AV312 - Lecture 14

Vineeth B. S.

Department of Avionics,
Indian Institute of Space Science and Technology.

Figures from “Communication Systems” by Haykin and “An Intro. to Analog and Digital Commn.” by Haykin and Moher

6th September 2016

Review of last classes

- Delta modulation
- Read Delta-Sigma modulation and Differential PCM from the textbook

Today's class

- Discussion about delta modulation
- Digital transmission
  - An example is PCM transmission
  - How to do digital transmission over baseband and passband channels?
- Today's scribes are Nikunj Gupta and Nitish Kumar for the first hour
- Today's scribes are Niwhashini and Palle Ananya for the second hour

Discussion about Delta modulation - a counter example

- We had interpreted delta modulation as a signalling scheme that signals "changes" in a signal from the n^{th} sampling instant to the $(n+1)^{th}$.
- Why not signal the quantized form of the difference $m(nT_s + T_s) - m(nT_s)$ instead of $m(nT_s + T_s) - m_q(nT_s)$? The intuition is that a staircase waveform is what is available at the receiver.

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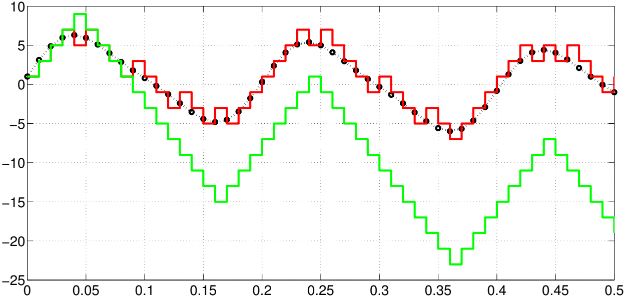
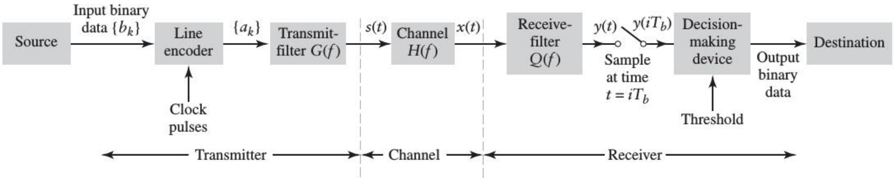


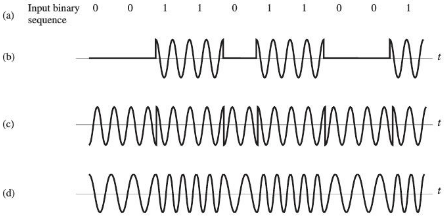
Digital transmission



- Source of digital information - characterized by bit duration T_b (or bit rate)
- Converted into a line code whose levels are represented by a_k (say $-A$ and $+A$)
- Further transformation of a_k to "match" the signal to the channel (what if the channel were bandpass?)
- We obtain a continuous time signal $s(t)$ which is transmitted over the channel
- At the receiver need to convert it into a digital signal - so synchronized sampling, usually at rate T_b
- A decision device decides whether 0 or 1 was transmitted
- M-ary transmission - transmit groups of bits using multiple levels in a_k.

Transmission over Passband channels

- A sinusoidal carrier signal $c(t) = A_c cos(2\pi f_c t + \phi_c)$
- Binary amplitude shift keying (BASK)
- Binary phase shift keying (BPSK)
- Binary frequency shift keying (BFSK)
- A convenient normalization for unit carrier energy for a bit duration; $A_c = \sqrt{\frac{2}{T_b}}$



Binary amplitude shift keying

- For $kT_b \leq t \leq (k+1)T_b$

$$b(t) = \begin{cases} \sqrt{E_b}, \text{ for } b_k = 1 \\ 0, \text{ for } b_k = 0. \end{cases}$$

- $s(t) = b(t)c(t)$

$$s(t) = \begin{cases} \sqrt{\frac{2E_b}{T_b}} cos(2\pi f_c t), \text{ for } b_k = 1 \\ 0, \text{ for } b_k = 0. \end{cases}$$

- Average transmitted energy $\frac{E_b}{2}$
- Generation of BASK signal - can a multiplier be used?
- Detection of a BASK signal - what property does the envelope have?

Binary phase shift keying

- For $kT_b \leq t \leq (k+1)T_b$

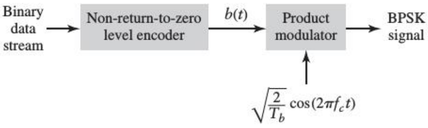
$$b(t) = \begin{cases} \sqrt{E_b}, & \text{for } b_k = 1 \\ -\sqrt{E_b}, & \text{for } b_k = 0. \end{cases}$$

- $s(t) = b(t)c(t)$

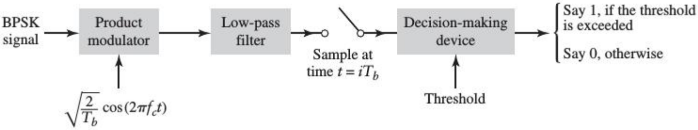
$$s(t) = \begin{cases} \sqrt{\frac{2E_b}{T_b}} cos(2\pi f_c t), & \text{for } b_k = 1 \\ -\sqrt{\frac{2E_b}{T_b}} cos(2\pi f_c t), & \text{for } b_k = 0. \end{cases}$$

- Average transmitted energy E_b
- Generation of BPSK signal - can a multipler be used?
- Detection of a BPSK signal - does the envelope detector work here?

Generation and coherent detection of BPSK-ed $s(t)$



(a)



(b)

- The receiver is coherent; the local carrier has to be synchronous in phase as well as frequency to the transmitted (actually received) carrier.
- Note that the transmitter and receiver architecture is similar to that for DSBSC.
- Need to be careful about the cutoff frequency of the low pass filter.

Binary frequency shift keying

- For $kT_b \leq t < (k+1)T_b$

$$s(t) = \begin{cases} \sqrt{\frac{2E_b}{T_b}} cos(2\pi f_1 t), \text{ for } b_k = 1 \\ \sqrt{\frac{2E_b}{T_b}} cos(2\pi f_2 t), \text{ for } b_k = 0. \end{cases}$$

- BFSK could have continuous phase or discontinuous phase
- For continuous phase $f_1(kT_b + T_b) = f_2(kT_b) + 2m\pi$

Power spectrum of BPSK

- We are not really interested in analysing a deterministic sequence of bits, but rather a random sequence.
- We will revisit this analysis in the second pass.
- Note that we are interested in the power spectrum, more precisely it is a normalized power spectrum.
- The BPSK-ed $s(t) = b(t)c(t)$, where $b(t)$ is a pulse train with $\sqrt{E_b}$ and $-\sqrt{E_b}$ levels.
- Suppose we have a rectangular pulse $p(t)$ of duration T_b (assume non-zero in $[0, T_b)$) and amplitude A. What is the normalized energy spectrum $|P(f)|^2$ of this pulse?

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- Suppose we have a rectangular pulse $p(t)$ of duration T_b (assume non-zero in $[0, T_b)$) and amplitude A. What is the normalized energy spectrum $|P(f)|^2$ of this pulse?
- $|P(f)|^2 = A^2 T_b^2 sinc^2(\pi f T_b)$
- Suppose we take bit sequences of length n and compute their normalized energy spectrums
- An average normalized power spectrum $G(f)$ can be obtained as $\frac{1}{nT_b} \times$ energy spectrum of n bit sequence.
- Turns out that the normalized energy spectrum for n pulses is $nA^2 T_b^2 sinc^2(\pi f T_b)$
- Therefore, the normalized power spectrum $|B(f)|^2$ is $A^2 T_b sinc^2(\pi f T_b)$

Power spectrum of BPSK

- So $|B(f)|^2$ is $A^2 Tsinc^2(\pi f T_b)$
- We are translating this baseband spectrum to f_c and $-f_c$ when we are multiplying it by the carrier signal $c(t)$
- What is the normalized power spectrum of the BPSK signal?

Power spectrum of BPSK

- So $|B(f)|^2$ is $A^2 T sinc^2(\pi f T_b)$
- We are translating this baseband spectrum to f_c and $-f_c$ when we are multiplying it by the carrier signal $c(t)$
- What is the normalized power spectrum of the BPSK signal?
- It is approximately $\frac{1}{4}\left[A^2 T_b sinc^2(\pi(f - f_c)T_b) + A^2 T_b sinc^2(\pi(f + f_c)T_b)\right]$

Power spectrum of BASK

- A BASK $s(t)$ is $\frac{A}{2} cos(2\pi f_c t) + \frac{s_{PSK}(t)}{2}$!
- We think of the BASK signal as a carrier component along with a BPSK signal.
- The spectrum has a carrier component at f_c, which is not present for BPSK.

Power spectrum of BFSK

- A BFSK $s(t)$ is the sum of two BASK signals
- $s(t) = b(t)\sqrt{\frac{2}{T_b}}cos(2\pi f_1 t) + (1 - b(t))\sqrt{\frac{2}{T_b}}cos(2\pi f_2 t)$
- The spectrum of $s(t)$ can be obtained approximately as the sum of two BASK spectrums!

Quadriphase shift keying (QPSK)

- For $kT \leq t < (k+1)T$

$$s(t) = \sqrt{\frac{2E}{T}} cos\left(2\pi f_c t + (2i-1)\frac{\pi}{4}\right),$$

where $i \in \{1, 2, 3, 4\}$

- Note that the time interval T is possibly different from T_b
- A generalized version is M-ary PSK
- Recall quadrature carrier multiplexing - two signals multiplexed together using quadrature carriers but no increase in bandwidth
- $s(t) = \sqrt{\frac{2E}{T}} cos\left((2i-1)\frac{\pi}{4}\right) cos(2\pi f_c t) - \sqrt{\frac{2E}{T}} sin\left((2i-1)\frac{\pi}{4}\right) sin(2\pi f_c t)$
  - Combination of two BPSK signals - the bits can be chosen independently
  - A representation using vectors - constellation diagram

QPSK - generation and detection