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UESTC4004
Digital Communications

Bandpass modulation & demodulation

Lecture Preview

- Baseband vs Passband Communication
  - What is passband communication
  - Why we perform passband communication
  - How the perform passband communication
- Binary modulations & Demodulations
  - Amplitude Shift Keying (ASK)
  - Frequency Shift Keying (FSK)
  - Phase Shift Keying (PSK)

Disclaimer: Some parts of this lecture are taken from lecture 7: Communications II by Prof. K. K. Leung, Imperial College London

Bandpass Modulation

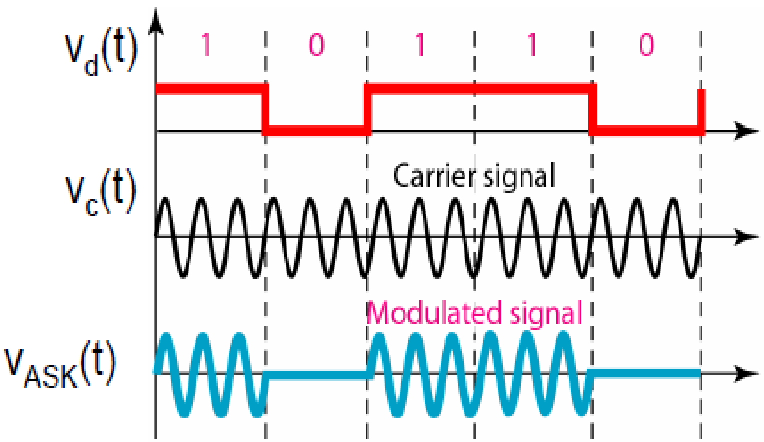
- The process of ‘riding’ the information over the carrier.
- Why we perform modulation?
  - Ease of transmission
  - Multiplexing

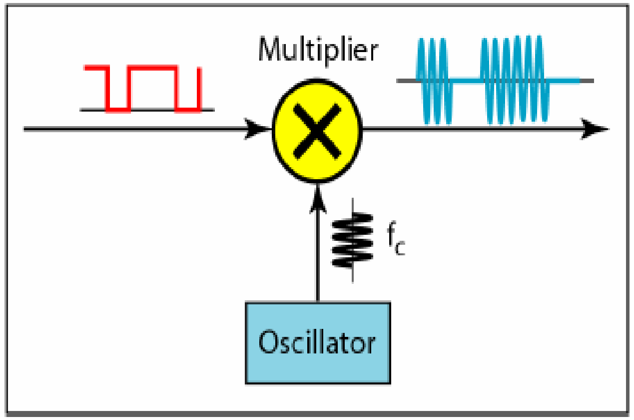
Discussions

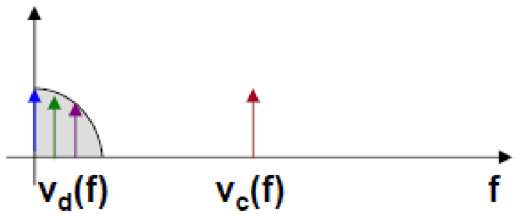
- Should we keep the carrier frequency as high as possible to make the antenna size small? What might be the negative impact of increasing the carrier frequency?

Binary Amplitude Shift Keying (B-ASK)

The amplitude of the modulated signal changes with the change in data bits.







B-ASK

How the spectrum looks like after modulation?

ASK Demodulation and Applications

Demodulation: need to confirm the presence or absence of a sinusoid in a given time interval

Advantages: simplicity

Disadvantages: very susceptible to noise interference because noise affects the amplitude

Applications: used to transmit digital data over optical fibre

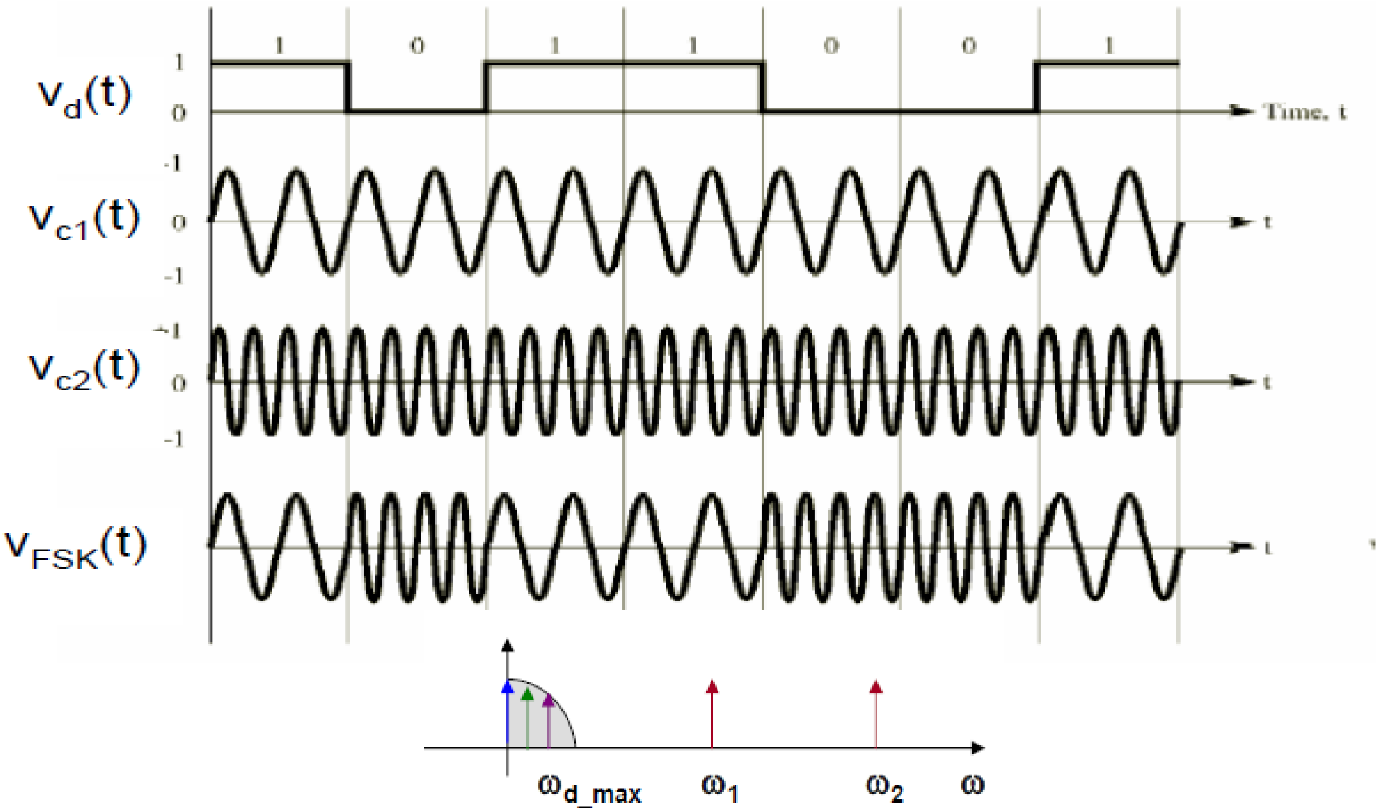
Example: M-ary ASK

- Consider ASK modulation with 4 levels, 1, 2, 3 and 4.
- Plot the 4-ary timing waveform for a binary sequence 1011101101. Then modulate the information signal with a carrier of f_c Hz. Represent the modulated signal in both time and frequency domain. Hint: You could assign the bit combinations to amplitude levels as below:

Bit combination	Amplitude levels
00	1
01	2
10	3
11	4

Binary Frequency Shift Keying (B-FSK)

The frequency of the modulated signals changes with the change in data bits.



B-FSK

How the spectrum looks like after modulation?

FSK Demodulation and Applications

Demodulation: need to determine which of the two possible frequencies is present at a given time

Advantages: less susceptible to errors than ASK. Receiver looks for specific frequency changes over a number of intervals so amplitude(noise) spikes can be ignored.

Disadvantages: uses twice the bandwidth as compared to ASK

Applications: over voice lines, in high frequency radio transmission etc.

Example: M-ary FSK

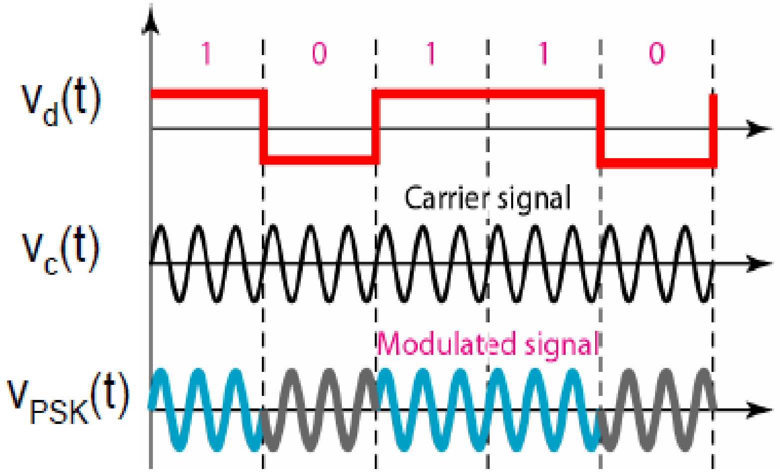
- Consider 4-ary FSK with f_{c1}=100 MHz, f_{c2}=200 MHz, f_{c3}=300 MHz and f_{c4}=400 MHz.
- Plot the 4-ary timing waveform for a binary sequence 1011101101. Then modulate the information signal using 4-ary FSK. Consider most significant bit as the start of the bit sequence. Represent the modulated signal in both time and frequency domain.

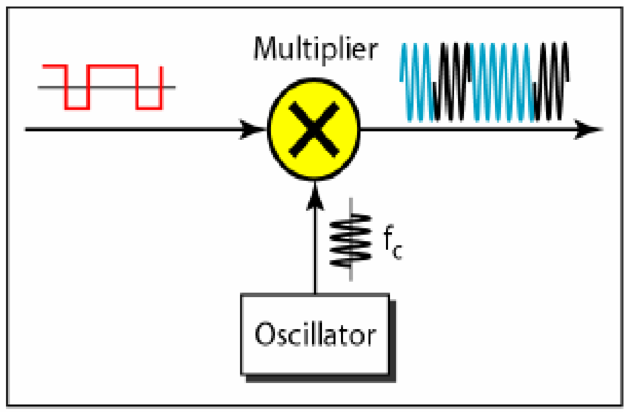
Hint: You could assign the bit combinations to frequency values as below:

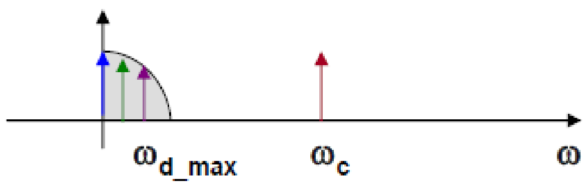
Bit combination	Carrier Frequencies
00	f_{c1}
01	f_{c2}
10	f_{c3}
11	f_{c4}

Binary Phase Shift Keying (BPSK)

The modulated signal's phase changes with the change in data bits.







BPSK

How the spectrum looks like after modulation?

PSK

Demodulation: demodulator must determine the phase of the received sinusoid with respect to some reference phase

Advantages: less susceptible to errors than ASK, while it occupies the same bandwidth as ASK. It means more efficient use of bandwidth is possible compared to FSK which may result in higher data rates.

Disadvantages: more complex signal detection/recovery process than ASK and FSK

Applications: variants of PSK are used in several wireless systems including WLAN, Bluetooth etc.

Bandpass demodulation

Coherent (synchronous) detection

- At first, we use a bandpass filter to reject out-of-band noise
- Then we multiply the incoming waveform with **a cosine of the carrier frequency**. This requires a **carrier regeneration** of same phase and frequency as that of the modulator
- Finally, we use a low pass filter to recover baseband information

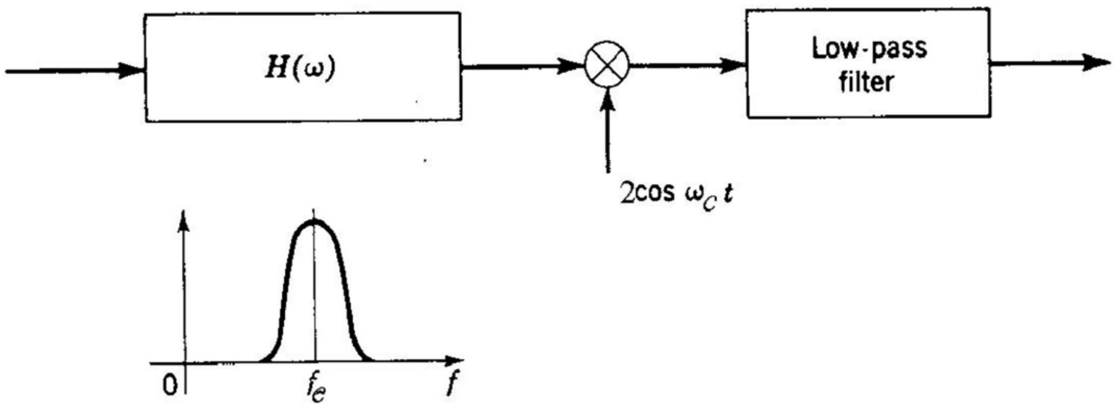
Noncoherent detection (envelope detection etc.)

- The received does not make any explicit efforts to estimate the phase
- Simpler implementation at the cost of some error loss

ASK Coherent Demodulation

- ASK modulated signal

$$s_0(t) = 0$$
$$s_1(t) = A\cos(2\pi f_c t)$$



At the receiver, BPF followed by carrier demodulation and LPF to recover transmitted signal

ASK Coherent Demodulation

- Assuming an equiprobable transmission of 0s and 1s.
- The probability of error is given by:

$$\boxed{P_{e,ASK} = Q(\frac{A}{2\sigma_0})}$$

- Remember from last lecture

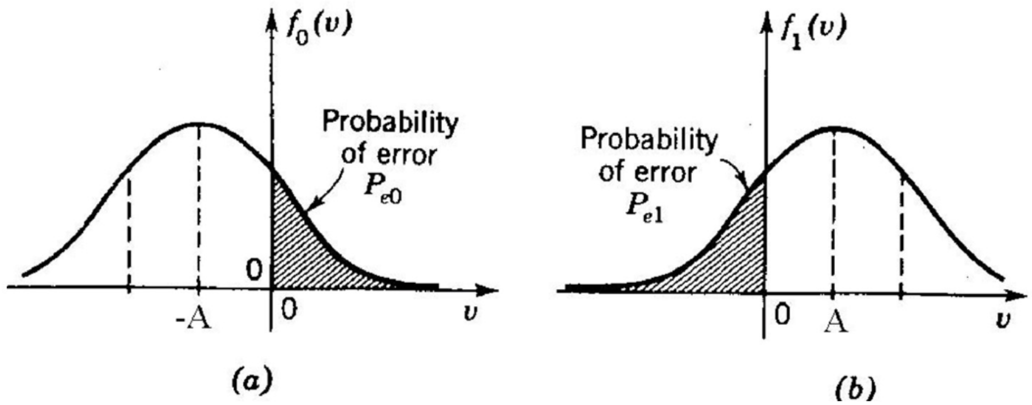
$$\boxed{P_B = Q\left(\frac{a_1 - a_0}{2\sigma_0}\right)} \Leftarrow equation\ B.18$$

PSK Coherent Demodulation

- PSK modulated signal

$$\boxed{s(t) = A(t)\cos(2\pi f_c t),} \quad A(t) \in \{-A, A\}$$

Probability density functions for PSK for equiprobable 0s and 1s in noise:
(a): symbol 0 transmitted (b): symbol 1 transmitted



PSK Coherent Demodulation

- Error probability would be:

$$\boxed{P_{e,PSK} = Q(\frac{A}{\sigma_0})}$$

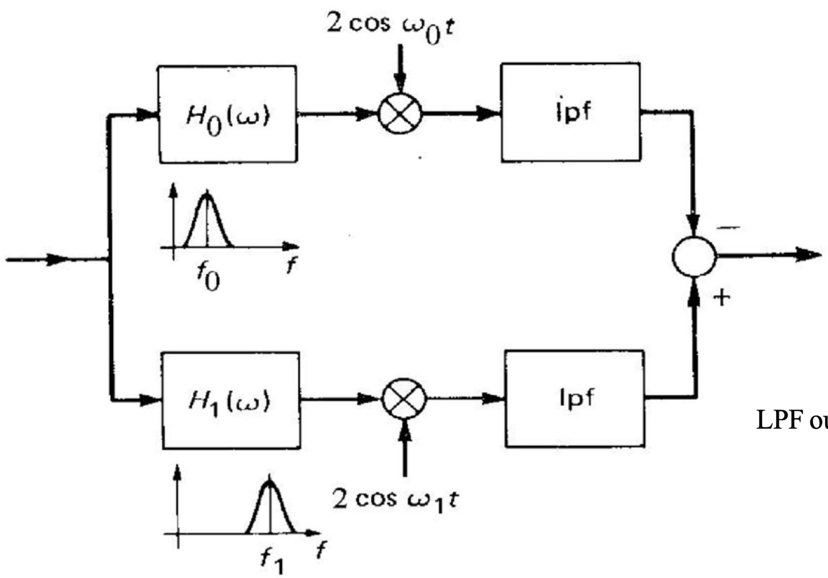
- Error probability for PSK is smaller than that of ASK $P_{e,ASK} = Q(\frac{A}{2\sigma_0})$

$$P_e = Q\left(\frac{a_1 - a_0}{2\sigma_0}\right) \quad \begin{cases} P_{e,PSK} = Q\left(\frac{A}{\sigma_0}\right) \\ P_{e,ASK} = Q\left(\frac{A}{2\sigma_0}\right) \end{cases}$$

FSK Coherent Demodulation

- FSK modulated signal

$$
\begin{aligned}
s_0(t) &= A\cos(2\pi f_0 t), && \text{if symbol 0 is transmitted} \\
s_1(t) &= A\cos(2\pi f_1 t), && \text{if symbol 1 is transmitted}
\end{aligned}
$$



$$
\text{LPF output on each branch} = \begin{cases} \text{A} + \text{noise} & \text{if symbol present} \\ \text{noise} & \text{if symbol not present} \end{cases}
$$

FSK Coherent Demodulation

Output if a symbol 1were transmitted

$$y_1(t) = A + [n_1(t) - n_0(t)]$$

Output if a symbol 0 were transmitted

$$y_0(t) = -A + [n_1(t) - n_0(t)]$$

- Similar to PSK but the difference is noise.
- The noises in the two channels are independent
- the variances add and therefore the noise variance has doubled

$$\boxed{P_{e,FSK} = Q\left(\frac{A}{\sqrt{2}\sigma_0}\right)}$$

Error Probability: ASK vs PSK vs FSK

ASK/PSK/FSK $\xrightarrow{\text{Trans}}$ Receive

h(t) ← demodu + detect

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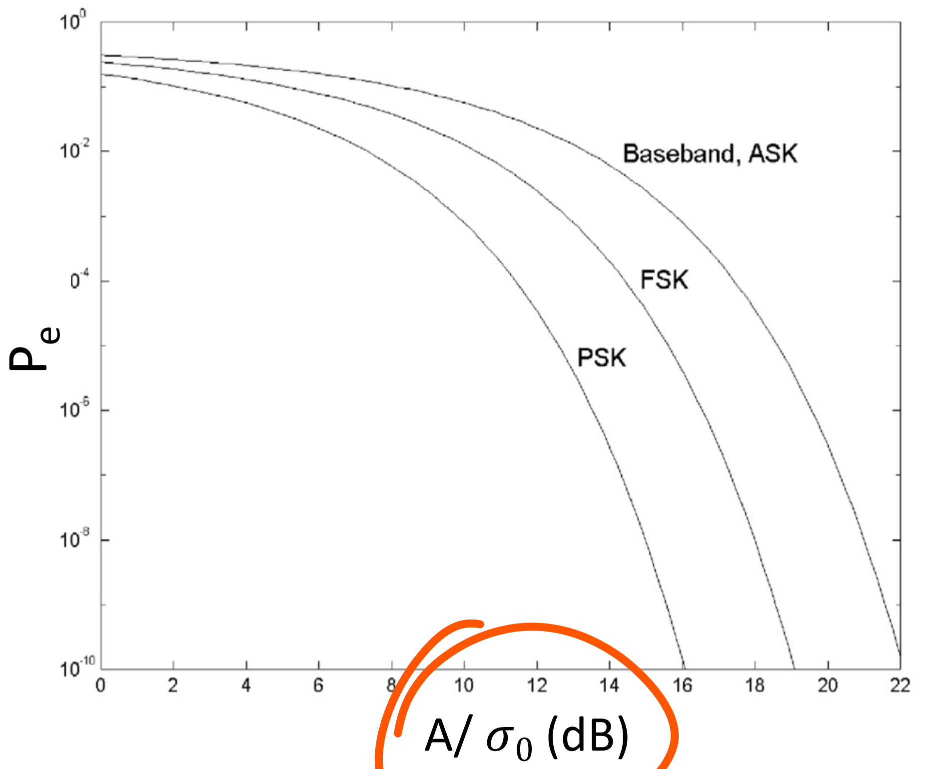

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Review Questions

- What is bandpass modulation?
- How ASK is different than PSK? $S_p = A(t)\cos(2\pi f_c t)$ $A = \{1, -1\ (0)$
- Is FSK better than ASK with regards to bandwidth utilisation? No.

$$P_e: \left.\begin{aligned} &ASK: Q\left(\frac{A}{2\sigma_0}\right) \\ &PSK: Q\left(\frac{A}{\sigma_0}\right) \\ &FSK: Q\left(\frac{A}{\sqrt{2}\sigma_0}\right) \end{aligned}\right\} Q\left(\frac{a_1 - a_0}{2\sigma_0}\right)$$

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