Part 15 RFID Devices
And
DOD UHF Radar – Ground Based

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Summary

The NTIA has applied an ITU-R M.1462 protection criteria of –6 dB interference to the radar noise floor for their analysis and in support of their objections to the current FCC proposed rulemaking, FCC ET Docket 01-278, for Part 15 devices. This rulemaking does not increase the field intensity or power levels now allowed by current Part 15 rules but does propose to extend the duty cycle for RFID devices. RFID devices and radio amateur stations currently share the 420 – 450 MHz band with these radar systems. The NTIA analysis approach is used to calculate the ranges for RFID devices and radio amateur stations to meet the INR –6 dB ITU criteria. The effects of typical signal processing techniques used by surveillance radar systems were not considered in the NTIA analysis.

This paper presents the basis and rationale for the radar systems to operate effectively with the proposed low power Part 15 RFID devices with extended duty cycles and high power (1,500 watts to 1,500,000 watts EIRP) radio amateur stations that are now deployed. The –6 dB INR metric of unwanted signal acceptability based on signal level or range is shown to be poor qualitative measure of radar effectiveness. The actual measurement of radar effectiveness is based on statistical decision and probability theory that is used for radar signal processing. Radar signal processing techniques are applied to demonstrate how the radar systems are able to contend with the signals that share the same frequency.

The conclusion that the signal processing normally applied by these airborne radar surveillance systems not only allow them to be effective today, but will continue to be effective with the RFID low power duty cycle proposed by the Part 15 rulemaking, is supported by the technical analysis provided herein.

Introduction

The National Telecommunications and Information Administration (NTIA) Office of Spectrum Management has expressed a concern on potential interference to government radar systems operating in the 420 – 450 MHz band. This concern was initiated by the Part 15 proposed rulemaking (FCC ET Docket 01-278) for RFID systems operating in the 425 – 435 MHz band. This paper will analyze the coexistence of the Part 15 RFID devices operating under the conditions proposed with the UHF ground based radar systems and determine if harmful interference results.

The proposed rulemaking imposes the same field strength limit now required in Part 15.231(a) and currently being used by Savi Technology RFID interrogators and tags operating at 433.92 MHz in both DOD and commercial applications. The current Part 15 rule and the proposed rulemaking would allow maximum field strength of 11,000 microvolts per meter measured at a distance of 3 meters using equipment with an average detection function. The maximum peak level permitted would be 110,000 microvolts per meter also measured at 3 meters. This is the same limit now required in 15.231 and used by Savi RFID interrogators with a ten- percent transmit duty factor. The FCC rulemaking and Savi Technology have proposed that the current rules be changed to allow the current 110,000 microvolts per meter at 3 meters to be used for data transmissions between the RFID interrogators and tags for up to 120 seconds with at least a 10 second silent period between transmission. Retransmission would be permitted in the event of data errors occurring. This change would allow the RFID interrogator and tag to exchange the data contents in the tag in one transmission. Under the current Part 15 rules this exchange when a wired interrogator network and database is not available results in many short transmissions between the interrogator and tag over a 30 minute period.

Analysis

This analysis will use the same equations and radar processing capabilities used by the NTIA for radar system analysis. Additional signal processing capabilities of typical chirp and clutter processing techniques are also applied. The radar system parameters are provided by an ITU document ITU-R M.1462, Characteristics of and Protection Criteria for Radars Operating in the Radiolocation Service in the Frequency Range 420 – 450 MHz. The analysis will look at the Part 15 emissions that are within the surveillance radar antenna main beam and in the antenna sidelobe regions using the interference to noise ratio (INR) protection criteria of ITU-R M. 1462, INR = -6 dB. Radar and RFID bandwidth considerations will be applied along with typical radar signal processing techniques to verify that harmful interference that prevents radar effective operation does not exist. Finally, comparison of amateur radio operations in the 420 – 450 MHz band and ground radar system operations will be provided to show compatibility with amateur stations with EIRP radiation levels of 1.5 million watts.

The link equation used by the NTIA for communication systems with directional antennas to determine received power levels is:

$$P_r = \frac{G_r G_t P_t l^2}{16p^2 r^2} \qquad (1)$$

where G_r and G_t are receive and transmit antenna gains,

P_t and P_r are received and transmitted power,

r is the range between the transmitter and receiver, and

l is wavelength.

RFID Proposed Rulemaking Parameters

The maximum field strength proposed in the current rulemaking is 11,000 microvolts per meter measured at a distance of 3 meters using equipment with an average detection function. The maximum peak field strength proposed is 110,000 microvolts per meter measured at 3 meters. Transmit time proposed is a maximum of 120 seconds, with allowances for retransmission if a data error should occur. This results in the following RFID parameters:

Field Strength at 3 meters:	11,000 microvolts average. 110,000 microvolts maximum with 120 second transmit time.

The ground surveillance radar parameters referenced in ITU-R M.1462 are as follows.

Frequency Band: 420-450 MHz

<u>Transmitters and System: General</u>
Up to 5 MW
High Gain Antennas
Polarization: Circular
Scan: EL 3 to 60 degrees; AZ 120-degree sectors, 2 sectors

Track: 1 MHz or 5 MHz chirp
Pulse Repetition Rate (Hz): up to 41

<u>Transmitter:</u>

Power:	Up to 5 MW
Pulse Duration:	0.25, 0.5, 1, 2, 4, 8, 16 msec
Duty Cycle (average):	25%
Pulse Frequency Modulation:	(Linear Chirp)
Search:	100-350 kHz

<u>Antenna Type:</u>

Planar Array:	22+ meter diameter
Antenna Gain:	38.5 dBi
Antenna Scan:	EL: 3-85 degrees; AZ: ± 60 degrees x2
Antenna Beamwidth:	EL: 2.2 degrees; AZ: 2.2 degrees

Receiver:

Noise Temperature: $\leq$450 degrees K

NF = 10 log (1+ T_c/290) = 4.06 dB

IF Bandwidth (MHz) = 1 MHz or 5 MHz

The radar system thermal noise threshold may be calculated using the following equation.

$$P_t = -204 \text{ dBW} + 10 \log B_{IF} + NF_{dB} \qquad (2)$$

N_o (1 MHz) = -139.94 dBW or –109.94 dBm

N_o (5 MHz) = -132.95 dBW or –102.95 dBm

The equation from Freeman, Radio System Design for Telecommunications, Wiley Interscience, page 830, A2.14, may be used to convert the 11,000 microvolts per meter field intensity to power.

$$P(mW) = \frac{1.89972x10^{-8} E^2}{f^2} \qquad (3)$$

where, E is microvolts per meter and
f is frequency in MHz.

Using equation (3) to calculate the power level produced by 11,000 microvolts field intensity at 3 meters one can then use equation (1) to determine the radiated power level at the RFID device.

The average power level at the 3-meter point is

$$P(mW) = \frac{1.89972x10^{-8}(11{,}000)^2}{(433.92)^2} = 1.22x10^{-5}\, mW\,.$$

Using the same equation the peak power at the 3-meter point is

$$P(mW) = \frac{1.89972x10^{-8}(110{,}000)^2}{(433.92)^2} = 1.22x10^{-3}\, mW\,.$$

Solving equation (1) for transmit power using the range of 3 meters the average and peak power at the RFID source may be determined.

$$P_t(mW) = \frac{16p^2 r^2 P_r}{G_r G_t l^2} \qquad (4)$$

where P_r at 3 meters is 12.2 microwatts,
G_r and G_t are 1, 0 dBi antenna gain,
l is 0.69 at 433.92 MHz, and
r is 3 meters.

The average power at the RFID source is

$$P_t = \frac{16p^2(3)^2(1.22x10^{-5})}{(1)(1)(0.69)^2} = 3.641x10^{-2} mW = 36.41 \text{ microwatts,}$$

and the peak power at the RFID source is

$$P_t(mWpeak) = \frac{16p^2(3)^2(1.22x10^{-3})}{(1)(1)(0.69)^2} = 3.641 \text{ mW peak.}$$

The thermal noise threshold for the ground radar system was calculated as –109.94 dBm. Using this noise threshold and the ITU-R M.1462 recommended protection criteria that the undesired signal be at least 6 dB below the receiver noise floor, INR = - 6 dB, the acceptable received signal level without radar processing is –115.94 dBm.

If the difference in radar receiver bandwidth of 1 MHz and the Savi modulation bandwidth of 96 kHz is accounted for then the acceptable received signal level may then be 10.2 dB higher, -105.74 dBm, RSL(I) + W. A 5 MHz radar receiver bandwidth results in 17.6 higher received signal levels.

W = 10 log [1/0.096] = 10.2 dB

or

W = 10 log [5/0.096] = 17.6 dB (5)

Additional improvements are achieved through the use of MTI and Doppler processing techniques. The following section will address the RFID signals without consideration of MTI and Doppler signal processing, which will be considered in later sections.

Using the ITU-R M.1462 recommended INR criteria of –6 dB without the radar-RFID bandwidth consideration, the received signal would be –115.94 dBm or less. If the RFID modulated bandwidth was considered, then the received signal could be –105.74 dBm. Using equation (1) and these received signal criteria, the range necessary to achieve the free space loss necessary to produce these signal levels for both the average radiated power and peak power can be determined. Converting equation (1) to dBm:

$$P_{dbm} = 10\log\frac{G_1 G_2 P_t l^2}{16p^2 r^2} \qquad (6)$$

where G_1 is 38.5 dBi or 7079 numeric gain,
G_2 is 0 dBi or 1 numeric gain,
P_t is the RFID power, 3.644 mW peak or 36.41 microwatt average,
l is the wavelength in meters and,
r is the distance in meters.

Using equation (6) and the acceptable received power level for the average power radiated, one obtains the following range to meet the ITU criteria of –6 dB INR for signals within the 2.2 degree radar antenna beam:

$$\begin{aligned} -115.94dBm &= 10\log\frac{(7049)(1)(0.03641)(0.69)^2}{16p^2 r^2} \\ &= 10\log\,(0.7738)/r^2 \\ r &= [(0.7738)10^{11.594}]^{1/2} = 551.2km \end{aligned}$$

In a similar manner, using the peak power radiated of 3.644 mW, the in-beam range can be determined to be 5,514 km. If the signal bandwidth differences are considered then the in-beam range to meet the ITU recommendation reduces to 170.3 km for the average power and 1,704 km for the peak power radiated. In applying the ITU –6 dB INR criteria, one must keep in mind that this does not necessarily imply harmful interference to the radar but only that the RFID signal is –6 dB below the noise floor of the radar receiver and is undetectable. This will be discussed further when typical surveillance radar signal processing techniques are considered.

These same equations can be applied to the case where the RFID device is not in the main beam of the radar antenna. The sidelobe levels of these surveillance radar systems is at least 30 dB below the peak of the beam resulting in 8.5 dB antenna gain. Using the previous equations, the range reduces to 174 km for the RFID peak power case and 17.5 km for the average power condition and the –6 dB INR criteria. Considering the signal bandwidth differences reduces these ranges to 54 km and 5.4 km.

Radio Amateur

The 420 – 450 MHz band is also assigned for amateur radio operations in the United States and Region 1 and in the other parts of the world the amateurs have 430 – 450 MHz assigned. The operating power limits for amateurs in this band is 1500 watts. These operations may use Omni-directional antennas or directional antennas with gains of 30 dB resulting in EIRP's of 1,500,000 watts, such as the Amateur EME stations operating in the 432 – 433 MHz segment. The ranges necessary to meet the –6 dB INR criteria applied to the RFID devices for the in beam scenarios are 111.8 million kilometers for the 1.5 million watt EIRP case and 3.5 million km for the 1500 watt EIRP case. These ranges reduce to 3.5 million km and 112,116 km, respectively, for the out of beam case. The ranges are further reduced when the 2 kHz SSB amateur modulation and the 1MHz or 5 MHz radar receiver bandwidth are considered. The in-beam ranges are 1703 km for the high power case and 170.3 km for the 1500 watt and 1 MHz radar receiver bandwidth case. The ranges calculated for the 5 MHz radar receiver bandwidth are 726.6 km and 72.6 km respectively. In the sidelobe regions, these reduce to 53.98 km and 5.3 km and 23 km and 2.3 km for the different power levels and radar receiver bandwidths.

Radar Antenna Beam to RFID System Geometry

The radar antenna array beam center is located approximately 20 meters above the ground level and has a scan range in the elevation plane of 3 to 85 degrees. The RFID interrogator is positioned not more than 10 meters above ground level. The geometry between these two systems when separated by at least 650 meters place the RFID system at least one beamwidth below the edge of the radar main beam bottom edge. This places the RFID signal in the sidelobe region of the radar antenna pattern that is at least 30 dB below the peak of the main beam. The analysis will consider the effects of RFID signal intersection with the radar main beam and sidelobe interactions for completeness of the analysis.

Analysis Summary

The following table provides a summary of the results produced in the previous sections for the ranges that the ITU INR –6 criteria is satisfied with out signal processing.

Analysis Scenario	RFID		Amateur Radio	
	ITU Criteria INR = -6 dB	Signal BW W = 10.2 / 17.6 dB	1500 W Omni	1.5 MW Directional
In-beam P(ave)	551 km	170 km/ 72.6	3.5 million km	112 million km
In-beam P(peak)	5514 km	1704 km/ 726.6 km	-----	-----
Out of beam P(ave)	17.5 km	5.4 km/ 2.3 km	112,117 km	3.3 million km
Out of beam P(peak)	174 km	54 km/ 23 km	-----	------

Table 1 Summary of Analysis Results for RFID and Amateur Radio Signals received by 420 – 450 MHz Ground Radar Systems with INR's of – 6 dB.
Note: Geometry precludes main beam interaction for RFID systems.

Radar Signal Processing

Ground radar systems must also contend with ground clutter return signals, in addition to other unwanted signals, that are received from undesired land scatters. This surface clutter is described by the radar clutter cross section per unit area illuminated and will vary as a function of the grazing angle. The clutter returns will be in the range of –20 dB to –30 dB for 10 to 20 degree grazing angles. It is for this reason that the radar antenna beam and scan angle is limited at low elevation angles. This antenna technique and radar signal processing are used to improve the capabilities of these ground radar systems and eliminate unwanted signals.

In order to operate and be capable of detecting small radar cross section targets such as low flying missiles and aircraft, these surveillance radar systems must use signal processing techniques to eliminate the unwanted signals. The more classical techniques include range gates, linear chirp modulation, pulse averaging, MTI (Moving Target Indicator), and Doppler signal processing. Each of these techniques will be discussed briefly in the following sections and one will quickly come to the conclusion that signal processing is vital for the operation of these ground surveillance radar systems.

Pulse averaging can be accomplished by integrating n return pulses to increase the received return signal power for detection. Range gates can be used in conjunction with pulse averaging to exclude unwanted signals and increasing the detection level of the desired pulse(s). The improvements to the desired signal is typically in the range of 20 dB to 30 dB. This is particularly useful during initial signal acquisition stage prior to entering the tracking stage.

Linear chirp modulation and signal processing is used to increase the detection level of radar signal returns over unwanted signals. The gain is proportional to 10log BT, where B is the radar bandwidth and T is the chirp pulse time. The improvement in signal-to-noise improvement will range 15 dB to 20 dB for typical chirp radar.

Good radar practice requires clutter return signals that are received from undesired scatters such as land and sea surface returns to be minimized if not completely eliminated to prevent degraded detection of desired targets. Delay-line cancellers are used to process moving targets and reject stationary clutter returns. The single delay-line canceller will produce processing gains of 20 to 40 dB and a double delay-line canceller will produce processing gains of 40 to 80 dB.

As a part of the clutter processing, the Doppler processing allows the radar system to discriminate between signals received from fixed or slow moving returns or signals from fixed emitters and high-speed objects. This is a powerful processing technique for surveillance radar systems in that it allows the system to reject signals detected from amateur and RFID devices operating on the radar frequency.

Another aspect of the clutter processing is the use of range gates. Unwanted detected signals from a point source can be identified and rejected by gating the radar receiver to a time synchronized with the expected return of a wanted return that has been identified and being tracked. The dynamics of the airborne radar and desired returns from fast moving targets and the fixed nature of the unwanted signals allows the airborne radar to be effective in detecting and tracking desired targets while receiving and rejecting unwanted signals.

Many of these surveillance radar systems will also use an interference elimination technique of looking at the magnitude of a number of the pulses received during the beam scan, average those received signals and reject those that are greater than 5 times the average of those received from that range-azimuth.

Applying pulse averaging and delay-line cancellers and other signal processing techniques produce processing gains of 60 to 110 dB. Applying only 85 dB of signal processing will reduce the range interaction value for the peak power in-beam case (as shown in Table 2) to less than 15 meters, if it were possible for the energy emitted by an RFID to be within the beam.

Use of the ITU-R M. 1462 criteria of a INR of –6dB would at first appear to be applicable to determining that there were no harmful impairment to the operational and performance capability of ground-based radar systems which by their nature can see for long distance with sensitive receivers. The ITU criteria have been used for protection of point to point communication links and satellite links for many years. Radar systems must contend with the unwanted signal returns for proper operation and for that reason make extensive use of signal processing techniques to have the required capabilities to be effective. The metric of unwanted signal acceptability based on signal level or range is only a qualitative measure of radar effectiveness. The actual measurement of radar effectiveness is based on statistical decision and probability theory. Two references for radar system design and operation are:

Radar Detection, J.V. DiFranco and W.L. Rubin, Artech House and
Introduction to Radar Systems, Merrill Skolnik, McGraw-Hill Publishing.

The publication by Skolnik provides an excellent example (Chapter 4, pages 127 – 129) of a Moving Target Detector radar processor and clutter reduction or elimination of the FAA's Airport Surveillance Radars (ASR). These ground surveillance civilian ASR radar systems based on developments by the MIT Lincoln Laboratory were designed and built by Texas Instruments and Raytheon.

The ranges of signal processing improvements achieved by these ground radar systems are summarized as follows.

Processing Technique	Minimum Improvement	Maximum Improvement
Bandwidth (1MHz/5MHz)	10.2 dB	13.3 dB
Pulse Averaging	20.0 dB	30.0 dB
Linear Chirp	15.0 dB	20.0 dB
Clutter/Doppler	40.0 dB	80.0 dB
Total Improvements	85.2 dB	143.3 dB

Analysis Scenario	RFID		Amateur Radio (without signal processing)	
	ITU Criteria INR = -6 dB	Signal Processing	1500 W Omni	1.5 MW Directional
In-beam P(ave)	551 km *	31 m *	199 km	6291 km
In-beam P(peak)	5514 km *	310 m *	-----	-----
Out of beam P(ave)	17.5 km	1 m	6.3 km	199 km
Out of beam P(peak)	174 km	9.82 m	-----	------

Table 2 Summary of Analysis Results for RFID without radar signal processing and with 85 dB of radar signal processing and Amateur Radio Signals with signal processing received by 420 – 450 MHz Ground Radar Systems with INR ‘s of – 6 dB. * Geometry precludes RFID main beam interaction.

Conclusions

Use of the ITU-R M. 1462 criteria of a INR of –6dB would at first appear to be applicable to determining that there were no harmful impairment to the operational and performance capability of ground radar systems which by their nature can see for long distance with sensitive receivers. The ITU criteria have been used for protection of point to point communication links and satellite links for many years. Radar systems must contend with the unwanted signal returns for proper operation and for that reason make extensive use of signal processing techniques to have the required capabilities to be effective.

It is important to remember that the current Part 15 rulemaking maintains the same average and peak power levels being used by existing RFID devices.

The following conclusions can be drawn from the preceding sections.

- **The proposed Part 15 rulemaking uses the same average and peak power levels currently imposed by the Part 15 rules and these power levels do not cause harmful interference to the ground radar systems.**

- **The RFID devices peak power transmissions may be extended from their current 10 percent duty cycle to transmission periods of up to 120 seconds under the proposed Part 15 rulemaking for RFID devices without creating new threats to the operational capabilities of the surveillance radars.**

- **The radio amateur operators that currently share the band with the radar systems operate at levels of 56 dB to 86 dB higher than that allowed for RFID devices; i.e., the EME amateur station has an output power level of over 400 million times stronger than the maximum peak RFID power level.**

- **The radar's own normal clutter return in itself is enough to degrade and impair the operation of these surveillance radar systems if not addressed and requires signal processing to be used to be effective.**

- **The radar signal processing capabilities allow the radar systems to be effective not only in the presence of clutter but also when the large amateur signals and low–level Part 15 signals are detected in the band.**

- **Use of the ITU –6 dB INR criteria does not provide a measure of radar capability (or lack there of) or proper radar operation. Radar signal processing capabilities must also be considered.**

- **Ground radar systems use antenna and advanced radar signal processing capabilities to achieve their operational capabilities.**

- **The existing amateur and Part 15 RFID devices do not provide harmful interference to the ground radar systems per the definition of Part 15.3 (m).**

- **The proposed Part 15 rulemaking extending the RFID current peak 110,000 microvolts per meter field intensity transmit time to 120 seconds will not result in harmful interference since it will not degrade or interrupt the radar operation.**