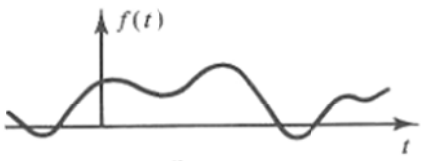
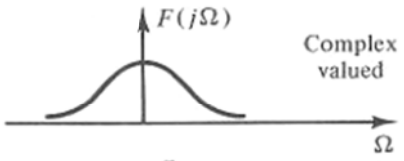
NONPERIODIC CONTINUOUS-TIME

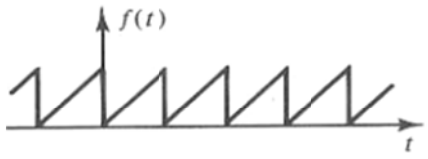


Fourier transform

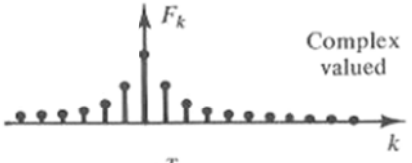


$$f(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} F(j\Omega)e^{j\Omega t}\,d\Omega \qquad F(j\Omega) = \int_{-\infty}^{\infty} f(t)e^{-j\Omega t}\,dt$$

PERIODIC CONTINUOUS-TIME

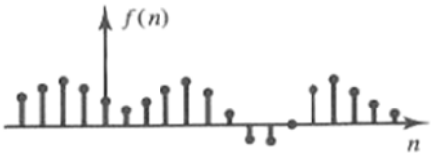


Fourier series

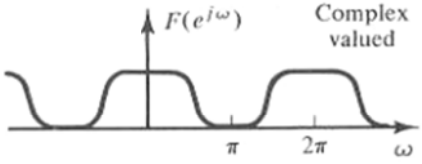


$$f(t) = \sum_{n=-\infty}^{\infty} F_k e^{jk\Omega_0 t} \qquad \Omega_0 = 2\pi/T \qquad F_k = \frac{1}{T}\int_0^T f(t)e^{-jk\Omega_0 t}\,dt$$

NONPERIODIC DISCRETE-TIME

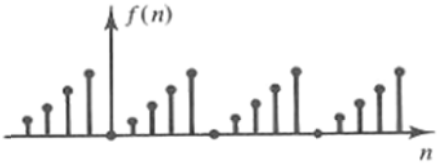


Fourier transform

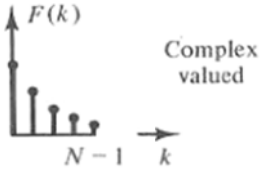


$$f(n) = \frac{1}{2\pi}\int_{-\pi}^{\pi} F(e^{j\omega})e^{j\omega n}\,d\omega \qquad F(e^{j\omega}) = \sum_{n=-\infty}^{\infty} f(n)e^{-j\omega n}$$

PERIODIC DISCRETE-TIME

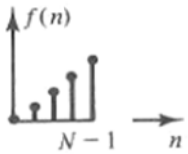


Fourier series

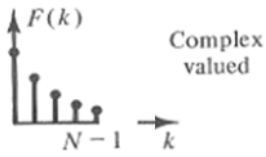


$$f(n) = \frac{1}{N}\sum_{k=0}^{N-1} F(k)e^{(j\frac{2\pi}{N}nk)} \qquad F(k) = \sum_{n=0}^{N-1} f(n)e^{(-j\frac{2\pi}{N}nk)}$$

FIXED LENGTH DISCRETE-TIME



Discrete Fourier transform



$$f(n) = \frac{1}{N}\sum_{k=0}^{N-1} F(k)e^{(j\frac{2\pi}{N}nk)} \qquad F(k) = \sum_{n=0}^{N-1} f(n)e^{(-j\frac{2\pi}{N}nk)}$$

Where $[\Omega : \text{digital frequency}]$ $(\omega : \text{continuous frequency})$

	Time domain	Frequency domain
Fourier Transform pair (FT)	$x(t) = \int_{f=-\infty}^{\infty} X(f) e^{j2\pi ft} df$	$X(f) = \int_{t=-\infty}^{\infty} x(t) e^{-j2\pi ft} dt$
Fourier Series pair (FS)	$x(t) = \sum_{n=-\infty}^{\infty} X_k e^{\frac{j2\pi kt}{T}}$	$X_k = \frac{1}{T} \int_0^T x(t) e^{\frac{j2\pi kt}{T}} dt$
Discrete time Fourier Transform (DTFT)	$x[n] = \frac{1}{2\pi} \int_{-\pi}^{\pi} X(\Omega) e^{j\Omega t} d\Omega$	$X(\Omega) = \sum_{n=-\infty}^{\infty} x[n] e^{-j\Omega n}$
Z transform only (ZT)		$X(z) = \sum_{n=-\infty}^{\infty} x[n] z^{-n}$
Discrete Fourier Series pair (DFS)	$x[n] = \frac{1}{N} \sum_{k=0}^{N-1} X[k] e^{\frac{j2\pi kn}{N}}$ $n = 0 \sim N-1$	$X[k] = \sum_{n=0}^{N-1} x[n] e^{\frac{-j2\pi kn}{N}}$ $k = 0 \sim N-1$
Discrete Fourier Transform pair (DFT)	$x[n] = \frac{1}{N} \sum_{k=0}^{N-1} X[k] e^{\frac{j2\pi kn}{N}}$ $n = 0 \sim N-1$	$X[k] = \sum_{n=0}^{N-1} x[n] e^{\frac{-j2\pi kn}{N}}$ $k = 0 \sim N-1$

Hearing test

CD sampling rate: 44100 **samples/second**
DAT sampling rate: 48000 **samples/second**

```
clc;
clear all;

f = 200;% frequency that I want to hear.

fs = 44100; % sampling frequency
time_dur = 3; % totoal time that you want to hear.

n = 0:fs*time_dur; % total number of samples

x = sin(2*pi*f*n/fs);
plot(n,x)
sound(x,fs);
```

```
clc; clear all;

f = 2;
t = 0:0.01:1;
[X,Y] = meshgrid(t,t);
z = cos(2*pi*f*X);

surfc(X,Y,z)
% grid;
```

Ch 01 Digital signal processing.

What is DSP (digital signal processing)?

- The study of signals in a digital representation and the processing methods of these signals (*Wikipedia*)

- DSP includes subfields like: audio and speech signal processing, sonar and radar signal processing, sensor array processing, spectral estimation, statistical signal processing, image processing, signal processing for communications, biomedical signal processing, etc (*Wikipedia*)

Definition: A **signal** is a function that conveys information, generally about the state or behavior of a physical system.

Definition: **Signal Processing** is an operation or transformation on a signal.

Definition: **Digital Signal Processing** (DSP) is an operation or transformation (done in software) of a signal on a computer or other special purpose digital hardware.

What are the advantages and disadvantages of DSP?

Advantages

- **Flexibility**: processing done in software
- **Adaptability**: possible time-varying (adaptive) systems - systems that "learn" about their environment
- **Accuracy**: typical 16 bit precision can be used to specify very accurate system parameters
- **Cost**: digital signal processors continue to increase performance/price
- **New Possibilities**: complicated or impossible analog may now be simplified or even possible with DSP

Disadvantages

- **Requires a powerful computer** – computational horsepower proportional to sample rate and complexity of processing.

Applications of DSP

- Touch-Tone™ telephones
- Edge detection in images
- Digital signal and image filtering
- Seismic analysis
- Text recognition
- Speech recognition
- Magnetic resonance image (MRI) scans
- Music synthesis
- Bar code readers
- Sonar processing
- Satellite image analysis
- Digital mapping
- Cellular telephones
- Digital cameras
- Detection of narcotics and explosives
- Speech synthesis
- Echo cancellation
- Cochlear implants
- Antilock brakes
- Signal and image compression
- Noise reduction
- Companding
- High definition television (HDTV)
- Digital audio
- Encryption
- Motor control
- Remote medical monitoring
- Smart appliances
- Home security
- High speed modems

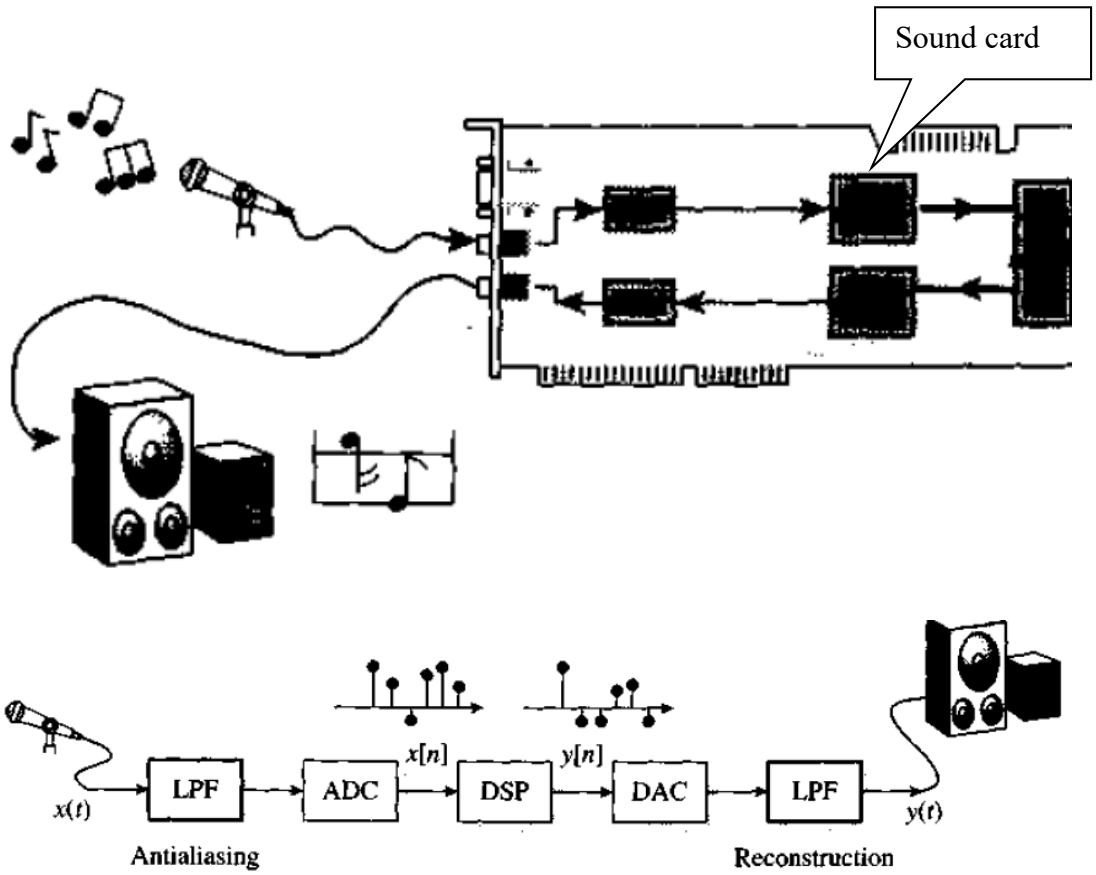
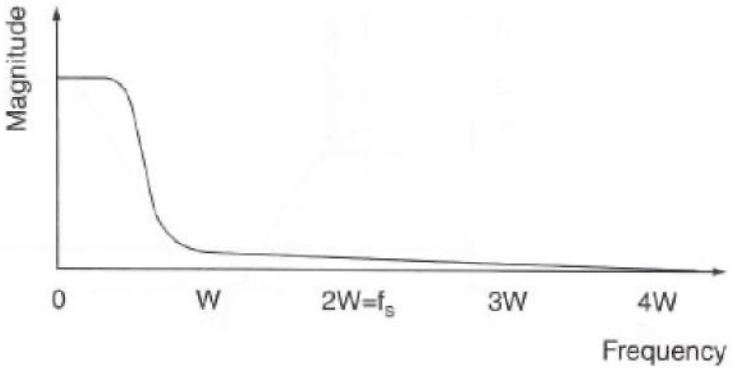
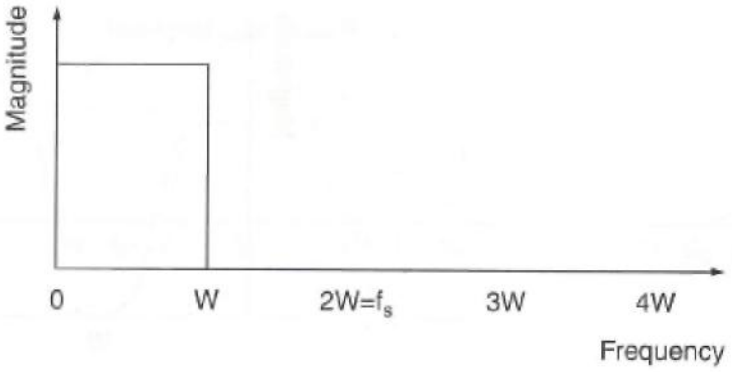


Figure 1: Example with sound card

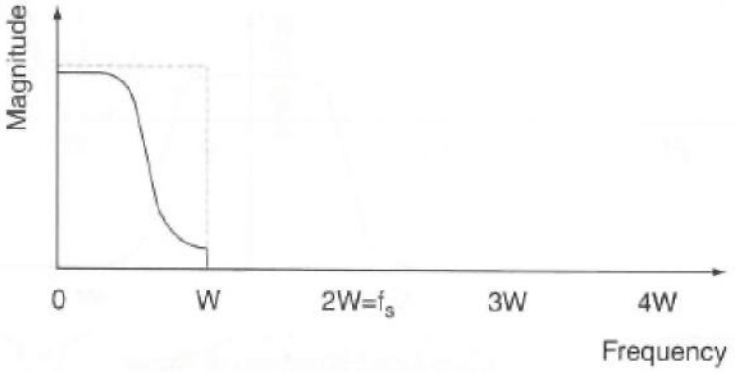
Prefilter (Anti-aliasing filter)



(a) Analog Signal Spectrum

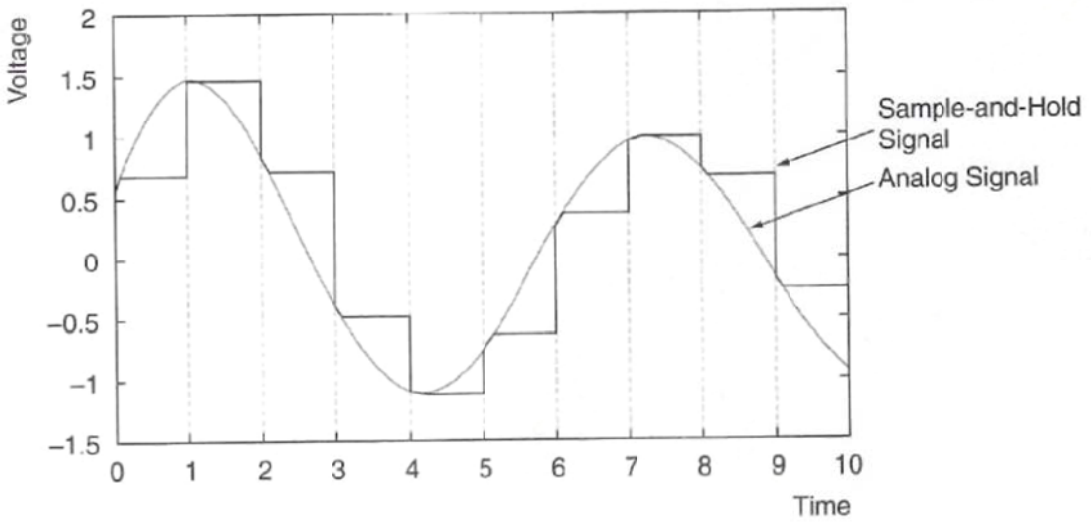


(b) Filter Shape for Analog Antialiasing Filter

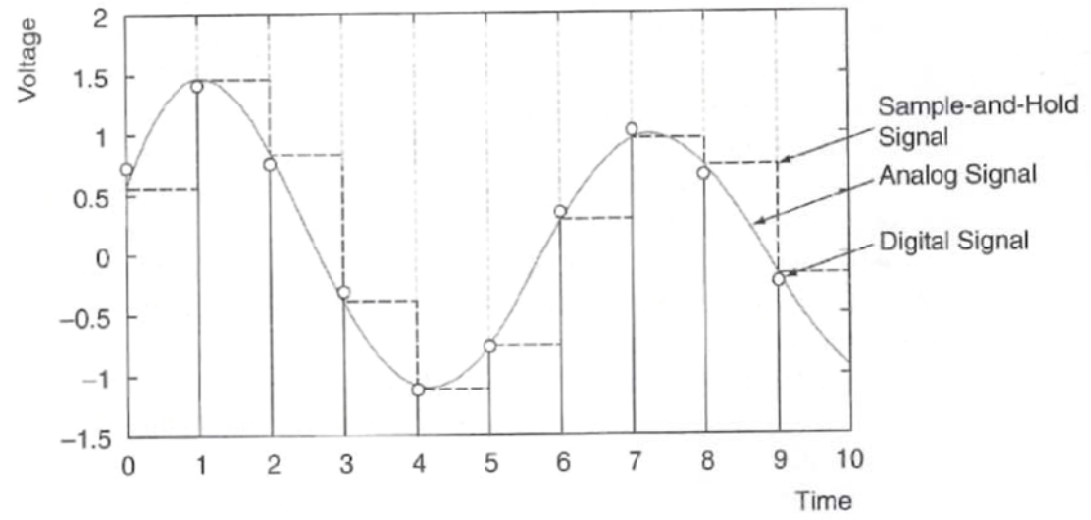


(c) Filtered Analog Signal Spectrum

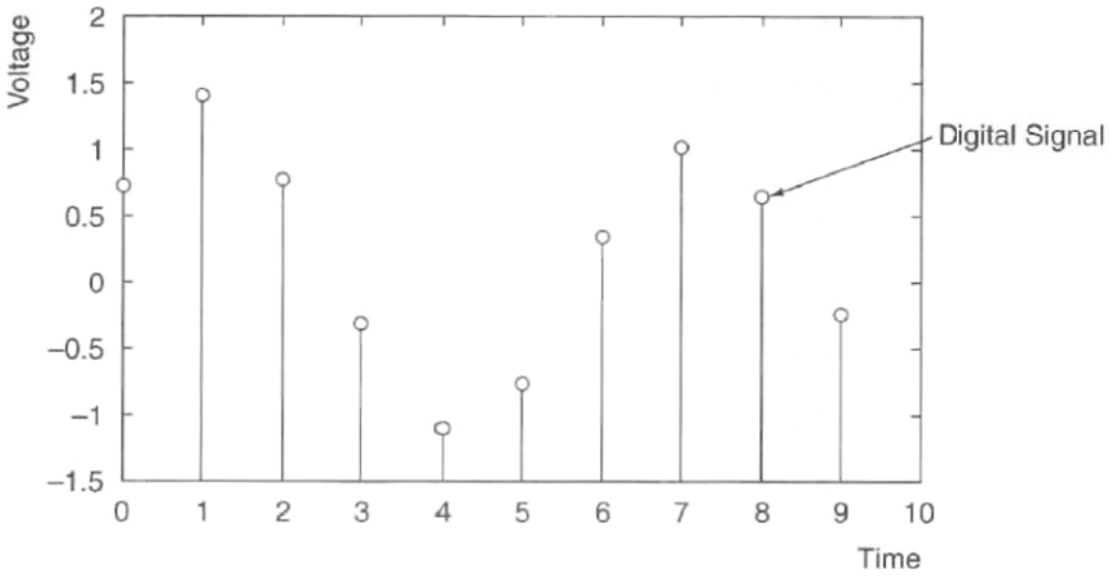
Sample and hold



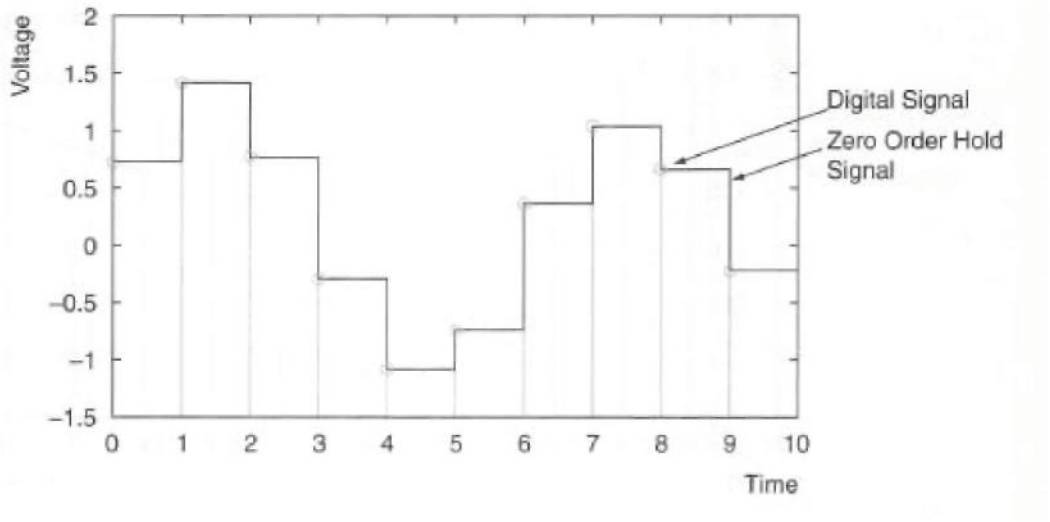
Quantization and digitization



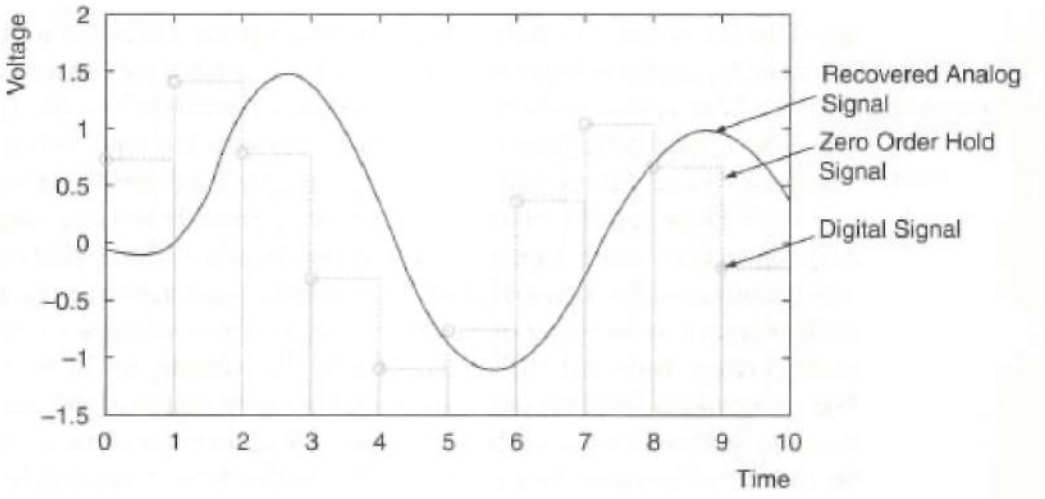
Digital signal



D/A conversion

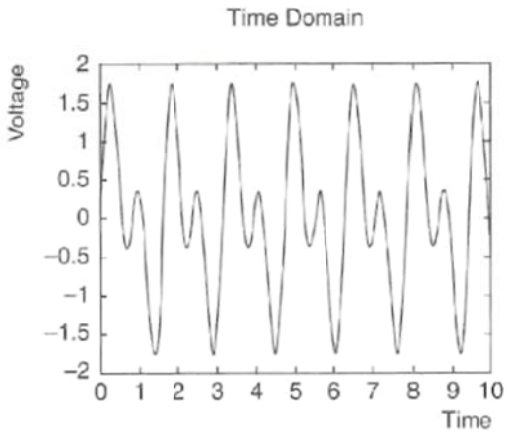


Zero order hold signal

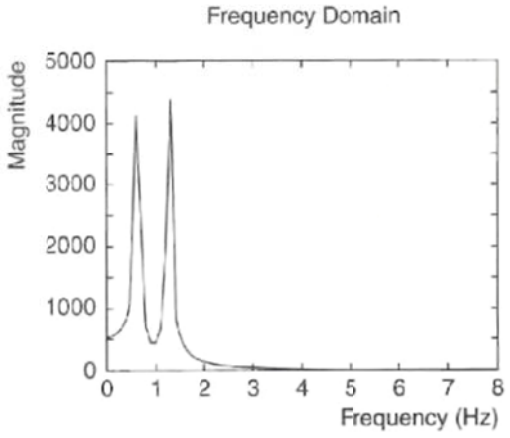


Recovered analog signal after smoothing

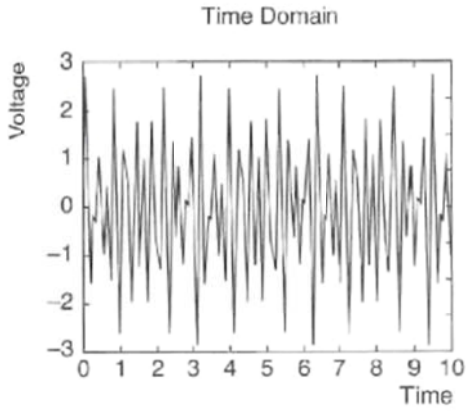
Examples of digital signals and spectra



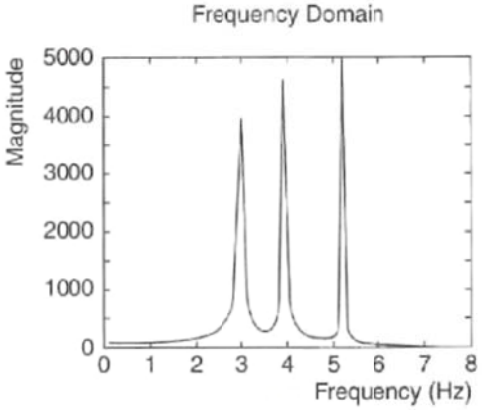
(a) Slowly changing signal



Spectrum of signal



(b) Quickly changing signal



Spectrum of signal