Analog Pulse Amplitude Modulation

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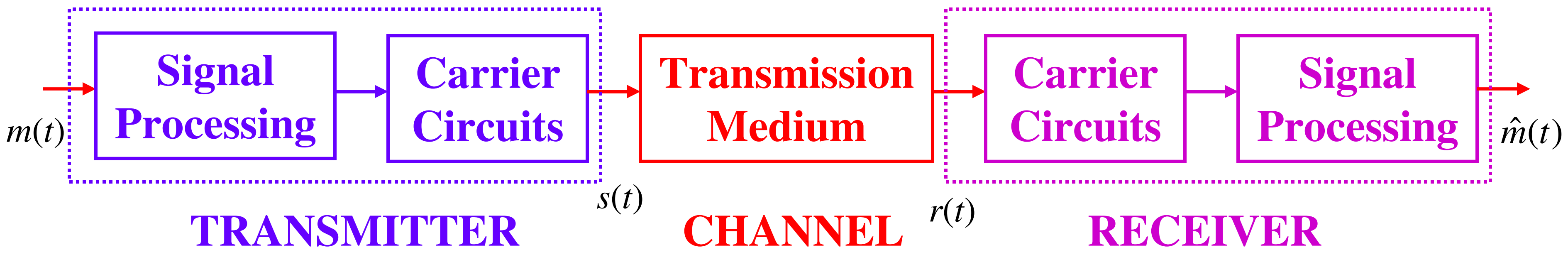
Communication Systems

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

Transmitter

- **Signal processing**
  - Conditions the 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 into a frequency band appropriate for the channel
  - Uses analog and/or digital modulation

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**

Wireline Channel Impairments

- **Linear time-invariant effects**

  Attenuation: dependent on channel frequency response

  Spreading: finite extent of each transmitted pulse increases, i.e. pulse widens (see next slide)

- **Linear time-varying effects**

  Phase jitter: sinusoid at same fixed frequency experiences different phase shifts when passing through channel (i.e. time-varying phase response)

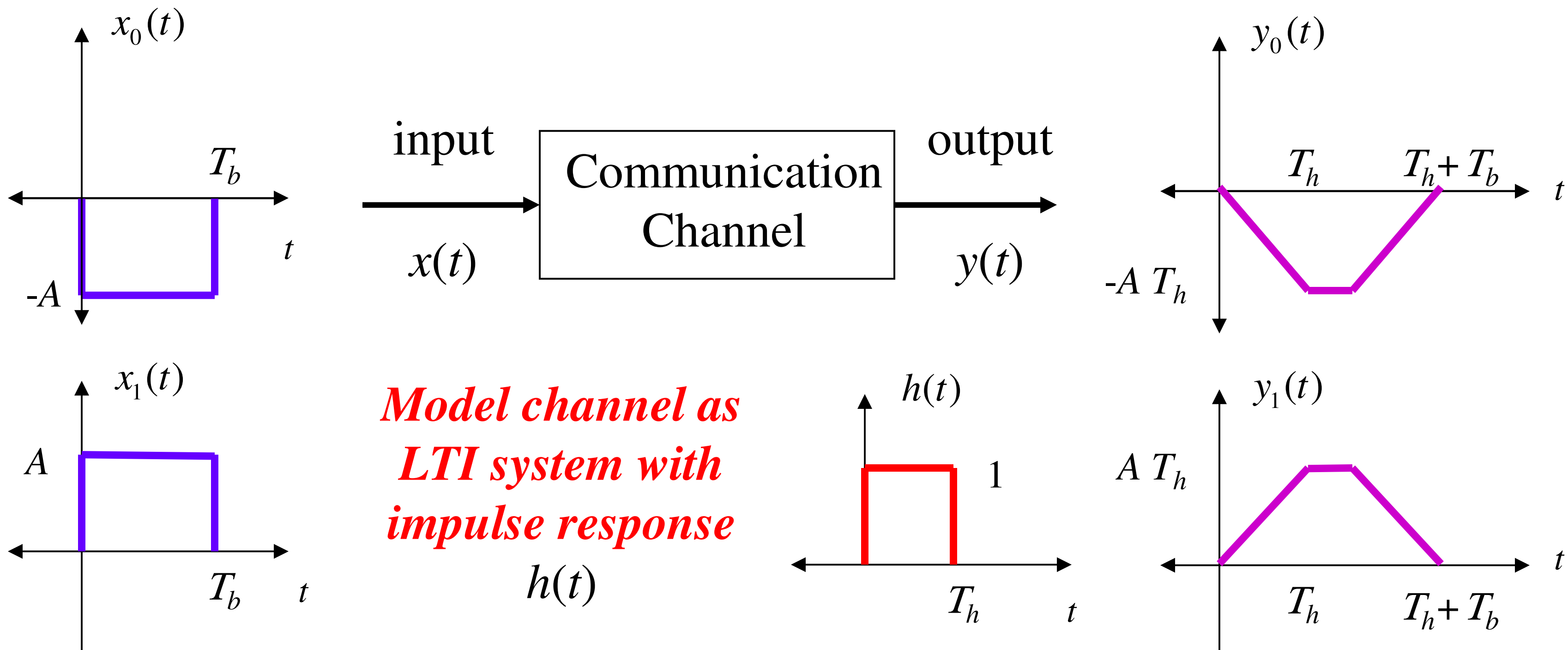
- **Nonlinear effects**

  Additive noise: arises from many sources in transmitter, channel, and receiver (e.g. thermal noise)

  Harmonics: due to squaring & other nonlinear transformations (e.g. in power amplifiers)

Wireline Channel Impairments

- **Analog transmission over communication channels**
- **Spreading in time domain due to convolution of transmitted waveform & channel impulse response**



Assume that $T_h < T_b$

Wireless Channel Impairments

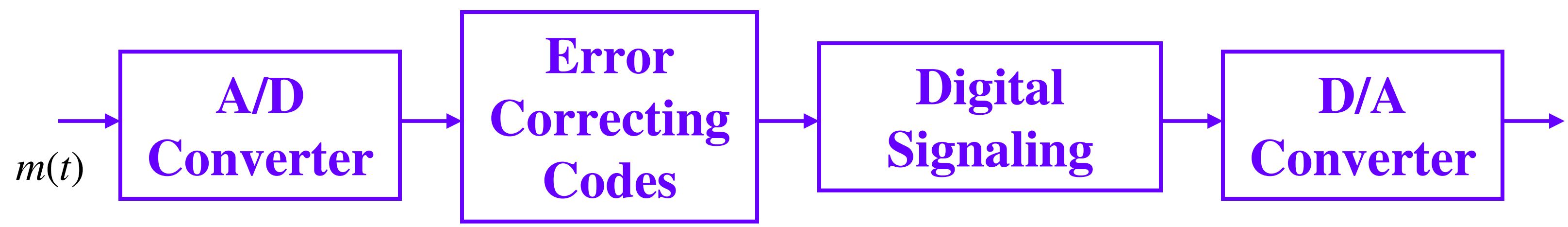
- **Same as wireline channel impairments plus others**
- **Fading: multiplicative noise**
  - Example: talking on a cellular phone while driving a car when the reception fades in and out

Receiver and Information Sinks

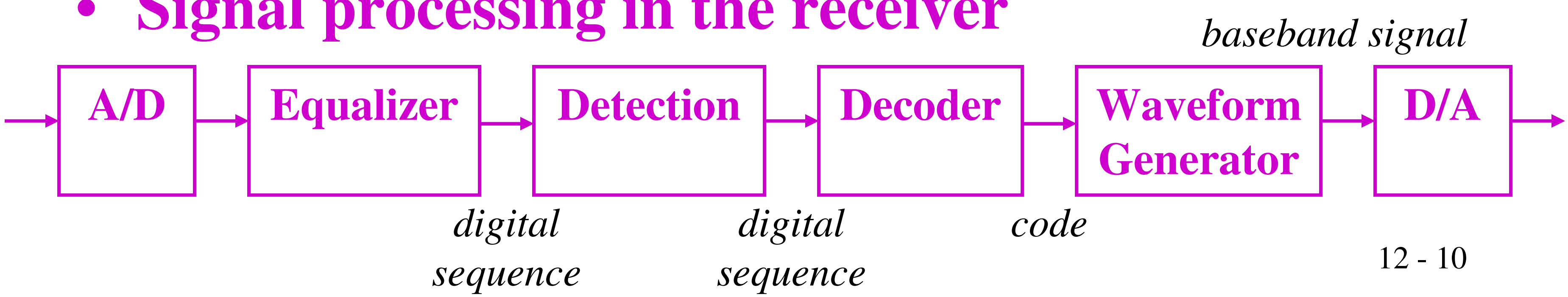
- **Receiver**
  - Carrier circuits undo effects of carrier circuits in transmitter, e.g. demodulate from a bandpass signal to a baseband signal
  - Signal processing subsystem extracts and enhances the baseband signal
- **Information sinks**
  - Output devices, e.g. computer screens, speakers, TV screens

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 the transmitter**



- **Signal processing in the receiver**

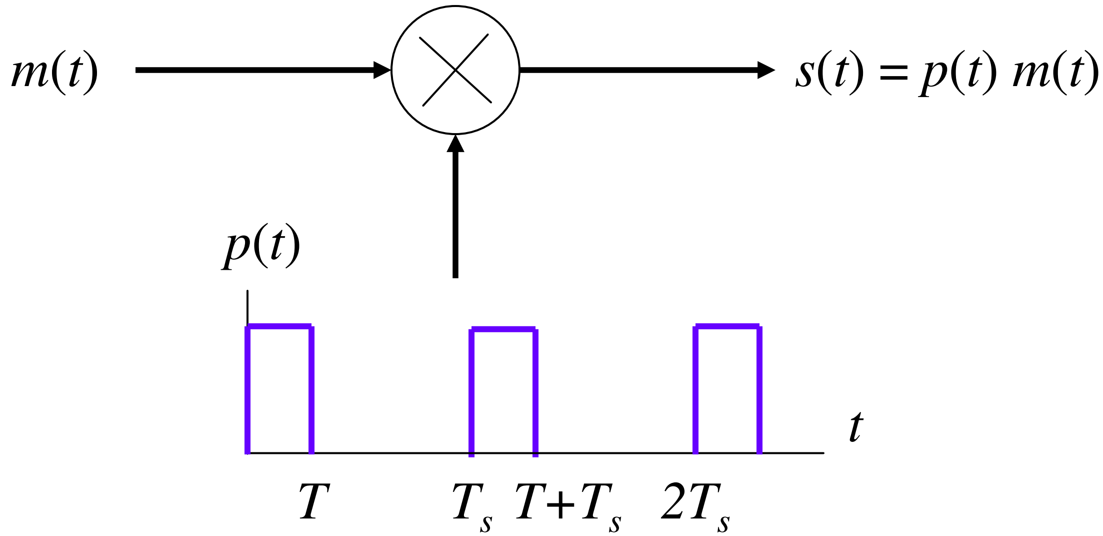


Single-Carrier Modulation Methods

- **Analog communication**
  - Transmit and receive analog waveforms
  - Amplitude Modulation (AM)
  - Phase Modulation (PM)
  - Freq. Modulation (FM)
  - Quadrature Amplitude Modulation (QAM)
  - Pulse Amplitude Modulation (PAM)
- **Digital communication**
  - Same but treat transmission and reception as digitized
  - Amplitude Shift Keying (ASK)
  - Phase Shift Keying (PSK)
  - Freq. Shift Keying (FSK)
  - QAM
  - PAM

Pulse Amplitude Modulation (PAM)

- **Amplitude of periodic pulse train is varied with a sampled message signal *m***
  - **Digital PAM**: coded pulses of the sampled and quantized message signal are transmitted (lectures 12 and 13)
  - **Analog PAM**: periodic pulse train with period T_s is the carrier (below)



Analog PAM

- **Pulse amplitude varied with amplitude of sampled message**

  Sample message every T_s

  Hold sample for T seconds ($T < T_s$)

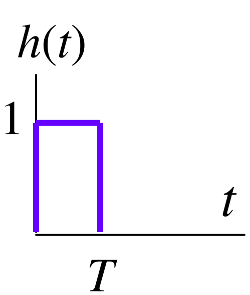
  Bandwidth $\propto 1/T$

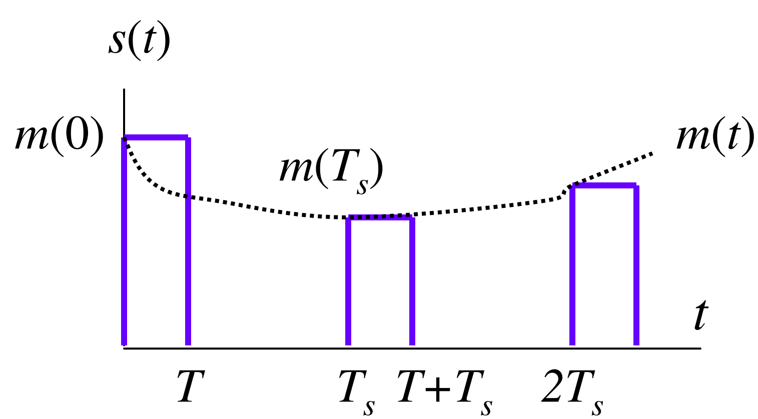
- **Transmitted signal**

$$s(t) = \sum_{n=-\infty}^{\infty} \underbrace{m(T_s\, n)}_{\textit{sample}} \underbrace{h(t - T_s n)}_{\textit{hold}}$$

$h(t)$ is a rectangular pulse of duration T units

$$h(t) = \begin{cases} 1 & \text{for } 0 < t < T \\ 1/2 & \text{for } t = 0, t = T \\ 0 & \text{otherwise} \end{cases}$$





As $T \to 0$,

$$\frac{1}{T} h(t) \to \delta(t)$$

Analog PAM

- **Transmitted signal**

$$s(t) = \sum_{n=-\infty}^{\infty} m(T_s\, n)\, h(t - T_s\, n)$$

$$= \sum_{n=-\infty}^{\infty} m(T_s\, n)\left(\delta(t - T_s\, n) * h(t)\right)$$

$$= \underbrace{\left[\sum_{n=-\infty}^{\infty} m(T_s\, n)\, \delta(t - T_s\, n)\right]}_{m_{sampled}(t)} * h(t)$$

- **Fourier transform**

$$S(f) = M_{\text{sampled}}(f)\, H(f)$$

$$= f_s \sum_{k=-\infty}^{\infty} M(f - f_s\, k)\, H(f)$$

$$H(f) = T \operatorname{sinc}(\pi\, f\, T)\, e^{-j\, 2\pi\, f\, T/2}$$

$$= T \operatorname{sinc}(\pi\, f\, T)\, e^{-j\pi\, f\, T}$$

- **Equalization of sample and hold distortion added in transmitter**
  - $H(f)$ causes amplitude distortion and delay of $T/2$
  - Equalize amplitude distortion by post-filtering with magnitude response

$$\frac{1}{H(f)} = \frac{1}{T \operatorname{sinc}(\pi\, f\, T)} = \frac{\pi\, f}{\sin(\pi\, f\, T)}$$

  - Negligible distortion (less than 0.5%) if $\frac{T}{T_s} \leq 0.1$

Analog PAM

- **Requires transmitted pulses to**

  Not be significantly corrupted in amplitude

  Experience roughly uniform delay

- **Useful in time-division multiplexing**

  public switched telephone network T1 (E1) line
  time-division multiplexes 24 (32) voice channels

  Bit rate of 1.544 (2.048) Mbps for duty cycle < 10%

- **Other analog pulse modulation methods**

  Pulse-duration modulation (PDM),
  a.k.a. pulse width modulation (PWM)

  Pulse-position modulation (PPM): used
  in some optical pulse modulation systems.