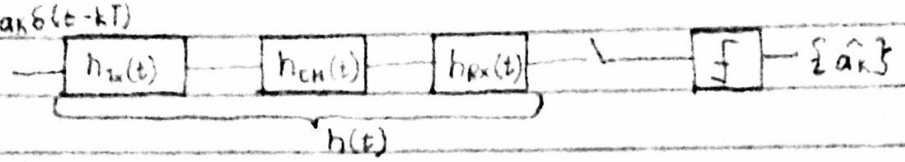
11/04/15

Lecture 15

ISI

* no noise

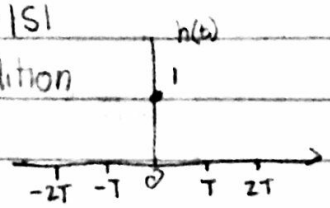
$\sum a_k \delta(t-kT)$



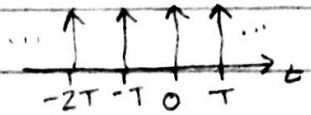
$$h(t) = \begin{cases} 1, & t=0 \\ 0, & t=kT,\ k\neq 0 \end{cases}$$

Best $h(t)$? (min BW)

No-ISI condition



$h(t)\sum\delta(t-kT) = \delta(t)$



↳ Nyquist condition

→ FT

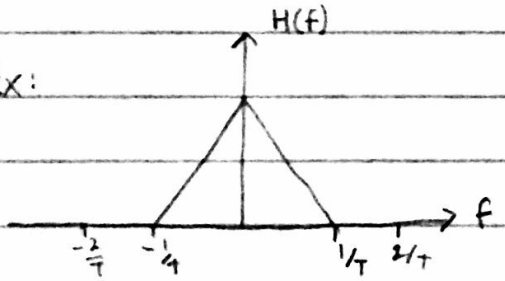
↳ $FT(h(t)) * FT(\sum\delta(t-kT)) = 1$

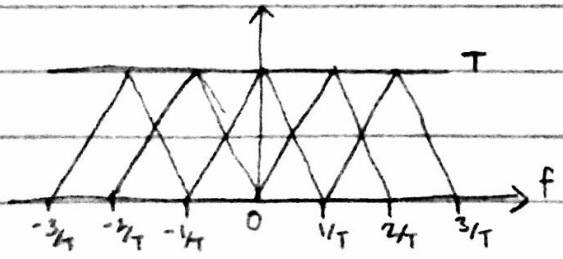
→ $H(f) * \frac{1}{T}\sum\delta(f-\frac{k}{T}) = 1$

→ $\frac{1}{T}\sum H(f-\frac{k}{T}) = 1$

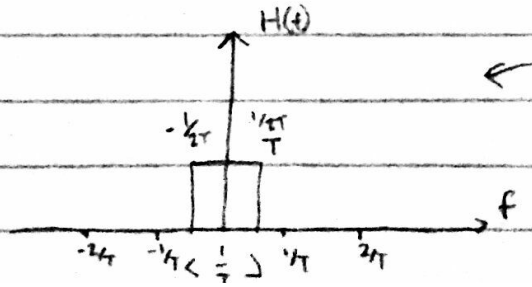
$\boxed{\sum_{-\infty}^{\infty} H(f-\frac{k}{T}) = T}$ Nyquist no ISI condition

Ex:

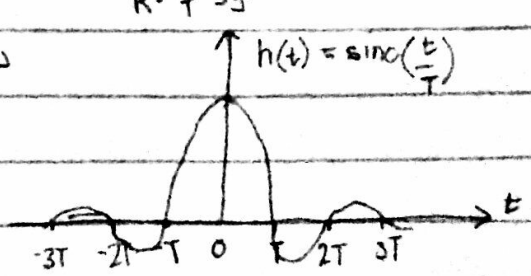




H(f) with min BW?

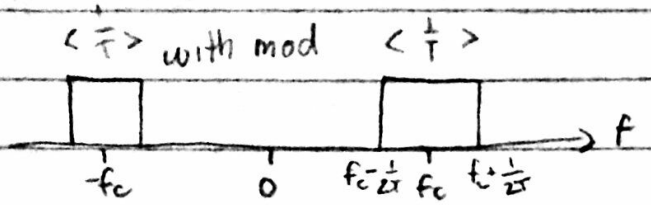


$R = \frac{1}{T}$ syms/sec



$BW = \frac{1}{2T} = \frac{R}{2}$ Spectral Efficiency $= \frac{R}{BW} = \frac{R}{R/2} = 2$

$SE_{max,sym,baseband} = 2$ symbols/sec/Hz



$SE_{max,sym,mod} = 1$ symbols/sec/Hz

$R = SE \times B$

$= \underbrace{\frac{\text{syms/sec}}{\text{Hz}} \times \text{Hz}}_{\text{sym/sec}}$

Packing Rate: What is the max # of bits you can pack in a symbol?

bits/sym

64QAM $\rightarrow \log_2 64 = 6$ bits/sym

Why not just use high M-ary all the time? Because noise

Packing Rate $= \log_2(1+SNR)$ bits/sym

Ex: SNR = 9 dB

$\log_2(1+8) = \log_2 9 = 3.2$ bits/sym

$SE_{max} = 1 \frac{\text{sym/sec}}{\text{Hz}} \times \log_2(1+SNR) \frac{\text{bits}}{\text{sym}}$

$= \log_2(1+SNR)$ bits/sec/Hz

Nyquist + Shannon

↳ $BW \times SE_{max} = W \log_2(1+SNR) = R_{max}$

BW, SE_{max}

$R_{max} = nW \log_2(1+SNR)$

↳ $\min(n_{Tx}, n_{Rx})$ = mimo gain

Ex: 4G LTE-Advanced

Carrier aggregation: 5 × 20 MHz = 100 MHz

64 QAM

8-layer MIMO

$8 \times 100\,\text{MHz} \times \overbrace{\log_2 64}^{6\ \text{bits/sec/Hz}} \times 1\ \text{sym/sec/Hz}$

$= 4.8\ \text{Gb/s} \leftarrow \text{peak}$

~ 2035-2040 : 6G

Design 1 Tbps

Find n, W, SNR

such that

$nW \underbrace{\log_2(1+SNR)}_{12} = 12\ \text{Tbps}$

$\downarrow 100 \quad \downarrow 100\,\text{GHz}$

[80 90 GHz]

$\uparrow$ 4096 QAM

SE:
- LTE/LTE-A → 64 QAM → 6 bit/sec/Hz
- V.92 → 4096 QAM → 12 bits/sec/Hz
- 56 kbps
- VDSL-2+ → 15 bits/sec/Hz

fiber: binary: 1 bit/sec/Hz