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Abstract: The massive application of new lighting technologies and the phase out of incandescent lamps present an important challenge in terms of flicker. The standardized flicker measurement procedure and the existing compatibility levels were based on the response of the incandescent lamp. In order to test the sensitivity of modern lamps to voltage fluctuations, the working group (MT 1) of IECTC34 has developed an objective immunity test protocol. This work presents the main issues that were critical in the implementation of the immunity test system and the results obtained from a set of lamps selected for a Round Robin Test performed by different entities which also took part on the development of the immunity test protocol.

# A PROTOCOL TO TEST THE SENSITIVITY OF LIGHTING EQUIPMENT TO VOLTAGE FLUCTUATIONS

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## ABSTRACT

*The massive application of new lighting technologies and the phase out of incandescent lamps present an important challenge in terms of flicker. The standardized flicker measurement procedure and the existing compatibility levels were based on the response of the incandescent lamp. In order to test the sensitivity of modern lamps to voltage fluctuations, the working group (MT 1) of IEC-TC34 has developed an objective immunity test protocol. This work presents the main issues that were critical in the implementation of the immunity test system and the results obtained from a set of lamps selected for a Round Robin Test performed by different entities which also took part on the development of the immunity test protocol.*

## INTRODUCTION

Flicker is defined as the impression of unsteadiness of visual sensation induced by variations in the light of a lamp produced by fluctuations of its supply voltage. The IEC 61000-4-15 standard [1] defines the functional and design specifications of a flickermeter to objectively quantify the level of irritation in terms of the flicker severity value, $P_{st}$. The design of the IEC flickermeter was based on the perception of humans to voltage fluctuations applied to a 60 W incandescent lamp, the leading lighting technology at the time the standard was developed. The irritability threshold or $P_{st} = 1$ curve [2] establishes the limit at which flicker would become annoying for the 50% of the observers subjected to the light fluctuation of an incandescent lamp.

The way flicker is measured is facing a great challenge due to banning of non-efficient lamps. During the last years, some works revealed the existence of high flicker severity levels however without reported complaints from low-voltage users [3, 4]. The massive application of efficient lighting technologies and their supposedly lower sensitivity to voltage fluctuations was suggested as one of the possible reasons for these inconsistencies [4]. Under this premise, the increase of the compatibility levels was proposed as a solution to properly reflect the less sensitive response of new lamps. The feasibility of this approach was assessed by the working group C4.111 of CIGRE [5]. The study performed by this group concluded that this solution could not be practical as technological updates in new lighting technologies can involve different responses to voltage fluctuation showing even a more sensitive behaviour than the incandescent lamp.

An alternative solution could be to adjust the flicker measurement procedure to a new reference lighting technology. This solution would not be practical for several reasons: the rapid advancements in lighting technologies make the establishment of a new reference lamp unfeasible; the existing equipment on the market has been designed using the existing flicker curve; if the new reference lamp presents a more sensitive response than the incandescent lamp the compatibility requirements would need to be tightened.

The proper solution could be the limitation of the light fluctuations during the design process of the lamps so that the existing compatibility levels and flicker measurement procedure could still be in use. Along this line, a working group (MT 1) of IEC-TC34, with the support of IEC-SC77A-WG2, developed a technical report (TR) (IEC/TR 61547-1) [6] containing the procedure for the immunity test of lamps against voltage fluctuations. This paper presents the main critical aspects of the development of the method for the objective voltage-fluctuation immunity test. The paper also presents the results obtained from the immunity analysis of a set of lamps. Some of these lamps were tested in a comparative way through a small Round Robin Test (RRT) conducted between different entities collaborating in the MT1 working group.

## IMMUNITY TEST OF LAMPS

The main objective of the TR is to establish a common and objective reference for evaluating the immunity of the lamps in terms of illuminance flicker. The proposed methodology includes the description of the test system, the requirements for the test system verification and the procedure for the immunity test.

### Test system description

The test system consists of three parts: the generation of the test voltage, the photometric measurement of the light and the flicker assessment (Figure 1).

First, the voltage test signal, u(t), is generated by means of a test waveform generator and an amplifier in order to supply the equipment under test (EUT) adequately. Then, the light output of the EUT is measured by the optical sensor. Both, the EUT and the light sensor are located in an optically shielded environment to avoid disturbances from light sources other than the EUT. The output voltage of the light sensor, $u_E(t)$, representing the

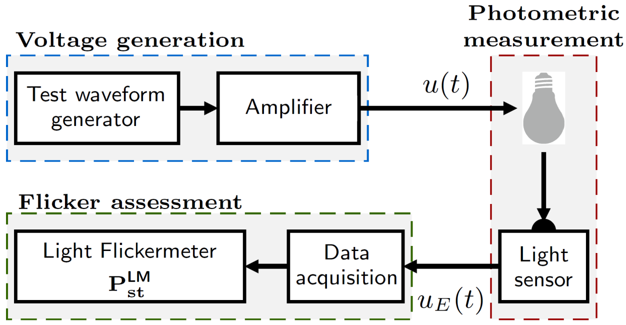


*Figure 1 : Block diagram of the test system.*

illuminance of the EUT, is recorded. Finally, the EUT's sensitivity is analyzed by means of the flicker severity value, $P_{st}^{LM}$, obtained from the illuminance signal, $u_E(t)$, using a light flickermeter.

## Verification Procedure

In order to limit the uncertainties of the immunity test and to assess the accuracy of the test system, the protocol recommends performing a number of verification tests.

**Mains voltage parameters**

The correct operation and implementation of the system for the generation of the supply voltage of the EUT have to be verified. To that end, four parameters need to be controlled: the rms-level of the main signal and its mains frequency and the level of the voltage fluctuation and its fluctuation frequency.

**Light sensor and transimpedance amplifier**

Three different aspects need to be verified: the absence of an offset voltage when the light sensor is covered; the linearity of the sensor by placing the photodiode at different distances from the lamp and the clipping level of the voltage output of the amplifier.

**Light flickermeter**

The implementation of the light flickermeter is verified by using a set of standardized illuminance waveforms selected to give exactly $P_{st}^{LM} = 1$ with a tolerance of 5%.

## Test procedure

The EUT is mounted in the optically shielded enclosure and, after switching it on, a sufficient stabilization time is applied. The EUT is subjected to rectangular voltage fluctuations with the recommended specific levels of relative voltage changes and fluctuation frequencies represented in Table 1. These values are taken from the IEC flickermeter performance test specifications given in the standard IEC 61000-4-15 [1]. These voltage tests provide a value of $P_{st} = 1$ corresponding to the flicker irritability curve. The acquired illuminance signal, $u_E(t)$, is assessed by the light flickermeter measuring the corresponding $P_{st}^{LM}$ levels. For a specific EUT, if its $P_{st}^{LM}$ value is equal to 1 the EUT is experienced to have the same flicker behavior as a 60W incandescent lamp. If $P_{st}^{LM} < 1$ the EUT would have less sensitive behavior than the incandescent lamp; $P_{st}^{LM} > 1$ would indicate a worse flicker behavior than the incandescent lamp.

*Table 1: Test specification for the voltage signals applied in the immunity test procedure of the lamps.*

| Voltage changes per minute (cpm) | Modulation frequency ($f_m$) | Relative voltage fluctuation ($d = \Delta V/V$) |
|---|---|---|
| 39 | 0.3250 | 0.894 |
| 110 | 0.9167 | 0.722 |
| 1056 | 8.8 | 0.275 |
| 1620 | 13.5 | 0.407 |
| 4000 | 33.3 | 2.343 |

# CRITICAL ISSUES IN THE TEST SYSTEM IMPLEMENTATION

The implementation of the test system presents some critical aspects which were detected during the immunity protocol definition.

## Light flickermeter

**Description of the light flickermeter**

The implementation of the light flickermeter is based on the one described in [7] and starting from the specifications of the IEC flickermeter [1].

The IEC flickermeter models the response of the lamp-eye-brain system to fluctuations in the supply voltage of the lamp by means of 5 different blocks (Figure 2a). This model was designed on the 60 W incandescent lamp.

The design of the light flickermeter is based on the IEC flickermeter but with the modification of two main aspects: the input is the light output of the lamp instead of the voltage signal and the parts of the IEC flickermeter related to the response of the incandescent lamp need to be removed. Figure 2b represents the block diagram of the light flickermeter. In the light flickermeter, block 2 and the part corresponding to the response of the lamp of block 3 of Figure 2a are eliminated. Additionally, block 1 is adapted in order to normalize the illuminance input signal into an internal reference value.

**Adjustment of the light flickermeter**

In Figure 2a-b the output of block 4 and C respectively represents the instantaneous flicker sensation, $P_{inst}$. As the relative amplitude of the voltage fluctuation, $\Delta V/V$, is expressed in perceptual units relative to the rms value of the supply voltage, the flickermeter must be adjusted in order to measure at any nominal voltage level. For this reason, the IEC flickermeter is adjusted so that $P_{inst} = 1$ when a sinusoidal voltage fluctuation of $f_m = 8.8$ Hz and relative voltage amplitude of $\Delta V/V = 0.25\%$ is applied. The problem arises with the adjustment of the light flickermeter. The immunity protocol must provide a method to perform the adjustment of the light flickermeter. The light flickermeter should be adjusted with the light output of an incandescent lamp subjected to the aforementioned sinusoidal voltage. However, the incandescent lamp will be no longer available in the market and the still existing incandescent lamps can provide dispersion in the $P_{st}^{LM}$ values when one of them is selected for the adjustment of the light flickermeter.

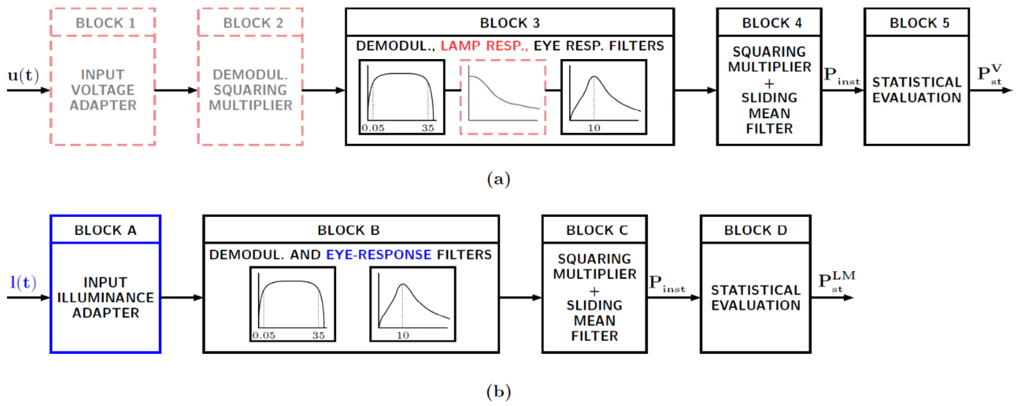


*Figure 2: (a) Block diagram of the IEC flickermeter; (b) Block diagram of the light flickermeter.*

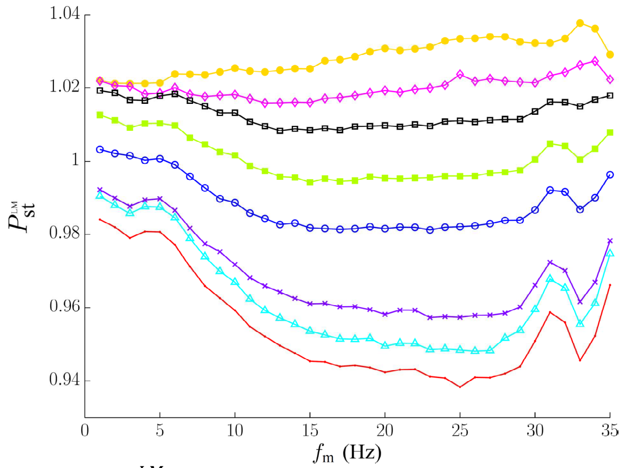


*Figure 3: $P_{st}^{LM}$ values of 8 incandescent lamps subjected to the rectangular fluctuations related to $P_{st} = 1$ curve.*

Figure 3 shows the $P_{st}^{LM}$ values of 8 standard incandescent lamps, represented with different colours, subjected to the rectangular fluctuations corresponding to the $P_{st} = 1$ curve. The light flickermeter was adjusted with the light of the lamp represented in black. A relevant maximum dispersion of almost 10% can be observed between all the incandescent lamps.

In view of the difficulty in adjusting the light flickermeter with an actual incandescent lamp, the use of an incandescent lamp model was proposed. To that end, the lamp model presented in [7] was selected. This model consists of three blocks represented in Figure 4. In block L1 an input voltage adapter is implemented in order to make the measurement independent of the grid nominal voltage level. Block L2 reflects the behavior of the incandescent lamp in the conversion of the input energy into the output illuminance. Finally, in block L3 the response of the incandescent lamp to voltage fluctuations is represented.

However, after adjusting the light flickermeter using this incandescent lamp model, inconsistencies were found when testing actual incandescent lamps. The incandescent lamps were subjected to the test voltages indicated in Table 1 but the obtained results far exceeded

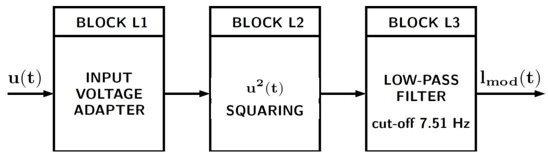


*Figure 4: Model of the 60 W incandescent lamp [6]*

the reference value, $P_{st} = 1$. These differences stem from the inability of the model of Figure 4 to represent the actual illuminance of the incandescent lamp. This lamp model provides an accurate relationship between the relative illuminance fluctuation values, $\Delta L/L$ at different fluctuation frequencies $f_m$. However, these values do not reflect their true relationship with the relative voltage fluctuation values, $\Delta V/V$. That is two incandescent lamps with two gain curves, $\frac{\Delta L/L}{\Delta V/V}$, exactly related with a constant factor of 2 would be represented by the same lamp model without reflecting their different sensitivities.

To overcome this problem, it was needed to determine the actual illuminance level, $L_{mod}^{New}$, in order to obtain adequate $\Delta L/L$ values:

$$\frac{\Delta L_{mod}}{L_{mod}^{New}} = \frac{\Delta L_{lamp}}{L_{lamp}} \rightarrow L_{mod}^{New} = \frac{\Delta L_{mod}}{\Delta L_{lamp}/L_{lamp}}, \quad (1)$$

where $\Delta L_{lamp}/L_{lamp}$ is the relative amplitude of the illuminance obtained experimentally from an actual incandescent lamp and $\Delta L_{mod}$ is the amplitude of the illuminance fluctuation obtained from the output of the lamp model, $l_{mod}(t)$.

This modification required experimental tests to obtain the actual $\Delta L_{lamp}/L_{lamp}$ of incandescent lamps when subjected to the sinusoidal voltage fluctuation test. The $L_{mod}^{New}$ value was calculated for each of the 8 incandescent lamps and the mean value of the obtained results was selected as the $L_{mod}^{New}$-value to be applied in the new model (Figure 5). This model calculates the illuminance signal, $l_{mod}^{New}(t)$ which provides the actual relationship between the amplitude of the fluctuation and the illuminance level, $\Delta L_{mod}/L_{mod}^{New}$.

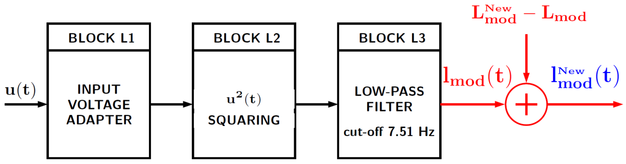


*Figure 5: Modified model of the 60 W incandescent lamp*

Based in the modified model of the incandescent lamp, the following illuminance waveform pattern is provided in the TR in order to facilitate the adjustment procedure of the light flickermeter:

$$E(t) = \left\{1 + \frac{d_E}{2}.\sin(2\pi f_m t)\right\}, \qquad (2)$$

where $f_m = 8.8$ Hz, and $d_E = 0.630\%$ which was obtained by means of the lamp model of Figure 5. In this way, the light flickermeter should be adjusted so that $P_{inst} = 1$ when the illuminance waveform *E(t)* is applied.

## Other critical issues

### Illuminance sampling process

Unlike the incandescent lamp, the light output of some types of lamps may contain spectral components at frequencies well above 100 Hz (kHz-range) which do not produce flicker. However, depending on the sampling frequency used, these higher frequencies can be undersampled leading to aliasing which introduce artefacts in the light signal. To avoid this effect, an anti-aliasing filter is recommended to be placed between the amplifier output of the light sensor and the measurement system. Additionally, in accordance with the Nyquist criterion the sampling frequency must be at least twice the bandwidth of the signal. The illuminance signal has a spectrum of interest that is at least twice the spectrum of interest of the mains voltage signal for incandescent lamps. That is, with a mains voltage signal of 50 Hz and an amplitude modulation ranging from 0.5Hz to 40 Hz, the mains voltage signal extends up to 100 Hz. However, as mentioned before, non-incandescent lighting can present higher frequencies depending on the driver technology applied. In these cases, the sampling frequency should be selected in conjunction with the cut-off frequency of the anti-aliasing filter applied. In the TR, a quite conservative recommendation is described: a sample rate of 10 kS/s is recommended with a low-pass filter characterized by a cut-off frequency of 1 kHz.

### Duration of the test signals

In order to establish the minimum duration of the voltage fluctuation and recording of the illuminance the periodicity of the test signals and the transient response of the filters of the light flickermeter must be taken into account. The transient response of the light flickermeter's response is dominated by the illuminance adapter (block A). This block consists of a low-pass filter with a time constant of 10 s which reaches the steady state response at approximately 50 s. Thus, 60 s are recommended for the filters response. The evaluation period should contain an integer number of voltage fluctuation periods. To achieve this and according to the modulation frequencies given in Table 1, a minimum duration of 120 s is needed. In total, a duration of application of the voltage fluctuation of 180 s is recommended.

## RESULTS OF THE IMMUNITY TEST OF A SET OF LAMPS

In order to verify the adequacy of the specifications established for the immunity test and to test the reproducibility of the method a small RRT was conducted by Philips Innovation Services and the University of the Basque Country (UBC). For the RRT, the immunity test was executed using a sample of five lamp of different lighting technologies.

The verification process carried out by both entities fully satisfied the requirements indicated in the TR. For the immunity test, the lamp samples represented in Table 2 were subjected to the voltage test signals specified in Table 1. It should be noted that the lamp INC2 was only analyzed by Philips, as the lamp got damaged in transit and it did not arrive in good condition at UBC.

Figure 6 shows the $P_{st}^{LM}$ values obtained during the RRT for each lamp under test. A good consistency between the $P_{st}^{LM}$ values obtained by both entities for the lamps INC1, CFL1 and CFL2 can be observed. This fact confirms the reproducibility of the test method. The differences obtained with LED1 lamp were due to the erratic response that the lamp itself showed during the tests. The measurements with this lamp were repeated several times showing a very unstable behavior. On the other hand, between the incandescent lamps differences in their responses can be observed. As a standard 60 W-incandescent lamp, INC2 provided $P_{st}^{LM}$ values close to the unity. However, another 60 W-incandescent lamp INC1, a specific type for rigid applications, due to specific constructive properties of its filament, this lamp presented $P_{st}^{LM}$ values below the unity.

The immunity analysis of the lamps tested in the RRT revealed less sensitive behavior of all the lamps when compared with the standard incandescent lamp INC2.

However, this behavior cannot be generalized to all the

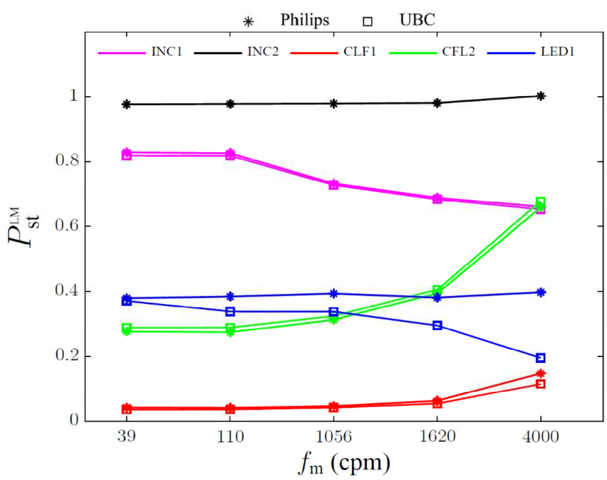


*Figure 6: Immunity test results of the RRT.*

*Table 2: List of lamps subjected to the immunity test.*

| Lamp Id | Type | Brand | Wattage (W) | Nominal voltage (V) | Freq. (Hz) | Lumen (lm) | Warning up time (min) | |
|---|---|---|---|---|---|---|---|---|
| INC1 | Incandescent lamp-frosted-rough service | Philips | 60 | 230 | 50 | 515 | - |  |
| INC2* | Incandescent lamp-clear | Gamma | 60 | 230 | 50 | Not available | - |  |
| CFL1 | Tornado Energy Saver | Gamma | 60 | 230 | 50 | 1220 | 15 |  |
| CFL2 | Genie | Philips | 8 | 230 | 50 | 420 | 15 |  |
| LED1 | Master LEDbulb MV | Philips | 20 | 230 | 50 | 1521 | 10 |  |
| CFL3 | Softone (dimmable) | Philips | 12 | 230 | 50 | 600 | 15 |  |
| CFL4 | Biax F18DBX | General Electric | 18 | 230 | 50 | 1050 | 15 |  |
| FL1 | Linear fluorescent | Sylvania | 18 | 230 | 50 | 1050 | 15 |  |

RRT

* Only tested by Philips as it did not arrived in good condition to UBC

lamps or lighting equipment that can be found in the market. Table 3 shows additional $P_{st}^{LM}$ values obtained by applying the immunity test to 3 other lamps which were not part of the RRT. As can be seen, at some $f_m$ these lamps present a more sensitive behavior than the incandescent lamp, that is $P_{st}^{LM} > 1$, or sensitivities close to the incandescent lamp, $P_{st}^{LM} \approx 1$. Faced with the possibility that new lighting technologies can present more sensitive behavior than the incandescent lamp, the immunity test of the lamps takes even more importance.

*Table 3: $P_{st}^{LM}$ values obtained from the immunity test of three additional lamps analyzed by UBC.*

| $f_m$ (cpm) | 39 | 110 | 1056 | 1620 | 4000 |
|---|---|---|---|---|---|
| CFL3 | **1.057** | **1.050** | 0.866 | 0.678 | **1.284** |
| CFL4 | 0.506 | 0.530 | 0.604 | 0.747 | **1.612** |
| FL1 | 0.359 | 0.359 | 0.401 | 0.500 | **1.375** |

## CONCLUSIONS

In view of the difficulty of adapting the flicker measurement procedure and the compatibility levels to a new reference lamp, the immunity tests of the lamps or lighting equipment should guarantee the absence of flicker with the massive application of new lighting technologies. In this paper, the main issues that needed to be taken into account during the development of the immunity test protocol are summarized and the adopted proper solutions are explained. The validity of the immunity test method has been verified and the reproducibility of the method has been proven through the execution of a small RRT.

The next steps to be taken in the immunity analysis of the lamps would be oriented towards two lines. First, the analysis of the linearity response of the lamps when subjected to proportional input voltage fluctuations. That is, the immunity analysis performed for a flicker severity level of $P_{st} = 1$ should be verified at higher flicker severity levels. Second, the analysis of the response of the lamps to voltage fluctuations at higher frequencies, including interharmonics. It should be noted that incandescent type of lamps are immune to high frequency interharmonics and therefore, there are no defined compatibility levels that would represent the irritability threshold at these frequencies. However, other lighting technologies, due to e.g. non-linear behavior, may induce flicker due to voltage fluctuations at higher frequencies.

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