ELEC6014 Radio Communications Networks and Systems

Professor Sheng Chen: Building 53, Room 4005
E-mail: sqc@ecs.soton.ac.uk
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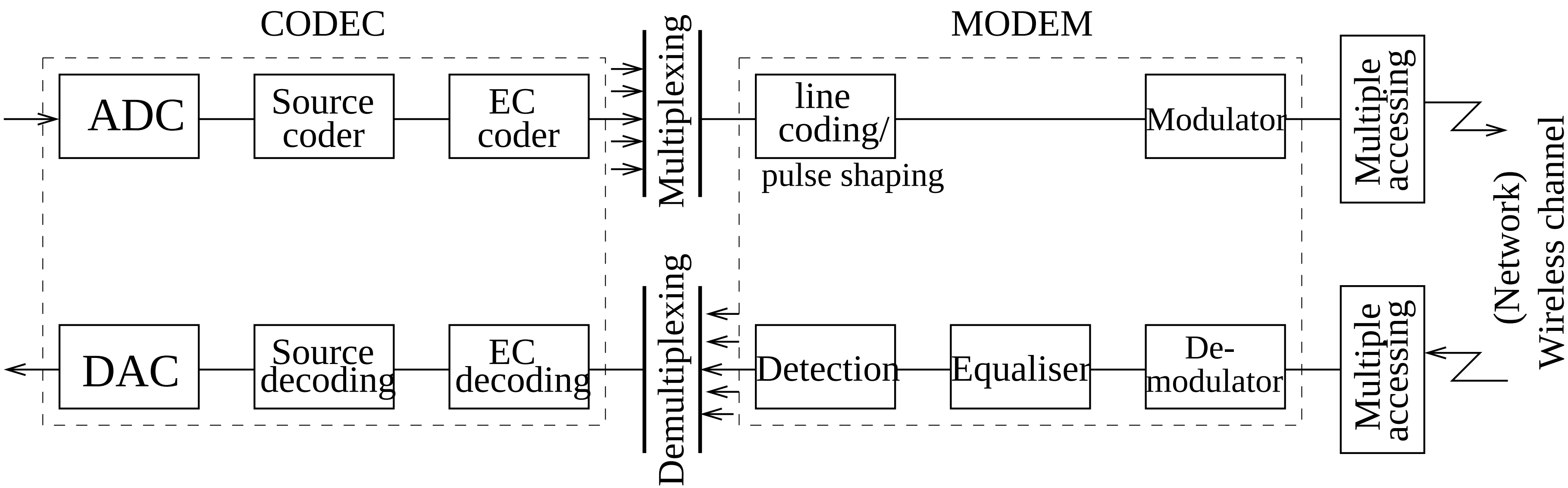
Reading Texts:

- L. Hanzo, W. Webb and T. Keller, *Single- and Multi-Carrier Quadrature Amplitude Modulation: Principles and Applications for Personal Communications, WLANs and Broadcasting*. Wiley, Chichester, 2000.
- R. Steele and L. Hanzo, eds. *Mobile Radio Communications: Second and Third Generation Cellular and WATM Systems*. 2nd Edition, John Wiley, Chichester, 1999.
- T.S. Rappaport, *Wireless Communications: Principles and Practice*. Prentice-Hall, 1996.
- A. Paulraj, R. Nabar and D. Gore, *Introduction to Space-Time Wireless Communications*. Cambridge University Press, 2003.
- D. Tse, and P. Viswanath, *Fundamentals of Wireless Communication*. Cambridge University Press, 2005.

System Overview



Transmitter

- **Source coding**: analogue to digital, data compression to remove redundancy
- **Error control coding**: add redundancy for error detection and correction at receiver
- **Multiplexing**: accommodate several simultaneous transmissions, i.e. combine several low-rate signals to a high-rate one
- **Line coding/pulse shaping**: how bits are transmitted and how to limit transmit signal bandwidth
- **Modulator**: modulate baseband signal by carrier frequency for radio transmission

System Overview (continue)

Medium

- **Multiple access**: multiple transceiver pairs (users) to share common transmission medium
  This is about how different users are *physically* separated, separation can be in frequency, and/or time, and/or other means
- **Transmission channel**: which can distort signal and corrupt signal with noise
  Note that distortion includes intersymbol interference (ISI) and/or multiple access interference (MAI)

Receiver

- **Demodulator**: carrier recovery and remove carrier, i.e. passband signal $\longrightarrow$ baseband one
- **Equaliser**: compensate channel distortion (ISI) and/or multiuser detection for combating MAI
- **Detection**: make decisions on received symbols/bits, which can be hard or soft one depending on what sort of channel decoding scheme used
- **Error control decoding**: detect and correct errors in bits, which can be hard, or soft, or iterative (turbo), and it can even be iterative with equaliser and multiuser detector
- **Source decoding**: recover original digital data, digital to analogue

Mathematical Revision

- Time function $x(t)$ $\underset{\text{Fourier transform}}{\Longleftrightarrow}$ Frequency spectrum $X(f)$

  $X(f)$ is two-size (artificial negative frequency) and complex-valued (amplitude and phase spectra)

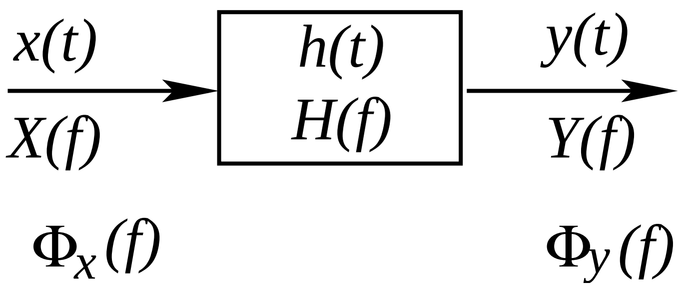
- Baseband sampling theorem: if $x(t)$ is bandlimited to B and sampling rate $\geq 2B$, $x(t)$ can be reconstructed from samples

- Baseband Nyquist criterion for zero ISI: transmission rate f_b, require at least $f_b/2$ baseband bandwidth

- Linear system theory: impulse response $h(t)$ and its transfer function $H(f)$

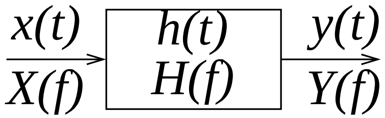
  Power spectrum density of output

$$\Phi_y(f) = |H(f)|^2 \Phi_x(f)$$

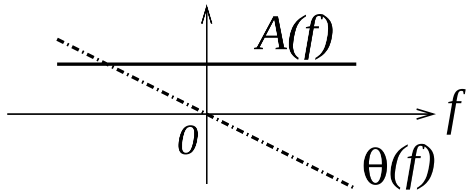


Channel Fundamentals

- Ideal (baseband) channel:



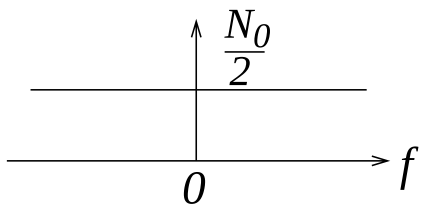
Channel



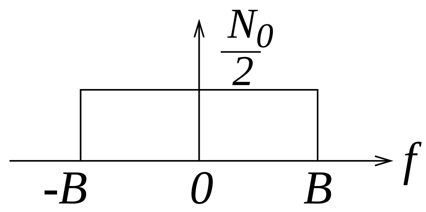
Distortionless

$$y(t) = \alpha x(t - t_d) \rightarrow H(f) = \alpha \exp(-j2\pi f\, t_d): \; |H(f)| = \alpha \text{ and } \angle H(f) = -2\pi f t_d$$

- Channel noise (in baseband):



WN



bandlimited WN

White noise has a constant PSD. Since power is area under PSD, white noise has infinitely large power. But communication system is bandlimited

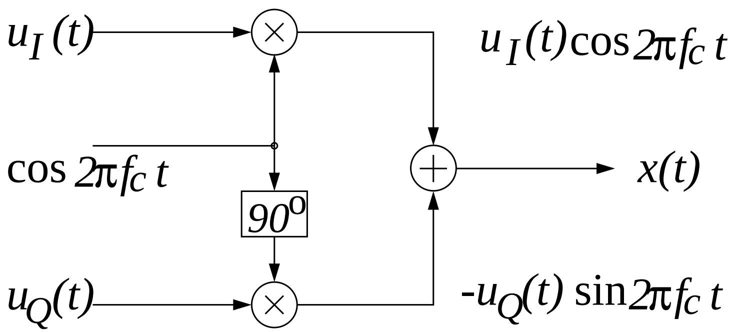
- Channel capacity*: $C = B_p \log_2(1 + \text{SNR})$ (bps), where SNR is channel signal to noise ratio and B_p is passband channel bandwidth (Hz)

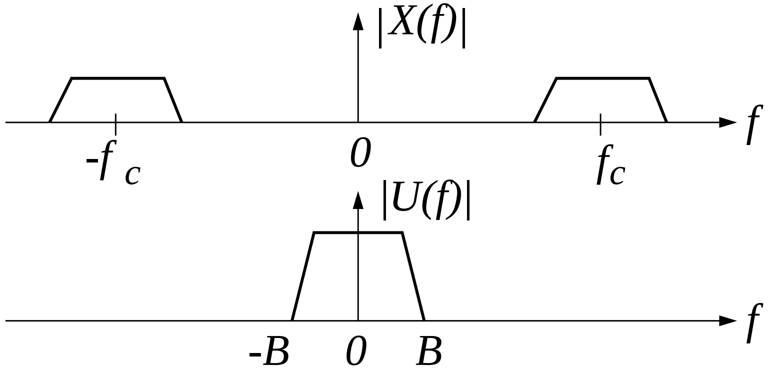
* This is for ideal channel with Gaussian signal. For digital signal or dispersive channel, is channel capacity larger or smaller than ideal case?

Bandpass / Baseband Signals

- Let a **bandpass signal** be: $x(t) = a(t)\cos(2\pi f_c t + \phi(t))$, and its spectrum $X(f)$
- Define a **baseband complex envelope**: $u(t) = a(t)\exp(j\phi(t)) = u_I(t) + ju_Q(t)$, and its spectrum $U(f)$ Assumption: signal $X(f)$ bandwidth $<< f_c$ then $\rightarrow$
- Relationship: $u(t)\exp(j2\pi f_c t) = (u_I(t) + ju_Q(t))(\cos 2\pi f_c t + j\sin 2\pi f_c t)$

$$x(t) = \mathrm{Re}[u(t)\exp(j2\pi f_c t)] \qquad X(f) = \frac{1}{2}[U(f - f_c) + U^*(-f - f_c)]$$





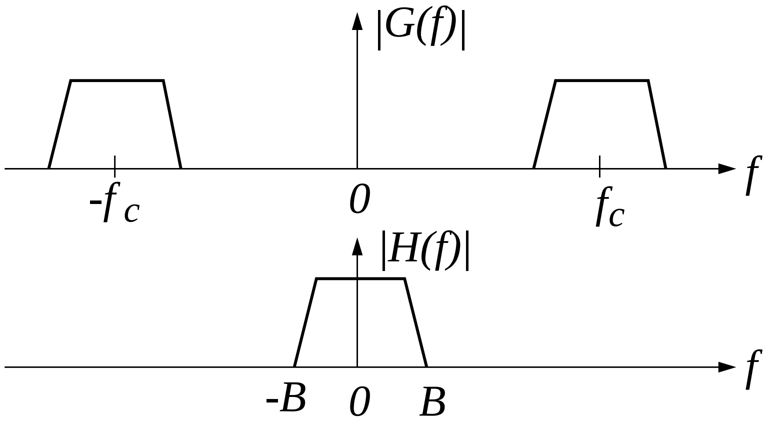
Bandpass / Baseband Systems

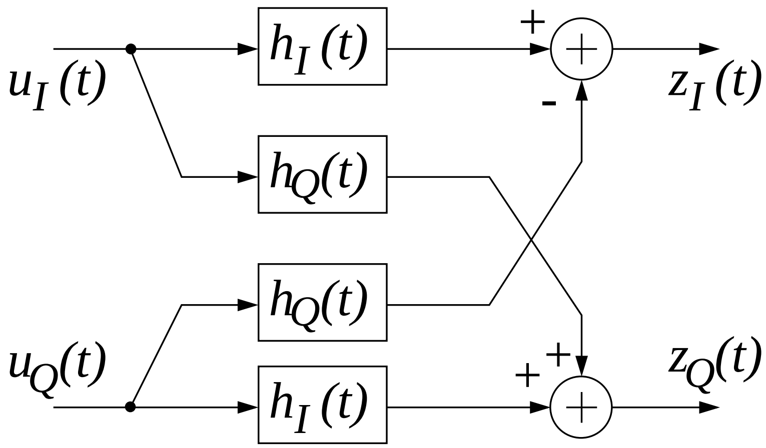
- **Bandpass** signal and system: $x(t), X(f) \rightarrow \lceil g(t), G(f) \rfloor \rightarrow y(t), Y(f)$
- **Baseband** signal and system: $u(t), U(f) \rightarrow \lceil h(t), H(f) \rfloor \rightarrow z(t), Z(f)$
- Relationship between baseband and passband systems is:

$$G(f) = H(f - f_c) + H^*(-f - f_c)$$

- Noting $X(f) = \frac{1}{2}[U(f - f_c) + U^*(-f - f_c)]$, passband output spectrum is:

$$Y(f) = \frac{1}{2}[H(f - f_c)U(f - f_c) + H^*(-f - f_c)U^*(-f - f_c)]$$





Bandpass / Baseband (continue)

- Passband output signal: $y(t) = \text{Re}[z(t) \exp(j2\pi f_c t)]$, where baseband signal $z(t) = z_I(t) + jz_Q(t)$, and with $\star$ denoting convolution

$$z_I(t) = h_I(t) \star u_I(t) - h_Q(t) \star u_Q(t) \qquad z_Q(t) = h_I(t) \star u_Q(t) + h_Q(t) \star u_I(t)$$

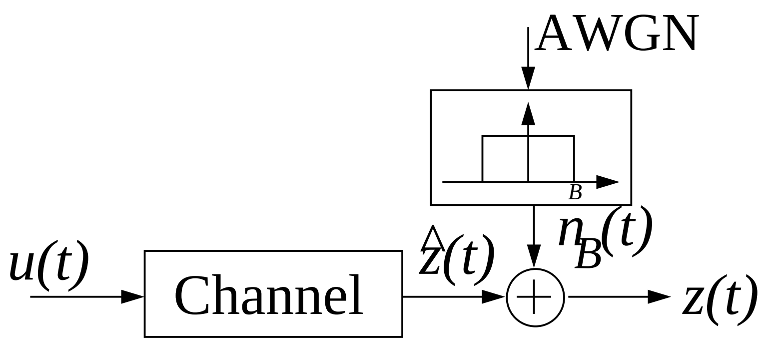
- **Comment 1**: Recall complex-valued representation of inphase and quadrature components $\longrightarrow$ link to baseband complex envelope
- **Comment 2**: Real-world passband CIR $g(t)$ is real-valued $\longrightarrow$ baseband equivalent CIR $h(t)$ is complex-valued

- Baseband equivalent channel model:

  Again real-world noise is real-valued, but equivalent baseband noise is a complex-valued AWGN

$$n(t) = n_I(t) + jn_Q(t)$$

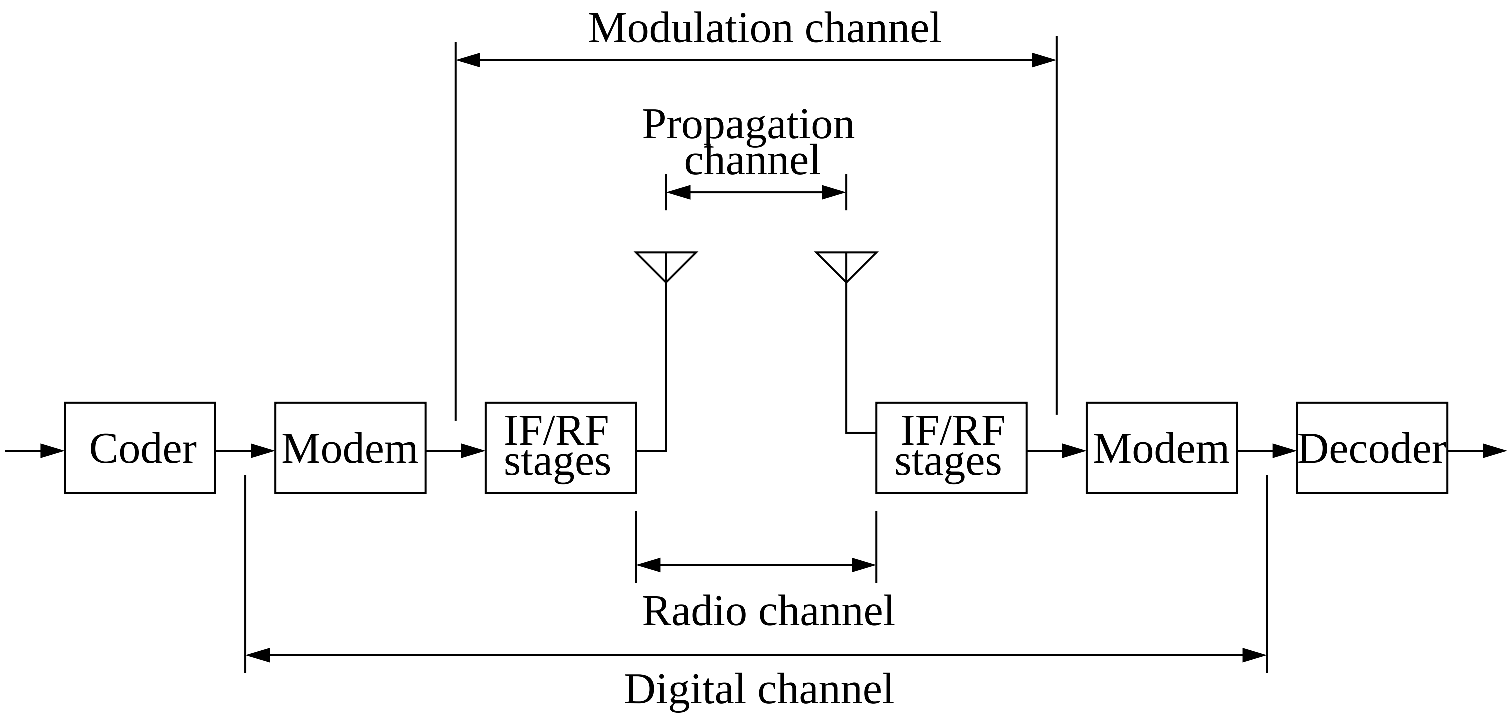
  which is bandlimited by the Rx filter



- **Comment 3**: Analysis and simulation are much easier in equivalent baseband

Mobile Radio Channel Definitions

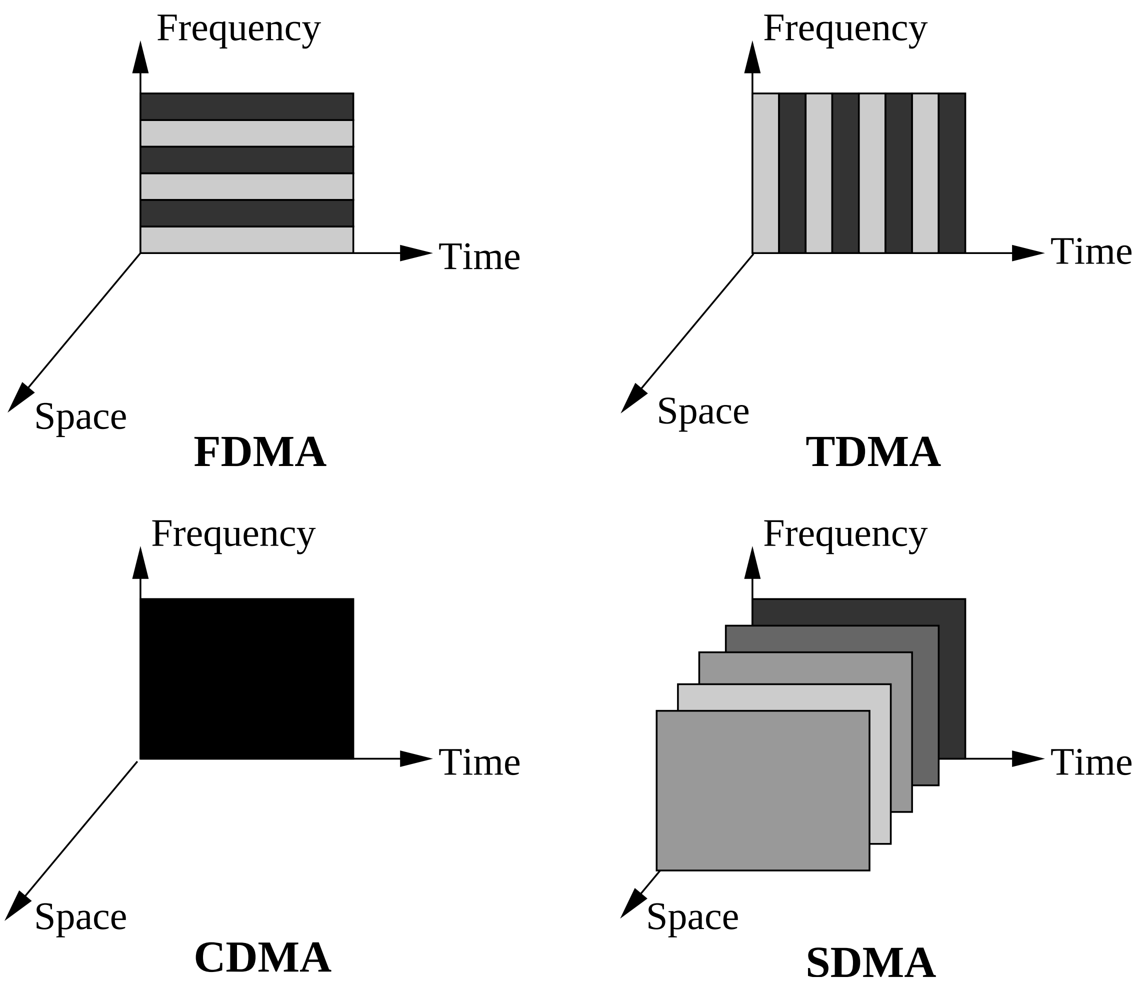
- The term "channel" depends on the context. Sometime it refers to the whole communication system, sometime part of it. Here are some of definitions



- For example, when designing decision circuit and equaliser, it is convenient to consider channel as "digital channel"

Wireless Access Technology

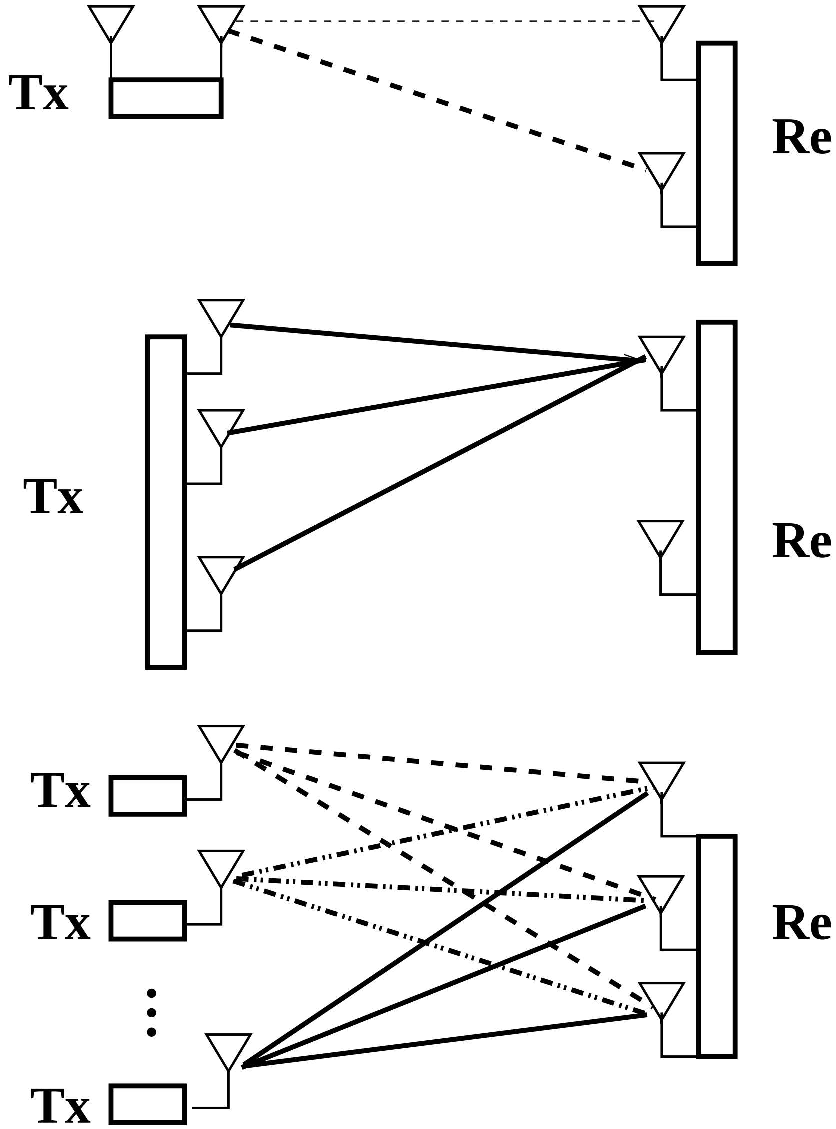
- **Spectrum**: basic resource
- **User separation**: Users must be separated in some way
- **Multiple access**: separation ("channels") can be in
  - frequency domain (different frequency bands)
  - time domain (different time slots)
  - code domain (different spreading codes)
  - spatial domain (different CIRs as seen at multiple Rx antennas)



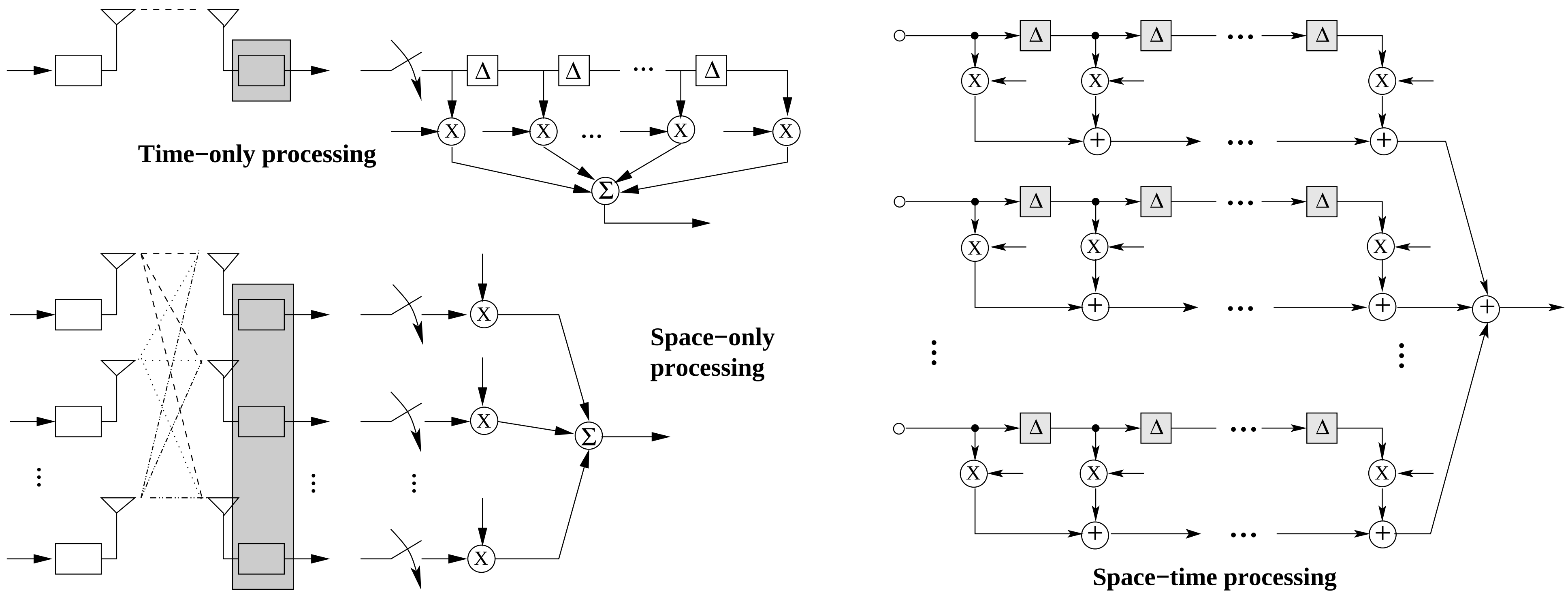
"**New**" multiple access techniques: interleaver division multiple access, channel code division multiple access

MIMO Technology

- Create **diversity** for combating fading
  - With sufficient antenna spacing (10 wavelengths), each antenna experiences independent fading → When one signal is in its deep fade, others are unlikely the same
- Increase **throughput**
  - Data stream is first S/P, each sub-sequence mapped to an antenna → This creates many "digital pipes" to support higher rate
- Support **multiple users**
  - With multiple receive antennas, each spatially separated user has a unique set of CIRs seen at receiver → This enables SDMA



Space-Time Processing



- Basic processing is in time domain, i.e. temporal filtering, or equivalently in frequency domain
- With aid of multiple antennas (smart antenna), processing in spatial domain can be exploited, e.g. space-time coding, beamforming, and space-time equalisation
- **Space-time processing** are powerful technology for improving system capacity, coverage and quality of service

Summary

- **System overview**: knowing each part of study fits into this overall picture
- **Revision**: time - Fourier transform - spectrum, sampling theorem, Nyquist criterion for zero ISI, linear system theory
- **Channel fundamentals**: ideal channel, white noise, channel capacity
- **Bandpass/baseband**: signals, systems, relationships, why consider equivalent complex-valued baseband forms
- **Multiple access**: user separation, frequency, time, code and/or spatial "channels"
- **MIMO**: diversity for combating fading, increase throughput, support multi users
- **Space-time processing**: exploits temporal and/or spatial domain processing