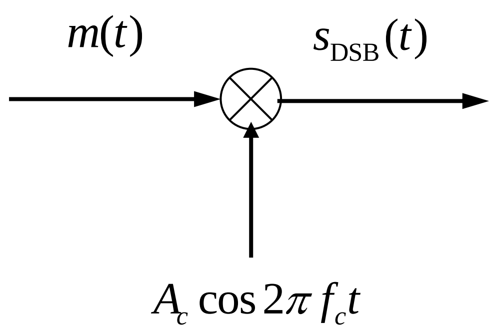
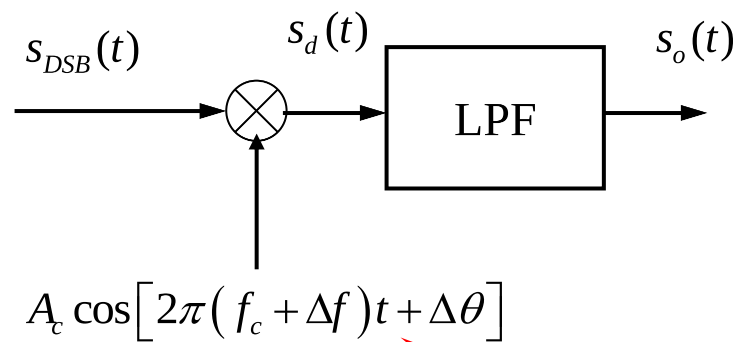
第7讲 模拟幅度调制

1. 抑制载波双边带(DSB-SC)调制
2. 常规调幅调制（AM）
3. 单边带(single sideband, SSB)调制
4. 模拟幅度调制系统的抗噪声性能

1. 抑制载波双边带(DSB-SC)调制

- 调制器与相干解调器





载波提取

$$s_{DSB}(t) = A_c m(t)\cos 2\pi f_c t$$

$$s_d(t) = m(t)\cos 2\pi f_c t \cos\left[2\pi\left(f_c+\Delta f\right)t+\theta_0\right]$$

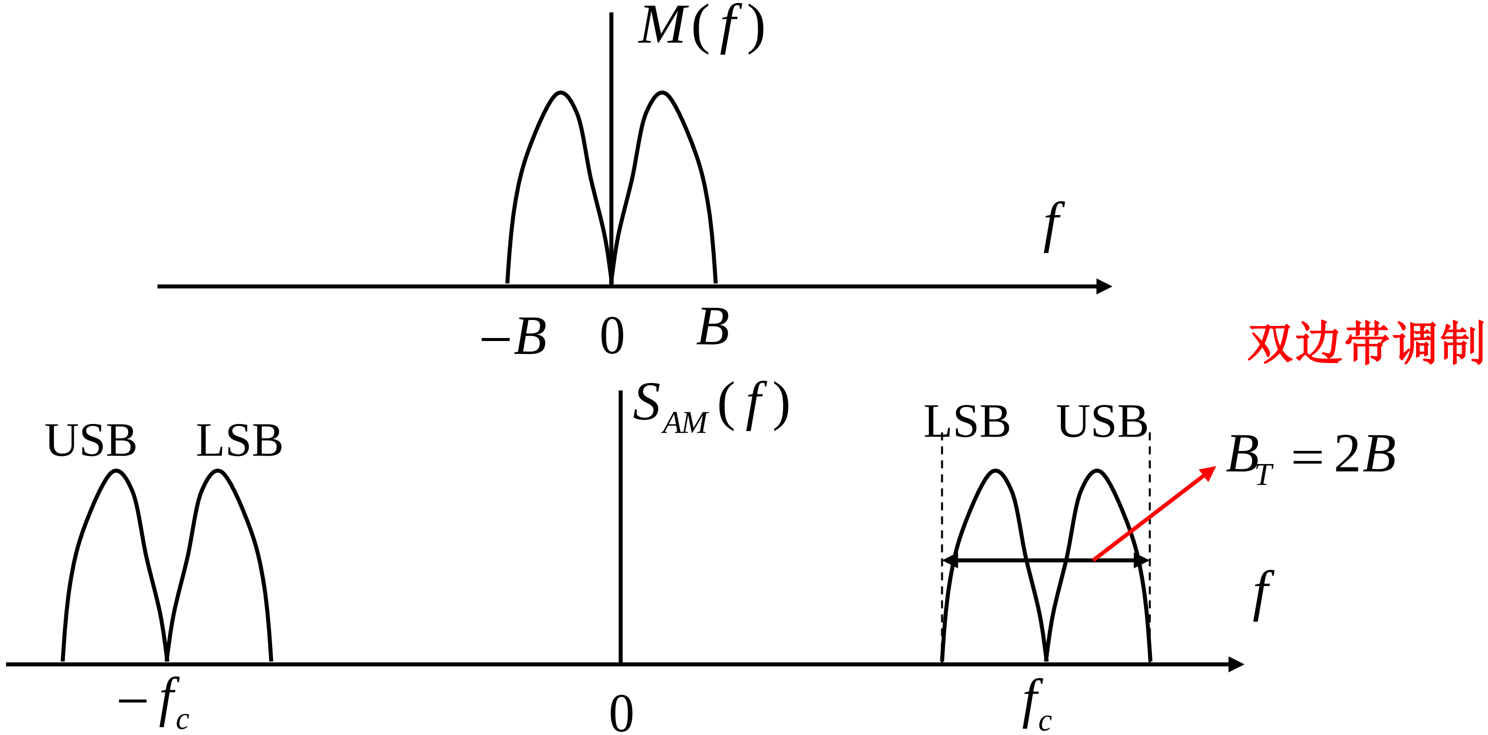
$$= \frac{1}{2}m(t)\left\{\cos\left(2\pi\Delta f t+\Delta\theta\right)+\cos\left[2\pi\left(2f_c+\Delta f\right)t+\Delta\theta\right]\right\}$$

$$s_o(t) = \frac{1}{2}m(t)\cos\left(2\pi\Delta f t+\Delta\theta\right)$$

DSB-SC信号的频谱

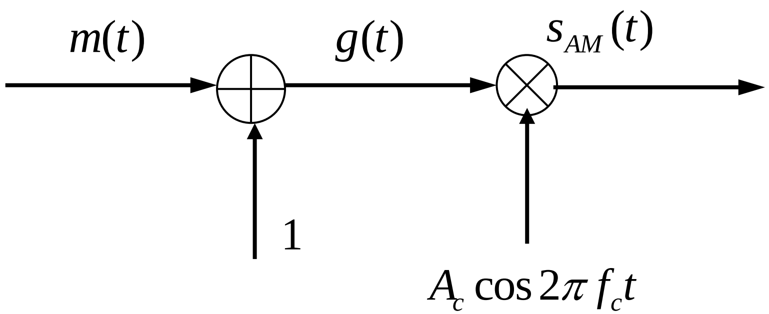
$$s_{\text{DSB}}(t) = A_c m(t)\cos 2\pi f_c t$$

$$S_{\text{DSB}}(f) = \frac{A_c}{2}\left[M(f - f_c) + M(f - f_c)\right]$$



2. 常规调幅调制（AM）

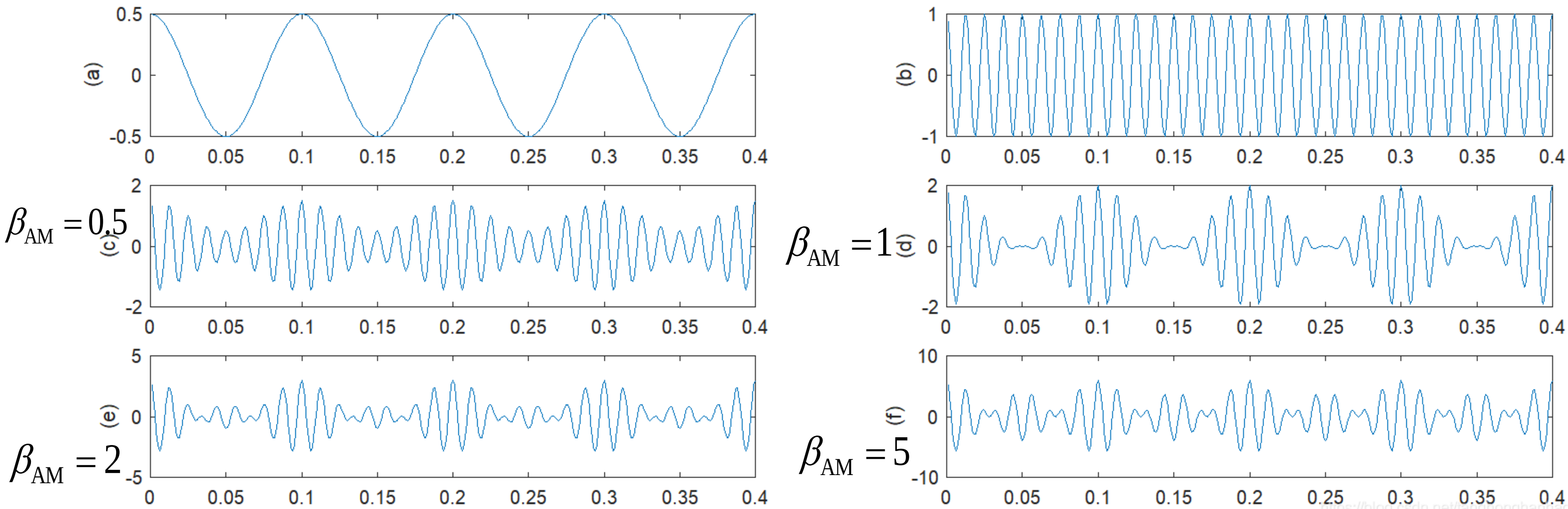
- 调制器



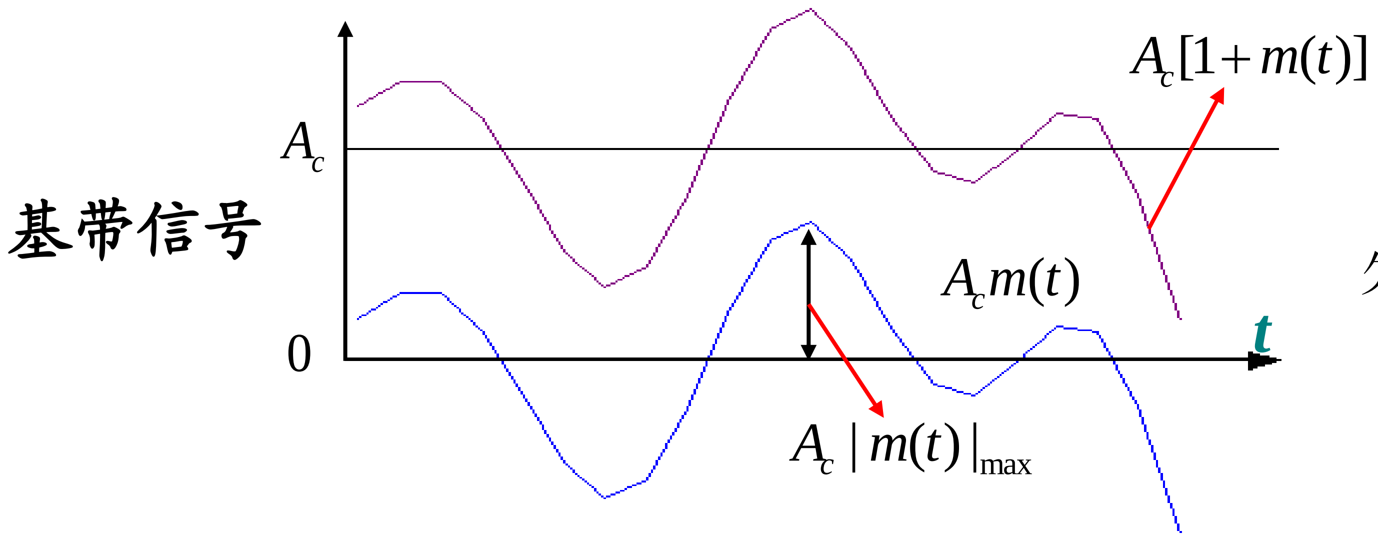
$$s_{AM}(t) = A_c[1 + m(t)]\cos 2\pi f_c t$$

调幅指数： $\boxed{\beta_{AM} = \max|m(t)|}$

AM信号波形

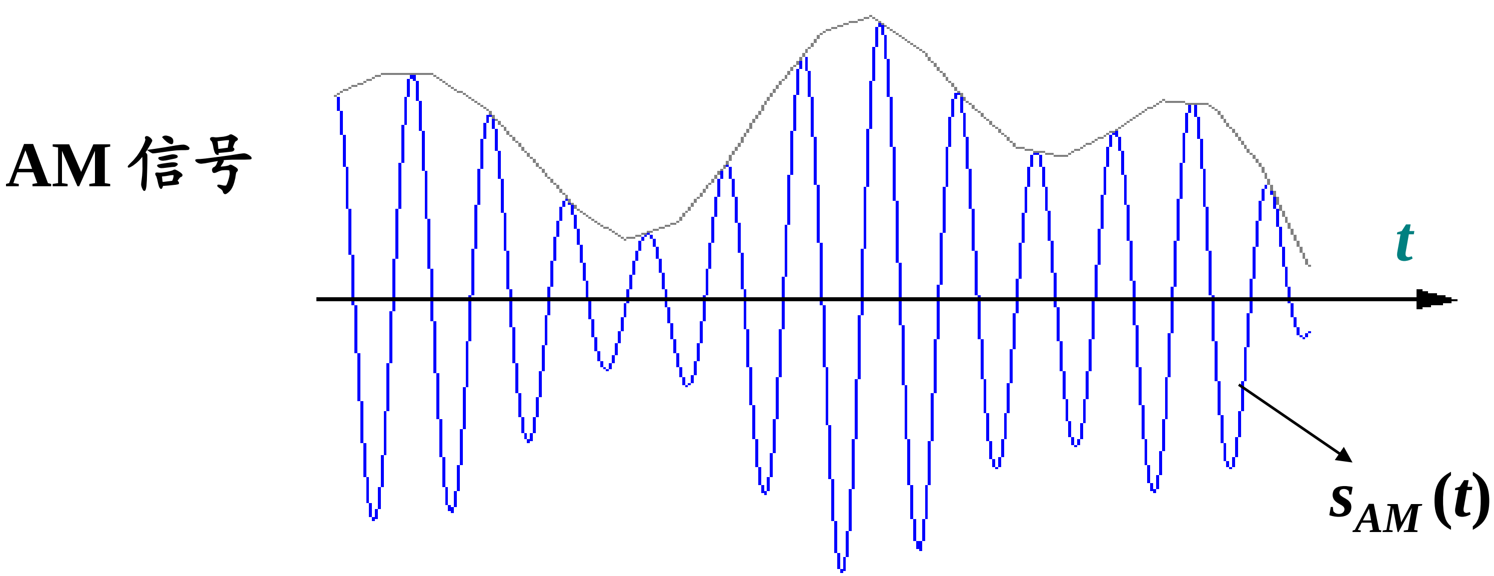

(a)
(b)
$\beta_{AM}=0.5$
(c)
$\beta_{AM}=1$
(d)
$\beta_{AM}=2$
(e)
$\beta_{AM}=5$
(f)
0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4

AM信号波形



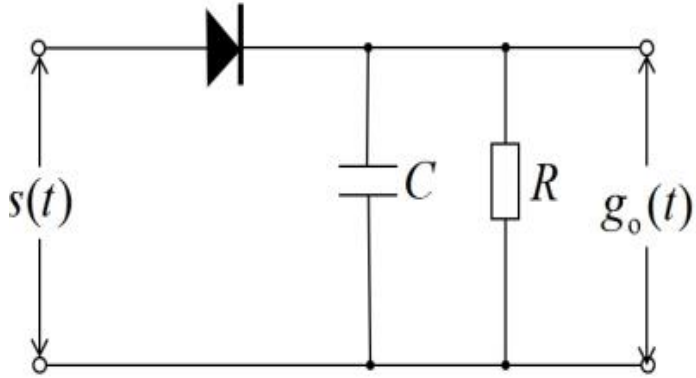
$\boxed{\beta_{AM} \le 1}$

欠调制与临界调制

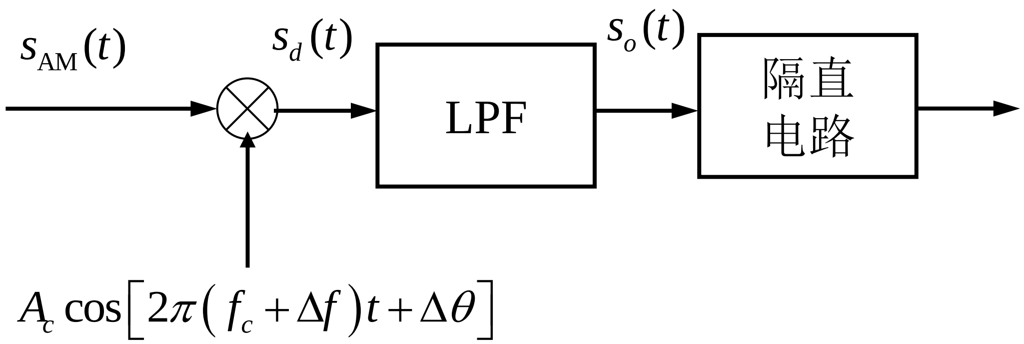


AM信号解调

包络检波



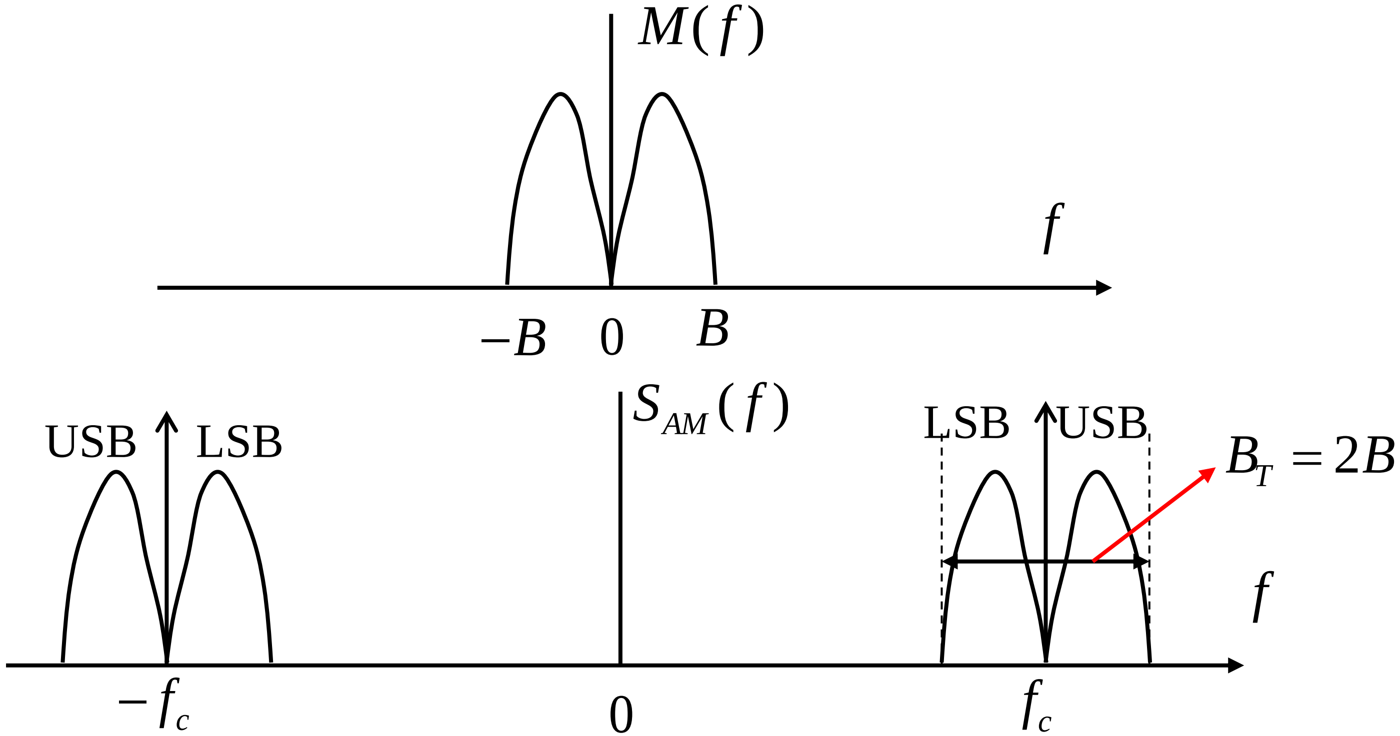
相干解调



AM信号的频谱

$$s_{\mathrm{AM}}(t) = A_c[1+m(t)]\cos 2\pi f_c t$$

$$S_{\mathrm{AM}}(f) = \frac{A_c}{2}[\delta(f-f_c)+\delta(f+f_c)] + \frac{A_c}{2}[M(f-f_c)+M(f-f_c)]$$



AM信号的功率

- 归一化平均功率

$$\overline{s_{AM}^2(t)} = \overline{A_c^2\left[1+m(t)\right]^2\cos^2 2\pi f_c t}$$

$$= \frac{1}{2}A_c^2\overline{\left[1+m(t)\right]^2} + \frac{1}{2}A_c^2\overline{\left[1+m(t)\right]^2\cos 4\pi f_c t}$$

$$= \underset{\substack{\text{discrete}\\ \text{carrier power}}}{\frac{1}{2}A_c^2} + \underbrace{\frac{1}{2}A_c^2\overline{m^2(t)}}_{\text{sideband power}}$$

$$\boxed{P_{AM} = P_c + P_m = \frac{1}{2}A_c^2 + \frac{A_c^2}{2}\overline{m^2(t)}}$$

- 调制效率

$$\eta_{AM} = \frac{P_m}{P_{AM}} = \frac{P_m}{P_c + P_m} = \frac{\overline{m^2(t)}}{1+\overline{m^2(t)}}$$

$$\boxed{\beta_{AM} \le 1 \;\Rightarrow\; \left\langle m^2(t)\right\rangle \le 1 \;\Rightarrow\; \eta_{AM} \le 50\%}$$

单音信号如何？

单选题 1分

设置

若基带信号为单音信号$m(t)=\cos 2\pi f_m t$，载波信号$c(t)=20\cos 2\pi f_c t$，其中$f_m=100$Hz，$f_c=10$kHz。则AM已调信号$s_{AM}(t)$的带宽、功率、调制效率分别为：

A 200Hz，300W，0.33

B 20kHz，100W，0.5

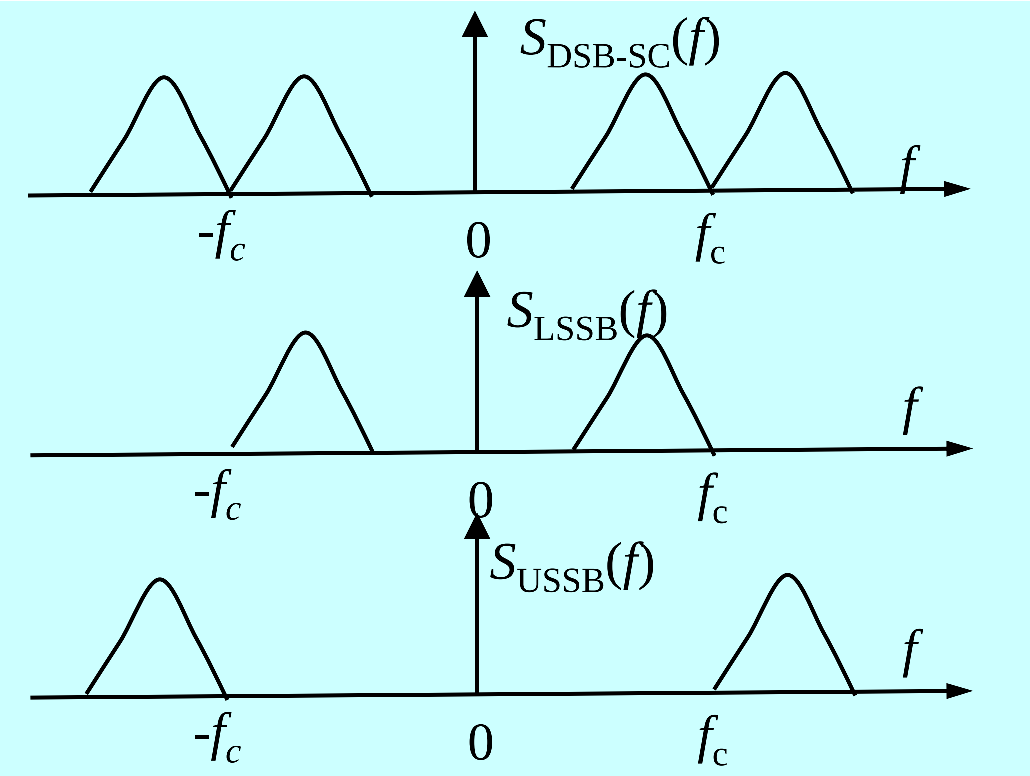
C 10kHz，200W，1

D 100Hz，400W，0.2

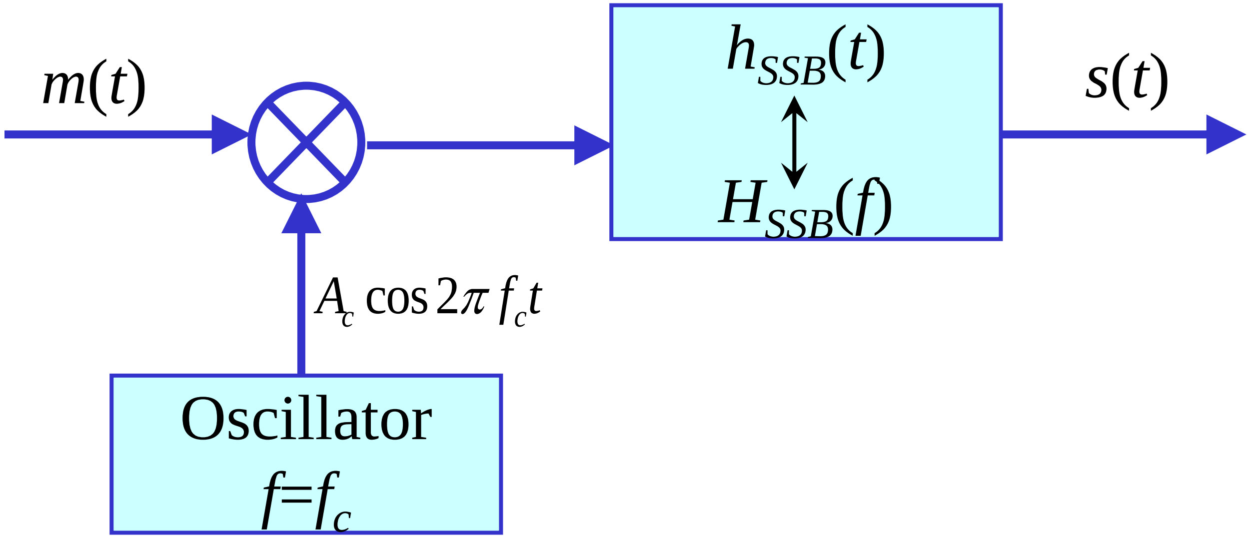
提交

3. 单边带(Single sideband, SSB)调制

- 上边带(***upper single sideband***, USSB)信号
- 下边带(***lower single sideband***, LSSB)信号



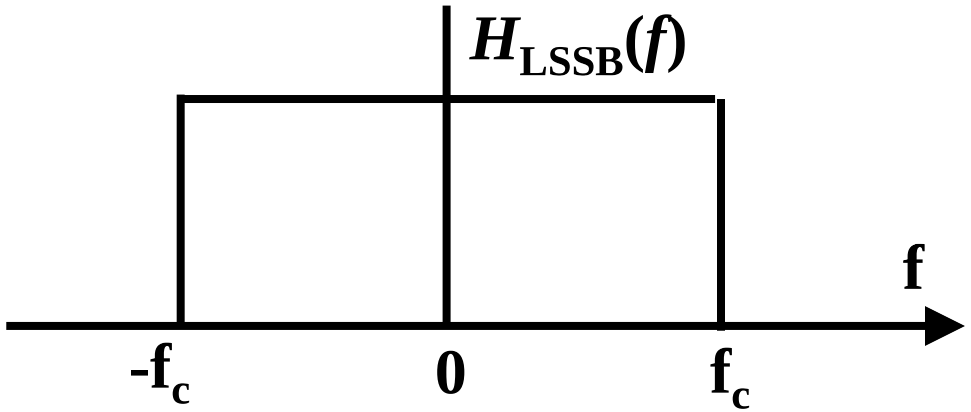
滤波法信号产生SSB信号



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

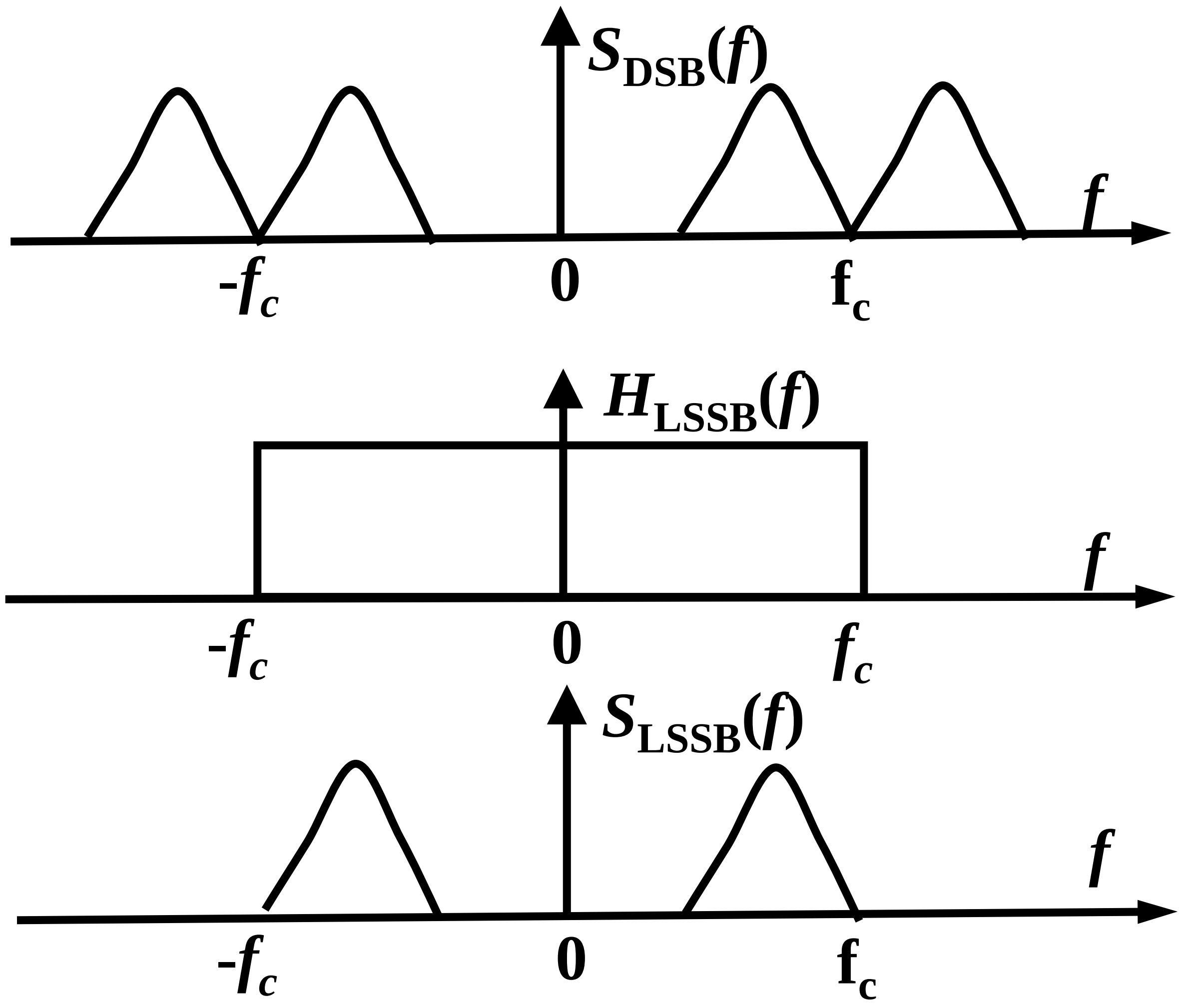
下边带滤波器

$$H_{LSSB}(f)=\begin{cases}1, & |f|<f_c\\ 0, & |f|\geq f_c\end{cases}$$



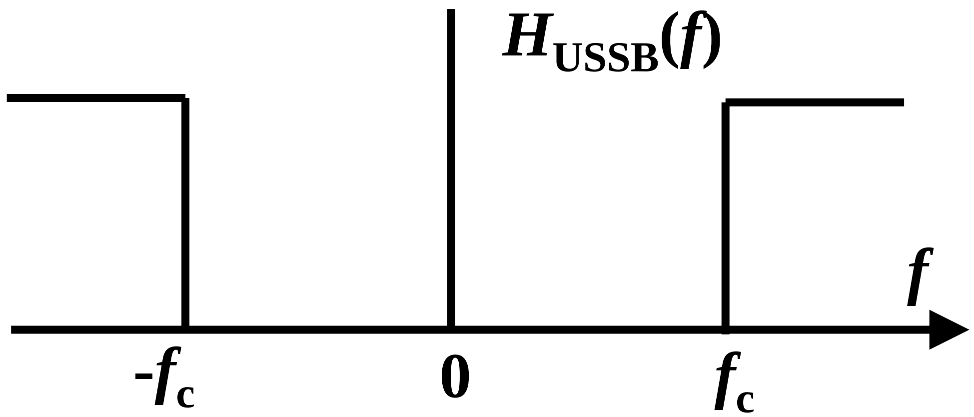
$$H_{LSSB}(f)=\frac{1}{2}[\mathrm{sgn}(f+f_c)-\mathrm{sgn}(f-f_c)]$$

滤波法信号产生LSSB信号



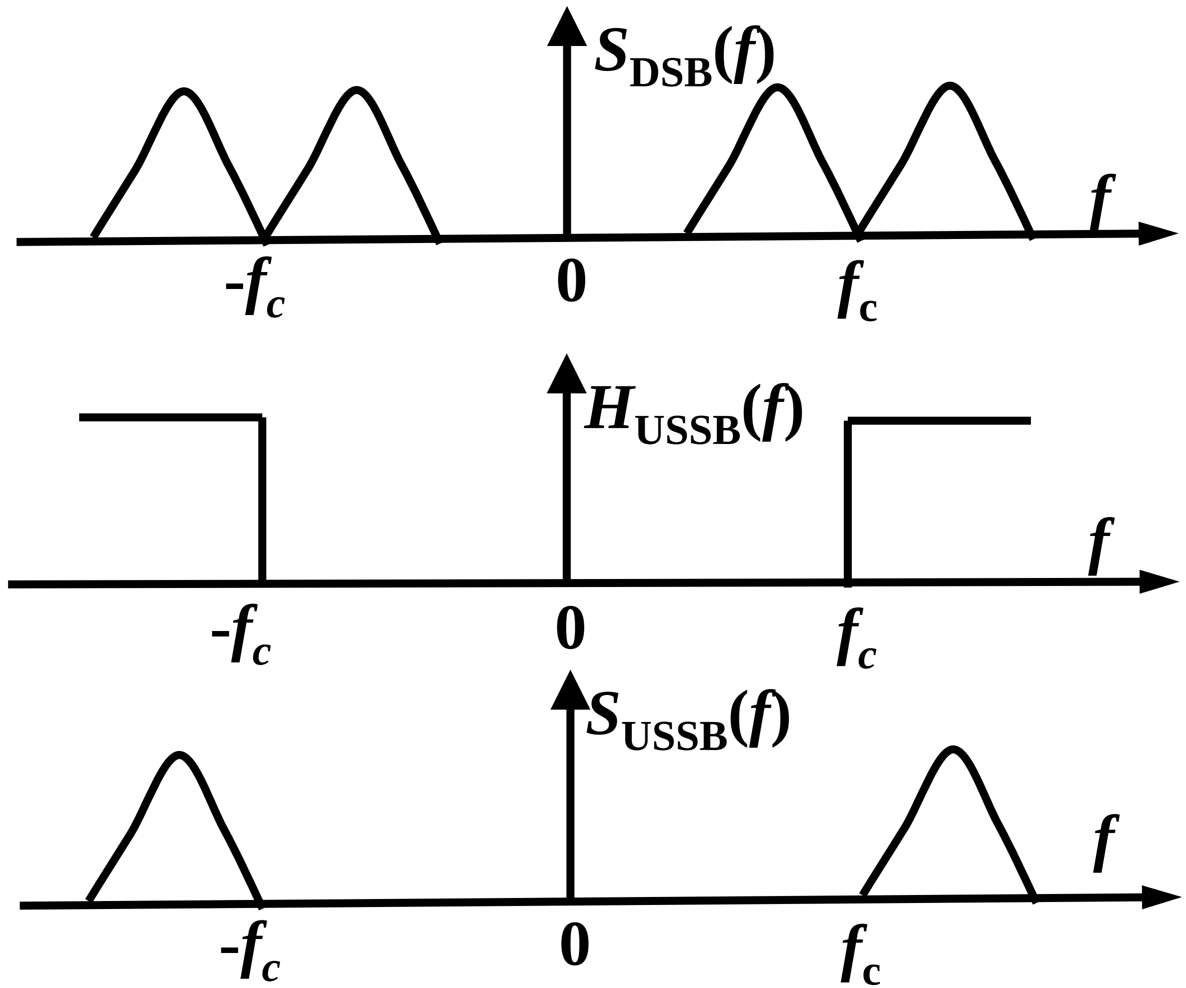
上边带滤波器

$$H_{USSB}(f)=\begin{cases}1, & |f|>f_c\\ 0, & |f|\le f_c\end{cases}$$



$$H_{USSB}(f)=1-H_{LSB}(f)$$

滤波法信号产生USSB信号



相移法产生LSSB信号

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

$$H_{LSB}(f)=\frac{1}{2}[\mathrm{sgn}(f+f_c)-\mathrm{sgn}(f-f_c)]$$

$$\begin{aligned}S_{LSSB}(f)&=\frac{1}{2}[M(f-f_c)+M(f+f_c)]H_{LSB}(f)\\&=\frac{1}{4}[M(f-f_c)+M(f+f_c)]\\&\quad+\frac{1}{4}[M(f+f_c)\cdot\mathrm{sgn}(f+f_c)-M(f-f_c)\cdot\mathrm{sgn}(f-f_c)]\end{aligned}$$

相移法产生LSSB信号

$$m(t)\cos 2\pi f_c t \leftrightarrow \frac{1}{2}[M(f-f_c)+M(f+f_c)]$$

$$\hat{m}(t)\sin 2\pi f_c t \leftrightarrow \frac{1}{2}[M(f+f_c)\cdot \text{sgn}(f+f_c)$$

$$-M(f-f_c)\cdot \text{sgn}(f-f_c)]$$

$$S_{LSSB}(t)=\frac{1}{2}[m(t)\cos 2\pi f_c t+\hat{m}(t)\sin 2\pi f_c t]$$

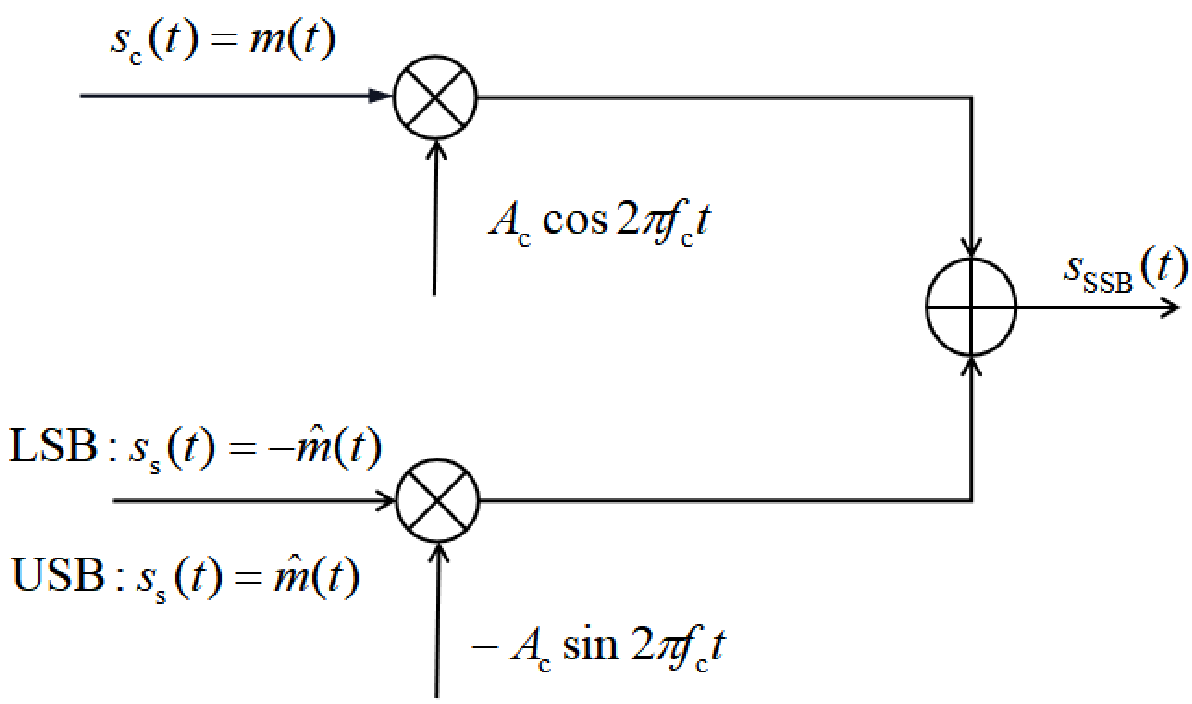
相移法产生USSB信号

$$H_{USSB}(f) = 1 - H_{LSSB}(f)$$

$$S_{USSB}(f) = S_{DSSB}(f)[1 - H_{LSSB}(f)] = S_{DSSB}(f) - S_{LSSB}(f)$$

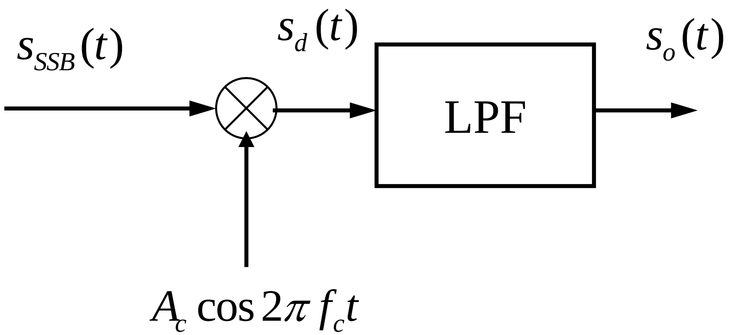
$$\begin{aligned} s_{USSB}(t) &= s_{DSSB}(t) - s_{LSSB}(t) \\ &= m(t)\cos 2\pi f_c t - \frac{1}{2}[m(t)\cos 2\pi f_c t + \hat{m}(t)\sin 2\pi f_c t] \\ &= \frac{1}{2}[m(t)\cos 2\pi f_c t - \hat{m}(t)\sin 2\pi f_c t] \end{aligned}$$

相移法模型



$s_c(t) = m(t)$
$A_c \cos 2\pi f_c t$
$s_{SSB}(t)$
LSB : $s_s(t) = -\hat{m}(t)$
USB : $s_s(t) = \hat{m}(t)$
$-A_c \sin 2\pi f_c t$

SSB信号相干解调



$$s_{SSB}(t) = \frac{A_c}{2} m(t) \cos 2\pi f_c t \mp \frac{A_c}{2} \hat{m}(t) \sin 2\pi f_c t$$

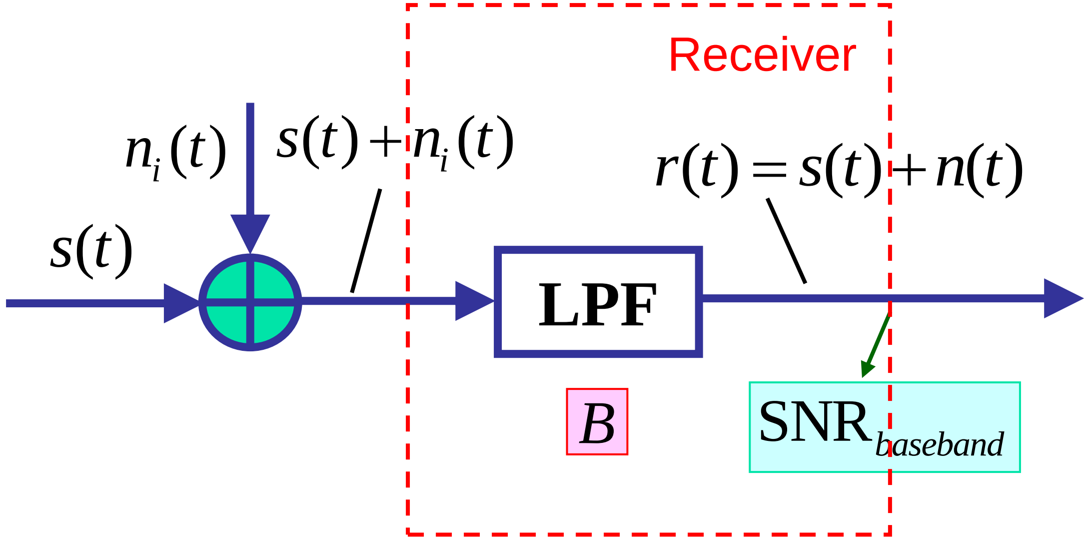
$$s_d(t) = \frac{A_c}{4} m(t) + \frac{A_c}{4} m(t) \cos 4\pi f_c t \mp \frac{A_c}{4} \hat{m}(t) \sin 4\pi f_c t$$

$$s_o(t) = \frac{A_c}{4} m(t)$$

4. 模拟幅度调制系统的抗噪声性能

4.1 基带模拟传输系统抗噪声性能分析模型
4.2 模拟调制系统抗噪声性能分析模型
4.3 带通AWGN
4.4 DSB-SC相干解调抗噪声性能
4.5 SSB相干解调抗噪声性能
4.6 AM相干解调抗噪声性能
4.7 抗噪声性能比较

4.1 基带模拟传输系统抗噪声性能分析模型



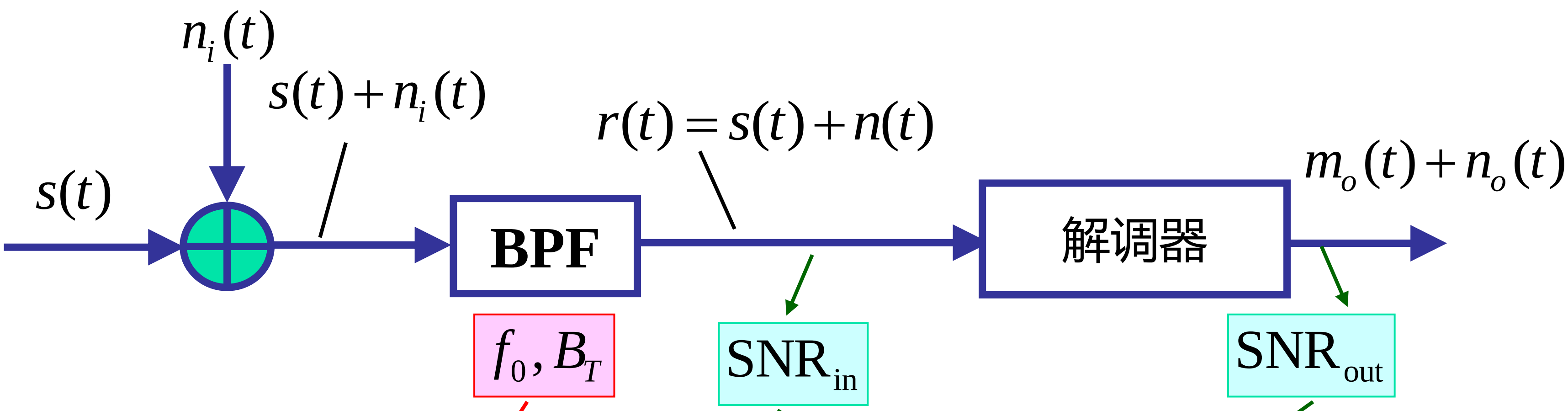
$$s(t)=m(t)$$

$$P_S=\overline{m^2(t)}=P_m$$

$$P_N=n_0B$$

$$\text{SNR}_{\text{baseband}}=\frac{P_S}{P_N}=\frac{P_m}{n_0B}$$

4.2 模拟调制系统抗噪声性能分析模型



$$B_T=\begin{cases}2B, & for\ AM\ and\ DSB-SC\\ B, & for\ SSB\end{cases}$$

$$G=\frac{\mathrm{SNR}_{\mathrm{out}}}{\mathrm{SNR}_{\mathrm{in}}}$$

4.3 带通AWGN

- 带通随机过程

$$n(t)=\mathrm{Re}\left\{\tilde{n}(t)e^{j2\pi f_c t}\right\}$$

- 基带随机过程（复包络）

$$\tilde{n}(t)=n_c(t)+jn_s(t)$$

- 带通随机过程表示

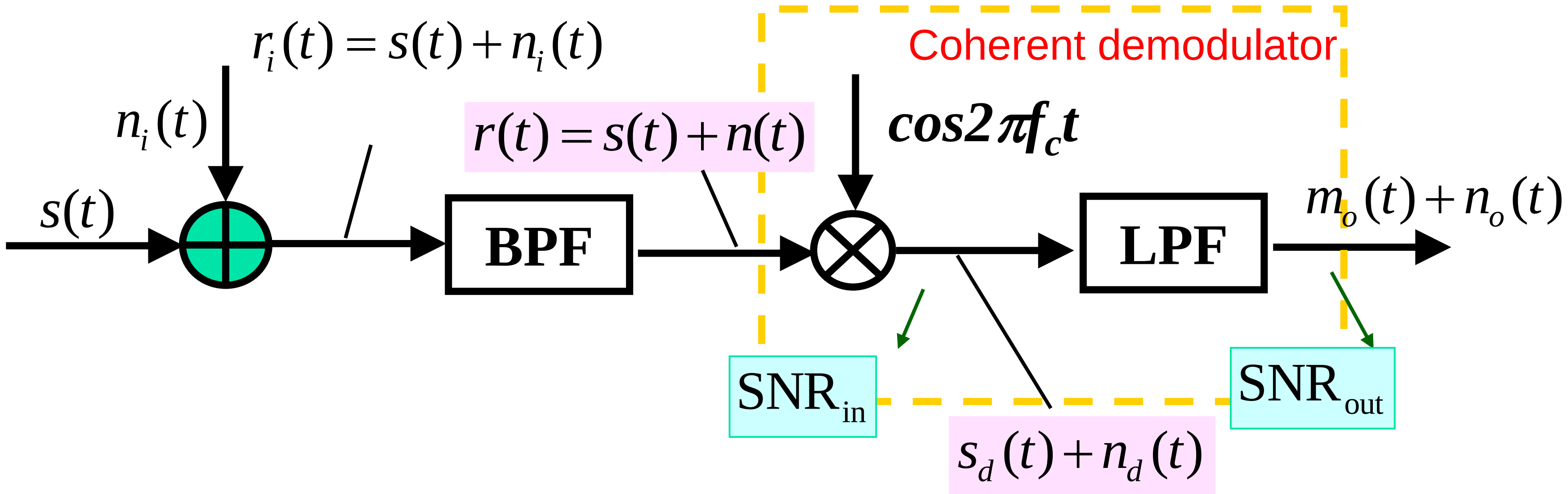
$$\begin{aligned}n(t)&=\mathrm{Re}\left\{\left[n_c(t)+jn_s(t)\right]\left[\cos 2\pi f_c t+j\sin 2\pi f_c t\right]\right\}\\&=n_c(t)\cos 2\pi f_c t-n_s(t)\sin 2\pi f_c t\end{aligned}$$

其中

$$E\left[n(t)\right]=E\left[n_c(t)\right]=E\left[n_s(t)\right]=0$$

$$E\left[n^2(t)\right]=E\left[n_c^2(t)\right]=E\left[n_s^2(t)\right]=\sigma_n^2$$

4.4 DSB-SC相干解调抗噪声性能



$$s(t)=A_c m(t)\cos 2\pi f_c t$$

$$s_d(t)=A_c m(t)\cos^2 2\pi f_c t$$

$$=\frac{A_c}{2}m(t)\left[1+\cos 4\pi f_c t\right]$$

$$s_o(t)=\frac{A_c}{2}m(t)$$

$$n(t)=n_c(t)\cos 2\pi f_c t-n_s(t)\sin 2\pi f_c t$$

$$n_d(t)=n_c(t)\cos^2 2\pi f_c t-n_s(t)\sin 2\pi f_c t\cos 2\pi f_c t$$

$$=\frac{1}{2}n_c(t)+\frac{1}{2}n_c(t)\cos 4\pi f_c t-\frac{1}{2}n_s(t)\sin 4\pi f_c t$$

$$n_o(t)=\frac{1}{2}n_c(t)$$

4.4 DSB-SC相干解调抗噪声性能

- Input SNR

$$S_{in} = \overline{s^2(t)} = \frac{A_c^2}{2}\overline{m^2(t)} = \frac{A_c^2 P_m}{2}$$

$$N_{in} = E\left[n^2(t)\right] = n_0 B_{DSB-SC} = 2n_0 B$$

$$where\ B\ is\ the\ bandwidth\ of\ \ m(t)$$

$$(S/N)_{in} = \frac{S_{in}}{N_{in}} = \frac{1}{2} \cdot \frac{A_c^2 P_m}{2n_0 B}$$

- Output SNR

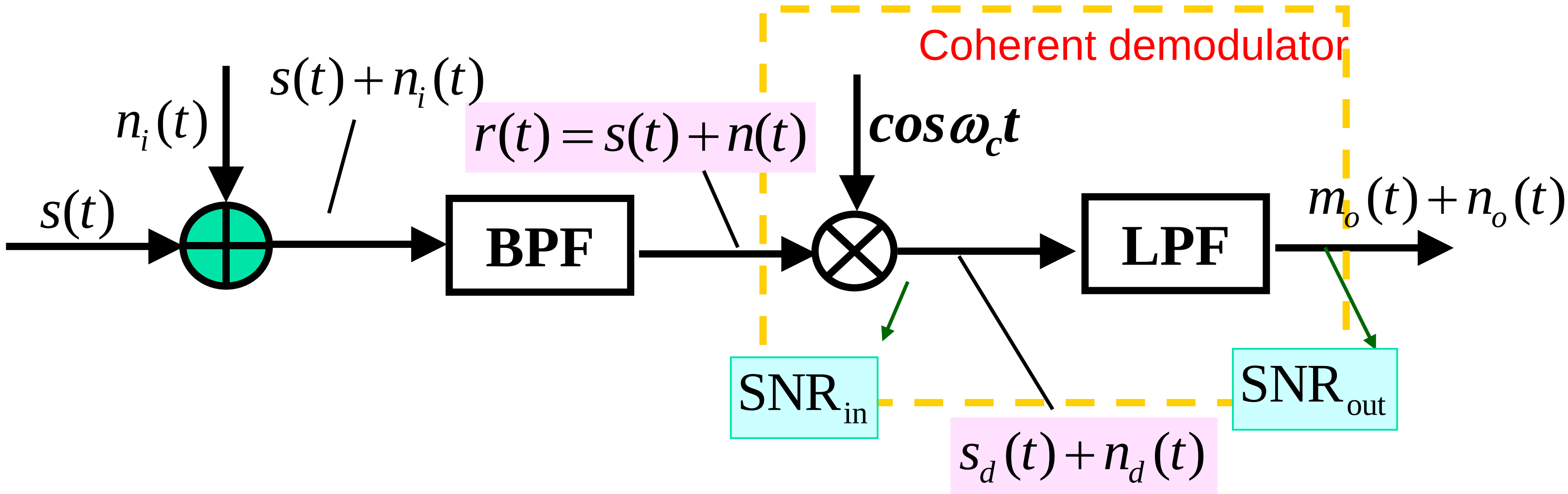
$$S_{out} = E\left[s_o^2(t)\right] = \frac{A_c^2 P_M}{4} = \frac{1}{2} S_{in}$$

$$N_{out} = E\left[n_o^2(t)\right] = \frac{1}{4} E\left[n_c^2(t)\right] = \frac{1}{4} N_{in}$$

$$(S/N)_{out} = \frac{S_{out}}{N_{out}} = 2\frac{S_{in}}{N_{in}} = \frac{A_c^2 P_m}{2n_0 B}$$

$$\boxed{G_{DSB-SC} = 2}$$

4.5 SSB相干解调抗噪声性能



$$s(t)=\frac{A_c}{2}m(t)\cos 2\pi f_c t \mp \frac{A_c}{2}\hat{m}(t)\sin 2\pi f_c t$$

$$s_d(t)=\frac{A_c}{4}m(t)+\frac{A_c}{4}m(t)\cos 4\pi f_c t \mp \frac{A_c}{4}\hat{m}(t)\sin 4\pi f_c t$$

$$s_o(t)=\frac{A_c}{4}m(t)$$

$$n(t)=n_c(t)\cos 2\pi f_c t - n_s(t)\sin 2\pi f_c t$$

$$n_d(t)=n_c(t)\cos^2 2\pi f_c t - n_s(t)\sin 2\pi f_c t\cos 2\pi f_c t$$

$$=\frac{1}{2}n_c(t)+\frac{1}{2}n_c(t)\cos 4\pi f_c t-\frac{1}{2}n_s(t)\sin 4\pi f_c t$$

$$n_o(t)=\frac{1}{2}n_c(t)$$

4.5 SSB相干解调抗噪声性能

- Input SNR

$$S_{in}=\left\langle s^2(t)\right\rangle=\frac{A_c^2\cdot P_m}{4}$$

$$N_{in}=E\left[n^2(t)\right]=n_0B_{SSB}=n_0B$$

B: $m(t)$的带宽

$$(S/N)_{in}=\frac{S_{in}}{N_{in}}=\frac{1}{4}\cdot\frac{A_c^2P_m}{n_0B}$$

- Output SNR

$$S_{out}=\left\langle s_o^2(t)\right\rangle=\frac{\left\langle m^2(t)\right\rangle}{16}=\frac{1}{4}S_{in}$$

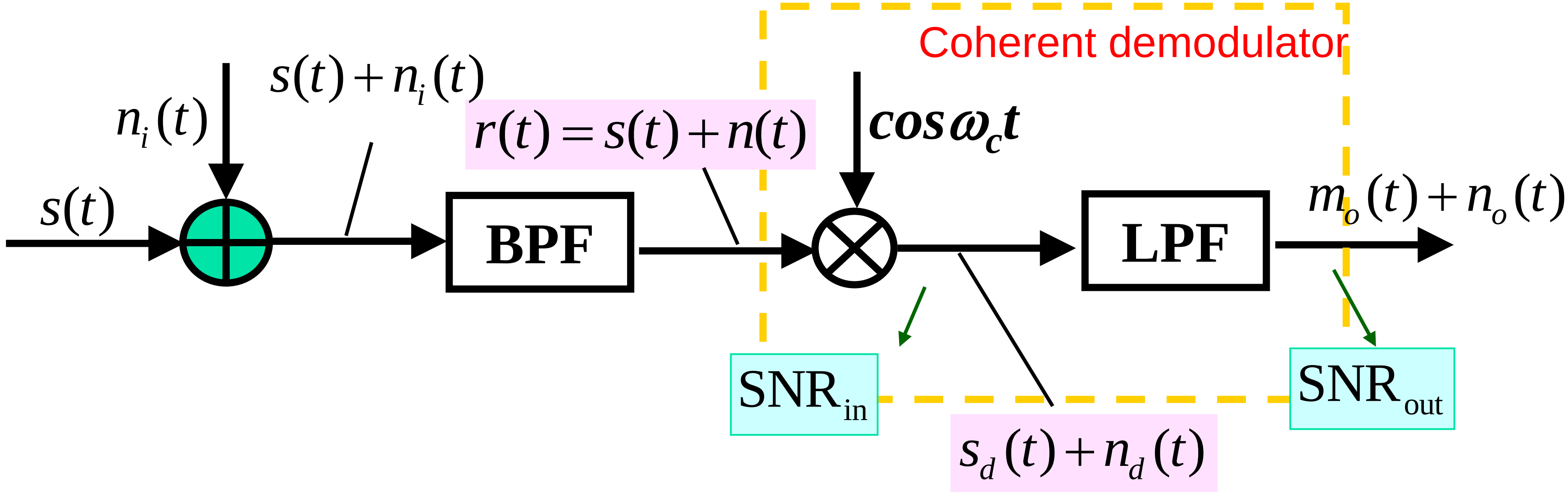
$$N_{out}=E\left[n_o^2(t)\right]=\frac{1}{4}E\left[n_c^2(t)\right]=\frac{1}{4}N_{in}$$

$$(S/N)_{out}=\frac{S_{out}}{N_{out}}=\frac{S_{in}}{N_{in}}=\frac{1}{4}\frac{A_c^2P_m}{n_0B}$$

$$\boxed{G_{SSB}=1}$$

However, the noise performance of SSB system is equivalent to DSB-SC system. Why?

4.6 AM相干解调抗噪声性能



$$s(t)=A_c\left[m(t)+1\right]\cos 2\pi f_c t$$

$$s_d(t)=\frac{1}{2}A_c\left[m(t)+1\right]\left[1+\cos 4\pi f_c t\right]$$

$$s_o(t)=\frac{1}{2}A_c m(t)$$

$$n(t)=n_c(t)\cos 2\pi f_c t-n_s(t)\sin 2\pi f_c t$$

$$n_d(t)=n_c(t)\cos^2 2\pi f_c t-n_s(t)\sin 2\pi f_c t\cos 2\pi f_c t$$

$$=\frac{1}{2}n_c(t)+\frac{1}{2}n_c(t)\cos 4\pi f_c t-\frac{1}{2}n_s(t)\sin 4\pi f_c t$$

$$n_o(t)=\frac{1}{2}n_c(t)$$

4.6 AM相干解调抗噪声性能

- Input SNR

$$S_{in} = \langle s^2(t) \rangle = \frac{A_c^2}{2}[1+P_m]$$

$$N_{in} = E\left[n^2(t)\right] = n_0 B_{AM} = 2n_0 B$$

where B is the bandwidth of m(t)

$$(S/N)_{in} = \frac{S_{in}}{N_{in}} = \frac{\frac{A_c^2}{2}[1+P_m]}{2n_0 B}$$

- Output SNR

$$S_{out} = \langle s_o^2(t) \rangle = \frac{A_c^2 P_m}{4}$$

$$N_{out} = E\left[n_o^2(t)\right] = \frac{1}{4} E\left[n_c^2(t)\right] = \frac{1}{4} N_{in}$$

$$(S/N)_{out} = \frac{S_{out}}{N_{out}} = \frac{A_c^2 P_M}{2n_0 B}$$

$$\boxed{G_{AM} = \frac{2P_M}{1+P_M}}$$

4.7 抗噪声性能比较

	$s(t)$	BW	S_{in}	$(SNR)_{in}$	$(SNR)_{out}$	G
Baseband	$\frac{\sqrt{2}}{2}A_c m(t)$	B	$\frac{1}{2}A_c^2\overline{m^2}$	$\frac{A_c^2 P_M}{2n_0 B}$	$\frac{A_c^2 P_M}{2n_0 B}$	1
DSB-SC	$A_c m(t)\cos\omega_c t$	$2B$	$\frac{1}{2}A_c^2\overline{m^2}$	$\frac{1}{2}\cdot\frac{A_c^2 P_M}{2n_0 B}$	$\frac{A_c^2 P_M}{2n_0 B}$	2
SSB	$\frac{\sqrt{2}}{2}A_c\left[m(t)\cos\omega_c t + \hat{m}(t)\sin\omega_c t\right]$	B	$\frac{1}{2}A_c^2\overline{m^2}$	$\frac{A_c^2 P_M}{2n_0 B}$	$\frac{A_c^2 P_M}{2n_0 B}$	1
AM (coherent Detection, 100% sinewave modulation)	$A_c\left[1+m(t)\right]\cos\omega_c t$	$2B$	$\frac{1}{2}A_c^2\left(1+\overline{m^2}\right)$	$\frac{\frac{1}{2}A_c^2(1+P_M)}{2n_0 B}$	$\frac{A_c^2 P_M}{2n_0 B}$	$\frac{2P_M}{1+P_M}$

多选题 1分

设置

若基带信号m(t)带宽为B，AWGN单边功率谱密度N_0相等，解调器输出信噪比相等，下列说法中正确的是

A AM调制时发送信号功率最大

B SSB与DSB发送信号功率相等

C SSB与DSB解调器输入信噪比相等

D 基带传输接收滤波器带宽最小为B

提交