AVD623: Communication Systems-II

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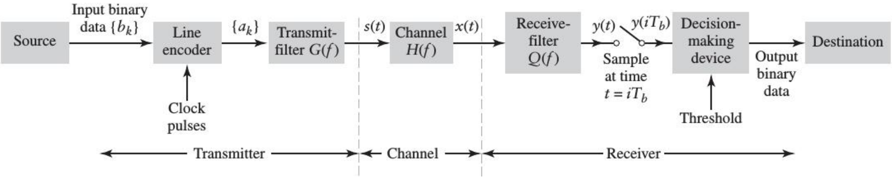
Lecture 7

Figures are taken from “Communication Systems” by Simon Haykin, “Communication Systems” by Stern and Mahmoud, and “Software receiver design” by Sethares and Johnson.

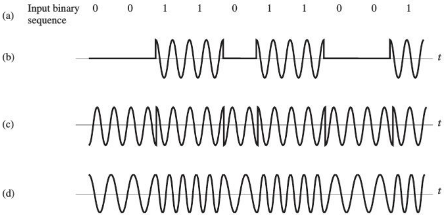
Digital transmission



- 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 $\frac{E_b}{2}$

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

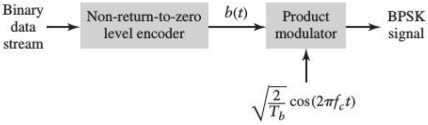
Binary frequency shift keying

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

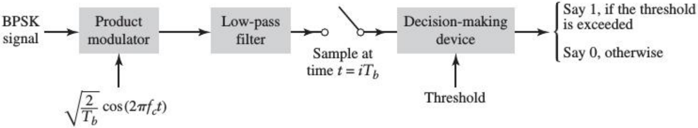
$$s(t) = \begin{cases} \sqrt{\frac{2E_b}{T_b}} cos(2\pi f_1 t), & \text{for } b_k = 1 \\ \sqrt{\frac{2E_b}{T_b}} cos(2\pi f_2 t), & \text{for } b_k = 0. \end{cases}$$

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

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.

Two issues - Carrier and Timing/Clock Recovery

- A local oscillator needs to produce a replica of the carrier at the receiver
- Replica $\Rightarrow$ match in both frequency and phase
- Difference in frequencies $\Rightarrow$ time varying (linear) difference in phase

$$cos(2\pi f_1 t) \text{ and } cos(2\pi f_2 t)$$

- A clock circuit needs to tick off bit periods and sample the received continuous time waveform at the appropriate times within each bit period

Is carrier (both phase and frequency) recovery essential?

- Not essential! We can tradeoff decoding error probability with the complexity required for carrier recovery using non-coherent detection schemes
- Recall what an envelope detector circuit does

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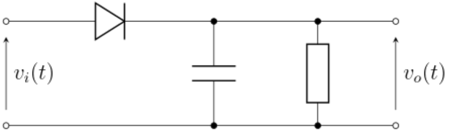

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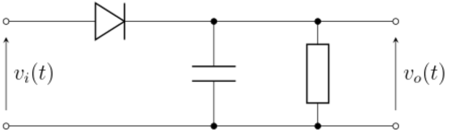


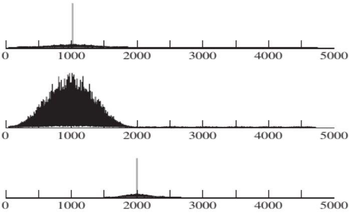
- How to use the envelope detector for BASK?
- How to use the envelope detector for BFSK?

How to do carrier recovery?

Phase and frequency estimation using

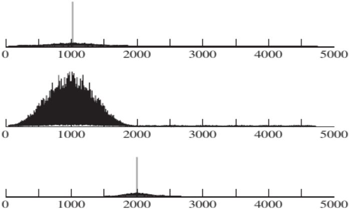
- FFT
- Phase locked loops
- Squared difference loop
- Costas loop
- Decision directed tracking

Phase and frequency estimation using FFT



- The simplest case is when the carrier is sent along with the signal - e.g. large carrier AM
- In this case, there is a large amount of energy at the carrier frequency. So if we take an FFT (with suitable resolution), then the point where the FFT magnitude is maximum can be taken as the carrier, and the phase of the FFT at that point is taken as the phase of the carrier
- Suppose the carrier is suppressed as in the case of DSBSC. Then the above method does not work!

Phase and frequency estimation using FFT



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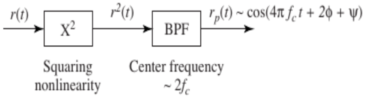
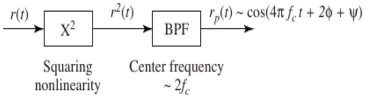


Phase and frequency estimation using FFT



- Suppose the received signal is $r(t) = s(t)cos(2\pi f_c t + \phi)$
- After squaring we have

$$r^2(t) = \frac{s^2(t)}{2}\left[1 + cos(4\pi f_c t + 2\phi)\right]$$

- The $s^2(t)$ consists of an average constant value $s^2_{avg}(t)$ and a varying value $v(t)$
- Suppose we have a narrow bandpass filter at $2f_c$ then the filtered output would contain a large carrier component (but at $2f_c$ and with double the phase ϕ), which can be recovered using FFT as before.