Title	Study on Electromagnetic Fields emitted by Fluorescent and Compact Fluorescent Lamps
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Abstract	This document reports on a study about electromagnetic fields emitted by fluorescent and compact lamps.

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1. Introduction

In the scope of the **monIT** Project [1], an extensive survey of electromagnetic fields (EMFs) present in several indoor environments has been carried out. Although these measurements are always performed near the antennas of mobile communication systems, it was found that fluorescent and compact fluorescent lamps are also important sources of radiation to take into consideration in that kind of environments. These lamps are typically installed on ceilings or on desks at a small distance from the human head and body.

With the purpose of saving energy, modern fluorescent and compact lamps use electronic ballasts operating at frequencies higher than 20 kHz. However, the high frequency currents generated to increase lamp efficiency can generate significant radiated noise (an increase of EMF levels), since the whole lamp acts like an antenna.

More than increasing EMF levels in a particular environment, the radiated emissions from ballasts may cause electronic interference with other devices. There are several reported cases of electromagnetic interference in noise-sensitive applications, like the ones present in airplanes [2], radiofrequency hearing aids [3], [4], infrared TV remote controls [5], among others [6], [7].

With the purpose of analysing EMFs emitted by compact fluorescent lamps, a case study was carried out at Instituto de Telecomunicações – IT (http://www.it.pt), with the purpose of analysing other EMF sources present in indoor scenarios, where usually measurements are performed, aiming essentially at base stations from mobile communications systems. Two different lamps have been analysed, both in terms of their radiated frequency spectrum and of their compliance with European EMF recommended levels [8].

This document is composed by two more chapters, besides the current one. The following chapter has a detailed description of the case study carried out at IT. It starts by describing the study performed in the [100 kHZ, 5 MHz] frequency band, namely the measurement site, the equipment used and the obtained results, and finalises with the results from the additional measurement campaign carried out for frequencies below 100 kHz. In the last chapter, the main conclusions of the report are drawn.

2. Case study at IT

2.1. Objectives and description of the study

The objective of this study is twofold. On the one hand, it intends to analyse EMF spectrum emitted by compact fluorescent lamps, and on the other, it also aims at evaluating compliance of EMF levels emitted by these lamps with the European EMF exposure thresholds [8].

EMF levels emitted by two particular compact lamps are analysed, according to a specific measurement procedure developed for this case study, within the [100 kHz, 5 MHz] frequency band. Figure 1 represents the lamps under study and Table 1 presents their technical characteristics.

a) Lamp 1. b) Lamp 2.

Figure 1 – Lamps under study.

Table 1 – Technical characteristics of the lamps under study.

	Lamp 1	Lamp 2
Manufacturer	IKEA	OSRAM
Luminance [lm]	600	1 200
Power [W]	11	21

Figure 2 presents the measurement procedure developed for this study, which was applied to the two lamps under analysis, thus, allowing a comparison of results.

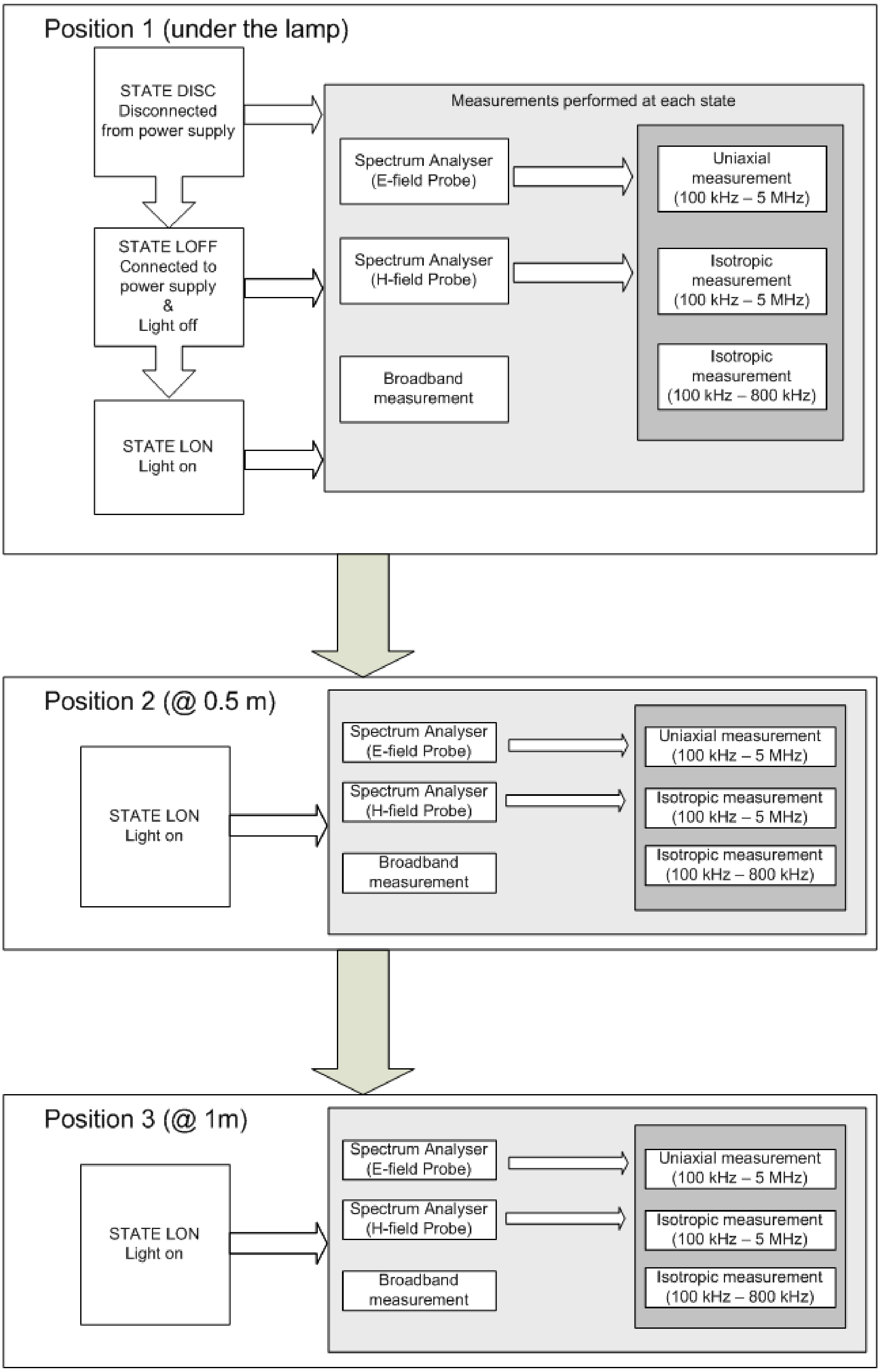


Figure 2 – Measurement procedure.

As shown in Figure 2, measurements are performed on three positions at increasing distances from the lamp. At position 1, exactly under the lamp, measurements are conducted considering three states:

- State DISC: Device disconnected from power supply;
- State LOFF: Device connected to power supply and light off;
- State LON: Light on.

At positions 2 and 3, 0.5 and 1 m respectively apart from the lamp, measurements are performed considering only state LON. Only this state is considered mainly because minor EMF levels are expected at these distances. As the overall dimension of the lamps under study is very small compared to the involved wavelengths (in the order of hundreds of metres), measurements are performed in the far-field zone.

For all scenarios, detailed frequency and broadband measurements were carried out using the equipment described in Section 2.2.

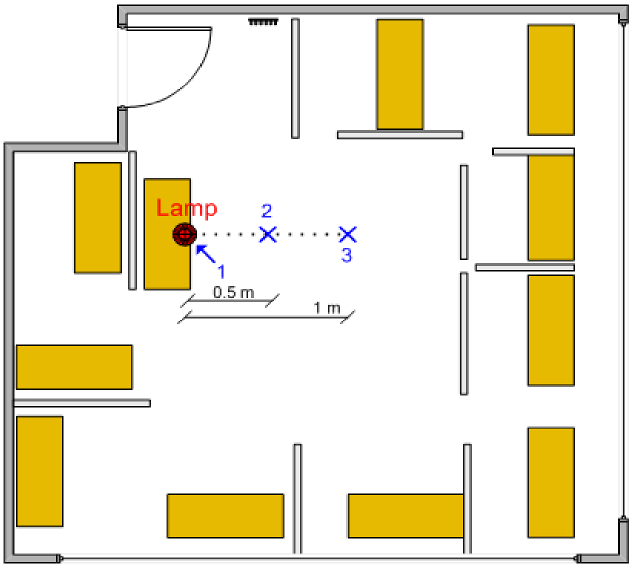
2.2. Description of the measurement site and equipment

The measurement campaign was carried out at IT, in a working room with the configuration presented in Figure 3.

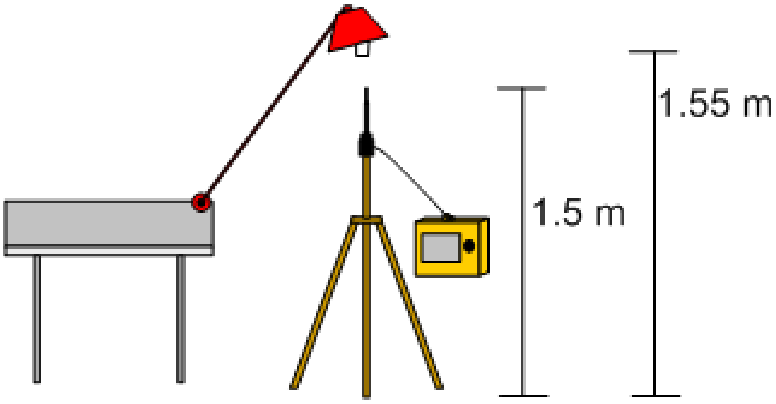
Other transmitters were identified inside and outside the room:

- Inside: other light devices located in the ceiling, which may influence the measurement;
- Outside: mobile, radio and television communication systems, which should not influence the measurement, as their emissions fall outside the measurement frequency band.

The Narda SRM-3000 [9] spectrum analyser was used, with uniaxial electric, *E*, and magnetic, *H*, field probes, both working in the [100 kHz, 300 MHz] frequency band. Table 2 presents the technical characteristics of this equipment. The values of expanded uncertainty indicated in product information are presented in Table 3.



a) Top view



b) Side view

Figure 3 – Sketch of the measurement site.

The broadband equipment used for measurements was the PMM 8053 system [10], with an *E* field probe working in the [100 kHz, 3 GHz] frequency band. Table 4 presents the technical characteristics of this device, and Table 5 presents its uncertainty values, estimated in [11] and based on the calibration certificate and on manufacturer specifications.

Table 2 – Technical characteristics of frequency selective equipment.

Manufacturer	Narda	
Model	SRM-3000, with single-axis *E* and *H* field probes	
Date last calibration	SRM-3000	2005/10/27
	E field probe	2005/10/27
	H field probe	2005/10/27
Frequency band [MHz]	SRM-3000	0.1 – 3000
	E field probe	0.1 – 300
	H field probe	0.1 – 300
Resolution Bandwidth (RBW)	1 kHz to 5 MHz	
Sweep time [ms]	< 650 for maximum sweep width (5 MHz RBW)	
Dynamic range[1)]	*E* field probe	125 µV/m – 36 V/m
	H field probe	0.4 µA/m – 71 A/m
Intrinsic noise [dBm]	-121 (RBW=1 kHz)	

1) Characteristic measurement dynamic range for 10 dB signal to noise ratio (RBW=1 kHz).

Table 3 – Measurement uncertainty of frequency selective equipment.

Frequency Range [MHz]	Expanded Uncertainty, *U* (*k* = 2) [dB] (in conjunction with SRM basic unit and 1.5m RF cable)	
	E field probe	*H* field probe
0.1 – 20	2.7	2.7
20.1 – 300	2.0	2.0

Note: Temperature ranges from +15ºC to +30ºC.

Table 4 – Technical characteristics of broadband equipment.

Manufacturer	PMM	
Model	8053A, with *E* field probe EP-330	
Date last calibration	8053A	2005/04/11
	EP-330	2005/04/20
Frequency band [MHz]	0.1 – 3000	
Amplitude Range [V/m]	0.3 – 300	
Dynamic Range [dB]	> 60	
Resolution [V/m]	0.01	
Sensibility [V/m]	0.3	
H rejection [dB]	> 20	

Table 5 – Measurement uncertainty of broadband equipment.

Uncertainty sources	Uncertainty, x_i			Standard Uncertainty $u(x_i)$
	Value [dB]	Value [%]	Probability Distribution	
Absolute Error	0.8	9.65	Rectangular ($\sqrt{3}$)	0.06
Flatness (0.3 MHz – 3 GHz)	1.5	18.85	Rectangular ($\sqrt{3}$)	0.12
Isotropy	1.0	12.20	Rectangular ($\sqrt{3}$)	0.07
Temperature (20ºC – 60ºC)	0.1	1.16	Rectangular ($\sqrt{3}$)	0.01
Calibration	---	15.0	Normal (1.96)	0.08
Combined Standard Uncertainty, $u_c(y)$				0.17 (1.36 dB)
Expanded Uncertainty, U (k = 1.96)				0.33 (2.47 dB)

2.3. Report of Measurements

2.3.1. Spectrum analysis

In Figures 4 and 5, one can observe *E* and *H* field measurements in the [100 kHz, 5 MHz] frequency band, for the three states (DISC, LOFF and LON), for Lamp 1. Figures 6 and 7 show the same results for Lamp 2.

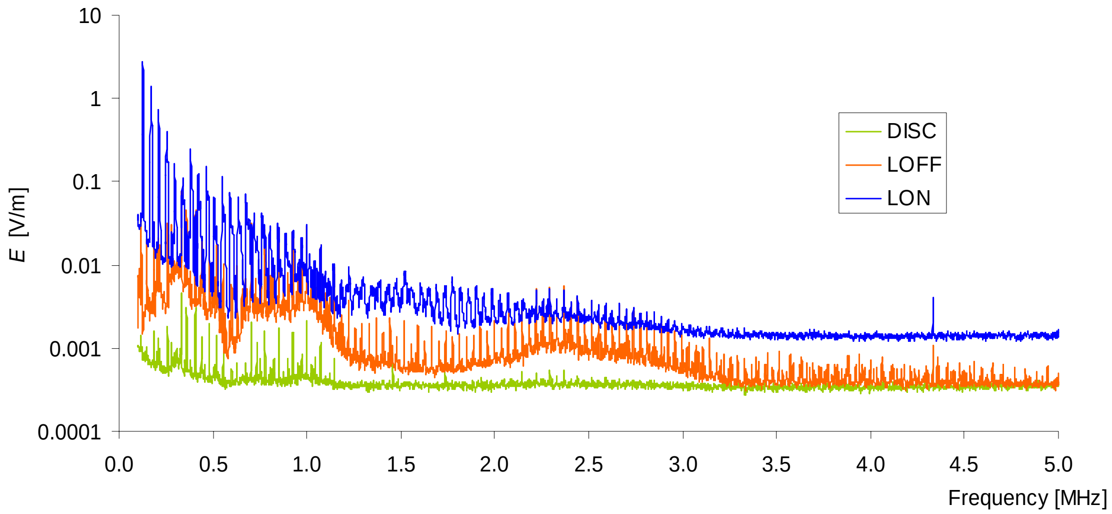


Figure 4 – *E* field measurements: [100 kHz, 5 MHz] (Lamp 1, Position 1).

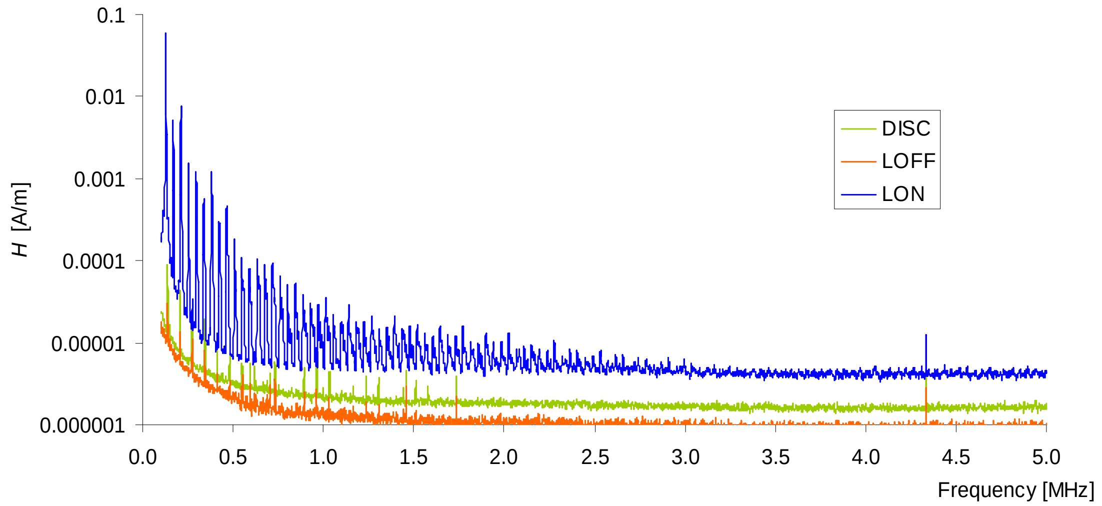


Figure 5 – *H* field measurements: [100 kHz, 5 MHz] (Lamp 1, Position 1).

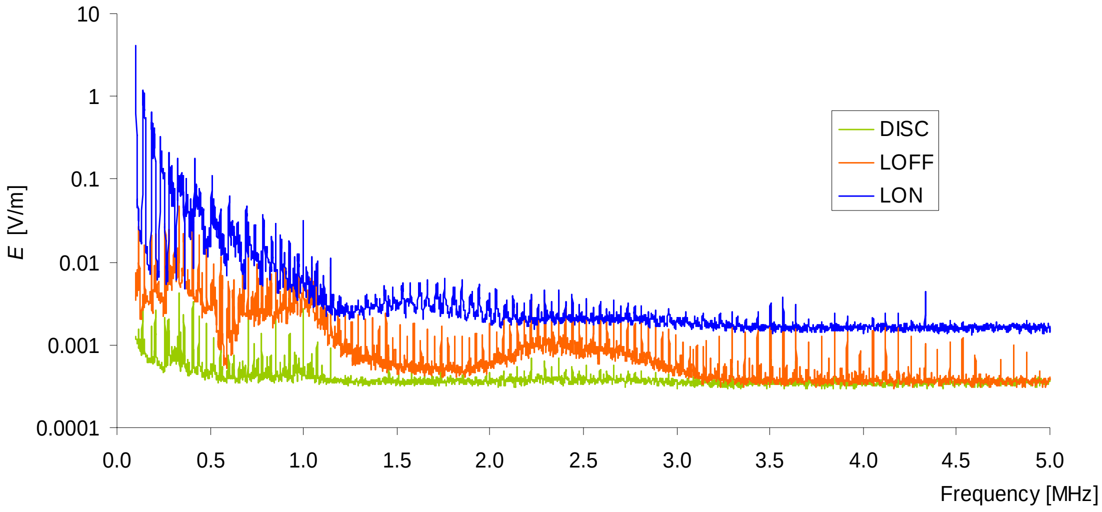


Figure 6 – *E* field measurements: [100 kHz, 5 MHz] (Lamp 2, Position 1).

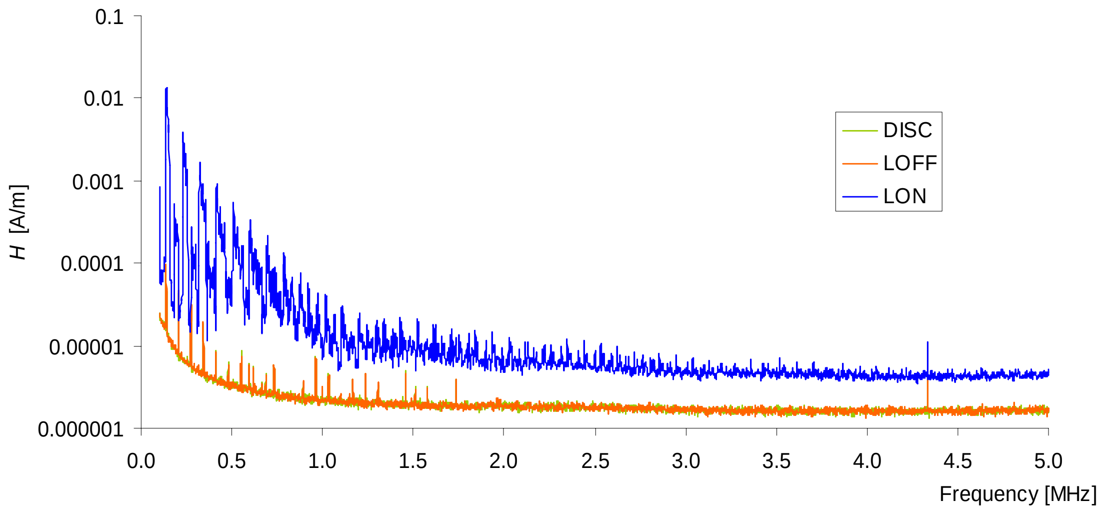


Figure 7 – *H* field measurements: [100 kHz, 5 MHz] (Lamp 2, Position 1).

EMF emission measurements show that lamps exhibit significant emission levels. Moreover, results show an increase of *E* field levels when a lighting device is simply connected to power supply with the light off; although this does not happen with *H* field measurements. This result was expected, as when in state LOFF, there is no electric current flow, thus, no considerable magnetic field exists. When the light is turned on, a significant increase of both *E* and *H* field levels is observed. These results were observed for both lamps, although with slight different frequency spectra.

For both lamps, one can observe a significant contribution of emissions in the [0.1, 1] MHz frequency band. This is valid for both *E* and *H* field measurements and for all the three states.

Even, in the DISC state, one can identify peaks in this frequency band, probably coming from the lamps on the ceiling of the room (which were in LOFF state).

For both lamps (in LON state), additional measurements were performed in the [100, 800] kHz frequency bands, in order to identify the various harmonics in a more accurate way, Figure 8 and Figure 9.

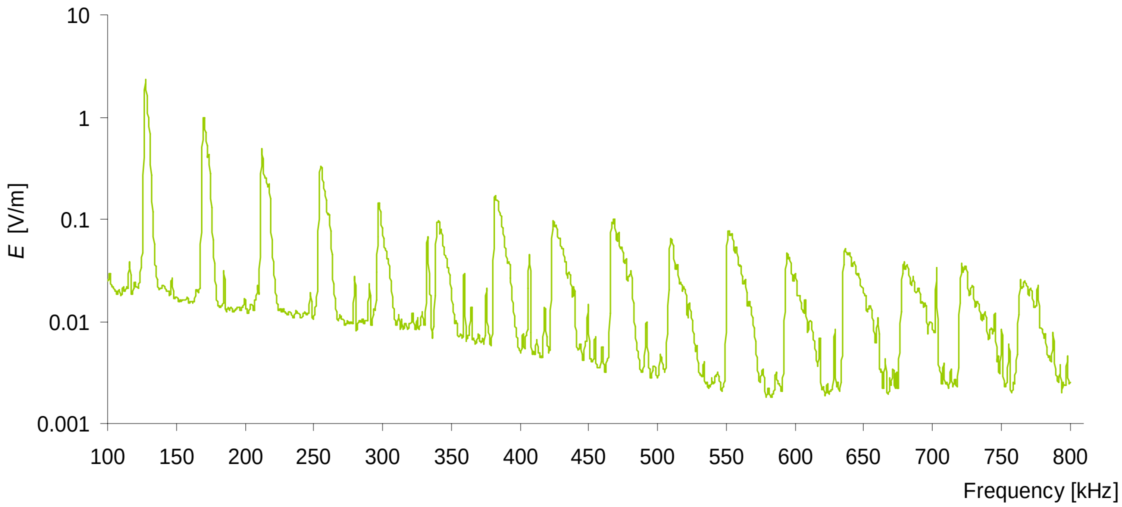


Figure 8 – *E* field measurements: [100 kHz, 800 kHz] (Lamp 1, Position 1, LON).

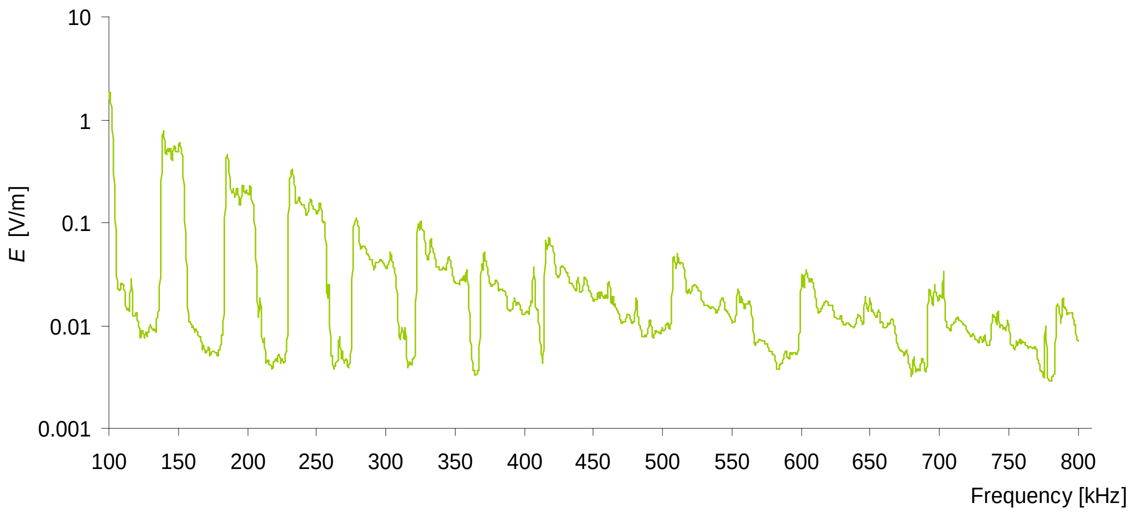


Figure 9 – *E* field measurements: [100 kHz, 800 kHz] (Lamp 2, Position 1, LON).

As the frequency of operation of electronic ballasts may vary from 20 kHz up 100 kHz, and as the minimum frequency at which measurement probes can operate is 100 kHz, it was not possible to identify the frequency of operation of the lamps under test, although various harmonics are visible. Additional measurements were performed in order to identify the frequency of operation (see Section 2.4).

In Figures 10 and 11, one can observe *E* and *H* field measurements within the [100 kHz, 5 MHz] frequency band, at the three measurement positions, for Lamp 1. Figures 12 and 13 show the same results for Lamp 2.

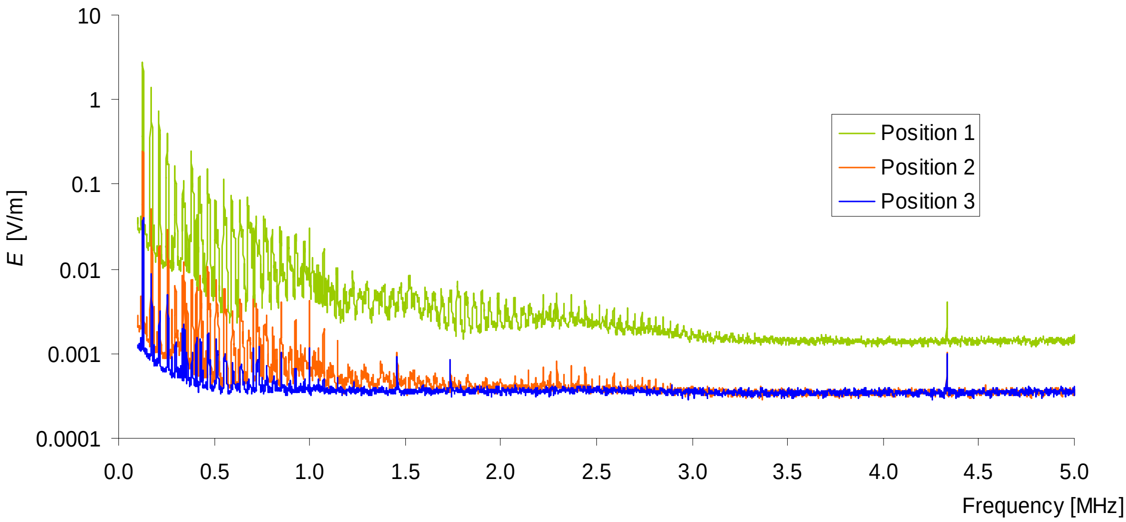


Figure 10 – *E* field measurements, at three different positions (Lamp 1, LON).

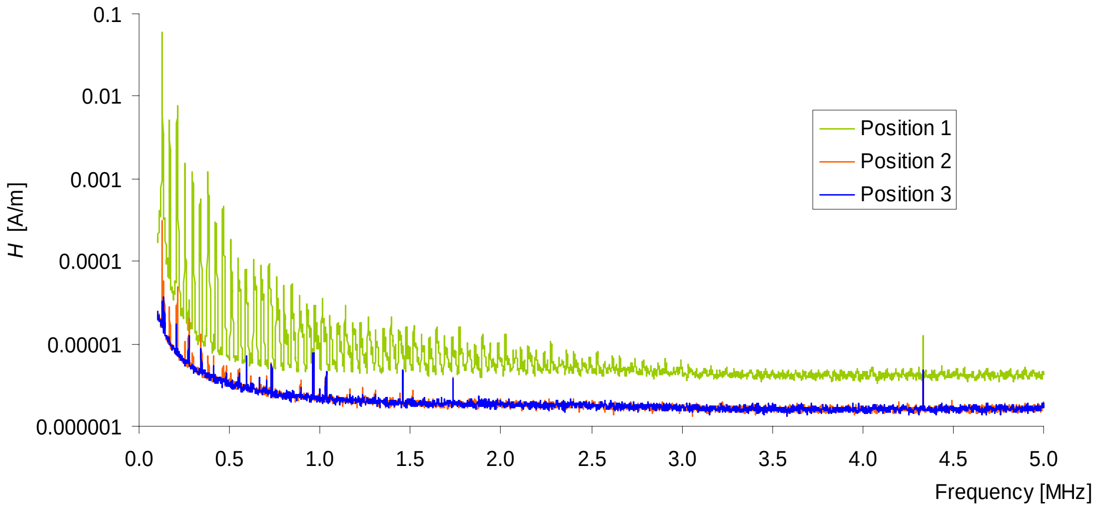


Figure 11 – *H* field measurements, at three different positions (Lamp 1, LON).

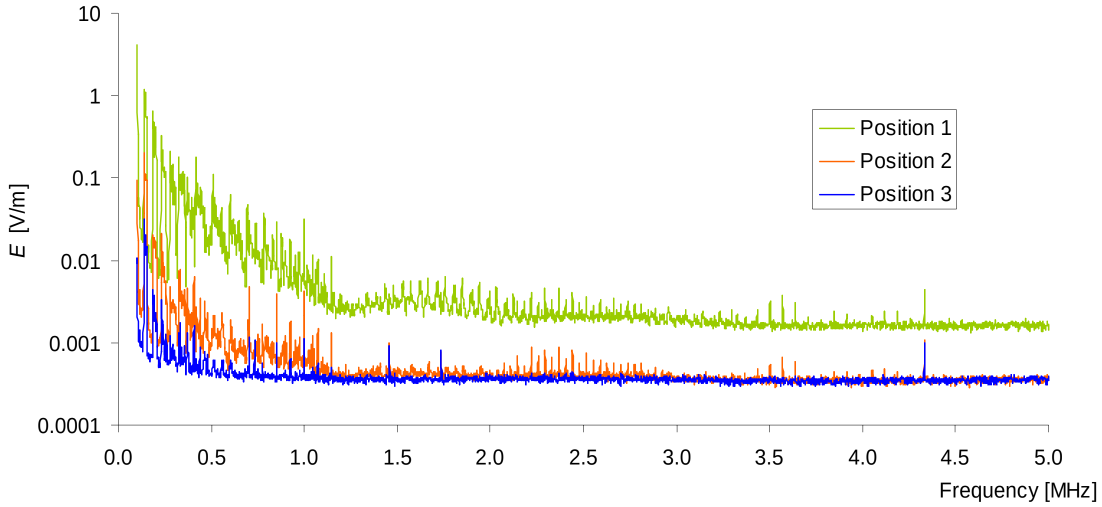


Figure 12 – *E* field measurements, at three different positions (Lamp 2, LON).

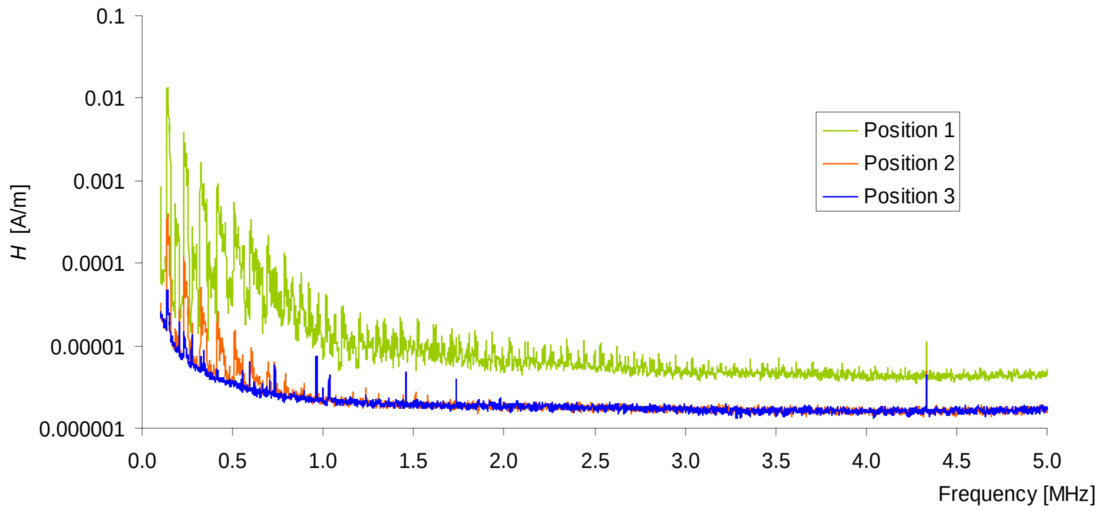


Figure 13 – *H* field measurements, at three different positions (Lamp 2, LON).

As expected, one observes that EMF values rapidly decay when the distance to the lighting device increases. In spite of this, at 0.5 and 1 m away from the lamps, one can still observe the spectral lines in the [100, 800] kHz frequency band.

2.3.2. Evaluation of EMFs Compliance

This section presents the compliance evaluation of EMFs measured with both the spectrum analyser and the broadband equipment.

For spectrum analyser results, as it is not practical to present the results for all the frequencies measured within the overall measurement frequency band, only the emissions exceeding a threshold level of 40 dB below the reference level are reported here. The results presented correspond to Position 1 and to the state where the higher EMF levels were verified, which is state LON.

Reference levels corresponding to the frequencies of significant emissions are E_{lim} = 87 V/m and H_{lim} = 5 mA/m. Table 5 and Table 6 present the compliance evaluation for *E* and *H* field measurements for Lamp 1, respectively. *E* field measurements of Lamp 2 are presented in Table 7. For Lamp 2, there were no *H* field emissions exceeding the threshold level of 40 dB, thus, not being reported here.

Table 5 – Comparison between *E* field measurements and reference thresholds: [100 kHz, 5 MHz] (Lamp 1).

Frequency [kHz]	E_i [V/m]	E_i/E_{lim} [dB]
125.39	1.33	-36.32
126.37	2.49	-30.85
127.34	2.78	-29.90
128.32	2.15	-32.15
129.30	1.55	-34.96
130.27	1.17	-37.40
131.25	0.69	-42.00
168.36	1.22	-37.04
169.34	1.39	-35.93
170.31	1.07	-38.22

According to [8], as there is simultaneous exposure to fields of different frequencies, total exposure ratios referred to electrical stimulation effects and also to thermal effect circumstances must be calculated, and should be lower than 1. The results of these calculations are presented in Table 8.

Table 6 – Comparison between *H* field measurements and reference thresholds: [100 kHz, 5 MHz] (Lamp 1).

Frequency [kHz]	H_j [mA/m]	H_j/H_{lim} [dB]
126.4	0.06	-39.05
127.3	0.06	-38.64

Table 7 – Comparison between *E* field measurements and reference thresholds: [100 kHz, 5 MHz] (Lamp 2).

Frequency [kHz]	E_i [V/m]	E_i/E_{lim} [dB]
100.00	4.17	-26.39
100.98	3.75	-27.32
101.95	3.21	-28.65
102.93	2.24	-31.77
103.91	1.06	-38.28
138.09	0.95	-39.22
139.06	1.21	-37.16
140.04	1.04	-38.46
141.02	1.00	-38.77
141.99	1.12	-37.78
142.97	0.92	-39.49
147.85	1.08	-38.12
148.83	0.97	-39.06

Concerning broadband measurements, results are presented in Table 9 and Table 10, for Lamps 1 and 2 respectively. In this case, measurements are compared with the strictest threshold within the measurement frequency band, which is E_{lim} = 28 V/m.

Table 8 – Total exposure quotients.

		Lamp 1	Lamp 2
Electrical stimulation effects	$\sum_{i=1Hz}^{1MHz}\left(\frac{E_i}{E_{\lim}}\right)+\sum_{i>1MHz}^{10MHz}\left(\frac{E_i}{E_{\lim_{sup}}}\right)$	0.140000	0.261000
	$\sum_{j=1Hz}^{150kHz}\left(\frac{H_j}{H_{\lim}}\right)+\sum_{j>150kHz}^{10MHz}\left(\frac{H_j}{H_{\lim_{sup}}}\right)$	0.114000	-
Thermal effect circumstances	$\sum_{i=100kHz}^{1MHz}\left(\frac{E_i}{E_{\lim_{inf}}}\right)^2+\sum_{i>1MHz}^{300GHz}\left(\frac{E_i}{E_{\lim_i}}\right)^2$	0.000517	0.000803
	$\sum_{j=100kHz}^{150kHz}\left(\frac{H_j}{H_{\lim_{inf}}}\right)^2+\sum_{j>150kHz}^{300GHz}\left(\frac{H_j}{H_{\lim}}\right)^2$	0.000197	-

Note: $E_{\lim_{sup}}$ = 87 V/m, $H_{\lim_{sup}}$ = 5 A/m, $E_{\lim_{inf}}$ = 87/$f^{1/2}$ V/m, $H_{\lim_{inf}}$ = 0.73/f A/m and E_{lim} and H_{lim} are the reference frequency dependent thresholds.

Table 9 – Broadband measurements (Lamp 1).

Position / State	E [V/m]	E/E_{lim} [dB]
1 / DISC	0.92	-29.67
1 / LOFF	0.87	-30.15
1 / LON	15.16	-5.33
2 / LON	1.14	-27.81
3 / LON	1.05	-28.52

Table 10 – Broadband measurements (Lamp 2).

Position / State	*E* [V/m]	E/E_{lim} [dB]
1 / DISC	0.94	-29.48
1 / LOFF	0.77	-31.21
1 / LON	50.46	5.12
2 / LON	1.35	-26.34
3 / LON	1.08	-28.27

The high levels of *E* field obtained in both lamps at Position 1 and state LON, compared with the values measured at Positions 2 and 3, suggest a considerable interference between the probe and the radiating device. It is inferred that this equipment is particularly sensitive for performing measurements at such small distances from the radiating device. So, the values presented in Tables 9 and 10, corresponding to Position 1 and state LON should not be considered.

As expected, when comparing the results obtained from both lamps, it is observed that, in the immediate vicinity of the lighting device, EMF levels emitted depend on the lamp power.

Concerning the results obtained from frequency selective and also from broadband measurements, one can conclude that EMF emissions from both lamps under test are in compliance with the EMF reference levels within the [100 kHZ, 3GHz] frequency band.

As the spectral evaluation was not performed in the entire frequency band of the lamps, it is not possible to conclude if the lamps under test are in compliance with the EMF reference thresholds. Additional measurements at frequencies lower than 100 kHz were required to conclude the evaluation of compliance. An additional measurement campaign was then carried out for those frequencies, being described in the following section.

2.4. Additional measurement campaign

The objective of the additional measurement campaign is to analyse the EMF spectrum emitted by the two compact fluorescent lamps under study for frequencies below 100 kHz. This analysis allows one to obtain the frequency of operation of the electronic ballasts of the two lamps, and also to conclude about the compliance of these lamps with the EMF reference levels.

The measurement procedure for this additional campaign consisted on a single measurement exactly under the lamp, considering state LON.

The measurement was carried out in a room with other light devices located in the ceiling and various laboratory equipment in close proximity, Figure 14.

Figure 14 – Measurement environment for the additional campaign.

The Anritsu MS2601B [12] spectrum analyser was used, working in the [9 kHz, 2.2 GHz] frequency band. Table 11 presents the technical characteristics of this equipment. A common electronics cable was connected to the spectrum analyser, Figure 15, acting as receiving antenna.

For both lamps, measurements of received power, *P*, were conducted in the [10 kHz, 800 kHz] frequency band. The results of these measurements are represented in Figures 16 and 17. Note that, due to the inexistence of a hardware/software interface to download measurement data from the spectrum analyser, only the peak values are represented (orange dots). The previous measurements carried out with Narda SRM-3000 spectrum analyser for Position 1, state LON and [100 kHz, 800 kHz] frequency band are also represented in Figures 16 and 17 (blue line).

Table 11 – Technical characteristics of Anritsu MS2601B.

Manufacturer	Anritsu
Model	MS2601B
Frequency band	9 kHz – 2.2 GHz
RBW	30 Hz to 1 MHz
Sweep time [ms]	50 ms to 1000 s
Dynamic range	-120 dBm to 50 dBm

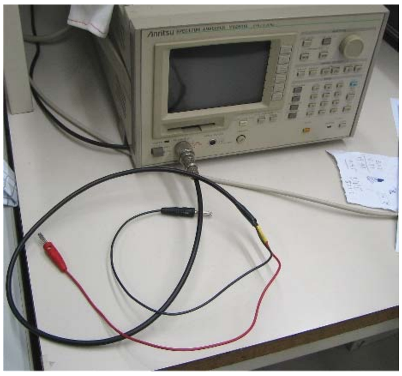


Figure 15 – Cable used as receiving antenna.

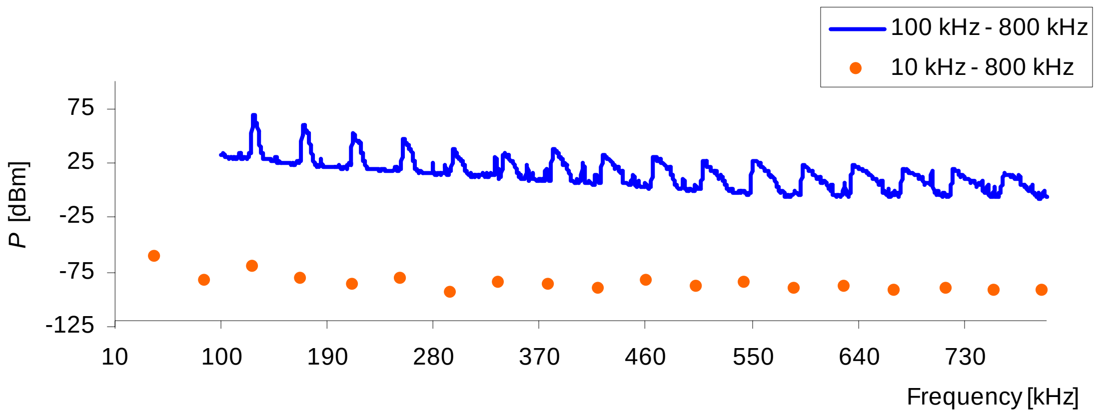


Figure 16 – Results from the additional measurement campaign (Lamp 1).

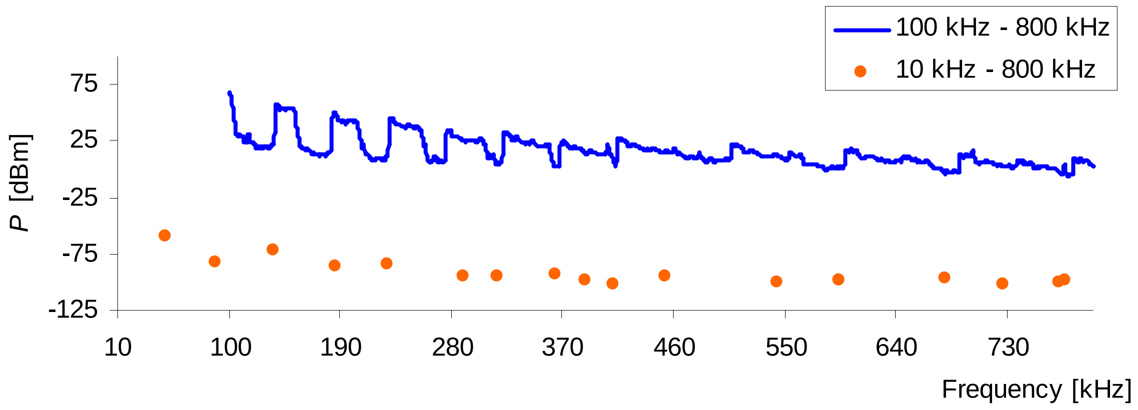


Figure 17 – Results from the additional measurement campaign (Lamp 2).

There was no available information about the cable used as receiving antenna in this additional measurement campaign. A simple calibration procedure was performed in order to convert the power levels measured with the cable into *E*-field values. This calibration procedure consists in the comparison of results for frequencies above 100 kHz obtained by the additional measurement campaign with those obtained in the same conditions by the Narda SRM-3000. Then, results are extrapolated for frequencies below 100 kHz. The step-by-step procedure is explained below:

- The first three peak values above 100 kHz from the additional measurement campaign and from the Narda SRM-3000 measurement were taken and compared, Figure 18.

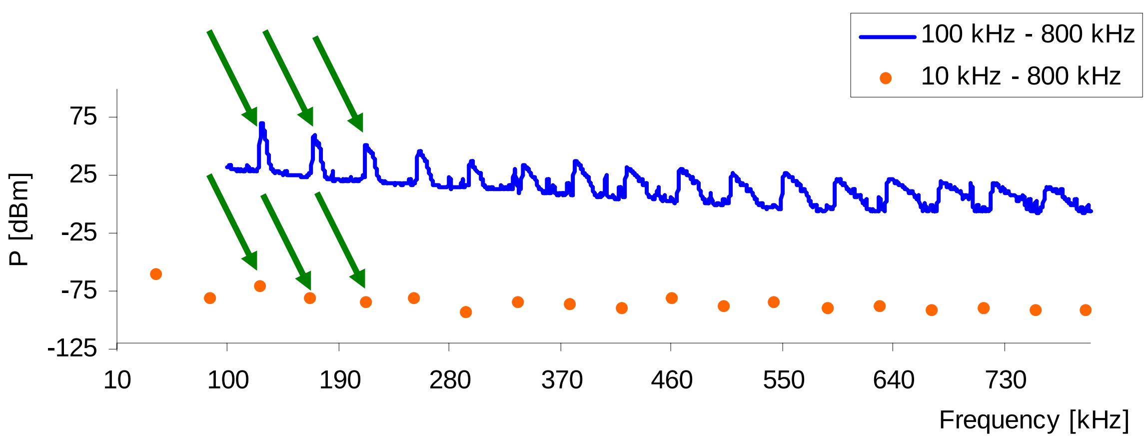


Figure 18 – Example of comparison of results.

- The average difference, *F*, between the considered peaks was estimated.

- The *F* factor was added to the power measurements for frequencies below 100 kHz.

- The power values are converted into *E*-field ones, according to the characteristics of the *E*-field probe of the Narda SRM-3000 (short dipole, antenna gain = 1.76 dBi).

Table 12 and Table 13 present the comparison of peak values for Lamps 1 and 2, respectively. One may observe that, as expected, the results for both lamps lead to a similar value of *F*.

Table 12 – (Lamp 1).

Narda SRM-3000 [100 kHz, 800 kHZ]		Additional Campaign [10 kHz, 800 kHz]		
f [kHz]	$P_{srm3000}$ [dBm]	*f* [kHz]	P_{cable} [dBm]	$P_{srm3000}$-P_{cable} [dB]
127.83	69.76	126.9	-70.68	140.44
169.82	59.76	168.0	-81.27	141.03
212.31	51.84	212.2	-85.99	137.83
			F [dB]	139.77

Table 13 – (Lamp 2).

Narda SRM-3000 [100 kHz, 800 kHZ]		Additional Campaign [10 kHz, 800 kHz]		
f [kHz]	$P_{srm3000}$ [dBm]	*f* [kHz]	P_{cable} [dBm]	$P_{srm3000}$-P_{cable} [dB]
100.98	69.71	89.0	-83.05	152.76
139.55	59.55	136.4	-72.42	131.97
185.94	52.27	187.0	-85.76	138.03
			F [dB]	140.92

Based on *F*, the *E*-field levels for frequencies below 100 kHz were estimated and compared with the reference thresholds for both lamps. The reference level in terms of *E*-field corresponding to these frequencies is E_{lim} = 87 V/m. Tables 14 and 15 present the evaluation of compliance for *E* for Lamp 1 and Lamp 2, respectively.

Table 14 – Comparison between *E* field measurements and reference thresholds: [10 kHz, 100 kHz] (Lamp 1).

Frequency [kHz]	E_i [V/m]	E_i/E_{lim} [dB]
43.20	2.21	-31.9
85.80	0.39	-47.0

Table 15 – Comparison between *E* field measurements and reference thresholds: [10 kHz, 100 kHz] (Lamp 2).

Frequency [kHz]	E_i [V/m]	E_i/E_{lim} [dB]
49.50	3.28	-28.5
89.00	0.41	-46.5

The values obtained in the additional measurement campaign must be added to the total exposure ratios (in terms of *E*-field) referred to electrical stimulation effects, which should be lower than 1. The results of these calculations are presented in Table 16.

Table 16 – Total exposure quotients.

		Lamp 1	Lamp 2
Electrical stimulation effects	$\sum_{i=1Hz}^{1MHz}\left(\frac{E_i}{E_{\mathrm{lim}}}\right)+\sum_{i>1MHz}^{10MHz}\left(\frac{E_i}{E_{\mathrm{lim}_{\mathrm{sup}}}}\right)$	0.184245	0.303679

Note: E_{lim} is the reference frequency dependent threshold and $E_{\mathrm{lim}_{\mathrm{sup}}}$ = 87 V/m.

3. Conclusions

The extensive survey of EMFs carried out in the scope of the **monIT** Project [1], has shown that fluorescent and compact fluorescent lamps are one of the main sources of radiation present in indoor environments. With the purpose of analysing EMFs emitted by these lamps, a case study was carried out, where two compact fluorescent lamps have been analysed, in terms of both their radiated frequency spectrum and their compliance with European EMF recommended levels.

EMF emission measurements in the [100 kHz, 5 MHz] frequency band show that lamps used everyday in homes, workplaces, subways, shopping centres and so on, exhibit significant emission levels at high frequencies. For the lamps under test, significant emissions were found within the [100 kHz, 800 kHz] frequency band. Additional measurements carried out in frequencies below 100 kHz allowed to identify the frequency of operation of electronic ballasts, which was found to be 43.2 kHz for Lamp 1 and 49.5 kHz for Lamp 2. Several harmonics, spaced about 40 kHz, were found for both Lamp 1 and Lamp 2. Lamp 2 presents larger spectral lines than the ones identified for Lamp 1.

The two lamps under study were chosen with different powers, in order to verify the relation between lamp power and EMF levels emitted. As expected, the analysis of results shows that, in the immediate vicinity of a lamp, EMF levels emitted by lighting devices depend on the lamp power.

Results suggest that the broadband equipment is particularly sensitive to interferences with the radiating devices, thus, not being appropriated for performing measurements at very small distances from the lamp, *e.g.*, right below the lamp. Nevertheless, this equipment produces reliable measurements at a distance of 0.5 m from the light device.

Concerning the results obtained from frequency selective and also from broadband measurements, one can conclude that EMF emissions from both lamps under test are in compliance with the EMF reference thresholds.

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