EXECUTIVE SUMMARY

Radars play critical roles in national security, air traffic control, weather observation and warning, scientific applications, mapping, search and rescue operations, and other safety-of-life missions. Radar transmitter and receiver characteristics are engineered to successfully accomplish their missions in these areas. The technical characteristics of radars (such as high transmitter peak power levels and very sensitive designs for the receivers) have typically resulted in exclusive or primary spectrum allocations for radar operations in selected radio bands.

In recent years, spectrum crowding has led to proposals for reduction of available spectrum for exclusive or primary radar operations, as well as for co-channel (or nearly co-channel) spectrum sharing between radars and non-radar (communication-type) signals. It has been proposed in various forums, for example, that communication signals can (and should) share spectrum bands with radar systems. Such proposals typically presume that radar receivers will not suffer undue loss of performance due to such sharing as long as the interference levels are relatively low. Some sharing analyses assume that radar receivers are relatively robust against radio frequency (RF) interference effects from communication signals at low levels.

Such proposals raise critical questions regarding the robustness of radar receiver performance in the presence of RF interference, especially at low levels. These include: At what power levels do interfering signals cause adverse effects on the performance of radar receivers? How are interference effects manifested in radar receivers? What are the interference levels at which radar receivers lose desired targets? What if any low-level interference effects occur on radar receiver displays? Are radar targets only lost at the edge of radar coverage?

To answer these questions this report's authors have performed extensive tests and measurements on many radar receivers performing a variety of critically important missions in several spectrum bands. Radar types that have been examined include: short-range and long-range air traffic control; fixed ground-based weather surveillance; airborne weather surveillance; and maritime navigation and surface search. The radars that have been tested operate in the spectrum bands: 1215-1400 MHz; 2700-2900 MHz; 2900-3700 MHz; and 8500-10500 MHz.

The most important results of this work can be summarized in four major findings:

1) Interference with communication-type signals degrades radar performance at interference-to-noise (*I/N*) levels between -9 dB and -2 dB (well *below* the internal noise of the radar receivers). One radar lost targets at an *I/N* level of -10 dB, and *I/N* = -6 dB caused all but one of the radars to lose targets. Future improvements to weather radars are predicted to render them vulnerable at *I/N* levels as low as -14 dB.

2) In contrast to the effects of interference from communication signal modulations, pulsed interference at low duty cycles (less than about 1-3%) is tolerated at *I/N* ratios as high as +30 dB to +63 dB. In other words, the radar receivers that were tested performed very robustly in the presence of the type of signals that are transmitted by other radars. Radars tend to share spectrum well with other radars.

3) When radar targets are lost due to low-level interference, those losses are insidious. There are no overt indications to radar operators or even to sophisticated radar software that losses are occurring. No dramatic indications such as flashing strobes on radar screens are observed. This insidiousness can make low-level interference more dangerous than higher levels that will generate strobes and other obvious warning indications for operators or processing software.

Even when radars experience serious performance degradation due to low-level interference, it is very unlikely that such interference will be identifiable as such. It is therefore unlikely that such interference will ever result in reports to spectrum management authorities even when it causes loss of desired targets. Since low-level interference is not expected to be identified or to generate reports when it occurs, lack of such reports *cannot* be taken to mean that such interference does not occur.

4) Interference can (and will) cause loss of targets at any distance from any radar station; loss of targets due to radio interference is not directly related to distance of targets from radar stations. When radar performance is reduced by some number of decibels, X, then all targets that were within X decibels of disappearing from coverage will be lost. Range from the radar is not a factor in this relationship. Interference can cause loss of desired, large targets (such as commercial airliners, oil tankers, and cargo ships) at long distances, as well as small targets at close distances. Low-observable targets that could be lost include, for example, light aircraft; business jets; incoming missiles; missile warheads; floating debris including partially submerged (and therefore dangerous) shipping containers; life boats; kayaks, canoes, dinghies; periscopes; and swimmers in life jackets.

Because any marginal radar target can potentially be lost at any distance in the presence of radio interference, radio interference does not translate directly into an equivalent radar range reduction. While "range reduction" due to interference can be used as a metric, its use must be qualified with the (unrealistic) condition of a fixed, constant cross section for all desired targets.

Taken together, the technical results in this report show that radar receivers are not generally robust against low-level interference from non-radar (communication-type) radio signals. The low thresholds at which interference effects occur, the insidious characteristics of such interference, and the wide range of distances over which radar receivers can experience interference effects are critical technical indications that, to avoid impairment of radar operations, care must be taken to ensure that radar receivers are not subjected to unnecessary interference from non-radar signals above identified thresholds. Conversely, radars have now been shown to operate robustly when they share spectrum with other radar signals having low duty cycles (i.e., when the interference duty cycles are less than about 1-3%).