Communication Systems

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Telephone Touchtone Signal

- **Dual-tone multiple frequency (DTMF) signaling**
  - Sum of a sinusoid from low-frequency group and high-frequency group
  - On for 40-60 *ms* and off for rest of signal interval

	1209 Hz	1336 Hz	1477 Hz	1633 Hz
697 Hz	1	2	3	A
770 Hz	4	5	6	B
852 Hz	7	8	9	C
941 Hz	*	0	#	D

  - Signal interval: 100 *ms* for AT&T, 80 *ms* for ITU
  - Keys A-D are for military and radio signaling applications
- **Standards**
  - AT&T: 10 digits/s maximum dialing rate (40 bits/s)
  - ITU Q.24: 12.5 digits/s maximum dialing rate (50 bits/s)

Communication Systems

- **Information sources**
  - Message signal $m(t)$ is information source to be sent
  - Possible information sources include voice, music, images, video, and data, which are baseband (lowpass) signals
  - Baseband signals have power concentrated near DC
- **Basic structure of analog communication system shown below**

Transmitter

- **Signal processing**
  - Conditions message signal
  - Lowpass filtering to make sure that the message signal occupies a specific bandwidth, e.g. in AM and FM radio, each station is assigned a slot in the frequency domain.
  - In a digital communications system, we might add redundancy to the message bit stream $m[n]$ to assist in error detection (and possibly correction) in the receiver

Transmitter

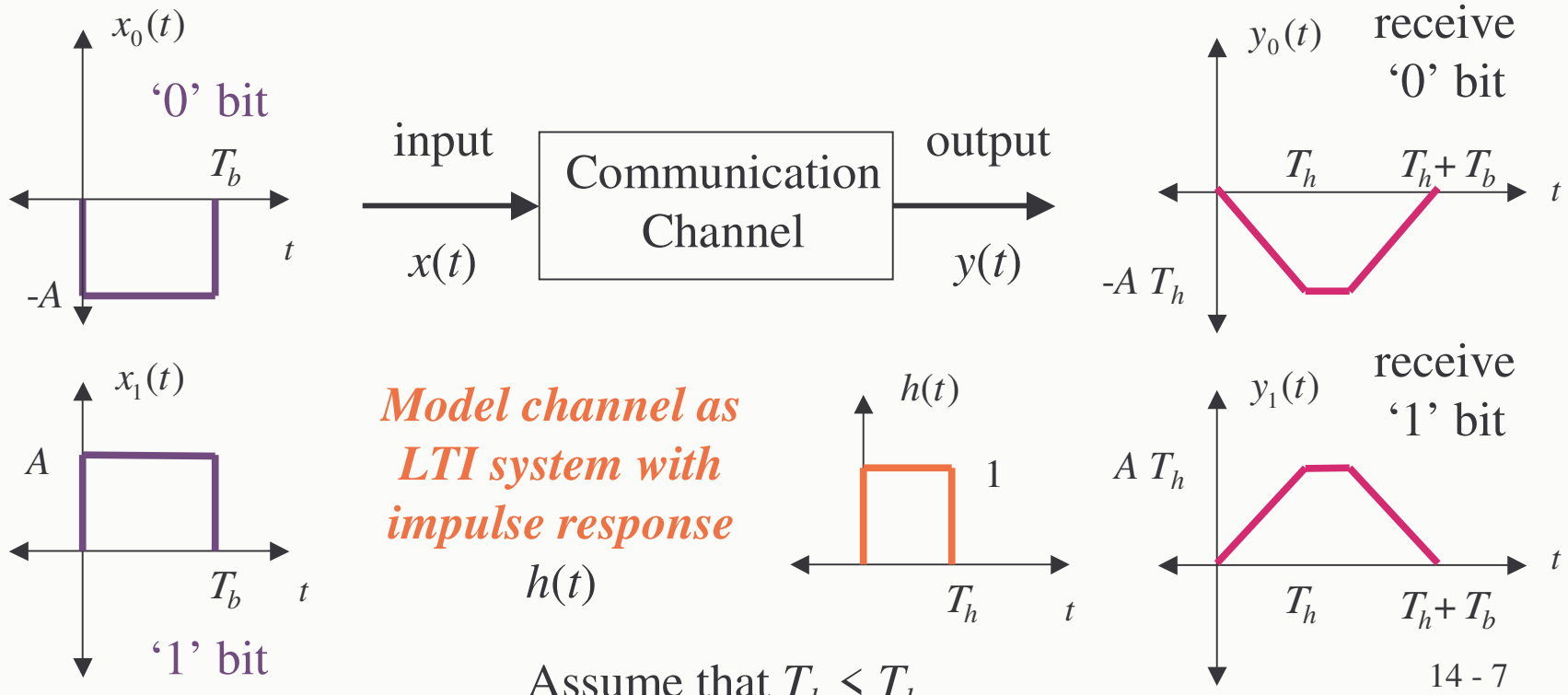
- **Carrier circuits**
  - Convert baseband signal (centered at 0 Hz) into frequency band appropriate for channel (centered at carrier frequency)
  - In FM radio, carrier frequency is radio station frequency, e.g. 94.7 MHz for Mix FM in Austin, TX
  - Upconversion uses analog and/or digital modulation
  - Analog amplitude modulation would multiply input baseband signal by sinusoid at the carrier frequency

Channel

- **Transmission medium**
  - Wireline (twisted pair, coaxial, fiber optics)
  - Wireless (indoor/air, outdoor/air, underwater, space)
- **Propagating signals experience a gradual degradation over distance**
- **Boosting improves signal and reduces noise, e.g. repeaters**

Transmit One Bit

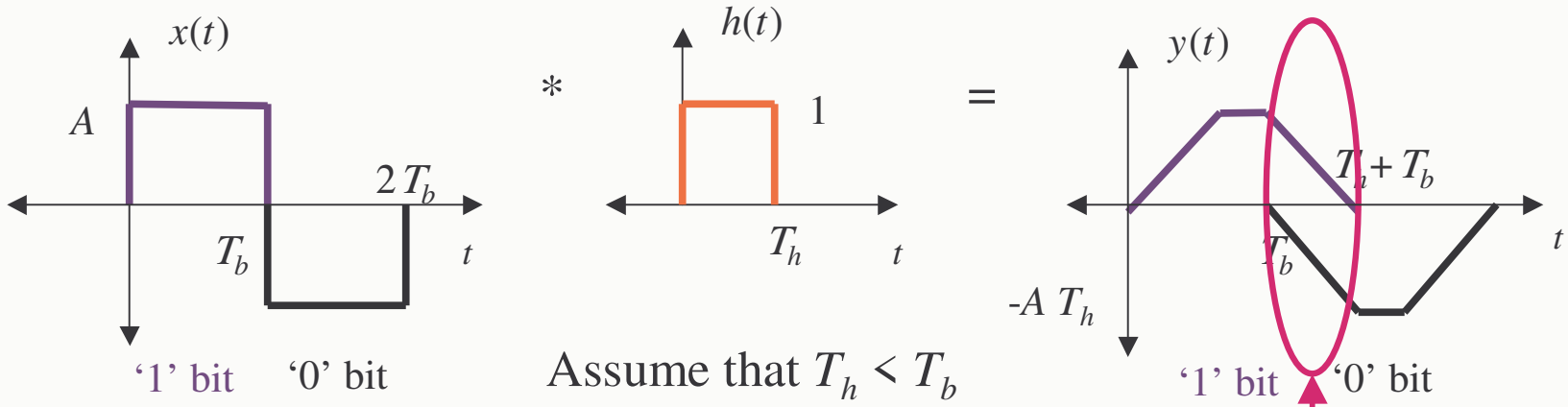
- **Transmission over communication channel (e.g. telephone line) is analog**
- **2-level digital pulse amplitude modulation**



Assume that $T_h < T_b$

Transmit Two Bits (Interference)

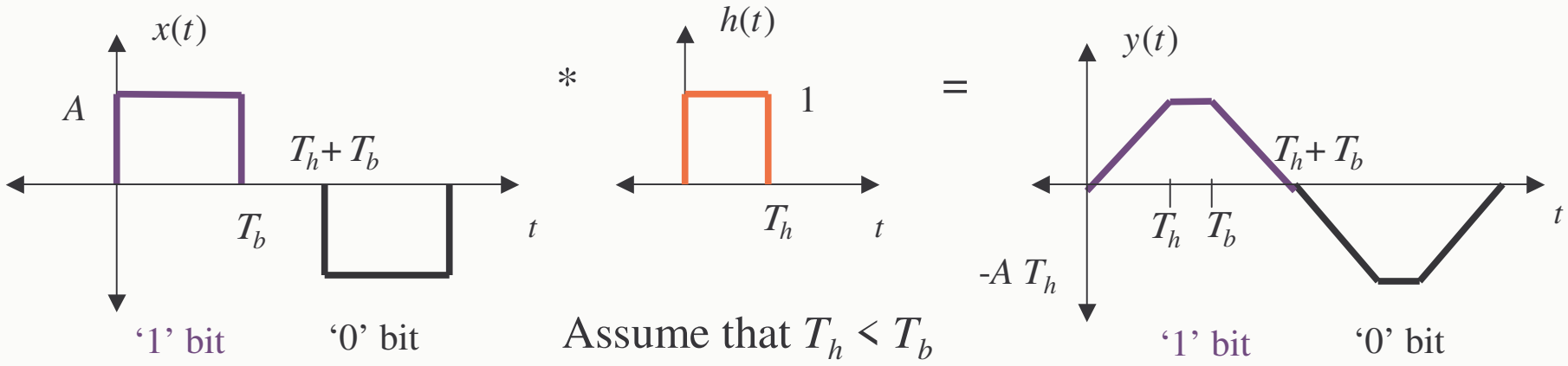
- **Transmitting two bits (pulses) back-to-back will cause overlap (interference) at the receiver**



- **Sample $y(t)$ at T_b, 2 T_b, …, and threshold with threshold of zero**
- **Change in transmitter to prevent intersymbol interference (ISI)?**

Transmit Two Bits (No Interference)

- **Prevent intersymbol interference by waiting T_h seconds between pulses (called a guard period)**



Assume that $T_h < T_b$

- **Disadvantages?**

Wireline Channel Impairments

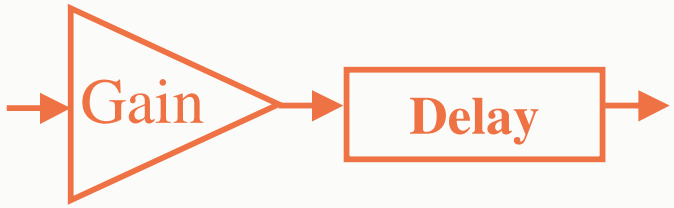
- ***Attenuation*: linear distortion that is dependent on the frequency response of the channel.**
- ***Spreading*: the finite extent of each transmitted pulse increases, i.e. pulse widens**
  - Transmit pulse length T_s
  - Channel impulse response length T_h
  - Resulting waveform due to convolution has duration $T_s + T_h$
- ***Phase jitter*: same sinusoid experiences different phase shifts in time-varying channel**
- ***Additive noise*: arises from many sources in the transmitter, channel, and receiver**

Wireless Channel Impairments

- **Same as wireline channel impairments plus others**
- **Fading: multiplicative noise**
  - Example: talking on a cellular phone while driving a car when the reception fades in and out
- **Multiple propagation paths**
  - Multiple ways for transmitted signal to arrive at receiver
- **Simplified channel model for simulation**
  - Finite impulse response filter plus
  - Additive white Gaussian noise

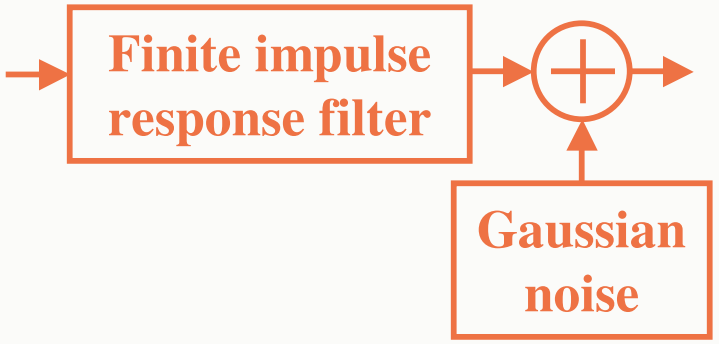
Channel Modeling

- **Ideal channel**

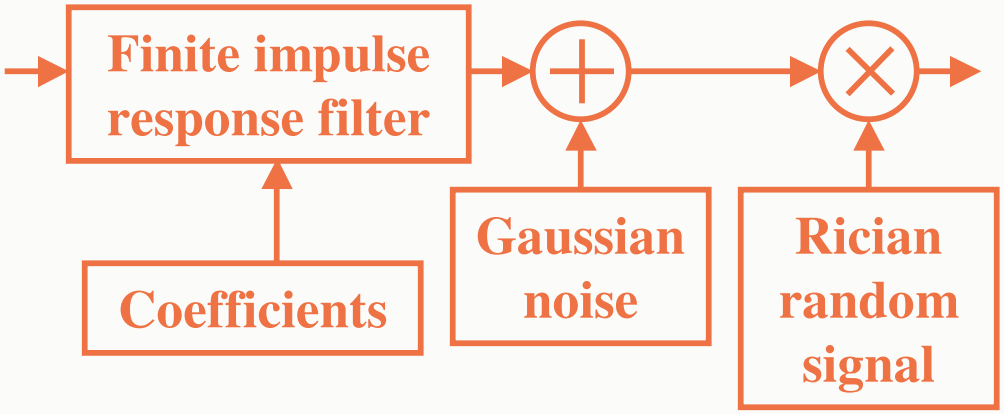


All blocks are homogeneous synchronous dataflow

- **Simplified channel**



- **Time varying fading channel**

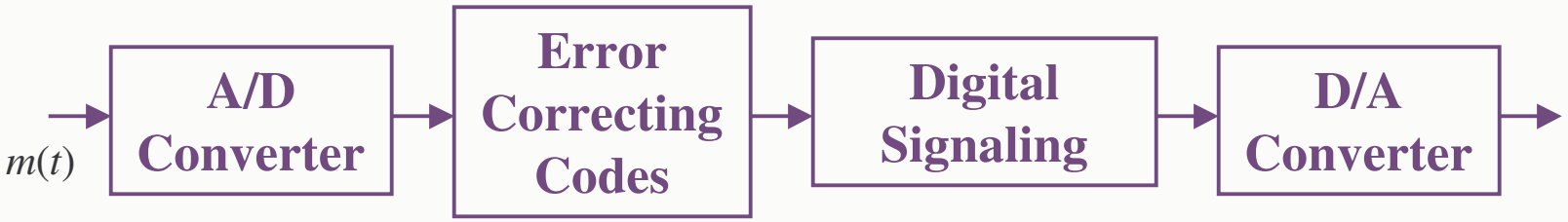


Receiver and Information Sinks

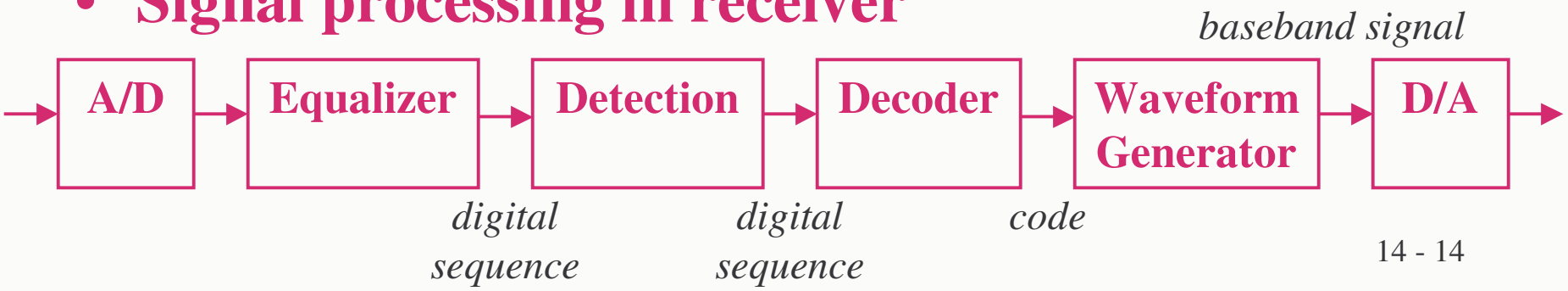
- **Receiver**
  - Carrier circuits convert transmission band (centered at carrier frequency) to baseband signal (centered at 0 Hz)
  - Signal processing subsystem extracts and enhances the baseband signal
- **Information sinks**
  - Output devices, e.g. computer screens, speakers, TV screens

Hybrid Communication Systems

- **Mixed analog and digital signal processing in the transmitter and receiver**
  - Example: message signal is digital but broadcast over an analog channel (compressed speech in digital cell phones)
- **Signal processing in transmitter**



- **Signal processing in receiver**



Amplitude Modulation by Cosine

- **Multiplication in time: convolution in Fourier domain of baseband signal $f(t)$**

$$y(t) = f(t)\cos(\omega_c t)$$

$$Y(\omega) = \frac{1}{2\pi} F(\omega) * \pi(\delta(\omega+\omega_c) + \delta(\omega-\omega_c))$$

- **Sifting property of Dirac delta functional**

$$x(t) * \delta(t) = \int_{-\infty}^{\infty} \delta(\tau) x(t-\tau) d\tau = x(t)$$

$$x(t) * \delta(t-t_0) = \int_{-\infty}^{\infty} \delta(\tau-t_0) x(t-\tau) d\tau = x(t-t_0)$$

- **Fourier transform**

$$Y(\omega) = \frac{1}{2} F(\omega+\omega_c) + \frac{1}{2} F(\omega-\omega_c)$$

Two copies of $F(\omega)$

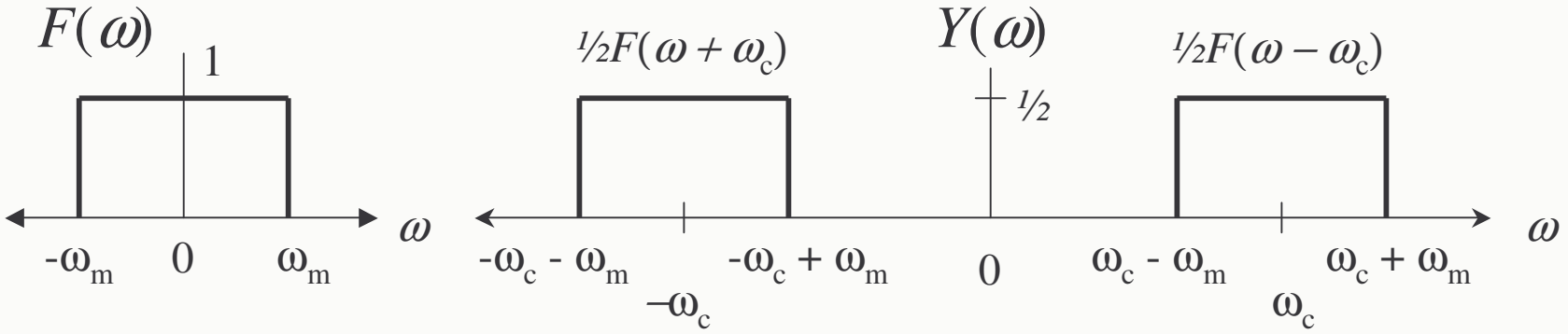
Amplitude Modulation by Cosine

- **Example:** $y(t) = f(t)\cos(\omega_c t)$

  $f(t)$ is baseband (lowpass) signal with bandwidth ω_m

  $\omega_m << \omega_c$

  $Y(\omega)$ is real-valued if $F(\omega)$ is real-valued



- **Demodulation: modulation then lowpass filtering**
- **Similar derivation for modulation with** $\sin(\omega_c t)$

Amplitude Modulation by Sine

- **Multiplication in time is convolution in Fourier domain baseband signal *f(t)***

$$y(t) = f(t)\sin(\omega_c t)$$

$$Y(\omega) = \frac{1}{2\pi} F(\omega) * j\pi\left(\delta(\omega+\omega_c) - \delta(\omega-\omega_c)\right)$$

- **Sifting property of the Dirac delta functional**

$$x(t) * \delta(t) = \int_{-\infty}^{\infty} \delta(\tau)\, x(t-\tau)\, d\tau = x(t)$$

$$x(t) * \delta(t-t_0) = \int_{-\infty}^{\infty} \delta(\tau-t_0)\, x(t-\tau)\, d\tau = x(t-t_0)$$

- **Fourier transform**

$$Y(\omega) = \frac{j}{2} F(\omega+\omega_c) - \frac{j}{2} F(\omega-\omega_c)$$

Two copies of $F(\omega)$

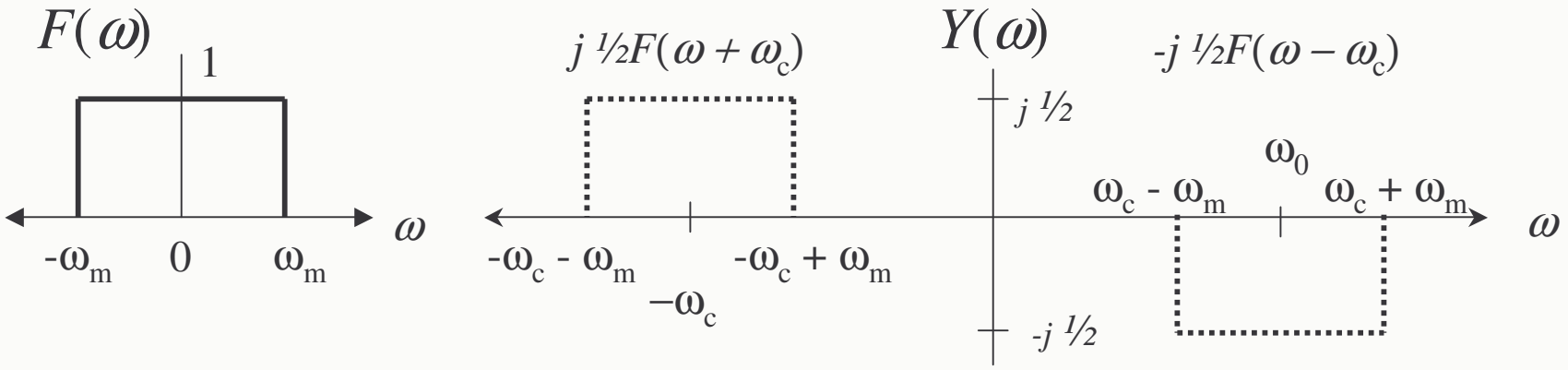
Amplitude Modulation by Sine

- **Example:** $y(t) = f(t)\ \sin(\omega_0 t)$

  Assume $f(t)$ is an ideal lowpass signal with bandwidth ω_1

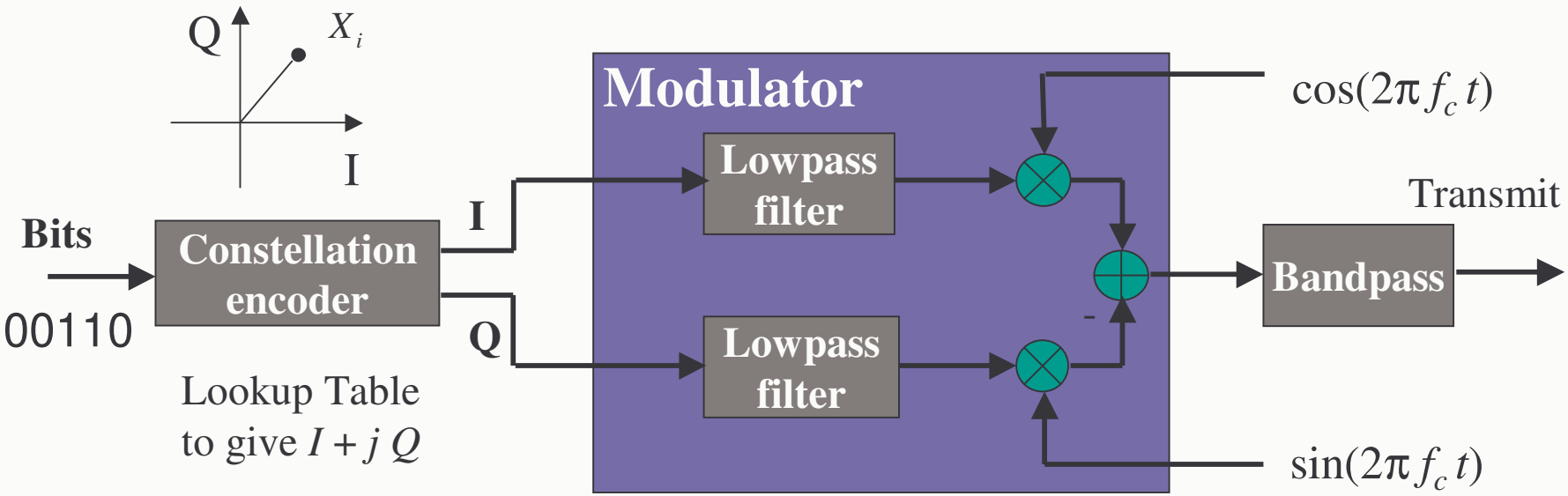
  Assume $\omega_1 << \omega_0$

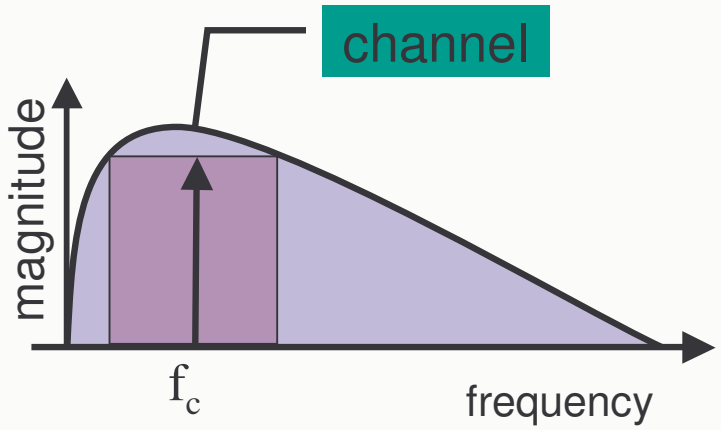
  $Y(\omega)$ is imaginary-valued if $F(\omega)$ is real-valued



- **Demodulation: modulation then lowpass filtering**

Quadrature Amplitude Modulation





- One carrier
- Single signal
- Occupies all available transmission bandwidth

Universal Data Type

- **Envelope representation**
  - Carrier (center) frequency
  - Baseband signal
    - **In-phase component**
    - **Quadrature component**
    - **Time step (sampling period of baseband signal)**
- **Baseband representation**
  - Carrier frequency of zero