Principles of Communications
ECS 332

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3. Modulation

Office Hours:
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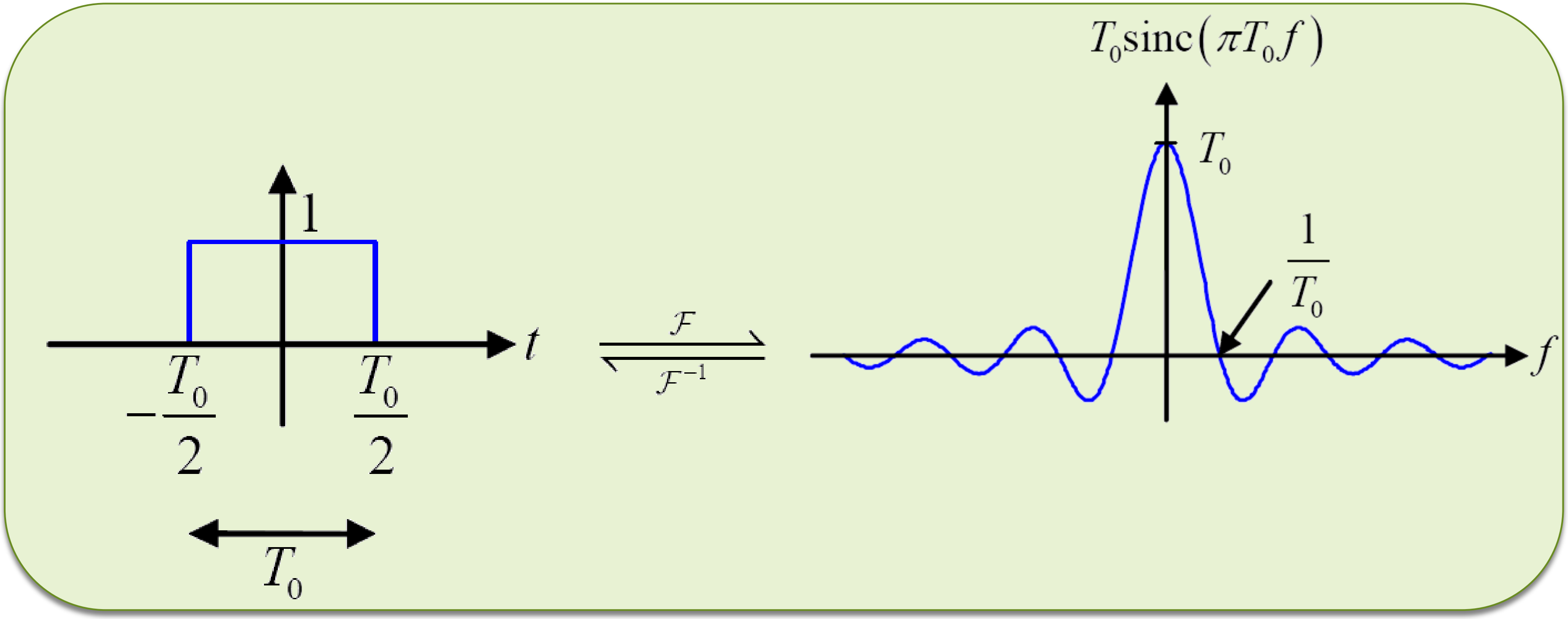
Monday	**14:40-16:00**
Friday	**14:00-16:00**

Frequency-Domain Analysis

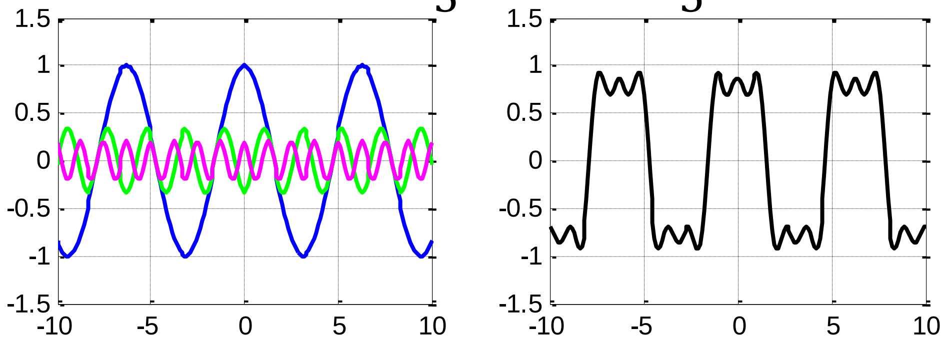


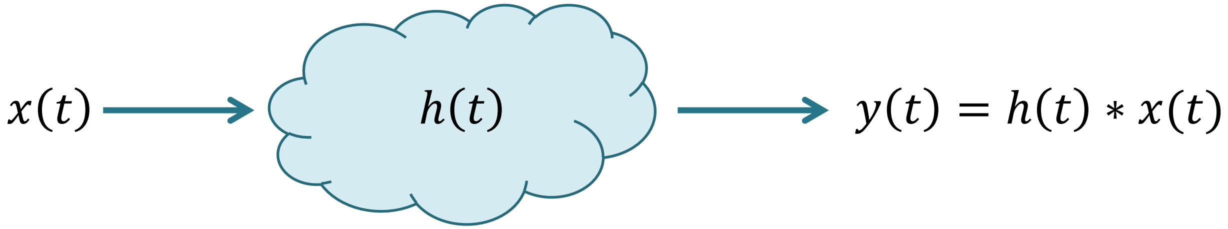
Shifting Properties: $g(t-t_0) \overset{\mathcal{F}}{\rightleftharpoons} e^{-j2\pi f t_0} G(f)$ $\quad e^{j2\pi f_0 t} g(t) \overset{\mathcal{F}}{\rightleftharpoons} G(f-f_0)$

Modulation: $m(t)\cos(2\pi f_c t) \overset{\mathcal{F}}{\rightleftharpoons} \frac{1}{2} M(f-f_c) + \frac{1}{2} M(f+f_c)$

Test Signal

$$x(t) = \cos(t) - \frac{1}{3}\cos(3t) + \frac{1}{5}\cos(5t)$$

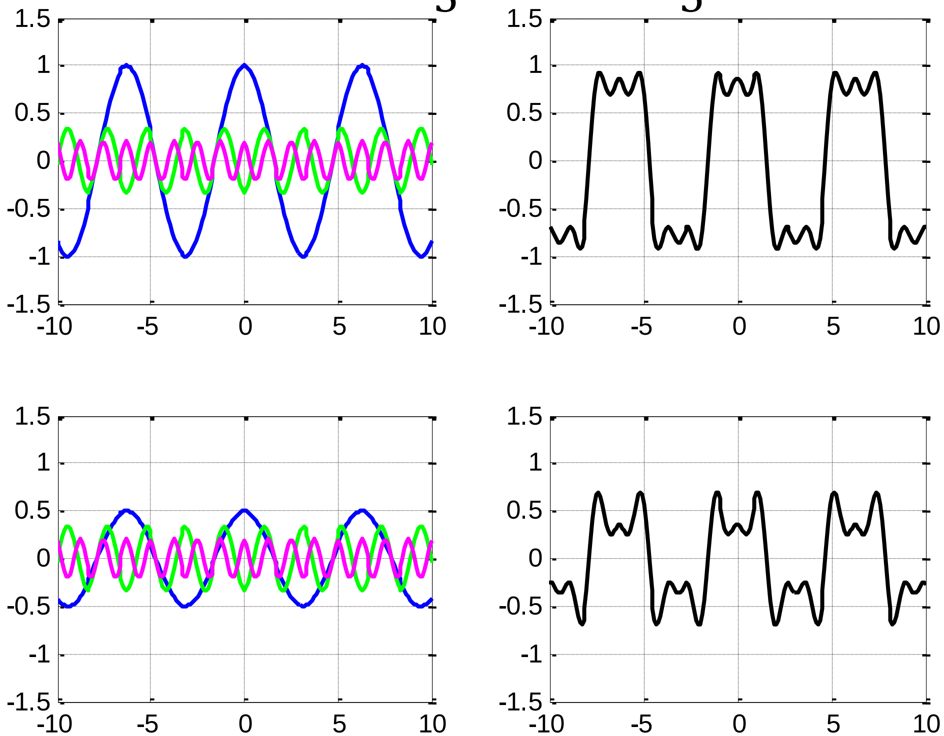




Distortion: Low Frequency Attenuation

$f = 1/2\pi$, $f = 3/2\pi$, $f = 5/2\pi$

$$x(t) = \cos(t) - \frac{1}{3}\cos(3t) + \frac{1}{5}\cos(5t)$$



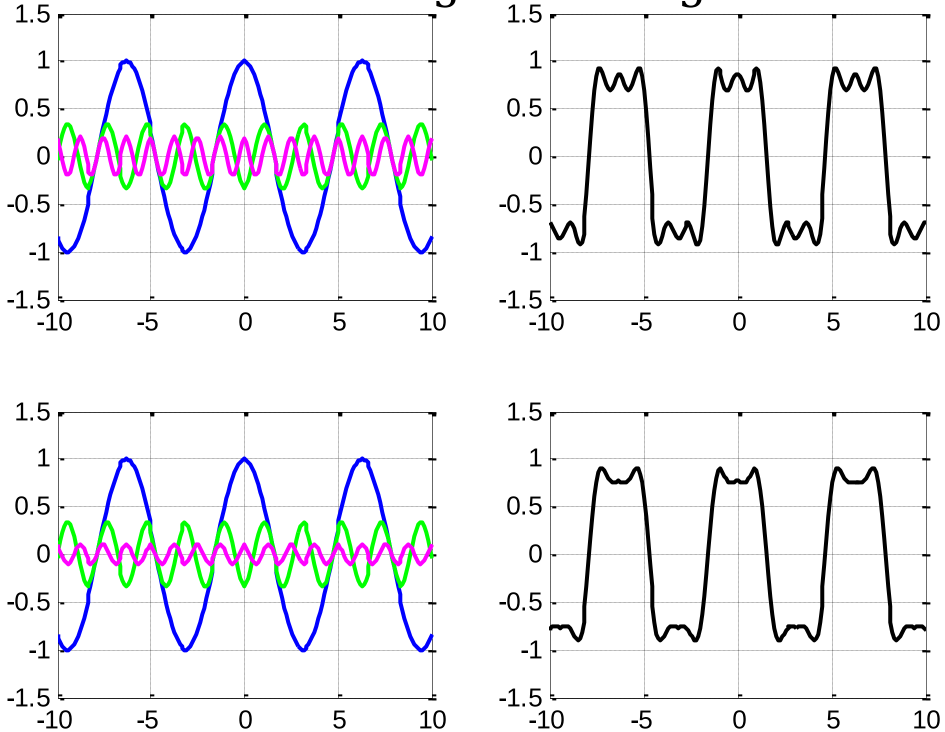
$$y(t) = \frac{1}{2}\cos(t) - \frac{1}{3}\cos(3t) + \frac{1}{5}\cos(5t)$$

$$\cos(\alpha) = \frac{e^{j\alpha} + e^{-j\alpha}}{2}$$

$$\cos(2\pi f_0 t) = \frac{e^{j2\pi f_0 t} + e^{-j2\pi f_0 t}}{2}$$

Distortion: High Frequency Attenuation

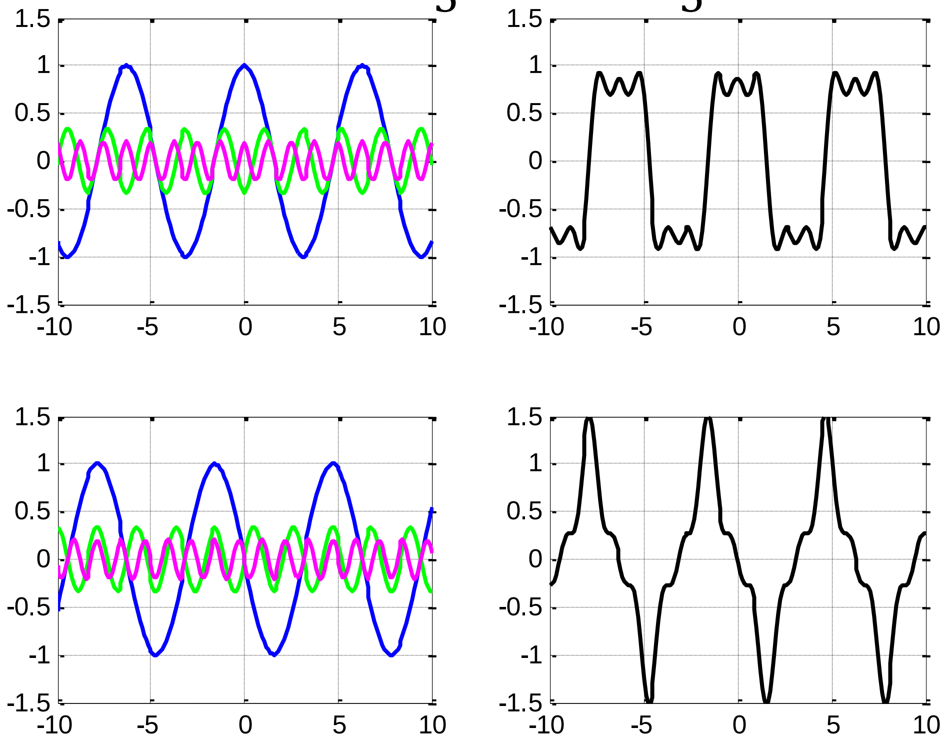
$$x(t) = \cos(t) - \frac{1}{3}\cos(3t) + \frac{1}{5}\cos(5t)$$



$$y(t) = \cos(t) - \frac{1}{3}\cos(3t) + \frac{1}{2}\frac{1}{5}\cos(5t)$$

Distortion: Constant Phase Shift

$$x(t) = \cos(t) - \frac{1}{3}\cos(3t) + \frac{1}{5}\cos(5t)$$



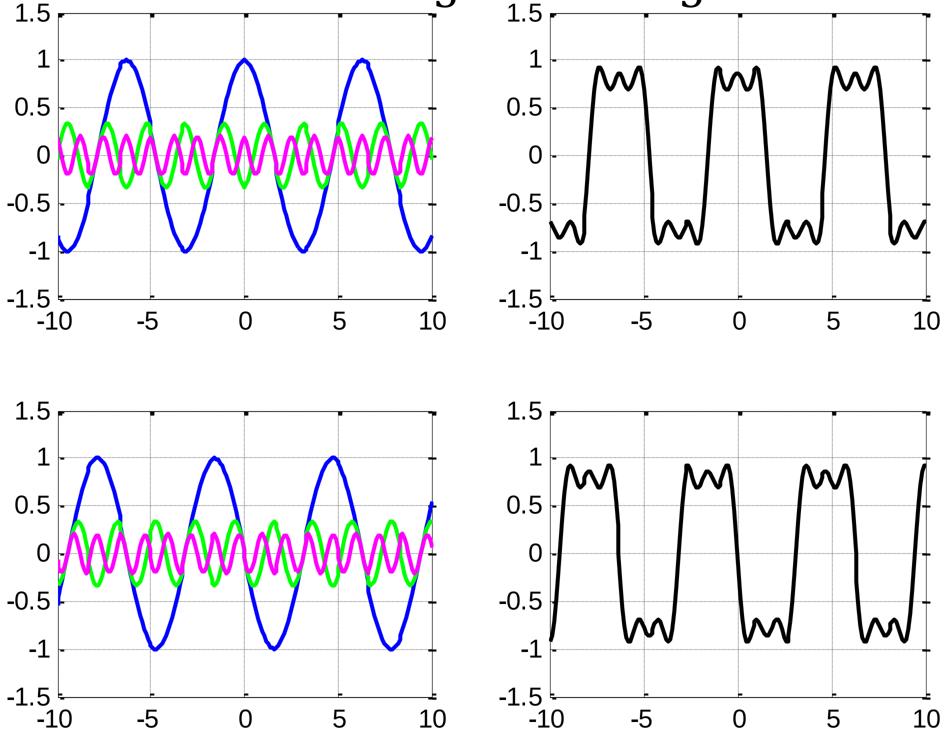
Components of the distorted signal all attain maximum or minimum values at the same time.

$$y(t) = \cos\left(t + \frac{\pi}{2}\right) - \frac{1}{3}\cos\left(3t + \frac{\pi}{2}\right) + \frac{1}{5}\cos\left(5t + \frac{\pi}{2}\right)$$

Surprising fact: an untrained human ear is curiously insensitive to phase distortion. The waveforms above would sound just about the same when driving a loudspeaker. Thus, phase distortion is seldom of concern in voice and music transmission.

Linear Phase Shift

$$x(t) = \cos(t) - \frac{1}{3}\cos(3t) + \frac{1}{5}\cos(5t)$$

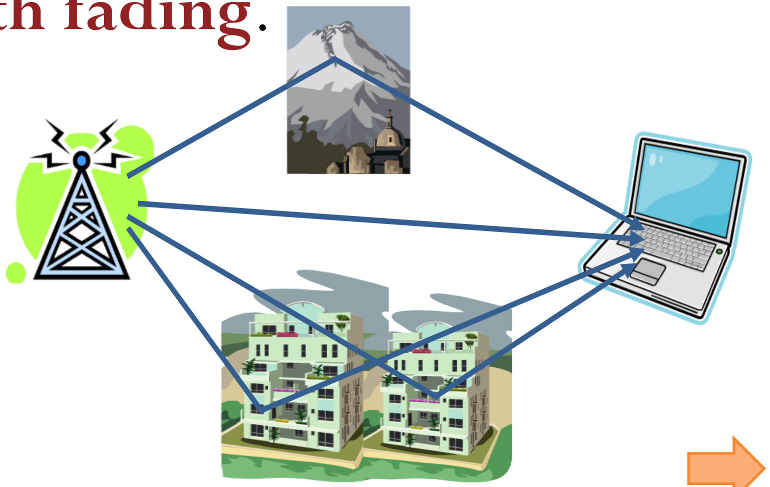


$$y(t) = \cos\left(t + \frac{\pi}{2}\right) - \frac{1}{3}\cos\left(3t + 3\frac{\pi}{2}\right) + \frac{1}{5}\cos\left(5t + 5\frac{\pi}{2}\right)$$

$$= \cos\left(t + \frac{\pi}{2}\right) - \frac{1}{3}\cos\left(3\left(t + \frac{\pi}{2}\right)\right) + \frac{1}{5}\cos\left(5\left(t + \frac{\pi}{2}\right)\right) = x\left(t + \frac{\pi}{2}\right)$$ Same as time-shift!

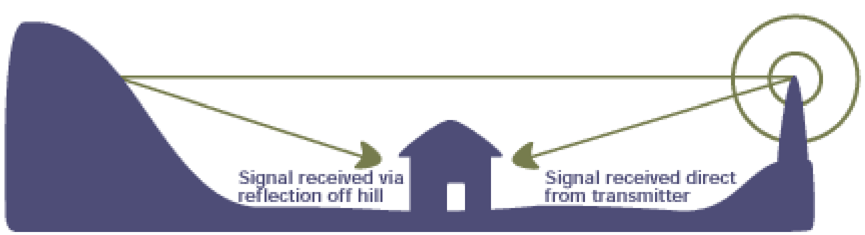
Multipath Propagation

- In a wireless mobile communication system, a transmitted signal propagating through the wireless channel often encounters multiple reflective paths until it reaches the receiver
- We refer to this phenomenon as **multipath propagation** and it causes fluctuation of the amplitude and phase of the received signal.
- We call this fluctuation **multipath fading**.



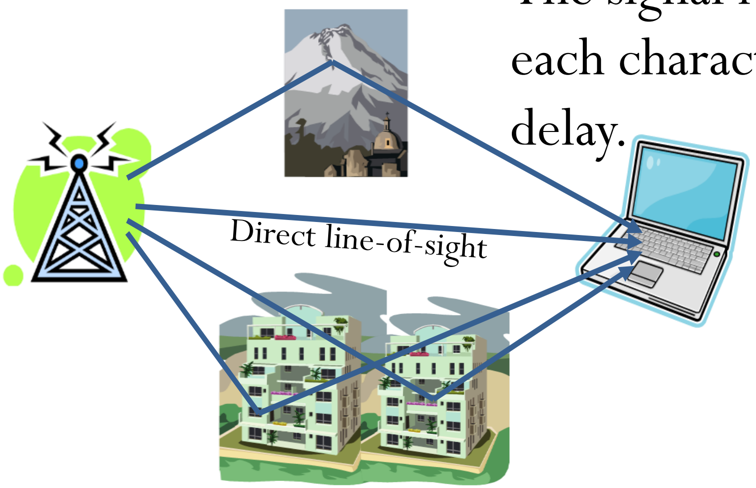
Remark: Reflections due to mismatched impedance on a cable system produce the same effect

Similar Problem: Ghosting



Wireless Comm. and Multipath Fading

The signal received consists of a number of reflected rays, each characterized by a different amount of attenuation and delay.

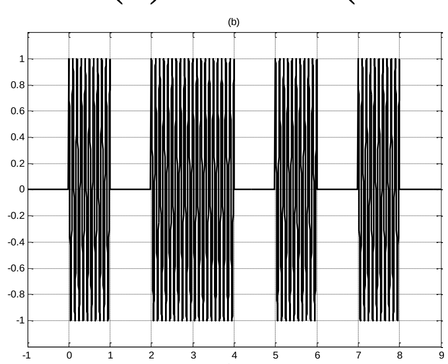


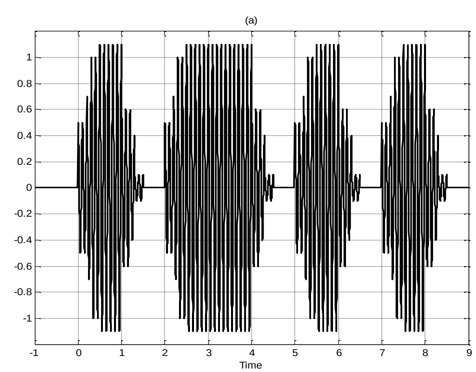
$$y(t) = x(t) * h(t) + n(t) = \sum_{i=0}^{v} \beta_i x(t - \tau_i) + n(t)$$

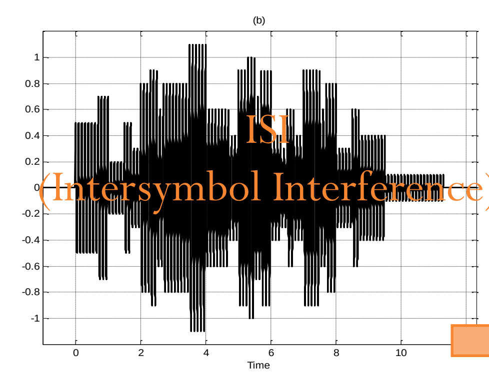
$$h(t) = \sum_{i=0}^{v} \beta_i \delta(t - \tau_i)$$

$$h_1(t) = 0.5\delta(t) + 0.2\delta(t - 0.2T_s) + 0.3\delta(t - 0.3T_s) + 0.1\delta(t - 0.5T_s)$$

$$h_2(t) = 0.5\delta(t) + 0.2\delta(t - 0.7T_s) + 0.3\delta(t - 1.5T_s) + 0.1\delta(t - 2.3T_s)$$



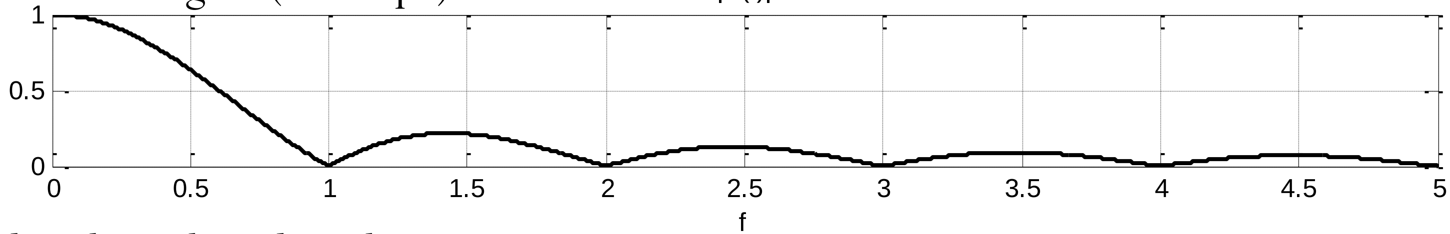




Frequency Domain

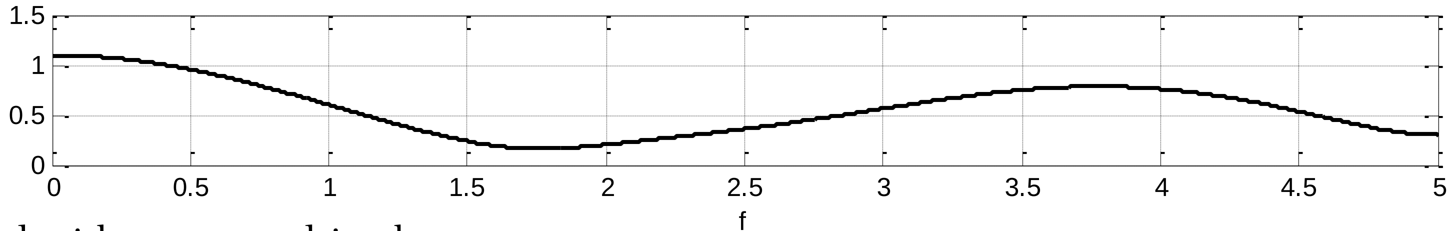
The transmitted signal (envelope)

|P(f)|



Channel with weak multipath

$|H_1(f)|$



Channel with strong multipath

$|H_2(f)|$