Visible Light Communication (VLC)

An introductory guide
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What is VLC?
Visible Light Communication (VLC) is the use of the visible light portion of the electromagnetic spectrum to transmit information. This is in contrast to established forms of wireless communication such as Wi-Fi which uses radio frequency (RF) signals to transmit data.

With VLC, data is transmitted by modulating the intensity of the light in such a way that it is not perceptible to the human eye. The data is received by a photo-sensitive detector which demodulates the light signal into electronic form.

VLC is a category of Optical Wireless Communications (OWC). OWC includes infra-red and ultra-violet communications as well as visible light. However, VLC is unique in that the same visible light energy used for illumination may also be used for communication.

How does VLC work?
When a constant current is applied to an LED light bulb a constant stream of photons are emitted from the bulb which we observe as visible light. If we vary the current up and down slowly the output intensity of the light we see dims up and down. Because LED bulbs are semi-conductor devices we can actually vary the current, and hence the optical output, at extremely high speeds which are imperceptible to the human eye but which can be detected by a photo-detector device. Using this technique high speed information can be transmitted from an LED light bulb.

Radio frequency communication requires radio circuits, antennas and complex receivers, whereas VLC is much simpler and use direct modulation methods similar to those used in low-cost infra-red communications devices such as remote control units. Infra-red communication is limited in power due to eye safety requirements, whereas LED light bulbs have high intensities and can achieve very large data rates.

How might VLC be deployed?
The dramatic growth in the use of LEDs (Light Emitting Diodes) for lighting provides the opportunity to incorporate VLC technology into LED bulb drive circuits.
The use of LEDs for data communication has been given the “Li-Fi” moniker. However, VLC or Li-Fi is not really a competitor to Wi-Fi. Although VLC is used to off-load data from existing Wi-Fi networks, future implementations may provide no uplink capability and so existing wireless or wired network infrastructure is used in a complimentary fashion.

VLC is particularly suitable for many popular internet “content consumption” applications such as video and audio downloads, web browsing, etc. These applications place heavy demands on the downlink bandwidth, but require minimal uplink capacity. In this way, the majority of the internet traffic is off-loaded from existing RF channels, so extending the Wi-Fi capacity.

**Advantages of VLC**

RF spectrum capacity is congested, expansion opportunities are limited, and may require expensive licenses. In addition, there are also health and safety concerns from electro-magnetic radiation.

VLC has a number of benefits over RF.

**Capacity**

- Bandwidth. The visible light spectrum is plentiful (10,000 more than RF spectrum), unlicensed and free to use.
- Data density. VLC can achieve about 1000x the data density of Wi-Fi because visible light can be well contained in a tight illumination area whereas RF tends to spread out and cause interference.
High speed – very high data rates can be achieved due to low interference, high device bandwidths and high intensity optical output.

Planning - Capacity planning is simple since there tends to be illumination infrastructure where people wish to communicate, and good signal strength can literally be seen. RF is invisible and makes planning more complex

**Efficiency**

- Low cost – requires fewer components than radio technology.
- LED illumination is already efficient and the data transmission requires negligible additional power.
- Underwater – RF transmission and propagation in water is extremely difficult but VLC works well in this environment.

**Safety**

- Safe – Life on earth has evolved through exposure to visible light. There are no known safety or health concerns for this technology.
- Non-hazardous – the transmission of light avoids the use of radio antenna systems that can cause sparks which are dangerous in certain environments.

**Security**

- Containment – It is difficult to eves drop on VLC signals since the signal is confined to closely defined illumination area and will not travel through walls.
- Control – Data may be directed from one device to another and the user can see where the data is going, there is no need for additional security such as pairing for RF interconnections such as Bluetooth.

**VLC Form Factors**

VLC transmission requires both a transmitter and a receiver. For full-duplex (bi-directional) transmission a transceiver unit (comprising both transmitter and receiver) is required at each end.

**Transmitter**

The transmitter circuit can be readily integrated into an LED light bulb drive circuits.

Connectivity of the LED bulbs into existing networks can be achieved in a number of ways including:

1. Power-line communications (PLC). This uses existing mains power cables to transmit the data to the bulb.
2. Power over Ethernet (PoE). The data communications and the power for the bulb are delivered over an Ethernet cable. The power is limited to around 50 watts using a Cat5 cable, but this is more than sufficient to power a modern LED fixture.

Both of the above methods avoid having to wire separate power and data connections.

Power-line communications is attractive as it does not require any new wiring to existing lighting installations for the data connection. For new installations, especially in commercial environments, power over Ethernet may be more attractive.

**Receiver**

As adoption and unit volumes grow, further miniaturisation and integration becomes cost-effective. The receiver module for a PC, laptop, or smart phone can begin as a separate unit, moving to a USB dongle, to full integration of a photo-detector in the device. Likewise for mobile devices including smart phones and tablets, the in-built camera or ambient light sensor (ALS) may initially be used as the photo-detector. However, the data-rates received through the camera or ALS are constrained by the hardware so eventually these devices will incorporate a high speed photo-detector, or suitably adapted camera or ALS.

The receiving device may use an infra-red channel, or even Wi-Fi or the cellular network at reduced data rates for the uplink if required.

**VLC Applications**

There are many applications for VLC. These include:
• **Smart Lighting.** Any private or public lighting including street lamps can be used to provide Li-Fi hotspots and the same communications and sensor infrastructure can be used to monitor and control lighting and data.

• **Indoor Positioning.** Transmission of a unique ID is all that is required for basic positioning. Multiple LED light bulbs can be used with trilateration for more accurate indoor positioning and navigation.

• **Mobile Connectivity.** Laptops, smart phones, tablets and other mobile devices can interconnect directly using VLC. Short range links give very high data rates and also provides security via the visible pairing method.

• **Hazardous Environments.** VLC provides a safe alternative to electromagnetic interference from RF communications in environments such as mines and petrochemical plants.

• **Vehicles & Transportation.** LED headlights and tail-lights are being introduced. Street lamps, signage and traffic signals are also moving to LED. This can be used for vehicle-to-vehicle and vehicle-to-roadside communications. This can be applied for road safety and traffic management.

• **Hospital & Healthcare.** VLC emits no electromagnetic interference and so does not interfere with medical instruments, nor is it interfered with by MRI scanners.

• **Wi-Fi Spectrum Relief.** Excess capacity demands of Wi-Fi networks can be off-loaded to VLC networks where available. This is especially effective on the downlink where bottlenecks tend to occur.

• **Aviation.** LEDs are being used in aircraft passenger cabins. VLC can be used to reduce weight and cabling and adding flexibility to seating layouts. The in-flight entertainment systems can be supported by VLC.

• **Underwater Communications.** Due to strong signal absorption in water, RF use is impractical. Acoustic waves have extremely low bandwidth and disturb marine life. VLC provides a solution for short-range communications.

• **RF Avoidance.** Some people claim they are hypersensitive to radio frequencies and are looking for an alternative. VLC is a good solution to this problem.

• **Toys.** Many toys incorporate LED lights and these can be used to enable extremely low-cost communication between interactive toys.

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**VLC Implementation**

VLC suppliers provide the components comprising circuits and firmware for both the transmitter and receiver. These components can be integrated into the bulb and consumer device electronics respectively.

The transmitter includes the proprietary firmware for modulating the LED output. The receiver includes a photo-detector and the firmware for demodulating the photo-detector output.

**Modulation**

There are a number of forms of modulation technique that can be employed. These include on-off keying (OOK), pulse width modulation (PWM), pulse position modulation (PPM), pulse amplitude modulation (PAM).
(PAM), orthogonal frequency division multiplexing (OFDM) or even colour-shift keying (CSK). Further information on these techniques is available in the journals in the Further Reading section below.

The VLC physical layer and media access control are currently the subject of industry standardisation efforts (see Standards section below).

LED Types
Different types of LEDs may be employed. These include single colour quasi-white (blue) LEDs with phosphor coatings and RGB LEDs. With RGB LEDs, each of the individual coloured LEDs can be used simultaneously to multiplex data transmission, whereas the single colour LEDs use only intensity based modulation techniques. For most lighting purposes single colour LEDs tend to be used because of their low cost and high efficiency.

VLC Suppliers
There are currently very few VLC equipment suppliers. When selecting a VLC partner, careful consideration must be placed on the efficiency of the product and the data rates which can be achieved. The product roadmap supported by particular suppliers does vary widely.

Further Reading


Standards
There are already discussions about VLC within relevant standardisation groups. Most notably:

- IEEE 802.15 Task Group 7 IEEE 802.15.7 http://www.ieee802.org/15/pub/TG7.html. This now exists as a draft standard.

- The Visible Light Communication Consortium: (http://www.vlcc.net) based in Japan has added a visible light physical layer to the existing IrDA infra-red standard. This standard is optimised for device-to-device applications.