Case 0 target
Measured interference level
to produce change radar basic parameters:
Change in Pd 60 - 55%
Decrease in Range Accuracy/Discrimination
Decrease in Bearing Accuracy/Discrimination
Compare with theory
Does it match ?
NO
YES
Field Testing
Conduct – Field Testing
With no interference
With interference level
Set to the relevant levels identified earlier, i.e.
change for Pd, change for bearing
Assessed relevant parameters:
Detection Range (Pd)
Minimum Range
Dynamic Range
Range Accuracy
Range Discrimination
Bearing Accuracy
Bearing Discrimination
Decrease
interference
level
Assess
potential
why not?
Is there a
degradation
with interference?
YES
NO
Repeat trial with more operators and
include sufficient stress/fatigue and
other factors
NO
Human Factors
considered and
implementeed?
YES
Protection criteria

Summary

Primary protection criteria proposed based on concept of 'no perceived degradation in radar performance'

- Pd degradation from 60% to 55%, measured using Swerling 0 target in the clear (no clutter) at a constant false alarm rate with radar mode with lowest FAR and largest number of bursts ('worst case' conditions)

Protection levels have been modelled using the proposed criteria for 16 radar systems

- Results are consistent with recommended protection levels from other recent studies

Methodology for acceptance testing has been recommended with two stages of testing

- Primary protection criteria assessment under controlled 'worst case' laboratory conditions
- Verification of no degradation of other parameters including human factors under operational conditions

Use of baseband modelling in conjunction with test programme is recommended to provide a cost effective solution

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