

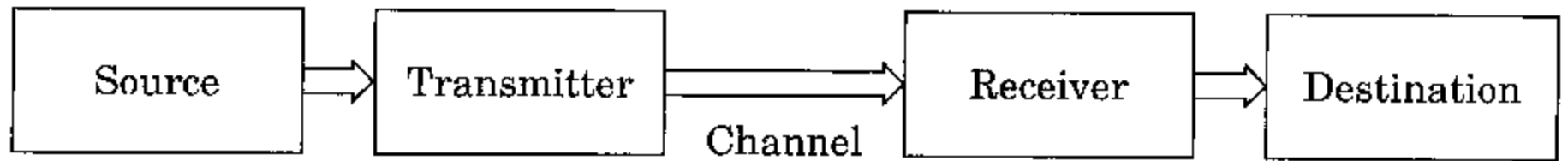
Digital Communications and Signals

CTEC1631/2010F
Digital Signal Processing

ELEMENTS OF A COMMUNICATION SYSTEM

- Source
- Transmitter
- Channel
- Receiver
- Destination

Elements of a Communication System



SOURCE EXAMPLES

- Analog/digital audio and video
- Data communications

TRANSMITTER

- Radio and T.V. Stations
- Cell Phones
- Dispatch Systems
- INFORMATION SIGNAL IS COMBINED WITH
A MODULATING SIGNAL

CHANNEL

- Pair of Conductors
- Fibre Optic Cable
- Free Space

RECEIVER

- Demodulator
- Detector

DESTINATION

- Image Display
- Speaker
- Computer

COMMUNICATION CONSIDERATIONS

- Types of Modulation: A.M., F.M etc.

equation for
sine wave
carrier

$$e(t) = E_c \sin(\omega_c t + \theta)$$

where : $e(t)$ instantaneous voltage as a function of time

E_c = peak voltage

ω_c = frequency in radians per second

t = time in seconds

θ = phase angle in radians

- Bandwidth $I = ktB$ k is modulation type constant and B = channel bandwidth
- FDM
- TDM
- Band Allocations

TYPES OF MODULATION

- ANALOG:
AM, FM and PM
- DIGITAL:
FSK, PSK, QPSK and QAM

SIGNAL BANDWIDTH

- How much bandwidth is required by an unmodulated sine wave carrier?
- Shannon-Hartley Law
- What is the Baseband signal?
 - the band of frequencies occupied by the information signal.

Shannon-Hartley

The Shannon–Hartley theorem states the channel capacity C , meaning the theoretical tightest upper bound on the information rate (excluding error correcting codes) of clean (or arbitrarily low bit error rate) data that can be sent with a given average signal power S through an analog communication channel subject to additive white Gaussian noise of power N , is:

Shannon-Hartley (2)

$$C = B \log_2 \left(1 + \frac{S}{N} \right)$$

Where

C is the channel capacity in bits per second;

B is the bandwidth of the channel in hertz (passband bandwidth in case of a modulated signal);

S is the total received signal power over the bandwidth (in case of a modulated signal, often denoted C, i.e. modulated carrier), measured in watt or volt²;

Shannon-Hartley (3)

$$C = B \log_2 \left(1 + \frac{S}{N} \right)$$

N is the total noise or interference power over the bandwidth, measured in watt or volt²; and

S/N is the signal-to-noise ratio (SNR) or the carrier-to-noise ratio (CNR) of the communication signal to the Gaussian noise interference expressed as a linear power ratio (not as logarithmic decibels).

Shannon-Hartley (4)

Nyquist determined that the number of independent pulses that could be put through a channel per unit time is limited to twice the bandwidth of the channel:

$$f_p \leq 2B$$

where f_p is the pulse frequency (in pulses per second) and B is the

bandwidth (in hertz). The quantity $2B$ later came to be called the Nyquist rate, and transmitting at the limiting pulse rate of $2B$ pulses per second as signalling at the **Nyquist rate**.

FOURIER SERIES

- Any well-behaved periodic waveform can be represented as a series of sine and or cosine waves at multiples of its fundamental frequency plus a d.c. offset where it exists.
- $x(t) = A_0/2 + A_1 \cos(\omega t) + B_1 \sin(\omega t) + A_2 \cos(2\omega t) + B_2 \sin(2\omega t) + A_3 \cos(3\omega t) + B_3 \sin(3\omega t) + \dots$

where: $x(t)$ = any well behaved function of time

A_n and B_n = real number coefficients

ω = radian frequency of the fundamental

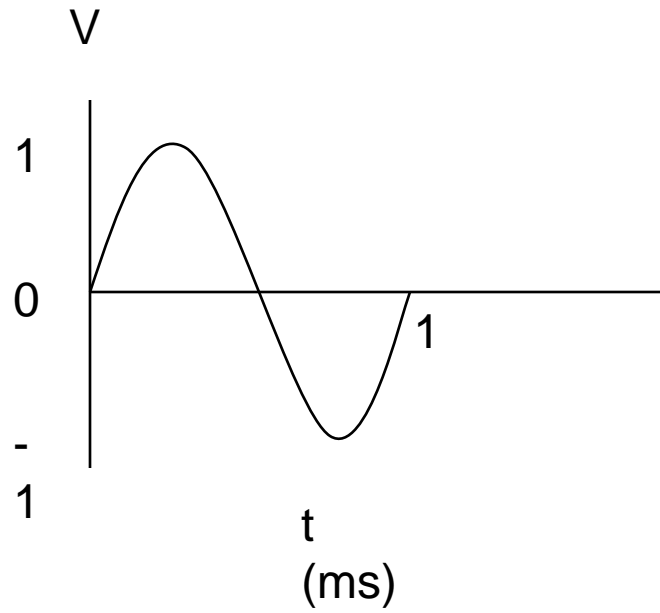
$f = 1/T, \omega = 2\pi f \approx 6.28 f$

FOURIER POLYNOMIAL OF DEGREE n

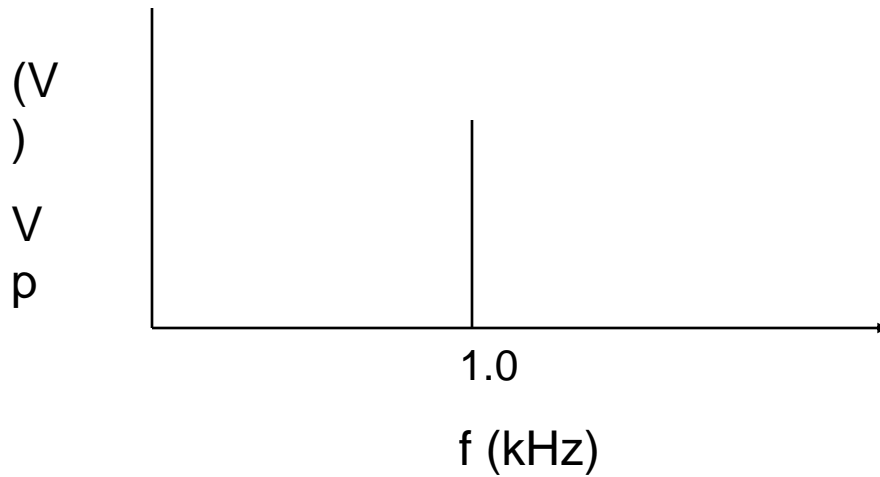
$$a_0 + \sum_{k=1}^n a_k \cos kx + \sum_{k=1}^n b_k \sin kx$$

$k = 1, 2, \dots, n$ and repeats every 2π

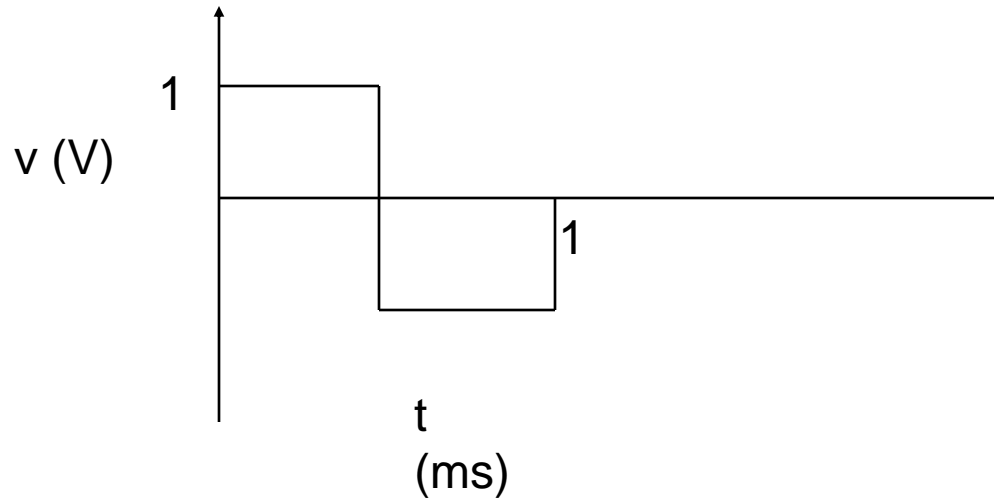
Time Domain

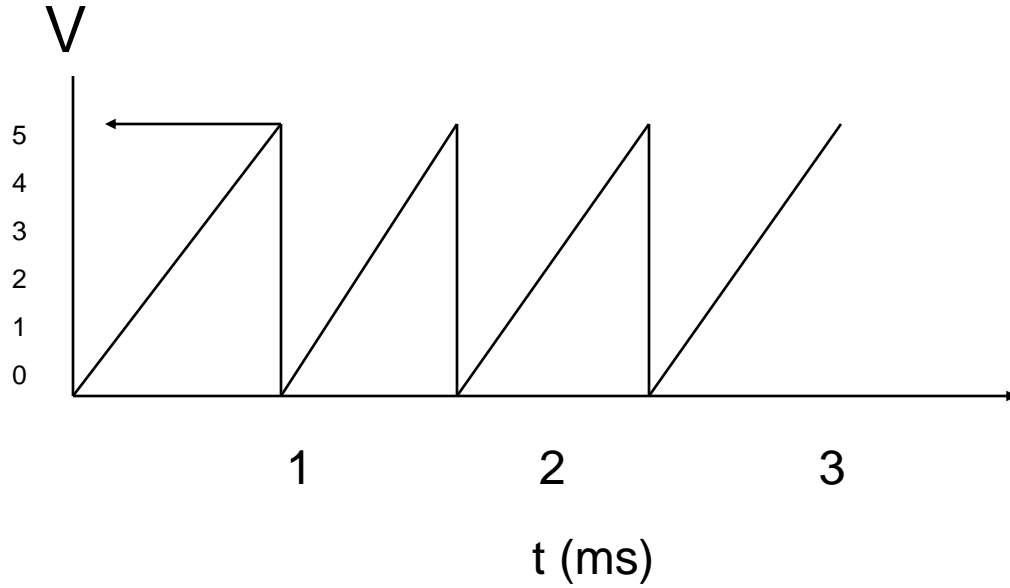


Frequency Domain



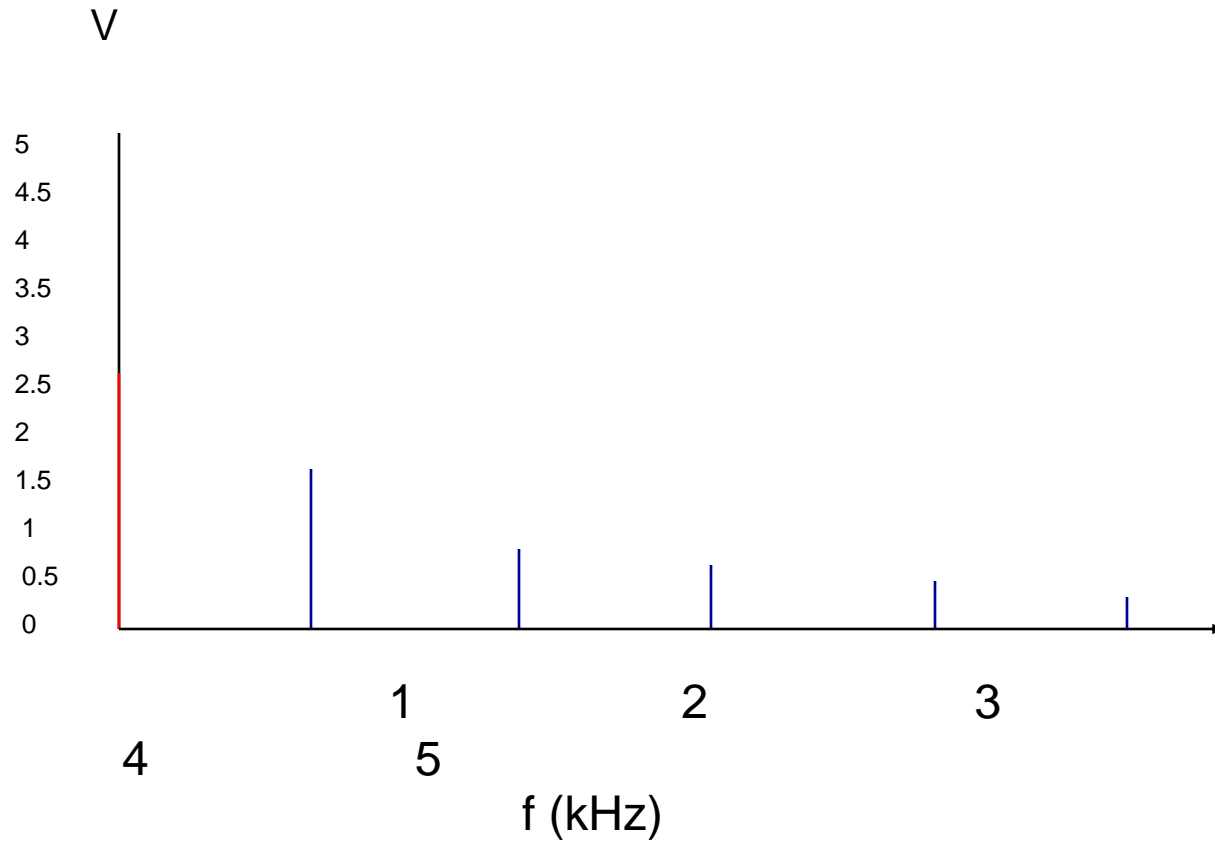
Identify the location of harmonic content, in the frequency domain, for the square wave below.





Find the Fourier series for the signal above.

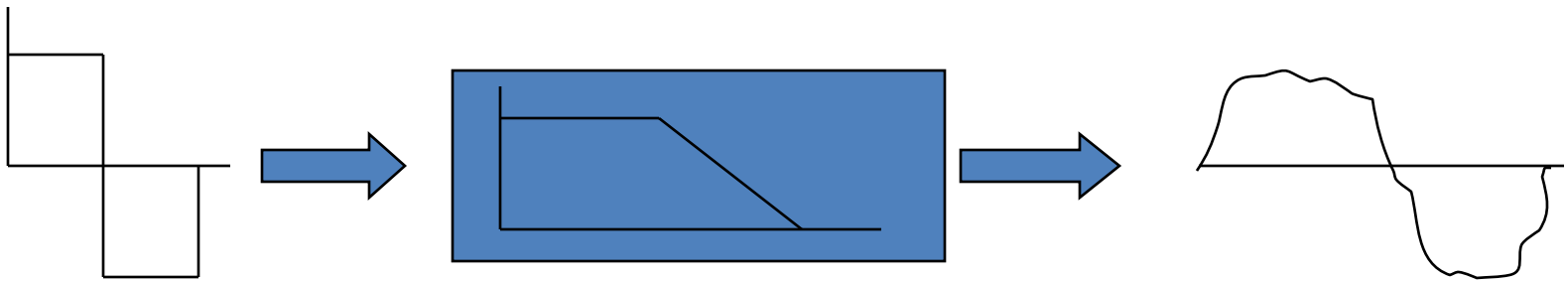
$$v(t) = \frac{A}{2} - \left(\frac{A}{\pi} \right) \left(\sin \omega t + \frac{1}{2} \sin 2\omega t + \frac{1}{3} \sin 3\omega t \dots \right)$$



$$v(t) = 2.5 - 1.59 \left[\sin(2\pi \times 10^3 t) + 0.5 \sin(4\pi \times 10^3 t) + 0.33 \sin(6\pi \times 10^3 t) + \dots \right] \text{V}$$

Filters and Signals

Why is the output signal distorted?



Some significant frequency components have not passed through the filter. Assume an input frequency of 1 Mhz. Where does the cutoff frequency of the filter fall?

NOISE AND COMMUNICATIONS

- Where does noise originate in a communication system?
 1. Channel
 2. Equipment
- **DEFINE:**
 - undesired random variations that interfere with the desired signal and inhibit communication.
- **REMEDIES?**
 1. Reduce Bandwidth
 2. Increase transmitter power
 3. Low Noise Amplifiers

Transmission and Distortions

Distortions:

- Harmonic
- Intermodulation
- Nonlinear frequency response
- Nonlinear phase response
- Noise
- Interference

TYPES OF NOISE

- TWO CATEGORIES:
 1. External Noise
 2. Internal Noise

EXTERNAL NOISE

1. Equipment Noise:

- automobile engines
- electric motors
- computers
- light dimmers

2. ATMOSPHERIC NOISE (STATIC)

- Lightning
- Noise Blanking

3. SPACE NOISE

- Radiation from the Sun (solar noise)
- Stellar or Sky Noise (stars)

INTERNAL NOISE

- 1. Equipment Noise
- 2. Quantization noise

Signal-to-Noise Ratio

- Signal-to-noise ratio is defined as the power ratio between a signal (meaningful information) and the background noise (unwanted signal):

$$\text{SNR} = \frac{P_{\text{signal}}}{P_{\text{noise}}}$$

- where P is average power. Both signal and noise power must be measured at the same or equivalent points in a system, and within the same system bandwidth.

Signal-to-Noise Ratio (2)

- In decibels the formula can be rewritten as:

$$\text{SNR}_{\text{dB}} = 10 \log_{10} \left(\frac{A_{\text{signal}}}{A_{\text{noise}}} \right)^2 = 20 \log_{10} \left(\frac{A_{\text{signal}}}{A_{\text{noise}}} \right)$$

where A is root mean square (RMS) amplitude (for example, RMS voltage).

Signal-to-Noise Ratio (3)

- Dynamic range measures the ratio between the strongest un-distorted signal on a channel and the minimum discernable signal, which for most purposes is the noise level.
- SNR measures the ratio between an arbitrary signal level (not necessarily the most powerful signal possible) and noise.

Signal-to-Noise Ratio (4)

- Measuring signal-to-noise ratios requires the selection of a representative or reference signal.
- In audio engineering, the reference signal is usually a sine wave at a standardized nominal or alignment level, such as 1 kHz at +4 dBu (1.228 VRMS).

Signal-to-Noise Ratio (5)

- For **digital** signals, the number of bits used to represent the measurement determines the maximum possible signal-to-noise ratio.
- This is because the minimum possible noise level is the error caused by the quantization noise.

Signal-to-Noise Ratio (6)

- For n -bit integers (i.e., **fixed point DSP**) with equal distance between quantization levels the dynamic range (DR) is also determined.
- The quantization noise is a uniformly-distributed random signal with a peak-to-peak amplitude of one quantization level, making the amplitude ratio $2^n/1$.

Signal-to-Noise Ratio (7)

$$DR_{\text{dB}} = \text{SNR}_{\text{dB}} = 20 \log_{10}(2^n) \approx 6.02 \cdot n$$

- This relationship is the origin of statements like "16-bit audio has a dynamic range of 96 dB".
- Each extra bit increases the dynamic range by roughly 6 dB.

Signal-to-Noise Ratio (8)

- Assuming sinusoidal input signals, the quantization noise approximates a sawtooth wave with peak-to-peak amplitude of one quantization level and uniform distribution.
- In this case, the SNR is approximately

$$\text{SNR}_{\text{dB}} \approx 20 \log_{10}(2^n \sqrt{3/2}) \approx 6.02 \cdot n + 1.761$$

References

- Greg Swick, “ELNC545 Course Notes” (Winter 2003).
- http://en.wikipedia.org/wiki/Signal-to-noise_ratio
- http://en.wikipedia.org/wiki/Shannon-Hartley_theorem
- <http://en.wikipedia.org/wiki/Decibel>