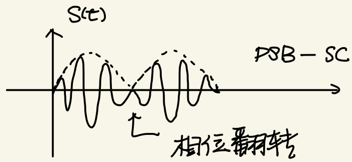
第四章

4.1

(1) $s(t) = m(t)c(t) = A_c \sin 2\pi f_m t \cdot \sin 2\pi f_c t$



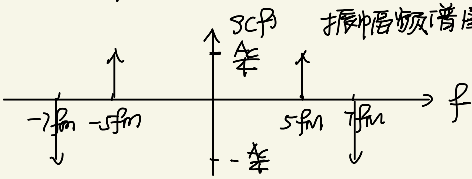
(2) $S(f) = \mathcal{F}\{s(t)\}$

$$= A_c \cdot \frac{\delta(f-f_m)-\delta(f+f_m)}{2j} \otimes \frac{\delta(f-f_c)-\delta(f+f_c)}{2j}$$

$$= -\frac{A_c}{4} \cdot [\,\delta(f-f_m-f_c) - \delta(f+f_m-f_c) - \delta(f-f_m+f_c) + \delta(f+f_m+f_c)\,]$$

$f_c = 6f_m$

$$S(f) = -\frac{A_c}{4}[\,\delta(f-7f_m) + \delta(f+7f_m) - \delta(f-5f_m) - \delta(f+5f_m)\,]$$



(3) $s(t) \longrightarrow \otimes \longrightarrow LPF \longrightarrow s_o(t)$

$\uparrow$ $\sin 2\pi f_c t$

（与载波同步）

① 先与解调信号（与载波同步）相乘，得到原始基带信号以及高频部分

② 通过低通滤波器得到原始信号

4.2 $s(t)=\cos(2\pi\times10^4t)+4\cos(2\pi\times1.1\times10^4t)+\cos(2\pi\times1.2\times10^4t)$

$f_1=10^4Hz$, $f_2=1.1\times10^4Hz$, $f_3=1.2\times10^4Hz$

(1) 载波信号频率为 1.1×10^4Hz.

调制信号频率为 $f_3-f_2=1KHz$、

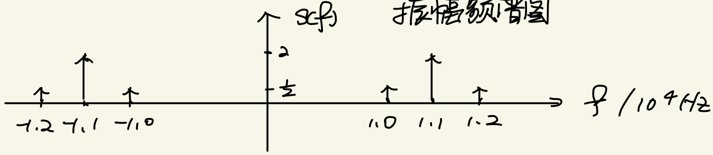
$$[A+m(t)]\cos(2\pi\times1.1\times10^4t)=s(t)$$

$$m(t)\cdot\cos(2\pi\times1.1\times10^4t)=\cos(2\pi\times10^4t)+\cos(2\pi\times1.2\times10^4t)$$

$$\begin{cases} m(t)=2\cos(2\pi\times0.1\times10^4t) \\ A=4 \end{cases}$$

$$\alpha=\frac{\max|m(t)|}{A}=\frac{2}{4}=\frac{1}{2}$$ ⇒ 调幅系数

(2) $S(f)=\mathcal{F}\{s(t)\}=\frac{1}{2}[\delta(f\pm10^4)+\delta(f\pm1.2\times10^4)+4\delta(f\pm1.1\times10^4)]$



(3) 包络检波法:

$s(t)$ ⟶ 整流器 ⟶ LPF ⟶ 隔直流电容

整流器只保留信号中大于零的部分

通过低通滤波器

再通过隔直流电容过滤掉直流分量

4.3 $s(t) = (1 + A\cos\omega_m t)\cos\omega_c t$

$f_m = 5\text{KHz}$, $f_c = 100\text{KHz}$, $A = 15$

(1) $A_c = 1$, $m(t) = 15\cos\omega_m t$

$$\alpha = \frac{\max|m(t)|}{A_c} = 15 > 1$$

此信号不能用包络检波器解调，因为此时调幅系数 > 1。

$s(t)$ 会出现相位翻转的情况。

(2) $s(t) \longrightarrow \otimes \longrightarrow \text{LPF} \longrightarrow s_o(t)$

$\uparrow$ $\cos 2\pi f_c t$

（与载波同步）

① 先与解调信号（与载波同步）相乘，得到原始基带信号以及高频部分

② 通过低通滤波器得到原始信号

(3) 接收信号 $s(t)$ $\longrightarrow$ 窄带滤波器 $\longrightarrow$ 载波分量

4.4 $s(t) = 2\cos 2\pi f_m t \cos 2\pi f_c t - 2\sin 2\pi f_m t \sin 2\pi f_c t$

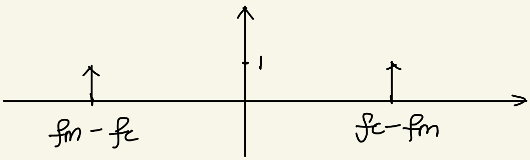
(1) $S(f) = \mathcal{F}\{s(t)\}$

$$= \frac{1}{2}\left(\delta(f+f_m) + \delta(f-f_m)\right) \otimes \left(\delta(f+f_c) + \delta(f-f_c)\right)$$
$$- \frac{1}{2}\left(\delta(f-f_m) - \delta(f+f_m)\right) \otimes \left(\delta(f-f_c) - \delta(f+f_c)\right)$$

$$= \frac{1}{2}\big(\delta(f+f_m \pm f_c) + \delta(f-f_m \pm f_c)$$
$$- \delta(f-f_m-f_c) + \delta(f-f_m+f_c) - \delta(f+f_m-f_c) + \delta(f+f_m+f_c)\big)$$

$$= \frac{1}{2}\left(2\delta(f+f_m+f_c) + 2\delta(f-f_m+f_c)\right)$$

$$= \delta(f+f_m+f_c) + \delta(f-f_m+f_c)$$



(2) 该信号的调制方式为 SSB-AM（单边带调制）

(3) 相干解调法

$$s(t) \longrightarrow \otimes \longrightarrow \text{LPF} \longrightarrow s_o(t)$$

$\cos 2\pi f_c t$ ↑ (与载波同步)

① 先与解调信号（与载波同步）相乘，得到原始基带信号以及高频部分

② 通过低通滤波器得到原始信号

4.5 单边带调幅，$2A_c = 100$, f_c 为 800 KHz.

$m(t) = \cos 2000\pi t + 2\sin 2000\pi t$

(1) $\hat{m}(t) = \sin 2000\pi t - 2\cos 2000\pi t$

(2) 下边带:

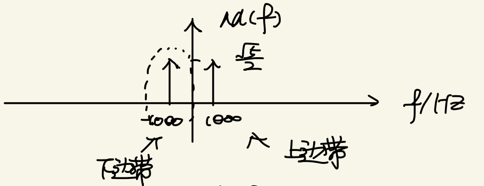
$S_l(t) = m(t)\cos 2\pi f_c t + \hat{m}(t)\sin 2\pi f_c t$

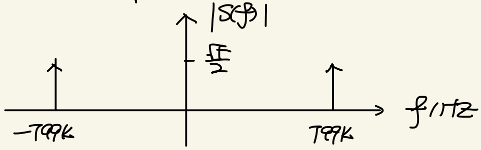
$= (\cos 2000\pi t + 2\sin 2000\pi t)\cos 1600\times 10^3\pi t +$

$(\sin 2000\pi t - 2\cos 2000\pi t)\sin 1600\times 10^3\pi t$

(3) $M(f) = \frac{1}{2}\delta(f\pm 1000) - j[\delta(f-1000) - \delta(f+1000)]$

$|M(f)| = \frac{\sqrt{5}}{2}\delta(f+1000) + \frac{\sqrt{5}}{2}\delta(f-1000)$





4.6 $s(t) = [A_c + m(t)]\cos 2\pi f_c t$, $\overline{m(t)} = 0$

$s(t)$ 的包络 $A(t) = A_c + m(t)$. 求调幅系数, 调制效率

解: 调幅系数 $\alpha = \dfrac{\max(m(t))}{A_c}$

由图可知 $\overline{A(t)} = 25V$, 因为 $\overline{m(t)} = 0$. $A_c = 25V$ (常数)

由图可知 $|A(t)|_{max} = 40V$. 因此 $A_c + |m(t)|_{max} = 40V$

$\max|m(t)| = 40 - 25 = 15V$

$$\alpha = \frac{15}{25} = 0.6$$

调制效率 $\eta = \dfrac{P_m}{A_c^2 + P_m} = \dfrac{P_m}{P_A}$

$$P_A = \frac{1}{T}\int_0^T [A(t)]^2\,dt = \frac{1}{T}\left(\int_0^{\frac{T}{2}} \left(\frac{30}{T}t + 25\right)^2 dt + \int_{\frac{T}{2}}^{T} \left(\frac{30}{T}t - 5\right)^2 dt\right)$$

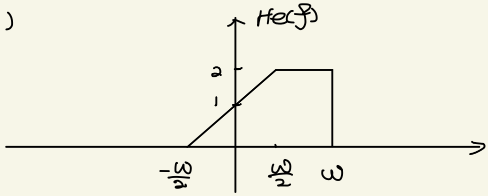
$$= \frac{1}{T}\left(\frac{T}{30}\cdot\frac{1}{3}\left(\frac{30}{T}t + 25\right)^3\Big|_0^{\frac{T}{2}} + \frac{T}{30}\cdot\frac{1}{3}\left(\frac{30}{T}t - 5\right)^3\Big|_{\frac{T}{2}}^{T}\right)$$

$$= \frac{1}{90}\left(40^3 + 25^3 - 10^3\right) \approx 873.61\ W$$

$$\eta = \frac{P_A - A_c^2}{P_A} = 1 - \frac{A_c^2}{P_A} \approx 28.46\ \%$$

4.7

(1)



$H_e(f) = \frac{1}{2} H_2(f)$

取2倍正频，移 $f_c \to 0$，乘 $\frac{1}{2}$

(2) $m'(t) = m(t)\cos(2\pi f_c t)$

$$M'(f) = \frac{1}{2}[M(f+f_c) + M(f-f_c)]$$

$$S(f) = M'(f)H(f) = \frac{1}{2}[M(f+f_c)H_+(f) + M(f-f_c)H_-(f)]$$

$$S_c(f) = \frac{1}{2}[M(f)H_+(f-f_c) + M(f)H_-(f+f_c)]$$

$$H_+(f-f_c) + H_-(f+f_c) = \begin{cases} 2, & |f|<W \\ 0, & \text{others} \end{cases}$$

$$S_c(f) = M(f) \Rightarrow I(t) = m(t)$$

(3) 相干解调法

$$S(t) \longrightarrow \otimes \longrightarrow LPF \longrightarrow S_o(t)$$

$\uparrow$ $\cos 2\pi f_c t$（与载波同步）

① 先与解调信号（与载波同步）相乘，得到原始基带信号以及高频部分

② 通过低通滤波器得到原始信号

4.8 调频: $s(t)=10\cos(2\pi\times10^6 t+4\cos 200\pi t)$

① 已调信号的平均功率

$$P_s=\int_{-\infty}^{+\infty}100\cos^2(\qquad)dt=50$$

② 调制指数 K_f.

$$2\pi K_f=4\Rightarrow K_f=\frac{4}{2\pi}=\frac{2}{\pi}$$

③ 最大频偏

$$f_{max}=f_c+\Delta f_{max}=10^6+\frac{1}{2\pi}\cdot\left|\frac{d(4\cos 200\pi t)}{dt}\right|_{max}$$

$$=10^6+400=1000.4Hz$$

④ 调制信号的带宽

$$W\approx2(1+\beta)f_m$$

$$\beta=\frac{K_f\cdot|m(t)|_{max}}{f_m}=\frac{\frac{2}{\pi}\cdot200\pi}{100}=4$$

$$W\approx10f_m=1KHz$$

4.9 $s(t) = 100\cos(2\pi f_c t + 4\sin 2000\pi t)$

(1) $s(t)$ 的带宽

$W = 2(1+\beta) f_m$ ， $f_m = 1000 Hz$

$\beta_p = K_p \cdot |m(t)|_{max} = 4$

$W = 10 f_m = 10^4 Hz$

(2) f_m 加倍后 (FM) ， $f_m = 2000' Hz$

$K_f = \frac{2}{\pi}$， $m(t) = 4000\pi \cos(4000\pi t)$

$\beta_f = \frac{K_f \cdot |m(t)|_{max}}{f_m} = 4$

$W = 2(1+\beta_f) f_m' = 2\times 10^4 Hz$

(3) f_m 加倍后 (PM)

$K_p = 4$， $m(t) = \sin 2000\pi t$

$\beta_p = K_p \cdot |m(t)|_{max} = 4$

$W = 2(1+\beta_f) f_m' = 2\times 10^4 Hz$

4.10

(1) AM 调制信号

(2) SSB — AM 下边单调制信号

(3) 频率调制信号 (FM)

(4) 相位调制信号 (PM)

4.11

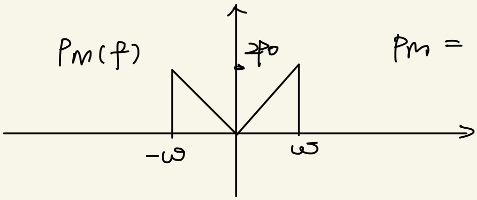
解: $r(t) = s(t) + n_c(t)\cos w_c t - n_s(t)\sin w_c t$

$$r_o(t) = LPF\{ s(t)\cos w_c t + n_c(t)\cos^2 w_c t - n_s(t)\cos w_c t \sin w_c t \}$$

$$= \underset{\substack{\uparrow \\ \text{系数}}}{K} \cdot (m(t) + n(t))$$

$$\gamma_o = \frac{P_m}{P_n}, \quad P_n = \frac{N_0}{2} \cdot 2W \cdot 2 = 2N_0W$$

$P_m(f)$



$$P_m = 2P_0 \cdot W = 2P_0W$$

$$\gamma_o = \frac{P_m}{P_n} = \frac{2P_0W}{2N_0W} = \frac{P_0}{N_0}$$

4.12

(1) 已调信号为SSB信号，$G = 1$，$y_o = y_i$

$$10\log_{10} x = 80,\quad x = 10^8 \ (\text{衰减})$$

$$\overline{P_i} = P_{发} \times 10^{-8} = 40\,kW \times 10^{-8} = 4\times10^{-4}\,W$$

$$\overline{P_n} = \frac{N_0}{2}\cdot 2W = N_0 W = 2\times10^{-10}\times10^{4}\,W = 2\times10^{-6}\,W$$

$$y_o = y_i = \frac{\overline{P_i}}{\overline{P_n}} = \frac{4\times10^{-4}\,W}{2\times10^{-6}\,W} = 200$$

(2) $\alpha = 0.85 = \dfrac{\max|m(t)|}{A}$

AM调制：$G = 2\gamma$，$y_o = 2\gamma\cdot y_i$

$$\gamma = \frac{P_m^2}{A^2 + P_M^2} = \frac{\alpha^2 P_{mn}^2}{1+\alpha^2 P_{mn}^2} \approx 0.028$$

$$\overline{P_i} = 4\times10^{-4}\,W \ (\text{无变化})$$

$$\overline{P_n} = 2N_0W = 4\times10^{-6}\,W$$

$$y_i = \frac{\overline{P_i}}{\overline{P_n}} = 100$$

$$y_o = 2\gamma\cdot100 = 200\gamma = 5.62$$

4.13

(1) $W_m = 48\ kHz.$

$\Delta f = k_f \cdot |m(t)|_{max} = 480\ kHz$

$W = (\frac{\Delta f}{W_m} + 1) W_m = (\frac{480\ kHz}{48\ kHz} + 1) W_m = 48\ kHz \times 11 = 528\ kHz$

(2)

FM信号 $\longrightarrow$ 限幅器带通 $\longrightarrow$ $\frac{d}{dt}(\cdot)$ 微分器 $\longrightarrow$ 包络检波器 $\longrightarrow$ LPF $\longrightarrow$ $m_o(t)$