MODULASYON

Bir bilgi sinyalinin, yayılım ortamında iletilebilmesi için başka bir taşıyıcı sinyal üzerine aktarılması olayına "modülasyon" adı verilir.

Genelde orijinal sinyal taşıyıcının genlik, faz veya frekansına modüle edilir.

Taşıyıcı İşaret
(carrier)

Mesaj (Bilgi) Kaynağı

Modulasyon

Verici

Alıcı

Demodulasyon

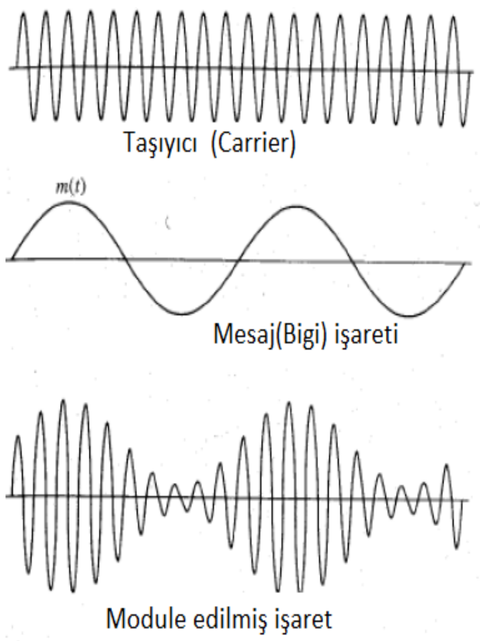
Mesajın Değerlendirilmesi

Mesaj İşareti
message signal

Module edilmiş işaret

Mesaj İşareti

Örnek olarak genlık modulasyonunda taşıyıcının genlıği mesaj işaretinin genliğine göre değiştirilir.



1.1.4. Modülasyon

Genel olarak modülasyon, bilgiyi iletilebilecek bir seviyeye çıkarma işlemi olarak tanımlanır. Bu işlem için çoğunlukla düşük frekanslı bilgi sinyalini yüksek frekanslı bir sinyale bindirilmesi ile yapılır. Anlamlı bir bilgi (ses, görüntü, renk veya veri) taşıyan düşük frekanslı sinyale bilgi sinyali ya da mesaj sinyali (fm) olarak adlandırılır. Bilgi sinyaline göre bir veya daha fazla parametresi değiştirilen yüksek frekanslı sinyale taşıyıcı sinyal (fc) olarak isimlendirilir. Bilgi sinyaline gör bir veya daha fazla parametresi değiştirilmiş sinyale modüleli sinyal denir.

1.1.5. Modülasyonun Gerekliliği

Dinleyiciler için duyma mesafesindeki iki farklı müzik programını ayırt etmek çok güç olur. Şayet bu programların biri 100 kHz ile 110 kHz aralığındaki bantta diğer programda 120 kHz ile 130 kHz arasındaki banttan yayınlansa dinleyici istediği frekans aralığını seçerek istediği müzik programını dinleyebilir. İşte bu işlem modülasyon ile gerçekleştirilebilir.

İkinci bir neden ise anten boyu ile ilgilidir. Bilgi işaretini göndermek için gerekli anten boyu, dalga boyunun katları olmak zorundadır. Anten boyları genellikle $\lambda/2$ ve $\lambda/4$ uzunluktadır. Bilgi işaretinin frekansı düşük olduğundan dalga boyları çok büyüktür. Dolayısıyla bilgi işaretini modülesiz olarak iletebilmek için kullanılacak anten boyları da çok büyük olmak zorundadır. Çoğu zaman bu büyüklükte anten kullanmak imkânsızdır. Halbuki bilgi sinyali kendinden çok yüksek frekanslı bir taşıyıcı sinyal ile modüle edildiğinde bilgi çok daha küçük boyutlu antenler vasıtasıyla gönderilebilir. Bunu şöyle bir örnekle açıklayalım: 20 KHz'lik yani $\lambda = \frac{300*10^6}{20*10^3} = 15*10^3 m = 15Km$ dalga boyuna sahip bir bilgi sinyalini modülesiz olarak göndermek istersek kullanacağımız antenin boyu $\frac{\lambda}{4} = \frac{15Km}{4} = 3,75Km.$ olmalıdır. Oysaki bu bilgi sinyalini 20 MHz'lik yani

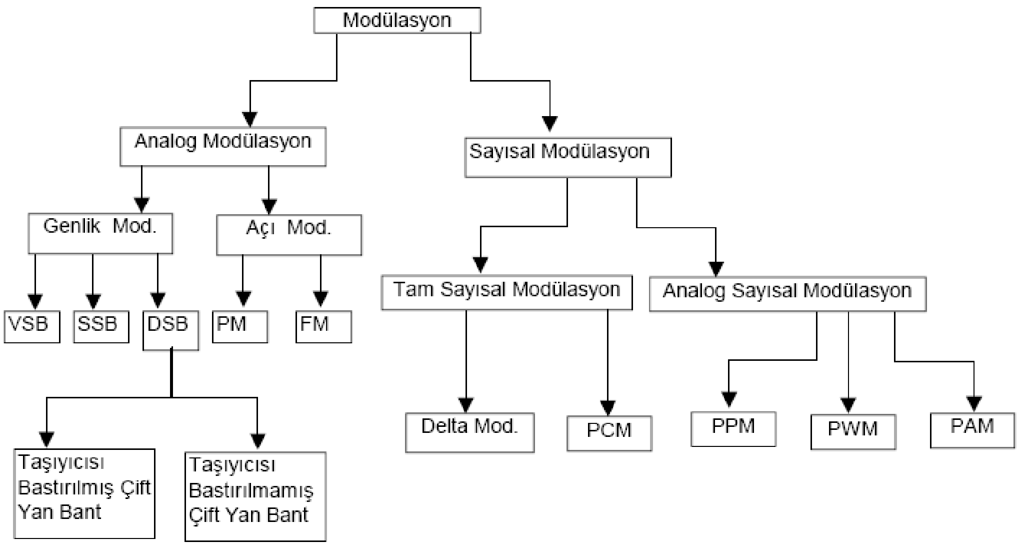
$$\lambda = \frac{300*10^6}{20*10^6} = 15m$$

dalga boyuna sahip bir taşıyıcı sinyalle modüle edersek kullanacağımız anten boyutunun $\frac{\lambda}{4} = \frac{15m}{4} = 3,75m.$ olması yeterli olacaktır. Bu anteni yapmak hem mümkün olacaktır hem de maliyeti çok az olacaktır.

Bir diğer nedense en önemlisi yüksek frekanslı elektromanyetik dalga enerjisi uzak mesafeler kat edebilir. Böylece bilgi uzak mesafelere ulaşmış olur.

1.1.6. Modülasyon Çeşitleri

Modülasyon temel olarak analog modülasyon ve sayısal modülasyon olarak ikiye ayrılır. Analog ve sayısal modülasyonun da kendi içinde çeşitli türleri vardır. Farklı modülasyon türleri aşağıdaki tabloda belirtilmiştir.

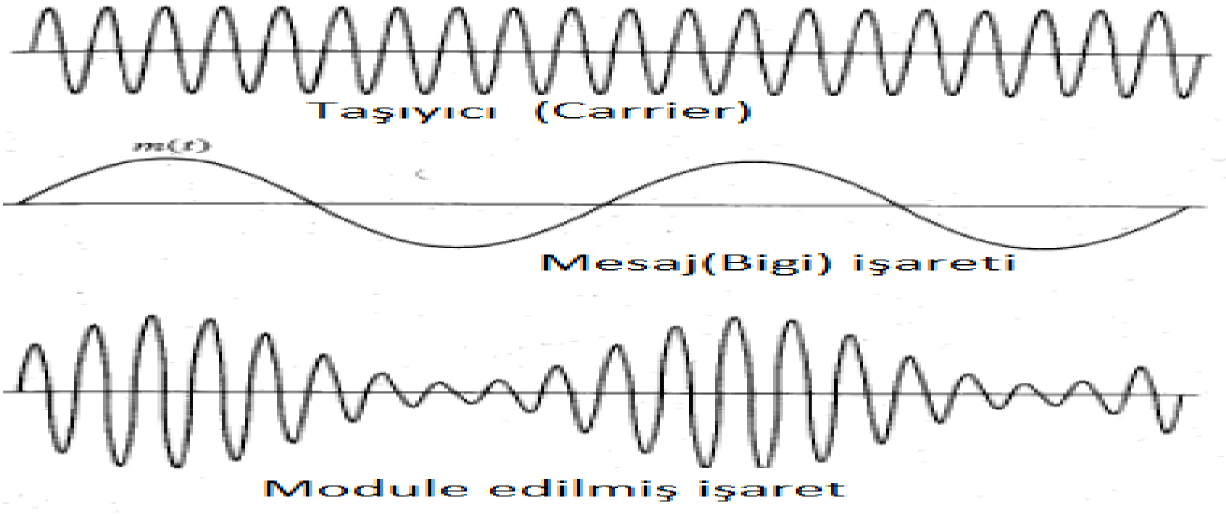


Tablo 1.1: Modülasyon çeşitleri

Bu tabloda
VSB: Artık yan bant modülasyonu
SSB: Tek yan bant modülasyonu
DSB: Çift yan bant modülasyonu
PM: Faz modülasyonu
FM: Frekans modülasyonu
PCM: Darbe kod modülasyonu
PPM: Darbe pozisyon modülasyonu
PWM: Darbe genıklik modülasyonu
PAM: Darbe genlik modülasyonu ifade etmektedir.

GENLIK MODULASYONU

Genlik modülasyonunda bilgi sinyalinin genliği artarken taşıyıcı sinyalinin de genliği artar. En üst seviyeye bilgi sinyalinin pozitif alternanstaki maksimum değerinde ulaşılır.
Bilgi sinyalinin genliği düşmeye başladığında taşıyıcı sinyalinde genliği düşer. En alt seviyeye bilgi sinyalinin negatif alternasındaki maksimum seviyesinde ulaşılır. Genel olarak genlik modülasyonun oluşumu bu şekilde açıklanabilir.



Taşıyıcı (Carriet)

Mesaj İşareti (information signal)

Genlık Modulasyonlu işaret (amplitude modulated sigmal)

HATIRLATMALAR

$$F\{\cos At\} = \delta(f-A) + \delta(f+A)$$

$$\cos(X)\cos(Y) = \frac{1}{2}[\cos(X+Y) + \cos(X-Y)]$$

1/2 δ(f+P) **M(f)** 1/2 δ(f-P)

-P **P** **f**

m(t)=cos(2π P t)

$$M(f) = \frac{1}{2}\delta(f-P) + \delta(f+P)$$

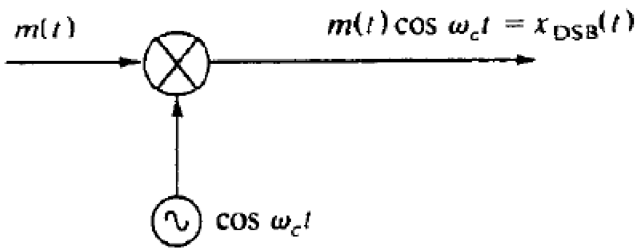
s(t)=m(t)cos(2π Xt)

M(f) **S(f)**

-D D -X-D -X+D X-D X+D **f**

-- --------------------------------

TAŞIYICISI BSTIRILMIŞ ÇİFT YAN BANTLI GENLİK MODULASYONU,
SUPRESSED CARIIER DOUBLE SIDED AMPLITUDE MODULATION



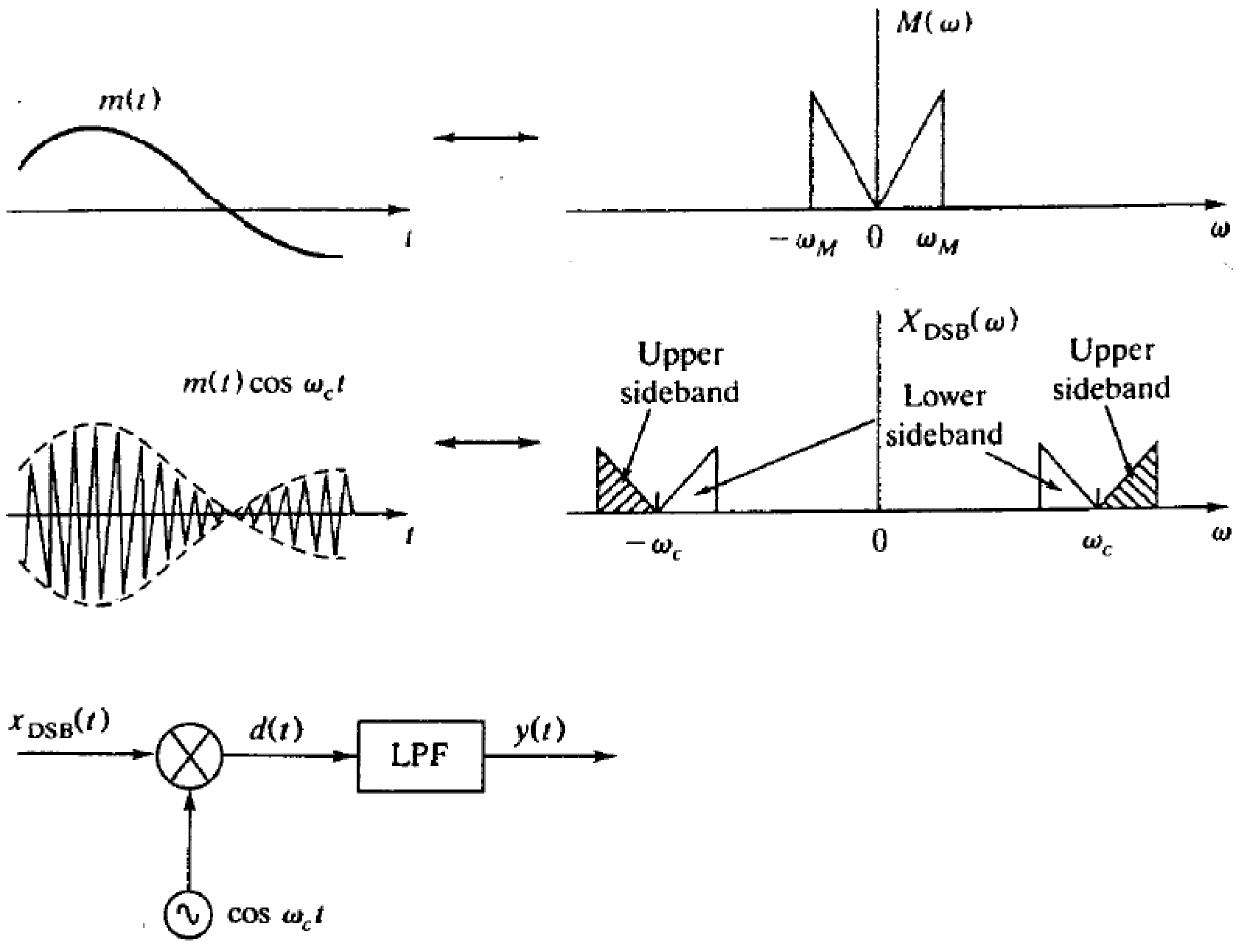
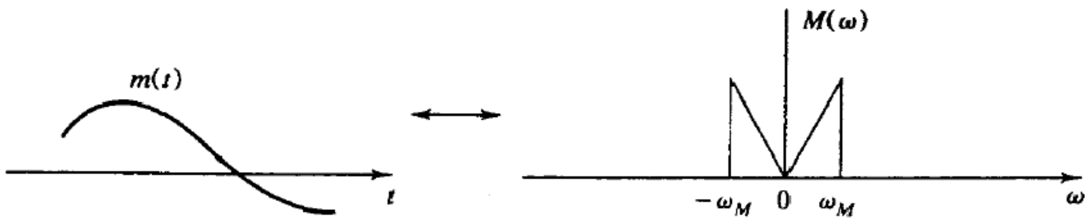
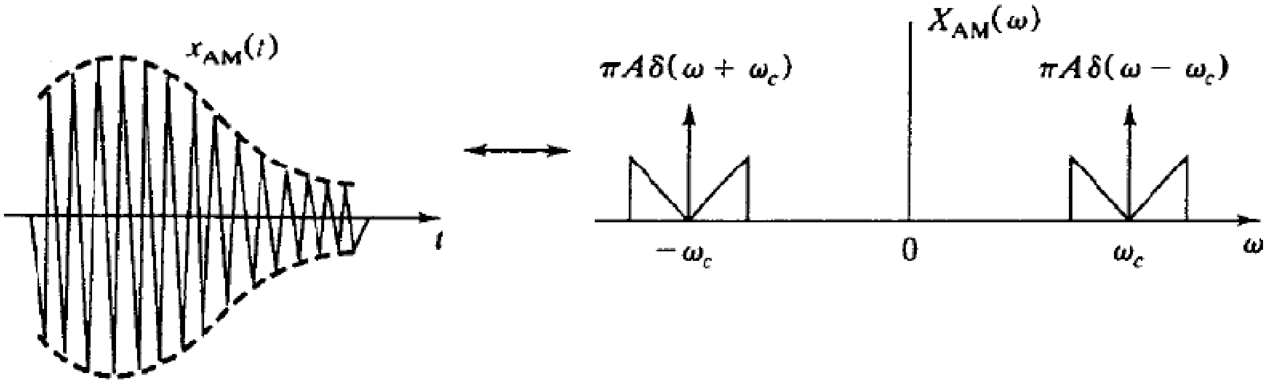


Fig. 3-2 Synchronous demodulator

ORDİNARY DOUBLE SIDED AMPLITUDE MODULATION
ÇİFT YAN BANTLI GENLİK MODULASYONU





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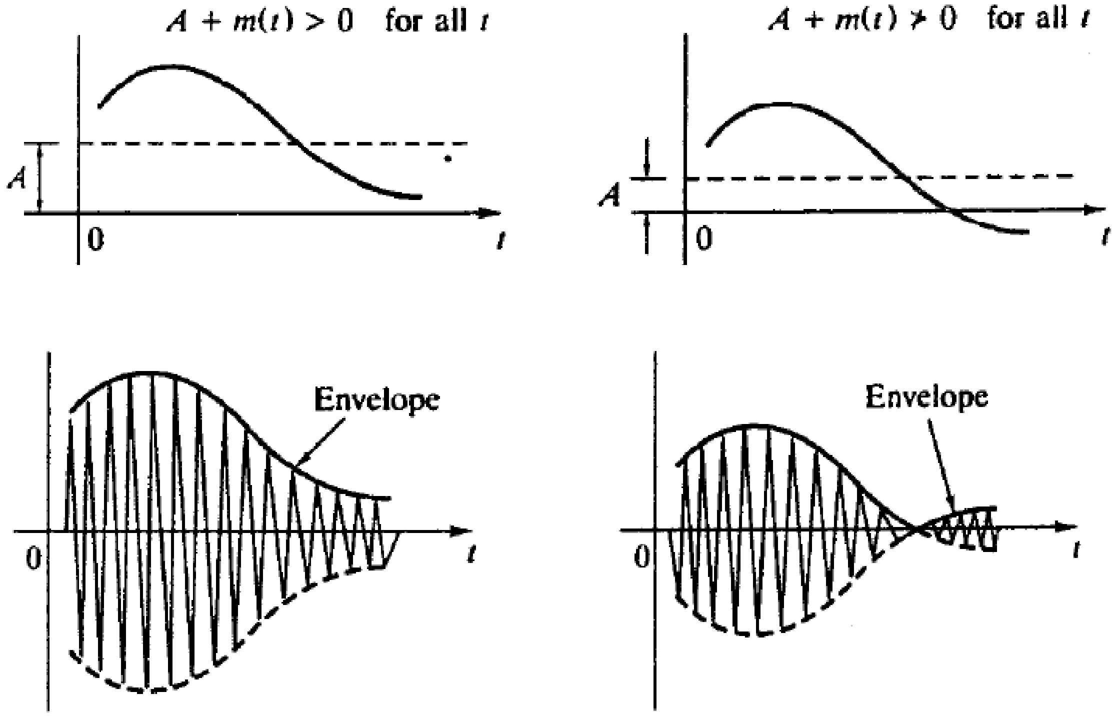


Fig. 3-4 AM signal and its envelope

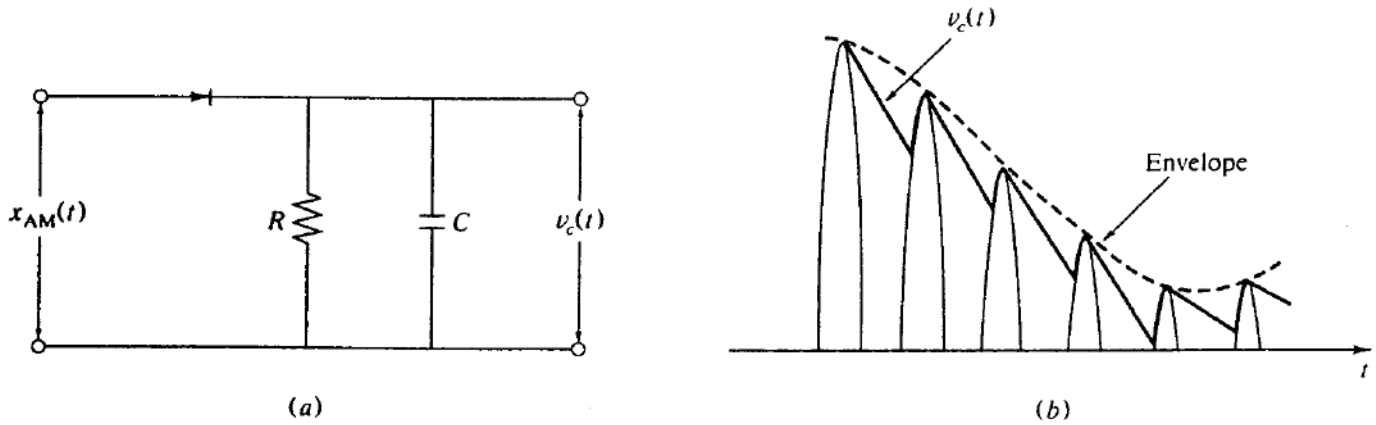
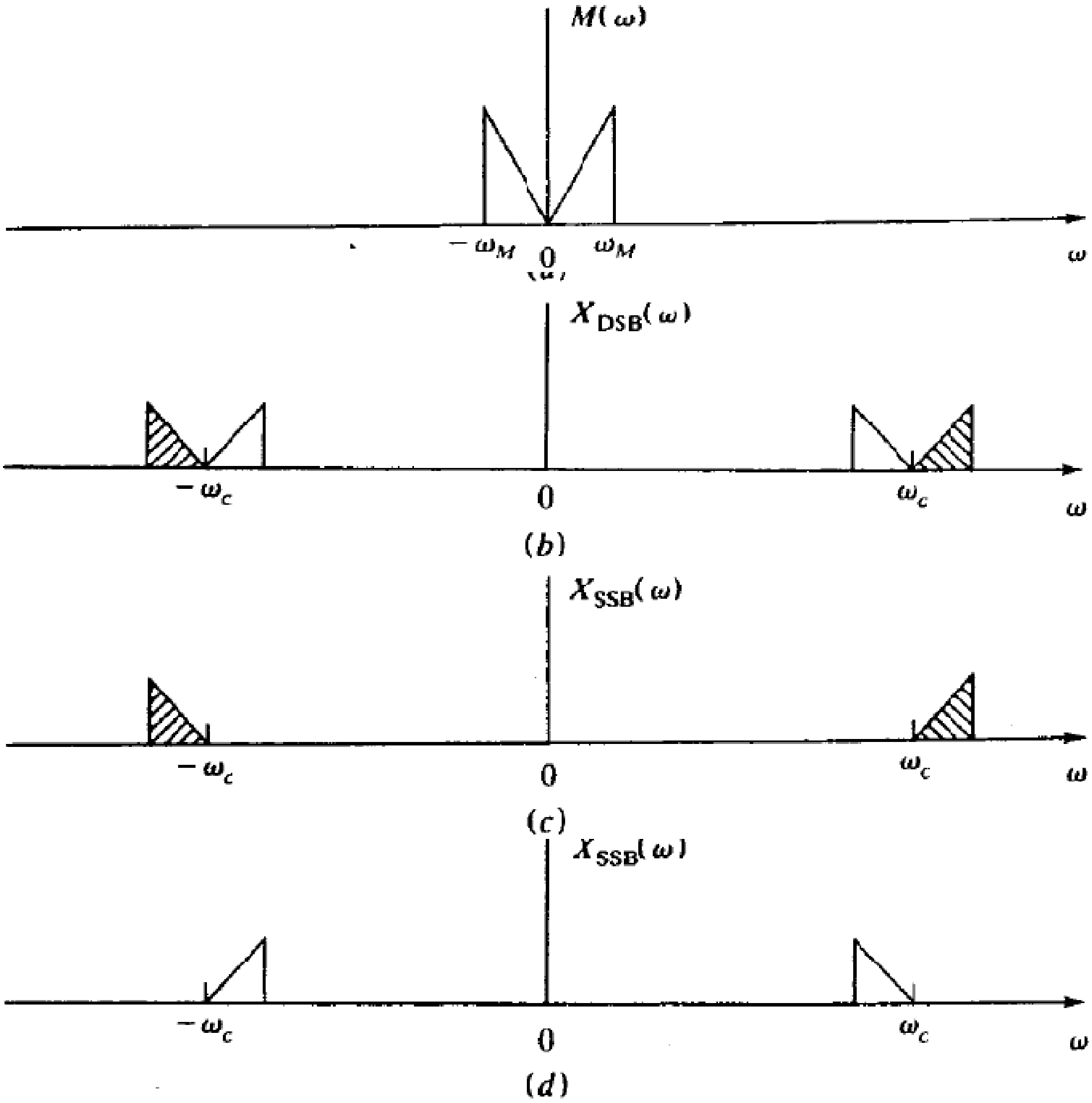
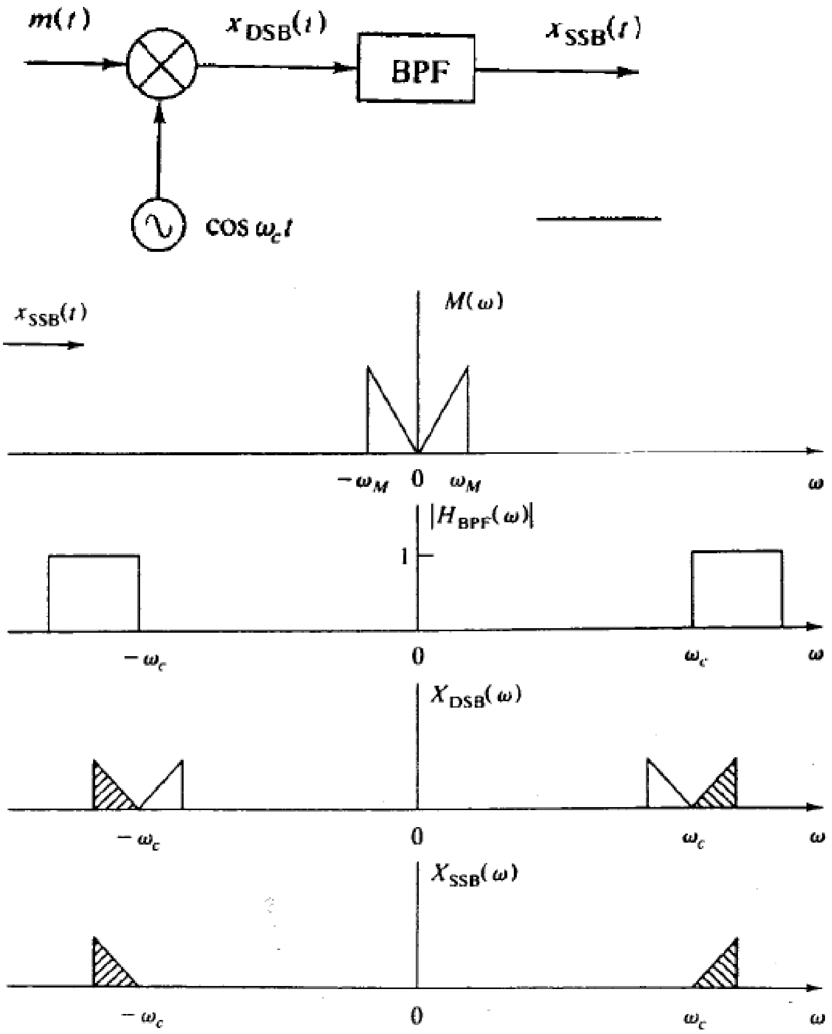


Fig. 3-5 Envelope detector for AM

SSB MODULATION





SSB sıgnal modulatıon

B. Demodulation of SSB Signals:

Demodulation of SSB signals can be achieved easily by using the coherent detector as used in the DSB demodulation, that is, by multiplying $x_{SSB}(t)$ by a local carrier and passing the resulting signal through a low-pass filter. This is illustrated in Fig. 3-9.

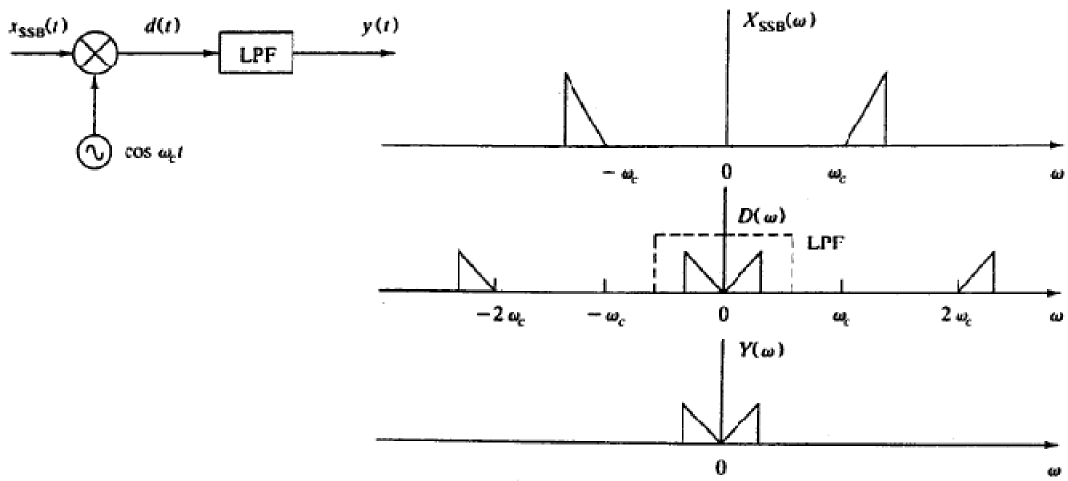
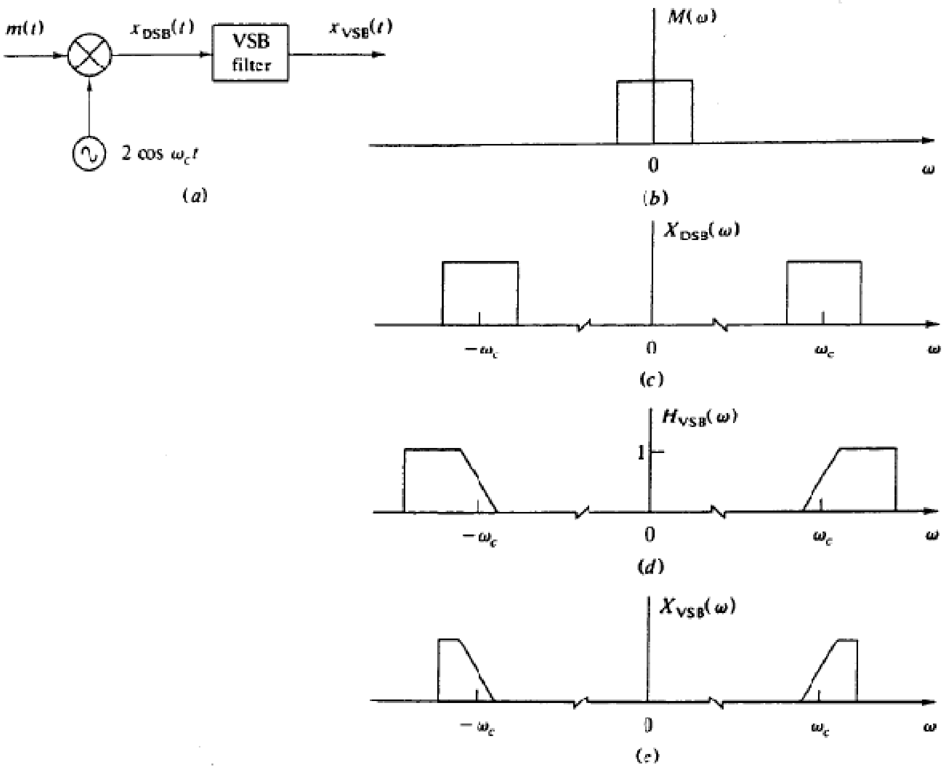


Fig. 3-9 Synchronous demodulation of SSB signals

A. Generation of VSB Signals:

A VSB signal can be generated by passing a DSB signal through a sideband-shaping filter (or vestigial filter), as shown in Fig. 3-10 (*a*). Figure 3-10 (*b*) to (*e*) illustrates the spectrum of a VSB signal [$x_{VSB}(t)$] in relation to that of the message signal $m(t)$, assuming that the lower sideband is transformed to vestigial sideband.



FREQUENCY TRANSLATION

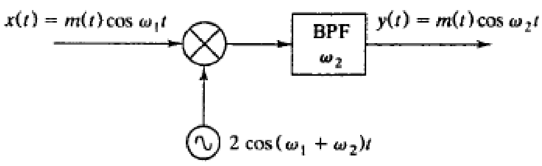


Fig. 3-14 Frequency mixer

FREQUENCY DIVISION MULTIPLEXING

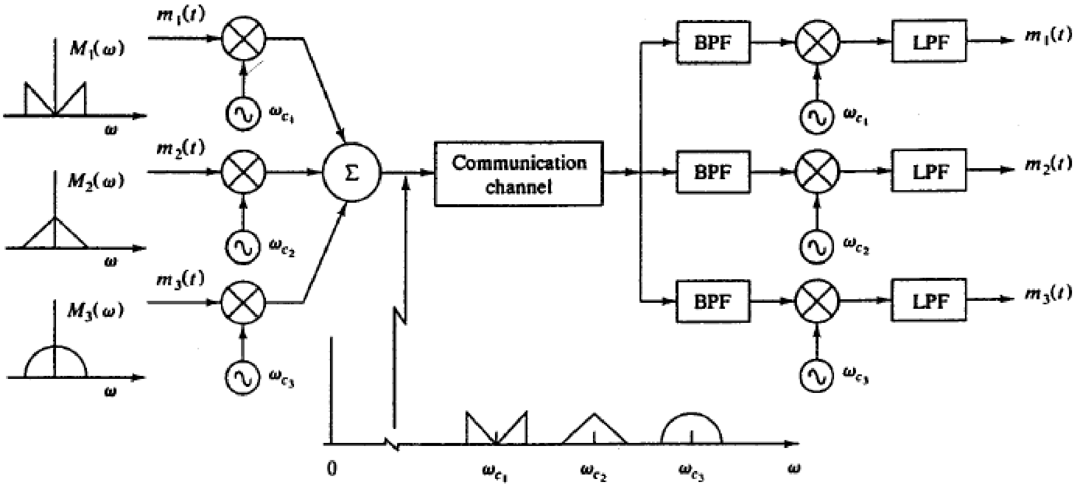


Fig. 3-15 Frequency-division multiplexing

Amplitude modulation

Amplitude of the carrier wave is varied about a mean value, linearly with the baseband signal. $m(t)$.

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

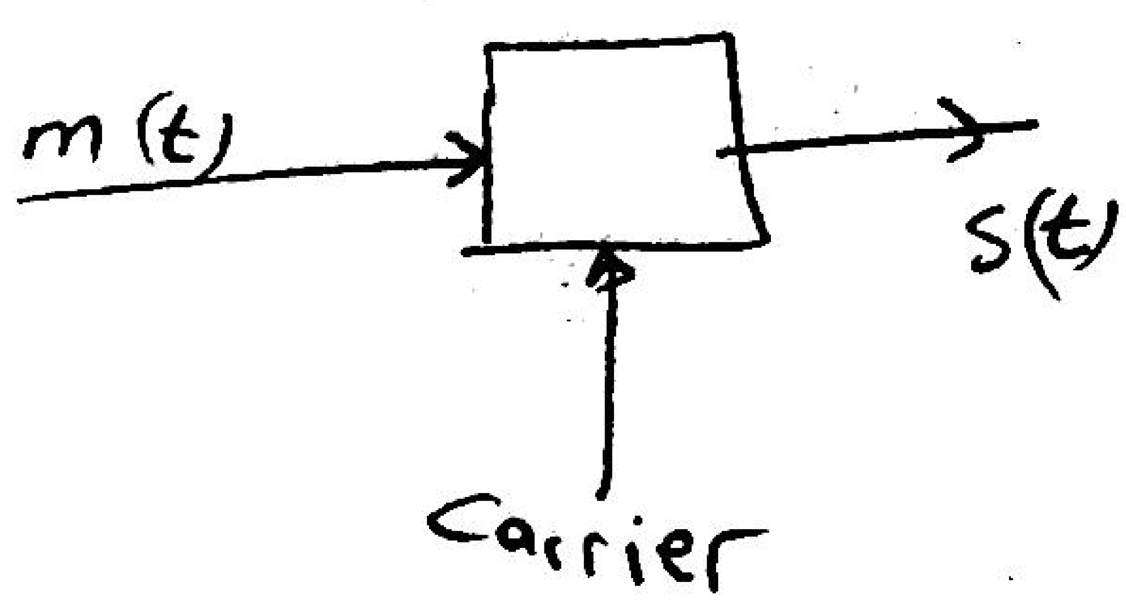
$m(t)$ = information signal

f_c = carrier frequency

A_c = carrier amplitude

K_a = constant (amlitudue sensitivity)

$s(t)$ = modulated signal



$f_c >> W$

f_c = carrier frequency

W = bandwidth of $m(t)$

$S(f)$ = fourier Transform of $s(t)$

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

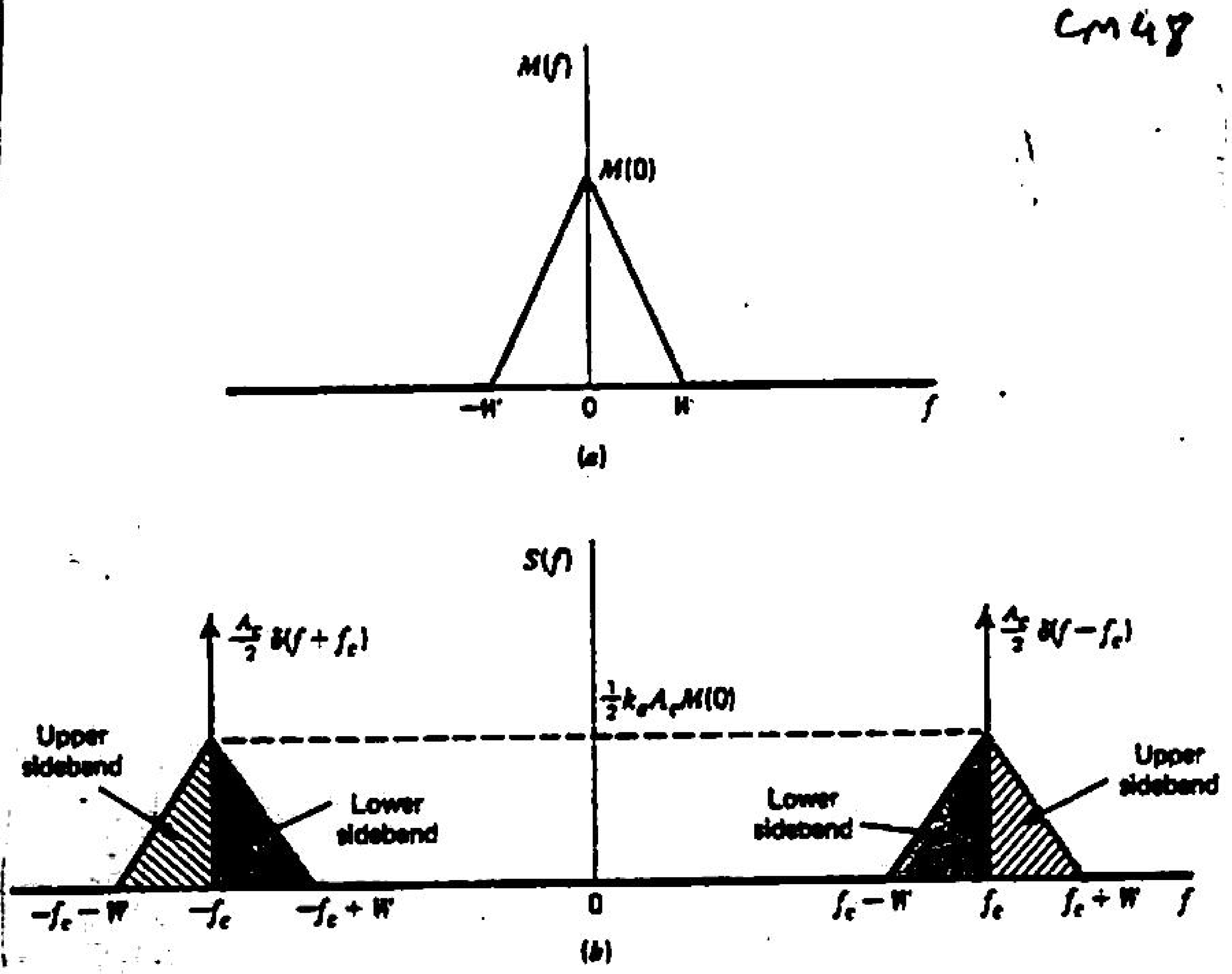
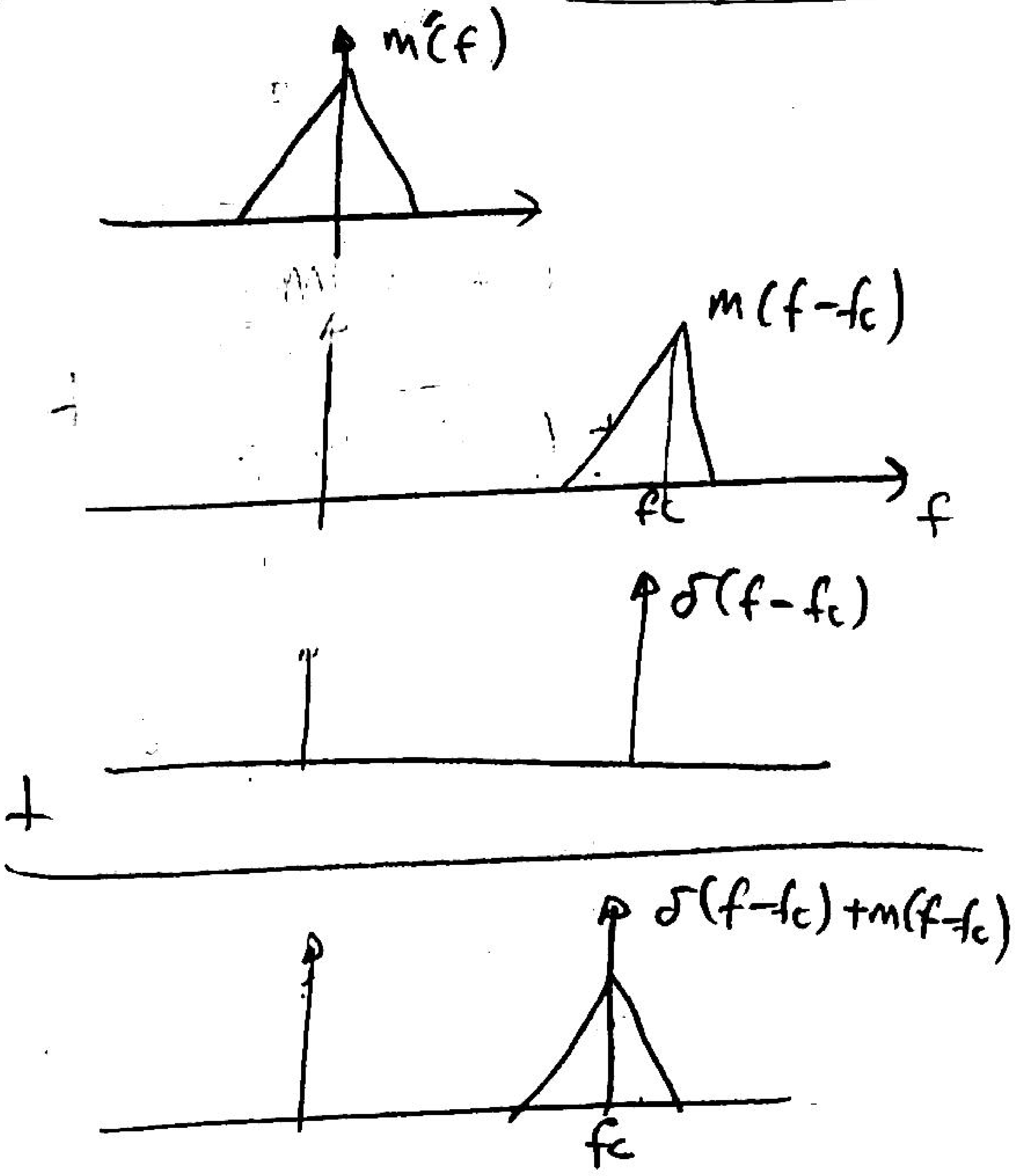
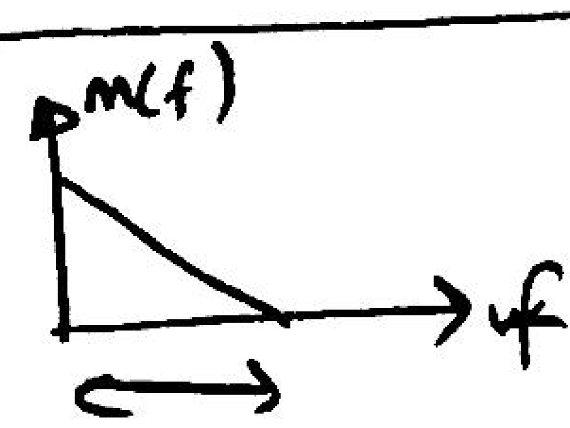
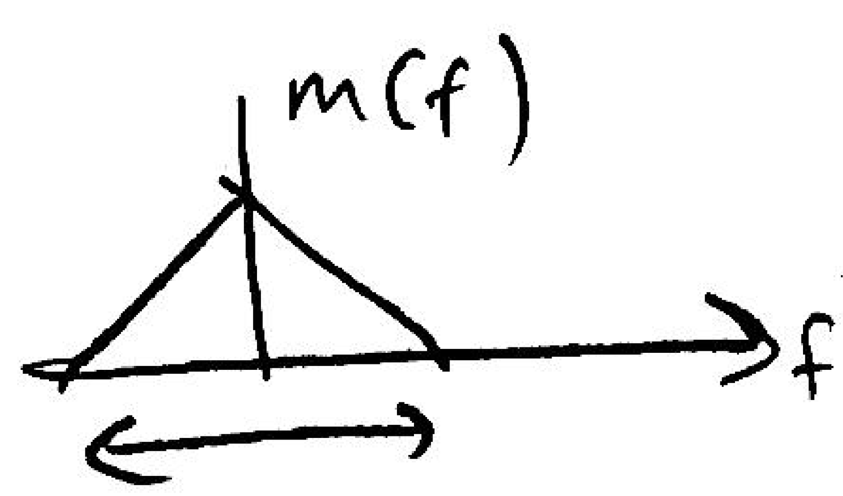


Figure 3.2 (a) Spectrum of baseband signal. (b) Spectrum of AM wave.



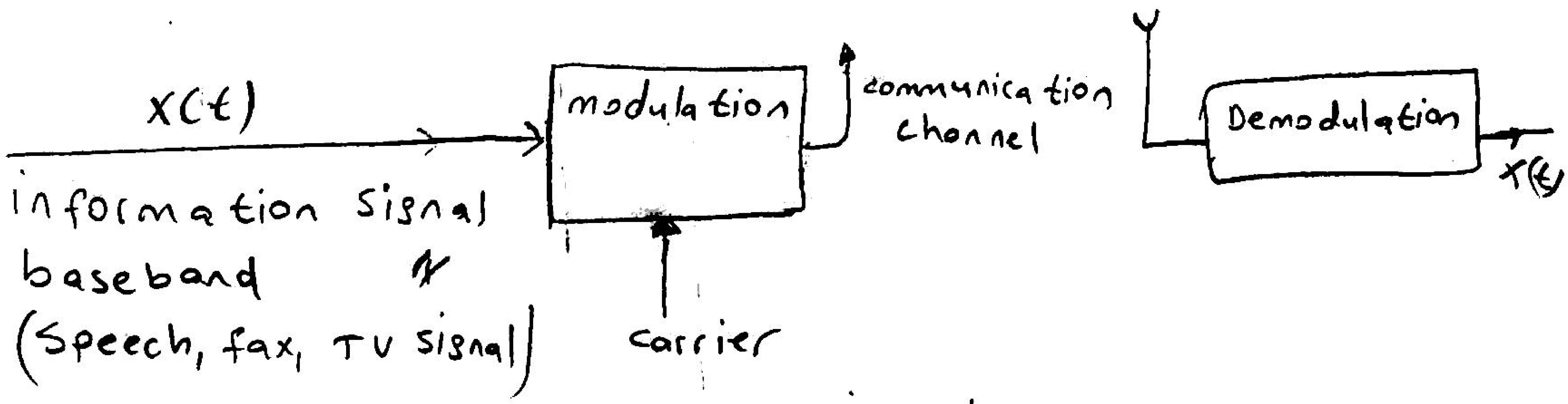


W = message bandwidth

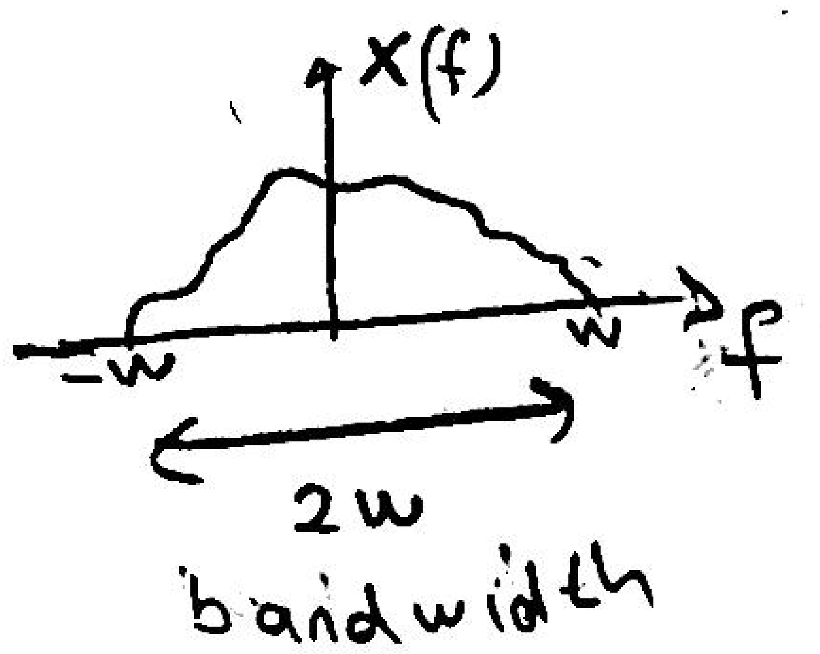


2W = transmission bandwidth

Continuous wave modulation



Baseband signal bandwidth: The range of frequencies Of X(t). Carrier is usually a single frequency.



Speech signal   w = 3000 hz for telephone
                w = 15000 hz for music.

TV signal — w = 5MHz = 5000.000 hz.

computer modem   28K = 28000
                 56K = 56000

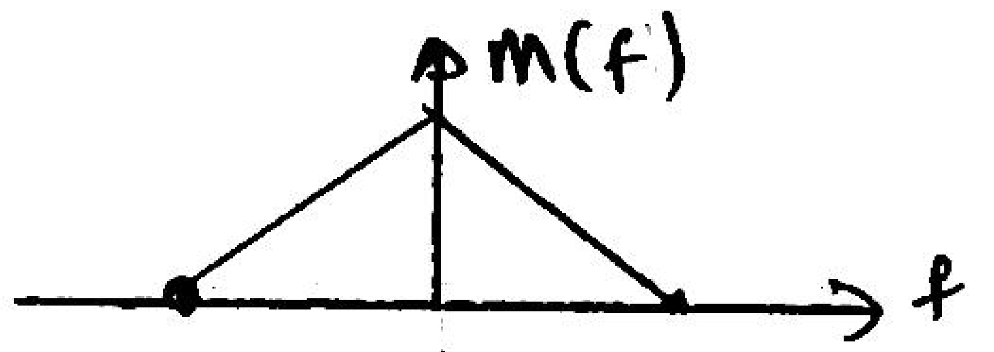
Carrier	long wave radio	1.5MHz – 20MHz
	FM radio	80 MHz – 100MHz
	TV	70 MHz – 400 MHz (UHF)
	satellite	8-9 – 12 GHz
	mobile Telephone	450 MHz – 900MHz – 1800MHz.

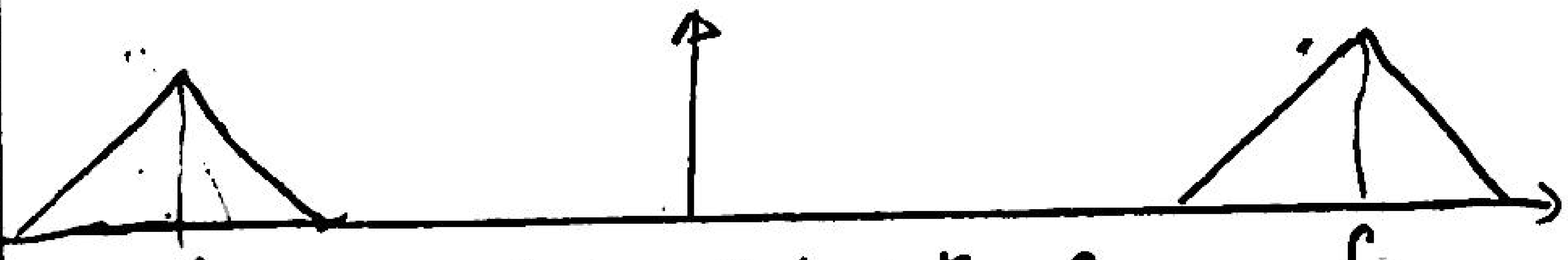
1 MHz = 10^6 Hertz.

1 GHz = 10^9 Hertz.

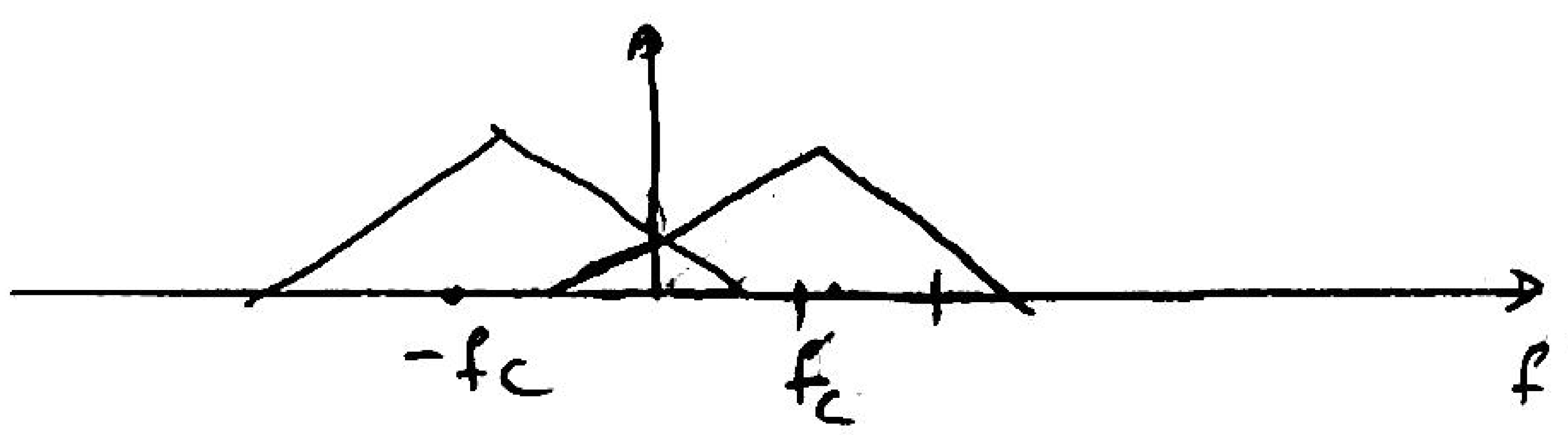
cm 49

f_c must be high





acceptable f_c

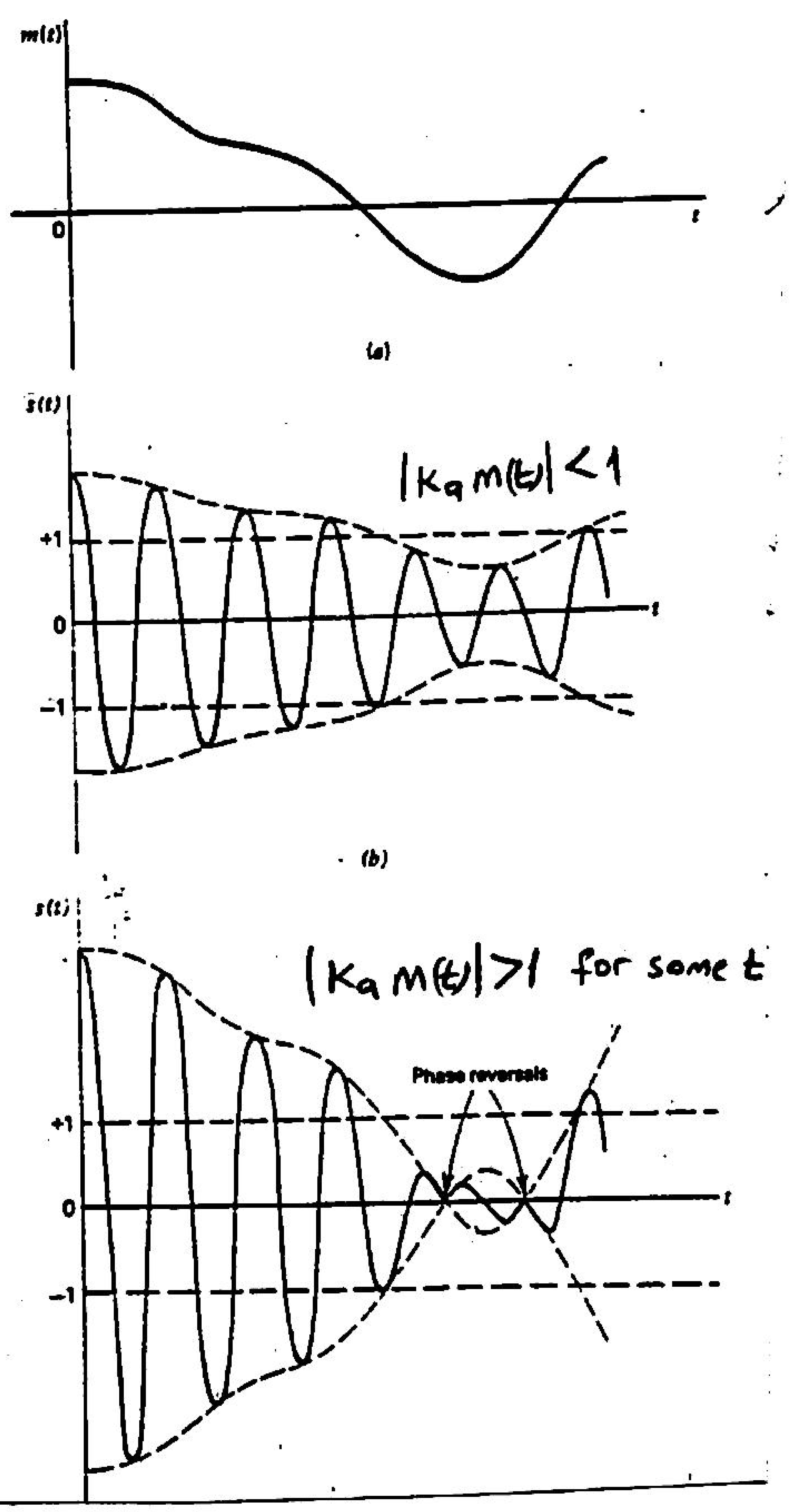


f_c is small

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

k_a should be chosen small

$|k_a m(t)| < 1$ for all t



Single tone modulation

$$m(t) = A_m \cos 2\pi f_m t$$

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

Define $\mu = k_a A_m$

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

μ = modulation factor

μ must be less than 1

$$s(t)_{max} = A_c(1+\mu)$$

$$s(t)_{min} = A_c(1-\mu)$$

$$\frac{s(t)_{max}}{s(t)_{min}} = \frac{A_c(1+\mu)}{A_c(1-\mu)}$$

or

$$\mu = \frac{s(t)_{max} - s(t)_{min}}{s(t)_{max} + s(t)_{min}}$$

$$\cos a \cos b = \frac{1}{2}\left[\cos(a+b) + \cos(a-b)\right]$$

$\cos 2\pi f_c t \cos 2\pi f_m t =$

$$\frac{1}{2} \cos 2\pi(f_c - f_m)t + \frac{1}{2}\cos 2\pi(f_c - f_m)t$$

$$s(t) = A_c \cos 2\pi f_c t + \frac{1}{2}\mu A_c \cos 2\pi(f_c + f_m)t$$

$$+ \frac{1}{2}\mu A_c \cos(2\pi(f_c - f_m)t$$

$$S(f) = \frac{1}{2}A_c\left[\delta(f-f_c) + \delta(f+f_c)\right]$$

$$+ \frac{1}{4}\mu A_c\left[\delta(f-f_c-f_m) + \delta(f+f_c+f_m)\right]$$

$$+ \frac{1}{4}\mu A_c\left[\delta(f-f_c+f_m) + \delta(f+f_c-f_m)\right]$$

CM50

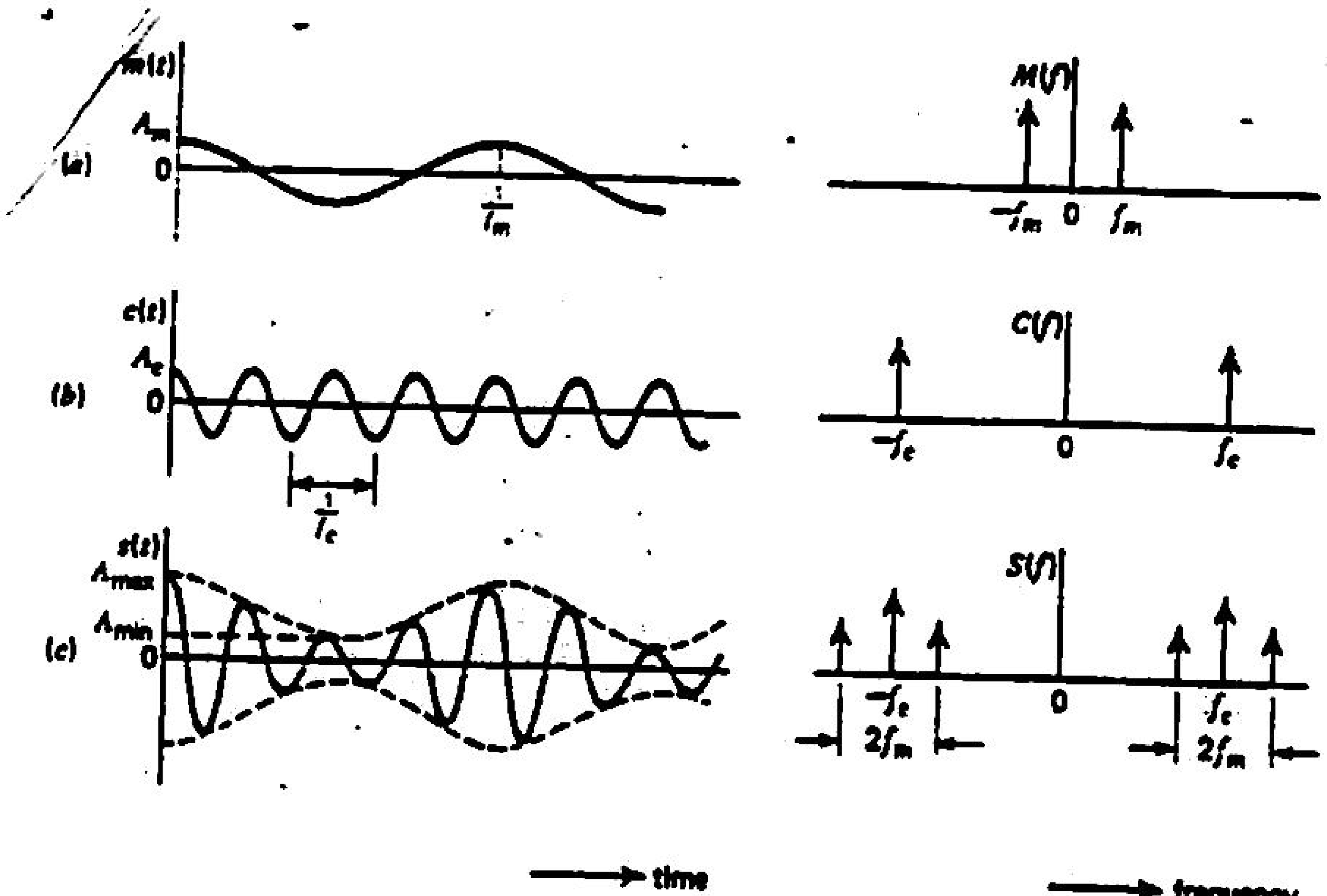


Figure 3.3 Illustrating the time-domain (on the left) and frequency-domain (on the right) characteristics of standard amplitude modulation produced by a single tone. (a) Modulating wave. (b) Carrier wave. (c) AM wave.

Average power

$x(t) = \delta(t) \longrightarrow P = |x(t)|^2 = 1$

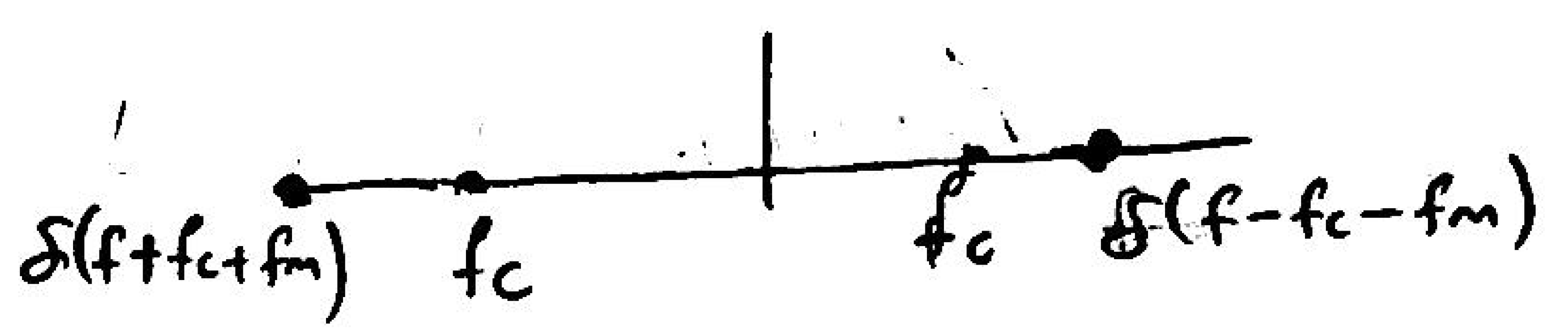
$\frac{1}{2} A_c [\delta(f - f_c)] \rightarrow P = \left\{\frac{1}{2} A_c\right]^2 = \frac{1}{4} A_c^2$

Carrier power $\quad \frac{1}{4} A_c^2 + \frac{1}{4} A_c^2 = \frac{1}{2} A_c^2$

Upper side frequency power

$f - f_c - f_m \qquad f + f_c + f_m$

$\left\{\frac{1}{4} \mu A_c\right\}^2 + \left\{\frac{1}{4} \mu A_c\right\}^2 = \frac{1}{8} \mu^2 A_c^2$



Lower side frequency power

$= \frac{1}{8} \mu^2 A_c^2$

$\frac{\text{Total side band power}}{\text{Total power}} = \frac{\frac{1}{8}\mu^2 A_c^2 + \frac{1}{8}\mu^2 A_c^2}{\frac{1}{8}\mu^2 A_c^2 + \frac{1}{8}\mu^2 A_c^2 + \frac{1}{2} A_c^2}$

$= \frac{\frac{1}{4}\mu^2}{\frac{1}{4}\mu^2 + \frac{1}{2}} = \frac{\mu^2}{\mu^2 + 2}$

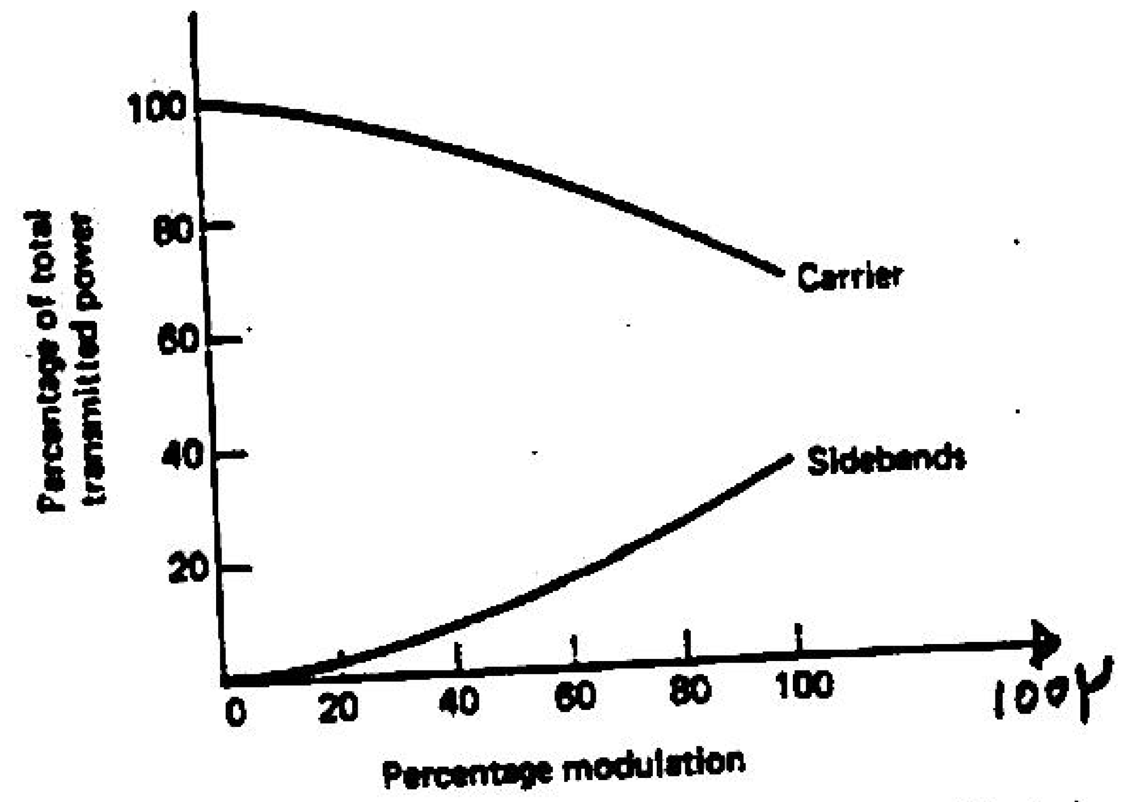


Figure 3.4 Variations of carrier power and total sideband power with percentage modulation.

We want the sideband powers as high as possible.

We do not want to transmit more carrier power.

μ must be high (for power)

μ must be less than 1

(if $\mu > 0$ over modulation)

Note

$\cos^2 x = \frac{1}{2} + \frac{1}{2}\cos 2x$

$\cos^3 x = \frac{3}{4}\cos x + \frac{1}{4}\cos 3x$

$\cos^4 x = \frac{3}{8} + \frac{1}{2}\cos 2x + \frac{1}{8}\cos 4x$

$\sin^2 x = \frac{1}{2} - \frac{1}{2}\cos 2x$

$\sin^3 x = \frac{3}{4}\sin x - \frac{1}{4}\sin 3x$

$\sin^4 x = \frac{3}{8} - \frac{1}{2}\cos 2x + \frac{1}{8}\cos 4x$

$\sin(a+b) = \sin a \cos b + \sin b \cos a$

$\cos(a+b) = \cos a \cos b - \sin a \sin b$

$\cos a \cos b = \frac{1}{2}[\cos(a+b) + \cos(a-b)]$

$\sin a \sin b = \frac{1}{2}\{-\cos(a+b) + \cos(a-b)$

$\sin x \cos y = \frac{1}{2}\{\sin(x+y) + \sin(x-y)\}$

$\cos^2 2\pi f_c t = \underset{\downarrow\\ 0}{\frac{1}{2}} + \frac{1}{2}\underset{\downarrow\\ 2f_c}{\cos 2\pi 2 f_c t}$

$\cos^2 2\pi f_c t$ contains zero and $2f_c$ frequencies

$\cos^3 2\pi f_c t = \frac{3}{4}\cos 2\pi f_c t + \frac{1}{4}\cos 2\pi 3 f_c t$

$\cos^3 2\pi f_c t$ contains f_c and $3f_c$ frequencies

$\cos^4 2\pi f_c t$ contains zero, $2f_c$, $4f_c$ frequencies

A constant term has zero frequency

$2 = 2\cos 2\pi \times 0 \times f_c t$

$x(t) = \cos 2\pi 8 t \qquad y(t) = \cos 2\pi 5 t$

$x(t)\,y(t) = \cos(2\pi 8 t)\cos(2\pi 5 t)$

$= \frac{1}{2}\cos 2\pi 13 t + \frac{1}{2}\cos 2\pi 3 t$

$x(t)$ has 8 hertz

$y(t)$ has 5 hertz

$x(t)\,y(t)$ has 13 hertz and 3 hertz

$x(t)\,y(t)$ does not have 8 and 3 hertz

Result:

$V_2(t)$ contains

1) Useful term

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

at the following frequencies

f_c

$f_c - w < f < f_c + w$

2) other terms at the following frequencies

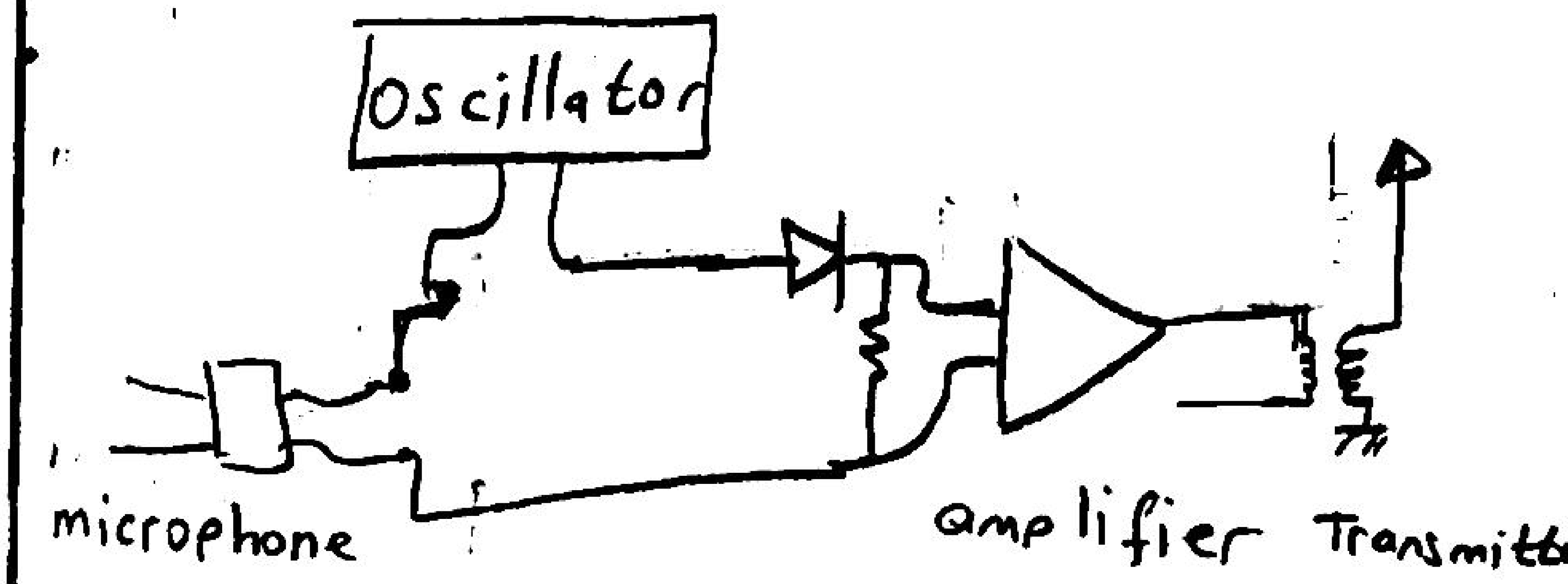
0

$-w < f < w$

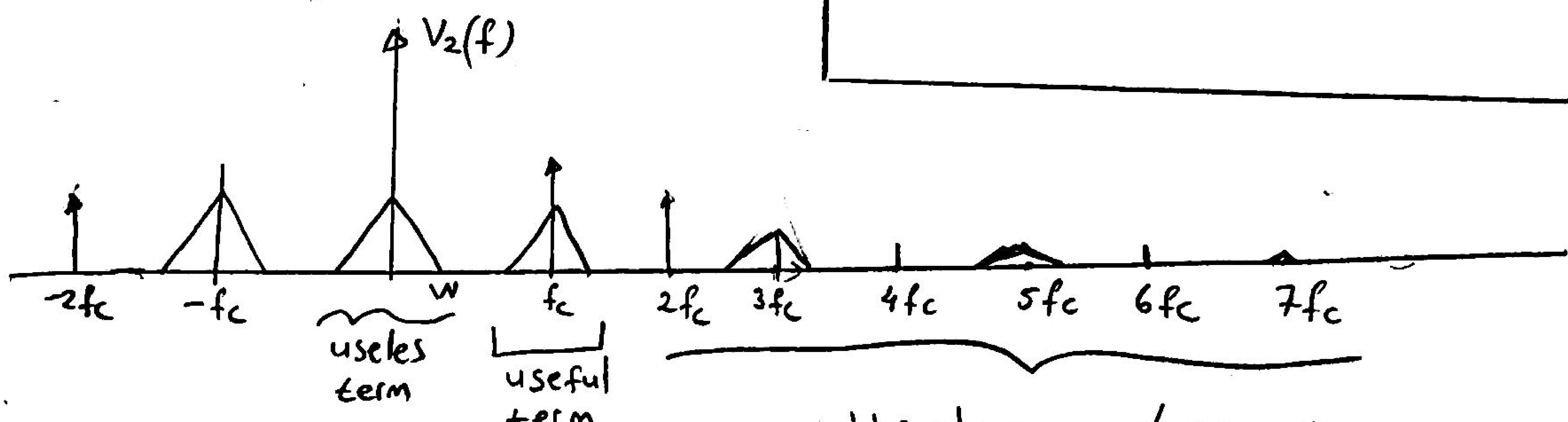
$2f_c$

$3f_c - w < f < 3f_c + w$

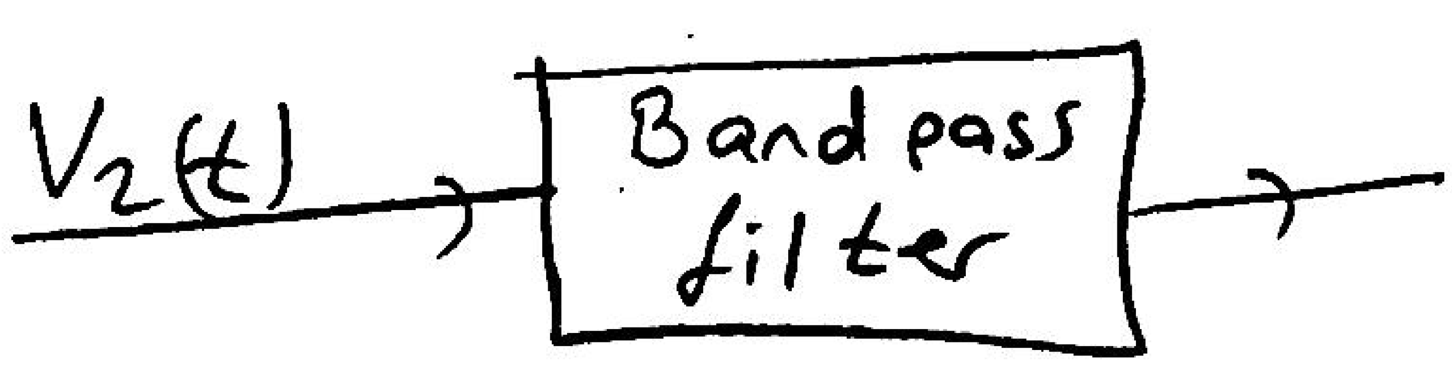
$4f_c$

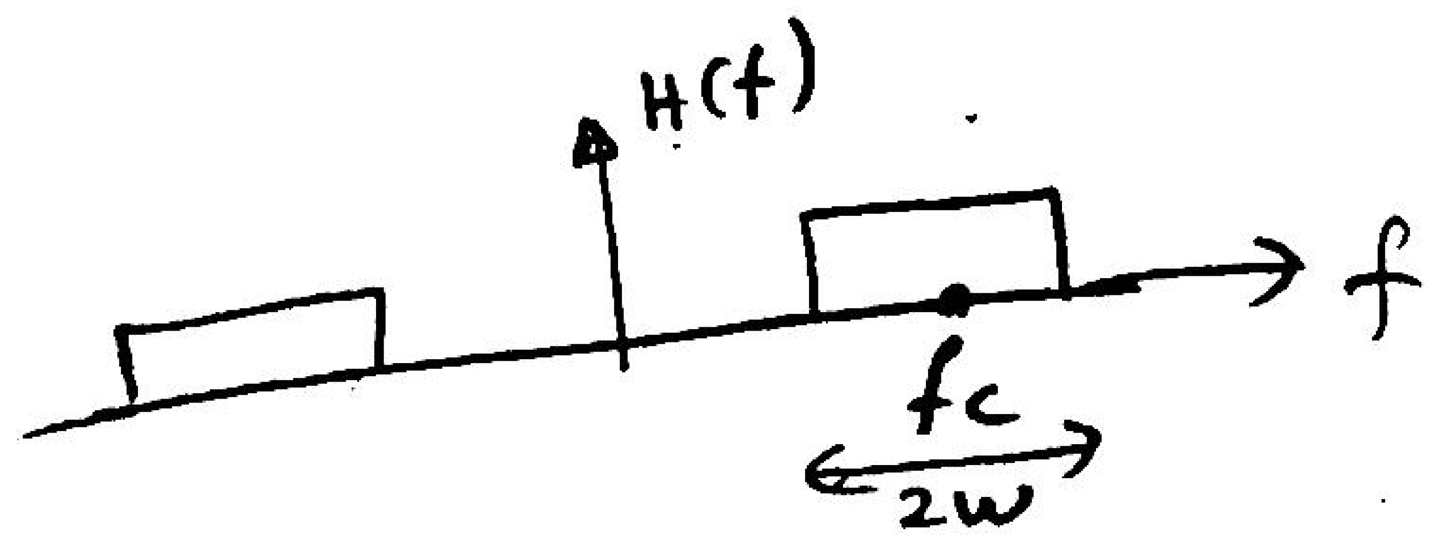


A simple circuit to Transmit $m(t)$.



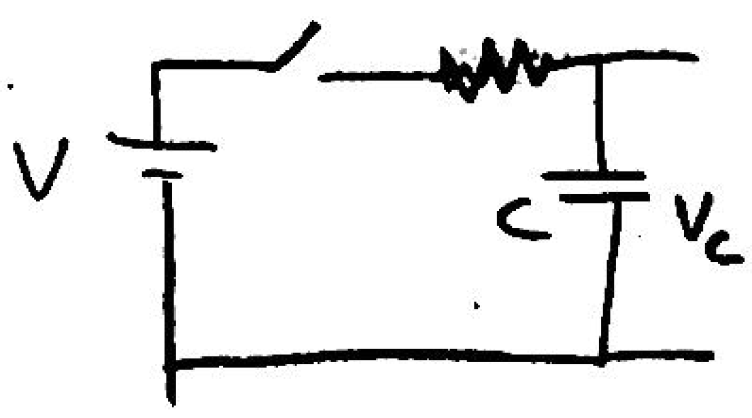
useles terms

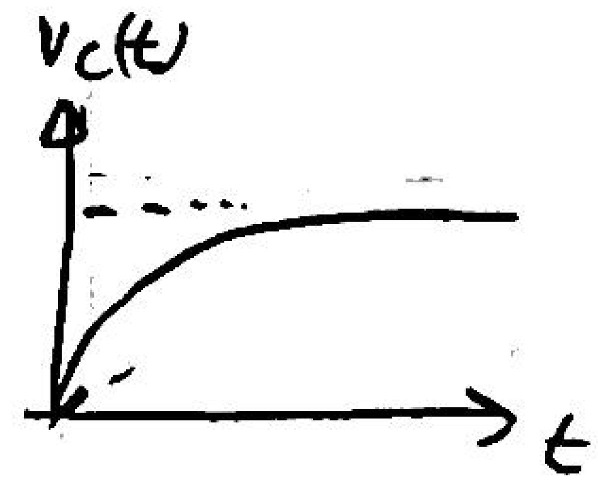


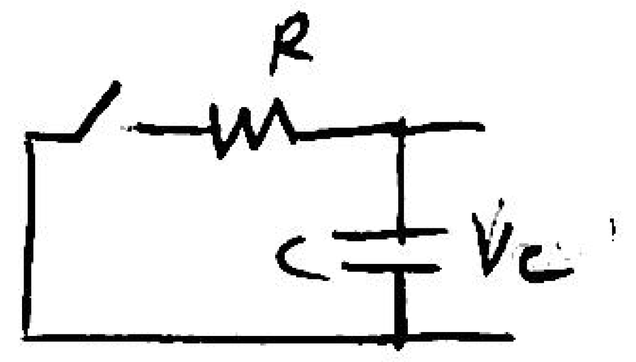


Envelope Detector

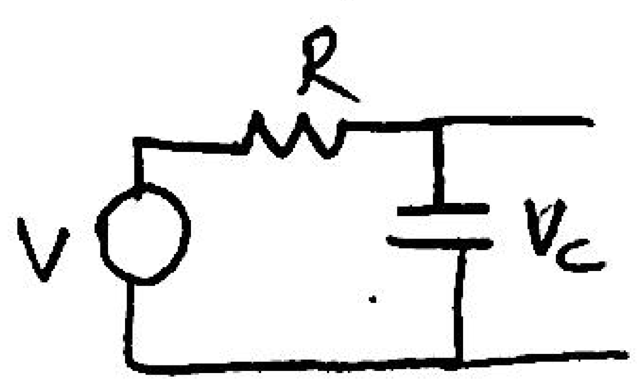
How to get m(t) from s(t).

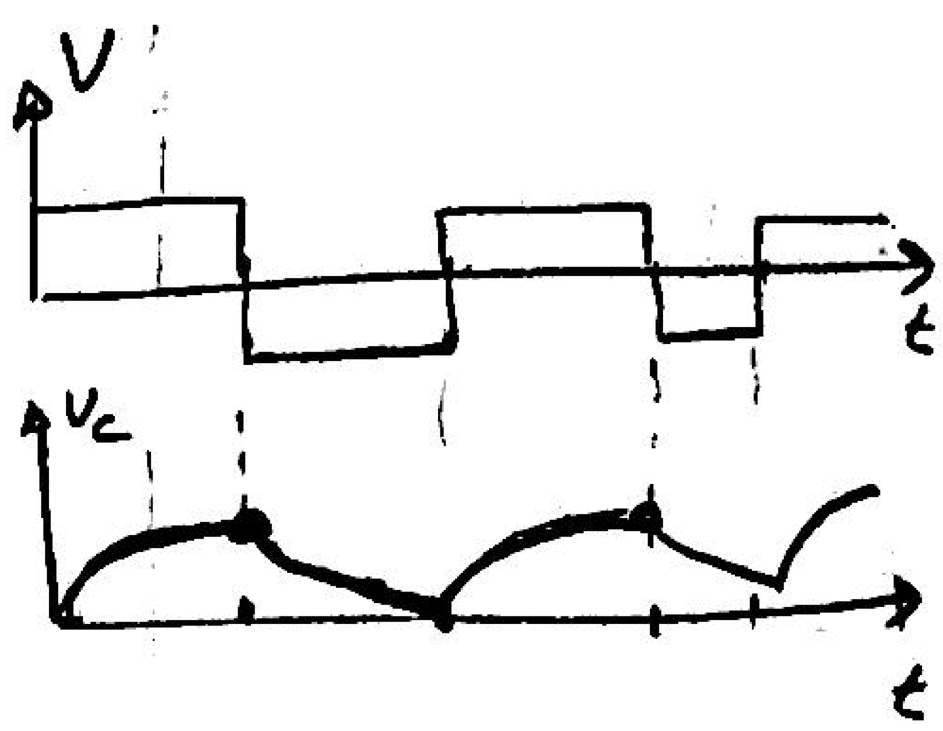


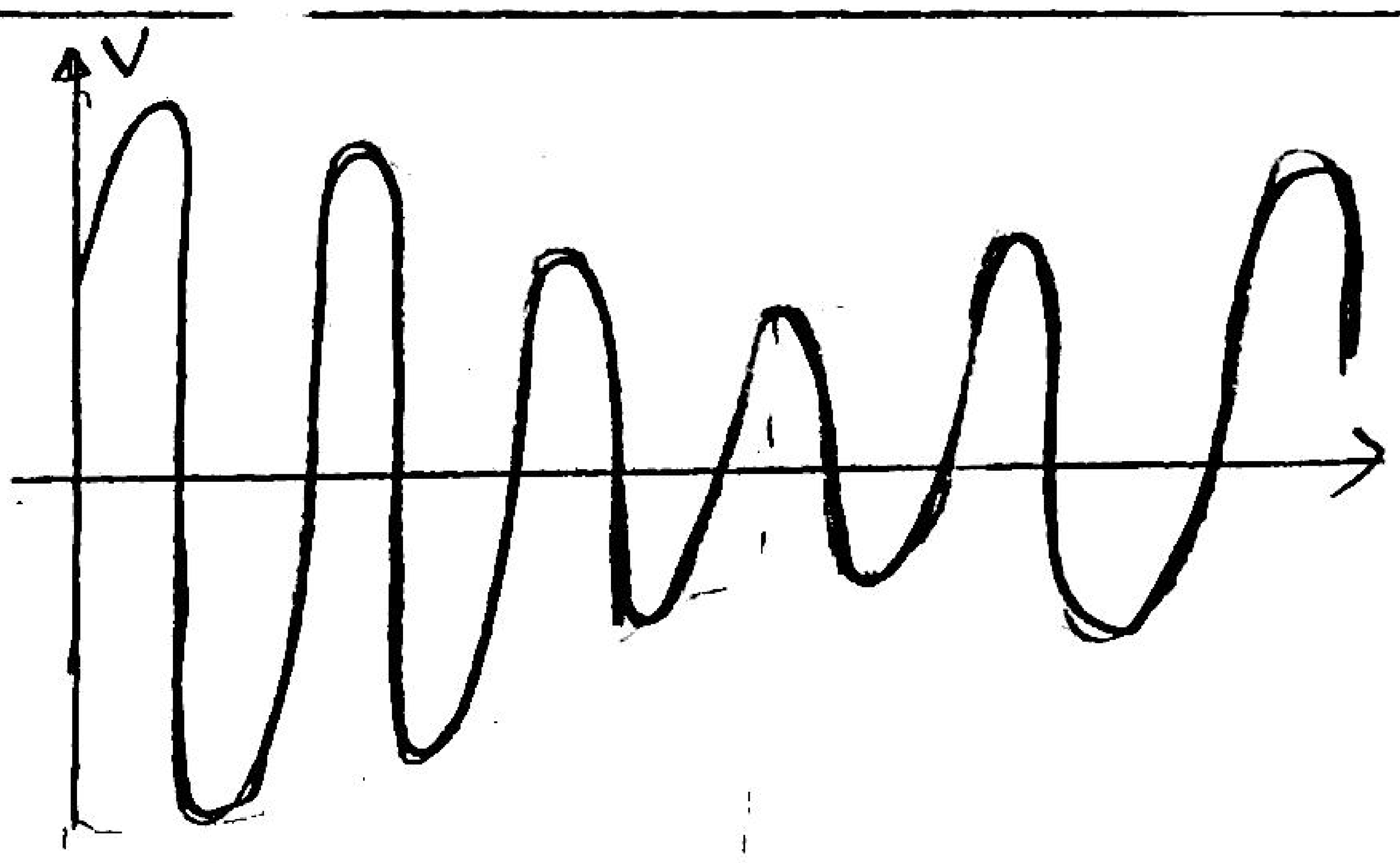


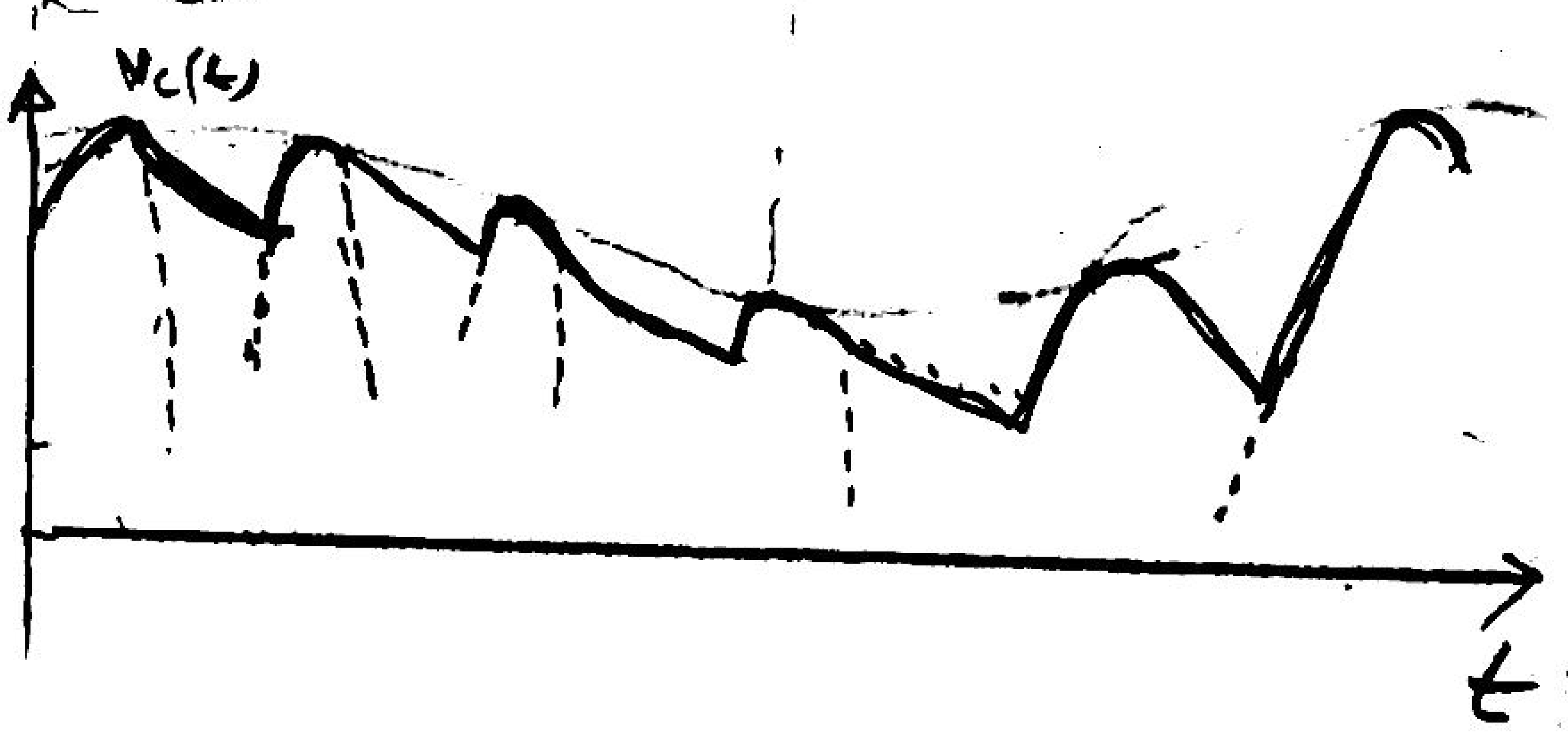


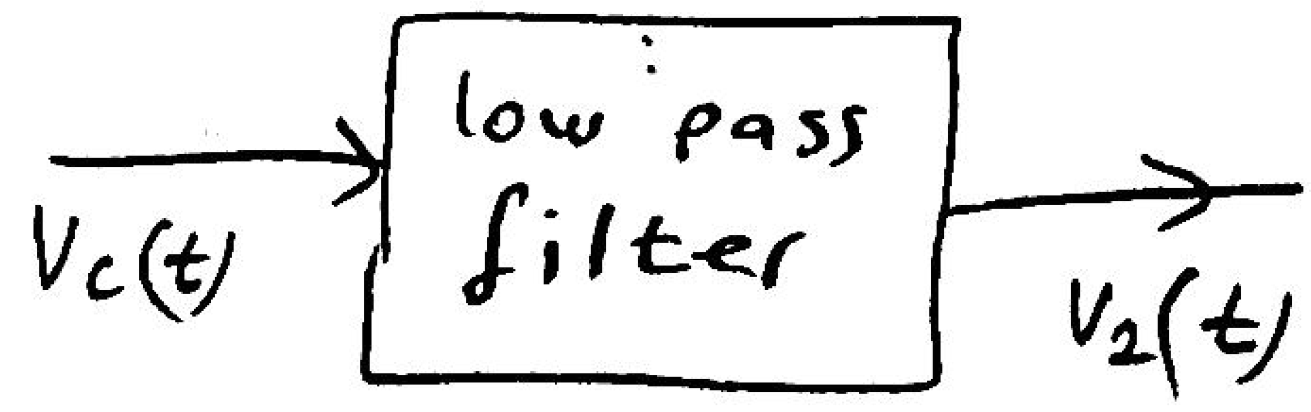
$V_c(0)=V$

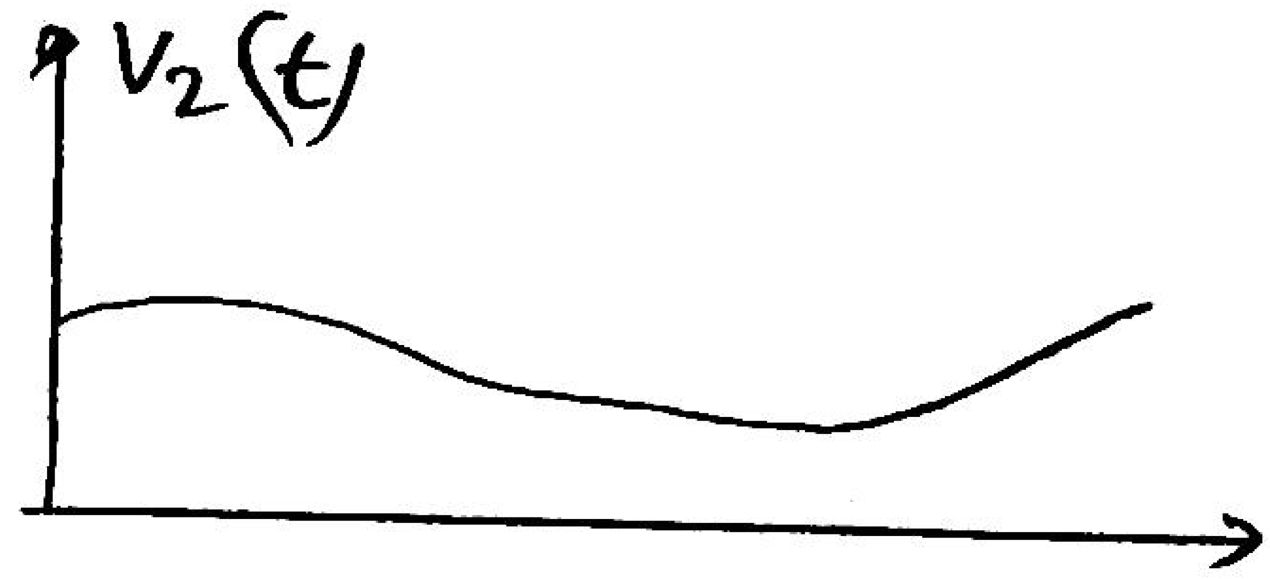












$V_2(t)$ is similar to the message signal $m(t)$.

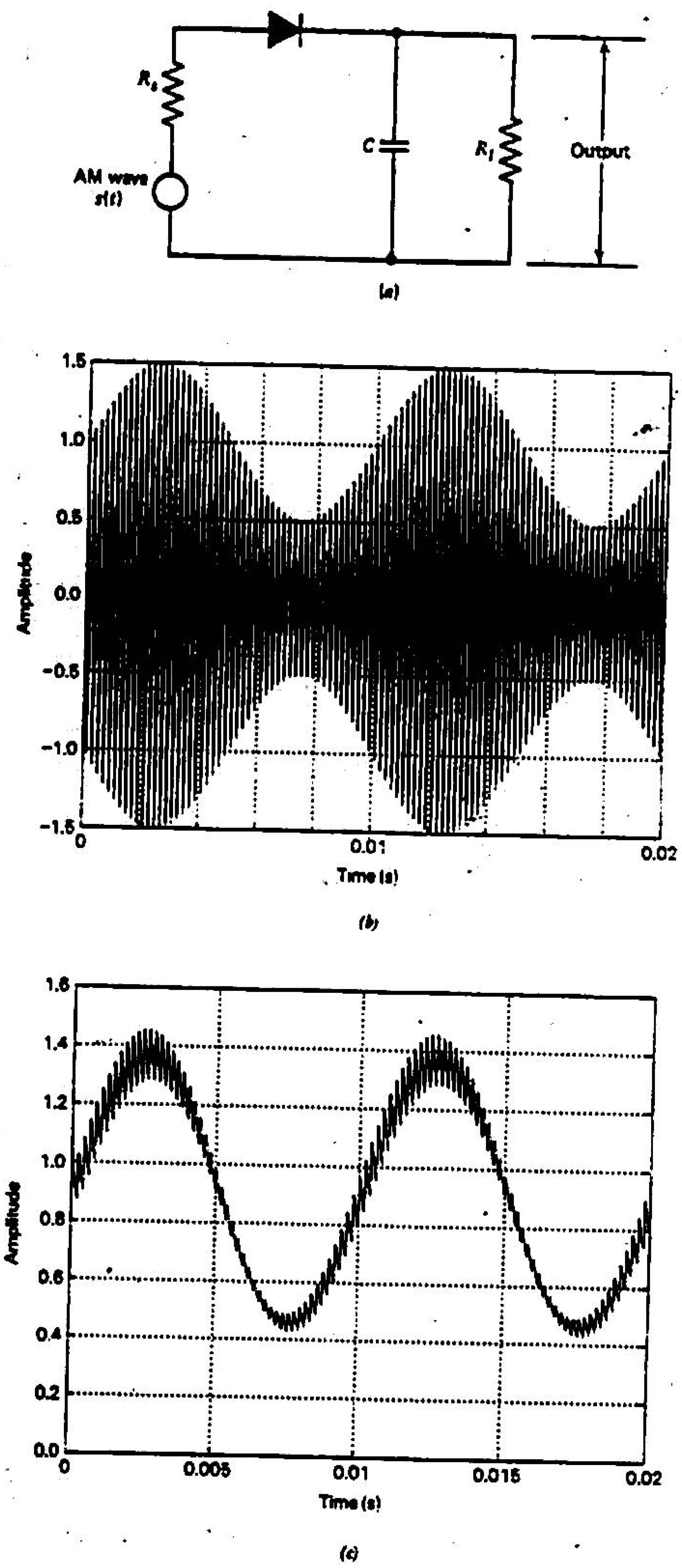
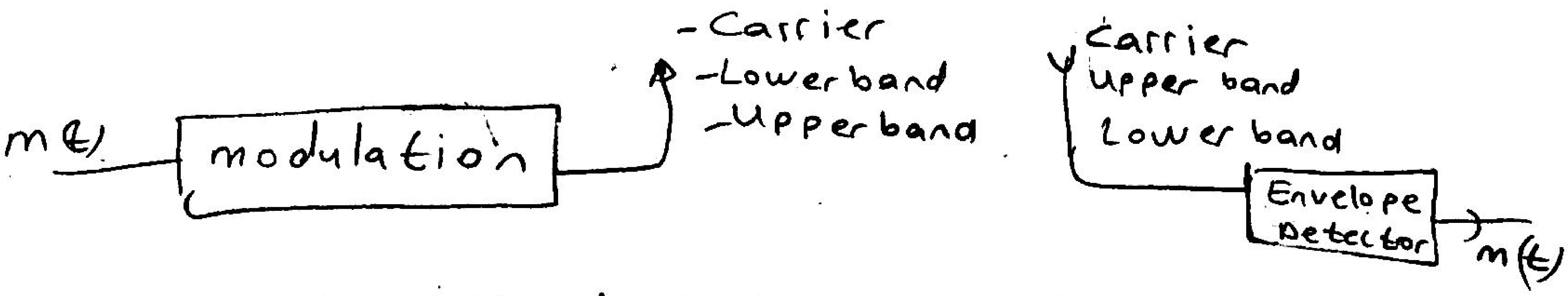


Figure 3.7 Envelope detector. (*a*) Circuit diagram. (*b*) AM wave input. (*c*) Envelope detector output.

Problems of Amplitude modulation

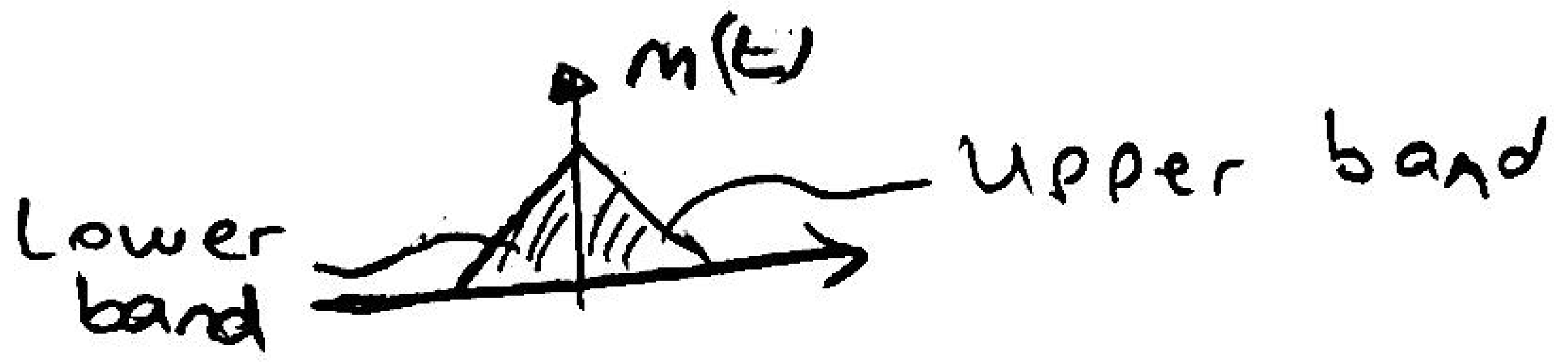


We need m(t) only.

Carrier Consumes <u>power</u>

Lower band and upper band <u>Occupy</u> bands and consume <u>power.</u>

We can carry only upper band or only lower band. Because Lower band and upper bands are symetrical.



Solution

1) Double side-band supressed carrier modulation

2) Vestigial side band modulation

3) Single side band modulation

Double Sided Supressed Carrier modulation

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

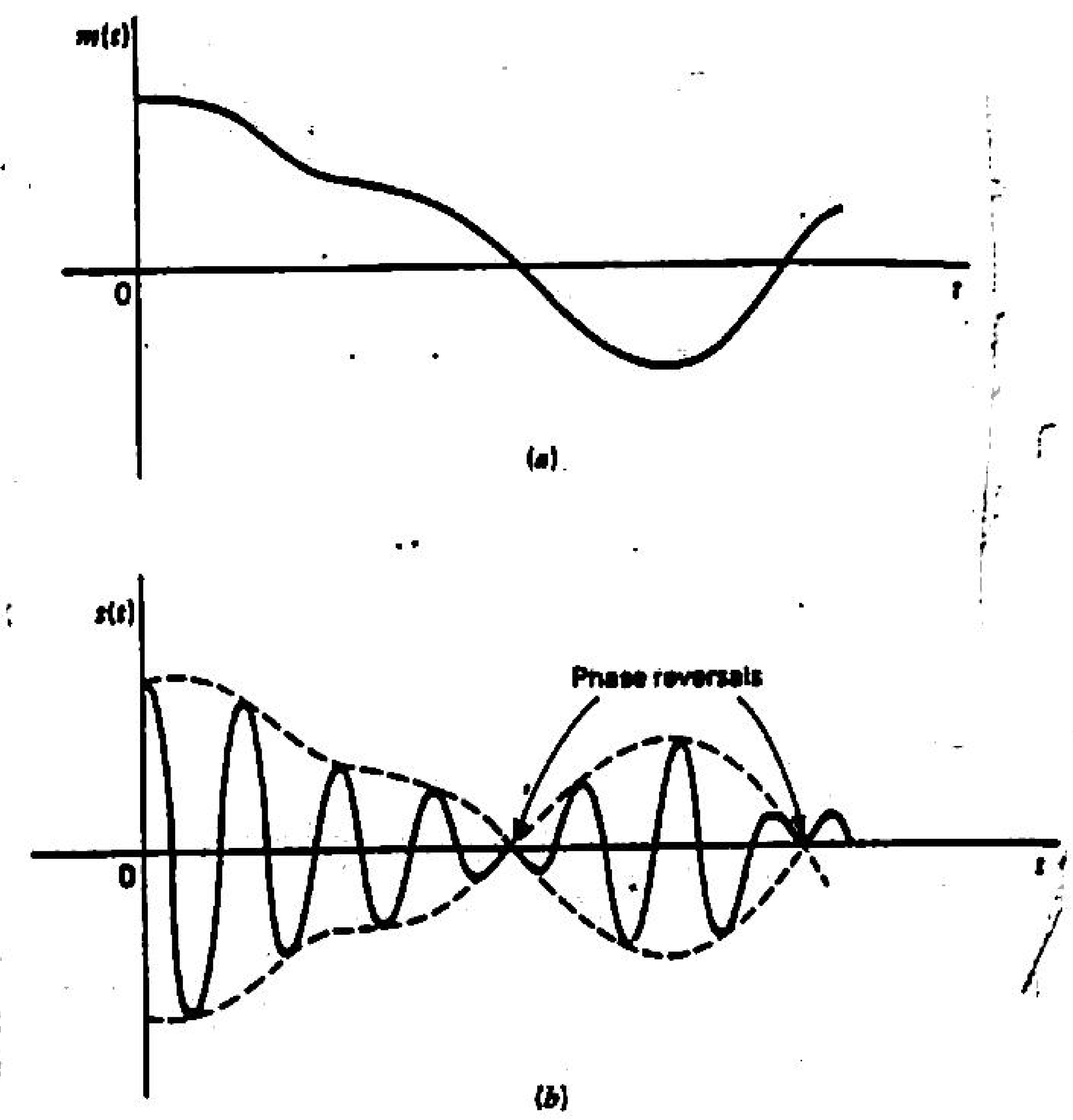


Figure 3.8 (a) Baseband signal. (b) DSB-SC modulated wave.

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

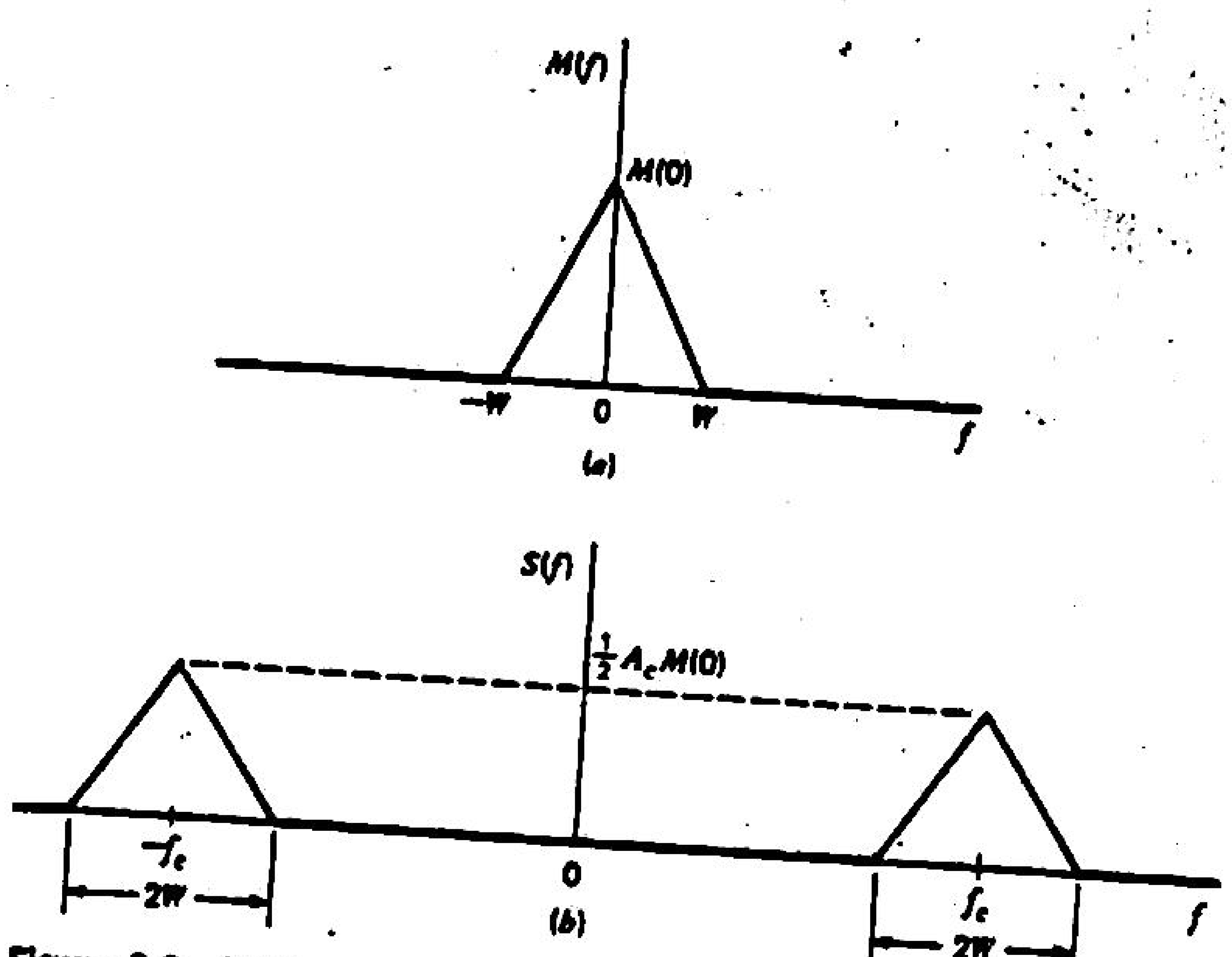
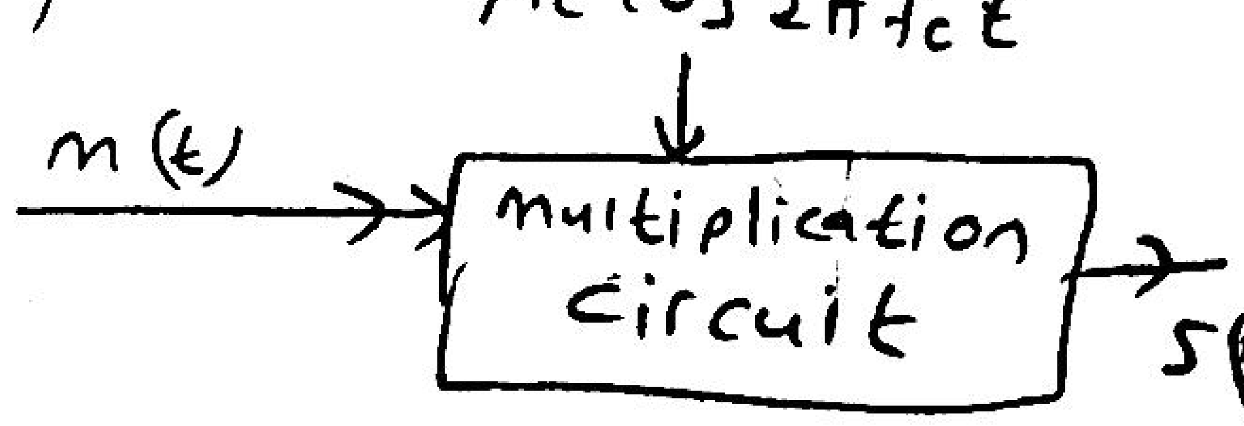


Figure 3.9 (a) Spectrum of baseband signal. (b) Spectrum of DSB-SC modulated wave.

How to obtain s(t)

1)



2) Ring modulator

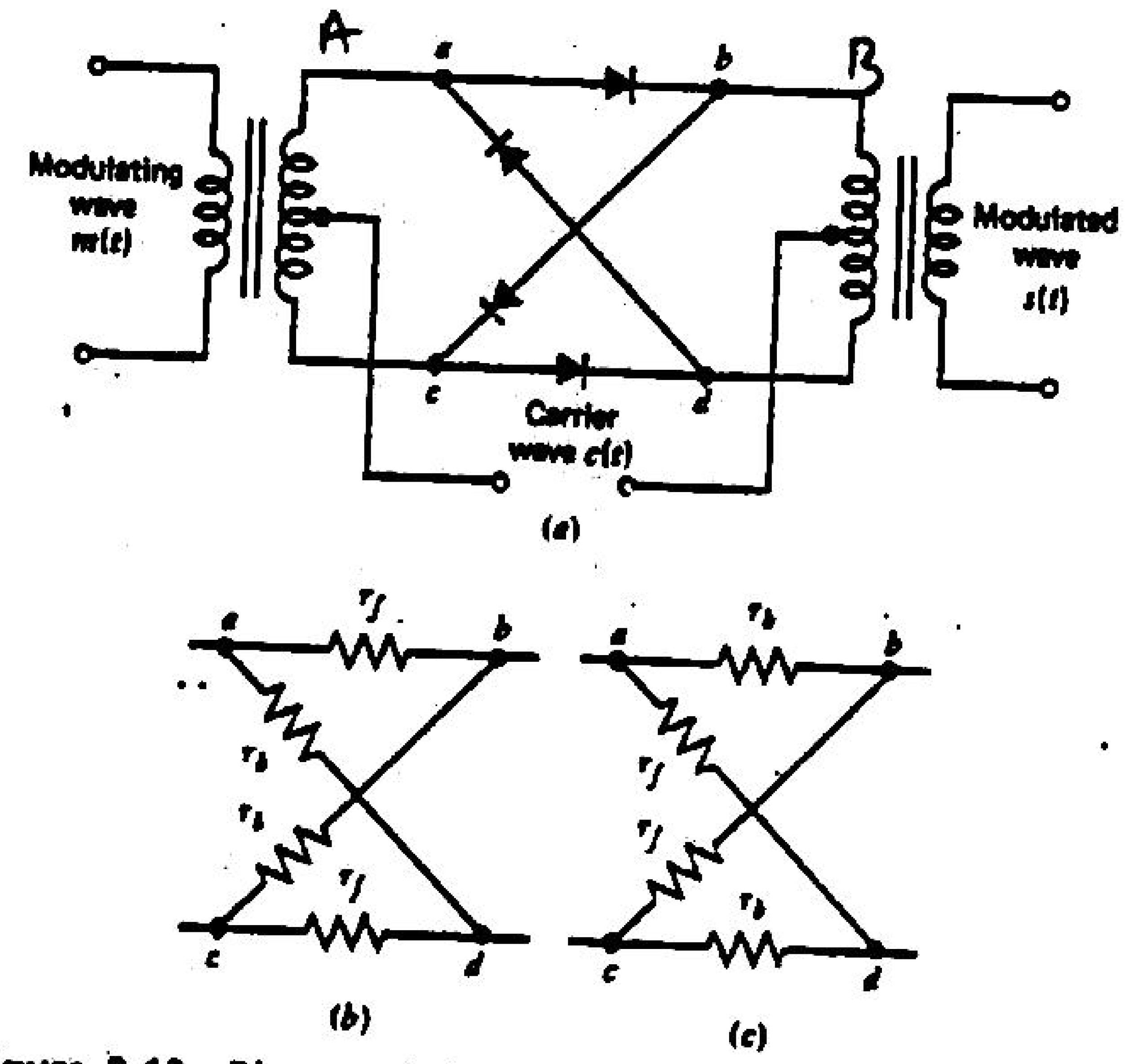
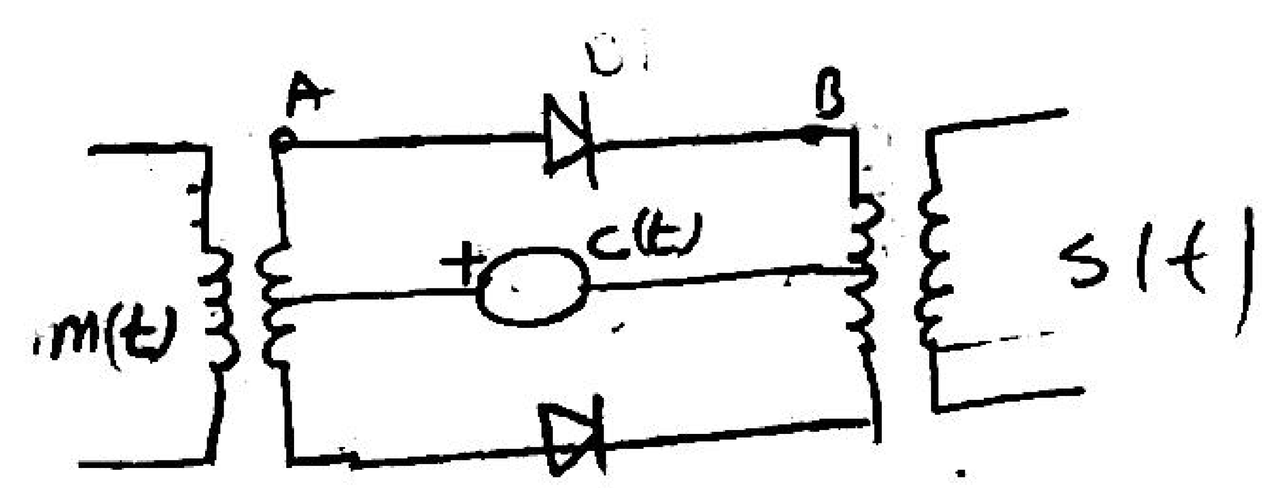
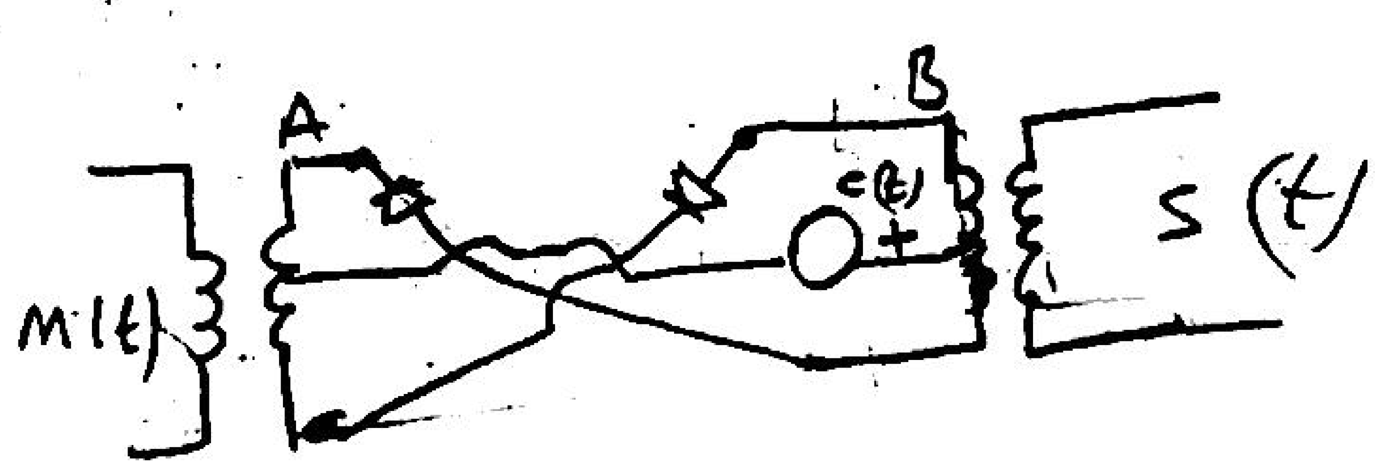


Figure 3.10 Ring modulator. (a) Circuit diagram. (b) Illustrating the condition when the outer diodes are switched on and the inner diodes are switched off. (c) Illustrating the condition when the outer diodes are switched off and the inner diodes are switched on.

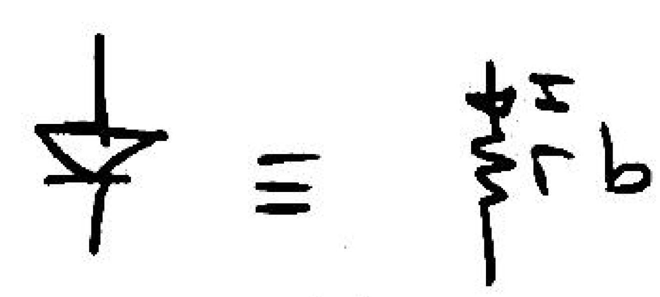


$V_A > V_B$



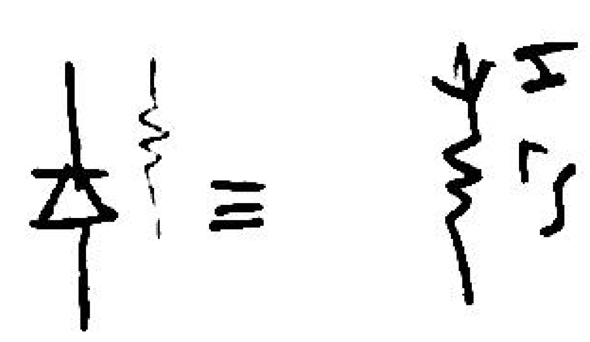
$V_B > V_A$

when a diode conducts



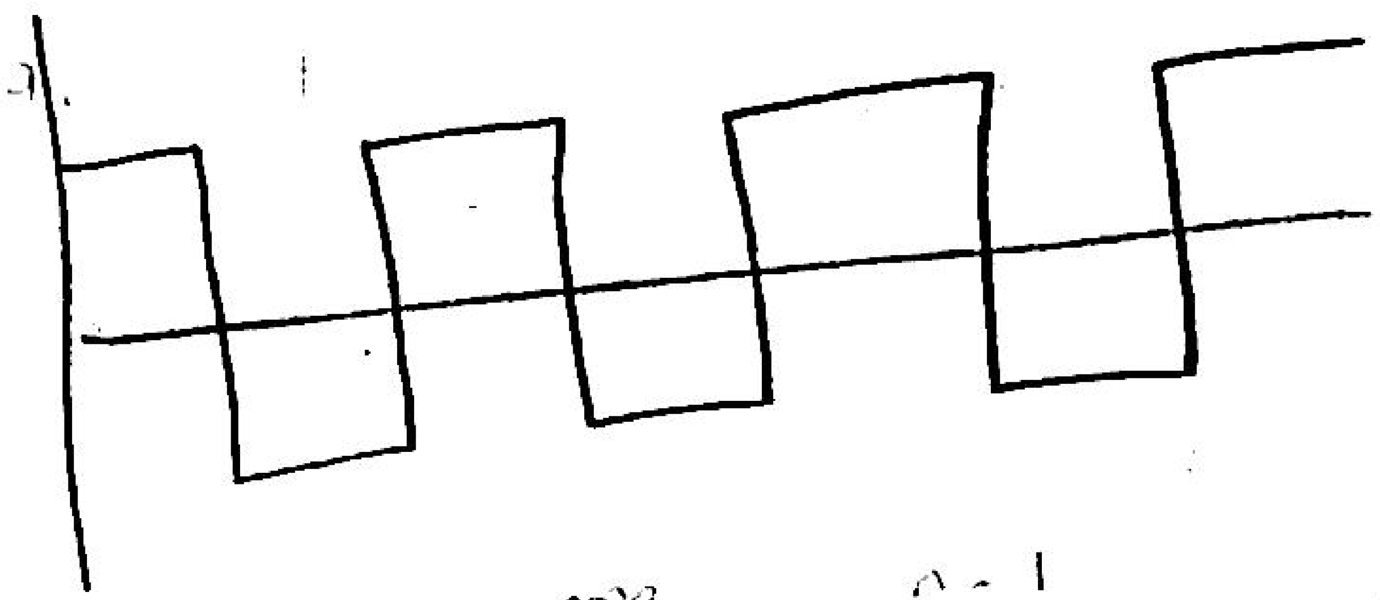
$r_b \doteq 0.1\,\Omega - 50\,\Omega$

when a diode reverse biased



$r_s = 10^6 - 10^{12}\,\Omega$ (very high

Carrier appears as Square wave:



$$c(t) = \frac{4}{\pi} \sum_{n=1}^{\infty} \frac{(-1)^{n-1}}{2n-1} \cos 2\pi f_c (2n-1)$$

$$s(t) = c(t)\, m(t)$$
$$= \frac{4}{\pi} \sum_{n=1}^{\infty} \frac{(-1)^{n-1}}{2n-1} \cos 2\pi f_c (2n-1) \cdot m(t)$$

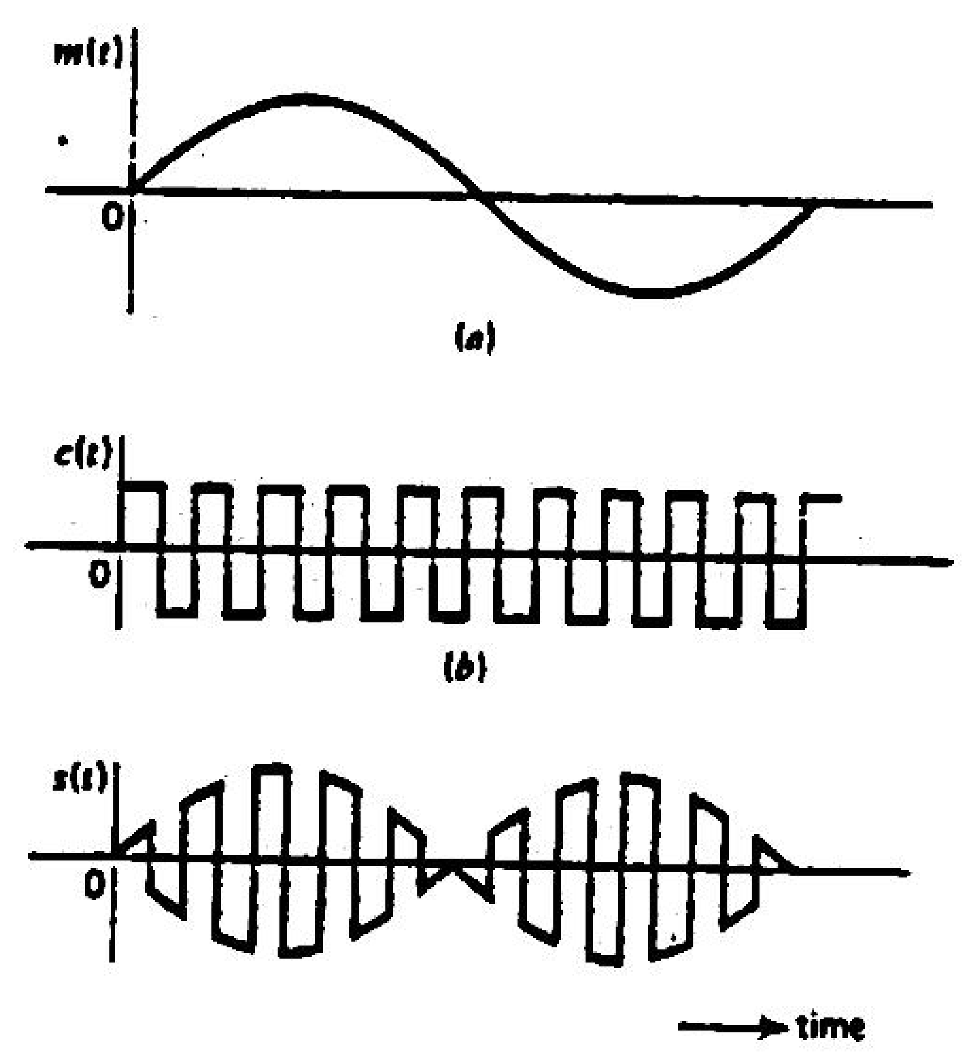


Figure 3.11 Waveforms illustrating the operation of the ring modulator for a sinusoidal modulating wave. (a) Modulating wave. (b) Square-wave carrier. (c) Modulated wave.

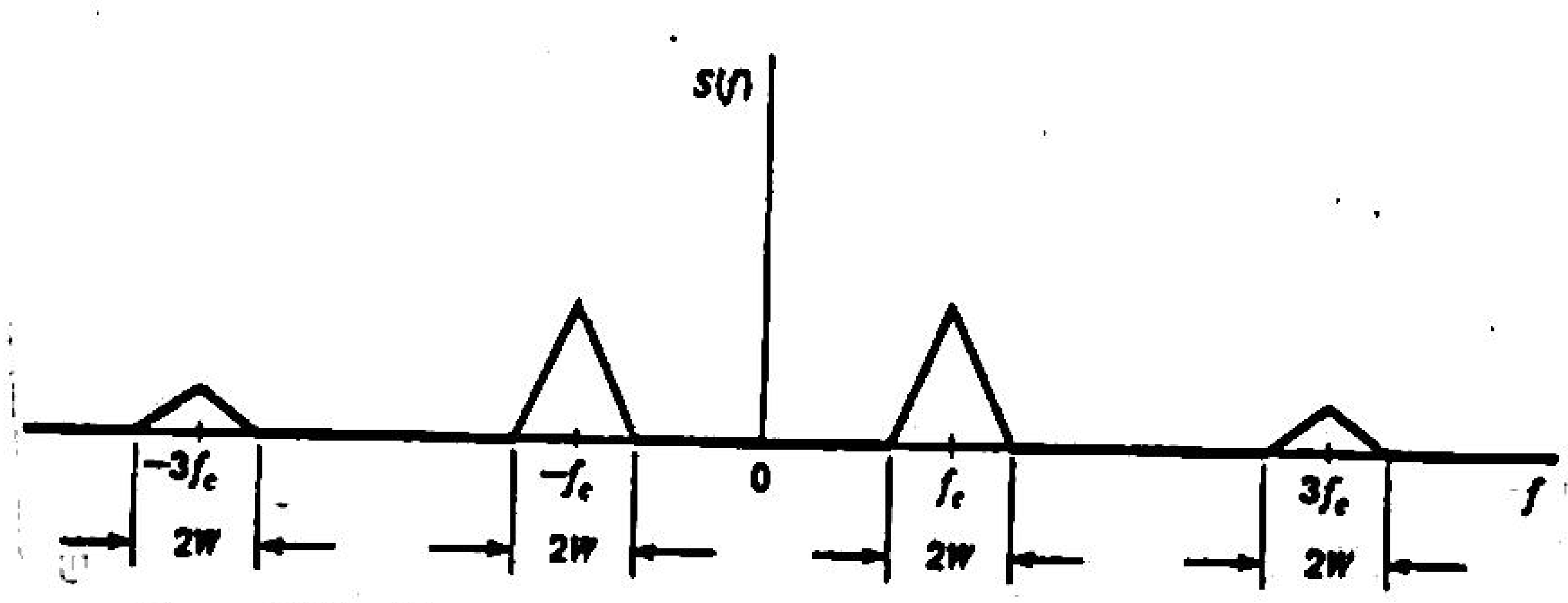


Figure 3.12 Illustrating the spectrum of ring modulator output.

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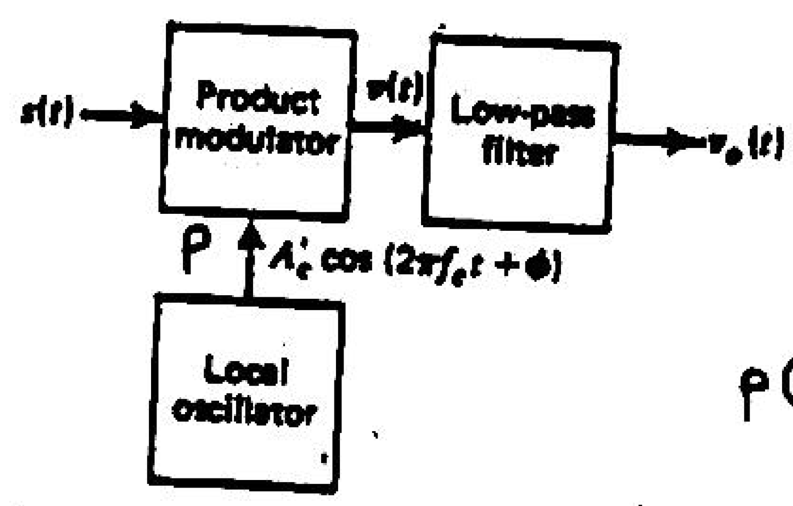
Coherent detection

when we receive $s(t)$ we assume we know f_c before. If we know f_c we use coherent detection



$p(t) = A_c' \cos(2\pi f_c t + \phi)$

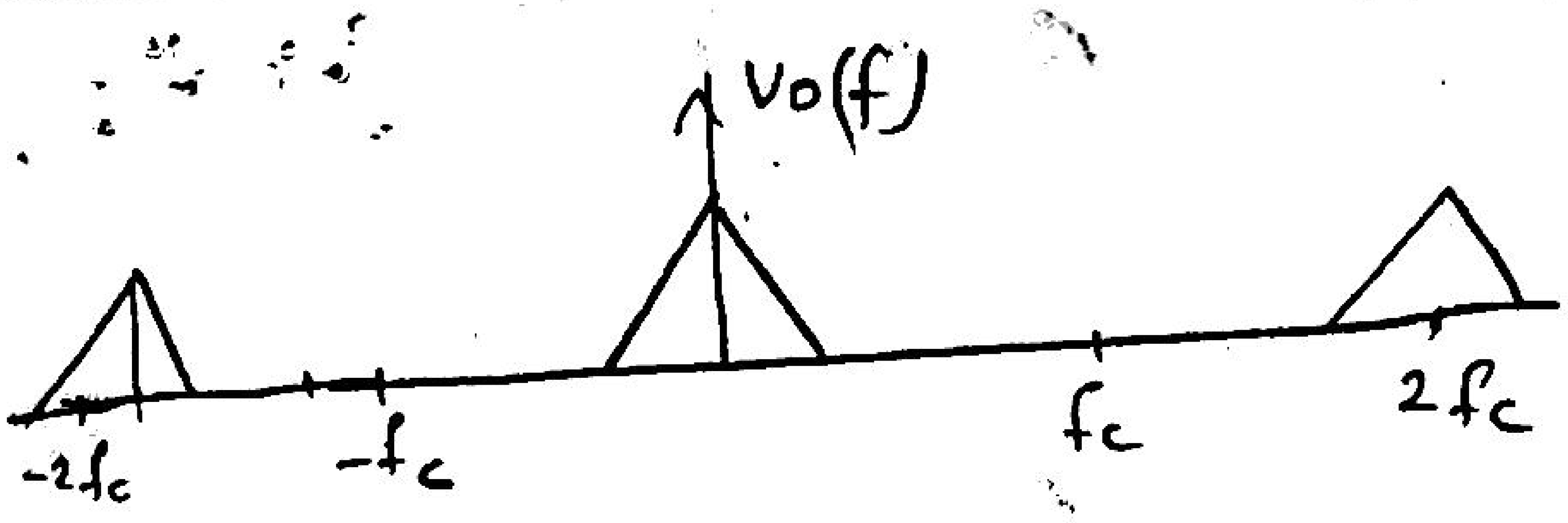
Figure 3.13 Coherent detection of DSB-SC modulated wave.

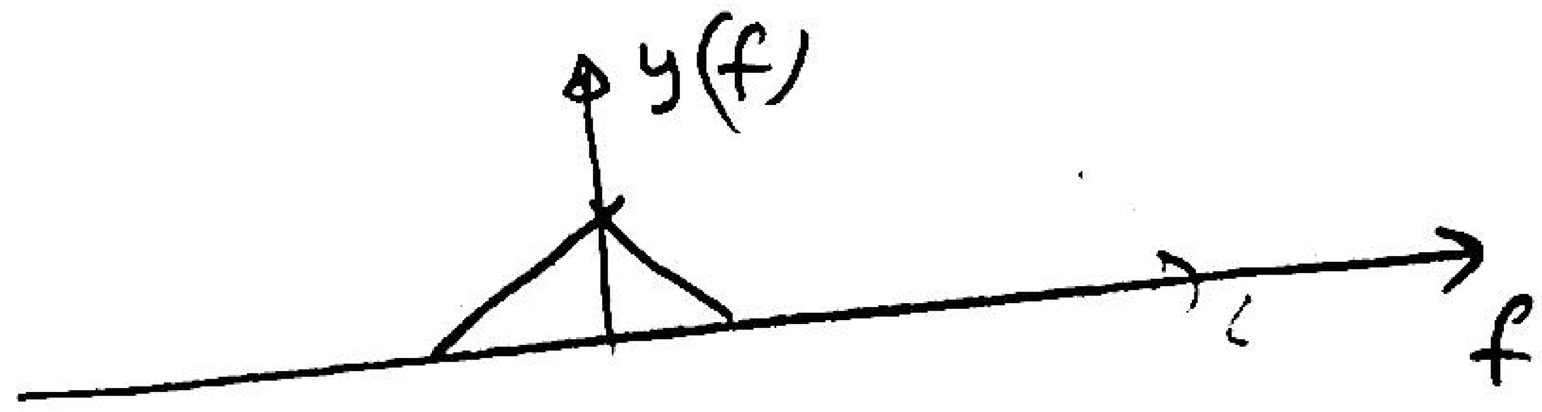
$$s(t) = c(t)\, m(t) = A_c \cos 2\pi f_c t\, m(t)$$

$$V_o(t) = s(t) \cdot p(t)$$

Local oscillator should produce sine wave with same frequency and phase of original carrier

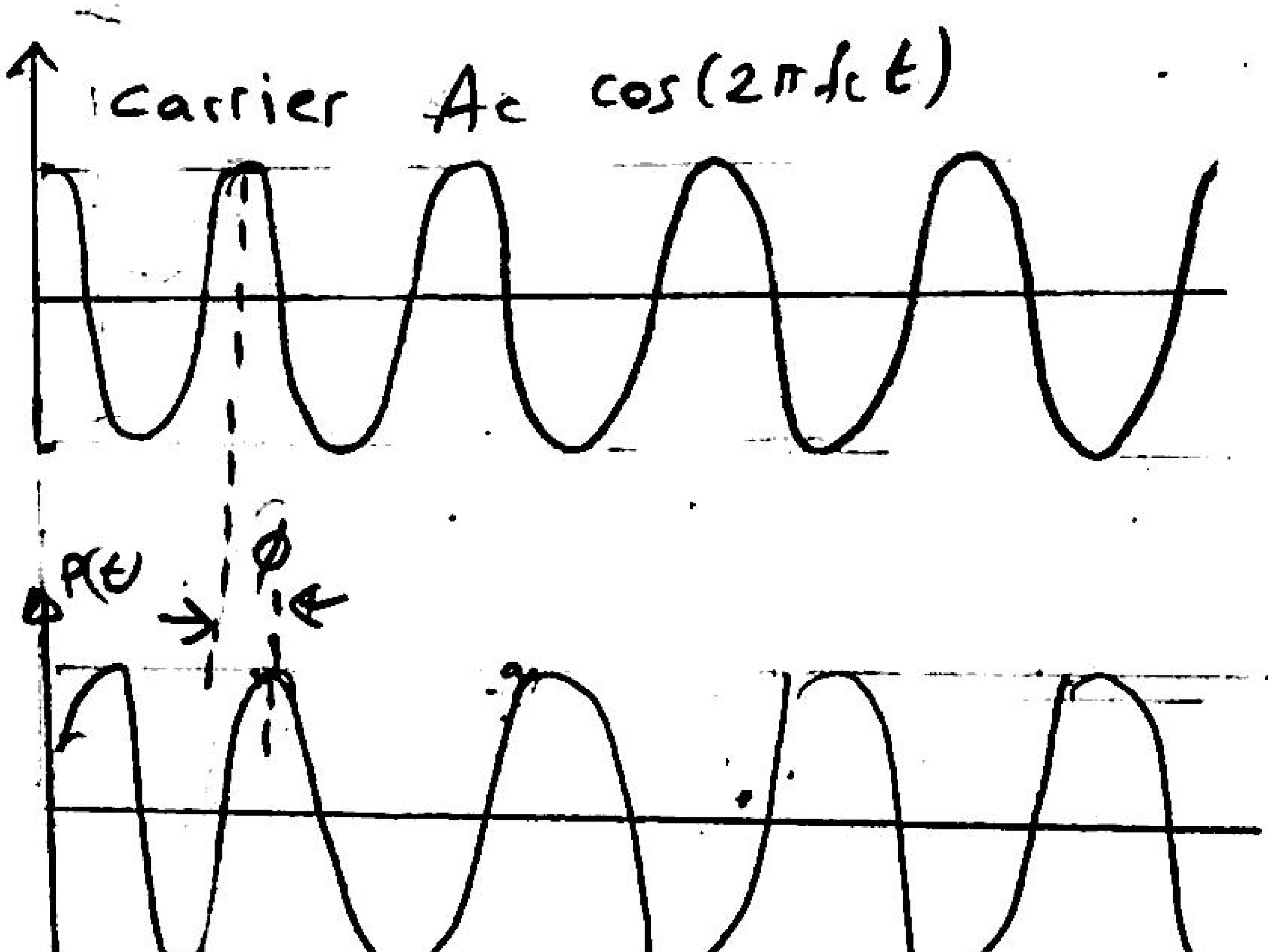
$$V_o(t) = s(t)\, p(t)$$
$$= \left[A_c \cos 2\pi f_c t\, m(t)\right] A_c' \cos(2\pi f_c t)$$
$$= m(t) \left[A_c A_c' \cos^2 2\pi f_c t\right]$$
$$= A_c A_c' m(t) \left(\frac{1}{2} + \frac{1}{2} \cos 2\pi 2 f_c t\right)$$
$$= \underbrace{\frac{A_c A_c'}{2} m(t)}_{\text{message Signal}} + \underbrace{m(t) \frac{A_c A_c'}{2} \cos 2\pi f_c 2t}_{\text{high frequency term.}}$$





In Practice it is impossible to obtain

$p(t) = A_c' \cos(2\pi f_c t)$



There is a phase difference between the carrier and locally produced p(t).

$$V_o(t) = s(t)\ p(t)$$

$$= [A_c \cos 2\pi f_c t\ m(t)]\ A_c' \cos(2\pi f_c t - \phi)$$

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

$$\cos A \cos B = \frac{1}{2}[\cos(A+B) + \cos(A-B)]$$

$$= A_c A_c' m(t) \frac{1}{2}[\cos(4\pi f_c t - \phi) + \cos\phi]$$

$$= \underbrace{\frac{A_c A_c'}{2} m(t) \cos\phi}_{\text{message signal}} + \underbrace{\frac{A_c A_c'}{2} m(t) \cos(4\pi f_c t - \phi)}_{\text{high frequency term}}$$

if ϕ = constant we can get m(t) easily

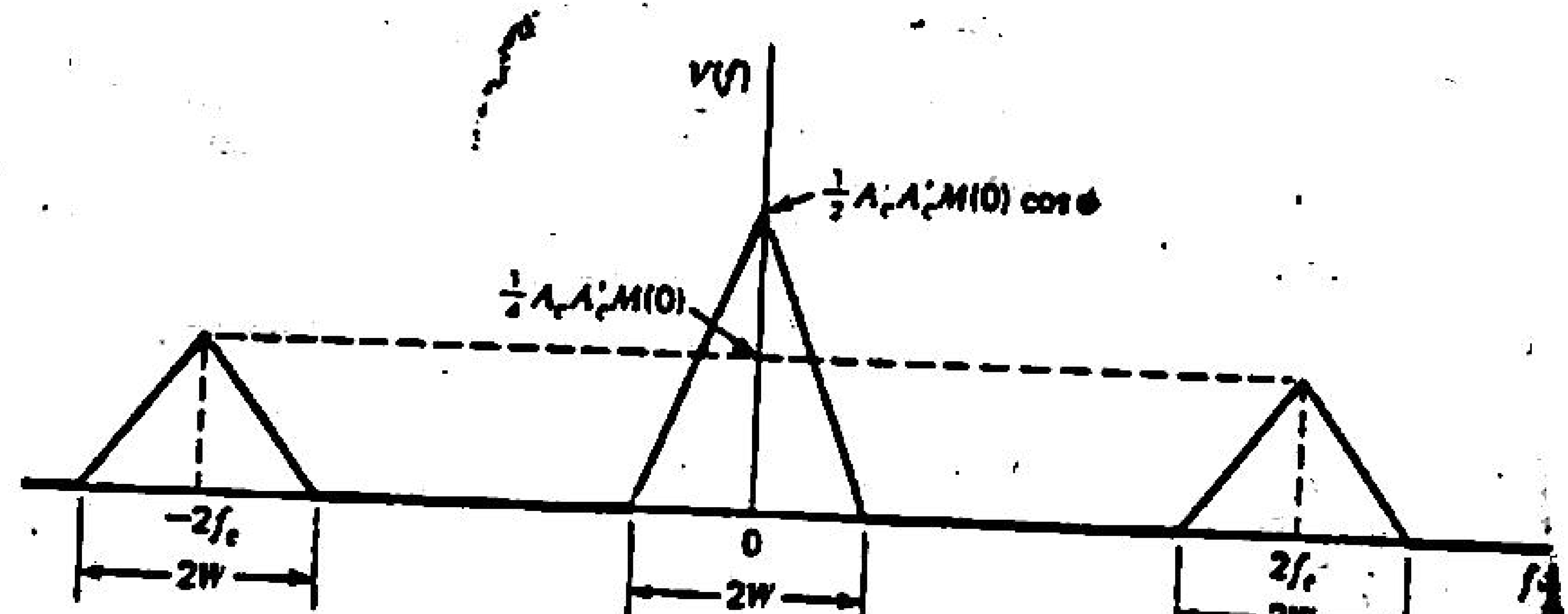
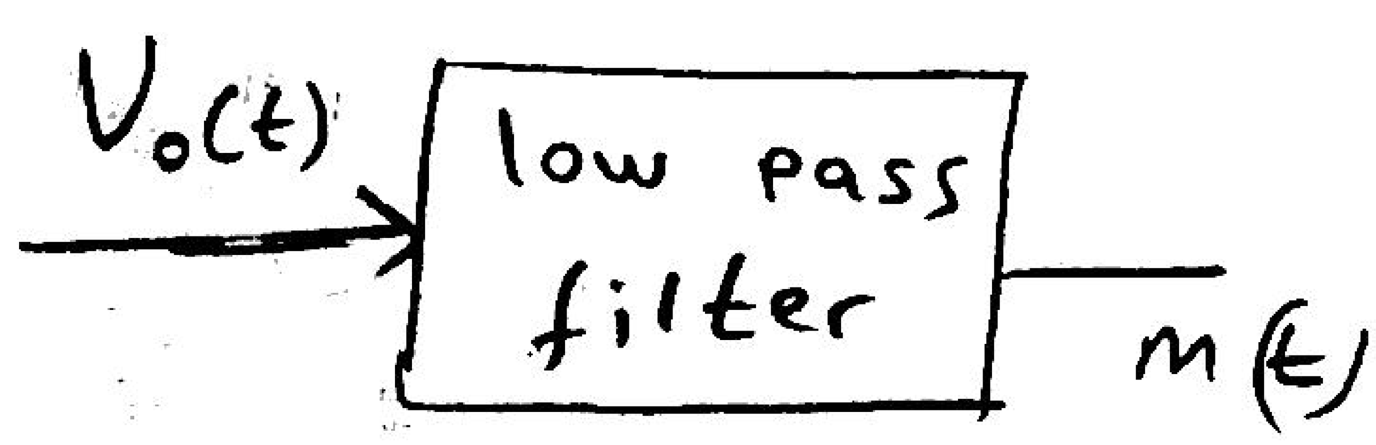


Figure 3.14 Illustrating the spectrum of a product modulator output with a DSB-SC modulated wave as input.



Costas Receiver

$$V_o(t) = \frac{A_c A_c'}{2} m(t) \cos\phi + \text{high frequency terms}$$

if $\phi =$ constant we easily get $m(t)$

In practice ϕ varies.

if $\phi = 0$ $\quad \cos\phi = 1$

$\phi = \frac{\pi}{2}$ $\quad \cos\phi = 0$ (No signal)

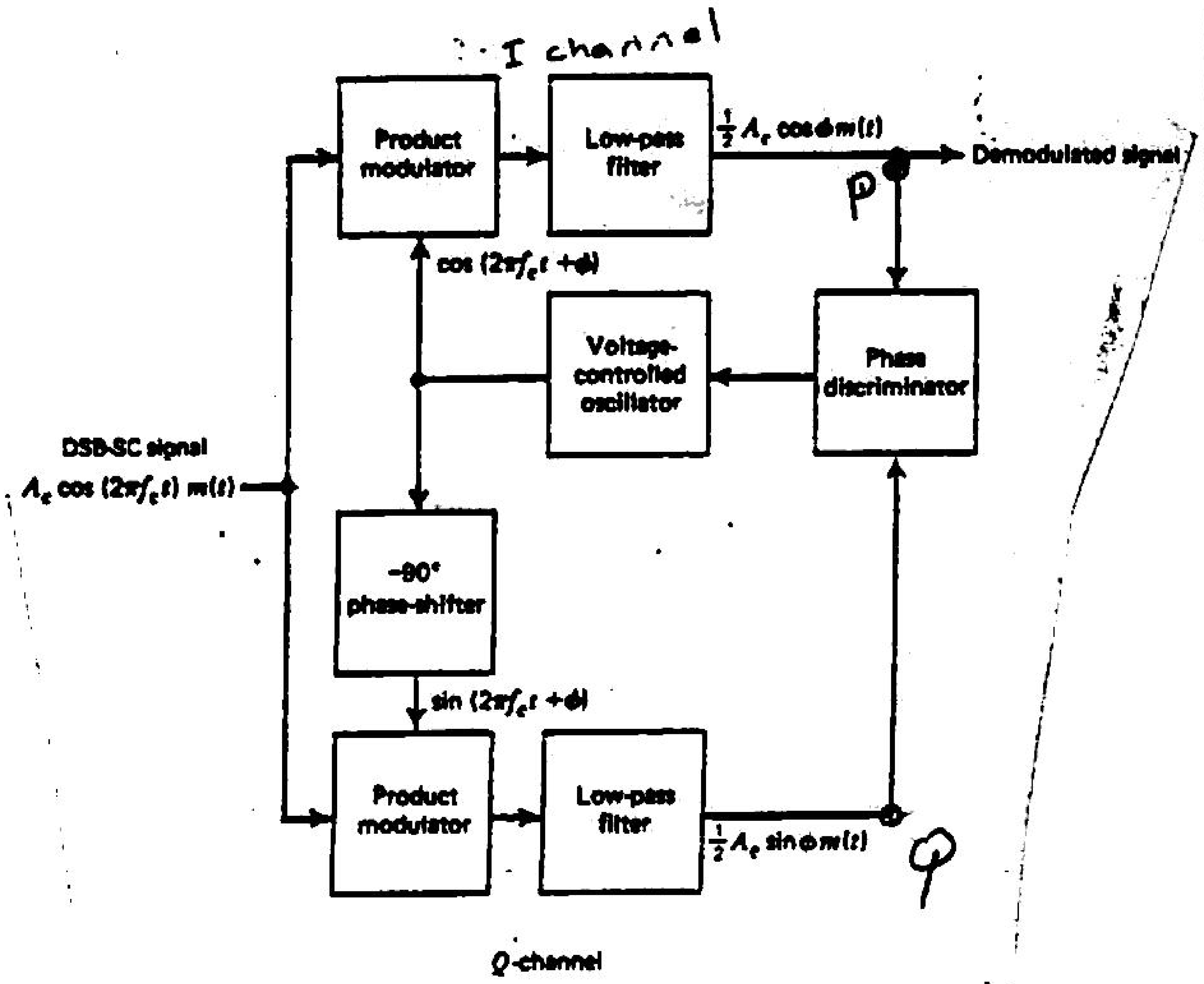


Figure 3.15 Costas receiver.

I channel is in phase with the carrier

φ channel is quadrature (90° difference) with the carrier.

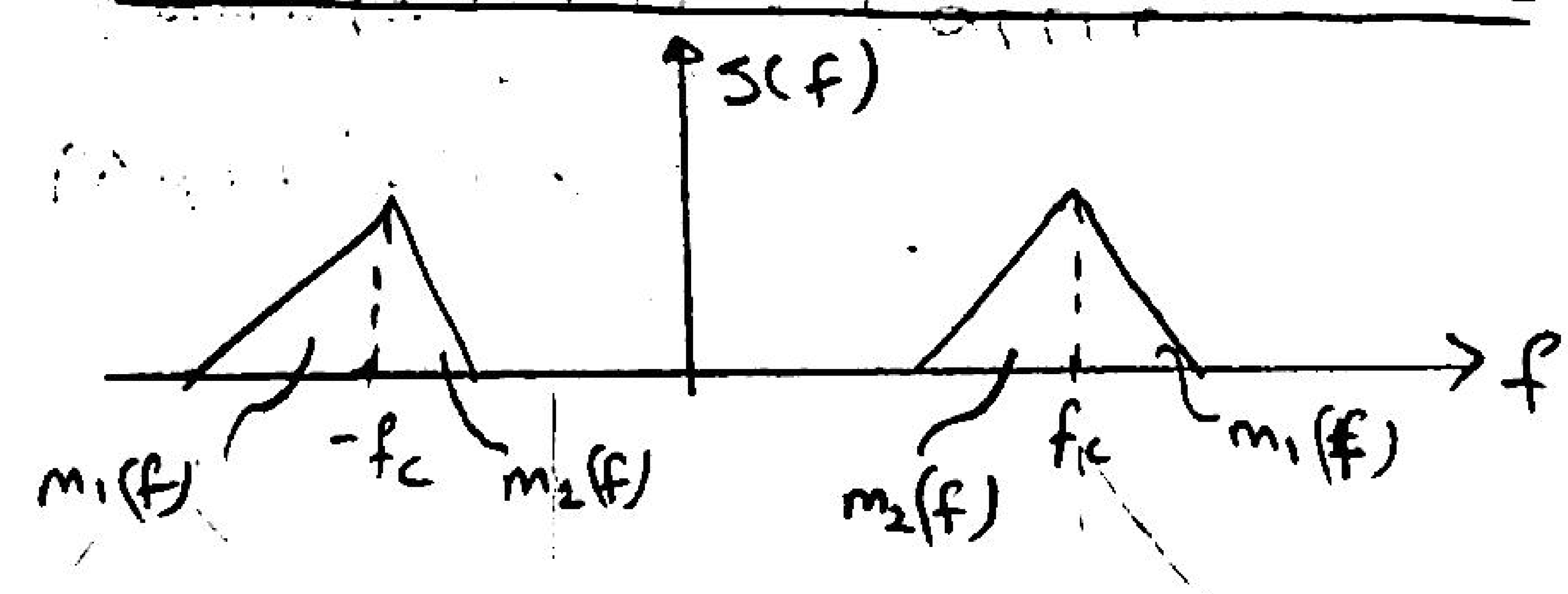
if carrier phase changes Then the output at P and φ changes.

Phase discriminator measures the phases of P and φ, and produces a dc voltage. This DC voltage is proportional to the phase shift ϕ.

This DC voltage is used by voltage controlled oscillator.

The feedback mechanism automaticaly changes the phase of the voltage controlled oscillator.

Quadrature Carrier Multiplexing



$$S(t) = A_c M_1(t)\cos 2\pi f_c t + A_c M_2(t)\sin 2\pi f_c t$$

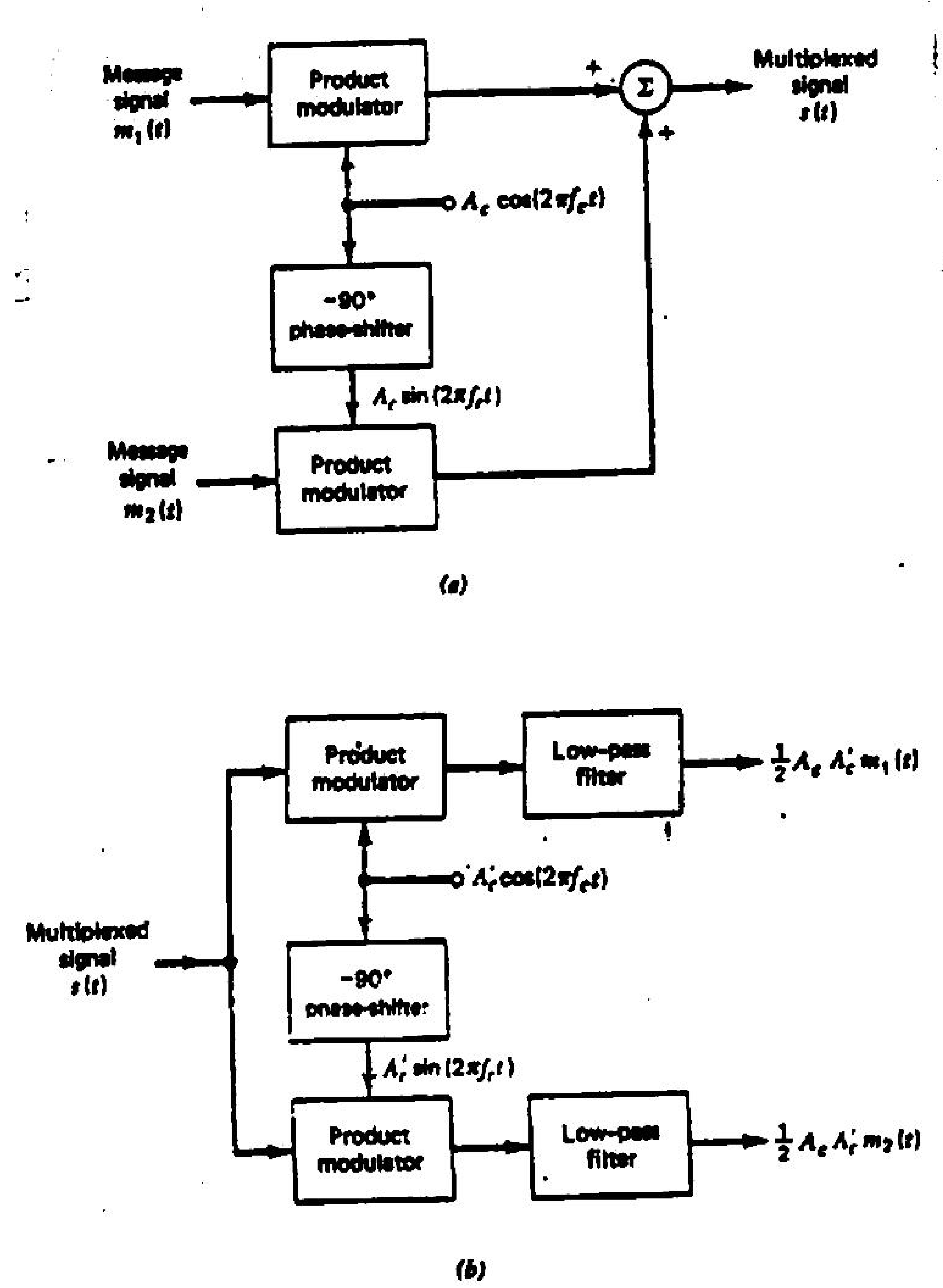
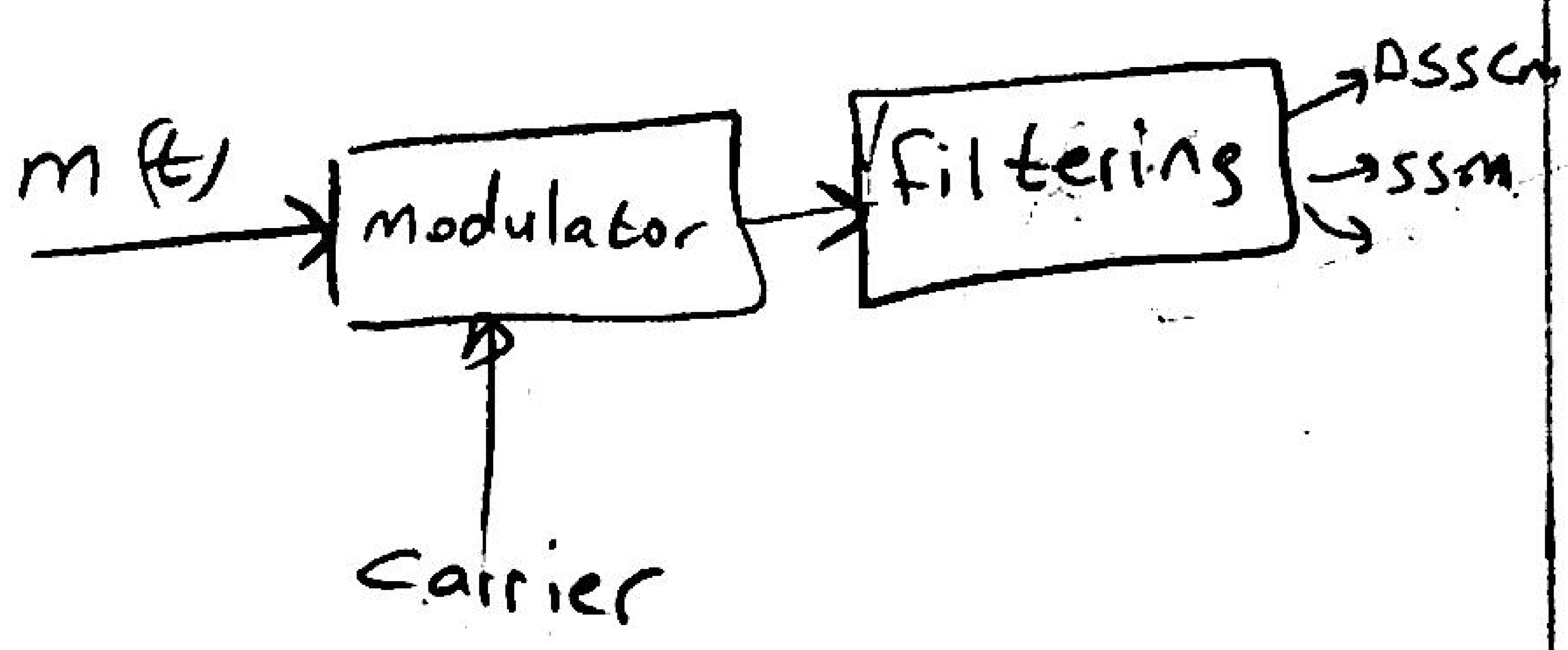
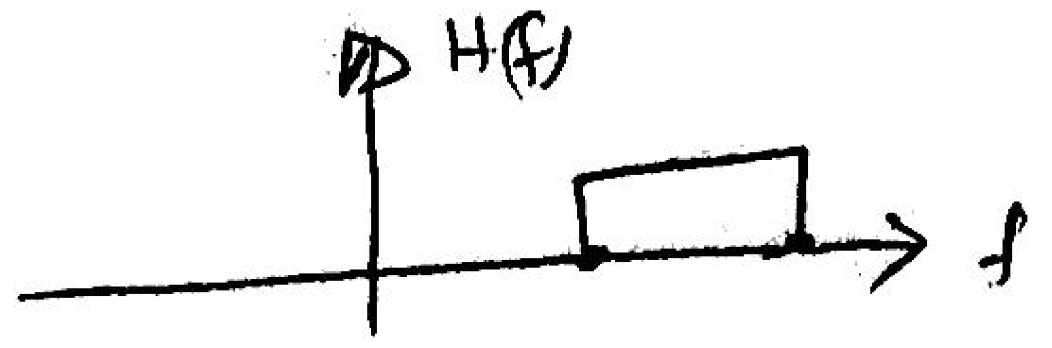


Figure 3.16 Quadrature–carrier multiplexing system. (a) Transmitter. (b) Receiver.

Filtering of sidebands



How do we design filters?



An ideal filter is impossible

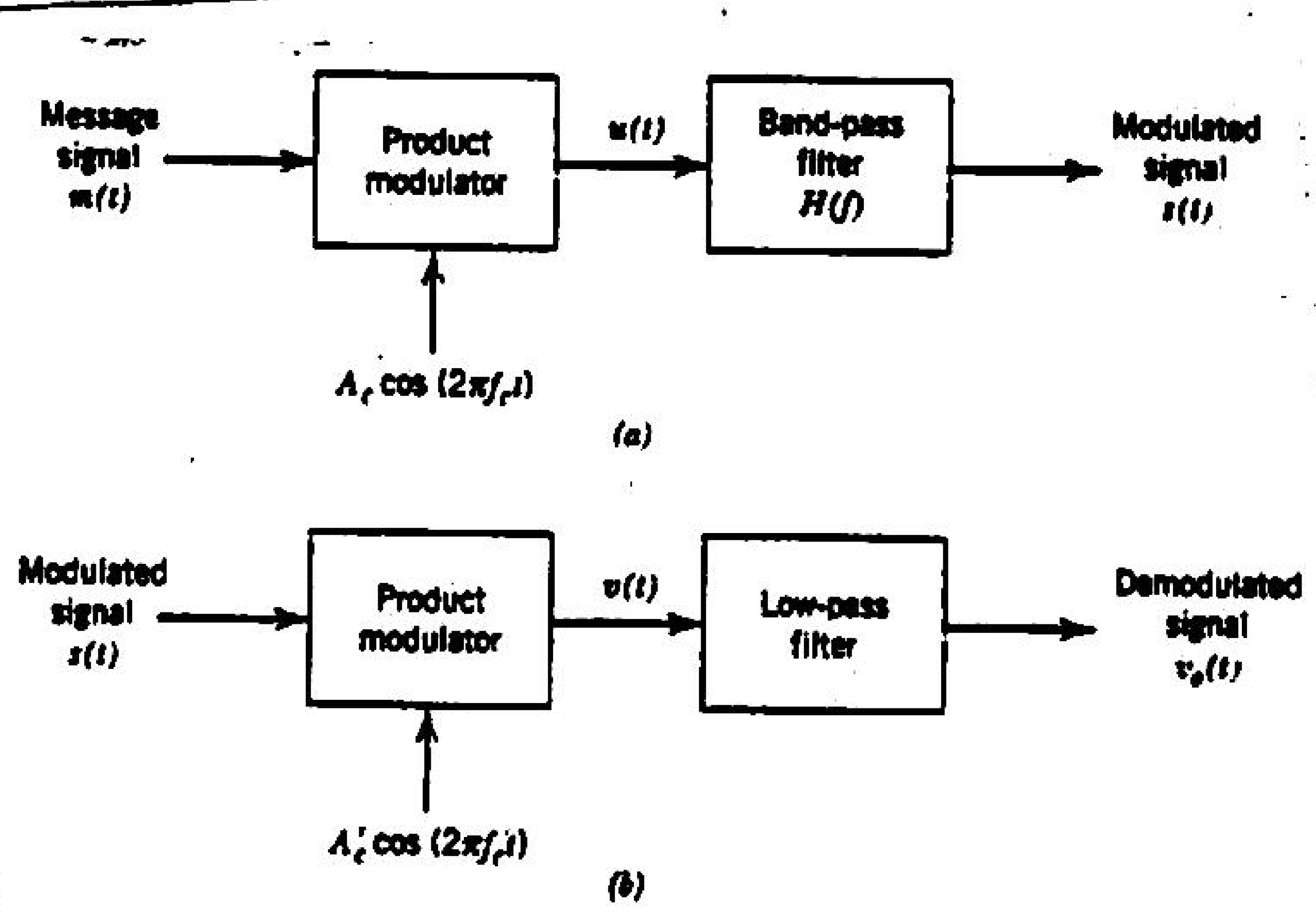


Figure 3.17 (a) Filtering scheme for processing sidebands. (b) Coherent detector for recovering the message signal.

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

$$U(f) = \frac{A_c}{2}\left[m(f-f_c) + m(f+f_c)\right]$$

$$s(f) = U(f)\; H(f)$$

$$= \frac{A_c}{2}\left[m(f-f_c) + (f+f_c)\right] H(f)$$

for coherent detectors

$$V(t) = A_c' \cos(2\pi f_c t)\; s(t)$$

$$V(f) = \frac{A_c'}{2}\left[S(f-f_c) + S(f+f_c)\right]$$

$$V(f) = \frac{A_c'}{2}\Big\{\Big[\frac{A_c}{2} m(f-f_c-f_c) + \frac{A_c}{2} m(f-f_c+f_c)\Big] H(f-f_c)$$

$$+ \frac{A_c}{2} m(f+f_c-f_c) + \frac{A_c}{2} m(f+f_c+f_c)\, H(f+f_c)\Big\}$$

$$= \frac{A_c' A_c}{4}\Big\{\left[m(f-2f_c) + m(f)\right] H(f-f_c)$$

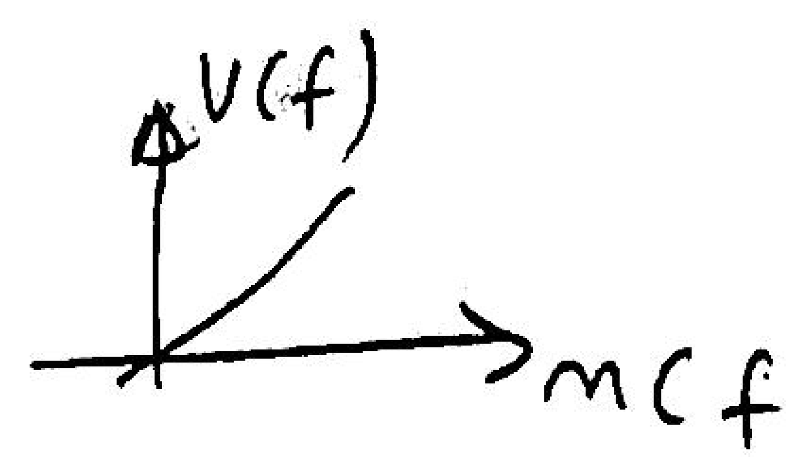
$$+ \left[m(f) + m(f+2f_c)\right] H(f+f_c)\Big\}$$

High frequency components are filtered by low-pass filter. Remaining terms.

$$V_o(f) = \frac{A_c' A_c}{4}\, m(f)\left\{H(f-f_c) + H(f+f_c)\right\}$$

We want Linear relationship

$$\boxed{V_o(f) = \alpha\, m(f)}$$



Result

$$H(f-f_c) + H(f+f_c) = \text{constant}$$
for $-W < f < W$

One selection

$$H(f-f_c) + H(f+f_c) = 2$$

then

$$V_o(f) = \frac{A_c' A_c}{4}\, m(f) \cdot 2 = \frac{A_c' A_c}{2}\, m(f)$$

$$V_o(f) = \frac{A_c' A_c}{2} M(f)$$

$$s(t) = s_I(t)\cos(2\pi f_c t) - s_Q(t)\sin(2\pi f_c t)$$

$s_I(t)$ = In phase Component

$s_Q(t)$ = Quadrature component

$$s_I(f) = \begin{cases} s(f-f_c) + s(f+f_c) & -w<f<w \\ 0 & \text{else} \end{cases}$$

Since

$$s(f) = U(f)\, H(f)$$

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

$$s(f-f_c) = \frac{A_c}{2}\left[M(f-f_c-f_c) + M(f-f_c+f_c)\right] H(f-f_c)$$

$$S(f+f_c) = \frac{A_c}{2}\left[M(f+f_c-f_c) + M(f+f_c+f_c)\right] H(f+f_c)$$

$$s_I(f) = S(f-f_c) + S(f+f_c)$$

$$= \frac{A_c}{2} M(f)\, H(f-f_c) + \frac{A_c}{2} M(f)\, H(f+f_c)$$

$$= \frac{1}{2} A_c M(f)\left[H(f-f_c) + H(f+f_c)\right)$$

Note $M(f-2f_c) = 0$

$M(f+2f_c) = 0$

Because $M(f) = 0$

Outside $-w<f<w$

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We Assume that

$$H(f-f_c) + H(f+f_c) = \text{constant}$$
$$= 1$$

$$s_I(f) = \frac{1}{2} A_c M(f) \quad -w<f<w$$

In time domain

$$\boxed{s_I(t) = \frac{1}{2} A_c\, m(t)}$$

In a similar method

$$s_Q(t) = \frac{1}{2} A_c\, m'(t)$$

$$m(f) \longrightarrow \boxed{H_Q(f)} \longrightarrow m'(f)$$

$$H_Q(f) = j\left[H(f-f_c) - H(f+f_c)\right]$$

$$s(t) = \frac{A_c}{2}\left[m(t)\cos(2\pi f_c t) - m'(t)\sin(2\pi f_c t)\right]$$

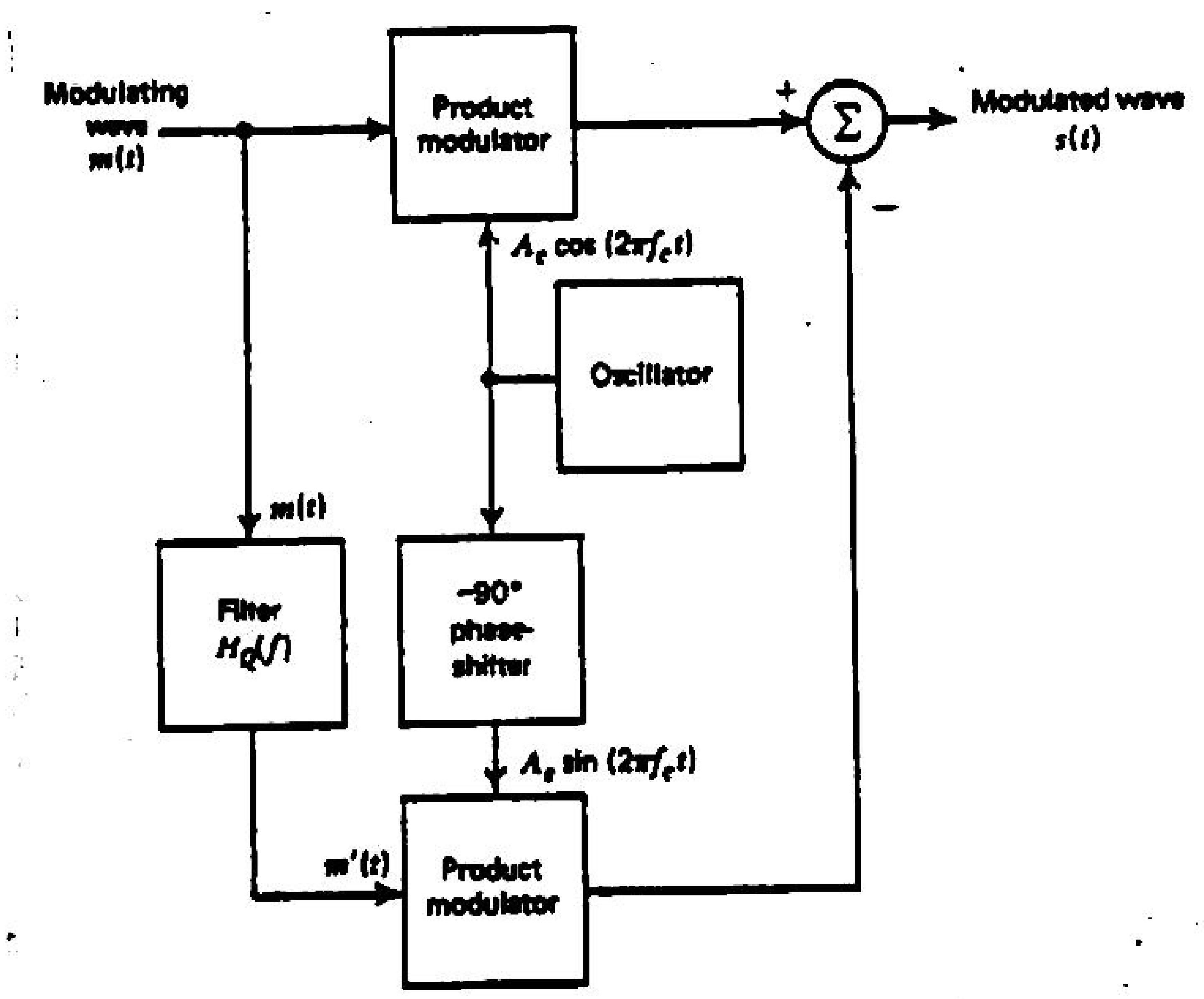
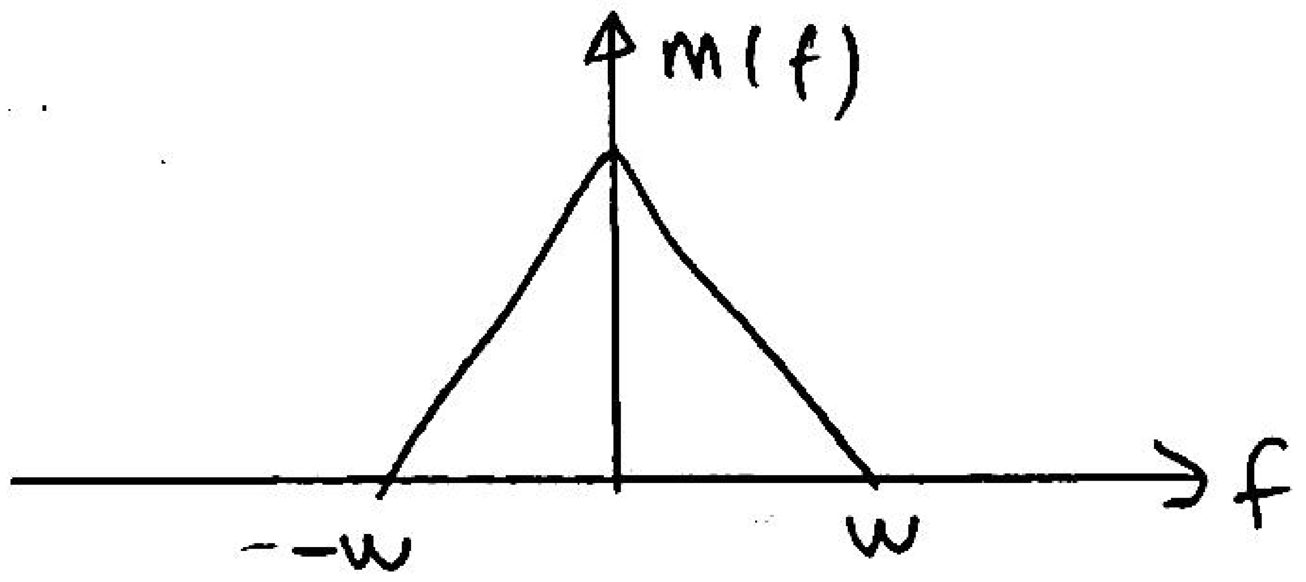
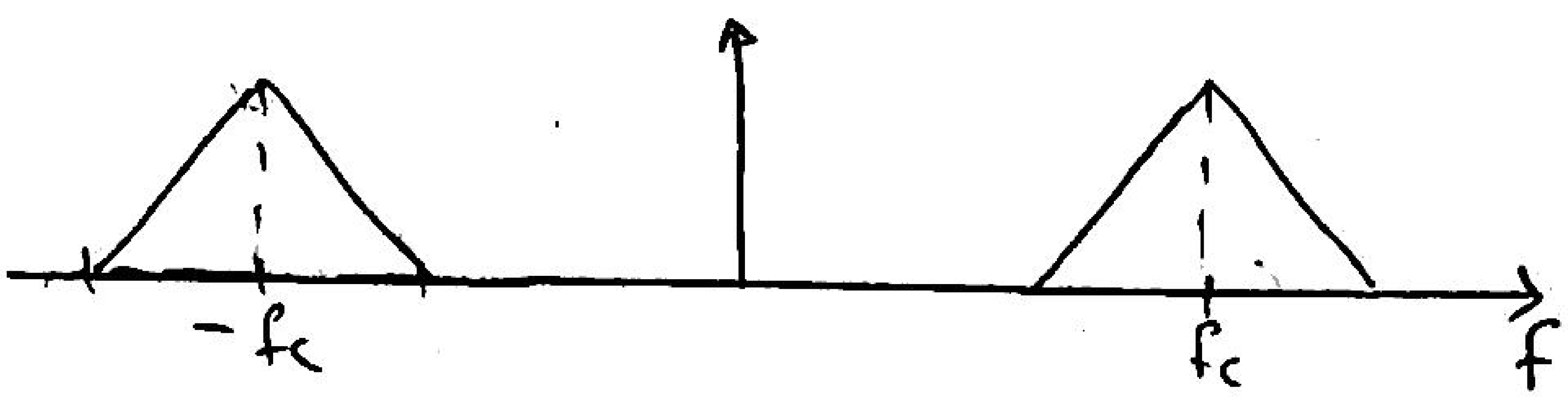


Figure 3.18 Block diagram of phase discrimination method for processing sidebands.

Vestigial side band Modulat





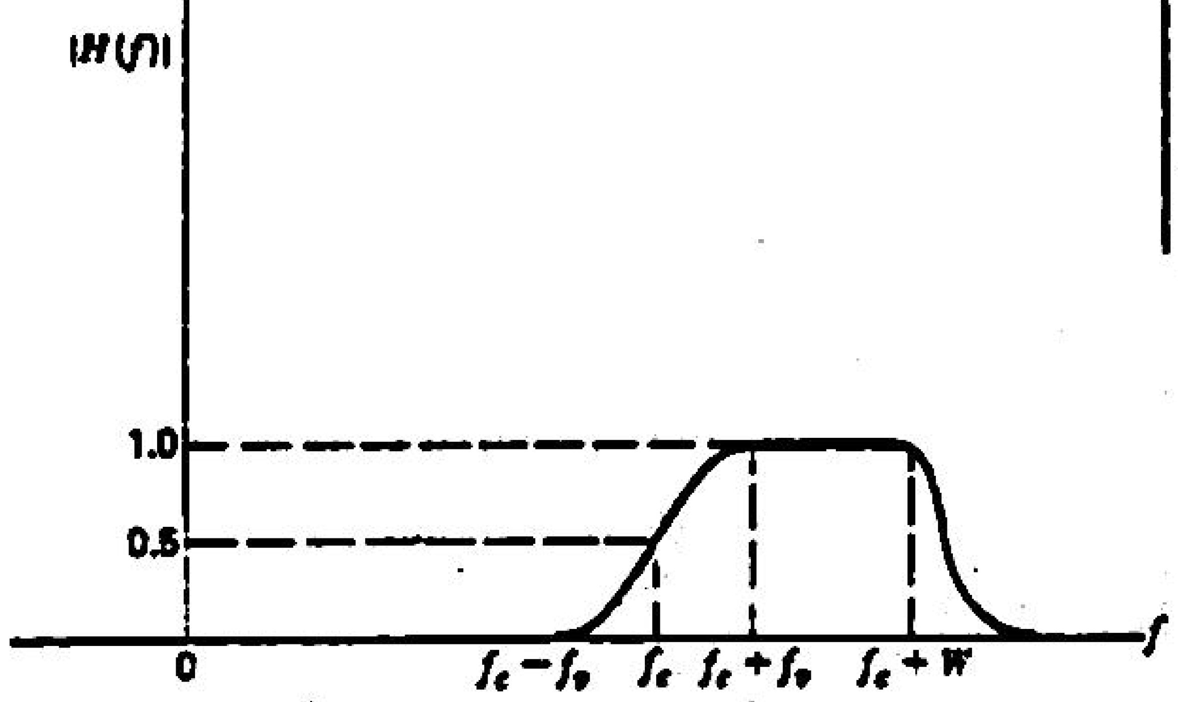


Figure 3.19 Amplitude response of VSB filter; only positive-frequency portion is shown.

$f_c - f_v < f < f_c + f_v$ belongs to the lower frequency components.

Vestigial sideband modulation is used where Lower freqencies are very important, such as TV signals.

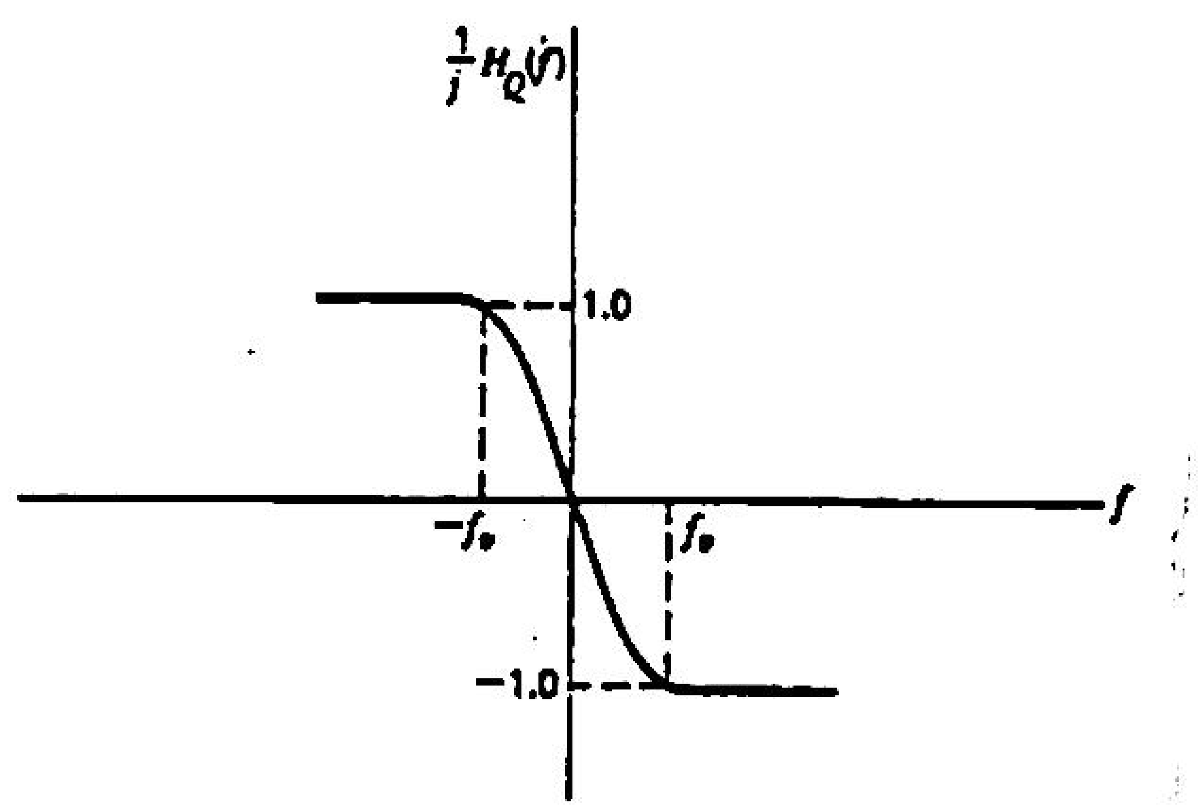


Figure 3.20 Frequency response of filter for producing the quadrature component of the VSB wave.

Television signals.

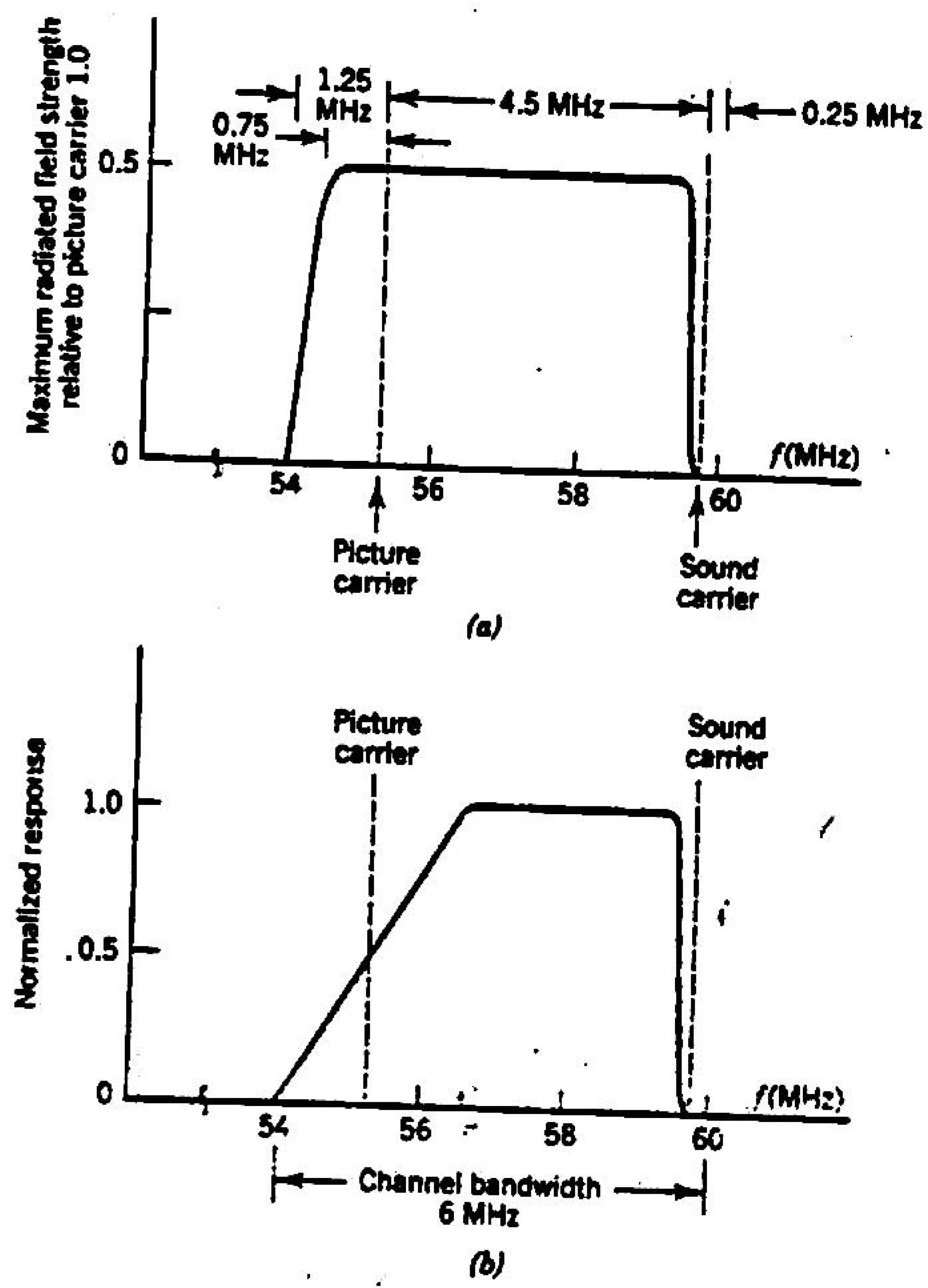
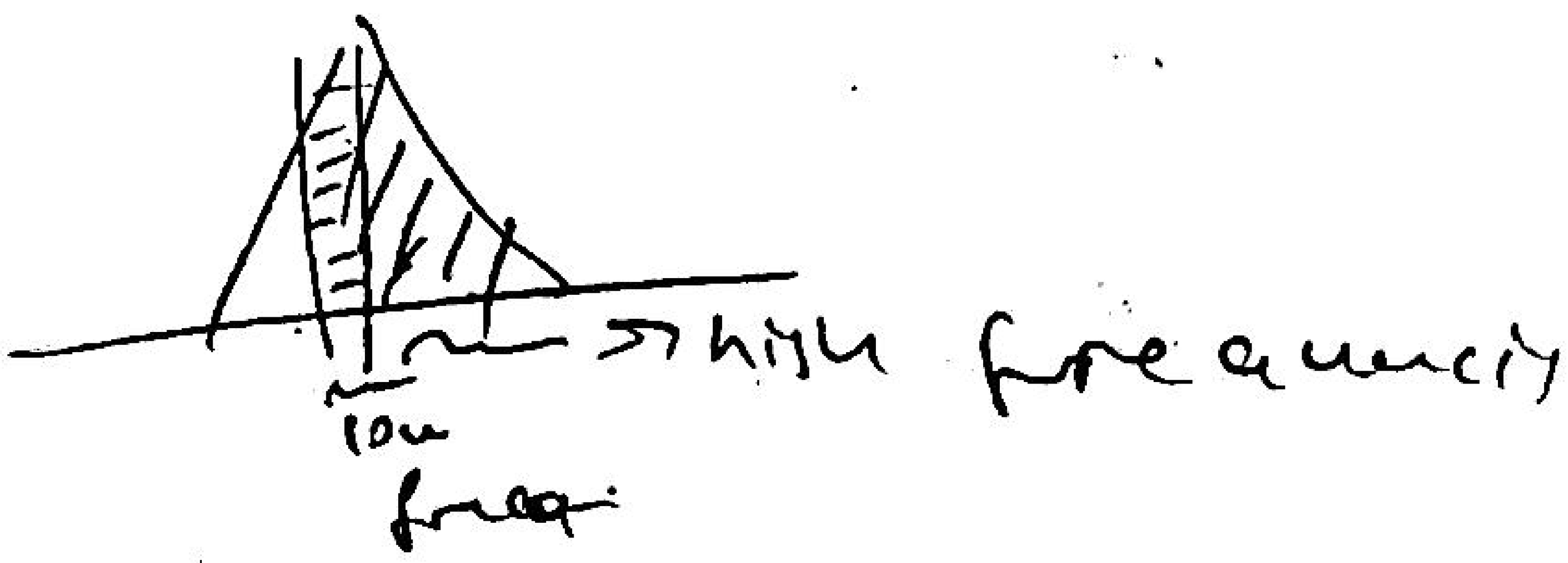


Figure 3.21 (a) Idealized amplitude spectrum of a transmitted TV signal. (b) Amplitude response of VSB shaping filter in the receiver.

in vestigial side band Mod.

upper side band and some portion of lower side band is transmitted



B if lower frequencies are important such as TV signals.

High frequencies are transmitted only upper
lower " are " lower and upper band.

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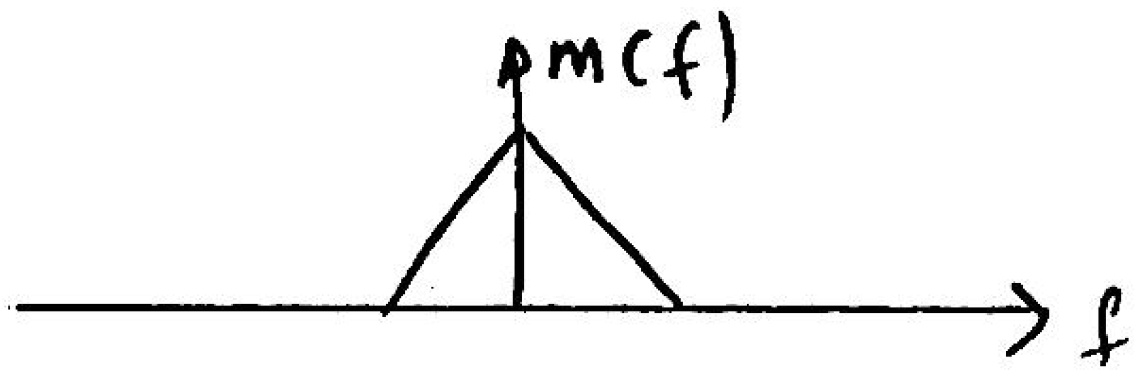
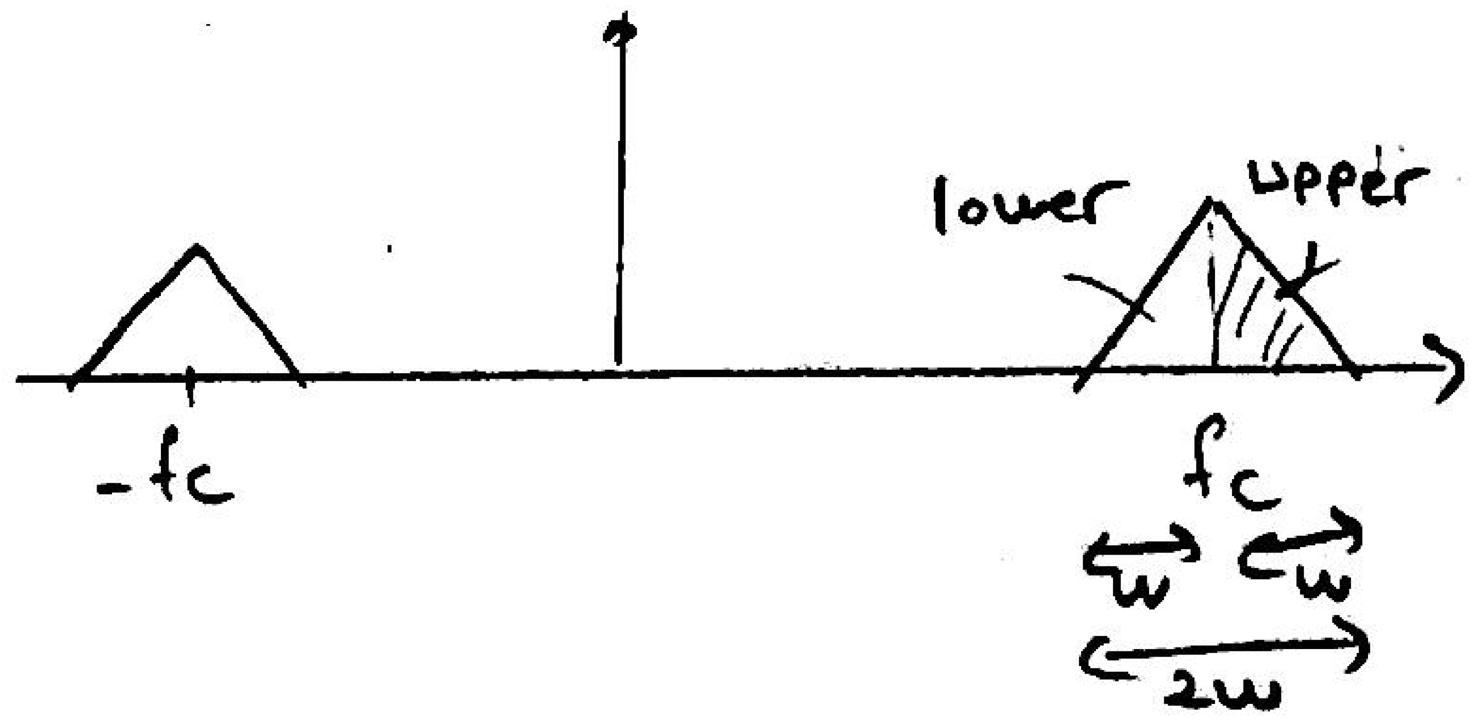
Single side band Modul.





We transmit only upper or only lower sideband.

We transmit bandwidth of W only not 2w.

More bandwidth requires more power.

Main problem is seperation of upper and Lower bands.

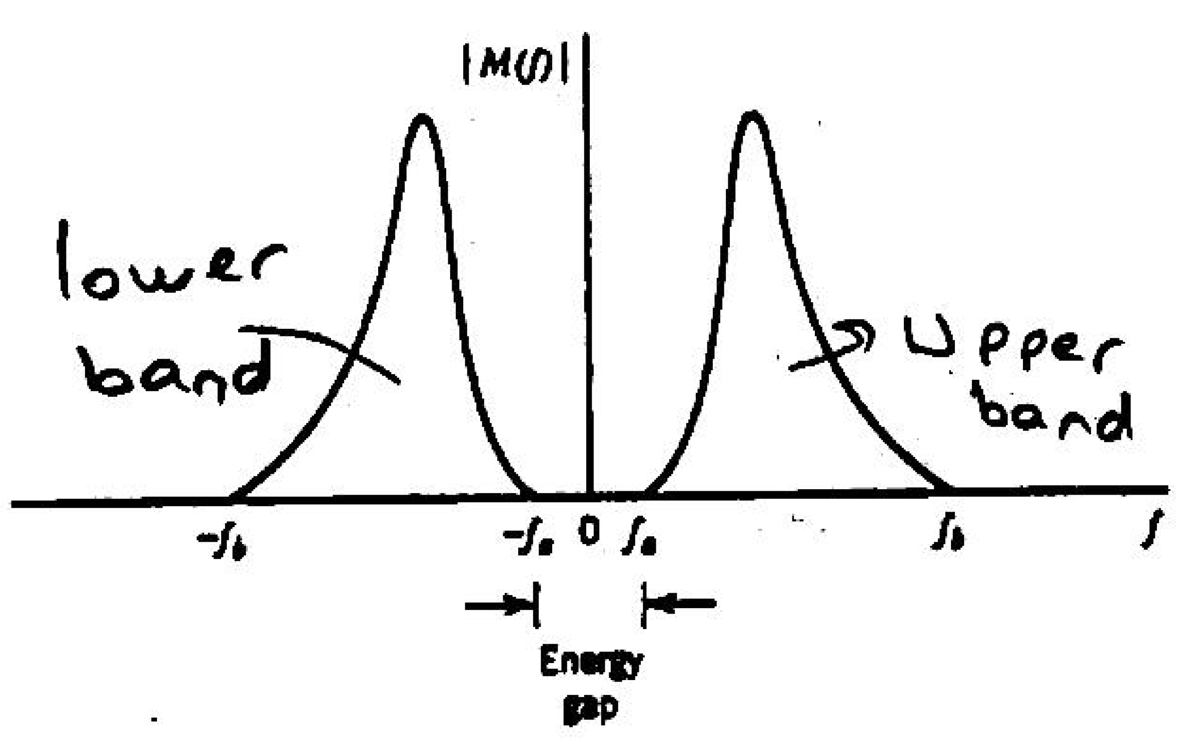


Figure 3.22 Spectrum of a message signal $m(t)$ with an energy gap centered around the origin.

For speech signals.

$fa = 300$ hz so energy gap is 600 hz.

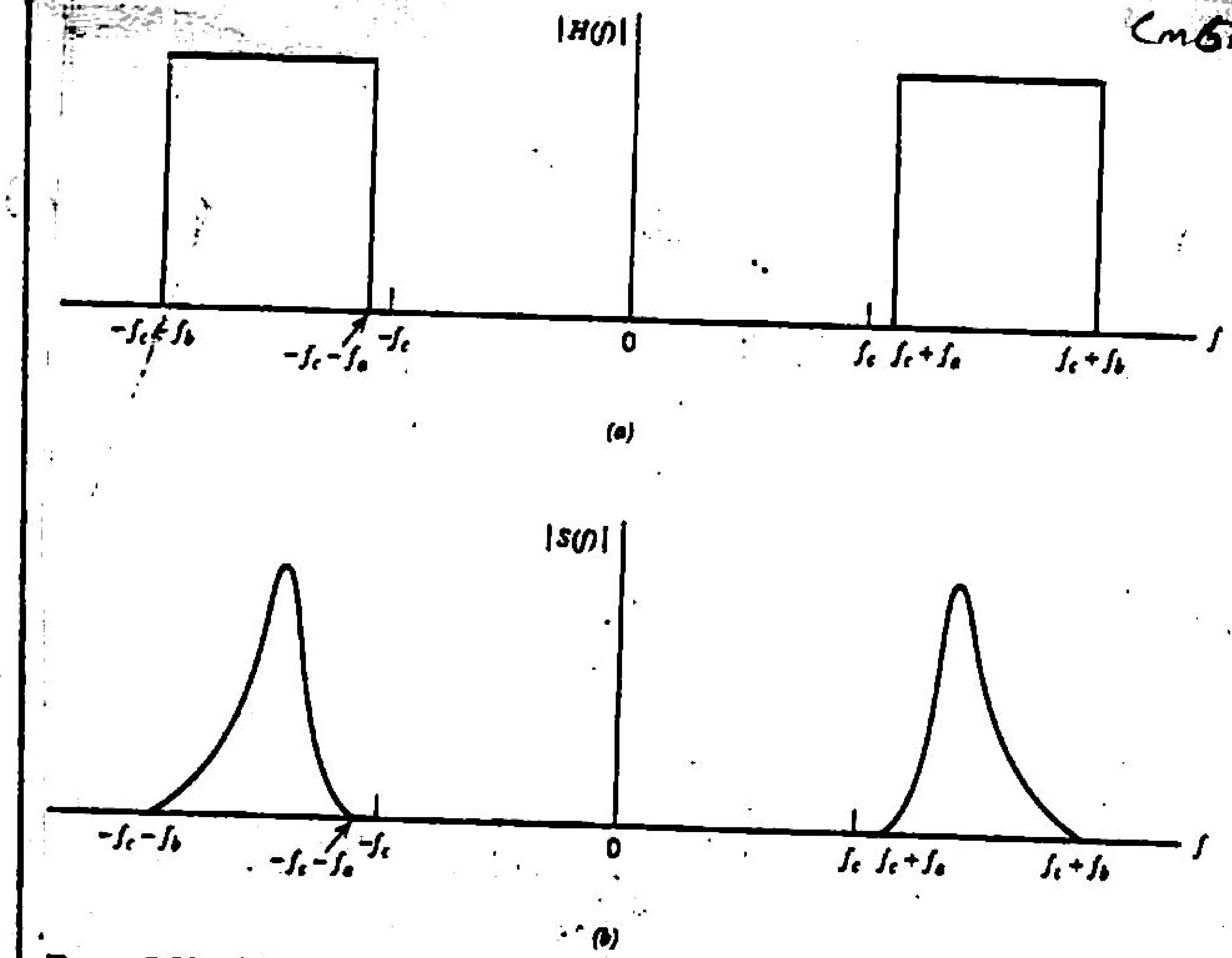


Figure 3.23 (a) Idealized frequency response of band-pass filter. (b) Spectrum of SSB signal containing the upper sideband.

- The desired sideband lies inside the passband of the filter.
- The unwanted sideband lies inside the stopband of the filter.
- The filter's transition band, separating the passband from the stopband, is twice the lowest frequency component of the message signal.

This kind of frequency discrimination usually requires the use of highly selective filters, which can only be realized in practice by means of crystal resonators.[6]

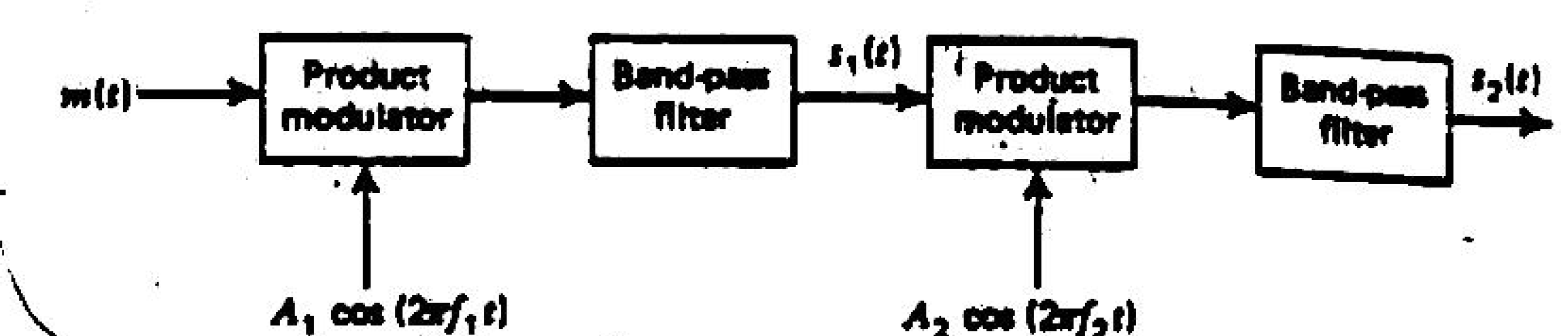
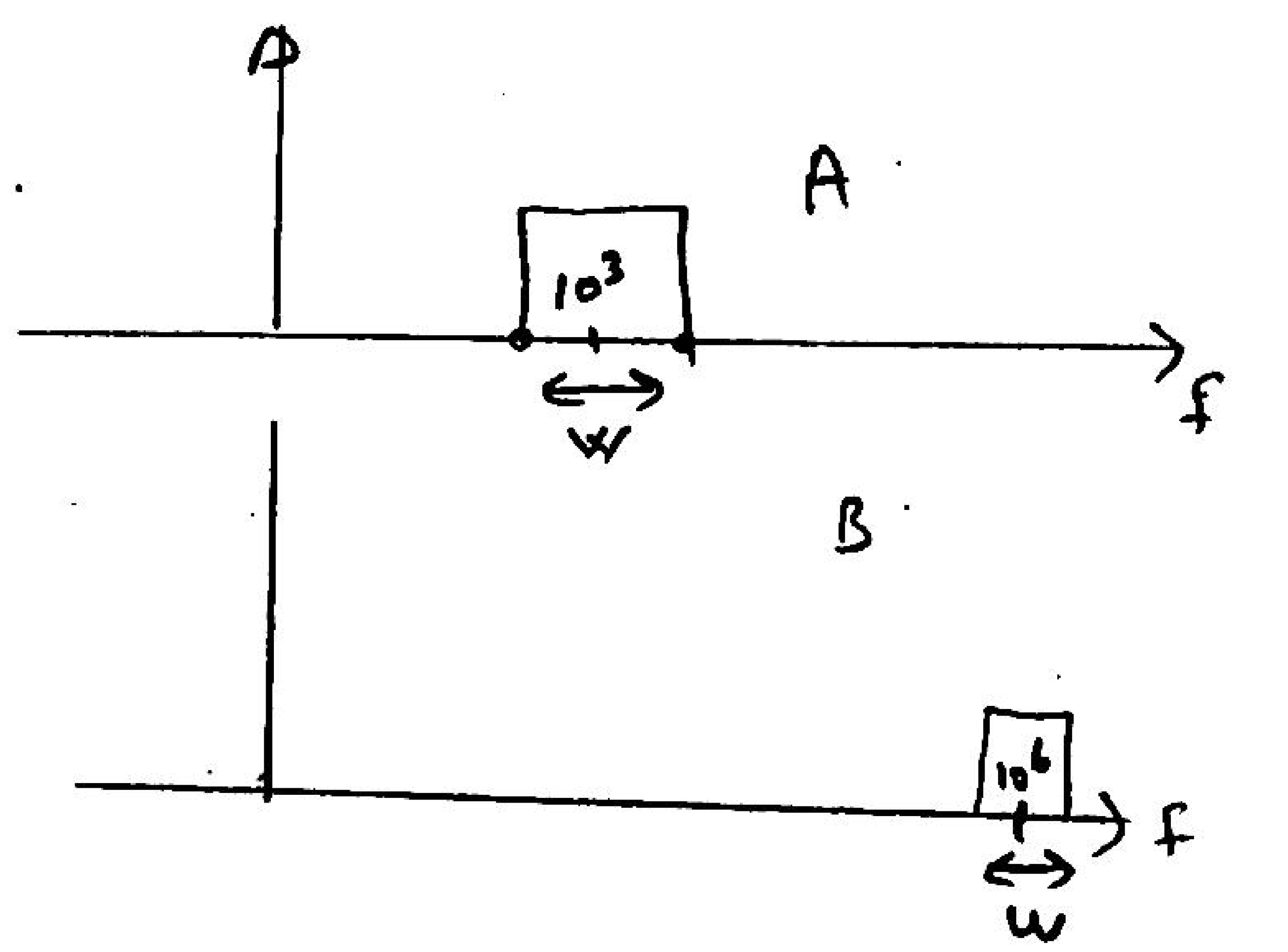


Figure 3.24 Block diagram of a two-stage SSB modulator.

..., translating a voice signal to the high-frequency region of the radio spectrum), it becomes very difficult to design an appropriate filter



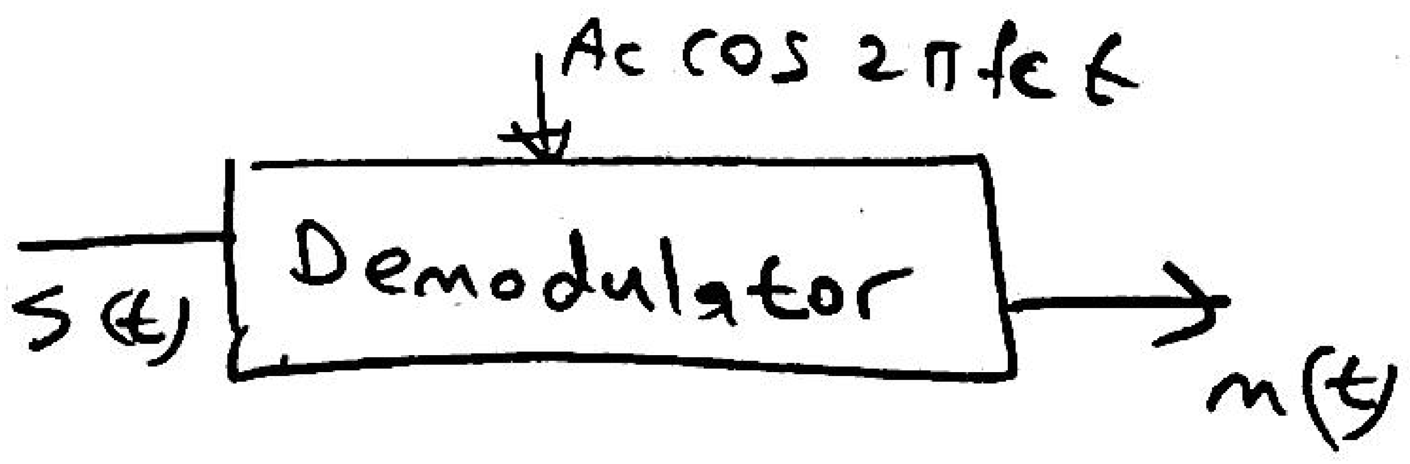
Filter A is easier to design then the filter B.

$s(t) = ?$

$s(t) = \frac{1}{2} A_c m(t) \cos(2\pi f_c t) - \frac{1}{2} A_c \hat{m}(t) \sin(2\pi f_c t)$

$\hat{m}(t)$ Hilbert transform of $m(t)$

Demodulation of SSB signals



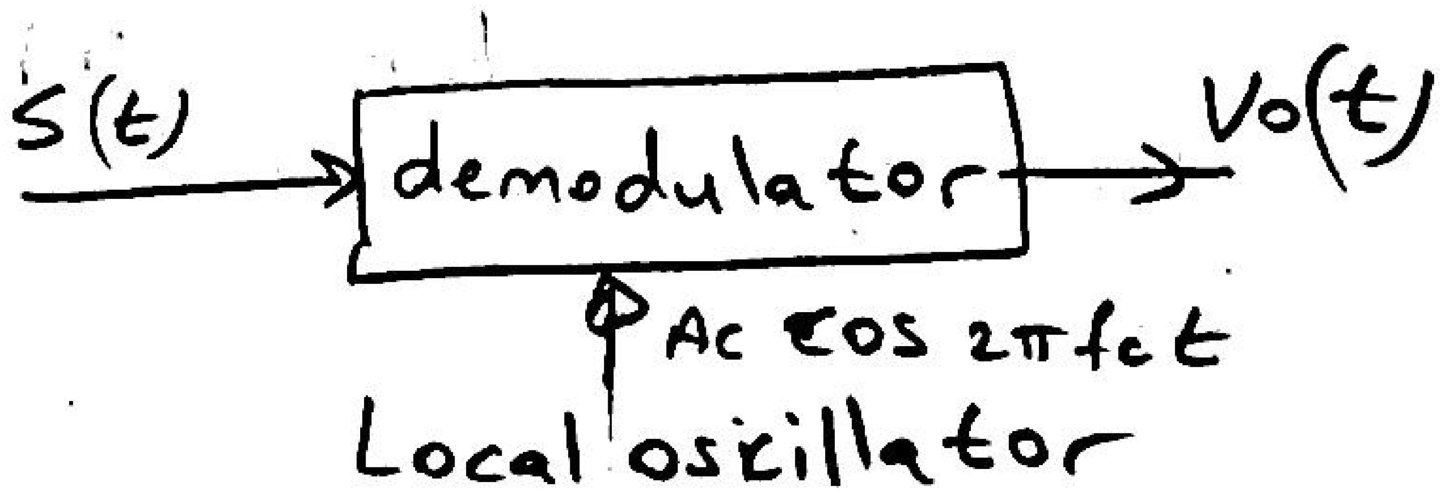
We need carrier signal $\cos(2\pi f_c t)$

Solution:

1) Transmit carrier signal together with $s(t)$ (power requirement)

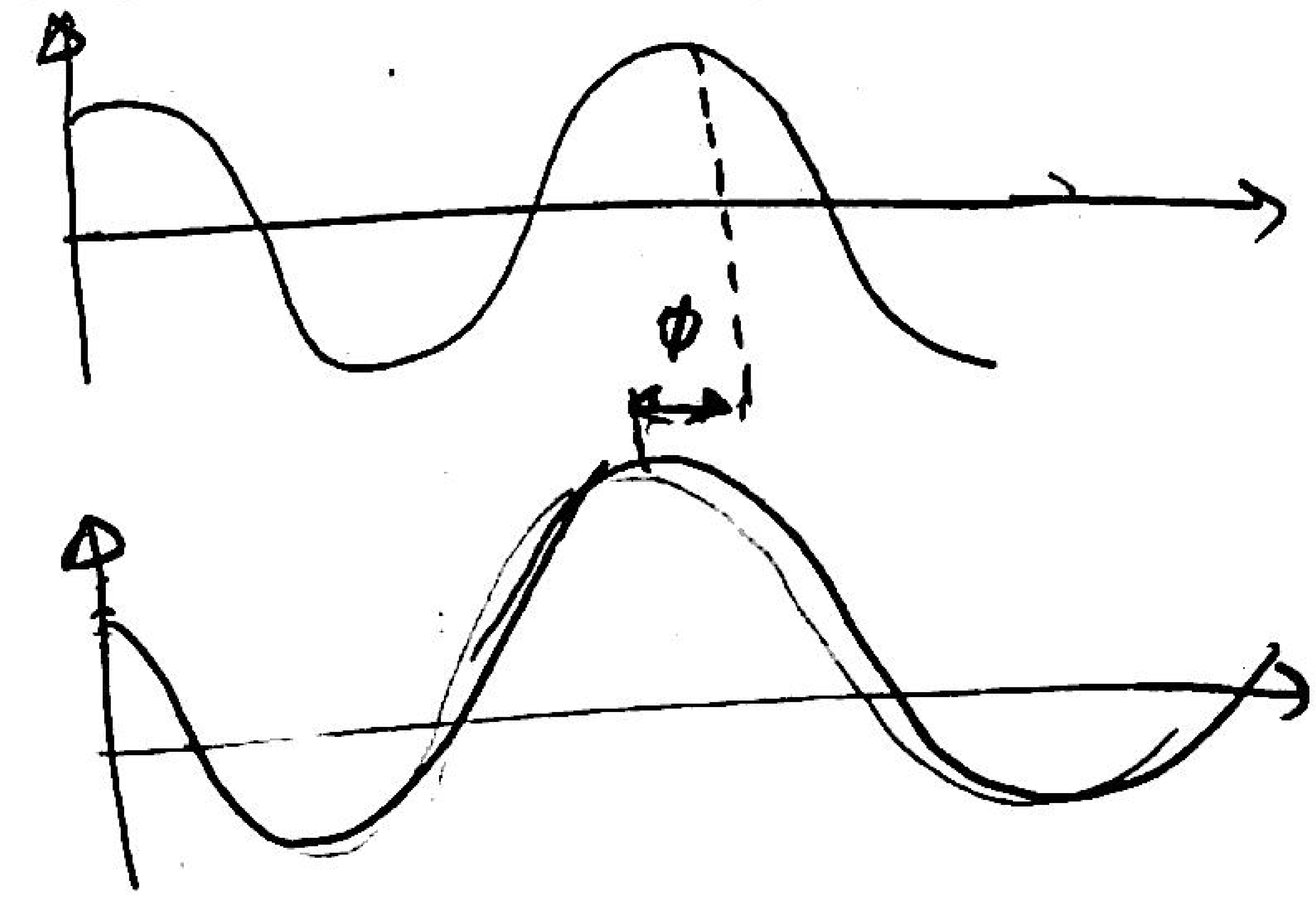
2) Produce carrier signal at the receiver. (Phase error)

The effect of phase error



$v_o(t) = \frac{1}{4} A_c' A_c [m(t) \cos\phi + \hat{m}(t) \sin\phi]$

ϕ is the phase error between the actual carrier and Locally produced carrier



$V_o(f) = \frac{1}{4} A_c' A_c [M(f) \cos\phi + \hat{M}(f) \sin\phi]$

$\hat{m}(t)$ is Hilbert transform of $m(t)$

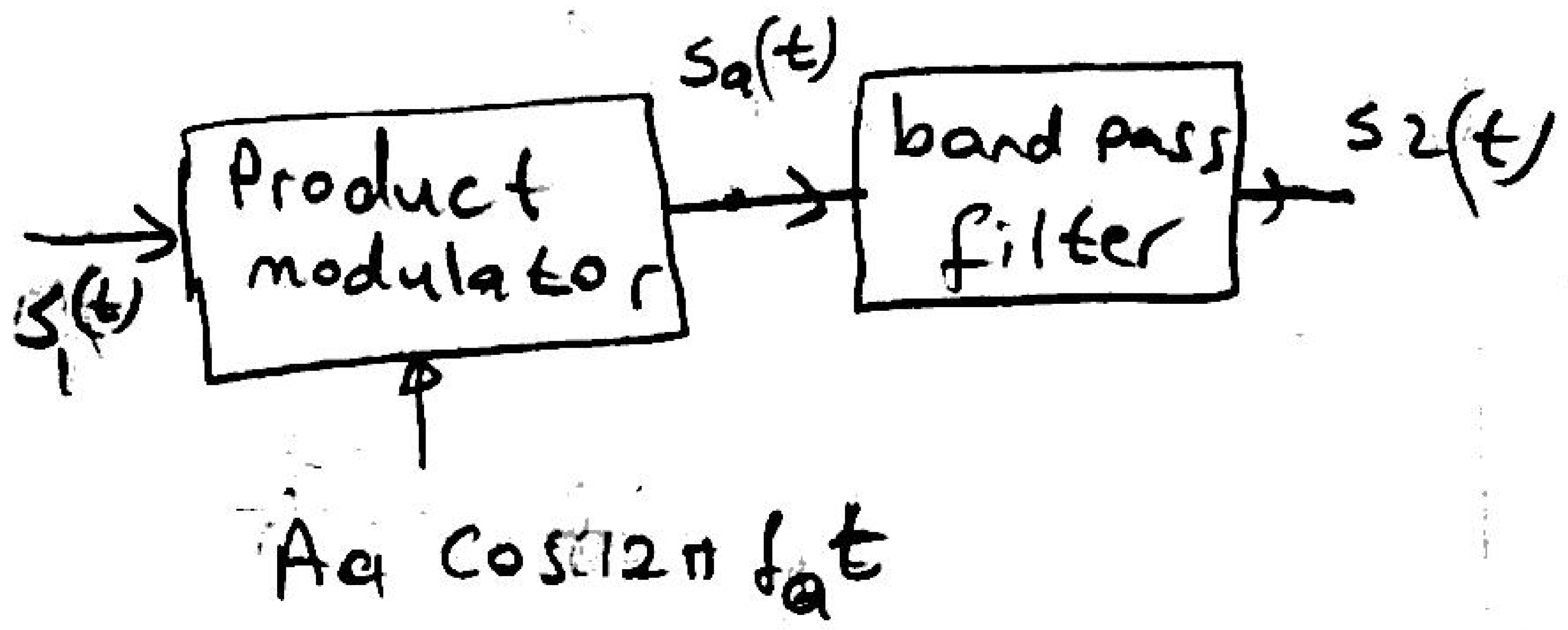
$\hat{M}(f) = -j\,\mathrm{sgn}(f)\,M(f)$

$$V_o(f) = \begin{cases} \frac{1}{4} A_c' A_c M(f) e^{-j\phi} & f > 0 \\ \frac{1}{4} A_c' A_c M(f) e^{j\phi} & f < 0 \end{cases}$$

ϕ = Phase error causes Problem in TV.

cm7!

Frequency Translation



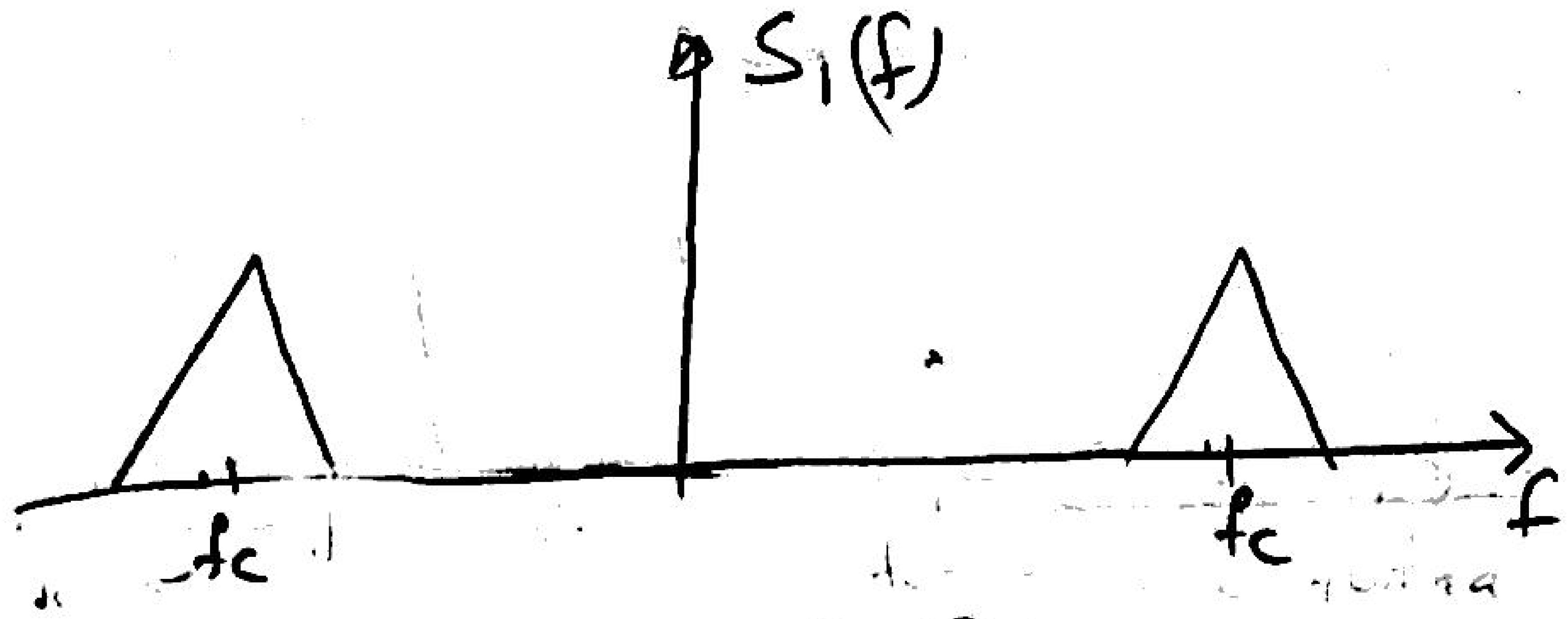
$s_1(t)$ = modulated wave with Carrier f_c

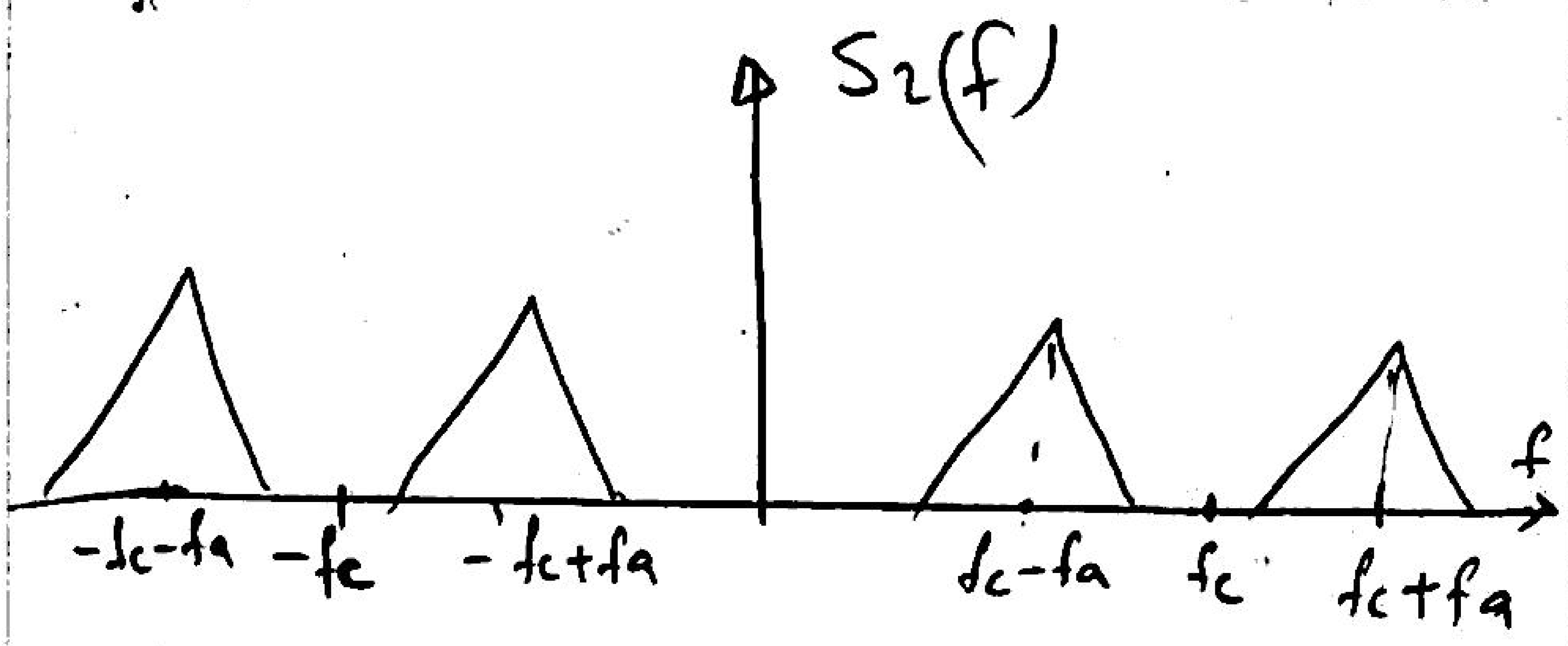
$$S_1(t) = A_c \cos(2\pi f_c t)\, m(t)$$

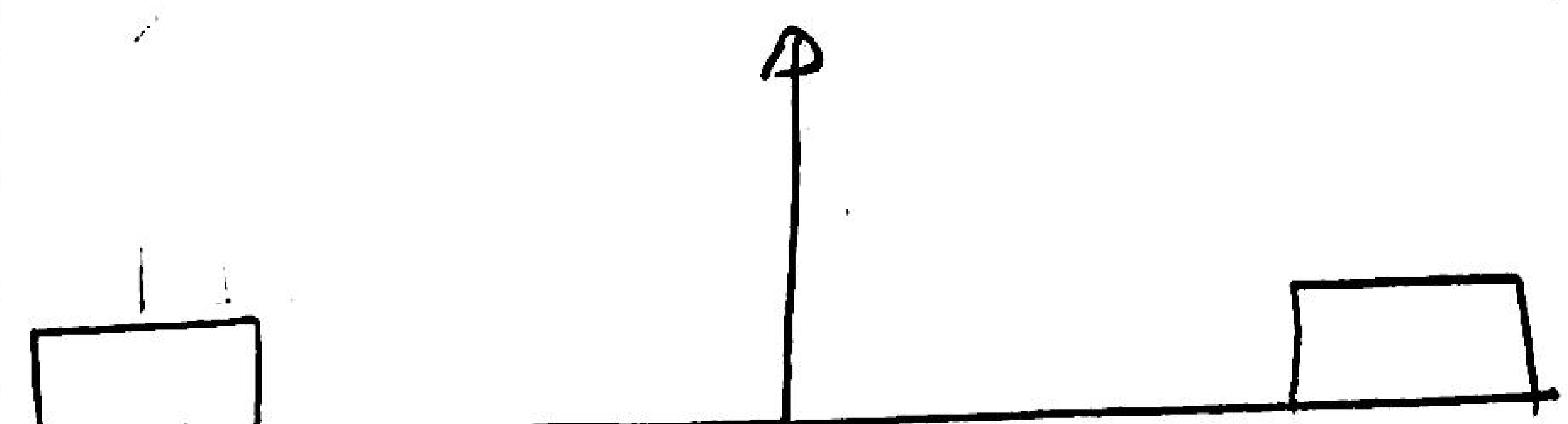
$$S_a(t) = S_1(t)\, A_a \cos 2\pi f_a t$$

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

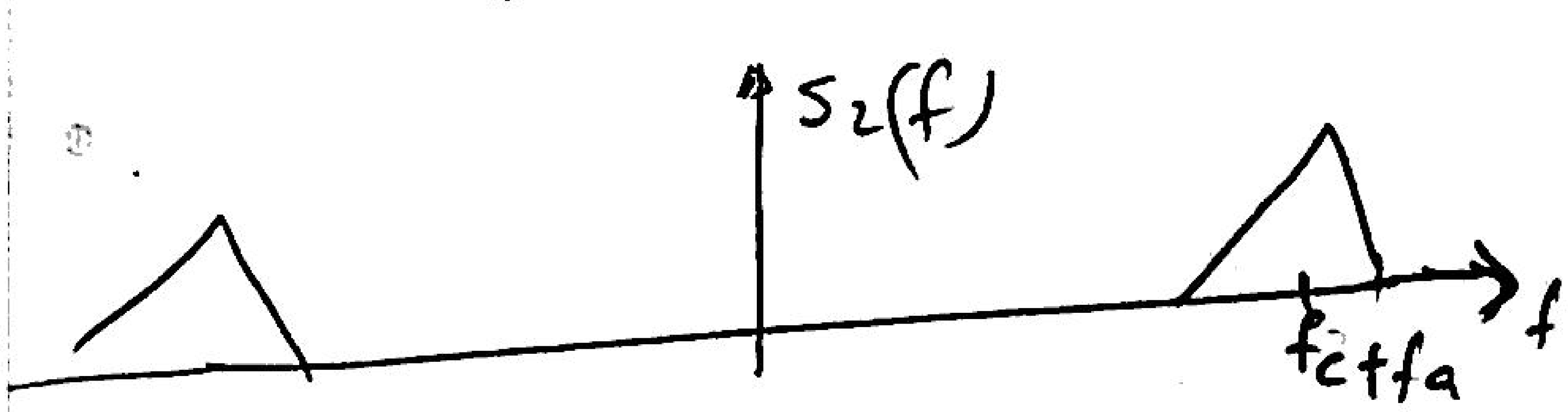
$$= A_c A_a m(t) \left[\tfrac{1}{2} \cos 2\pi (f_c - f_a) t + \cos 2\pi (f_c + f_a) t \right]$$





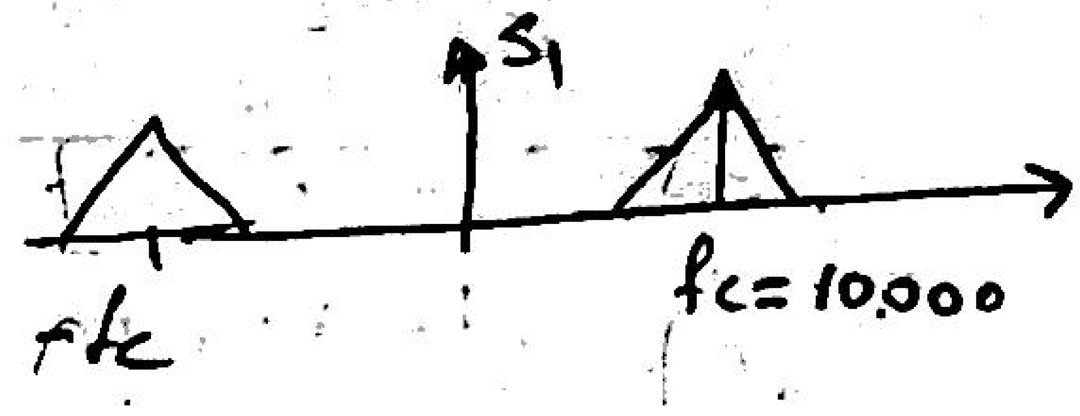


Bandpass filter

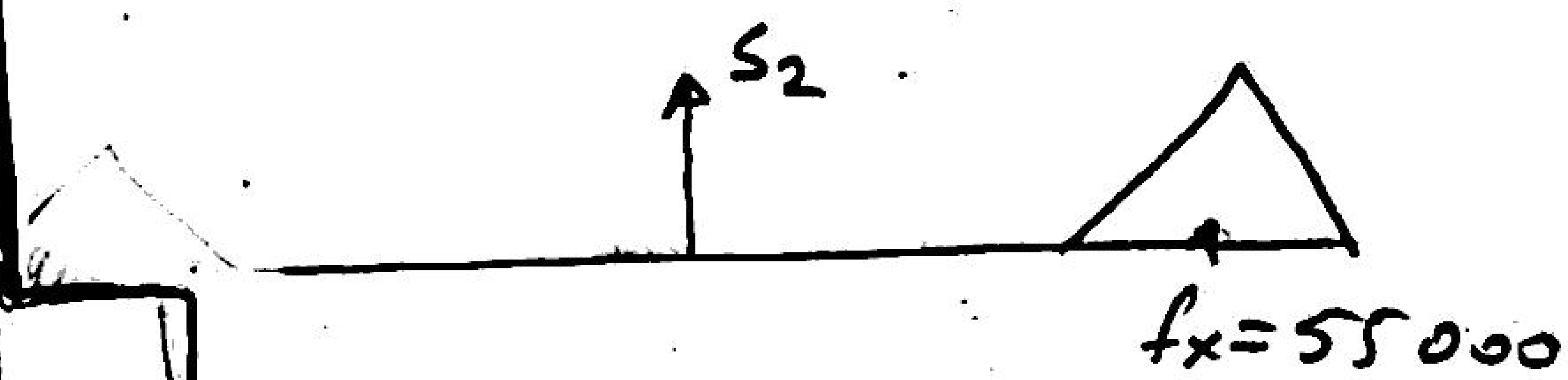


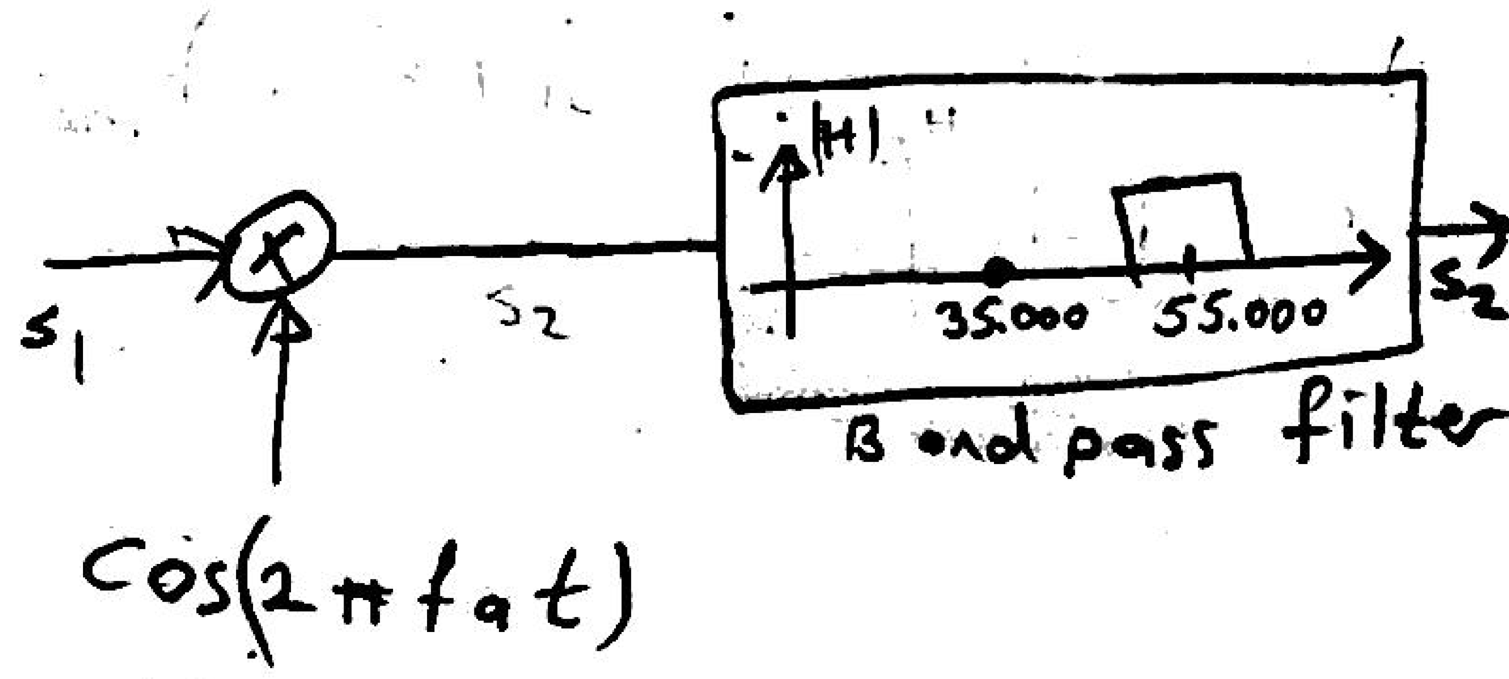
if you want to shift from f_c to f_c+f_a or f_c-f_a then multiply by f_a.

Example:



To shift to 55000 multiply by $f_a = 45000$.

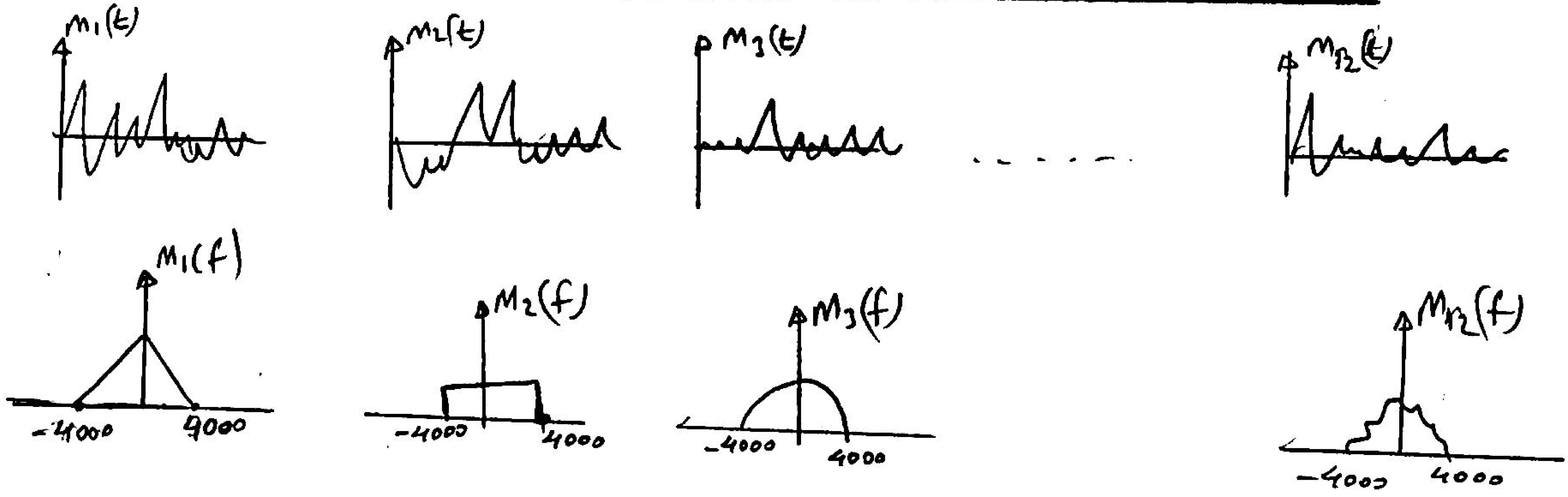


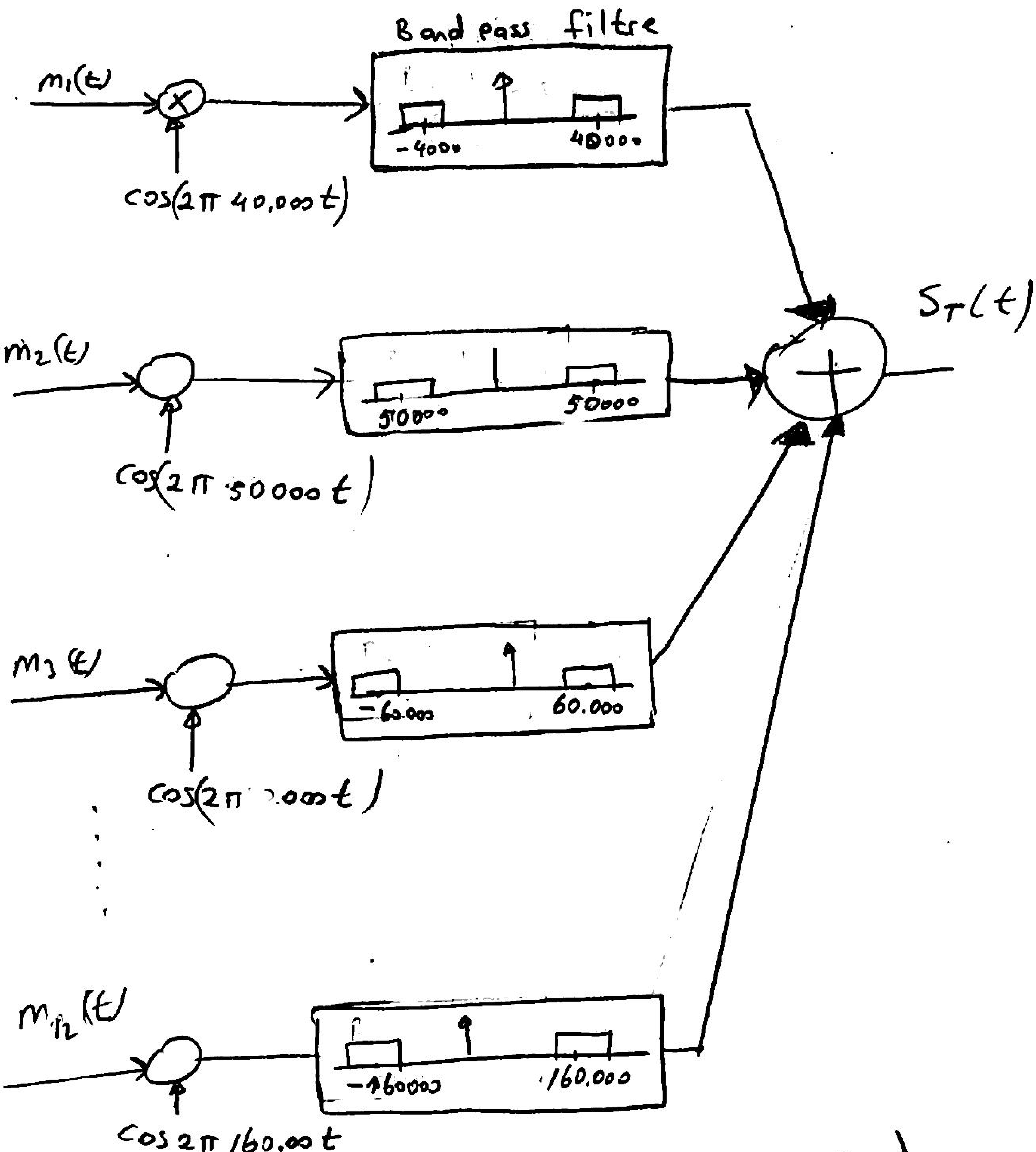


$$S_2 = m(t) \cos(2\pi\, 10.000\, t) \cos(2\pi\, 45000\, t)$$

$$= \tfrac{1}{2} m(t) \left[\cos(2\pi\, 35000\, t) + \cos(2\pi\, 55000\, t) \right]$$

Frequency Division multiplexing





Cm 73

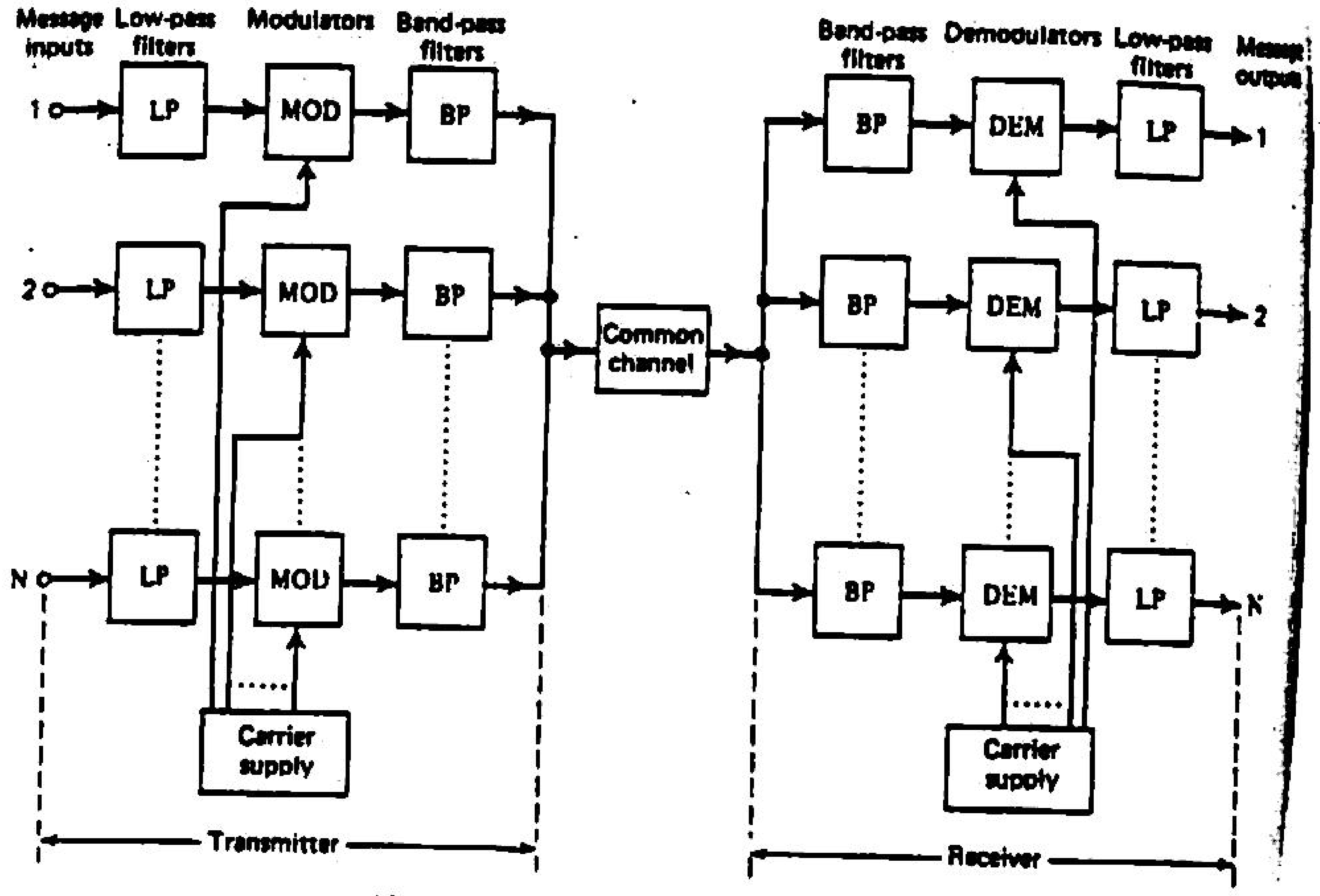
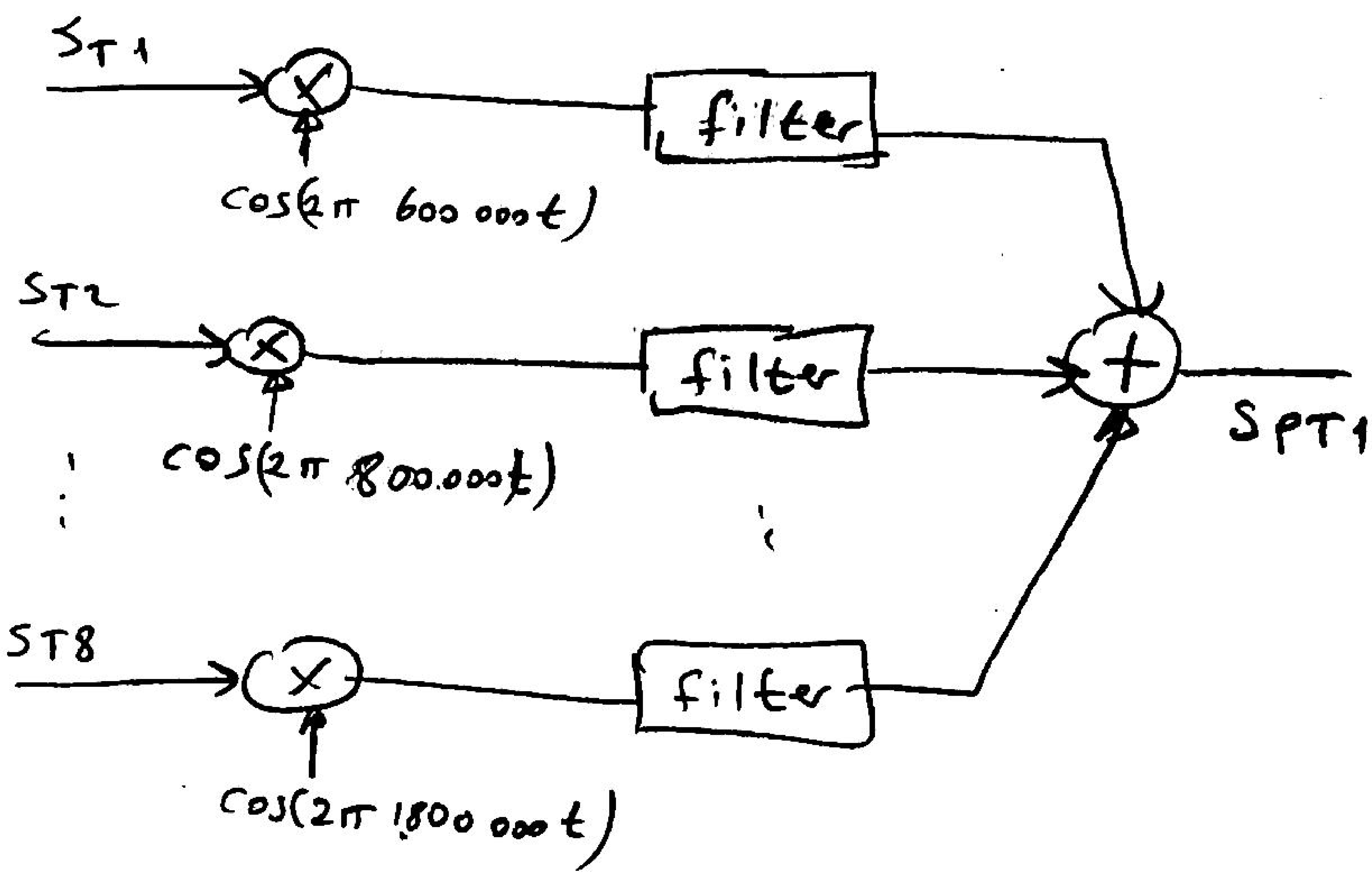


Figure 3.27 Block diagram of FDM system.



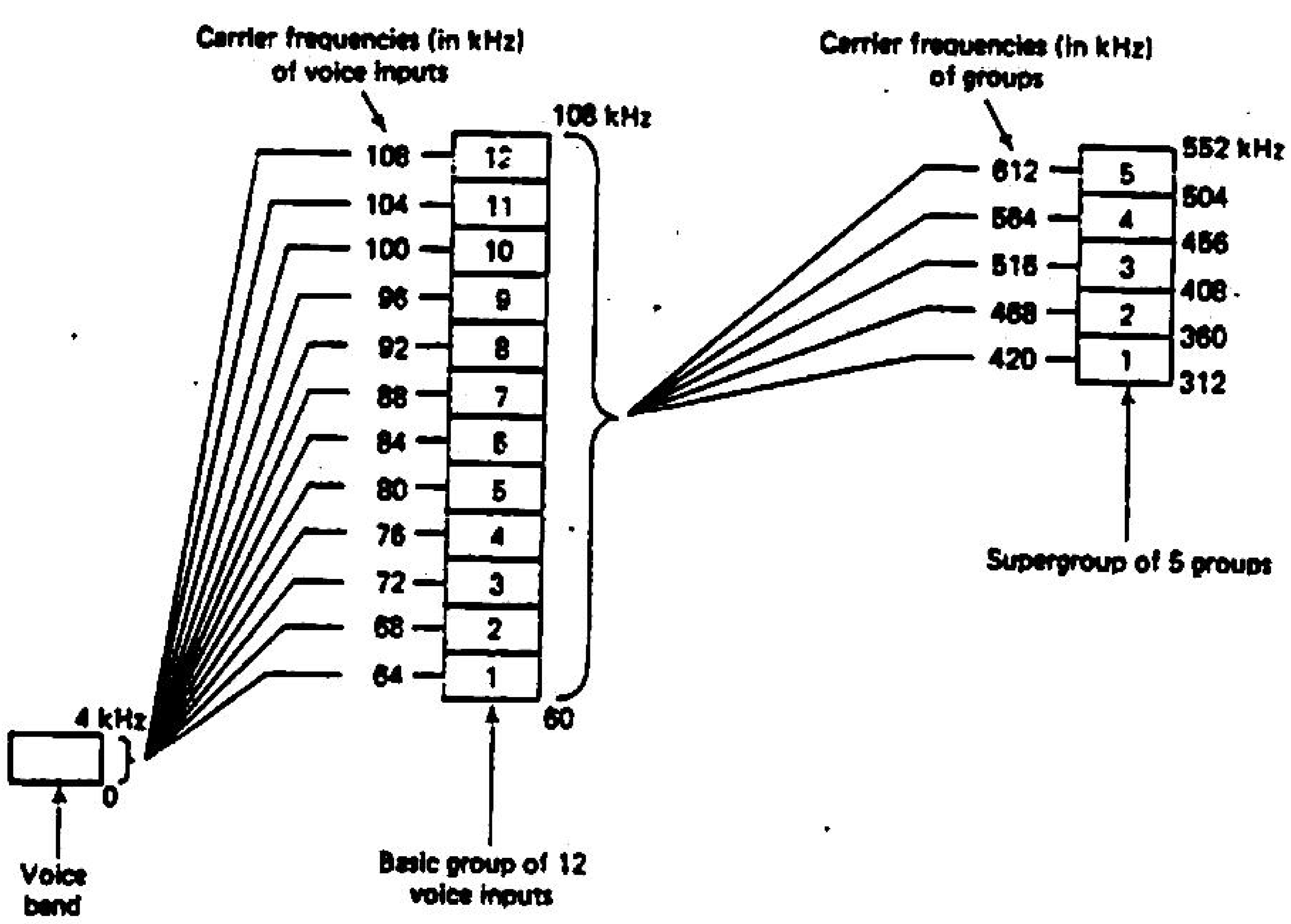
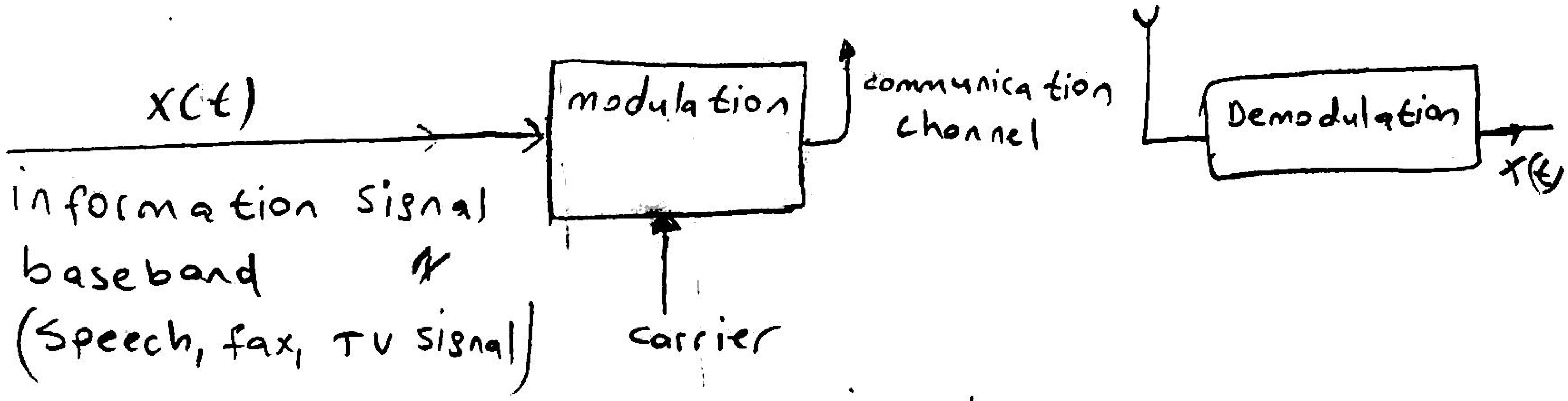
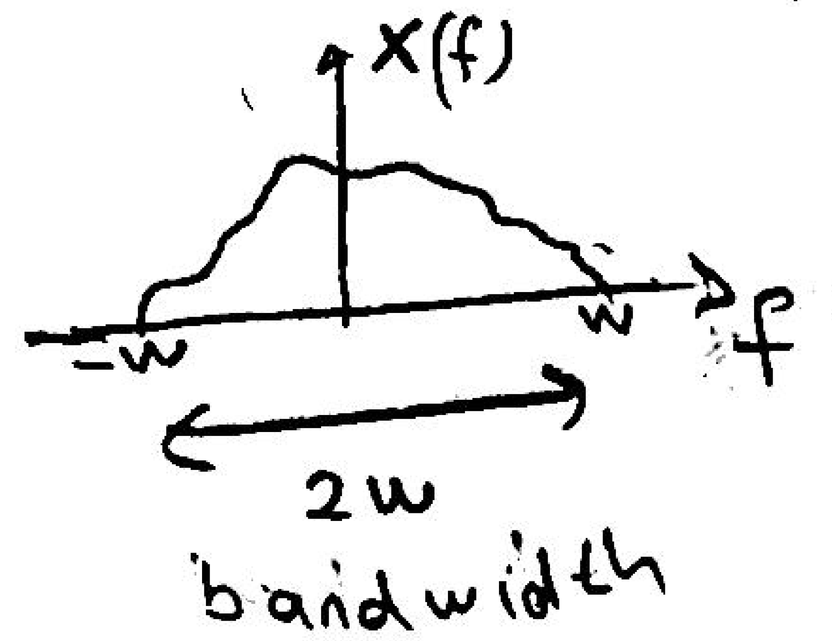


Figure 3.28 Illustrating the modulation steps in an FDM system.

Continuous wave modulation



Baseband signal bandwidth: The range of frequencies Of X(t). Carrier is usually a single frequency.



Speech signal w = 3000 hz for telephone

w = 15000 hz for music.

TV signal - w = 5MHz = 5000.000 hz.

computer modem 28K = 28000

56K = 56000

Carrier long wave radio 1.5 MHz - 20 MHz

FM radio 80 MHz - 100 MHz

TV 70 MHz - 400 MHz (UHF)

satellite 8-9 - 12 GHz

mobile Telephone 450 MHz - 900 MHz - 1800 MHz.

1 MHz = 10^6 Hertz.

1 GHz = 10^9 Hertz.

Amplitude modulation

Amplitude of the carrier wave is varied about a mean value, Linearly with the baseband signal. $m(t)$.

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

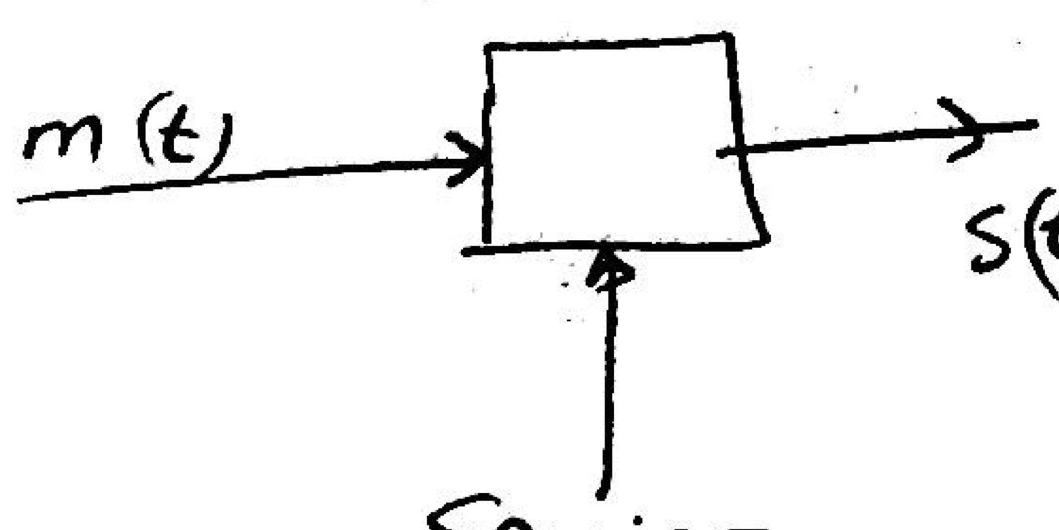
$m(t)$ = information signal

f_c = carrier frequency

A_c = carrier amplitude

K_a = constant (amlitudue sensitivity)

$s(t)$ = modulated signal



$f_c \gg W$

f_c = carrier frequency

W = bandwidth of $m(t)$

$S(f)$ = Fourier Transform of $s(t)$

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

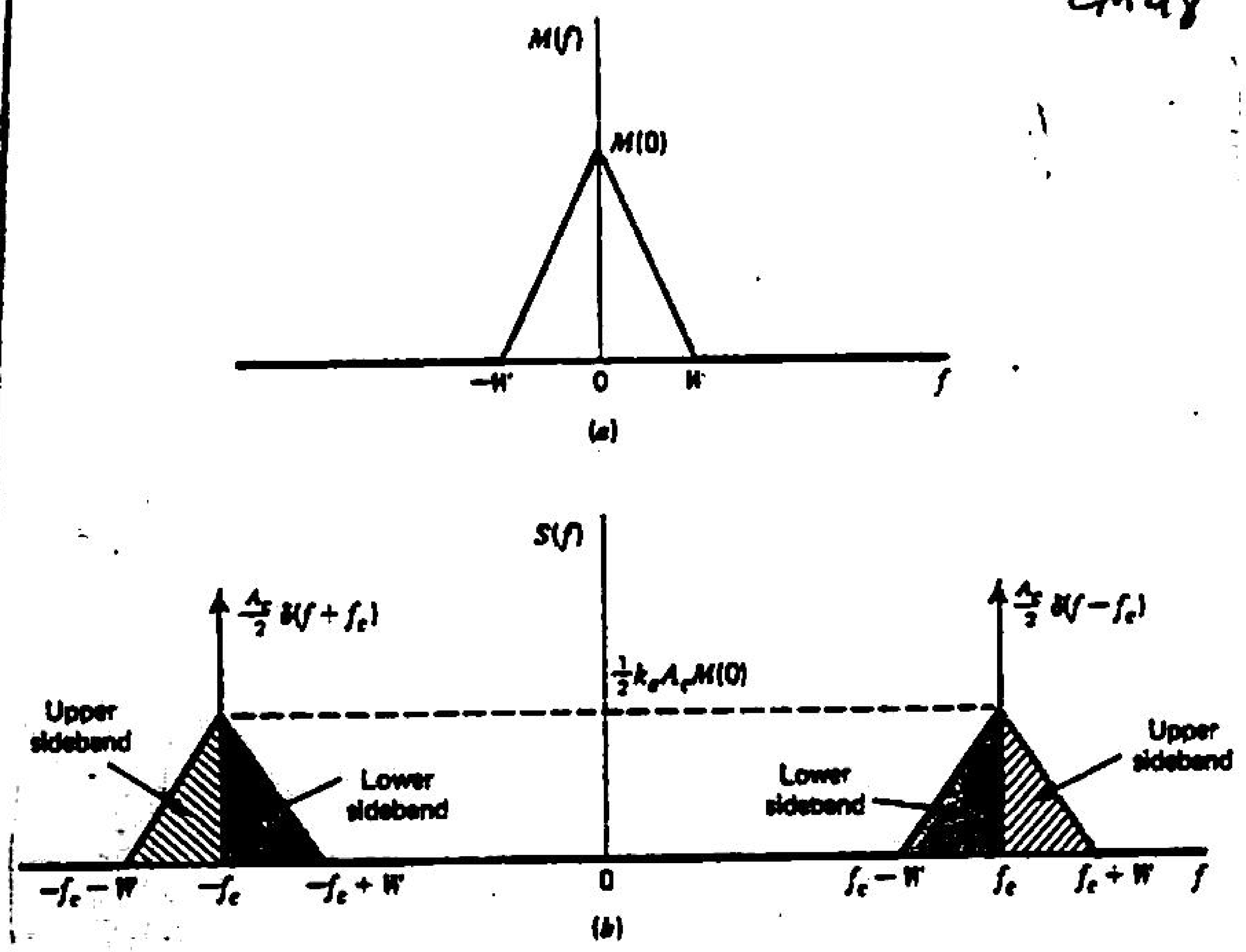
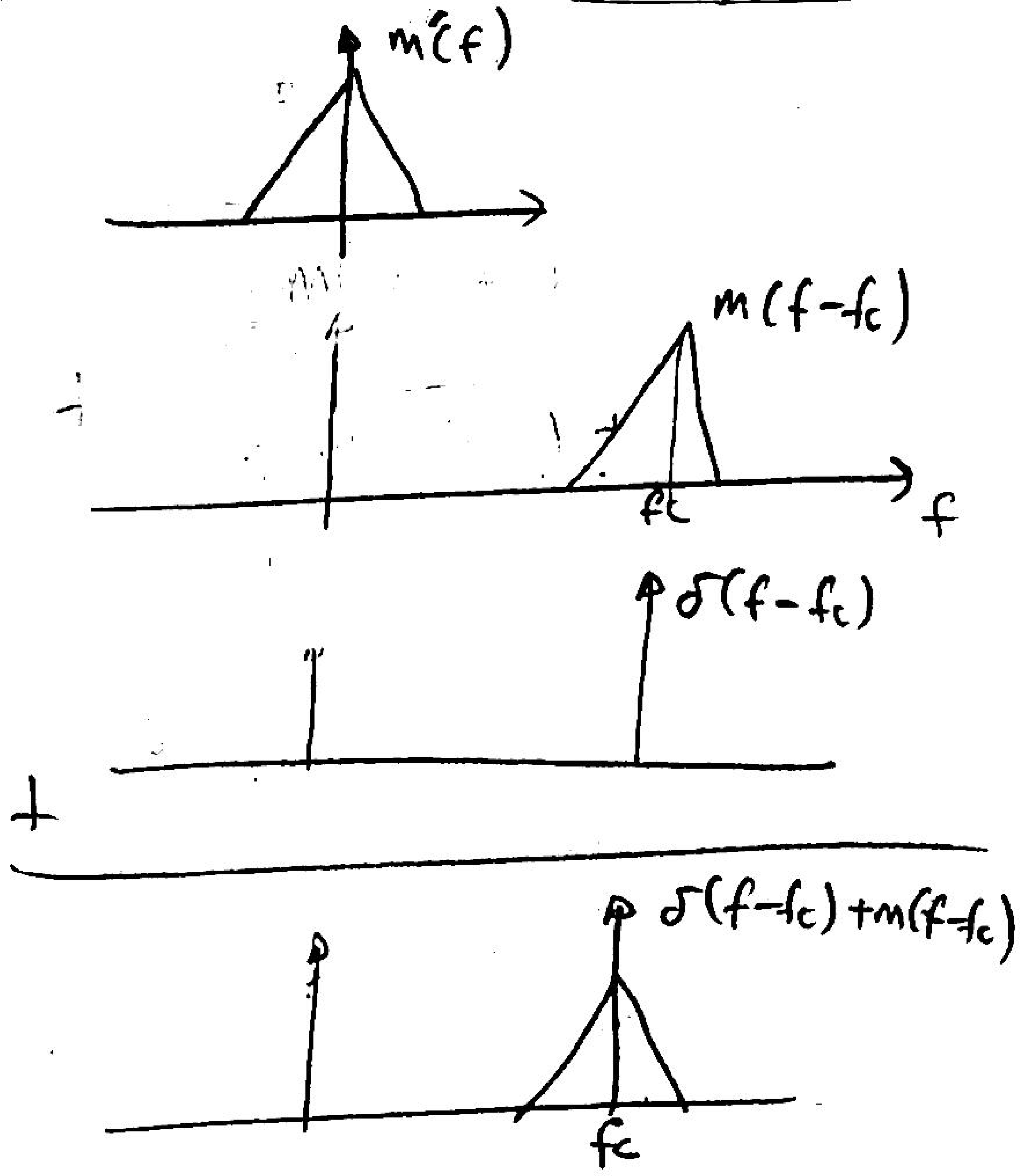
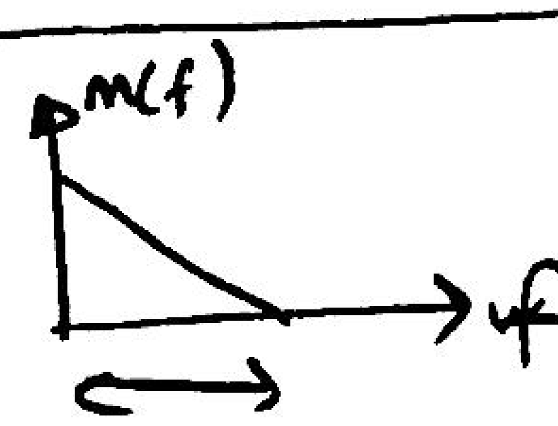
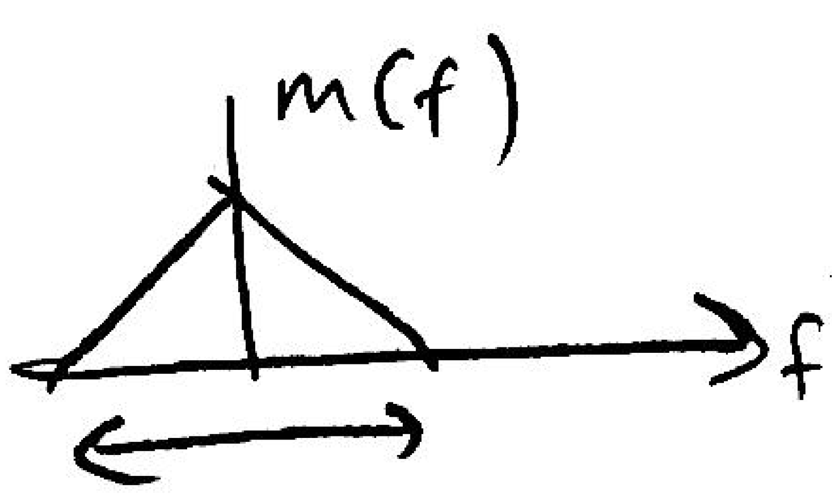


Figure 3.2 (a) Spectrum of baseband signal. (b) Spectrum of AM wave.



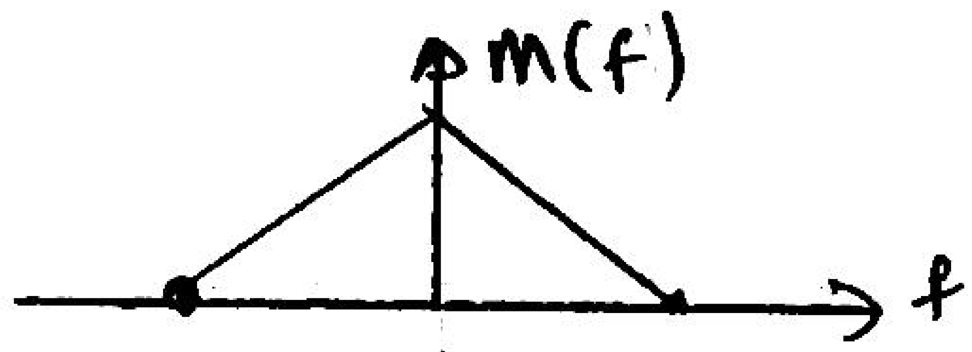


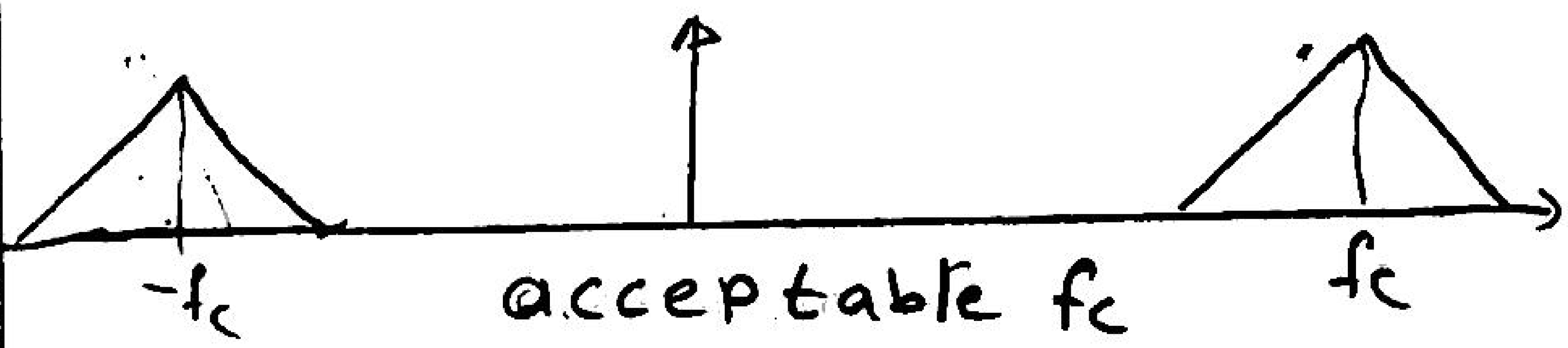
W = message bandwidth



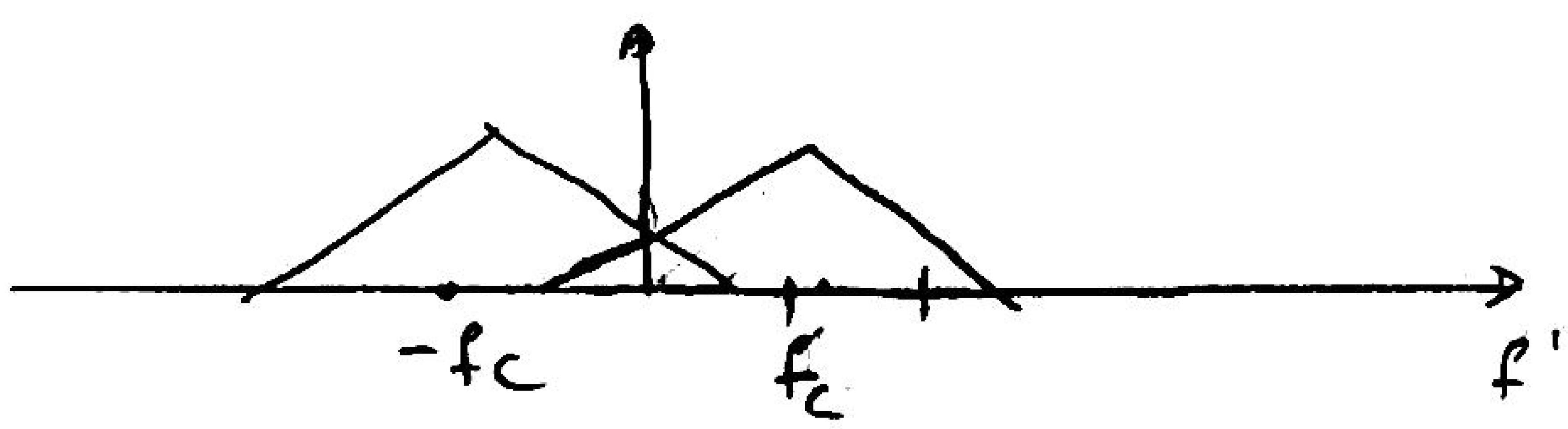
$2W$ = transmission bandwidth

f_c must be high





acceptable f_c

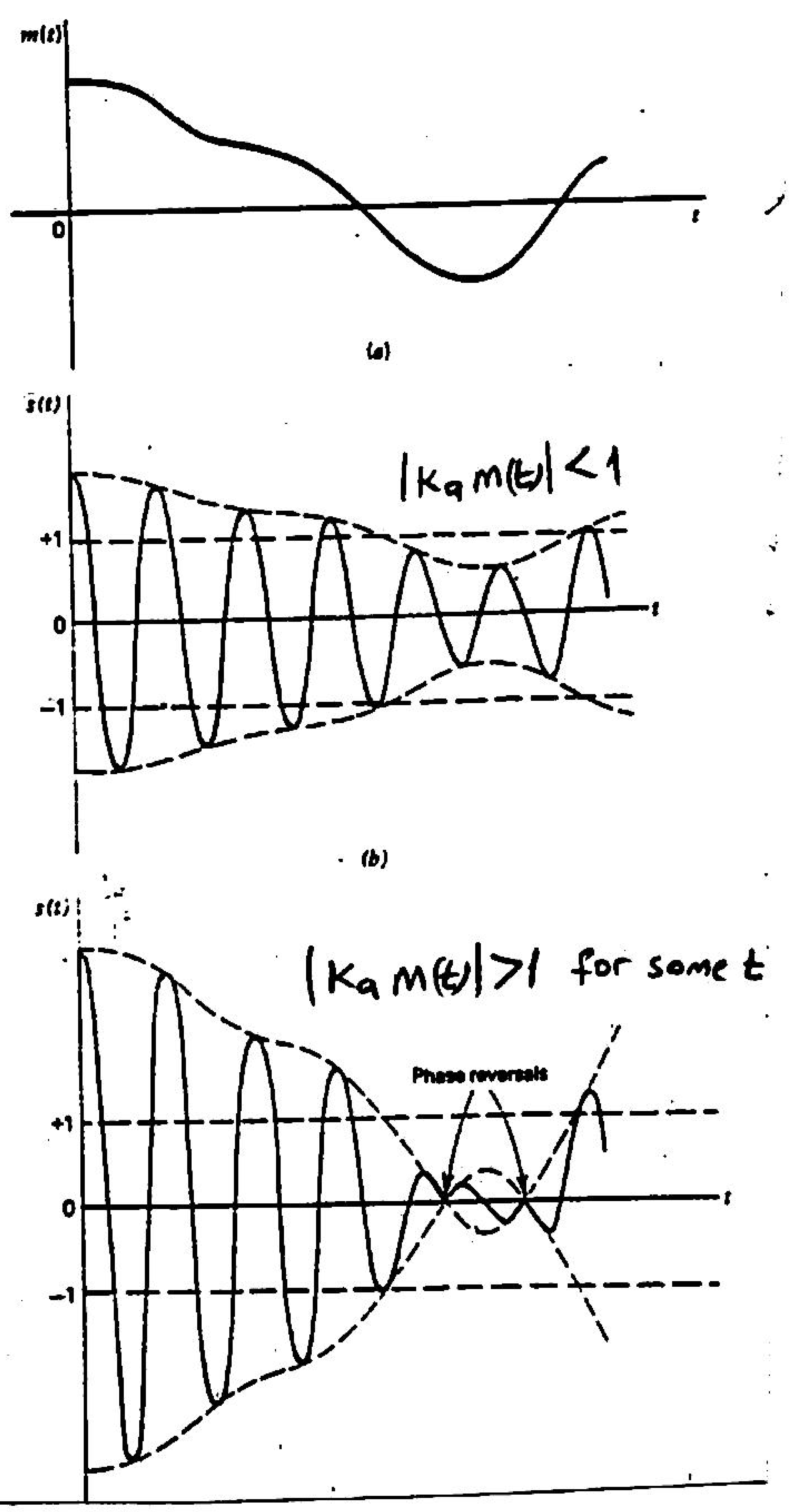


f_c is small

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

k_a should be chosen small

$|k_a m(t)| < 1$ for all t



Single tone modulation

$$m(t) = A_m \cos 2\pi f_m t$$

$$s(t) = A_c \cos 2\pi f_c t\,[1 + k_a A_m \cos 2\pi f_m t]$$

Define $\mu = k_a A_m$

$$s(t) = A_c \cos 2\pi f_c t\,[1 + \mu \cos 2\pi f_m t]$$

μ = modulation factor

μ must be less than 1

$$s(t)_{max} = A_c(1+\mu)$$

$$s(t)_{min} = A_c(1-\mu)$$

$$\frac{s(t)_{max}}{s(t)_{min}} = \frac{A_c(1+\mu)}{A_c(1-\mu)}$$

or

$$\mu = \frac{s(t)_{max} - s(t)_{min}}{s(t)_{max} + s(t)_{min}}$$

$$\cos a \cos b = \frac{1}{2}[\cos(a+b) + \cos(a-b)]$$

$\cos 2\pi f_c t \cos 2\pi f_m t =$

$$\frac{1}{2} \cos 2\pi(f_c - f_m)t + \frac{1}{2}\cos 2\pi(f_c - f_m)t$$

$$s(t) = A_c \cos 2\pi f_c t + \frac{1}{2}\mu A_c \cos 2\pi(f_c + f_m)t$$

$$+ \frac{1}{2}\mu A_c \cos(2\pi(f_c - f_m)t$$

$$S(f) = \frac{1}{2}A_c[\delta(f-f_c) + \delta(f+f_c)]$$

$$+ \frac{1}{4}\mu A_c[\delta(f-f_c-f_m) + \delta(f+f_c+f_m)]$$

$$+ \frac{1}{4}\mu A_c[\delta(f-f_c+f_m) + \delta(f+f_c-f_m)]$$

CM50

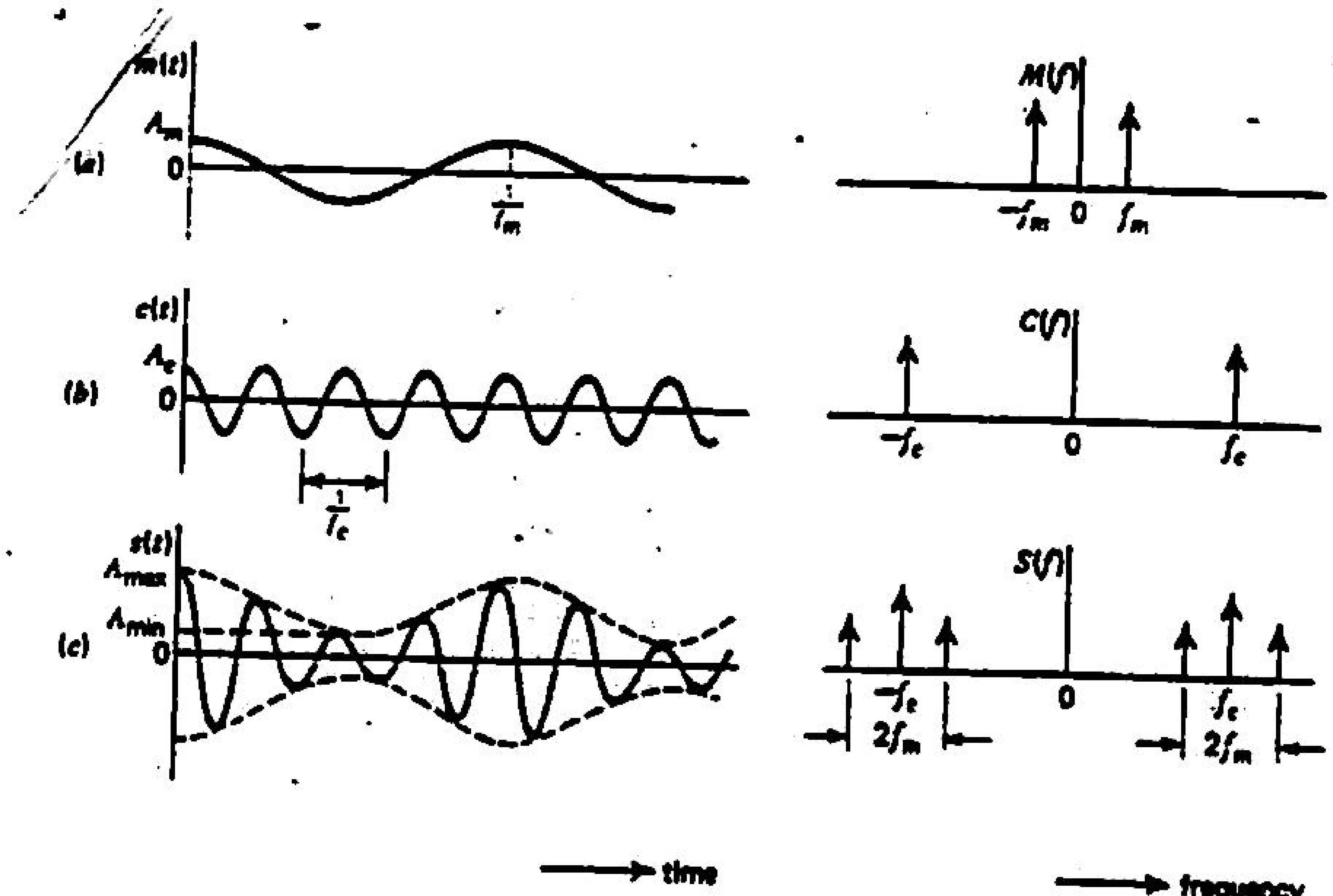


Figure 3.3 Illustrating the time-domain (on the left) and frequency-domain (on the right) characteristics of standard amplitude modulation produced by a single tone. (a) Modulating wave. (b) Carrier wave. (c) AM wave.

Average power

$$x(t)=\delta(t) \rightarrow P=|x(t)|^2=1$$

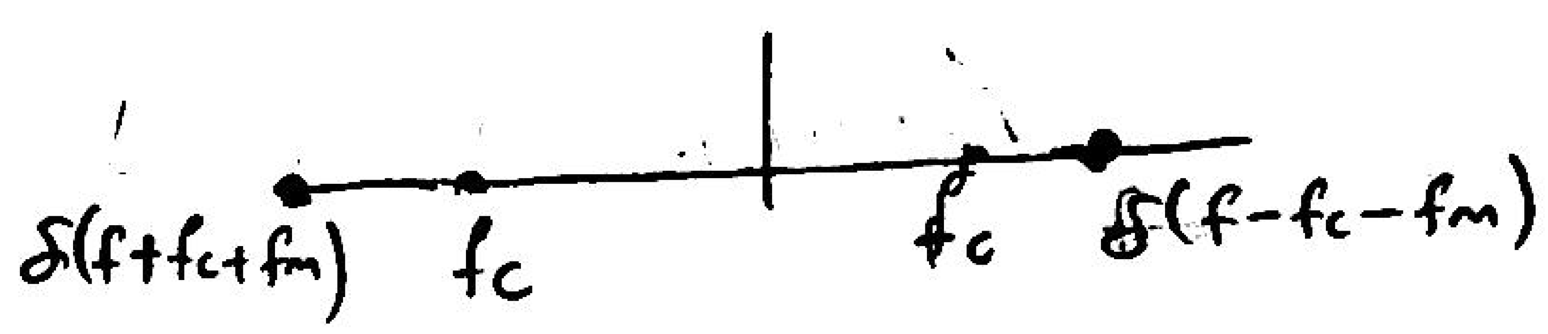
$$\frac{1}{2}A_c[\delta(f-f_c)] \rightarrow P=\left\{\frac{1}{2}A_c\right]^2=\frac{1}{4}A_c^2$$

Carrier power $\frac{1}{4}A_c^2+\frac{1}{4}A_c^2=\frac{1}{2}A_c^2$

Upper side frequency power

$$f-f_c-f_m \qquad f+f_c+f_m$$

$$\left\{\frac{1}{4}\mu A_c\right\}^2+\left\{\frac{1}{4}\mu A_c\right\}^2=\frac{1}{8}\mu^2 A_c^2$$



Lower side frequency power

$$=\frac{1}{8}\mu^2 A_c^2$$

$$\frac{\text{Total side bond power}}{\text{Total power}}=\frac{\frac{1}{8}\mu^2A_c^2+\frac{1}{8}\mu^2A_c^2}{\frac{1}{8}\mu^2A_c^2+\frac{1}{8}\mu^2A_c^2+\frac{1}{2}A_c^2}$$

$$=\frac{\frac{1}{4}\mu^2}{\frac{1}{4}\mu^2+\frac{1}{2}}=\frac{\mu^2}{\mu^2+2}$$

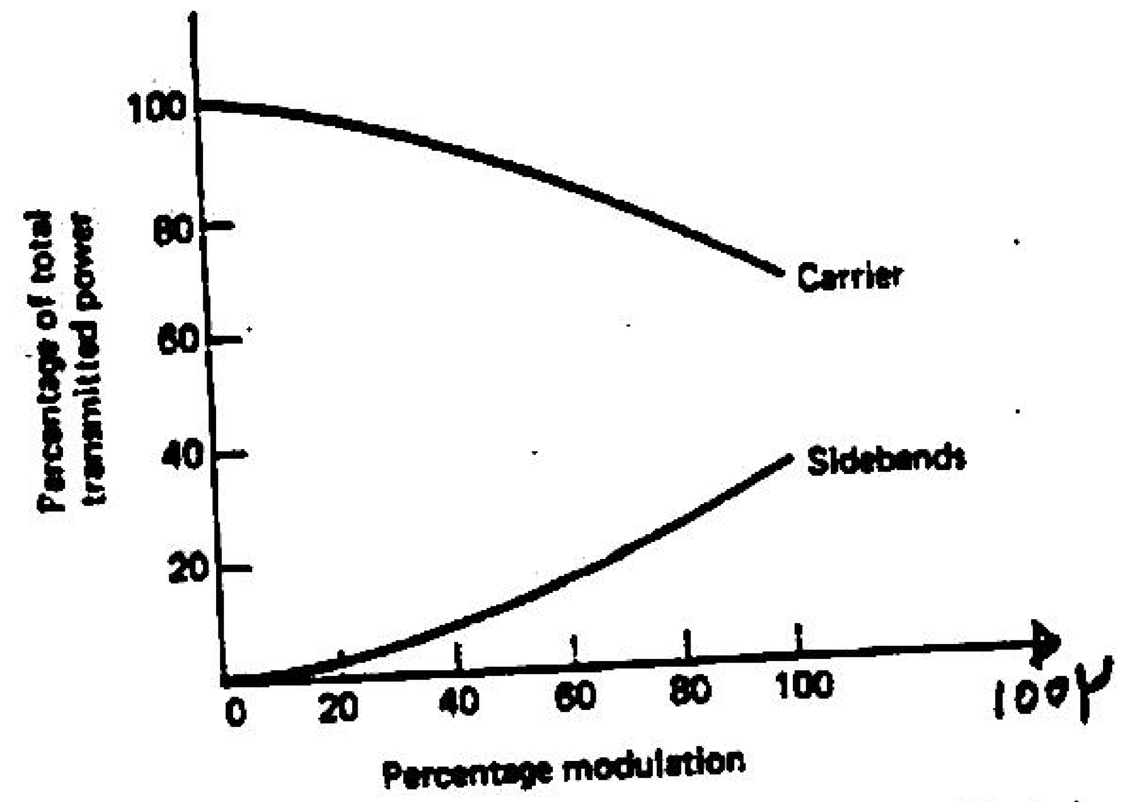


Figure 3.4 Variations of carrier power and total sideband power with percentage modulation.

We want the sideband powers as high as possible.

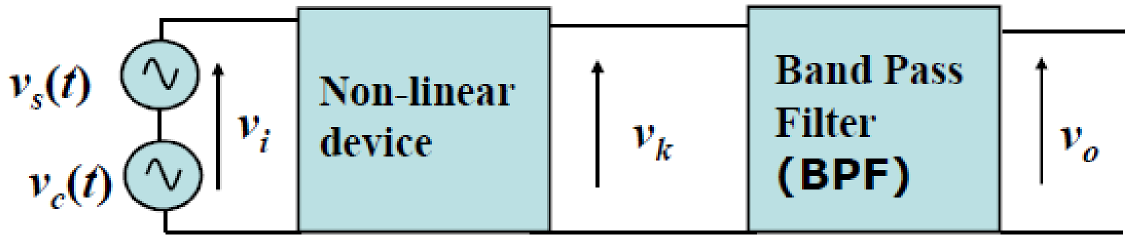
We do not want to transmit more carrier power.

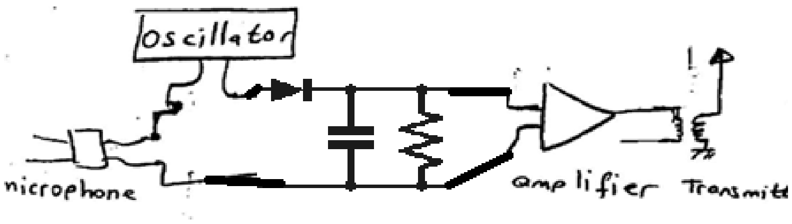
μ must be high (for power)

μ must be less than 1

(if $\mu > 0$ overmodulation)

Genlik Modulasyon Devresi





Basit bir genlik moduasyon devresi.

$I_D(t)$, $V_D(t)$ diyot akim ve gerilimi olmak uzere diyot karakteristigi $I_D(t) = e^{kV_D(t)}$ **seklindedir. Yani nonlineer bir ozellik gosterir.**

$v_c(t)$: carrier (osiloskoptan gelen tasiyici isaret)

$v_S(t)$: mesaj isareti

$v_i(t)= v_C(t)+ v_S(t)= E_C \cos(w_C t) + E_S \cos(w_S t)$

Diyot karakteristigi ustel bir ozellik sergiler.

$$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \frac{x^4}{4!} + \frac{x^5}{5!} + ...$$

$$e^{v_i(t)} = e^{v_C(t)+v_S(t)} = e^{E_C\cos(w_C t)+E_S\cos(w_S t)}$$

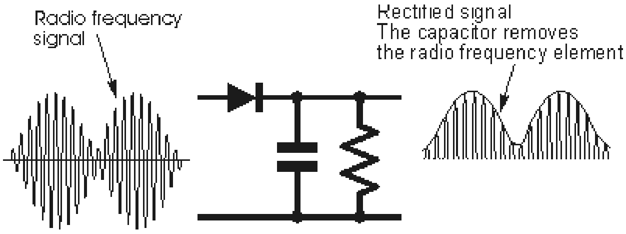
$$= 1 + E_C\cos(w_C t) + E_S\cos(w_S t) + \frac{(E_C\cos(w_C t) + E_S\cos(w_S t))^2}{2!} + \frac{(E_C\cos(w_C t) + E_S\cos(w_S t))^3}{3!} + ...$$

Bu terimler duzenlenirse

$$\begin{aligned} v_k &= E_0 + m_1\left(E_s \cos\omega_s t + E_c \cos\omega_c t\right) + m_2\left(E_s \cos\omega_s t + E_c \cos\omega_c t\right)^2 + ... \\ &= E_0 + m_1 E_s \cos\omega_s t + m_1 E_c \cos\omega_c t + m_2 E_s^{\,2} \cos^2\omega_s t + m_2 E_c^{\,2} \cos^2\omega_c t \\ &\quad + 2m_2 E_s E_c \cos\omega_s t \cos\omega_c t + ... \\ &= E_0 + m_1 E_s \cos\omega_s t + \boxed{m_1 E_c \cos\omega_c t} + m_2 E_s^{\,2} \cos^2\omega_s t + m_2 E_c^{\,2} \cos^2\omega_c t \\ &\quad \boxed{+ m_2 E_s E_c \left\{\cos(\omega_c + \omega_s)t + \cos(\omega_c - \omega_s)t\right\}} + ... \end{aligned}$$

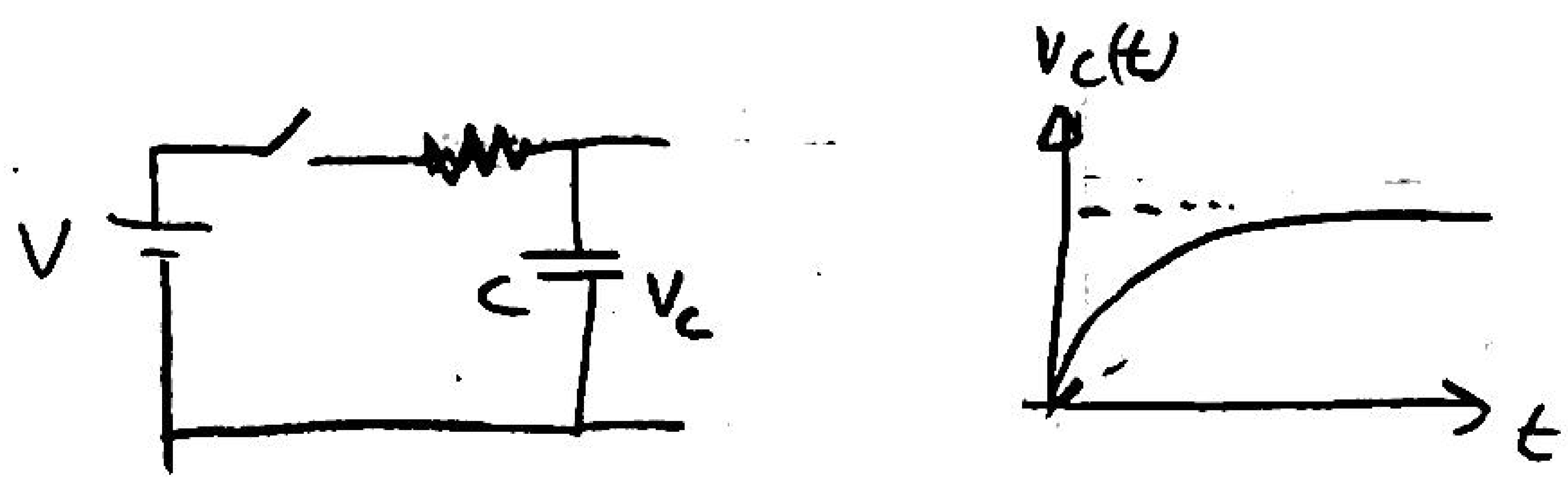
Bir band pass filtre ile $\cos(w_S t)\cos(w_C t)$ carpimi sonucu olusan $(w_S - w_C)$ ve $(w_S + w_C)$ frekanslari haric diger butun frekanslar filtrelenirse cikista v_0 elde edilir. Bu da bizim elde etmek istedigimiz genlik modulasyonlu isarettir.

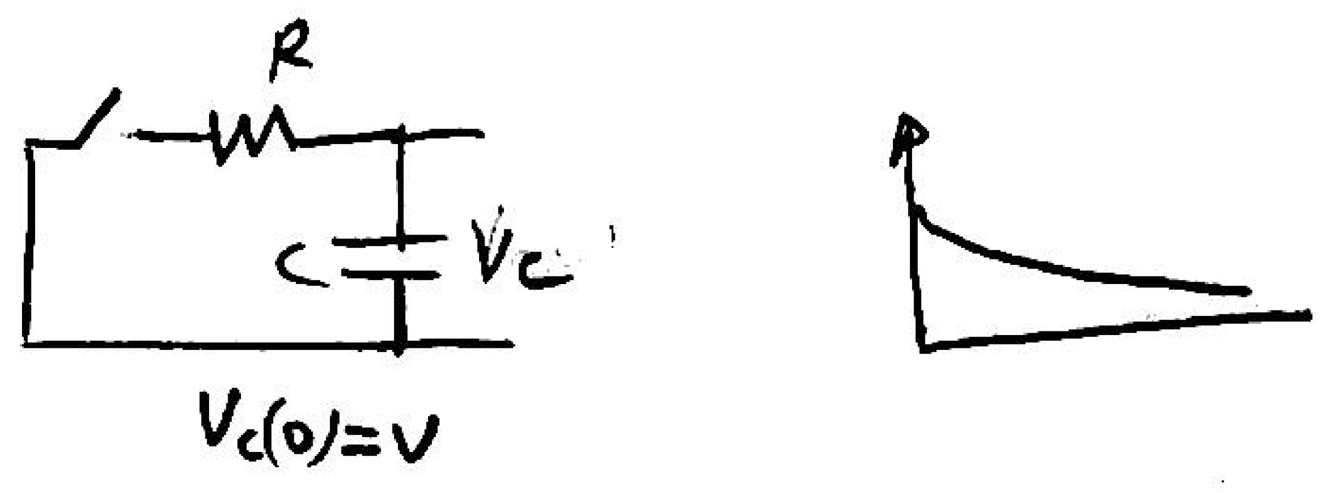
$$\begin{aligned} v_o &= m_1 E_c \cos\omega_c t + m_2 E_s E_c \{\cos(\omega_c + \omega_s)t + \cos(\omega_c - \omega_s)t\} \\ &= m_1 E_c\left(1 + 2\frac{m_2}{m_1} E_s \cos\omega_s t\right)\cos\omega_c t \end{aligned}$$

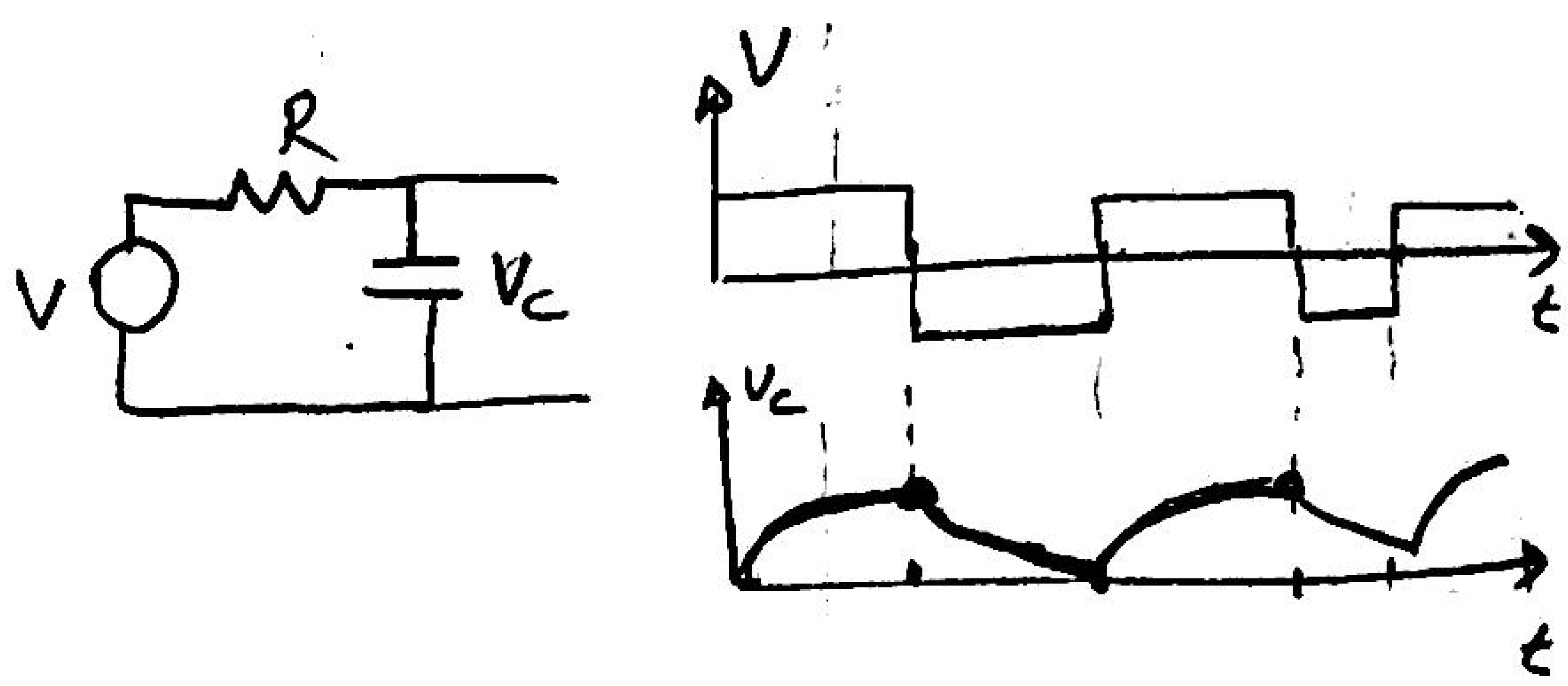

Radio frequency signal
Rectified signal
The capacitor removes
the radio frequency element

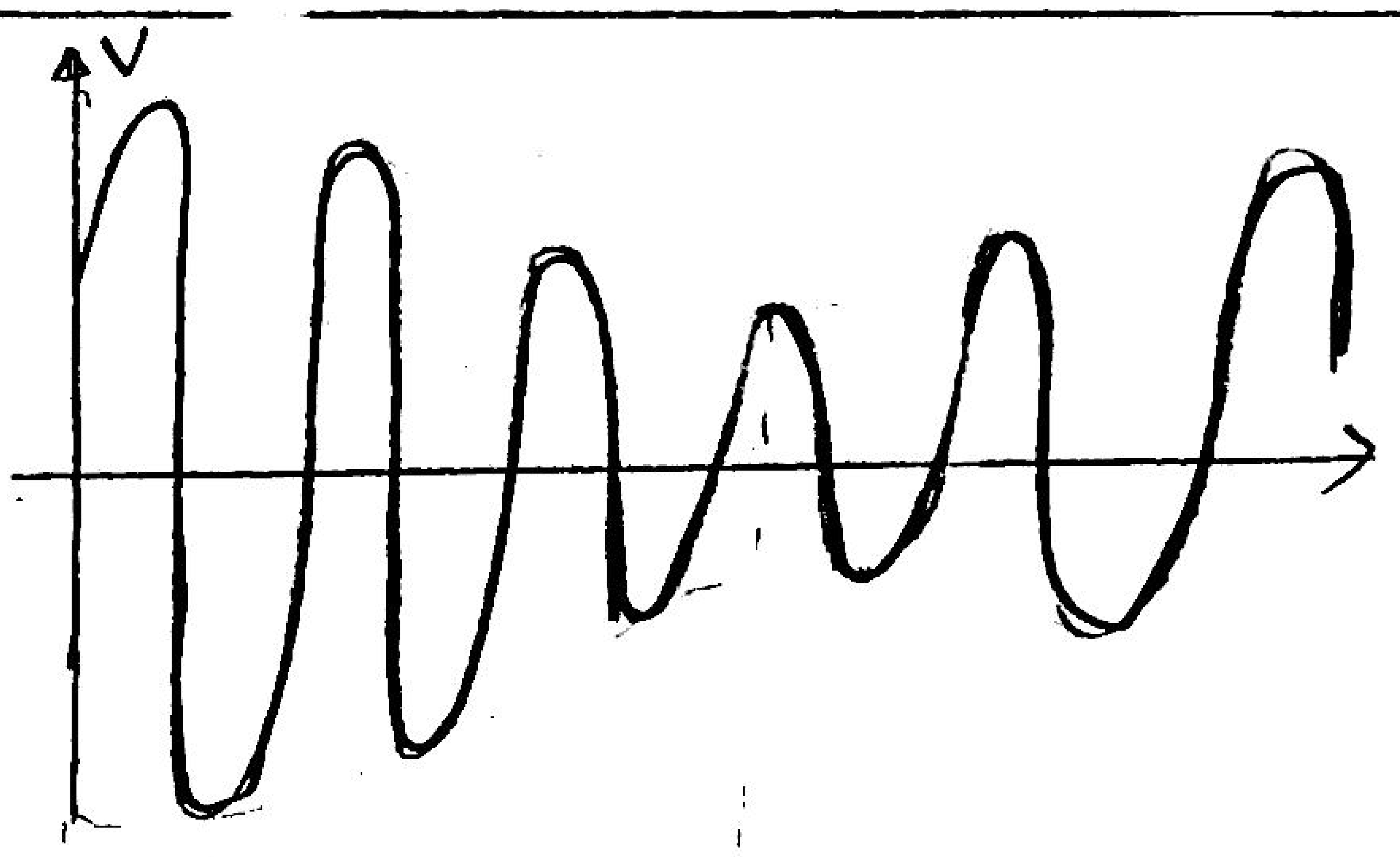
Envelope Detector

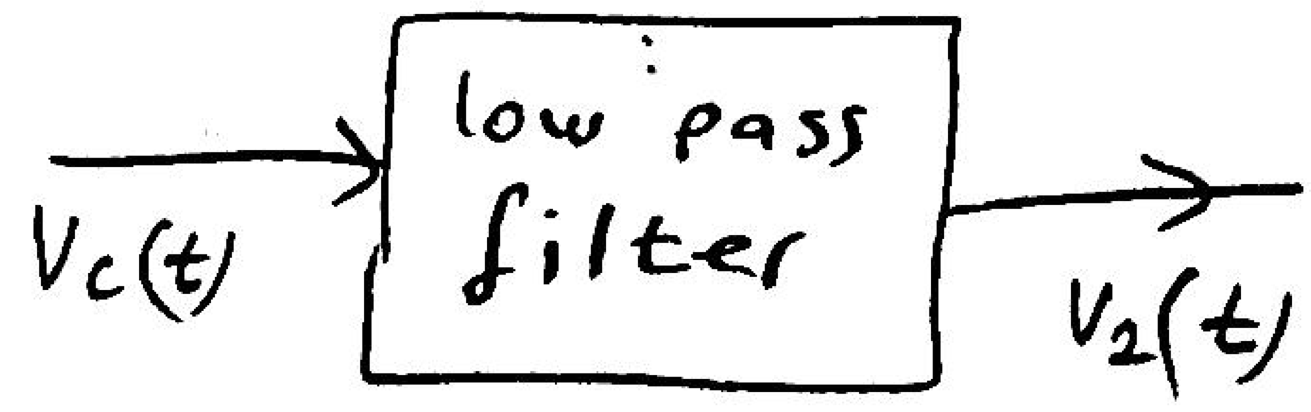
How to get $m(t)$ from $s(t)$.

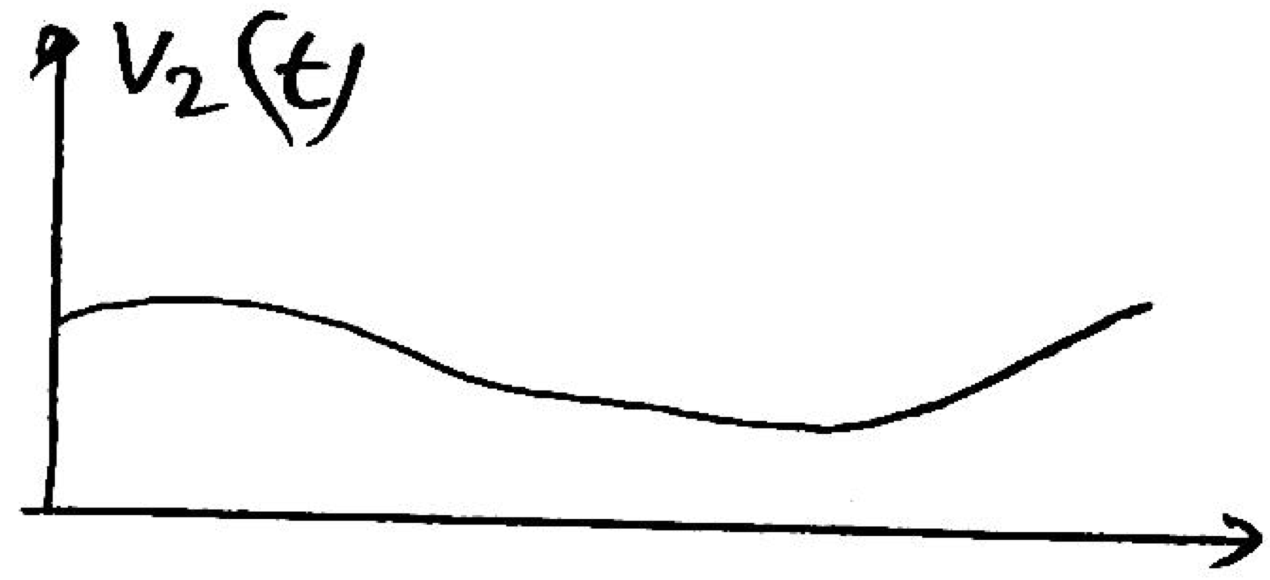












$V_2(t)$ is similar to the message signal $m(t)$.

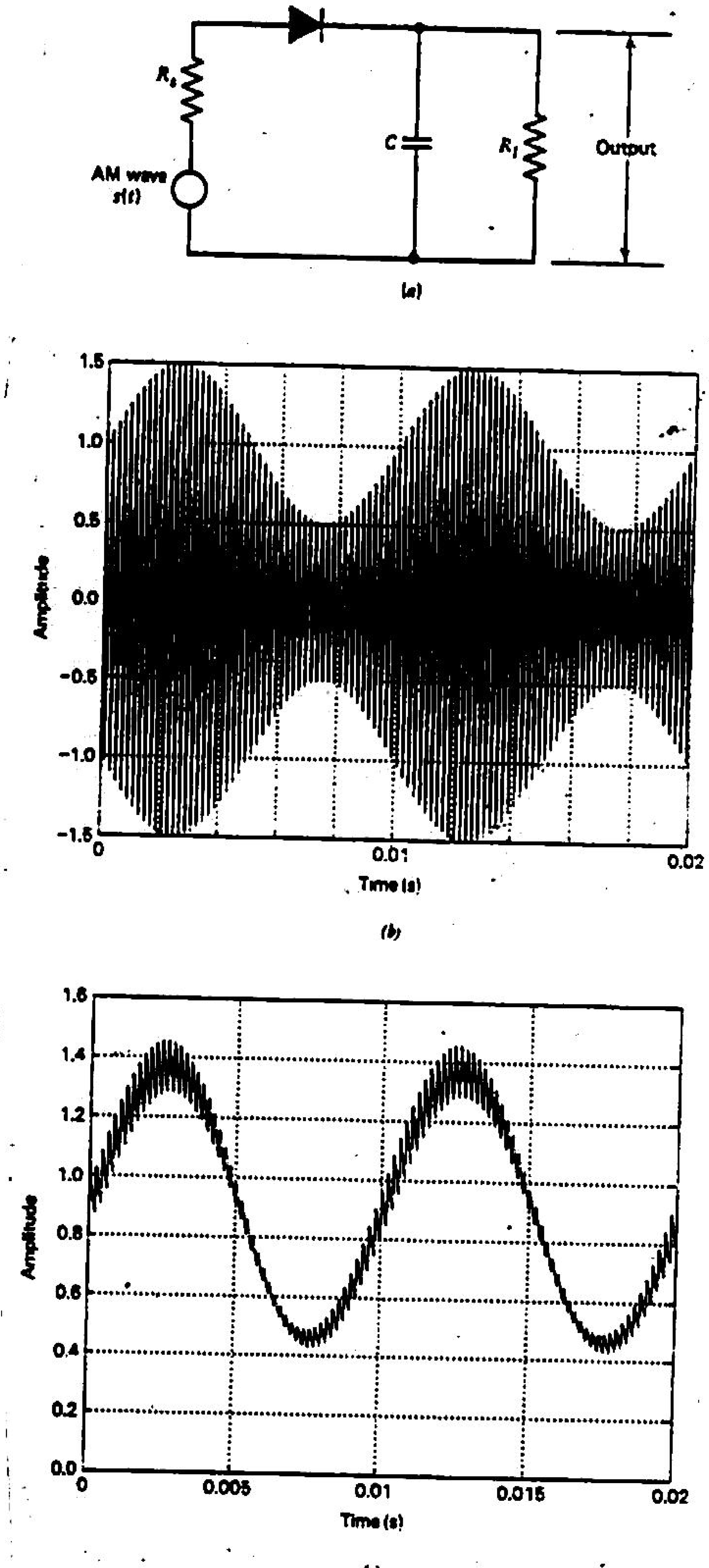
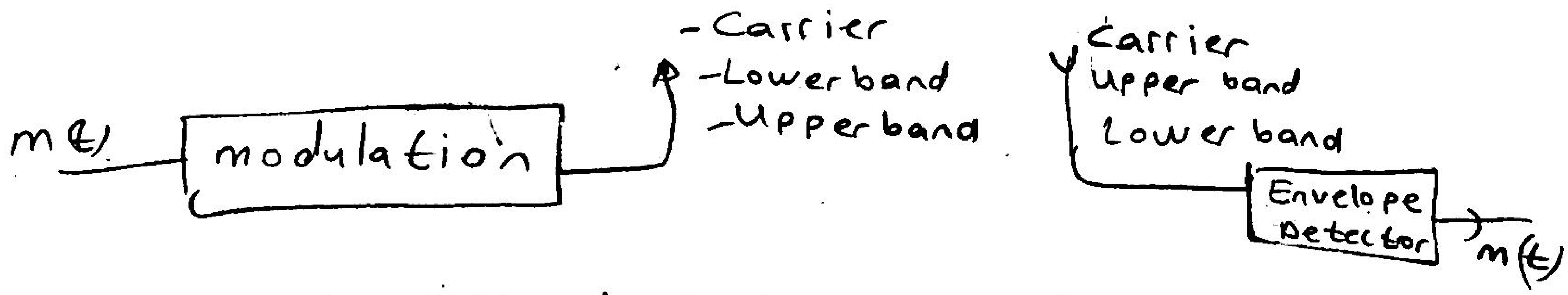


Figure 3.7 Envelope detector. *(a)* Circuit diagram. *(b)* AM wave input. *(c)* Envelope detector output.

Problems of Amplitude modulation

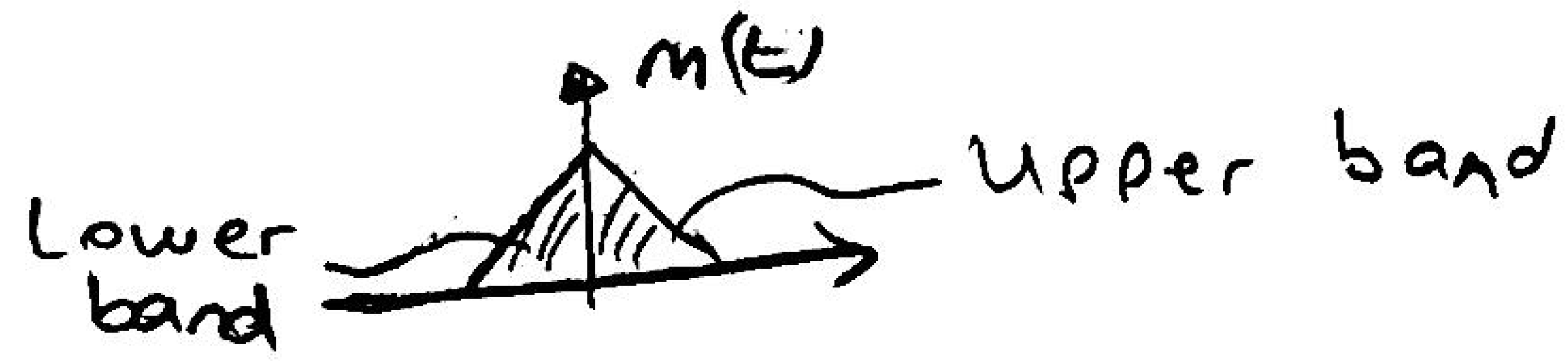


We need m(t) only.

Carrier Consumes power

Lower band and upper band Occupy bands and consume power.

We can carry only upper band or only lower band. Because Lower band and upper bands are symetrical.



Solution

1) Double side-band supressed carrier modulation

2) Vestigial side band modulation

3) Single side band modulation

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Double Sided Supressed Carrier modulation

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

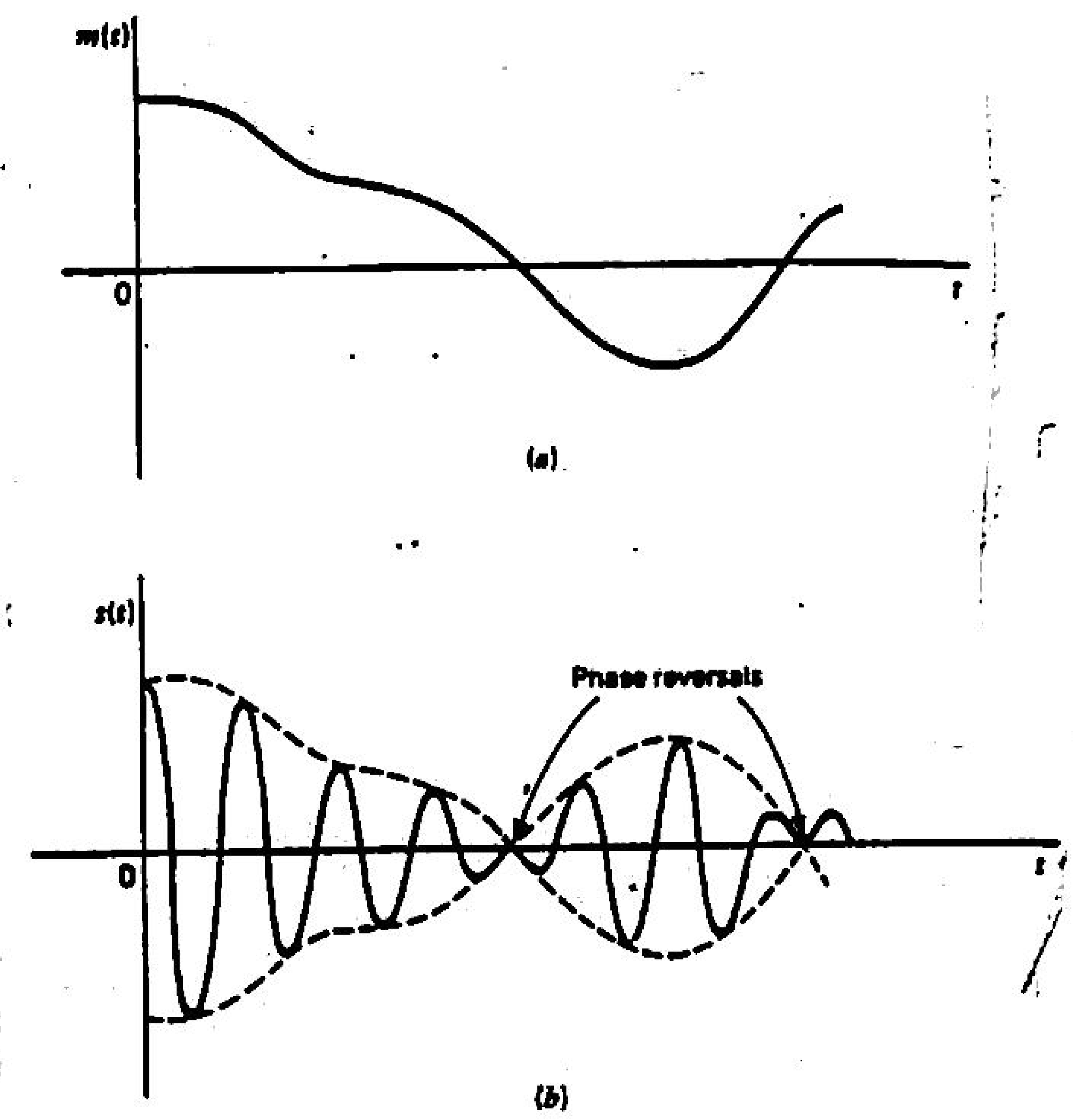


Figure 3.8 (a) Baseband signal. (b) DSB-SC modulated wave.

$$S(f) = \frac{1}{2} A_c \left[M(f-f_c) + M(f+f_c) \right]$$

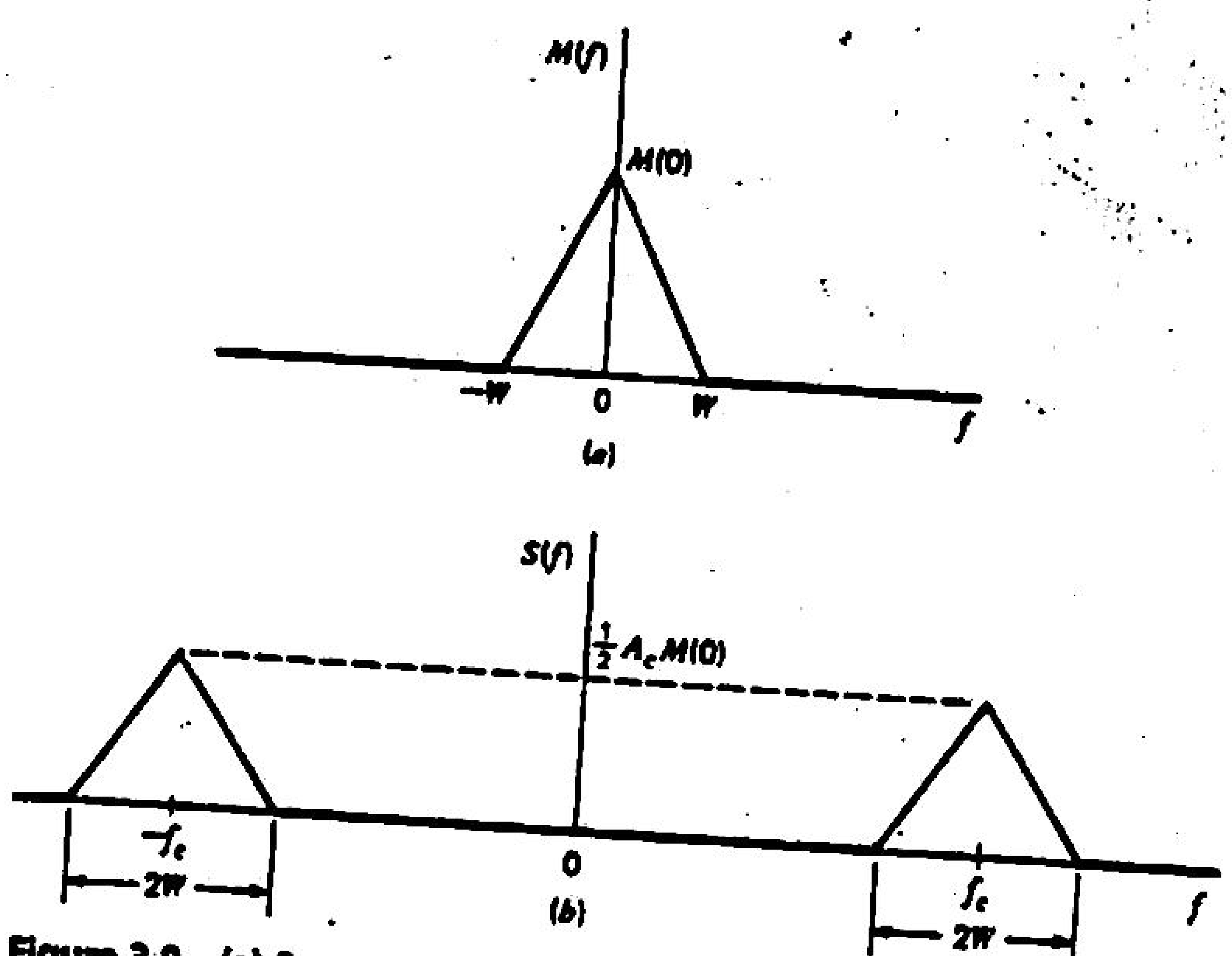
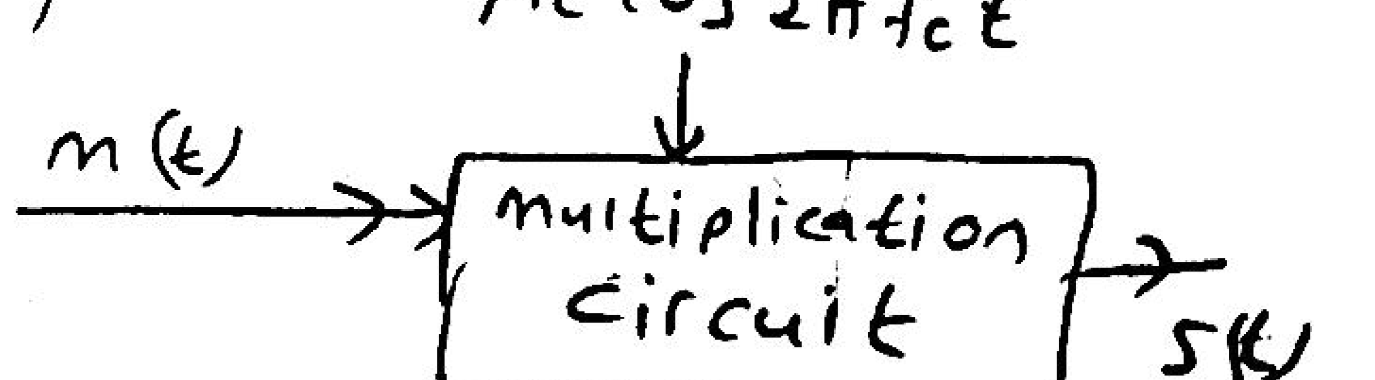


Figure 3.9 (a) Spectrum of baseband signal. (b) Spectrum of DSB-SC modulated wave.

How to obtain s(t)

1)



2) Ring modulator

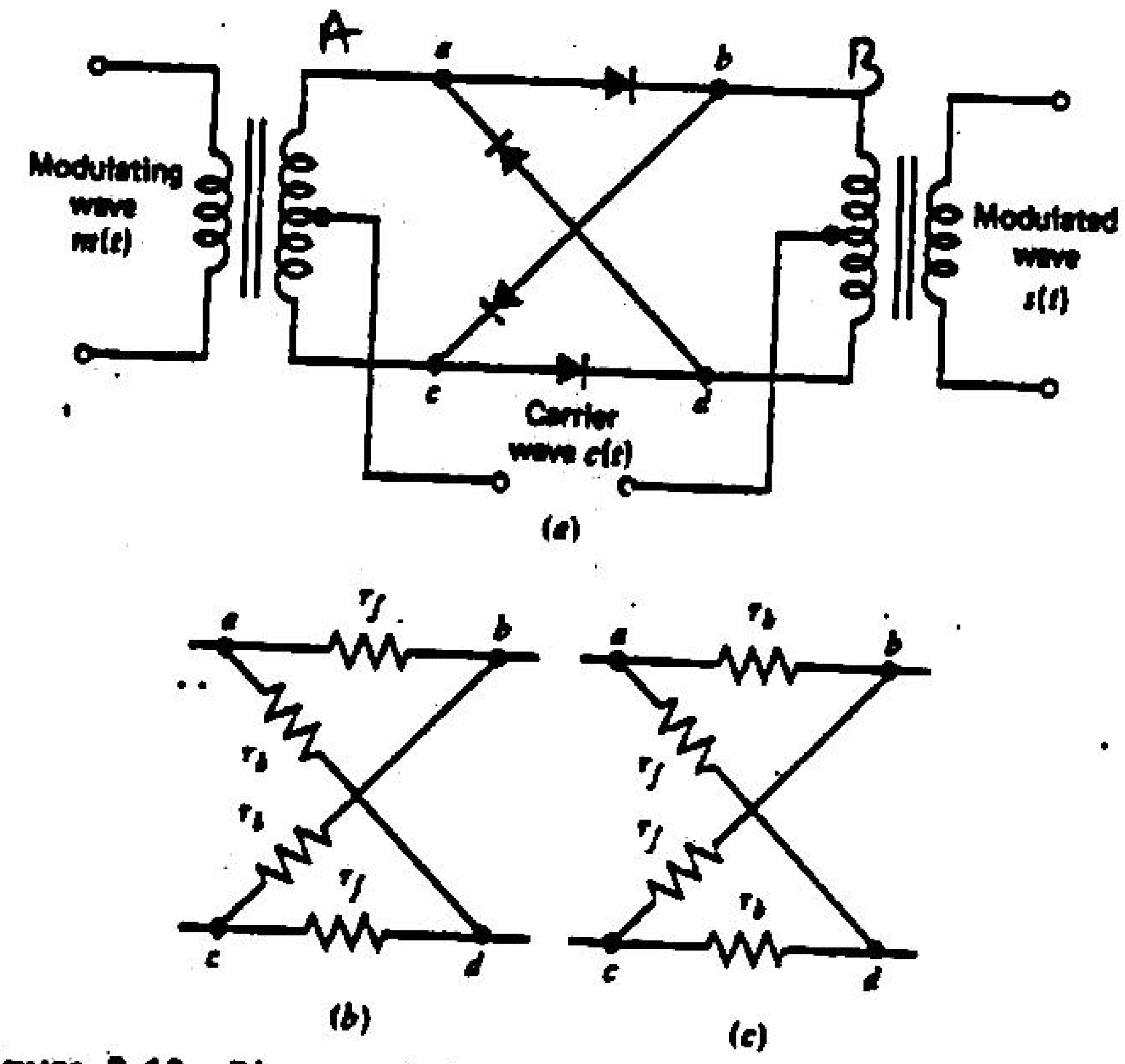
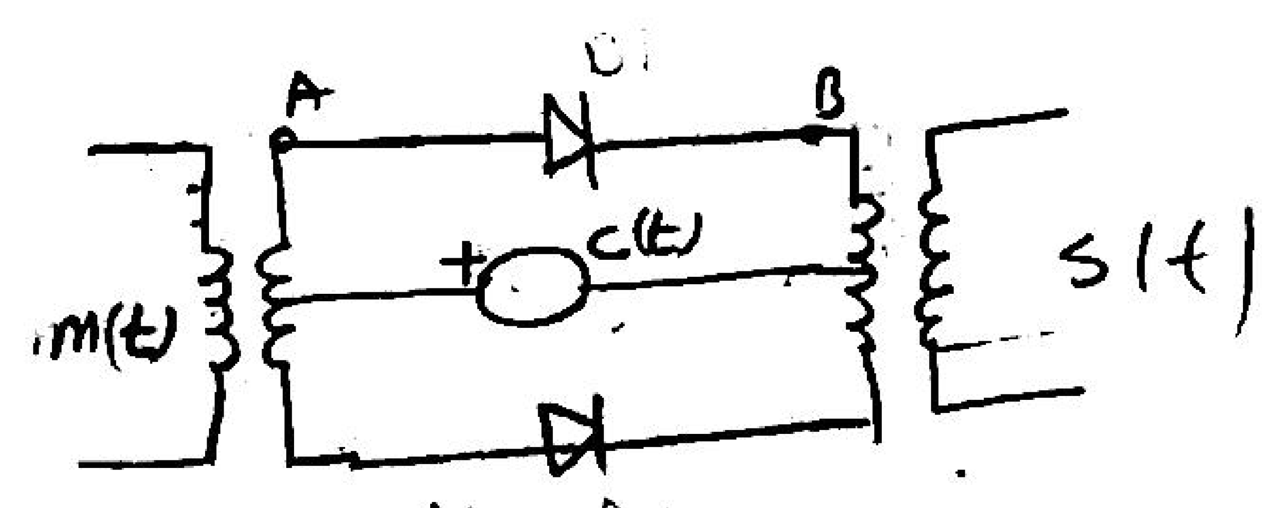
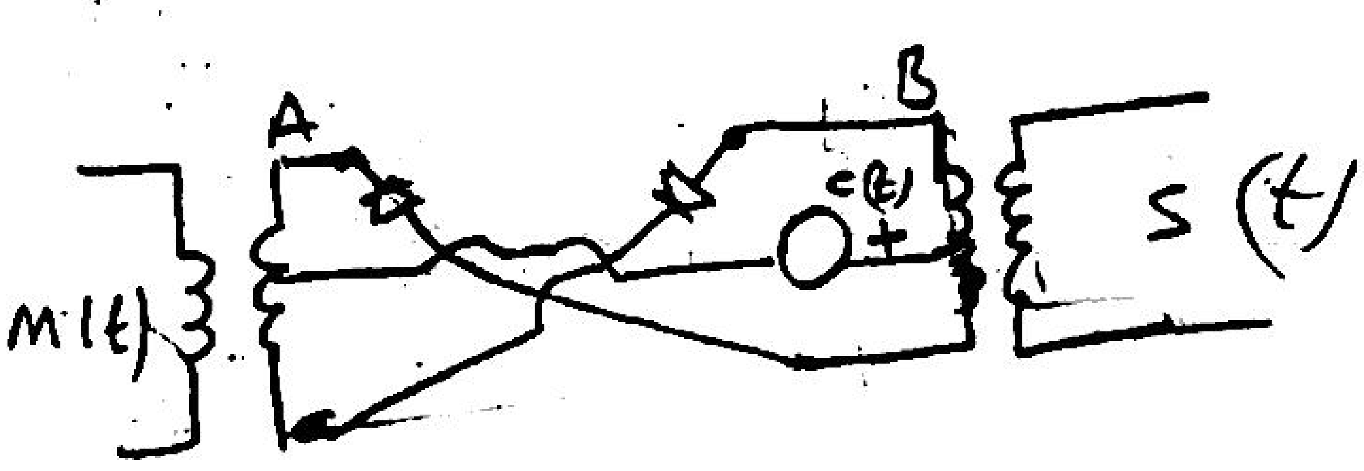


Figure 3.10 Ring modulator. (a) Circuit diagram. (b) Illustrating the condition when the outer diodes are switched on and the inner diodes are switched off. (c) Illustrating the condition when the outer diodes are switched off and the inner diodes are switched on.

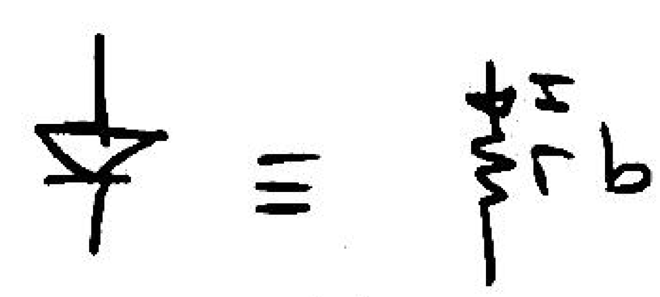


$V_A > V_B$



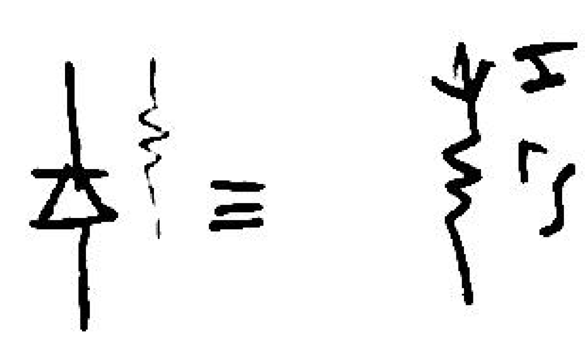
$V_B > V_A$

when a diode conducts



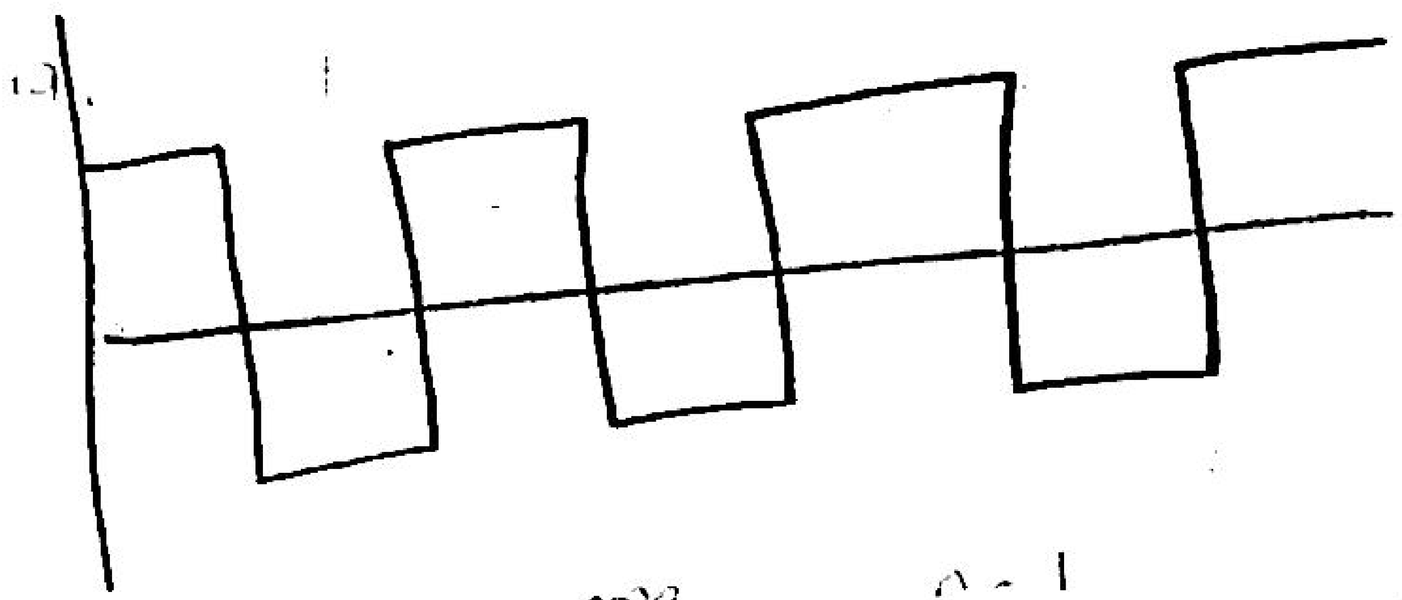
$r_b \doteq 0.1\,\Omega - 50\,\Omega$

when a diode reverse biased



$r_s = 10^6 - 10^{12}\,\Omega$ (very high

Carrier appears as Square wave:



$$c(t) = \frac{4}{\pi} \sum_{n=1}^{\infty} \frac{(-1)^{n-1}}{2n-1} \cos 2\pi f_c (2n-1)$$

$$s(t) = c(t)\, m(t)$$

$$= \frac{4}{\pi} \sum_{n=1}^{\infty} \frac{(-1)^{n-1}}{2n-1} \cos 2\pi f_c (2n-1) .\, m(t)$$

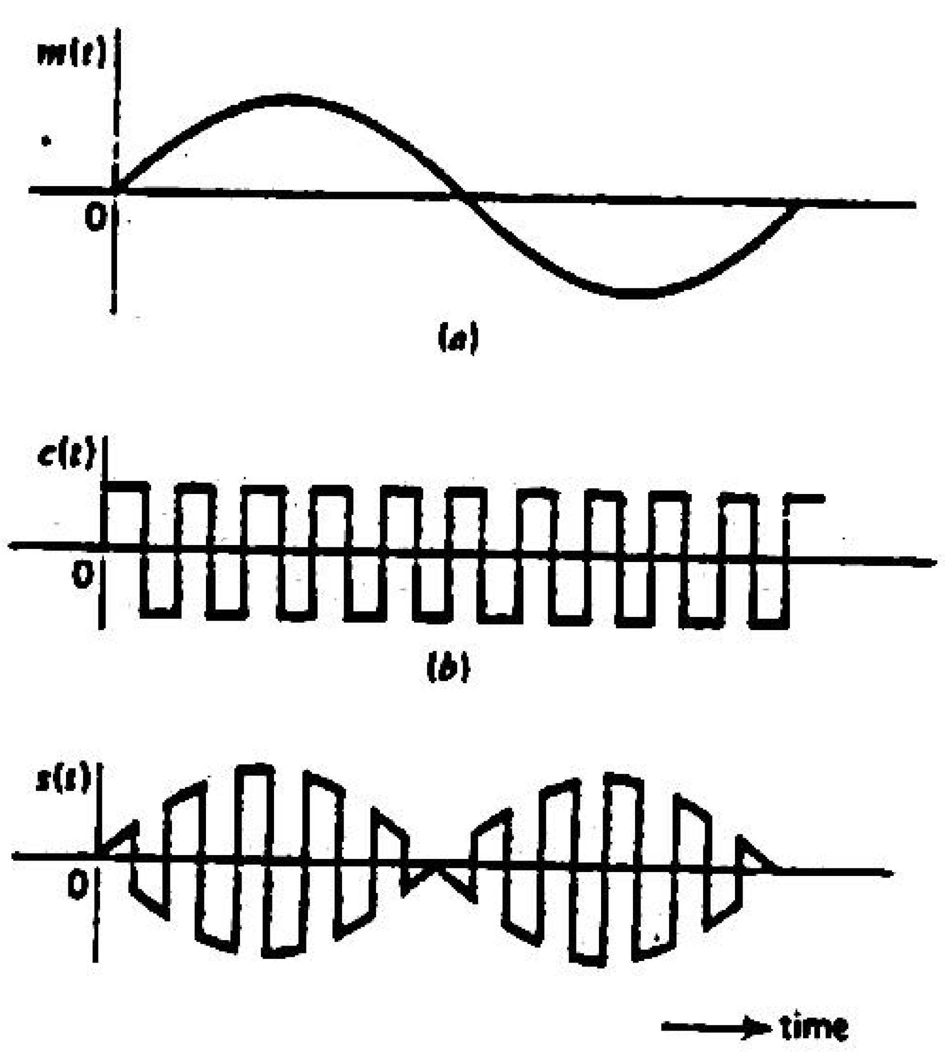


Figure 3.11 Waveforms illustrating the operation of the ring modulator for a sinusoidal modulating wave. (a) Modulating wave. (b) Square-wave carrier. (c) Modulated wave.

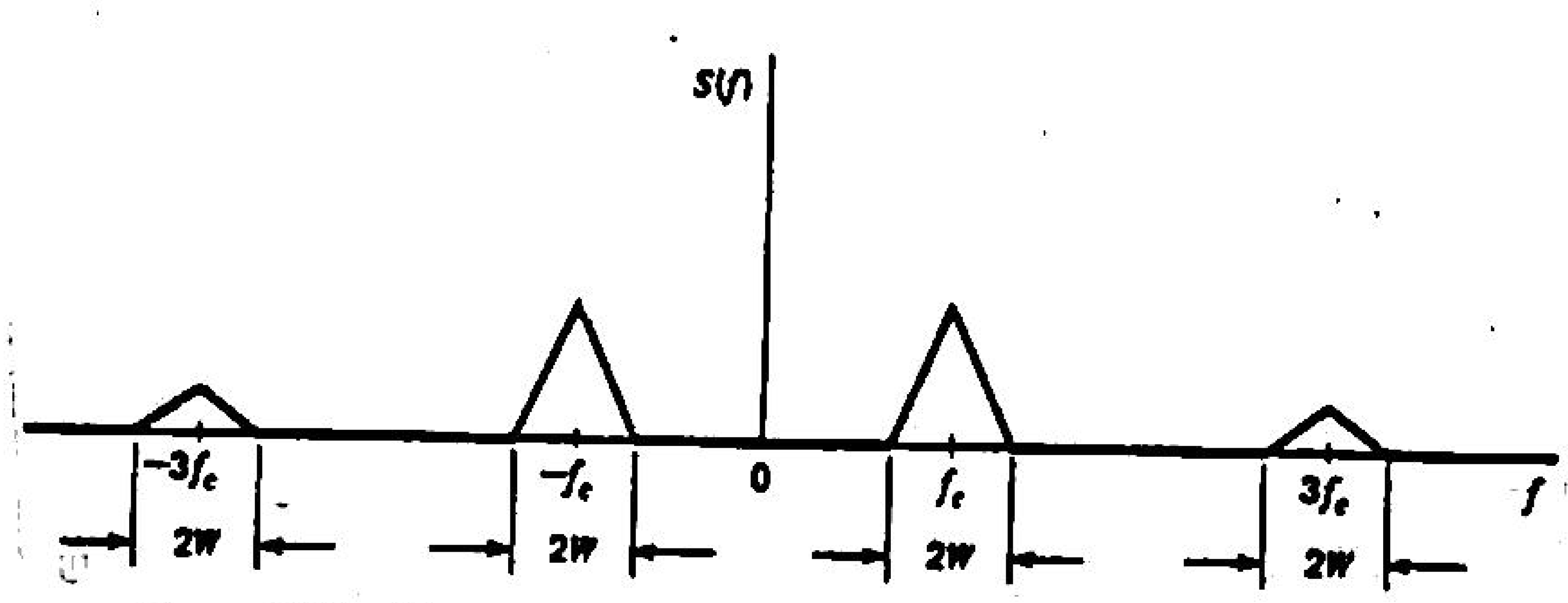


Figure 3.12 Illustrating the spectrum of ring modulator output.

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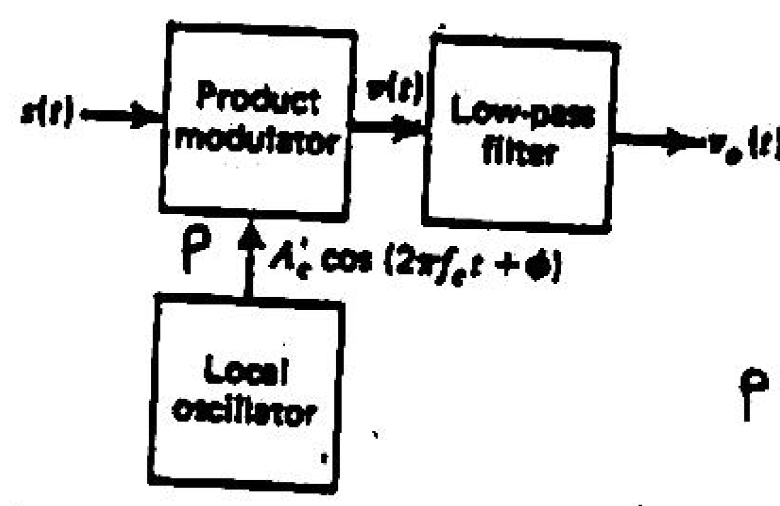
Coherent detection

when we receive $s(t)$ we assume we know f_c before. If we know f_c we use coherent detection



$p(t) = A_c' \cos(2\pi f_c t + \phi$

Figure 3.13 Coherent detection of DSB-SC modulated wave.

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

$$V_o(t) = s(t) . p(t)$$

Local oscillator should produce sine wave with same frequency and phase of original carrier

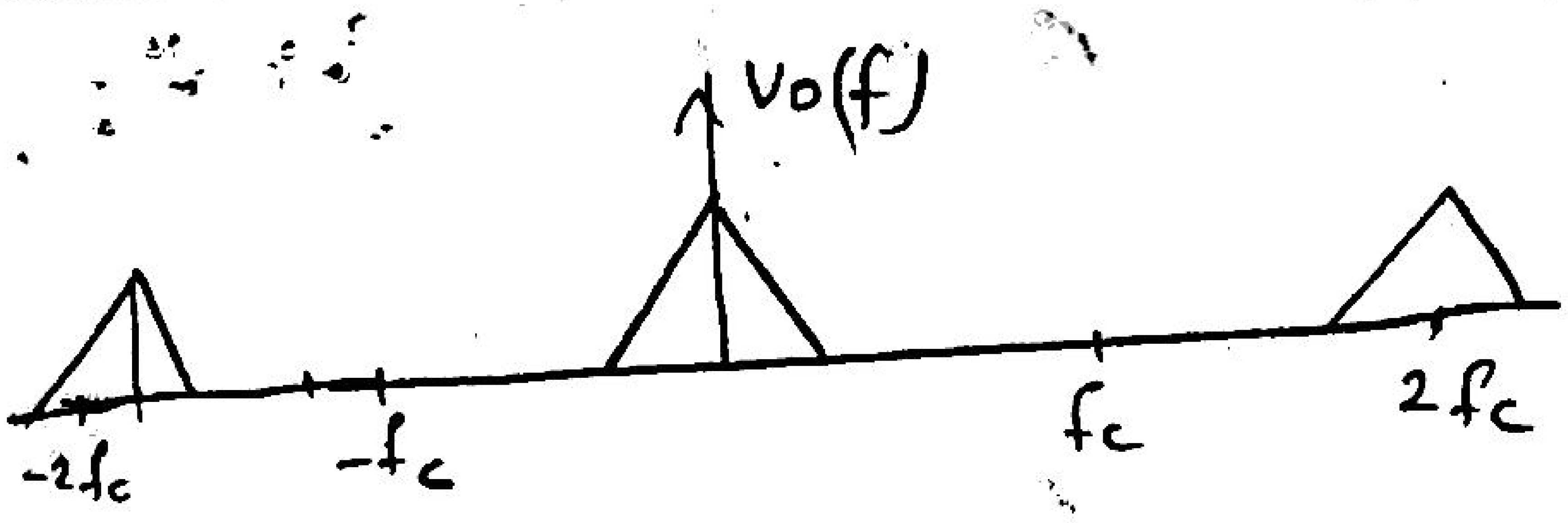
$$V_o(t) = s(t)\, p(t)$$

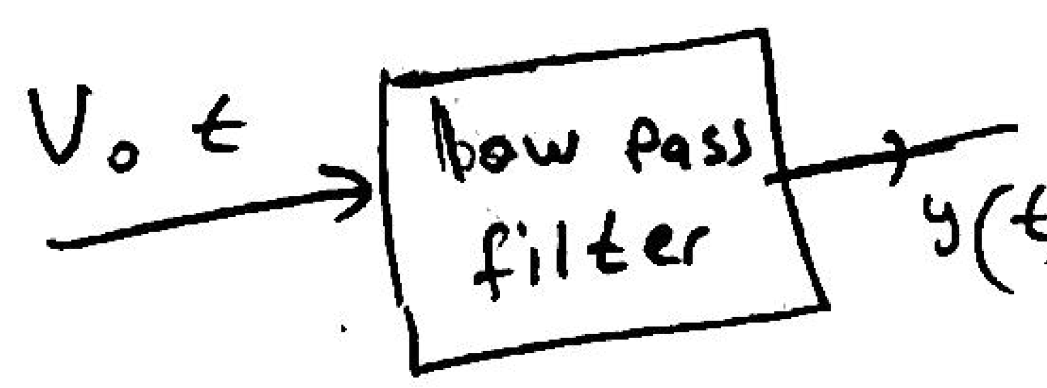
$$= \left[A_c \cos 2\pi f_c t\, m(t)\right] A_c' \cos(2\pi f_c t)$$

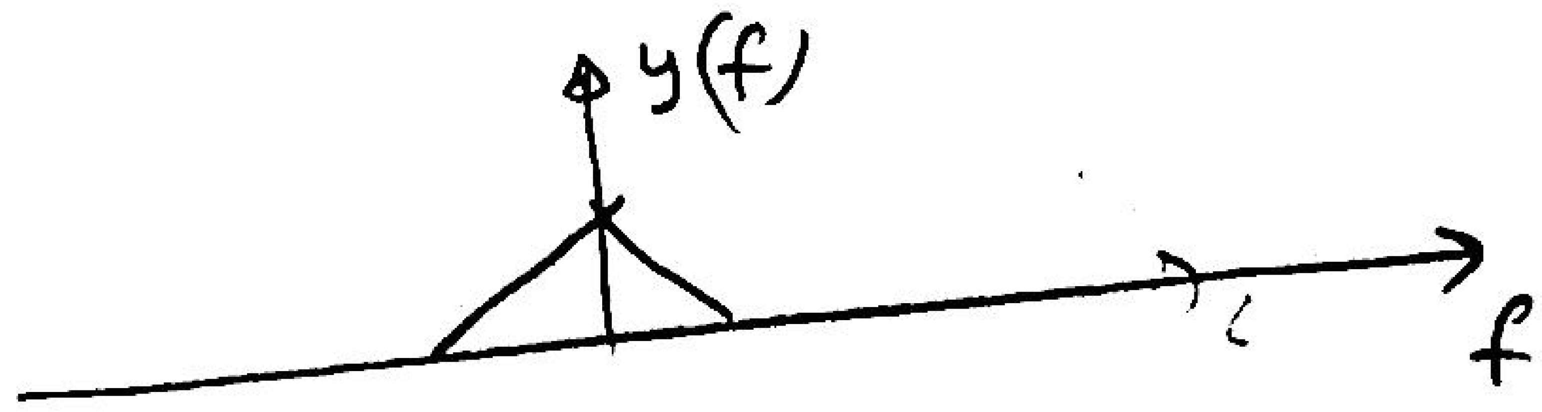
$$= m(t) \left[A_c A_c' \cos^2 2\pi f_c t \right]$$

$$= A_c A_c' m(t) \left(\frac{1}{2} + \frac{1}{2} \cos 2\pi 2 f_c t \right)$$

$$= \underbrace{\frac{A_c A_c'}{2} m(t)}_{\text{message signal}} + \underbrace{m(t) \frac{A_c A_c'}{2} \cos 2\pi f_c 2t}_{\text{high frequency term.}}$$

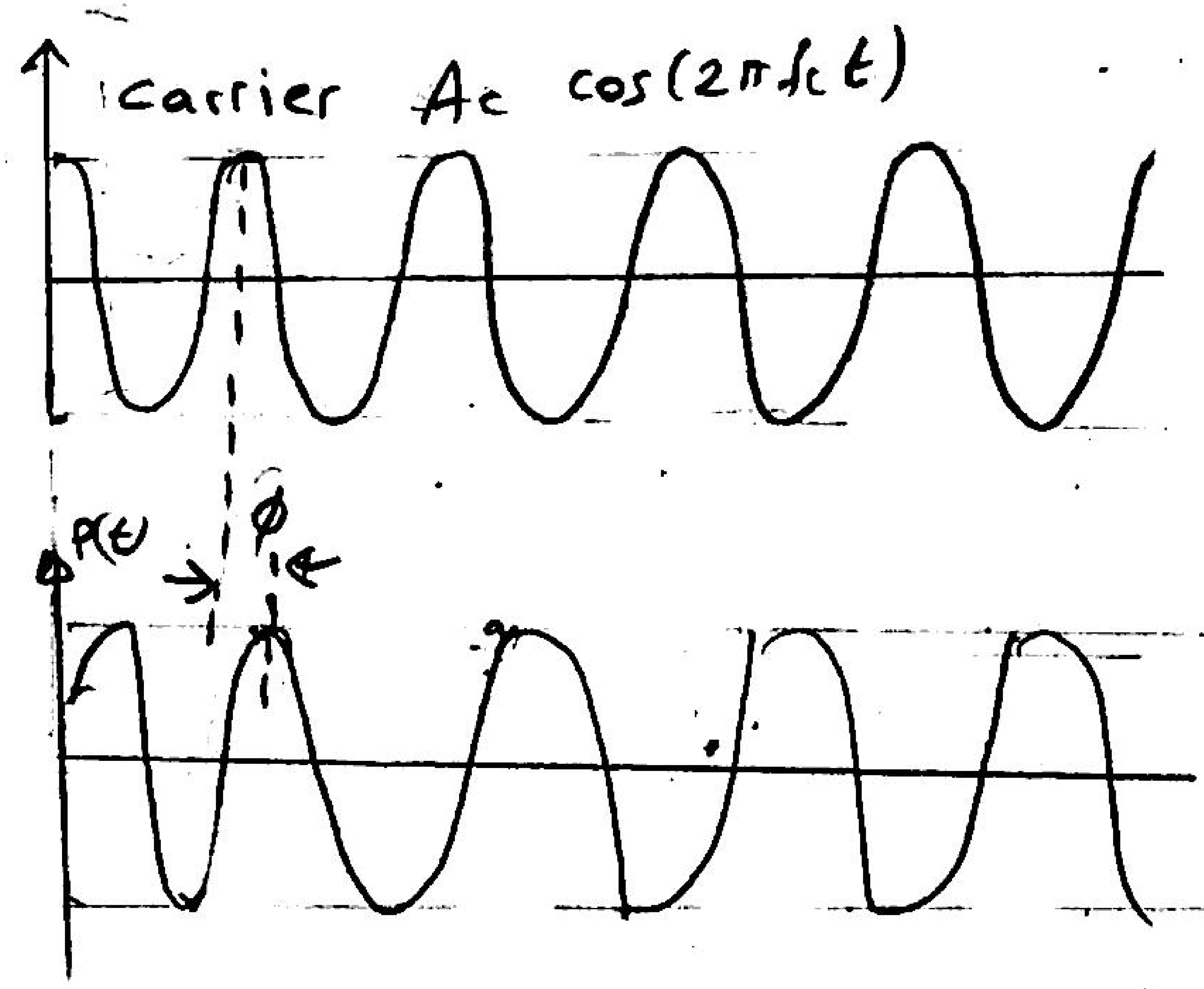






In Practice it is impossible to obtain

$p(t) = A_c' \cos(2\pi f_c t)$



There is a phase difference between the carrier and locally produced $p(t)$.

$$V_o(t) = s(t)\; p(t)$$

$$= \left[A_c \cos 2\pi f_c t \; m(t)\right] A_c' \cos(2\pi f_c t - \phi)$$

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

$$\cos A \cos B = \frac{1}{2}\left[\cos(A+B) + \cos(A-B)\right]$$

$$= A_c A_c' m(t) \frac{1}{2}\left[\cos(4\pi f_c t - \phi) + \cos\phi\right]$$

$$= \underbrace{\frac{A_c A_c'}{2} m(t) \cos\phi}_{\text{message signal}} + \underbrace{\frac{A_c A_c'}{2} m(t) \cos(4\pi f_c t - \phi)}_{\text{high freaueny term}}$$

if ϕ = constant we can get $m(t)$ easily

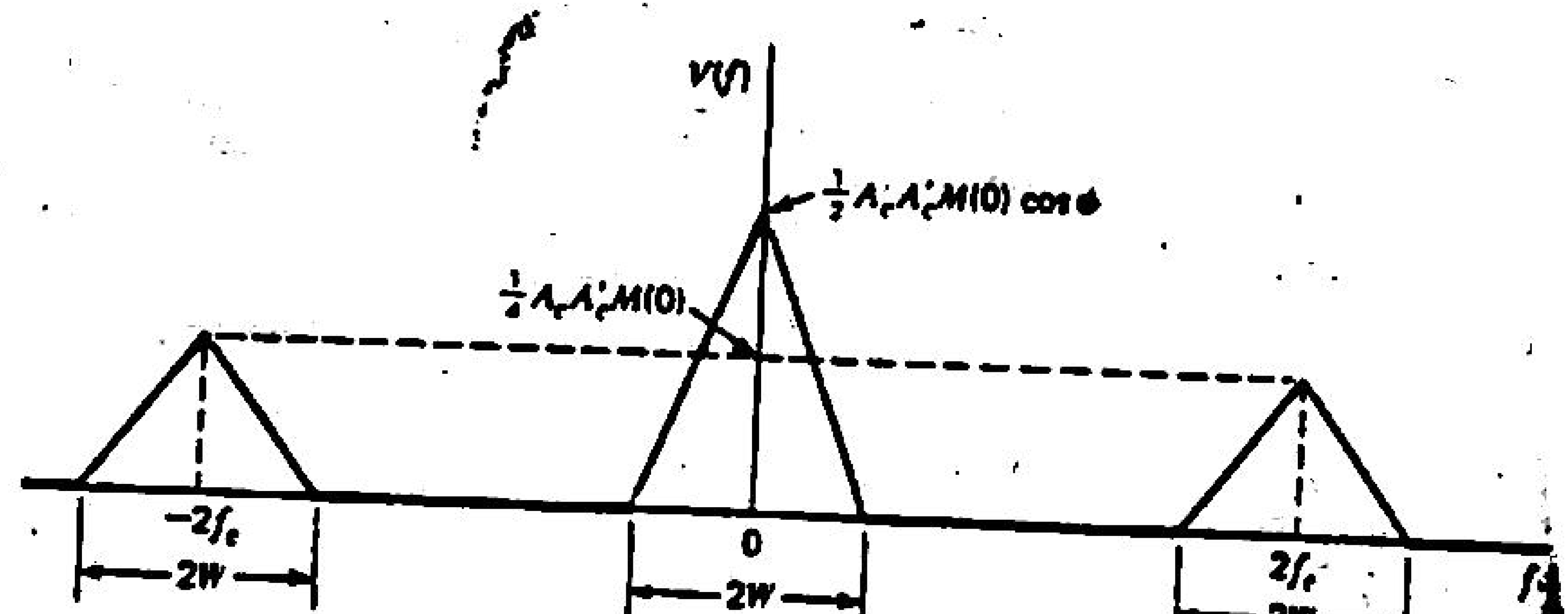
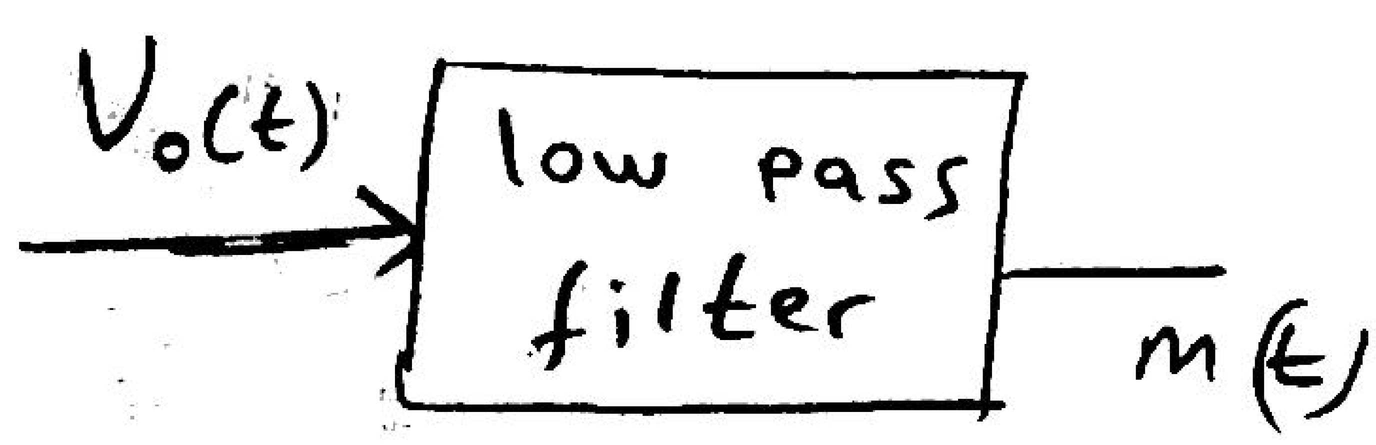


Figure 3.14 Illustrating the spectrum of a product modulator output with a DSB-SC modulated wave as input.



CMBS

Costas Receiver

$V_o(t) = \frac{A_c A_c'}{2} m(t) \cos\phi +$ high frequency terms

if $\phi =$ constant we easily get $m(t)$

In practice ϕ varies.

if $\phi = 0$ $\quad \cos\phi = 1$

$\phi = \frac{\pi}{2}$ $\quad \cos\phi = 0$ (No signal)

I channel

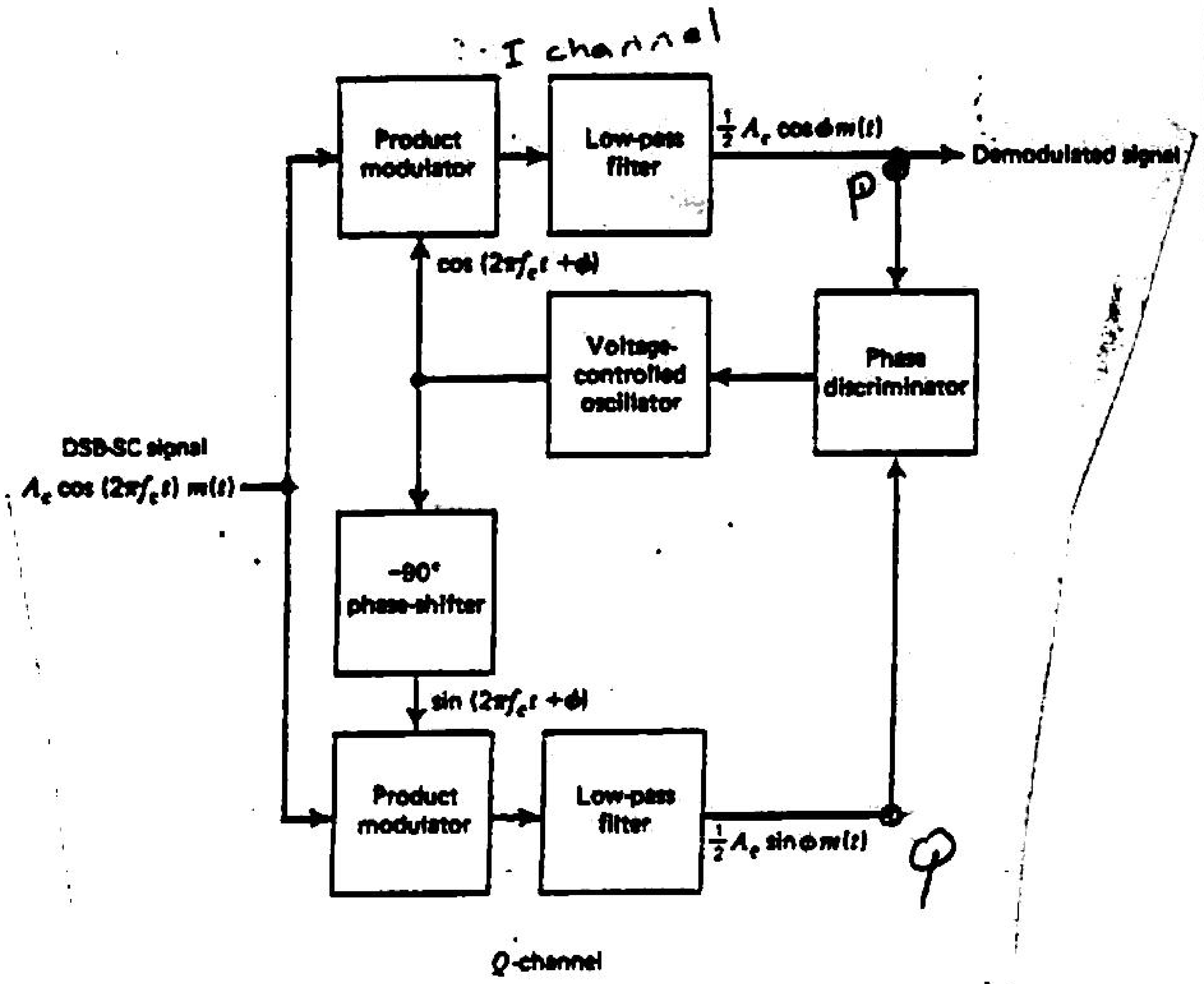


Figure 3.15 Costas receiver.

I channel is in phase with the carrier

Q channel is quadrature (90° difference) with the carrier.

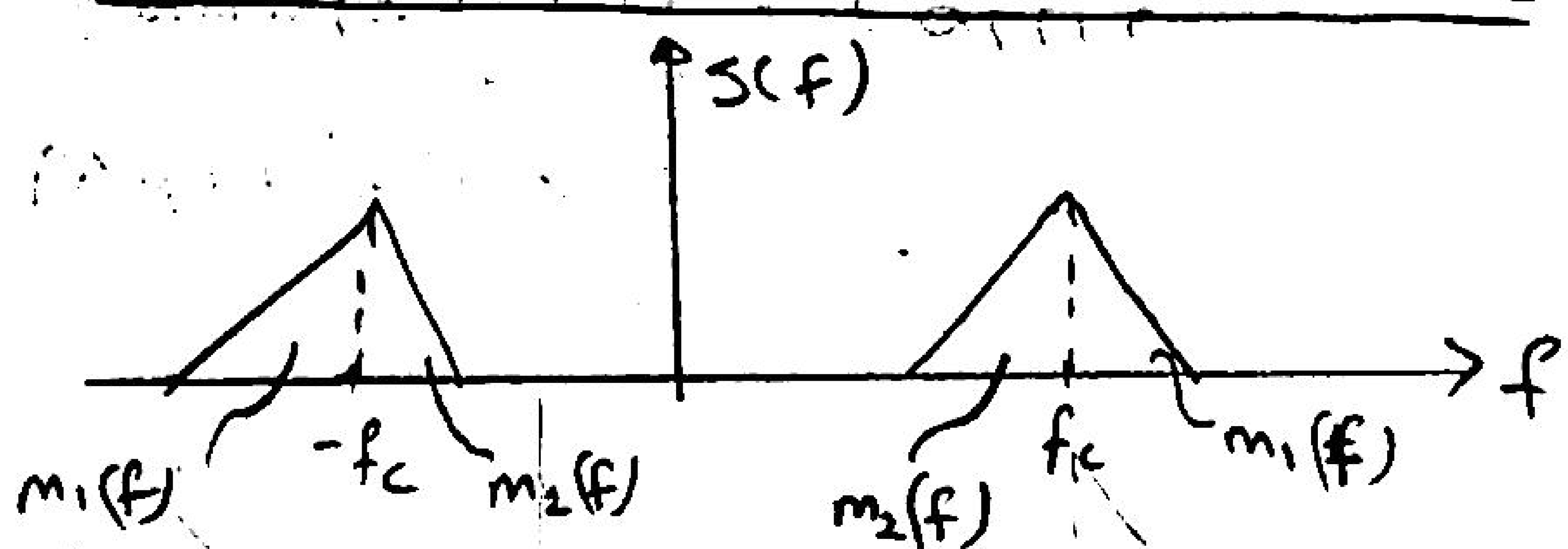
if carrier phase changes Then the output at P and Q changes.

Phase discriminator measures the phases of P and Q, and produces a dc voltage. This DC voltage is proportional to the phase shift ϕ.

This DC voltage is used by voltage controlled oscillator.

The feedback mechanism automaticaly changes the phase of the voltage controlled oscillator.

Quadrature carrier Multiplexing



$S(t) = A_c m_1(t) \cos 2\pi f_c t + A_c m_2(t) \sin 2\pi f_c t$

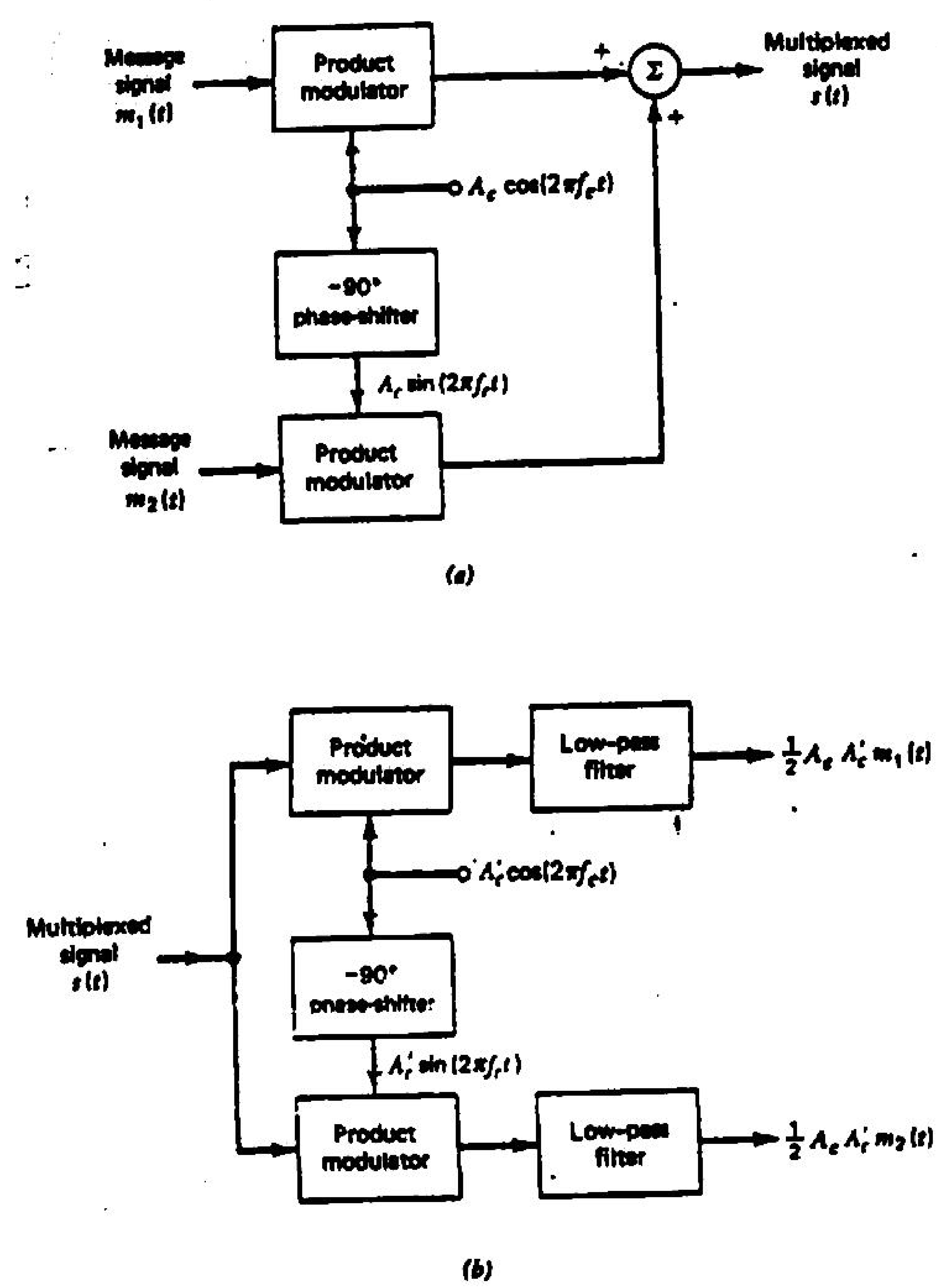
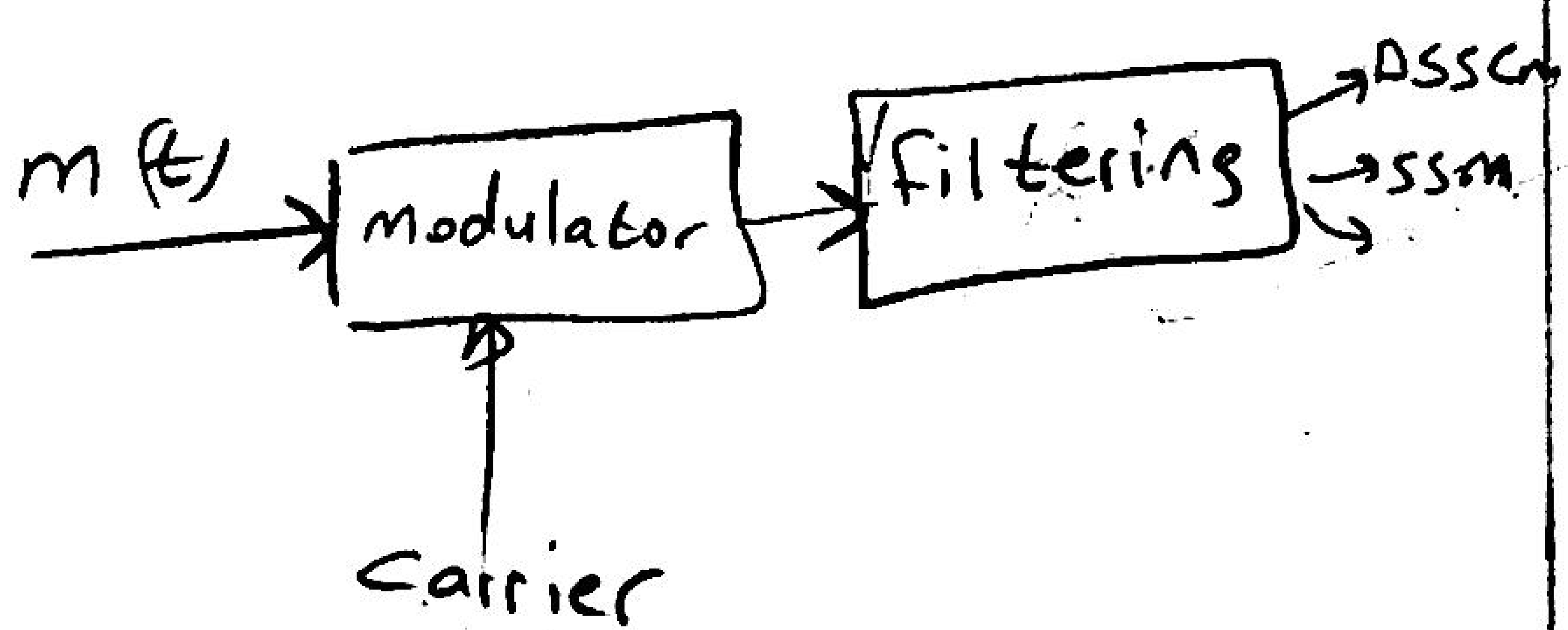
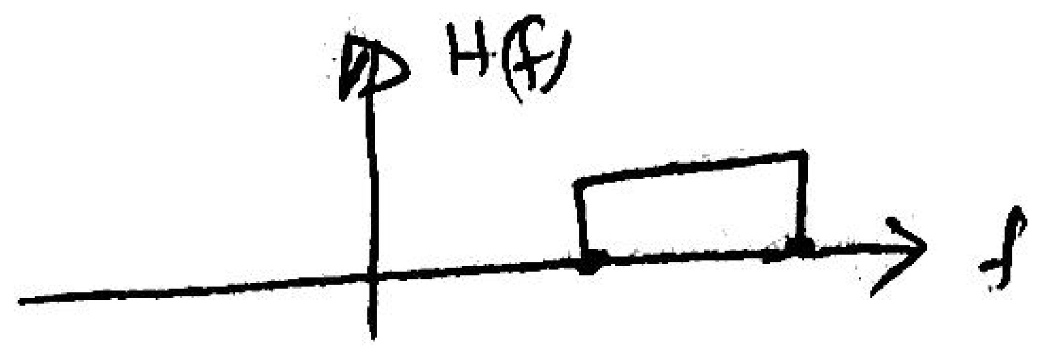


Figure 3.16 Quadrature-carrier multiplexing system. (a) Transmitter. (b) Receiver.

Filtering of sidebands



How do we design filters?



An ideal filter is impossible

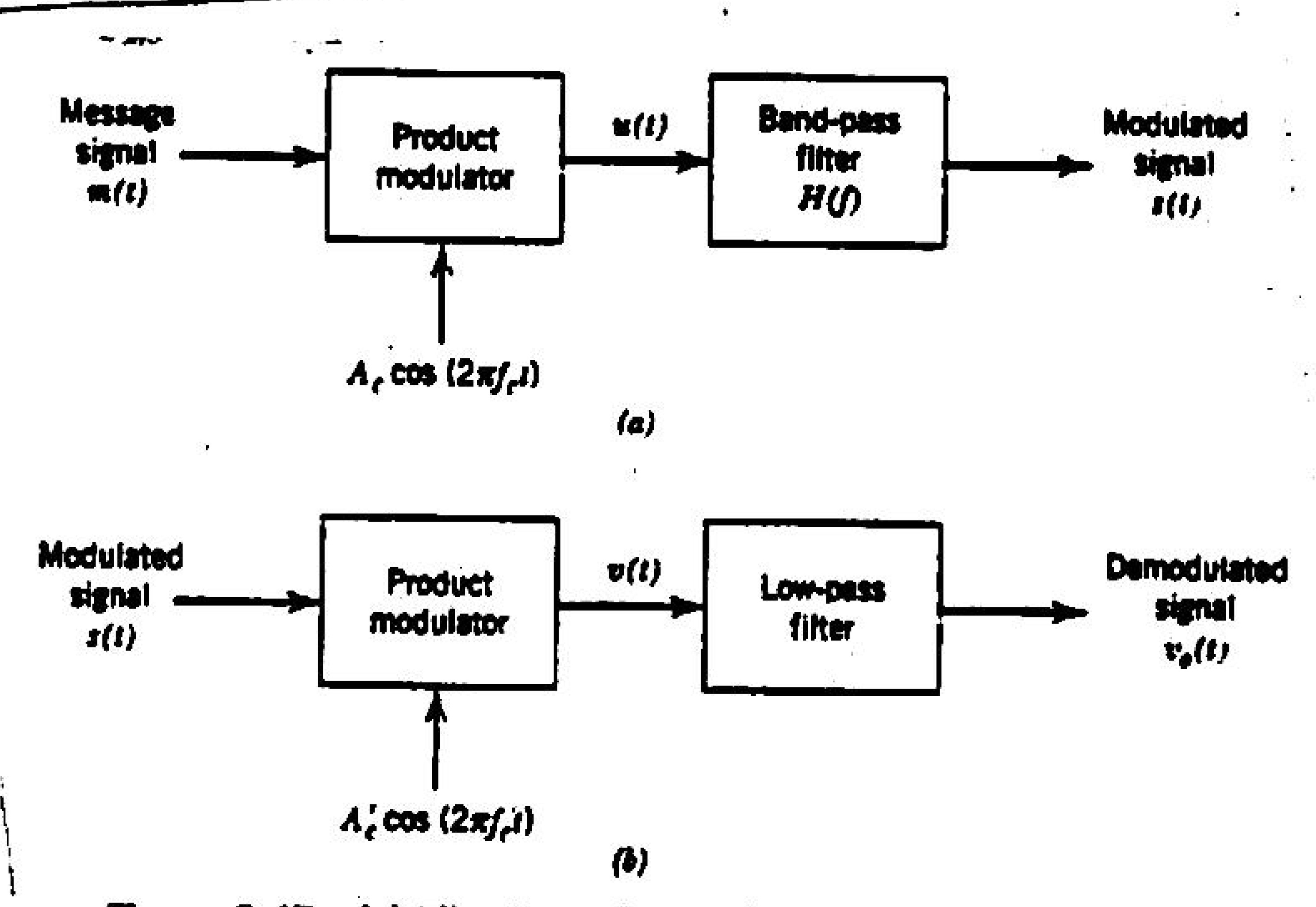


Figure 3.17 (a) Filtering scheme for processing sidebands. (b) Coherent detector for recovering the message signal.

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

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

$$S(f) = U(f)\, H(f)$$

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

for coherent detectors

$$v(t) = A_c' \cos(2\pi f_c t)\, s(t)$$

$$V(f) = \frac{A_c'}{2}\left[S(f-f_c) + S(f+f_c)\right]$$

$$V(f) = \frac{A_c'}{2}\left\{\left[\frac{A_c}{2} M(f-f_c-f_c) + \frac{A_c}{2} M(f-f_c+f_c)\right] H(f-f_c) + \left[\frac{A_c}{2} M(f+f_c-f_c) + \frac{A_c}{2} M(f+f_c+f_c)\right] H(f+f_c)\right\}$$

$$= \frac{A_c' A_c}{4}\left\{\left[M(f-2f_c) + M(f)\right] H(f-f_c) + \left[M(f) + M(f+2f_c)\right] H(f+f_c)\right\}$$

High frequency components are filtered by low-pass filter. Remaining terms.

$$V_o(f) = \frac{A_c' A_c}{4} M(f)\left\{H(f-f_c) + H(f+f_c)\right\}$$

We want linear relationship

$$\boxed{V_o(f) = \alpha\, M(f)}$$

Result

$$H(f-f_c) + H(f+f_c) = \text{constant}$$

for $-W < f < W$

One selection

$$H(f-f_c) + H(f+f_c) = 2$$

then

$$V_o(f) = \frac{A_c' A_c}{4} M(f) \cdot 2 = \frac{A_c' A_c}{2} M(f)$$

$$V_o(f) = \frac{A_c' A_c}{2} M(f)$$

$$s(t) = s_I(t)\cos(2\pi f_c t) - s_Q(t)\sin(2\pi f_c t)$$

$s_I(t)$ = In phase component

$s_Q(t)$ = Quadrature component

$$S_I(f) = \begin{cases} S(f-f_c) + S(f+f_c) & -w<f<w \\ 0 & \text{else} \end{cases}$$

Since

$$S(f) = U(f)\,H(f)$$
$$= \frac{A_c}{2}\left[M(f-f_c) + M(f+f_c)\right] H(f)$$

$$S(f-f_c) = \frac{A_c}{2}\left[M(f-f_c-f_c) + M(f-f_c+f_c)\right] H(f-f_c)$$

$$S(f+f_c) = \frac{A_c}{2}\left[M(f+f_c-f_c) + M(f+f_c+f_c)\right] H(f+f_c)$$

$$S_I(f) = S(f-f_c) + S(f+f_c)$$
$$= \frac{A_c}{2} M(f)\,H(f-f_c) + \frac{A_c}{2} M(f)\,H(f+f_c)$$
$$= \frac{1}{2} A_c M(f)\left[H(f-f_c) + H(f+f_c)\right]$$

Note $M(f-2f_c) = 0$

$M(f+2f_c) = 0$

Because $M(f) = 0$

Outside $-w<f<w$

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We Assume that

$$H(f-f_c) + H(f+f_c) = \text{constant} = 1$$

$$S_I(f) = \frac{1}{2} A_c M(f) \quad -w<f<w$$

In time domain

$$\boxed{s_I(t) = \frac{1}{2} A_c\, m(t)}$$

In a similar method

$$s_Q(t) = \frac{1}{2} A_c\, m'(t)$$

$$M(f) \xrightarrow{\boxed{H_Q(f)}} M'(f)$$

$$H_Q(f) = j\left[H(f-f_c) - H(f+f_c)\right]$$

$$s(t) = \frac{A_c}{2}\left[m(t)\cos(2\pi f_c t) - m'(t)\sin(2\pi f_c t)\right]$$

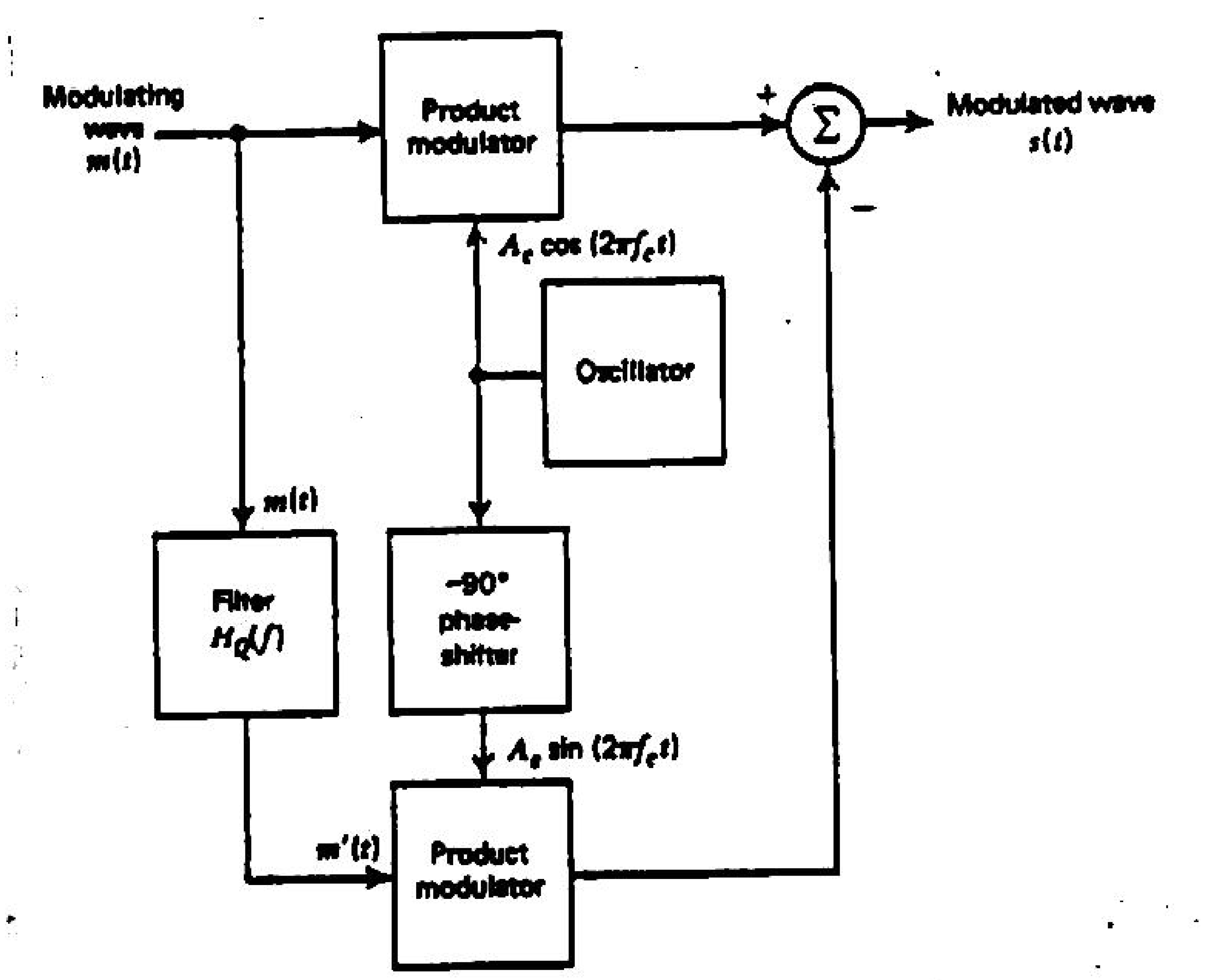
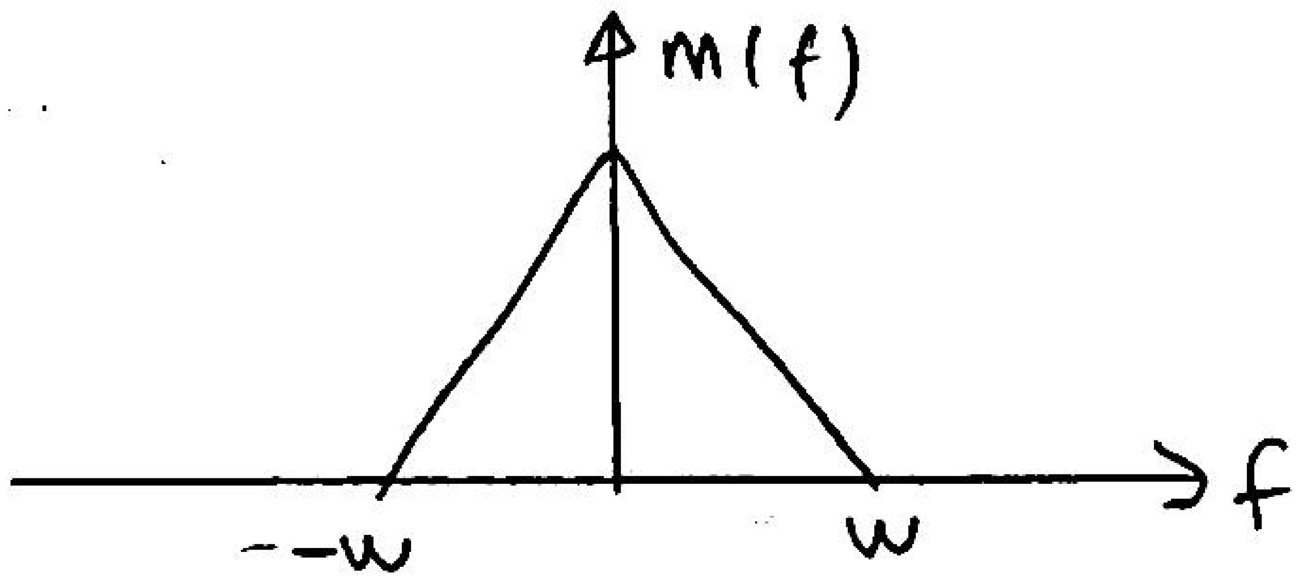
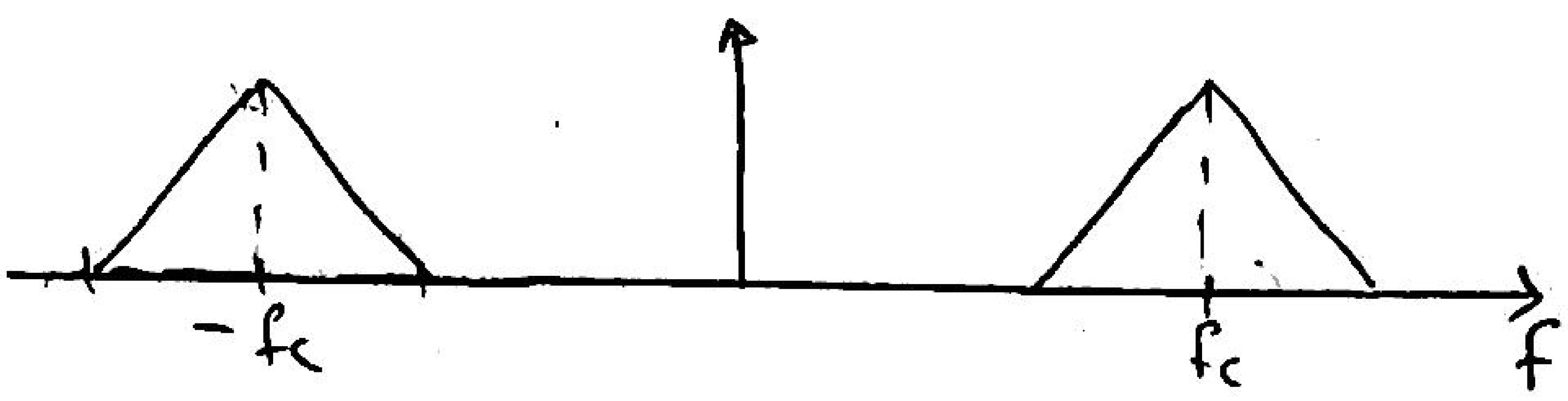


Figure 3.18 Block diagram of phase discrimination method for processing sidebands.

Vestigial side band Modulat





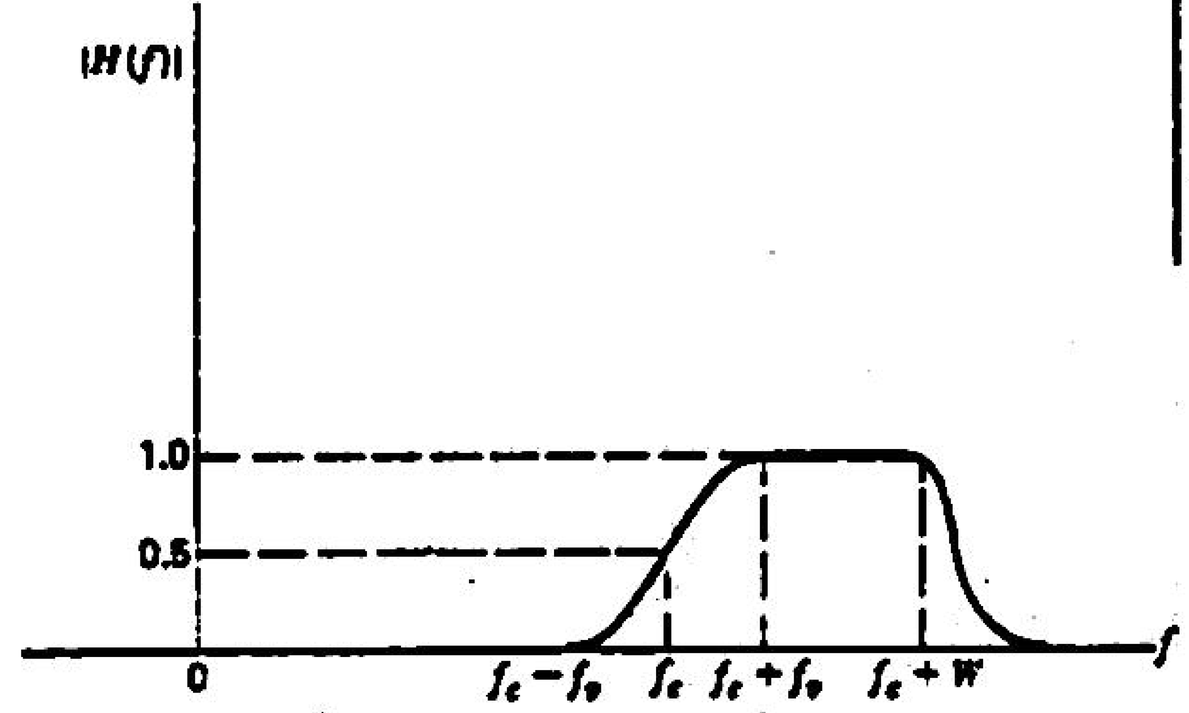


Figure 3.19 Amplitude response of VSB filter; only positive-frequency portion is shown.

$f_c - f_v < f < f_c + f_v$ belongs to the lower frequency components.

Vestigial sideband modulation is used where Lower frequencies are very important, such as TV signals.

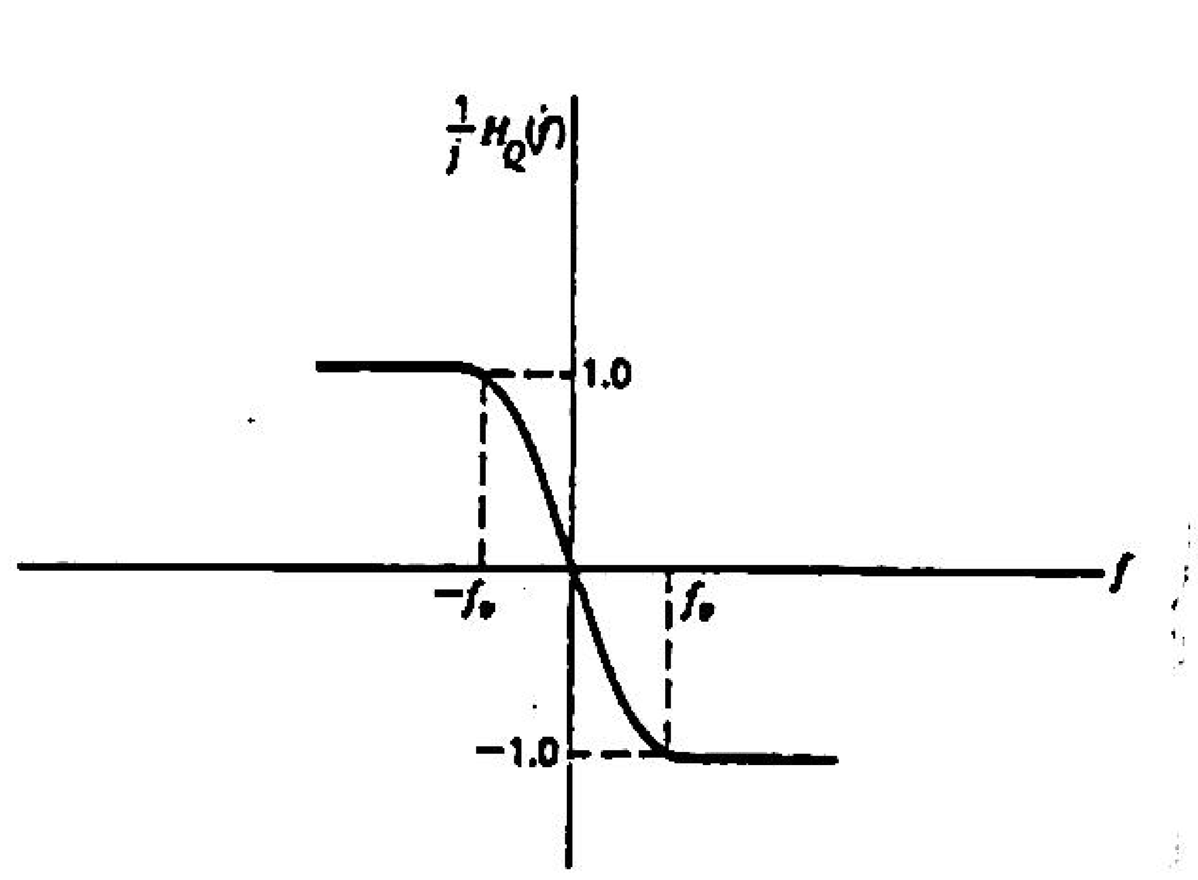


Figure 3.20 Frequency response of filter for producing the quadrature component of the VSB wave.

Television signals.

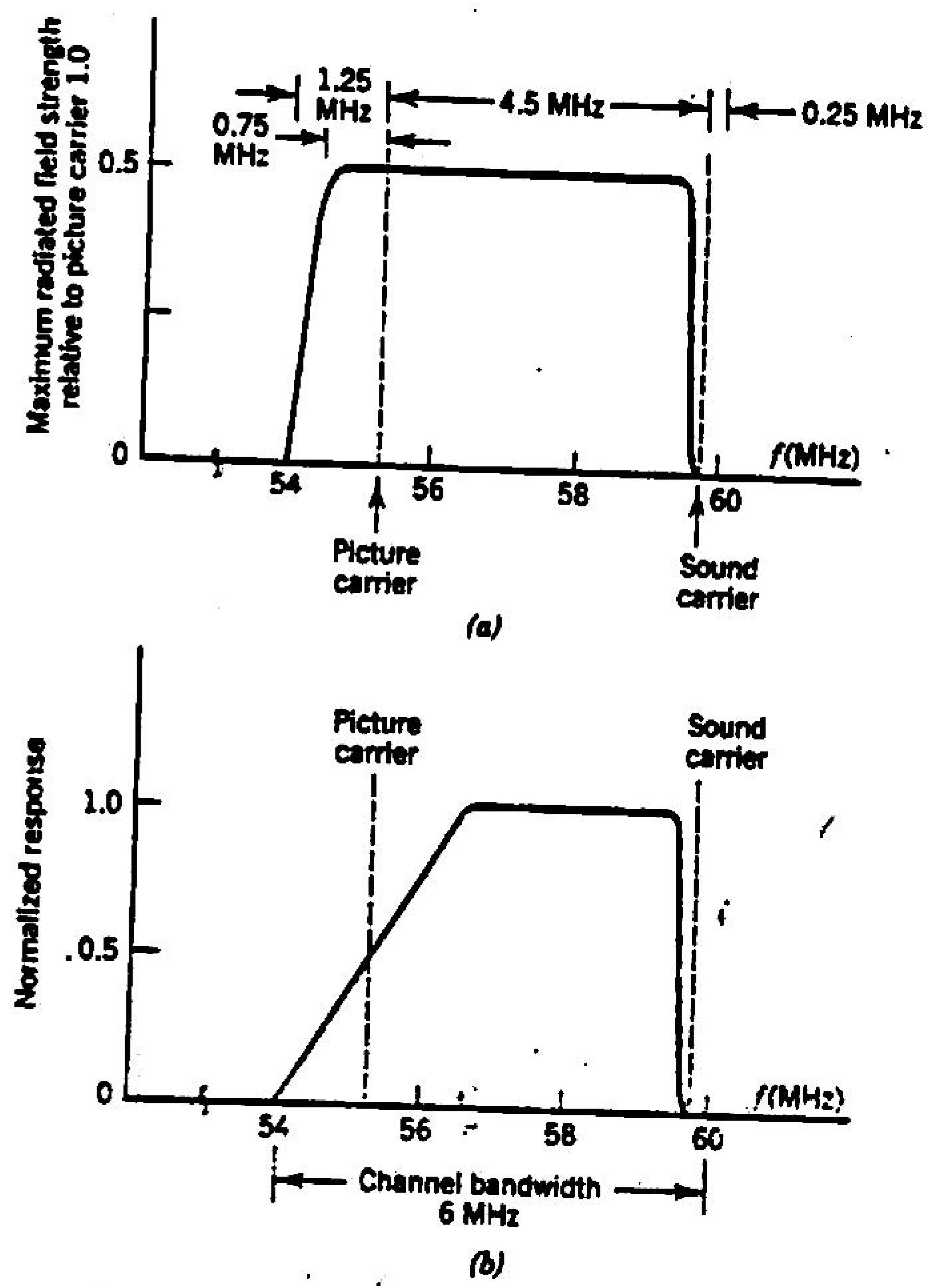
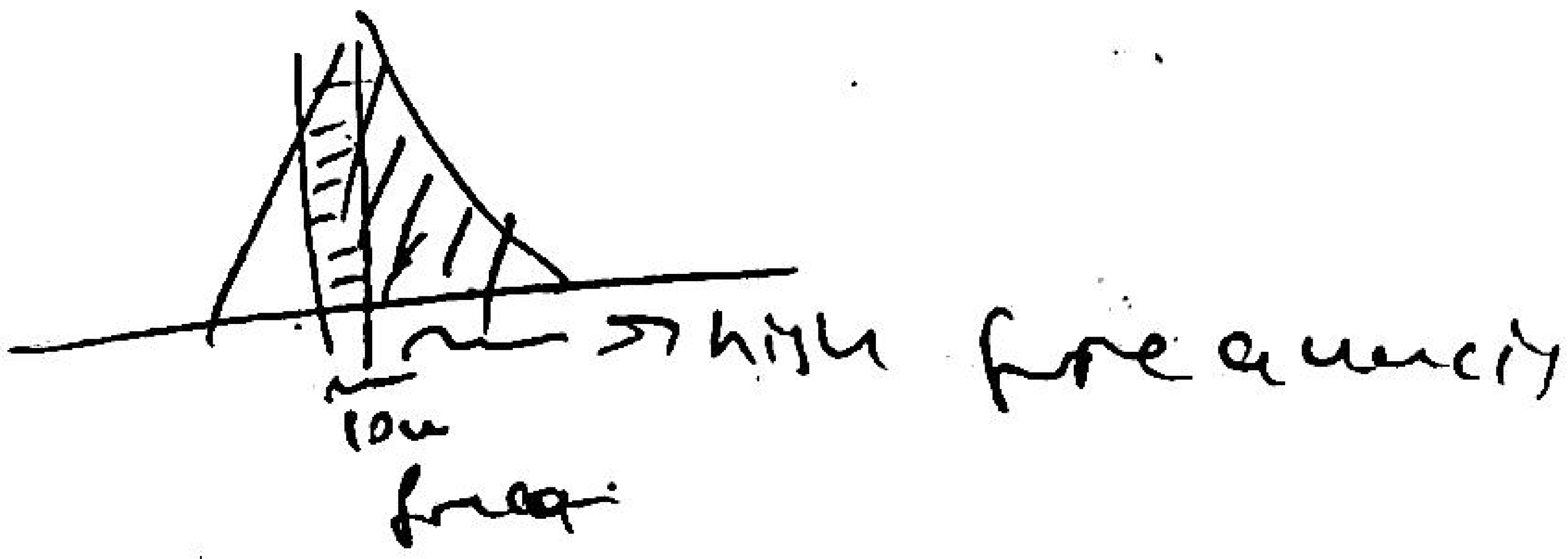


Figure 3.21 *(a)* Idealized amplitude spectrum of a transmitted TV signal. *(b)* Amplitude response of VSB shaping filter in the receiver.

in vestigial side band Mod.

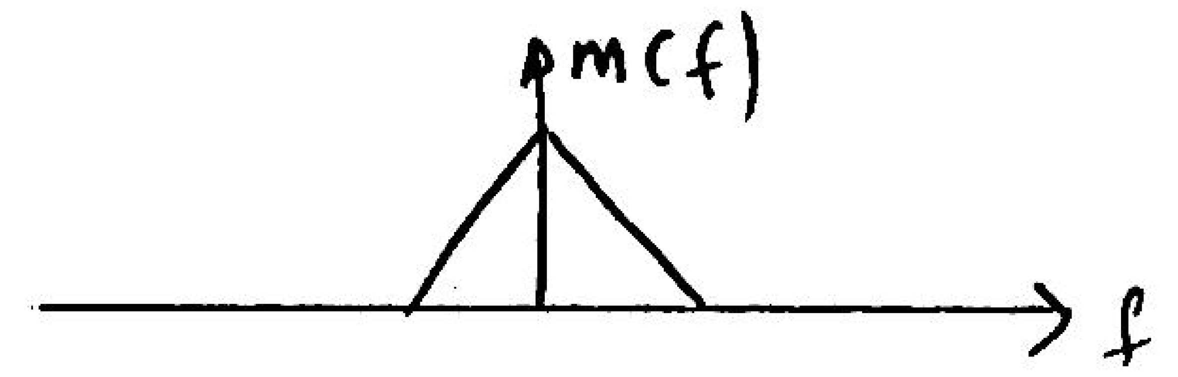
upper side band and some portion of lower side band is transmitted

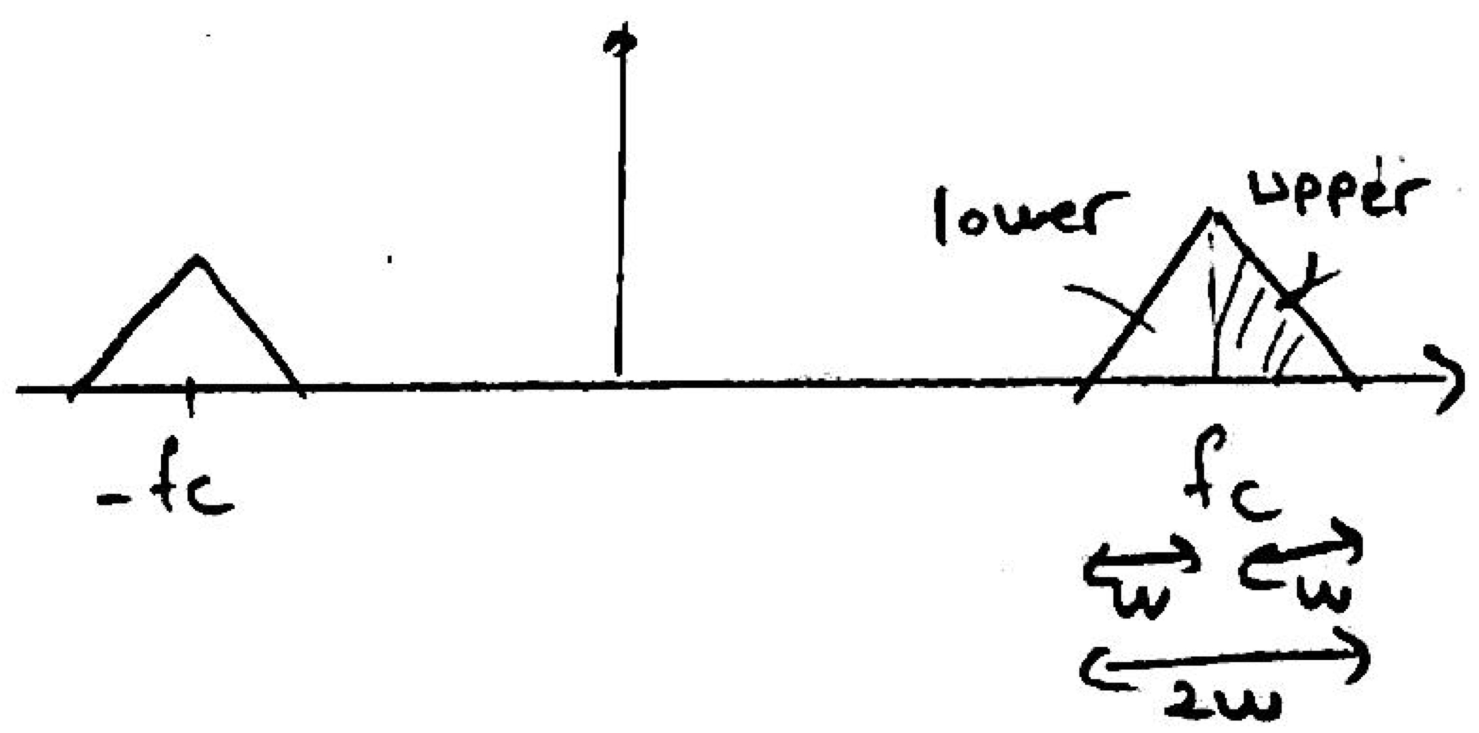


B if lower frequencies are important such as TV signals.

High frequency are transmitte only upper
lower " are " lower and upper band.

Single side band Modul.





We transmit only upper or only lower sideband.

We transmit bandwidth of W only not 2w.

More bandwidth requires more power.

Main problem is seperation of upper and Lower bands.

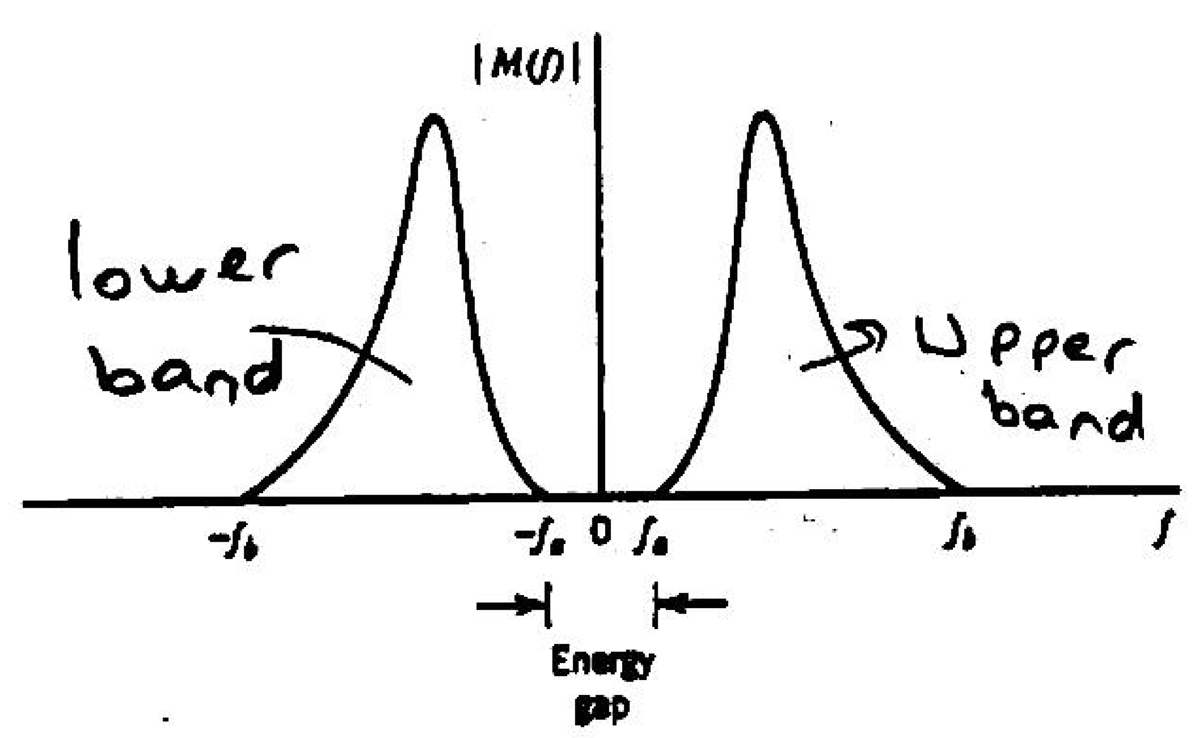


Figure 3.22 Spectrum of a message signal $m(t)$ with an energy gap centered around the origin.

For speech signals.

$f_a = 300$ hz So energy gap is 600 hz.

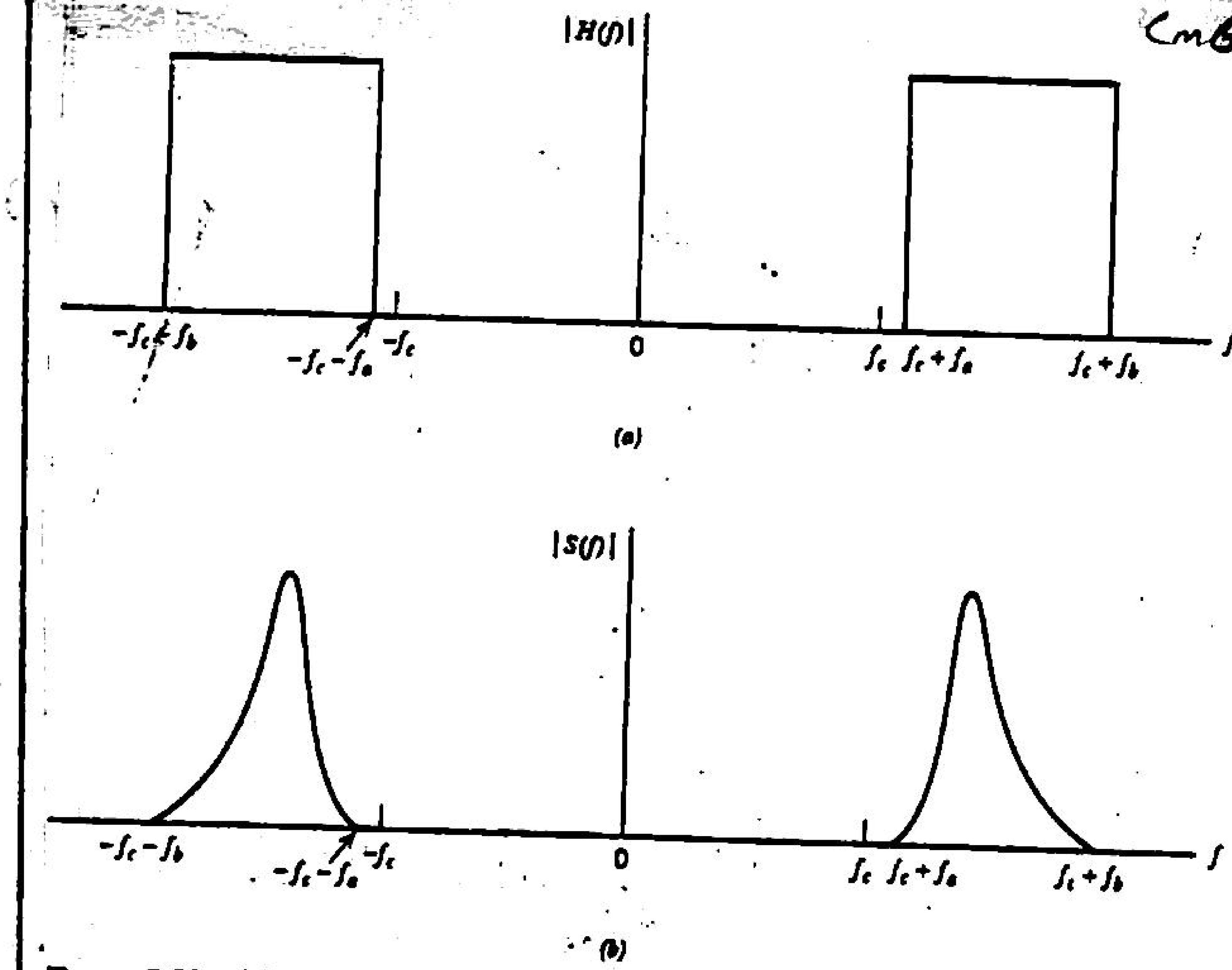


Figure 3.23 (*a*) Idealized frequency response of band-pass filter. (*b*) Spectrum of SSB signal containing the upper sideband.

- The desired sideband lies inside the passband of the filter.
- The unwanted sideband lies inside the stopband of the filter.
- The filter's transition band, separating the passband from the stopband, is twice the lowest frequency component of the message signal.

This kind of frequency discrimination usually requires the use of highly selective filters, which can only be realized in practice by means of crystal resonators.[4]

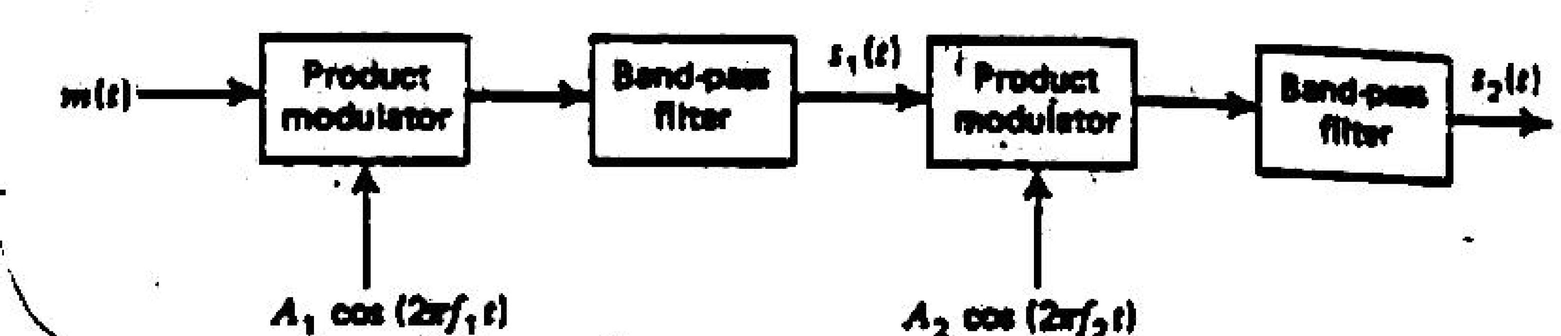
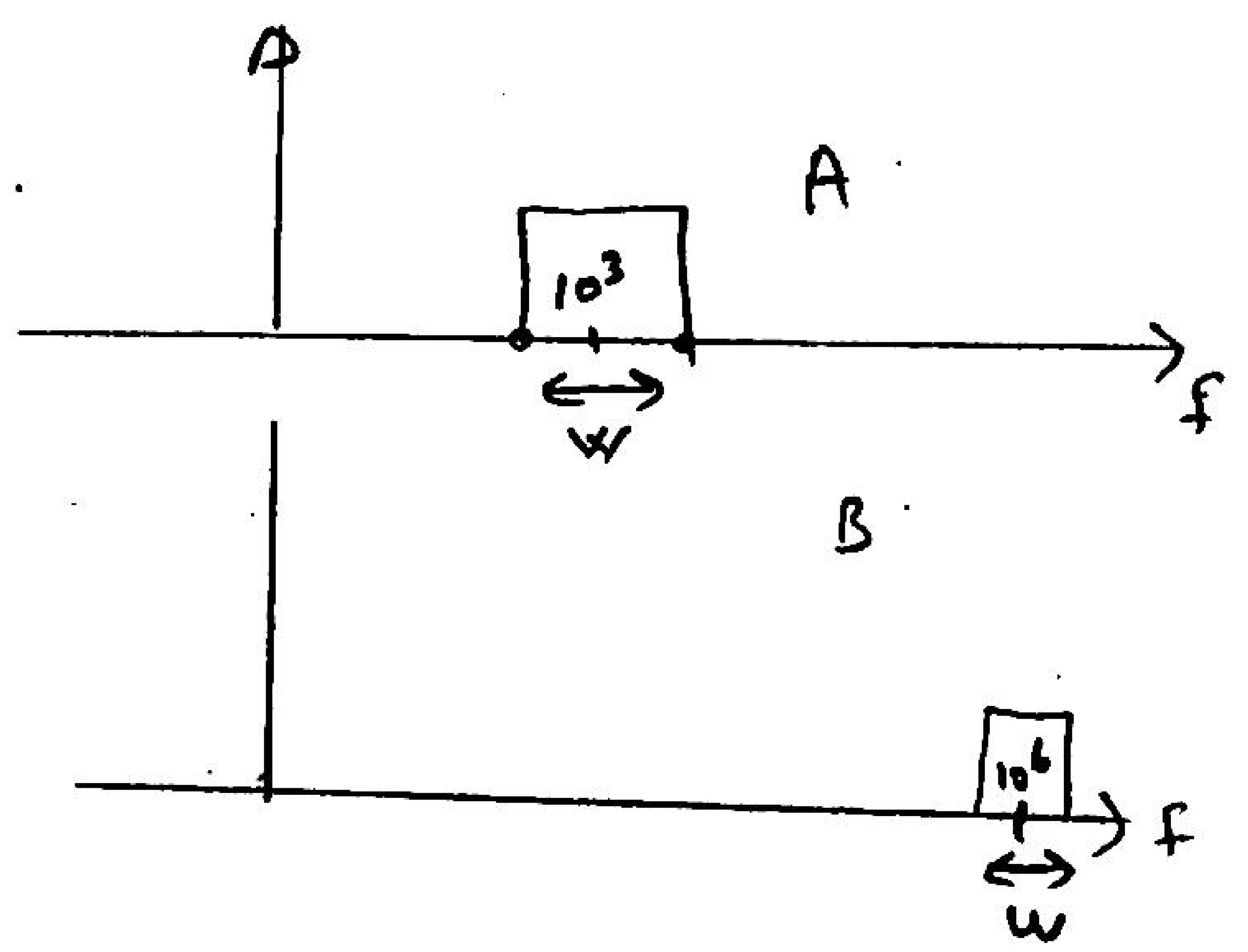


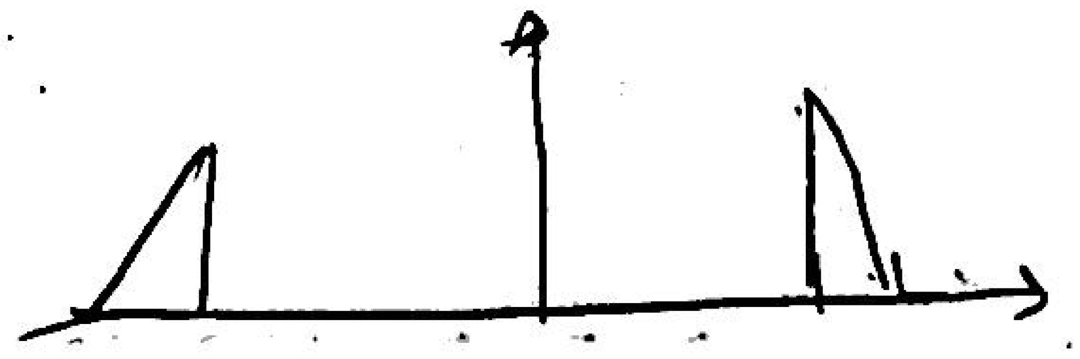
Figure 3.24 Block diagram of a two-stage SSB modulator.

..., translating a voice signal to the high-frequency region of the radio spectrum), it becomes very difficult to design an appropriate filter



Filter A is easier to design then the filter B.

$s(t)\cos(2\pi f_c t)\, m(t)$ $\Rightarrow$

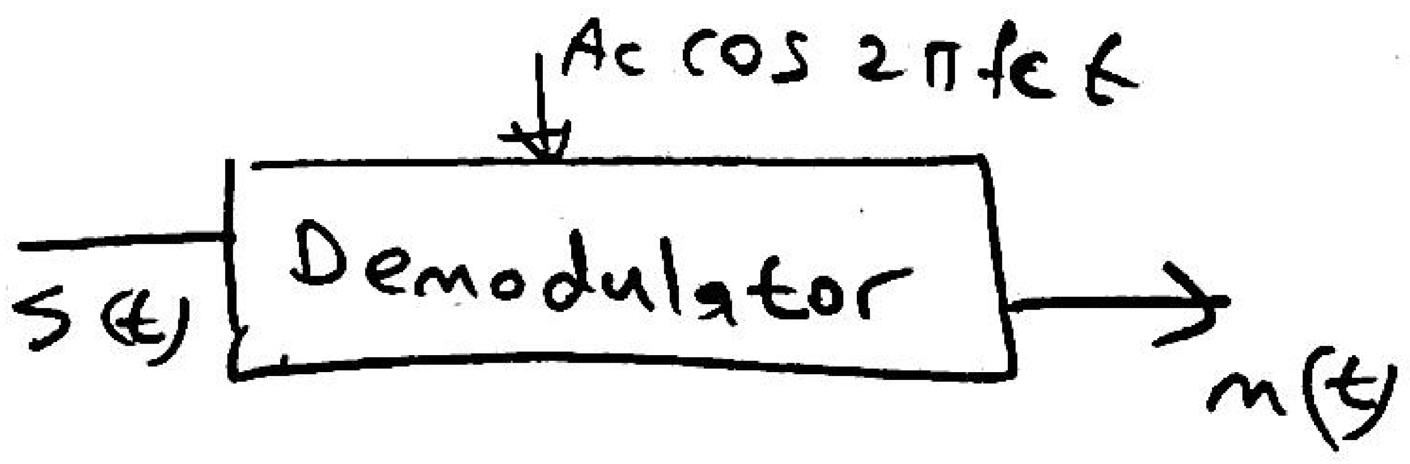


$s(t) = ?$

$$s(t)=\frac{1}{2}A_c m(t)\cos(2\pi f_c t)-\frac{1}{2}A_c\hat{m}(t)\sin(2\pi f_c t)$$

$\hat{m}(t)$ Hilbert transform of $m(t)$

Demodulation of SSB signals

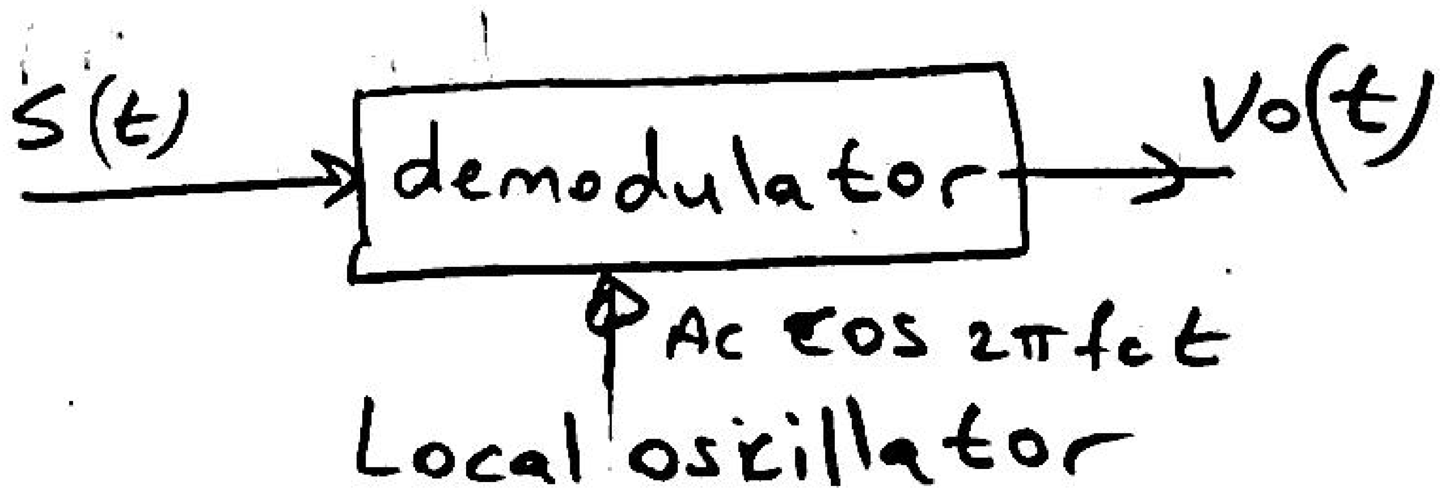


We need carrier signal $\cos(2\pi f_c t)$

Solution:

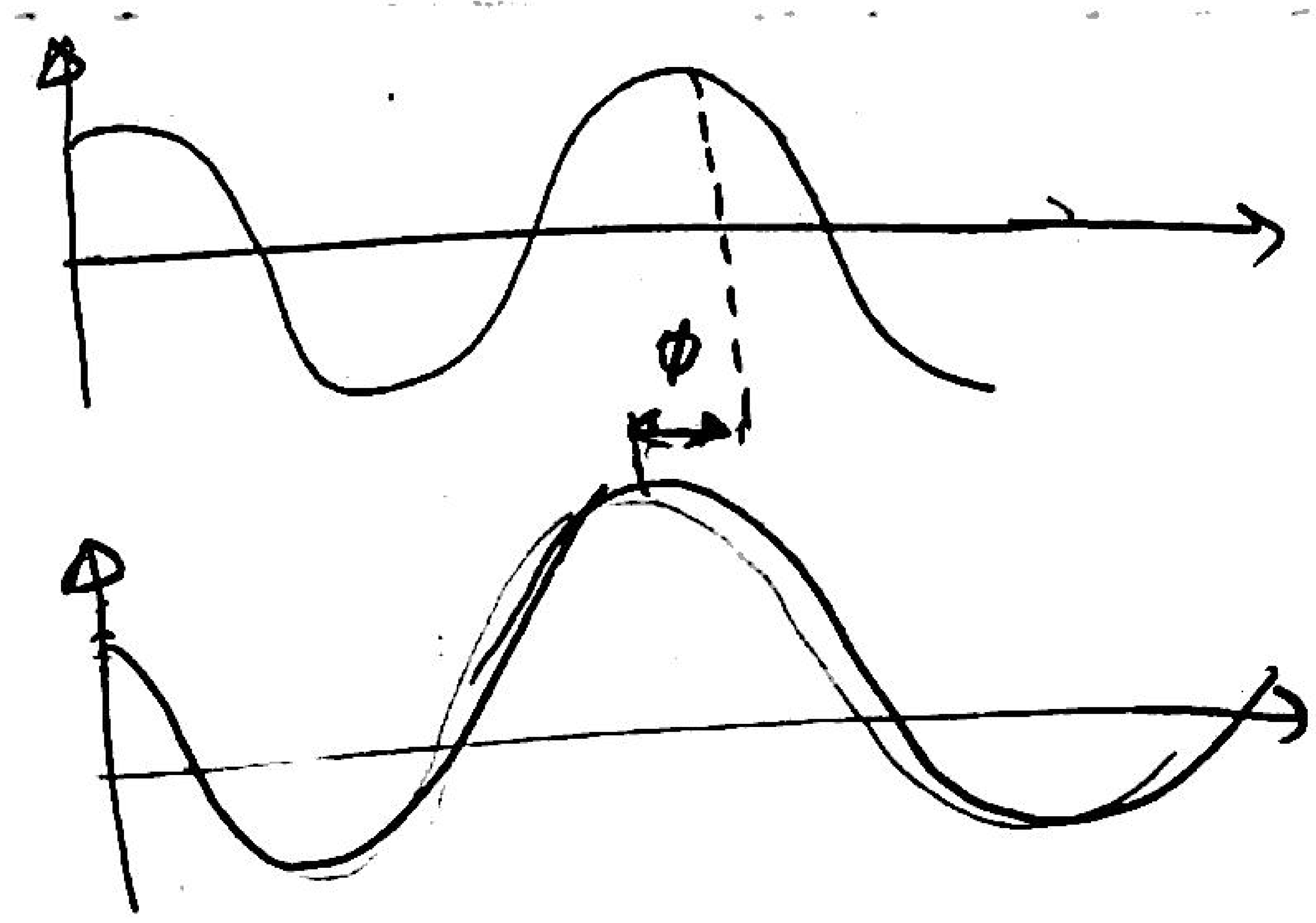
1) Transmit carrier signal together with s(t) (Power requirement)
2) Produce carrier signal at the receiver. (Phase error)

"The effect of phase error"



$$V_o(t) = \frac{1}{4}A_c' A_c\{m(t)\cos\phi + \hat{m}(t)\sin\phi\}$$

ϕ is the phase error between the actual carrier and Locally produced carrier



$$V_o(f) = \frac{1}{4}A_c' A_c\left[M(f)\cos\phi + \hat{M}(f)\sin\phi\right]$$

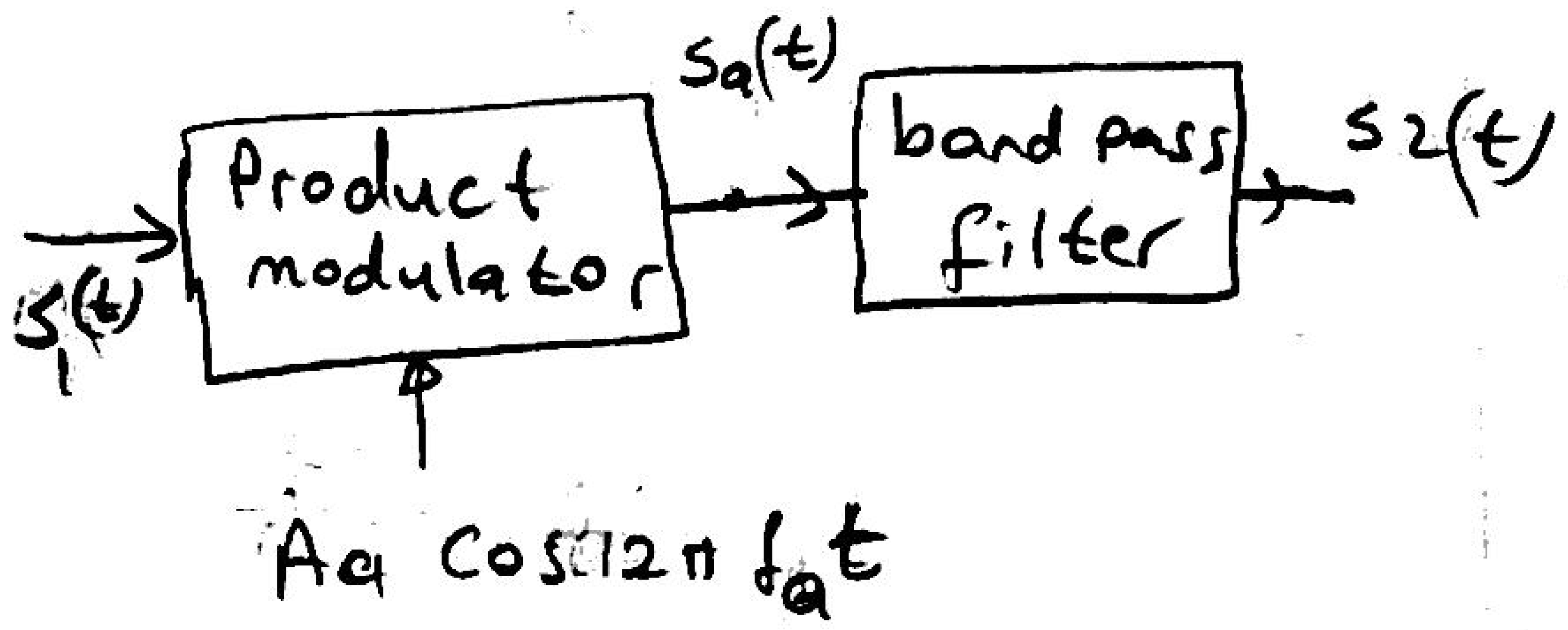
$\hat{m}(t)$ is Hilbert transform of $m(t)$

$$\hat{M}(f) = -j\,\mathrm{sgn}(f)\, M(f)$$

$$V_o(f)=\begin{cases}\frac{1}{4}A_c' A_c M(f)e^{-j\phi} & f>0\\ \frac{1}{4}A_c' A_c M(f)e^{j\phi} & f<0\end{cases}$$

ϕ = Phase error causes Problem in TV.

Frequency Translation



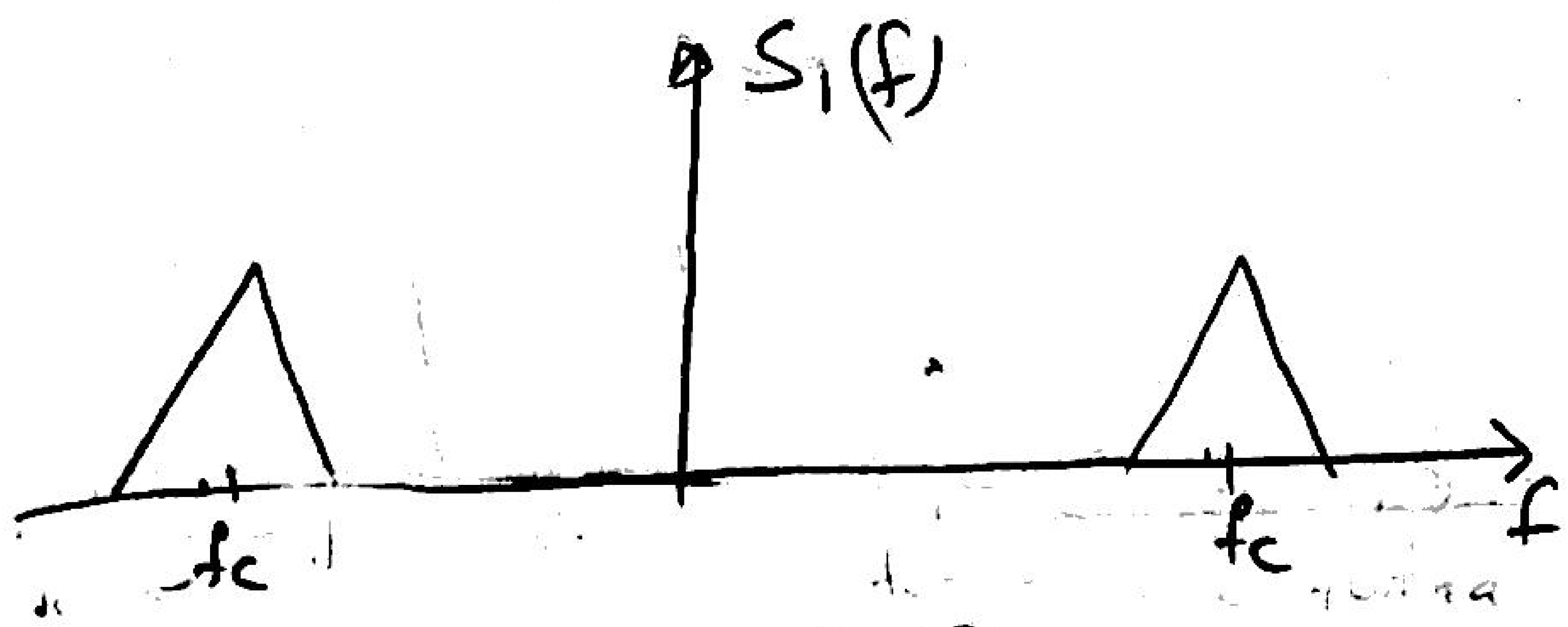
$s_1(t)$ = modulated wave with carrier f_c

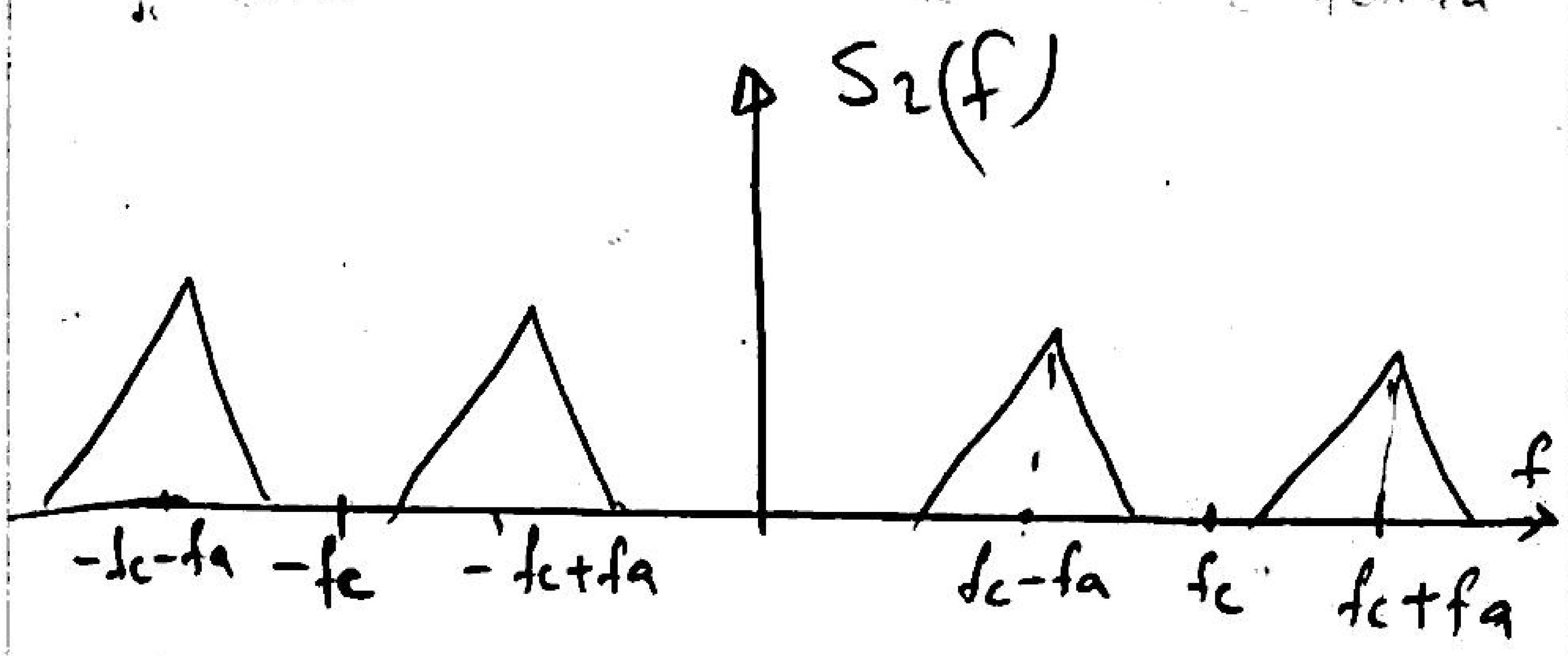
$$s_1(t) = A_c \cos(2\pi f_c t)\, m(t)$$

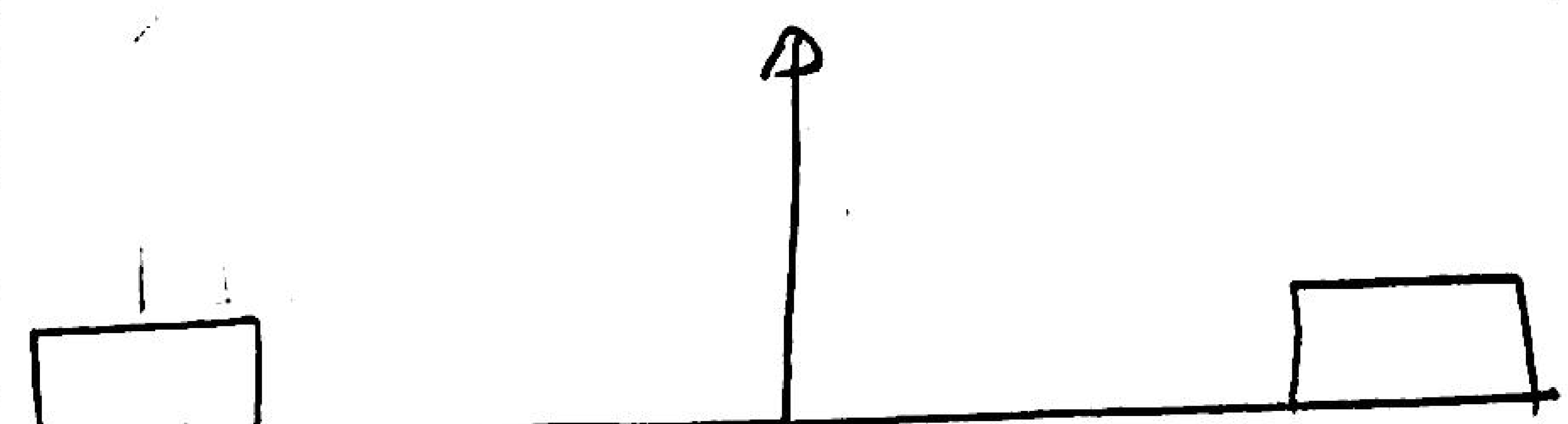
$$s_a(t) = s_1(t)\, A_a \cos 2\pi f_a t$$

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

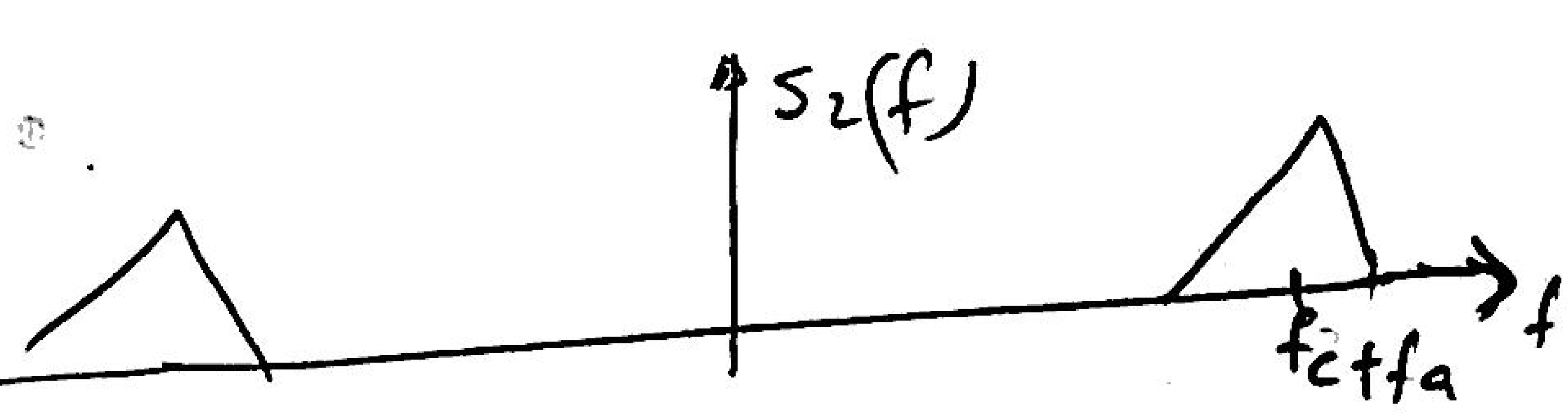
$$= A_c A_a\, m(t) \left[\tfrac{1}{2} \cos 2\pi (f_c - f_a) t + \cos 2\pi (f_c + f_a) t \right]$$







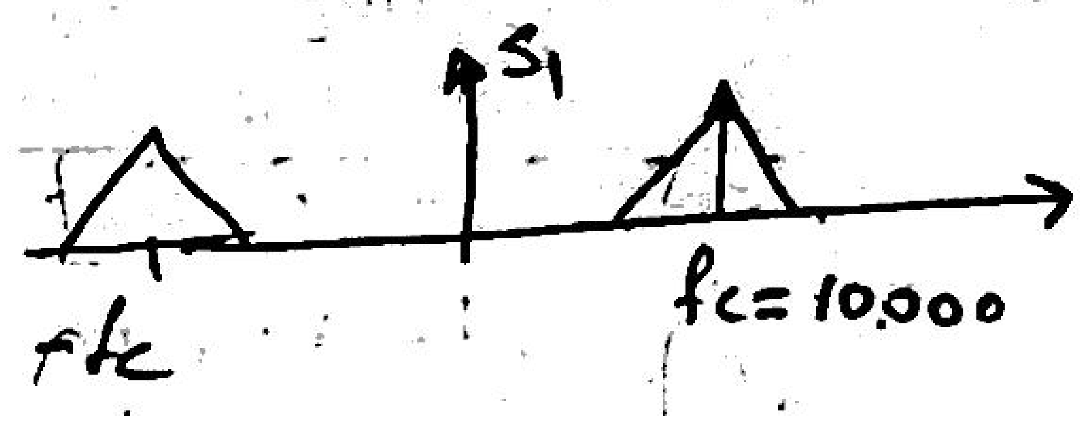
Band pass filter



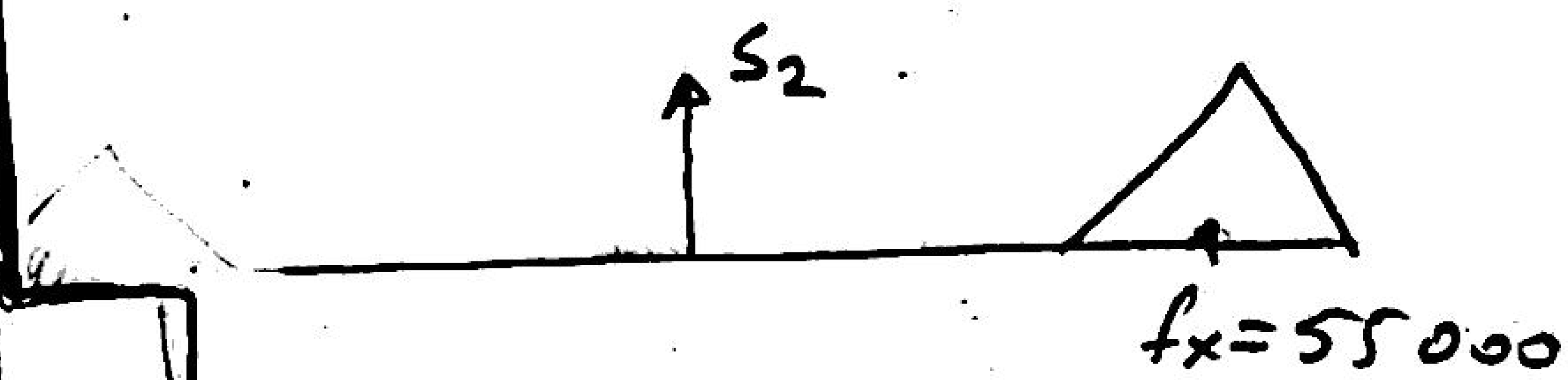
cm7!

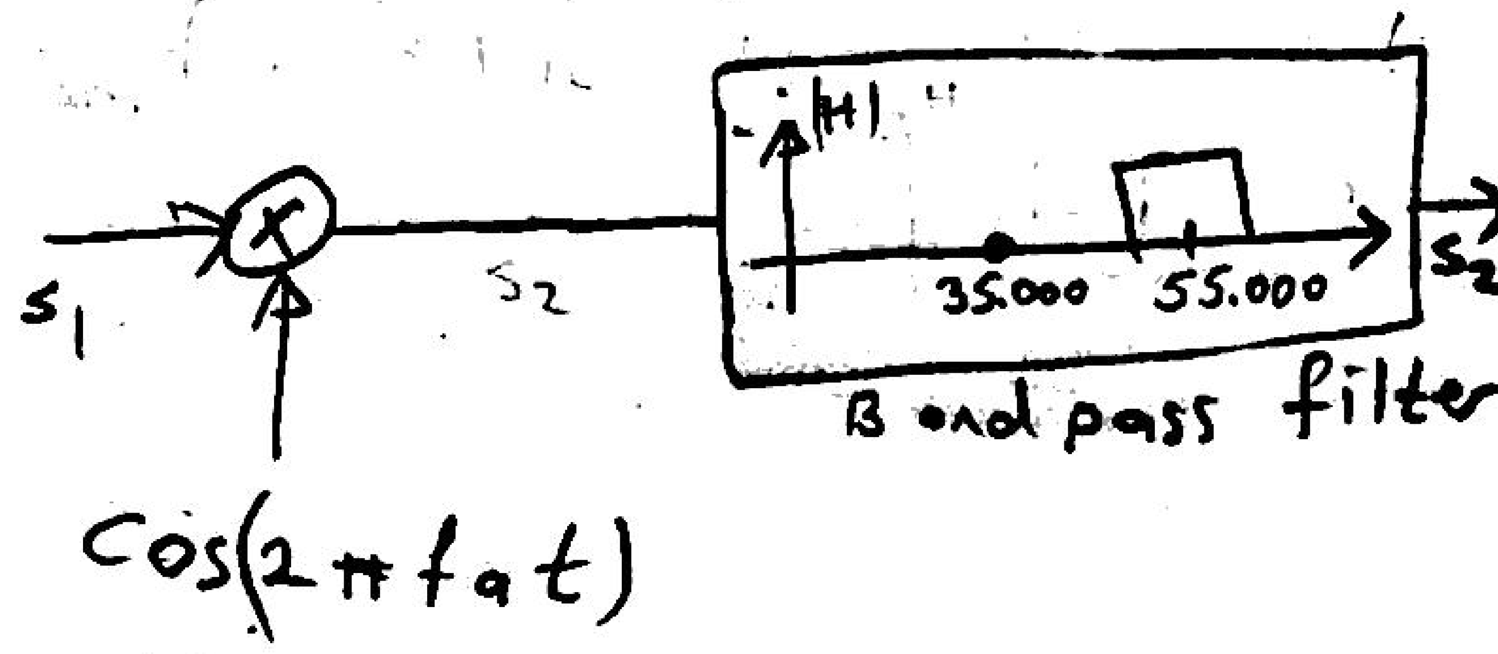
if you want to shift from f_c to f_c+f_a or f_c-f_a then multiply by f_a.

Example:



To shift to 55000 multiply by $f_a = 45000$.

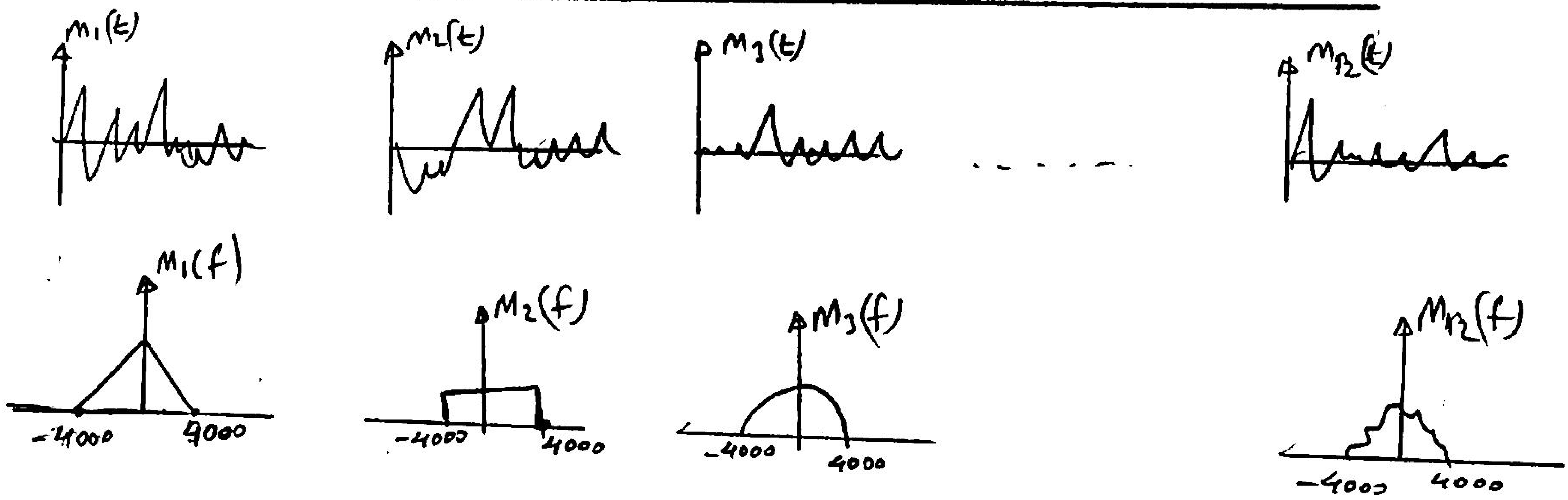


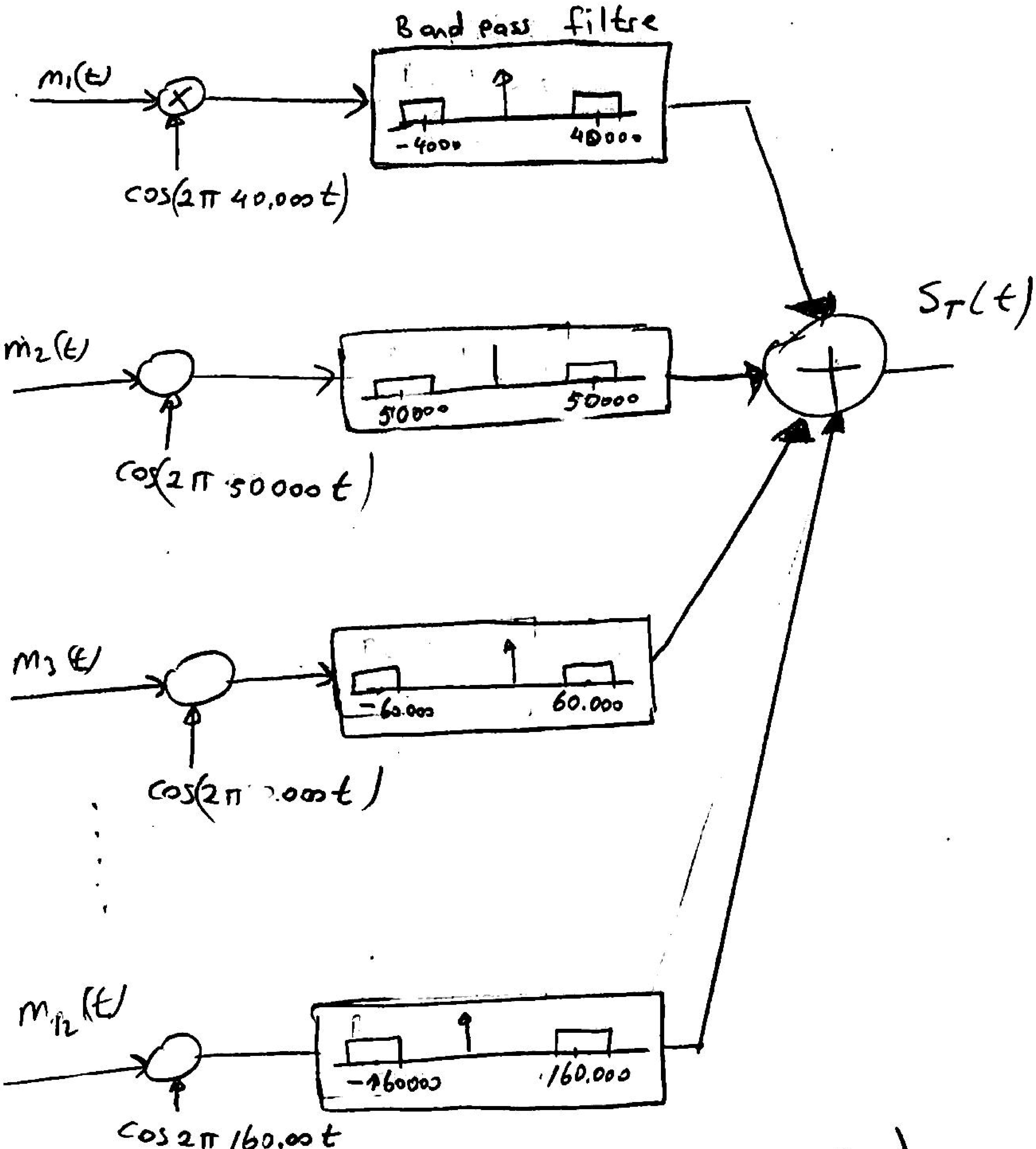


$$s_2 = m(t) \cos(2\pi\, 10.000\, t) \cos(2\pi\, 45000\, t)$$

$$= \tfrac{1}{2} m(t) \left[\cos(2\pi\, 35000\, t) + \cos(2\pi\, 55000\, t) \right]$$

Frequency Division multiplexing





Cm 73

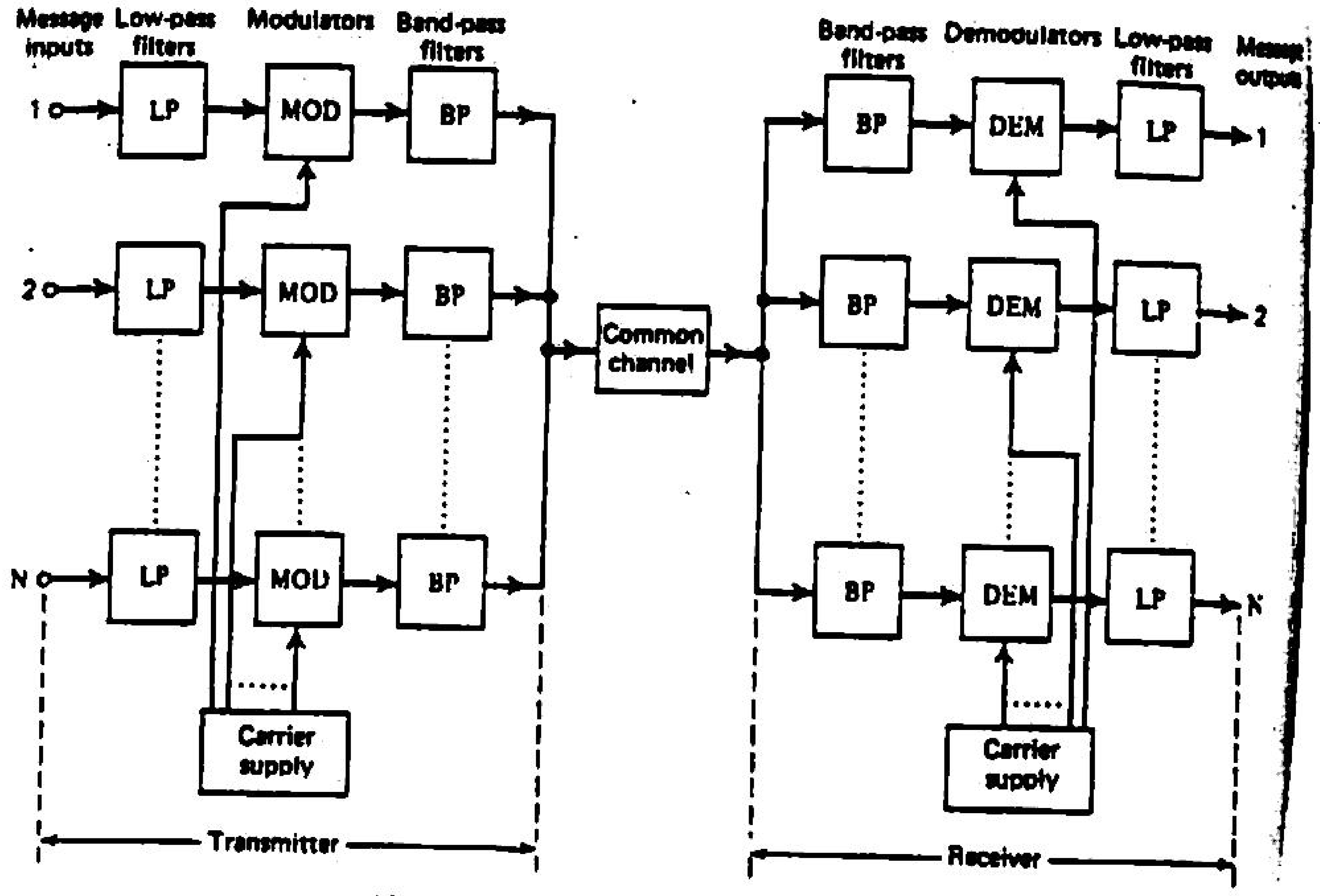
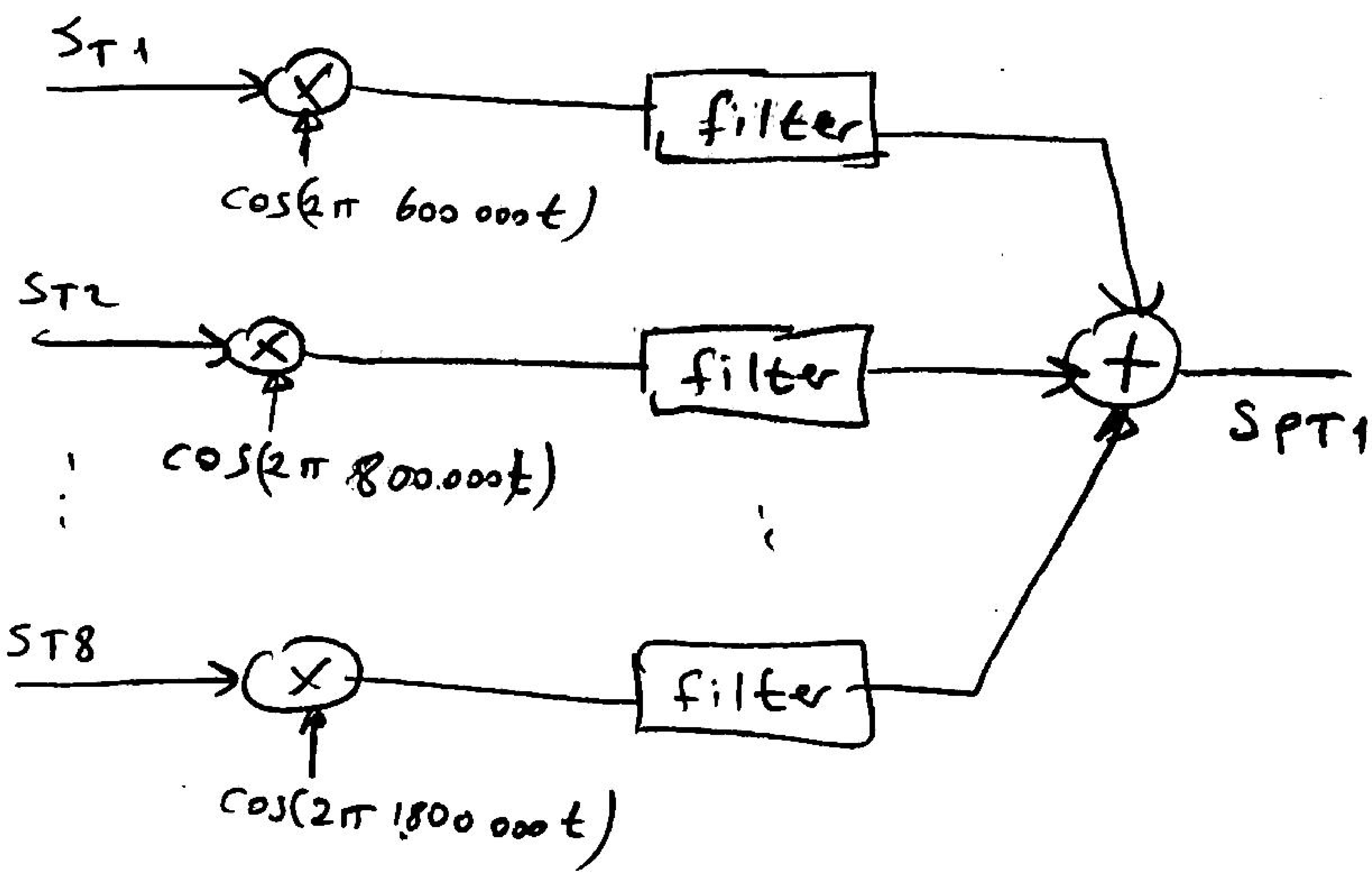


Figure 3.27 Block diagram of FDM system.



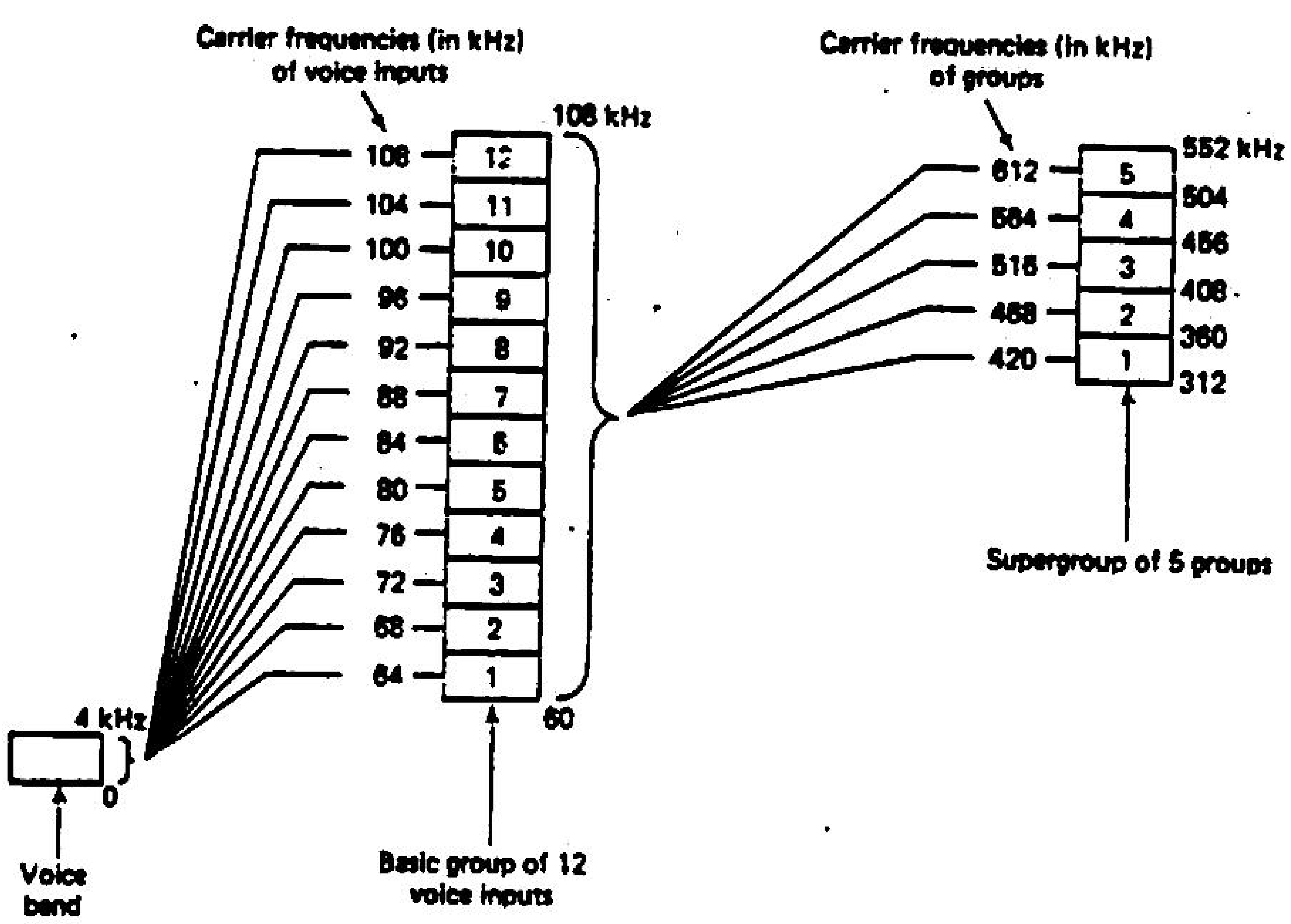
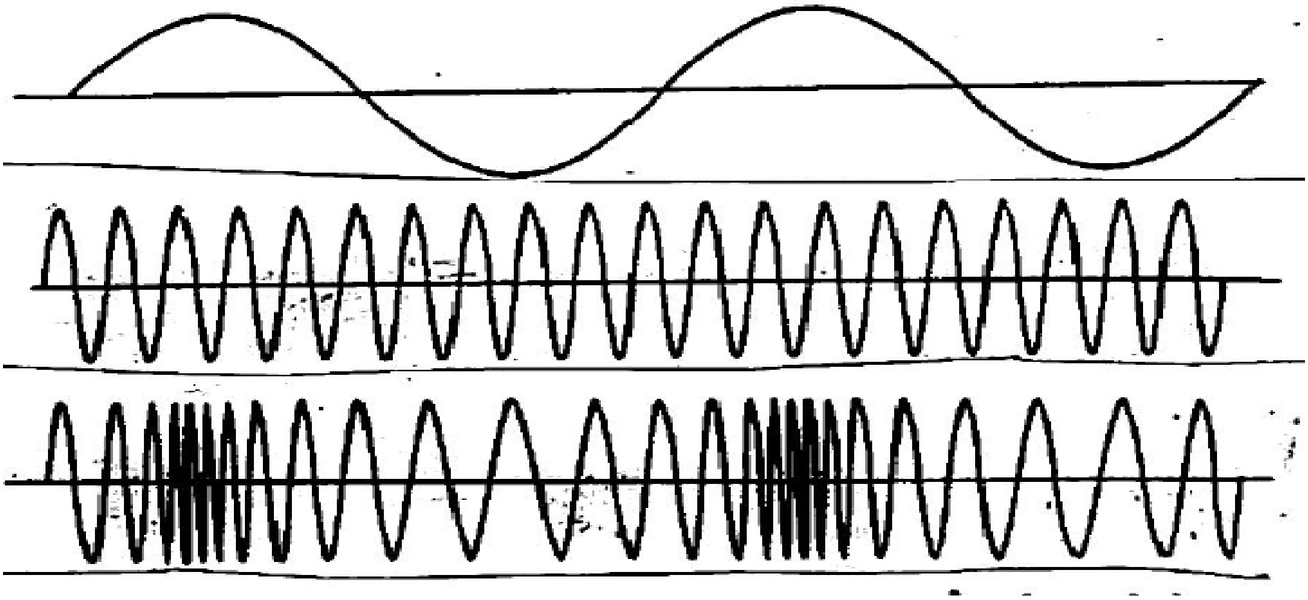


Figure 3.28 Illustrating the modulation steps in an FDM system.

FREKANS MODULASYONU

Frekans modülasyonunda bilgi sinyali yok iken yayın için ayrılan merkez frekans iletilir. Bilgi sinyalinin pozitif alternaslarında modüleli sinyalin frekansı artmakta, negatif sinyallerinde modüleli sinyalin frekansı azalmaktadır. Taşıyıcı frekansındaki bu değişime frekans sapması denir. Δfc ile gösterilir. Aşağıdaki şekilde bu olay gösterilmiştir.



Aşağıdaki tabloda FM bandında yayın yapan kuruluşların frekans bandı, bant genişliği ve izin verilen maksimum ses frekansı gösterilmiştir. FM radyo yayınında bant genişliği 200 KHz iken bu bandın başında ve sonunda 25KHz'lik koruyucu bant ayrılmaktadır.

Servis Tipi	**Frekans Aralığı**	**BW**	**Δfc**	**En yüksek ses**
Ticari FM radyo yayını	88.00MHz ile 108.00MHz	200 KHz	±75 KHz	15 KHz
Televizyon ses iletimi	Resim Taşıyıcı frekansının 4.5 MHz üstü	100 KHz	±25KHz Manuel ve ±50 KHz Stereo	15 KHz
Toplum güvenliği	50.00 MHz ile 122.00 MHz	20 KHz	±5 KHz	3 KHz
Amatör ve iş radyo bandı	216.00 MHz ile 470108.00 MHz	15KHz	±3 KHz	3 KHz

Frekans Modülasyon İhtiyacı
Genlik modülasyonunun iletim sırasındaki gürültülerden çok fazla etkilenmesi ve taşınmak istenen sinyallerin bozulması neticesinde frekans modülasyonu geliştirilmiştir.

Frekans Modülasyonunun Avantajları ve Dezavantajları Avantajları:
Sinyal üzerine binen gürültü seviyesi kesilebildiği için ses kalitesi yüksektir.

Frekans modülasyonunun gürültü bağışıklığı, genlik modülasyonundan daha iyidir.

FM'in yakalama etkisi vardır. Bu etkiden dolayı istenmeyen sinyalleri kolaylıkla yok edebilir. Aynı frekanstaki iki sinyalden hangisinin çıkış gücü fazla ise o sinyalin alıcı tarafından alınmasına yakalama etkisi (capture) denir.

Dezavantajları:
FM çok büyük bant genişliği kullanır.
FM devreleri daha pahalıdır.

1.3.3. Frekans Modülasyonunda Bant Genişliği
Bir FM işaretin sonsuz sayıda yan banttı vardır. Bu durum FM yayınının bant genişliği arttırmaktadır. Mr. Fred BASEL çalışmaları sonucunda bir FM işaretinin yan bant sayısını modülasyon indisine göre gösteren tabloyu hazırlamıştır.

Mod. İnd.	J_0 Taşıyıcı	J_1 1 st	J_2 2nd	J_3 3d	J_4 4th	J_5 5th	J_6 6th	J_7 7th	J_8 8th
0,0	1,00	-	-	-	-	-	-	-	-
0,25	0,98	0,12	-	-	-	-	-	-	-
0,5	0,94	0,24	0,03	-	-	-	-	-	-
1,5	0,51	0,56	0,23	0,06	0,01	-	-	-	-
1	0,77	0,44	0,11	0,02	-	-	-	-	-
2	0,22	0,58	0,35	0,13	0,03	-	-	-	-
3	-0,26	0,34	0,49	0,31	0,13	0,04	0,01	-	-
4	-0,40	-0,07	0,36	0,43	0,28	0,13	0,05	0,02	-
5	-0,18	-0,33	0,05	0,36	0,39	0,26	0,13	0,05	0,02

Bessel Fonksiyonuna bağlı olarak elde edilen, modülasyon indisine bağlı yan bant ve taşıyıcı genliklerini gösterir tablo

Angle modulation

$$s(t) = A_c \cos[\theta_i(t)]$$

$$\theta_i(t) = 2\pi f_c t \quad \text{(carrier)}$$

phase modulation

$$\theta_i(t) = 2\pi f_c t + k_p\, m(t)$$

K_p = constant

$$s(t) = A_c \cos\{2\pi f_c t + k_p\, m(t)\}$$

frequency modulation

$$f_i(t) = f_c + K_f\, m(t)$$

K_f = constant

angular velocity $= \dfrac{d\theta}{dt}$

$$\omega = \frac{d\theta}{dt}$$

or

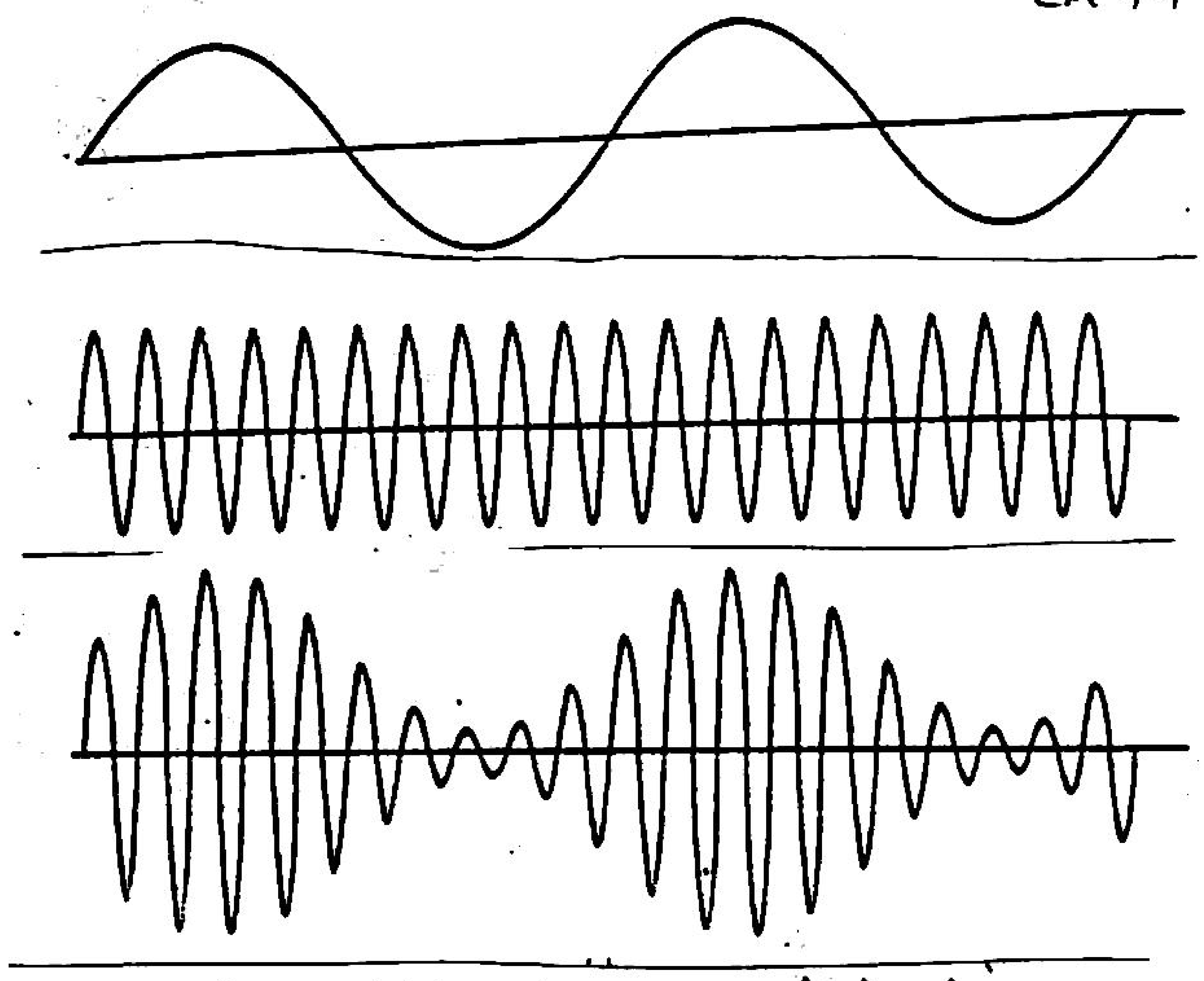
$$\theta = \int_0^t \omega\, dt = \int_0^t 2\pi f\, dt$$

$$\theta_i = \int_0^t 2\pi f_i(t)\, dt =$$

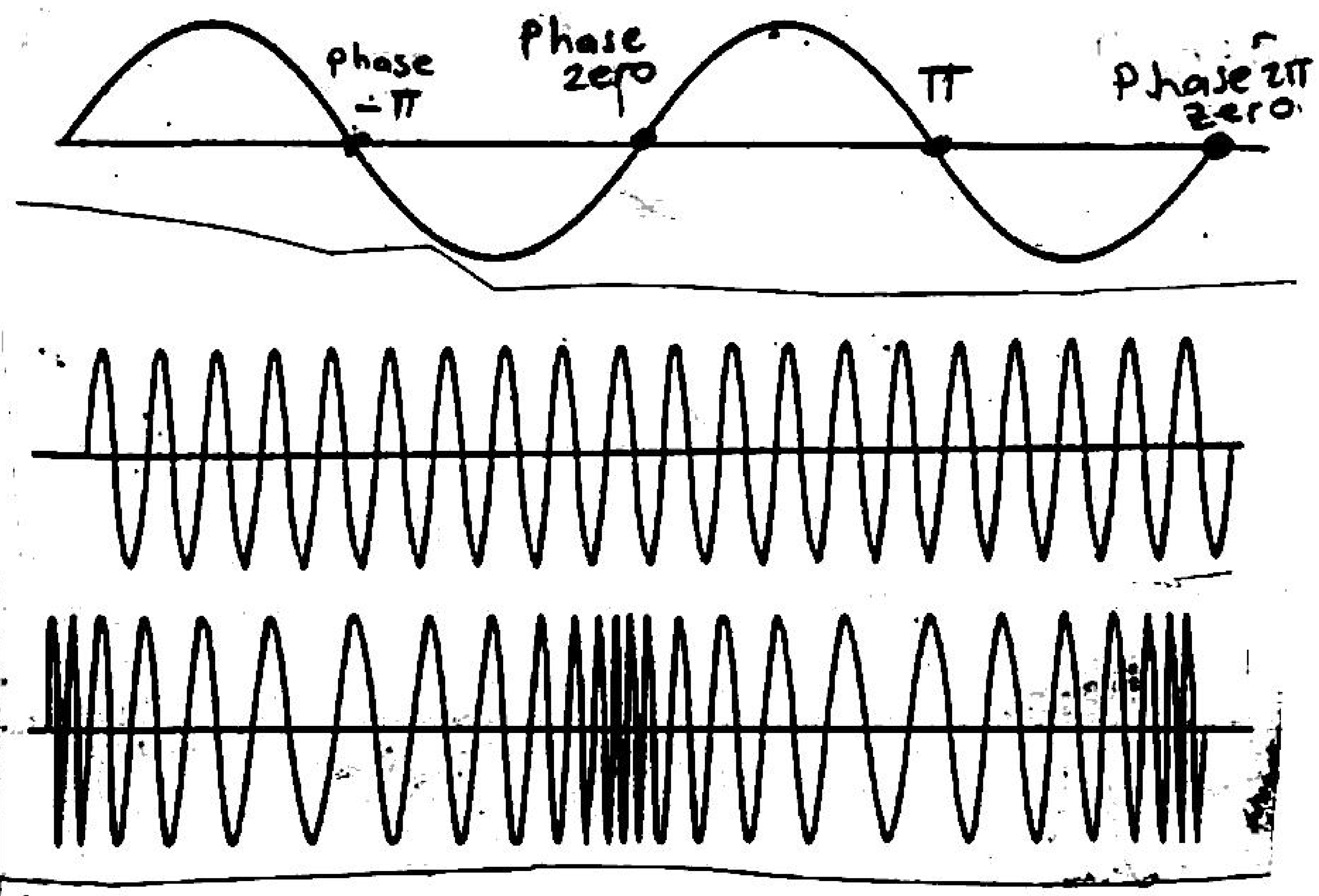
$$\theta_i = \int_0^t 2\pi[f_c + K_f\, m(t)]\, dt$$

$$\theta_i = 2\pi f_c t + 2\pi K_f \int_0^t m(t)\, dt$$

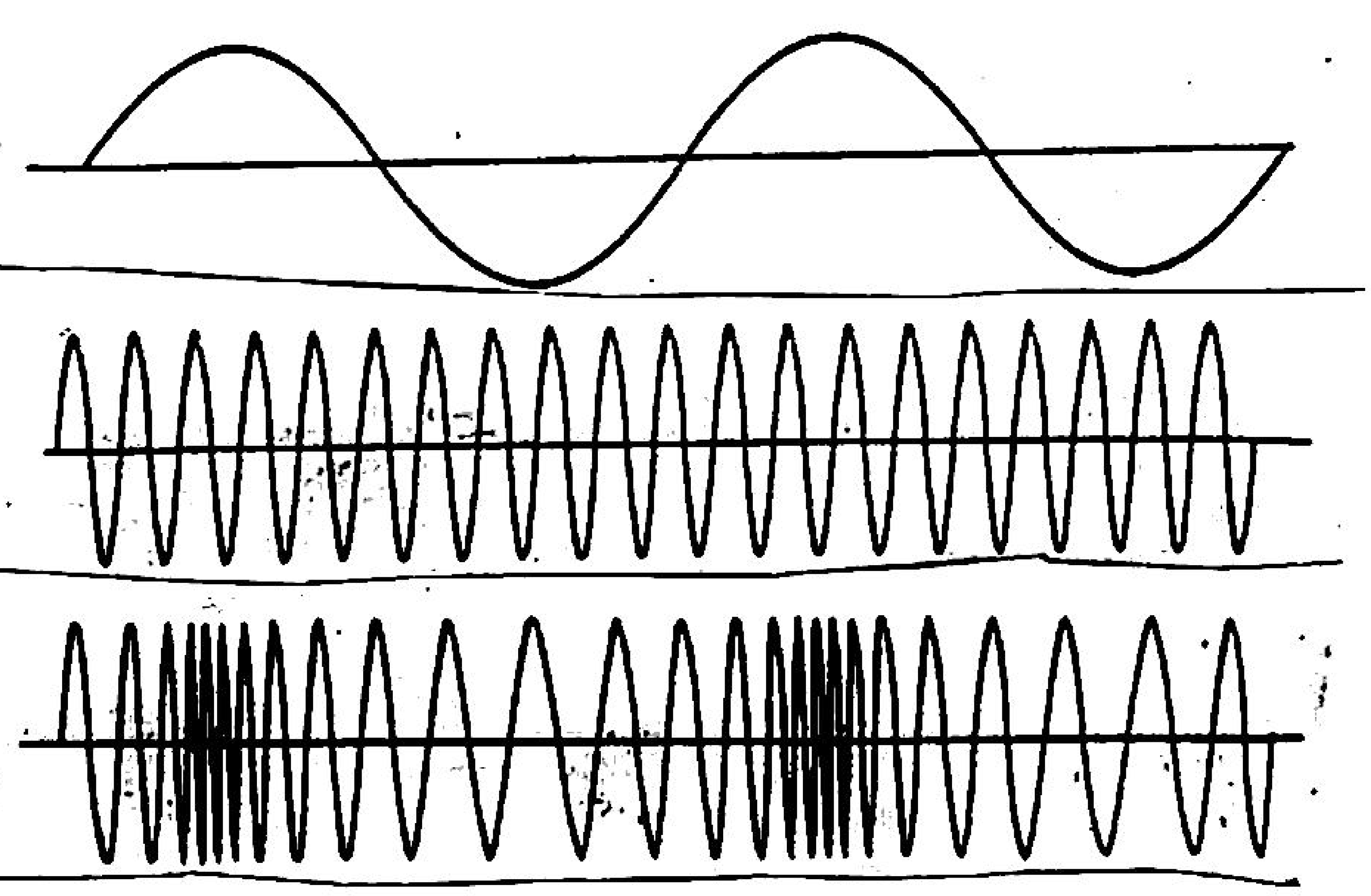
$$s(t) = A_c \cos\left[2\pi f_c t + 2\pi K_f \int_0^t m(t)\, dt\right]$$



Amplitude modulation



Phase modulation



Frequency modulation

Frequency modulation

Single tone modulation

$m(t) = A_m \cos(2\pi f_m t)$

$f_i(t) = f_c + k_f\, m(t)$

$f_i(t) = f_c + k_f A_m \cos(2\pi f_m t)$

$\Delta f = K_f A_m$

Δf = maximum frequency deviation

$$\theta_i(t) = 2\pi \int_0^t f_i(t)\, dt$$

$$= 2\pi f_c t + \frac{\Delta f}{f_m} \sin(2\pi f_m t)$$

$$\beta = \frac{\Delta f}{f_m} = \frac{K_f A_m}{f_m}$$

β = modulation index

$$s(t) = A_c \cos[2\pi f_c t + \beta \sin 2\pi f_m t]$$

$\beta \ll 1$ radian narrow band fm

$\beta \gg 1$ radian wide band fm

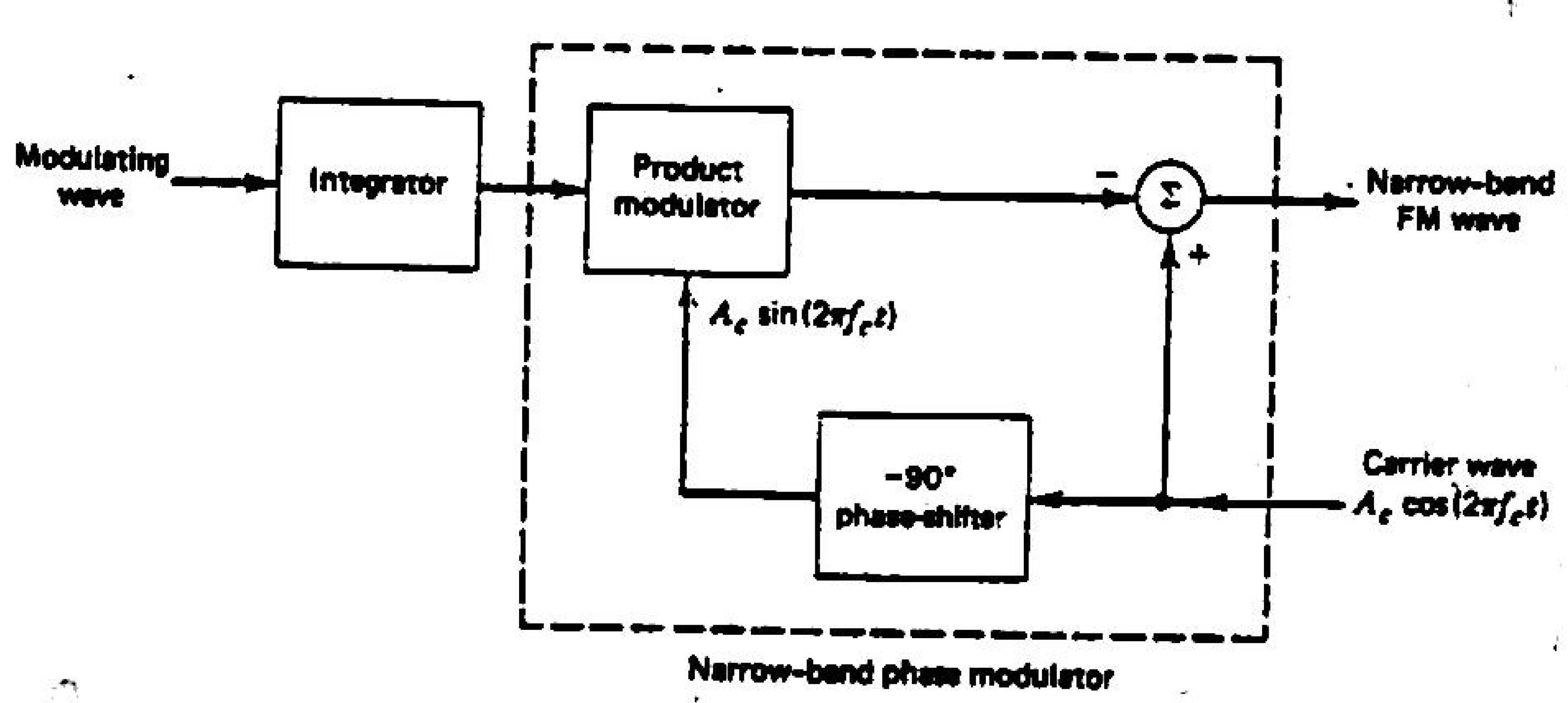


Figure 3.31 Block diagram of a method for generating a narrow-band FM signal.

Narrow band fm.

$$s(t) = A_c \cos[2\pi f_c t + \beta \sin(2\pi f_m t)]$$

$\cos(a+b) = \cos a \cos b - \sin a \sin b$

$$s(t) = A_c \{\cos 2\pi f_c t \cos[\beta \sin(2\pi f_m t)] - \sin(2\pi f_c t) \sin[\beta \sin(2\pi f_m t)]\}$$

β is small

$\beta \sin 2\pi f_m t \cong 0$

$\cos[\beta \sin 2\pi f_m t] = 1$

$\sin[\beta \sin(2\pi f_m t)] \cong \beta \sin(2\pi f_m t)$

Note

if x is small

$\cos x \cong 0$

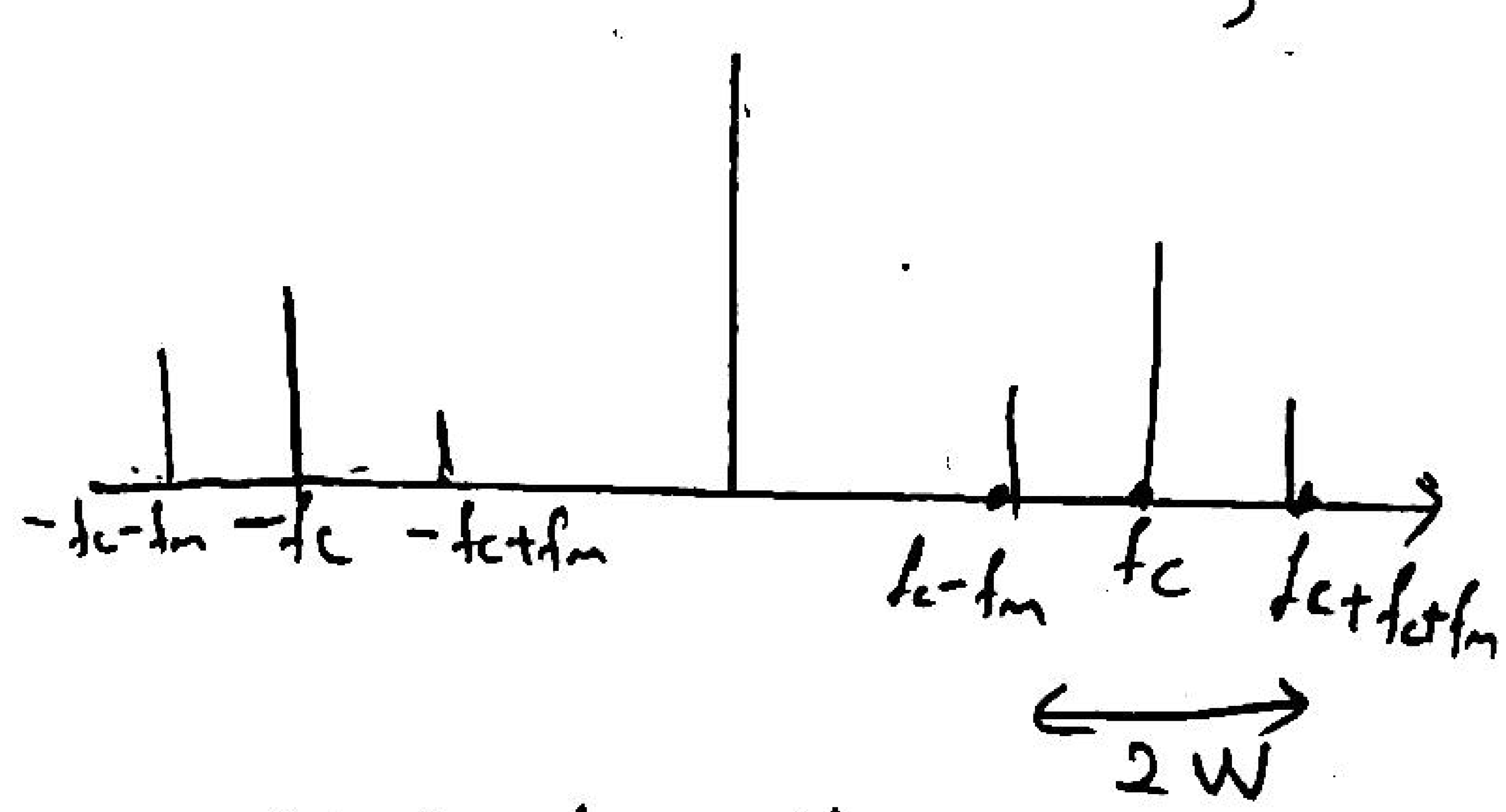
$\sin x \cong x$

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

$\sin a \sin b = [-\cos(a+b) + \cos(a-b)$

$$s(t) = A_c \cos 2\pi f_c t - \beta A_c \tfrac{1}{2}\{\cos[2\pi f_c t + 2\pi f_m t] + \cos[2\pi f_c t - 2\pi f_m t]\}$$

$$= A_c \cos 2\pi f_c t + \tfrac{1}{2}\beta A_c\{\cos 2\pi(f_c + f_m)t + \cos 2\pi(f_c - f_m)t\}$$



$W = m(t)$ bandwidth.

narrow band fm requires $2W$ bandwidth

wide band frequency modulation

$$s(t) = A_c \cos[2\pi f_c t + \beta \sin(2\pi f_m t)]$$

Define $\tilde{s}(t) = A_c e^{j\beta \sin 2\pi f_m t}$

then

$$s(t) = Re\{\tilde{s}(t) e^{j2\pi f_c t}\}$$

Note: Komplex fourier Series

$$x(t) = \sum_{k=-\infty}^{\infty} c_k e^{jk w_0 t}$$

$w_0 = 2\pi f$

$$c_k = \frac{1}{T}\int_{-T/2}^{T/2} x(t) e^{-jk w_0 t}$$

Expand $\tilde{s}(t)$ into fourier Series

$$\tilde{s}(t) = \sum_{n=-\infty}^{\infty} c_n e^{j2\pi f_m t}$$

$$c_n = \frac{1}{T}\int_{-\frac{T}{2}}^{T/2} \tilde{s}(t) e^{-j2\pi n f_m t} dt$$

$T = \frac{1}{f_m}$

$$= \frac{1}{T}\int_{-T/2}^{T/2} A_c e^{j\beta 2\pi f_m t - j2\pi n f_m t} dt$$

Define $x = 2\pi f_m t$

$dx = 2\pi f_m dt$

$dt = \frac{dx}{2\pi f_m}$

$T = \frac{1}{f_m}$

$$\int_{t=-\frac{T}{2}}^{T/2}$$

$$\int^{x = 2\pi f_m t = 2\pi f_m \frac{T}{2} = \pi}$$

$x = 2\pi f_m t = 2\pi f_m(-\frac{T}{2}) = -\pi$

$$c_n = \frac{1}{T}\int_{-\pi}^{\pi} A_c e^{j\beta \sin x - jnx} \frac{dx}{2\pi f_m}$$

$T f_m = 1$

$$c_n = \frac{A_c}{2\pi}\int_{-\pi}^{\pi} e^{j(\beta \sin x - nx)} dx$$

Define

$$J_n(\beta) = \frac{1}{2\pi}\int_{-\pi}^{\pi} e^{j(\beta \sin x - nx)} dx$$

$$\boxed{c_n = A_c J_n(\beta)}$$

$J_n(\beta) = n^{th}$ order bessel function

$$\tilde{s}(t) = \sum_{n=-\infty}^{\infty} c_n \, e^{j2\pi n f_m t}$$

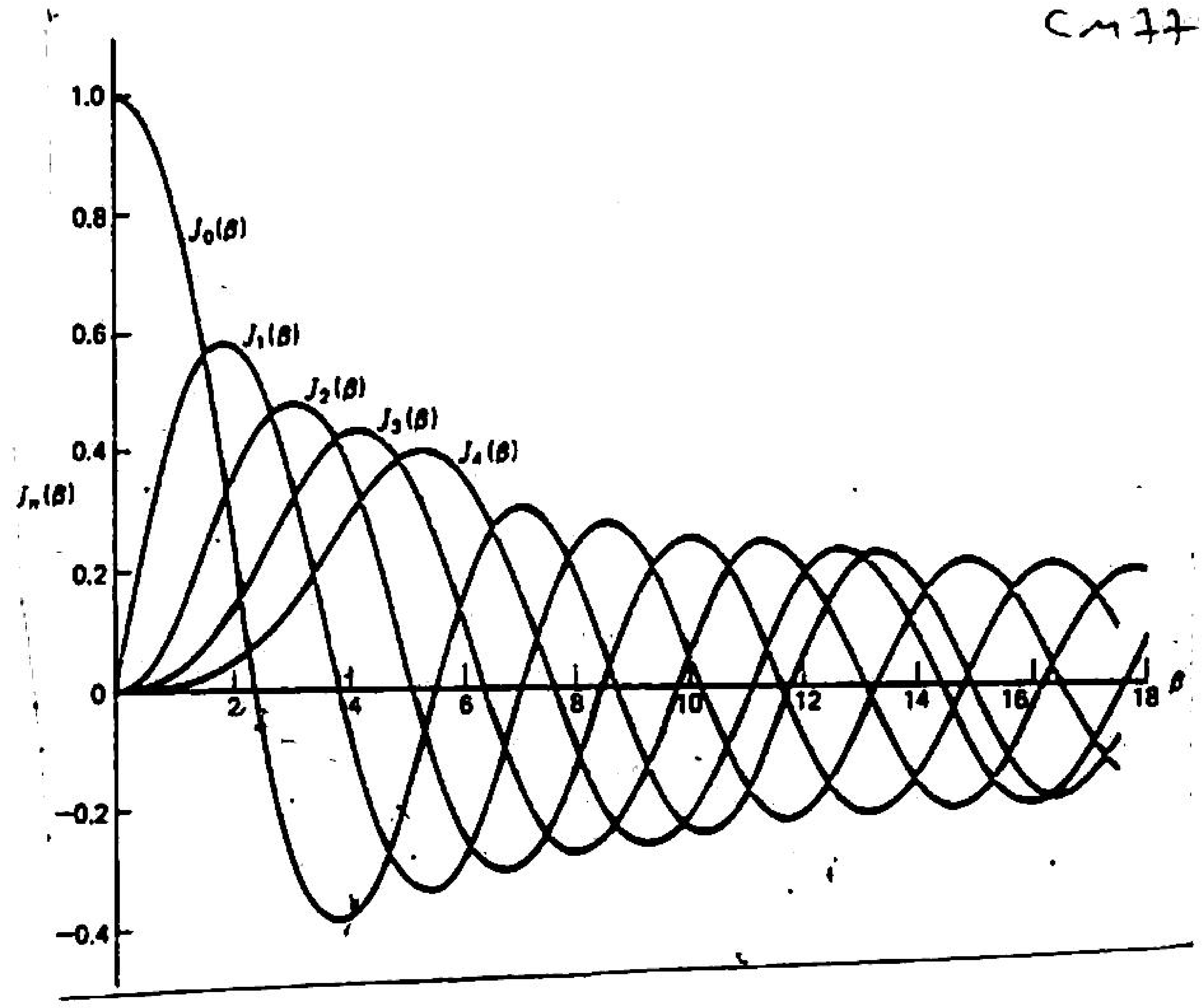
$$= A_c \sum_{n=-\infty}^{\infty} J_n(\beta) \, e^{j2\pi n f_m t}$$

$$s(t) = A_c \, Re\left[\sum_{n=-\infty}^{\infty} J_n(\beta) \, e^{j2\pi(f_c + n f_m)t}\right]$$

$$= A_c \sum_{n=-\infty}^{\infty} J_n(\beta) \, Re\left\{e^{j2\pi(f_c+nf_m)t}\right\}$$

Order of $\sum$ and $Re\{\}$ are changed

$$= A_c \sum_{n=-\infty}^{\infty} J_n(\beta) \cos\left[2\pi(f_c+nf_m)t\right]$$

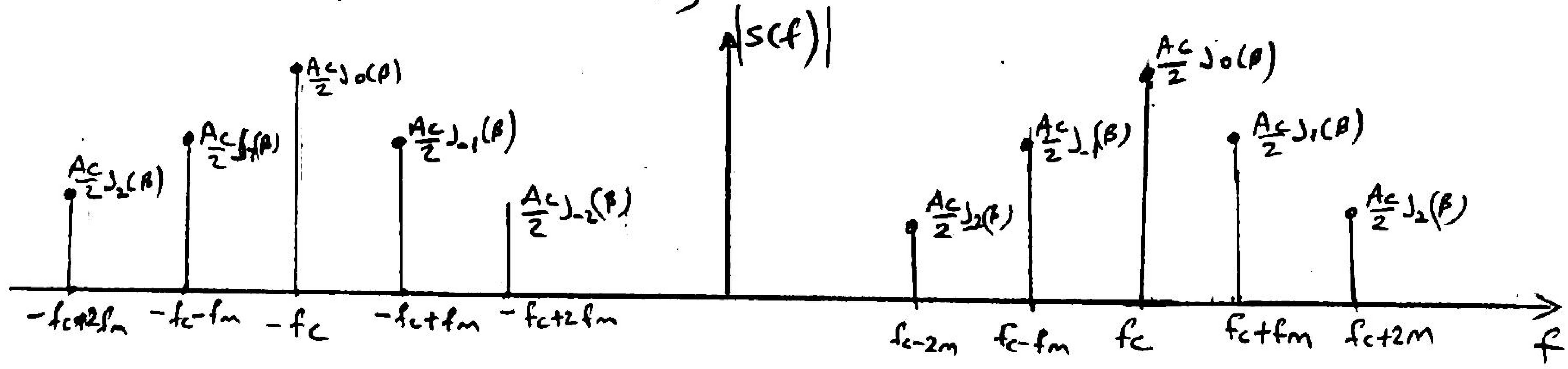


β is small

$J_2(\beta) \cong 0$

$J_3(\beta) \cong 0$

$$S(f) = \frac{A_c}{2} \sum_{n=-\infty}^{\infty} J_n(\beta) \left[\delta(f - f_c - n f_m) + \delta(f + f_c + n f_m)\right]$$



Note $\quad J_n(\beta) = J_{-n}(\beta) \quad$ n even

$\quad J_n(\beta) = -J_{-n}(\beta) \quad$ n odd

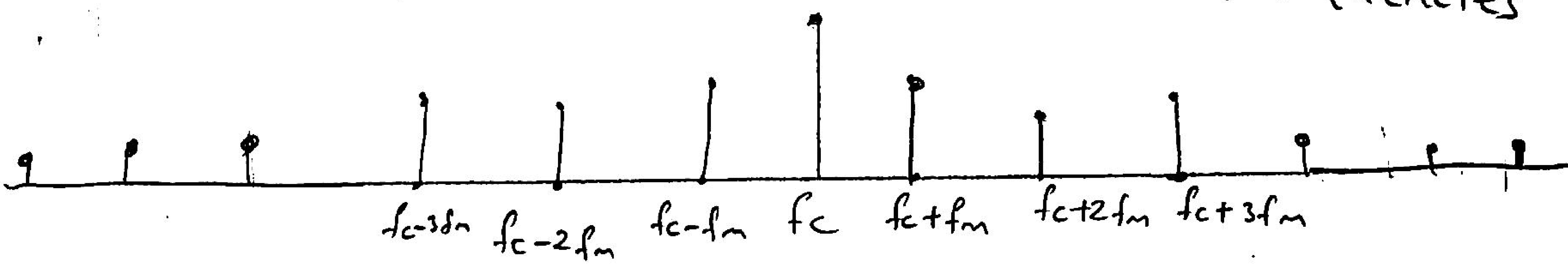
if β is small $\quad J_0(\beta) \cong 1$

$J_1(\beta) = \frac{1}{2}$

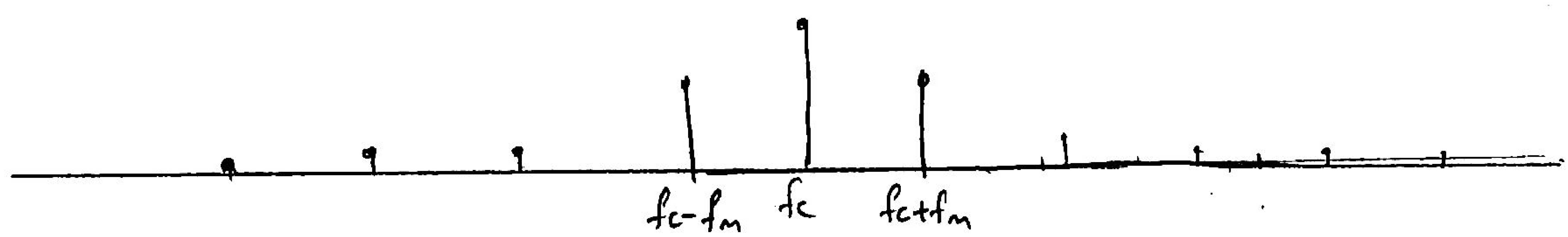
$J_3(\beta) = J_4(\beta) = J_5(\beta) \cong 0$

Obsevations

1) Spectrum of fm signal contains a carrier component and an infinite number of side frequencies

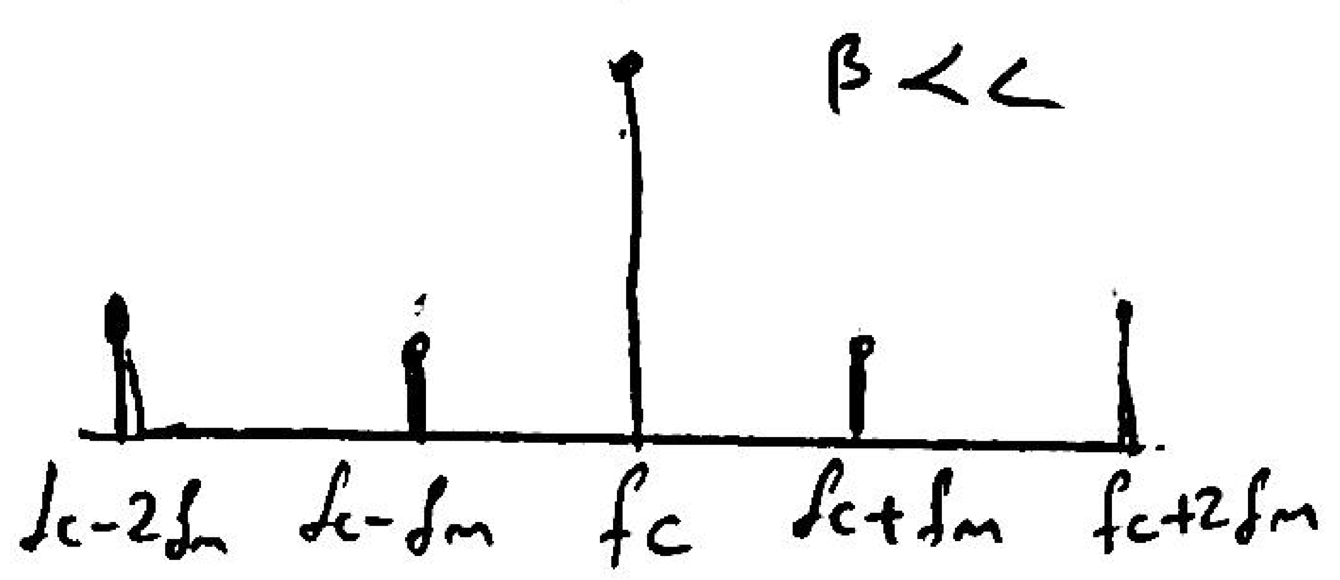


2) if β is small Only $f_c \mp f_m$ are important



3) Average power is $P = \frac{1}{2} A_c^2$

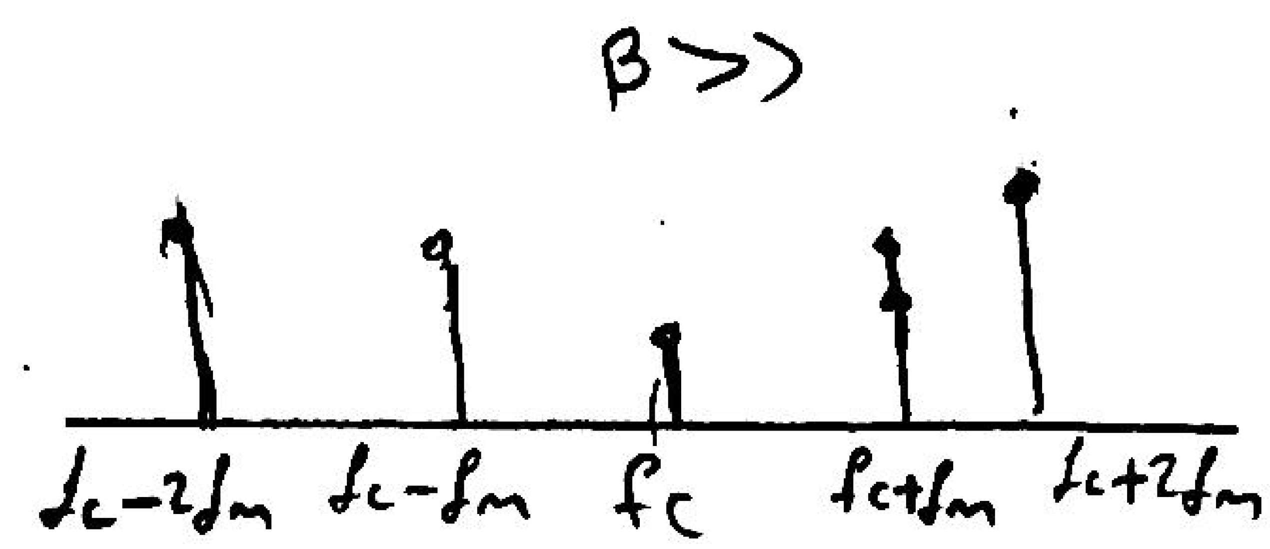
We want this power is spent on side freauencies. (not spent on carrier)



Undesired

(waste of power)

power is used to transmit carrier)



Desired

(good use of power)

Power is used to transmit information)

Example 3

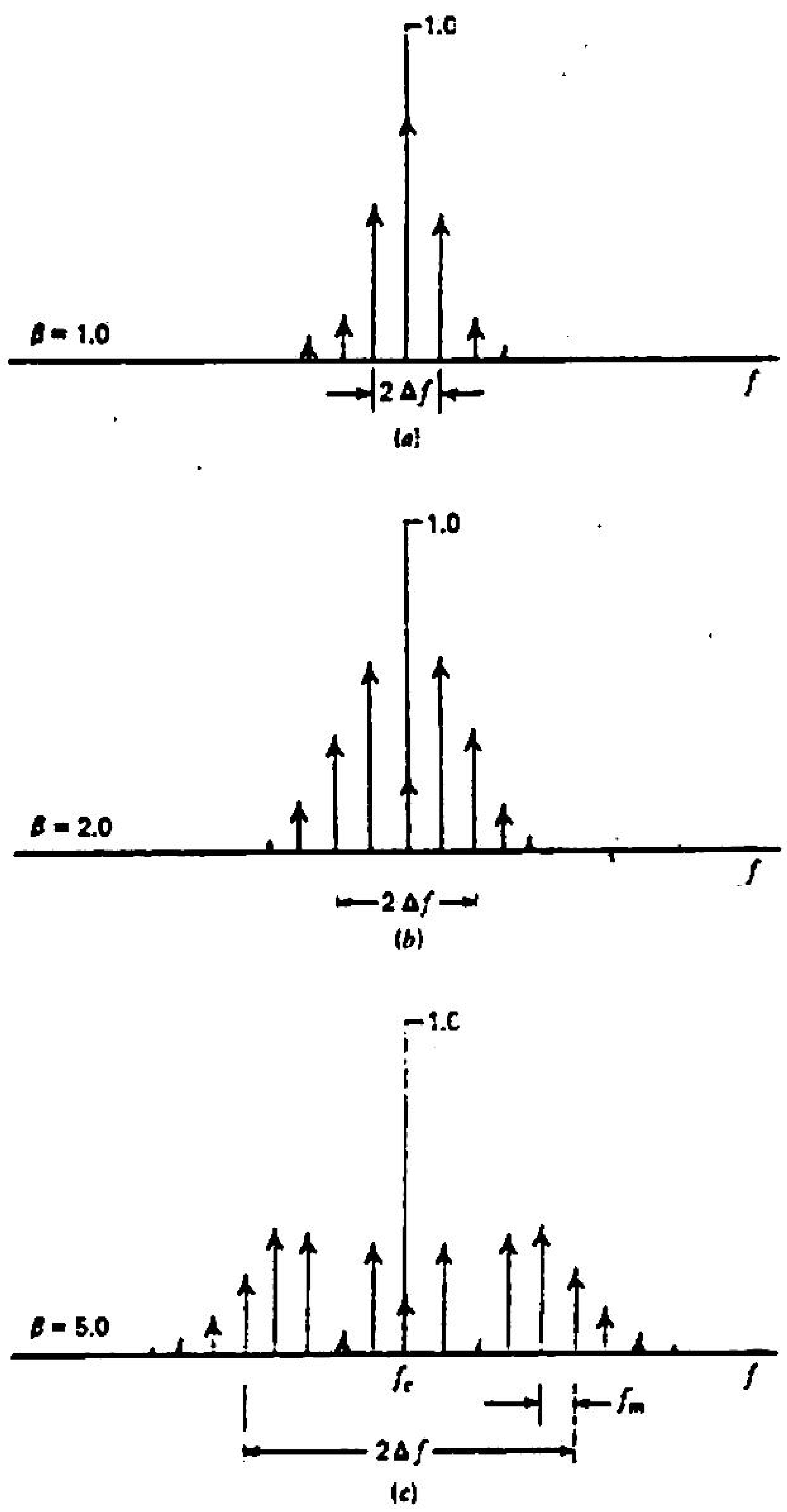


Figure 3.34 Discrete amplitude spectra of an FM signal, normalized with respect to the carrier amplitude, for the case of sinusoidal modulation of fixed frequency and varying amplitude. Only the spectra for positive frequencies are shown.

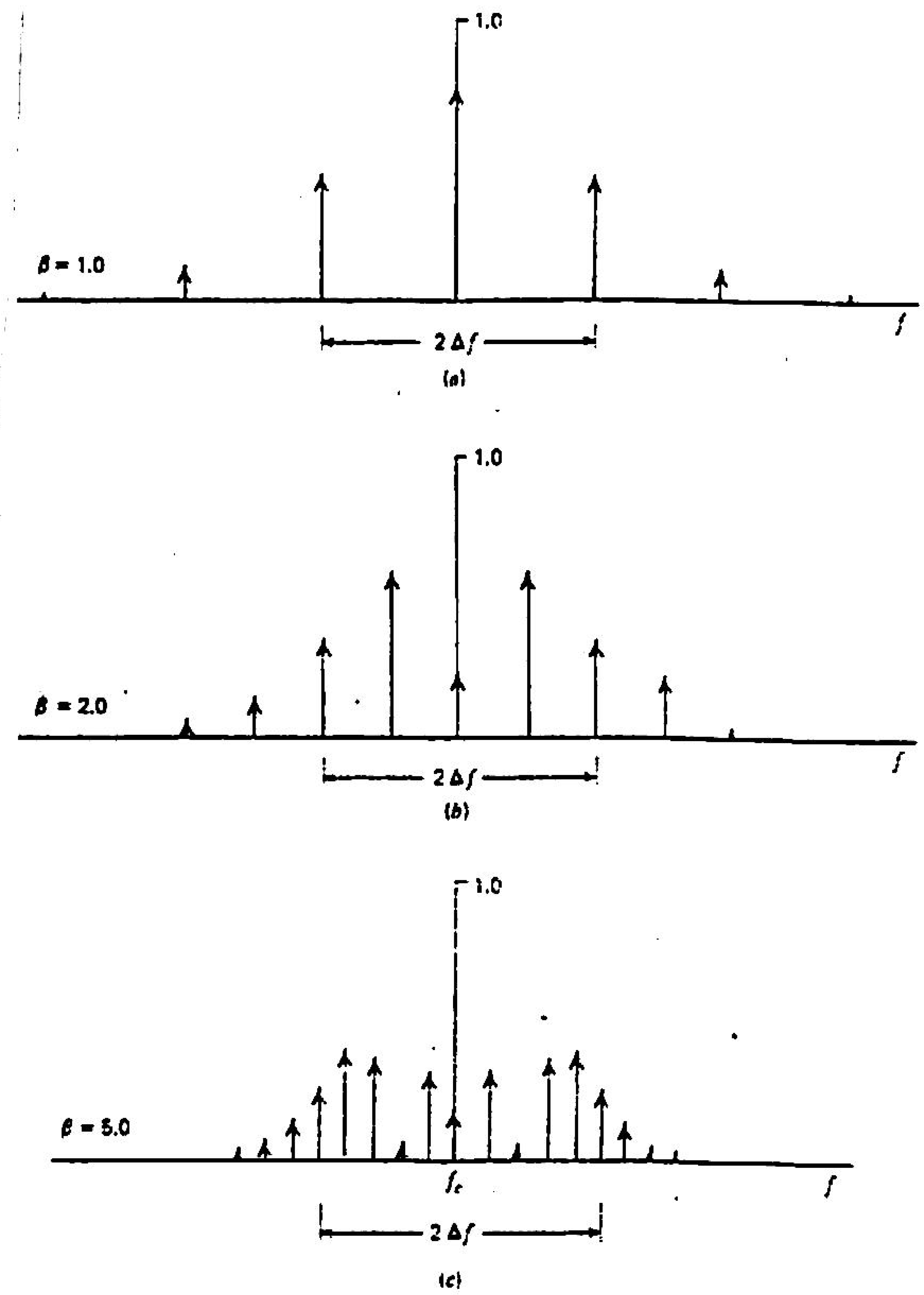


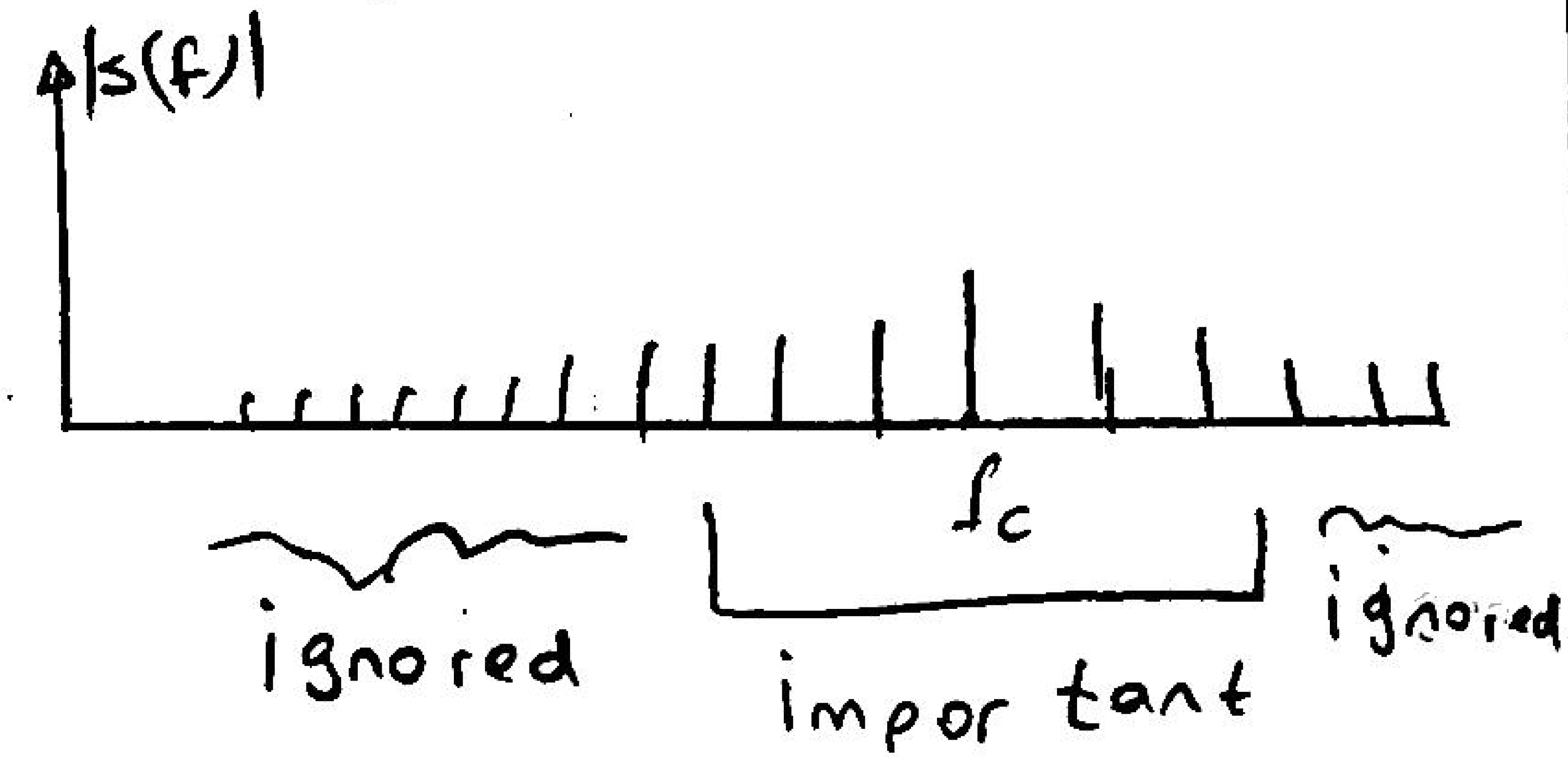
Figure 3.35 Discrete amplitude spectra of an FM signal, normalized with respect to the carrier amplitude, for the case of sinusoidal modulation of varying frequency and fixed amplitude. Only the spectra for positive frequencies are shown.

$\Delta f = k_f A_m$ $\quad \beta = \dfrac{\Delta f}{f_m}$ $\quad m(t) = A_m \cos(2\pi f_m t)$

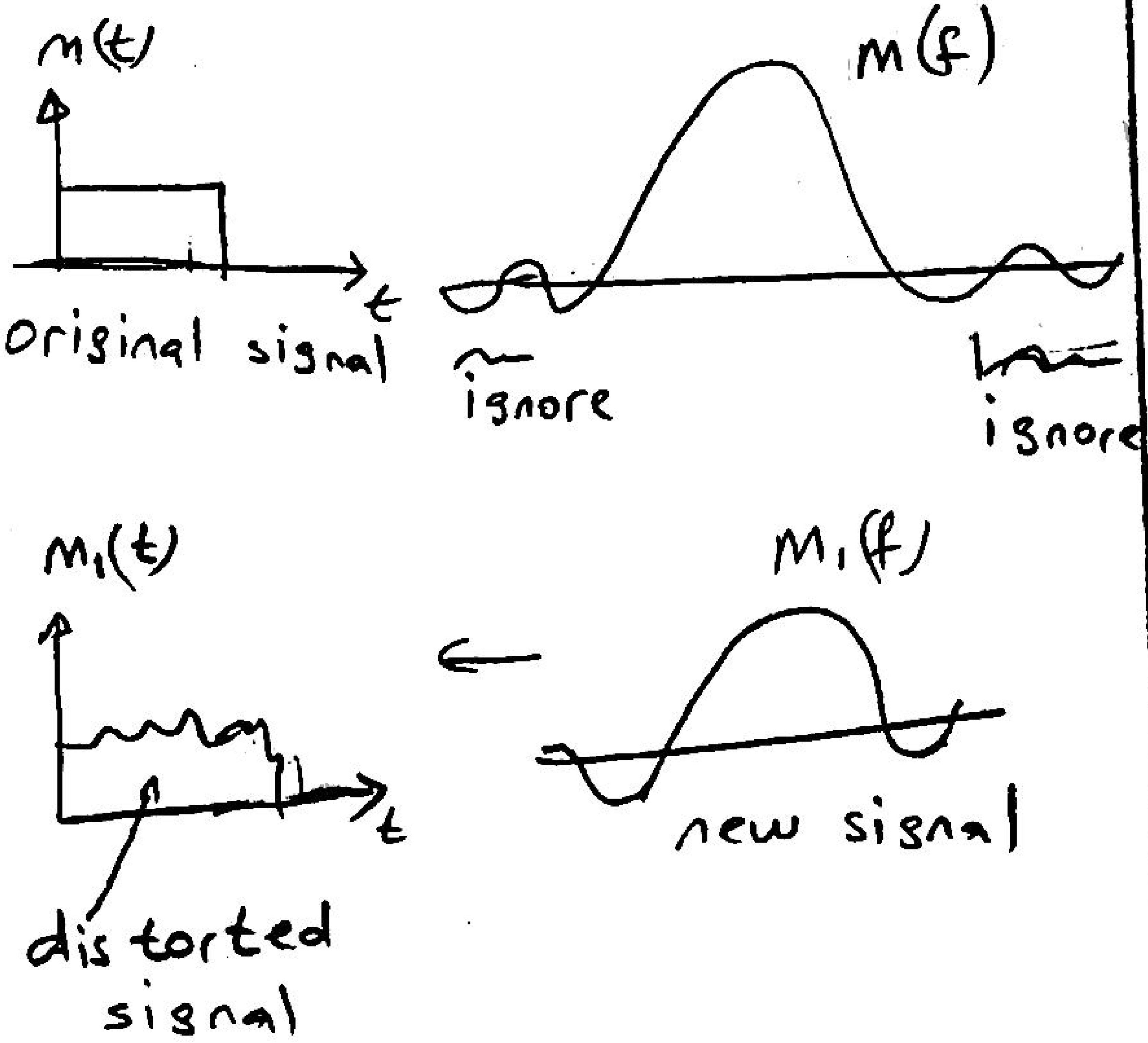
if β is increased all spectrum the bandwidth of fm wave appraches the Limiting value $\underline{2\Delta f}$.

Cmgo

Transmission Bandwidth of fm Signal



Ignoring side freauencies cause dis torsion.



Carson's Rule

$$B_T \cong 2\Delta f + 2f_m = 2\Delta f + 2\frac{\Delta f}{\beta}$$

$$= 2\Delta f\left(1 + \frac{1}{\beta}\right)$$

B_T = Transmission bandwidth

Table 3.1 Number of Significant Side Frequencies of a Wide-band FM Signal for Varying Modulation Index

Modulation Index β	Number of Significant Side Frequencies $2n_{max}$
0.1	2
0.3	4
0.5	4
1.0	6
2.0	8
5.0	16
10.0	28
20.0	50
30.0	70

The more side frequencies the better quality

EXAMPLE 4

In North America, the maximum value of frequency deviation Δf is fix 75 kHz for commercial FM broadcasting by radio. If we take the modul frequency $W = 15$ kHz, which is typically the "maximum" audio frequer interest in FM transmission, we find that the corresponding value of the tion ratio is

$$D = \frac{75}{15} = 5$$

Using Carson's rule of Eq. (S.81), replacing β by D, and replacing f_m b the approximate value of the transmission bandwidth of the FM sigr. obtained as

$$B_T = 2(75 + 15) = 180 \text{ kHz}$$

Generation of fm signals

Indirect fm:

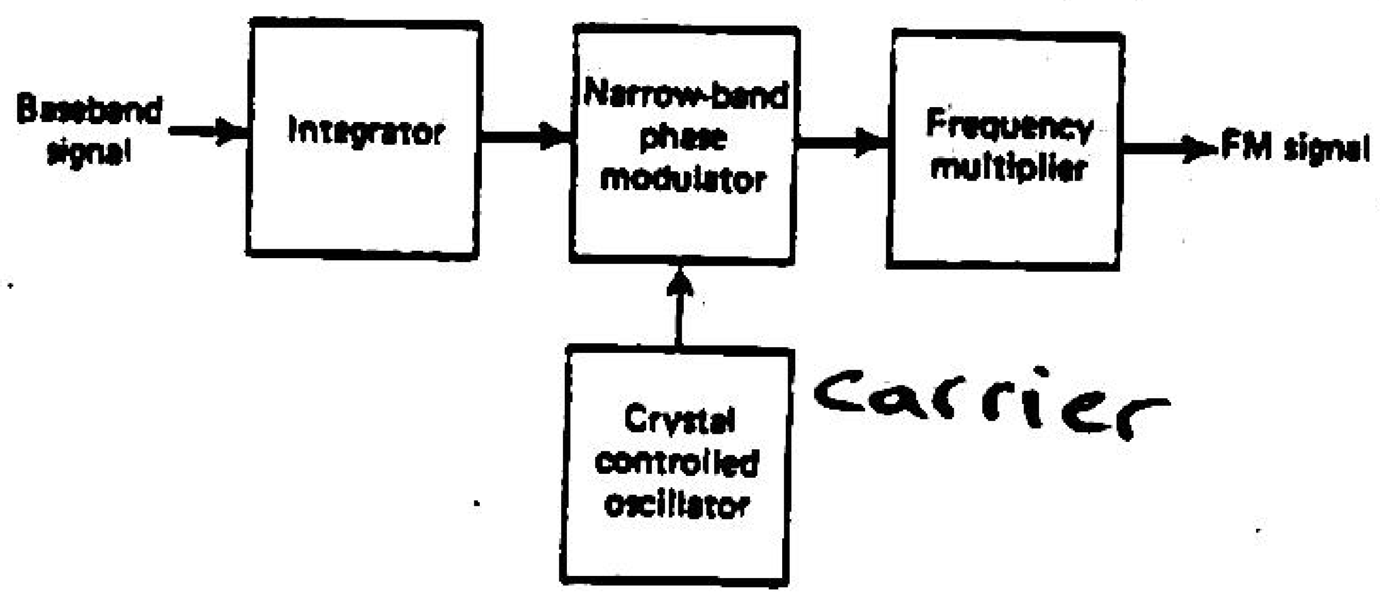


Figure 3.37 Block diagram of the indirect method of generating a wide-band FM signal.

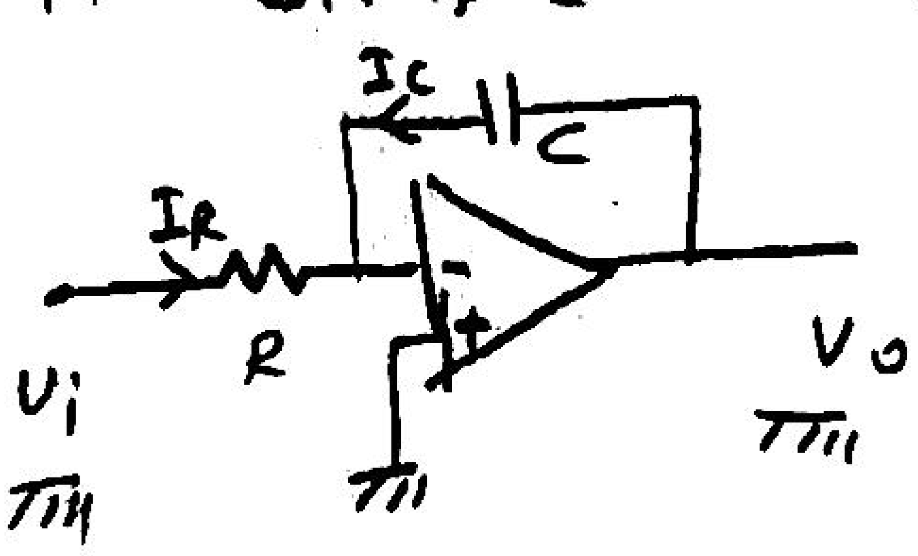
$w = \frac{d\theta}{dt}$ w = radial frequency
$w = 2\pi f$

f = frequency in Hertz

θ = angle phase

$\theta = \int_0^t w\,dt$

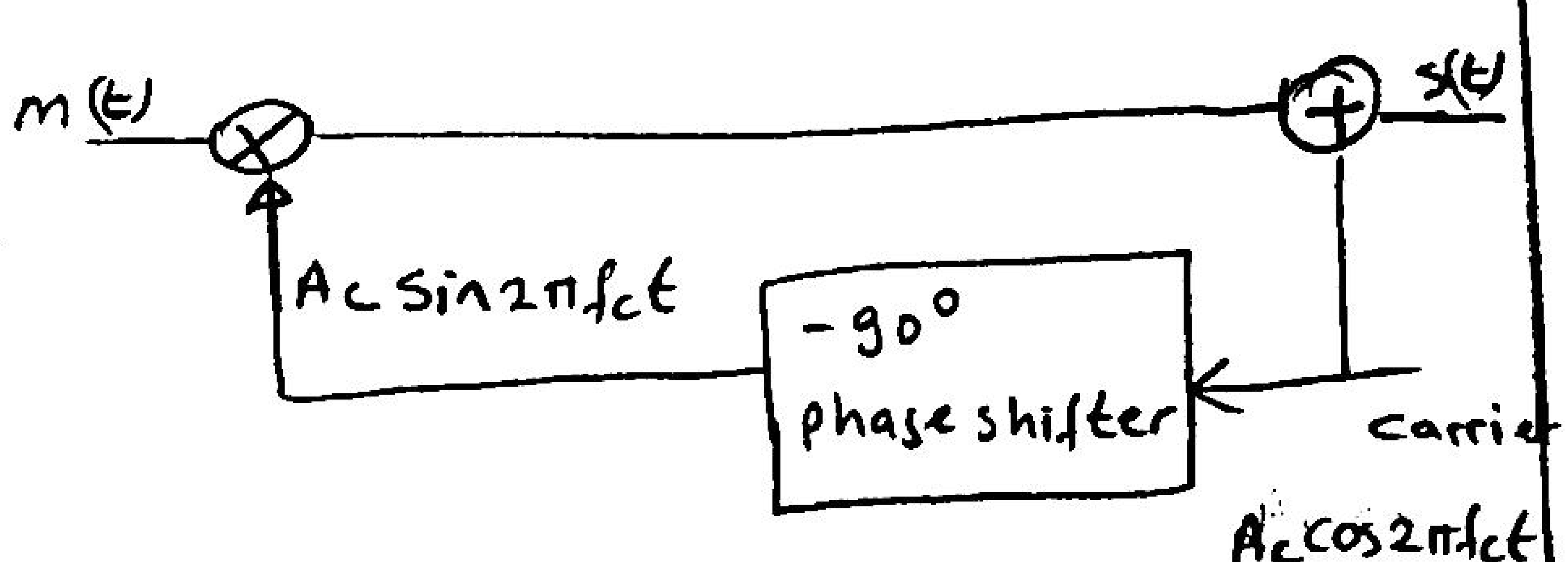
A simple integration circuit



$I_C = -I_R$

$C\frac{dV_c}{dt} = -\frac{V_i}{R}$

$V_o = V_c = -\frac{1}{RC}\int_0^t V_i(t)$

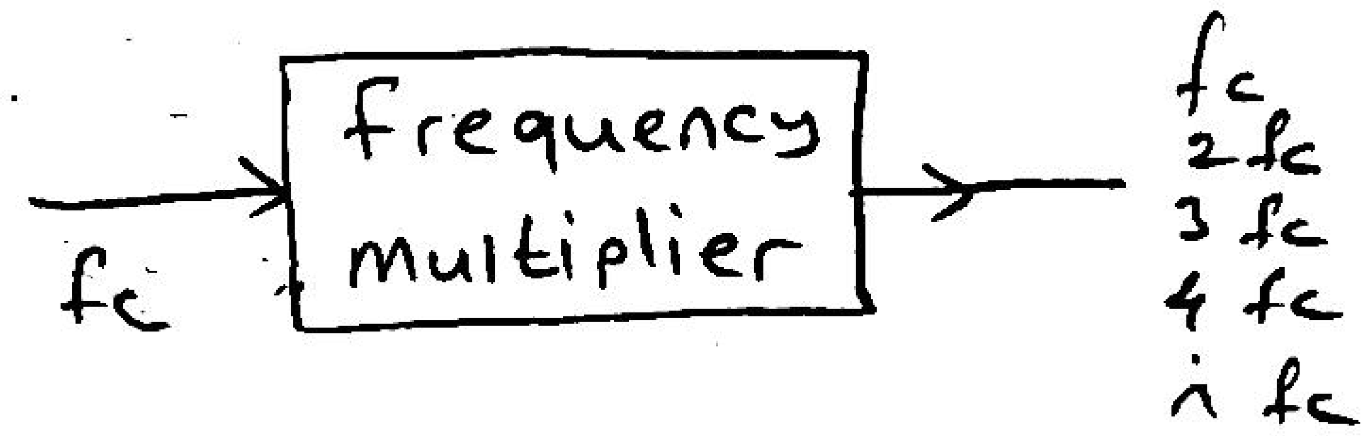


Narrow band fm

Narrow band fm signal

$S(t) = A_c \cos 2\pi f_c t - \beta A_c \sin(2\pi f_c t)\sin(2\pi f_m t)$

Crystal oscillator = Provides costant frequency



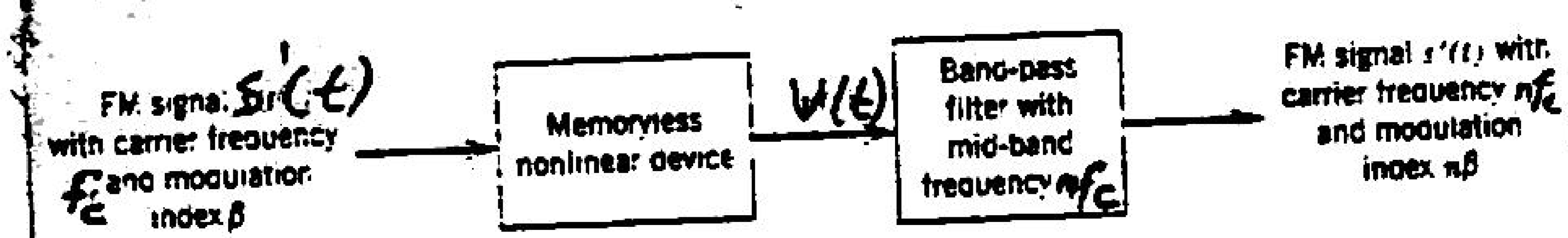
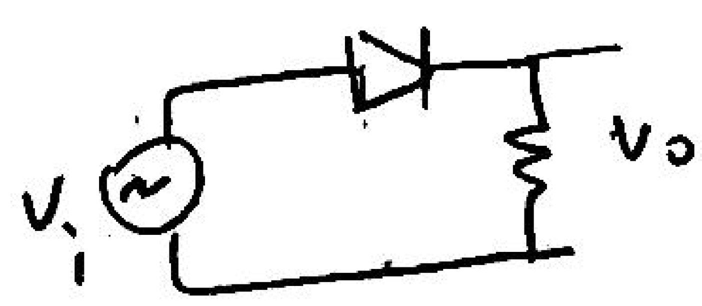


Figure 3.38 Block diagram of frequency multiplier.

$V(t) = a_1 s(t) + a_2[s(t)]^2 + \ldots\ldots + a_n[s(t)]^n$

A simple nonlinear device



$I = I_s e^{\alpha V_i}$

$V_o = RI = RI_s e^{\alpha v_i}$

$e^{\alpha v_i} = 1 + \alpha v_i + \frac{(\alpha v_i)^2}{2!} + \frac{(\alpha V_i)^3}{3!} + \ldots$

$V_o = RI_s + (RI_s\alpha)v_i + (\frac{1}{2}RI_s\alpha^2)V_i^2 + \ldots$

see page cm52

$\cos^2 x =$

$\cos^3 x =$

$\cos^4 x =$

$\cos^5 x =$

$(a+b)^2 = a^2 + 2ab + b^2$

$(a+b)^3 = a^3 + 3a^2b + 3ab^2 + b^3$

$(a+b)^4 = a^4 + 4a^3b + 6a^2b^2 + 4ab^3 + b^4$

$(a+b)^n = a^n + \cdots$

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

$$[s(t)]^4 = A_c^4 \cos^4 2\pi f_c t - 4 A_c^3 \cos^3 2\pi f_c t \; \beta A_c \sin(2\pi f_c t) \sin(2\pi f_m t)$$
$$+ 6 A_c^2 \cos^2 2\pi f_c t \; \beta^2 A_c^2 \sin^2 \sin(2\pi f_c t) \sin^2(2\pi f_m t)$$
$$+ \cdots$$

$$\cos^3 x = \frac{3}{4}\cos x + \frac{1}{4}\cos 3x$$

$$\cos^3 2\pi f_c t = \frac{3}{4}\cos 2\pi f_c t + \frac{1}{4}\cos 2\pi \, 3f_c \, t$$

$$\sin a \sin b = \frac{1}{2}[\cos(a-b) - \cos(a+b)]$$

$$\sin(2\pi f_c t)\sin(2\pi f_m t) = \frac{1}{2}[\cos 2\pi(f_c - f_m)t - \cos 2\pi(f_c + f_m)t]$$

$$\cos^3 2\pi f_c t \sin(2\pi f_c t) \sin(2\pi f_m t) = \ldots$$

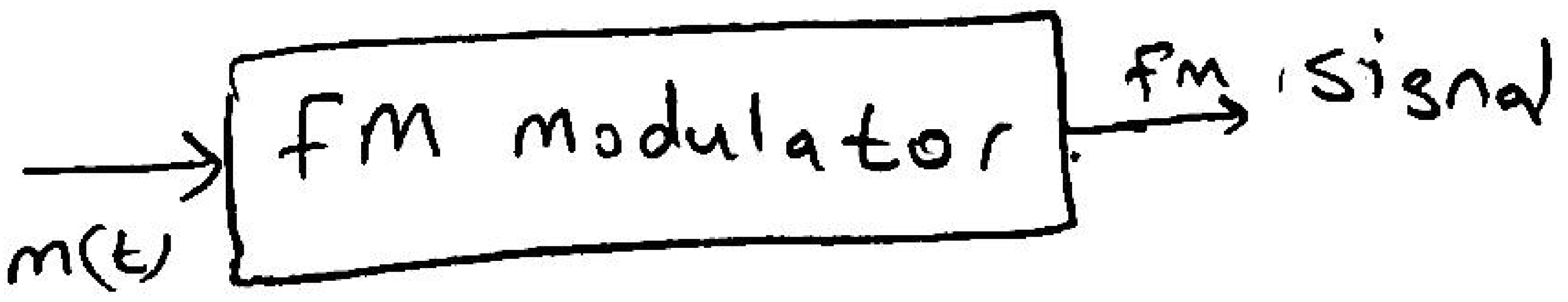
$$\frac{3}{4}\cos 2\pi f_c t + \frac{1}{4}\cos(2\pi 3f_c t) \sin(2\pi f_c t) \sin(2\pi f_m t) = \cdots$$
$$\cdots + (\ldots)\cos 2\pi(3f_c + f_c + f_m)t + \cdots$$
$$+ (\;)\cos(2\pi(3f_c - f_c - f_m)t + \cdots$$

Result $[s(t)]^4$ contains $4f_c + f_m$ and $4f_c - f_m$ frequencies plus many other frequencies

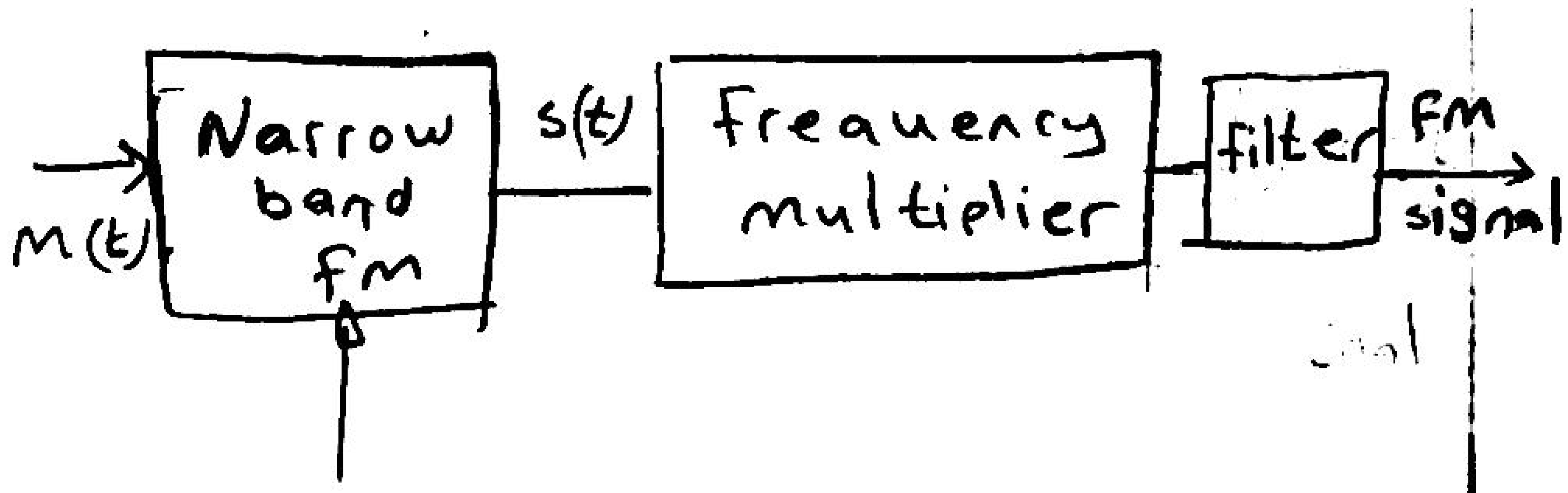
$\longrightarrow \boxed{[s(t)]^4} \longrightarrow \boxed{\text{filter}} \xrightarrow{\text{only}}$ $4f_c + f_m$ and $4f_c - f_m$ frequencies

Note:
We assume $s(t)$ is narrow band and we made the approximation β is small.

Generation of FM signals



Indirect FM



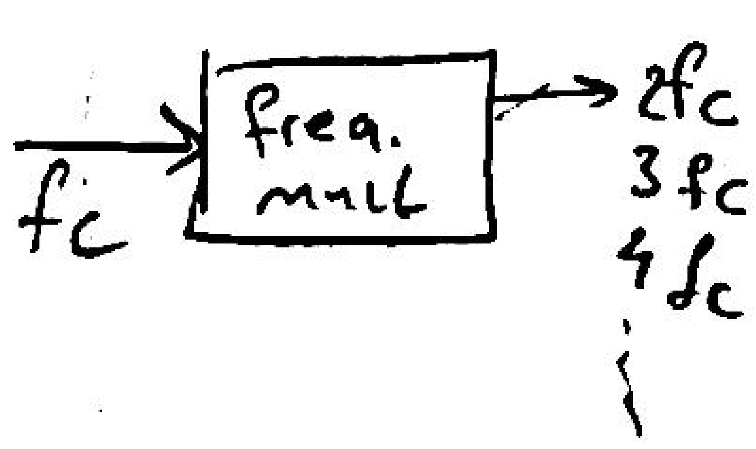
$A_c \cos 2\pi f_x t$

crystal oscillator

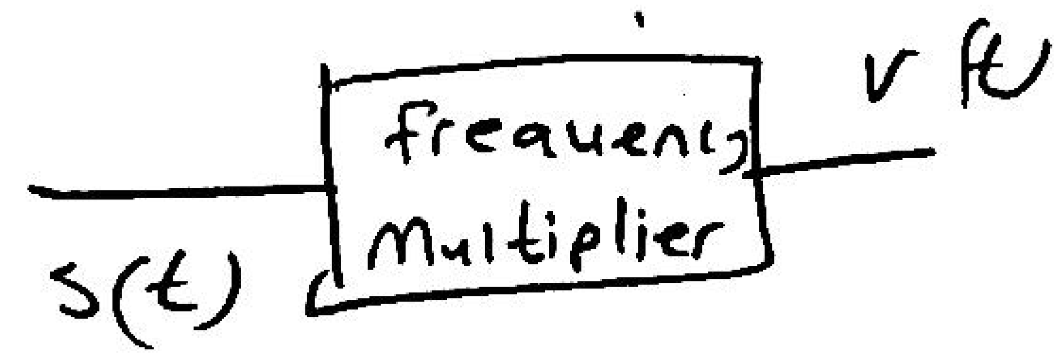
Narrow band fm modulator output

$$s(t) = A_c \cos\left[2\pi f_c t + 2\pi K_f \int_0^t m(t)\,dt\right]$$

frequency multiplier produce multiples of input frequency

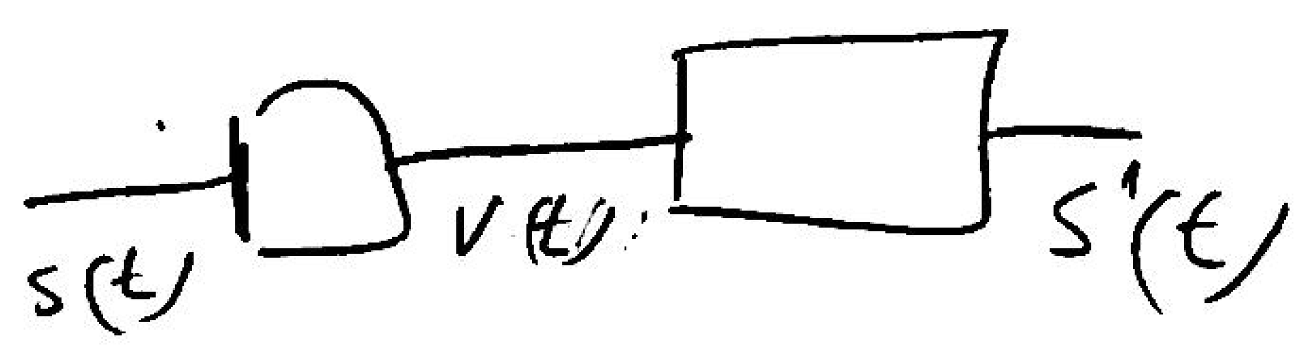


frequency multiplier is a nonLinear device



$$v(t) = a_1 s + a_2 s^2 + a_3 s^3 + \dots$$

After filtering



$$s'(t) = A_c' \cos\left[2\pi n f_c t + 2\pi n k_f \int_0^t m(t)\,dt\right]$$

frequency is

$$f_i(t) = n f_c + n k_f m(t)$$

Note $\cos 2\pi f_x t \Rightarrow$ frequency f_x

$\cos\left[2\pi\left(n f_c t + n k_f \int_0^t m(t)\right)\right] \Rightarrow$ frequency $f_i(t)$

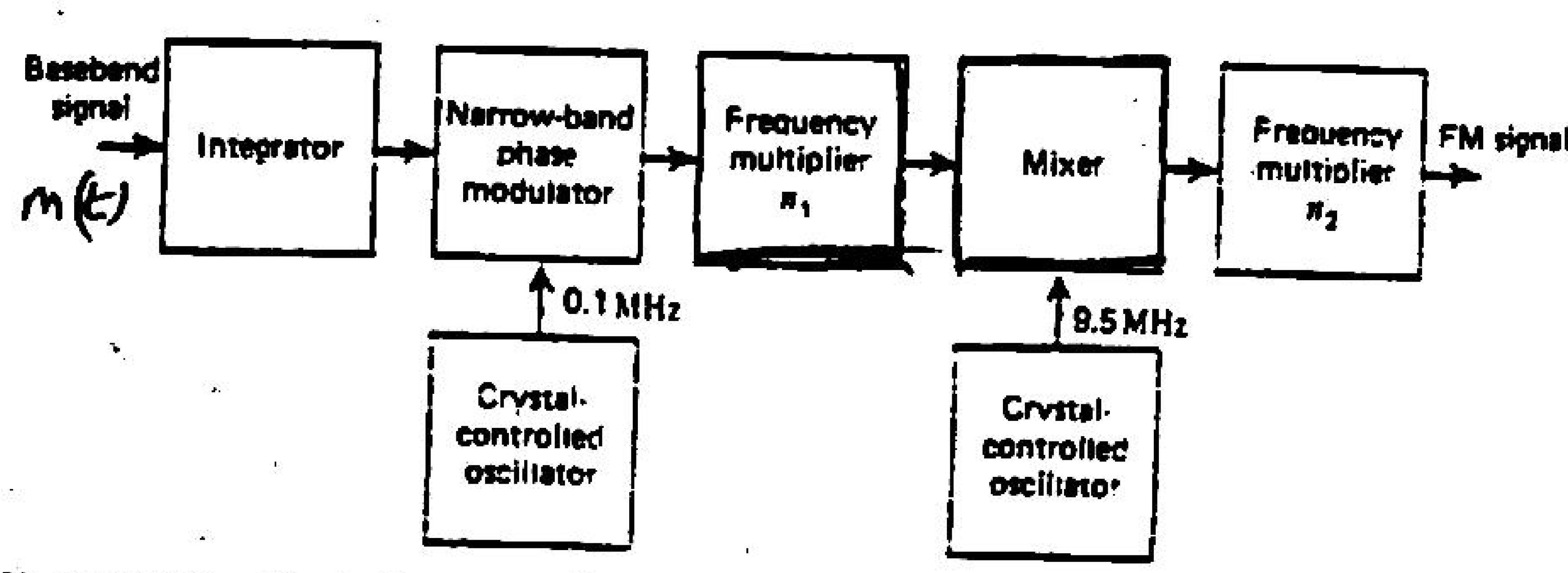
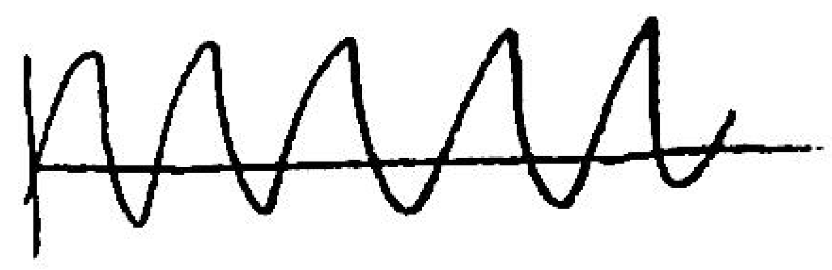


Figure 3.39 Block diagram of the wide-band frequency modulator for Example 5.

	At the Phase Modulator Output	At the First Frequency Multiplier Output	At the Mixer Output	At the Second Frequency Multiplier Output
Carrier frequency	0.1 MHz	7.5 MHz	2.0 MHz	100 MHz
Frequency deviation	20 Hz	1.5 kHz	1.5 kHz	75 kHz

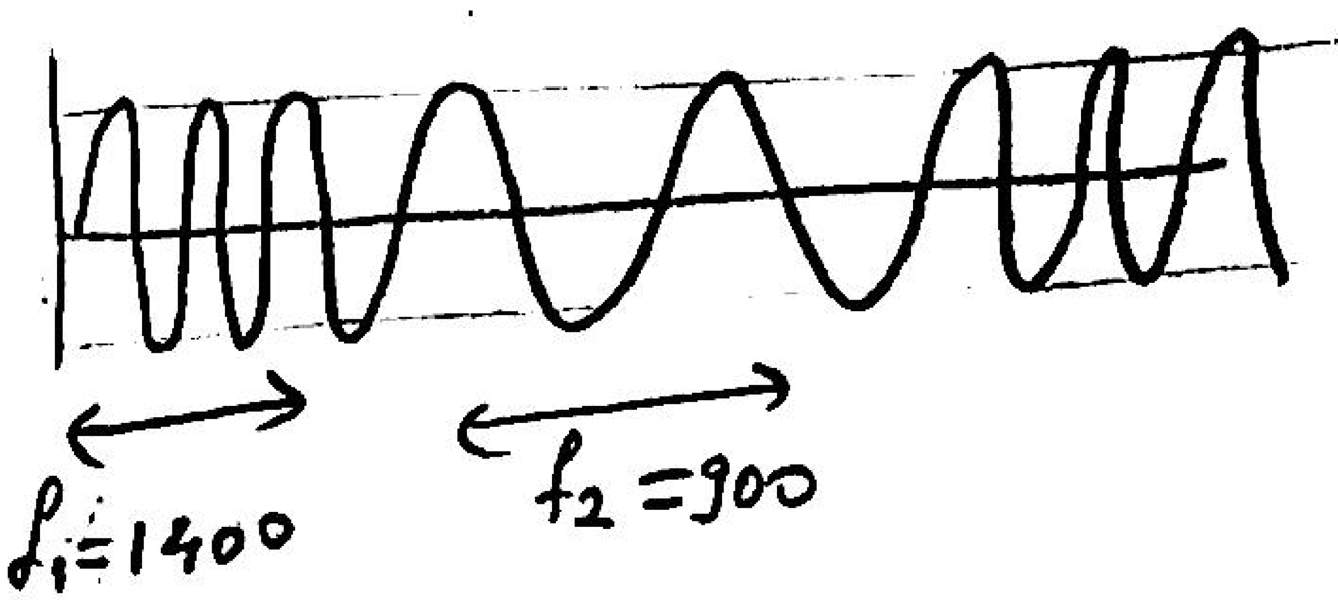
A mixer multiplies two signals.

frequency deviation:



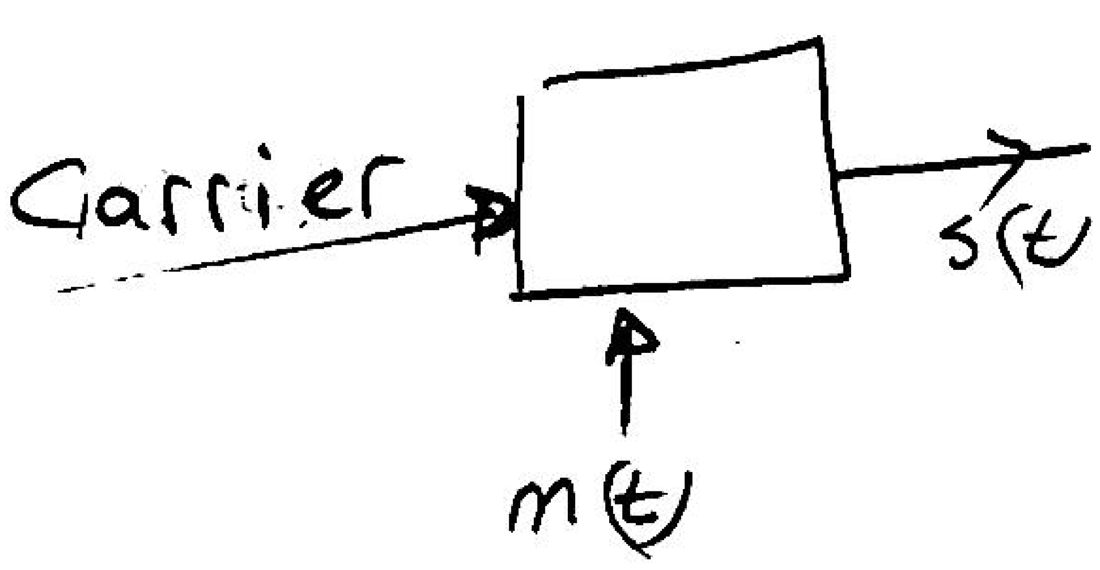
$A_c \cos 2\pi\, 1000\, t$

After modulation.



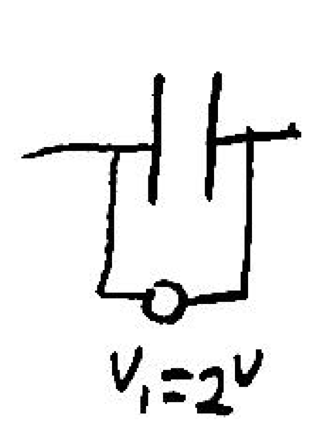
frequency deviation due to $m(t)$ $1400 - 900 = 500$ h.

Direct FM:

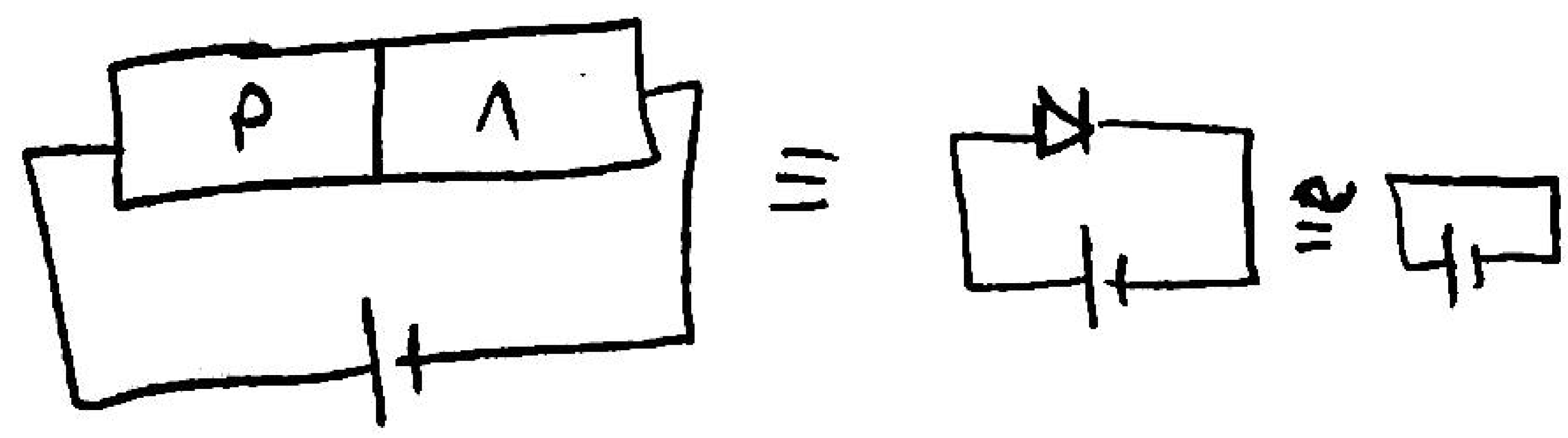


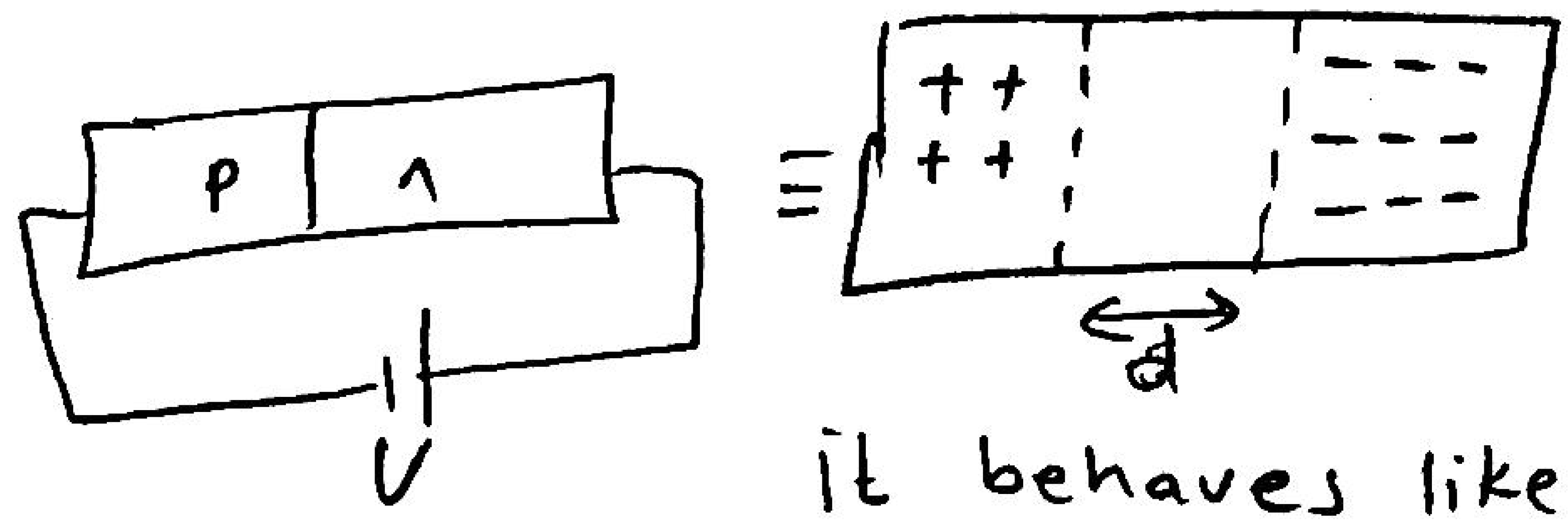
carrier frequency is varied directly with $m(t)$

Varactor: A voltage variable capacitor.



Typical varactor is p n junction





it behaves like capacitor

V increases $\Rightarrow$ d increases $\Rightarrow$ C increases

An Oscillator produces a sinusoidal wave.

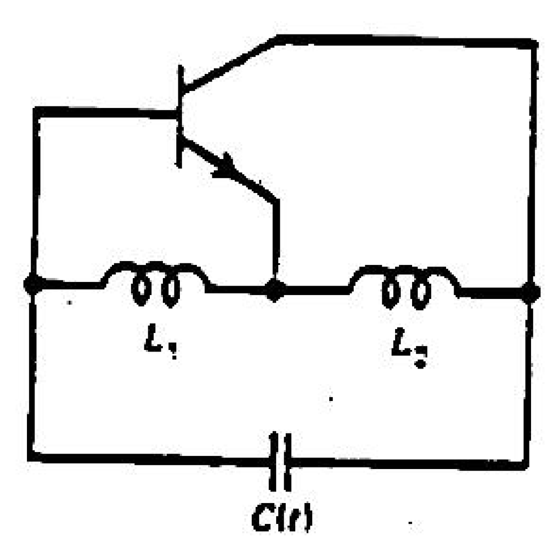


Figure 3.40 Hartley oscillator.

Oscillation frequency is

$$f_i(t) = \frac{1}{2\pi\sqrt{(L_1 + L_2)C(t)}}$$

$c(t)$ is a varactor, $c(t)$ is changed by $m(t)$.

if $m(t) = 0$ $\quad c(t) = C_0$ and

$$f_0 = \frac{1}{2\pi\sqrt{(L_1 + L_2)C_0}}$$

f_0 is carrier frequency (unmodulated carrier frequency)

$\dot{m}(t)$ changes $\Rightarrow C(t)$ changes

$$C(t) = C_0 + \Delta C \cos(2\pi f_m t)$$

$$C(t) = C_0\left[1 + \frac{\Delta C}{C_0}\cos(2\pi f_m t)\right]$$

$$f_i(t) = \frac{1}{2\pi\sqrt{(L_1+L_2)\,C_0\left[1+\frac{\Delta C}{C_0}\cos(2\pi f_m t)\right]}}$$

$$= \underbrace{\frac{1}{2\pi\sqrt{(L_1+L_2)C_0}}}_{f_0} \cdot \frac{1}{\sqrt{1+\frac{\Delta C}{C_0}\cos(2\pi f_m t)}}$$

$$= f_i(t) = f_0\left[1 + \frac{\Delta C}{C_0}\cos(2\pi f_m t)\right]^{-1/2}$$

if x is small

$$\frac{1}{\sqrt{1+x}} \cong 1 - 0.5x \quad \text{(Taylor series)}$$

if ΔC is small

$$\frac{1}{\sqrt{1+\frac{\Delta C}{C_0}\cos(2\pi f_m t)}} \cong 1 - 0.5\frac{\Delta C}{C_0}\cos(2\pi f_m t)$$

$$f_i(t) = f_0\left[1 - \frac{\Delta C}{2C_0}\cos(2\pi f_m t)\right]$$

Define

$$\frac{\Delta C}{2C_0} = -\frac{\Delta f}{f_0}$$

$$\boxed{f_i(t) = f_0 + \Delta f \cos(2\pi f_m t)}$$

Carrier frequency f_i is changed by the information signal $\underline{\cos 2\pi f_m t}$

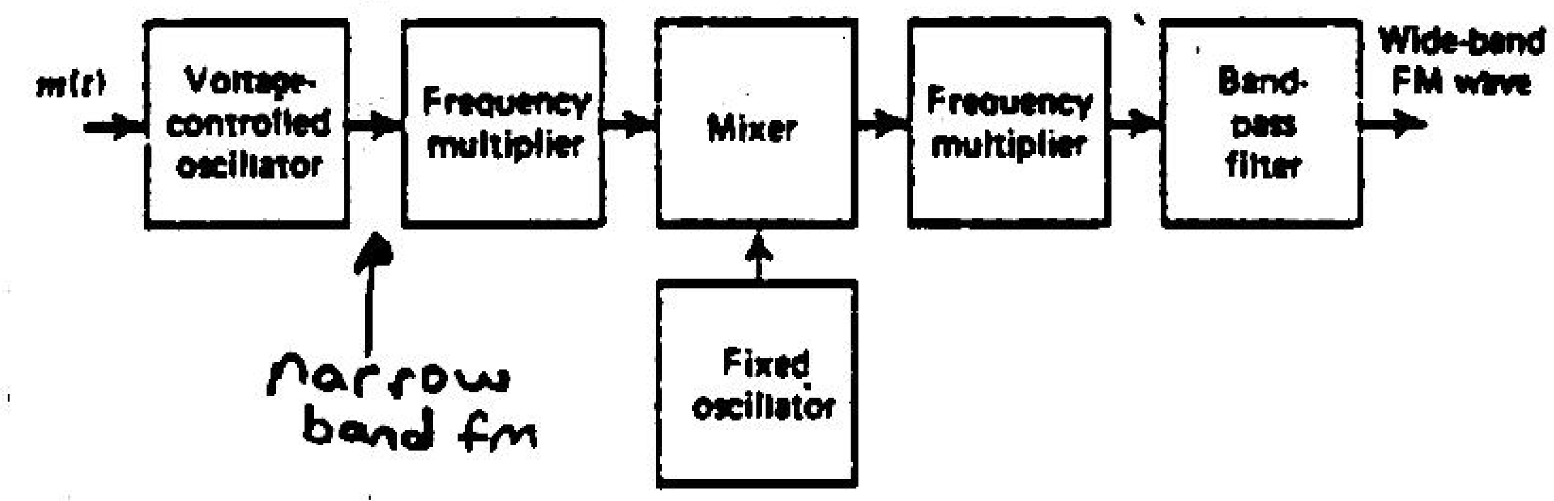
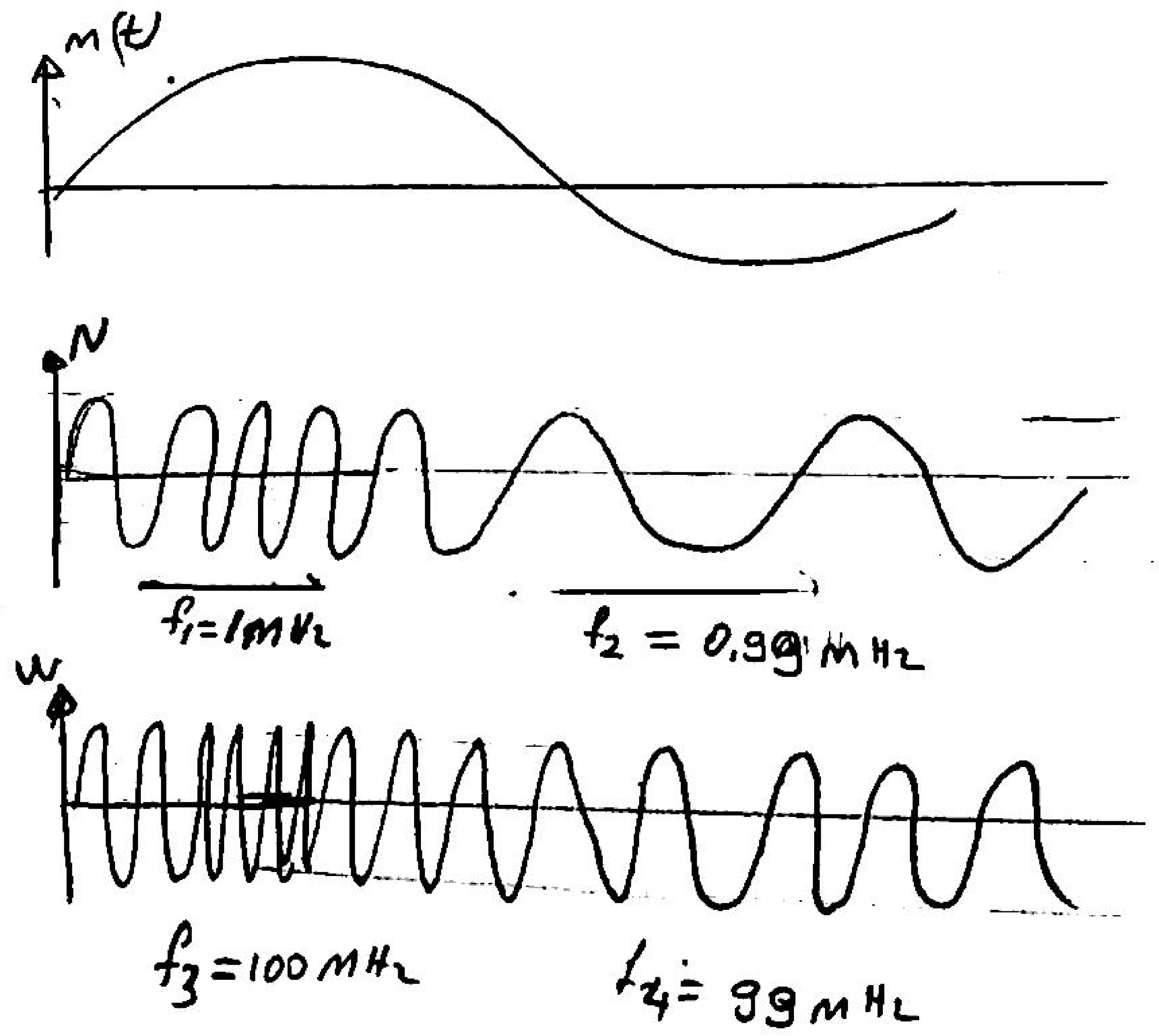


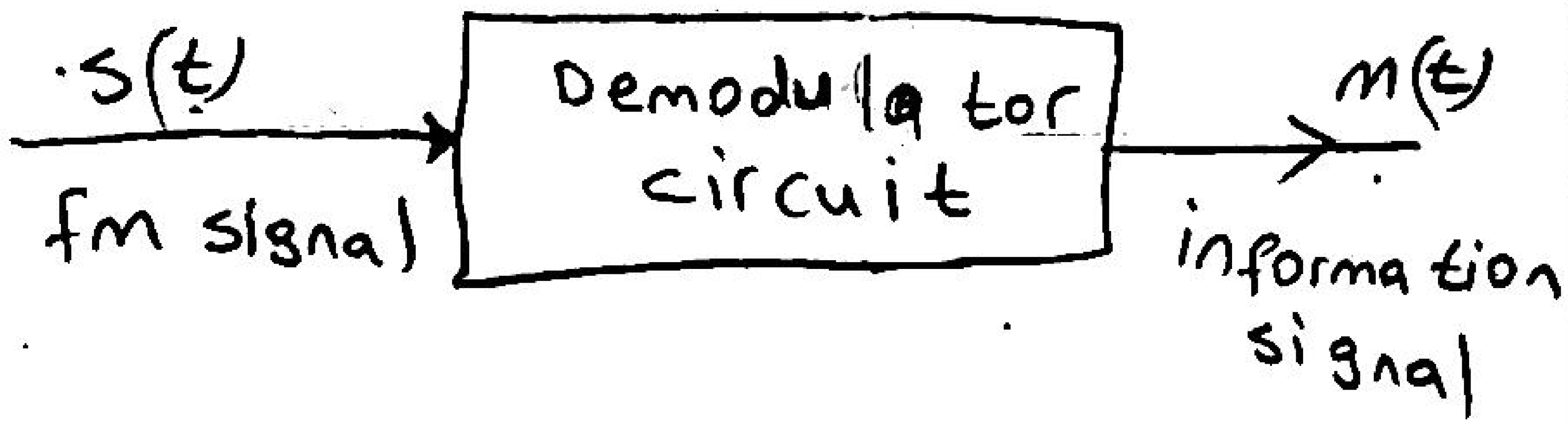
Figure 3.41 Block diagram of wide-band frequency modulator using a voltage-controlled oscillator.



Narrow band fm frequency deviation $f_2 - f_2 = \underline{0.01\,MHz}$

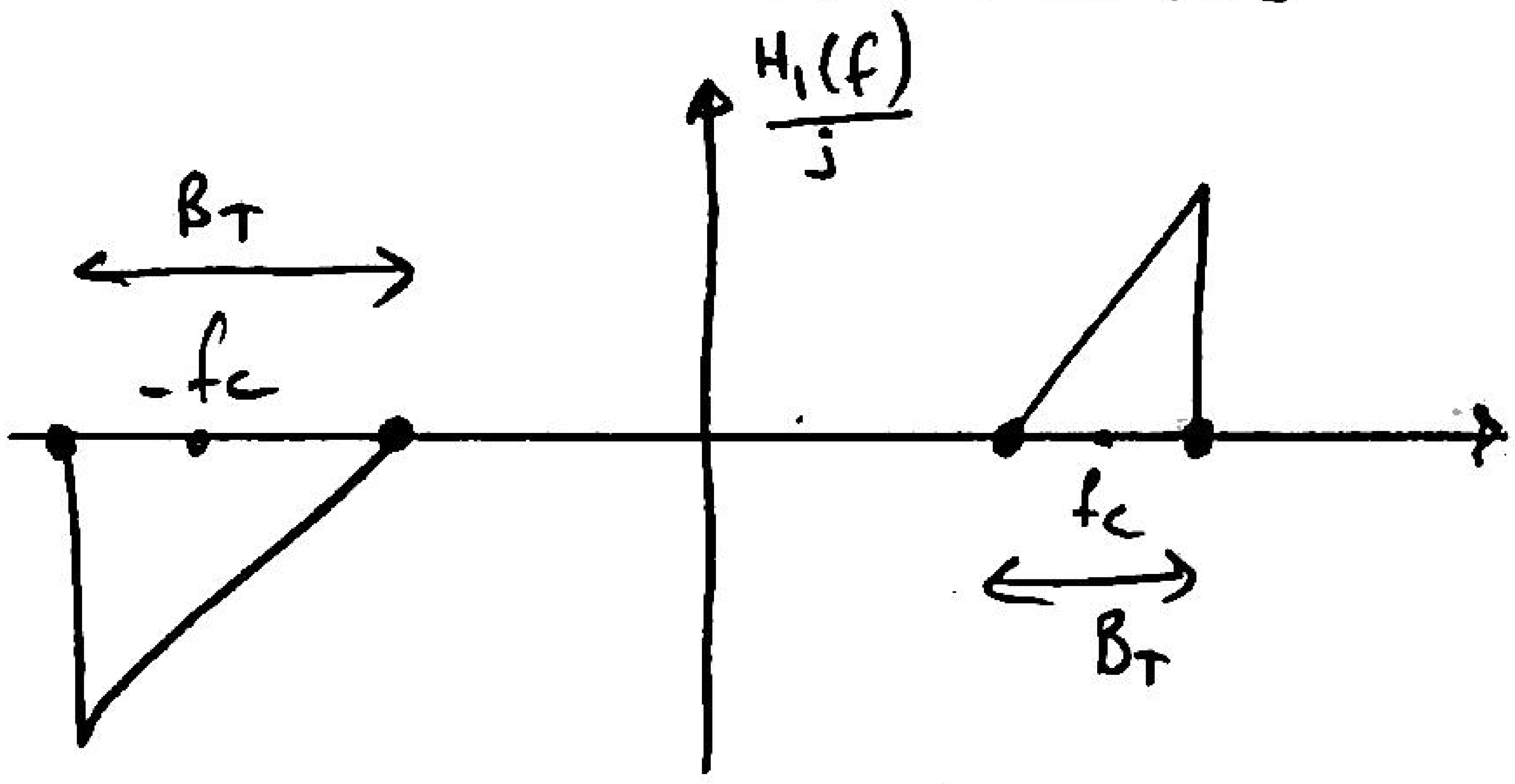
Wide band fm frequency deviation $f_3 - f_4 = \underline{1\,MHz}$

Demodulation of fm signal



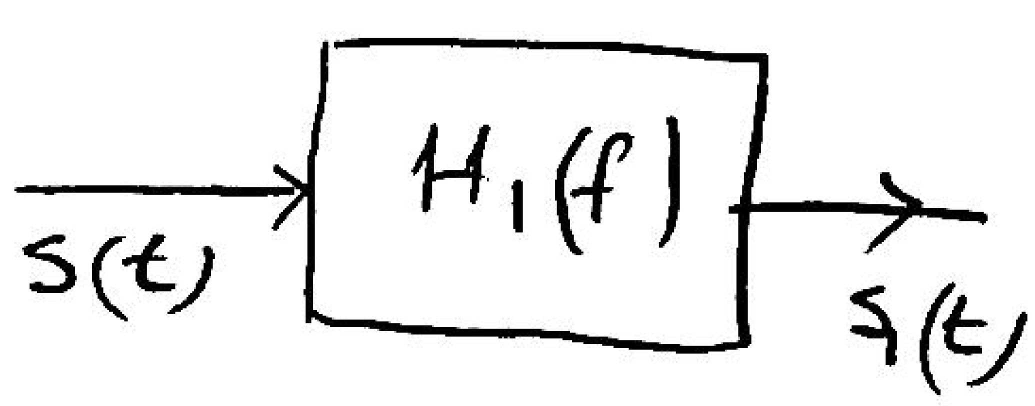
$$s(t) = A_c \cos\left[2\pi f_c t + 2\pi k_f \int_0^t m(\lambda)\, d\lambda\right]$$

frequency discriminator



$$H_1(f) = \begin{cases} j2\pi a\left(f - f_c + \frac{B_T}{2}\right) & f_c - \frac{B_T}{2} \leq f \leq f_c + \frac{B_T}{2} \\ j2\pi a\left(f + f_c - \frac{B_T}{2}\right) & -f_c - \frac{B_T}{2} \leq f \leq -f_c + \frac{B_T}{2} \\ 0 & \text{elsewhere} \end{cases}$$

Question? what is the output

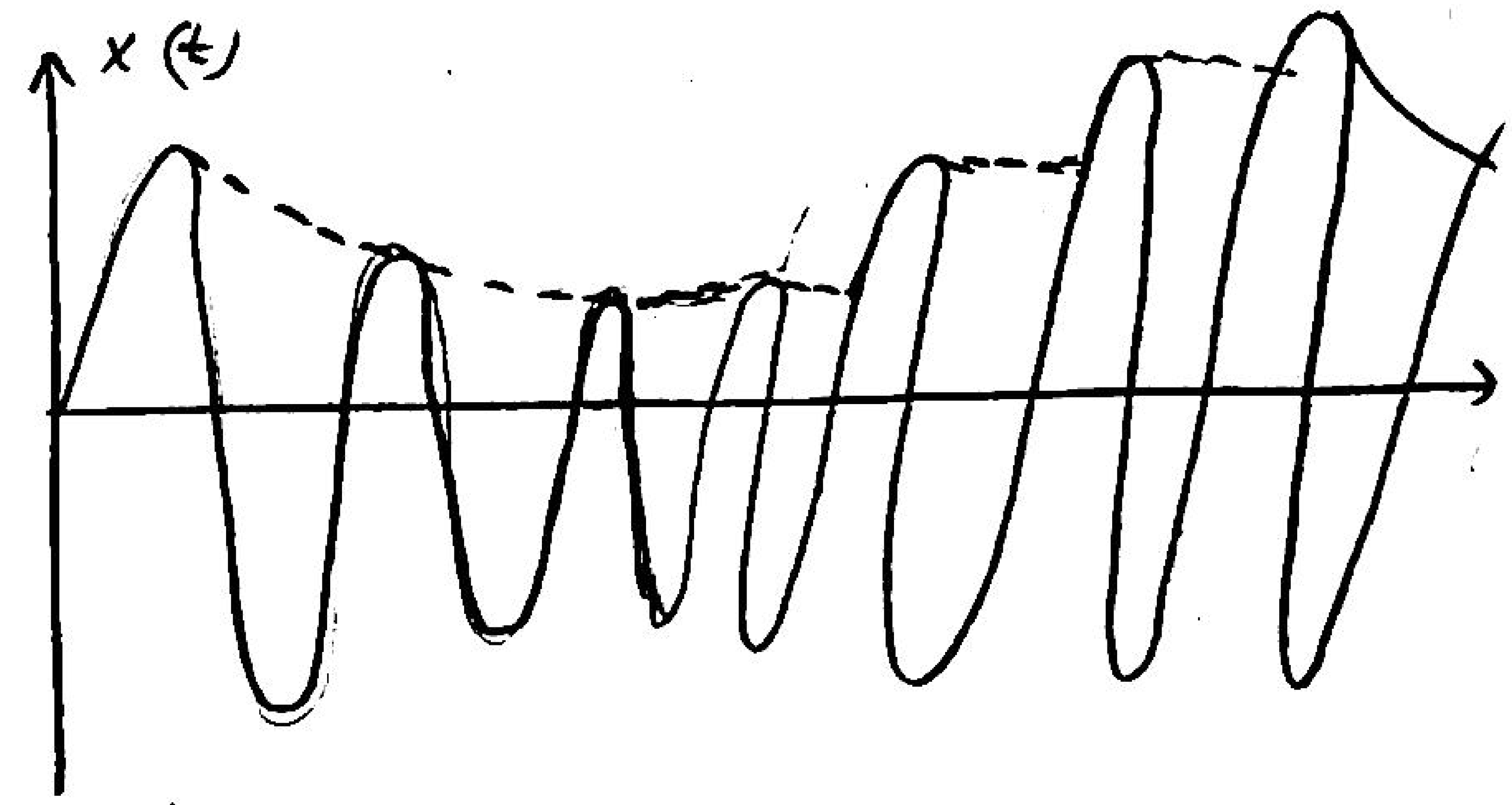


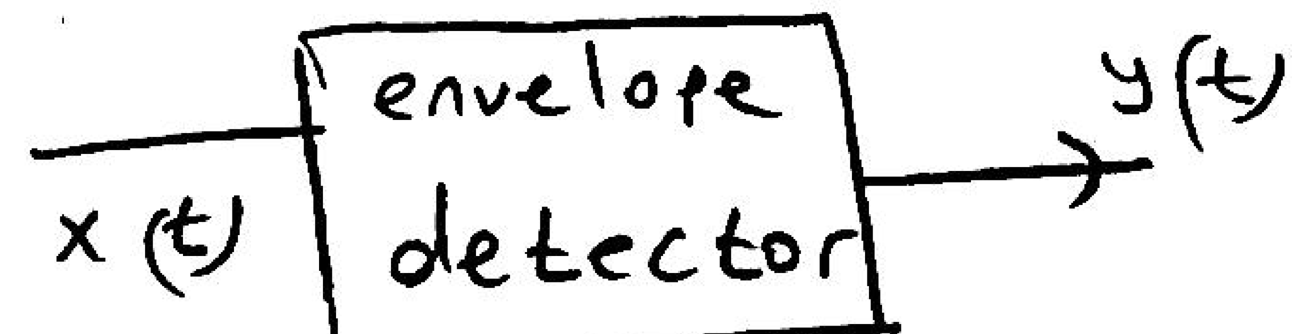
Answer

$$s_1(t) = \pi B_T a A_c\left[1 + \frac{2k_f}{B_T} m(t)\right] \cos\left[2\pi f_c t + 2\pi k_f \int_0^t m(\lambda)\, d\lambda + \frac{\pi}{2}\right]$$

(Detail page 123)

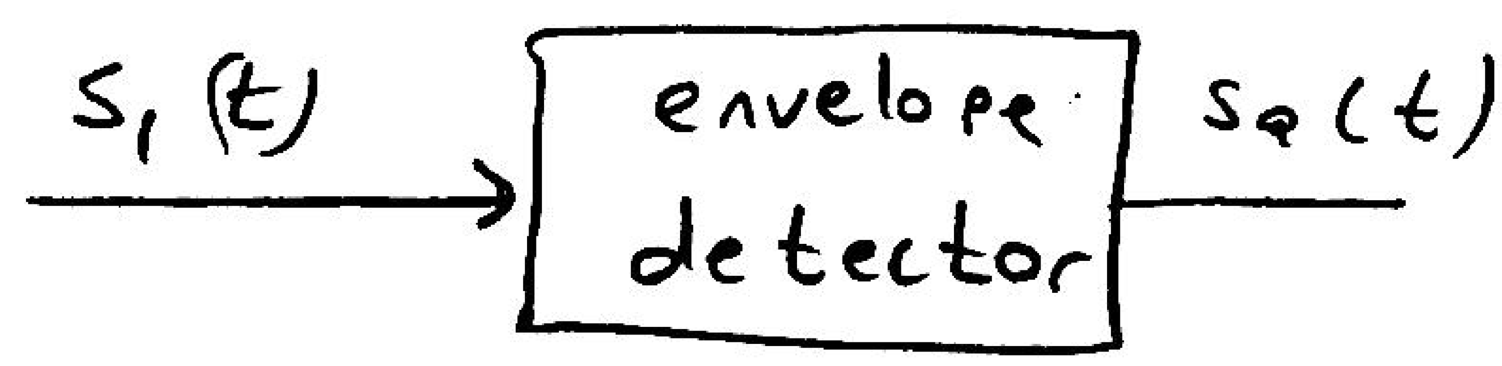
Reminder = Envelope detector



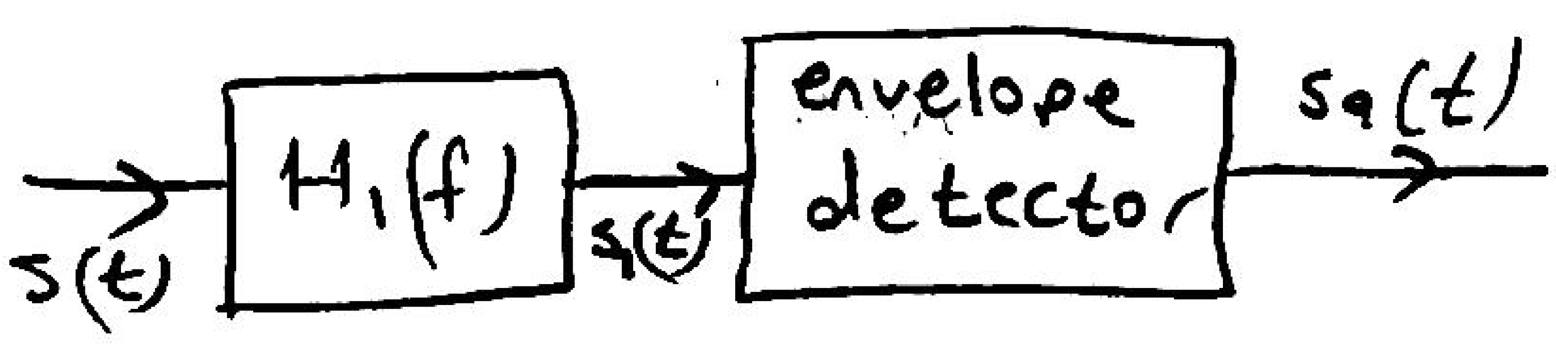


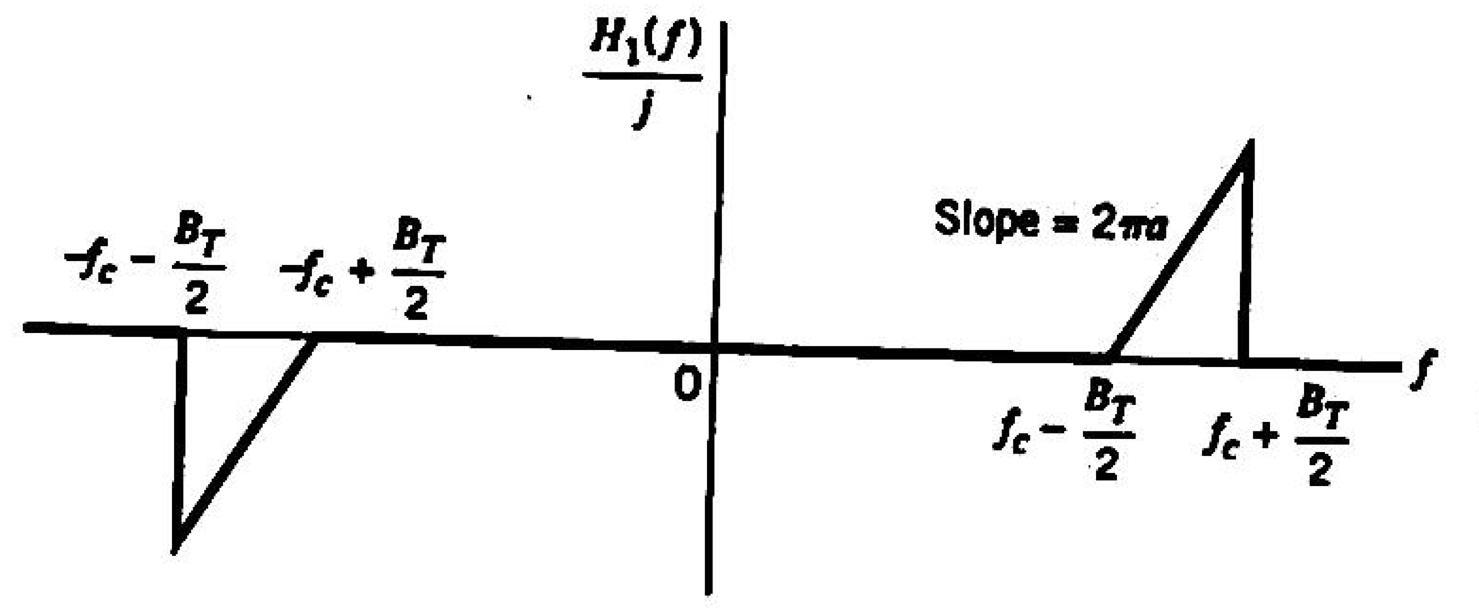
$$x(t) = m(t) \cdot [1 + \cos 2\pi f_c t]$$

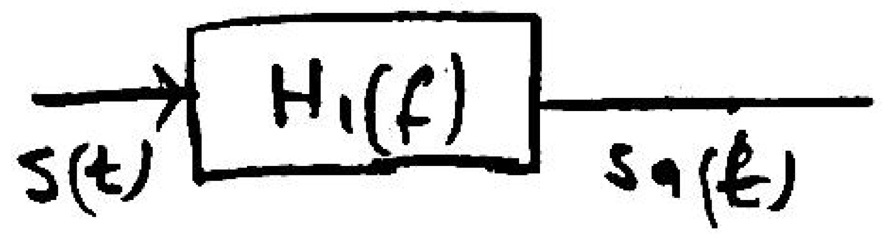
$$y(t) \cong m(t).$$

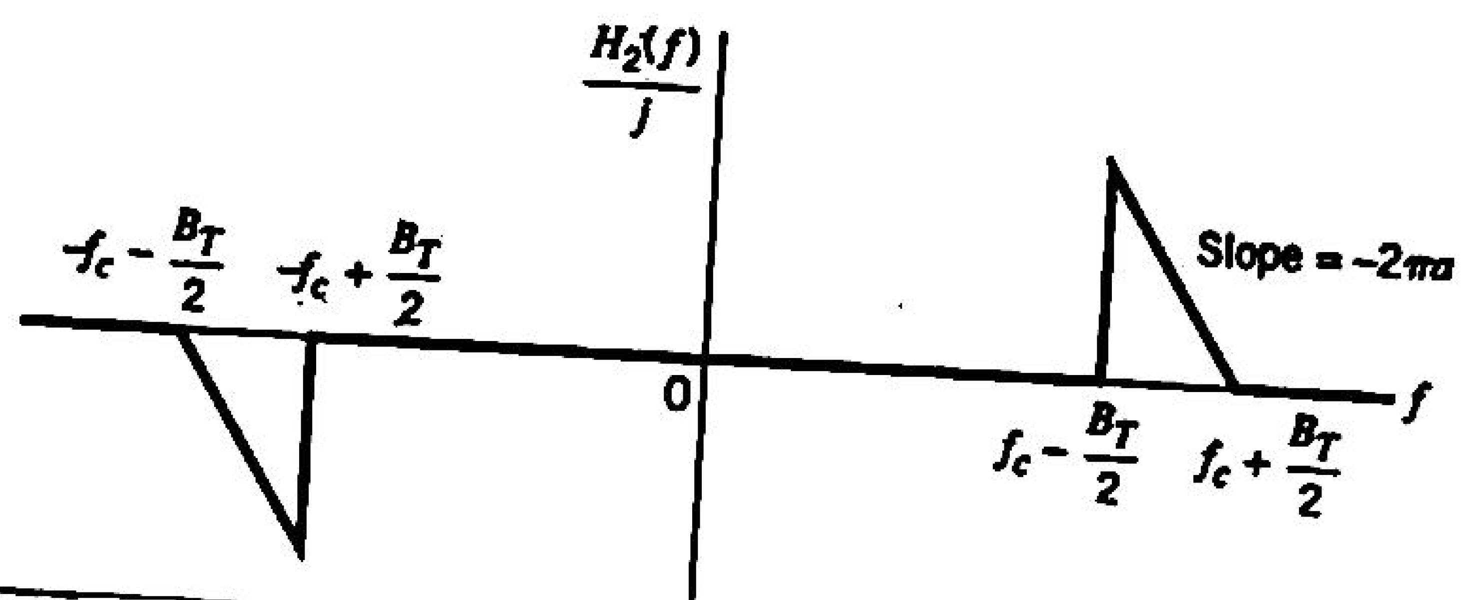


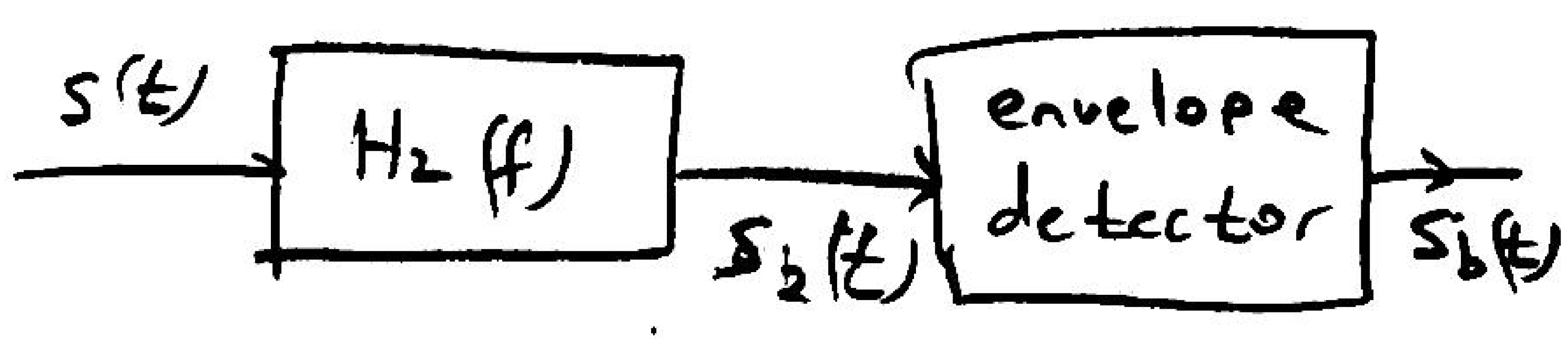
$$s_a(t) \cong \pi B_T a A_c\left[1 + \frac{2k_f}{B_T} m(t)\right]$$



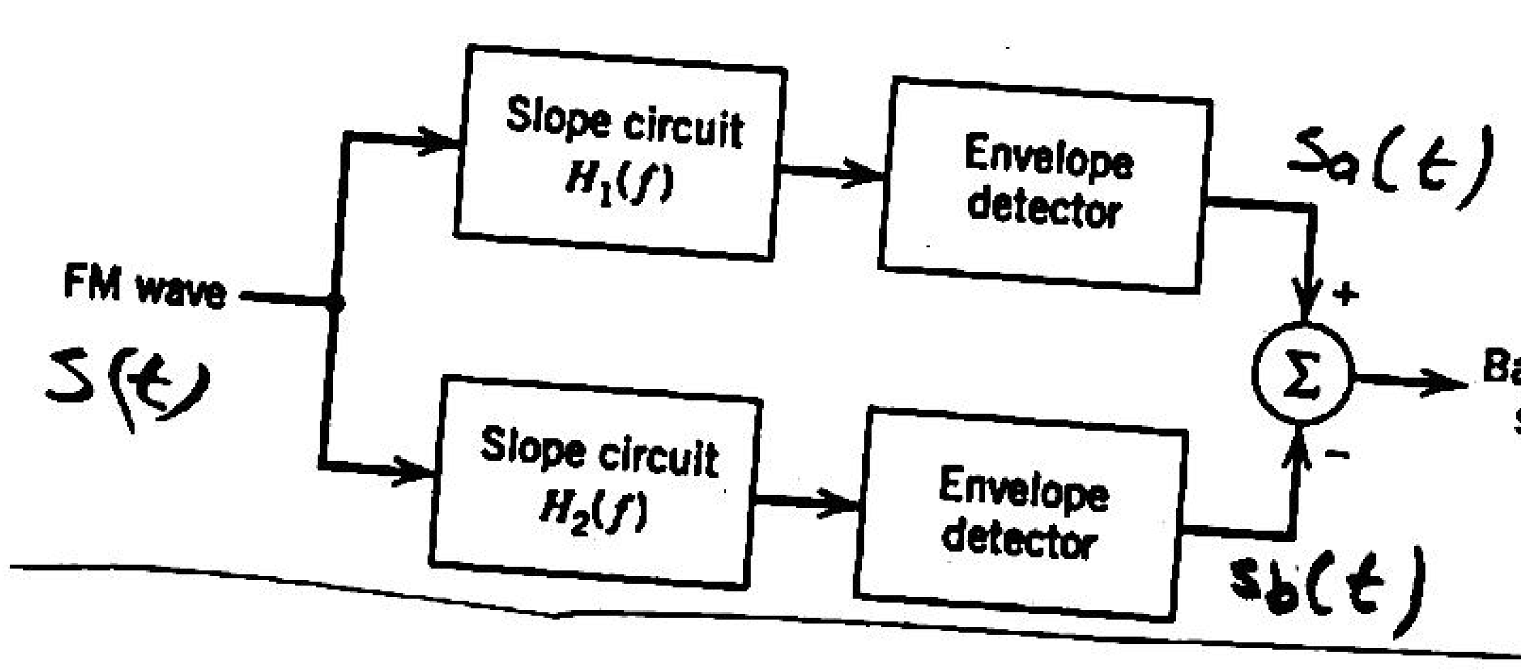








$$S_B(t) = \pi B_T a A_c\left[1 - \frac{2k_f}{B_T} m(t)\right]$$



$$S_a(t) + S_b(t) = \pi B_T a A_c\left[1 + \frac{2k_f}{B_T} m(t)\right] - \pi B_T a A_c\left[1 - \frac{2k_f}{B_T} m(t)\right]$$

$$= \underbrace{4\pi k_f a A_c}_{\text{constant}} \ \underbrace{m(t)}_{\text{information signal}}$$

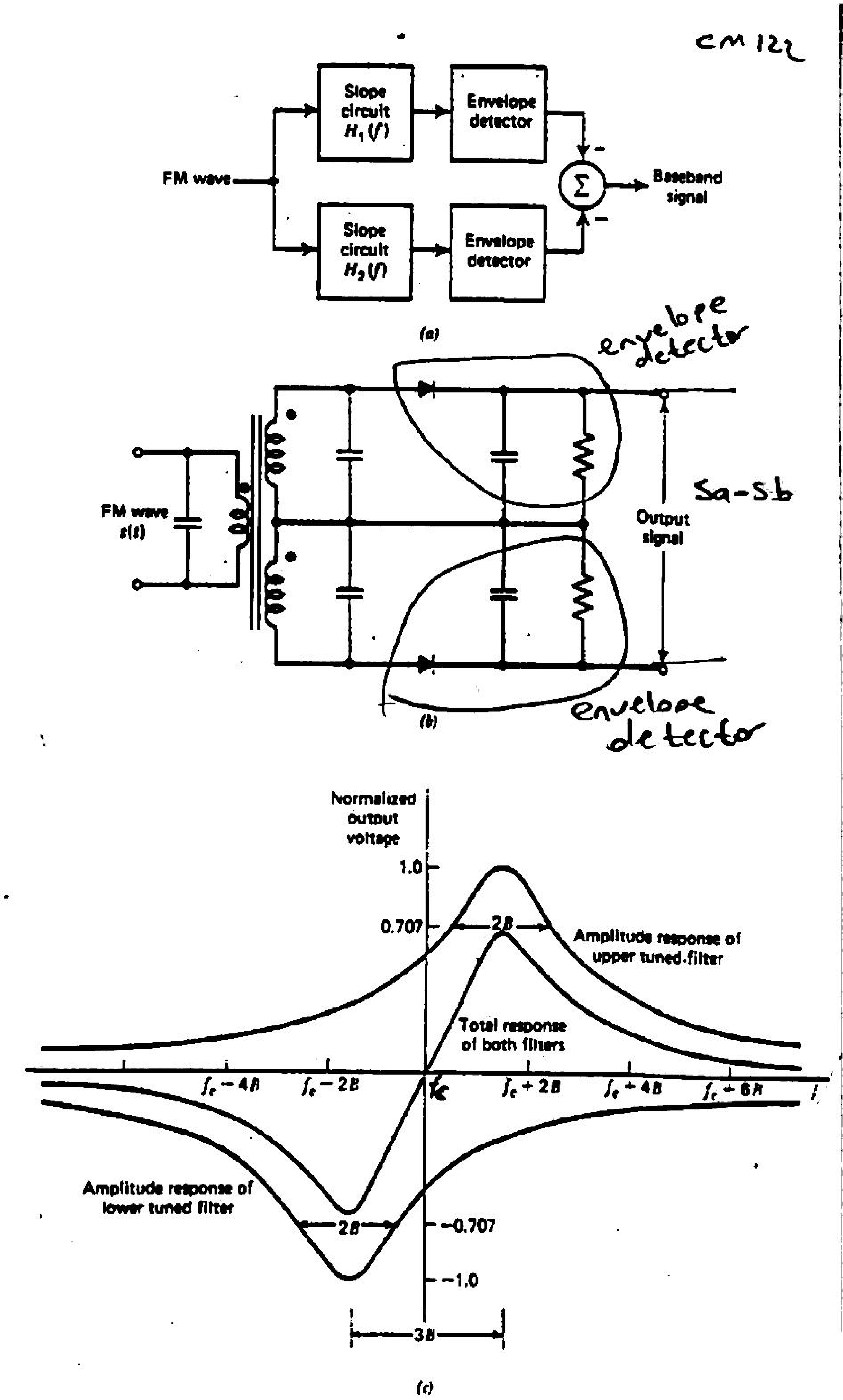
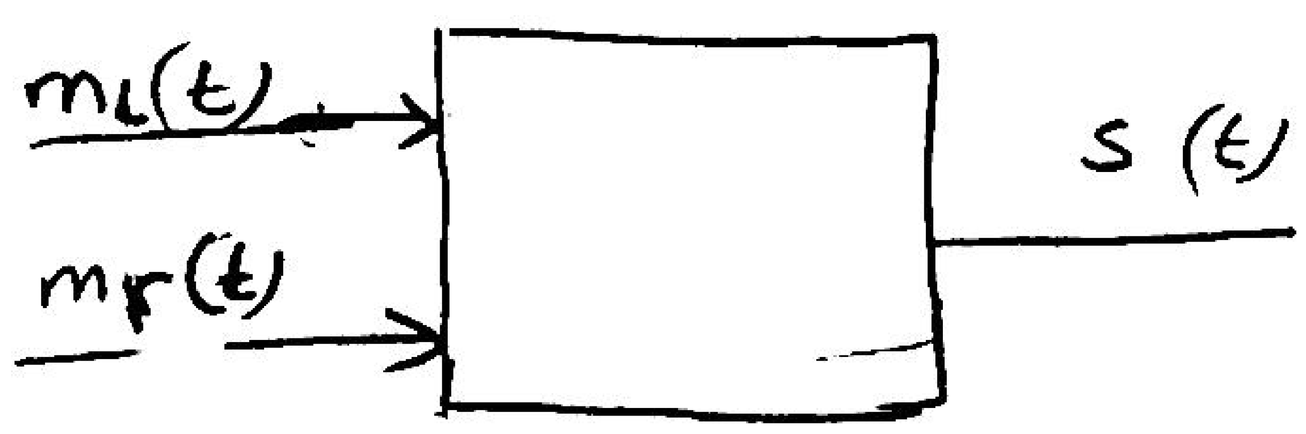
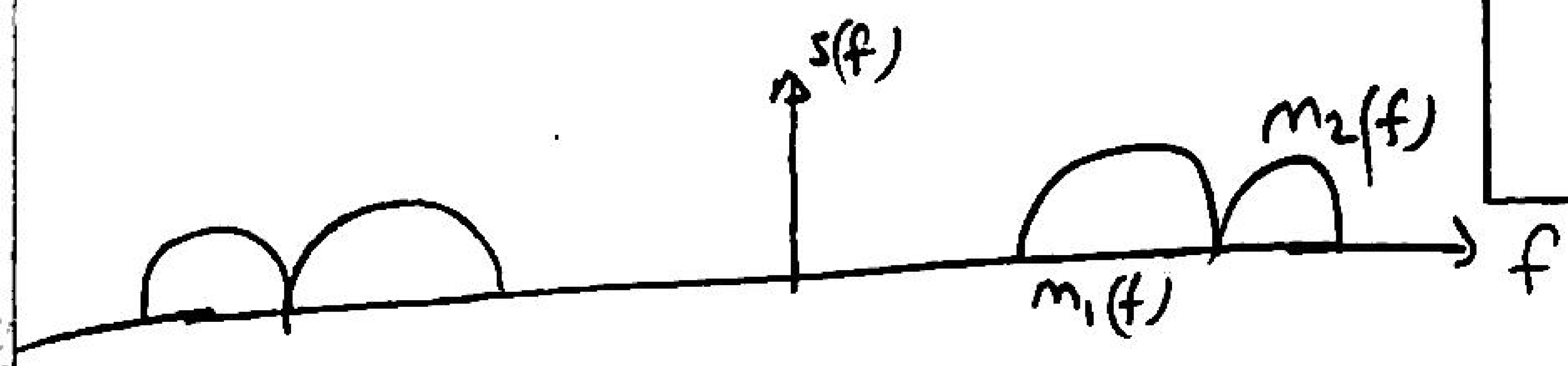


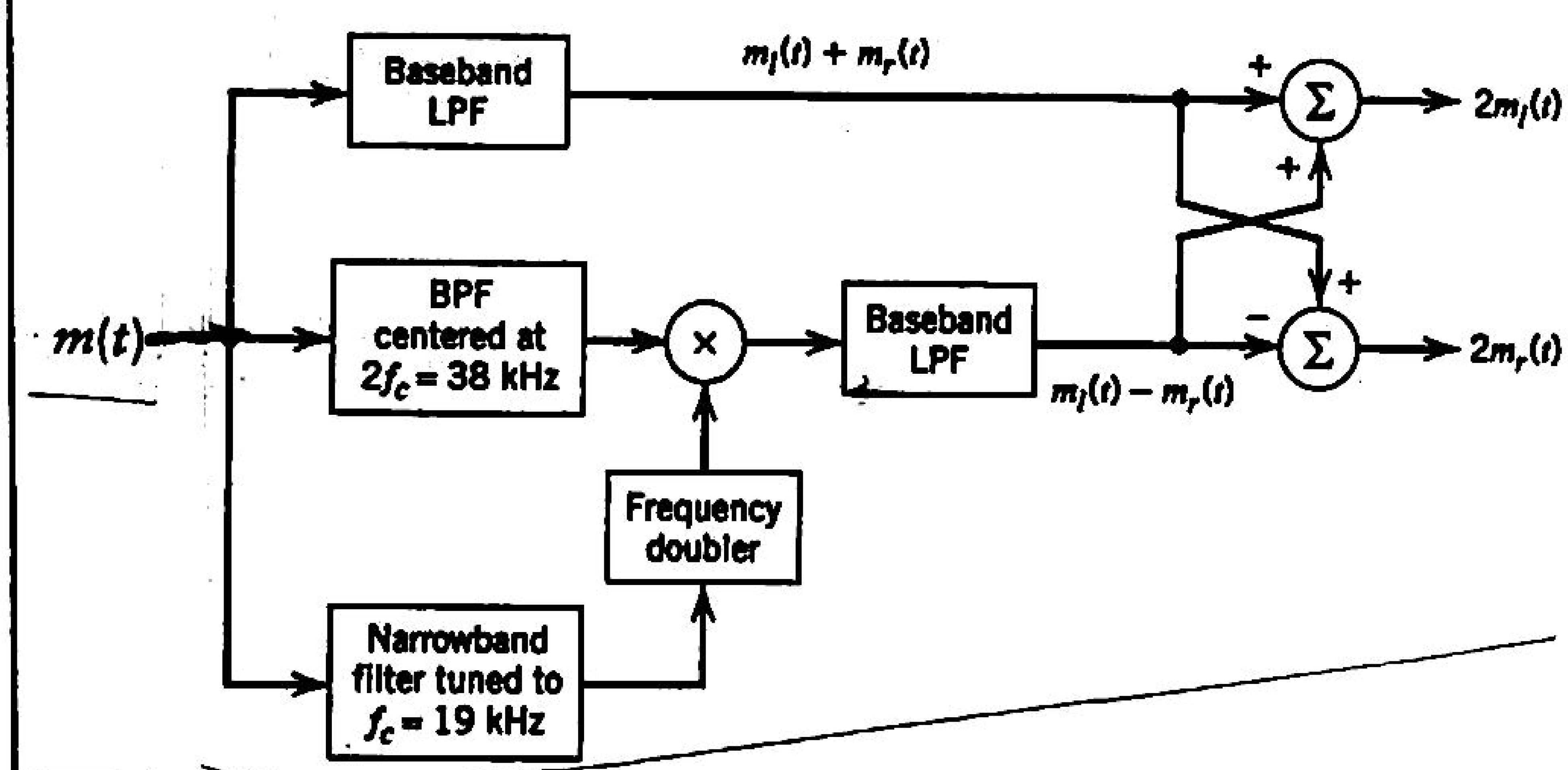
Figure 3.44 Balanced frequency discriminator. (a) Block diagram. (b) Circuit diagram. (c) Frequency response.

CM123

FM stereo multiplexing



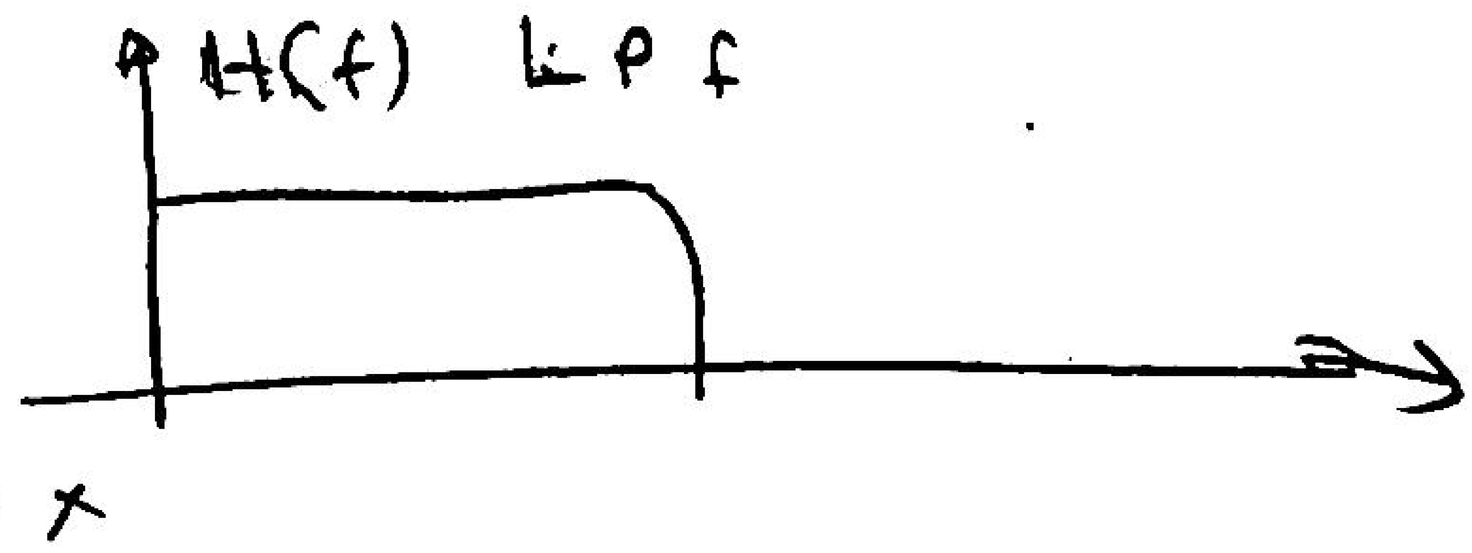




Demultiplexer in receiver of FM

LPF = low pass filter

BPF = band pass filter

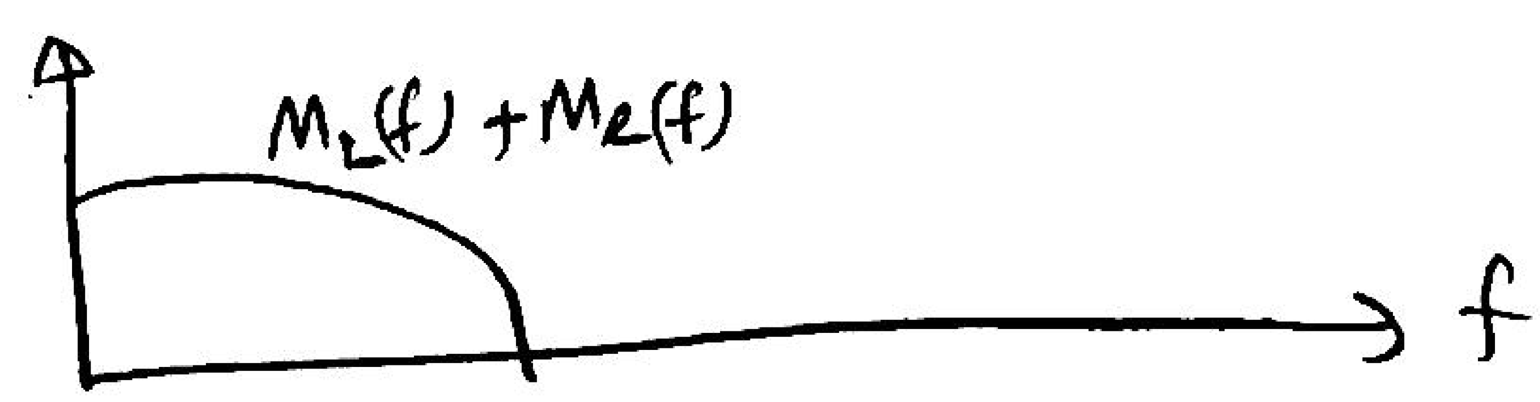


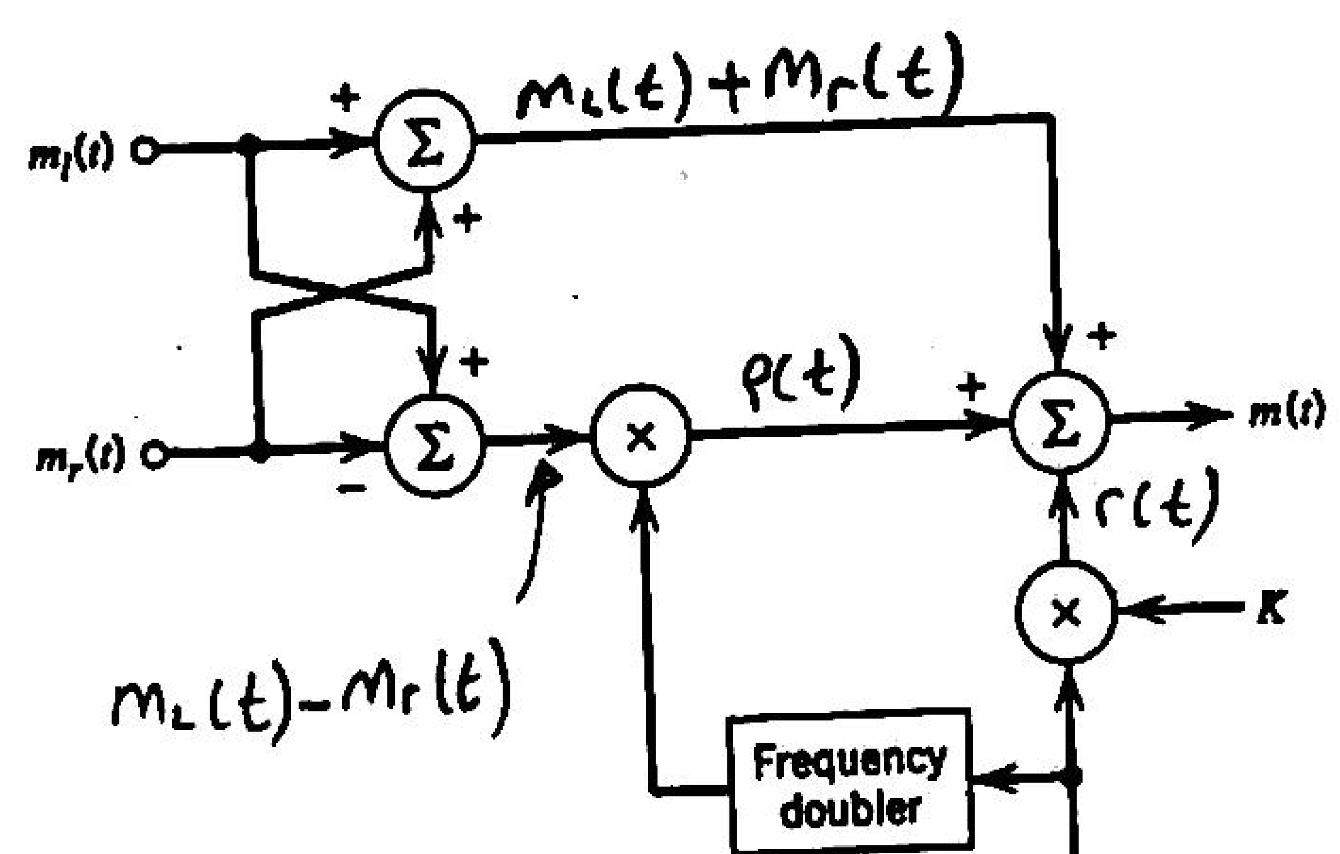
FM stereo transmitter standards

1) Total bandwidth must be in allocated FM channel

2) It must be compatible with non-stereo radio

non-stereo radios must be able to process the same signal



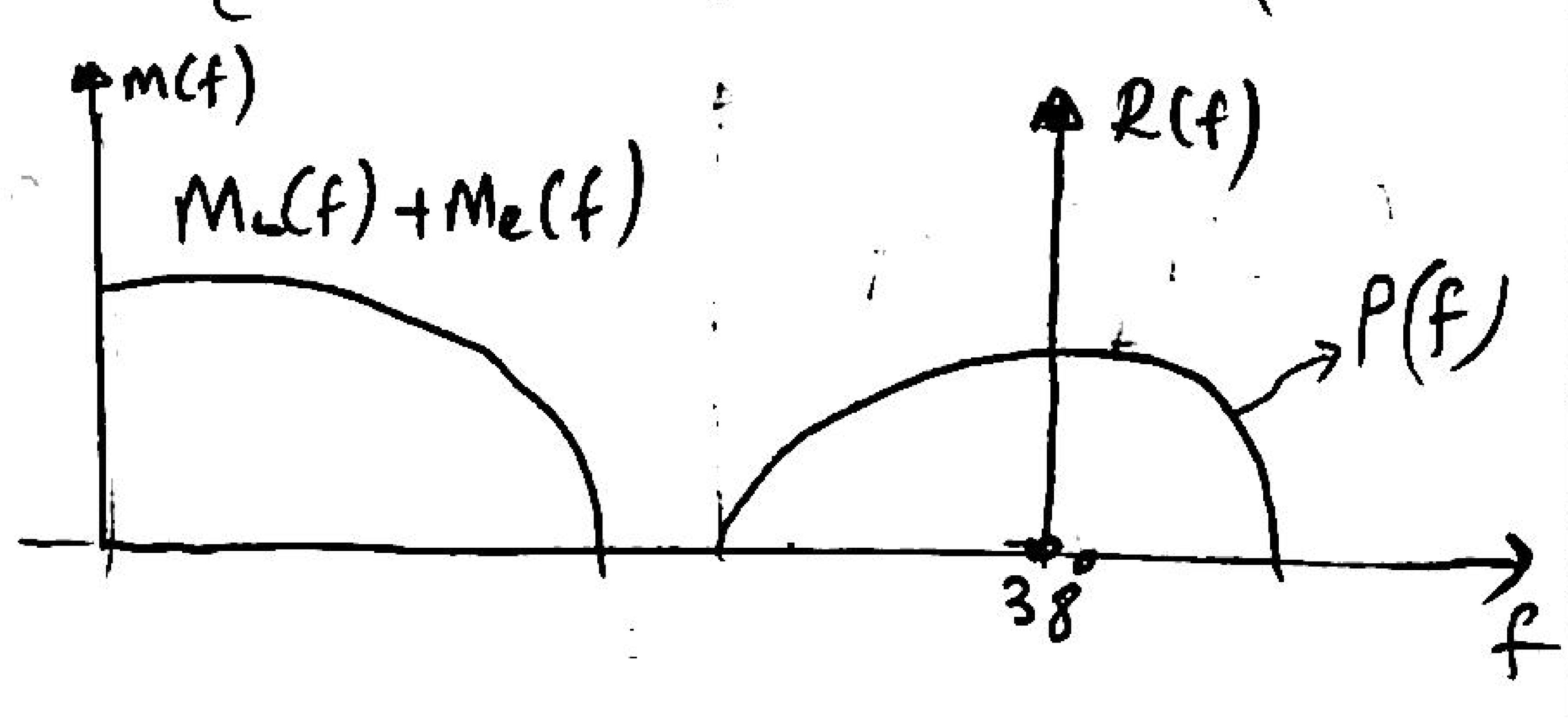


Multiplexer in transmitter of FM stereo

$$p(t) = \{M_L(t) - M_r(t)\} \cos\{2\pi (2f_c) t\}$$

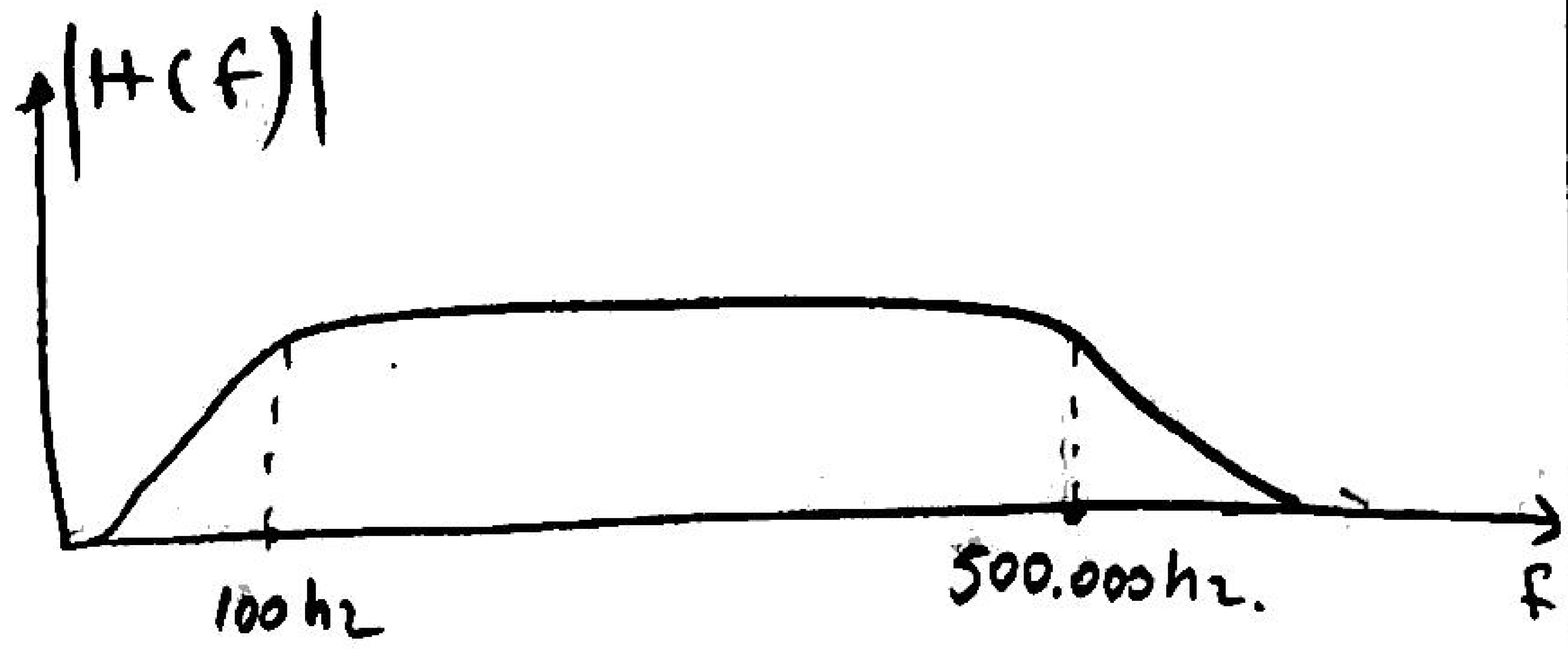
$$r(t) = K \cdot \cos 2\pi f_c(t)$$

$$m(t) = [m_L(t) + M_R(t)] + p(t) + r(t)$$



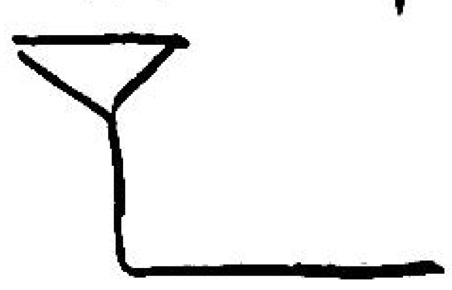
Superheterodyne Receiver

Reminder: A typical amplifier frequency response is shown



This amplifier cannot be used for $f > 500.000$ hz.

Antenna



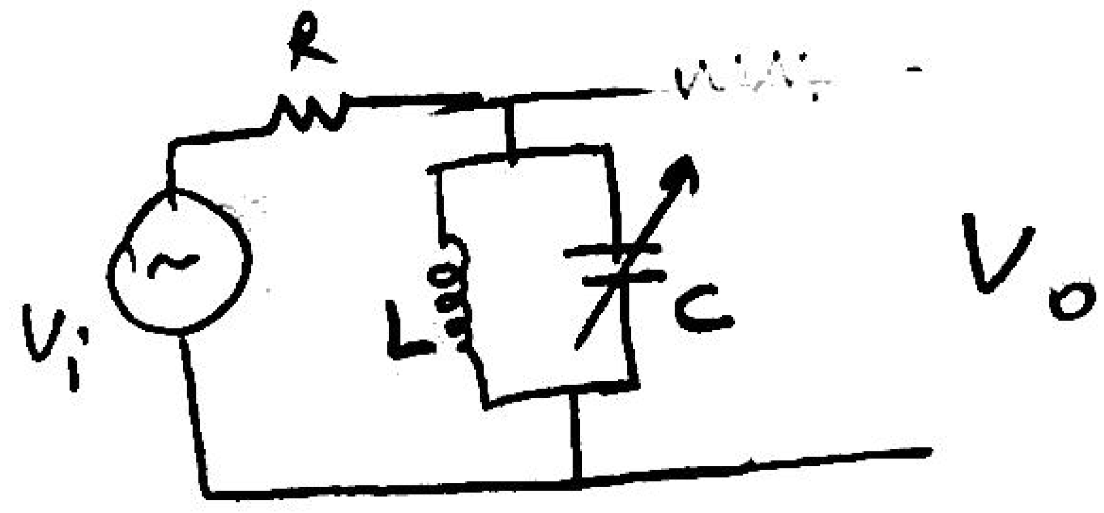
5 mHz – radio channel 1
10 mHz " " 2
15 mHz " " 10
88 – mHz " " 30
109 mHz " " 50

Signals at different frequencies comes from the antenna.

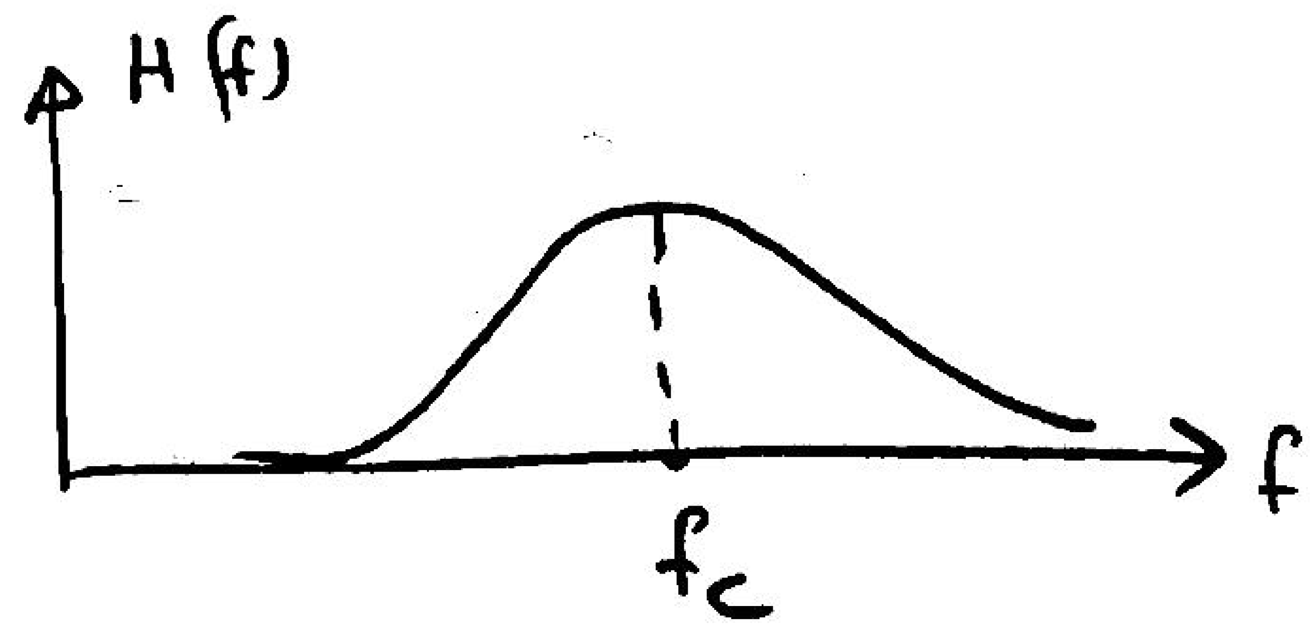
There is no amplifier for these range

1.6 mHz ——— 108 mHz.

RF section picks up the desired signal by a resonant circuit



$$H(f) = \frac{V_o(f)}{V_i(f)} = \frac{L}{L + R(1 - w^2 LC)}$$

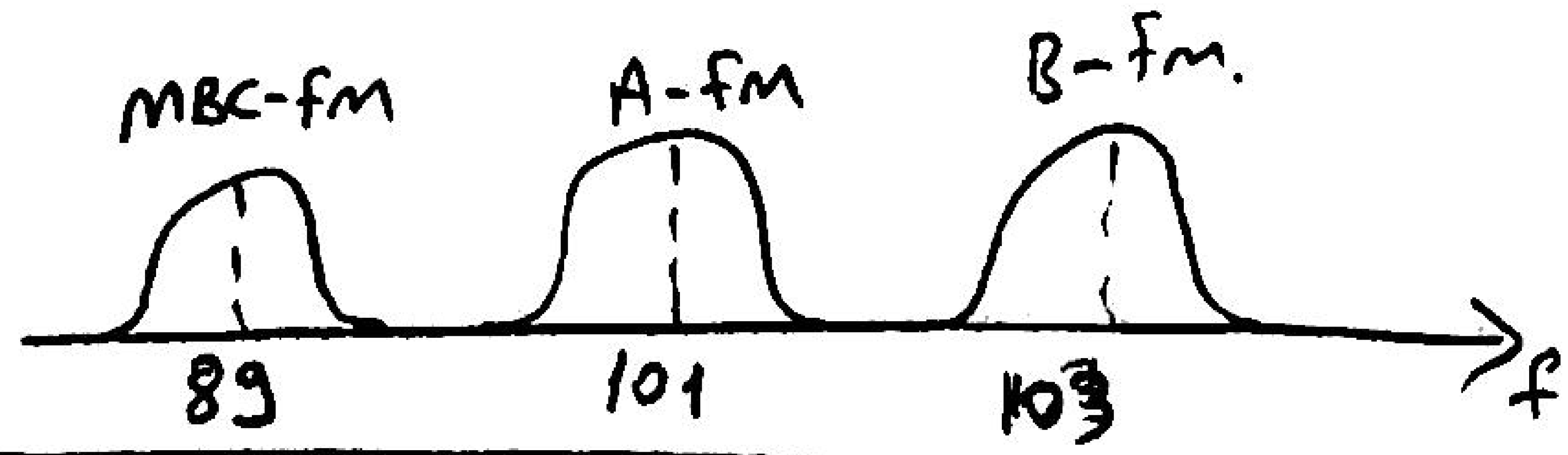


if $1 - w^2 LC = 0 \Rightarrow V_o(f) = V_i(f)$

$1 - w^2 LC = 0 \qquad w^2 = \frac{1}{LC}$

$$f_c = \frac{1}{2\pi\sqrt{LC}}$$

when we change capacitor we shift $H_i(f)$.



Solution: Superheterodyne receiver

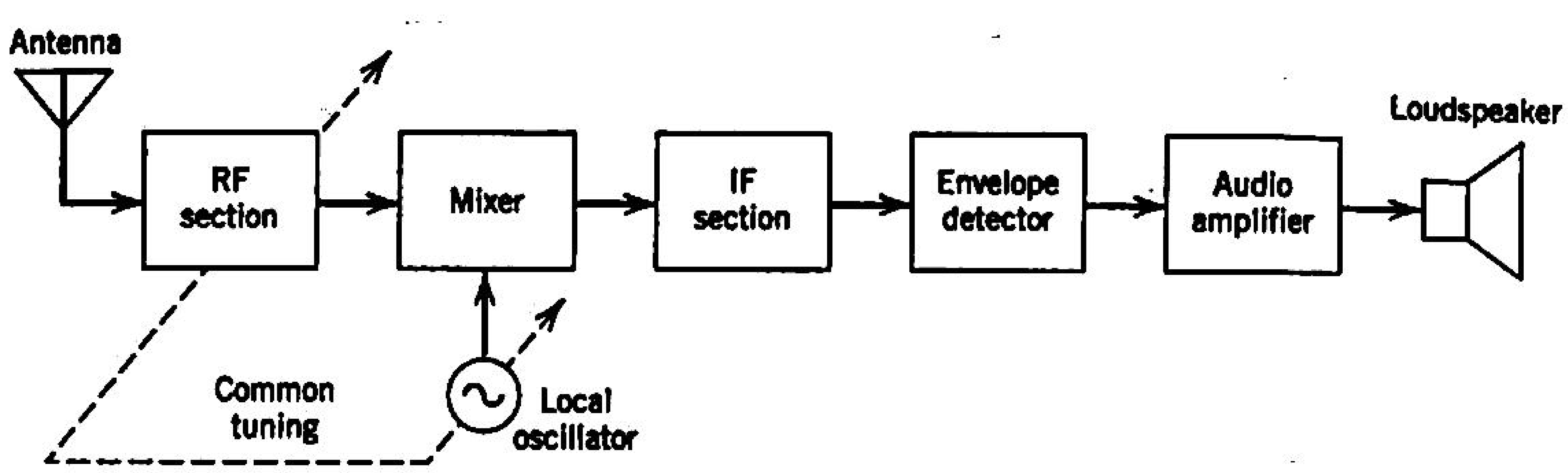
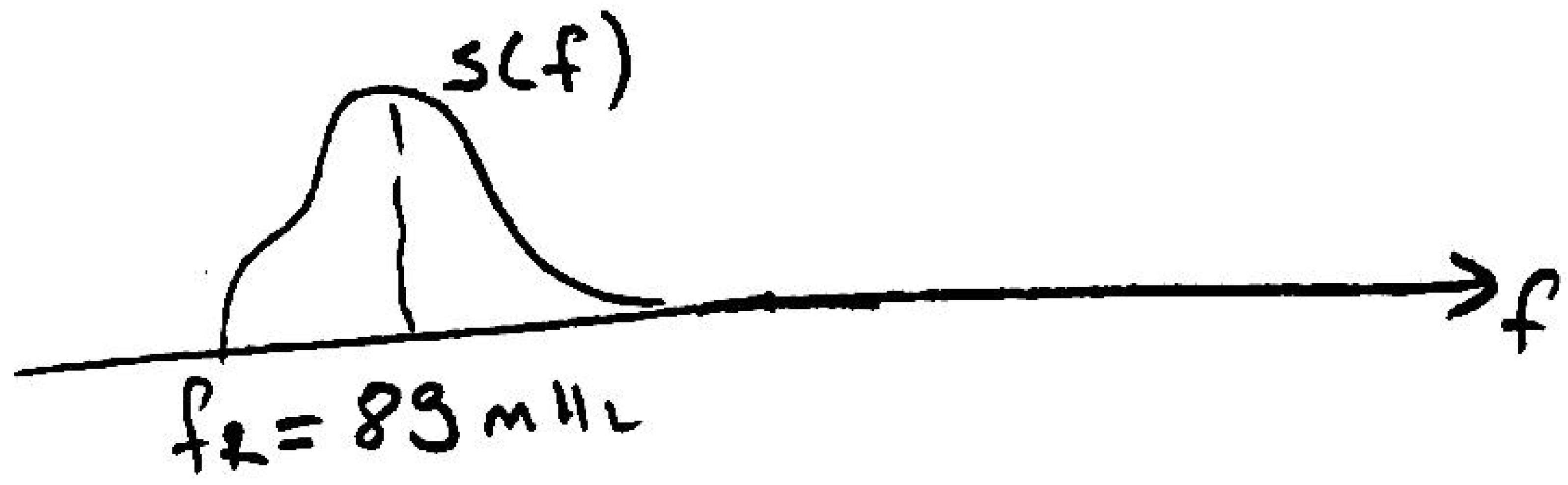
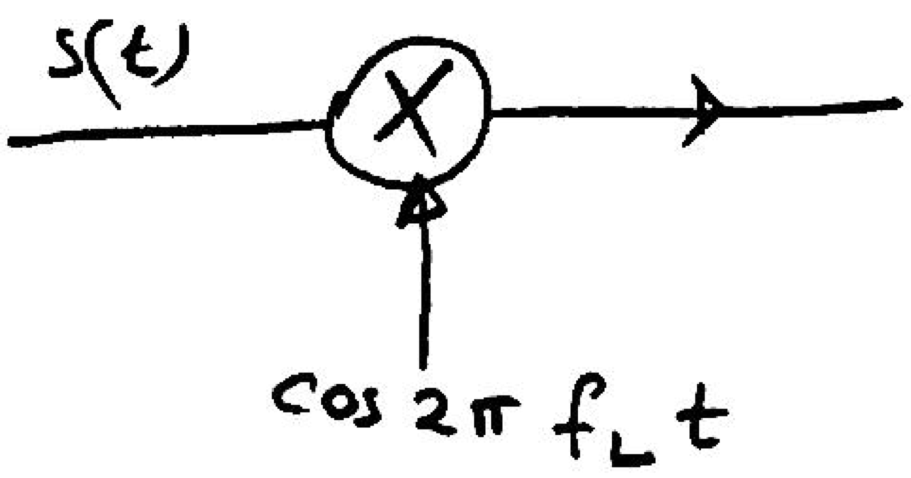
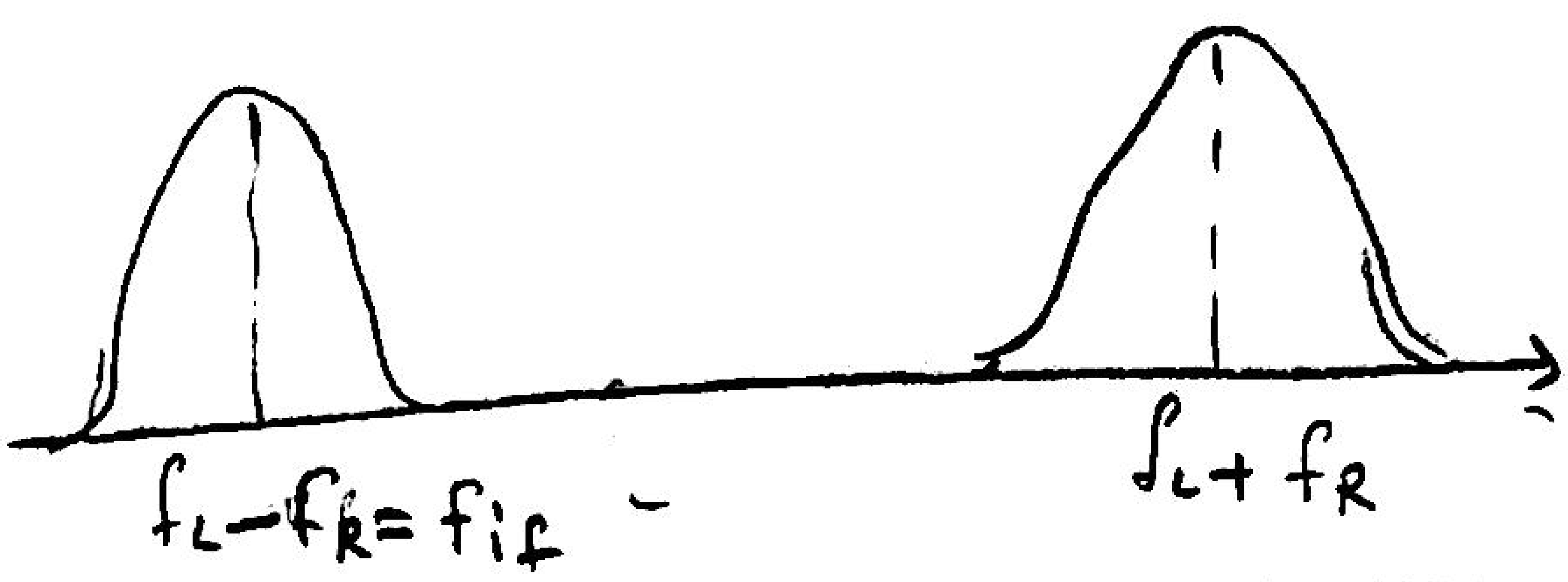


FIGURE 2.32 Basic elements of an AM radio receiver of the superheterodyne type.

After RF section we have







$f_{if} = \begin{cases} 10 \text{ MHz} & \text{for fm radios} \\ 0{,}5 \text{ MHz} & \text{for AM radios} \end{cases}$

Bandwidths $= \begin{cases} 200 \text{ kHz} & \text{for fm} \\ 10 \text{ kHz} & \text{" AM.} \end{cases}$

---

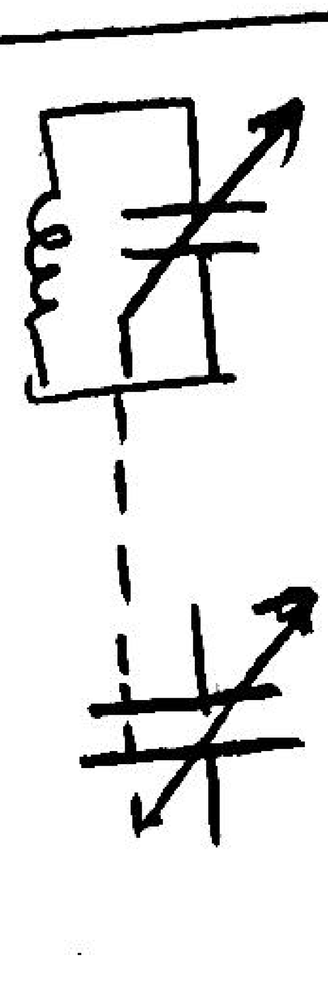
f_L changes so that

$f_L - f_R = f_{if}$ = constant always

$f_R = 88$ MHz $f_L = 78$ MHz

$f_{if} = 88 - 78 = 10$

$f_R = 106$ $f_L = 96$ $f_{if} = 10$



RF section resonant capacitor

Oscillator capacitor

two capacitors change simultaneously (at the same time)

Cm B2

Result = Incoming signal has any frequency.

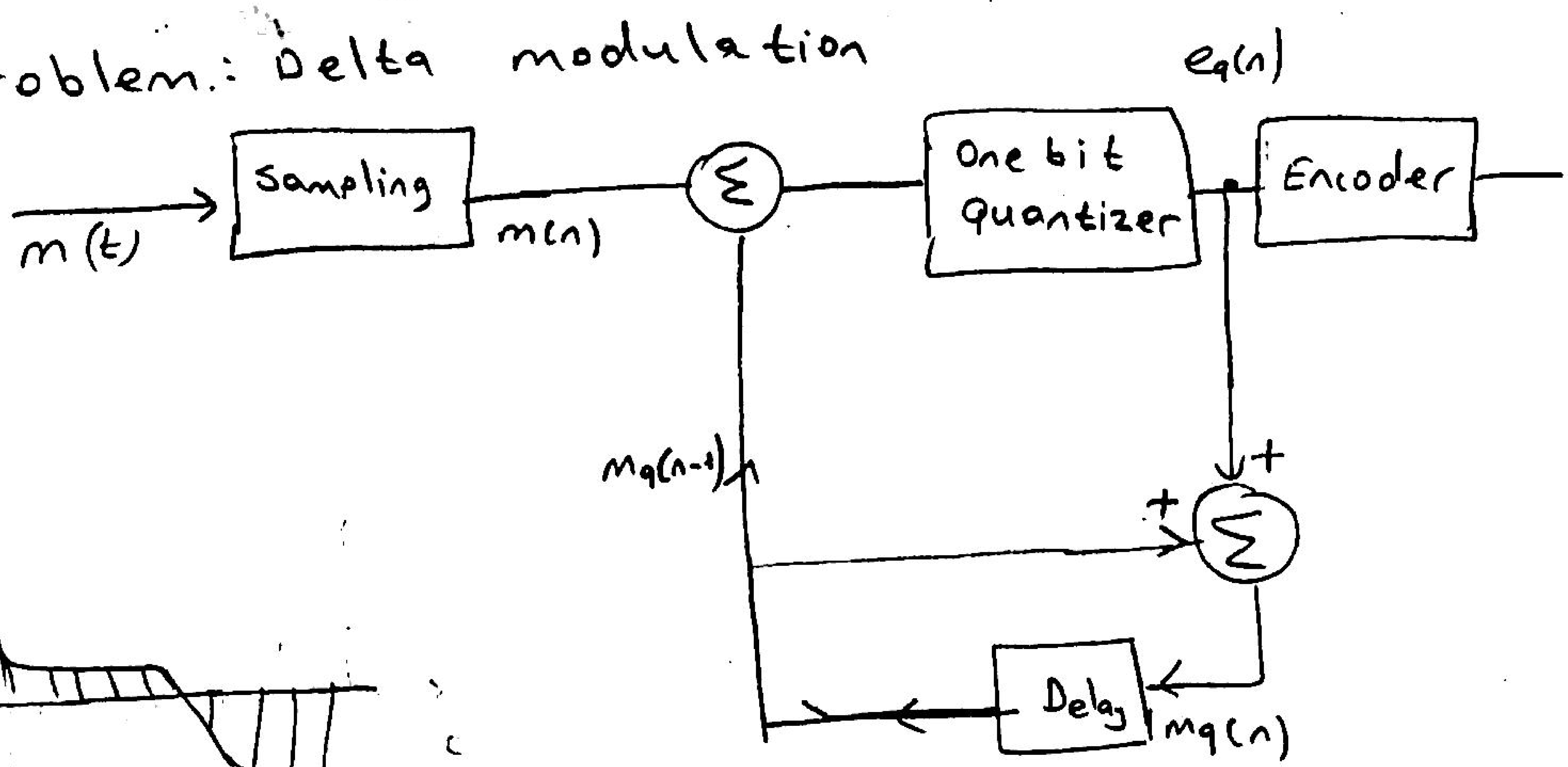
If section signal has constant frequencies

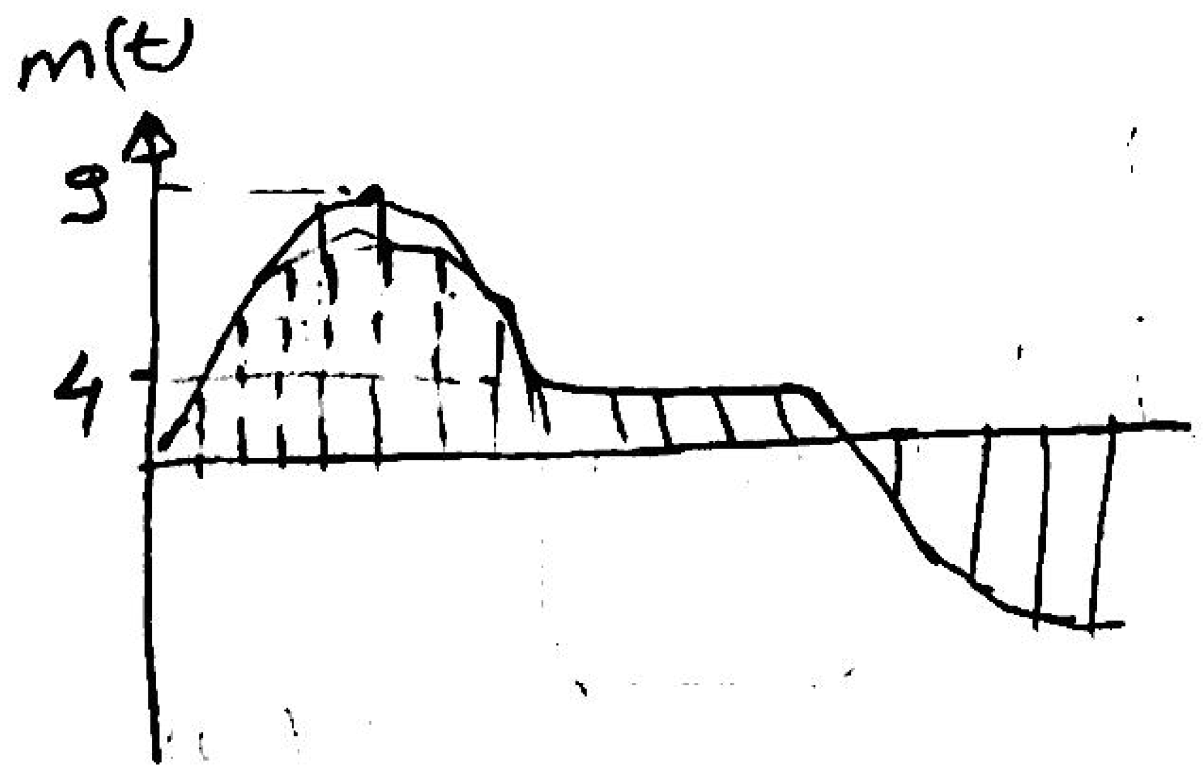
AM radios
If section may contain a simple amplifier

FM radios.
If section contains FM demodulator.

Output of envelope detector is the information signal.

Example problem: Delta modulation





n	$m(n)$	$e(n)$	$e_q(n)$	$m_q(n)$
1	2	2	1.5	1.5
2	4	2.5	1.5	3
3	6	3	1.5	4.5
4	7	2.5	1.5	6
5	8	2	1.5	7.5
6	9	1.5	1.5	9
7	7	-2	-1.5	7.5
8	4	-3.5	+1.5	6
9	4	-2	-1.5	4.5
10	4	-0.5	-1.5	3
11	4	+1	+1.5	4.5
12	4	-0.5	-1.5	3
13	4	1	+1.5	4.5
14	4	-0.5	-1.5	3
15	-2	-5	-1.5	-1.5
16	-3	-4.5	-1.5	0
17	-4	-5.5	-1.5	-1.5

$\Delta = 1.5$

assume $m_q(0) = 0$

$e(n) = m(n) - m_q(n-1)$

$e_q(n) = \Delta \quad \mathrm{sgn}(e(n))$

$m_q(n) = m_q(n-1) + e_q(n)$

$e(1) = m(1) - 0 = 2 - 0 = 2$

$e_q(1) = \Delta \cdot (+) = +\Delta = 1.5$

$m_q(1) = m_q(0) + \Delta = \Delta = 1.5$

$e(2) = m(2) - m_q(1) = 4 - 1.5 = 2.5$

$e_q(2) = \Delta \cdot (+) = 1.5$

$m_q(2) = m_q(1) + \Delta = 3$

$e(3) = m(3) - m_q(2) = 6 - 3 = 3$

$e_q(3) = \Delta \cdot (+) = 1.5$

$m_q(3) = m_q(2) + \Delta = 3 + 1.5 = 4.5$

$e(4) = m(4) - m_q(3) = 7 - 4.5$

Carrier: Taşıyıcı İşaret:
Information signal: Bilgi (mesaj işareti)
Amplitude: Genlik.
Carrier amplitude: Taşıyıcının Genliği
Frequency: Frekans.
Amplitude Modulation: Genlik Modulasyonu
Modulated Signal: Module edilmiş işaret
Constant:Sabit.
Bandwidth: Bant Genişliği
Baseband Signal: Temel işsret.
Message Bandwidth: Mesaj işaretinin bant genişliği.
Transmission Bandwidth: İletim hattındaki işaretinin işgal ettiği bant genişliği.
Continuous wave:Sürekli Dalga.
Communication Channel: Haberleşme kanalı.
Speech: Konuşma.
Long Wave: Uzun Dalga.
Satelite: Uydu
Mobile Telephone: Cep Telefonu.
Acceptable: Kabul edilebilir.
Transmit: İletmek
Low pass filter: Alçak geçiren filtre
High pass filter: Yüksek geçiren filtre
Band pass filter: Bant geçiren filtre
Band stop filter: Bant Sönduren filtre
Envelope Detector: Zarf Detektörü
Transmitter: Verıcı
Receiver: Alıcı