# DIGITAL COMMUNICATIONS

- Lectures
  - Contact time: 2 x 1hr x 12= 24hrs
  - Tuesdays 10:15-11:05 (6E2.1)
  - Fridays 15:15-16:05 (6E2.1)
- Lecturer
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# Recommended Textbooks

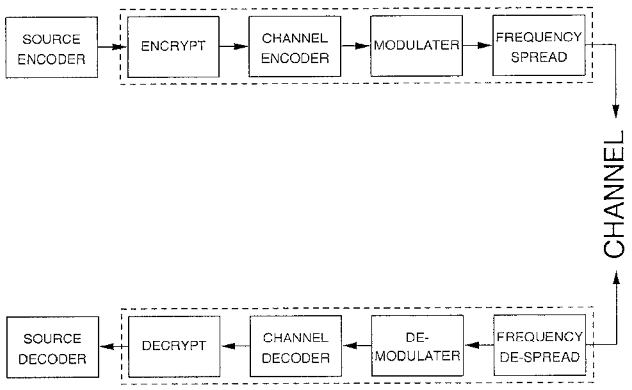
- There are zillions of texts available that cover the material in this course. The cheaper and better ones are:
- *"Digital Communications: Fundamentals and Applications",* Bernard Sklar, Prentice-Hall, 776pp, cost approx. £25
- *"Digital Communications",* Ian Glover and Peter Grant, Prentice-Hall, 734pp, cost approx £25

# Textbooks (cont.)

- Sklar:
  *"Easy to read. Covers more than is in the syllabus, and is pitched at about the right sort of level. Covers convolutional coding and spread spectrum in more detail than G&G. Also covers encryption"*
- Glover & Grant:
  *"Very readable, easy to understand. Covers more than the syllabus - useful for some 4th year options"*
- I would strongly encourage you to purchase one of these books if possible.



# Block Diagram of a Digital Communications System



# Channel Encoder

- Provides protection again transmission errors by selectively inserting redundant data
- The source encoder usually removes redundant information. The channel encoder inserts redundant information in a very selective manner
- We will look at the role error error correction coding plays in digital communications systems



# Modulator

- Converts digital data into a continuous waveform suitable for transmission over a channel (usually as a sinusoid)

- Information is transmitted over the channel by varying one (or more) of the following:
  - Frequency
  - Phase
  - Amplitude

# Examples of Modulation

- ASK (Amplitude Shift Keying)
  "1"= $A_0 \cos(2\pi f_c t)$
  "0"= $0$
- FSK (Frequency Shift Keying)
  "1"= $A_0 \cos(2\pi f_1 t)$
  "0"= $A_0 \cos(2\pi f_2 t)$
- PSK (Phase Shift Keying)
  "1"= $A_0 \cos(2\pi f_c t)$
  "0"= $A_0 \cos(2\pi f_c t + \pi)$



# Notes on Modulation

- The choice of modulation greatly effects the system performance
- Modern communications theory views channel coding and modulation as a single operations. This results in so-called "*trellis codes*" which can yield incredible performance
- We will study the most common digital modulation techniques: QPSK, OQPSK, and MSK

## The Channel

- The channel carries the signal. Could be wire, free-space, magnetic disk system
- Real-world channels experience attenuation, noise (interference), fading
- Fading is particularly important in mobile and satellite communications
- In this course, we will assume a simple channel model - AWGN (additive white Gaussian noise)



## What makes a good comms. system?

- Large data rate (bits/sec.)
- Small bandwidth (Hz)
- Small signal power (Watts, dBW or dBm)
- Low distortion (S/N, or BER)
- Low cost - high complexity does not necessarily mean high cost
- In practical systems, as in every engineering design, there are *trade-offs* to be made in achieving these goals

# Data rate vs. Bandwidth

- For a fixed S/N ratio, increased data rate means shorter data pulses - thus larger bandwidth
- This can't be avoided: Claude Shannon,1948
- The ratio of the data rate to the bandwidth is the *bandwidth efficiency*, $\eta_B$
- We want a large bandwidth efficiency $\eta_B$



# Fidelity vs. Signal Power

- One way to get an error free signal would be to use an enormous amount of power to blast over the noise!
- Some types of modulation achieve relative error free transmission at lower powers than others
- The *energy efficiency* is : $\eta_E = E_b / N_0 \big|_{P_b = 10^{-6}}$
- We want a small $\eta_E$

## Bandwidth efficiency vs. Energy efficiency

- It is possible for a system design to trade between bandwidth and energy efficiency
- Examples:
  - Binary modulation sends only a single bit per symbol
    *m*-ary modulation can send multiple bits, but is more susceptible to error
  - Error correction coding improves BER, but increases bandwidth
- This is a fundamental trade-off in digital communications



## The master plan...

- Channel coding
  - Block codes
  - Convolution codes
- Digital modulation techniques
  - QPSK, OQPSK, MSK and FSK
- Spread spectrum techniques
  - FH and DS generation and detection
- Encryption and decryption

## Channel coding

- Used for improving the error performance (ie. lowering the BER) when the S/N ratio cannot be increased;
  - fixed signal power, e.g. satellite downlink
  - combat fading or jamming
- Channel coding adds *redundancy* to the encoded source data by inserting extra code digits in such a manner that the receiver can possibly *detect* and even *correct* errors introduced by the channel
- The resulting codes are usually (but not always) binary. We will only consider binary codes here.



## Channel coding: classes of code

There are two basic classes of code

- Block codes: the sequence of message bits from the source is sub-divided into fixed length blocks. To these fixed length message block a number of parity of bits are added. The parity bits are derived from the message bits

- Convolutional codes: a sliding sequence of past message bits are used to generate the code.

Both systems are extensively used in data storage (CD) and communications systems (GSM)

## Channel coding: to *detect* or *correct?*

- Both block and convolution codes can be used for FEC (*forward-error-correction*), but the widest application of block coding over band-limited channels has been in error *detection*
- If any error is *detected* in a received data block the transmitter is notified to repeat the data block - this is known as the ARQ (*automatic request for re-transmission)* system. This scheme requires extra storage at the transmitter and importantly a return channel (albeit a slow narrow band one)
- Error *detection* schemes yield a lower overall probability of error than error *correction* schemes



## Channel coding: data errors

- Data errors - always likely when a digital message is transmitted or storage
  - Transmission systems: subject to noise due to external interfering signals and noise generated within the receiver
  - Signal distortion: reduces the noise margin at the detector which renders the data more susceptible to error
  - Digital storage: always prone to error since ultimately the data is stored in *analogue* form; as a charge pattern (DRAM) as a magnetic pattern on a storage medium (e.g. Hard disks) or as a change in polarization (e.g. MO disks)

# Channel coding: error types

Errors can be classified into two types;

- Random errors: equal probability of error at all times. The probability of an error at a particular time is not influenced by the error history. That is to say the *errors are independent*
  - Random errors are associated with the presence of white noise - this gives rise to the classic relationship between S/N ratio and the BER or $P_b$
  - For example; for binary PSK, the probability of a bit error is

$$P_b = Q\left[\sqrt{2E_b / N_0}\right]$$



# Channel coding: error types

- Burst errors: occur when the likelihood of error is greater at certain times than others
- Common causes of burst errors:
  - Radio signal fading (multi-path, obstructions, rain)
  - Interference from large electrical machines, EMI
  - Lightning (electrical storms)
- The *bursty* channel is broadly described by a two-state model. In the burst state $P_b \to 0.5$ at other times (the non-burst period) $P_b$ is low $< 10^{-3}$ (say). Transitions from one state to the other occur at random times.

# Channel coding: error types

- The statistics of a channel consist of parameters like the *time between bursts* and *burst length*. Each of these parameters will have its own probability distribution
- In either state the transmission path will be described by its *random error performance*
- Special codes and procedures to deal with burst errors will be described later in the course ...