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X-band Wave Radar
Radiation Hazards to Personnel

FutureWaves™ Wave-i 1.00 RF Exposure Statements

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1.0	Initial Draft	John Kusters	26 NOV 2019

1. Overview

This document addresses the potential hazard to personnel of using X-band radar and recommended mitigations to reduce risk of that hazard. Specific direction to mitigate this hazard is provided per each unique FutureWaves™ installation. This document serves as a general overview of the RF exposure risks and RF Exposure Safety Distances.

The antenna gain used with this transmitter should be 28 dBi or less and all persons should maintain a minimum safety separation distance of 35cm while functioning properly.

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2. Background

Various organizations and countries have developed exposure standards for radio frequency (RF) energy. These standards recommend safe levels of exposure for both the general public and for workers. In the United States, the Federal Communications Commission (FCC) has adopted and used recognized safety guidelines for evaluating RF environmental exposure since 1985.

The FCC guidelines for human exposure to RF fields were derived from the recommendations of two expert organizations, the National Council on Radiation Protection and Measurements (NCRP) and the Institute of Electrical and Electronics Engineers (IEEE). Expert scientists and engineers developed both the NCRP exposure criteria and the IEEE standard after extensive reviews of the scientific literature related to RF biological effects. The exposure guidelines are based on thresholds for known adverse effects, and they incorporate appropriate margins of safety. Many countries in Europe and elsewhere use exposure guidelines developed by the International Commission on Nonionizing Radiation Protection (ICNIRP). The ICNIRP safety limits are generally similar to those of the NCRP and IEEE, with a few exceptions. The NCRP, IEEE, and ICNIRP exposure guidelines state the threshold level at which harmful biological effects may occur, and the values for maximum permissible exposure (MPE) recommended for power density are based on this threshold level.

The industrial specifications set for radiation hazard to personnel are contained in ANSI/IEEE C95.1-2005 (IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz) and the United States Federal Communications Commission (FCC) Title 47 Section 1.1310 – Radiofrequency radiation exposure limits. Per these references the occupational/controlled MPE limits for an X-band (8.0 to 12.0 GHz) radar is a power density of ***5 mW/cm²*** for a 6 minute averaging time. Occupational/Controlled MPE limits apply in situations in which persons are exposed as a consequence of their employment provided those persons are fully aware of the potential for exposure and can exercise control over their exposure. These MPE recommendations are made to protect against established adverse health effects in human beings associated with exposure to electric, magnetic and electromagnetic fields in the frequency range of 3 kHz to 300 GHz. The recommendations are expressed in terms of basic restrictions (BRs) and MPE values. The BRs are limits on internal fields, specific absorption rate (SAR), and current density; the MPEs, which are derived from the BRs, are limits on external fields and induced and contact current. The recommendations, which protect against effects associated with electrostimulation and tissue and whole-body heating, are intended to apply to all human exposures except for exposure of patients by, or under the direction of, physicians and medical professionals. These recommendations are not intended for the purpose of preventing interference with medical and other devices that may exhibit susceptibility to RF fields.

Using the MPE limit an effective safety zone around the radar transmitters can be determined and a boundary established to reduce risk of excessive exposure. To calculate this safety zone APS used IEEE Std C95.3™-2002 (R2008) - Recommended Practice for Measurements and Computations of Radio Frequency Electromagnetic Fields With Respect to Human Exposure to Such Fields, 100 kHz–300 GHz. In determining the safety zone for a radar system a number of factors affecting the RF power density must be considered:

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- Radar systems send electromagnetic waves in pulses and not continuously. This makes the average power emitted much lower than the peak pulse power.
- Radars are directional and the RF energy they generate is contained in beams that are very narrow and resemble the beam of a spotlight. RF levels away from the main beam fall off rapidly. In most cases, these levels are thousands of times lower than in the main beam.
- Many radars have antennas which are continuously rotating and thus constantly changing the direction of the beam.

3. Wave Radar Specifications

The FutureWaves™ X-band Wave Radar is a magnetron-based peak pulsed-power marine radar with a slotted-array V-pol antenna.   Specifications are:

Parameter	Value	Units
Transmitter Peak Power	25	kW
Transmitter Frequency	9410 ± 30	MHz
Pulse Length	50, 250, 750	ns
Pulse Repetition Frequency (PRF)	2100, 1300, 650	Hz
Antenna Horizontal Beam Width	1.8	deg, -3dB beam width
Antenna Vertical Beam Width	23	deg, -3dB beam width
Antenna Main Beam Gain	28	dBi relative to isotropic
Horizontal side lobes at +/-10 deg.	-26	dB relative to main lobe
Horizontal side lobes elsewhere	<-29	dB relative to main lobe
Rotation Rate	144	deg/sec
Operating Modes:	Mode 1: 50 ns pulse at 2100 Hz PRF	
	Mode 2: 250 ns pulse at 1300 Hz PRF	
	Mode 3: 750 ns pulse at 650 Hz PRF	

4. Calculations

To meet the power density limitation of 5 mW/cm^2 a safety zone is determined by using the power density, P_D, (watts/square meter) equation:

$$P_D = \frac{P_{AVG} G_t}{4\pi r^2}$$

where G_t is the transmitter antenna gain (as a ratio) and

$$P_{AVG} = P_{peak} \times PRF \times \tau$$

where τ is the pulse length or duration in seconds.

In the case of directional scanning antennas, such as this wave radar application, the power at any point/time is varying with the rotation, and the average power density at a fixed point is

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reduced by the value of the effective antenna-pattern beam-width, θ_{BW}, divided by the scanning angle (the number of degrees of antenna rotation during a scan):

$$P_{D_{scan}} = P_{D_{fixed}} \times \theta_{BW}/360$$

Solving for the safety range where the power density, $P_{D_{MPE}}$, limitation is met:

$$R_{safety} = \sqrt{\frac{P_{AVG} G_t}{P_{D_{MPE}}(360/\theta_{BW})4\pi}}$$

As an example for the wave radar in mode 1 (50 ns pulse length and 2100 Hz PRF) and inserting the specification values we have:

$$P_{AVG} = 25\ kW \times 2100\ Hz \times 50\ ns = 2{,}625\ mW$$

$$R_{safety} = \sqrt{\frac{2{,}625\ mW \ \times 631}{5\ mW/cm^2 \times (360/3.6) \times 4\pi}}$$

where for antenna gain of 28 dB: $G_t = 10^{2.8} = 631$

The result is a safety zone with: $R_{safety} = 16.2\ cm$ for mode 1.

For mode 2 (250 ns pulse length and 1300 Hz PRF), the result is 29 cm, and for mode 3 (750 ns pulse length and 650 Hz PRF), the most limiting case, the result is 35 cm.

Thus for the wave radar operating in its normal scanning mode the power density limitation is met outside a radius of 35 cm from the unit. With the transmitting unit located at the top of a 2.5m mast, the 35 cm safety distance is met at deck level for persons of height up to 2m.

Should the radar malfunction and stop scanning/rotating yet continue to transmit, the safety radius is increased by a factor of 10. In order to account for this worst case scenario of a malfunction while in mode 3, signs as shown in Figure will be posted at this distance (3.5 m) from the radar masts.

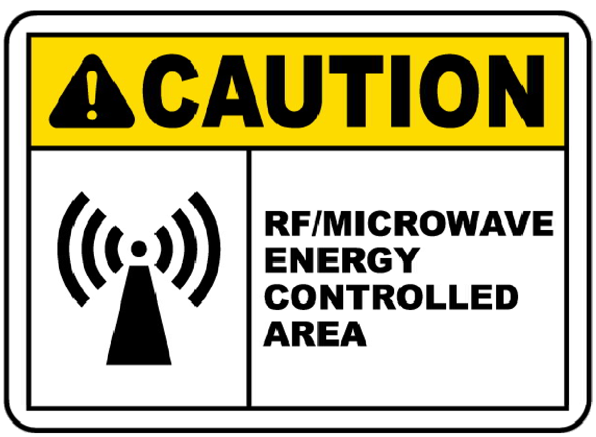

Figure 1: Radar Warning Sign