LIGHT MODULATION: A NEW WAY OF LOOKING AT LIGHTING

By Anadi A. Martel

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Our brain is finely attuned to pulsations, and our attention is spontaneously attracted to vibrating phenomena. This is obvious enough with, for example, the mesmerizing effect of stroboscopes. In fact, this sensitivity is such that in roadway lighting design particular care is taken to avoid any potential flicker effect.

Why then should lighting designers be interested in pulsing light, apart from its uses in disco light ambiance? A new technique called "Light Modulation" show us that there's more to pulsing light than what we are used to seeing.

Light Modulation overcomes two basic limitations of stroboscope-like lighting effects. First, stroboscopic light pulses generally alternate between fully-On and fully-Off states, producing intense flashes as illustrated in Figure 1a. However this need not be so: modern lighting technology allows a more sophisticated proportional control of light intensity, which can be used to generate more subtle pulsing variations, as shown in Figure 1b. The depth of such pulsations can be made so small that the resulting effect is barely perceptible, creating a gentle, shimmering vibration instead of a brain-hammering flicker.

Secondly, stroboscopic light usually involves a single pulsing light source acting on the whole visual field. A better understanding of finer details of the visual system now allows us to create more complex light patterns with an adapted emphasis on various parts of the visual field. Multi-zone, synchronized light projections can exploit the laterality and peripheral sensitivity of the eye-brain structure, resulting in subtler perceptual influences.

Once these limitations are removed, pulsing patterns add a new, fascinating dimension to the way we perceive light. Through the dynamic and fluid quality they bring, light suddenly becomes "alive".

How is this achieved? Light Modulation processors apply to light a technology similar to that which has previously been used in sound synthesizers. This is implemented with arrays of inter-connected Low-Frequency Oscillators (or "LFOs") controlling, or "modulating", the two basic parameters of light: color and intensity. In the current generation of Light Modulation processors designed by Sensortech Inc. up to 30 LFOs are available to create complex light patterns.

While it is straightforward to modulate the intensity of a light source by varying the power applied to it, modulating its color (or equivalently, its wavelength) is trickier. Since there currently exists no economical light sources with directly adjustable wavelength, the easiest way of achieving color control is through *additive synthesis*: by adjusting the intensity of light sources with 3 primary colors (usually Red, Blue and Green or "RGB") and mixing their output on a projection surface, it is possible to create the full color gamut (this being, of course, the method used by TV and computer displays). In practice the 3 light sources may be discrete color projectors pointing at the same area, or preferably tri-color projectors already incorporating 3 aligned primary color sources. The projectors can be of various powers and type (incandescent, LED,…).

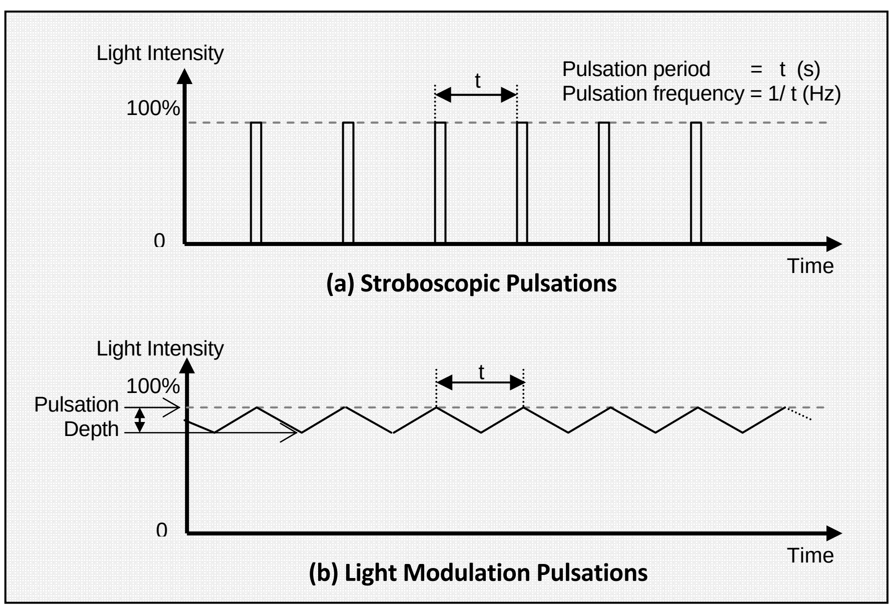

Figure 1 – Not all pulsations are alike…

While both light pulsations illustrated above have the same frequency, the Light Modulated ones (b) are far less aggressive than the classic stroboscopic ones (a).

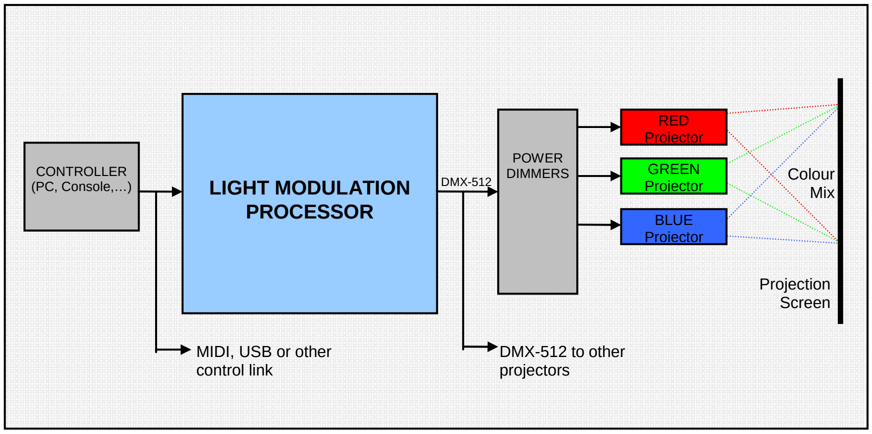

Figure 2 – Integration of a Light Modulation processor in a light projection environment. The processor accepts commands from a Controller, which may be a PC, a custom lighting Console or a dedicated device. Its internal LFO-based modulation structure generates light levels for an array of RGB light sources, which it typically drives through an industry-standard DMX link.

Such tri-color "Groups" of light sources can then be multiplied to create light patterns of arbitrary size and complexity. Figure 3 show a typical "light-wall" installation with 5 Groups linearly overlapping over a projection surface, entirely adequate to create superb light modulation effects. More involved 2- and 3-dimensional arrays are also possible.

How is Light Modulation different from existing lighting control techniques?

In a normal light design environment, light "scenes" are created by setting the intensity of each light projector. Transitions, fade-ins and fade-outs are then programmed by interpolation between successive light scenes. With a Light Modulation processor, what's being set are the various parameters of the LFOs, which will then keep on oscillating on their own: a few simple commands can set in motion an intricate, flowing, self-generating light pattern which would be difficult or highly impractical to simulate in the normal scene-based environment.

In the more advanced Light Modulation devices, the modulation parameters of each LFO may include: output amplitude, frequency, phase, duty cycle and waveshape. When multiplied by a large number of LFOs, this can result in a bewildering amount of over 100 available parameters. As the designers of classic sound synthesizers have already found out, the most difficult task in creating a successful modulation processor is to organize the numerous control parameters in coherent and optimized ways. Because many control combinations lead to uninteresting or even annoying effects, a substantial consolidation of options is needed. While the underlying principle of Light Modulation is simple enough, years of refinement through trial and error were required to bring the technique to its current level of usability.

A world of vibrations: not such an esoteric business…

Using oscillators by definition involves creating light pulsations with specific frequencies. The objective effect of various frequencies on viewers is not a particularly esoteric phenomenon: it derives from resonances with physiological properties, many of them being well-known. Working with Light Modulation, it is possible for the first time to tap into these vibrational effects in a safe way even for public lighting installations.

Figure 4 shows the frequency range where Light Modulation operates: broadly speaking, from 1/50 to 50Hz (or cycles per second). The upper limit of this range is determined by what is known as the *flicker fusion* frequency: this is the highest frequency that the eye can commonly perceive, above which a pulsing light increasingly looks like an averaged continuous source. Generating higher frequencies can be of interest, but not for purely visual effects. In practical terms, however, not all lighting sources can generate pulsations up to the flicker fusion frequency: the thermal inertia of their filaments limit even the fastest incandescent light bulbs to around 20Hz. By contrast, LED light sources can easily be driven at much higher frequencies.

The lower limit of the range corresponds to roughly 1 cycle per minute. Below this, oscillations are so slow that they stop being perceived as a single connected phenomenon.

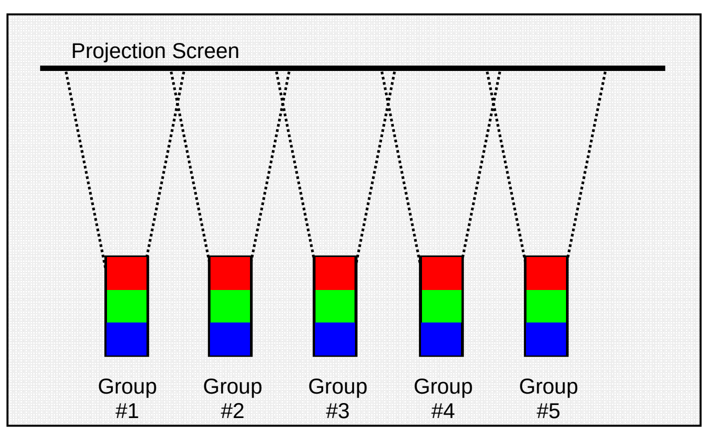

Figure 3 – Typical linear configuration of tri-color RGB projector Groups for a "Light-Wall" Light Modulation installation. While 5 Groups are shown here, current Light Modulation processors can each handle up to 10 Groups

Perhaps not coincidentally, right at the center of this range (at around 1Hz) sits the threshold between what can be called in perceptual terms the *frequency* and *time domains*: oscillations above this are perceived as unified vibrations (frequency perception domain), while below they become slow enough for the brain to resolve them into the constituent phases of each cycle (time perception domain). Light Modulation effects fall into the area merging these two domains.

A whole class of interesting time-perception related effects is accessible through the control of the LFOs' phase, which corresponds to time delays of the oscillations. A few simple commands coordinating the phase differences of pulsations in various projection zones result in beautiful flowing light patterns with an uncannily "organic" feel. Such time-perception domain phase control is a key difference between Light Modulation processors and sound synthesizers, which operate entirely in the frequency-perception domain.

Many fundamental biological phenomena are related to frequencies accessible through Light Modulation, and their pulsations resonate deeply within us. For example, pulsations near the typical heartbeat frequency of 1.2Hz immediately attract us. Another striking example is the 7.8Hz frequency known as the "Schumann Resonance", which relates to the resonance frequency of the electromagnetic field surrounding the Earth; living organisms have been permeated by this field during their whole evolution and for most of us, delicate light pulsations at that frequency are profoundly soothing.

Brainwaves are another fundamental biological phenomenon, and they are important enough to deserve a discussion of their own.

The Brainwave Entrainment Question

The range of EEG (Electro-Encephalographic) waves generated by our brain, at about 1 to 30Hz, is fully within the Light Modulation spectrum. It is well established that when we are exposed to light pulsations within the frequency range of our brainwaves, the brain has a tendency to eventually fall in sync with the driving source: this phenomenon is known as *photic brainwave entrainment* (an equivalent phenomenon also exists with sound). Since different brainwave frequencies are associated to different mind states, it follows that through light pulsations we can actually have an influence on our mood and state of mind.

A detailed description of brainwaves is beyond the scope of this article. However, we can mention that a whole class of light devices specifically designed for photic brainwave entrainment already exists. These devices usually act as stroboscopes to deliver the strongly pulsing light needed to effectively entrain brainwaves; they are meant to be used by individuals interested in experimenting on themselves. Just as discotheque stroboscopic light effects, they have to be used with care since exposure to pulsating light may increase the risk of an epileptic seizure in a small proportion of the population. While this risk is minimal (current research indicates that 1 in 20,000 adults over 25 have this photosensitivity, without necessarily being aware of it), it cannot be ignored. It accounts, for instance, for the above-mentioned considerations in roadway lighting design to avoid flicker at certain frequencies.

In addition to the epilepsy-related risk, the idea of using ambient lighting to influence viewers' brainwaves is ethically debatable. But the Light Modulation process described here brings a new aspect to the question, by virtue of its ability to control more finely the light pulsation depth and spatial distribution than has previously been possible. By toning down pulsations until they are barely perceptible, a new mode of interacting with brainwaves is revealed. Here the point is not to entrain brainwaves, but rather to imbue the light with the particular qualities related to brainwave frequencies.

Embedding pulsations at non-invasive "homeopathic" levels results into what could be called a "psychoactivation" of light. Light softly shimmering at frequencies in the Beta range (14-30Hz) has a zesty wakening quality; fine pulsations in the Alpha range (8-13Hz) are peaceful and relaxing; subtle vibrations in the Theta range (4-7Hz) intrigue and inspire creativity.

Pulsation depths of 5-15% with smooth modulating waveshapes such as sine or triangle waves are usually optimal to achieve these effects. Powerful Light Modulation functions further enhance the optimization of non-invasive brainwave-related light patterns. Through an independent control of multiple projection zones, the pulsations can be focused on the peripheral field of vision,

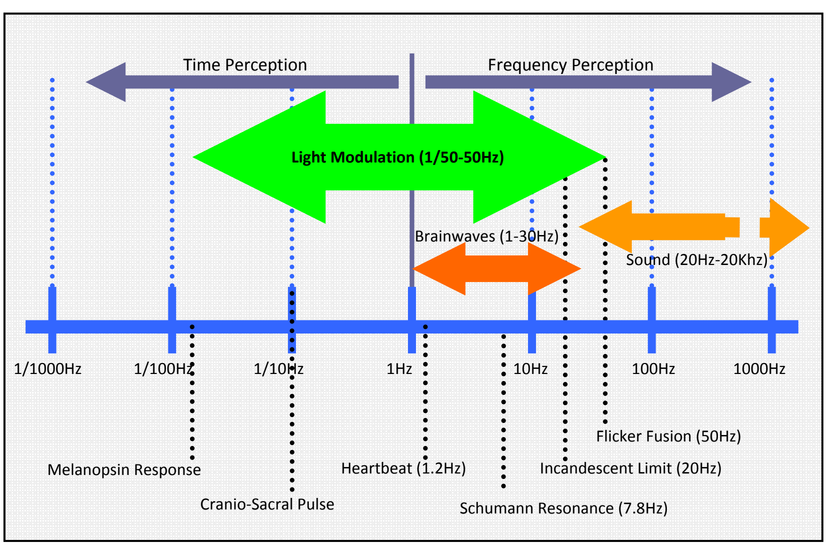

Figure 4 – A World of Vibrations: the frequency range spanned by Light Modulation overlaps the range of human brainwaves, and other frequencies of physiological significance.

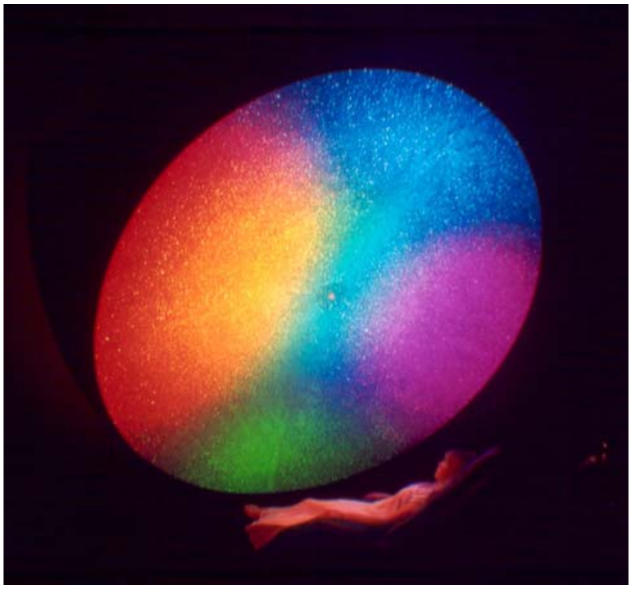

Figure 5 – Sensora: a multi-sensorial environment showcasing Light Modulation. The viewer rests under an inclined hemispherical screen, immersed in a field of pure colors.

where the retina has a higher temporal resolution and where they are more easily accepted; and a coordinated phase and frequency control of each zone creates a fluid, dynamic distribution of the pulsations over the projection area.

Rather than impose themselves on the brain, the pulsations are now just a gentle invitation giving the light a new character. Together with the actual colors and dynamic flow of light, the brainwave component becomes another creative element in the Light Modulation toolbox of the lighting designer.

Riding the LED color revolution

Light-Emitting Diodes (LED) systems are currently revolutionizing the lighting industry, and one of the most striking consequences has been a world-wide explosion in the fascination with colored light projections, color-changing ambiances and new “mood-lighting” concepts. It is now common to see colored light walls in hotel lobbies, color-changing corridors in airports, not to mention whole bridges and buildings illuminated in multi-colors.

These installations all require some form of color controller to generate interesting light variations. And while most of these controllers now operate with traditional scene-based light control principles, they are in fact ideally suited to benefit from Light Modulation oscillator-based processing and its ability to create complex flowing patterns from just a few simple commands.

The typical topology of many LED light-walls currently being deployed is similar to the linear configuration shown in Figure 3 (or to its 2- and 3-D extensions) and is therefore directly compatible with Light Modulation – especially considering that LED light sources are often tri-colored with independent Red-Blue-Green emitters.

It seems to be only a matter of time before innovative lighting designers discover the rich control possibilities of Light Modulation, and use them to invent new types of light ambiances. These “Light Paintings” will be as different from the simple stroboscopic effects of the past as the music of modern sound synthesizers is removed from rudimentary sine wave tones.

Sensora: a multi-sensorial experiment

The full potential of Light Modulation is being showcased in the “Sensora”, a unique multi-sensorial immersive installation developed by the author. Sensora uses a large hemispherical screen wide enough to cover the field of vision, combining light with a spatialized surround-sound environment and a special reclining chair equipped with an array of kinesthetic sound transducers. This experimental system demonstrates how light, rather than being just a support for other mediums, can become an art form in itself.

About the author:

Anadi A. Martel is a physicist specializing in audio-visual and LED electronics design, and a founding member of the *International Light Association.* He is president of Sensortech Inc. www.sensora.com, a small R&D company holding his patents on Light Modulation. He resides in Canada and can be contacted at info@sensora.com.