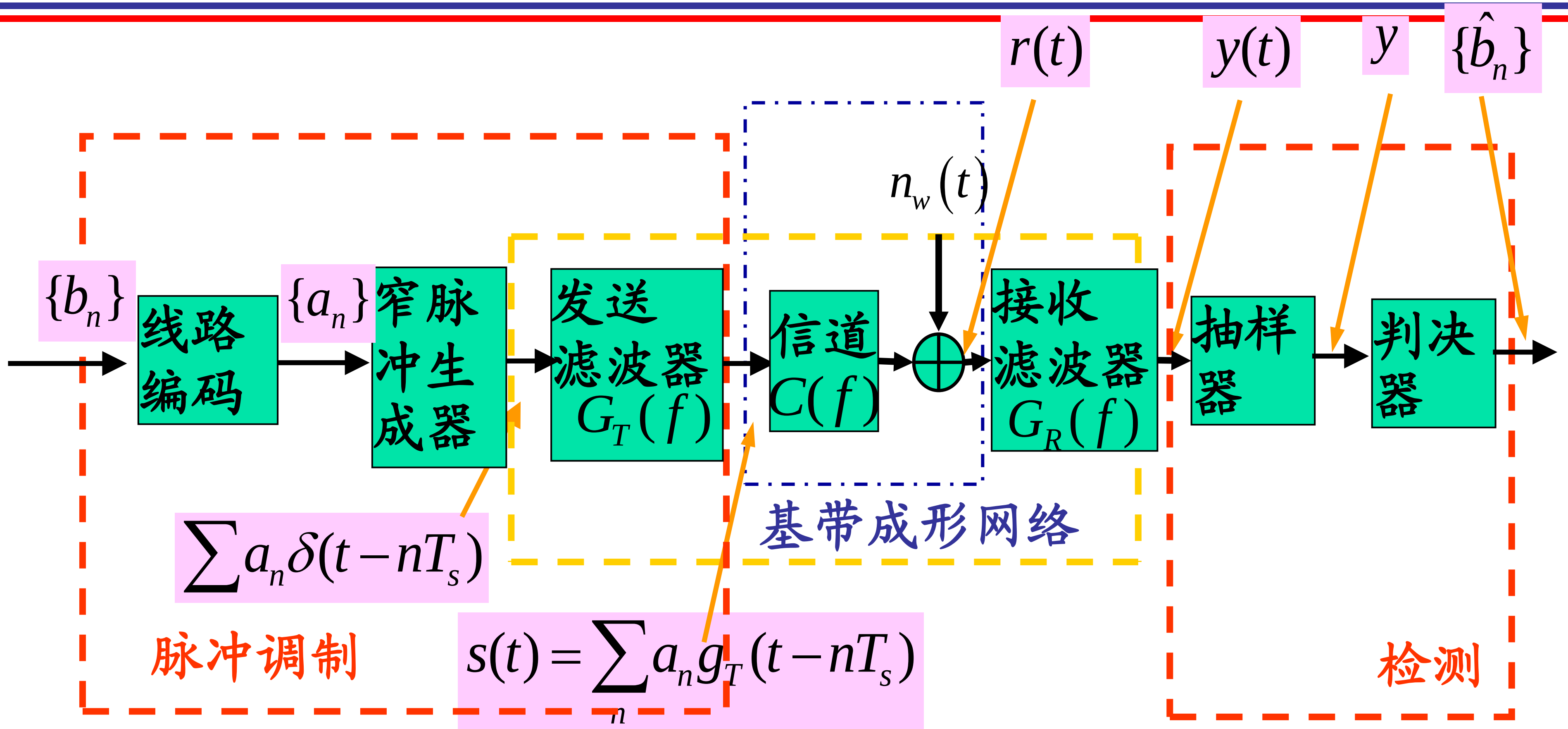
第15讲 二进制频带传输

数字基带传输系统



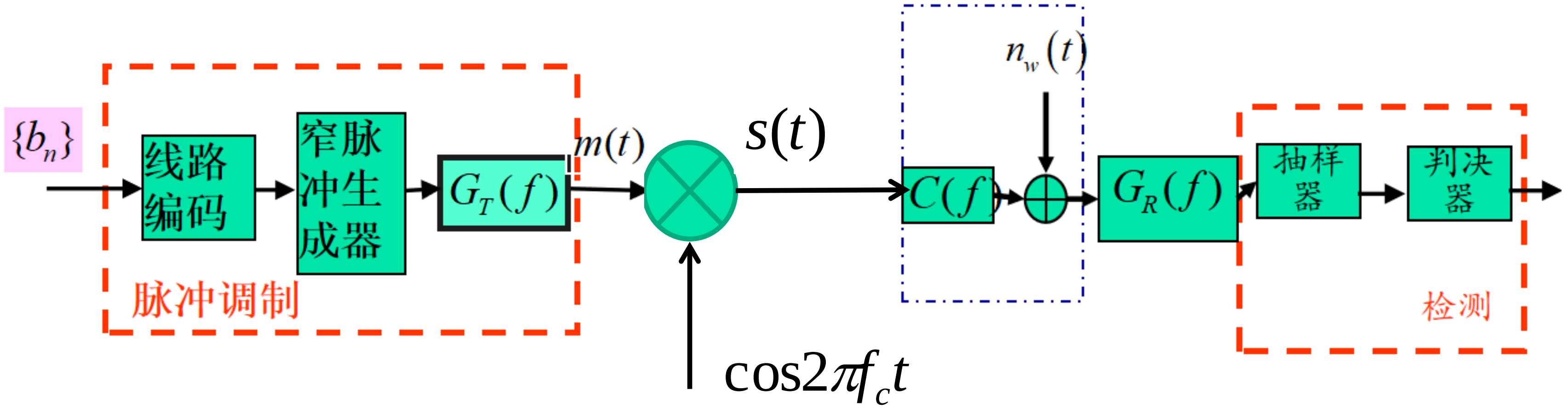
$$g(t)=g_T(t)*c(t)\xleftrightarrow{F.T.}G(f)=G_T(f)C(f)$$

$$h(t)=g(t)*g_R(t)\xleftrightarrow{F.T.}H(f)=G_T(f)C(f)G_R(f)$$

问题的引入

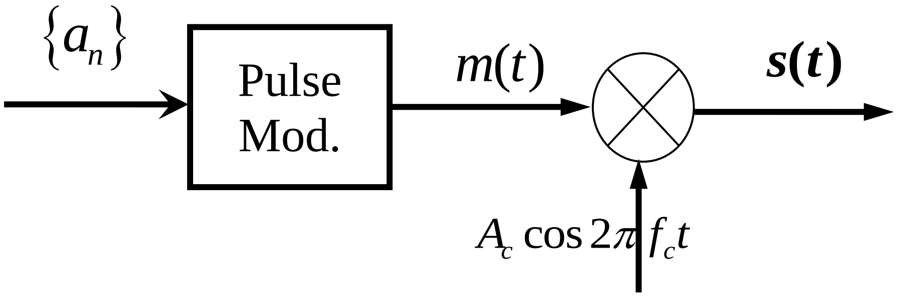
- 模拟调制系统
  - 调制原理与调制器模型
  - 频谱分析
  - 解调原理与解调器模型
  - 抗噪声性能分析
- 数字基带传输系统
  - 脉冲调制原理与脉冲调制器设计（线路编码、发送滤波器）
  - 信号功率谱密度分析
  - 检测原理与检测器模型
  - 误码性能分析
  - 频带无限与频带有限信号

数字频带传输系统

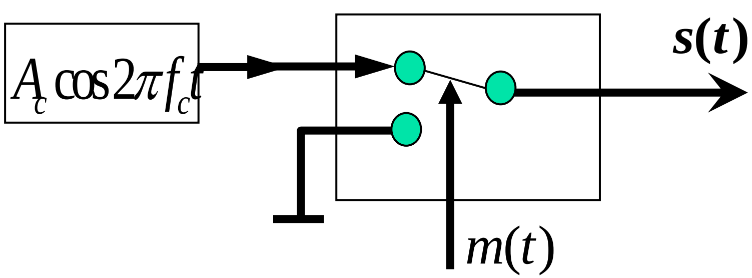


1、2ASK

1.1 两种2ASK调制器



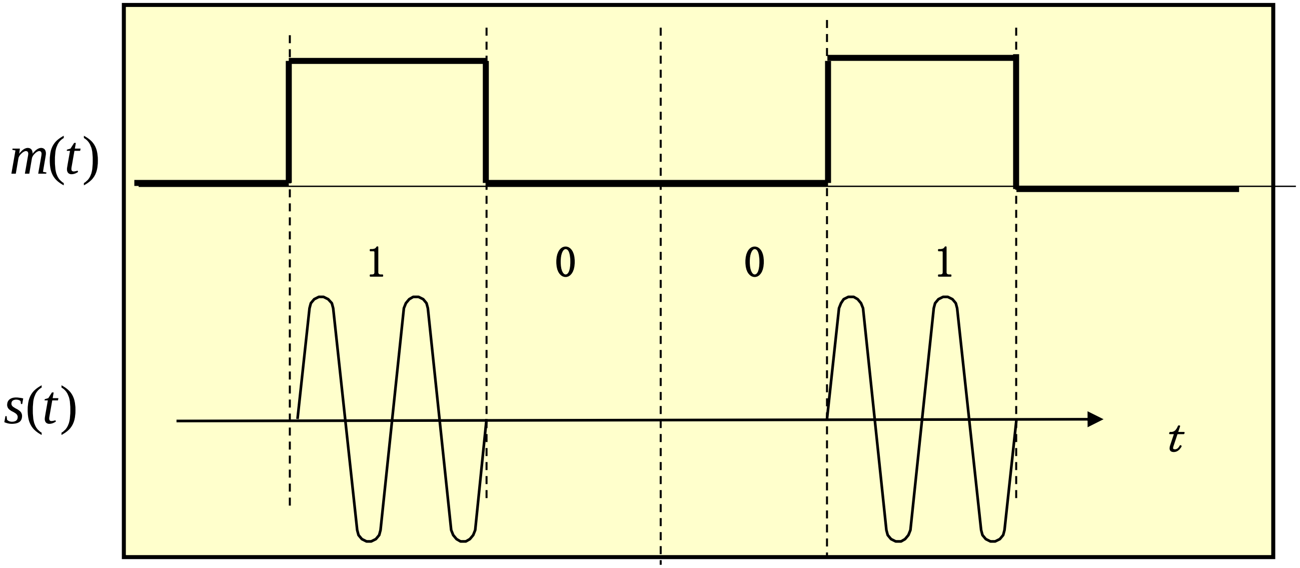
(a) DSB-SC Modulator



(b) Keying Modulator

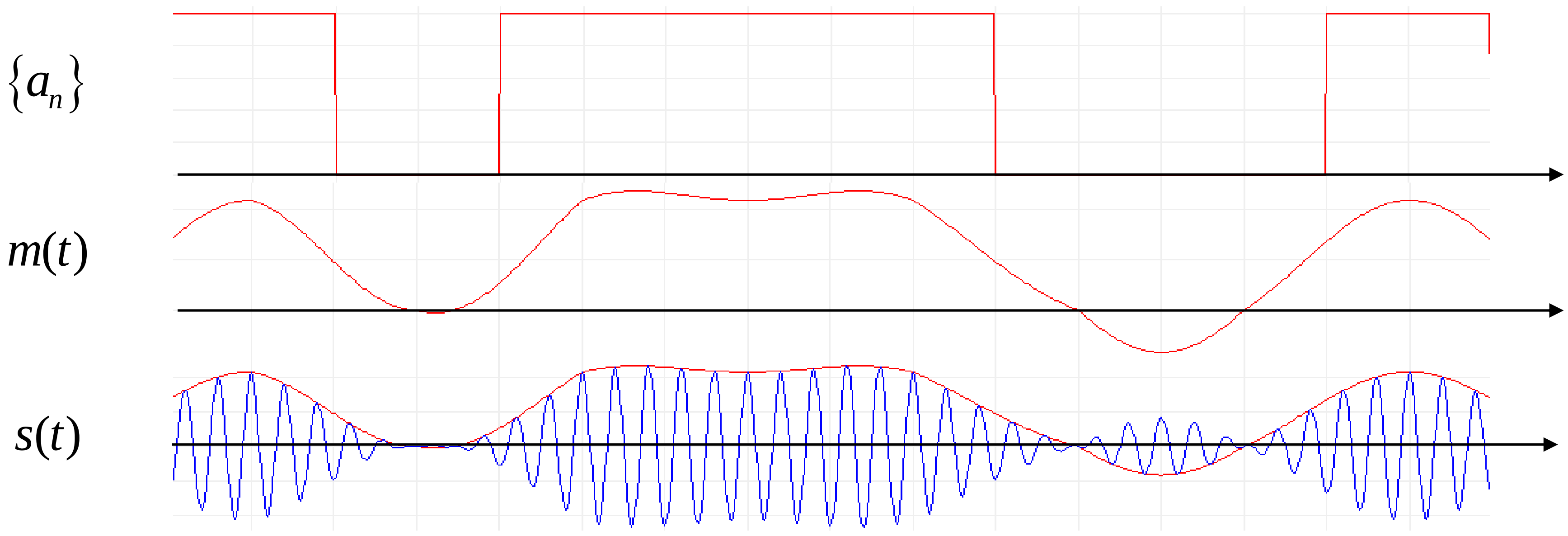
1.2 两种2ASK波形

（1）无限带宽2ASK信号（基带脉冲为方波）



1.2 两种2ASK波形

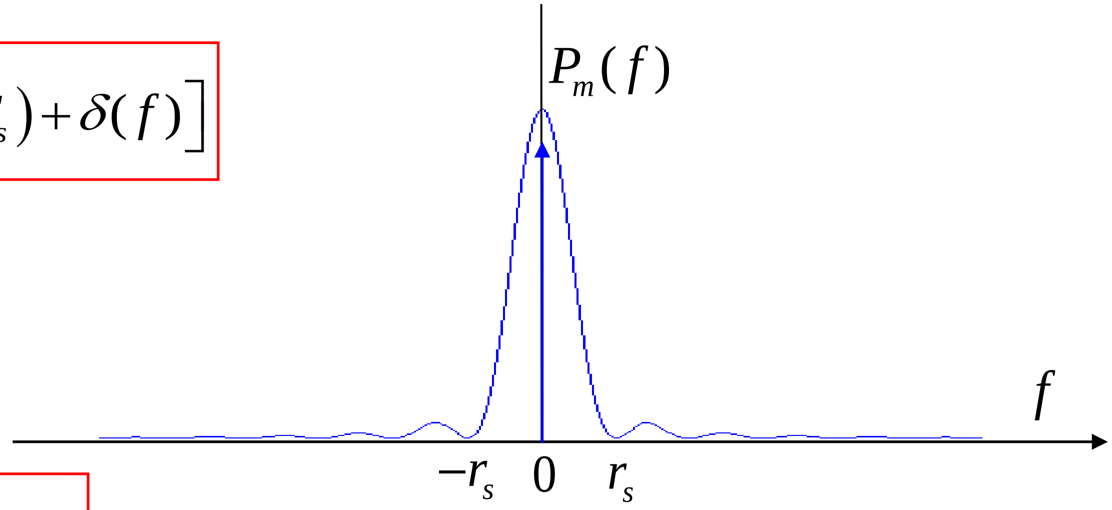
（2）有限带宽2ASK信号（基带脉冲为根升余弦波形）



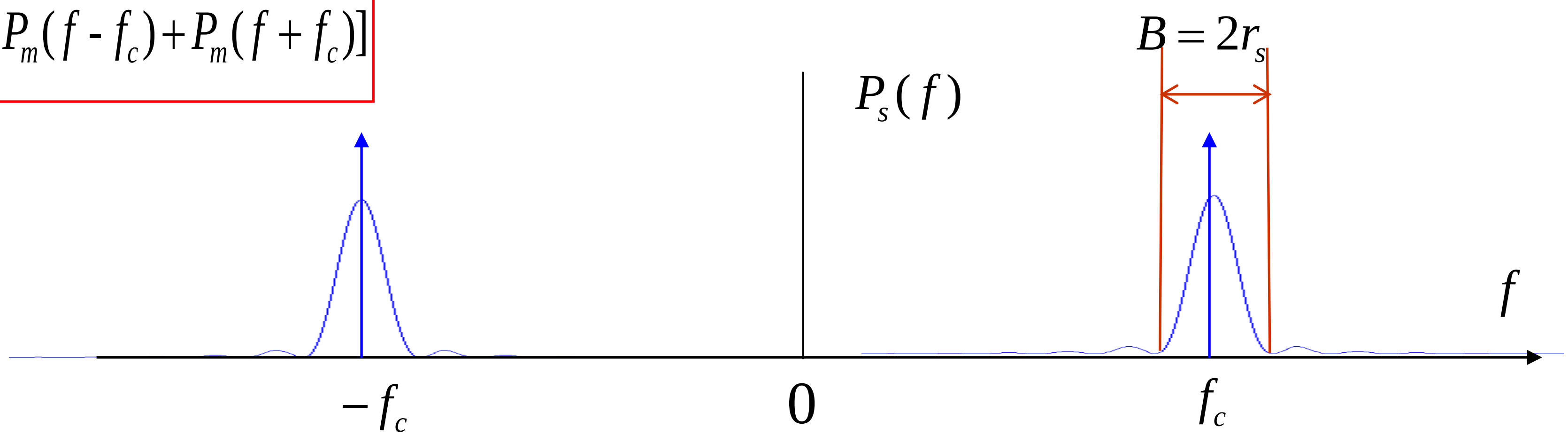
1.2 2ASK信号功率谱密度

（1）无限带宽2ASK信号功率谱密度

$$\boxed{P_m(f)=\frac{A_c^2}{2}\left[T_s Sa^2(\pi f T_s)+\delta(f)\right]}$$



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



1.2 2ASK信号功率谱密度

（2）带限2ASK信号功率谱密度

$$P_m(f)=\frac{1}{4T_s}|G_T(f)|^2+\frac{1}{4T_s^2}\left|G_T(0)\right|^2\delta(f)$$

$$|G_T(f)|^2=\left|H_{RC}(f)\right|$$

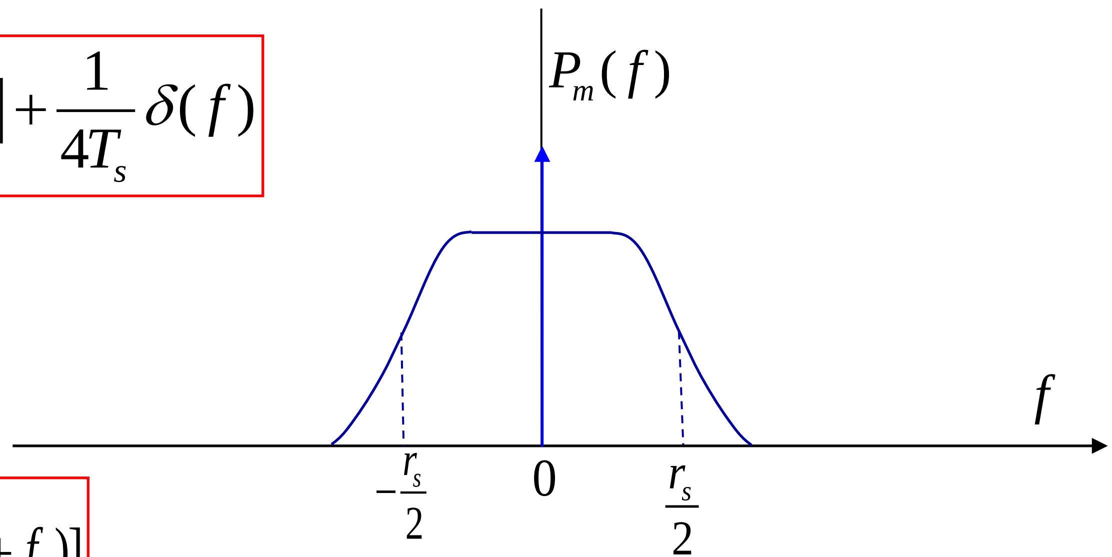
$$P_m(f)=\frac{1}{4T_s}\left|H_{RC}(f)\right|+\frac{1}{4T_s^2}\left|H_{RC}(0)\right|\delta(f)=\frac{1}{4T_s}\left|H_{RC}(f)\right|+\frac{1}{4T_s}\delta(f)$$

$$H_{RC}(f)=\begin{cases} T_s,|f|<\frac{1}{2T_s}(1-\alpha) \\ \frac{T_s}{2}\{1-\sin[\frac{T_s}{\alpha}(f-\frac{1}{2T_s})]\},|\frac{1}{2T_s}(1-\alpha)\le|f|\le\frac{1}{2T_s}(1+\alpha) \\ 0,|f|>\frac{1}{2T_s}(1+\alpha) \end{cases}$$

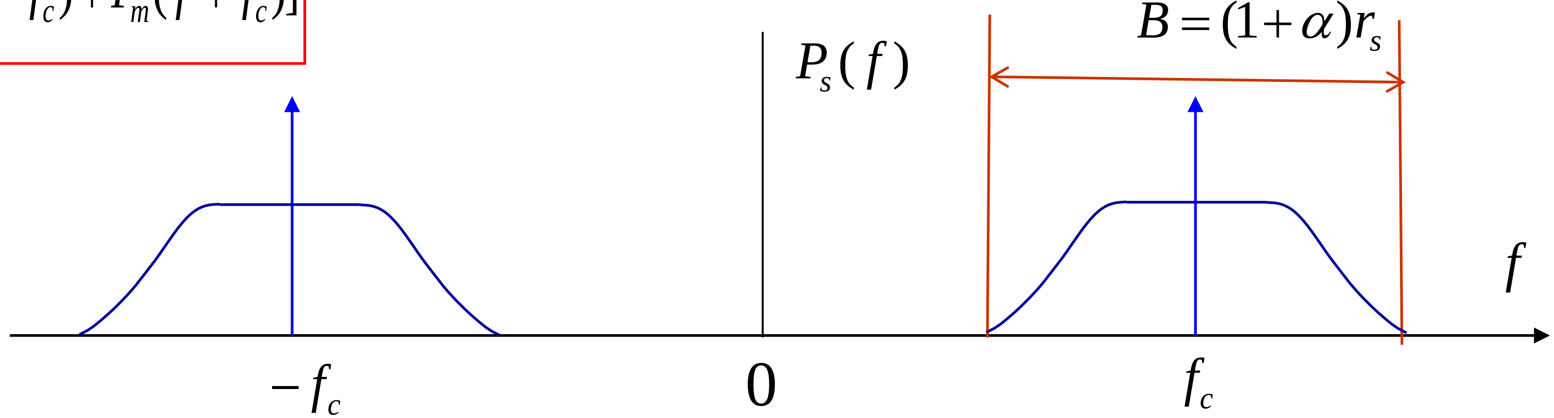
1.2 2ASK信号功率谱密度

（2）带限2ASK信号功率谱密度

$$P_m(f)=\frac{1}{4T_s}\left|H_{RC}(f)\right|+\frac{1}{4T_s}\delta(f)$$



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



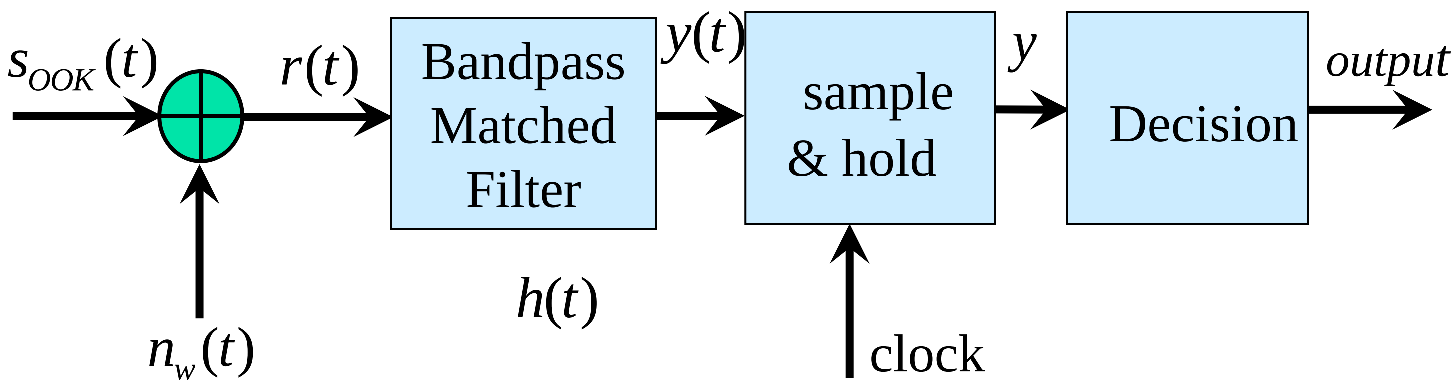
1.3 2ASK信号的解调

（1）AWGN信道条件下OOK的最佳接收

（2）在理想限带及AWGN信道条件下OOK信号的最佳接收

（3）OOK信号的非相干解调

(1) AWGN信道条件下OOK的最佳接收(1/4)



$$s(t)=\begin{cases} s_1(t)=A\cos 2\pi f_c t, & "1" \\ s_2(t)=0, & "0" \end{cases}$$

$$h(t)=s_1(T_b-t), 0\le t\le T_b$$

(1) AWGN信道条件下OOK的最佳接收(2/4)

$$h(t)=s_1(t)=A\cos 2\pi f_c t\,\mathrm{Rect}\left(\frac{t}{T_b}\right)$$

$$H(f)=AT_b\,\mathrm{Sa}\left(\pi f T_b\right)*\frac{1}{2}\left[\delta(f-f_c)+\delta(f+f_c)\right]$$

$$=\frac{AT_b}{2}\left\{\mathrm{Sa}\left[\pi T_b(f-f_c)\right]+\mathrm{Sa}\left[\pi T_b(f+f_c)\right]\right\}$$

$$y(t)=r(t)*h(t)=\int_0^t r(\tau)h(t-\tau)d\tau$$

$$=\int_0^t r(\tau)s_1(T_b-t+\tau)d\tau=\int_0^t\left[s_1(\tau)+n_w(\tau)\right]s_1(T_b-t+\tau)d\tau$$

$$y\equiv y(T)=\int_0^{T_b}\left[s_1(\tau)+n_w(\tau)\right]s_1(\tau)d\tau=\int_0^{T_b}s_1^2(\tau)d\tau+\int_0^{T_b}s_1(\tau)n_w(\tau)d\tau=E_1+Z$$

$$E_1=\int_0^{T_b}s_1^2(\tau)d\tau=\frac{A^2}{2}T_b\qquad E(Z\,|\,s_1)=0\qquad D(Z\,|\,s_1)=\frac{N_0}{2}E_1$$

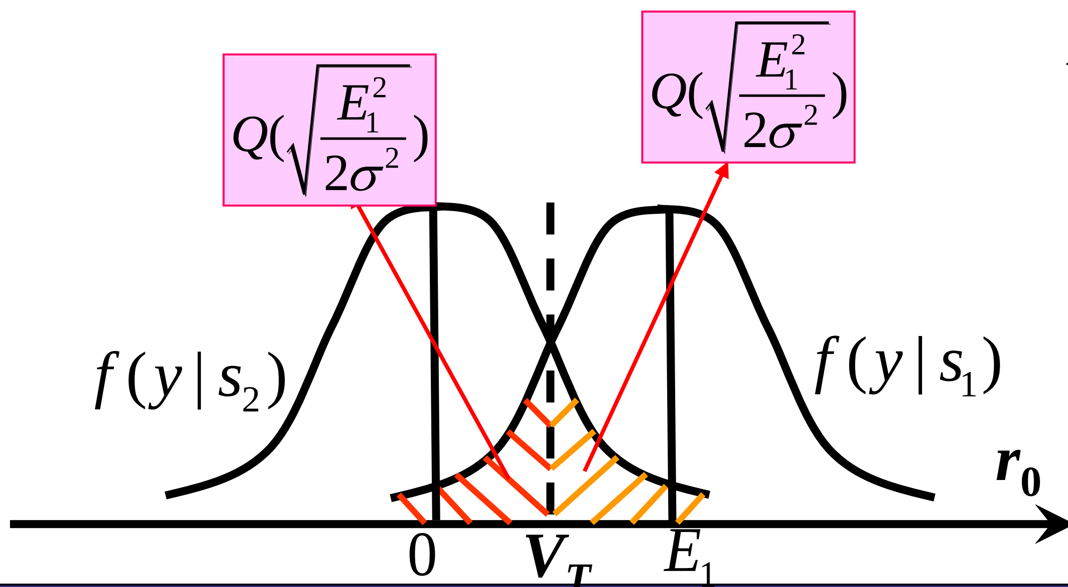
(1) AWGN信道条件下OOK的最佳接收(3/4)

$$p(y|s_1)=\frac{1}{\sqrt{2\pi\sigma^2}}\exp\left[-\frac{(y-E_1)^2}{2\sigma^2}\right]\Rightarrow P_{e1}=Q\left(\sqrt{\frac{E_1^2}{4\sigma^2}}\right)=Q\left(\sqrt{\frac{E_1^2}{2E_1N_0}}\right)=Q\left(\sqrt{\frac{E_1}{2N_0}}\right)$$

发 "0"→$s_2(t)$ $y\equiv y(T)=\int_0^T\left[s_2(\tau)+n_w(\tau)\right]s_1(\tau)d\tau=Z$

$$p(y|s_2)=\frac{1}{\sqrt{2\pi\sigma^2}}\exp\left[-\frac{y^2}{2\sigma^2}\right]\Rightarrow P_{e2}=Q\left(\sqrt{\frac{E_1^2}{4\sigma^2}}\right)=Q\left(\sqrt{\frac{E_1^2}{2E_1N_0}}\right)=Q\left(\sqrt{\frac{E_1}{2N_0}}\right)$$

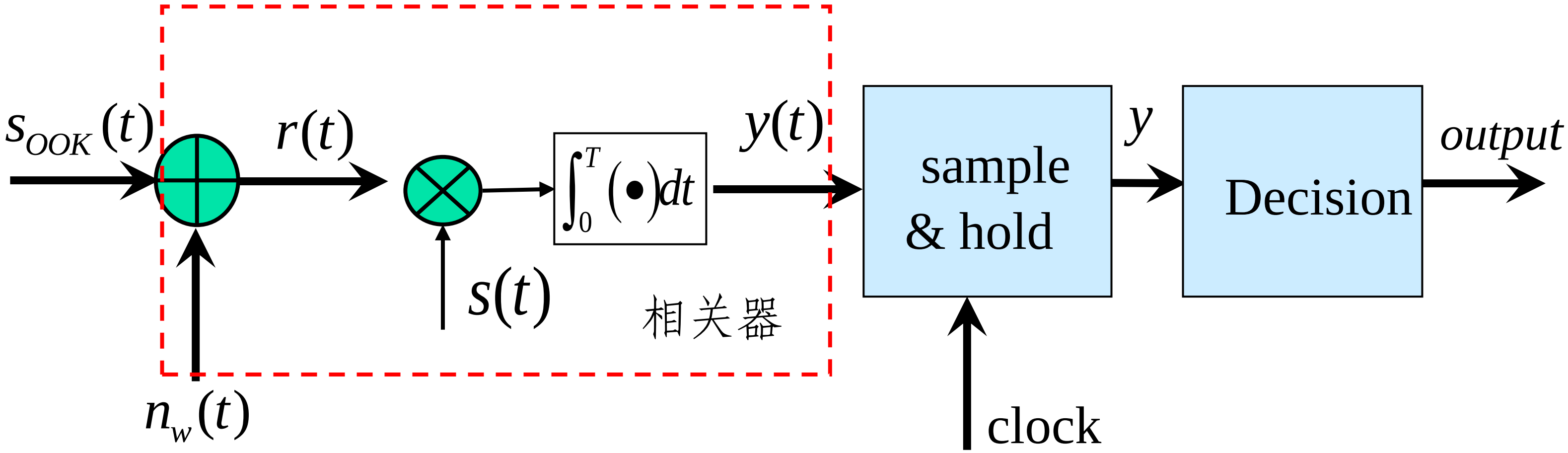
$$E_b=\frac{E_1}{2}=\frac{A^2}{4}T_b$$



$$\boxed{P_b=Q\left(\sqrt{\frac{E_b}{N_0}}\right)}$$

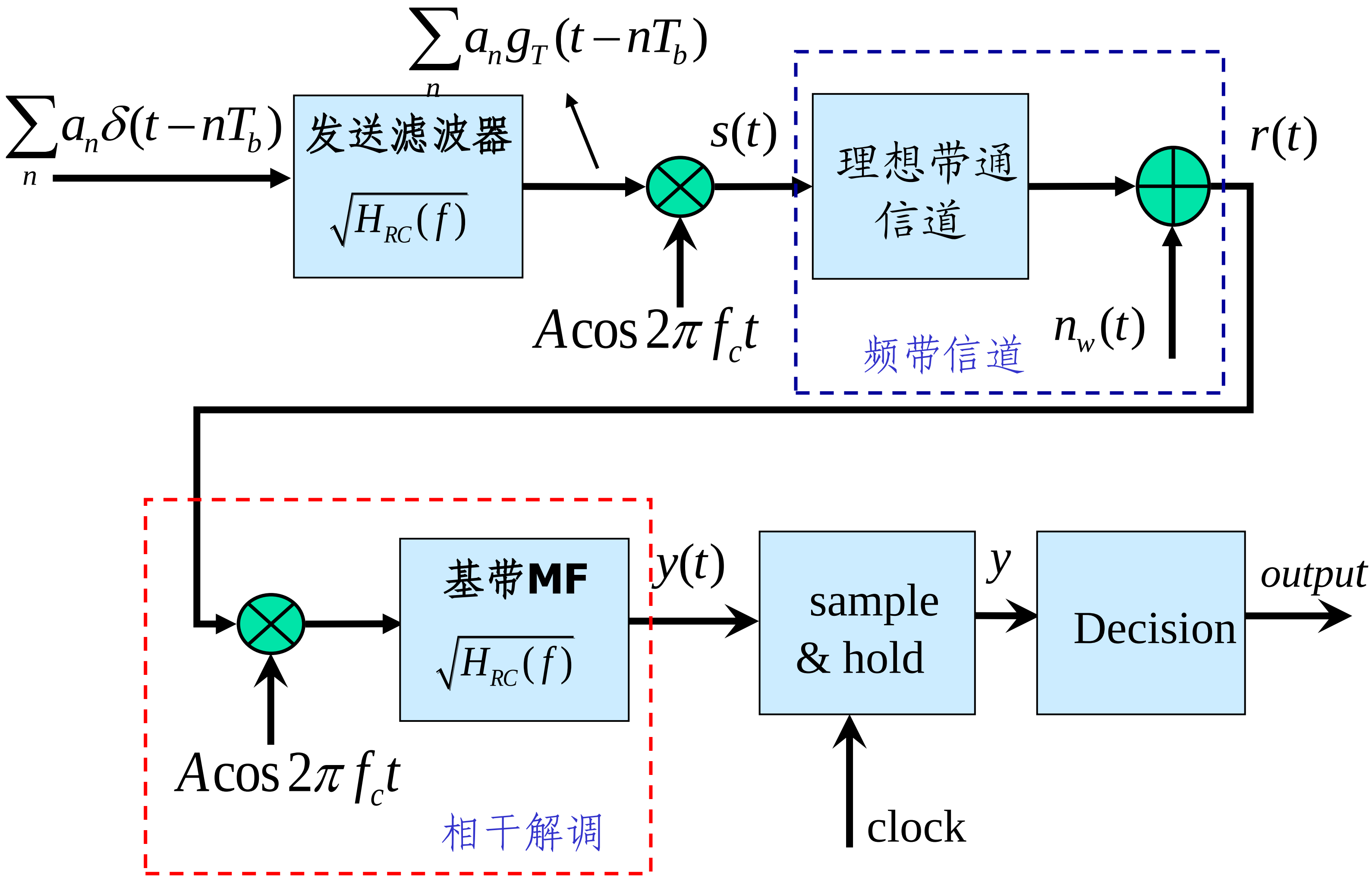
(1) AWGN信道条件下OOK的最佳接收(4/4)

- 匹配滤波器等效形式：相关接收机(Correlator)



$$y(t) = \int_0^{T_b} \left[s(t) + n_w(t) \right] s_1(t) dt$$

(2) 理想限带及AWGN信道OOK信号最佳接收(1/2)



(2)理想限带及AWGN信道OOK信号最佳接收(2/2)

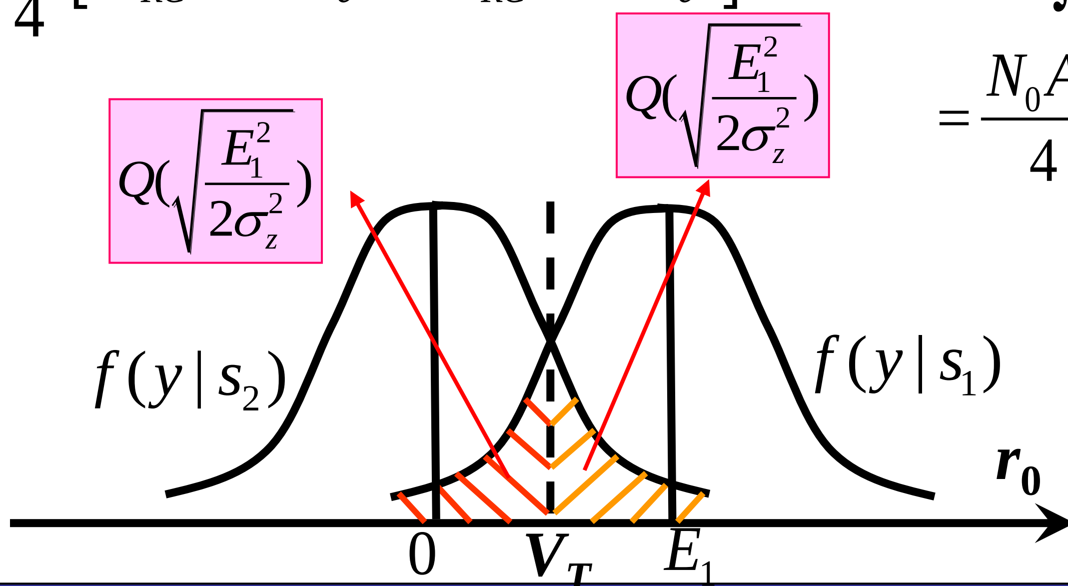
$$s(t)=\begin{cases} s_1(t)=Ag_T(t)\cos 2\pi f_c t, & "1" \\ s_2(t)=0, & "0" \end{cases} \qquad y=\begin{cases} E_1+Z, & "1" \\ Z, & "0" \end{cases}$$

$$h(t)=s_1(t_0-t)=s_1(t)$$

$$E_1=\int_{-\infty}^{\infty} s_1^2(\tau)d\tau=\frac{A^2}{2}\int_{-\infty}^{\infty} g_T^2(\tau)d\tau=\frac{A^2}{2}\int_{-\infty}^{\infty}|G_T(f)|^2 df = \frac{A^2}{2}\int_{-\infty}^{\infty}|H_{RC}(f)|df$$

$$P_Z(f)=\frac{A^2}{4}\left[H_{RC}(f-f_c)+H_{RC}(f+f_c)\right] \qquad \sigma_Z^2=\int_{-\infty}^{\infty} P_z(f)df$$

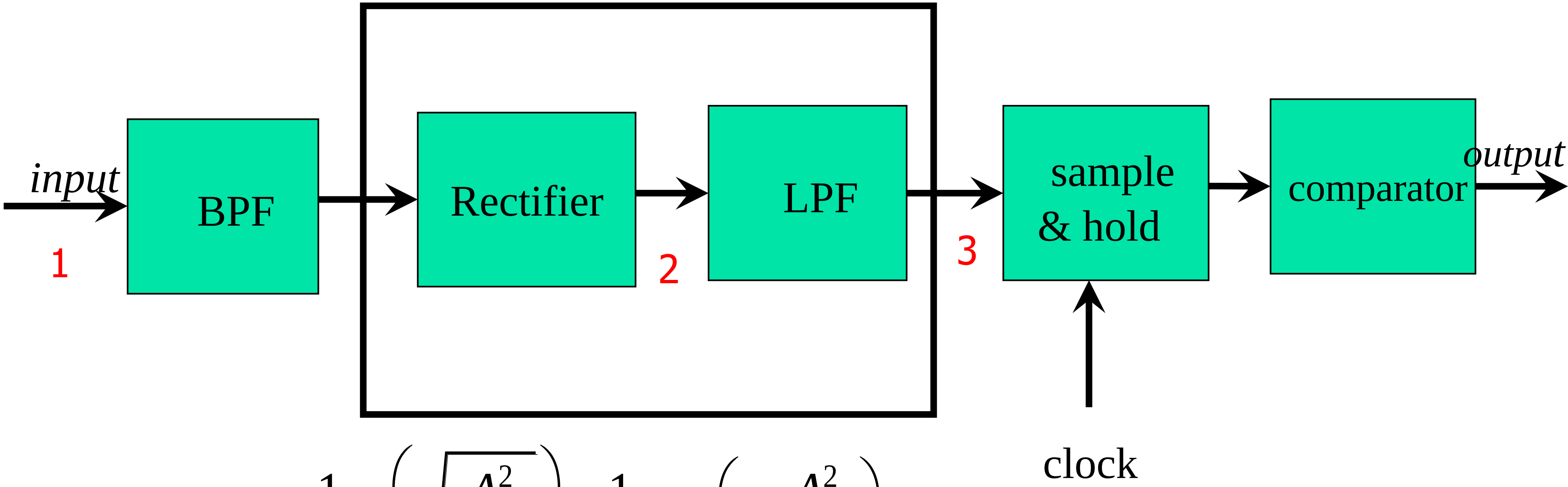
$$=\frac{N_0A^2}{4}\int_{-\infty}^{\infty}|H_{RC}(f)|df=\frac{N_0E_1}{2}$$



$$E_b=\frac{E_1}{2}$$

$$\boxed{P_b=Q(\sqrt{\frac{E_b}{N_0}})}$$

(3) OOK信号的非相干解调



$$P_b \approx \frac{1}{2}Q\left(\sqrt{\frac{A^2}{4\sigma^2}}\right)+\frac{1}{2}\exp\left(-\frac{A^2}{8\sigma^2}\right)$$

$$P_b \approx \frac{1}{2}\exp\left(-\frac{A^2T_b}{4}\frac{r_b}{2N_0B}\right)=\frac{1}{2}\exp\left(-\frac{E_b}{2N_0}\cdot\frac{r_b}{B}\right)$$

多选题 1分

设置

某2ASK传输系统，若符号传输速率为10kHz，则下列说法中正确的是

A 该2ASK信号的最小带宽为10kHz

B 该2ASK信号的最小带宽为20kHz

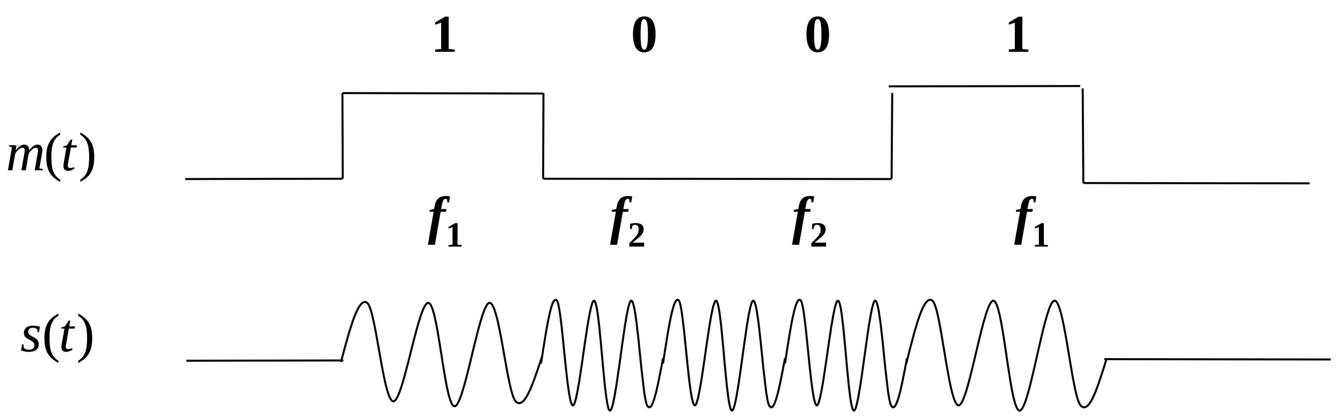
C 若基带信号采用不归零方波，则该2ASK信号第一过零点带宽为10kHz

D 若基带信号采用不归零方波，则该2ASK信号第一过零点带宽为20kHz

提交

2、2FSK

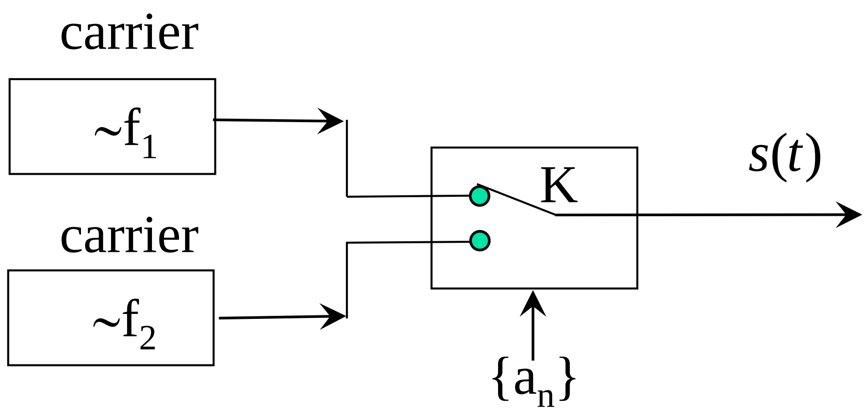
2.1 2FSK信号与两种调制器



$$s(t)=\begin{cases} A_c\cos\left(2\pi f_1 t+\varphi_1\right) & '1' \\ A_c\cos\left(2\pi f_2 t+\varphi_2\right) & '0' \end{cases} \qquad 0\le t\le T_b$$

2.1 2FSK信号与两种调制器

（1）相位不连续2FSK信号

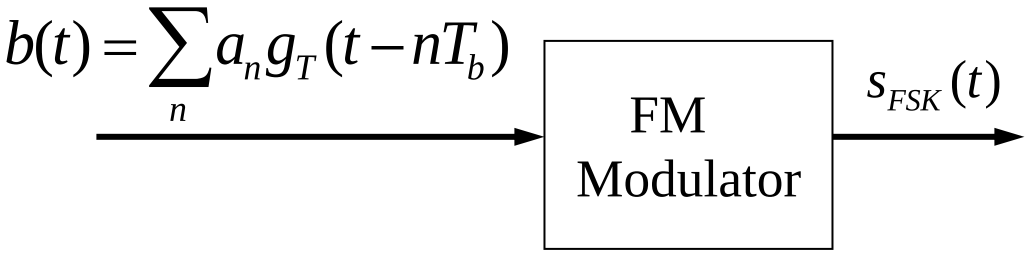


(a) FSK modulator with discontinuous phase

$$s_{FSK}(t)=\begin{cases} s_1(t)=A\cos 2\pi f_1 t, "1" \\ s_2(t)=A\cos 2\pi f_2 t, "0" \end{cases} 0\le t\le T_b$$

FSK modulator

（2）相位连续2FSK信号



(b) FSK modulator with
continuous phase

$$s_{FSK}(t)=A\cos\left[2\pi f_c t+2\pi K_f\int_{-\infty}^{t} b(\tau)d\tau\right]=\mathrm{Re}\left[v(t)e^{j2\pi f_c t}\right]$$

$$v(t)=Ae^{j\theta(t)}$$

$$\theta(t)=2\pi K_f\int_{-\infty}^{t} b(\tau)d\tau$$

2.2 2FSK信号之间的相关性

$$\rho_{12} = \frac{1}{E_b}\int_0^{T_b} s_1(t)s_2(t)dt \qquad E_b = \frac{A^2}{2}T_b$$

$$s_{FSK}(t) = \begin{cases} s_1(t) = A\cos 2\pi\left(f_c + \Delta f\right)t, "1" \\ s_2(t) = A\cos 2\pi\left(f_c - \Delta f\right)t, "0" \end{cases} 0 \le t \le T_b$$

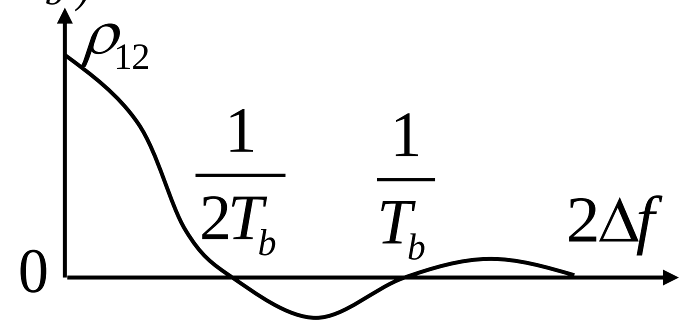
$$\rho_{12} = \frac{A^2}{E_b}\int_0^{T_b}\left[\cos 2\pi\left(f_c + \Delta f\right)t \times \cos 2\pi\left(f_c - \Delta f\right)t\right]dt$$

$$\rho_{12} = \frac{1}{T_b}\int_0^{T_b}\left[\cos 2\pi\cdot 2\Delta f\cdot t + \cos 2\pi\cdot 2f_c\cdot t\right]dt$$

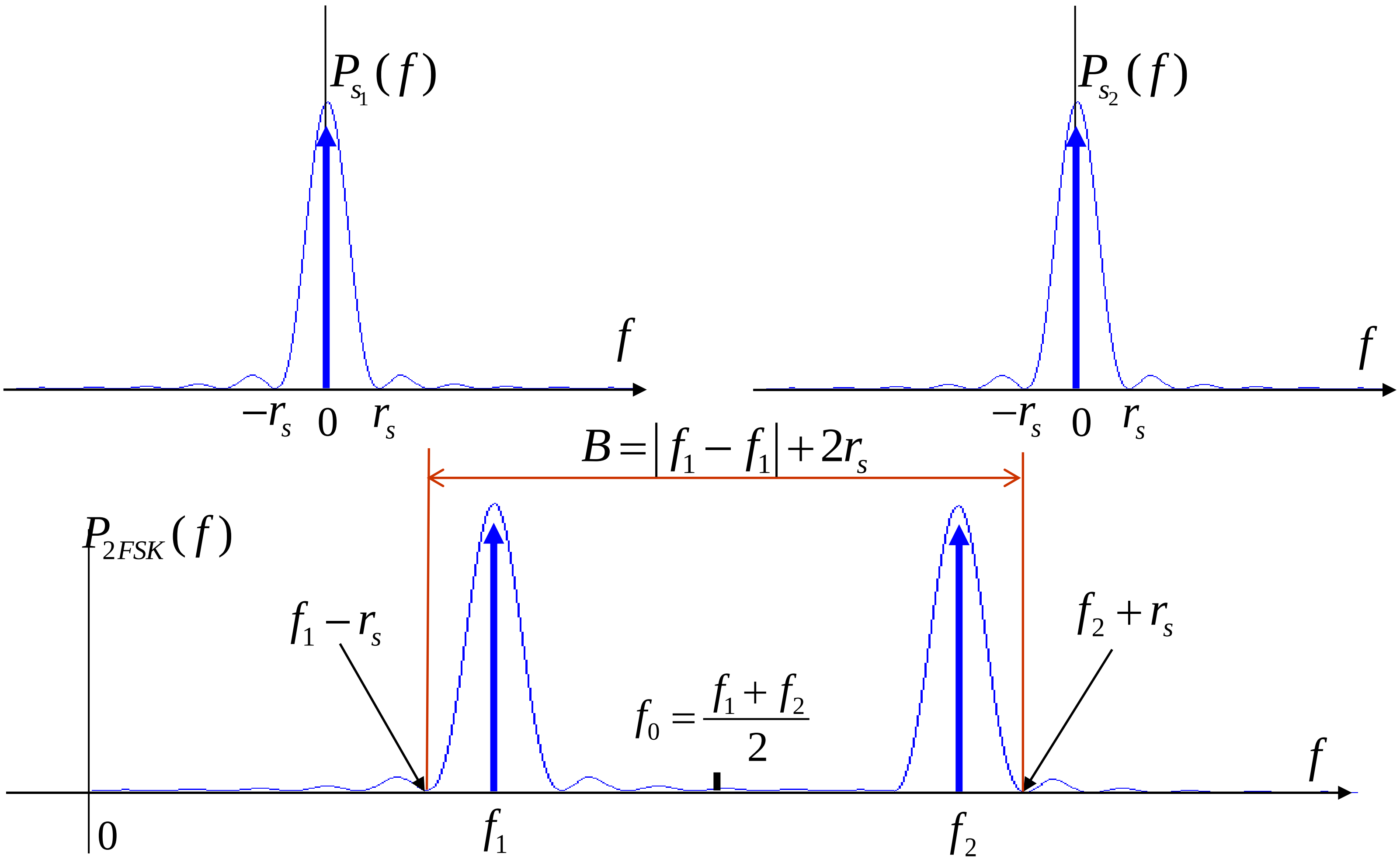
$$= \mathrm{Sa}\left(2\pi\cdot 2\Delta f\cdot T_b\right) + \mathrm{Sa}\left(2\pi\cdot 2f_c\cdot T_b\right)$$

$$\approx \mathrm{Sa}\left(2\pi\cdot 2\Delta f\cdot T_b\right)$$

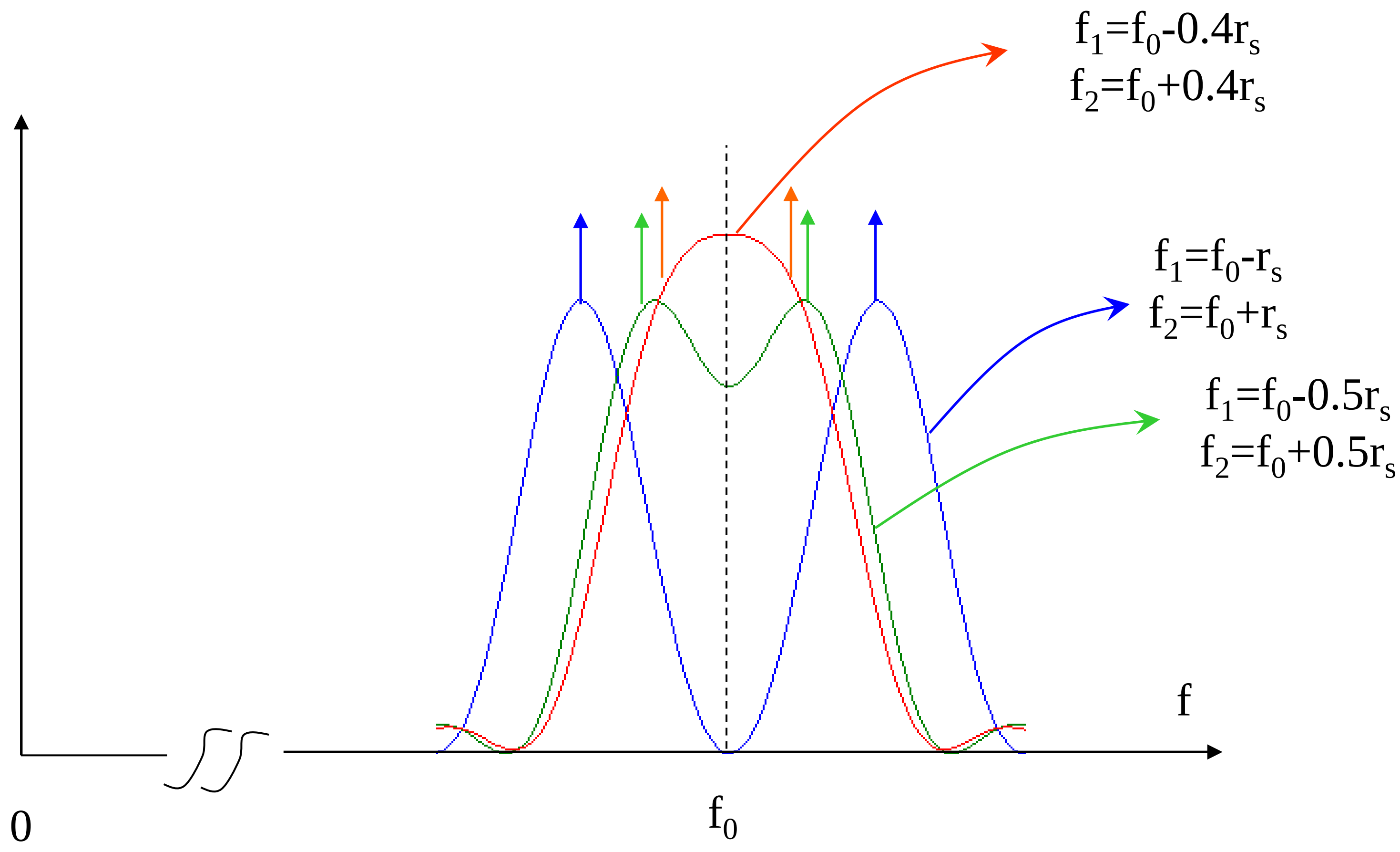
$$2\Delta f = \frac{1}{2T_b}, orthogonal \quad FSK$$



2.3 2FSK信号功率谱密度

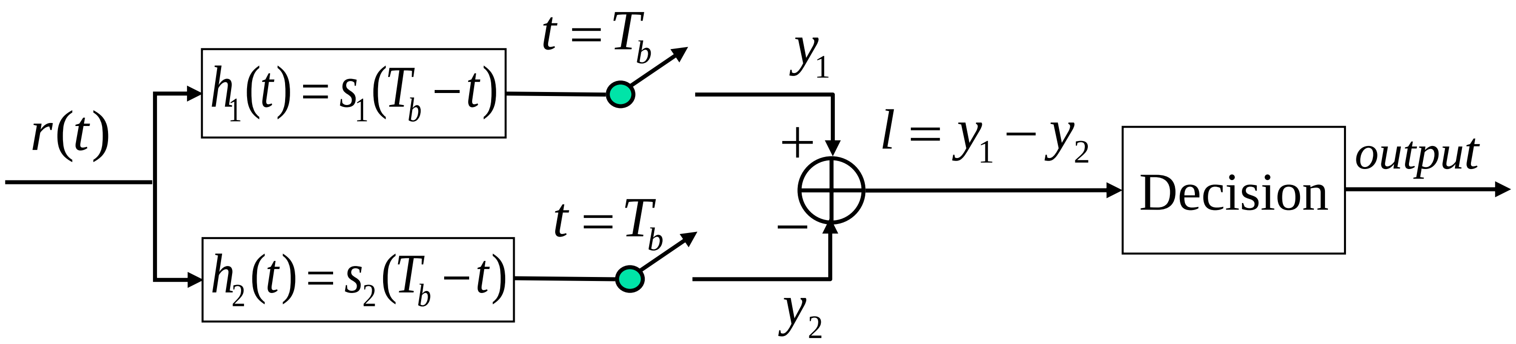


$$P_{2FSK}(f) = \frac{1}{4}\left[P_{s_1}(f - f_1) + P_{s_1}(f + f_1)\right] + \frac{1}{4}\left[P_{s_2}(f - f_2) + P_{s_2}(f + f_2)\right]$$

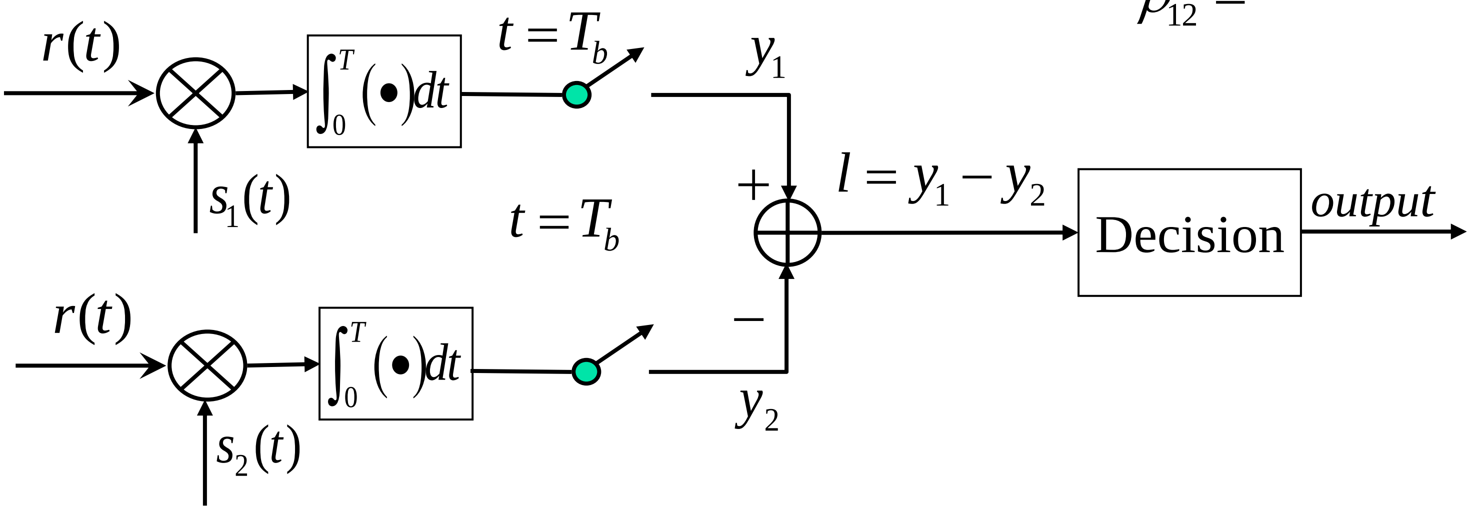


$f_1=f_0-0.4r_s$
$f_2=f_0+0.4r_s$
$f_1=f_0-r_s$
$f_2=f_0+r_s$
$f_1=f_0-0.5r_s$
$f_2=f_0+0.5r_s$
f
0
f_0

2.4 AWGN信道正交2FSK最佳接收(1/2)



$\rho_{12} =$



2.4AWGN信道正交2FSK最佳接收(2/2)

发 $s_1(t)$

$$y_1 = y_1(T_b) = E_b + Z_1 \qquad Z_1 = \int_0^{T_b} n_w(t)s_1(t)dt$$
$$y_2 = y_2(T_b) = Z_2 \qquad Z_2 = \int_0^{T_b} n_w(t)s_2(t)dt$$

发 $s_2(t)$

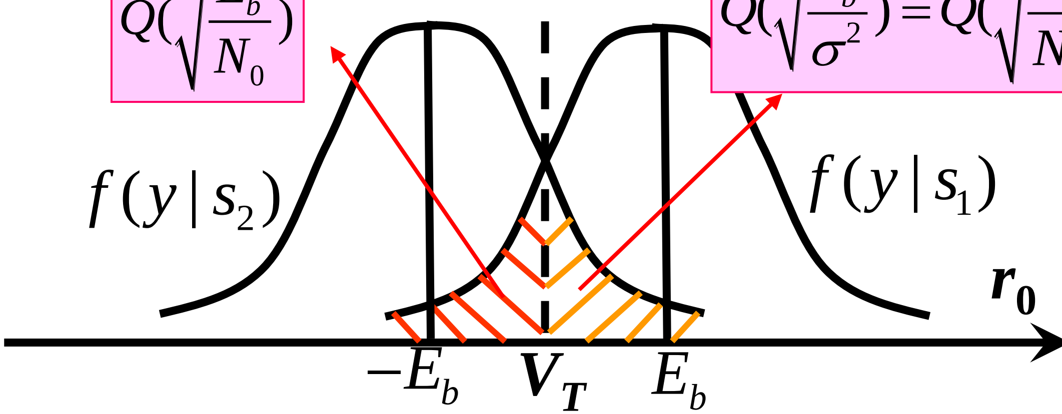
$$y_1 = y_1(T_b) = Z_1 \qquad Z_1 = \int_0^{T_b} n_w(t)s_1(t)dt$$
$$y_2 = y_2(T_b) = E_b + Z_2 \qquad Z_2 = \int_0^{T_b} n_w(t)s_2(t)dt$$

$$l = y_1 - y_2 = \begin{cases} E_b + Z_1 - Z_2, 发 s_1(\mathrm{t}) \\ -E_b + Z_2 - Z_1, 发 s_2(\mathrm{t}) \end{cases}$$

$$E(l \mid s_1) = E(y_1 \mid s_1) - E(y_2 \mid s_2) = E_b$$
$$D(l \mid s_1) = E\left\{[Z_1 - Z_2]^2\right\} = 2E\left(Z_1^2\right) = N_0 E_b$$

$$Q(\sqrt{\frac{E_b}{N_0}})$$

$$Q(\sqrt{\frac{E_b^2}{\sigma^2}}) = Q(\sqrt{\frac{E_b}{N_0}})$$



$$P_b = Q(\sqrt{\frac{E_b}{N_0}})$$

多选题 1分

设置

某2FSK传输系统，若符号传输速率为10kHz，载波频率为900kHz和1MHz，若基带波形为方波，则下列说法中正确的是

A 信号带宽为无穷大

B 信号第一过零点带宽为120kHz

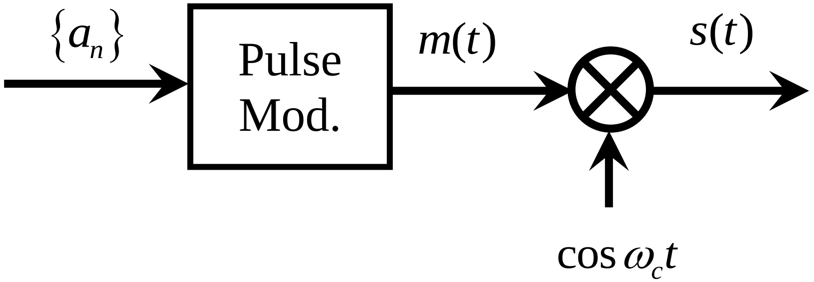
C 信号为带限信号

D 信号第一过零点带宽为110kHz

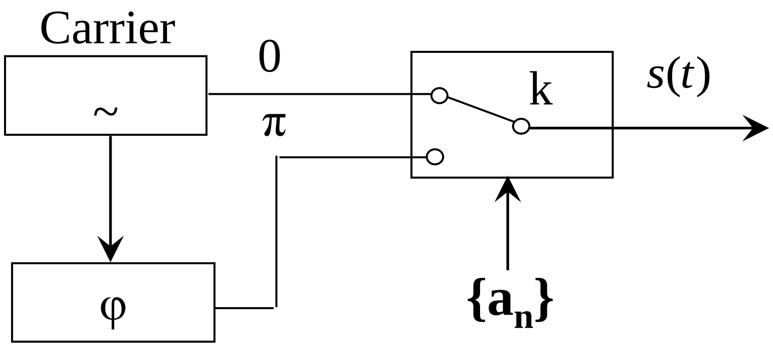
提交

3、2PSK

3.1 两种调制器



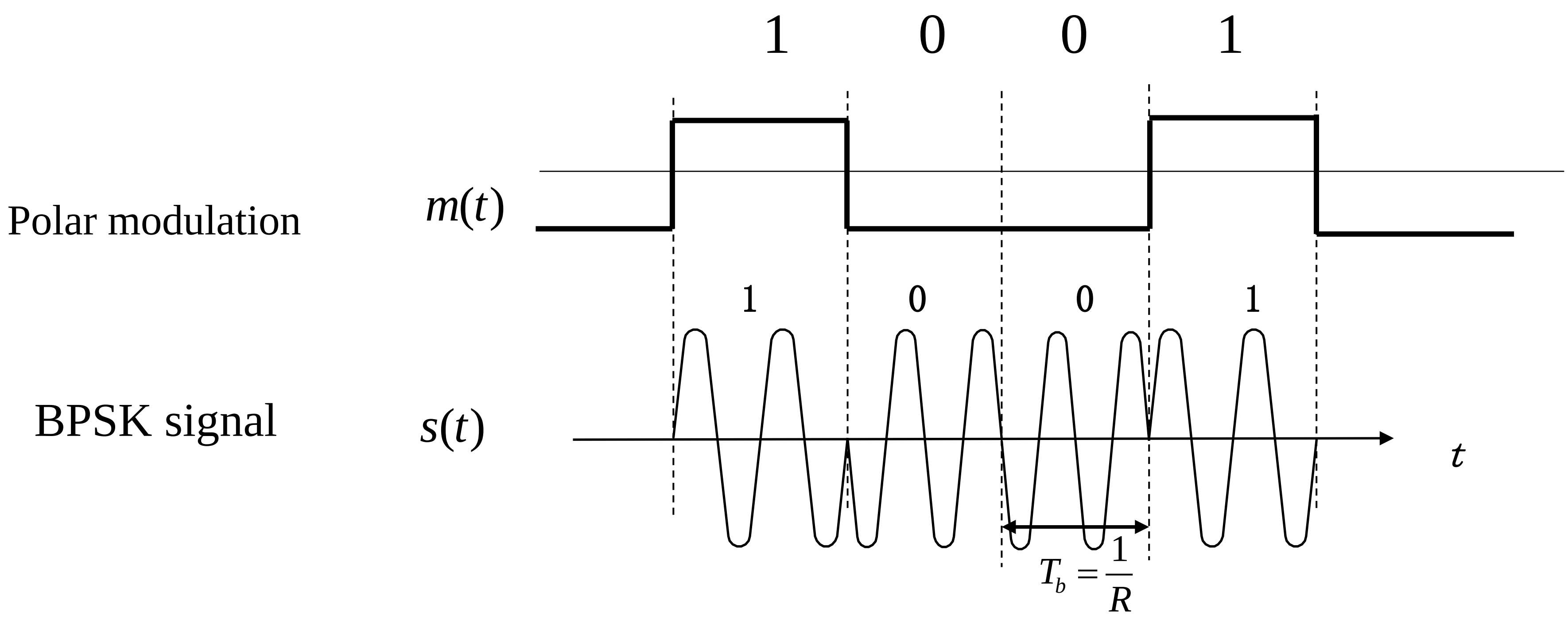
(a) DSB-SC modulator



(b) Shifting keying modulator

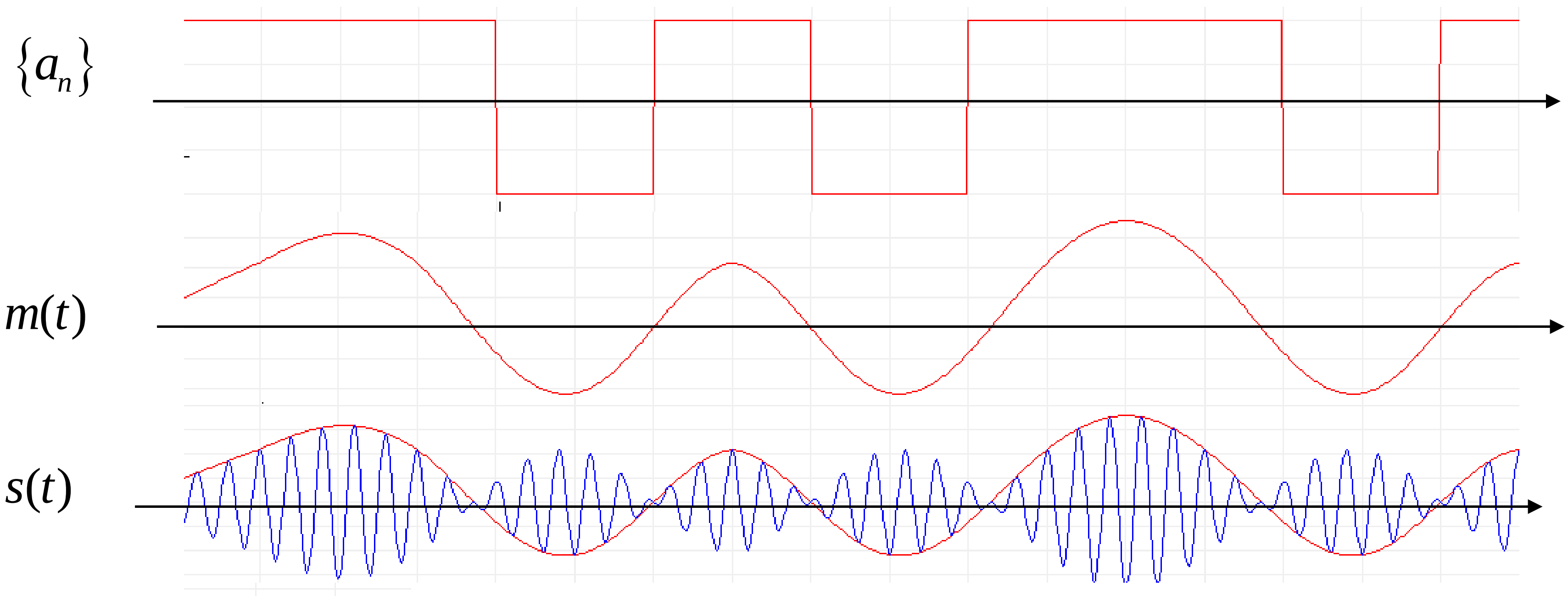
3.2 两种信号波形

- BPSK



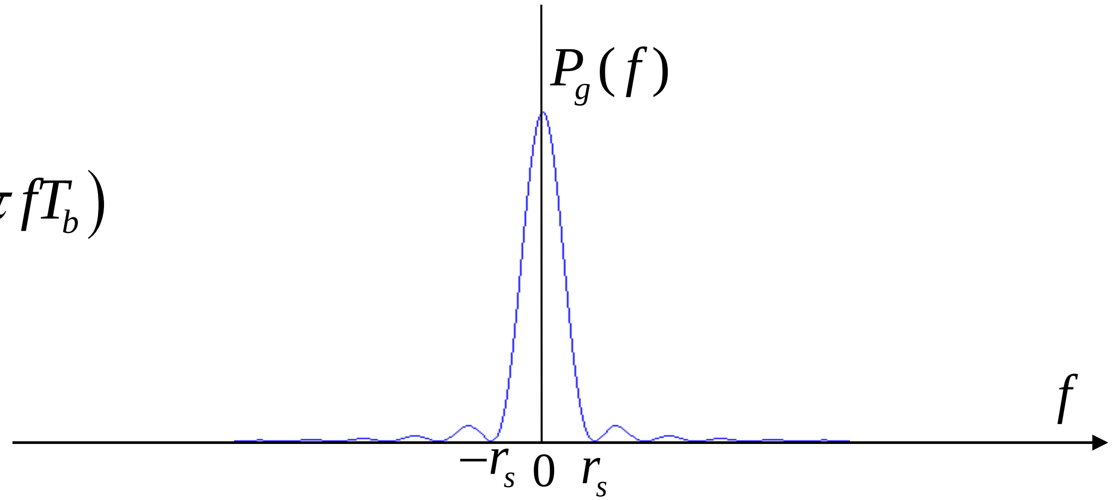
3.2 两种信号波形

- DSB-SC with pulse shaping

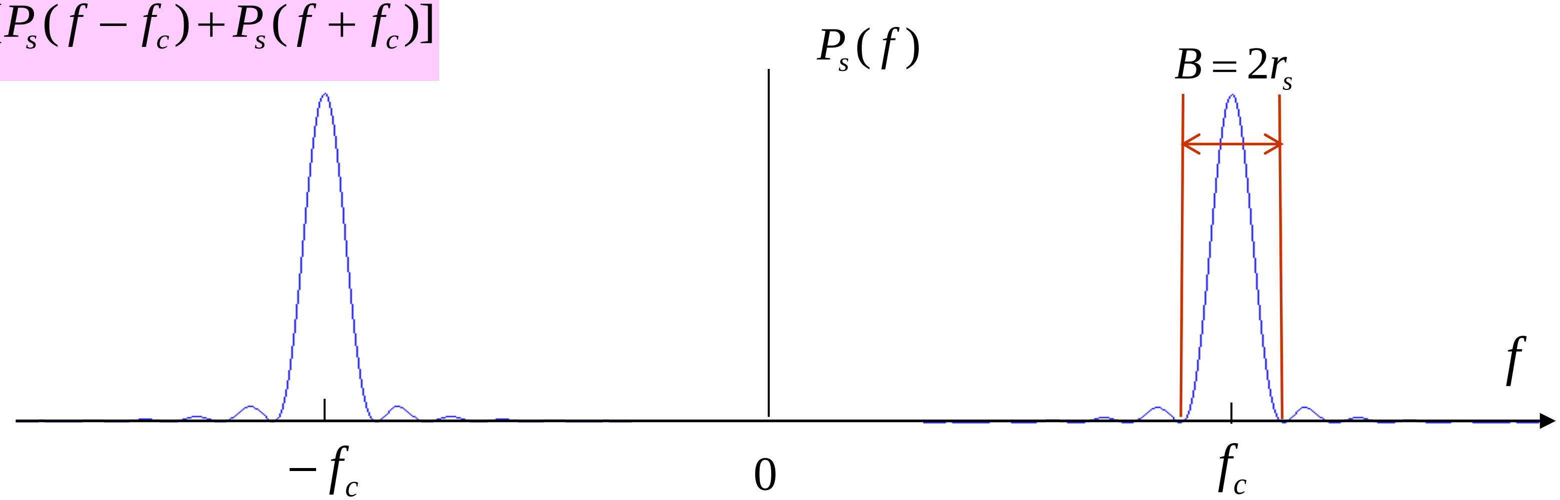


3.3 BPSK信号功率谱密度

$$P_g(f) = A_c^2 T_b Sa^2\left(\pi f T_b\right)$$



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

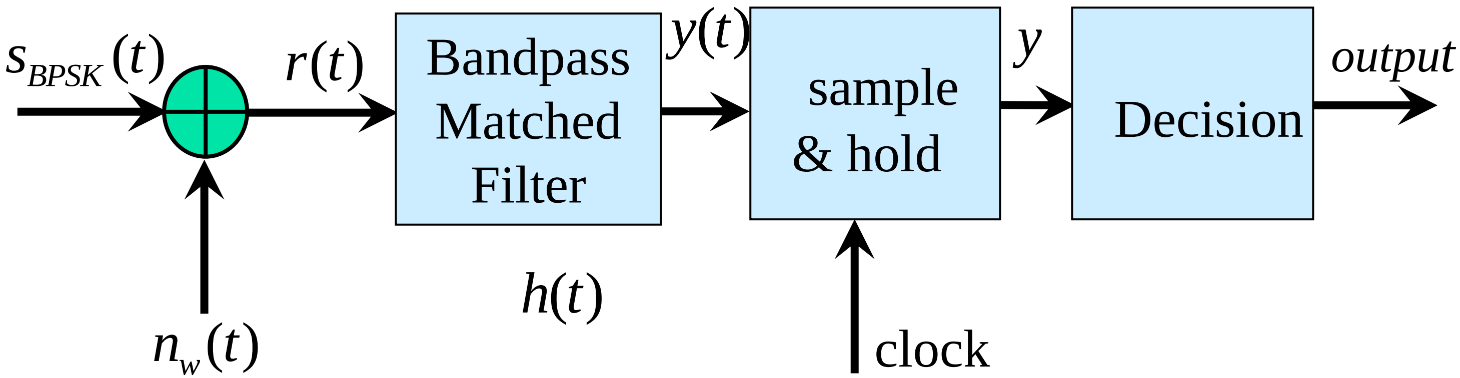


3.4 BPSK信号解调

(1) AWGN信道条件下BPSK的最佳接收

(2) 在理想限带及AWGN信道条件下BPSK信号的最佳接收

(1) AWGN信道条件下BPSK的最佳接收(1/3)



$$s(t)=\begin{cases} s_1(t)=A\cos 2\pi f_c t,"1" \\ s_2(t)=-A\cos 2\pi f_c t,"0" \end{cases}$$

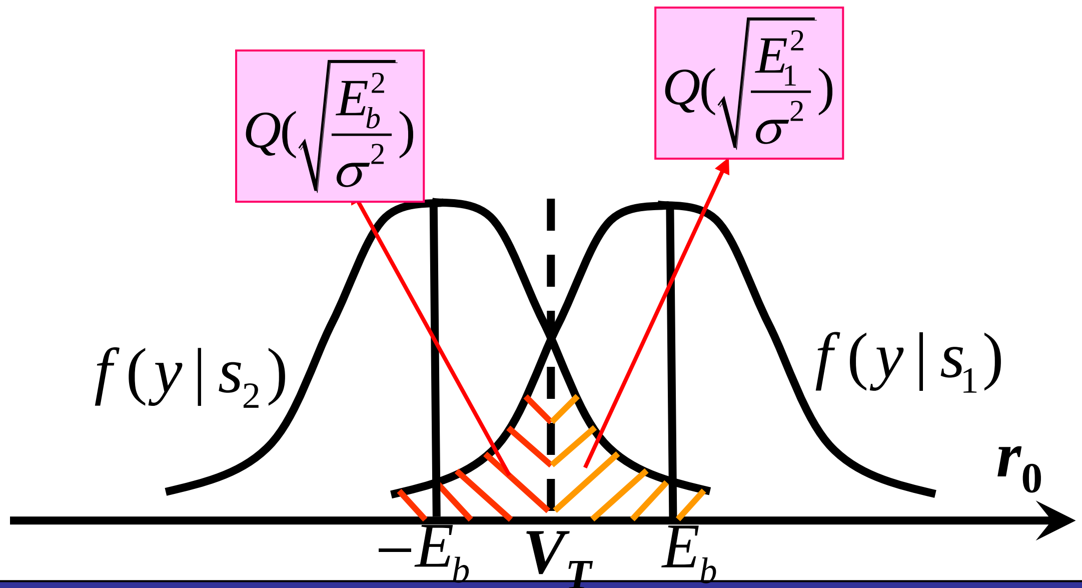
$$h(t)=s_1(T_b-t), 0\le t\le T_b$$

(1)AWGN信道条件下BPSK的最佳接收(2/3)

$$y=\begin{cases}E_b+Z,\text{"1"}\\-E_b+Z,\text{"0"}\end{cases}\qquad D(Z)=\sigma^2=\frac{E_bN_0}{2}$$

$$p(y|s_1)=\frac{1}{\sqrt{2\pi\sigma^2}}\exp\left[-\frac{(y-E_b)^2}{\sigma^2}\right]\Rightarrow P_{e1}=Q\left(\sqrt{\frac{E_b^2}{\sigma^2}}\right)=Q\left(\sqrt{\frac{2E_b}{N_0}}\right)$$

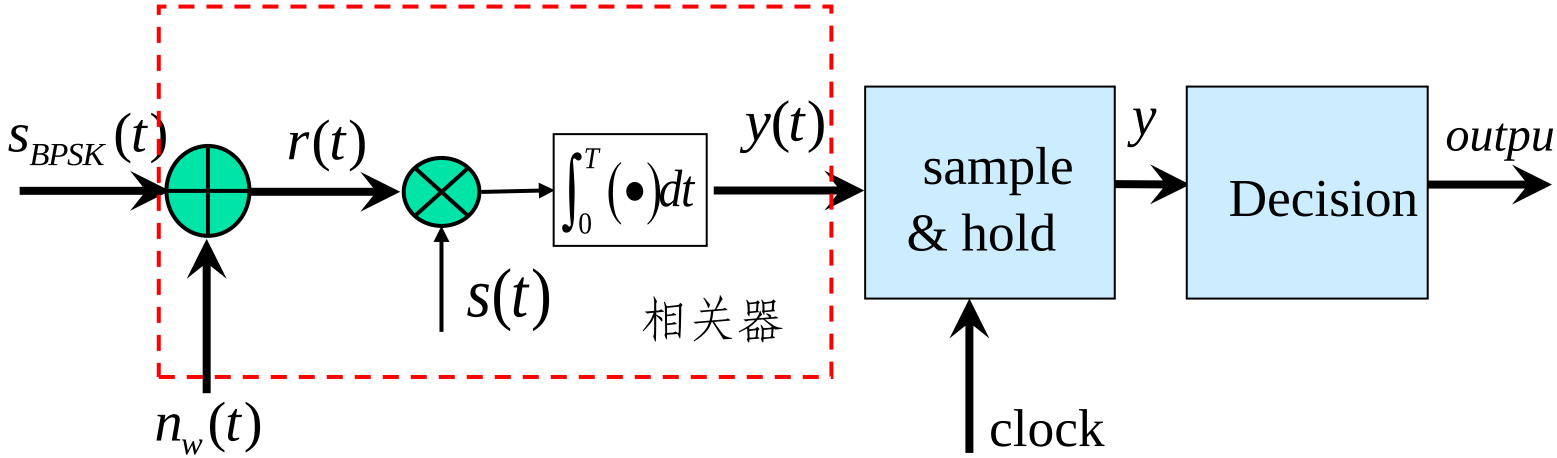
$$p(y|s_2)=\frac{1}{\sqrt{2\pi\sigma^2}}\exp\left[-\frac{(y+E_b)^2}{\sigma^2}\right]\Rightarrow P_{e2}=Q\left(\sqrt{\frac{E_b^2}{\sigma^2}}\right)=Q\left(\sqrt{\frac{2E_b}{N_0}}\right)$$



$$\boxed{P_b=Q\left(\sqrt{\frac{2E_b}{N_0}}\right)}$$

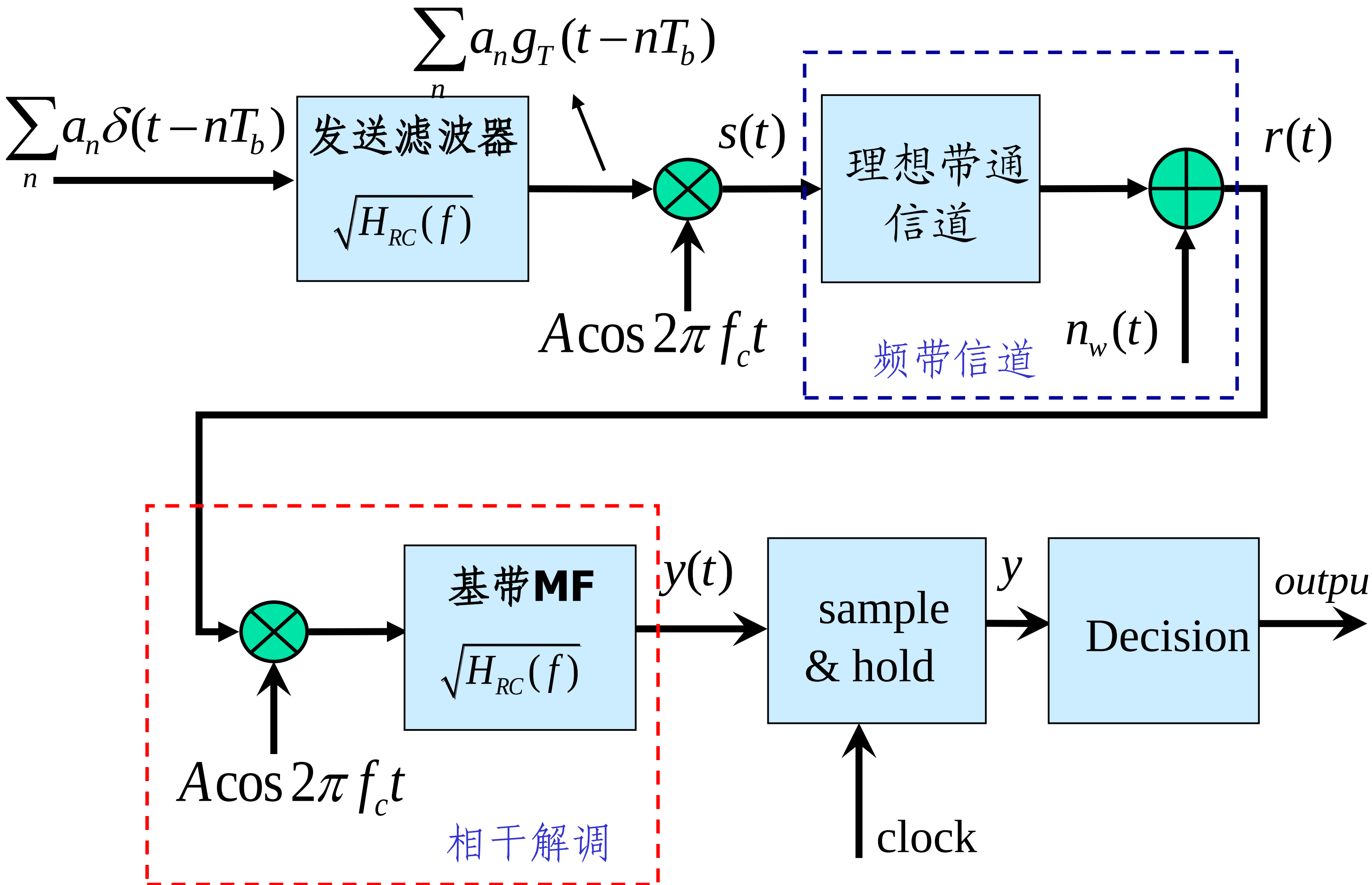
(1)AWGN信道条件下BPSK的最佳接收(3/3)

- 匹配滤波器等效形式：相关接收机(Correlator)



$$y(t)=\int_0^{T_b}\left[s(t)+n_w(t)\right]s_1(t)dt$$

(2)理想限带及AWGN信道BPSK信号最佳接收(1/2)

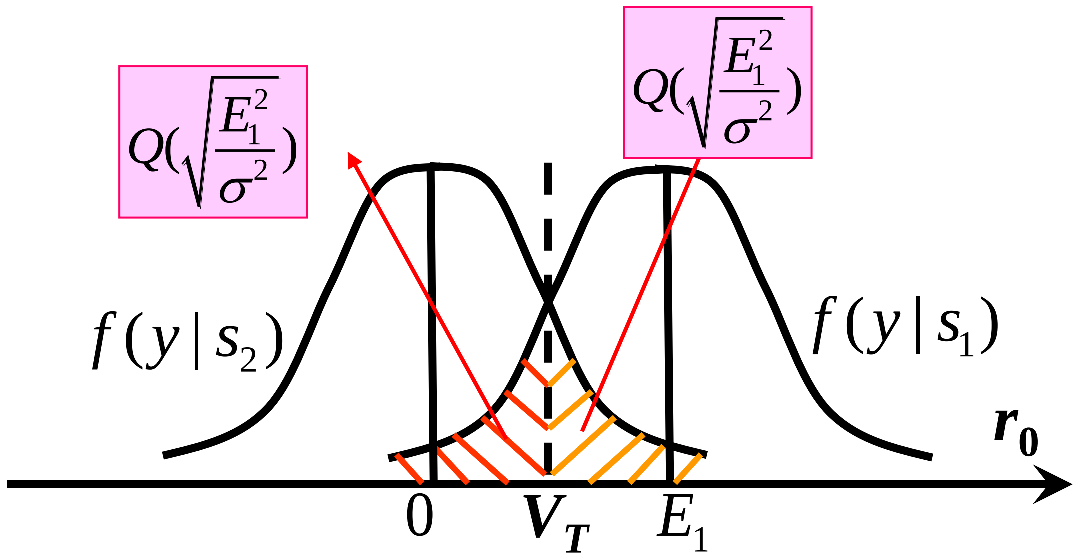


(2)理想限带及AWGN信道BPSK信号最佳接收(2/2)

$$s(t)=\begin{cases} s_1(t)=Ag_T(t)\cos 2\pi f_c t, "1" \\ s_2(t)=-Ag_T(t)\cos 2\pi f_c t "0" \end{cases} \qquad y=\begin{cases} E_b+Z, "1" \\ -E_b+Z, \qquad "0" \end{cases}$$

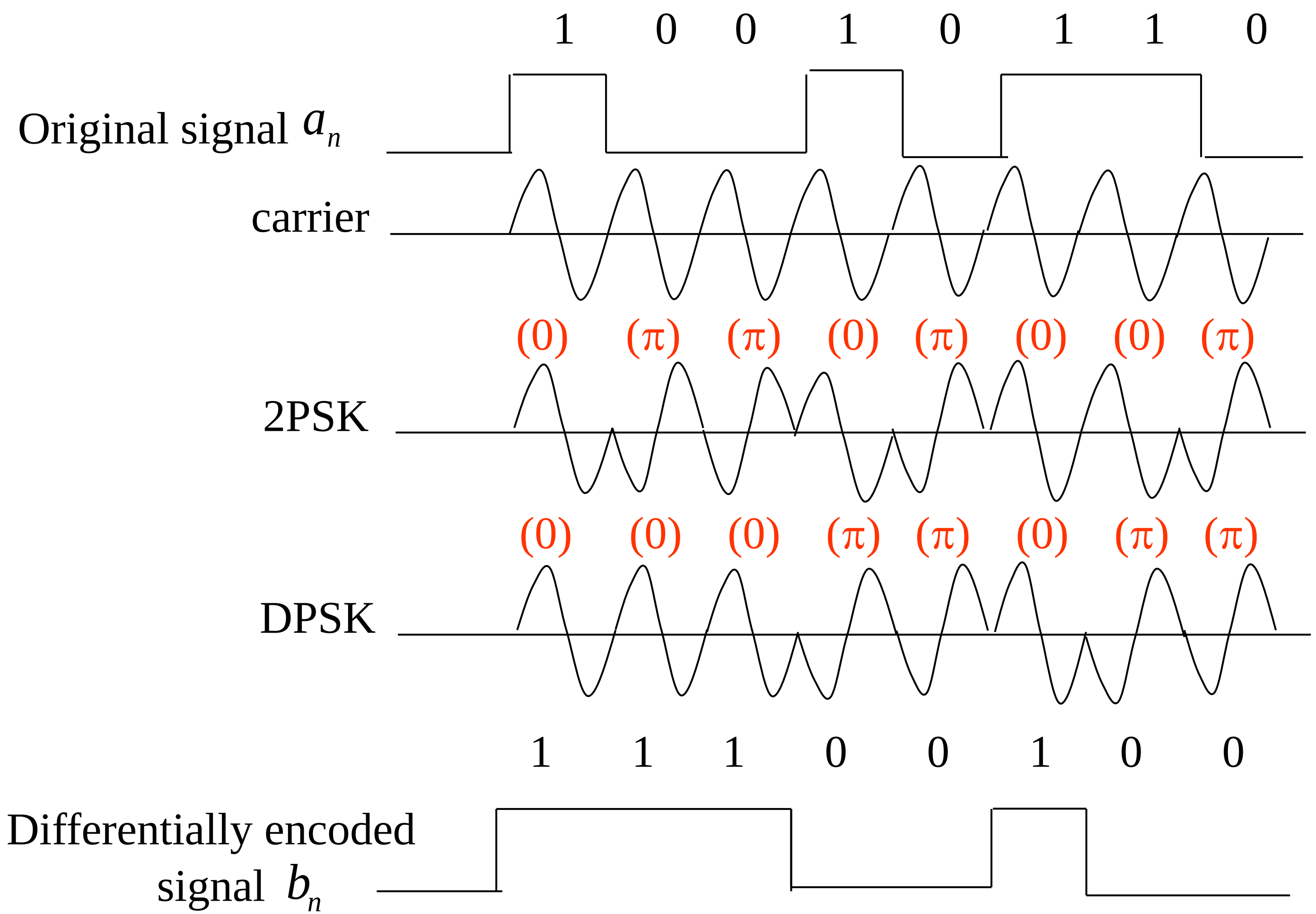
$$h(t)=s_1(t_0-t)=s_1(t), 0\le t\le t_0$$

$$E_b=\frac{A^2}{2}\int_{-\infty}^{\infty}\left|H_{RC}(f)\right|df \qquad D(z)=\sigma^2=\frac{N_0E_b}{2}$$

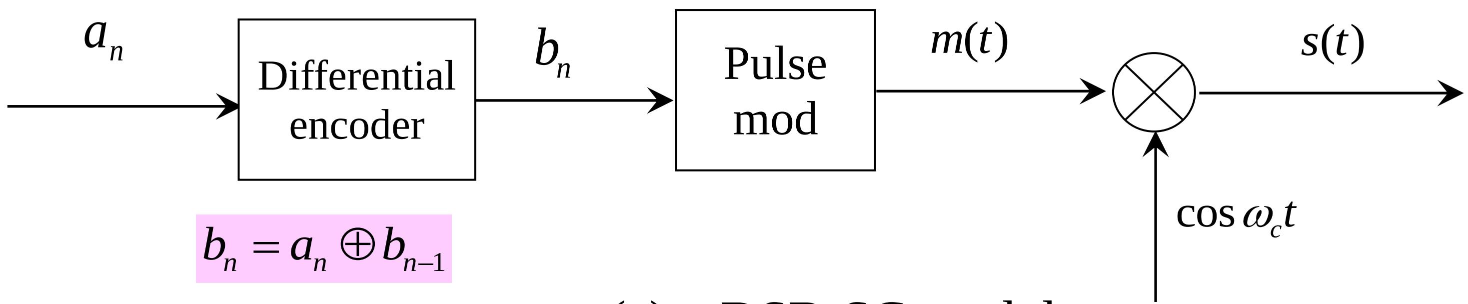


$$P_b=Q\left(\sqrt{\frac{2E_b}{N_0}}\right)$$

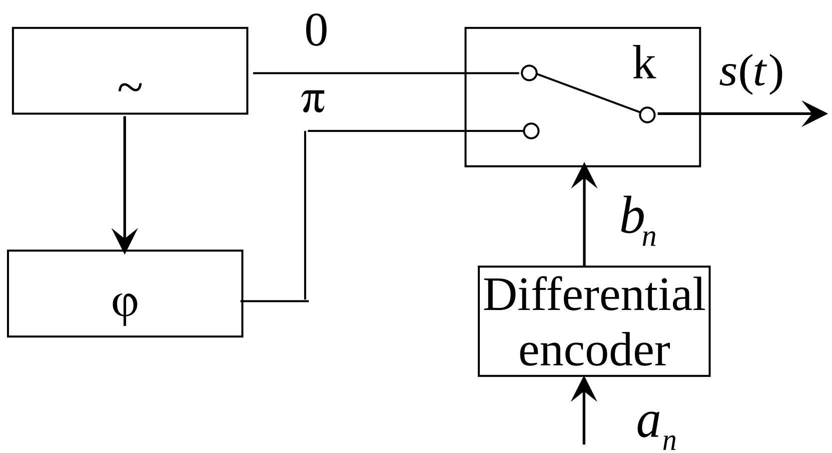
3.5 Differential phase-shift keying (DPSK)



DPSK modulator

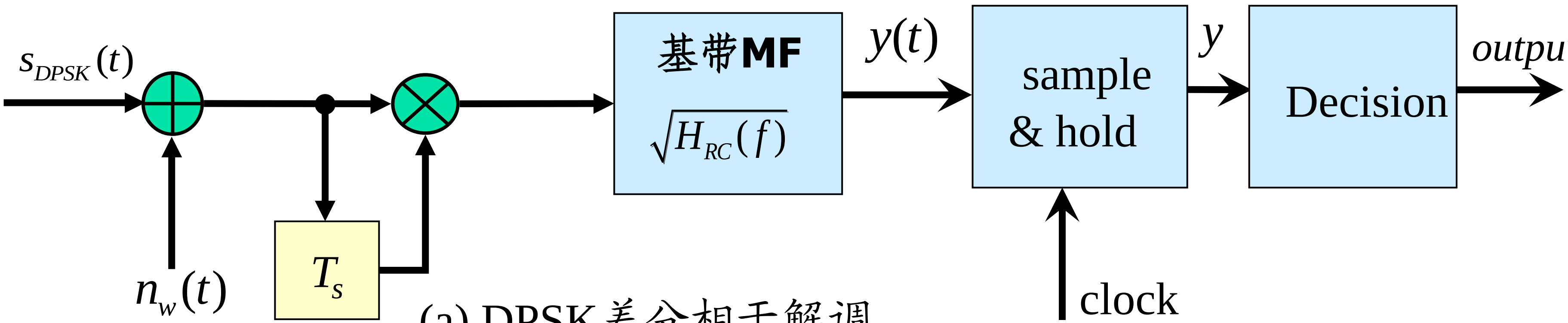


(a) DSB-SC modulator

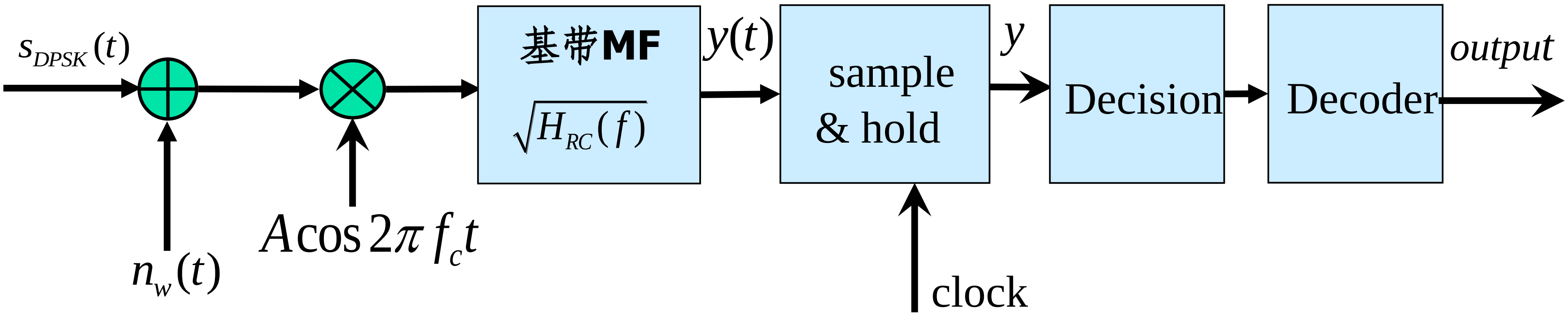


(b) Shift keying modulator

DPSK demodulator

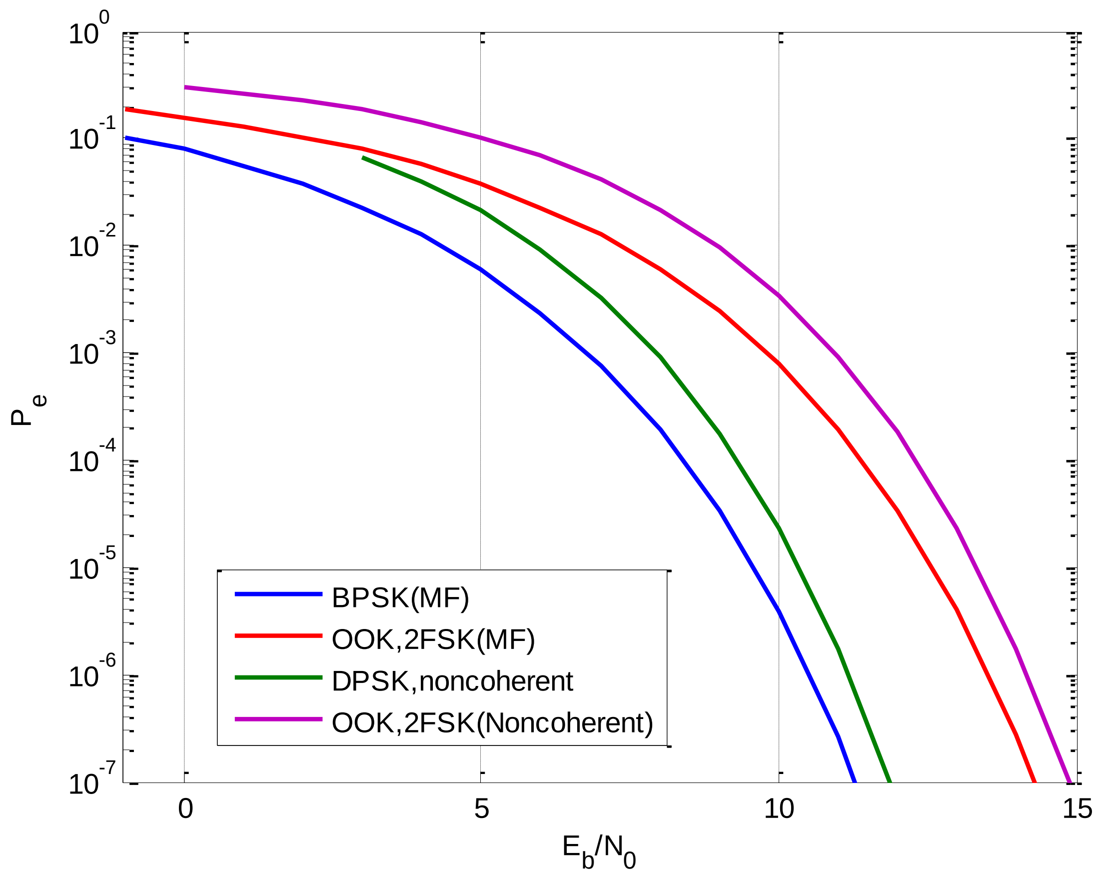


(a) DPSK差分相干解调



(b) DPSK相干解调

误码率结果比较



10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
P_e
0
5
10
15
E_b/N_0
BPSK(MF)
OOK,2FSK(MF)
DPSK,noncoherent
OOK,2FSK(Noncoherent)

单选题 1分

设置

此题未设答案

下列二进制频带传输系统中，误码性能最好的是

A 2ASK非相干解调

B 2PSK相干解调

C 2FSK相干解调

D 2DPSK非相干解调

提交