Visible Light Communication

Seminar Kommunikationsstandards
in der Medizintechnik

29. Juni 2010

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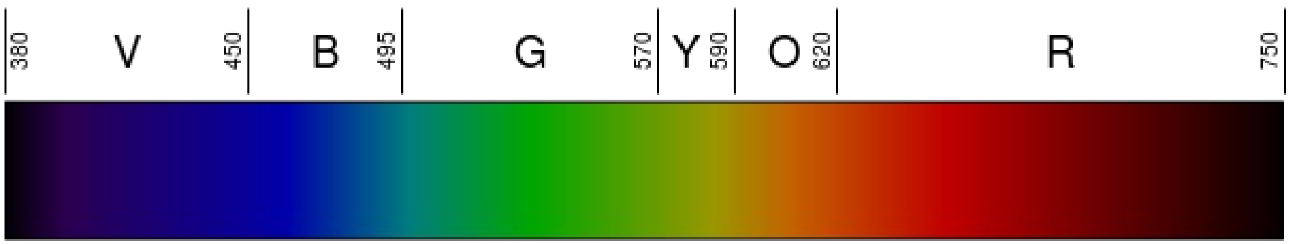
Outline

- motivation
- history
- technology and modulation
- current standards
- applications
- conclusion and outlook

Visible Light

- visible light is all around us
- part of the visually-perceivable electromagnetic spectrum
- spectrum of visible light ranges from 380nm to 750nm



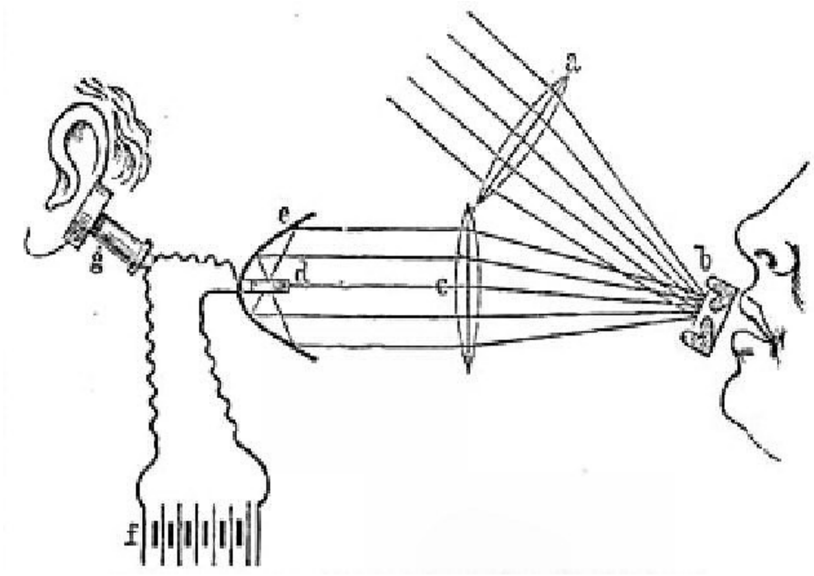
(source: http://www.etud.insa-toulouse.fr/~tkabir/code/cietorgb.html, public domain)

Motivation

- visible light does not cause any health problems
- no EM-interference occurs
- save to use in hospitals
- no expensive patent-license necessary
- no interception because the transmission range is narrowly confined
- ever-increasing market share of LEDs makes VLC ubiquitously available

The Photophone (1/2)

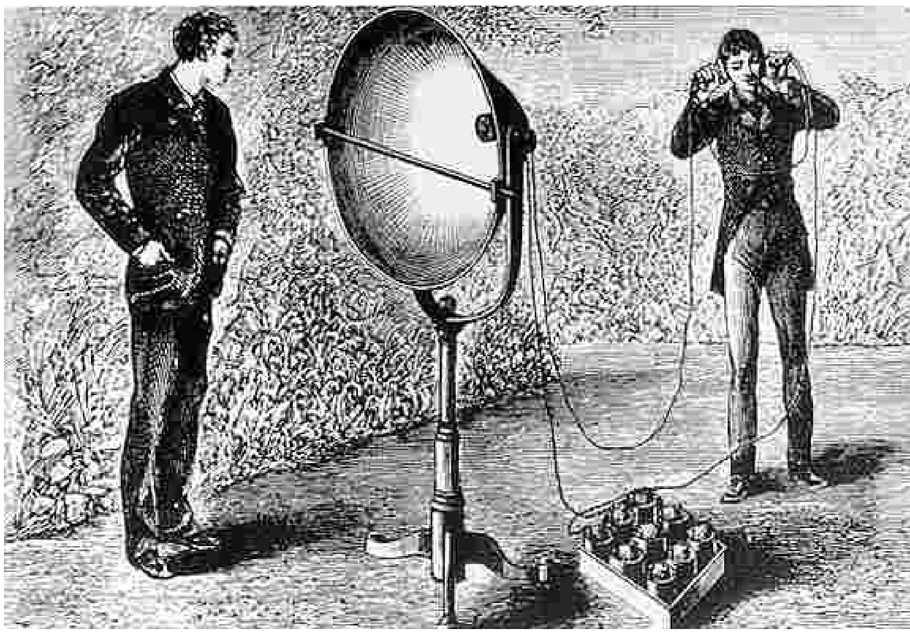
- the photophone was developed by Alexander Graham Bell and his assistant Charles Tainter in 1880
- first method for wireless verbal communication
- below is a schematic view from one of Bell's papers

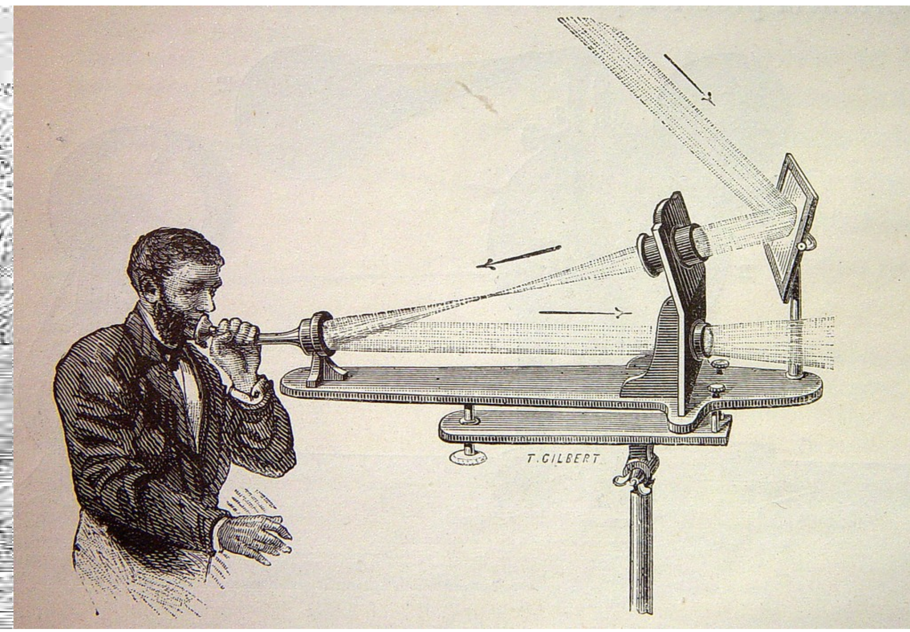


(source: Meyers Konversationslexikon, 1888)

The Photophone (2/2)

- Bell and his assistant using the photophone for transmitting and receiving data





(source: http://www.bluehaze.com.au/modlight/ModLightBiblio.htm,
http://www.flickr.com/photos/fdctsevilla/4074931746/
author(s) unknown)

Visible Light Communications Consortium

- the Visible Light Communication Consortium was established in 2003 by Japanese tech-companies
- aims to standardize VLC technology
  - avoid fragmentation of different protocols and implementations
- two standards are proposed:
  - JEITA CP-1221
  - JEITA CP-1222
- also tries to raise public awareness for VLC and promote its applications
- standardization efforts for physical and media access layer are also done by IEEE 802.15, Task Group 7

VLCC Members

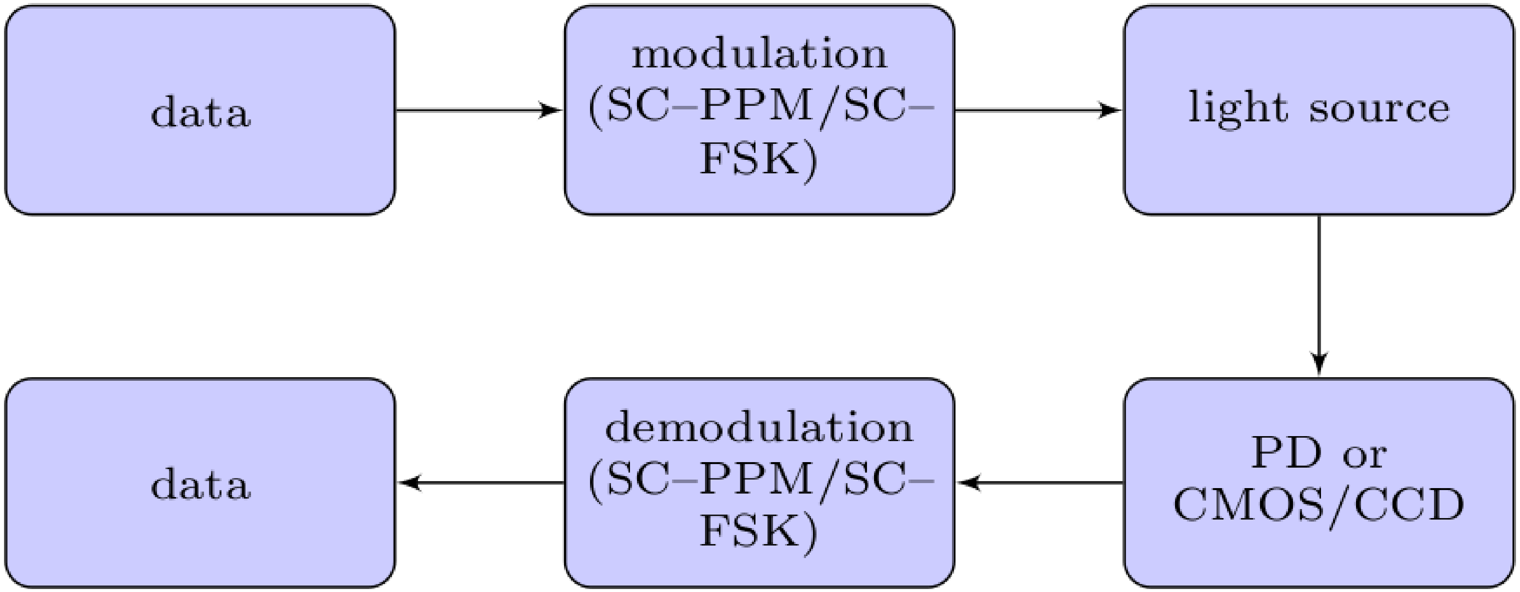
- NEC Corporation
- Panasonic Electric Works Co., Ltd
- The Nippon Signal Co., Ltd
- Toshiba Corporation
- Japan Rural Information System Association
- Samsung Electronics Co., Ltd
- NTT DoCoMo, Inc
- Casio Computer Co., Ltd
- Nakagawa Laboratories, Inc.
- Outstanding Technology Co., Ltd
- Sumitomo Mitsui Construction Co., Ltd
- Tamura Corporation
- Sharp Corporation
- Japan Coast Guard
- Comtech 2000 Corporation
- RISE Co., Ltd
- Japan Traffic Management Technology Association
- NHK

Technology (1/3)

- every kind of light source could be used as sender
- LEDs are the predominant choice for transmitters
- they can be switched on and off in very short intervals
- receivers
  - photodiode receivers
  - CCD and CMOS sensors

Technology (2/3)

- schematic view of the entire process of transmitting and receiving data

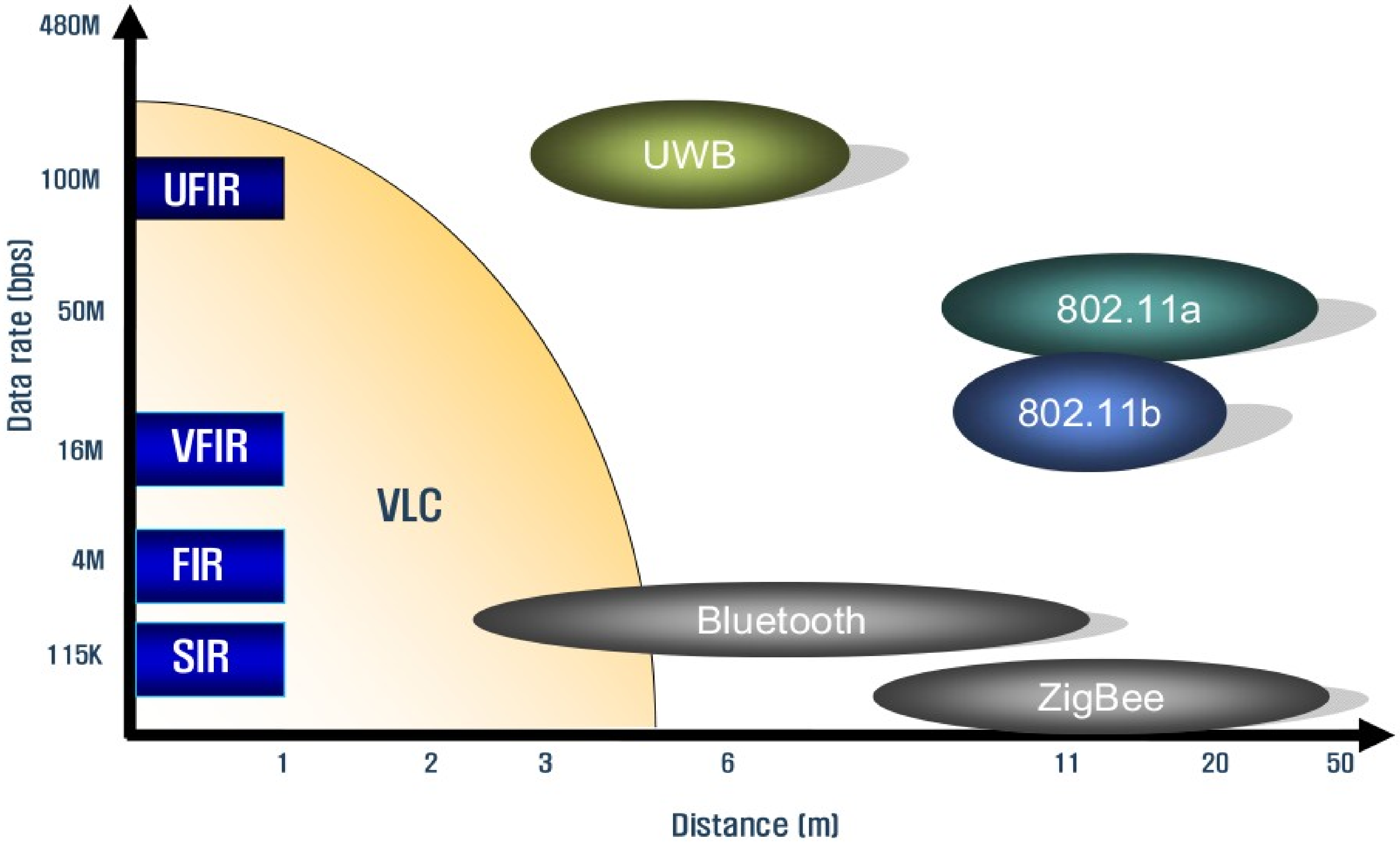


(source: based on a schematic view shown in [1])

Technology (3/3)

- phosphorus LEDs can achieve up to 40 Mbps
- by using RGB LEDs data rates can go up to 100 Mbps
- RCLEDs (resonant cavity LEDs) can achieve data rates up to 500 Mbps
  - RCLEDS use Bragg reflectors (which serve as mirrors) to enhance the emitted light
  - they also have increased spectral purity when compared to conventional LEDs which further improves communication capabilities
- LEDs are energy-efficient and are becoming increasingly inexpensive

Comparison to other wireless technologies



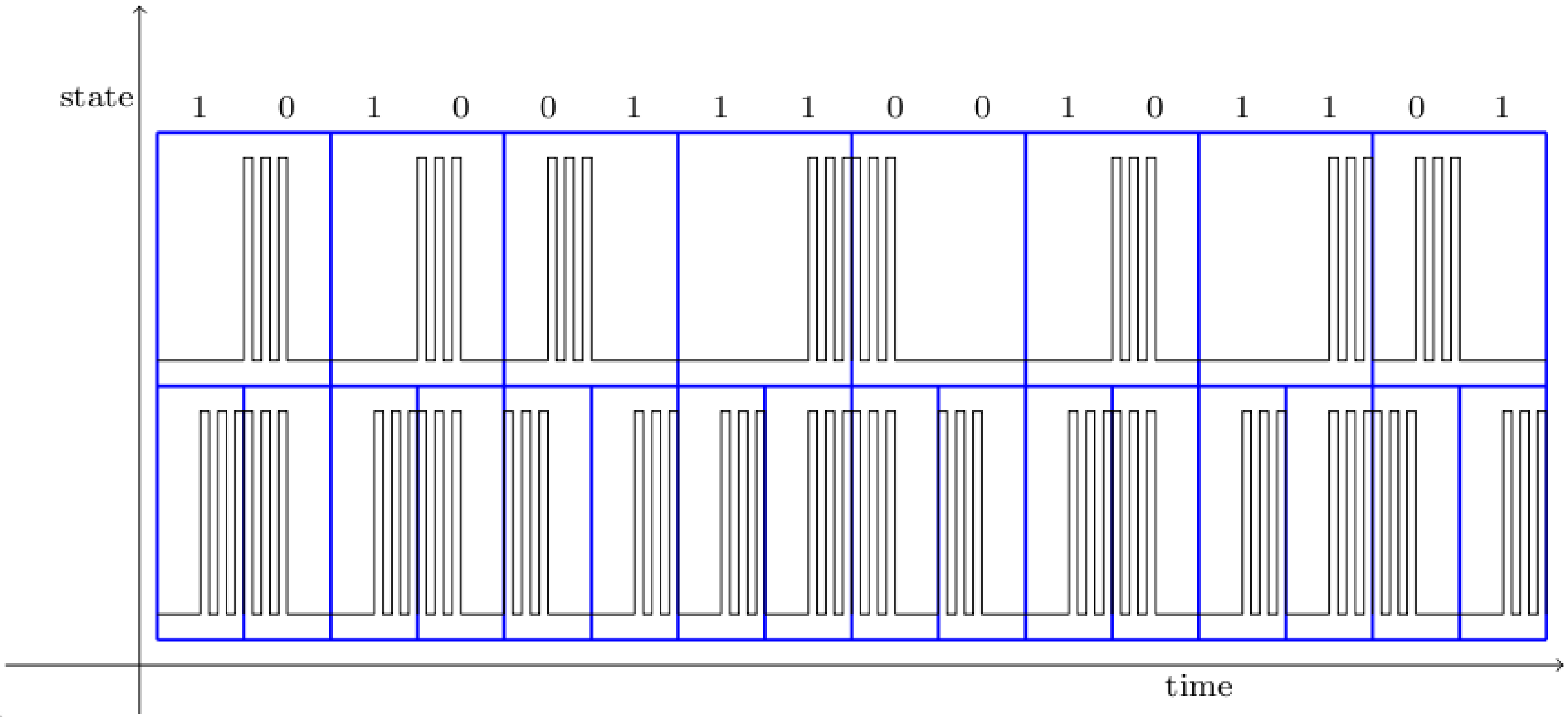
(source: IEEE VLC Tutorial http://www.ieee802.org/15/pub/TG7.html [2])

Data transmission

- modulation (with respect to VLC) is used to transform the data (given as a sequence of 0s and 1s) into a series of light pulses
- two main alternative modulation schemes:
  - sub-carrier pulse position modulation (SC-kPPM):
    - data is separated into groups of log k bits each and there is only a single pulse for each group
  - frequency shift keying (FSK):
    - signal frequency determines whether or not the currently transferred bit is 0 or 1
- point of confusion: the frequency of light pulses is modulated, not the frequency of the light itself

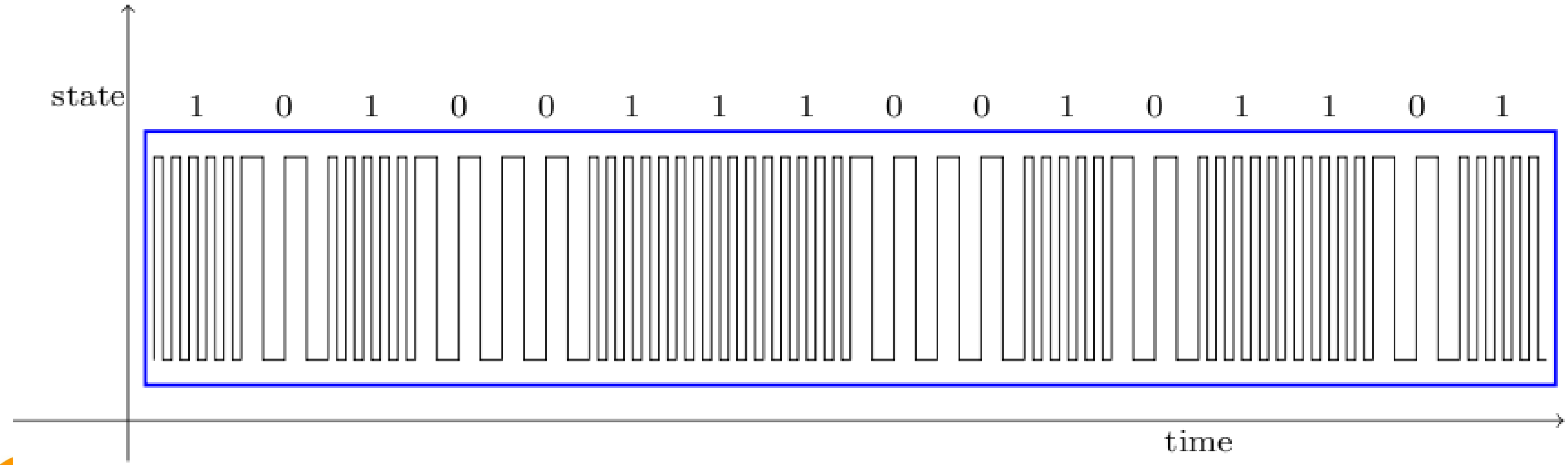
Sub-carrier pulse position modulation

- data is separated into blocks of log k bits
- k possibilities for each block
- transmission time of a single pulse determines which of the k possibilities is represented by the current block



Frequency shift keying

- two distinct values (0 and 1) are represented by two distinct pulse frequencies
- this (simple) form of FSK is also referred to as binary FSK, more complicated forms exist (in theory)



Standardization efforts

- in 2007, the VLCC proposed two different standards:
  - Visible Light Communication System Standard
  - Visible Light ID System Standard
- JEITA (Japan Electronics and Information Technology Industries Association) accepted these standards as JEITA CP-1221 and JEITA CP-1222

JEITA CP-1221 (1/2)

- motivation:
  - avoid fragmentation and proprietary protocols
  - prevent interference
- light that is used for communication purposes must be within a range of 380nm to 750nm
- emitted light must be within a particular range with an accuracy of 1nm
- sub-carrier (SC) modulation is proposed (as opposed to modulating the frequency of the actual light)

JEITA CP-1221 (2/2)

- there are three major frequency ranges:
  - range 1 (15 kHz to 40 kHz):
    - communication purposes
  - range 2 (40kHz to 1 MHz):
    - fluorescent lights cannot use this range
    - they are too slow and generate too much noise
  - range 3 (> 1 MHz):
    - should only be used for vast data transmission with special LEDs

JEITA CP-1222

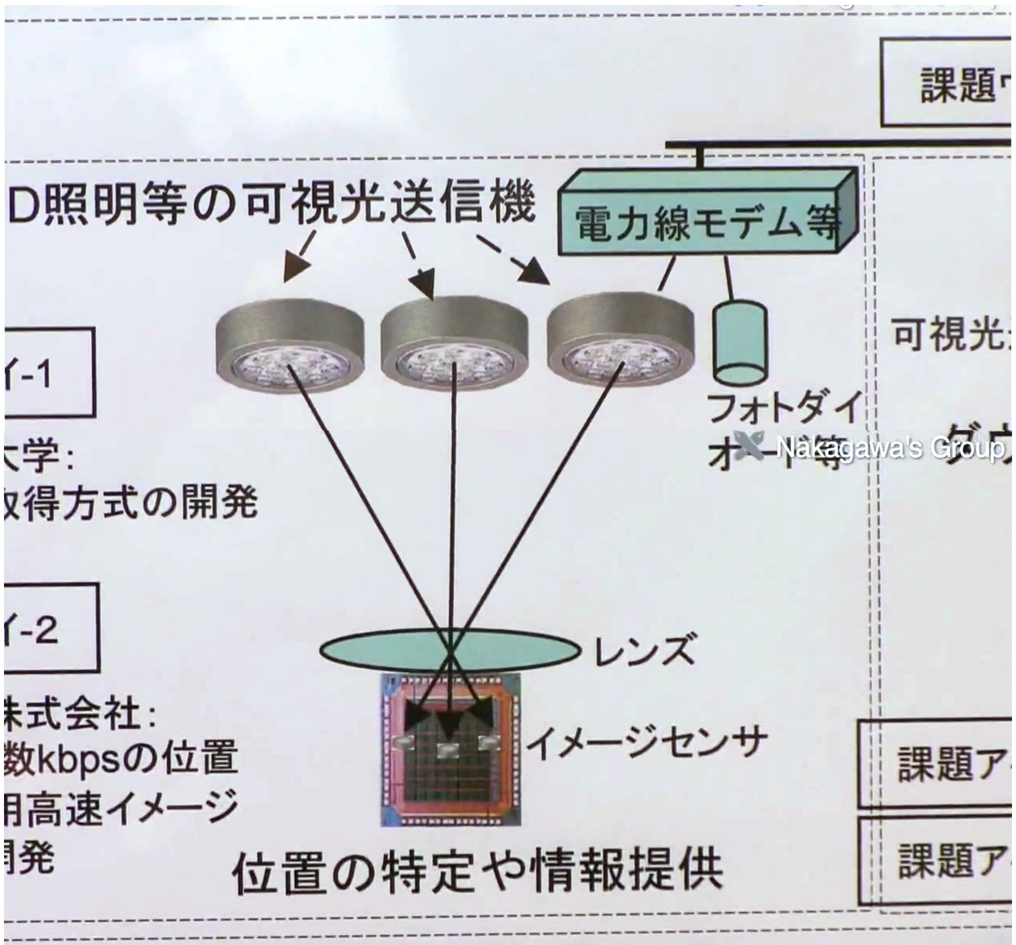
- according to Shinichiro Haruyama (vice chairman of the VLCC) the following recommendations are proposed by JEITA CP-1222 (see [3] for more details):
  - SC frequency: 28.8 kHz
  - transmission rate: 4.8 kbps
  - modulation: SC-4PPM (chosen to avoid flickering)
  - cyclic redundancy checks (CRC) for error detection/correction

Localization

- GPS has very limited use indoors because of interference
- VLC can be used for indoor location estimation
- general idea: when light from a source is received, the receiver must be close to the source
- estimation of current location based on data received from several light sources (to increase accuracy)

Localization

- light of different sources is projected through a lense onto an image sensor
- distances to light sources are estimated based on this projection



(source: http://www.youtube.com/watch?v=QEh5f49LsB4)

Further Applications

- VLC in combination with Powerline Communication
- smart stores/museums
- image sensor communication
- vehicle to vehicle communication
- RONJA
  - 10 Mbps bandwidth and 1.4 km range

(source: http://images.twibright.com/tns/18b2.html)

Providing an uplink

- VLC is a natural broadcast medium
- sending back information to the source is sometimes desired
- there are three major approaches to providing an uplink to the camera (as discussed in [4]):
  - co-locating the light source with a VLC receiver
    - advantage: data can be sent back
    - drawback: sending light back is costly (energy-wise)
  - using a retro-reflector to return incident light
    - advantage: data can be sent back from several sources in parallel
    - drawback: uplink data rates are rather low using this approach
  - fitting the light source with a RF or IR receiver
    - advantage: data can be sent back fast
    - drawback: no VLC is used, all disadvantages of not using VLC (EM-interference etc.)

Conclusion and Outlook

- increasing data rate
  - more advanced modulation
  - parallelize communication by using groups of emitters and receivers (optical MIMO: Multi-Input, Multi-Output)
- standardization efforts
  - technical requirements and other regulations (eye-safety, illumination constraints etc.) have to be combined
- VLC is a promising technology even if it is still in a very early stage
- it has a wide variety of prospective applications

References

- H.Sugiyama, S.Haruyama, M.Nakagawa. Experimental investigation of modulation method for visible-light communications [1]
- IEEE VLC tutorial (http://www.ieee802.org/15/pub/TG7.html) [2]
- Japan's Visible Light Communications Consortium and Its Standardization Activities (Shinichiro Haruyama, Ph.D) [3]
- Visible Light Communications: challenges and possibilities: Dominic C. O’Brien et al. [4]