The characteristics of CFLs; beyond the harmonics

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Abstract— **Large numbers of Compact Fluorescent Lamps (CFLs) are entering the power system and therefore it is important to understand their behaviour and possible detrimental impact. The main area of concern to-date has been the possible negative impact they will have on harmonic levels in the distribution system. This paper investigates some of the characteristics of CFLs that are often overlooked, or of which little is known. In particular; interference with Infrared Remote Controlled Devices, Conducted Radio Frequency Interference (RFI), inrush current at switch ON and failure modes are investigated.**

Keywords- Compact Fluorescent Lamps, Inrush current, infrared, Life-time

I. INTRODUCTION

The drive for energy efficiency has led to many public campaigns to persuade householders to replace their incandescent lamps with Compact Fluorescent Lamps (CFLs). This has resulted in very large numbers of CFLs entering the power system. The main area of concern to-date has been the nonlinear nature of CFLs and the possible negative impact they will have on harmonic levels in the distribution system. This paper however examines the characteristics of CFLs that are often overlooked or of which little is known.

(1) Interference with Infrared Remote Controlled Devices due to emission of modulated light in the infrared spectrum.

(2) Inrush current at switch ON.

(3) Conducted Radio Frequency Interference (RFI).

(4) Life-time and failure modes.

The measurements demonstrated the ability of infrared remote controlled devices to be adversely affected by CFLs. Reducing the sensitivity of the infrared controlled device can overcome this, but at the cost of reduced remote controller range.

Inrush current was investigated due to the failure of a timer-switch controlling multiple CFLs. The inrush current is of course dependent on the point on the voltage waveform at which the CFL is switched on, and currents of up to 14 Amps were recorded (worst case) for one 20W CFL. This is particularly an issue whenever there are multiple CFLs controlled by timers or motion detectors. Failure to consider this will result in switch failures.

Conducted RFI was measured for a number of different brands and the results showed they all complied with IEC CISPR15 limits, although the RF emissions spectrum varied widely.

Many CFLs have a place on their PCB for a PTC (Positive Temperature Coefficient thermsistor), but it is not installed. Since the purpose of the PTC is to remove the stress of cold starts, one question is whether the manufacturer stated life-times are with or without the PTC installed. Life-time tests have clearly shown the sensitivity of life-time on temperature and that the stated life-time was met without the PTC for the brand tested (Ecobulb).

II. INTERFERENCE WITH INFRARED REMOTE CONTROLLED DEVICES

A. Background

There have been reports of CFLs interfering with infrared remote controlled devices. Sometimes the devices will not react on remote control signals when a CFL is turned ON and at other times the devices execute infrared commands without anyone using the remote control [1]. Most reports have involved Skybox which is a product of Sky, a provider for satellite TV in New Zealand. The infrared receiver used in the current Skyboxes is the TSOP343, designed to receive infrared signals with a carrier frequency of 40 kHz.

There are two main signalling methods used for infrared remote controllers, Pulse Width Modulation (PWM, also known as SIRC) and bi-phased modulation (also known as RC5). The Skybox remote controller uses PWM signal. A logical “one” is transmitted by sending a pulse and a logical “zero” is transmitted by silence (see Fig. 1).

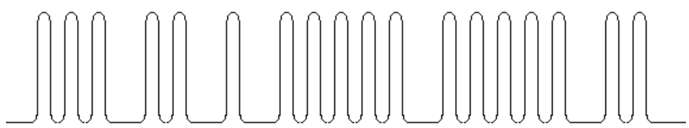

Fig. 1. Example signal transmitted by a Sky remote control

B. Spectral Measurements

In a darkroom a spectrometer (Lastek 74050 and the CCD sensor Larry 2048) was used to check the infrared output from various CFLs, as shown in Fig. 2. The spectrometer was designed to measure the visible spectrum (400nm-750nm) and its sensitivity drops dramatically as the wavelength increases. The spectrometer works by use of a motorized prism, which splits the spectrum and directs an approximately monochromatic beam, at the selected wavelength, onto the sensor. Although it was not possible to measure the complete IR range (750 nm to 100 µm), measurements showed that the Skybox remote controller operates at a wavelength of about 910nm. Although above the spectrometer's designed frequency range, tests showed that it responded to these frequencies and up to 1000nm. The sensitivity decreases when the wavelength gets higher, as shown by the graph displayed in Fig. 3. Correction factors were developed (shown in Fig. 3).

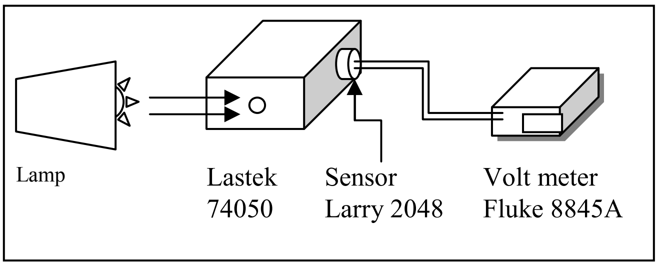

Fig. 2. Experimental setup 1.

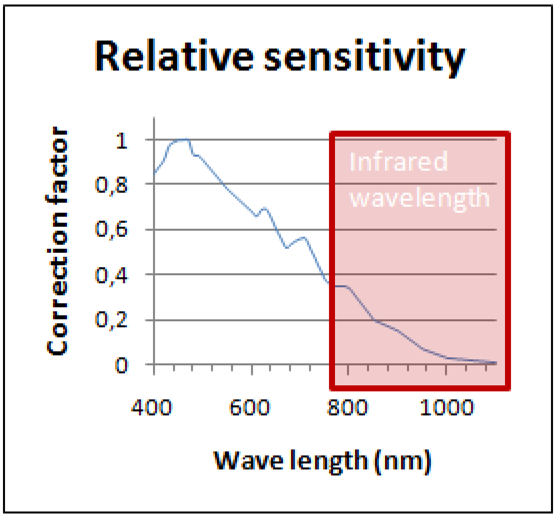

Fig. 3. Correction Factor.

Table I
Measured Infrared Transmission from different sources

	Wavelength (nm)	Delta V (V)
No source	910	0.002
Remote Controller	910	0.215
Ecobulb 1	910	0.017
Ecobulb 2	910	0.019
Incandescent Lamp	910	2.505

To measure the relative strength of the infrared signal, at 910nm, the test setup shown in Fig. 4 was used. Measurements were made with the spectrometer aperture completely open and the difference between the voltage with the aperture open and closed was taken as a measure of the signal strength. This was necessary because of drift, due to such factors as temperature drift that occurred due to the electrical power consumption. From Table I a delta V of 0.215 V for the remote controller was measured, compared to 2.505 V for the incandescent lamp. Ecobulb 1 had been removed from service as it caused mal-operation of a Skybox and Ecobulb 2 was tested to ensure Ecobulb 1 was not an abnormal lamp.

As shown in Table II, both the Ecobulbs transmit a relatively small amount of infrared. To investigate the infrared signal further a special purpose receiver was developed using an infrared photo transistor. Fig. 5 shows the output for the Skybox remote controller while Fig. 6 gives the output from an Ecobulb. The 100 Hz ripple is clearly seen, as well as switching noise. Although the 100 Hz ripple is too low a frequency to affect the Skybox, the switching noise is reasonably broad and at a frequency that can affect it.

Infrared light is reflected just like visible light; this means the lamp holder has a big influence on the way the IR light is transmitted and various tests were performed to quantify this.

Table II Effect of the series inductance

L (mH)	I_{peak} (Amps)
0	14.1
0.25	13.2
0.5	12.3
1.0	11.5

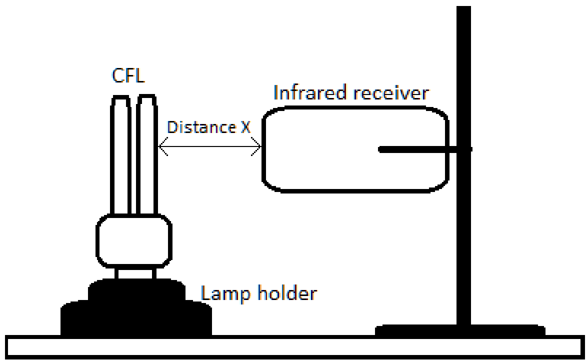

Fig. 4. Experimental setup 2.

It has been shown that CFLs can interfere with Infrared remote controlled devices. Most CFLs work on a fixed switching frequency. Therefore the likelihood of interference with a remote IR controller is small, as the switching frequency must be in the range of the receiver's infrared frequency sensitivity. As the Ecobulb has a wideband switching frequency, modulated by the amplitude of the full wave rectified internal DC bus, it has a higher likelihood of interfering with infrared remote controllers.

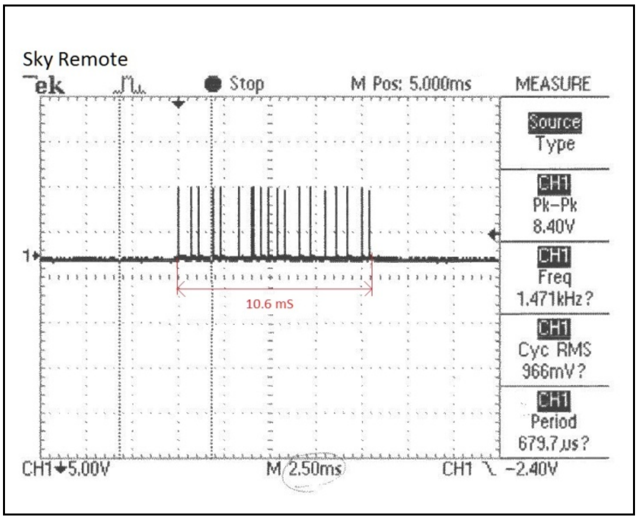

Fig. 5. Measured pulses from Infrared Remote controller.

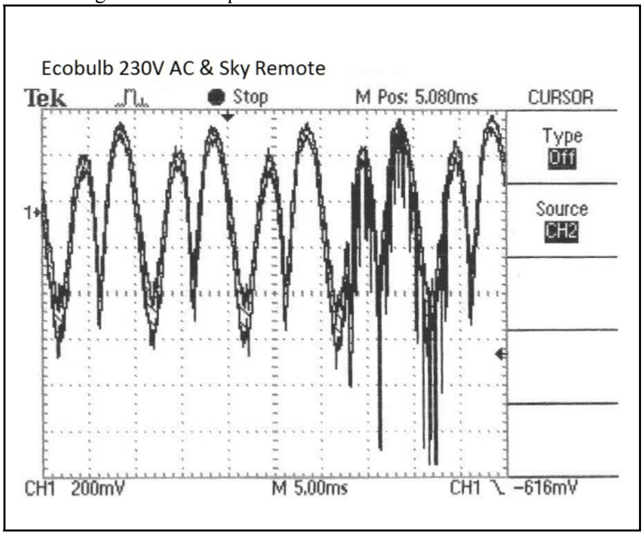

Fig. 6. Measured Infrared with Ecobulb.

III. Inrush Current

The motivation for this study was the frequent failure of timers controlling multiple CFLs. Although when started the timers function correctly, within a week the timer fails to turn the CFLs OFF. One possible mechanism is the inrush current welding the contacts closed when switched ON.

CFLs have capacitor smoothing of the dc voltage and as such appear capacitive to the ac system, causing an inrush to occur when switched ON. The main factors influencing the inrush current are [4,5]:

- CFL ballast circuit design.
- Inductance of the power source and cable.
- Point on voltage waveform when switched ON.

The ON-degree offset facility of a Chroma 61504 sine wave voltage source was used to control at what point in the cycle of the voltage waveform the power is turned ON. As expected for a capacitive circuit, the inrush was minimum at zero degrees and maximum at 90 degrees. Fig. 7 summarizes the results. Switching at zero the in-rush for the Ecobulb was 1.16 Amps, for the Philips, 0.53 Amps and for the Elite, 0.94 A. The Elite had an inrush of around 14.3 Amps at 90 degrees. A study into the influence of supply inductance in limiting the inrush was also performed and summarized in Table II. All CFLs tested were 20W and the Ecobulb has a nominal current rating (rms) of 79mA. The effect of switching multiple CFLs was also investigated. The inrush with one CFL was multiplied by two and compared to the measured inrush for two CFLs, as displayed in Fig. 8. Although they do not exactly match they are close. An unexpected phenomenon observed was that the expected current is bigger than the actual current on the positive half cycle. But on the negative half cycle the expected current is smaller than the actual current (Fig. 8).

Finally the inrush was measured for a rack of 20 CFLs. When switched at 90 degrees the peak current drawn by the CFLs was 116 Amps. The peak was reached after 100 µS and decreased over a period of 400 µS.

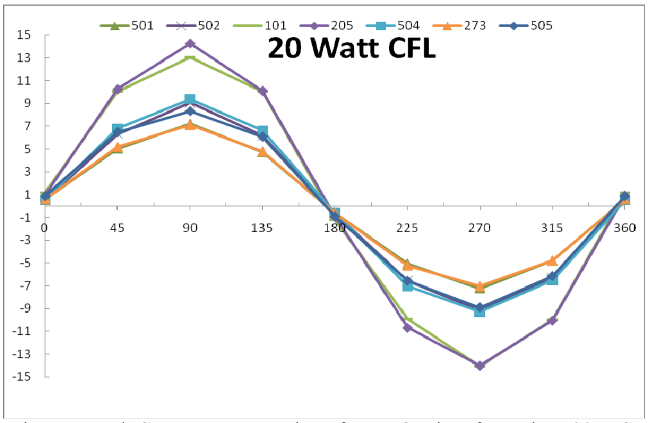

Fig. 7. Inrush Current as a Function of Turn-On time for various 20W CFL models.

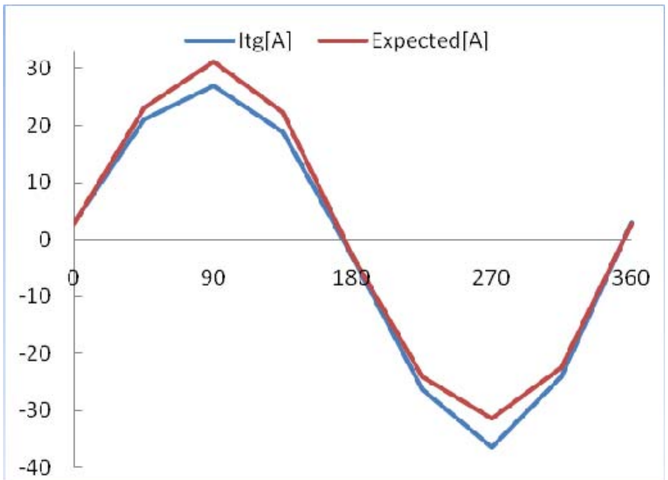

Fig. 8. Measured Inrush current when multiple CFLs are switched ON.

IV. Radio Frequency Interference (RFI)

When performing RFI measurements it is important to measure the interference caused by the Device Under Test (DUT) only and exclude the pre-existing distortion. To filter the distortion from other sources a Line Impedance Stabilization Network (LISN) is used. Its main functions are (i) a low pass filter with a cross over at the 50 Hz freq and transferring the conducted interference voltage produced by the DUT to a spectrum analyzer, (ii) absorb the unwanted conducted noise coming from the mains to the DUT, and also prevent distortion created by the DUT to leak back to the mains.

The CISPR 15 standard describes the setup for the RFI measurement [2]. The CFL must be placed in a conical metal housing as shown in Fig. 9. The metal housing is hung above a metal plate of 2m x 2 m. (see Fig. 10). This is the earthed conducting surface and is connected to the reference earth of LISN. The lamp is hung 0.4 metres above the plate and the lead between the lamp and the LISN is 1 metre. The disturbance voltage is measured at the supply terminals.

Fig. 9. The Conical metal housing for the CFL.

Fig. 10 Test Setup: the ground plane, lamp holder and Spectrum analyser.

Because the measurements could not be performed in a Faraday cage, as the setup is too large, filtering and estimation of noise is required. The complete frequency range of 9 kHz to 30 MHz was scanned. At first the LISN and the spectrum analyzer were connected to the normal mains. At the lower frequencies there was noticeable distortion as shown in Fig. 11. Also there is a peak measured at 32.688kHz; this is probably caused by a digital clock, the oscillation frequency of the crystal used for most digital clocks being 32.768kHz [3]. The harmonics of this peak are also seen in Fig. 11, at a frequency of 65.536kHz and 98.304kHz. At the higher frequencies (150 kHz to 30 MHz) not much distortion was noticeable, as shown in Fig. 12.

Connecting the LISN to a programmable AC power supply (Chroma) proved to be unsuitable as, although the peaks at 32.688kHz and its harmonics were gone, large peaks at the switching frequency of the Chroma (100 kHz) and its harmonics became evident.

A 50 Hz rotating sine-wave generator was tried as a power source for the LISN (Spectrum analyzer connected to the normal mains). This resulted in a lower noise level, shown in Figs. 13 & 14, and therefore was used for the CFL RFI measurements.

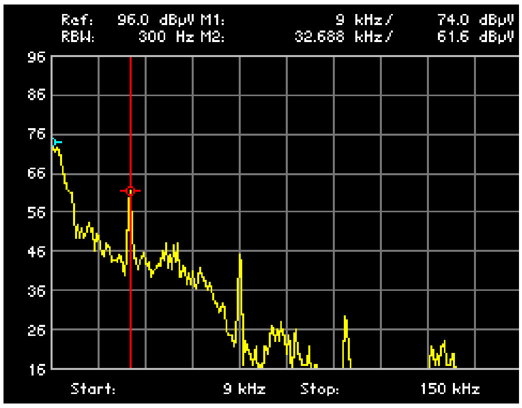

Fig. 11. Spectrum of 9 kHz - 150 kHz; light turned off

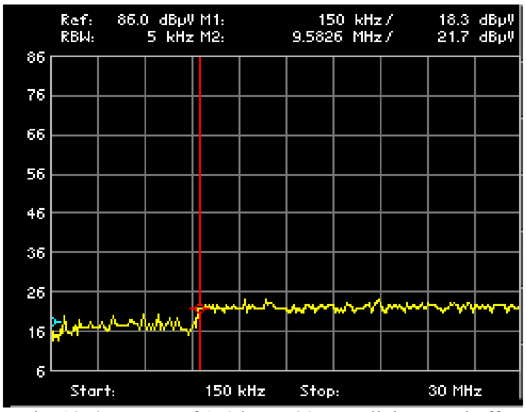

Fig. 12. Spectrum of 150 kHz - 30MHz; light turned off.

All CFLs tested passed the limits according to CISPR15. In the screenshots of 9 kHz to 200 kHz, recorded by the spectrum analyzer, is a clear view of the switching frequency of the CFLs. These have higher harmonics, which are also visible in the screenshots. The 1st harmonics of the different CFLs are shown in Table III. The Nelson, Basix and Ecobulb had the highest peaks. Philips and Osram performed the best in the 9 kHz to 200 kHz range. The Basix and Nelson have a fixed switching frequency, these peaks being narrow. The other three have wider peaks due to switching frequency of the CFL being modulated by the 100Hz rectified voltage waveform. The Ecobulb has the widest peaks, the first harmonic being 38.8 kHz to 50.3 kHz wide (see Fig. 15), nicely straddling the Skybox 40 kHz carrier. The second harmonic of the switching frequency is twice as wide and the third is three times as wide. That pattern is visible until they start to overlap and the pattern becomes too difficult to observe.

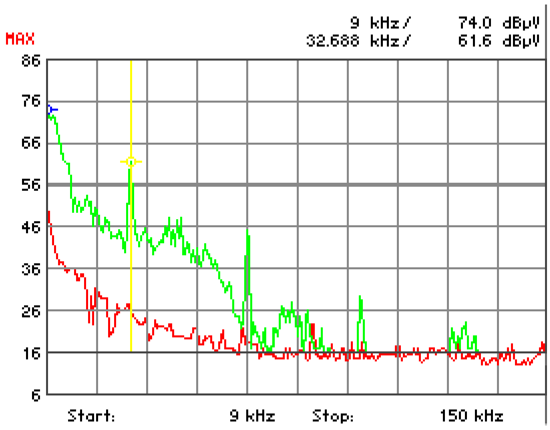

Fig. 13. Green – LISN connected to normal mains, Red – LISN connected to generator.

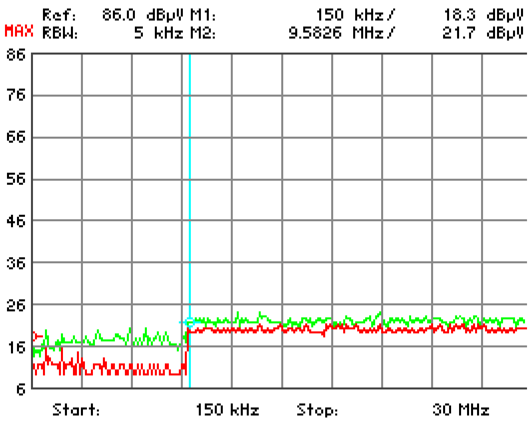

Fig. 14. Green – LISN connected to normal mains, Red – LISN connected to generator.

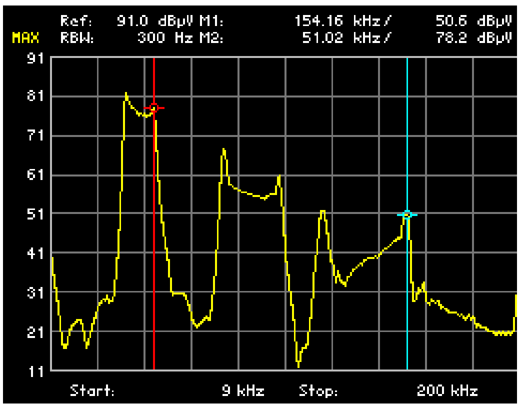

Fig. 15. Ecobulb spectrum in 9 kHz to 200 kHz range.

Table III Switching frequency from the different CFLs

CFL	1st harmonic freq [kHz]	Amplitude [dBµV]
Basix	28.1	78.4
Ecobulb	33.8	81.5
Nelson	31.2	79.7
Osram	42.6	60.3
Philips	30.4	67.7

V. LIFETIME TESTING

People are unhappy when their CFL, which has a life-time rating of 10,000 hours, blows up after a short period. This is because people do not understand what lifetime ratings mean. In the standards, lifetime is defined as the hours of operation when 50% of the sample has failed. Minimum sample size is 20 lamps and the testing regime differs slightly for Europe and USA, yet the principle is the same. Both assume the main cause of failure is repeated switching of lamps. In Europe the lamps are subjected to a 3 hour cycle where the lamps are switched off for 15 minutes to allow them to cool down and on for 2 hours 45 minutes (typical of an evening usage). In USA's STAR programme the lamps are on for 3 hours and 20 minutes is then allowed for the lamps to cool down, before switching them on for another 3 hours. This is awkward as the 3 hours & 20 minutes does not fit nicely into a 24 hour day - therefore a standard 24 hour timer cannot be used. Also, 40 minutes off period is required every week if each week is to be the same. A lamp is considered to have failed, not when it stops glowing, but when the light output drops to 50% or less of the initial level.

Fig. 16 CFL Life-time tester.

A lifetime tester has been developed to test the claim of manufacturers regarding their product. This tester, shown in Fig. 16, consists of two trays, each with 20 CFLs. The lamps on the bottom tray are oriented upward while the lamps point downward on the top tray. The reason for this is to test the effect of orientation on CFL lifetime. Due to the timers readily available, a 24 hour timer, with a 3 hour cycle and an OFF period of 20 minutes within the 3 hours, was used. A box of 60 CFLs was obtained and out of this 6 CFLs were faulty and could not be used in the tester. The preliminary results are shown in Fig. 17.

It is clear that the CFLs exceeded expectations in terms of stated lifetime (10,000 hours). The higher earlier failures of the CFLs on the bottom tray can be attributed to their ability to cool faster due to orientation and hence more loss of emission material on start-up.

The failed CFLs were dismantled and the ballast connected to a good tube to verify this was the cause of failure and not the ballast. In most cases the tube was the component that had failed. The lifetime in a typical residential house is expected to be less, as this experiment was carried out in the Power Electronics laboratory and the temperature swing in the laboratory environment is not as large as in most people's homes. With the top lamps facing down all the heat produced rises into the ballasts, thereby "cooking" the ballasts, and accelerating the failure of the ballasts. Therefore over time it would be expected that this would show up as a secondary mechanism over a longer period.

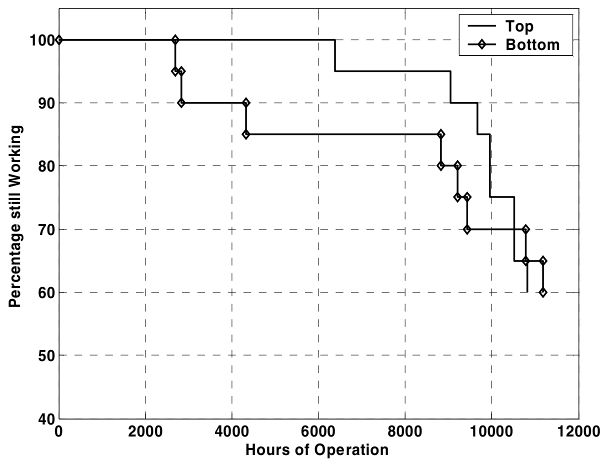

Fig. 17 CFL Life-time results so far.

VI. Conclusion

The mechanism of interference with infrared remote controlled devices due to CFLs has been investigated. This shows that it is caused by the modulated light in the infrared spectrum, not by the fact there is high emission in the infrared region. Incandescent lamps have a far higher level of emission in the infrared region, but no significant modulation.

Inrush current at switch ON of CFLs has been shown to very large. This inrush current is far larger than might be expected from such a low power device.

Conducted Radio Frequency Interference (RFI) measurements showed that all CFLs tested passed the limits according to CISPR15.

Lifetime tests showed the Ecobulb exceeded the stated life-time of 10,000 hours and that the main failure mode was the loss of emission material due to cold starts. The different orientation clearly demonstrated this.

Acknowledgment

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