Model of Communications System

Example Communications System

Data Transmission

- Data transmission occurs between the **Transmitter** and the **Receiver**.
- The data is *encoded* onto a *transmission signal* and the signal is transmitted across a *transmission system*.
- **Encoding** involves changing a characteristic of the signal to represent the data:
  - The more changes that can be made to a signal increases the amount of data that can be transmitted.

Transmission Signal

- The **Transmission Signal** is either some form of electro-magnetic wave (EM) or an electrical signal:
  - Examples of e-m waves used for data transmission include radio waves, light waves, microwaves.
  - Examples of electrical signals include Alternating-Current (A/C), Voltage pulses etc.
  - The simplest form of a signal is a **Sine Wave**.

Transmission System

- In its simplest form a **Transmission System** is some type of transmission medium which maybe either:
  - Guided e.g. Electric Cable, Fibre Optic Cable
  - Unguided - Electromagnetic Waves in Space

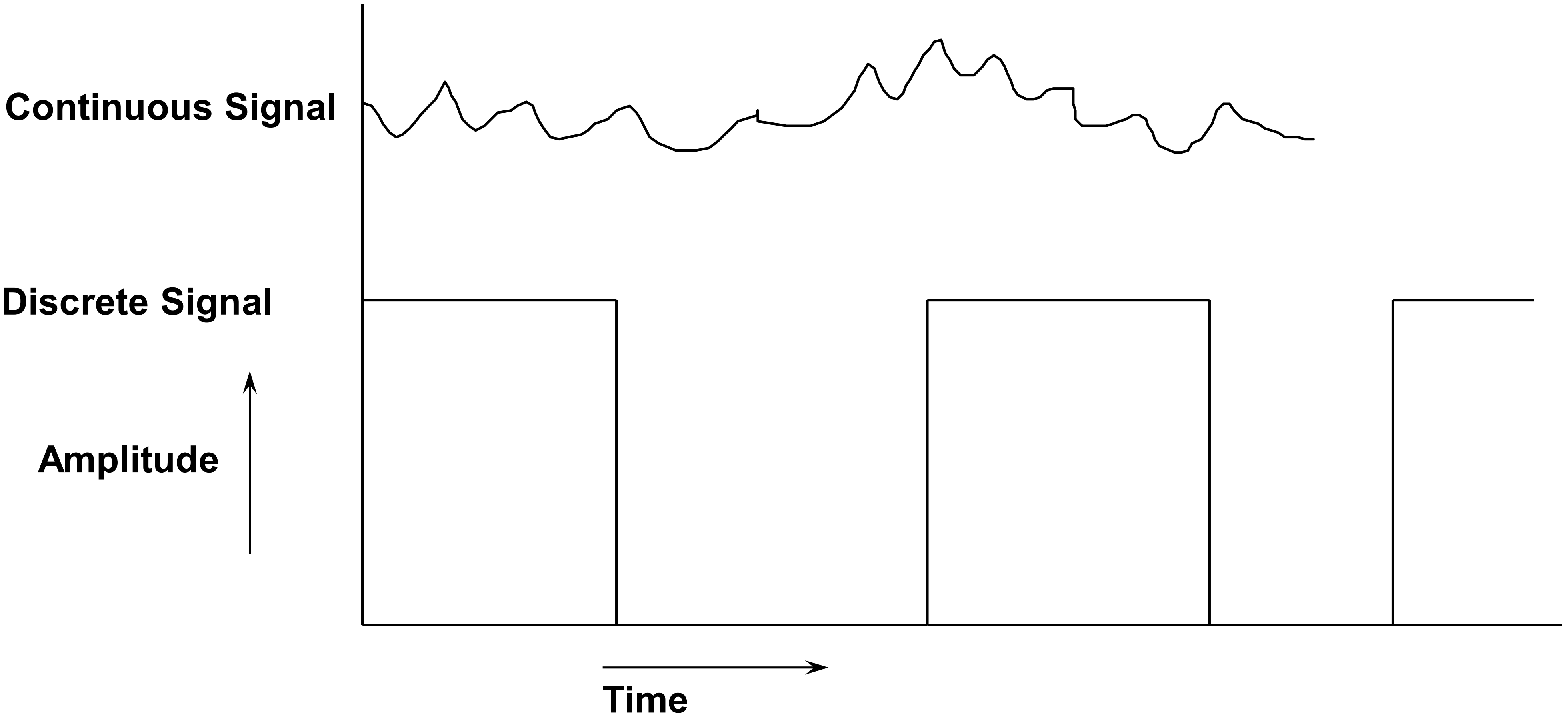
Successful Data Transmission

- The successful transmission of data depends upon <u>two</u> factors:
  - The quality of the *transmission signal*
  - The characteristics of the *transmission system/medium*

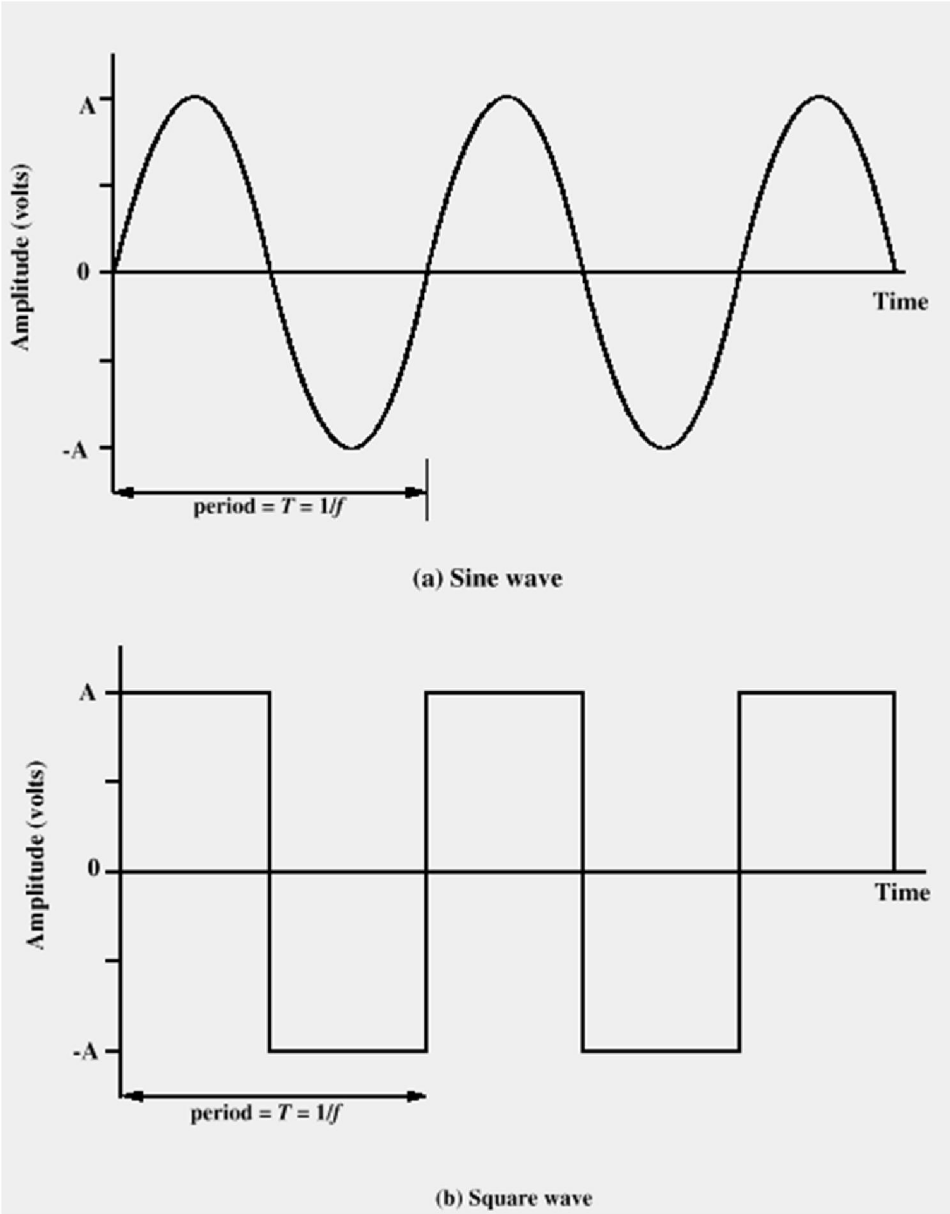
Signal Characteristics

- Continuous
  - No breaks or discontinuities within signal
  - Example is a speech signal
- Discrete
  - Contains a finite number of discrete values
  - Example is computer or binary data
- Periodic
  - Repeats itself after some fixed time
- Aperiodic
  - No repetition of signal pattern

Continuous and Discrete Signals



Periodic Signals



(a) Sine wave

(b) Square wave

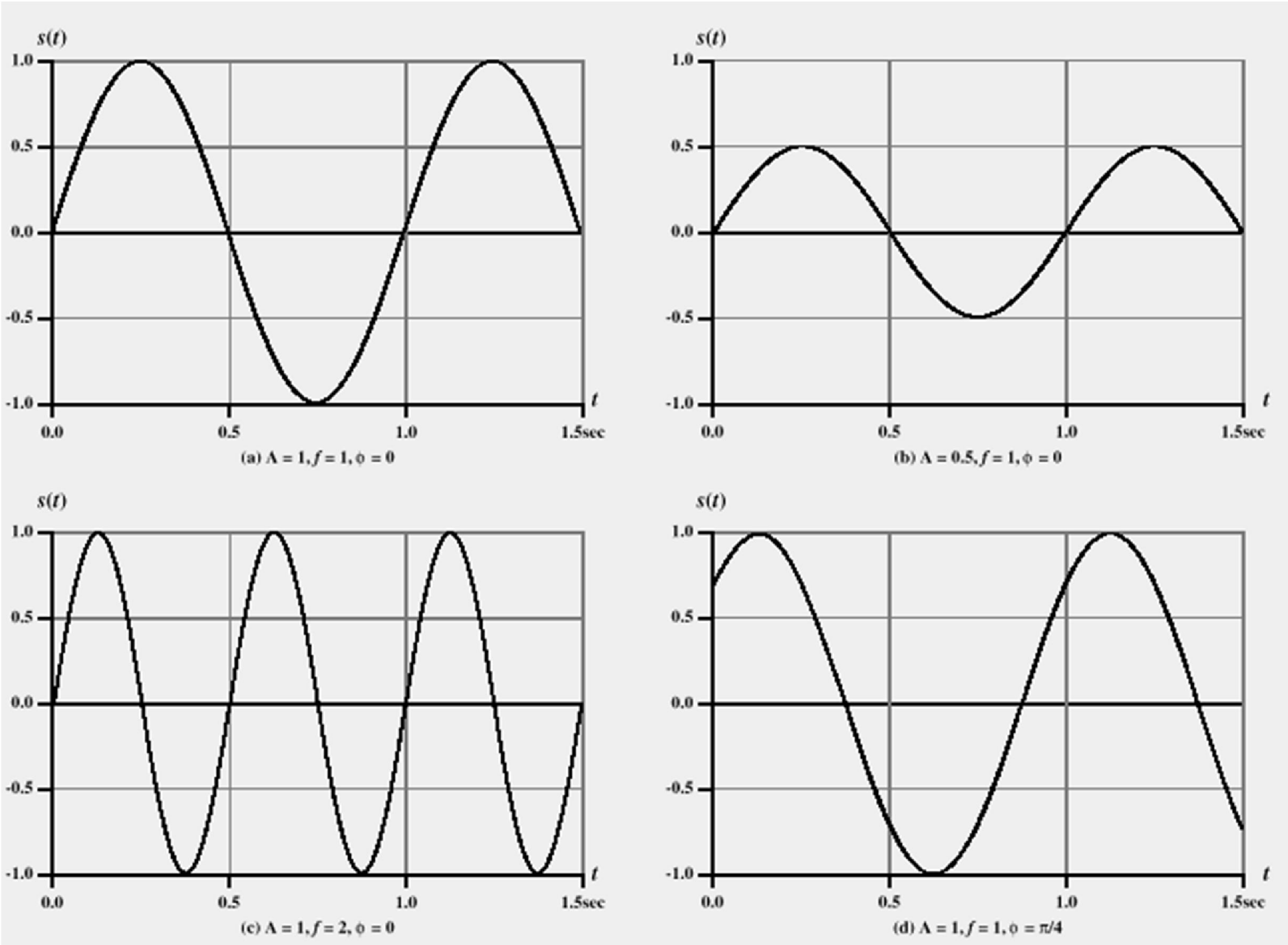
Sine Wave Characteristics

- The general equation applies:

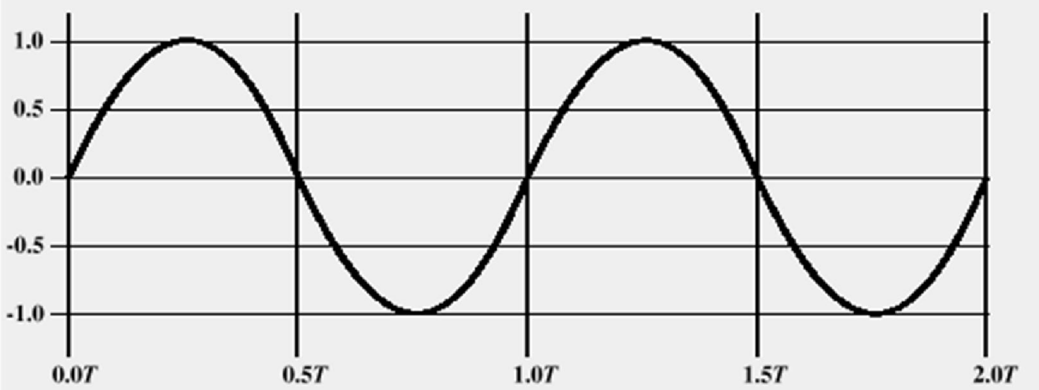
$$s(t) = A\sin(2\pi . ft + \phi)$$

- Where:
  - Amplitude (*A*) is the peak value of the waveform
  - Frequency (*f*) is the number of repetitions per sec. Measured in Hertz (Hz.). Inverse of the period
  - Phase (*Ø*) is a measure of the relative position within a cycle of a signal. Measured in degrees or radians
- All three characteristics can be varied to give different waveforms

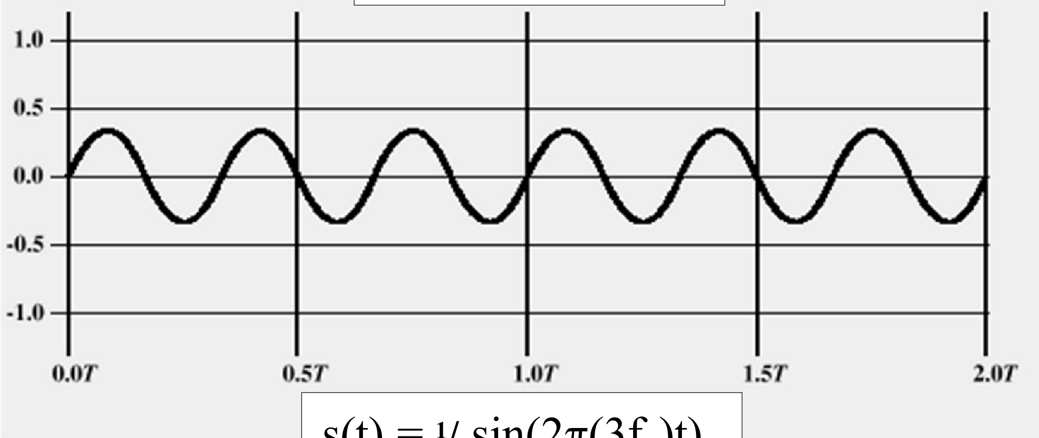
Varying Sine Wave Characteristics



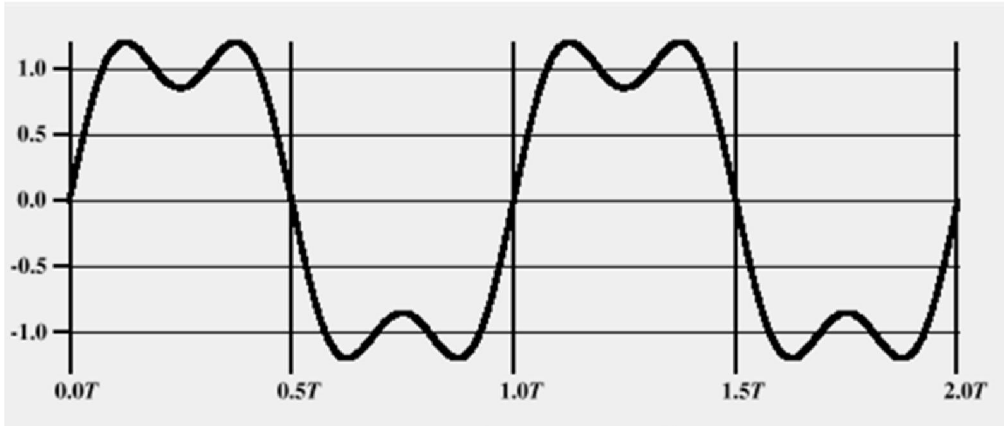
Addition of Frequency Components



$s(t) = \sin(2\pi f_1 t)$

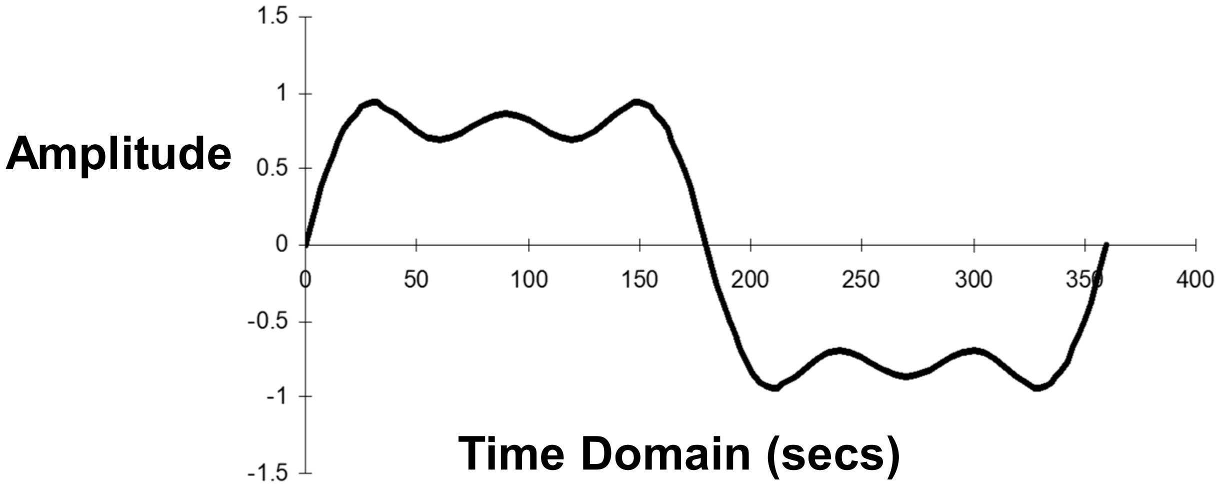


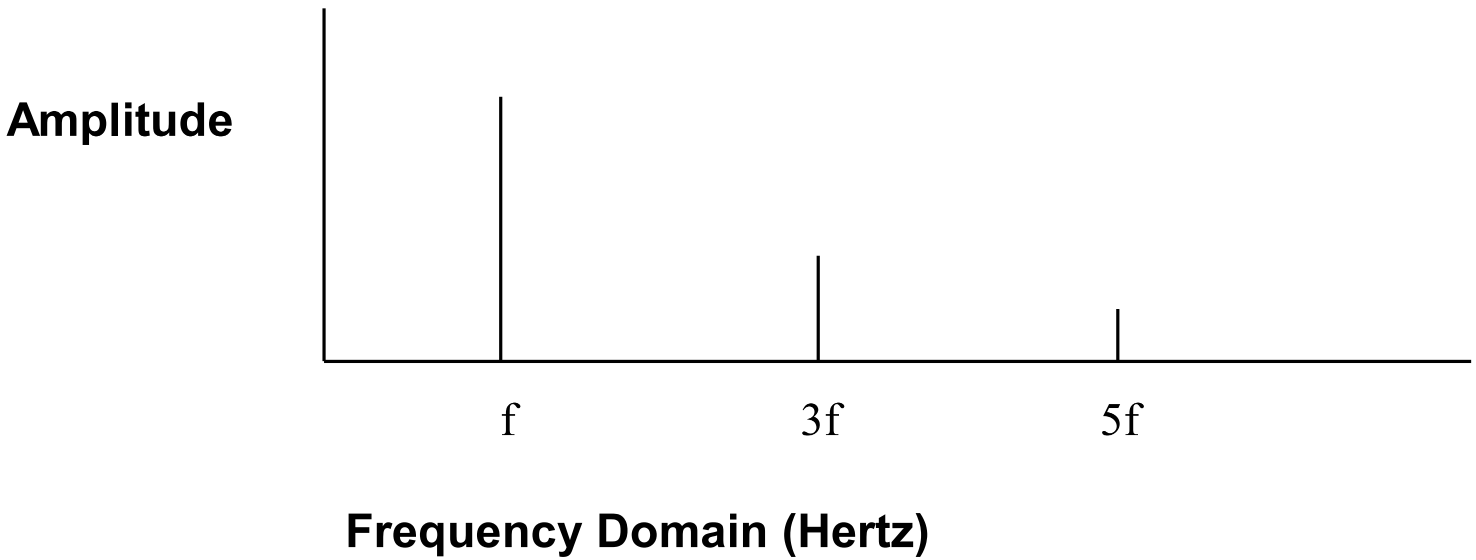
$s(t) = {}^1\!/_3 \sin(2\pi(3f_1)t)$



$s(t) = \sin(2\pi f_1 t) + {}^1\!/_3 \sin(2\pi(3f_1)t)$

Time Domain and Frequency Domain





Fourier Analysis

- By *Fourier Analysis* any signal can be expressed as the sum of a *series* of sinusoidal components of different frequencies
- This is of fundamental importance:
  - The effects of *transmission media* on a *signal* can be analysed by examining the effects on these *component sinusoids*

Signalling Concepts

- Spectrum
  - The range of frequencies contained in a signal.
    - For the above sample signal the spectrum *ranges from* f_1 to $3f_1$
- Absolute Bandwidth = width of spectrum
    - For the above sample signal the bandwidth is $2f_1$ (i.e. $3f_1$ - f_1)
- Effective Bandwidth
  - Signals with sharp rising and falling edges in the time domain have very wide Absolute Bandwidth
  - Most energy is contained in relatively narrow band called the *Effective Bandwidth*
- DC Component
  - Signals with a component at zero frequency

Fourier Analysis

- By Fourier Analysis any signal can be expressed as the sum of a series of sinusoidal components of various frequencies
- This is of fundamental importance since effects of transmission media on a signal can be analysed by analysing the effects on component sinusoids

Full Representation of Square Wave

$$s(t) = A \sum_{\substack{K=1 \\ \square\ldots odd}}^{\infty} \frac{1}{K} SIN(2\pi.kft)$$

Transmission System Characteristics

- All Transmission Systems (Tx Systems) are limited (restricted) in the range of signal frequencies that they can carry.
- This restriction is known as **The System Bandwidth** and results from:
  - The physical properties of the components that comprise the system
  - The physical properties of matter and energy

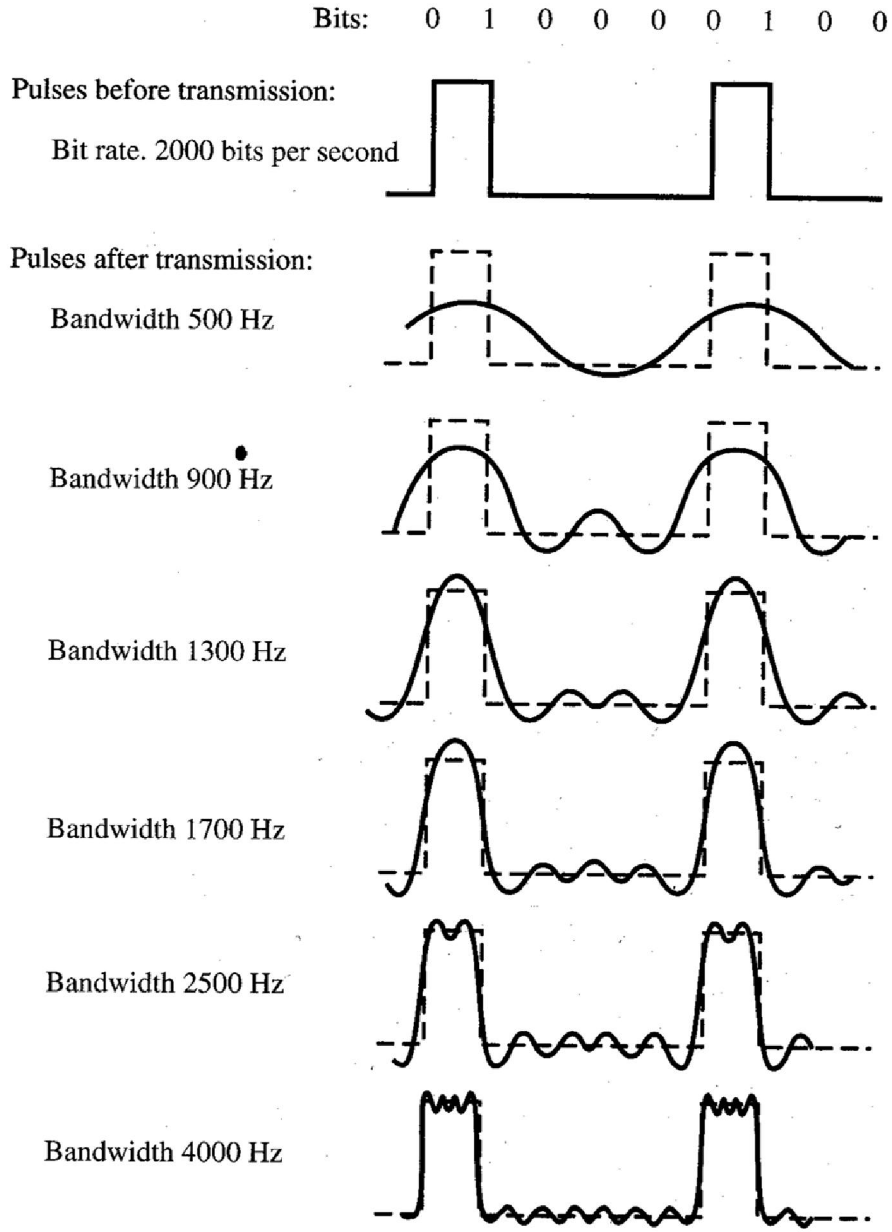
Relationship between Data Rate & Bandwidth

- The bandwidth of a transmission system can be described as:

"The fastest continuously oscillating signal that can be sent (transmitted) across the transmission system. It is represented in Hertz (Hz)."

- The effects of System Bandwidth is to limit the speed of transmission of data (Data Rate).

Relationship between Data Rate & Bandwidth



Explanation of previous slide

- The Source transmits a *digital* signal with the bit pattern shown (010000100).
- The first Tx System imposes a significant BW restriction on the signal such that only one component (harmonic) passes through.
- The last Tx System allows more components (harmonics) to pass through which results in a more *‘readable’* signal

Relationship between Data Rate & Bandwidth

- This limitation has a direct effect on the maximum *data rate* achieveable across a transmission system
- Consider a transmission system that has a bandwidth of 15MHz…..

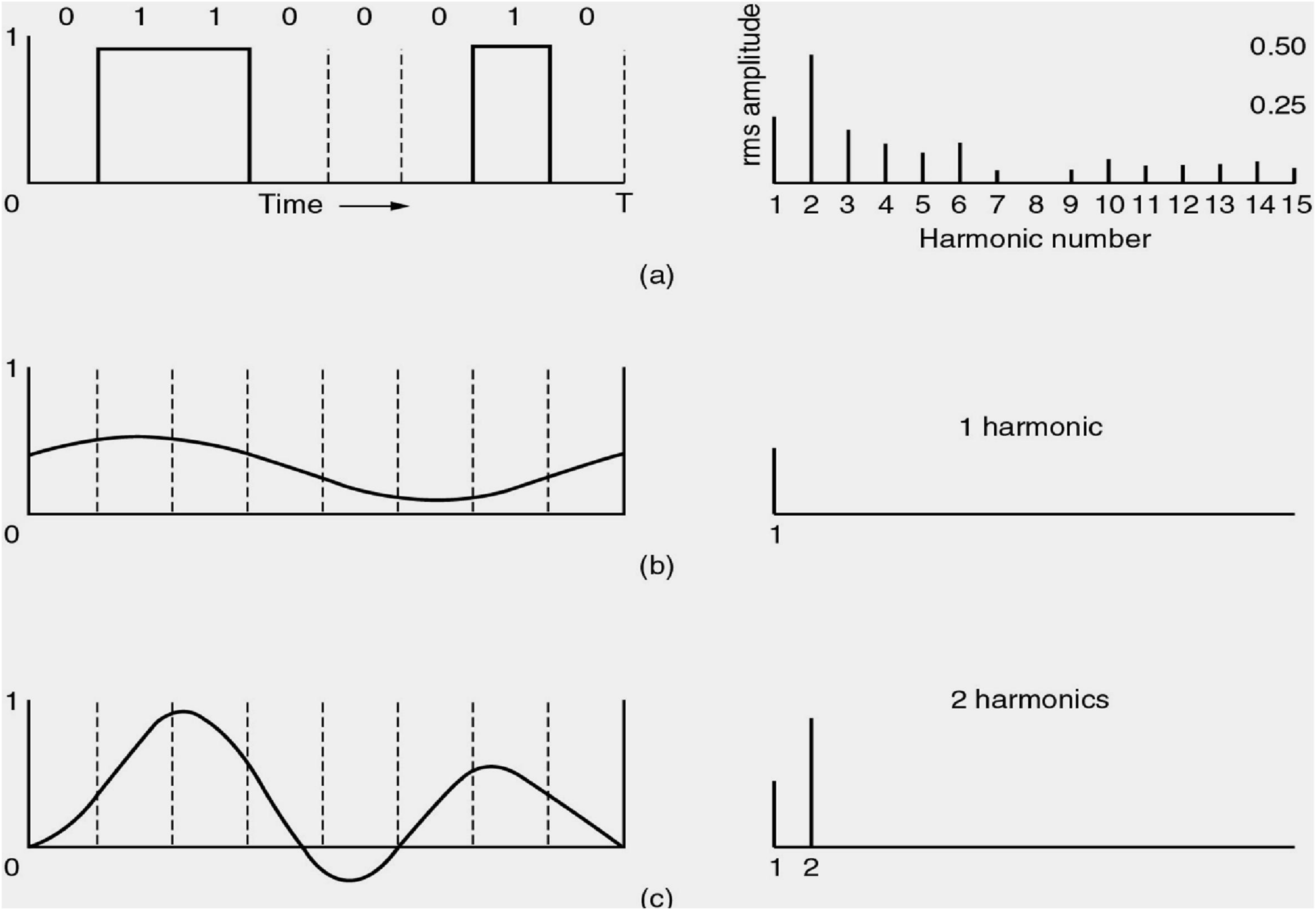
Relationship between Data Rate & Bandwidth

- Examples given in class used simplistic sine waves and composite waveforms to demonstrate the effect of Tx Sys BW on the received signal:
  – Observation: To preserve the shape of the received signal requires the speed of transmission of the signal (frequency) to be reduced.
  – The same effects can be shown for more complicated signals such as a pulse train (see next slides)

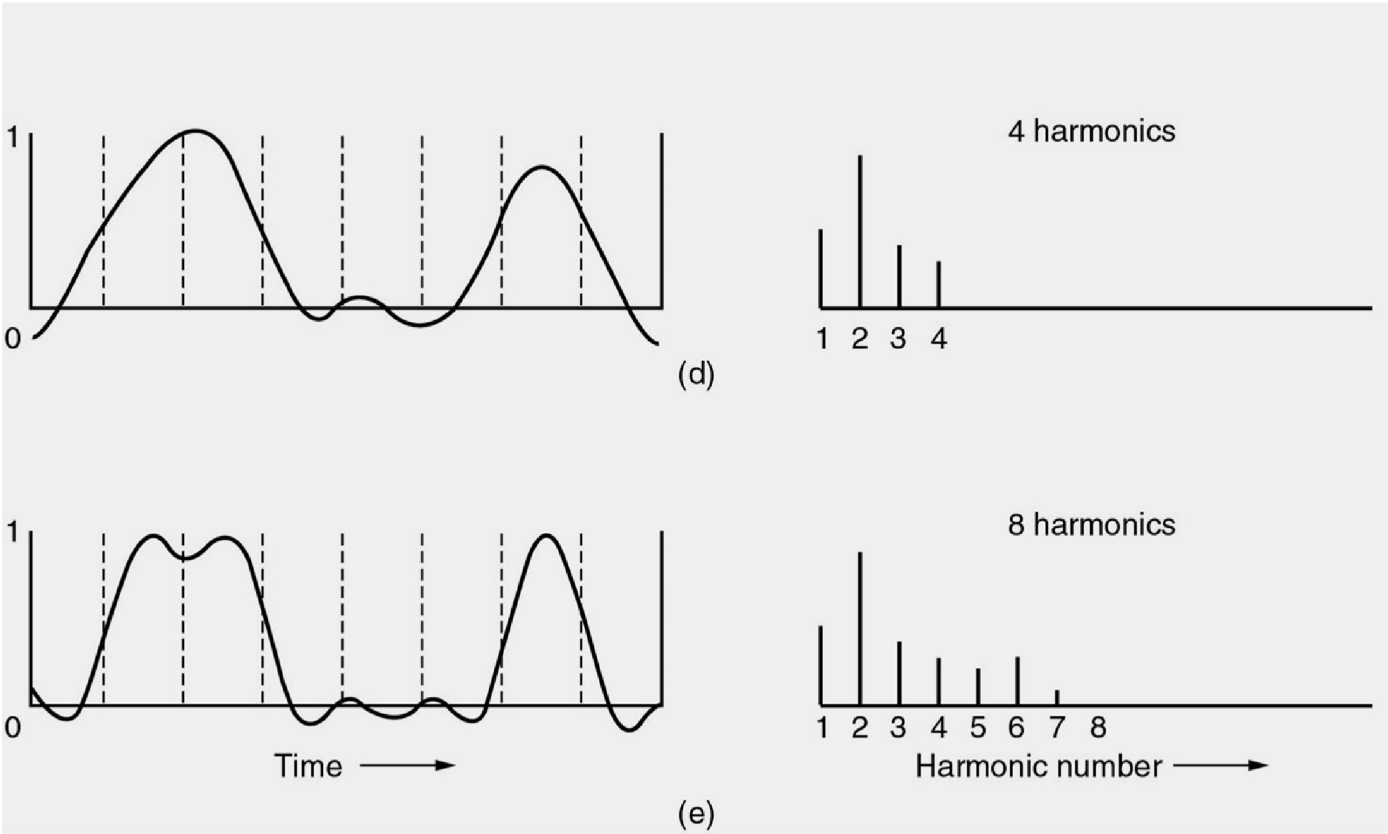
Varying the Data Rate

Bps	T (msec)	First harmonic (Hz)	# Harmonics sent
300	26.67	37.5	80
600	13.33	75	40
1200	6.67	150	20
2400	3.33	300	10
4800	1.67	600	5
9600	0.83	1200	2
19200	0.42	2400	1
38400	0.21	4800	0

Varying the Data Rate



Varying the Data Rate



Previous Slide Explained

- The previous slide shows a pulse train representing a binary sequence.
- The table shows how many harmonics are received by the Receiver at various data rates.
- The faster the pulse train is transmitted (higher data rate) the less harmonics are received at the Receiver:
  - This reduces the intelligibility of the signal.

Relationship between Data Rate & Bandwidth

- For a Transmission *System* the greater the bandwidth of the system the higher the data rate that can be achieved
- For a Transmission *Signal* the greater the speed (frequency) of the signal:
  - The greater the bandwidth of the signal
  - The more data can be transmitted

Conclusions

- In <u>digital</u> transmission the *square wave* is usually used to encode data.
- From previous discussions:
  - A *digital* waveform has an <u>infinite</u> number of harmonics (frequency components),
  - <u>All</u> Tx Systems have a *limited bandwidth.*
  - The more limited the bandwidth of the Tx System the greater the *distortion* i.e. <u>not</u> all components will get through

Conclusions

- In general for a digital signal carrying data at a rate of ***W* bps**, very good representation can be achieved with a Tx System bandwidth of ***W/2* Hz**.
  - For example: If the data rate of a signal is fixed at 2Mbps the Tx System Bandwidth required to facilitate this data rate would be approximately 1MHz.
  - Beware that this approximation is simply a guide and not an absolute value.
- Hence, there is a relationship between *data rate* and *Tx System Bandwidth*
- The next slides show the effects of increasing the data rate across a Tx System of fixed bandwidth.

Data and Signals - Concepts

- Consider the following entities:
  - Data
    - Entities that convey meaning
  - Signal
    - Electromagnetic wave with *encoded* data
  - Transmission System
    - The entity over which the *signal* is transmitted
- Each entity can be considered in terms of ***Analogue*** or ***Digital*** as follows.

Data and Signals - Concepts

- Analogue Data
  - Take on continuous values on some interval e.g. voice, temperature, pressure etc.
- Digital Data
  - Take on discrete values e.g. integers, text

Signals - Defined

- Analogue Signal
  - Continuously varying electromagnetic wave (representing data) that may be propagated over a transmission medium
- Digital Signal
  - Sequence of discrete, discontinuous voltage pulses (representing data) that may be propagated over a transmission medium

Data Transmission - Defined

- *Data Transmission* is the communication of data by the propagation and processing of signals:
  - *Analogue* data can be conveyed by an *analogue* signal e.g. ordinary telephone
  - *Digital* data can also be conveyed by an *analogue* signal when a ***MODEM*** is used.
  - *Analogue* data can be conveyed by a *digital* signal when a ***CODEC*** is used
  - *Digital* data can be conveyed by a *digital* signal e.g. digital transmitter
- Refer to the diagram in class.

Analogue Transmission - Defined

- *Analogue Transmission* is the propagation of analogue signals only:
  - i.e. some physical quantity (e.g. voltage) that changes continuously as a function of time
- There is **no** regard to the content (the *encoded* data) of the signal.
- As the transmitted analogue signal becomes ***attenuated*** with distance an ***amplifier*** can extend the range:
  - However, this also boosts *noise* so the signal eventually becomes *distorted*

Digital Transmission - Defined

- Digital transmission is the propagation of:
  - Analogue signals (with encoded *digital data*) **OR,** Digital signals
  - Digital transmission systems have regard to the encoded data.
- As the transmitted digital signal becomes *attenuated* with distance a ***repeater*** can extend the range:
  - A repeater receives the attenuated signal, recovers the digital data and re-transmits a new signal with no noise added.

Analogue V Digital Transmission

- Digital is Superior
  - Low cost of digital electronics
  - Data integrity - signal can be maintained free of noise
  - Capacity Utilisation - different digital signals can be ‘Multiplexed’ and ‘De-multiplexed’ more easily and thus share a signal channel
  - Security - Encryption can be more easily applied to digital data
  - Integration - Digitised analogue data can be mixed with digital and share the same facilities as other digital data