# Digital Communications 4 (ENG4052)

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## Course structure

- lectures
- coding laboratories
- tutorials (attempt them on your own first)

Skeleton lecture notes and supplementary materials on Moodle
`https://moodle.gla.ac.uk`

Recommended textbooks for further background:
*Communication Systems Engineering* by J. G. Proakis and M. Salehi
*Introduction to Communication Systems* by F. G. Stremler

Assessment:

50% open book exam (120 min) in April/May
50% coding laboratory reports

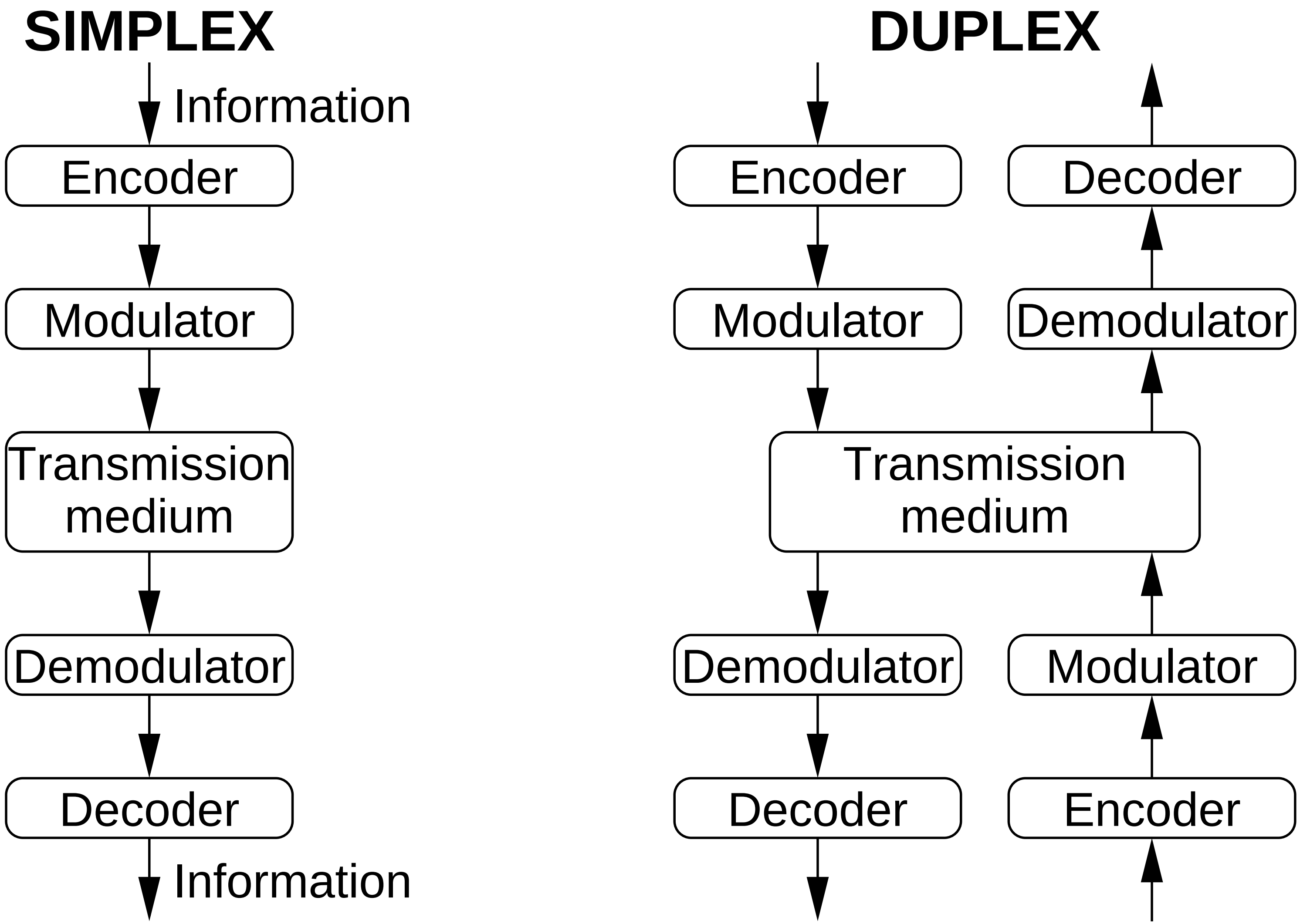
# Some useful internet resources

- OFCOM licenses portions of the electromagnetic spectrum in the UK for broadcasts and communications
  `http://www.ofcom.org.uk`
- International Telecommunications Union (UN)
  `http://www.itu.int`
- Electromagnetic spectrum
  `http://en.wikipedia.org/wiki/Electromagnetic_spectrum`

# Introduction

- Communication systems are designed to transmit information
- Most modern communication systems are based on Electromagnetic Waves (radio, microwave, optical) either in transmission line/waveguide or free space
  - large range (infinite ?) and fast ($3 \times 10^8\,\mathrm{m\,s^{-1}}$)
  - compatible with electronics, large bandwidth — many channels/services

# Communications system schematic



# Why Digital Communication Systems?

**Efficiency** The Source Coding Theorem allows quantification of just how complex a given message source is and allows us to exploit that complexity by source coding (compression). In analog communication, the only parameters of interest are message bandwidth and amplitude. We cannot exploit signal structure to achieve a more efficient communication system.

**Performance** Because of the Noisy Channel Coding Theorem, we have a specific criterion by which to formulate error-correcting codes that can bring us as close to error-free transmission as we might want. Even though we may send information by way of a noisy channel, digital schemes are capable of error-free transmission while analog ones cannot overcome channel disturbances.

**Flexibility** Digital communication systems can transmit real-valued discrete-time signals, which could be analog ones obtained by analog-to-digital conversion, and symbolic-valued ones (computer data, for example). Any signal that can be transmitted by analog means can be sent by digital means, with the only issue being the number of bits used in A/D conversion.

# Modulation

The information contained in one signal is transferred to another signal (usually at higher frequency), known as the carrier frequency.

- Shift to more easily broadcast/received frequencies.
  - an antenna is most efficient for a length $\lambda/4$
  - for $1\,\mathrm{kHz}$ this is $75\,\mathrm{km}$!
- Implement Frequency Division Multiplexing — different channels use different carrier frequencies (with a finite bandwidth).

The general form of a modulated sinusoidal signal at a carrier frequency of $\nu_c$ can be written ($\omega_c = 2\pi\nu_c$),

$$\phi(t) = a(t)\cos[\omega_c t + \gamma(t)]$$

**Amplitude modulation (AM)** $a(t)$ carries the information, $\gamma(t)$ is held constant.

**Angle modulation** $\gamma(t)$ carries the information, $a(t)$ is held constant, e.g. frequency modulation (FM) or phase modulation (PM).

**Quadrature Amplitude Modulation** both amplitude $a(t)$ and angle $\gamma(t)$ are varied to carry the information.

The effect of modulation on the spectrum is to create sideband(s) on either side of the carrier frequency.

# AM Spectrum

- setting $\gamma(t) = 0$,

$$\phi(t) = a(t) \cos \omega_c t$$

- Taking the Fourier transform (frequency shift property)

$$\begin{aligned}\Phi(\omega) &= \mathcal{F}\left\{\tfrac{1}{2} a(t)(\mathrm{e}^{\mathrm{j}\omega_c t} + \mathrm{e}^{-\mathrm{j}\omega_c t})\right\} \\ &= \tfrac{1}{2} A(\omega - \omega_c) + \tfrac{1}{2} A(\omega + \omega_c)\end{aligned}$$

where $A(\omega)$ is the spectrum of the modulating signal $a(t)$.

- Amplitude modulation translates the frequency spectrum of the signal by $\pm\nu_c$.

# AM Spectrum

- We see that both negative and positive frequencies of $a(t)$ are now expressed as positive frequencies, implying the bandwidth has doubled.

- We call the frequencies of the modulated signal above (below) $\nu_c$ the upper (lower) sideband.

- For example, AM radio stations are assigned $9\,\mathrm{kHz}$ channels but are limited to a $4.5\,\mathrm{kHz}$ bandwidth signal.

# M-ary Symbols

- In digital modulation, an analog carrier signal is modulated by a discrete signal.
- Digital modulation methods can be considered as digital-to-analog conversion and the corresponding demodulation or detection as analog-to-digital conversion.
- The changes in the carrier signal are chosen from a finite number of M alternative symbols (the modulation alphabet).

**Bit Rate** frequency of the system bit stream
**Symbol Rate** (or BAUD Rate) Bit Rate divided by number of bits per symbol
**Signal Bandwidth** depends on the Symbol Rate
**example:** bit sequence 00, 01, 10 and 11 are represented by $4\,(=2^2)$ symbols

# Fundamental Digital Modulation methods

**ASK** Amplitude Shift Keying: a finite number of amplitudes $a(t)$ are used.

**FSK** Frequency Shift Keying: a finite number of frequencies are used.

**PSK** Phase Shift Keying: a finite number of phases $\gamma(t)$ are used.

**QAM** Quadrature Amplitude Modulation: a finite number of at least two phases $\gamma(t)$ and at least two amplitudes $a(t)$are used.

# On-Off Keying (binary ASK)

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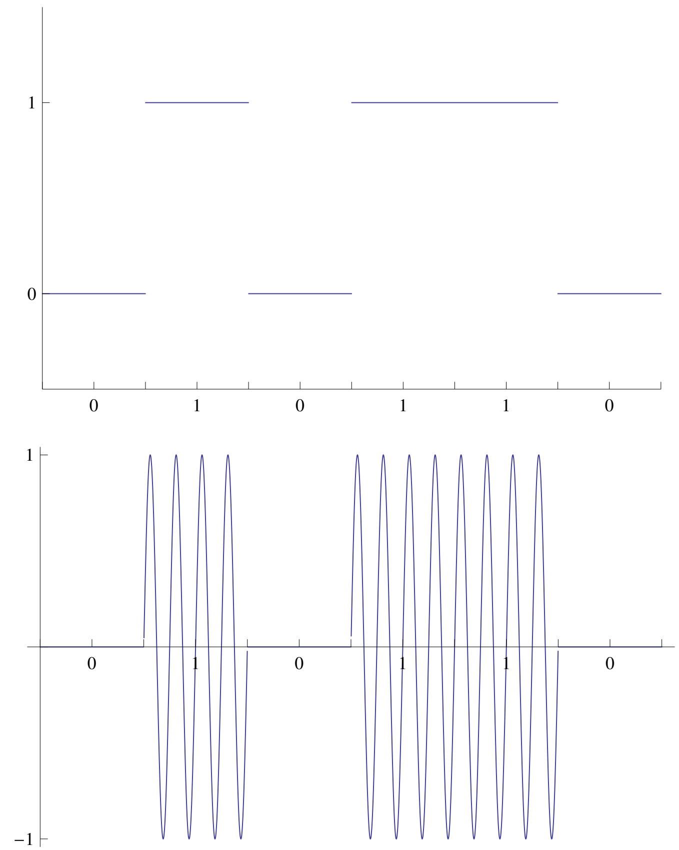
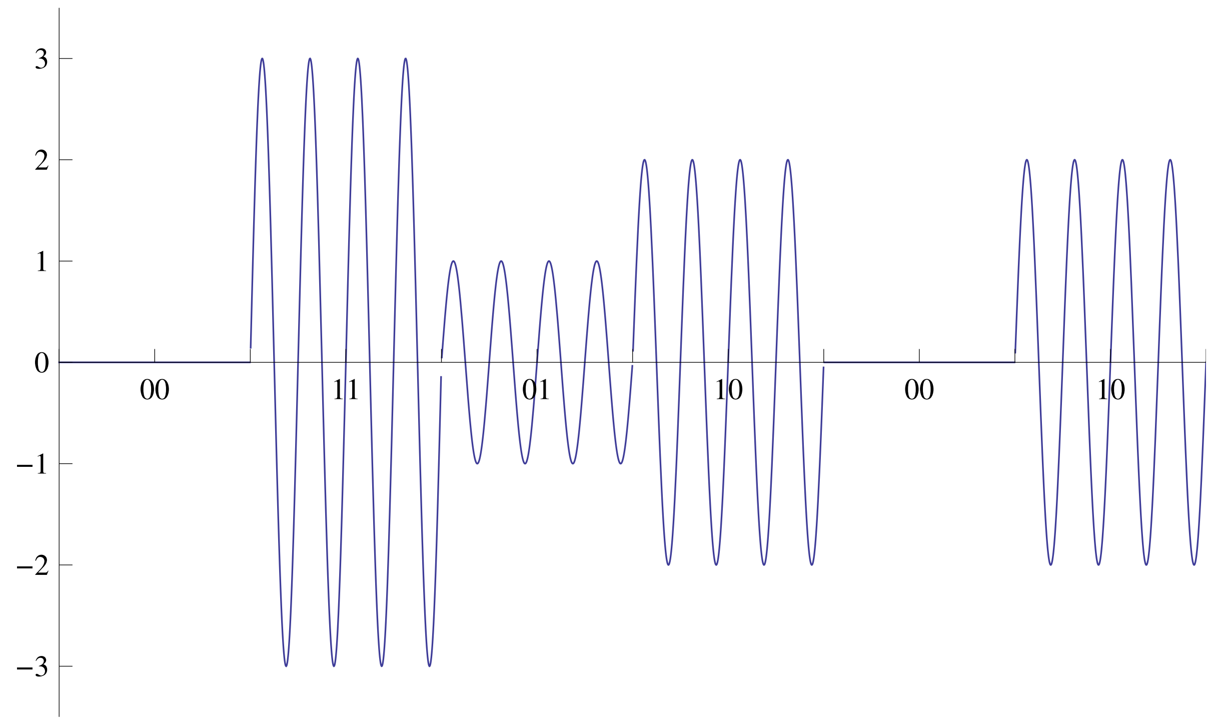



- Examples: Morse over RF, IrDA

# M-ary ASK

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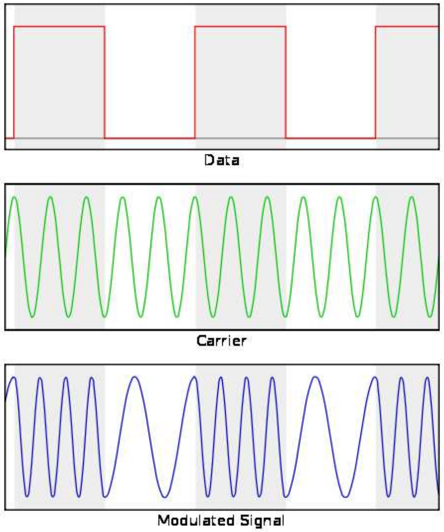
# Frequency Shift Keying

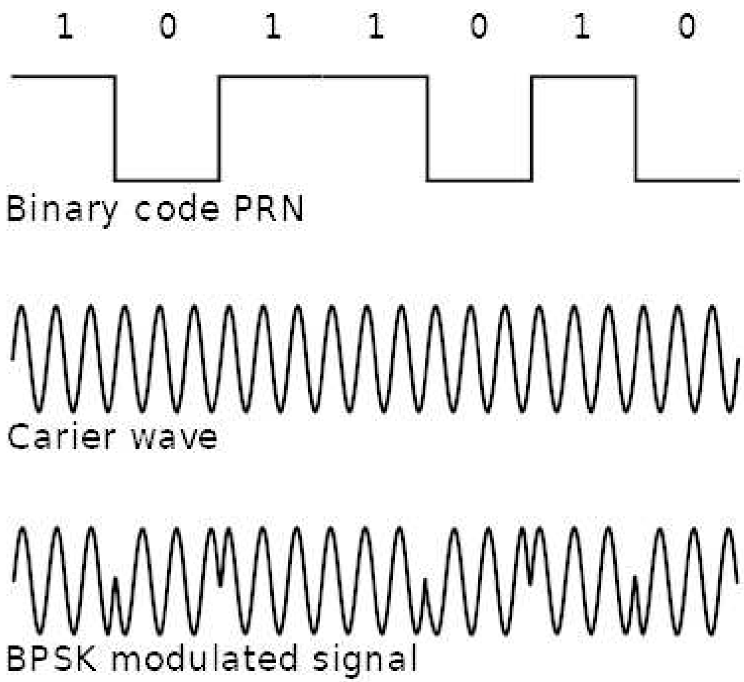


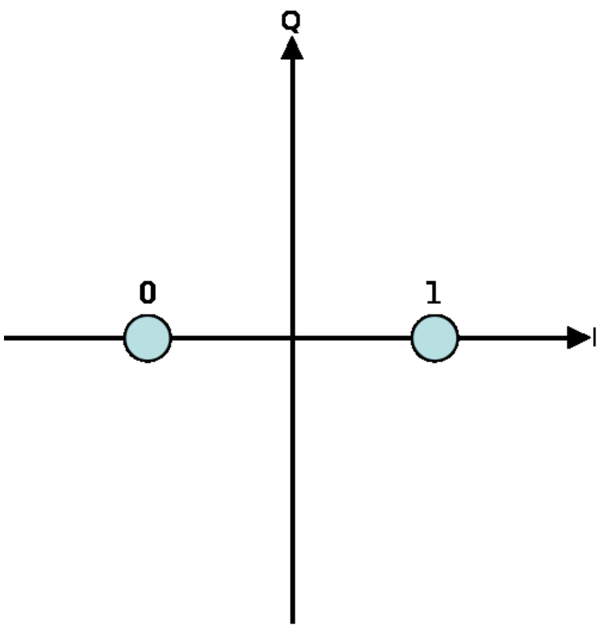

- Examples: Early telephone line modems, Caller ID, US Emergency Alert System
- minimum-shift keying (MSK) is a type of continuous-phase FSK, such that the difference between frequencies is half the bit rate
- A variant of MSK called Gaussian minimum-shift keying (GMSK) is used in the GSM mobile phone standard

# In-phase and Quadrature (I&Q)

- In-phase (I, e.g. $\cos \omega t$) and Quadrature (Q, e.g. $\sin \omega t$) components are orthogonal
- I & Q components combined in Analogue Modulation using balanced modulators
  - generation of SSB
  - generation of narrowband FM
- a constellation diagram is a representation of the symbols for a digital modulation scheme as points on the complex (I & Q) plane
  - amplitude and phase are the $(r, \theta)$ polar coordinates

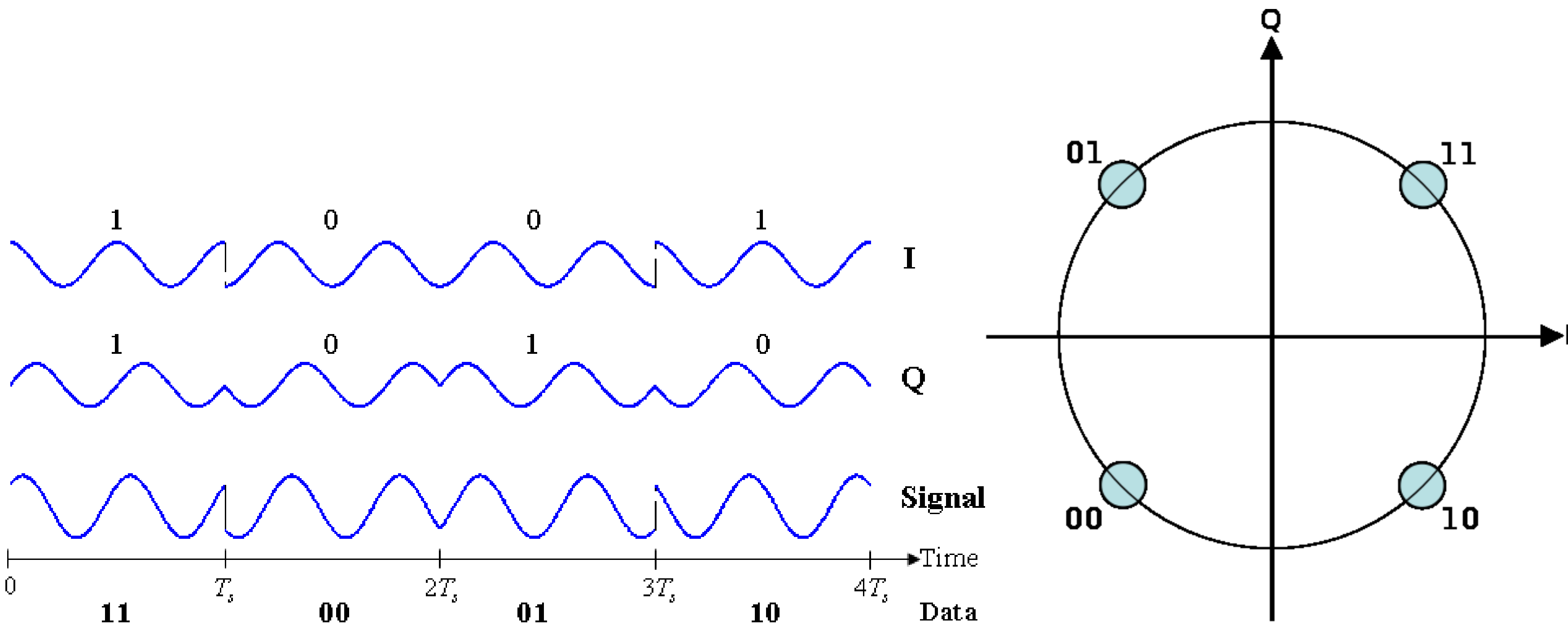
# Binary Phase-Shift Keying




- Requires coherent detection to resolve absolute phase
- or use Differential Phase-Shift Keying (DPSK) — conveys data by changing the phase

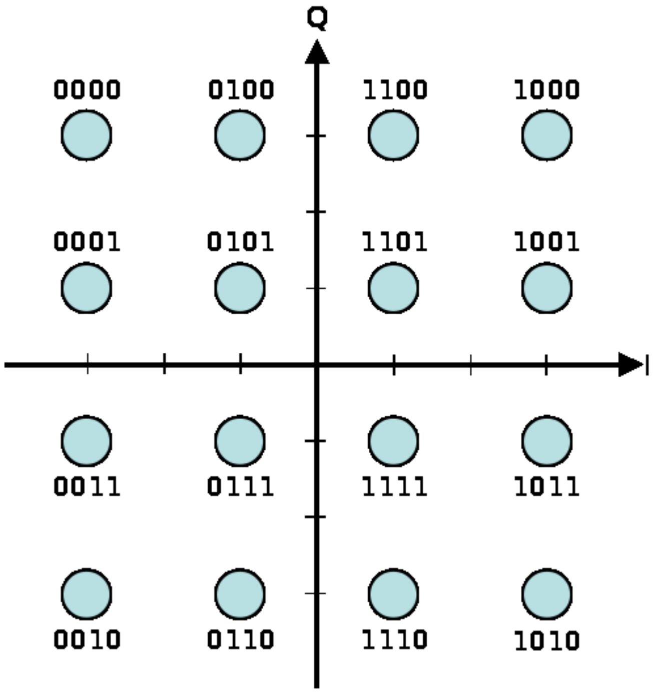
# Quadrature Phase-Shift Keying




Gray coded Quadrature Phase-Shift Keying (QPSK)

- BPSK/DBPSK/QPSK/DQPSK examples: wireless LAN IEEE802.11b and IEEE802.11g (lower data rates only), Bluetooth 2, some RFID standards
- QPSK and 8PSK used in satellite TV, higher-order PSK rarely used.

# Quadrature Amplitude Modulation




Gray coded square 16-QAM

- most common square 16-QAM, 64-QAM and 256-QAM
- UK digital terrestrial television: 64-QAM (256-QAM for Freeview HD)
- extensively used in digital telecommunication systems