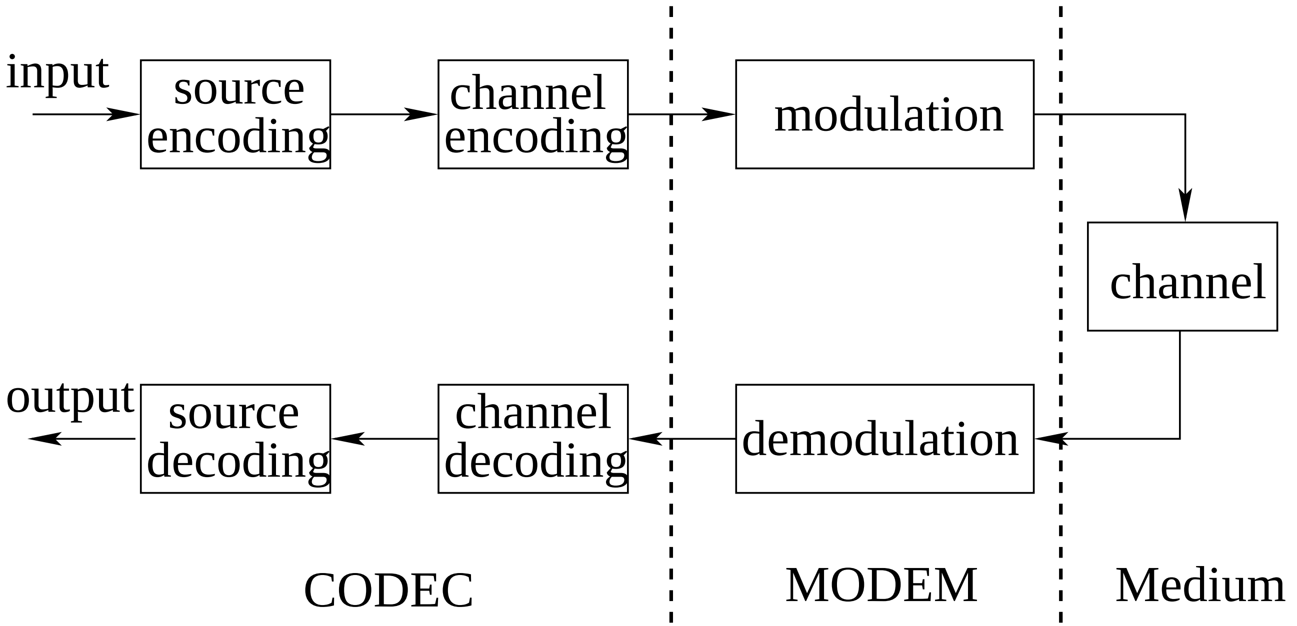
Digital Communication System

- Purpose: communicate information at certain **rate** between geographically separated locations reliably (**quality**)

  Important point: rate, quality ↔ **spectral bandwidth** requirement

- Major components: CODEC, MODEM and channel (transmission medium)



Digital Communication System (continue)

- A pair of transmitter (coder, modulator) and receiver (demodulator, decoder) is called *transceiver*
- Information theory provides us basic communication theory for communication system design, including CODEC and MODEM
- Detailed practical CODEC design, including source coding and channel coding, will be covered latter by the other lecturer
- This part considers MODEM (modulation/demodulation)
- The purpose of MODEM: **transfer the bit stream at certain rate over the communication medium reliably**
- Why *carrier* communication (modulation): low frequency signal cannot travel far, also most spectral resource (channels) are in RF

Digital Modulation

- In the old day, communications were *analogue*, analogue modulation techniques include amplitude modulation (AM), frequency modulation (FM), and phase modulation (PM)

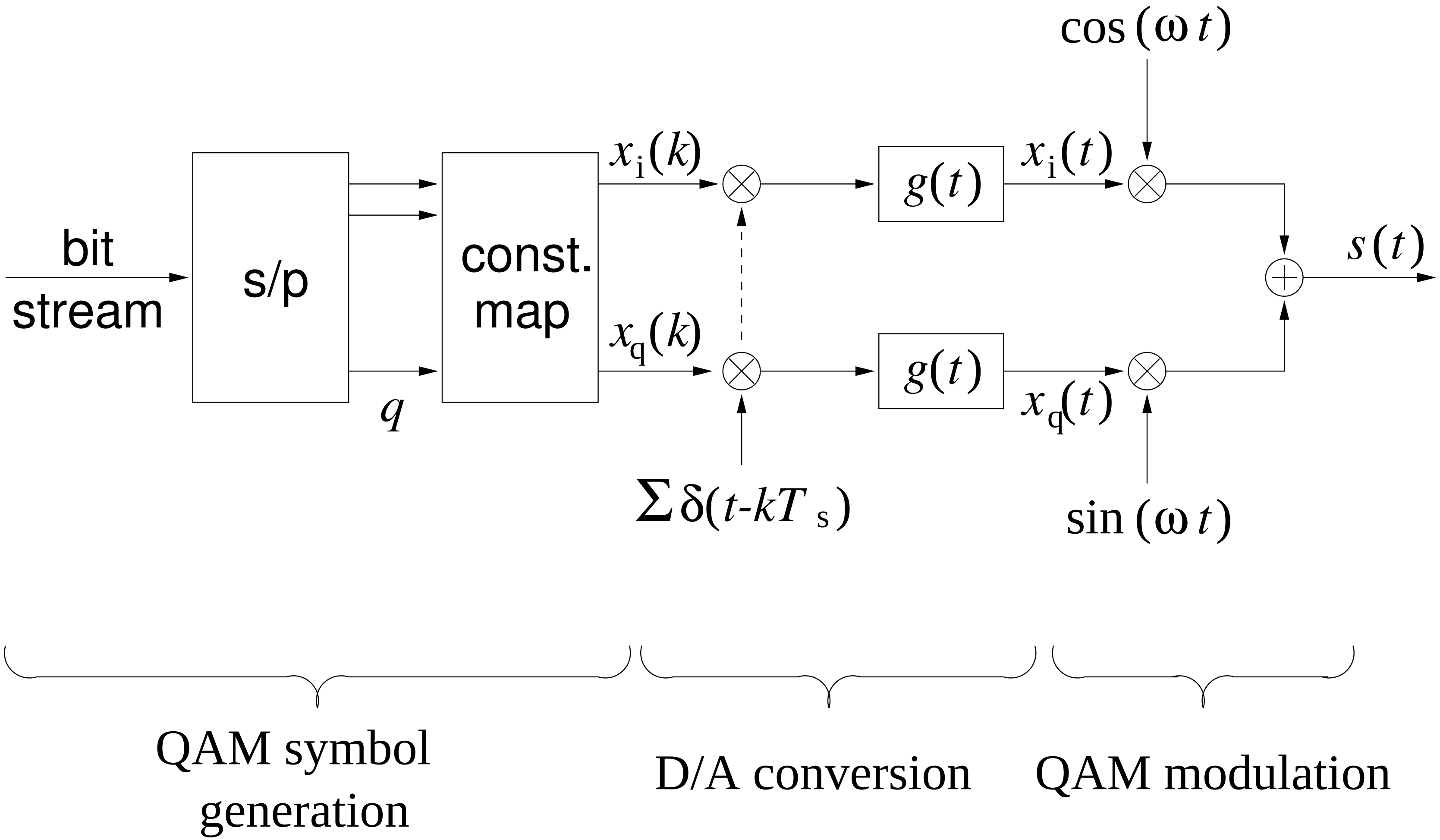
- Communications today are mostly all *digital*, equivalent digital modulation forms exist: amplitude shift keying (ASK), frequency shift keying (FSK), or phase shift keying (PSK)

  Sin waveform $A \sin(2\pi f_c t + \theta)$: amplitude A, frequency f_c, phase $\theta \longrightarrow$ three kinds of modulation

- A large number of other digital modulations are in use, and often combinations are employed

- We will consider quadrature amplitude modulation (QAM), which is a combination of ASK and PSK

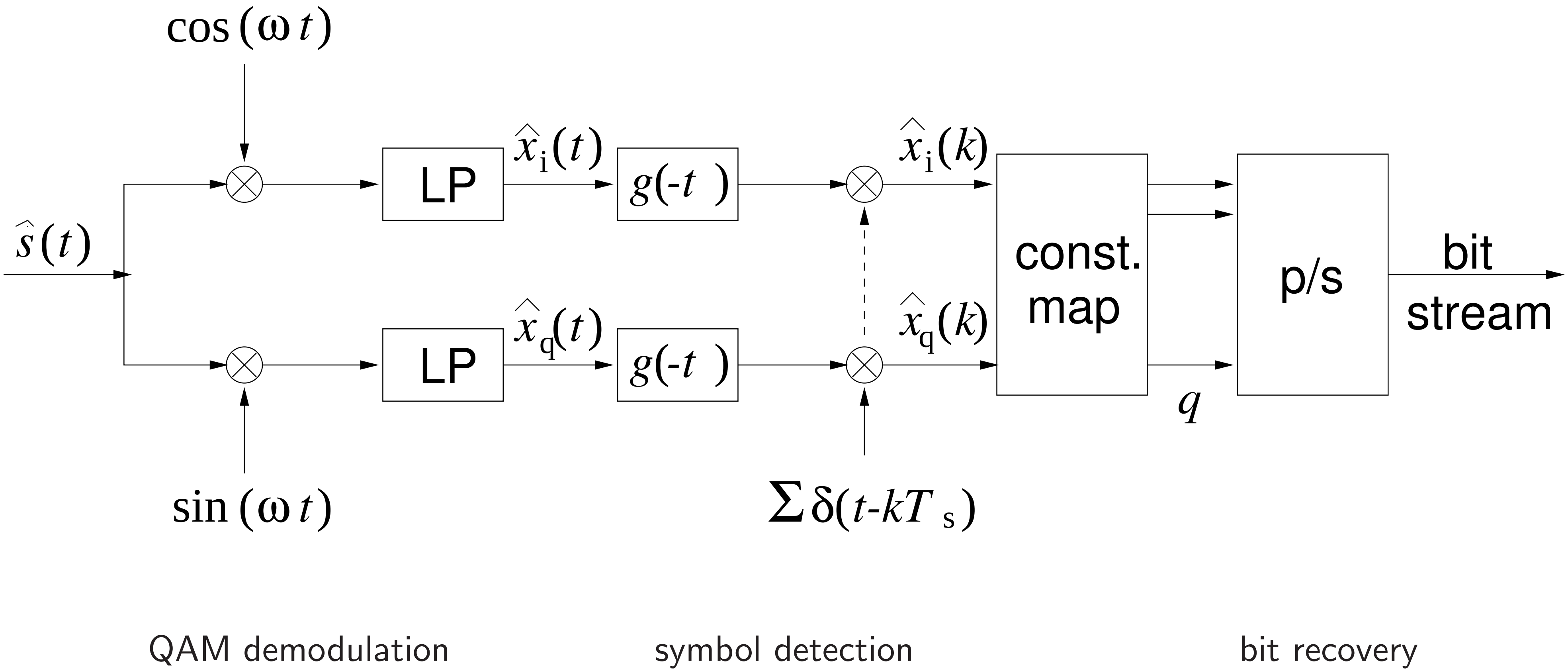
Quadrature Amplitude Modulation



Note: e.g., odd bits go to form $x_{\mathrm{i}}(k)$ and even bits to form $x_{\mathrm{q}}(k)$; $x_{\mathrm{i}}(k)$ and $x_{\mathrm{q}}(k)$ are in-phase and quadrature components of the $x_{\mathrm{i}}(k) + jx_{\mathrm{q}}(k)$ QAM symbol; $x_{\mathrm{i}}(k)$ and $x_{\mathrm{q}}(k)$ are M-ary symbols

D/A conversion is not "correct full name", should be called transmit filter, part of pulse shaping filter pair

Quadrature Amplitude Demodulation

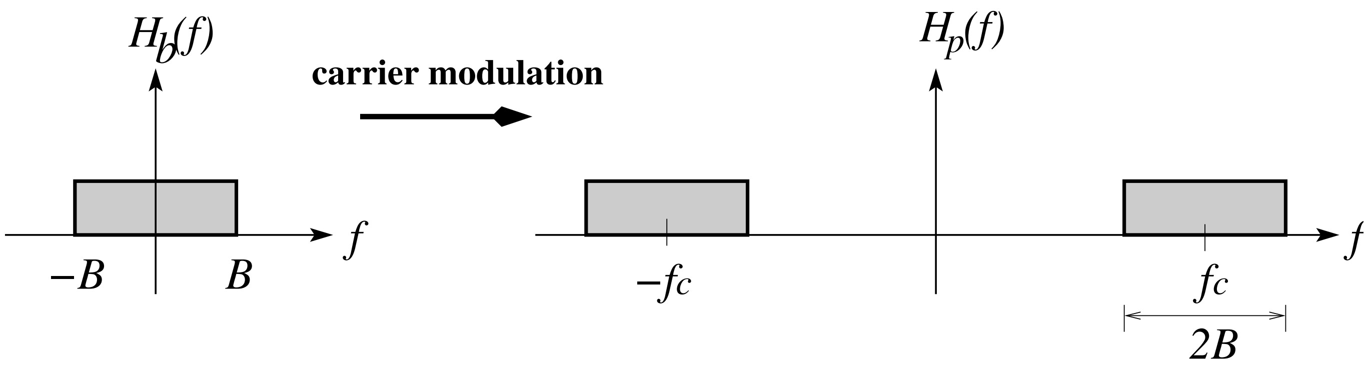


Note: in-phase and quadrature branches are "identical"; many issues, such as design of Tx/Rx filters $g(t)/g(-t)$, carrier recovery, synchronisation, can be studied using one branch

Channel (Medium) I

- Between modulator and demodulator is medium (channel)

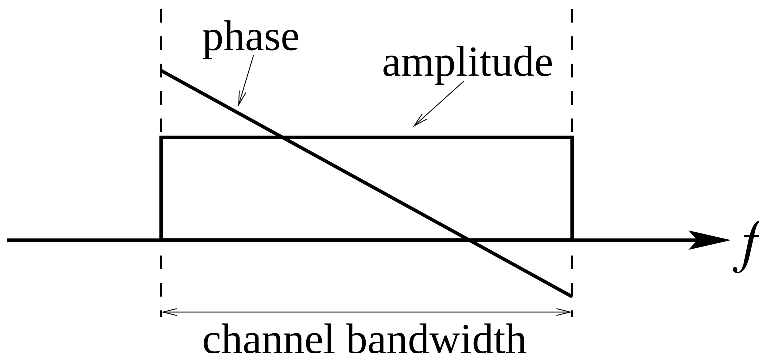
- Passband channel and baseband (remove modulator/demodulator) equivalence:



Baseband channel bandwidth $B \leftrightarrow$ passband channel bandwidth $2B$

- Communication is at passband channel but for analysis and design purpose one can consider equivalent baseband channel

- Channel has *finite* bandwidth, ideally phase is linear and amplitude is flat:

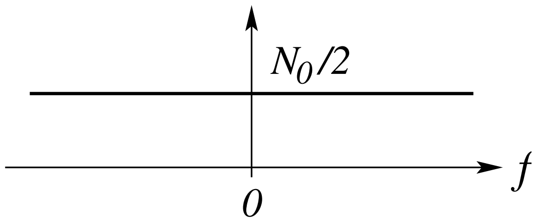


Channel (Medium) II

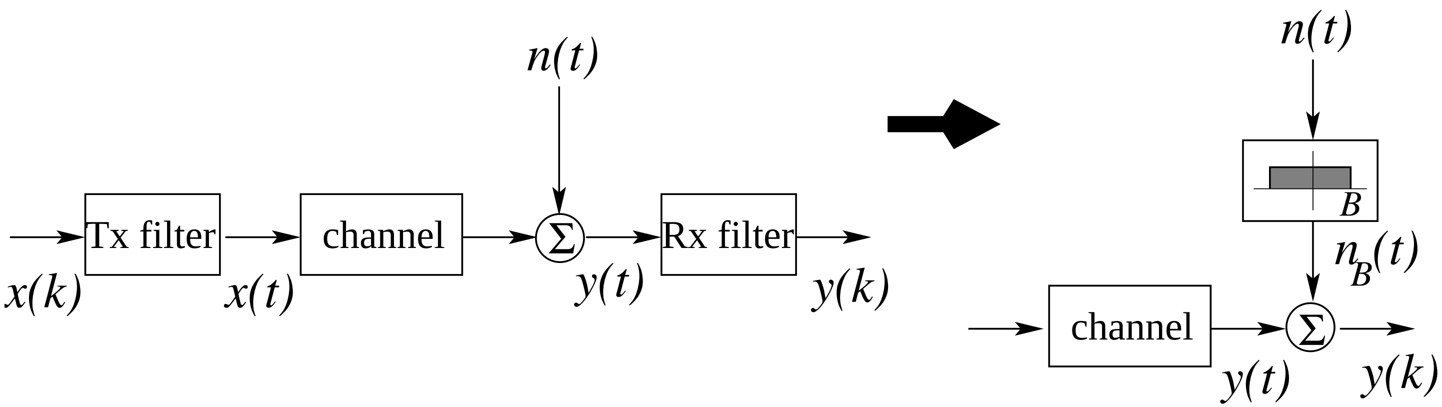
- Bandwidth is a prime consideration, and another consideration is noise level

- Channel noise: AWGN with a constant power spectrum density (PSD)

- Power is the area under PSD, so WN has infinitely large power



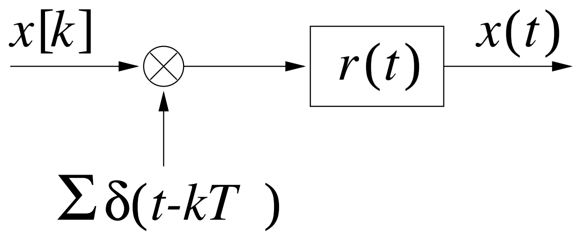
- But communication channels are bandlimited, so noise is also bandlimited and has a finite power:



Pulse Shaping I

- Unless transmission symbol rate f_s is very low, one cannot use impulse, narrow pulse or rectangular pulse to transmit data symbols, and discrete samples have to be *pulse shaped*
  - $\{x[k]\}$: transmitted symbols
  - $\sum \delta(t - kT_s)$: pulse clock (every T_s s a symbol is transmitted)
  - $r(t)$: combined impulse response of Tx/Rx filters, and channel

    $r(t) = g(-t) \star c(t) \star g(t)$ or $R(f) = G_R(f) \cdot C(f) \cdot R_T(f)$



  - Baseband (received) signal, assuming no noise

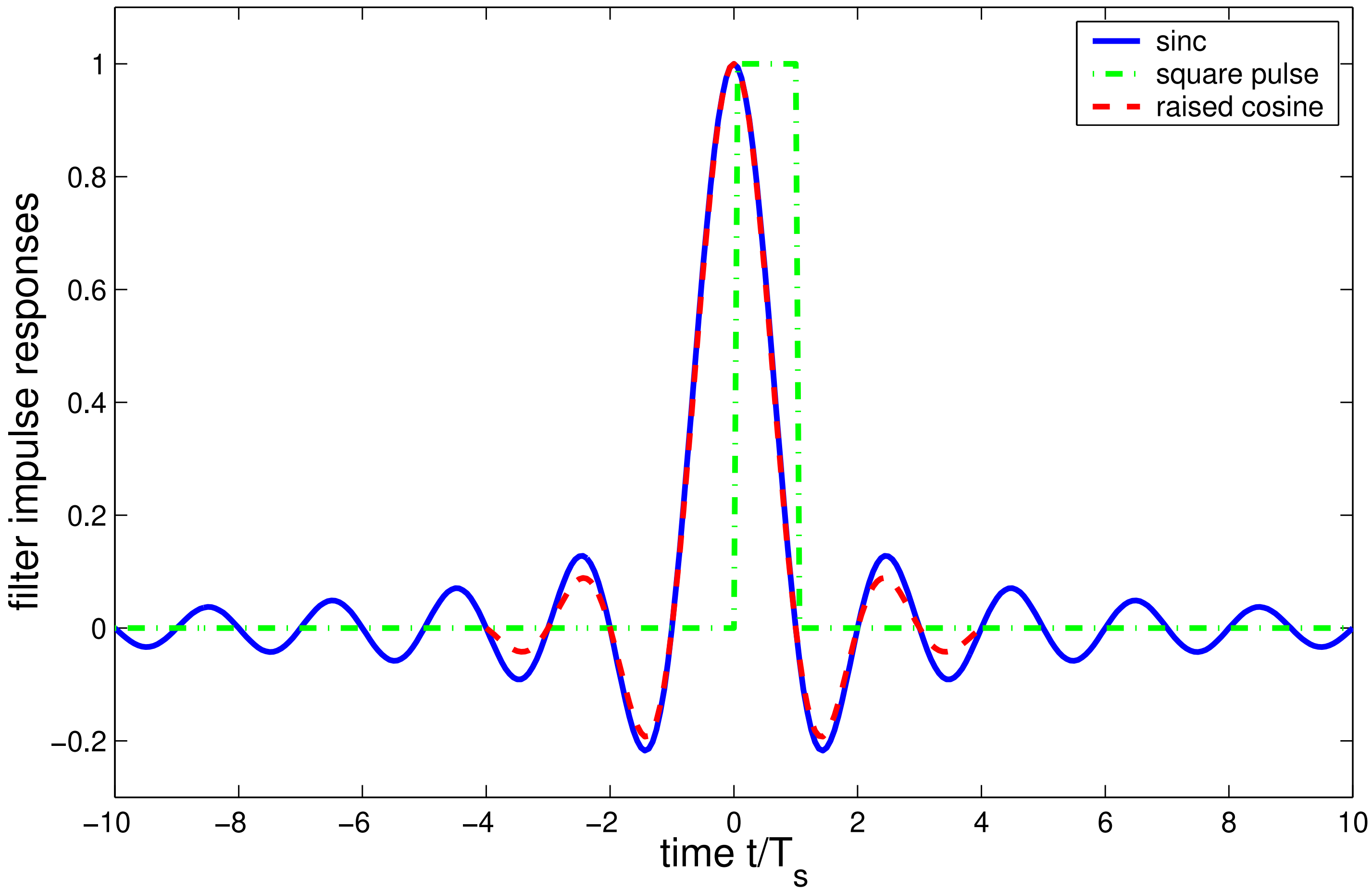
$$x(t) = r(t) \star \left(\sum x[k]\delta(t - kT_s) \right) = \int \sum r(t - \tau) \cdot x[k]\delta(\tau - kT_s)\, d\tau$$

$$= \sum_{k=-\infty}^{+\infty} x[k] \cdot r(t - kT_s)$$

- A number of choices for $r(t)$ would allow to retrieve the original data sample $x[k]$ from $x(t)$: what are the requirements for $r(t)$?

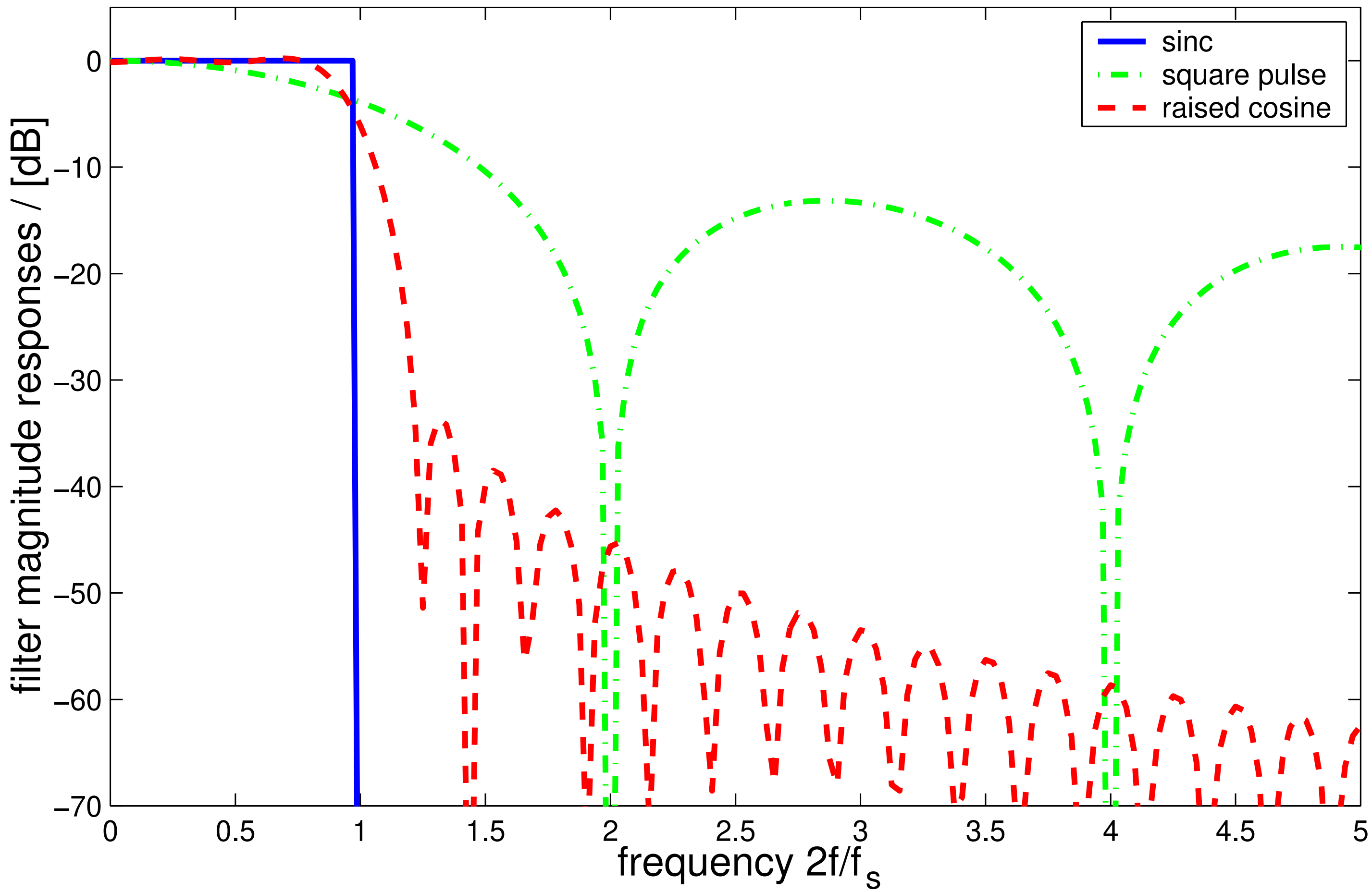
- To transmit at symbol rate f_s needs certain bandwidth B_T and B_T depends on which pulse shaping used — does the channel bandwidth B enough to accommodate B_T?

Pulse Shaping II — Time Domain



- sinc: assume $t \to \pm\infty$; square: last one T_s; and raised cosine: truncate to 8 T_ss
- All these filters have regular zero-crossing at symbol-rate spacing except $t = 0$ (**Nyquist** system), but they have different time supports

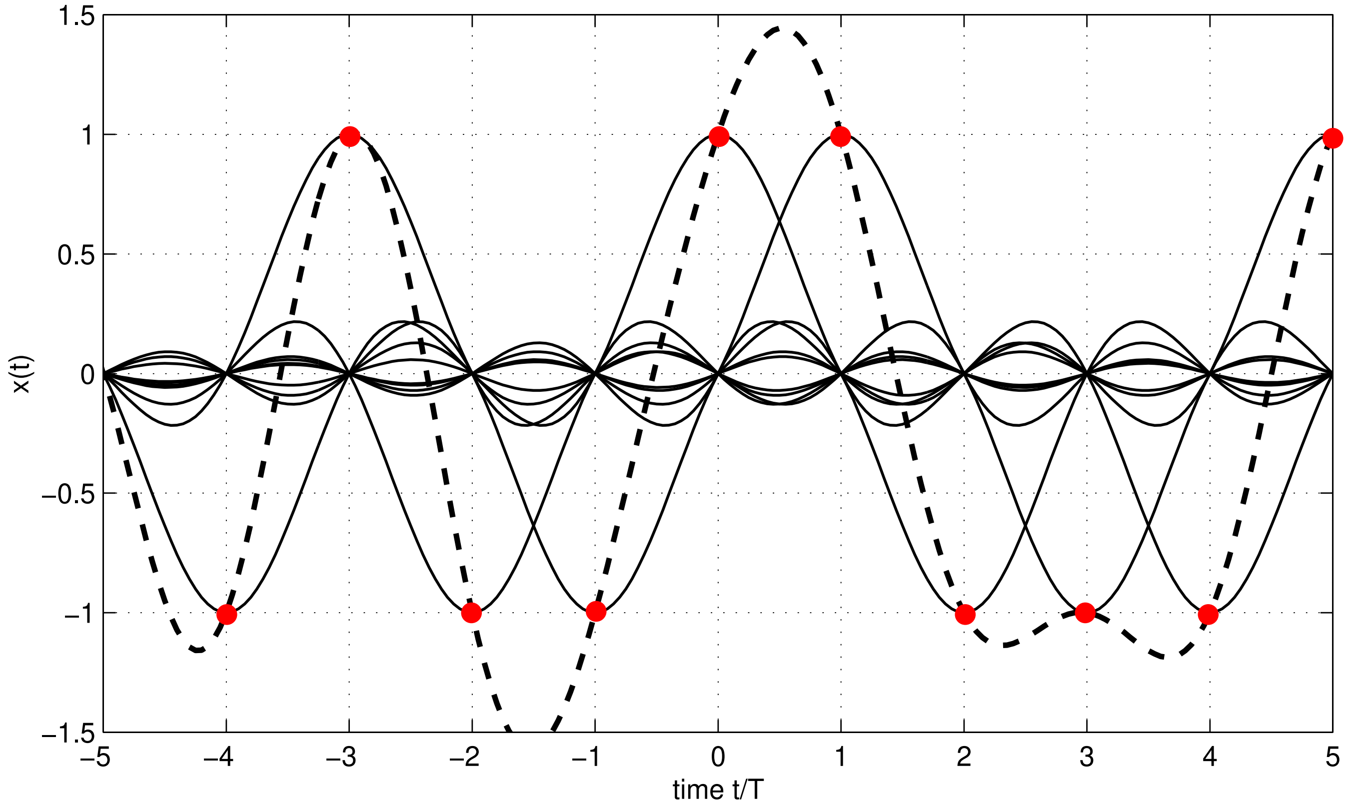
Pulse Shaping III — Frequency Domain



- Square pulse produces considerable excess bandwidth beyond the symbol rate f_s; sinc impractical to realize; truncated raised cosine easy to realize

Pulse Shaping IV

- Example: binary (± 1) $x[k]$, each is transmitted as a sinc pulse; the peak of different shifted sinc functions coincide with zero crossings of all other sincs:



- At receiver, sampling at correct symbol rate enables recovery of transmitted $x[k]$

Transmit and Receive Filters

- Pulse shaping fulfils two purposes: limit the transmission bandwidth, and enable to recover the correct sample values of transmitted symbols; such a pulse shaping $r(t)$ is called a Nyquist system

1. (Infinite) sinc has a (baseband) bandwidth $B_T = f_s/2$, (infinite) raised cosine has $f_s/2 \le B_T \le f_s$ depending on roll-off factor
2. A Nyquist time pulse have regular zero-crossing at symbol-rate spacings to avoid interference with neighboring pulses at correct sampling instances

- Nyquist system $r(t)$ is separated into transmit filter $g(t)$ and receive filter $g(-t)$ (square-root Nyquist systems)

1. The filter $g(-t)$ in the receiver is also called a matched Filter (to $g(t)$); $g(t)$ and $g(-t)$ are basically identical (square-root of $r(t)$)
2. This division of $r(t)$ enables suppression of out-of-band noise and results in the maximum received SNR

Summary

- Revisit major blocks of a digital communication system
- MODEM: responsible for transferring the bit stream at a given rate over the communication medium reliably
- Transmission channel (medium) has finite bandwidth and introduces noise, these are two factors that has to be considered in design
- Purpose of pulse shaping, how to design transmit and receive filters