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Wireless Access Method and Physical Layer Specification

Title: Safety Issues of the Baseband IR PHY

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Summary

This document presents a study of safety issues relevant to wireless indoor infrared systems. In particular, it addresses the safety requirements of the baseband dual-rate PPM system under consideration by the IEEE P802.11 [9]. In a companion document [11], a specification for the Emitter Radiation Pattern (ERP) is proposed. The present study is based on the most recent IEC standard on this subject [1]. The results show that the proposed ERP is in conformance with the IEC standard.

This work is being carried out as part of the ESPRIT.6892 - POWER (Portable Workstation for Education in Europe) project commissioned by the CEC.

I - Introduction

The limits imposed by safety regulations must be considered on the design of infrared (IR) communication systems. The limits are based on the maximum IR power density and/or radiant energy for which human exposure falls below the Maximum Permissible Exposure (MPE) levels [1]. The limits will set the maximum emitted power and minimum beam divergence of the emitting source.

Usually, diffuse IR wireless communication systems make use of LEDs as the emitting source. There is not a safety standard or a detailed study about safety limits imposed by LED radiation. Therefore, the limits are assumed to be those imposed by laser radiation. This study considers several standards for the safe use of laser systems [2, 3, 4, 5] and is based on the 1993 edition of the standard *IEC - 825-1 - Safety of Laser Products* [1], which is the most updated safety standard.

The system under study uses PPM modulation. It is being considered for standardisation by the IEEE P802.11 [6, 7, 8, 9]. The purpose of this study is to show that the optical emitter specification, including the ERP proposed in [11] and the total emitter power defined in [9], is in conformance with the IEC standard.

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II - Safety Considerations

The safety regulations specify the level of laser radiation to which people may be exposed without suffering adverse effects. The MPE levels represent the maximum limits to which persons may be exposed without suffering injury immediately or later in time. MPE values are set below known hazard levels and should be regarded as simple guides for safe exposure. Indoor IR communication systems make use of sources emitting in the infrared range, specially between 700 and 950 nm. They fall within the 400 nm to 1400 nm wavelength class defined in [1].

Hazards to the eye

In general, the human eye is the most sensible organ to radiation from laser sources. The cornea, aqueous humour, lens and vitreous humour are transparent for radiation at these wavelengths, which is then transmitted to the retina. Moreover, there is a significant concentration factor from the cornea to the retina Therefore, for these wavelengths, the greatest hazard is retinal damage.

The degree of hazard resulting from a given situation depends on a set of physical parameters of the irradiating source, the most important ones are wavelength, pulse duration, image size, irradiance, and radiant exposure. The distance between the source of radiation and the eye may also be of importance, depending on the source radiating characteristics. Thus:

- For a well collimated beam source, the hazard to the eye is virtually independent of the distance between the source and the eye [1].
- For a point-type diverging beam source, the hazard increases with decreasing distance between the source and the eye. The greatest hazard occurs at the shortest accommodation distance of the eye. With further distance reduction, the hazard decreases also, as there is a rapid growth of the retinal image and a corresponding reduction of the irradiance, even though more power may be collected. The shortest accommodation distance of the human eye is set to 100 mm at all wavelengths under study, as people cannot accommodate their eye to smaller distances [1].
- For an extended source, the hazard is again virtually independent of the distance between the emitting source and the eye as the retinal irradiance only depends on the source's radiance and on the lens characteristics of the eye [1].

Skin hazards

In general terms, the skin can tolerate a great deal more exposure to laser beam energy than the eye and therefore, all safety limits are imposed by the eye radiation exposure limits.

III - Evaluation of Safety Limits

In this section, we will evaluate the MPE safety level for the dual-rate PPM system under consideration by the IEEE P802.11. The baseband IR PHY proposal considers 16-PPM for 1 Mbit/s rate and 4-PPM for the 2 Mbit/s rate. The 2 Mbit/s system is the worst-case in terms of safety since the average emitted optical power is higher. Therefore, all system parameters used in the evaluation of the safety limits are taken from the draft specification [9] for the 2 Mbit/s system. Since the system does not operate in the visible part of the spectrum, eye protection is not afforded by the blink reflex. Following [1], a reasonable estimate of the hazardous chance exposure time for repetitively pulsed radiation can be taken considering a total exposure time of 10 seconds.

The PPM system is one example of repetitively pulsed radiation. There is only limited data on multiple pulsed exposure criteria. The MPE to be applied to repetitive exposures is determined by using the most restrictive of the following requirements [1]:

a) - The exposure from any single pulse within a pulse train shall not exceed the MPE for a single pulse.

b) - The average exposure for a pulse train of duration *T* shall not exceed the MPE for a single pulse of duration *T*.

c) - The exposure from any single pulse within a pulse train shall not exceed the MPE for a single pulse multiplied by the correction factor, $C_5=N^{-0.25}$. Where *N* is the number of pulses in the pulse train of duration *T*.

Usually, the emitting source of diffuse indoor IR wireless systems is an array of LEDs which can be considered an extended source. This results on less restrictive safety limits. However, we will consider, as first approach, the emitting source as a point source.

4-PPM MPE calculations

The total number of 4-PPM pulses in the exposure time of 10 s is $N = 2\,\mathrm{Mbit/s} * 10\,\mathrm{s} * 0.5 = 10^7$ pulses (in 4-PPM each 2 bits of data are encoded into 1 pulse). Applying each of the 3 criteria specified above:

a) *Single pulse irradiance* . From the draft specification for baseband IR PHY [9], the maximum pulse duration is $t_d = 260\,\mathrm{ns}$ and, from the IEC standard [1], when $1.0 \times 10^{-7} < t_d < 1.8 \times 10^{-5}$ s and $700 < \lambda < 1050$ nm the MPE radiant exposure is given by:

$$H_{MPE-single} = 5 \times 10^{-3} C_4 C_6 \qquad (1)$$

where $C_4 = 10^{0.02(\lambda - 700)} = 10^{0.02(850-700)} = 2.0$ and $C_6 = 1.0$ for point sources. Thus, the radiant exposure is $H_{MPE-single} = 10^{-2}\,\mathrm{Jm}^{-2}$

b) *Pulse train average irradiance* . For $T = 10$ s and $700 < \lambda < 1050$ nm

$$H_{MPE-single} = 10 t^{0.75} C_4 C_6 \qquad (2)$$

where $C_4 = 2.0$ and $C_6 = 1.0$. Then $H_{MPE} = 202.4\,\mathrm{Jm}^{-2}$. But since in $T = 10\,\mathrm{s}$ there are $N = 10^7$ pulses the average radiante exposure is:

$$H_{MPE-single-av} = \frac{202.4}{10^7} = 2.02 \times 10^{-5}\,\mathrm{Jm}^{-2}$$

c) *Repetitive pulse train irradiance* . For $N = 10^7$ pulses, the repetitive pulse criteria specifies that

$$H_{train} = H_{single} \times N^{-0.25} = 1.78 \times 10^{-4}\,\mathrm{Jm}^{-2} \qquad (3)$$

Since the average radiance criteria for the pulse train is the most restrictive (criteria b), the single pulse MPE for this system is $2.02 \times 10^{-5}\,\mathrm{Jm}^{-2}$. The single pulse MPE could also be expressed in terms of irradiance as:

$$E_{MPE} = \frac{H_{MPE}}{t_d} = 7.8\,\mathrm{mW/cm}^2$$

Lambertian emitter calculations

Assuming now that the emitting source is a single Lambertian LED emitting a total power of 2 W, we will evaluate the distance from the LED at which the maximum irradiance is smaller than the single pulse MPE evaluated above (this distance is known as the Nominal Ocular Hazard Distance, NOHD).

The irradiance of an LED can be evaluated using an extension of the Lambertian law:

$$E(\phi) = \frac{n+1}{2\pi} P_t \cos^n(\phi) \frac{1}{d^2} \qquad (4)$$

where P_t is the total emitted power, ϕ is the angle with the normal to the LED lens, d is the distance to the LED, and n is a parameter related with the HPBW [10] (for $HPBW=60°$, n is unity).

The maximum irradiance occurs at $\phi = 0°$ and is given by:

$$E_{max} = \frac{(n+1)P_t}{2\pi \times d^2} \qquad (5)$$

To guarantee that our system is in accordance with the MPE evaluated, the maximum irradiance has to be smaller than the evaluated MPE, therefore:

$$E_{max} \le E_{MPE} = \frac{(n+1)P_t}{2\pi \times d^2} \qquad (6)$$

From (6), the NOHD results:

$$d = \sqrt{\frac{(n+1)P_t}{2\pi \times E_{MPE}}} \qquad (7)$$

Finally, applying (7) results in an NOHD of 9 cm. Since this value is shorter than the accommodation distance the 4-PPM Lambertian emitter system can be considered safe.

However, if we considered an *HPBW=9°*, instead of a pure Lambertian emitter, the NOHD would be 68.2 cm and the system could not be considered safe at distances smaller than this value.

Extended source MPE calculations

The optimised ERP proposed for the IR PHY baseband standard [11] makes use of an array of LEDs. The LEDs have a large emitting area and can be considered extended sources. To completely evaluate the safety hazards of this array it is necessary to know the emitting area of each LED, the separation distance between LEDs, the orientation of each LED, etc. Such analysis is therefore very much dependent on the implementation options. Here, a simpler analysis of safety for the proposed ERP will be developed.

We assume that the narrowest LEDs used in the implementation of the proposed ERP have an HPBW of 9°, emit a peak power of 180 mW and have a lens diameter of approximately 4 mm. At the minimum accommodation distance, (d=10 cm), each LED subtends an angle of 40 mrad which is greater than the minimum angular subtense, $\alpha_{min} = 11$ mrad, for T_10s [1] and therefore these LEDs can be considered extended sources.

The MPE safety level for extended sources is the MPE evaluated for point sources increased by the factor, C_6. For an exposure time of 10 seconds, C_6 is given by [1]:

$$C_6 = \frac{\alpha}{\alpha_{min}} = \frac{40}{11} = 3.6$$

Thus, the MPE of the 4-PPM system using these LEDs is given by:

$$E_{MPE-extended} = E_{MPE-point} * C_6 = 7.8 * 3.6 = 28.2 \text{ mW/cm}^2$$

Considering the ERP of a single LED as specified above and using (7) the resulting NOHD is 7.6 cm. Since this distance is smaller than the minimum accommodation distance we conclude that each individual LED of the optimised array can be considered safe. If the radiation of the LEDs does not overlap in the near field, which is certainly allowed by the proposed ERP specification [11], the overall LED array can also be considered safe.

We note that the evaluated MPE limits are based on parameters defined for laser radiation. However, the system under study will most probably be implemented using an array of LEDs. Therefore, a greater safety margin is naturally acquired due to the incoherence of the emitted radiation.

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REFERENCES

[1] IEC 825 - 1, *"Safety of Laser Products - Part 1: Equipment Classification, Requirements, and User's Guide"*, 1993. Source: International Electrotechnical Commission, 3 Rue de Varembé, CH - 1121, Geneva 20, Switzerland.

[2] ANSI Z - 136.1, *"ANSI Standard for the Safe Use of Lasers"*, 1986. Source: American National Standard Institute, 1430 Broadway, New York, New York 10018.

[3] ANSI Z - 136.2, *"ANSI Standard for the Safe use of Optical Fiber Communication Systems Utilising Laser Diode and LED Sources"*, 1988. Source: Same as reference 2.

[4] ACGIH - *"1991 - 1992 Threshold Limit Values and Biological Exposure Indice for Chemical Substances and Physical Agents"*.

[5] For a more complete bibliographic list on laser safety see: Robert Weiner, *"Status of Laser Safety Requirements"*, Lasers & Optronics, 1991 Buying Guide.

[6] Adriano Moreira et al., *"Modulation/Encoding Techniques for Wireless Infrared Transmission"*, doc: IEEE P802.11-93/79, University of Aveiro, Portugal.

[7] Roger Samdahl, *"Baseband IR PHY Proposal"*, doc: IEEE P802.11-94/56, Photonics Corporation, USA.

[8] Adriano Moreira et al., *"IR PHY proposal"*, doc: IEEE P802.11-94/96, University of Aveiro, Portugal.

[9] Rui Valadas et al., *"Physical Layer Draft Specification for Baseband Infrared Media"*, doc:IEEE P802.11-94/152, University of Aveiro, Portugal.

[10] Cipriano Lomba et al., *"Update of Propagation Losses and Impulse Response of the Indoor Optical Channel"*, doc:IEEE P802.11-94/142, University of Aveiro, Portugal.

[11] Cipriano Lomba et al., *"Radiation Pattern Specification for the Baseband IR PHY"*, doc:IEEE P802.11-94/173, University of Aveiro, Portugal.