Republic of Iraq
Ministry of Higher Education and Scientific Research
University of Technology
Department of Computer Engineering and information Technology

Communication Engineering

Third Class
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BY
Dr. Hussam A. A. Al-obiady

1- Typical communication System

Communication: is the exchange of information (data) between two devises via some form of transmission medium such as wire cable. The communication devises must be part of a **communication system** make up of a combination of hardware (physical parts) and software (programs).

The effectiveness of the communication system depends on three fundamental characteristics.

1. Delivery: the system must deliver data to correct destination.
2. Accuracy: the system must send data accurately.
3. Timeliness: the system must deliver the data in timely manner.

Component of communication System: Typical Electrical communication system is shown in figure 1.

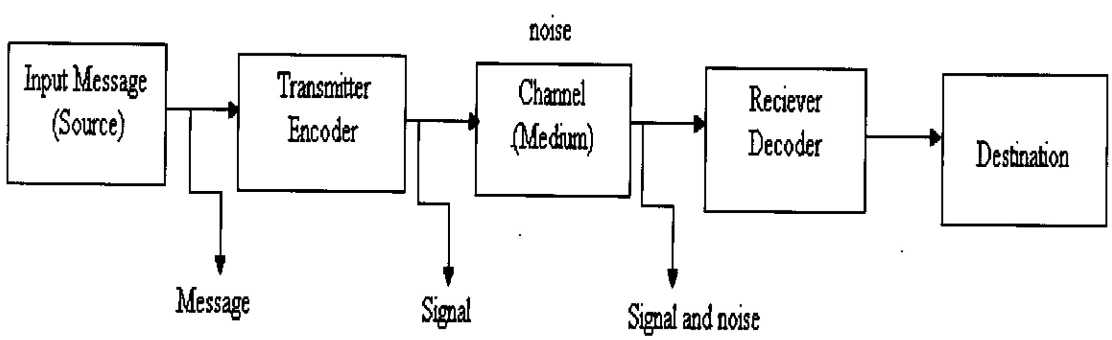


Fig. (1) Typical communication System.

1. **Message (source)** is the information to be communicated. It can consist of text, numbers, pictures, sound or video or any combination of these.
2. **Transmitter** converts the input message into electrical signal called baseband and modifies the baseband signal for efficient transmission.

3. **Channel (medium)** It is the physical path by which the message travel from sender to receiver. It could be a twisted pair, coaxial cable, optical fiber, or radio waves (terrestrial or satellite microwave).
4. **Receiver Decoder** reprocess the signal from the channel by undoing the signal modifies made at the transmitter and the channel and then convert the electrical signal to its original form -- message.
5. **Destination** The unit to which the message is communicated.

At the transmission channel the transmitted signal suffering from:

1- **Attenuation:** increase as the length of the channel increase

2- **Distortion:** caused by transmitting equipments and can be corrected at the receiver using equalizer.

3- **Additive noise:** random and unpredictable electrical signals generated naturally.

- TRANSMISSION MODE

There are three type of transmission modes in communication system call as

Simplex transmission is that transmission, which occurs in one direction

Half-duplex transmission permits transmission in either direction; however, transmission can occur in only one direction at a time

Full duplex here simultaneous communication is accomplished in both directions

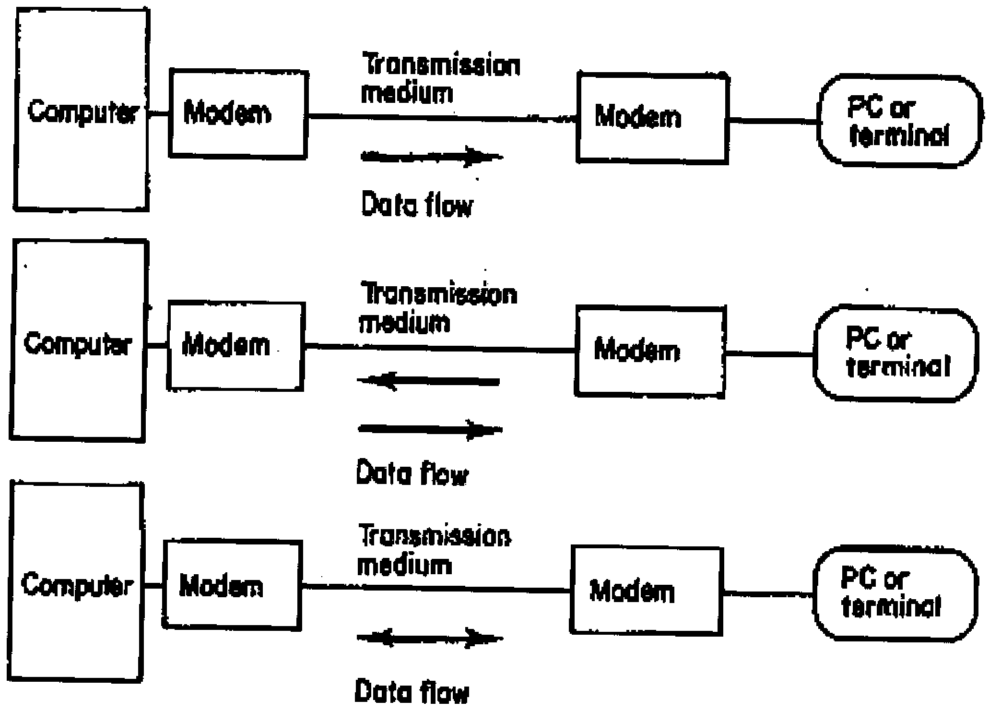


Figure 2 Simplex, half duplex and full duplex systems

2- Signals

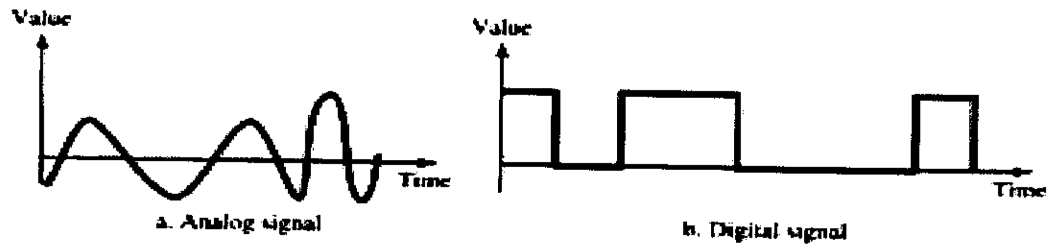
- Signals Classification

To be transmitted, data must be transformed to electromagnetic signals. The signal defined as an event capable to start action. It can observe physically realer valued (Voltage, Current, Power, temp. .. etc.)

- Analog and Digital Signals

Analog signal characterized by data whose value varies over a continues range (eg. The temperature, pressure, speech).

Digital signal constructed with a finite number of symbols (eg 26 letters, binary information).



- Periodic, A periodic and deterministic Signals

Periodic Signals complete a pattern within a measurable time frame called period (T) eg sin wave as shown figure 4

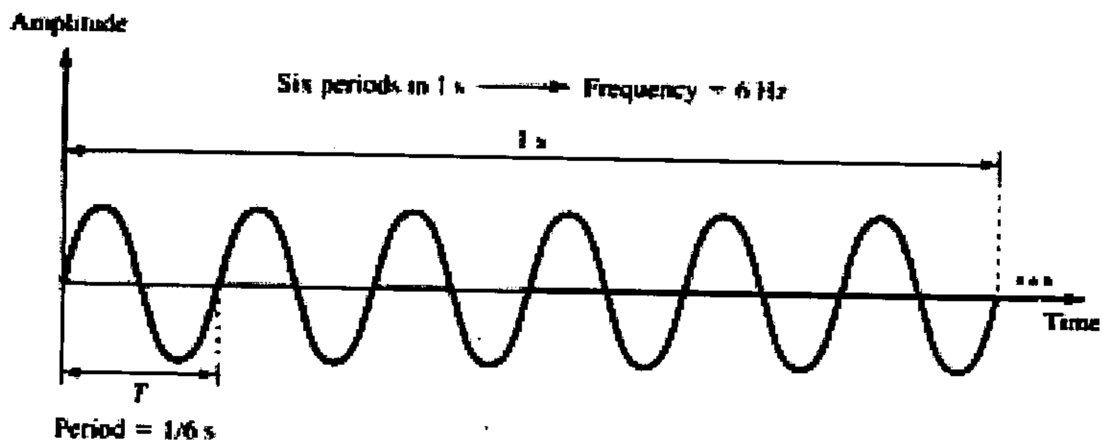


Figure 4 sin wave in time domain plot

Aperiodic signal repeat itself without exhibiting a pattern or cycle that repeat over a time.

Signal is to be deterministic if it can be expressed mathematically otherwise is said to be random. (eg noise)

- Time and Frequency Domain

A sin signal is comprehensively defined by its amplitude, frequency, and phase. The time domain plot of sin signal can be shown in figure 4 show the change of signal amplitude with respect to time (it is an amplitude verses time plot) frequency and phase are not explicitly measured on a time domain plot. Fig. 5 shows some examples of sin signals in time domain plot.

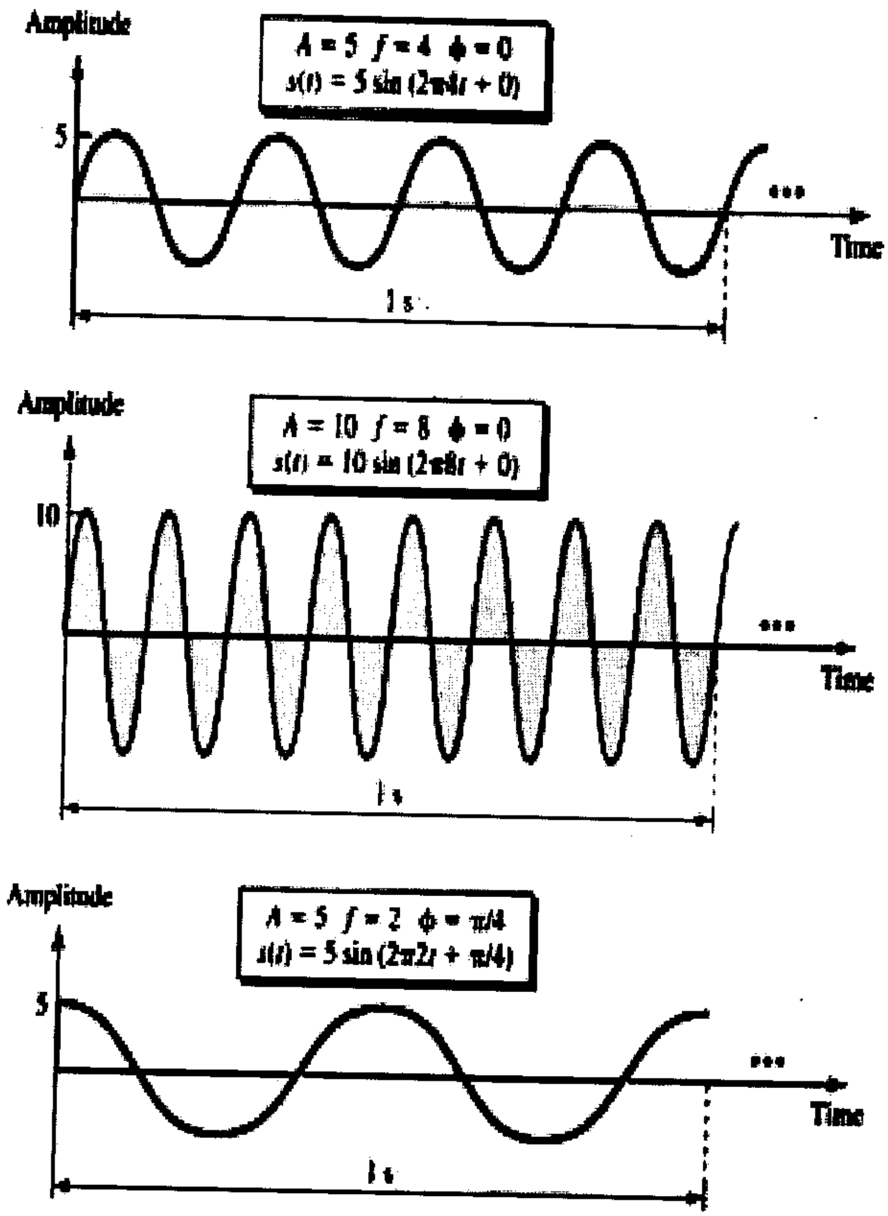


Fig. 5 sin signals in time domain plot

- Power and Energy

Signal are usually treated in terms of a voltage amplitude but sometime it's useful to known the power or Energy associated with signal such as noise.

Power the average power in periodic signal *f (t)* in resistance 1 ohm is

$$P = \frac{1}{T}\int_{-T/2}^{T/2} |f(t)|^2 dt$$

or

$$P = \sum_{-\infty}^{\infty} |C_n|^2$$

C_n: Fourier series coefficients value

P : average power (watt)

Energy for aperodic signal such as a signal pulse the average power tend to zero because 1/T tends to infinity.

$$E = \int_{-\infty}^{\infty} |f(t)|^2 dt$$

or

$$P = \frac{1}{2\pi}\int_{-\infty}^{\infty} |F(\omega)|^2 d\omega$$

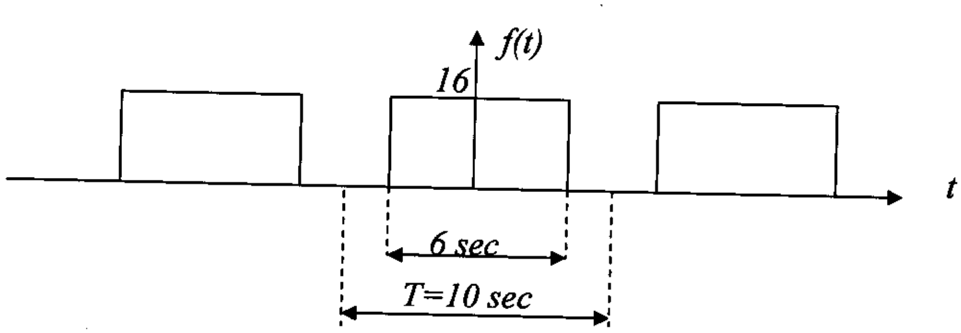
Where

E: average Energy (Joule)

F(w): Fourier transformer Equation

Example/ Find power and Energy for the signals shown in (a and b)

a)



$$f(t)=\begin{cases}0 & -5\le t<-3\\ 16 & -3\le t<3\\ 0 & 3\le t<5\end{cases}$$

Perodic signal Time T =10 sec

$$P=\frac{1}{T}\int_{-T/2}^{T/2}|f(t)|^2dt$$

$$P=\frac{1}{10}\left[\int_{-5}^{-3}0^2dt+\int_{-3}^{3}16^2dt+\int_{3}^{5}0^2dt\right]$$

$$P=\frac{1}{10}16^2t\Big|_{-3}^{3}$$

$$P=153.6 \quad watt$$

$$E=\infty \quad Joule$$

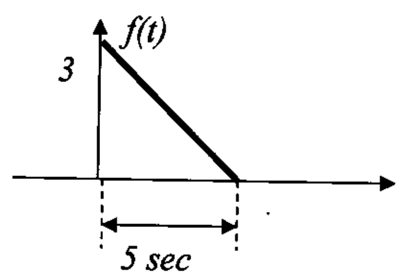
b)

$$\frac{y_2-y_1}{x_2-x_1}=\frac{y-y_1}{x-x_1}$$

$$\frac{0-5}{3-0}=\frac{f(t)-3}{t-0}$$

$$f(t)=-\frac{3}{5}t+3$$

$$f(t)=\begin{cases}0 & t\le 0\\ -\frac{3}{5}t+3 & 0\le t<5\\ 0 & t>5\end{cases}$$



$$E=\int_{-\infty}^{\infty}|f(t)|^2dt$$

$$E=\int_{0}^{5}(-\frac{3}{5}t+3)^2dt$$

$$E=\int_{0}^{5}(\frac{9}{25}t^2-\frac{18}{5}t+9)dt$$

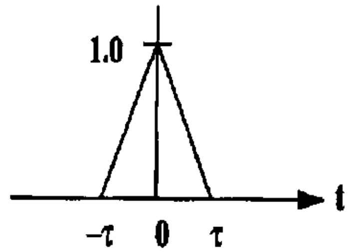
$$E=\frac{3}{25}t^3-\frac{9}{5}t^2+9t\Big|_{0}^{5}$$

$$E=75 \ Joule$$

$$P=0 \ Watt$$

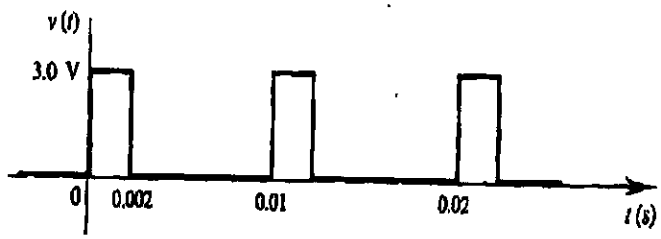
Q1) For the drawing signal shown below calculate power and Energy

(a)

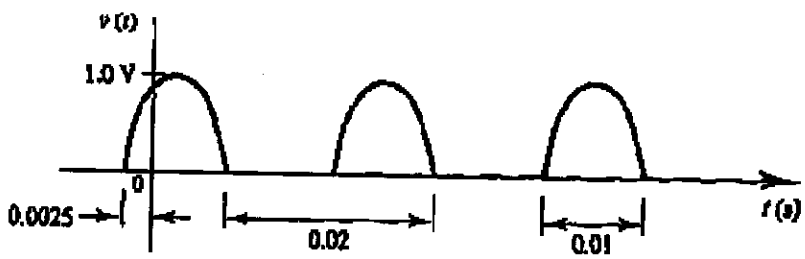


$\tau = 2 \ m\sec$

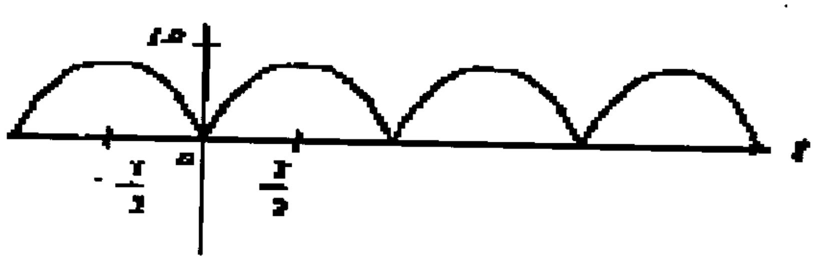
(b)



(c)



(d)



(e) $f(t) = \exp^{(-5t)} \qquad t \geq 0$

-SIGNAL ANALYSIS

Fourier Series

Almost any periodic signal of practical interest can be approximated by adding togother sinusoids with the correct frequencies, amplitudes, and phases. The fundamental frequacy f_1 is reciprocal of waveform's perod T.

$f_1=1/T$

The sinusoid with frequency $f_n = nf_1$ is called the nth harmonic of the fundamental. If the waveform being approximated has a non-zero mean value then, in addition to the set of sinusoids, a 0 Hz, constant, or DC term must be included in the sum. In general, then, the sinusoidal sum, which is called a Fourier series, is given by:

$$v(t) = C_0 + C_1 \cos(\omega_1 t + \phi_1) + C_2 \cos(\omega_2 t + \phi_2) + \cdots$$

where C_0 (V) is the DC term, $\omega_1 = 2\pi/T$ (rad/s) is the fundamental frequency and $\omega_2 = 2(2\pi/T)$ (rad/s) is the second harmonic frequency, etc. The series may be truncated

as

$$v(t) = C_0 + \sum_{n=1}^{\infty} (A_n \cos \omega_n t + B_n \sin \omega_n t)$$

Where

C_0 : DC coefficient

A_n and B_n: cosine and sine coefficients

$$C_0 = \frac{1}{T} \int_t^{t+T} v(t)\, dt$$

$$A_n = \frac{2}{T} \int_t^{t+T} v(t) \cos \omega_n t\, dt$$

$$B_n = +\frac{2}{T} \int_t^{t+T} v(t) \sin \omega_n t\, dt$$

The trigonometric form of the Fourier series complex form expressed as

$$v(t)=\sum_{n=-\infty}^{\infty} C_n \ \exp^{(j\omega\, n\, t)}$$

$$C_n=\frac{1}{T}\int_{-\infty}^{\infty} v(t)\exp^{(-j\omega\, n\, t)}\,dt$$

The relationship between fourier series and fourier series complex form as

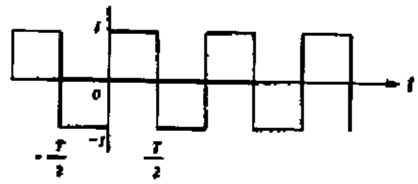
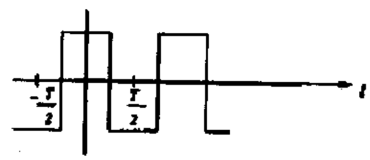
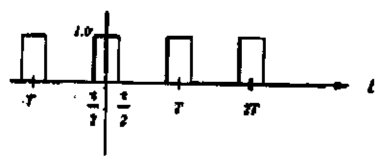
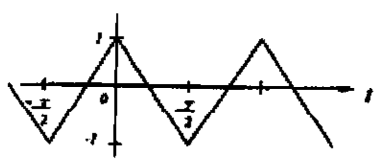
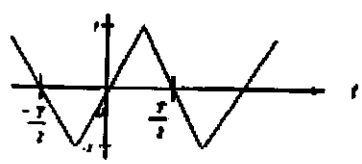
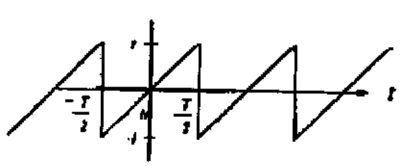
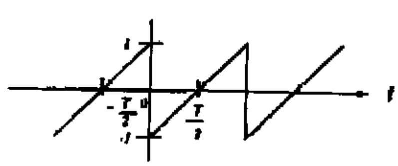
$$C_n=\sqrt{(A_n^2+B_n^2)}$$

$$\phi_n=\tan^{-1}(B_n/A_n)$$

where: the spectrum magnitude & discrete spectrum is C_n'

$$\tilde{C}_n' = \begin{cases} \tilde{C}_n/2 & \text{for } n>0 \\ C_0 & \text{for } n=0 \\ \tilde{C}_{-n}^*/2 & \text{for } n<0 \end{cases}$$

Table 2.2 ***Fourier series of commonly occurring waveforms.***

	$\frac{4}{\pi}\sum_{n=1}^{\infty}\frac{1}{2n-1}\sin\left[2\pi\frac{(2n-1)}{T}t\right]$
	$\frac{4}{\pi}\sum_{n=1}^{\infty}\frac{(-1)^{n+1}}{2n-1}\cos\left[2\pi\frac{(2n-1)}{T}t\right]$
	$\frac{\tau}{T}+\frac{2\tau}{T}\sum_{n=1}^{\infty}\text{sinc}\left(\frac{n\tau}{T}\right)\cos\left(2\pi\frac{n}{T}t\right)$
	$\frac{8}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{(2n-1)^2}\cos\left[2\pi\left(\frac{2n-1}{T}\right)t\right]$
	$\frac{8}{\pi^2}\sum_{n=1}^{\infty}\frac{(-1)^{n+1}}{(2n-1)^2}\sin\left[2\pi\left(\frac{2n-1}{T}\right)t\right]$
	$\frac{2}{\pi}\sum_{n=1}^{\infty}\frac{(-1)^{n+1}}{n}\sin\left[2\pi\left(\frac{n}{T}\right)t\right]$
	$-\frac{2}{\pi}\sum_{n=1}^{\infty}\frac{1}{n}\sin\left[2\pi\left(\frac{n}{T}\right)t\right]$

Example 2/ for the signal *f(t)* shown

$f(t) = 5 + 30\ \cos(50t) + 10\ \sin(100t) - 4\ \cos(150t) - 2\ \sin(250t)$

Find 1- periodic time

2- Magnitude of Fourier series coefficients (C_0, A_n, and B_n)

3- write function *f(t)* as Fourier series complex form.

4- Magnitude of and phase of Fourier series complex form coefficients (C_0, $|C_n|$, and ϕ_n)

5- calculate average power.

Sol/

1- $w = 50$ rad/sec

$$w = 2\pi\ f = \frac{2\pi}{T}$$

$$T = \frac{2\pi}{50} = 0.1256\ \text{sec}$$

2- $C_0 = 5$

$A_1 = 30$	**$B_1 = 0$**
$A_2 = 0$	**$B_2 = 10$**
$A_3 = -4$	**$B_3 = 0$**
$A_4 = 0$	**$B_4 = 0$**
$A_5 = 0$	**$B_5 = -2$**

3-

$$f(t) = 5 + 30\ \cos(50t) + 10\ \sin(100t) - 4\ \cos(150t) - 2\ \sin(250t)$$

$$f(t) = 5 + 30\frac{e^{j50t} + e^{-j50t}}{2} + 10\frac{e^{j100t} - e^{-j100t}}{j2} - 4\frac{e^{j150t} + e^{-j150t}}{2} - 2\frac{e^{j250t} - e^{-j250t}}{j2}$$

$$f(t) = \sum_{-\infty}^{\infty} C_n\ e^{jwnt}$$

$$f(t) = -je^{-j250t} - 2e^{-j150t} + j5e^{-j100t} + 15e^{-j50t} + 5 + 15e^{j50t} - j5e^{j100t} - 2e^{j150t} + je^{j250t}$$

$C_{-5} = -j$	$C_5 = j$
$C_{-4} = 0$	$C_{-4} = 0$

$C_{-3} = -2$ $\quad$ $C_4 = -2$

$C_{-2} = j5$ $\quad$ $C_2 = -j5$

$C_{-1} = 15$ $\quad$ $C_1 = 15$

$C_0 = 5$

4- $|C_0| = 5$ $\qquad$ $\phi_0 = 0$

$|C_{-1}| = |C_1| = 15$ $\qquad$ $\phi_{-1} = 0 \; \phi_1 = 0$

$|C_{-2}| = |C_2| = 5$ $\qquad$ $\phi_{-2} = 90^0 \qquad \phi_2 = -90^0 \; (\pi/2)$

$|C_{-3}| = |C_3| = 2$ $\qquad$ $\phi_{-3} = \phi_3 = 180^0 \; (\pi)$

$|C_{-4}| = |C_4| = 0$ $\qquad$ $\phi_{-4} = \phi_4 = 0^0$

$|C_{-5}| = |C_5| = 1$ $\qquad$ $\phi_{-5} = -90^0 \qquad \phi_5 = 90^0 \; (-\pi/2)$

5-

$$P = \sum_{-\infty}^{\infty} |C_n|$$
$$P = 5^2 + 2(15^2 + 5^2 + 2^2 + 0^2 + 1^2)$$
$$P = 535 \; watt$$

Q_2 / for the signal *f(t)* shown

$$f(t) = 50 + 30\ \cos(100t) + 10\ \sin(100t) - 3\ \cos(200t) - 7\ \sin(200t) + 3\ \sin(300t) + 7\ \cos(500t)$$

Find 1- periodic time

2- Magnitude of Fourier series coefficients (C_0, A_n, and B_n)

3- write function *f(t)* as Fourier series complex form.

4- Magnitude of and phase of Fourier series complex form coefficients (C_0, $|C_n|$, and ϕ_n)

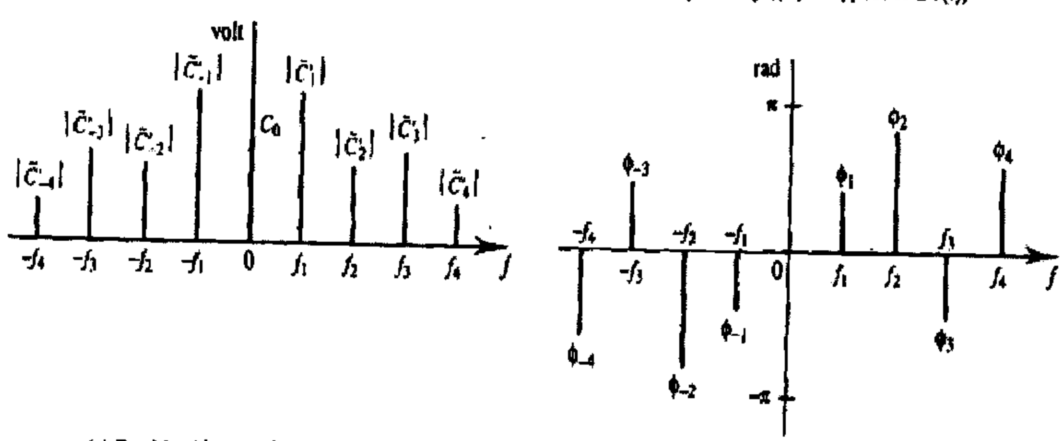
5- calculate average power.

- Discrete Spectrum

The Fourier series represents an infinte number of frequency components which added together yield the time function *f(t)* represented as afunction of frequency that call **FREQUANCY DOMIN** (Spectrum) *F(w)* of *F(f)* with amplitude of C_n.

Calculation of coefficients for waveforms with symmetry

For a waveform $v(t)$ with certain symmetry properties, the calculation of some, or all, of the Fourier coefficients is simplified. These symmetries and the corresponding simplifications for the calculation of C_0, A_n and B_n are shown in Table 2.1.



(a) Double sided amplitude spectrum

(b) Double sided phase spectrum

Example 3/ draw spectrum, magnitude, phase, and power spectral density for

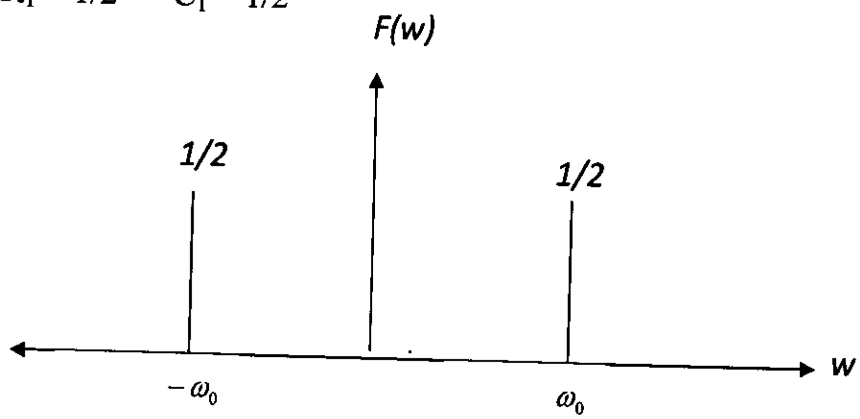
1-

$$f(t) = \cos(\omega_0 t)$$

$$f(t) = \frac{e^{j\omega_0 t} + e^{-j\omega_0 t}}{2}$$

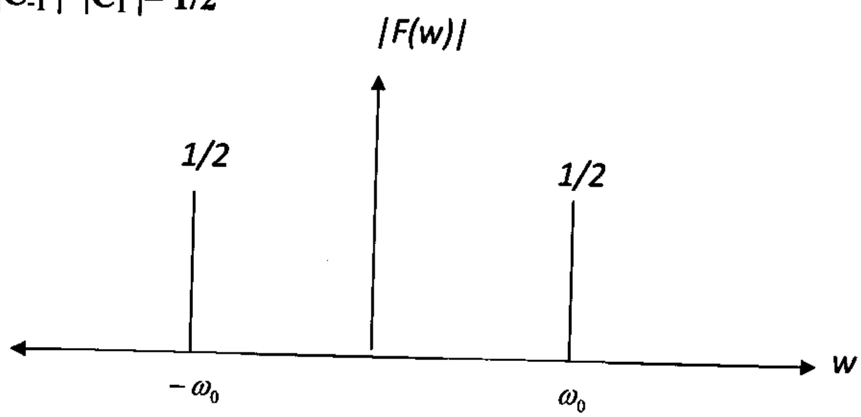
$$f(t) = \frac{e^{j\omega_0 t}}{2} + \frac{e^{-j\omega_0 t}}{2}$$

$C_{-1} = 1/2 \qquad C_1 = 1/2$



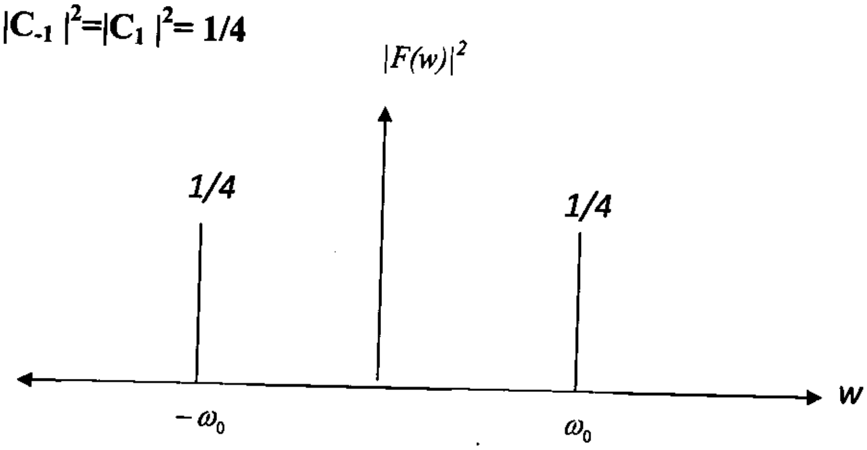
Spectrum

$|C_{-1}| = |C_1| = 1/2$



Magnitude Spectrum

$|C_{-1}|^2 = |C_1|^2 = 1/4$



Power Spectrum Density

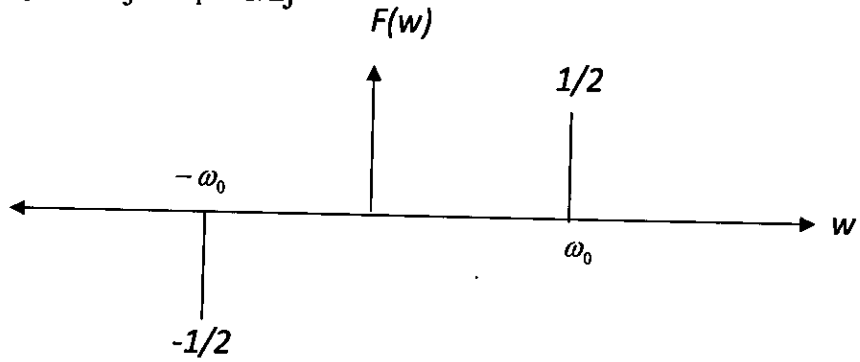
2-

$$f(t) = \sin(\omega_0 t)$$

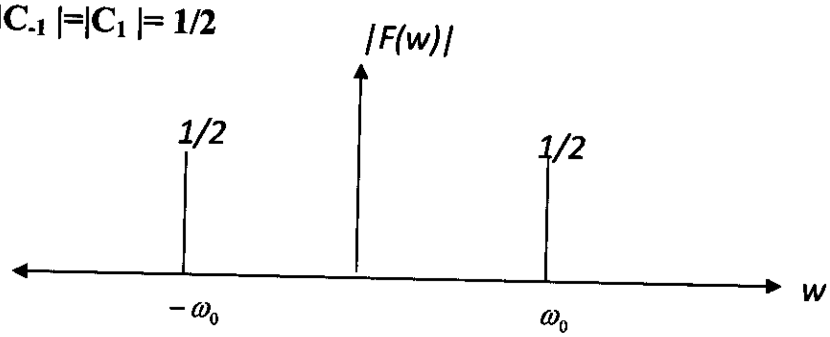
$$f(t) = \frac{e^{j\omega_0 t} - e^{-j\omega_0 t}}{2j}$$

$$f(t) = -j\frac{e^{j\omega_0 t}}{2} + j\frac{e^{-j\omega_0 t}}{2}$$

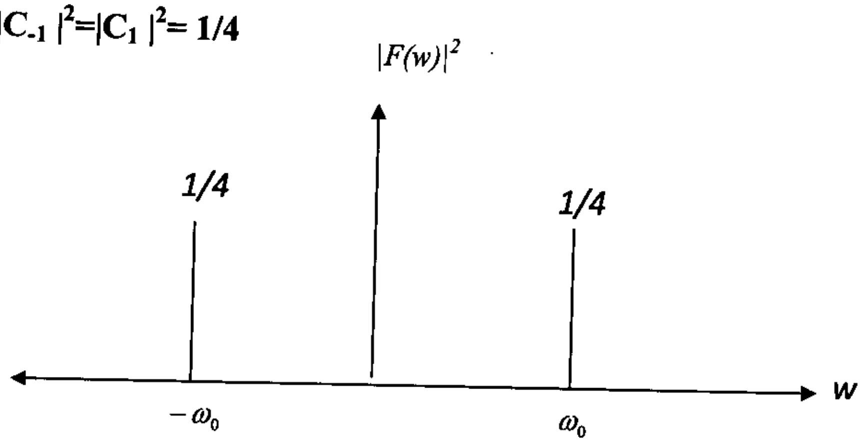
$C_{-1} = -1/2j \quad C_1 = 1/2j$



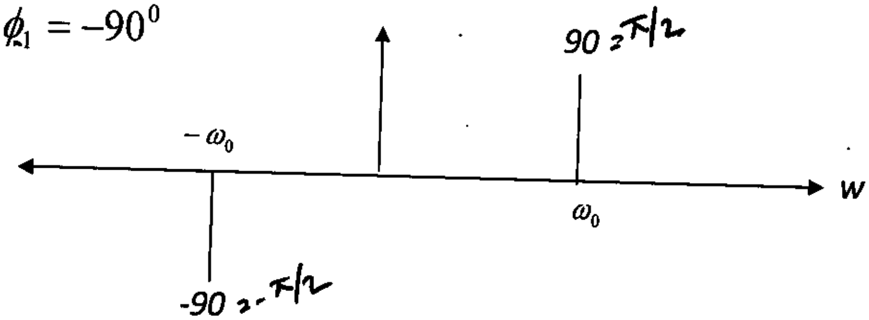
$|C_{-1}| = |C_1| = 1/2$



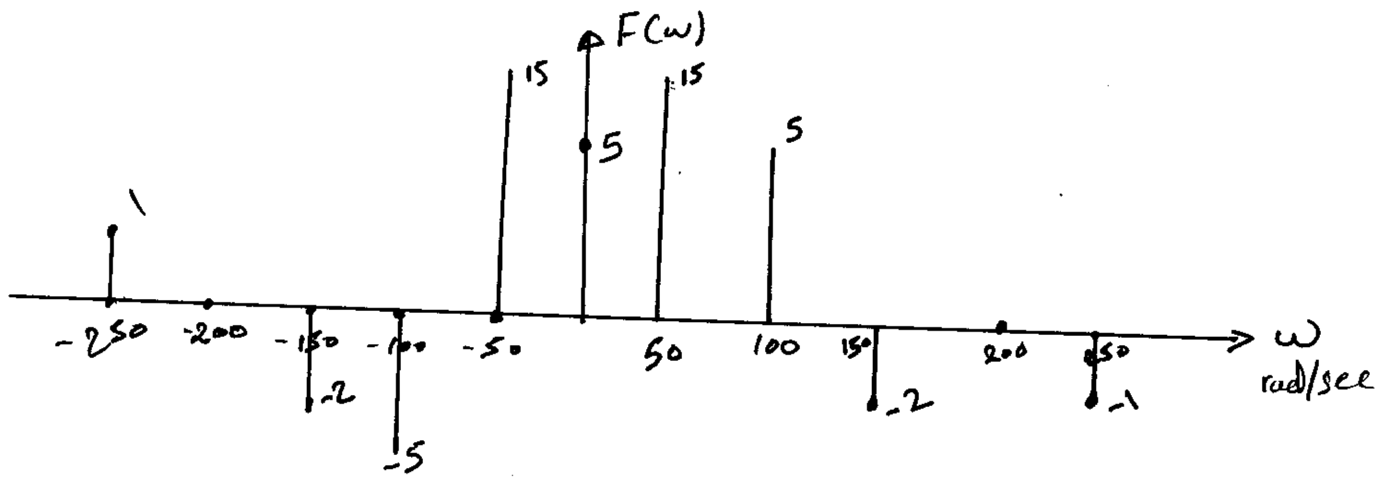
$|C_{-1}|^2 = |C_1|^2 = 1/4$

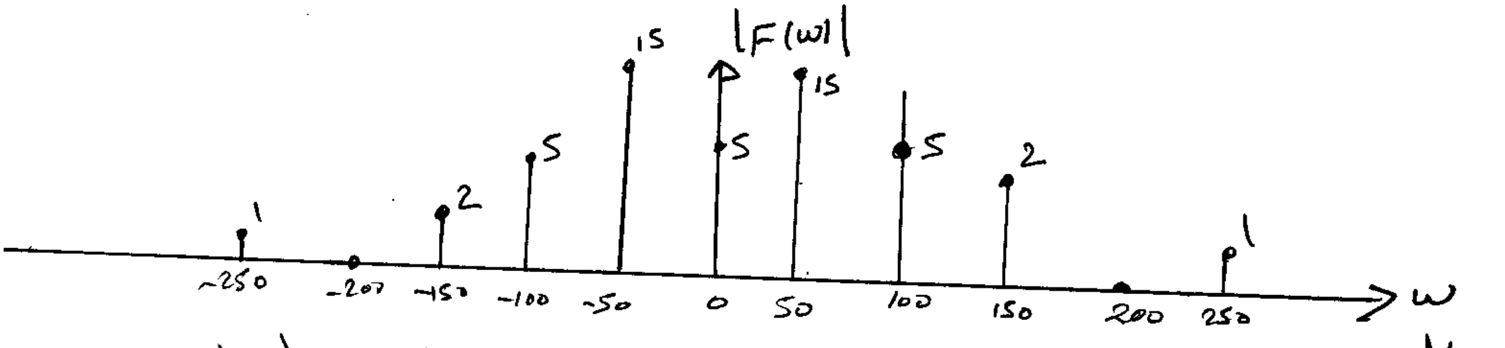


$$\phi_{+1} = 90^0$$
$$\phi_{-1} = -90^0$$

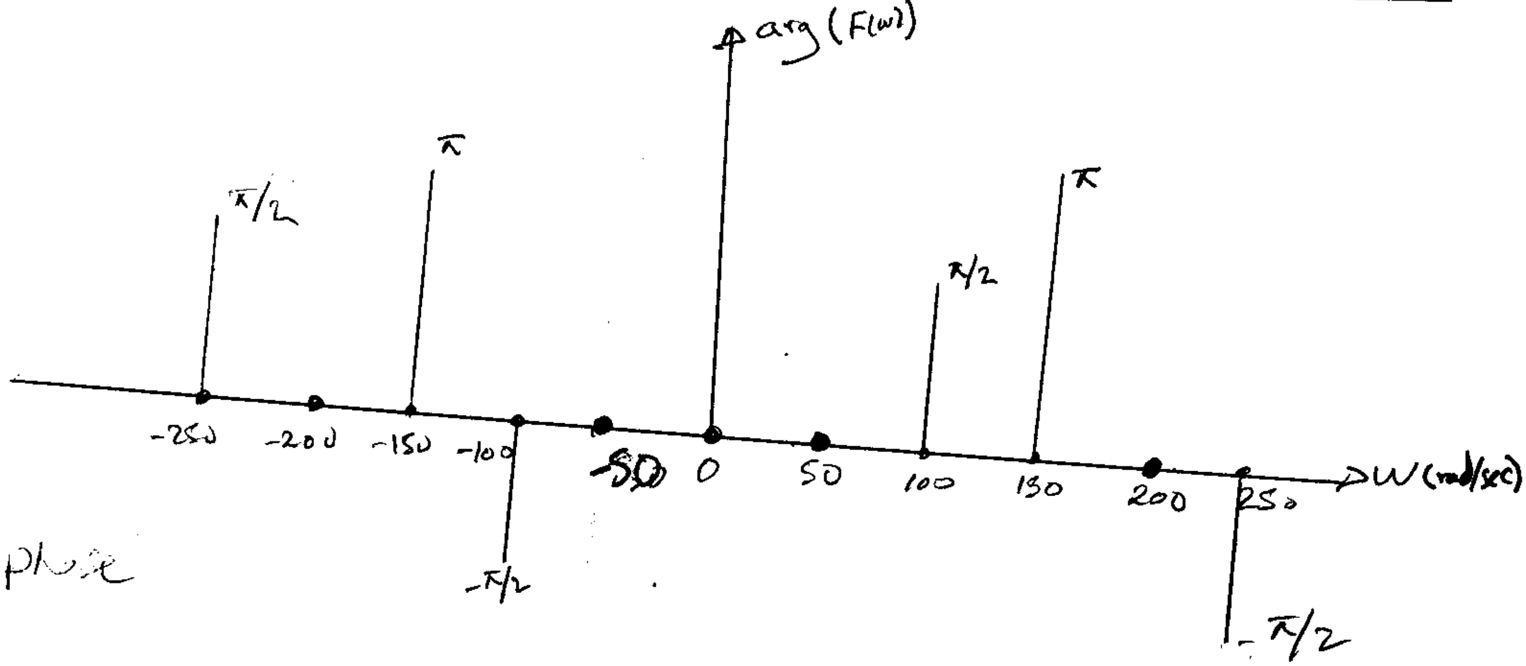


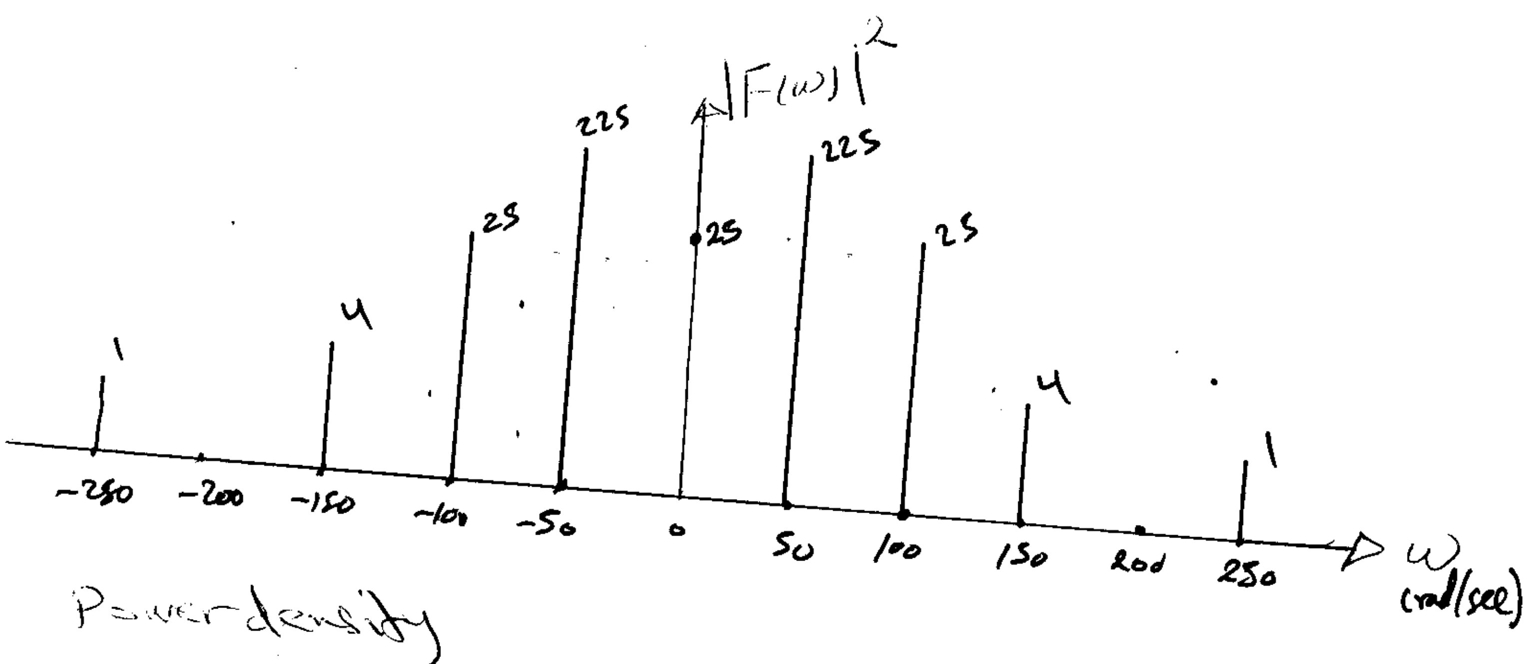
Example 4/ for Example 2 draw magnitude, phase, and power spectrum.





magnitude spectrum





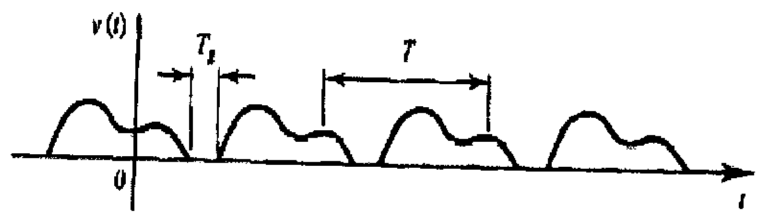
$$P = \sum_{n=-\infty}^{\infty} |c_n|^2 = 25 + 2(225 + 25 + 4 + 0 + 1)$$

$$= 535 \text{ watt}$$

- Fourier Transformer

The traditional way of approaching Fourier transforms is to treat them as a limiting case of a periodic signal Fourier series as the period, T, tends to infinity. Consider Figure 2.24. The waveform in this figure is periodic and pulsed with interpulse spacing, T_g. The amplitude and phase spectra of $v(t)$ are shown (schematically) in Figure 2.25(a) and (b) respectively. They are discrete (since $v(t)$ is periodic), have even and odd symmetry respectively (since $v(t)$ is real) and have line spacing $1/T$ Hz. If the interpulse spacing is now allowed to grow without limit (i.e. $T_g \to \infty$) then it follows that:

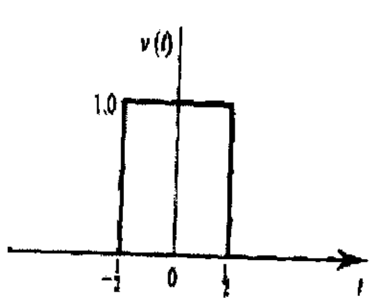
1. Period, $T \to \infty$.
2. Spacing of spectral lines, $1/T \to 0$.
3. The discrete spectrum becomes continuous (as $V(f)$ is defined at all points).
4. The signal becomes aperiodic (since only one pulse is left between $t = -\infty$ and $t = \infty$).

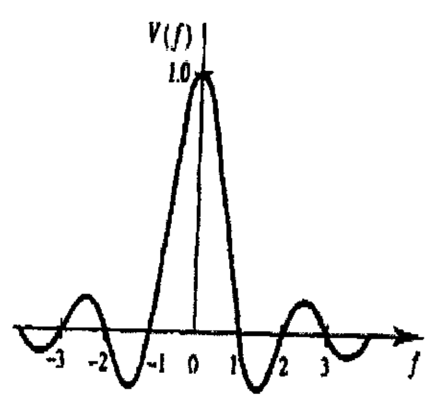


Fourier transform, is:

$$v(t) = \int_{-\infty}^{\infty} V(f)\, e^{j2\pi ft}\, df$$

For Example the Fourier transformation of the unit pulse shown in figure below the sinc function shown in part (b)

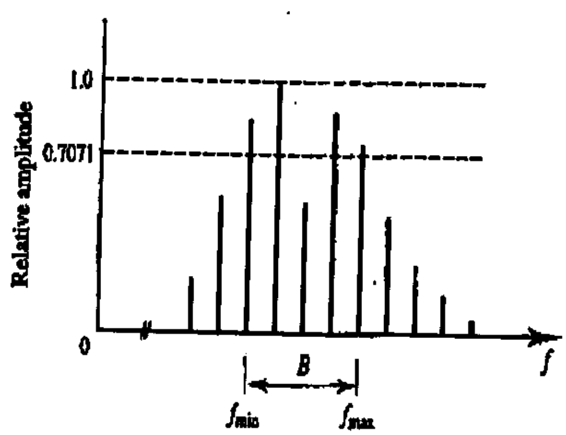




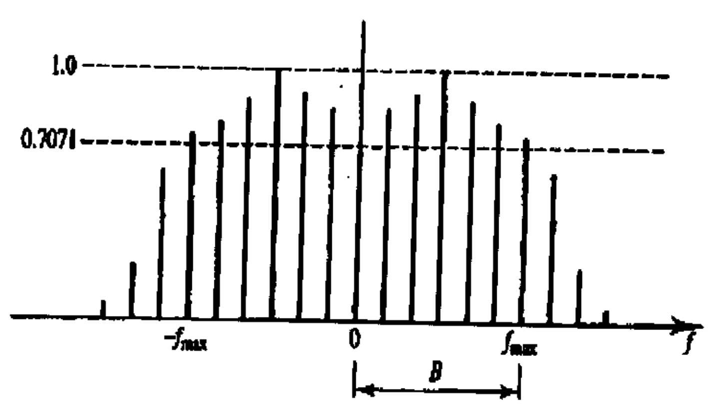
Bandwidth, rates of change, sampling and aliasing

The bandwidth, *B*, of a signal is defined as the difference (usually in Hz) between two nominal frequencies f_{max} and f_{min}. Loosely speaking f_{max} and f_{min} are, respectively, the frequencies above and below which the spectral components are assumed to be small. It is important to realise that these frequencies are often chosen using some fairly arbitrary rule, e.g. the frequencies at which spectral components have fallen to $1/\sqrt{2}$ of the peak spectral component. It would therefore be wrong to assume always that the frequency components of a signal outside its quoted bandwidth are negligible for all purposes, especially if the precise definition being used for *B* is vague or unknown.

The $1/\sqrt{2}$ definition of *B* is a common one and is *usually* implied if no other definition is explicitly given. It is normally called the half power or 3 dB bandwidth since the factor $1/\sqrt{2}$ refers to the voltage spectrum and $20 \log_{10}(1/\sqrt{2}) \approx -3$ dB. The 3 dB bandwidth of a periodic signal is illustrated in Figure 2.20(a). For baseband signals (i.e. signals with



(a) 3 dB bandwidth of a (bandpass) periodic signal



(b) 3 dB bandwidth of a (baseband) periodic signal shown on a double sided spectrum significant spectral components all the way down to their fundamental frequency, f_1, c even DC) f_{min} is 0 Hz, *not* $-f_{max}$. This is important to remember when considering tw sided spectra. The physical bandwidth is measured using positive frequencies or negativ frequencies only, not both, Figure 2.20(b).

In general, if a signal has no significant spectral components above f_H then it cannc change appreciably on a time scale much shorter than about $1/(8f_H)$. (This correspond to one eighth of a period of the highest frequency sinusoid present in the signal, Figur 2.21.) A corollary of this is that signals with large rates of change must have high value of f_H. A rectangular pulse stream, for example, contains changes which occur (i principle) infinitely quickly. This implies that it must contain spectral components wit infinite frequency. (In practice, of course, such pulse streams are, at best, onl approximately rectangular and therefore their spectra can be essentially bandlimited.)

Sampling refers to the process of recording the values of a signal or waveform a (usually) regularly spaced instants of time. A schematic diagram of how this might b achieved is shown in Figure 2.22. It is a surprising fact that if a signal having no spectra components with frequencies above f_H is sampled rapidly enough then the original continuous, signal can, in principle, be reconstructed from its samples *without error*. Th

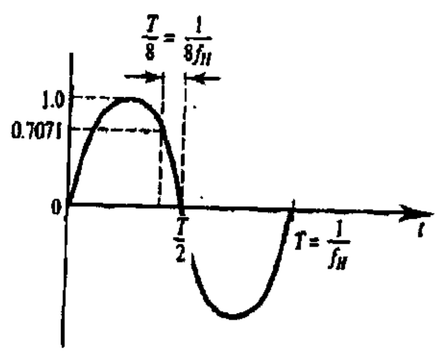
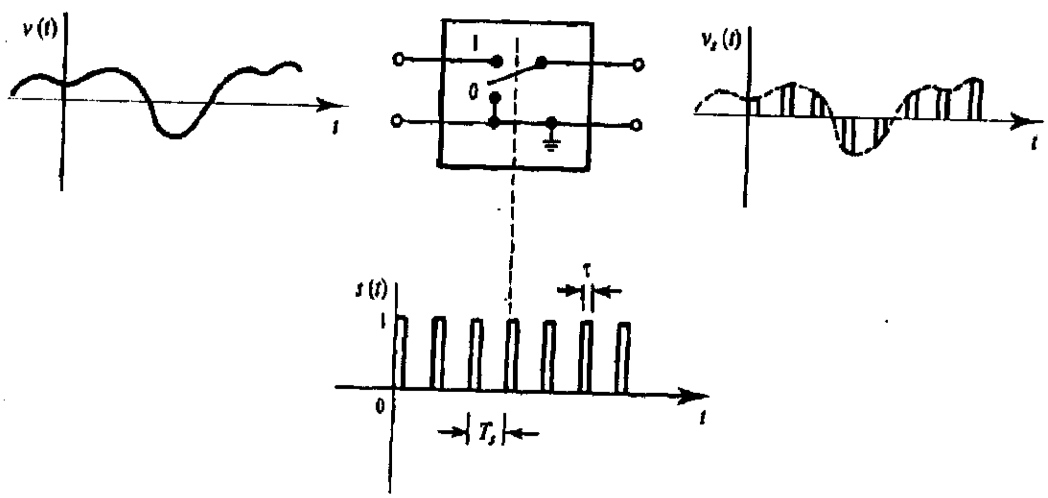


Figure 2.21 *Illustration of minimum time required for appreciable change of signal amplitude.*



minimum sampling rate or frequency, f_s, needed to achieve such ideal reconstruction is related to f_H by:

$$f_s \geq 2f_H \tag{2.31}$$

Equation (2.31) is called Nyquist's sampling theorem and is of central importance to digital communications. It will be discussed more rigourously in Chapter 5. Here, however, it is sufficient to demonstrate its reasonableness as follows.

Figure 2.23(a) shows a sinusoid which represents the highest frequency spectral component in a certain waveform. The sinusoid is sampled in accordance with equation (2.31), i.e. at a rate higher than twice its frequency. (When $f_s > 2f_H$ the signal is said to be *oversampled*.) Nyquist's theorem essentially says that there is one, and only one, sinusoid which can be drawn through the given sample points. Figure 2.23(b) shows the same sinusoid sampled at a rate $f_s = 2f_H$. (This might be called critical, or Nyquist rate, sampling.) There is still only one frequency of sine wave which can be drawn through

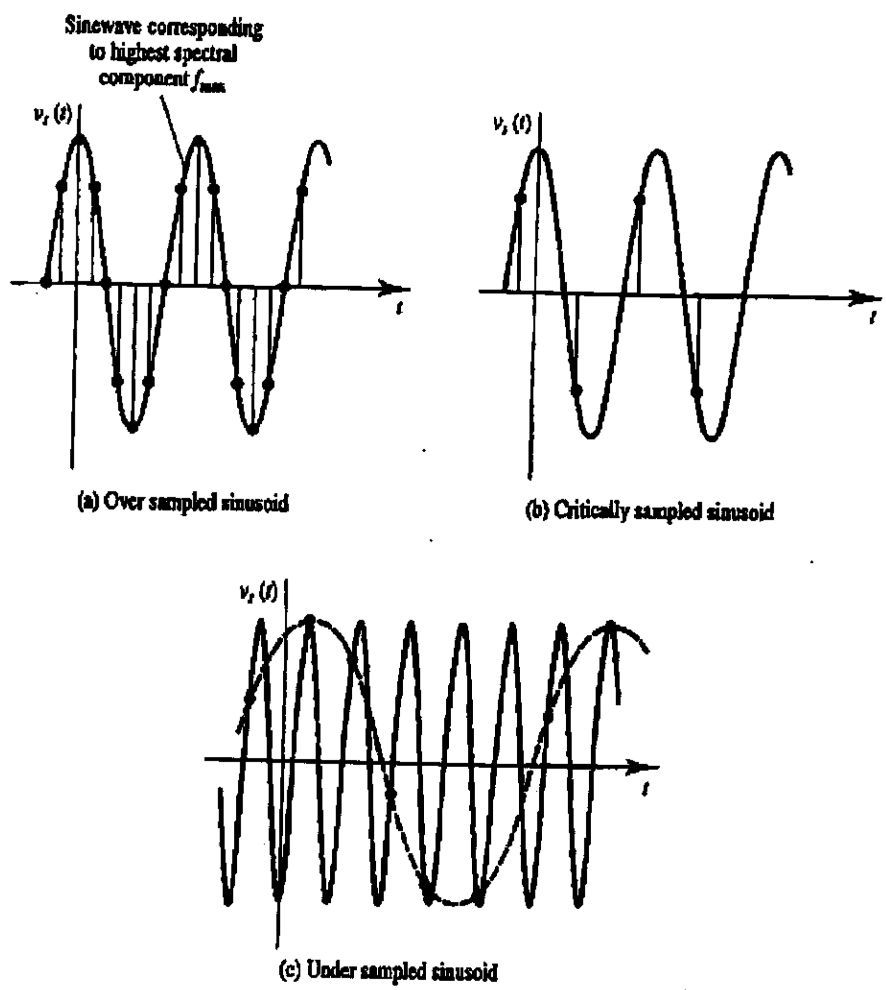


Figure 2.23 *Demonstration of the sampling theorem and alias frequency.*