Dipartimento INFOCOM
Universitá degli studi di
Roma "La Sapienza"

Departamento de Señales y
comunicaciones
ULPGC

Optical Communications

Telecommunication Engineering
School of Engineering
University of Rome La Sapienza
Rome, Italy
2005-2006

Lecture #6, May 25 2006

Modulation and Coding

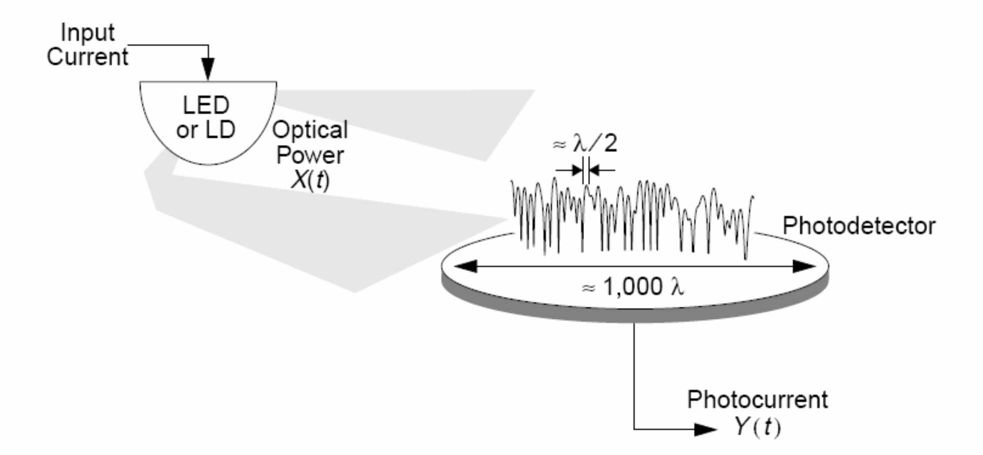
PART I

Intensity Modulation and Direct Detection IM/DD

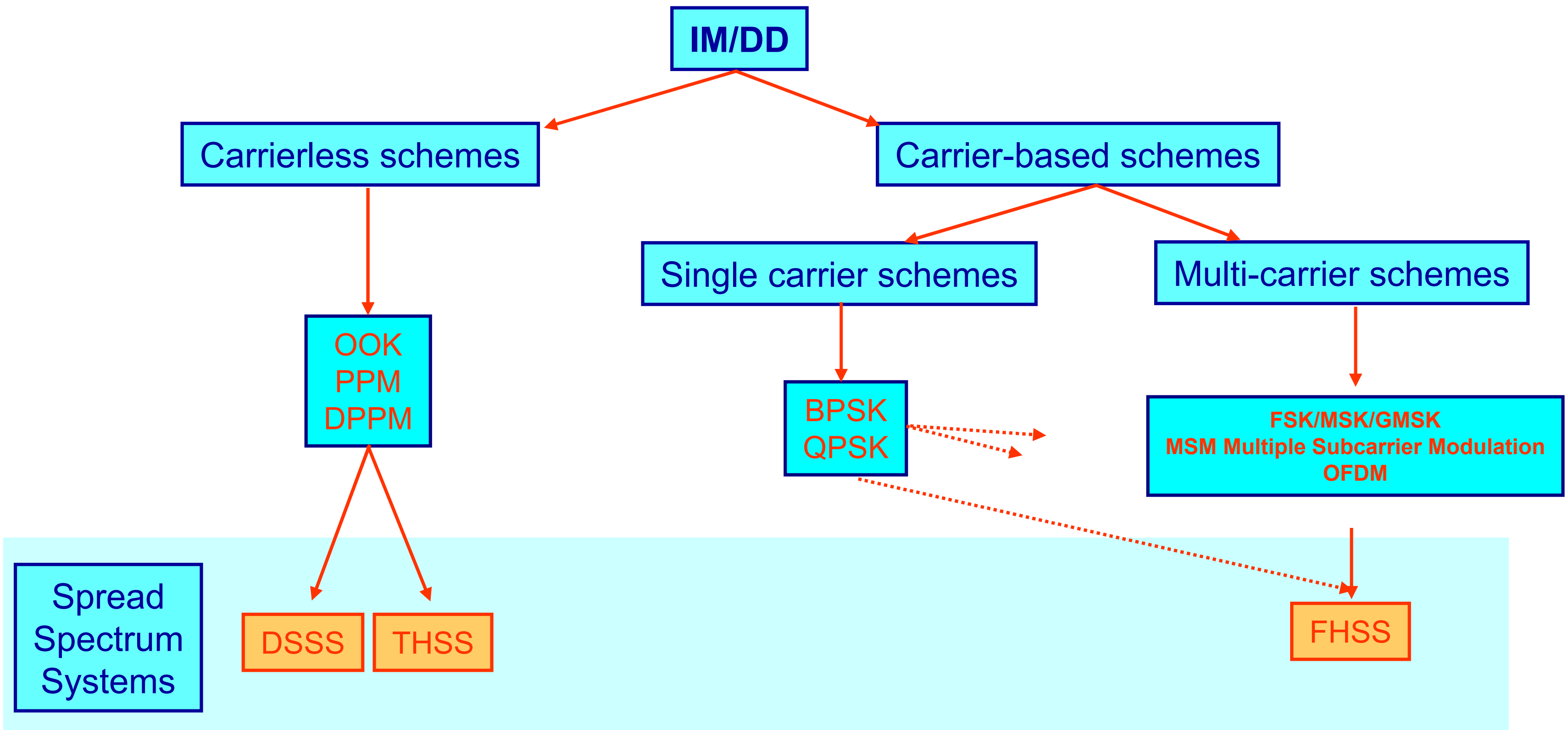
For infrared links, the most viable modulation is ***Intensity Modulation (IM),*** in which the information modulates instantaneous power.

The most practical detection technique is ***Direct Detection (DD)***, in which a photodetector produces a current proportional to the received instantaneous power, (*proportional to the square* of the received electrical field)

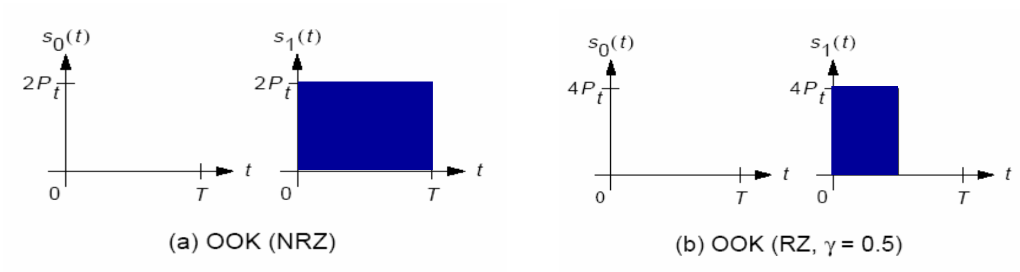
The transmitted waveform is the instantaneous optical power of the infrared emitter. The received waveform is the instantaneous current in the receiving photodetector, which is proportional to the integral over the photodetector surface of the total instantaneous optical power.



MODULATION AND CODING SCHEMES



ON-OFF KEYING

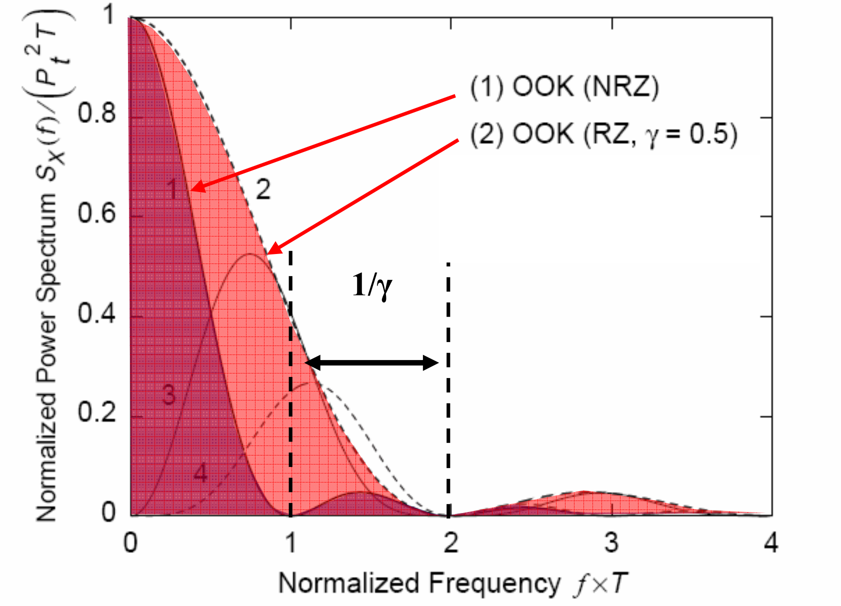


Waveforms of OOK using NRZ pulses and RZ pulses (with duty cycle γ=0.5)

- OOK is the simplest modulation to implement

- If the channel is distortion-free, the ideal maximum-likelihood (ML) receiver for OOK in AWGN consists in a continuous-time filter matched to the transmitted pulse shape, followed by a sampler and threshold detector set midway between the "low" and "high" pulse amplitudes

- OOK with NRZ pulses represents a good compromise between power and bandwidth requirements. The use of RZ pulses having a duty cycle γ increases the bandwidth requirement by a factor of 1/γ

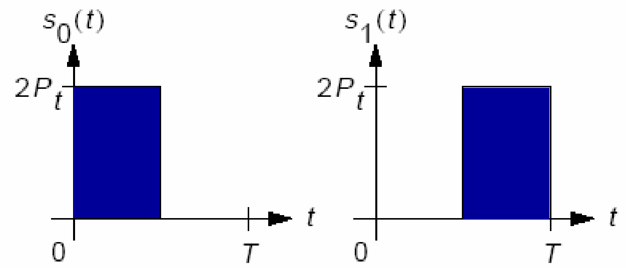


PULSE POSITION MODULATION

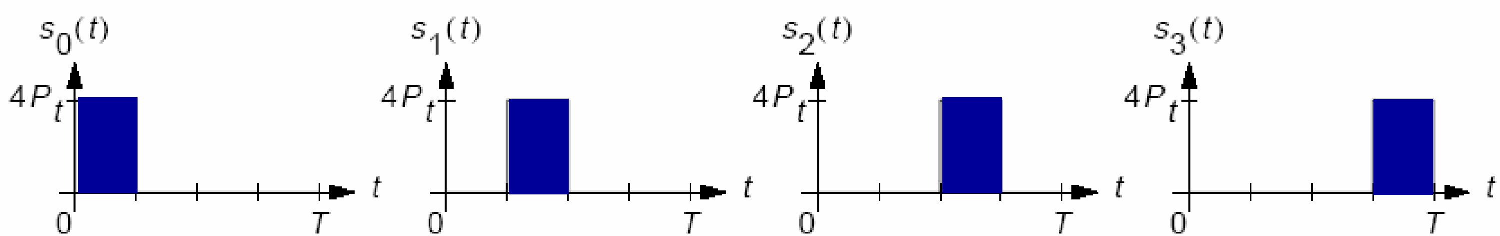
L-PPM uses *symbols* consisting of *L* time slots, which we will refer to as *chips*. A constant power $L{\cdot}P_t$ is transmitted during one of these chips and zero power is transmitted during the remaining *L*-1 chips, thereby encoding $\log_2 L$ bits in the position of the "active" chip.

For *L*=2, OOK and 2-PPM achieve same performance in AWGN

For *L*>2, *L*-PPM is an orthogonal modulation scheme that offers a decrease in average energy/bit requirement compared to OOK, at the expense of an increased bandwidth requirement.



2-PPM



4-PPM

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PULSE POSITION MODULATION

What we know from traditional modulation theory:

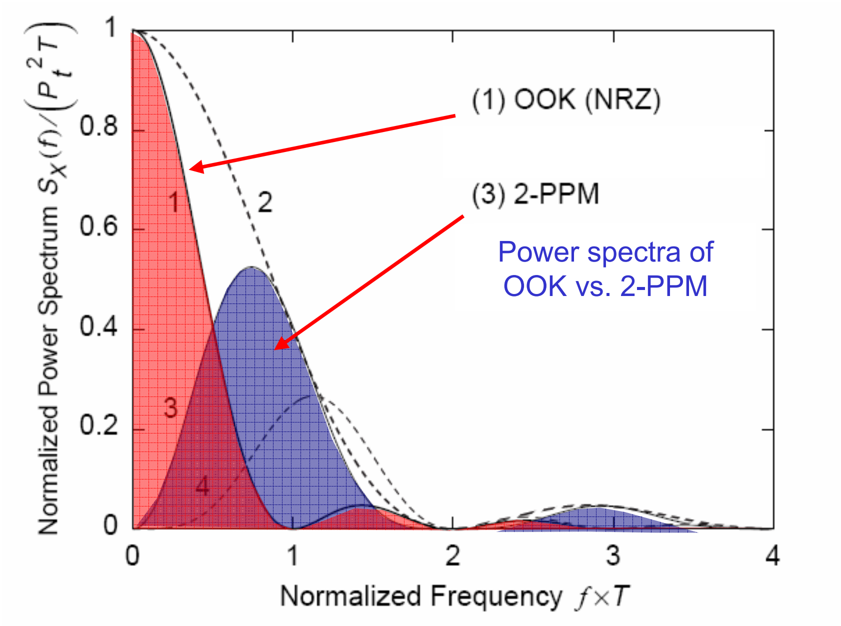
The average-power requirement *in* L-PPM (over pulse duration) decreases for increasing L, while peak power increases linearly with L. Noise is increased by a factor $L/\log_2 L$ determined by the increased bandwidth. As a result SNR goes with $\log_2 L$.

Drawbacks:

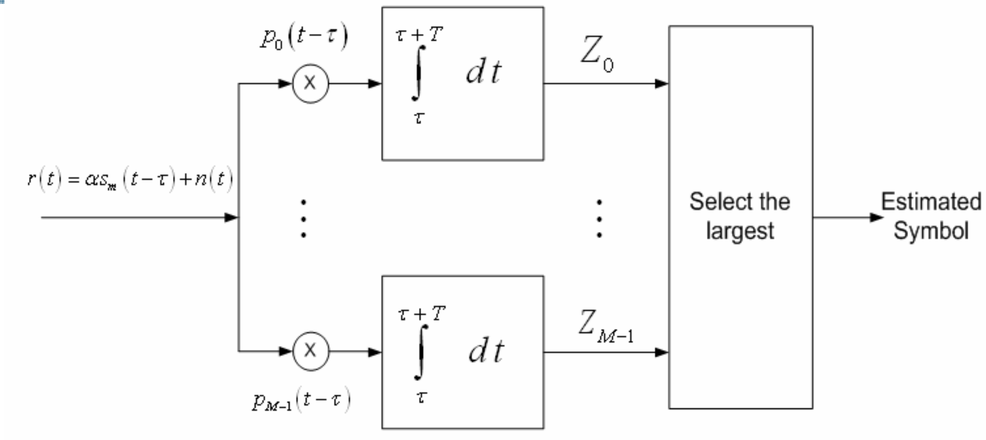
- Increased transmitter peak-power requirement.
- Needs for both chip- and symbol-level synchronization.

- For a given bit rate, L-PPM requires more bandwidth than OOK by a factor $L/\log_2 L$.

Example: 16-PPM requires four times more bandwidth than OOK



PULSE POSITION MODULATION



In the absence of multipath distortion, an optimum ML receiver for *L*-PPM employs a continuous-time filter matched to one chip, whose output is sampled at the chip rate. Each block of *L* samples is passed to a block decoder, which makes a symbol decision, yielding $\log_2 L$ information bits.

In the above scheme, indicated as *soft-decision decoding*, the block decoder chooses the largest of the *L* samples.
Alternately, it is possible to think of a sort of *hard-decision decoding*, in which each sample is quantized to “low” or “high” using a simple threshold detector, and the block decoder makes a symbol decision based on which sample is “high”. In cases where no sample, or more than one sample, is “high”, an error might occur.

While hard decoding is easier to implement, and is thus used in most commercial implementations, it produces about 1.5 dB optical power penalty with respect to soft decoding

PULSE POSITION MODULATION with Optical signals

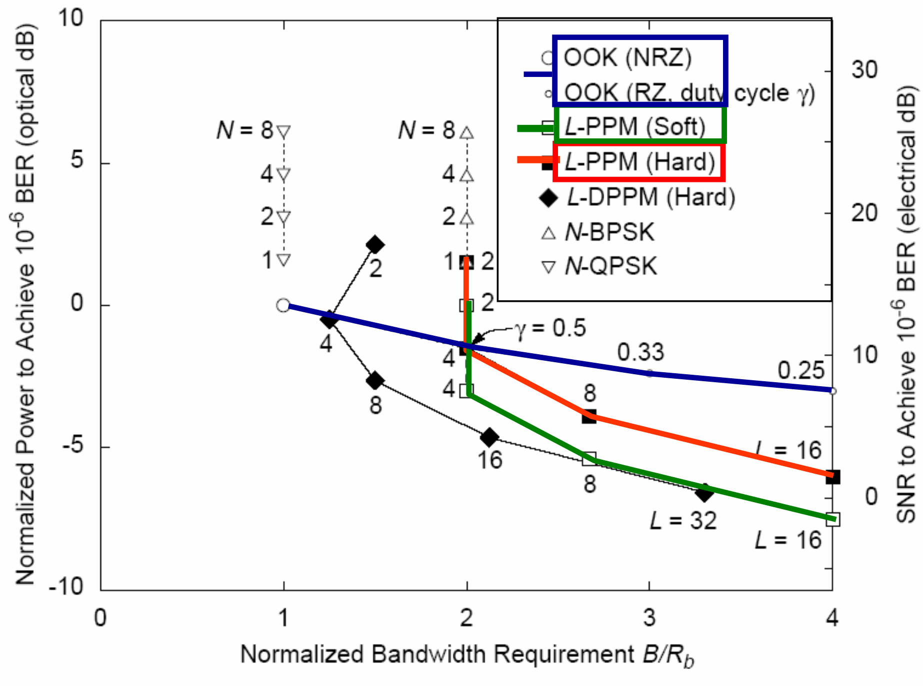
BEWARE:

Useful power is proportional to the square of the received optical power
Thus

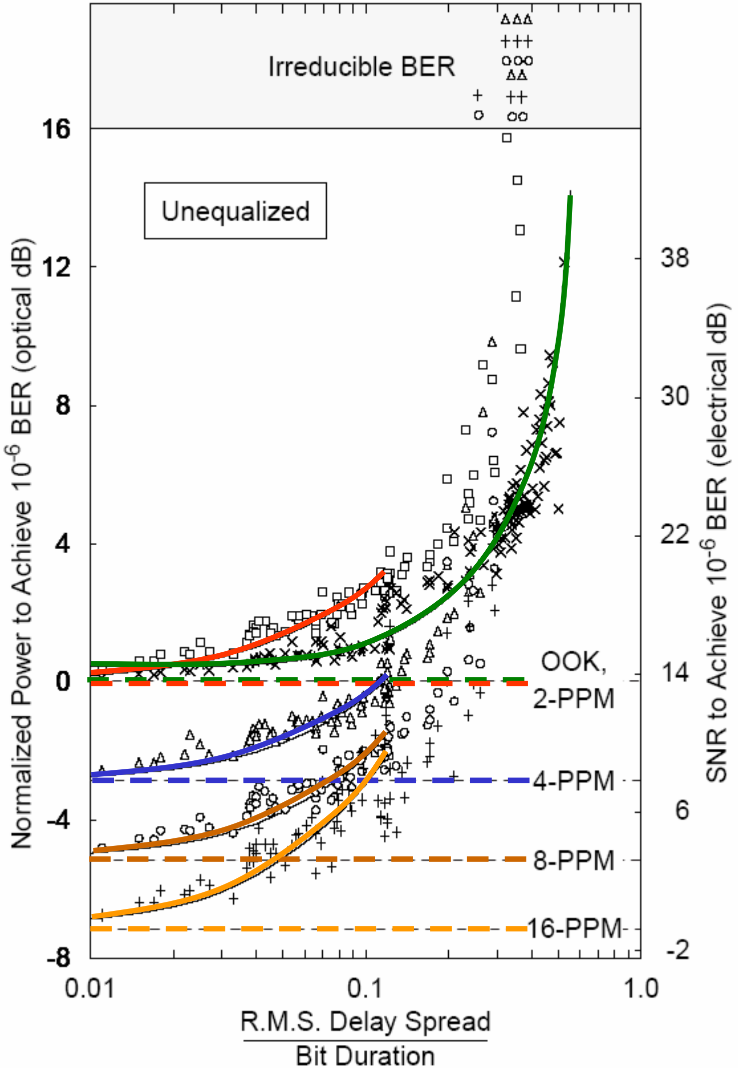
SNR_{PPM} goes with $L\log_2 L$

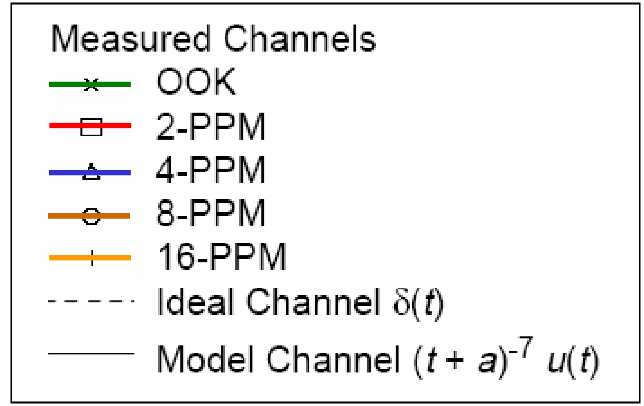
and

SNR_{OOK} goes with $1/\gamma$



Theoretical comparison of average power efficiency and bandwidth efficiency of several modulation schemes on nondistorting channels with IM/DD and AWGN.





Theoretical performance of OOK and 2-, 4-, 8- and 16-PPM at 10 and 30 Mb/s on measured multipath channels using unequalized receivers, which are optimal only on the ideal channel. The dashed lines indicate performance on the ideal channel, and the solid lines indicate performance with a channel model having an impulse response of the form $(t+a)^{-7}\cdot u(t)$, a is a parameter governing the delay spread.

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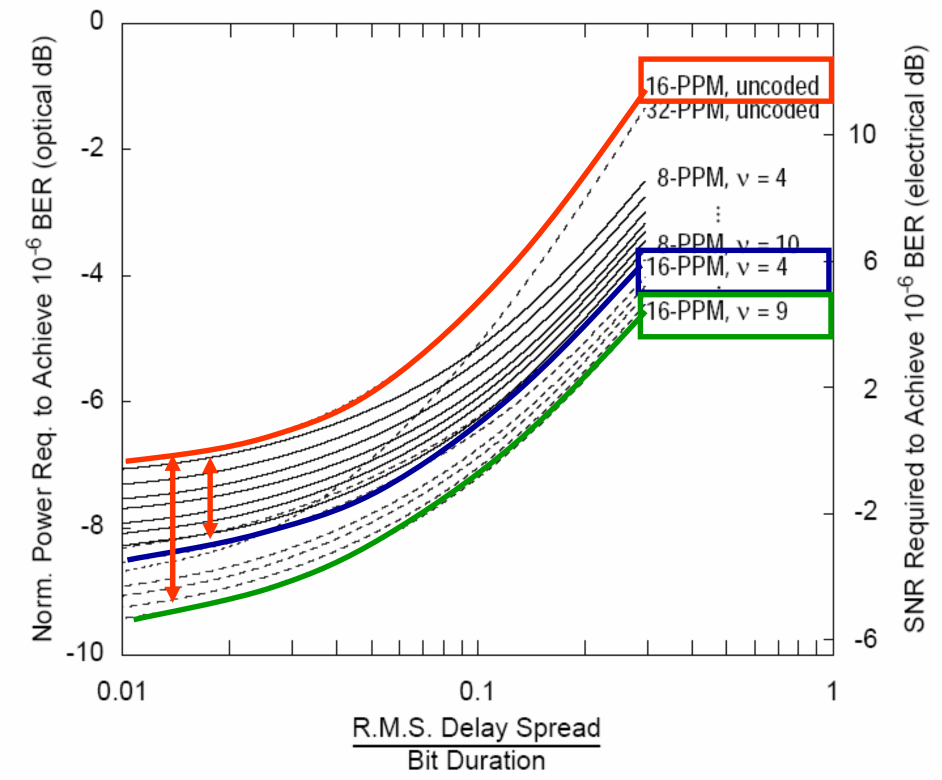
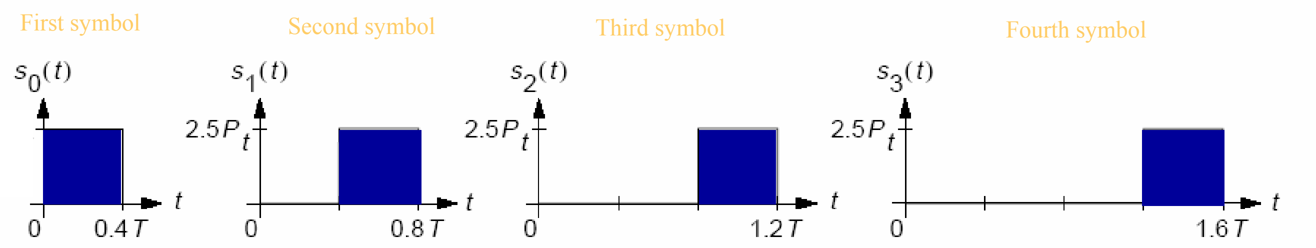
PULSE-POSITION MODULATION



Performance can be improved by using coding

DIFFERENTIAL PULSE-POSITION MODULATION



(b) 4-DPPM

For equiprobable symbols Pr(symbol)=0.25 and thus

Average symbol duration=0.25(0.4+0.8+1.2+1.6)T=T

Average energy/bit=0.4T*2.5P_T/2=0.5P_TT

The same average energy/bit would be obtained with a 4-PPM with peak power 4P_T

MODULATION SCHEMES WITH ELECTRICAL SUBCARRIER

In many applications, especially in wireless systems, modulations schemes using electrical subcarriers are used in order to:

- Avoid sending signal in the dc area, where noise components are concentrated

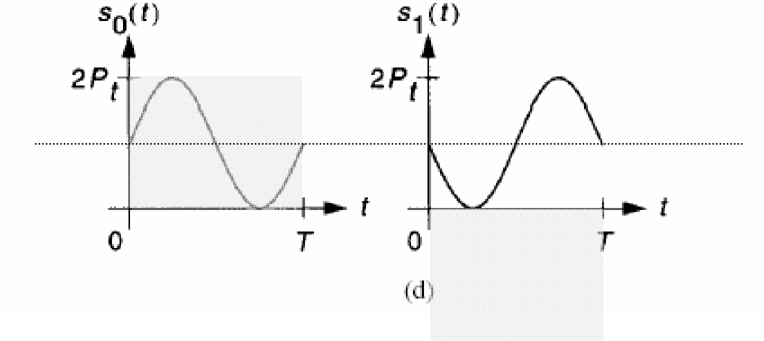
- Avoid interference with remote control or with other optical communication systems (such as IrDA)

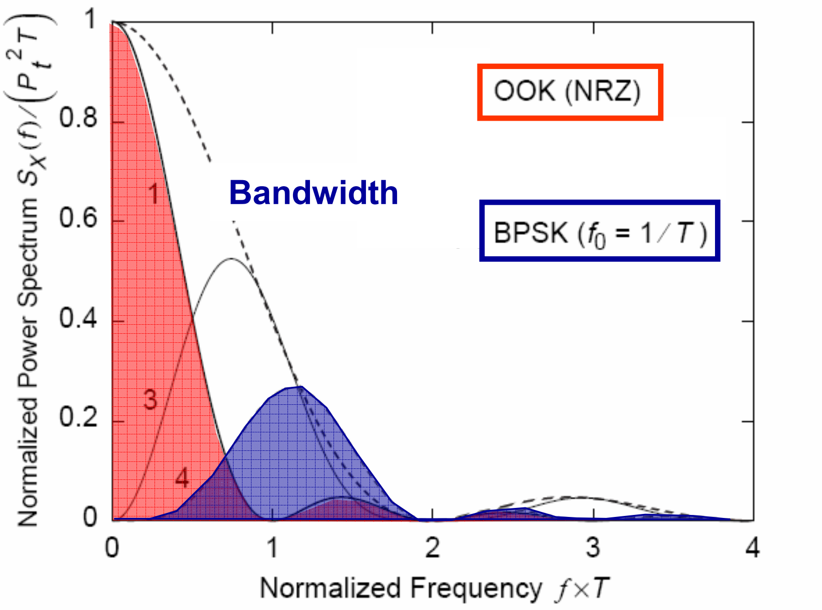
- Allow the use of FDMA schemes

There are two major possibilities: using one single carrier (BPSK or QPSK) or several carriers (MSM or MSK systems)

SINGLE SUBCARRIER MODULATION

BPSK



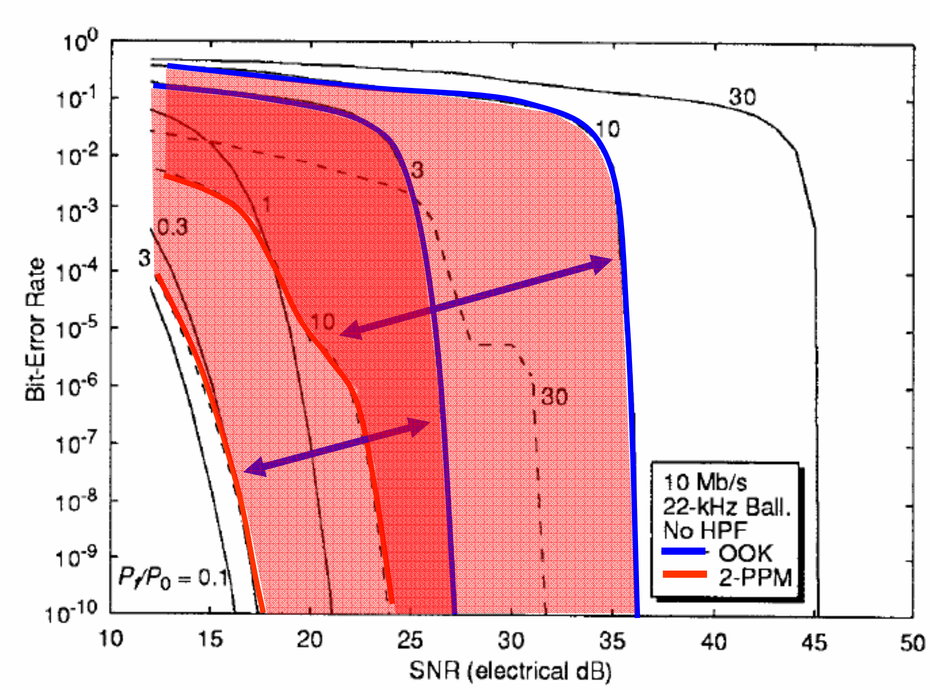


Power spectra of several modulations used in IR systems

In single-subcarrier modulation (SSM) a bit stream modulates a radio-frequency subcarrier, and this modulated subcarrier modulates *X(t),* the instantaneous power of the infrared transmitter.

Because the subcarrier is typically a sinusoid taking on negative and positive values, a d.c. bias must be added to satisfy the requirement to be nonnegative.

EFFECT OF FLUORESCENT LIGHT NOISE ON PERFORMANCE



BER curves for various ratios of P_f/P_0 for OOK and 2-PPM at 10 Mb/s. The fluorescent lamp is driven by a 22 kHz ballast and no highpass filter is employed

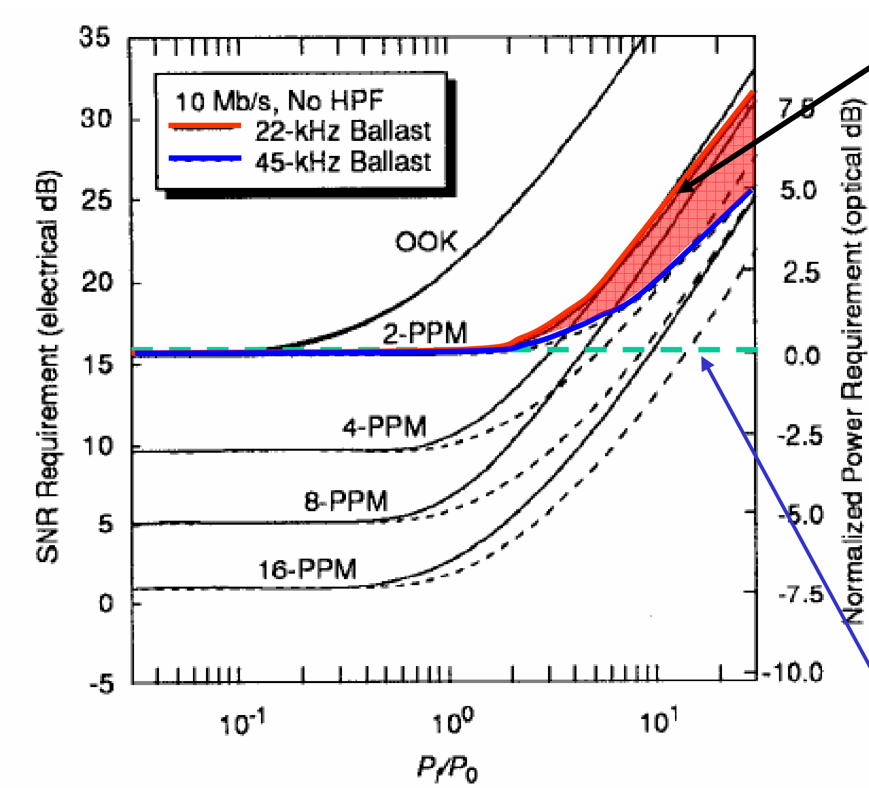
***P_f*:** Maximum absolute excursion (with respect to the mean) of the received fluorescent optical power waveform

***P_0*:** Is defined as the average optical power required to achieve 10^{-9} BER with OOK in the absence of fluorescent Light

As P_f/P_0 increases there is an increase in the required SNR

OOK is degraded more rapidly than 2-PPM (due to DC components)

EFFECT OF FLUORESCENT LIGHT NOISE ON PERFORMANCE



SNR increase needed

SNR and normalized optical power required to achieve 10^{-9} BER at 10 Mb/s versus P_f/P_0 with no highpass filter for 22 kHz and 45 kHz ballast

(0 dB corresponds to the P_0 power)

BER=10^{-9}

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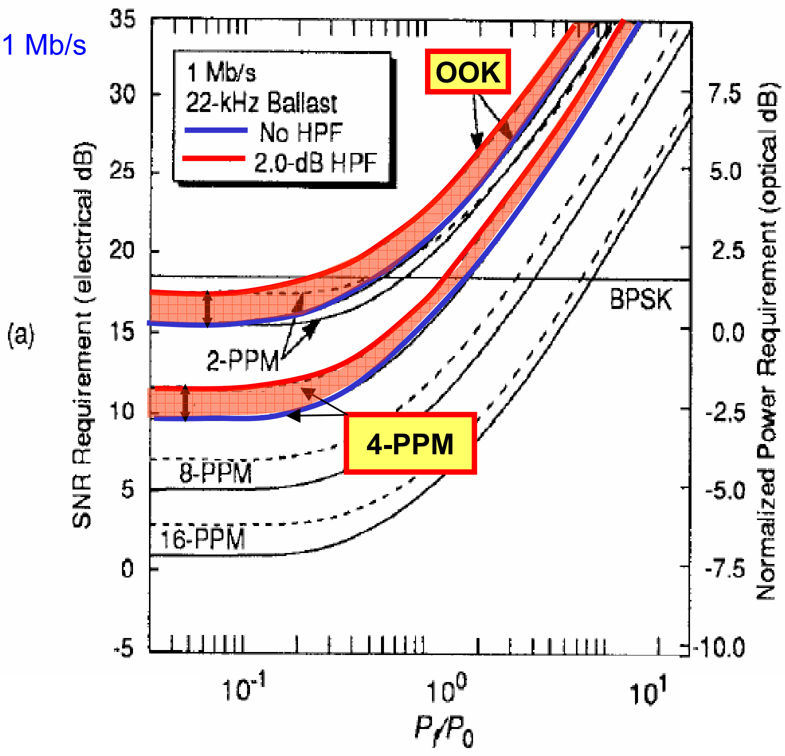
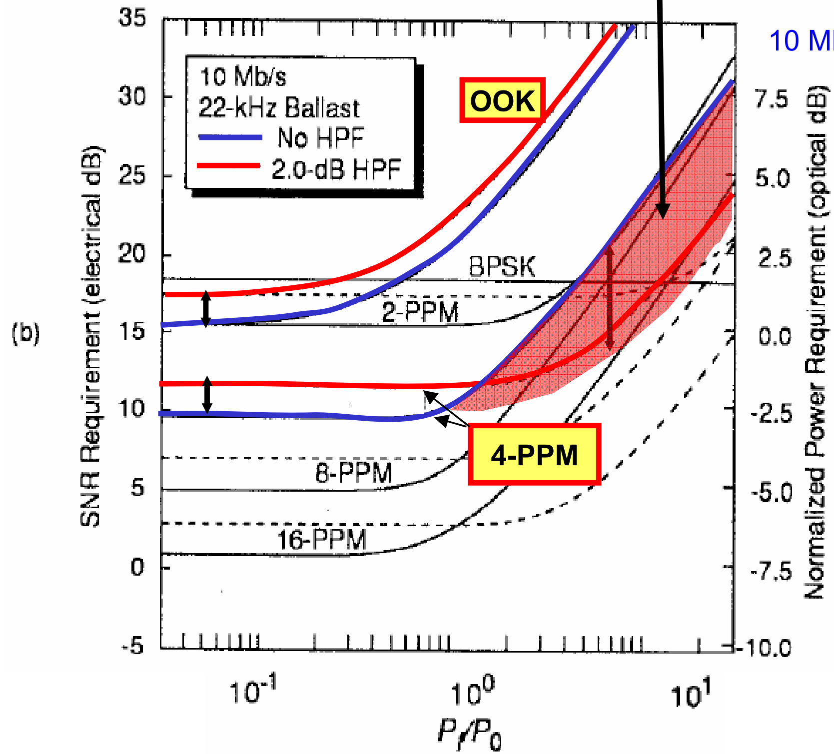
EFFECT OF FLUORESCENT LIGHT NOISE ON PERFORMANCE

1 Mb/s



SNR increase needed

10 Mb/s



SNR requirements and normalized optical power required to achieve 10^{-9} BER versus P_f/P_0 for 22 kHz with no highpass filter and with a highpass filter inducing a 2 dB SNR penalty

High pass filtering does not affect the performance on OOK!!
(but improves performance of PPM)

FURTHER READING

Narasimhan, R.; Audeh, M.D.; Kahn, J.M.; “Effect of electronic-ballast fluorescent lighting on wireless infrared links”, IEEE International Conference on Communications, Volume: 2 , 23-27 June 1996 Pages:1213 - 1219 vol.2