ISSN/2499-5347

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RT/2023/15/ENEA

ITALIAN NATIONAL AGENCY FOR NEW TECHNOLOGIES,
ENERGY AND SUSTAINABLE ECONOMIC DEVELOPMENT

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Vanni Lopresto

Abstract

The Jammer is an electromagnetic device capable of interrupting the radio communication channel and blocking the command signal of electrical and electronic equipment, through the emission of a series of radio frequency (RF) electromagnetic field pulses at the same frequencies of the signal to be hindered. Therefore, the jammer can represent a valid electronic countermeasure for protection against terrorist attacks or espionage, carried out also by drones. Nevertheless, since jammers intentionally emit RF electromagnetic fields to deliberately interfere with radio communications, they may also cause malfunctions or failures of friendly electrical equipment (e.g., two-way radios, computers, etc.) within their action range. Furthermore, the RF emissions of jammers can pose problems regarding the possible exceeding of the restrictions on human exposure to electromagnetic fields for the protection from possible health risks. Hence, in most countries the placing on the market and the use of jammers is regulated by strict provisions and is normally prohibited without a specific government authorization. This Technical Report illustrates the regulatory framework concerning the placing on the market and use of jammers, the radiated immunity requirements relating to basic safety and essential performance of electrical equipment, as well as the restrictions on human exposure to electromagnetic fields for the purpose of protection against possible health and safety risks. In addition, a case study concerning electromagnetic fields emitted by a portable jammer for defeating drone attacks is illustrated, with the purpose to determine the relevant safety distances for compliance with the requirements for radiated immunity of electrical equipment and the exposure restrictions for the general public.

Key words: *Electromagnetic fields, jammers, risk assessment, drones, human exposure, electromagnetic interferences.*

Riassunto

Il Jammer è un dispositivo elettromagnetico in grado di interrompere il canale di radiocomunicazione e bloccare il segnale di comando di apparecchiature elettriche ed elettroniche, attraverso l'emissione di una serie di impulsi di campo elettromagnetico a radiofrequenza (RF) alle stesse frequenze del segnale da ostacolare. Il jammer rappresenta quindi una valida contromisura elettronica per la protezione da attacchi terroristici o dallo spionaggio, realizzati anche tramite droni. Tuttavia, poiché i jammer emettono intenzionalmente campi elettromagnetici a RF allo scopo di interferire deliberatamente con le comunicazioni radio, essi possono causare malfunzionamenti o guasti anche di apparecchiature elettriche amiche (ad. es. ricetrasmittenti, computer, ecc.) che si trovino all'interno del loro raggio di azione. Inoltre, le emissioni a RF dei jammer possono porre problemi anche riguardo al possibile superamento dei limiti di esposizione a campi elettromagnetici vigenti per la protezione da possibili rischi per la salute delle persone. Pertanto, nella maggior parte dei Paesi l'immissione sul mercato e l'utilizzo dei jammer è regolato da disposizioni rigorose ed è normalmente vietato senza una specifica autorizzazione governativa. Nel presente Rapporto tecnico si illustra il quadro normativo di riferimento inerente all'immissione sul mercato e all'uso dei jammer, ai requisiti di immunità irradiata relativi alla sicurezza di base e alle prestazioni essenziali delle apparecchiature elettriche, nonché ai limiti vigenti per l'esposizione umana a campi elettromagnetici ai fini della protezione da possibili rischi per la salute e la sicurezza. Inoltre, viene illustrato un caso di studio inerente ai campi elettromagnetici emessi da un jammer portatile per il contrasto degli attacchi con droni, con lo scopo di determinare le distanze di sicurezza per il rispetto dei requisiti di immunità irradiata delle apparecchiature elettriche e dei limiti per l'esposizione della popolazione.

Parole chiave: Campi elettromagnetici, jammer, valutazione dei rischi, esposizione umana, interferenze elettromagnetiche.

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1. Scope of the technical report

This technical report outlines the regulatory framework as regards to the placing on the market and use of jamming devices, the radiated immunity requirements relating to basic safety and essential performance of equipment, and the restrictions on human exposure to electromagnetic fields (EMF) to protect from possible health and safety risks. Moreover, a risk assessment has been carried out as regards to the EMF emitted by a hand-held jammer for defeating drone attacks, with the purpose to determine the safety distances for respecting the relevant provisions regarding the radiated immunity of electrical equipment and the exposure restrictions for the general public.

2. Background

The Jammer is a device able to interrupt the radiocommunication channel and block the control signal of electronic equipment through the emission of a series of radiofrequency (RF) EMF pulses at the same frequencies of the signal to be hindered. In a military environment, the jammer represents a valid electronic counter measure for protecting, e.g., against terrorist attacks or against espionage, thanks to the ability to disrupt radiocommunications or radar surveillance. To be effective, the jammer power signal must be equal or higher than the signal power at the receiver, at least one order of magnitude, so that the two signals can collide and cancel each other. Some jamming devices can also be equipped with global navigation satellite system (GNSS) disruption capability that can jam commercial satellite navigation frequencies.

Jamming devices can be classified as mobile and stationary. Mobile jammers include hand-held, land-vehicle portable, and airborne. The hand-held jammer is installed inside a case so that use in adverse (environmental, weather-related, etc.) conditions does not compromise its functionalities. Its purpose is to protect against improvised explosive devices, disrupt enemy communications, defeat drone attacks, etc. For example, in case of a drone approaching a forward operating base, hovering over a large crowd, snooping into secure/private areas, or flying in restricted airspace, a hand-held jammer can be employed to quickly interrupt the drone command link causing the drone to either crash, hover in place, or land.

Typical operational frequencies of jammers range from approximately 400 MHz to 6 GHz with continuous linear frequency sweep, while transmitted power vary based on the effective

range and directional gain, from some watts for hand-held devices to tens or hundreds of watts for high-power and long-range applications.

Since jammers intentionally emit RF-EMF for the purposes of deliberately interfering with radio communications, they may also cause malfunction or break down of friendly electrical equipment within their effective range, particularly if using omnidirectional antennas. Likewise, RF emissions from jammers may pose issues concerning possible exceeding of EMF restrictions on human exposure for protection from possible health and safety risks, as regards to any subjects in their proximity [1].

Based on the above reported issues, impacting on the safety of both electrical equipment and individuals, in most countries the placing on the market and the use of jamming devices is regulated by strict provisions and is normally prohibited without a specific government authorisation.

3. Regulatory framework

3.1. Regulatory framework on placing on the market and use of jamming devices

In the United States of America (USA), the federal law prohibits the operation, marketing, or sale of any type of jamming equipment that interferes with authorized radio communications, including cellular and personal communication services, police radar, and Global Positioning Systems (GPS). The Communications Act of 1934 (47 U.S.C. § 301) [2] requires persons operating or using radio transmitters to be licensed or authorized under the Commission's rules. Unauthorised use, marketing or sale of jamming devices is a violation of US federal law. Accordingly, jammers cannot be offered for sale or lease in the USA until authorization is obtained. Sale to non-US customers is subject to review and authorization under the International Traffic in Arms Regulations (ITAR) [3].

In Europe, the Electromagnetic Compatibility (EMC) Directive 2014/30/EU [4] and the Radio Equipment Directive 2014/53/EU [5] place strict requirements on all electrical and electronic apparatus placed on the market or taken into service, which must not cause excessive interference. Jamming devices cannot therefore be legally placed on the market within the European Union for use under these Directives. The placing on the market or the use of jammers within the European Union is not allowed except in the very limited context of authorised use which may be permitted by a national legislation use (e.g., police or military radio installations) [6]. Likewise, the Italian law prohibits the unauthorized use of jammers,

which constitutes the types of crime referred to in articles 340, 617 and 617-*bis* of the Criminal Procedure Code.

3.2. Regulatory framework on requirements for radiated immunity of electrical equipment

The international standard IEC 61000-4-3:2020 [7], establishes a common reference for evaluating the radiated immunity of electrical equipment when subjected to radiofrequency (RF) electromagnetic fields for frequencies higher than 80 MHz with no upper frequency limitation. In particular, the standard establishes the test levels and related strength of radiated electric (*E*) field, in terms of maximum root-mean-square (rms) values, for protection against radiated RF emissions generated by general-purpose, digital radio telephones and other RF emitting devices (TABLE 1).

TABLE 1. *Radiated immunity test levels related to RF emissions from general-purpose, digital radio telephones and other RF emitting devices (source: IEC 61000-4-3:2020)*

Test Level	**Radiated *E*-field strength [V/m]**
1	1
2	3
3	10
4	30
X	Special

Note to TABLE 1:

- Test field strength (maximum rms value) is related to unmodulated carrier signal.
- Level X is an open test level, and the associated field strength may be any value. This level may be given in the product standard.

The following classes of immunity from radiated EMF emissions in the environment (electromagnetic environment) are related to the field levels of IEC 61000-4-3 listed in TABLE 1.

- *Class 1*: Low-level electromagnetic radiation environment. Levels typical of local radio/television stations located at more than 1 km, and transmitters/receivers of low power.

- *Class 2*: Moderate electromagnetic radiation environment. Low power portable transceivers (typically less than 1 W rating) are in use, but with restrictions on use in close proximity to the equipment. A typical residential or commercial environment.
- *Class 3*: Severe electromagnetic radiation environment. Portable transceivers (2 W rating or more) are in use relatively close to the equipment but not less than 1 m. High power broadcast transmitters are in close proximity to the equipment and ISM equipment may be located close by. A typical industrial environment.
- *Class 4*: Portable transceivers are in use within less than 1 m of the equipment. Other sources of significant interference may be within 1 m of the equipment.
- *Class x*: x is an open level which might be negotiated and specified in the product standard or equipment specification.

General-purpose electrical equipment, such as information and communications technology (ICT) equipment with intended use in a moderate electromagnetic radiation environment typical of residential or commercial environment, are normally tested for *Class 2* radiated immunity level (TABLE 1).

Electrical equipment with intended use in specific environments or applications may be required to be tested against more severe levels of radiated immunity to ensure higher protection from radiated interferences, as specified in the relevant product standards. The international standard IEC 60601–1-2:2014 [8] specifies a radiated RF immunity level of 10 V/m for medical electrical equipment with intended use in environments with electromagnetic disturbances that might be not well characterised or well controlled in terms of amplitude and probability of occurrence, such as domestic and commercial environments. The US military standard MIL-STD-461G envisages a radiated *E*-field strength of 50 V/m for radiated immunity testing of army-ground equipment or subsystems [9].

3.3. Regulatory framework on limitation of human exposure to EMF

The restrictions on human exposure to EMF, established by international guidelines and European regulations, aim at protecting against direct and indirect effects arising when the exposure levels exceed certain threshold values. To this purpose, appropriate reduction factors are applied to set the occupational limits with respect to the threshold values ascertained for the onset of adverse effects, i.e., thermal effects and electrical stimulation. Additional reduction factors are applied to the exposure restrictions of general public, including individuals at particular risk such as bearer of medical devices and pregnant women.

The US Code of Federal Regulations 47 CFR 1.1310 [10] addresses exposure to EMF within the frequency range of 100 kHz to 6 GHz (inclusive). The limits are expressed as Maximum Permissible Exposure (MPE), i.e., ambient levels to evaluate the environmental impact of human exposure to RF-EMF for both occupational/controlled exposure and general population/uncontrolled exposure.

The European Directive 2013/35/EU defines the exposure limit values (ELV) and the action levels (AL) to limit the exposure of workers to EMF up to 300 GHz [11]. Likewise, the Council Recommendation 1999/519/EC defines the basic restrictions (BR) and the reference levels (RL) for the limitation of exposure of general public to EMF up to 300 GHz [12]. The BR and the ELV are expressed as *in situ* restrictions based directly on established short-term and acute direct effects, whereas the RL and the AL are expressed as ambient levels (unperturbed rms values to be averaged over any six-minute period) provided for practical exposure-assessment to determine whether the BR and the ELV are likely to be exceeded or to take, where appropriate, relevant protection or prevention measures.

It is to be noted that compliance with the exposure restrictions for the general public ensures compliance with the requirements for workers without further assessment.

In Italy, pursuant the Framework Law 36/2001 [13], occupational exposures to EMFs unrelated and not necessary to the specific working task assigned, namely non-professional exposures, are to be assimilated to those of general public for which the related exposure restrictions apply. To protect against exposure to EMF generated at frequencies between 100 kHz and 300 GHz, generated by sources not attributable to fixed telecommunications and radio and television systems, the complete set of restrictions established in the Council Recommendation 1999/519/EC apply [14].

For wearers of active implanted medical devices (AIMD) − e.g., pacemakers, implanted cardiac defibrillators, etc. − the European technical standard EN 50527-1:2016 [15] establishes that the assessment of compliance with the RL for the general public in the Council Recommendation 1999/519/EC [12] is to be carried out without including any time average for frequencies above 100 kHz, for the purpose of protecting from possible interference with the normal operation of AIMD.

4. EMF risk assessment

4.1. Equipment technical specifications

The device under assessment is a hand-held jammer (*Dronebuster BLK-3B*, manufactured by Flex Force Enterprises Inc., Portland, OR, USA) used for defeating drone attacks, 56 cm long, weight under 3 kg, not requiring any external power source or auxiliary equipment (Figure 1).

Figure 1. Hand-held jammer Dronebuster BLK-3B (source: Flex Force Enterprises Inc.)

The device is highly directional, with limited area of effect to reduce radiated interferences with friendly electrical equipment in the surroundings. The transmitted waveform is a continuous linear frequency sweep; therefore, duty cycle is 100%. The effective range depends upon the operational scenario and environment; the manufacturer declares an effective range over 2 km under normal operating conditions.

The transmitter power and antenna gain provided by the manufacturer are listed in TABLE 2. Antenna gain values listed in Table 2 are the peak gain at a front of the device in vertical polarization.

TABLE 2. Transmitter power and antenna gain of Dronebuster BLK-3B
(source: Flex Force Enterprises Inc.)

Frequency	Transmitter Power [dBm]	Antenna Gain [dBi]	Antenna Type
433 MHz	34	2.3	Folded dipole
915 MHz	34	6.5	3-element dipole
1,57 GHz	20	4	Tapered slot with Z match
2,4 GHz	38	9,3	Tapered slot with Z match
5,8 GHz	36	12,7	Tapered slot with Z match

4.2. Evaluation of compliance with the low-power exclusion level

A preliminary evaluation of compliance with the requirements for exposure to EMF (10 MHz − 300 GHz) has been carried out in accordance with the European technical standard EN 50663:2017 [16]. It is to be noted that equipment complying with the requirements for the general public is deemed to comply with the requirements for workers without further testing.

According to EN 50663:2017, low-power equipment is deemed to comply with the basic restrictions for the general public if it can be demonstrated that the maximum average total radiated power (P_{max}) cannot exceed the *low-power exclusion level*. Clause 6 of the referred standard provides the values of P_{max} not to be exceeded for conformity assessment with the relevant basic restrictions for the general public (TABLE 3).

TABLE 3. Low-power exclusion level Values of P_{max} not to be exceeded for conformity assessment with the basic restrictions for exposure of the general public (source EN 50663:2017)

Exposure tier	Region of body	P_{max} [mW]	P_{max} [dBm]
General public	Head and trunk	20	13
	Limbs	40	16
Workers	Head and trunk	100	20
	Limbs	200	23

Since the values of transmitter power listed in TABLE 2 exceed the values of P_{max} listed in TABLE 3, it can be inferred that the *Dronebuster BLK-3B* does not satisfy the *low-power exclusion level*, therefore *the device cannot be considered inherently compliant with the EMF exposure restrictions for the general public*. Consequently, it is necessary performing a more thorough risk assessment by means of calculations or measurements, in order to evaluate the EMF exposure levels generated by the device for comparison with the relevant exposure restrictions.

4.3. Field strength calculations

For the operational frequencies listed in TABLE 2, the far-field condition (i.e., $r \gg \lambda$, being r the distance from the antenna in m; $\lambda = c/f$ the wavelength in m; $c \cong 3 \cdot 10^8$ the light speed in vacuum in m/s; f the frequency in Hz) is always satisfied for distances from the device greater than 70 cm. Under these premises, the ambient electric (*E*) field strength in free space at a front of the device can be calculated by means of the following equation:

$$\left|\vec{E}\right| = \sqrt{S \cdot Z_0} = \frac{\sqrt{30\, P_t\, G_t}}{D} \quad (1)$$

Where:

- $\left|\vec{E}\right|$ is the electric field strength in terms of unperturbed rms value (V/m);
- $S = \frac{P_t\, G_t}{4\pi D^2}$ is the power flux density (W/m^2);
- P_t is the transmitter power (W);
- G_t is the antenna gain;
- $Z_0 = 120\pi$ is the intrinsic impedance of air (Ω);
- D is the distance from the antenna (m).

Provided that the far-field condition be satisfied and based on the values of transmitter power and antenna gain listed in TABLE 2, it is possible calculating by means of equation (1) the Safe separation distance (SSD) from the device so that a certain ambient *E*-field strength cannot be exceeded. Accordingly, it is possible calculating the SSD for the purpose of compliance with the restrictions on EMF exposure of the general public in terms of RL or MPE, as well as the SSD for compliance with a given level of radiated immunity for electrical equipment.

The calculation of SSD by equation (1) cannot be applied to assess exposure compliance of personnel using the jammer, because the device with its antenna is very close to the body, and hence the far-field condition required for calculation is not satisfied. In such a case, it is necessary performing an exposure assessment against the basic restrictions by way of dosimetry, which is however out of the scope of this report.

4.4. Calculations of Safe separation distances (SSD) for compliance with exposure restrictions of general public

In TABLE 4 are reported the SSD, calculated by means of equation (1) on the basis of the input values of transmitter power and antenna gain for the operational frequencies listed in TABLE 2, for the purpose of compliance with the ambient *E*-field related to general public exposure referred to in Council Recommendation 1999/519/CE (RLE). Likewise, TABLE 4 reports the MPE for ambient E-field related to uncontrolled and general public exposure referred to in US Code of Federal Regulations (FCC). Both the RL and MPE are intended here as maximum unperturbed rms values, i.e., without any temporal average, to account for risk of interference with AIMD.

TABLE 4. Safe separation distances (SSD) for compliance with EMF exposure restrictions of general public

Inputs					Outputs	
Frequency [GHz]	**P_t [dBm]**	**G_t [dBi]**	**RLE [V/m]**	**FCC [V/m]**	**SSD_{RLE} [m]**	**SSD_{MPE} [m]**
0,433	34	2,3	29	33	0,70* (0,40)	0,70* (0,34)
0,915	34	6,5	42	48	0,44	0,38
1,57	20	4	54	61	0,20* (0,05)	0,20* (0,05)
2,4	38	9,3	61	61	0,66	0,66
5,8	36	12,7	61	61	0,77	0,77

*Note to TABLE 4 − In case the SSD resulting from the calculation is smaller than the wavelength so that the far-field condition is not satisfied, then the corresponding wavelength has been identified as SSD.

Based on the results of calculations reported in TABLE 4, *a precautionary distance of 1 m from a front of the jammer under assessment can be identified as the SSD that ensures compliance with the relevant restrictions on exposure of general public to EMF for the purpose of protection from possible health and safety risks.*

4.5. Calculations of Safe separation distances (SSD) for radiated immunity of electrical equipment

In TABLE 5 are reported the SSD, calculated by means of equation (1) on the basis of the input values of transmitter power and antenna gain for the operational frequencies listed in TABLE 2, for the purpose of compliance with the requirements for radiated immunity of electrical equipment, both *Class 2* (3 V/m) and *Class 3* (10 V/m) referred to in IEC 61000-4-3, and with the requirements for radiated immunity of army-ground equipment referred to in MIL-STD-461G (50 V/m).

TABLE 5. Safe separation distances (SSD) for radiated immunity of electrical equipment

Inputs						Outputs		
Frequency [GHz]	**P_t [dBm]**	**G_t [dBi]**	**Class 2 [V/m]**	**Class 3 [V/m]**	**MIL [V/m]**	**$SSD_{Class\ 2}$ [m]**	**$SSD_{Class\ 3}$ [m]**	**SSD_{MIL} [m]**
0,433	34	2,3	3	10	50	3,77	1,13	0,70* (0,23)
0,915	34	6,5	3	10	50	6,12	1,83	0,37
1,57	20	4	3	10	50	0,92	0,27	0,20* (0,05)
2,4	38	9,3	3	10	50	13,38	4,01	0,80
5,8	36	12,7	3	10	50	15,72	4,72	0,94

*Note to TABLE 5 – In case the SSD resulting from the calculation is smaller than the wavelength so that the far-field condition is not satisfied, then the corresponding wavelength has been identified as SSD.

Therefore, based on the results of calculations reported in TABLE 5, *the precautionary SSD of 16 m, 5 m, and 1 m from the jammer under assessment should be kept by electrical equipment tested against radiated RF immunity level of 3 V/m (Class 2), 10 V/m (Class 3), and 50 V/m (army-ground), respectively*. It is worth noting that ICT equipment for general-purpose applications (e.g., personal computers and mobile phones) are usually tested against *Class 2* radiated immunity level.

5. Conclusions

In this report, the regulatory framework regarding the placing on the market and use of jamming devices has been outlined, along with the safety requirements relating to both the protection of electrical equipment against radiated electromagnetic interferences and the limitation of human exposure to radiofrequency (RF) electromagnetic fields (EMF).

A methodology based on calculations has been provided, in order to determine the safe separation distance (SSD) from a jamming device that allows compliance with the relevant safety provisions relating to radiated immunity of electrical equipment and limitation of EMF exposure of the general public. By this methodology, a risk assessment has been carried

out as regards to the EMF emitted by a hand-held jammer for defeating drone attacks, operating in the frequency range 433 MHz to 8 GHz with maximum transmitter power of 38 dBm. It is to be noted that the methodology cannot be applied to the personnel using the jammer, for which an exposure assessment against the relevant basic restrictions for occupational exposure should be carried out by way of dosimetry since the antenna is very close to the body.

The results of risk assessment evidenced that a SSD of 1 m ensures compliance with the restrictions on exposure of the general public referred to in Council Recommendation 1999/519/EC and US Code of Federal Regulations, whereas a SSD of 16 m ensures compliance with the requirements for radiated immunity of general-purpose ICT equipment referred to in IEC 61000-4-3:2020.

The outcome of risk assessment is related to the specific jammer under investigation. Nevertheless, it is apparent from this study that particular care must be taken regarding the safety of both individuals and equipment in the exposure scenario of jammers. In particular, *this study highlights that friendly electrical equipment may unintentionally be interfered by jammers up to distances significantly higher than the separation distance for safety of the general public.*

6. Acknowledgement

This study has been carried out within the European project INCLUDING – Innovative Cluster for Radiological and Nuclear Emergencies (www.including-h2020.eu), funded by the European Commission under the HORIZON 2020 program.

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Stampa: Laboratorio Tecnografico ENEA - C.R. Frascati
luglio 2023