Problems for chapter1

1. 1 Suppose that an information source is composed of 64 different symbols, of which 16 symbols have a probability of 1 / 32 and 48 symbols have a probability of 1 / 96. If the source sends out 1000 independent symbols per second, try to find the average information rate of the information source.

Answer:

$$H(X) = -\sum_{i=1}^{M} P(x_i)\log_2 P(x_i) = -\sum_{i=1}^{64} P(x_i)\log_2 P(x_i) = 16*\frac{1}{32}\log_2 32 + 48*\frac{1}{96}\log_2 96$$

=5.79 bits/symbol

$$R_b = mH = 1000*5.79 = 5790 \text{ b/s}$$

1.2: On the keyboard of a telephone there are 10 number keys (0~9).

$$P_1 = 0.3, P_3 = P_8 = 0.14,\ P_0 = P_2 = P_4 = P_5 = P_6 = P_7 = P_9 = 0.06$$

(1) Try to figure out the entropy of the information source of each key.

(2) If the rate of pressing keys is 2 p/s, try to figure out the information rate.

Answer:

(1) $H(x) = -\sum_{i=0}^{9} P(x_i)\log_2 P(\chi_i)$

$=-0.3\log_2 0.3 - 2\times 0.14\log_2 0.14 - 7\times 0.06\log_2 0.06$

=3.02 bits/key

(2) R_b=2*3.02=6.04 b/s

1. 3: The rate of transmitting binary code elements in a digital transmission system is 1200Baud, and the information rate of the system is calculated. What is the rate of system information if the system is changed to transmit octal message bits at the same rate?

Answer:

$$R_b = R_B \cdot \log_2 M = 1200*\log_2 2 = 1200 b/s$$

$$R_b = R_B \cdot \log_2 M = 1200*\log_2 8 = 3600 b/s$$

1.4.（摘自通信原理(英文版)樊昌信编著）An information source consists of A,B,C,and D. Assume each symbol occurs independently ,and the occurrence probabilities are respectively 1/4,1/4,3/16,and 5/16. Find the information content for each symbol in the information source.

Solution:

$I_A = \log_2\frac{1}{P(A)}$=-$\log_2 P(A)$=-$\log_2\frac{1}{4}$=2(b)

I_B=-$\log_2\frac{3}{16}$=2.415(b)

I_C=-$\log_2\frac{3}{16}$=2.415(b)

I_D=-$\log_2\frac{5}{16}$=1.678(b)

1.5（摘自通信原理(英文版)樊昌信编著） Assume an information source consists of 64 different symbols, the occurrence probability of 16 symbols among them is 1/32,and the occurrence probability of other 48 symbols is 1/96. If there are one thousand independent symbols per second sent out, find the average information rate of the information source.

Solution:

The entropy of the information source is:

H（X） $=-\sum_{i=1}^{M} P(x_i)\log_2 P(x_i) = -\sum_{i=1}^{64} P(x_i)\log_2 P(x_i) = 16*\frac{1}{32}\log_2 32 + 48*\frac{1}{96}\log_2 96 = 5.79$ （bit/state）

thus, the average information rate of the information source is:

R_b= m H（X）=1000*5.79 = 5790（ b/s）

1.6.（翻译自通信原理第 7 版 P16 题 1-6）Assume a signal source produces 2-ary signals, and the width of its symbol is 0.4ms.

(1)Find the information rate of the information source.

(2)Assume this information source is changed into 16-ary signals, with the same width of symbol, can you figure out the information rate of the information source?(Assume every signal appears with equal probability).

Solution:

(1)$R_B = \frac{1}{T_B} = \frac{1}{0.4\text{ms}} = 2500$（Baud）

$R_b = R_B \log_2 2 = 2500$ (b/s)

(2)$R_b = R_B \log_2 16 = 10000$(b/s)

1.7. If the width of the binary signal (equal probability) is 0.5ms,find the symbol rate and the information rate; if the information source produces 4-ary signals with equal probability, the width of the symbol remains unchanged, find the symbol rate and the information rate.

Solution:

2-ary equal probability signals:

H(x)=$\log_2 2$=1 b/state

R_B=$\frac{1}{T}$=$\frac{1}{0.5*10^{-3}}$=2000 B

R_b=R_B*H(x)=2000x1=2000 b/s

4-ary equal probability signals:

H(x)= $\log_2 4$=2 b/state

R_B is the same of the above,so R_B=2000 B

R_b=R_B*H(x)=2000x2=4000 b/s

1.8Calculate the average amount of information of four letter sequences whose issuing probabilies are 1/2,1/4,1/6 and 1/12 respectively.

解：可知信源的平均信息量为

$$H(x) = -\sum_{i=1}^{4} P(x_i) log_2 P(x_i)$$
$$= -\frac{1}{2} log_2 \frac{1}{2} - \frac{1}{4} log_2 \frac{1}{4} - \frac{1}{6} log_2 \frac{1}{6} - \frac{1}{12} log_2 \frac{1}{12}$$
$$= 0.5 + 0.5 + 0.4308 + 0.2988$$
$$= 1.730(bit/sym)$$

1.9When a message is transmitted using a 16bit code sequence,the code rate is 300 Baud. What is the rate at which the massage is transmitted if the binary code sequence is used instead?
解：可知信息速R_b率为

$$R_b = R_B log_2 M = 300 \cdot log_2 16 = 1200(bit/s)$$

1.10A message passes through a noisy channel at an information rate of 2M bit/s,and an average o f 72 bit error occurs at the output end of the receiver per hour. Try to find the bit error rate.
解：根据误比特率定义，可知

$$P_b = \frac{错误比特数}{传输总比特数} = \frac{72}{2 \times 10^6 \times 3600} = 10^{-8}$$

1.11（译自通信原理第 7 版习题 1-6）Assume a signal source produces binary signals, and the width of its symbol is 0.4ms.
（1）Find the information rate of the information source.
（2）Assume this information source is changed into 16-ary signals, with the same width of symbol, can you figure out the information rate of the information source?(Assume every signal appears with equal probability).
Solution：

（1）$R_B = \frac{1}{T_B} = \frac{1}{0.4ms} = 2500$（Baud）

$R_b = R_B \log_2 2 = 2500$ (b/s)

(2)$R_b = R_B \log_2 16 = 10000$(b/s)

1.12（译自通信原理第7版习题1-5）Assume that the output of a signal source is composed of 128 different symbols, of which 16 are 1/32 and other 112 are 1/224. The signal source sends out 1000 symbols per second, and each symbol is independent of each other. Try to find the average information rates of this information source.
Solution:

H(x) = $16 * \frac{1}{32} \log_2 32 + 112 * \frac{1}{224} \log_2 224$

$\approx 16 * \frac{1}{32}(5) + 112 * \frac{1}{224}(7.81)$

=2.5+3.905

=6.405(bits/state)

Because $R_B = 1000(B)$

$R_b = R_B * H$ =1000*6.405=$6.405*10^3$ (bit/s)

1.13The symbol set of an information source is composed of a, B, C, D and E. if each symbol appears independently, its probability of occurrence is 1 / 4, 1 / 8, 1 / 8, 3 / 16, 5 / 16. Try to find the average information quantity of the symbol of the information source.

$$H = -\sum_{i-1}^{n} P(x_i)\log_2 P(x_i)$$
$$= -\frac{1}{4}\log_2\frac{1}{4} - \frac{1}{8}\log_2\frac{1}{8} - \frac{1}{8}\log_2\frac{1}{8} - \frac{3}{16}\log_2\frac{3}{16} - \frac{5}{16}\log_2\frac{5}{16} = 2.23bit$$

1.14. A discrete information source outputs 8 different symbols x1, X2,... X8, and the symbol rate is 2400Baud. Among them, the probability of four symbols appearing is 1 / 16, 1 / 16, 1 / 8, 1 / 4, and other symbols appear with equal probability.

(1) Calculate the average information rate of the information source;

(2) Calculate the amount of information transmitted for 1 hour.

Solution:

(1)

$$H(x) = -\sum P(x_i)\log_2 P(x_i)$$
$$= -2\times\frac{1}{16}\log_2\frac{1}{16} - \frac{1}{8}\log_2\frac{1}{8} - \frac{1}{4}\log_2\frac{1}{4} - 4\times\frac{1}{8}\times\log_2\frac{1}{8} = 2.875bit$$

则信息的平均信息速率 $R_b = R_B \times H = 2400\times 2.875 = 6900 bit/s$

（2）传送 1h 的信息量为：

$$I = T\times R_b = 3600\times 6900 = 2.484\times 10^7 bit$$

第一章的计算比较简单，也很基础，信息量和熵的概念很重要。

传码率、传信率和误码率可以有效地帮助大家理解通信系统的性能指标，后面章节还会用到这些知识点。

Chapter 2 题库和作业刷一下即可

2.1 Let the stochastic process $\xi(t)$be expressed as

$$\xi(t) = 2\cos(2\pi t + \theta)$$

In the formula, θ is a discrete random variable, and $P(\theta = 0) = 1/2$ 、 $P(\theta = \pi/2) = 1/2$, and $E_\xi[\xi(1)]$and $R_\xi(0,1)$ are obtained.

Solution:

The mathematic expectation of $\xi(1)$:

$$E_\xi(1) = E[\xi(1)] = P(\theta = 0) * \xi(1)|_{\theta=0} + P\left(\theta = \frac{\pi}{2}\right) * \xi(1)|_{\theta=\frac{\pi}{2}} = 1$$

The correlation function $R_\xi(0,1)$:

$R_\xi(0,1) = E[\xi(0)\xi(1)] = E[4cos^2\theta]$

$$= P(\theta = 0) * 4cos^2\theta|_{\theta=0} + P\left(\theta = \frac{\pi}{2}\right) * 4cos^2\theta|_{\theta=\frac{\pi}{2}} = 2$$

2.2 Let $X(t)$ be a stationary stochastic process with mean value a and autocorrelation function $R_x(\tau)$, whose output through a linear system is

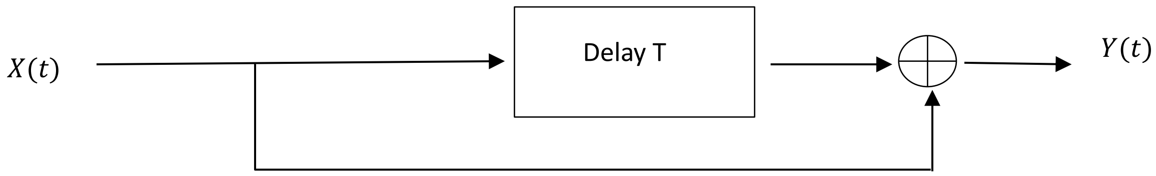
$$Y(t) = X(t) + X(t - T) \quad (T \text{ is the delay time})$$

(1) The block diagram of the linear system is drawn;

(2) The autocorrelation function and power spectral density of $Y(t)$ are obtained.

Solution:

(1) linear system:



(2)

$E[X(t)] = a$

$R_x(\tau) = E[X(t)X(t + \tau)]$

$P_x(f) = \int_{-\infty}^{\infty} R_x(\tau)e^{-j2\pi f\tau}\, d\tau$

autocorrelation function:

$R_y(\tau) = E[Y(t)Y(t + \tau)]$

$= E[X(t)X(t + \tau) + X(t)X(t + \tau - T) + X(t - T)X(t + \tau) + X(t - T)X(t + \tau - T)]$

$= E[X(t)X(t + \tau)] + E[X(t)X(t + \tau - T)] + E[X(t - T)X(t + \tau)] + E[X(t - T)X(t + \tau - T)]$

$= R_x(\tau) + R_x(\tau - T) + R_x(\tau + T) + R_x(\tau)$

$= 2R_x(\tau) + R_x(\tau - T) + R_x(\tau + T)$

power spectral density:

Seeking Laplace transform at both ends of system equation of linear system:

$$Y(s) = (1 + e^{-sT})X(s) \quad (s = j2\pi f)$$

So, the system function of the system:

$$H(s) = \frac{Y(s)}{X(s)} = 1 + e^{-sT}$$

So, $$H(f) = 1 + e^{-j2\pi f}$$

So, $$P_Y(f) = P_x(f)|H(f)|^2 = P_x(f) * (2 + 2\cos(2\pi fT))$$

2.3 It is known that the random processes $(t) = m(t)\cos(w_0 t + \theta)$. $m(t)$ is stationary processes in wide-sense and its autocorrelation function is

$$R_m(\tau) = \begin{cases} 1 + \tau\,, & -1 < \tau < 0 \\ 1 - \tau\,, & 0 \le \tau < 1 \\ 0\,, & others \end{cases}$$

The random variable θ is uniformly distributed in $[0, 2\pi]$. θ and $m(t)$ are independent of each other.
Try to prove $z(t)$ is stationary processes in wide-sense

Answer:

Because $m(t)$ is stationary processes in wide-sense,

We know $E[m(t)] = a, E[m(t_1)m(t_2)] = R_m(\tau)$

$E[z(t)] = E[m(t)\cos(w_0 t + \theta)] = E[m(t)] \cdot E[\cos(w_0 t + \theta)]$

$= E[m(t)] \cdot \int_0^{2\pi} \cos(w_0 t + \theta) \frac{1}{2\pi} d\theta$

$= 0$

$$R_Z(t_1, t_2) = E[z(t_1)z(t_2)]$$
$$= E[m(t_1)m(t_2) \cdot \cos(w_0 t_1 + \theta)\cos(w_0 t_2 + \theta)]$$
$$= R_m(\tau) \cdot E\left\{\frac{1}{2}\cos[2\theta + w_0(t_1 + t_2)] + \frac{1}{2}\cos[w_0(t_1 - t_2)]\right\}$$
$$= R_m(\tau) \cdot \frac{1}{2}\cos[w_0(t_1 - t_2)]$$
$$= R_m(\tau) \cdot \frac{1}{2}\cos[w_0(\tau)] = R_z(\tau)$$

2.4 Assume $s(t)$ is a stationary random pulse sequence, and its PSD is $P_S(f)$.
Try to find out the PSD of $e(t) = s(t)cosw_c t$
Answer:

$$R_e(\tau) = E[s(t)cosw_c t \cdot s(t+\tau)cosw_c(t+\tau)]$$
$$= E[s(t)s(t+\tau)] \cdot \frac{1}{2}E[cosw_c\tau + \cos w_c(\tau + 2t)]$$
$$= R_s(\tau) \cdot \frac{1}{2}cosw_c\tau$$
$$= R_s(\tau) \cdot \frac{1}{4}(e^{-jw_c\tau} + e^{jw_c\tau})$$

Since $R_s(\tau) \leftrightarrow P_s(f)$

Then $P_e(f) = \frac{1}{4}[P_s(f + f_c) + P_s(f - f_c)]$

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2.5.Find the autocorrelation function of product z(t)=x(t)y(t). It is known that x(t)and y(t)are statistically independent stationary stochastic processes, and their autocorrelation functions are $R_x(\tau)$, $R_y(\tau)$.

Solution:

$R_Z(t_1, t_2) = E[z(t_1)z(t_2)] = E[x(t_1)y(t_1)x(t_2)y(t_2)]$

$= E[x(t_1)x(t_2)y(t_1)y(t_2)]$

$= E[x(t_1)x(t_2)]E[y(t_1)y(t_2)]$

(Because x(t) and y(t) are statistically independent)

$=R_x(t_1,t_2)R_y(t_1,t_2)$
$=R_x(\tau)R_y(\tau)=R_z(\tau)$
（Because x(t) and y(t) are stable）
So z(t) is also a stationary process with $R_x(\tau)R_y(\tau)=R_z(\tau)$.

Problems for Chapter3

重点是香农定理的计算，多径效应的概念需要深入去理解，很多通信模型里会用到。

3.1Assume a sky wave radio channel is set up to reflect electromagnetic waves with the ionosphere of F2 layer at a height equal to 400km. The equivalent radius of the Earth is equal to 6370×4/3km, the transceiver antennas are all set up on the ground plane.Try to calculate how many kilometers can the communication distance reach?
Solution:

$$r+h=(6370\times 4/3+400)=8893(\text{km})$$

$$L=[(r+h)^2-r^2]^{1/2}=(8893^2-400^2)^{1/2}=2637(km)$$

So the communication distance is: $2L=5264km$

3.2 Suppose a black and white digital photograph has 4 million pixels, each pixel having 16 brightness levels. If the transmission is on a channel with a bandwidth of 3kHz and the signal-to-noise power ratio is equal to 20dB, how long does it take to transmit?
Solution:
According to Shannon formula, the maximum information rate (the maximum amount of average information that can be transmitted per second) of a channel is：

$$c_t=B\log_2(1+\frac{S}{N})=3000\log_2(1+100)\approx 19.96(kb/s)$$

The amount of information contained in a photo is:

$$I=4\times 10^6\times\log_2 16=16\times 10^6(bit)$$

Therefore $t=I/C_t=(16\times 10^6)/(19.96\times 10^3)=801.6(s)=13.36(min)$

3.3.Suppose the transfer function of the ideal channel is

$$\text{H}(\omega)=K_0e^{-jwt_d},$$

where K_0 and t_d are constants, try to analyze the time domain and frequency domain expressions of the output signal after the signal passes through the ideal channel, and discuss the results.

Solution:

Suppose the frequency spectrum of the input s(t) is represented by s(ω), then after passing through the above channel, the frequency spectrum of the output channel can be expressed as

$$S_O(\omega) = S(\omega)H(\omega) = K_0 S(\omega)e^{-jwt_d},$$

then the output signal is

$$S_O(t) = K_0 s(t - t_d),$$

it can be seen that the channel meets the condition of no distortion, and the attenuation multiple of any frequency component of the signal and the delay is the same, so the signal has no distortion during transmission.

3.4 Suppose a color picture is composed of 3×10^6 pixels, each pixel has 16 brightness levels, and each brightness level is assumed to appear with equal probability. Now, the color picture is transmitted in a channel with signal-to-noise ratio of 20dB. It is required to transmit in four minutes, and try to calculate the required channel bandwidth.

Answer：

$$I_p = log_2 16 = 4bit$$
$$\mathrm{I} = 3 \times 10^6 \times I_p = 1.2 \times 10^7 bit$$
$$R_b = \frac{I}{4 \times 60} = 5 \times 10^4 bit/s$$
$$\mathrm{B} = \frac{C}{log_2(1+\frac{S}{N})} = \frac{5\times10^4}{log_2(1+100)} \approx 6.27 \times 10^3 \mathrm{Hz}$$

3.5 Suppose that the equivalent resistance of the input circuit of a receiver is 600 Ω, the bandwidth of the input circuit is 6MHz, and the environment temperature is 27 ℃. Please calculate the effective value of the thermal noise voltage generated by the circuit.

Answer：

$$\mathrm{V} = \sqrt{4kTRB}$$

$$V = (4 \times 1.38 \times 10^{-23} \times 300 \times 600 \times 6 \times 10^6)^{\frac{1}{2}} = 7.72\mu V$$

3.6The computer terminal transmits data through the telephone channel. The bandwidth of the telephone channel is 3.2kHz, and the output signal-to-noise ratio (S / N) of the channel is 30 dB. The terminal outputs 256 symbols, and each symbol is independent of each other.

(1) Calculate the channel capacity

(2) the highest symbol rate of error free transmission.

(1)由已知条件可知

$10\log_{10}\frac{S}{N} = 30$dB 所以 S/N=1000 所以

$$C = B\log_2\left(1+\frac{S}{N}\right) = 3.2 * 10^3 * \log_2 1001 = 3.2 * 10^4 \ (bit/s)$$

(2) 无误码传输时 R_b=C=3.2 $*10^4$（bit/s）

$R_{BN}=R_b/\log_2 N=3.2*10^4/\log_2 256$=4000B

3.7 Each black-and-white TV image contains 3x10[5] lines, and each pixel has 16 equal brightness levels. 30 frames per second is required. If the signal output s / N = 30dB, calculate the minimum bandwidth of the channel required for transmission of the black-and-white TV image.

Answer: 每个像素所含信息量 H=$\log_2 16$=4bit

信道容量等于 C=4*3*10^5*30=3.6*10^7（bit/s）

又 S/N=1000=30dB

B=C/$\log_2\left(1+\frac{S}{N}\right)$=3.6*$10^4$HZ

3.8 The known color TV image is composed of 5×10^5 pixels. Set each pixel to have 64 color degrees and 16 brightness levels for each color degree. If all combinations of color and brightness levels are equally and statistically independent.

(1) Try to calculate the channel capacity needed to transmit 100 images per second;

(2) Calculate the required channel bandwidth if the received SNR is 30dB.

答：(1) $\mathrm{H(x)}=\log_2(16\times64)=10bit/pixel$

$\mathrm{I}=5\times10^5\times10=5\times10^6(bit)$

$\mathrm{C}=100\mathrm{I}=100\times5\times10^6=5\times10^6(bit/s)$

$R_b=C=B\cdot\log_2(1+\frac{S}{N})$

$\frac{S}{N}=10^{\frac{30}{10}}=1000$

$\mathrm{B}=\frac{R_b}{\log_2(1+\frac{S}{N})}=\frac{5\times10^8}{\log_2 1001}\approx\frac{5\times10^8}{10}=50(MHz)$

3.9 A Gaussian channel has a bandwidth of 5kHz.

(1)calculate the information capacity of the Gaussian channel for a signal-to-noise ratio of 20dB.

(2)If the signal-to-noise is increased to 30dB,calculate the bandwidth required to transmit the same information rate.

Answer:

(1) $SNR=10^{20/10}=100$

$$C_t=B\log_2\left(1+\frac{S}{n_0B}\right)=5000\times\log_2(1+100)=33291.1\ (b/s)$$

(2) $SNR=10^{30/10}=1000$

$$B=\frac{C_t}{\log_2\left(1+\frac{S}{n_0B}\right)}=\frac{33291.1}{\log_2(1+1000)}=3340.1\ (Hz)$$

3.10 Assume transmitted power $P_T=10W$,transmitting antenna gain $G_T=100$, receiving antenna gain $G_R=10$,propagation equals with $50km$,electromagnetic frequency is $800MHz$.Try to calculate received power and propagation loss.

The Electromagnetic frequency now is

$$\lambda=\frac{300}{800}=0.375m$$

$$P_R=\frac{\lambda^2P_TG_TG_R}{16\pi^2d^2}=\frac{(0.375)^2\times10\times100\times10}{16\pi^2\times(50\times1000)^2}=3.56\times10^{-9}(W)=3560(pW)$$

The propagation loss is

$$L_{fr} = \frac{P_T}{P_R} = \frac{16\pi^2 d^2}{\lambda^2 G_T G_R} = \frac{16\pi^2 \times (50 \times 1000)^2}{(0.375)^2 \times 100 \times 10} \approx 28 \times 10^8 \approx 94.5(dB)$$

Chapter 4

4.1.

The expression of the known AM signal is

$$s_{AM}(t) = A[1 + mcos\omega_m t]cos\omega_c t$$

Where: m is the amplitude modulation coefficient, defined as the ratio of the maximum amplitude A_m of the modulating signal to the maximum amplitude A of the carrier. ω_m is the modulation angular frequency, ω_C is the carrier angular frequency. Try to write:

(1) The relationship between the amplitude of the upper and lower side frequency and the amplitude of the carrier;

(2) The relationship between sideband power and carrier power;

(3) If the carrier power is 1kW, calculate the maximum sideband power;

(4)Spectrum expression of AM signal.

Answer:

(1) $s_{AM}(t) = A[1 + mcos\omega_m t]cos\omega_c t = Acos\omega_c t + mAcos\omega_m tcos\omega_c t$

$$= Acos\omega_c t + \frac{mA}{2}cos(\omega_c - \omega_m)t + \frac{mA}{2}cos(\omega_c + \omega_m)t$$

The carrier amplitude is A, and the amplitude of the upper and lower frequencies is $mA/2$。

(2) Using the method of finding the mean square value, the carrier power can be obtained as:

$$P_C = \overline{(Acos\omega_c t)^2} = \frac{A^2}{2}$$

Power of upper and lower sidebands

$$P_{USB} = P_{LSB} = \frac{(mA/2)^2}{2} = \frac{m^2A^2}{8} = \frac{1}{4}m^2P_C$$

Total sideband power

$$P_S = P_{LSB} + P_{USB} = \frac{1}{2}m^2P_C$$

Total transmit power

$$P_{AM} = P_c + P_s = \left(1 + \frac{1}{2}m^2\right)P_c$$

(3) It is known that $P_c = 1000W$, and the result of (2) shows that when $m = 1$, there is the maximum sideband power:

$$P_s = \frac{1}{2}P_c = 500W$$

(4)

$$\begin{aligned}S_{AM}(\omega) = A\pi[\delta(\omega+\omega_c)+\delta(\omega-\omega_c)] \\ +\frac{mA}{2}\pi[\delta(\omega+\omega_c-\omega_m)+\delta(\omega-\omega_c+\omega_m)] \\ +\frac{mA}{2}\pi[\delta(\omega+\omega_c+\omega_m)+\delta(\omega-\omega_c-\omega_m)]\end{aligned}$$

4.2

It is known that the modulated signal is a single-tone cosine signal of 8MHz, and the single power spectral density of channel noise is set as $n_0 = 5\times10^{-15}W/Hz$, and the channel loss α is 60dB. If the output SNR is required to be 40dB, find:

(1) Bandwidth and transmit power of AM signal at 100% modulation.

(2) Bandwidth and transmit power of the FM signal when the FM index is 5.

Answer:

(1) $B_{AM} = 2f_m = 2\times8\times10^6 = 16MHz \quad G_{AM} = \frac{2}{3}$

$$S_{AM} = \frac{S_o}{N_o}\cdot\frac{1}{G_{AM}}\cdot\alpha\cdot N_i = \frac{S_a}{N_o}\cdot\frac{1}{G_{AM}}\cdot\alpha\cdot n_0 B_{AM}$$

$$= 10^4\times\frac{3}{2}\times10^6\times5\times10^{-15}\times16\times10^6 = 1200W$$

(2) $B_{FM} = 2(m_f+1)f_m = 2\times(5+1)\times8\times10^6 = 96MHz$

$$G_{FM} = 3m^2{}_f(m_f+1) = 3\times25\times6 = 450$$

$$S_{FM} = \frac{S_o}{N_o}\cdot\frac{1}{G_{FM}}\cdot\alpha\cdot N_i = \frac{S_o}{N_o}\cdot\frac{1}{G_{AM}}\cdot\alpha\cdot n_0 B_{FM}$$

$$= 10^4\times\frac{1}{450}\times10^6\times5\times10^{-15}\times96\times10^6 = 10.67W$$

4.3

There is a wideband FM system, and the corresponding parameters are as follows：

$n_0 = 10^{-6}(W/Hz)$、$f_c = 1(MHz)$、$f_m = 5(KHz)$、$S_i = 1(kW)$、 and $\overline{m^2(t)} = 50(V^2)$,

$k_f = 1.5\pi\times10^4(rad/s\cdot v)$, $\Delta f = 75(kHz)$ .Try to find:

(1) Center frequency and bandwidth of band pass filter

(2) Demodulator input SNR

(3) Demodulator output SNR (where $\frac{S_o}{N_o} = \frac{3A^2k_f{}^2\overline{m^2(t)}}{8\pi^2 n_0 f_m^3}$)

(1) Center frequency $f_0 = f_c = 1MHz$

The bandwidth is $B = 2(\Delta f + f_m) = 2(75+5)\times10^3 = 160(kHz)$

(2)

$$N_i = n_0 B = 10^{-6}\times160\times10^3 = 0.16(W)$$

The input SNR is

$$\frac{S_i}{N_i}=\frac{10^3}{0.16}=6.25\times10^3=6250$$

(3)The output SNR is

$$\frac{S_o}{N_o}=\frac{3A^2{k_f}^2\overline{m^2(t)}}{8\pi^2 n_0 f_m^3}=\frac{3\times2000\times1.5^2\pi^2\times10^8\times50}{8\pi^2\times10^{-6}\times5^3\times10^9}=67.5\times10^6$$

4.4 It is known that the amplitude of a single frequency FM wave is 10V and the instantaneous frequency is $f(t)=10^6+10^4\cos2\pi\times10^3t$ Hz, try to write out the expression of this frequency modulation wave

(1)Expression of FM;

(2)Maximum frequency offset, *fm* index and band width of FM;

Solution:

1）Instantaneous angular frequency is

$$\omega(t)=2\pi f(t)=2\pi\times10^6+2\pi\times10^4\cos(2\pi\times10^3t),$$

total phase is $\theta=\int_{-\infty}^{t}w(\tau)d\tau=2\pi\times10^6t+10\sin(2\pi\times10^3t)$

Expression is $S_{FM}(t)=A\cos\theta(t)=10\cos(2\pi\times10^6t+\sin2\pi\times10^3t)$

2）Maximum frequency offset

$$\Delta f=\left|10^4\cos2\pi\times10^3t\right|_{\max}=10kHz$$

FM index: $m_f=\frac{\Delta f}{f_m}=\frac{10^4}{10^3}=10$

Bandwidth of FM wave : $B\approx2(\Delta f+f_m)=2(10+1)=22kHz$

4.5

Let the single side power spectral density of channel noise in AM modulation system be $P_n(f)=10^{-7}$W/Hz, the frequency band of modulated signal $m(t)$ is limited to 5 kHz, the carrier frequency is 100kHz, the sideband power of the demodulator input signal is 1W, the carrier power is 4W. If the input signal of the receiver passes through a suitable ideal band-pass filter, then it is added to the envelope detector for demodulation. Try to find:

(1) Signal to noise power ratio of demodulator input;

(2) Signal to noise power ratio of demodulator output;

(3) Modulation gain G.

Answer:

(1) Let the input signal of demodulator be $s_{AM}(t) = [A + m(t)]\cos\omega_c t$, and $\overline{m(t)} = 0$, Then the signal power

$$S_i = \frac{1}{2}A^2 + \frac{1}{2}\overline{m^2(t)} = P_c + P_s = 4 + 1 = 5(\mathrm{W})$$

Demodulator input noise power

$$N_i = P_n(f) \cdot B = 10^{-7} \times 2 \times 5 \times 10^3 = 10^{-3}(\mathrm{W})$$

Input SNR

$$\frac{S_i}{N_i} = 5000 \qquad (37dB)$$

(2) At high SNR : $[A+m(t)] \gg n_i(t)$, the output of ideal envelope detection is

$$E(t) \approx A + m(t) + n_c(t)$$

Where: $m(t)$ is output useful signal; $n_c(t)$ is output noise. The power of signal and noise is

$$S_o = \overline{m^2(t)} = 2P_s = 2 \times 1 = 2\mathrm{W}, N_o = \overline{n^2(t)} = N_i = 10^{-3}\mathrm{W}$$

So, output signal to noise ratio

$$\frac{S_o}{N_o} = 2000 \;\; (33dB)$$

(3) Modulation gain

$$G = \frac{S_o/N_o}{S_i/N_i} = \frac{2000}{5000} = \frac{2}{5}$$

这一章重要的指标是 G，在不同调制系统中如何计算，尤其是 AM 和 FM 两种调制体制下 G 的对比。

基本概念、定义，各种调制的波形、公式、调制和解调的模型、带宽和 G。数字带通系统模型就是这一章调制解调模型的扩展。

Chapter 5

5.1 The A law 13 segments is adopted to encode, the minimum quantization interval is 1 quantization unit, and the sampling pulse value is known to be -95Δ,Try to find :

(1) the output code group of the encoder at this point, and calculate the quantization error.

(2) the 11 - bit linear code corresponding to the output code set.

Solution:(1)The polarity bit c_1=0;

since $64 < 95 < 128$

The segment coding : $c_2c_3c_4 = 011$

$(95-64)/4 = 7....3$

The sample value is within the quantization level with the ordinal number of 7 in the 4^{th} segment

The inner segment coding is $c_5c_6c_7c_8 = 0111$

The PCM encoding is $c_1c_2c_3c_4c_5c_6c_7c_8 = 00110111$

Quantization error=3 Δ

(3) . $I_c = 64 + 7*4 = 92 = 2^6 + 2^4 + 2^3 + 2^2$

The 11-bit linear code is: 000 0101 1100

5.2 The sampling pulse value of the input signal is set as + 635Δ, and A-Law PCM code with 13 segments is adopted. Try to determine the encoder output code group and quantization error.

Solution: the output code group: $C_1C_2C_3C_4C_5C_6C_7C_8 = 11100011$

quantization error: 27Δ

关于 quantization error 的计算新旧版本有差异，以最新版本为准，即编码误差为起始电平，在这里为 635-608=27Δ，译码为取中点的位置：624，译码误差为：635-624=11Δ；

5.3

Let the signal of input sampling device be gate function $G_\tau(t)$ with width τ = 20ms. If the frequency component beyond the 10th zero point of its spectrum is ignored, try to find the minimum sampling frequency.

Solution: $f_1 = \frac{1}{\tau} = 50Hz$,$f_{10} = 10f_1 = 500Hz, f_s \geq 2f_{10} = 1000Hz$, the minimum sampling frequency is 1000Hz.

5.4The highest frequency of voice signal is known f_H=3400Hz. If linear PCM system is used for transmission, signal quantization noise ratio of S/N_q is required to be no less than 30dB. Try to find the Nyquist bandwidth required by this PCM system.

Solution:

$$\frac{S}{N_0}=2^{2N}=10^3 \qquad N=5$$

$B_{min}=\frac{1}{2}R_b=\frac{1}{2}N*f_S=f_H*N=5*3400=17kHz$ (第五章 PPT 中有这份原理的介绍)

5.5

Using A-law 13 segments encoding, if the output of PCM encoder is 10111010, find the range of sampling value.

Solution:

1) First, C_1=1, so the sampling value >0;
2) Second, $C_2C_3C_4$=011, so the sampling value is in the 4^{th} segment;
3) Finally, $C_5C_6C_7C_8$=1010, determine the range of sampling value.

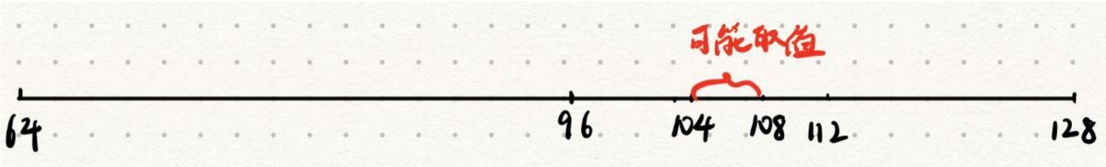
Successive comparisons:

C_5=1, the sampling value>96

C_6=0, the sampling value<112

C_7=1, the sampling value>104

C_8=0, the sampling value<108



Therefore, the range of sampling value is 104~108.

5.6. The analog signal m(t) with the highest frequency of 4.5MHz is coded by PCM according to A-law 13 segments.

Try to find:

(1) What is the lowest sampling frequency?

(2) What is the information rate of PCM coded signal?

Solution:

(1)According to the low-pass sampling theorem, the lowest sampling rate should be

$$f_S=2f_H=2\times4.5=9(\text{MHz})$$

(2) A law 13 segments is used for PCM coding, and each sample value is coded with 8 bits, so the information rate of PCM coded signal is as follows: $R_b=9\times8=72(\text{Mb/s})$

5.7 The frequency range of Base Group of 12-channel carrier telephone signal is 60 ~ 108KHz, try to find the lowest sampling frequency. （带通滤波器的采样定理）

Solution:

$$B = f_H - f_L = 108 - 60 = 48kHz$$

Because $\frac{f_H}{B} = 2.25$

$$n = 2, k = 2.25 - 2 = 0.25$$

The sampling frequency $f_s = 2B\left(1+\frac{k}{n}\right) = 2\times48\left(1+\frac{0.25}{2}\right) = 108kHz$

Chapter 6

6.1Binary code 100110000100001 is coded into AMI and HDB，and the code (suppose the polarity of the adjacent B code in front of the sequence is negative).

Solution：Encode the binary code 100110000100001 into AMI and HDB_3 codes (set the polarity of the adjacent B codes in front of the sequence to be negative)

AMI : +1 0 0 -1 +1 0 0 0 0 -1 0 0 0 0 +1

HDB_3: +1 0 0 -1 +1 0 0 0 +1 -1 0 0 0 -1 +1

6.2

If HDB_3 encoding is +10-1000-1+1000+1-1+1-100-1+10-1.Try to translate the original information code

Solution: HDB_3 +1 0 -1 0 0 0 -1 +1 0 0 0 +1 -1 +1 -1 0 0 -1 +1 0 -1

1 0 1 0 0 0 0 1 0 0 0 0 1 1 0 0 0 0 1 0 1

6.3. Suppose the message data stream is 1 0 0 0 0 1 0 0 0 0 1 1 0 0 0 0 1 1,try to get the AMI and HDB_3 encoding.

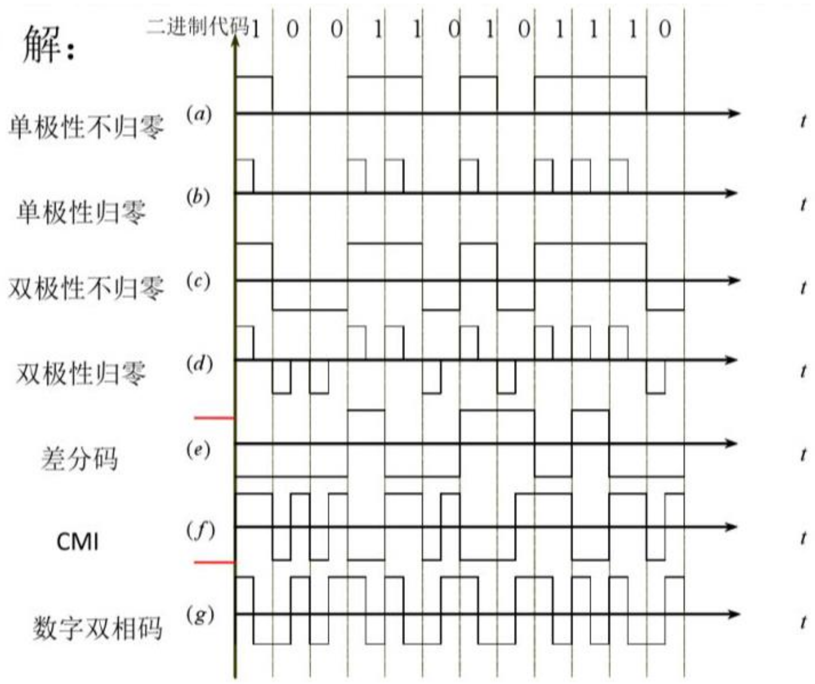
Solution: AMI: 1 0 0 0 0 -1 0 0 0 0 1 -1 0 0 0 0 1 -1

HDB_3:1 0 0 0 V -1 0 0 0 –V 1 -1 B 0 0 V 1 -1

以上都是针对 AMI 和 HDB_3 编码的内容，为必考题目。不仅会编译码，也要会画电波形（结合实验观察的波形）

6.4 Set the binary code as 100110101110 and take the rectangular pulse as an example to draw the corresponding a) unipolar, b) unipolar to 0, c) bipolar, d) bipolar to 0, e) difference, f) CMI and g) digital biphase code waveforms respectively.

解：

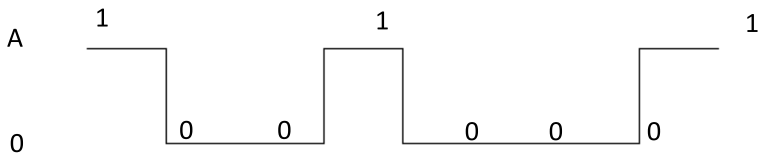


6.5

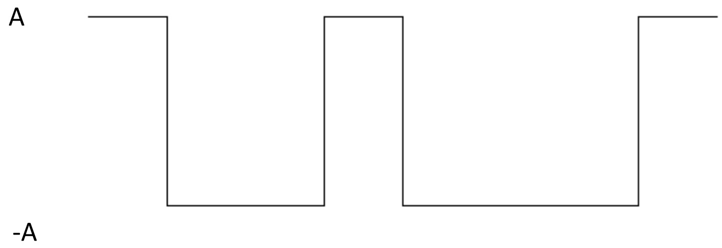
Suppose the information symbol is 10010001,draw the waveform of unipolar NRZ,polar NRZ,unipolar RZ,polar RZ and differential code.

Answer:

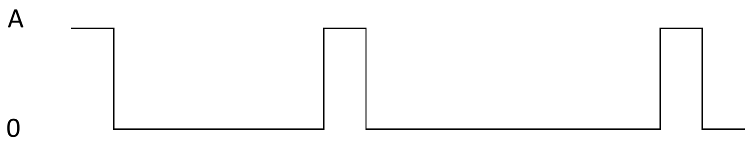
unipolar NRZ:



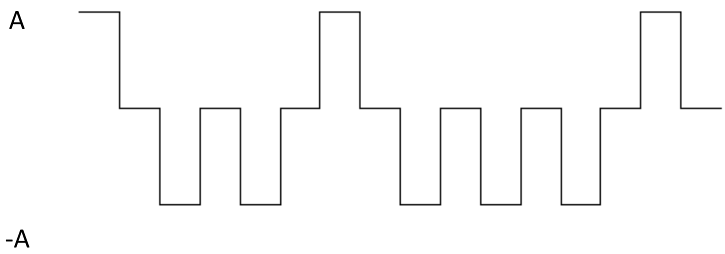
polar NRZ:



unipolar RZ:



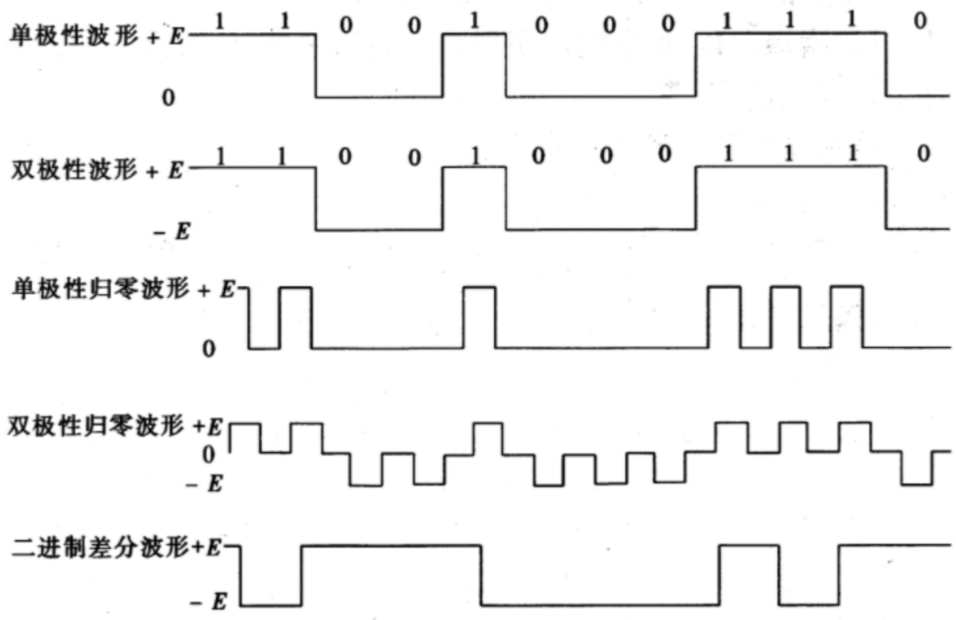
polar RZ:



differential code:

6.6

Set sequence of 11001000110 binary symbols, try taking rectangular pulse as an example, draw the unipolar NRZ,RZ ,polar NRZ ,RZ and differential encoding



以上为数字基带信号常用的电波形，单极性、双极型 RZ 和 NRZ 以及差分编码为必考波形。要求必须掌握。所有编码、基带信号波形、数字频带信号波形都要求拿尺子对齐了画，差分编码和差分 PSK（即 DPSK）需要有参考电平或参考载波（虚线画）。

这一章匹配滤波器的推导要会推，它是柯西-施瓦兹不等式的一个重要应用之一。并思考实验观测的眼图波形为什么是升余弦频谱的波形，掌握整个基带系统的设计依据。

6.7 Assuming that the frequency characteristic $|H(\omega)|$ of a baseband system is cosine roll down spectrum and the transmission signal is **a four level baseband** pulse sequence, the maximum information rate that can realize transmission without ISI is $Rb = 2400b/s$

(1) The system bandwidth and the highest band utilization ratio are obtained when the roll off coefficient $\alpha = 0.4$;

(2) The system bandwidth and the highest band utilization ratio are obtained when the roll off coefficient $\alpha = 1$;

Answer:

$$R_B = \frac{R_b}{\log_2 M} = \frac{2400}{2} = 1200(Baud)$$

(1) Because $\alpha = 0.4$

So the bandwidth is

$$B = (1+\alpha)f_N = \frac{1}{2}(1+0.4)R_B = 840(Hz)$$

the highest band utilization ratio is

$$\eta = \frac{R_B}{B} = \frac{2}{1+0.4} \approx 1.43(\text{Baud}/Hz)$$

$$\eta_b = \frac{R_b}{B} = \eta \log_2 M = 1.43 \times 2 = 2.86\ (b/(s \cdot Hz))$$

(2) Because $\alpha = 1$

So the bandwidth is

$$B = (1+\alpha)f_N = \frac{1}{2}(1+1)R_B = 1200(Hz)$$

the highest band utilization ratio is

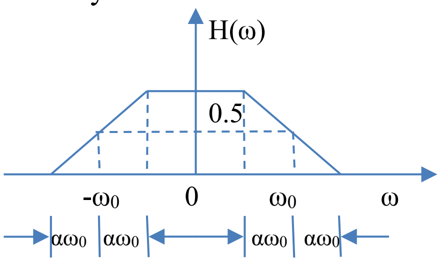
$$\eta = \frac{R_B}{B} = \frac{2}{1+1} = 1(\text{Baud}/Hz)$$

$$\eta_b = \frac{R_b}{B} = \eta \log_2 M = 1 \times 2 = 2\left(\left(\frac{b}{s \cdot Hz}\right)\right)$$

6.8 Suppose the transmission characteristic H(ω) of a certain digital baseband system is shown in the following figure, where α is a constant (0≤α≤1) :

(1) Whether the system can realize the condition of no ISI?

(2) What is the maximum bit transmission rate of the system? What is the bandwidth utilization of the system?



（1）The system can be equivalent to ideal rectangular low-pass characteristics：

$$H_{eq}(\omega)=\begin{cases} 1 & |\omega| \le \omega_0 \\ 0 & |\omega| > \omega_0 \end{cases}$$

Hence the system can realize the no ISI transmission

(2)The maximum symbol rare $R_B=2\omega_0/2\pi=\omega_0/\pi$,The bandwidth of this system B=（(1+α）ω_0）/2π

The maximum band efficiency : $\eta=R_B/B=2/(1+\alpha)$

Chapter 7

7.1Set the binary sequence to be 1011001, and the symbol rate is 2000Baud, The carrier signal is $sin\ (8\pi \times 10^3 t)$. Try to determine:

(1)How many carrier periods are included in each symbol?

(2)Draw the waveforms of OOK,2PSK and 2DPSK.And observe the characteristics of the waveforms.

(3)Calculate the first spectral zero bandwidth of 2ASK, 2PSK and 2DPSK.

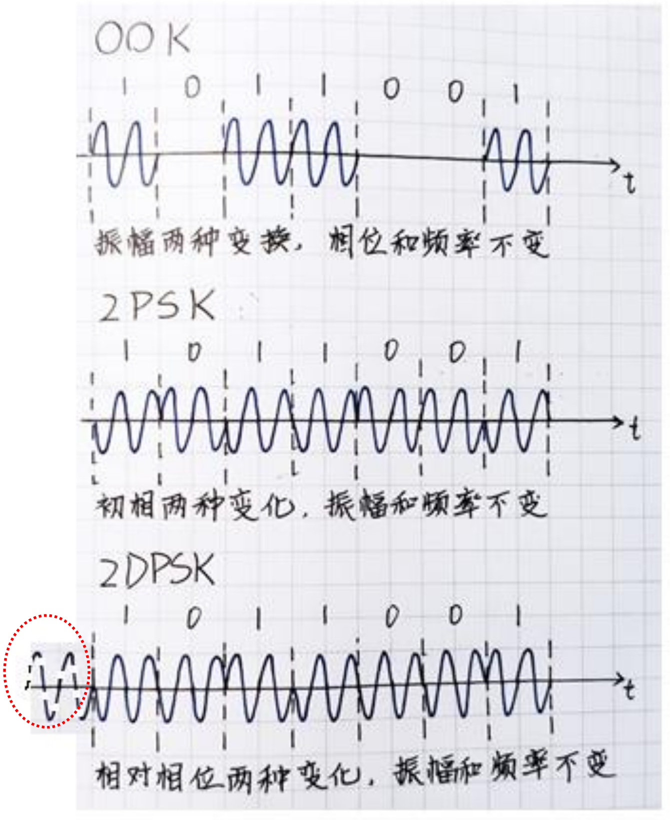
Solution:

1) The carrier frequence: $f_c = \frac{8\pi\times10^3}{2\pi} = 4000Hz$

$R_B = 2000\ \text{Baud}$

Therefore, each symbol includes 2 carrier periods

2) As shown in the following figure:



(注意：DPSK 起始时要有参考相位)

3) $B_{2PSK} = B_{2DPSK} = B_{2ASK} = 2R_B = 4000\ Hz$

7.2

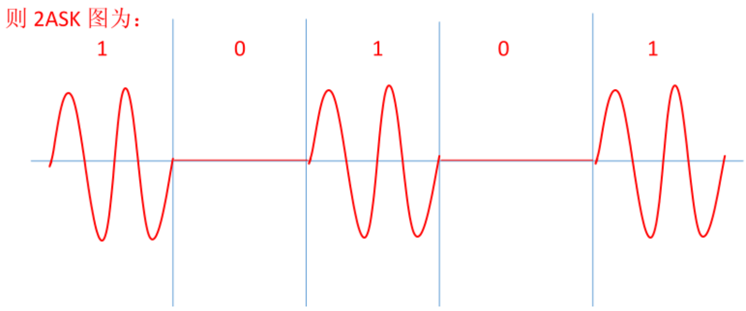
Send binary information for 10101, the symbol rate for 1200B，

（1）when the carrier frequency is 2400 HZ, draw 2 ASK signal waveform;

（2）When the two carrier frequencies of 2FSK are 1200 HZ and 2400 HZ respectively, the waveform is drawn.

（1）R_B=1200，T=1/1200 s

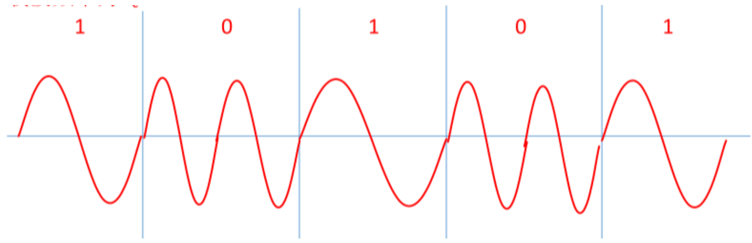
F_c=2400HZ，则 Tc=1/2400 s=T/2



（2）R_b=1200，T=1/1200 s

f_{c1}=1200HZ，则 T_{c1}=1/1200 s

f_{c2}=2400HZ，则 T_{c2}=1/2400 s, the waveform of 2FSK is as following:



7.3In the binary phase modulation system, the input SNR of demodulator is r = 10dB. Try to find the bit error rates of coherent demodulation 2PSK, coherent demodulation-code inverse transform 2DPSK and differential coherent demodulation 2DPSK.

Solution: 1）

According to $r = 10dB$

we can get $r = 10$

The bit error rates of coherent demodulation 2PSK is:

$$P_e = \frac{1}{2} erfc\sqrt{r} \approx \frac{1}{2\sqrt{r\pi}} e^{-r} = \frac{1}{2\sqrt{10\pi}} \times e^{-10} = 4 \times 10^{-6}$$

2）Because the bit error rates of coherent demodulation − code inverse transform 2DPSK is:

$P_e' = 2(1 - P_e)P_e$

P_e − the bit error rates of 2PSK

The BER of DPSK is $P_e' = 2P_e = 8 \times 10^{-6}$

3）the bit error rates of differential coherent demodulation 2PSK is:

$$P_e = \frac{1}{2} e^{-r} = \frac{1}{2} e^{-10} = 2.27 \times 10^{-5}$$

7.4、BER的综合对比，可以结合误码率曲线理解，并得到有效地结论For a digital pass band modulation system, assume the symbol rate is $R_B = 2 \times 10^6$Baud, the amplitude of the receive is $A = 800\mu V$ and the single-side PSD of the Gaussian noise is $n_0 = 4 \times 10^{-15} W/Hz$. Try to find:

（1）the symbol error probability of the ASK signal, the FSK signal and the DPSK signal when the envelope detection is used.

（2）the symbol error probability of the ASK signal, the FSK signal, the PSK signal and the DPSK signal when the coherent demodulation is used.

(3) From the BER results,

Solution:

The optimum bandwidth of the bandpass filter in the receiver is

$$B = B_{2ASK} = B_{2PSK} = B_{2DSPK} = 2R_B = 4 \times 10^6 Hz$$

Therefore, the mean power of the output noise of the bandpass filter is

$$\sigma_n^2 = n_0 B = 4 \times 10^{-15} \times 4 \times 10^6 = 1.6 \times 10^{-10} W$$

The output signal to noise ratio is

$$r = \frac{A^2}{2\sigma_n^2} = \frac{(800 \times 10^{-6})^2}{2 \times 1.6 \times 10^{-10}} = 20 \gg 1$$

（1）For the envelope detection:

2ASK

$$P_e = \frac{1}{2}e^{-\frac{r}{4}} = \frac{1}{2}e^{-5} \approx 3.37 \times 10^{-3}$$

2FSK

$$P_e = \frac{1}{2}e^{-\frac{r}{2}} = \frac{1}{2}e^{-10} \approx 2.37 \times 10^{-5}$$

2DPSK

$$P_e = \frac{1}{2}e^{-r} = \frac{1}{2}e^{-20} \approx 10^{-9}$$

（2）For the coherent demodulation:

2ASK

$$P_e = \frac{1}{\sqrt{\pi r}}e^{-\frac{r}{4}} \approx 8.5 \times 10^{-5}$$

2FSK

$$P_e = \frac{1}{\sqrt{2\pi r}}e^{-\frac{r}{2}} \approx 4.05 \times 10^{-6}$$

2PSK

$$P_e = \frac{1}{2\sqrt{\pi r}}e^{-r} \approx 1.26 \times 10^{-9}$$

2DPSK

$$P_e = \frac{1}{\sqrt{\pi r}}e^{-r} \approx 2.52 \times 10^{-9}$$

7.5 这个题目结合了实际的应用，比较好 Assume there is a space-ground communication system, the symbols rate is 0. 5MB, the bandwidth of receiver is 1MHz. Antenna gains of ground station and space station are respectively 40dB and 6dB, the path loss is (60+10lgd)dB, where d is the distance(km). Given the transmitting power is 10W, the double-side power spectral density of white noise is 2×10^{-12} W/Hz. Requiring the symbol emor probability of the system is Pe=10^{-5}, try to find the maximum communication distance under these conditions as below:

(1) Adopting 2FSK modulation and coherent demodulation.

(2) Adopting 2DPSK modulation and coherent demodulation.

Solution:

(1) Using 2FSK mode transmission, coherent demodulation, the bit error rate is

Pe=$\frac{1}{2}$erfc$\sqrt{\frac{r}{2}}$=10^{-5}

Using 2FSK mode transmission, coherent demodulation, the bit error rate is

$$\sigma_n^2 = n_0 B = 4 * 10^{-12} * 1 * 10^6 = 4 * 10^{-6}(W)$$

The square of receiving signal amplitude is

$$a^2 = 2r\sigma_n^2 = 1.464*10^{-4}(W)$$

The signal power attenuation is

$$10lg\frac{A^2/2}{a^2/2} = 10lg\frac{2*10}{1.464*10^{-4}} = 51.35(dB)$$

The pass loss is : 60+10lgd =51.35+40+6

The maximum communication distance is

$$d=10^{3.735}=5432(km)$$

(2) The bit error rate (BER) of 2DPSK transmission and differential coherent demodulation is analyzed

$$Pe=\frac{1}{2}e^{-r}=10^{-5}$$

the required SNR can be calculated r=10.82, the square of receiving signal amplitude is

$$a^2=2r\sigma_n^2=8.656*10^{-5}W$$

The signal power attenuation is

$$10lg\frac{A^2/2}{a^2/2}=56.63\text{dB}$$

The pass loss is : 60+10lgd =56.63+40+6

The maximum communication distance is

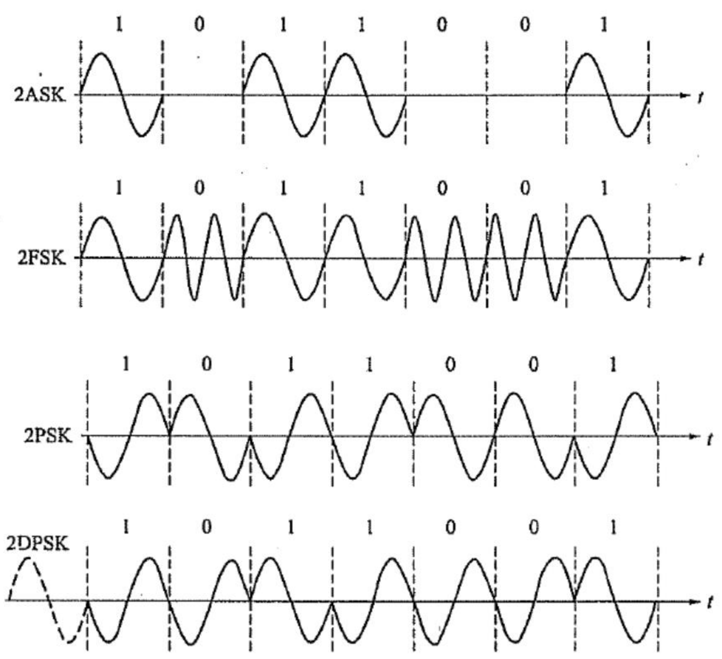
$$d=10^{3.963}=9183(km)$$

7.6

The highest frequency band utilization of the digital frequency **band pass** system is ____1___ B/HZ, The information transmission rate of the 8PSK system is $1500b/s$, and the minimum bandwidth of the transmission without the inter symbol interference is___500Hz___

(数字带通系统的带宽至少是基带信号带宽的 2 倍，二进制时：2FSK 是大于 2 倍，其余是 2 倍关系。因此最高的频带利用率只有基带理想情况下的一半，即 1，这个 1，按照 Baud 来算时，二进制和多进制都是 1，按照 b/s 即传信率来算频带利用率时，多进制是二进制的 $\log_2 M$ 倍，所以更具应用价值。即：$\eta_b=\eta_B\log_2 M$

7.7 If the message signal is 1011001,draw 2ASK, 2FSK, 2PSK and 2DPSK signal waveform diagram respectively.



7.8 Suppose the bit rate of an MPSK system is 4800b/s, and the baseband signal is preprocessed by α=1 cosine roll-off filtering. Answer the following question:
1). 4PSK occupied channel bandwidth and frequency band utilization.
2).8PSK occupied channel bandwidth and frequency band utilization.
Solution:
1).Under 4PSK， $R_B = 2400$， the required Nyquist bandwidth is $f_N = 1200Hz$，
Because of cosine roll down， the actual baseband signal bandwidth is

$$f_B = (1 + \alpha)f_N = 2400Hz,$$

According to $B_{2PSK} = 2f_B$， we can get $B_{2PSK} = 2f_B = 4800Hz$，

$$\eta = \frac{R_b}{B_{2PSK}} = 1b/(s * Hz).$$

2). Under 8PSK， $R_B = 1600$， the required Nyquist bandwidth is $f_N = 800Hz$，
Because of cosine roll down， the actual baseband signal bandwidth is

$$f_B = (1 + \alpha)f_N = 1600Hz,$$

According to $B_{2PSK} = 2f_B$， we can get $B_{2PSK} = 2f_B = 3200Hz$，

$$\eta = \frac{R_b}{B_{2PSK}} = 1.5b/(s * Hz).$$

7.9 Assume the information transmission rate of a 4DPSK signal is 2400 bit, and the carrier frequency is 1800 Hz, how many carrier periods are contained in a symbol?
Solution: The code rate of the 4DPSK signal is

$$R_B = R_b/log_2 4 = 2400/2 = 1200 \text{Baud}$$

Therefore, $\frac{1800}{1200}=1.5$ carrier periods are contained in a symbol.

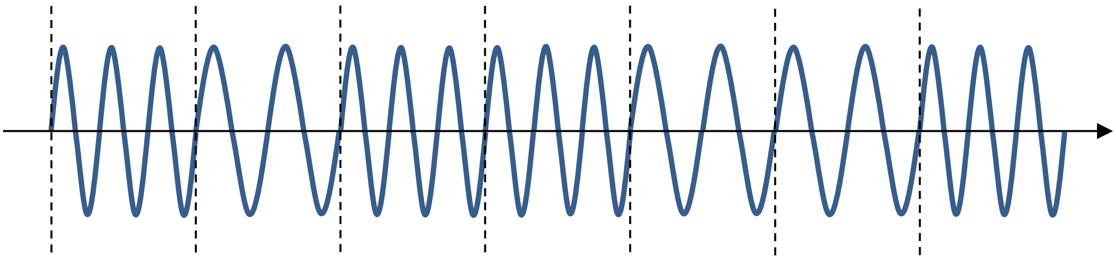
7.10Suppose the bit rate of a 2FSK modulation system is 2000Baud, and the carrier frequency of the modulated signal is 6000Hz (corresponding to "1" code) and 4000Hz (corresponding to "0" code).

(1) If the transmitted information sequence is 1011001, try to draw the waveform of 2FSK signal:

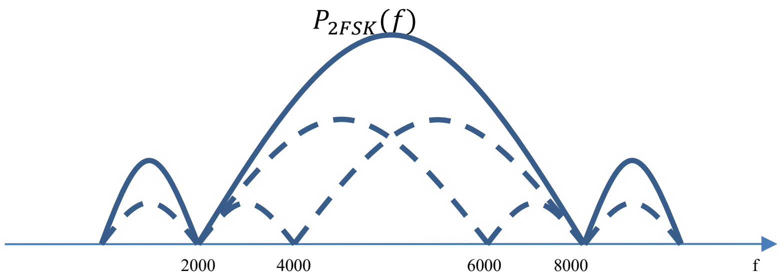
(2) Try to draw the power spectrum density diagram of 2FSK signal, and calculate the first spectrum zero bandwidth of 2FSK signal.

Solution：

(1) $f_1 = 6000 = 3R_B$, $f_2 = 4000 = 2R_B$, so there are three carrier periods in the code "1", and two carrier periods in the code "0 "



（1）



The bandwidth of 2FSK signal：

$$B_{2FSK} = |f_2 - f_1| + \frac{2}{T_B} = 6000 - 4000 + 4000 = 6000(Hz)$$

ASK、FSK 和 PSK（DPSK）的波形会画，BER、带宽会计算。误码率公式会给出，不用背。

新型数字调制技术中要求掌握 QPSK 的基本原理、框图和星座图、OFDM 的基本原理（正交概念和 IFFT/FFT），以及 16QAM 的星座图。

题库中，如果题目或答案有问题，请及时联系我。

除此之外，还涉及到一些新技术的题目（大纲里的指标点有这一项，也是必考的小知识点）：在阅读了课本第 8 章 Further reading：new technologies in communication systems 后，再参看以下网址进行学习：

1 无线通信中 MIMO （3min 的视频）举例是 2X2 的天线，现在 5G 是向 massive （大规模） MIMO 方向发展

https://www.bilibili.com/video/BV1gx411E7Zn?from=search&seid=2492632509906548642

https://www.bilibili.com/video/BV1EE41187j3?from=search&seid=14517711152553542470

2 超宽带技术（UWB）： 主要的一个应用就是室内的超精准定位。（GPS 和北斗无法做到），

因为可以发射纳秒级甚至亚纳秒级的窄脉冲，频域达到了非常宽的带宽，因而称为超宽带。书上 8.2 节有定义。

3　压缩感知：（理论性较强，需要有矩阵论、泛函和最优化相关的基础）

https://baike.baidu.com/item/压缩感知/164957?fr=aladdin

视频：

https://www.bilibili.com/video/BV1J4411W7Fc?from=search&seid=12113333280749532318

6G 和车联网的相关技术，自己在网上搜一下相关资料或视频，了解一下。除了手机，以后无人驾驶汽车也是一个非常重要的领域。

https://www.bilibili.com/video/BV1Pt411C7vU?from=search&seid=8620976170797989280

新技术的考点举例：比如给一个 MIMO 的模型，问这是什么系统的模型？有哪些优势？给个 UWB 波形，问这是什么系统的信号？或者给个定义式，问是什么系统，优势？等等吧，不会深入去问太多，只要知道个概念、模型、优势、应用就可以了。

先参照以上题库内容、平时的作业、PPT、课堂例题来复习，考前答疑再把范围适当缩减一些。祝各位同学复习顺利！