Ambient Light Noise and its Effect on Receiver Design for Indoor Wireless Optical Links

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Abstract:

Knowledge of ambient optical noise is essential for designers of free space optical links, for resilient designs. In this paper, a complete experimental characterisation of the most common ambient optical radiation is presented. The study includes Tungsten filament sources, low and high frequency fluorescent lights, IR headphones, TV remote controls, and daylight. Means to reduce their influence on the performance of the links are also given. The results are valuable towards setting a standard way of comparing wireless IR links, based on testing their performance under such ambient noise.

1. Introduction

The widespread use of portable and more recently palmtop computers allows people to take work wherever they are, in the office, at home, or in transit.

A key requirement to the effective use of such computers, is ease of connectivity between the portable and office PC, or two portables, for file exchange and printing documents.

Infrared optical links have been accepted as offering great potential for ease of connectivity without having to use fixed wire links.

In an effort to standardize optical links the Infrared Data Association has been formed [1], for new standards for reliable exchange of data between such devices. In parallel, other efforts are focused on achieving higher speeds, albeit with different user model, since one of the transceiver sets is attached to the ceiling, [2] using a direction beam, or by flooding the workspace with optical radiation [3], [4], so that reasonably omnidirectional communication is possible.

Unlike fibre optic links, where noise limiting the link performance is dependent on the components in use, free space optical links have the additional constraint that optical link noise is also depending on the ambient environment [3], [4]. Receiver photodetectors are exposed to ambient optical noise in office or home environments. The system designer therefore would need to accommodate for the various sources of “noise”, in order to build a noise immune or resistant to ambient noise optical link.

The term ambient noise is used loosely, and no further distinction is made here between noise (random process) and interference, such as that from sources with distinct harmonics, or other sources with emission which may not be described using a statistical process.

Of primary importance to the overall acceptance of such free space links, is low cost, eye safety, [5], [6] and low power consumption. The range of operation for such links is usually limited to less than 3 meters, for IRDA links.

The receivers must therefore be resistant to indoor ambient optical noise.

In this paper, the common indoor ambient optical noise sources are identified and characterized. The results presented here are useful for wireless optical receiver designs regardless of user model. Practical guidelines for optical receiver design are also discussed.

Optical radiation from the following sources is characterized, and is considered as noise:

a. Tungsten Lights
b. Low frequency fluorescent lights
c. High frequency fluorescent lights
d. IR headphones
e. TV Remote control
f. Daylight

On a desk near a window, daylight is likely to be dominant. Indoors away from windows the type of lighting such as fluorescent or incandescent lights are the major source of interference. In the home, there are two other sources of possible interference: Television remote control units and similar devices for audio control and possibly infrared audio headphones.

2. Characteristics of Ambient Light Sources:

Two types of measurements are presented for each ambient light source:

a. Optical spectrum: An optical spectrum analyser (OSA) was used. The spectral range of the measurements were from 600 nm to 1500 nm. Since Si photodiodes are commonly used in such link applications, the wavelength range of interest is mainly from 400 to 1000 nm. Daylight filters are in common use in free space optical links. Photodiodes with daylight filters are available at low cost, to prevent all visible optical emission from entering in the receiver. Daylight filters remove radiation of wavelength less than 760 nm, and it is a typical example to many other photodetectors.

b. Electrical modulation spectrum: Using a fast detector with receiver of bandwidth 30 MHz, the modulated light was detected from the various optical sources, and connected to an electrical spectrum analyser.

2.1 Tungsten Filament Lights:

Tungsten Filament angle poise lights are very common in offices as well as at home.

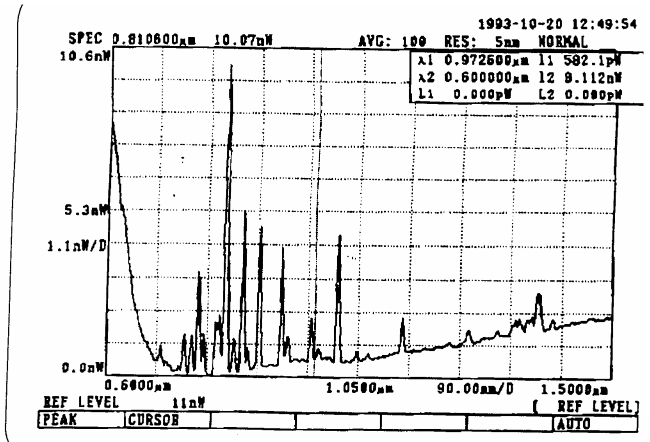

Figure 3: Low Frequency Fluorescent Lights: Optical Spectrum (600nm-1500nm)

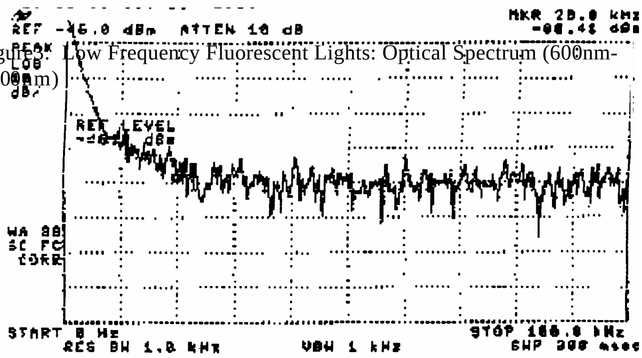

Figure 2: Tungsten lamp, Electrical modulation spectrum

Figure 1 shows the optical spectrum from a typical 60 W tungsten filament source. The spectrum is continuous and peaks at about 1000 nm.

By filtering optical spectrum of the lamp using the daylight filter, although the energy in the visible band is removed, there is still energy above 760 nm which is a cause of additional shot type noise, extending beyond 1000 nm. For a signal source at 780 nm, it is obvious that it would not be possible to remove all the tungsten source energy by optical filtering without affecting the signal energy as well. In addition, since the lamps use a.c. power, they also produce modulation harmonics.

The full electrical modulation spectrum generated by the lamps was measured by a RF spectrum analyser using the broadband receiver. This is shown in Figure 2.

There seem to be no distinct harmonics beyond 100 Hz, which can be eliminated by High Pass filtering. Ignoring the 1/f noise of the instrument (extreme left part of the trace), the spectrum is quite “flat” extending to over 100 kHz. Therefore after suitable high pass filtering tungsten source noise resembles very much like “white noise”.

2.2 Low Frequency Fluorescent Lights

Such lights are extensively used in ceiling lighting, as well as in angle poise lights. Their extensive use indoors makes the investigation of their influence on the IR link performance of great interest.

The optical spectrum of a low frequency fluorescent angle poise light is shown in Figure 3. The spectrum consists of a strong wide visible band followed by a discrete invisible to the eye emission components extending up to 1500 nm.

Using the daylight filter mentioned above, the optical spectrum up to 760 nm can be removed. The optical energy contained in this spectrum from 760 nm up to 1000 nm would potentially be detected by silicon photodiodes, and it is not possible to remove by optical filtering without affecting the optical signal as well.

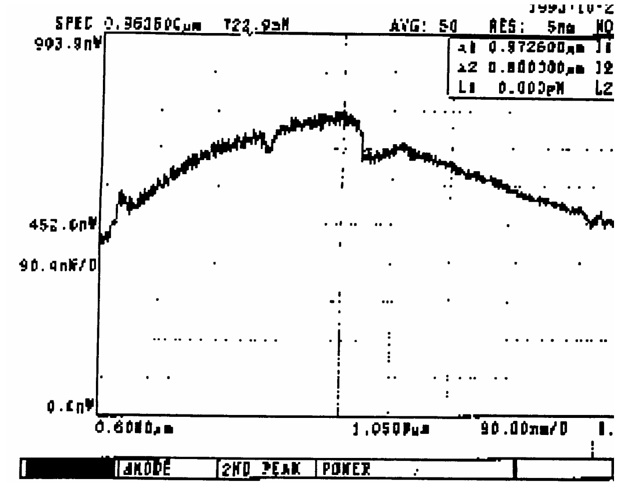

Figure 1: Tungsten Filament Lamp: Optical spectrum from 600nm to 1500nm.

The filtered spectral peaks however are an order of magnitude smaller than those of the tungsten lamp. The low level of optical energy in the filtered spectrum results in small contribution to shot noise.

It is well known that low frequency fluorescent lights “flicker” and contain 100 Hz harmonics.

In Figure 4, the harmonic content of the electrical spectrum is shown. From Figure 4, it is clear that the modulation harmonic content of the low frequency fluorescent lights are extending to 500 kHz in decreasing amplitude.

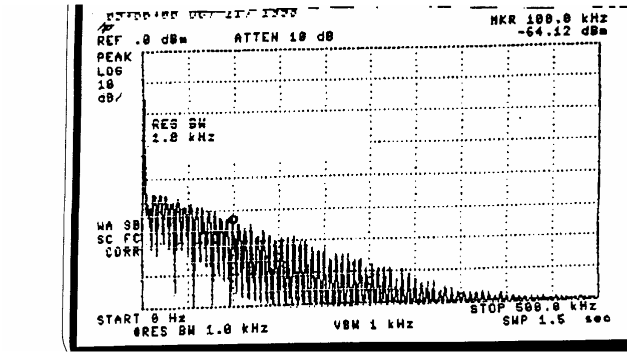

Figure 4: Low Frequency Fluorescent Lights: Electrical Spectrum. (0-600kHz)

The above spectral analysis lead us to deduce that it is possible to remove the “noise” effects of a low frequency fluorescent light by a combination of optical and a 500 kHz high pass electrical filtering.

2.3 High Frequency Fluorescent Lights

High Frequency Fluorescent Lights (HFFL), are a more recent development, and therefore not as widely used yet.

The attraction of HFFL as lighting is the lack of flicker to the eye and improved efficiency. They can be found in as ceiling lights and angle poise varieties. They are not widely in Europe yet, but more widespread in Japan and USA.

They may pose severe design constraints to IR free space links, and it is therefore important to characterise their light emission.

Figure 5 shows the optical spectrum of a Philips ST1.70 HF light tube from 600 nm to 1100 nm wavelength band. The spectrum is characterised by emission peaks, which are stronger in the visible wavelength range. The emission peaks however extend well into the detection range of Si detectors.

Using an optical daylight filter, the strongest optical peak, is about an order of magnitude smaller than the peak at 600 nm. Hence optical filtering can be effective in reducing the intensity of the peaks, albeit not completely.

The spectral content of this light is shown in Figure 6. We clearly see the decaying 60 Hz harmonics displayed to 1MHz. It is clear that high pass filtering is essential to remove as much as possible from the spectrum in Figure 6.

There is a compromise between the high pass filtering cutoff frequency and the encoded data frequency spectrum, determined by baseline wander. This also links to the nearest distance the receiver which the fluorescent lights are allowed to be.

2.3.1 Settling time of High Frequency Fluorescent Lights

The high frequency fluorescent lamps used have a time dependent optical spectral emission. The intensity of the visible light of such lamps increases gradually. On switch on, the visible light output is weak but within a few minutes it settles to its specified “normal” operation.