Double Side Band Suppressed Carrier (DSBSC)

- Power in a AM signal is given by $$\langle s^2(t)\rangle = \underbrace{\frac{1}{2}A_c^2}_{\text{Carrier Power}} + \underbrace{\frac{1}{2}A_c^2\langle m^2(t)\rangle}_{\text{Sideband power}}$$

➢ DSBSC is obtained by eliminating carrier component

If ***m*(*t*)** is assumed to have a zero DC level, then

$$\boxed{s(t) = A_c m(t)\cos\omega_c t}$$

Spectrum ➔ $$S(f) = \frac{A_c}{2}[M(f-f_c)+M(f+f_c)]$$

Power ➔ $$\langle s^2(t)\rangle = \frac{1}{2}A_c^2\langle m^2(t)\rangle$$

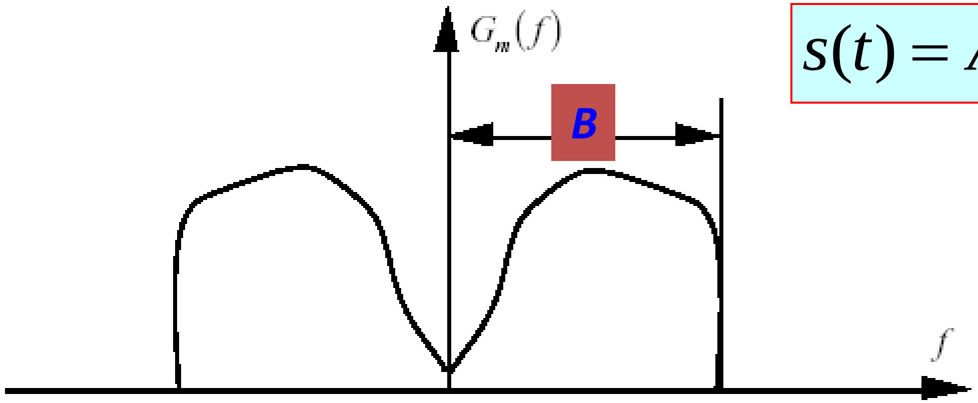
Modulation Efficiency ➔ $$E = \frac{\langle m^2(t)\rangle}{\langle m^2(t)\rangle}\times 100 = 100\%$$

Disadvantages of DSBSC:

- Less information about the carrier will be delivered to the receiver.
- Needs a coherent carrier detector at receiver

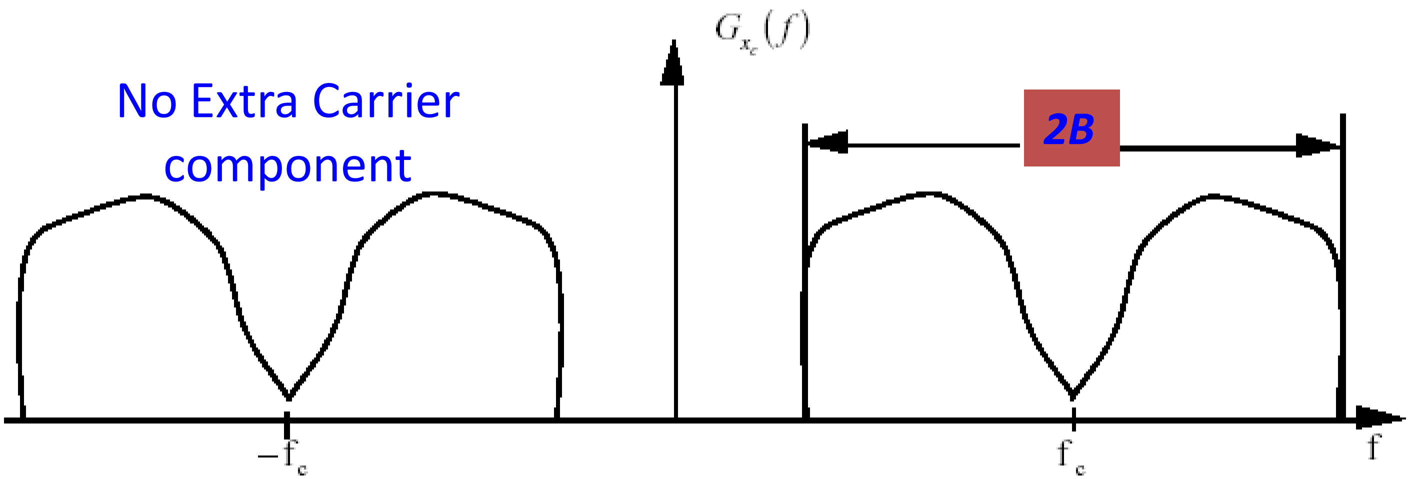
DSBSC Modulation

$$s(t) = A_c m(t) \cos \omega_c t$$



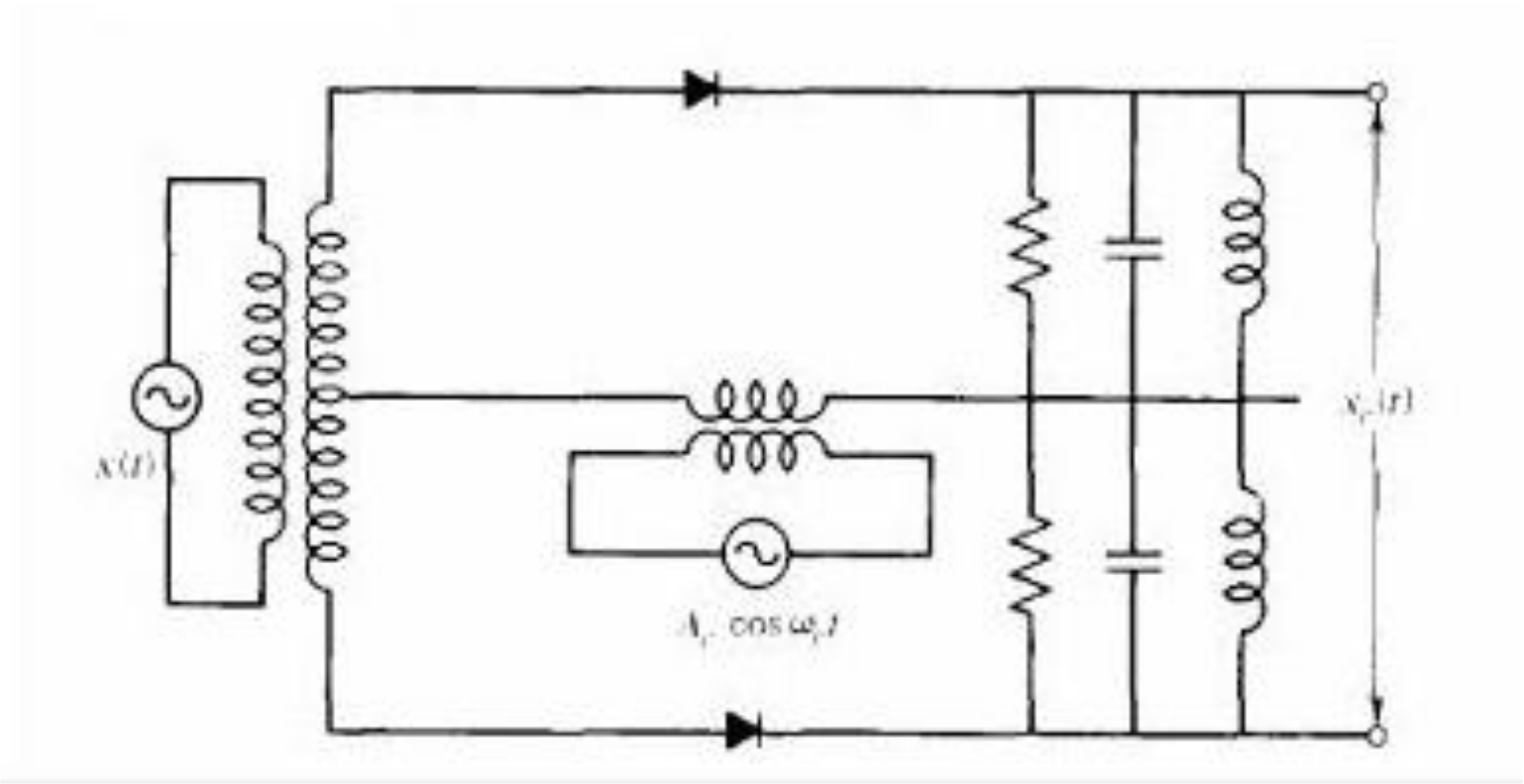
An Example of message energy spectral density.

No Extra Carrier component

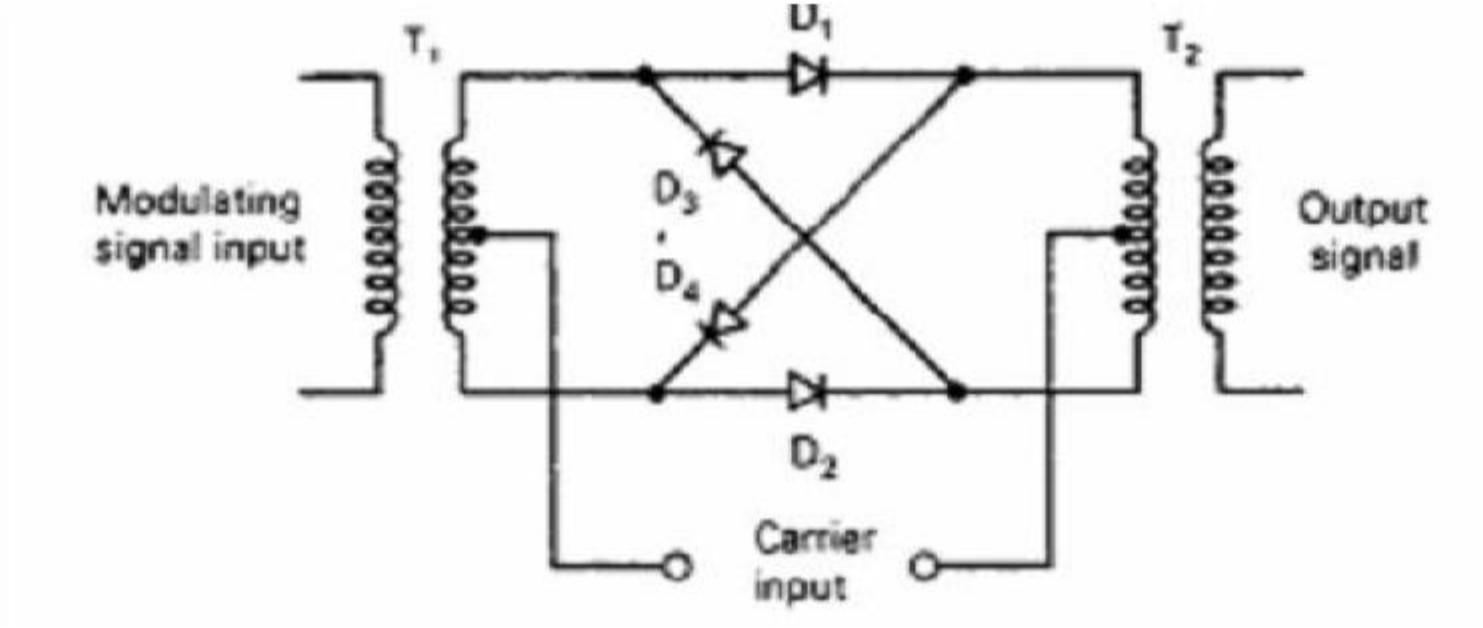


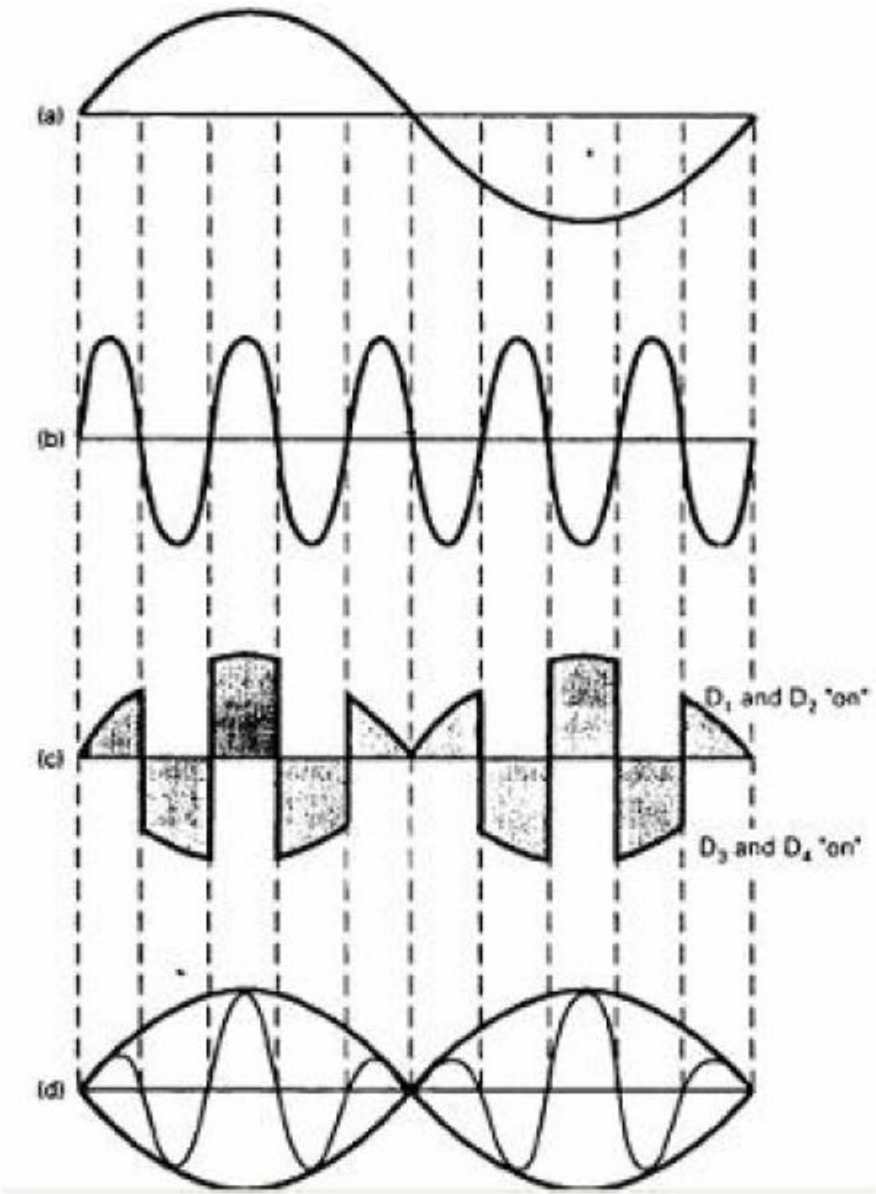
Energy spectrum of the DSBSC modulated message signal.

DSBSC Generation using Balanced Modulator



DSBSC Generation using Ring Modulator



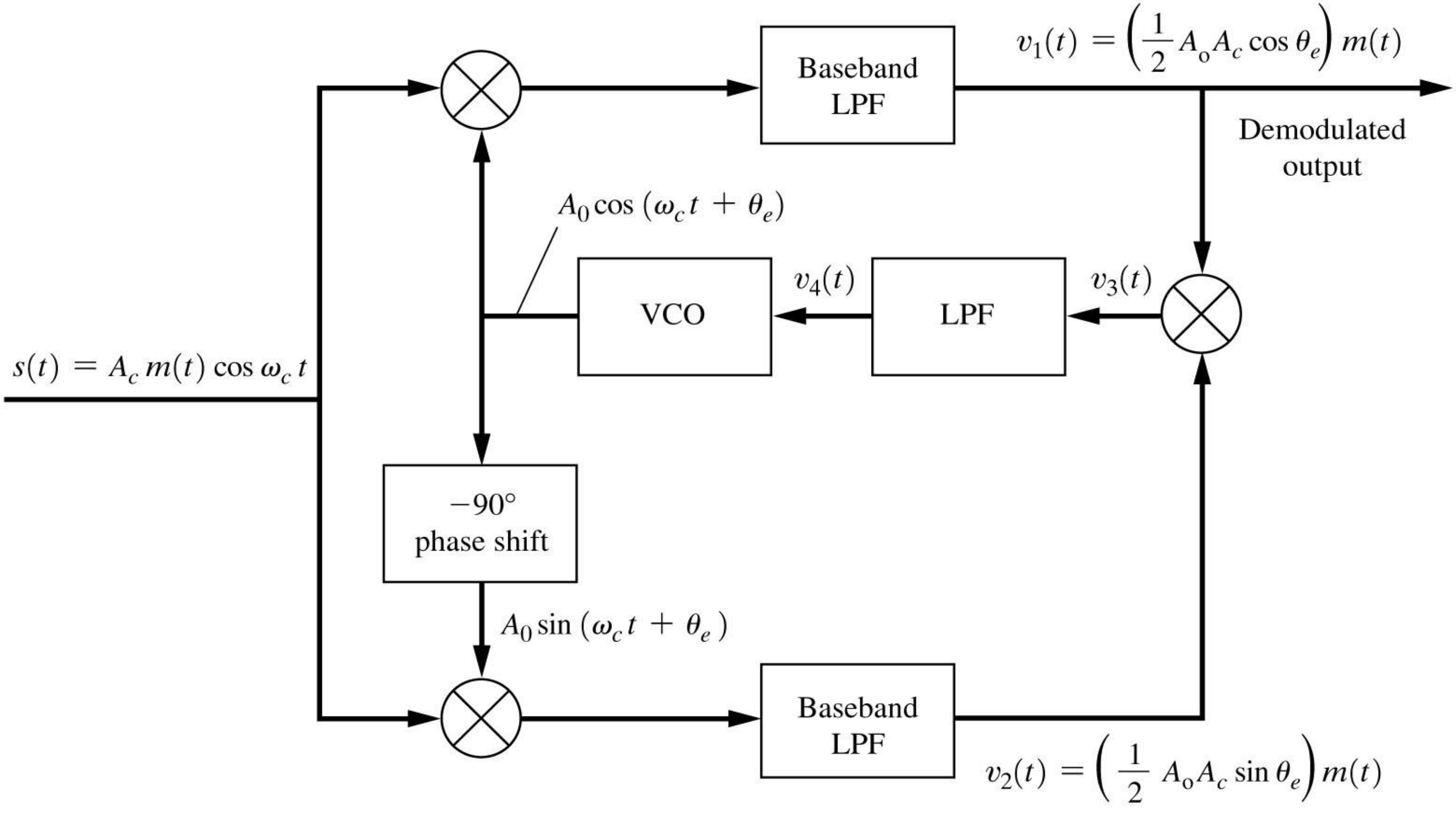

(a)
(b)
(c)
D₁ and D₂ "on"
D₃ and D₄ "on"
(d)

DSBSC Demodulation

- Synchronous Detection
- Envelope Detection after suitable carrier reinsertion

Carrier Recovery for DSBSC Demodulation

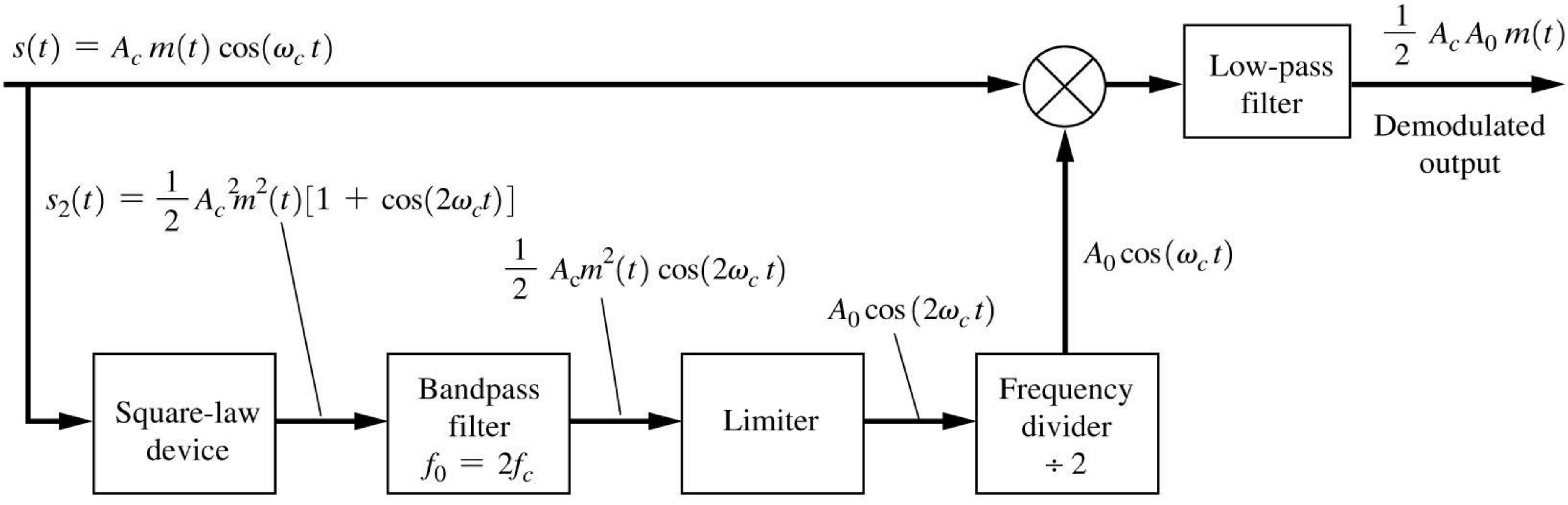
- Coherent reference for product detection of DSBSC can not be obtained by the use of ordinary PLL because there are no spectral line components at f_c.



(a) Costas Phase-Locked Loop

Carrier Recovery for DSBSC Demodulation

- A squaring loop can also be used to obtain coherent reference carrier for product detection of DSBSC. A frequency divider is needed to bring the double carrier frequency to f_c.

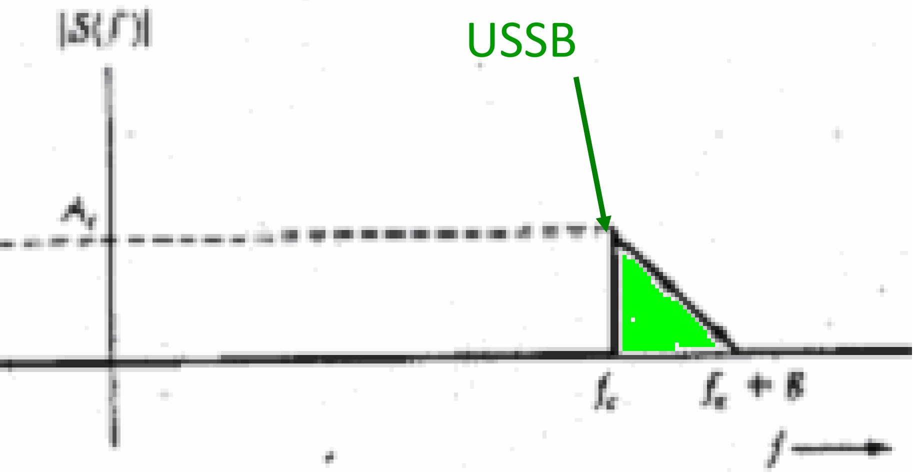


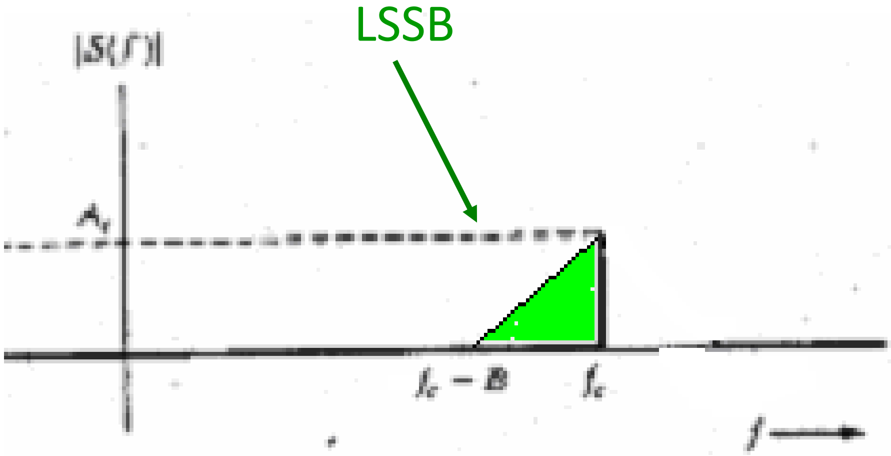
(b) Squaring Loop

Single Sideband (SSB) Modulation

- An **upper single sideband** (USSB) signal has a zero-valued spectrum for $|f| < f_c$
- A **lower single sideband** (LSSB) signal has a zero-valued spectrum for $|f| > f_c$
- **SSB-AM** – popular method ~ **BW** is *same* as that of the modulating signal.

Note: Normally SSB refers to SSB-AM type of signal


USSB


LSSB

Single Sideband Signal

- **Theorem :** A SSB signal has **Complex Envelope** and bandpass form as:

$$\boxed{g(t) = A_c\left[m(t) \pm j\hat{m}(t)\right]}$$

$$\boxed{s(t) = A_c\left[m(t)\ \cos\omega_c t\ \mp\ \hat{m}(t)\ \sin\omega_c t\right]}$$

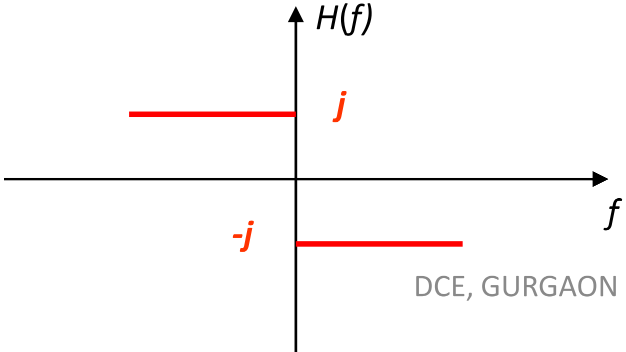
Upper sign (**-**) → USSB

Lower sign (**+**) → LSSB

$\hat{m}(t)$ – **Hilbert transform** of *m(t)* → $\hat{m}(t) \equiv m(t) * h(t)$ Where $h(t) = \dfrac{1}{\pi t}$

$$H(f) = \Im[h(t)] \quad \text{and} \quad H(f) = \begin{cases} -j, & f > 0 \\ j, & f < 0 \end{cases}$$

Hilbert Transform corresponds to a -90^0 phase shift



Single Sideband Signal

Proof: **Fourier transform of the complex envelope**

$$G(f) = A_c\left\{M(f) \pm j\Im\left[\hat{m}(t)\right]\right\} = A_c\left\{M(f) \pm j\hat{M}(f)\right\}$$

Upper sign → USSB
Lower sign → LSSB

Using $$\hat{m}(t) \equiv m(t) * h(t) \qquad \Rightarrow G(f) = A_c M(f)\left[1 \pm jH(f)\right]$$

$$G(f) = \begin{cases} 2A_c M(f), & f > 0 \\ 0, & f < 0 \end{cases}$$

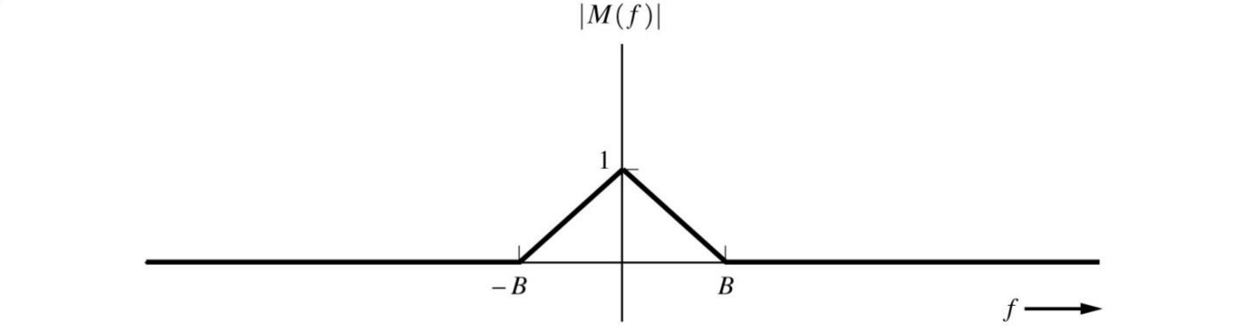
Recall $$V(f) = \frac{1}{2}\{G(f - f_c) + G^*[-(f + f_c)]\}$$

$$S(f) = A_c\begin{cases} M(f - f_c), & f > f_c \\ 0, & f < f_c \end{cases} + A_c\begin{cases} 0, & f > -f_c \\ M(f + f_c), & f < -f_c \end{cases}$$

Upper sign → USSB

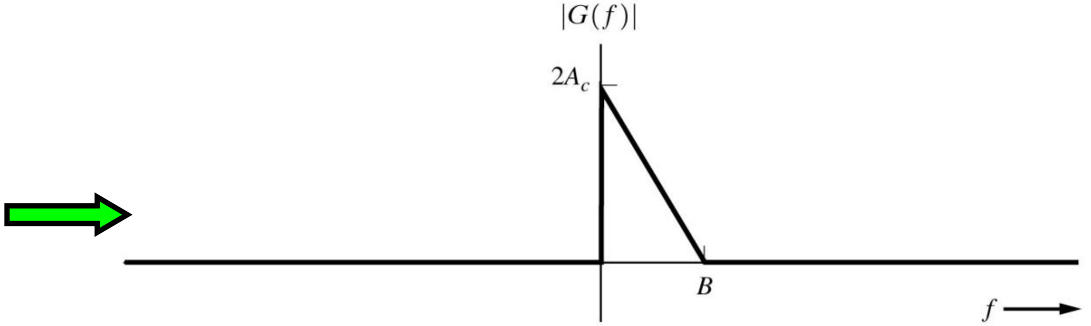
If **lower signs** were used → **LSSB** signal would have been obtained

Single Sideband Signal



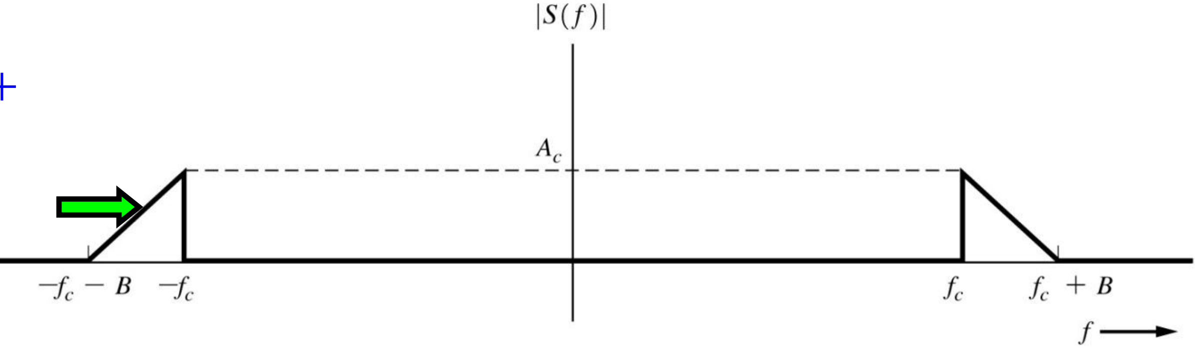
(a) Baseband Magnitude Spectrum

$$G(f)=\begin{cases}2A_cM(f), & f>0\\ 0, & f<0\end{cases}$$



(b) Magnitude of Corresponding Spectrum of the Complex Envelope for USSB

$$S(f)=A_c\begin{cases}M(f-f_c), & f>f_c\\ 0, & f<f_c\end{cases}+$$
$$A_c\begin{cases}0, & f>-f_c\\ M(f+f_c), & f<-f_c\end{cases}$$



(c) Magnitude of Corresponding Spectrum of the USSB Signal

SSB - Power

The **normalized average power** of the SSB signal

$$\langle s^2(t)\rangle = \frac{1}{2}\langle |g(t)|^2\rangle = \frac{1}{2}A_c^2\langle m^2(t)+[\hat{m}(t)]^2\rangle$$

Hilbert transform does not change power.

$$\langle \hat{m}(t)^2\rangle = \langle m^2(t)\rangle$$

SSB **signal power** is:

$$\langle s^2(t)\rangle = A_c^2\langle m^2(t)\rangle$$

Power gain factor

Power of the modulating signal

The **normalized peak envelope (PEP) power** is:

$$\frac{1}{2}\max\langle |g(t)|^2\rangle = \frac{1}{2}A_c^2\langle m^2(t)+[\hat{m}(t)]^2\rangle$$

Generation of SSB

SSB signals have *both* **AM** and **PM**.

The **complex envelope** of SSB: $g(t) = A_c[m(t) \pm j\hat{m}(t)]$

For the **AM** component, $R(t) = |g(t)| = A_c\sqrt{m^2(t) + [\hat{m}(t)]^2}$

For the **PM** component, $\theta(t) = \angle g(t) = \tan^{-1}\left[\frac{\pm\hat{m}(t)}{m(t)}\right]$

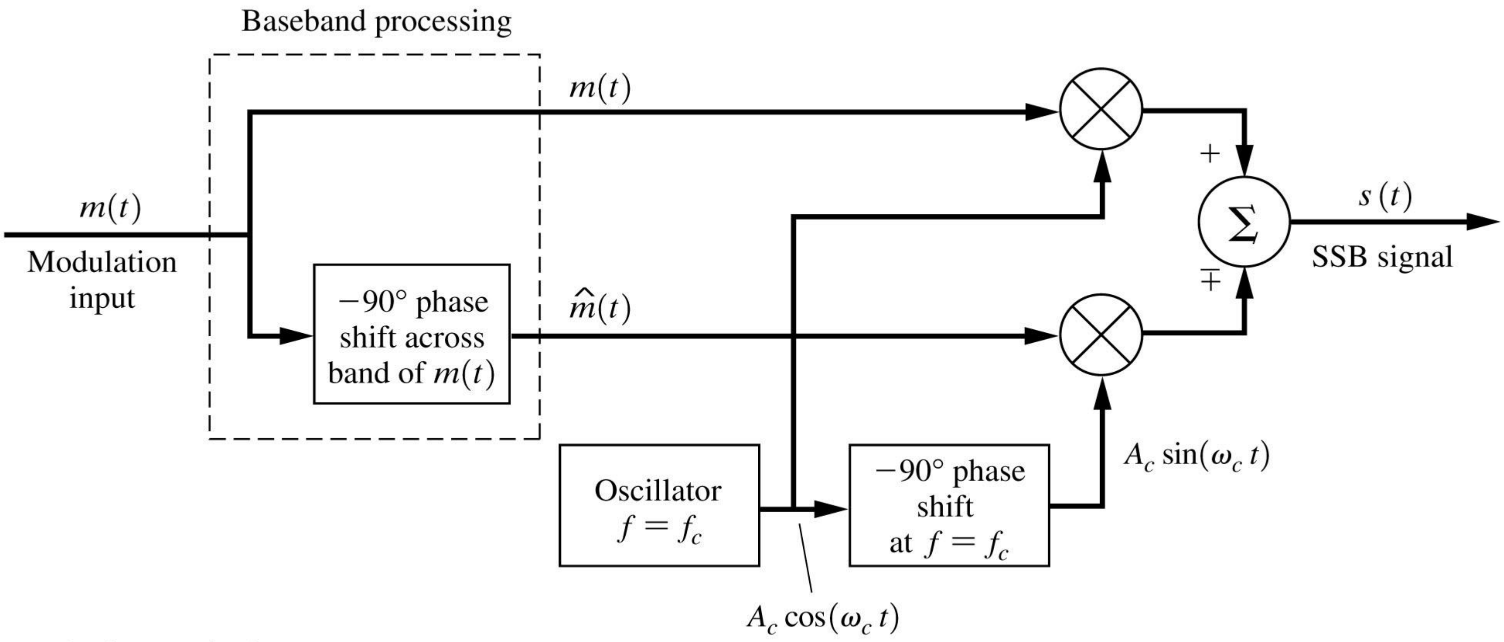
Advantages of SSB

- Superior detected signal-to-noise ratio compared to that of AM
- SSB has one-half the bandwidth of AM or DSB-SC signals

Generation of SSB

- SSB Can be generated using two techniques
  1. Phasing method
  2. Filter Method
- Phasing method $g(t) = A_c\left[m(t) \pm j\hat{m}(t)\right]$

This method is a special modulation type of IQ canonical form of Generalized transmitters discussed in Chapter 4 (Fig 4.28)

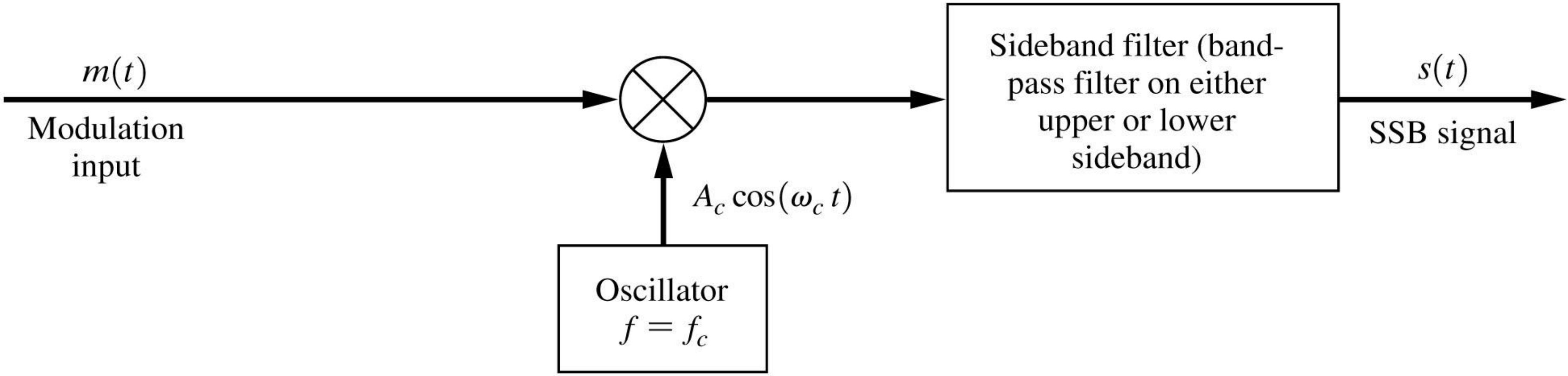


(a) Phasing Method

Generation of SSB

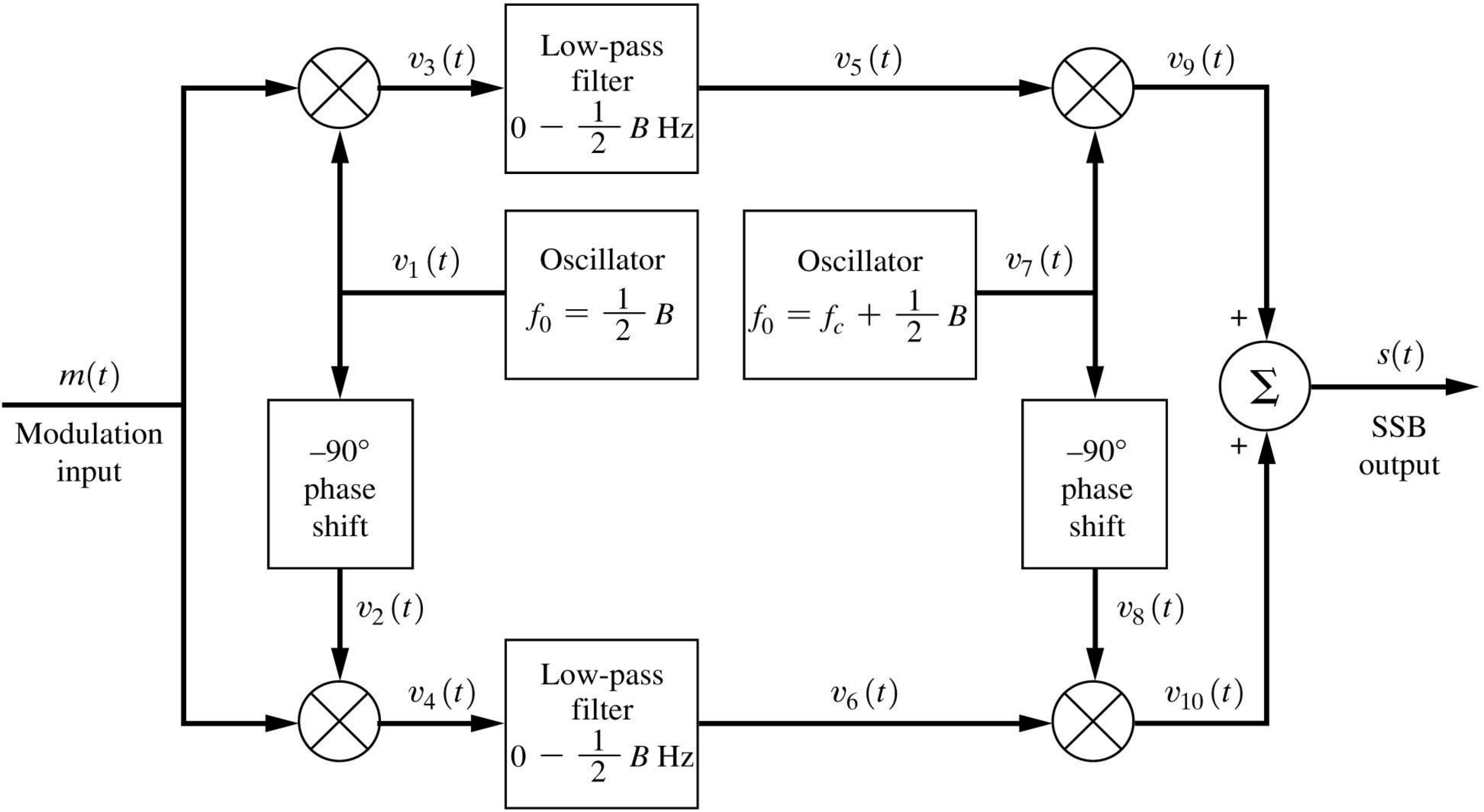
- **Filter Method**

The filtering method is a special case in which RF processing (with a sideband filter) is used to form the equivalent *g(t)*, instead of using baseband processing to generate *g(m)* directly. The filter method is the most popular method because excellent sideband suppression can be obtained when a crystal oscillator is used for the sideband filter. Crystal filters are relatively inexpensive when produced in quantity at standard IF frequencies.

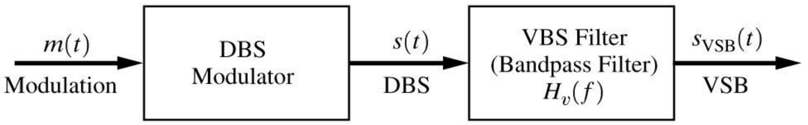


(b) Filter Method

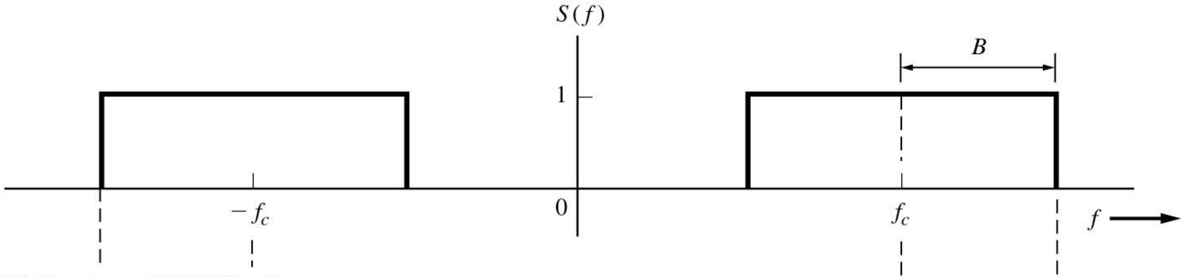
Weaver's Method for Generating SSB.



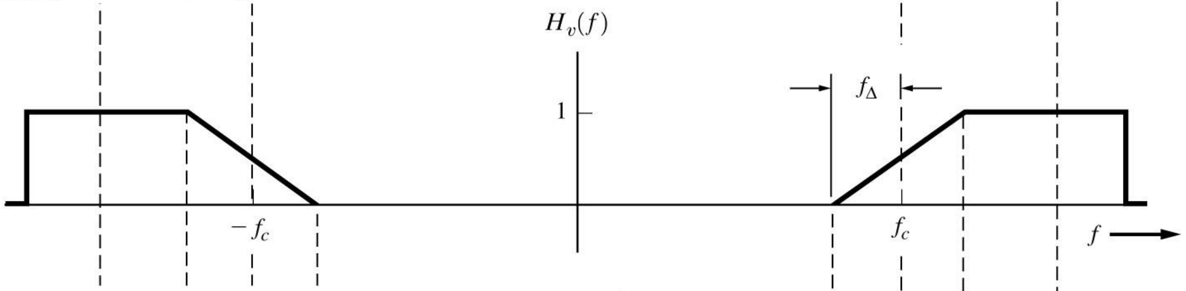
Generation of VSB



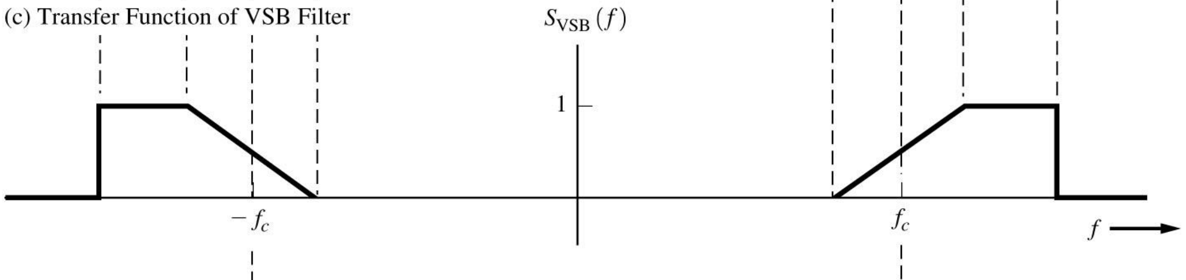
(a) Generation of VSB Signal



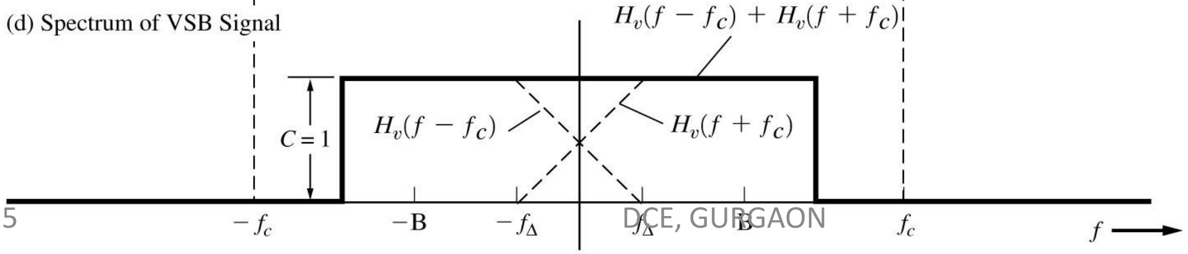
(b) Spectrum of DSB Signal



(c) Transfer Function of VSB Filter



(d) Spectrum of VSB Signal



(e) VSB Filter Constraint