University of Portsmouth
BSc (Hons) Computer Science
Third Year

Advanced Networks (ADNET)

M21276

September 2025 - January 2026

20 Credits

Thomas Boxall

thomas.boxall1@myport.ac.uk

Contents

Page 1

Lecture - Signal Encoding Techniques

2025-09-29 11:00 Asim

There is a deck of slides on Moodle introducing this module's structure & assessments, etc.

1.1 Introduction to Concepts

1.1.1 Computer Networks

Definitions

Computer Network A system that connects two or more computing devices for transmitting and sharing information (data)

There are a number of different activities which can be done on a network:

- Watching Videos
- Playing Games
- Sending and Receiving Messages (including not just text)
- Paying Bills

The core function of the network is to exchange data between interconnected devices.

1.1.2 Data & Signals

Data is the information which is transmitted between devices on the network. The type of the data depends on the context and may include:

- Video
- Audio
- Text
- Images

For data to be able to travel on the network - it has to be converted into digital or analog format. Once in either of these formats, the resultant data is known as *signals*.

Definitions

Signal Electromagnetic Waves that carry data
Analog Signal are signals which vary smoothly over time and have no fixed point to change at and don't have fixed levels
Discreet Signal are signals which maintain constant level for some time then then change to another constant level
Digital Signal are signals which have only two levels - one high to indicate on, or 1, and one

low to indicate off, or 0

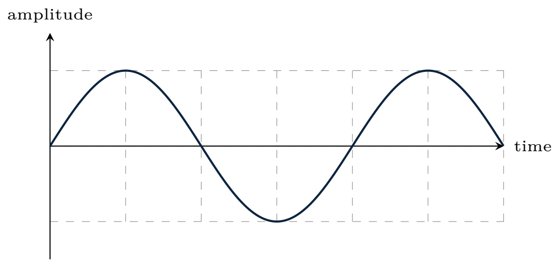

Figure 1.1: Analog Signal

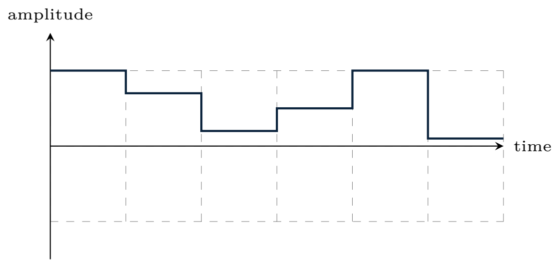

Figure 1.2: Discrete Signal

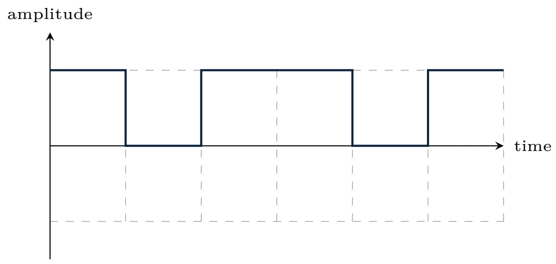

Figure 1.3: Digital Signal

1.2 Data Communications

Within a Data Communications Network - the data will convert between Digital and Analog data at various points. A *modem* may be used to complete this conversion.

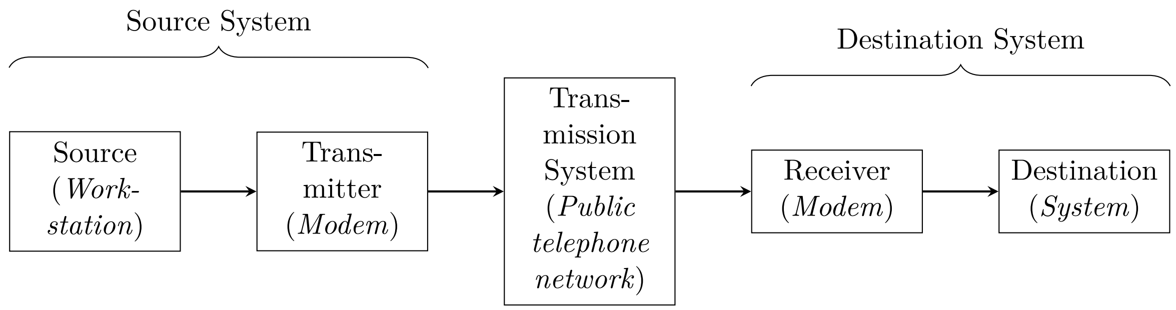

Figure 1.4: Block Diagram of Example Data Communications Signal Chain

In the above diagram, the *workstation* provides the *modem* with a digital signal. The modem then converts this digital signal into an analog signal which can be transmitted across the *Public Telephone Network* that uses analog signals. The receiving *modem* converts the signal to a digital format which the *server* receives.

In saying this, however, there are some devices which still work entirely on analog or digital signals. For example, the analog telephone network including the switching and transmission is entirely analog. There is also the inverse whereby there are entirely digital signals are processed.

1.3 Digital-To-Digital Signal Encoding

Digital signals are transmitted such that an individual value is transmitted for a defined period of time called the *bit duration*. The *bit duration* is known to both the sender and receiver, allowing the receiver to correctly interpret the transmitted signal which the sender will always transmit at the beginning of the bit duration. We assume the sender and receiver are synchronised and therefore the clock or is not transmitted.

The move between two different defined voltages within the transmission is called the *transition*.

As digital signals are discrete (meaning there are defined, absolute data levels) encoding a digital signal as another digital signal is considerably simpler as we don't have to convert one data level to another.

1.3.1 Nonreturn to Zero Level (NRZ-L)

This method only has two levels of data transmitted. It works through mapping the high data level (1) and low data level (0) to a signal level:

- 0 - represented by a high level signal
- 1 - represented by a low level signal

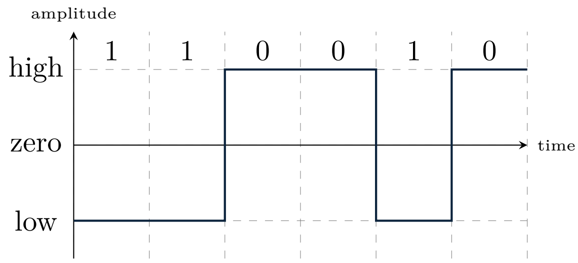

Figure 1.5: Example of NRZ-L Encoding using 110010

1.3.2 Nonreturn to Zero Inverted (NRZ-I)

This method is similar to NRZ-L in that it uses two levels of data transmitted: high and low. However it uses the transitions to define the data being transmitted. Looking at the bit following a transition point, even if there is no transition present:

- Where there is a transition (regardless of 1 to 0, or 0 to 1): the following signal bit is transmitted as is high
- Where there is not a transition (regardless of 1 to 1, or 0 to 0): the following signal bit is transmitted as low

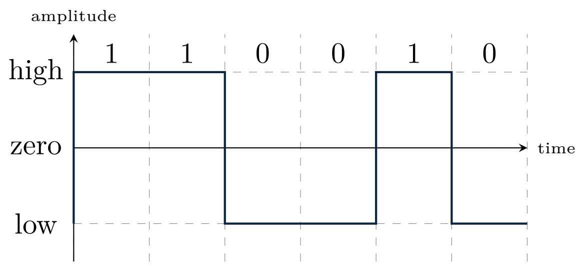

Figure 1.6: Example of NRZ-I Encoding using 110010

1.3.3 Bipolar-AMI

This has three signal levels: high, zero, and low. It works through setting the signal based on the bit to be transitioned to:

- 0 - represented by transmitting zero
- 1 - represented by alternating high and low values, regardless of it there is a 0 value in the middle

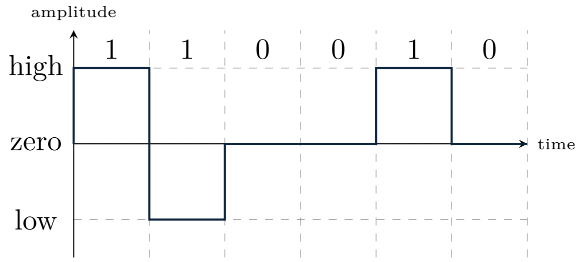

Figure 1.7: Example of Bipolar-AMI Encoding using 110010

1.3.4 Pseudoternary

This has three signal levels: high, zero, low. It works through setting the signal based on the bit to be transmitted:

- 0 - represented by alternating high and low values, regardless of if there is a 1 value in the middle of them
- 1 - represented by transmitting zero value

This is the inverse of Bipolar-AMI.

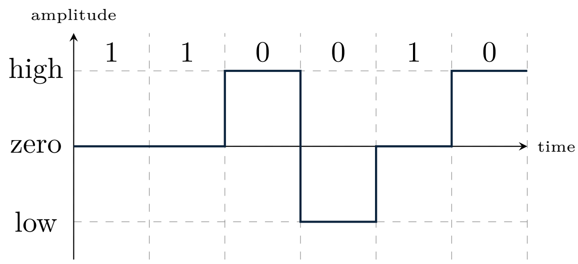

Figure 1.8: Example of Pseudoternary Encoding using 110010

1.3.5 Manchester

This has two signal levels: high and low. It works through having up-to two transitions per interval:

- 0 - represented by a transition from high to low in the middle of the interval (which for successive zeros will require a low-to-high transition at the start of the interval)
- 1 - represented by a transition from low to high in the middle of the interval (which for successive ones will require a high-to-low transition at the start of the interval)

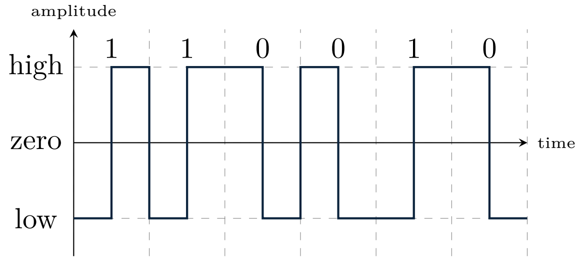

Figure 1.9: Example of Manchester Encoding using 110010

1.3.6 Differential Manchester

This has two signal levels: high and low. It works by always transitioning in the middle of the interval and then examining the transition at the beginning of the interval:

- 0 - represented by a transition at the beginning of the interval
- 1 - represented by no transition at the beginning of the interval

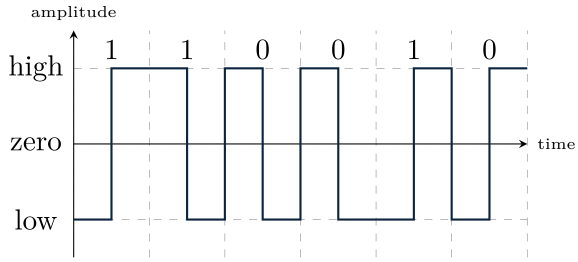

Figure 1.10: Example of Differential Manchester Encoding using 110010

1.3.7 Multi-Level Transmit 3 (MLT-3)

This uses three different signal levels: low, zero and high. It works by cycling through these states based on the bit to be transmitted:

- 0 - remain on the current signal level (regardless of signal level value)
- 1 - move to the next state in the cycle of signal levels (high - zero - low - zero repeat)

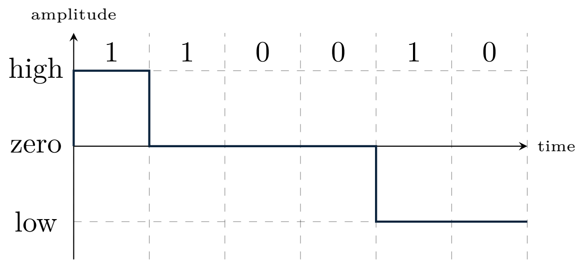

Figure 1.11: Example of MLT-3 Encoding using 110010

1.4 Electromagnetic Waves

Electromagnetic waves are the digital representation of an analog signal. They are considered to be smooth as they don't have fixed values. The key properties of any EM wave are as follows: Amplitude, Phase, Wavelength & Frequency.

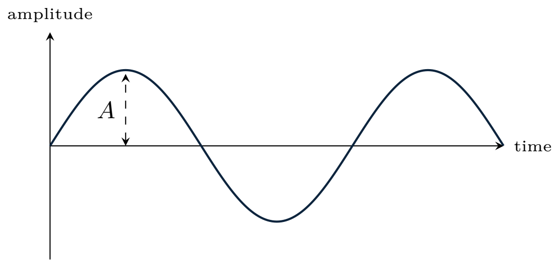

Figure 1.12: Electromagnetic Wave showing Amplitude (A)

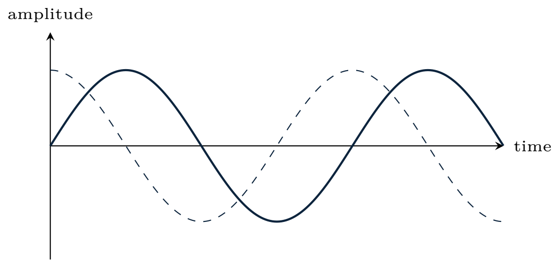

Figure 1.13: Electromagnetic Wave showing Phase (dashed)

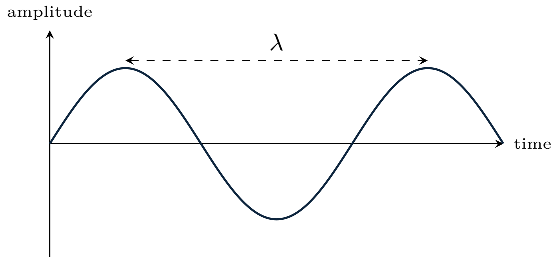

Figure 1.14: Electromagnetic Wave showing Wavelength (λ)

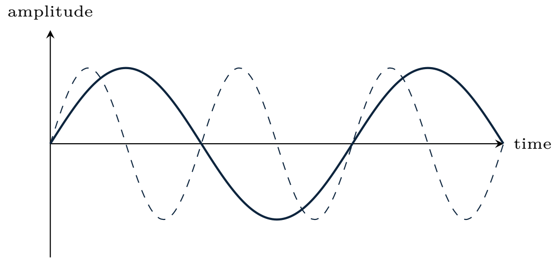

Figure 1.15: Electromagnetic Wave showing increased frequency (dashed)

1.4.1 Carrier Waves & Modulation

Definitions

Carrier Wave a continuous, periodic waveform that carries no information

A *carrier wave* is modified by an information-bearing signal to convey information. The modification can be by either changing: it's amplitude, frequency, phase, or some combination of the three. The process of modifying a carrier wave is called *modulation*.

1.5 Digital Data, Analog Signals

There are many examples of where digital data has to be transmitted through an analog medium. The most well-known of which being the public telephone network. This is designed to transmit voices, within the frequency of 300 to 3400 Hz; therefore a problem is presented when a digital device is connected to the network. This problem is overcome by connecting the digital device to a Modem (Modulator-Demodulator) which converts digital data to analog signals and the other way around.

There are a number of different methods which can be used to convert digital data onto a analog signal. These methods employ a carrier wave for the digital data to be modulated onto. For the subsequent examples - it's assumed the carrier wave is a sine wave.

1.5.1 Amplitude-Shift Keying

Amplitude-Shift Keying (ASK) modulation works by modulating the digital signal onto the amplitude of the carrier wave. Meaning that the amplitude of the carrier wave is increased for a digital 0 and decreased for a digital 1.

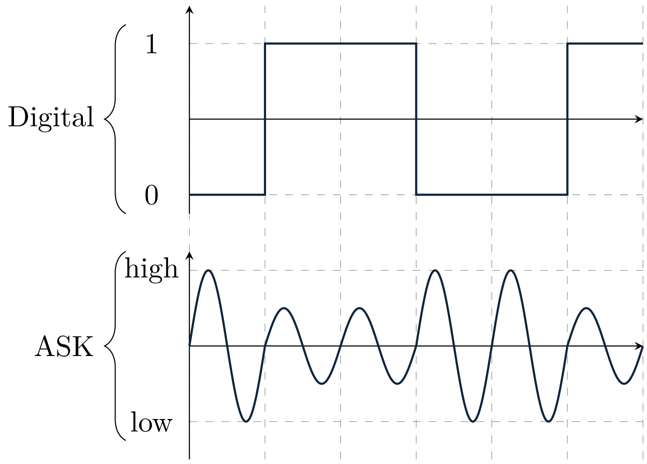

Figure 1.16: Example of ASK Modulation

1.5.2 Frequency-Shift Keying

Frequency-Shift Keying (FSK) modulation works by modulating the digital signal onto the frequency of the carrier wave. This means that the frequency of the carrier wave is increased for a digital 1 and decreased for a digital 0.

The sender and receiver may use different frequencies to allow full-duplex transmissions on the same channel. It is less susceptible to errors than ASK modulation is. FSK can be used for higher frequencies (3 - 30 MHz), radio and Local Area Network transmissions. It can also support Multiple Levels in MFSK.

The *bandwidth* of the transmission is the difference between the frequency of the high frequency (representing a 1) and the low frequency (representing a 0). Different frequency carrier waves will be used for sending and receiving on the same line.

The most common form of FSK is Binary FSK (BFSK) in which the two binary values are represented by two different frequencies near the carrier frequency:

- 0 - represented by $A\cos(2\pi f_1 t)$
- 1 - represented by $A\cos(2\pi f_2 t)$

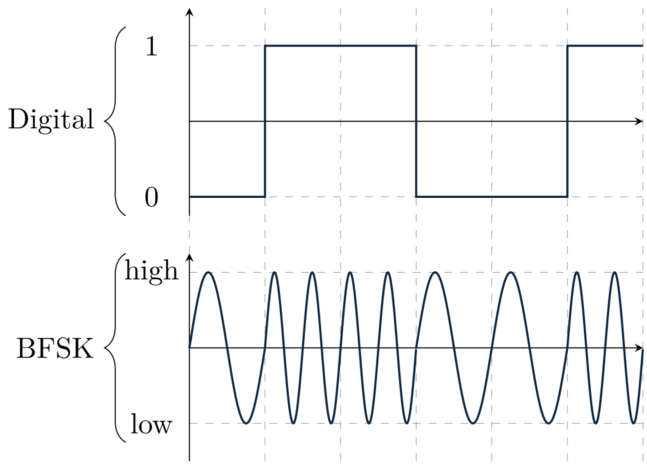

Figure 1.17: Example of BFSK Modulation

1.5.3 Phase Shift Keying

Phase Shift Keying (PSK) Modulation works by modulating the digital signal onto the phase of the carrier wave. This means that the phase of the carrier wave is adjusted to represent digital 0 and digital 1, respectively. There are two different types of PSK studied here.

1.5.3.1 Binary Phase Shift Keying

Binary PSK (BPSK) works by using two phases to represent two different binary digits (0 and 1) and shifting between them:

- 0 - represented by the sine wave $A\cos(2\pi ft + 180)$ which equals the sine wave $-A\cos(2\pi ft)$
- 1 - represented by the sine wave $A\cos(2\pi ft)$

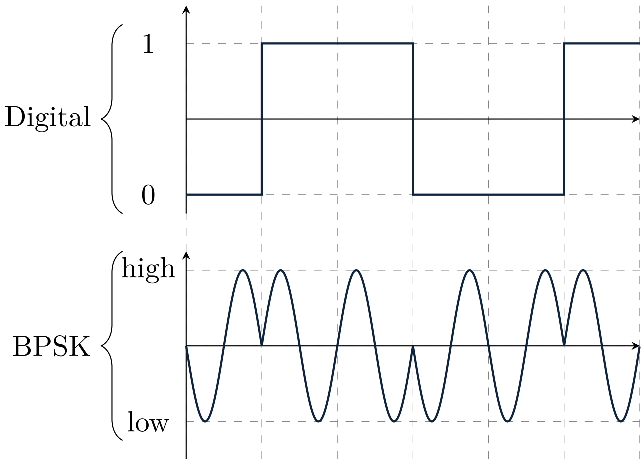

Figure 1.18: Example of BPSK Modulation

1.5.3.2 Differential Phase Shift Keying

Differential PSK (DPSK) works by referencing the previous bit in the current bit transmitted. DPSK removes the need for an accurate local oscillator phase at the receiver which is matched with the transmitter, because so long as the preceding phase is received correctly - the phase reference is accurate.

- 0 - send a signal similar to the previous one
- 1 - send a signal with phase shift as compared to the previous one

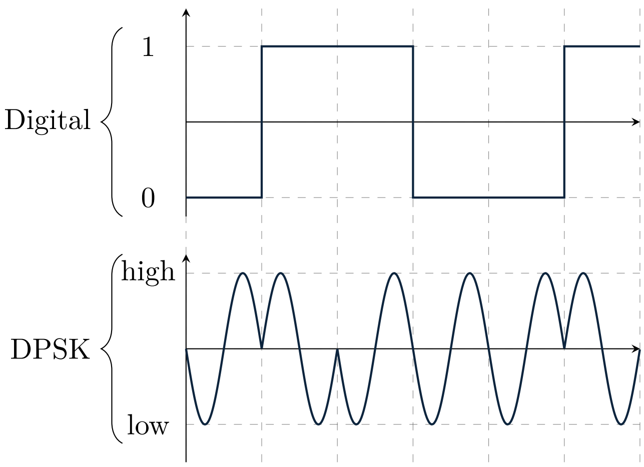

Figure 1.19: Example of DPSK Modulation

Page 2

Lecture - Spread Spectrum and Walsh Codes

2025-10-06 11:00 Asim

2.1 Communication Channels

There are two different types of Communications Channels (also sometimes referred to as *Communication Media* or *Transmission Media*).

Definitions

Guided Media Wired (Bounded) Media (i.e Twisted Pair, Coaxial, Fibre Optic)
Unguided Media Wireless Media (i.e. Microwave, Radio Wave. Cellular, Infrared, Satellite)

Within Guided Media, the electromagnetic waves are guided along a physical path. The medium can be considered to be *point-to-point* if it provides a direct link between two devices and those two devices are the only devices sharing the medium.

Unguided media is the opposite - where the electromagnetic waves are not guided through any physical containment, rather they transmit through air, vacuum or seawater.

The term *Direct Link* is used to refer to a transmission path where the signal is transmitted directly from sender to receiver without any intermediate devices. This can apply to both guided and unguided media. A *multipoint guided configuration* is a configuration such that more than two devices share the same medium.

A transmission may be simplex, half duplex or full duplex.

Definitions

Simplex a transmission in which signals are only transmitted in one direction; one station is the transmitter and the other is the receiver.
Half-Duplex a transmission in which both stations can transmit and receive but only one can transmit at one time therefore
Full-Duplex a transmission in which both stations can transmit and receive at the same time; which requires a medium is required for signals to be transmitted in both directions at the same time

In a full-duplex transmission system there may sometimes be an overlap in the frequency ranges used for each direction of transmission. This is sometimes acceptable and sometimes not - depending on the application. In any case, the overlap would be at the very edges of the frequency range; however this would still cause some interference.

There is a diagram detailing the frequencies used for different unguided transmissions available both in the slides on Moodle & in the textbook on page 109.

2.2 Interference and Noise

Often with transmissions - our signal may be interrupted in some way. This will alter the signal being transmitted which could change the data it represents - therefore garbling the resultant wave. Often this interference will come from *noise*.

Definitions

Interference The combination of two or more electromagnetic waveforms to form a resultant wave in which the displacement is either reinforced or cancelled

Noise An unwanted signal which is combined with desired signal

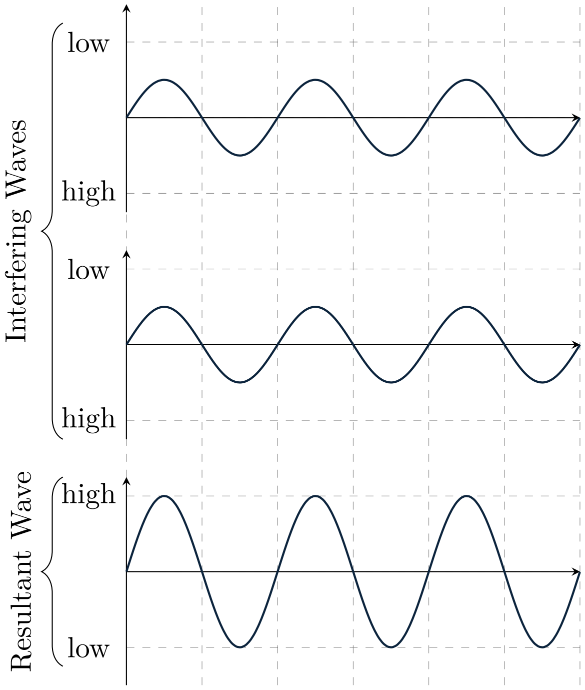

Figure 2.1: Constructive Interference

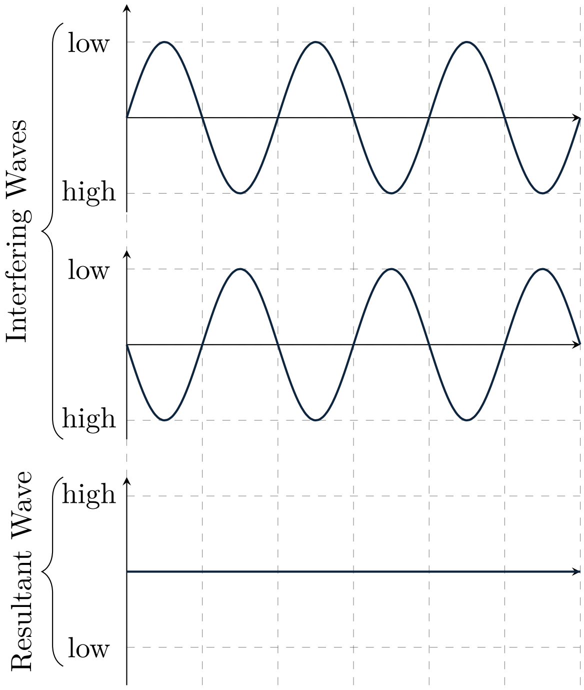

Figure 2.2: Destructive Interference

As we can see in the above figure, where we have two waves which are of the same phase interfering with each other - they will *interfere constructively* to increase the amplitude of the resultant wave. However where two waves in opposite phase interfere with each other - they will *interfere destructively* to effectively cancel each other our and the resultant wave has no amplitude.

For any data transmission, the received signal will consist of the transmitted signal, modified by the various distortions used by the transmission system, plus additional unwanted signals that are inserted somewhere between transmission and reception (which is referred to as *noise*).

Noise can be divided into four categories:

- Thermal Noise
- Intermodulation Noise
- Crosstalk
- Impulse Noise

2.3 Basic Definitions

Definitions

Data Rate The rate, in bits per second (bps), at which data can be communicated

Error The reception of a 1 where 0 was transmitted, or the reception of a 0 when a 1 was transmitted

Error Rate The rate at which errors occur

Frequency Bandwdith The difference between the upper and lower frequencies in a continuous band of frequencies

Channel Capacity The maximum rate at which information can be transmitted through a communication channel

Signal to Noise Ration (SNR) The ratio of the signal power to the noise power, measured in Decibels $10 \log_{10} \frac{\text{signal power}}{\text{noise power}}$

The *Channel Capacity* can be calculated using:

$$C = 2B \log_2 M$$

Where C is the channel capacity; B is the bandwidth; M is the signal or voltage levels.

The Nyquist Bandwidth Theory stipulates that if the rate of signal transmission is $2B$ then a signal with frequencies no greater than B is sufficient to carry the signal rate. The converse is also true. This limitation is due to the effect of intersymbol interference, which is produced by delay distortion. This is in essence based on the Nyquist Sampling Theorem (flashback to A-Level Electronics).

From this we can see that permitting all other things being equal, when we double the bandwidth - we double the error rate. The error rate then only gets worse as we increase the data rate because a higher data rate will mean the bits are shorter so more bits are affected by a given pattern of noise. Mathematician *Claude Shannon* tied these into a formula:

$$C = B \log_2(1 + SNR)$$

Where C is the capacity of the channel in bps and B is the bandwidth of the channel in Hertz.

2.4 Multiplexing

Definitions

Multiplexing A technique that allows the simultaneous transmission of multiple signals through the same channel or link; several signals are combined into a single composite signal

2.4.1 Frequency Division Multiplexing

In Frequency Division Multiplexing (FDM), the different message signals are modulated onto different carrier frequencies. This then means the signals being transmitted are separate from each other in the frequency domain. These modulated signals are then combined together to form the composite signal and this signal is sent over the shared medium or channel. To avoid the interference between the different message signals, a guard band is also kept between the message signals.

Graph of FDM?

2.4.2 Time Division Multiplexing

In Time Division Multiplexing (TDM), the channel is divided into several time slots, and each signal allocated during it's time slot. As a result - several signals share the channel without interfering with each other.

Graph of TDM?

2.5 Spread Spectrum

When transmitting our analog signals (whether these originated as digital or analog), we can spread the signal over a wider bandwidth to avoid jamming and frequency interception.

Spread Spectrum is a technique used by military and intelligence applications which is also used in Wireless and Cordless networks. There are a number of different techniques which can be used, we will explore 3 of them.

Definitions

Pseudorandom Noise (PN) is a deterministic sequence of bits which satisfies one or more of the standard tests for statistical randomness while being repeatable after a period

2.5.1 Frequency Hopping Spread Spectrum

In Frequency Hopping Spread Spectrum (FHSS), the signal is broadcast over a number of different radio frequencies, and the frequency used is changed at a fixed intervals which are generally extremely short (i.e. $1ms$). The receiver will hop between the different frequencies used in sync with the transmitter.

If the transmission is compromised, then the attacker would only hear unintelligible blips of the transmission. It would also thwart attempts to jam the signal as the attacker would only be able to block a few bits of the signal.

FHSS transmission systems tend to work with the binary data being fed into a modulator using a digital-to-analog encoding scheme (for example FSK or BPSK). The resultant signal is centred in a frequency. A PN source serves as an index into a table of frequencies; this is the spreading code. Each k bits of the PN source specifies one of the carrier frequencies. At each pre-agreed interval, a new carrier frequency is selected. This frequency is then modulated by the signal produced from the initial modulator to produce a new signal with the same shape, but now centred on the selected carrier frequency.

On reception - the spread spectrum signal is demodulated using the same sequence of frequencies derived from the PN source, and then demodulated to produce the output data.

2.5.2 Direct Sequence Spread Spectrum

Direct Sequence Spread Spectrum (DSSS) works by encoding a single bit to be transmitted (i.e. 1) as a multi-but sequence (i.e. 0110) using a spreading code. The *spreading code* spreads the signal across a wider frequency band in direct proportion to the number of bits used. Which means that a 4-bit spreading code spreads 1-bit of signal across a frequency band which is 4 times greater than a 1-bit spreading code. Of course, it doesn't have to be a 4-bit spreading code; it could be 10-bit or 20-bit.

A common method for encoding DSS is to combine the digital data input signal with a *Pseudorandom Noise (PN)* sequence (the individual bits within are called *chips*). The combined output signal is then referred to as a *chip sequence*.

In reality, this encoding process works by combining the digital data input signal with the Chip Sequence using an Exclusive Or (XOR) operation.

$$
\begin{aligned}
0 \oplus 0 &= 0 \\
0 \oplus 1 &= 1 \\
1 \oplus 0 &= 1 \\
1 \oplus 1 &= 0
\end{aligned}
$$

This produces a *combination bit stream* which has the data rate of the spreading code sequence, so therefore has a higher bandwidth than the information stream.

Finish the DSSS encoding graph diagram. Commented out in this document.

2.5.3 Code Division Multiple Access Spread Spectrum

Code Division Multiple Access (CDMA) is a multiplexing technique used with spread spectrum.

It works taking our data signal with a bit-rate R and assigning a unique code of n chips according to the Walsh Matrix. Then, if the user k sends a 1 - the transmitter sends the chip code ck; alternatively if the user k sends a 0 - the transmitter sends the chip code $\bar{c}k$ (which is represented in this module with as $c'k$).

The chip codes of all users will add up into a bipolar signal D. The receiver performs the decoding function for user k, for example, by the cartesian product $D \times ck$. If $D \times ck = n$ (the number of bits in the chip code), then bit 1 is received; else if $D \times ck = -n$ then bit 0 is received.

Example: CDMA

If we take the following users to have the following Chip Codes:

- User A Chip Codes: $(-1, -1, -1, -1)$
- User B Chip Codes: $(-1, +1, -1, +1)$
- User C Chip Codes: $(-1, -1, +1, +1)$
- User D Chip Codes: $(-1, +1, +1, -1)$

Case 1

User A sends 1, user B sends 1, user C sends 1, and user D sends 0 (represented as -1).
We sum their chip codes, for A, B, and C - these are as specified above; however for D we need to invert the chip codes because D is transmitting a 0 (-1).

$$
\begin{aligned}
A + B + C + D' &= (-1, -1, -1, -1) + (-1, +1, -1, +1) + (-1, -1, +1, +1) + (+1, -1, -1, +1) \\
&= (-2, -2, -2, 2)
\end{aligned}
$$

The receiver will receive this and perform an inner product multiplication using the Chip Code of A.

$$
\begin{aligned}
f &= (-2, -2, -2, 2) \times (-1, -1, -1, -1) \\
&= (-2 \times -1) + (-2 \times -1) + (-2 \times -1) + (2 \times -1) \\
&= 2 + 2 + 2 - 2 \\
&= 4
\end{aligned}
$$

Which therefore confirms that A is sending a bit 1.

Case 2

User A sends 0 (-1), user B sends 1, user C sends 1, and user D sends 0 (-1).

We sum their chip codes, this time inverting A and D because they're transmitting 0s.

$$\begin{aligned} A + B + C + D' &= (+1, +1, +1, +1) + (-1, +1, -1, +1) + (-1, -1, +1, +1) + (+1, -1, -1, +1) \\ &= (0, 0, 0, 4) \end{aligned}$$

Then we can find what the receiver decodes using A's chip code.:

$$\begin{aligned} f &= (0, 0, 0, 4) \times (-1, -1, -1, -1,) \\ &= (0 \times -1) + (0 \times -1) + (0 \times -1) + (4 \times -1) \\ &= 0 + 0 + 0 + -4 \\ &= -4 \end{aligned}$$

As this results to $-n$ (remembering n is the length of the users chip codes) - we know that A transforms to bit 0.