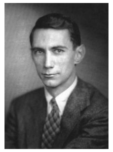
Foundation Layers

- ***Nyquist Sampling Theorem***
- Nyquist Stability Criterion
- Nyquist Noise
- Fax



- ***Shannon Capacity***
- Information Entropy
- Shannon's maxim
- Computer Chess
- Shannon's mouse

- Fourier Series
- ***Fourier Transform***
- Greenhouse Effect

TELE303 Wireless Communications

Lecture 2 – Transmission

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Outline

- Last lecture:
  - Signals
  - Time-domain concepts
  - *Frequency spectrum*
  - Nyquist bandwidth
  - Shannon's channel capacity
- This lecture:
  - Fourier transform
  - Transmission media
  - Multiplexing

The Duality (?)

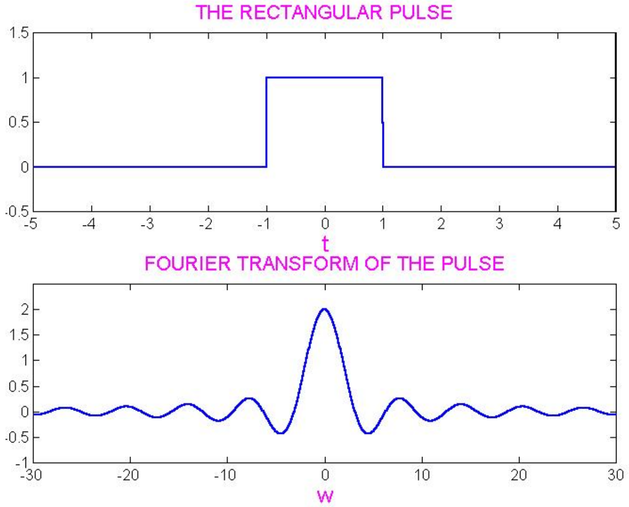
XOR with 0,1

- $0 \oslash 0=0$
- $0 \oslash 1=1$
- $1 \oslash 1=0$
- $1 \oslash 0=1$

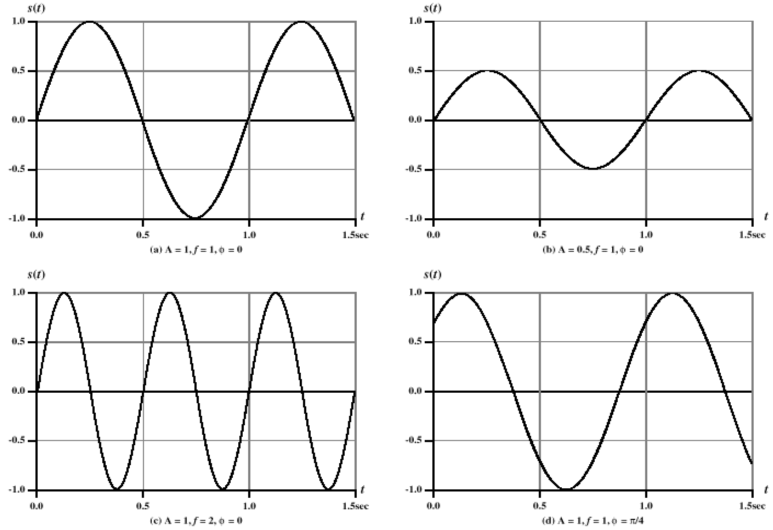
Multiplication w/ +1,-1

- (+1)×(+1)=+1
- (+1)×(-1)=-1
- …

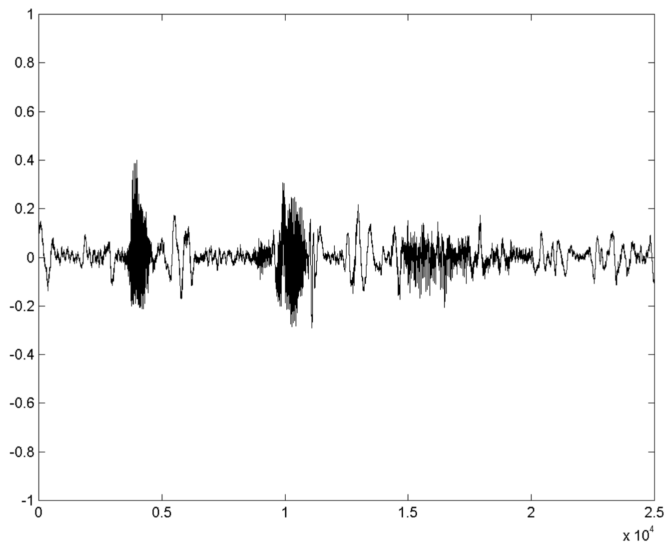
Question: how can we get the spectrum of a signal?



What we saw yesterday



What Real Signals Look Like



Fourier Transform

Fourier Series

- Fourier: any periodic signal can be represented by a sum of sinusoids, known as Fourier series:

$$x(t) = \frac{A_0}{2} + \sum_{n=1}^{\infty}\left[A_n \cos(2n\pi f_0 t) + B_n \sin(2n\pi f_0 t)\right]$$

- These sinusoids are orthogonal to each other, so we have

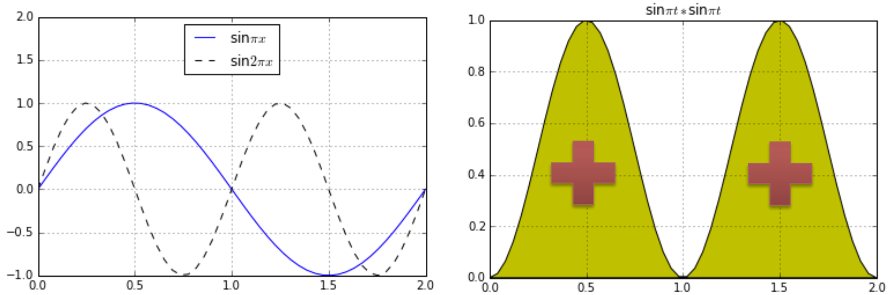
$$A_0 = \frac{2}{T}\int_0^T x(t)dt$$

$$A_n = \frac{2}{T}\int_0^T x(t)\cos(2\pi n f_0 t)dt$$

$$B_n = \frac{2}{T}\int_0^T x(t)\sin(2\pi n f_0 t)dt$$

Orthogonality: An Example

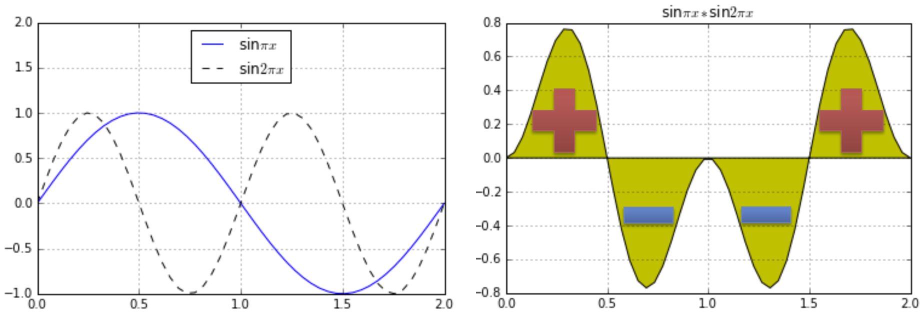
- $a(t) = \sin(2\pi f_1 t), f_1 = 1Hz$
  $b(t) = \sin(2\pi f_2 t), f_2 = 2Hz$
- $a(t)*a(t)$: T=1



$\int_T a(t)a(t)dt > 0$

➢ $\sin 2\pi f_1 t$ is *not* orthogonal to itself.

- $a(t)*b(t)$: now T=2



$\int_T a(t)b(t)dt = 0$

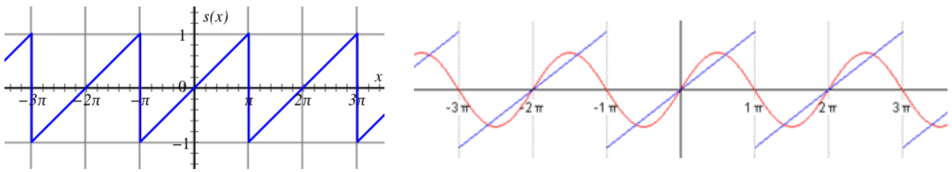
➢ $\sin 2\pi f_1 t$ *and* $\sin 2\pi(2f_1)t$ are orthogonal.

Periodic Signal: Fourier Series

$$x(t) = \frac{A_0}{2} + \sum_{n=1}^{\infty}\left[A_n \cos(2\pi n f_0 t) + B_n \sin(2\pi n f_0 t)\right]$$

$$A_n = \frac{2}{T}\int_T x(t)\cos(2\pi n f_0 t)dt$$

$$B_n = \frac{2}{T}\int_T x(t)\sin(2\pi n f_0 t)dt$$



Fourier Transform

- For aperiodic signal, Fourier representation becomes a continuum of frequencies.
- Integral transform
  - Forward: $x(t) \leftrightarrow X(f)$

    $$X(f) = \int_{-\infty}^{\infty} x(t) e^{-j2\pi ft} dt$$

  - Inverse:

    $$x(t) = \int_{-\infty}^{\infty} X(f) e^{j2\pi ft} df$$

Dealing with Digital Signals

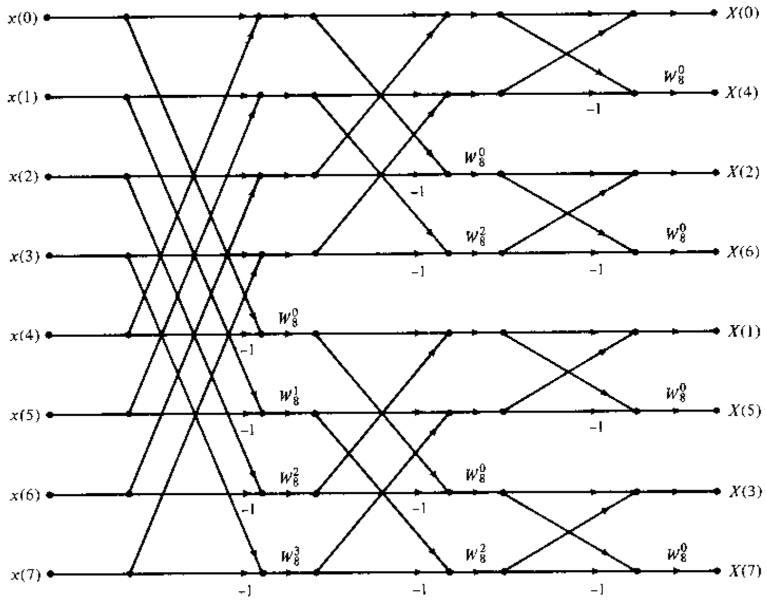
- $x[n]$ denotes digital signals
- Discrete Fourier Transform (DFT)
  - for finite duration discrete signals
  - defined on discrete frequencies using Fourier series:

$$X(k) = \frac{1}{N} \sum_{n=0}^{N-1} x[n] e^{-jk(2\pi/N)n}, k = 0,1,\ldots,N-1$$

$$x[n] = \sum_{k=0}^{N-1} X[k] e^{jk(2\pi/N)n}, n = 0,1,\ldots,N-1$$

- Fast algorithms exist for DFT: "FFT"

"Butterfly" FFT



Characteristics of F.T.

- Symmetry: $X(-f) = X(f)$ if x(t) is real and even
- Linearity: $ax_1(t) + bx_2(t) \Leftrightarrow aX_1(f) + bX_2(f)$
- Duality: $X(t) \Leftrightarrow x(-f)$
- Time shift → Phase shift in freq. domain
  - $x(t - t_0) \Leftrightarrow e^{j2\pi f t_0} X(f)$

Characteristics (more)

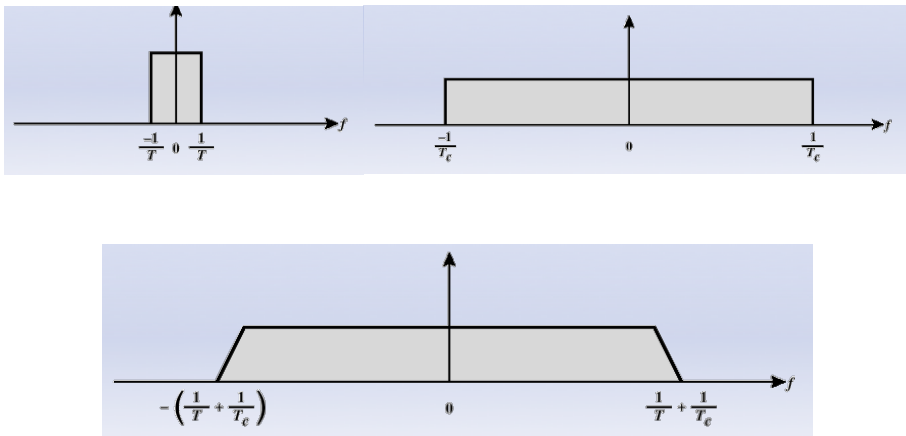
- Parseval's relation (on energy)
  - $\int_{-\infty}^{+\infty} |x(t)|^2 \, dt = \int_{-\infty}^{+\infty} |X(f)|^2 \, df$

❖ Convolution in T.D. is equivalent to multiplication in F.D.
  - $y(t) = x(t) * h(t) = \int_{-\infty}^{+\infty} x(\tau) h(t - \tau) d\tau$
  - $Y(f) = X(f)H(f)$

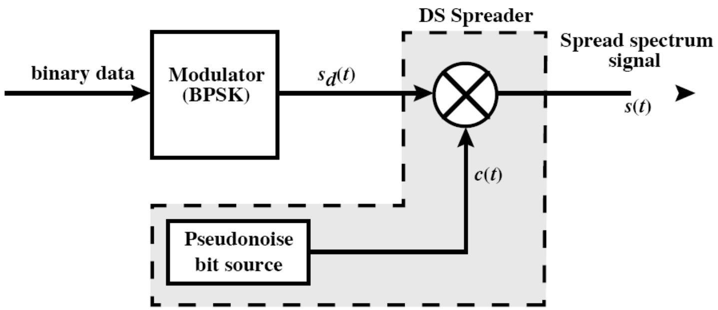
➢ What about multiplication in T.D.?

From Wolfram MathWorld

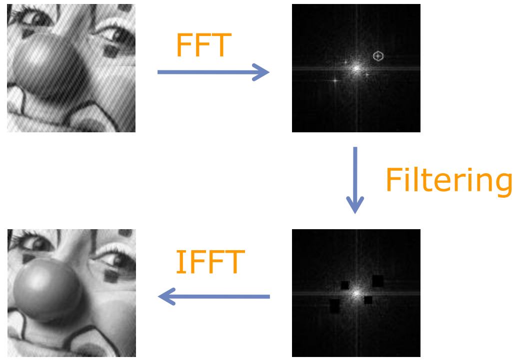
Spreading the Spectrum (Fig.7.9)



Example: Direct Sequence Spread Spectrum (Figure 9.7)



A Signal Processing Example – Noise Removal



http://www.mediacy.com/, retrieved on 2/2/2008

The Duality, again

- Convolution is expensive!
- Convolution in TD = multiplication in FD
  - Filtering in FD is handy (with the use of FFT/IFFT)

- Convolution in FD = multiplication in TD
  - Spread spectrum is handy in TD!

Media & Signaling

• • •

Transmission Media

- Transmission medium: Physical path between transmitter and receiver
- Guided Media
  - Waves are guided along a solid medium
  - E.g., copper twisted pair, copper coaxial cable, optical fibre
- Unguided Media
  - Provides means of transmission but does not guide electromagnetic signals
  - Usually referred to as wireless transmission
  - E.g., atmosphere, water, outer space

QUIZ TIME

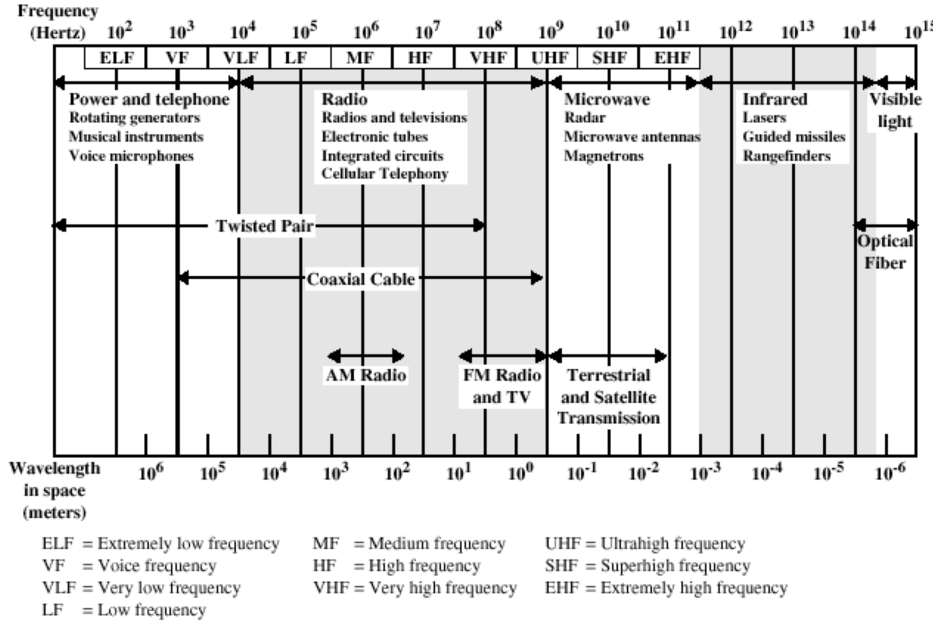


Figure 2.10 Electromagnetic Spectrum for Telecommunications

Unguided Media

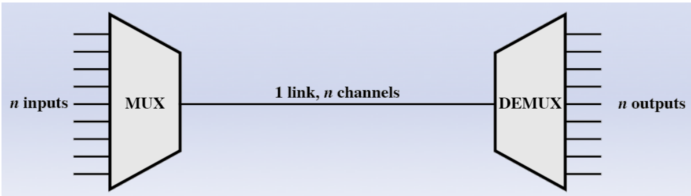
- Transmission and reception are achieved by means of an antenna
- Configurations for wireless transmission
  - Directional
  - Omnidirectional

General Frequency Ranges

- Radio frequency range
  - 30 MHz to 1 GHz
  - Suitable for omnidirectional applications
- Microwave frequency range
  - 1 GHz to 40 GHz
  - Directional beams possible
  - Suitable for point-to-point transmission
  - Used for satellite communications
- Infrared frequency range
  - Roughly, $3x10^{11}$ to $2x10^{14}$ Hz
  - Useful in local point-to-point multipoint applications within confined areas

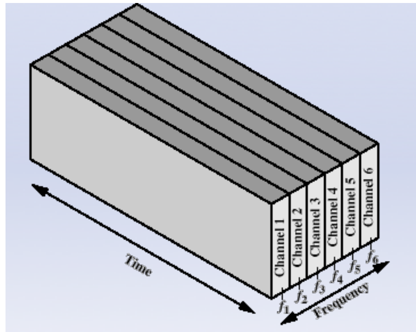
Multiplexing

- Capacity of transmission medium usually exceeds capacity required for transmission of a single signal
- Multiplexing - carrying multiple signals on a single medium, hence more efficient
- Two basic forms of multiplexing:
  - Frequency-division multiplexing (FDM)
  - Time-division multiplexing (TDM)



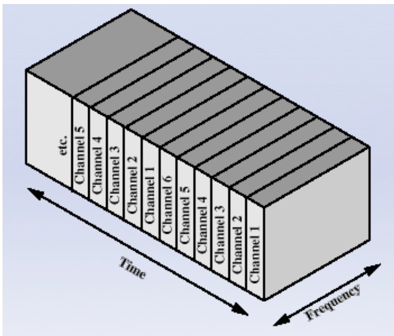
FDM

- Frequency-division multiplexing (FDM)
  - Takes advantage of the fact that the useful bandwidth of the medium exceeds the required bandwidth of a given signal
  - Guard-bands between channels needed
  - Easy to implement in analog system



TDM

- Time-division multiplexing (TDM)
  - Takes advantage of the fact that the achievable bit rate of the medium exceeds the required data rate of a digital signal
  - Can be synchronous or statistical
  - Format flexibility and lower power consumption



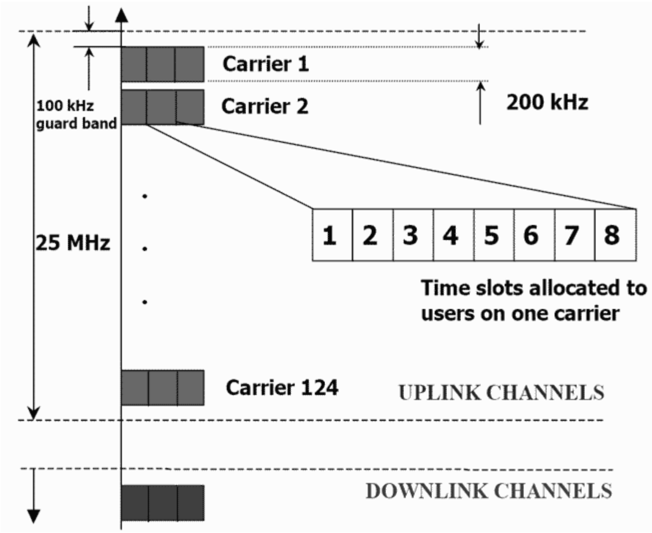
Duplexing: FDD vs TDD

- FDD: Frequency-Division Duplexing
  - Easy to implement
  - Needs guard band
- TDD: Time-Division Duplexing
  - Synchronisation required
  - Stringent requirement on RTT
  - Can be made adaptive
- FDD favoured in WCDMA
  - However: TD-SCDMA uses TDD.
- Both are supposed to be supported in new standards, e.g., IEEE 802.20.

Example: GSM

- FDMA/TDMA/FDD
- Forward and reverse channels use separate carrier frequencies (FDD).
- Each carrier supports up to 8 users via TDMA, each using a 13 kbps encoded speech signal, within a 200 kHz bandwidth.
- A total of 124 frequency carriers are available in the 25 MHz band in each direction.

FDMA/TDMA/FDD Scheme in GSM



Recap

- This lecture:
  - Frequency transform
  - Transmission media
  - Multiplexing
- Reading: Stallings Ch.2

- Next: propagation & encoding