



EPECentre Fluorescent Light Flicker Project: Stage I
'Fluorescent Light Flicker caused by Load Management Signals'

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ABSTRACT

This paper presents findings from a current research project conducted by the Electric Power Engineering Centre in partnership with Orion New Zealand Limited and Enermet Limited, to investigate fluorescent light flicker caused by audio ripple signals in distribution networks. Findings have shown that fittings with magnetic ballast are most affected and have caused problems in countries where a 175Hz carrier signal is used for load management. Orion NZ also operates the 175Hz ripple signalling system within urban Christchurch and has experienced similar problems. A suitable test system has been designed to accurately reproduce and measure the phenomena.

The system consists of a high powered AC signal generator that supplies the fluorescent fittings with 230V AC mains as well as the required ripple frequency. A high sample rate PC based data acquisition system measures the light produced from a fast response photometric detector; voltage and current are also measured simultaneously through the same system. The Lab-View software is used to collect and process measurements and to control the AC generator. A lighting booth is required to eliminate stray light and provide a testing platform for measurements and to gain a human perception of light flicker. With the information gathered, a theory will be developed and an economic solution will be proposed to reduce or eliminate this problem.

1. INTRODUCTION

Line Companies throughout New Zealand use audio ripple signals to perform various control functions, such as to manage peak loads on their networks. Common frequencies range from 110Hz to 1048Hz at about 1.1% to 3% of the fundamental voltage, generally with the higher signal levels used at the high frequencies. These signals are injected at various voltage levels e.g. 11kV, 33 kV, etc. The signals appear as inter-harmonics on the distribution system and in extreme cases, may be attenuated to around 0.6% of the fundamental voltage. In other extreme cases, where resonance with capacitors occur, the signal may be amplified to 10% of the network voltage. In some cases, these signals have the effect of causing fluorescent light fittings to flicker at a rate visible to the human eye.

The problem has been found to be most obvious when the ripple signal uses a 175Hz carrier. This has been experienced overseas and also within the Orion distribution network in urban Christchurch, the only area in New Zealand where this frequency is used. This paper presents Stage I of the Electric Power Engineering Centre (EPEC or EPECentre) research project into investigating the cause of fluorescent light flicker as a result of these audio ripple signals. Stage I required the research, design, and development of a test system to reproduce and measure this phenomenon. The discussion to follow also summaries possible causes of the light flicker.

Previously published papers [1, 2] in the area of 'fluorescent light inter-harmonic sensitivity' fail to find a definite explanation for the problem. Currently available flicker-meters standards [3, 4] all assess the flicker level from the voltage waveform using a standard incandescent lamp's response (linking voltage variation to luminesce) and therefore are not directly applicable to fluorescent lamps. For this project a different approach has been taken, the relationship between the light produced (perceived by the average human eye) and the voltage/current waveforms is being investigated. The aim of this research is to propose an economic solution to reduce or eliminate this problem.

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2. THE TEST SYSTEM

A test system was required to reproduce the ripple signal and impose it onto normal mains voltage to supply fluorescent fitting. Measurements of the light waveform and the supplied voltage and current will be used to determine how the inter-harmonic ripple signal interacts and produces the light variation.

The fluorescent fittings are to be powered by a programmable AC source, and the light produced is then detected using a photometer inside a lighting booth. A desktop PC interfaces to the AC power source to measure the light intensity, voltage and current waveforms. This provides full control and measurement of the system through two simple GUIs (Graphic User Interfaces).

1.1 Fluorescent Tubes and Ballasts

Fluorescent fittings using magnetic ballasts have been found to be more susceptible to the interharmonics than those with modern electronic ballasts; however, some electronic ballasts are susceptible. The flicker problem can be solved by replacement of the magnetic ballasts with modern electronic non-effect ballasts. This has the added benefits of high operating frequency (less normal light flicker), improved efficiency and longer tube life. However, in practical terms, this leads to the complete replacement of fittings at a cost which can be difficult to justify.

A set of fluorescent tubes and ballasts have been supplied and certain units have been marked as problematic. They have been obtained from industrial sites and include both types of ballasts; magnetic and electronic. A range of compact fluorescent bulbs are also available for immunity testing.

Fluorescent lights were invented around 1935 and are widely used for their high efficiency. The sealed tubes contain an inert gas, typically argon and a small amount of mercury. Current through the tube moves electrons and ions very rapidly and causes them to collide; electrons are stripped or moved into higher orbital energy bands of the gaseous molecules. As the electrons drop into lower orbital energy bands they emit photons at UV wavelengths. A phosphor coating inside the tube absorbs the UV and creates visible light. During starting the tube contains no free electrons or ion and therefore no current path can be formed. A starting circuit heats tungsten filaments at both ends of the tube, this creates free ions to allow current flow and once the path is established the filaments act as electrodes. The plasma has many free ions and therefore very low resistance; this is where a ballast is used to limit the current. Magnetic (sometimes called Inductive) ballasts contain a specially wound coil of wire which acts like an inductor. As the current flow through the ballast increases, the inductor generates a stronger magnetic field, this creates an opposing electromagnetic force in the coil and limits current flow. The ballasts are designed to achieve a current balance at the operating amperage of the tube. Electronic ballasts perform the same task by using transistors to limit current. A higher switching frequency can be achieved, pushing the natural flicker higher than the 100Hz produced by magnetic ballasts.

1.2 Ripple Generation

The Ripple Control System employing a "Telenerg" encoding format has been operational in Christchurch since 1988. Ripple Control Systems of various types have

been implemented for over 50 years for the management of peak load congestion. Receivers are fitted to control deferrable loads, such as; hot water cylinders, which have thermal storage to provide energy during the network congestion, space heating switching, for night rates and meter register control. Orion's Christchurch urban network currently uses a Telenerg "telegram" via a 175Hz ripple carrier frequency. The signal begins with a 1650ms start bit followed by 50 information bits 400ms long spaced at 600ms intervals. The signal takes a maximum of 52.25 seconds to transmit but this can vary depending on information sent. The signal receivers are set to guarantee to operate at 0.55% of the fundamental voltage. The next phase of the project aims to investigate perception of other ripple control signals operated throughout New Zealand and Australia, these include 217Hz, 233Hz, 317Hz, 283Hz, 475Hz, 744Hz and 1042Hz.

The waveform generator is required to supply the fluorescent fittings with mains voltage and the various ripple signal frequencies mentioned above. It must therefore supply 230VAC at fundamental 50Hz and as well as variable amounts of inter-harmonics commonly found on distribution networks. Inter-harmonics frequencies are also required to emulate the ripple signal. Currently Canterbury University has no equipment to easily and accurately reproduce the required waveforms. Research in commercially available programmable AC power supplies yielded the 61501 AC Power Source from Chroma ATE as the best solution.

The Chroma 61501 AC Power Source can provide up to 500VA of power at voltages 0 - 300Vrms AC and 0 - 424VDC. Its fundamental frequency is programmable between 15 and 1kHz and using DSP technology it can synthesis harmonics up to the 40th and inter-harmonics up to 2400Hz. Voltages of each harmonic component are configurable and the interharmonic also perform frequency sweeps. The unit has an external input to amplifier any waveform and impose it onto the output. The unit interfaces to a PC via RS232 or GPIB and is controlled and monitored by a Lab-View GUI. The unit will be programmed to pulse the interharmonics and thereby creating the ripple signals.

1.3 Photometry

Human perception of light flicker and spectral response differs from person to person. The CIE standard [5] photopic luminous efficiency function identifies how the average humans eye responds to different wavelengths of light. Some humans can detect light flicker over 100Hz. Photopic flux is a measurement of light power, expressed in lumens (lm). It is weighted to match the spectral sensitivity of the human eye i.e. $1 \text{ lm} = 1.464 \times 10^{-3} \text{ W}$ of light at 555nm. Illuminance is a measurement of photometric flux (light power) falling on a unit area, expressed in Lux (lm/m^2) [6]. By measuring light flicker we are only interested in the relative change in illuminance and the level at which humans are able to detect.

After research of commercially available light meters it was found that most financially viable units had sample rates of around 2.5samples/s. A higher sample rate is needed so a custom light meter was designed around the BPW21 photodiode. The photodiode was chosen for its spectral sensitivity shown in figure 1 and its current and illumination linearity typically 7nA/lux shown in figure 2.

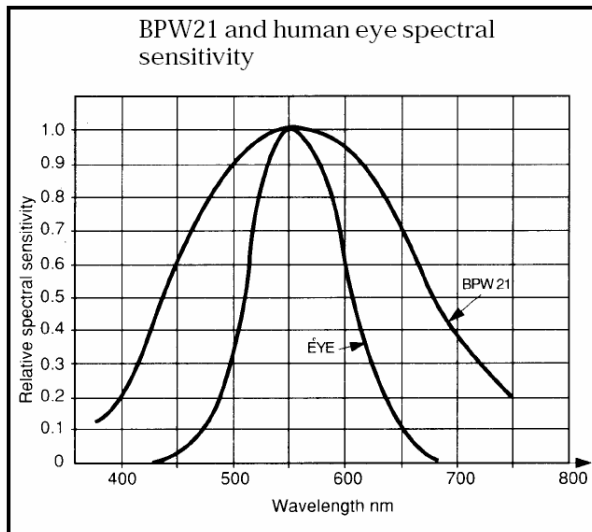


Figure 1. BPW21 Spectral Sensitivity

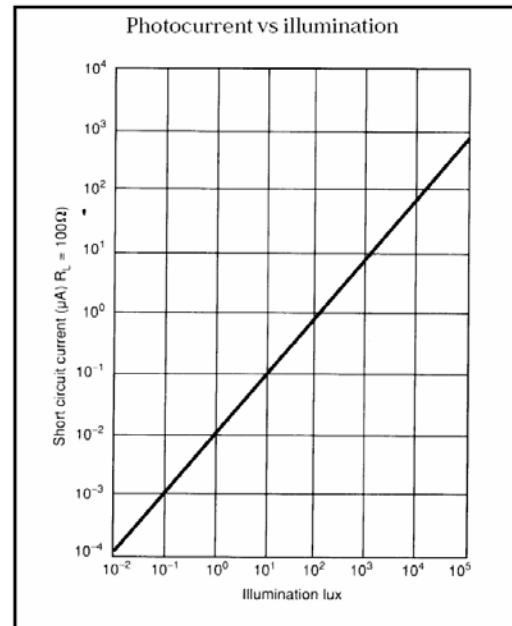


Figure 2. BPW21 Current vs Illumination

The photodiode has large capacitance which has reduces its bandwidth however with a rise time of only around $3.1\mu\text{s}$, it still exceeds the nyquist sampling rate. The diode has 7.5mm^2 of viewing active area and can measure light intensity up to 10^5 Lux. A simple op amp circuit is used convert the photocurrent into a voltage. Two photodiodes run in parallel with a dual pole dual throw rotary switch to vary the gain on the op amp, ultimately the sensing range. The circuit has been built on a PCB and mounted in a plastic box for noise reduction. Figure 3 shows the light intensity measured from a fluorescent tube and Figure 4 shows the light from a LED supplied by a square wave to demonstrate the detector bandwidth.

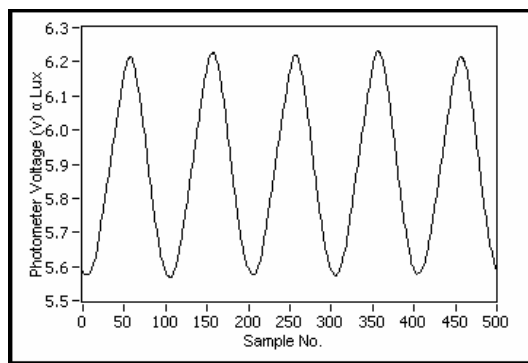


Figure 3. Fluorescent light 100Hz flicker measured via photodiode light meter through data acquisition card at 10kSamples/s

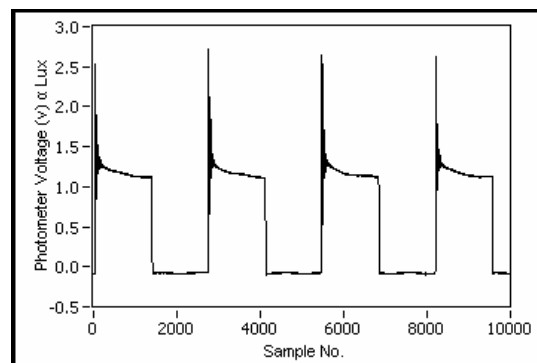


Figure 4. 37Hz Square-wave LED light pulse measured via photodiode light meter through data acquisition card at 100kSamples/s

To eliminate stray light, the fluorescent fittings will be enclosed in a lighting booth. The internal walls of the booth will be painted matte black to reduce reflections so that measurements will be taken from a point source. The photometer will be place behind a series of thin baffles to further reduce stray light and reduce the need for cosine correction. The photodiode light meter is to be calibrated against a commercial light meter and checked for linearity and thermal stability. Observers of different ages

will be subjected to varying amounts of flicker level to develop an understanding on human flicker perception. This study is to be based on the AS/NZS 4376 [4] and 4377 [7] standards using the same methodology but applying to fluorescent lighting. From this information acceptable flicker levels will be identified and used in testing and development of the possible solution.

1.4 Data Acquisition and Measurement

To obtain accurate relationships, the waveforms of luminance, voltage and current are measured by the same unit. This will synchronise the waveforms eliminating timing errors. A PC based solution was best as it enabled easy recording and analysis of the data.

A low end PCI-6013 Measurement Computing data acquisition (DAQ) card was purchased. The board is capable of 200kSamples/s over 8 differential channels. 16bit resolution is provided over 4 voltage ranges from $\pm 50\text{mV}$ to $\pm 10\text{V}$. The board connects to measurable voltages via a screw terminal block and software drivers integrate it into the LabView software.

A voltage divider and shunt resistor will scale the supply voltage and convert the supply current to voltage for measurement within the DAQ cards voltage range. The voltage divider will be designed produced a maximum peak voltage of 20V and the shunt resistor, a maximum peak voltage drop of 100mV. These signals pass through two signal conditioners that provide 1500Vrms isolation for safety and scale the output to a $\pm 5\text{V}$ range. Voltage and current meters will be used for calibration allowing the settings to be entered into LabView. The voltage output of the photodiode light meter will connect directly to the terminal block of the DAQ card.

The software allows for digital filtering and analysis using various methods including DFFT's and phase plots. Once filtered for noise, the frequencies present can be identified and their phase relationships used to construct how the interharmonics correspond to the light produced.

2. FLICKER STANDARDS

Light flicker is difficult to quantify as the human factor complicates the issue. Perceptibility varies from person to person and attempts have been made to quantify results. The Flickermeter design specifications from the AN/NZS 4376:1996 [4] (identical to the IEC 868:1986/AMD.1:1990 [3]) standard gives an approach to flicker measurement that can adapted to a wide range of situations (Note the IEC 1000-4-15 has replaced the IEC 868 flickermeter standard). The AS/NZS 4377:1996 [7] follows directly the IEC 868-0:1991 [8] standard and uses the flickermeter model to investigate the severity of light flicker. The flickermeter standard has based flicker perception by subjecting observers to a standard 60W incandescent bulb with varying amounts of voltage fluctuation. From this perception, statistical methods have developed a function relating flicker perception and the percentage of flicker duration over a set period. This has lead to short-term P_{st} severity calculations which have duration of 10minutes and long-term P_{lt} which combines multiple short-term values. A P_{st} value of 1 indicates 50% of observers will be irritated, $P_{st} > 1$ suggests more than 50% of the observers will be irritated. A similar method will be used but with direct correlation between light levels (Lux) and interharmonic levels.

3. THEORY

The variation (0.5 to 2%) in peak voltage from the 175Hz signal is not the direct cause of the light flicker. As the supply power crosses zero the current through the tube also drops to zero extinguishing the arc. The power increases the arc is re-ignited. It is speculated that the magnetic ballasts are very sensitive the angle of ignition and that the interharmonic ripple signals change the zero crossing angle. The 175Hz ripple signal interacts with the 50Hz fundamental creating a variation in ignition angle, at 25Hz. This sensitivity of the ballasts would then cause the light produced to fluctuate at this 25Hz rate, which is visible to humans. A complication factor is the interaction between the capacitive components in the light fitting and the inductance of the supply circuit and ballast. This may provide the conditions for resonance within the fittings.

4. CONCLUSION

Fluorescent fittings that use magnetic ballasts have been known to react to ripple control signals that use the 175Hz carrier frequency as found within Orion's Christchurch urban distribution network. An appropriate test system has been designed and developed to reproduce the phenomena. Immunity of other common ripple control frequencies is also to be investigated.

The test system measures illuminance and voltage\current which should lead to the understanding of how the ripple signal interacts with the ballast and tube. Light is measured using a photopic light meter with a higher frequency response than the human eye can detect. The light fittings are to be supplied with normal mains power (harmonics included) and the ripple signal as an interharmonic signal. The measurements are taken by a PC based data acquisition system which will also control the waveform generator. Studies of human perception are to identify acceptable flicker levels using an approach similar to current flicker-meter standards.

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