BAB I
PENGANTAR ke SISTEM KOMUNIKASI 1

1.1 Sistem Komunikasi

- *Komunikasi : Penyampaian informasi atau penyaluran informasi dari satu tempat ke tempat yang lain*
- *Sistem : Sekumpulan elemen yang dikelompokkan dalam suatu kesatuan yang bekerja sama untuk mencapai satu tujuan tertentu*
- *Sistem komunikasi : Suatu sistem yang bertujuan untuk menyampaikan atau menyalurkan informasi dari satu tempat ke tempat lain*

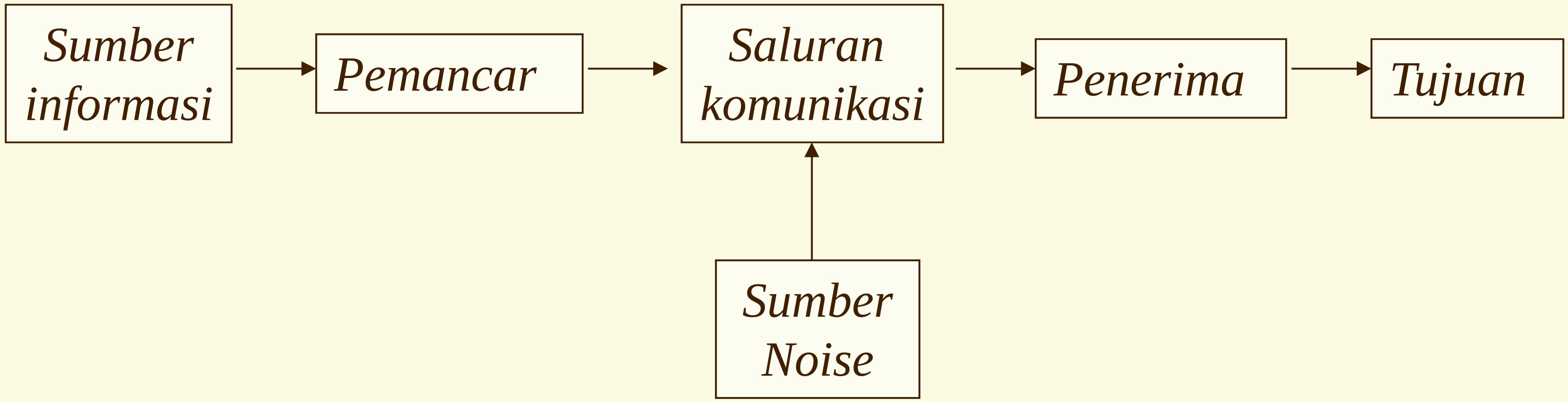
1.1.1 Macam-macam informasi

- *Suara, tulisan, gambar, data dan lain sebagainya*

1.1.2 Elemen dasar sistem komunikasi

- *Pemancar : Menghubungkan sinyal informasi dengan saluran komunikasi (media transmisi)*
- *Saluran komunikasi : Menghubungkan pemancar dengan penerima*
- *Penerima : Menerima informasi yang dikirim melalui saluran komunikasi*

1.1.3 Blok diagram sistem komunikasi



- Sumber informasi : diklarifikasikan dalam dua katagori yaitu analog (continous value) dan diskrit

- Pemancar : digunakan untuk mengubah pesan menjadi sinyal yang cocok untuk saluran komunikasi, jika pesan yang berasal dari sumber informasi tidak bersifat listrik, maka tidak bisa langsung dikirimkan

- Saluran komunikasi dan noise : saluran komunikasi ini dapat berupa udara, kabel, serat optik, wave guide dan sebagainya. Sedangkan noise merupakan gangguan dengan klasifikasi sebagai berikut : Internal noise dan External noise

- Penerima : menerima dan mendapatkan kembali sinyal termodulasi yang dipancarkan oleh pemancar setelah mengalami degradasi selama merambat dalam saluran komunikasi.

1.2 Pengantar modulasi dan macam-macamnya

1.2.1 Modulasi

- Suatu proses untuk merubah parameter gelombang pembawa (carrier) sebagai fungsi dari sinyal informasi

- Parameter gelombang pembawa :

- Amplitudo : modulasi amplitudo (AM)

- Frekuensi : modulasi frekuensi (FM)

- Phase : modulasi phase (PM)

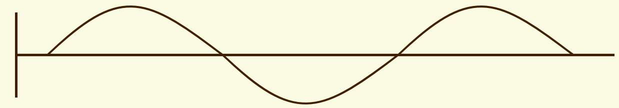
- Teknik modulasi : modulasi gelombang kontinyu dan modulasi pulsa

- Kegunaan modulasi : memudahkan radiasi, multiplexing, mengatasi keterbatasan peralatan, pembagian frekuensi dan mengurangi noise dan interferensi

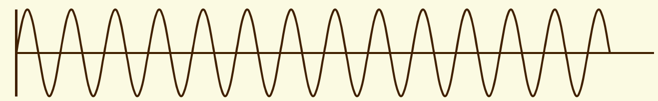
1.2.2 Macam-macam sistem modulasi

- Modulasi analog

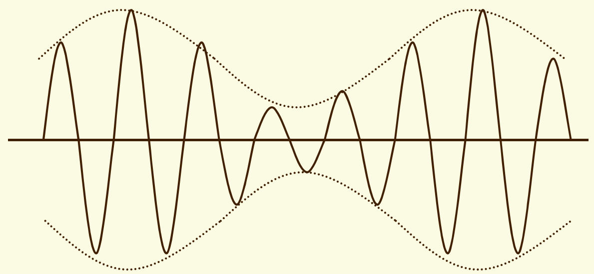
Sinyal pemodulasi



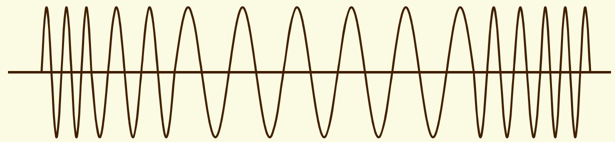
Sinyal termodulasi



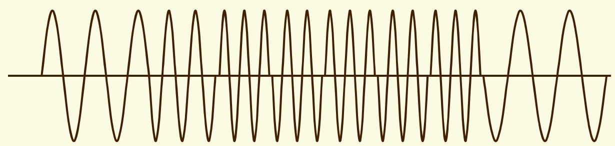
1. Modulasi amplitudo



2. Modulasi frekuensi



3. Modulasi phase



- Modulasi digital

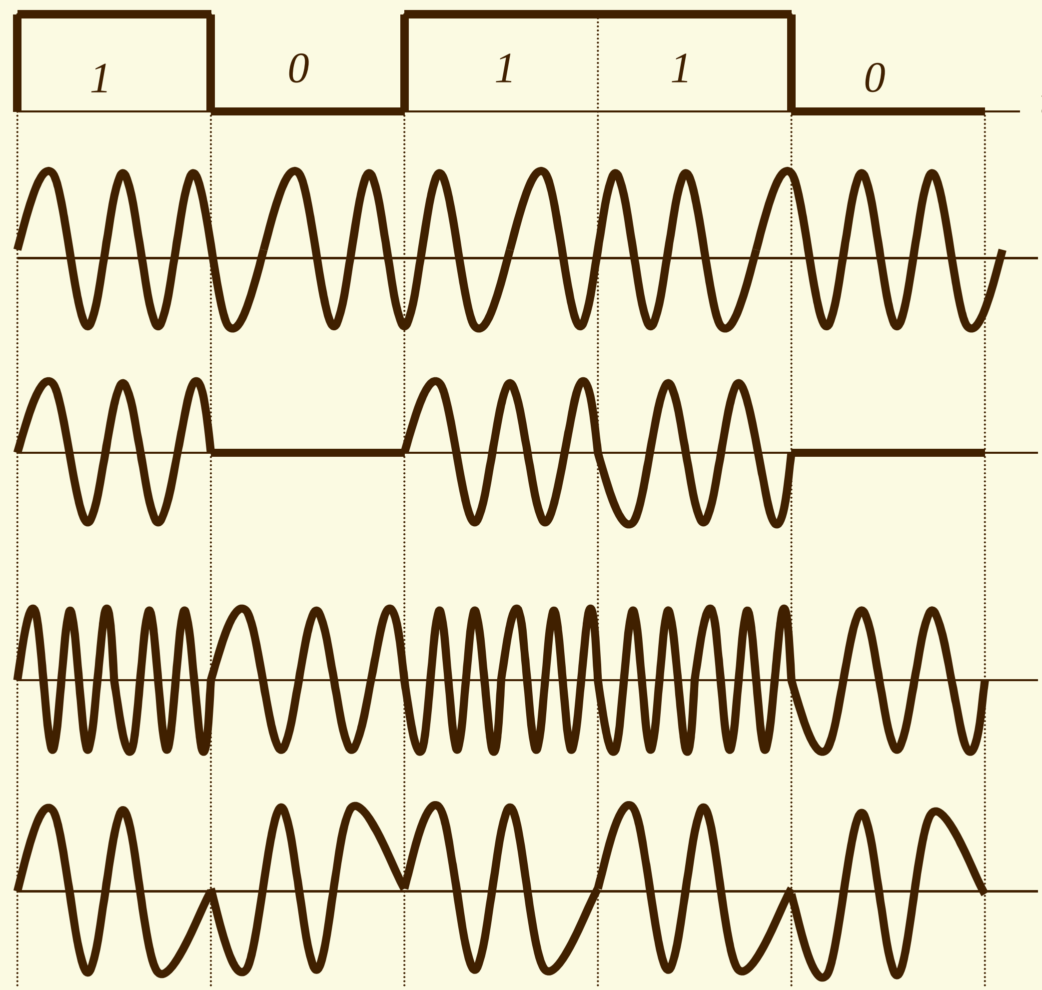
Sinyal pemodulasi

Sinyal termodulasi

1. Amplitudo shift keying

2. Frekuensi shift keying

3. Phase shift keying



BAB II
SISTEM MODULASI ANALOG

2.1 Pengertian modulasi analog

2.1.1 Gelombang pembawa (carrier) merupakan gelombang analog (kontinyu)

2.1.2 Parameter gelombang pembawa berupa :

- *Amplitudo : modulasi amplitudo (AM)*
- *Frekuensi : modulasi frekuensi (FM)*
- *Phase : modulasi phase (PM)*

2.2 Modulasi amplitudo

2.2.1 Sistem DSB-FC (Double Side Band Full Carrier)

- *Banyak digunakan dalam sistem siaran AM (amplitudo modulation)*
- *Menempati daerah frekuensi medium ataupun gelombang pendek (SW)*
- *Mempunyai persamaan gelombang sebagai berikut :*

a. Persamaan gelombang DSB-FC (AM)

$$e(t) = A(t) \cos \omega_c t \qquad \text{..............(2.1)}$$

dimana,

$A(t)$ = *amplitudo yang berubah-ubah sebagai fungsi waktu*

$\omega_c = 2\pi f_c$ = *frekuensi sudut*

f_c = *frekuensi gelombang pembawa (carrier frequency)*

b. Persamaan gelombang pembawa

$e_c(t) = E_c \cos \omega_c t \quad E_c$ = amplitudo

atau, $\omega_c = 2\pi f_c$

$e_c(t) = E_c \sin \omega_c t$

c. Persamaan gelombang pemodulasi (informasi)

$e_s(t) = E_s \cos \omega_s t$

E_s = amplitudo

$\omega_s = 2\pi f_s$ = frekuensi sudut

d. Setelah mengalami proses modulasi amplitudo

$A(t) = E_c + e_s(t)$

$= E_c + E_s \cos \omega_s t$

bila, index modulasi (m) = E_s/E_c -------> syarat : $0 < m \leq 1$

maka,

$A(t) = E_c + mE_c \cos \omega_s t$

$= E_c (1 + m \cos \omega_s t)$

e. Persamaan gelombang bermodulasi amplitudo

$$
\begin{aligned}
e_{AM} &= A(t)\,.\cos \omega_c t \\
&= E_c\,(1 + m\cos \omega_s t)\cos \omega_c t \\
&= E_c \cos \omega_c t + m\,E_c \cos \omega_s t \cos \omega_c t \\
&= E_c \cos \omega_c t + \frac{m\,E_c}{2}(\omega_c + \omega_s)t + \frac{m\,E_c}{2}(\omega_c - \omega_s)t
\end{aligned}
$$

Persamaan diatas mempunyai tiga komponen, yaitu

1. $E_c \cos \omega_c t$: *Gelombang pembawa*
2. $\frac{m\,E_c}{2}(\omega_c + \omega_s)t$: *Upper sideband*
3. $\frac{m\,E_c}{2}(\omega_c - \omega_s)t$: *Lower sideband*

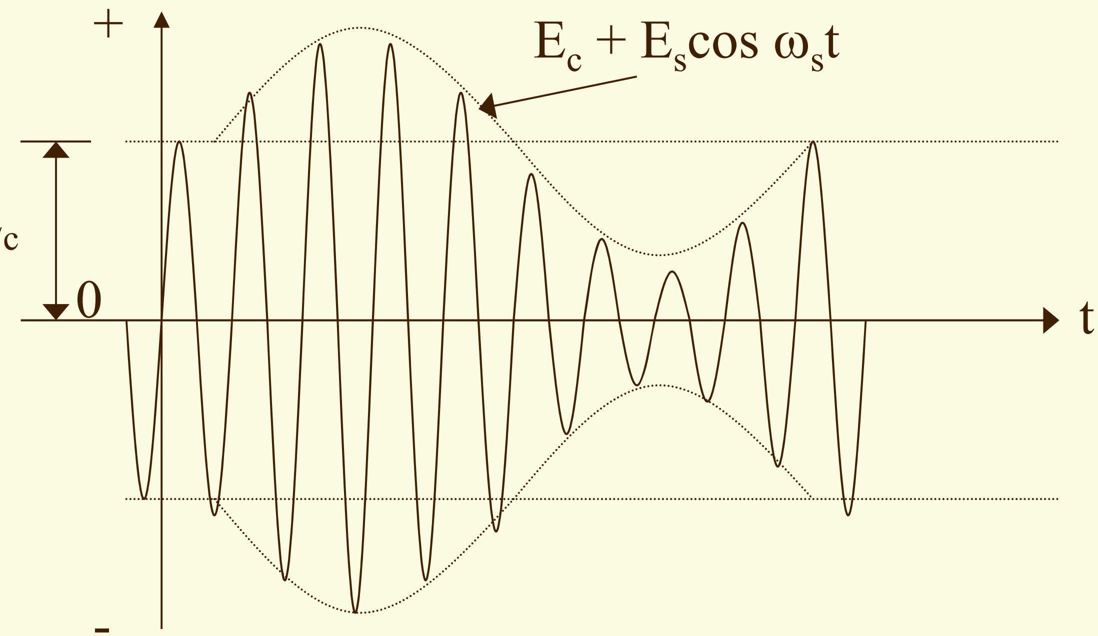
f. Bentuk gelombang DSB-FC

** Terdiri dari : - gelombang pembawa (carrier)*

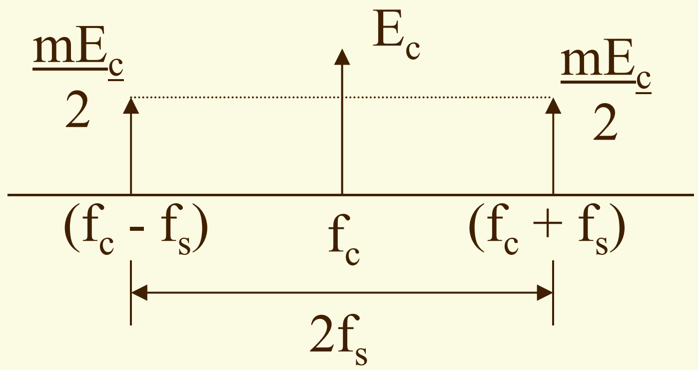
- gelombang USB

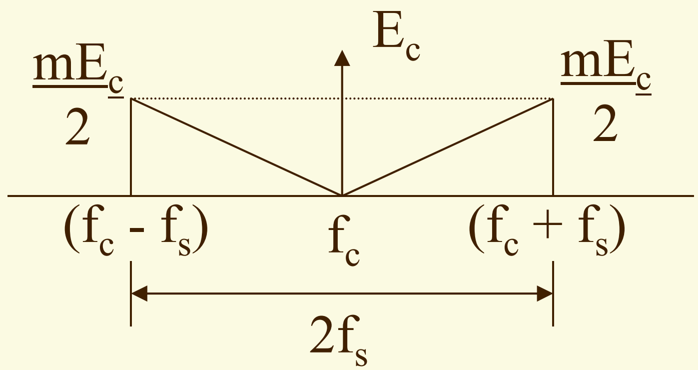
- gelombang LSB

** Bentuk :*



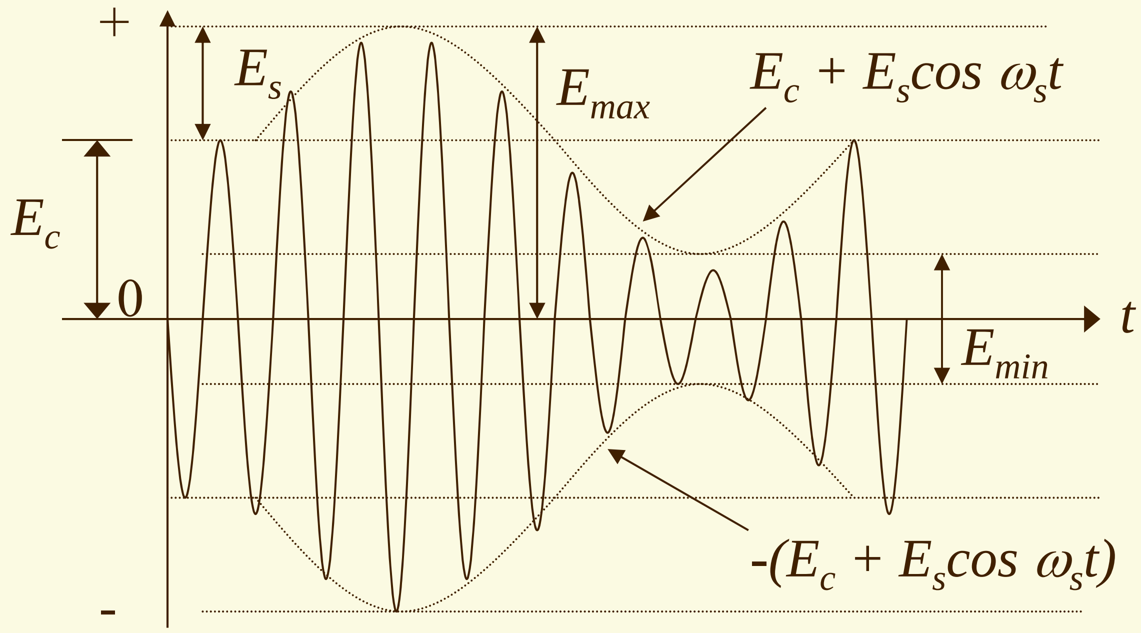
g. Spektrum frekuensi





Bandwidth : B = 2 x f_s

h. Index Modulasi



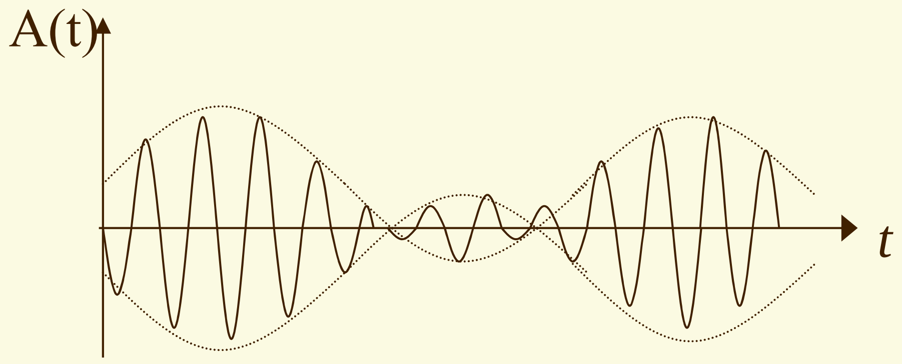
$$m = \frac{E_s}{E_c}$$

$$E_s = \frac{E_{max} - E_{min}}{2}$$

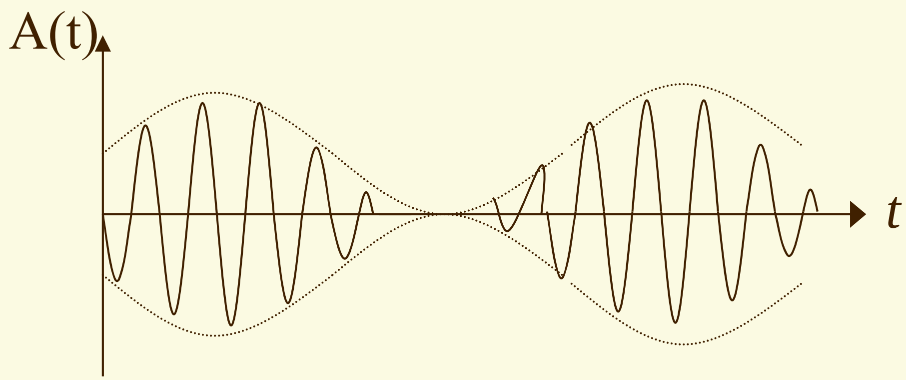
$$E_c = \frac{E_{max} + E_{min}}{2}$$

$$m = \frac{E_{max} - E_{min}}{E_{max} + E_{min}}$$

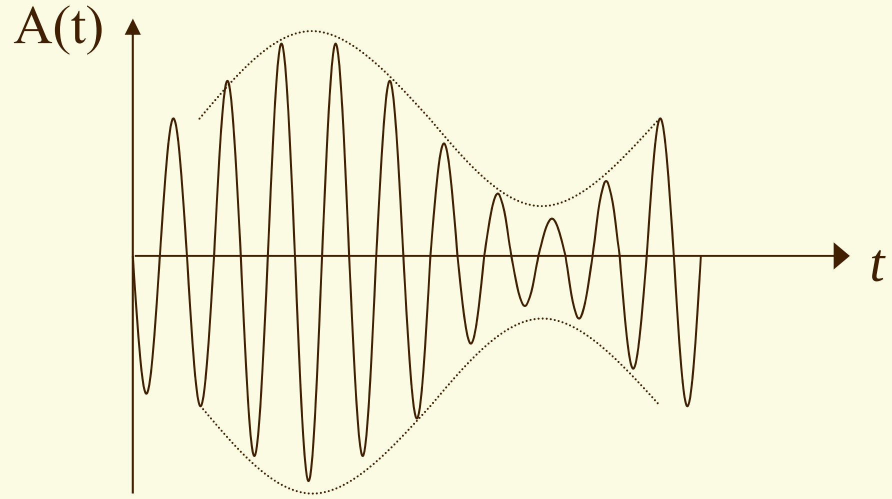
** m > 1*　　　　　*(Over modulasi)*



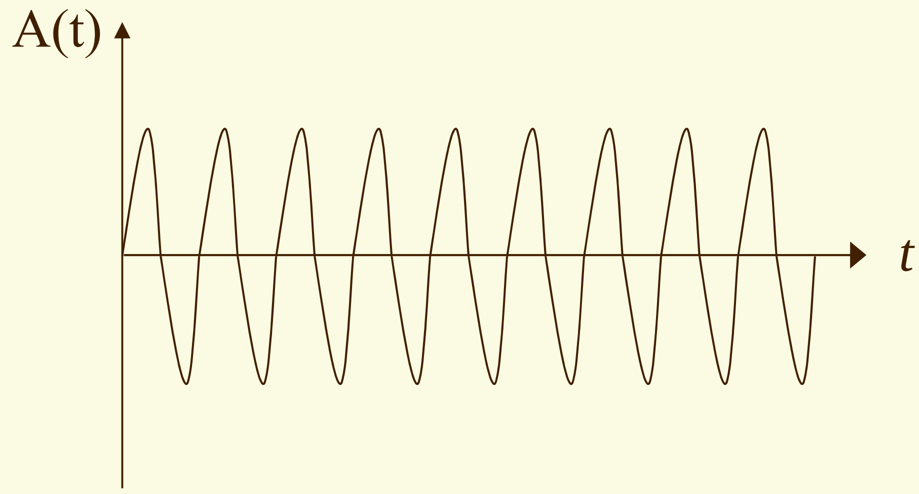
** m=1*　　　　　*100%*



* $m<1$

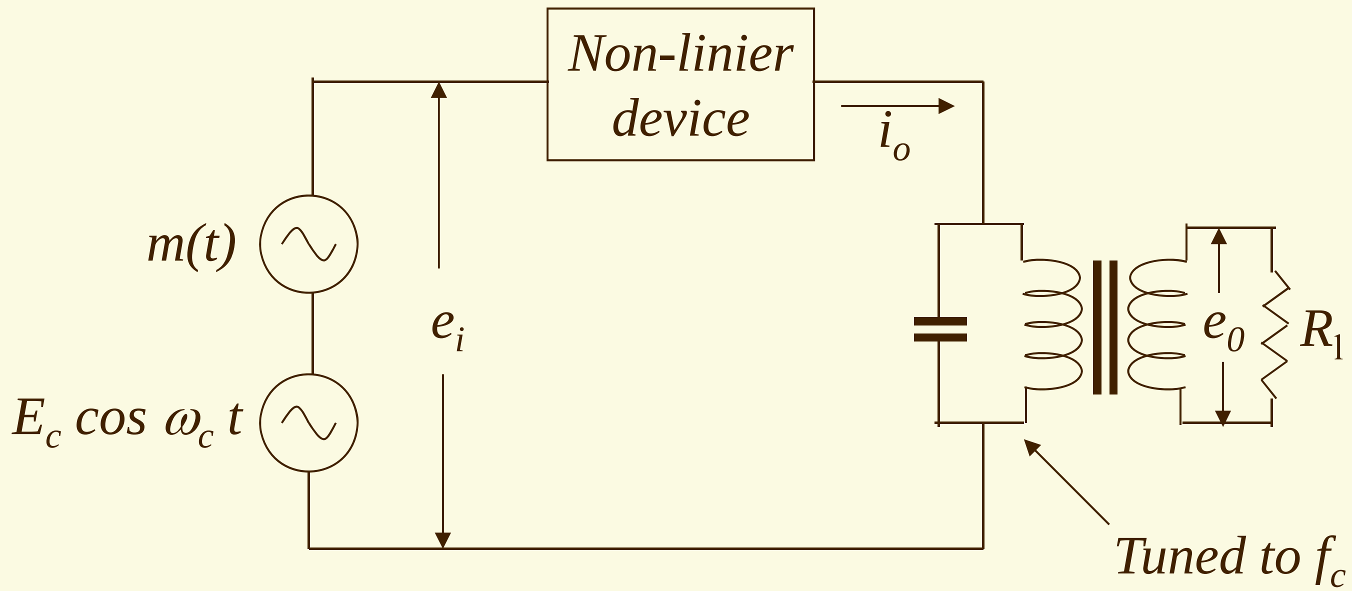


* $m = 0$ 0%

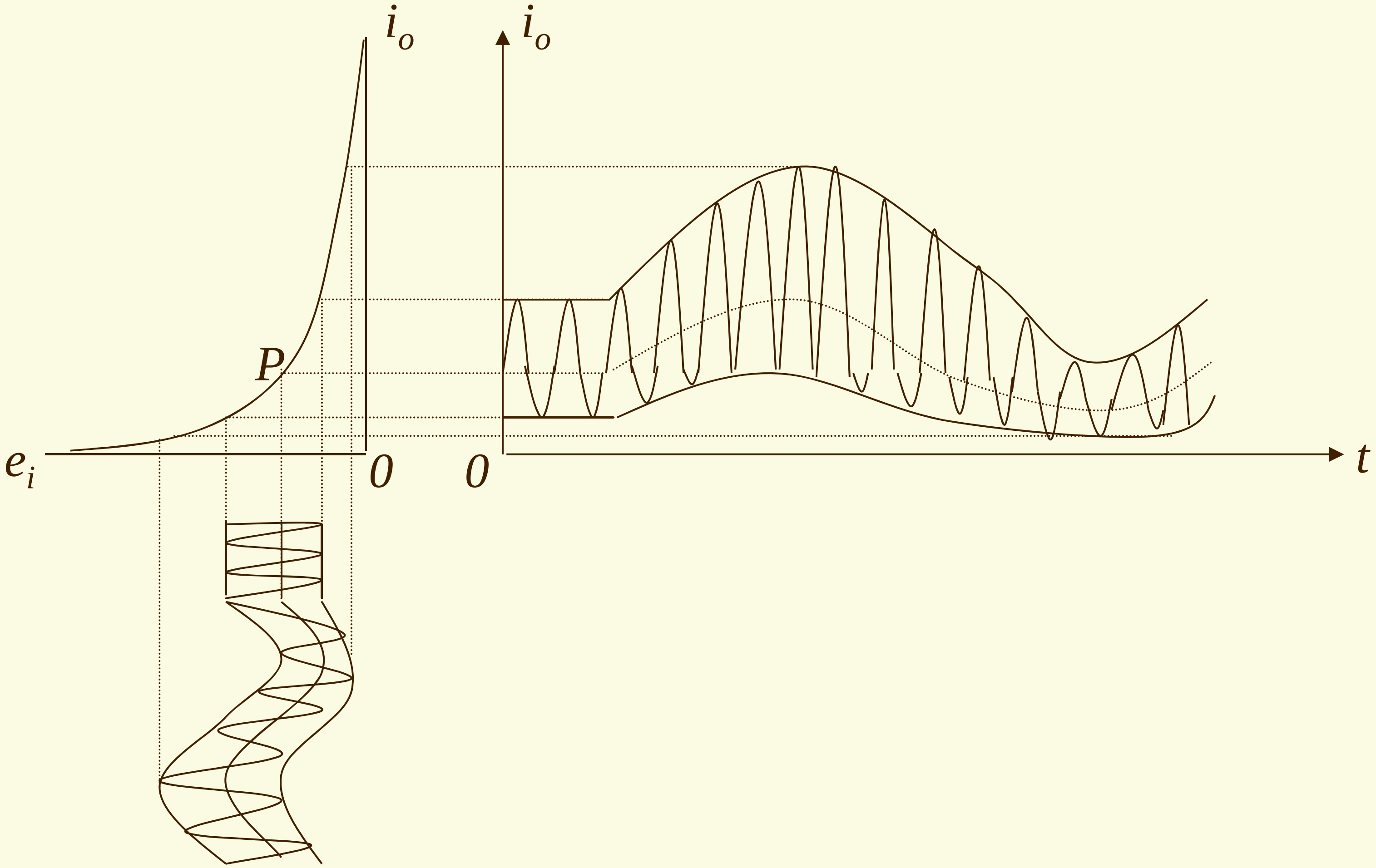


i. Teknik pembangkitan DSB-FC (AM)

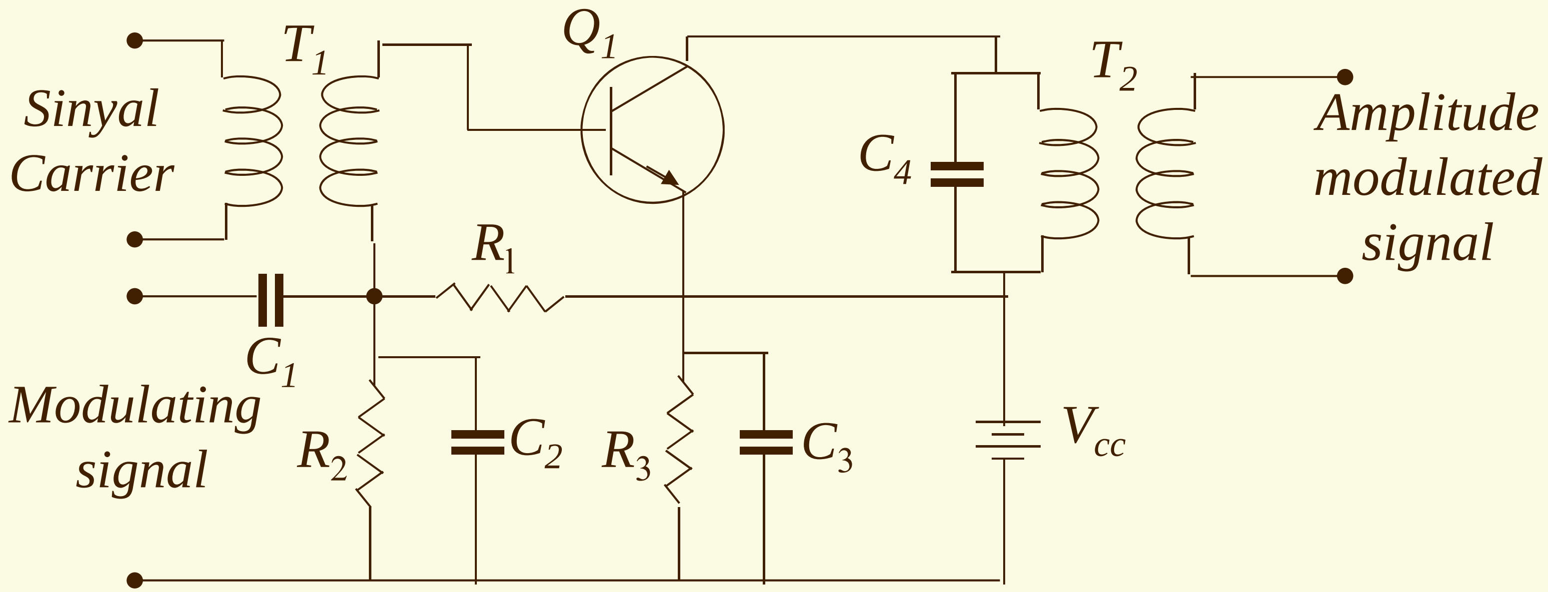
** Modulator non-linier*



- Karakteristik non-linier device

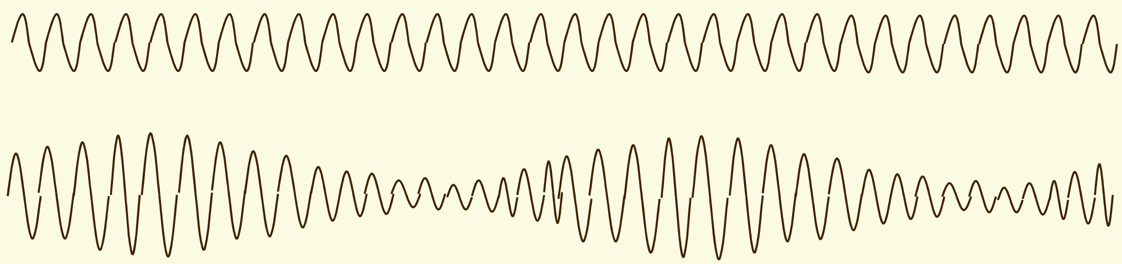


- Rangkaian modulator non-linier

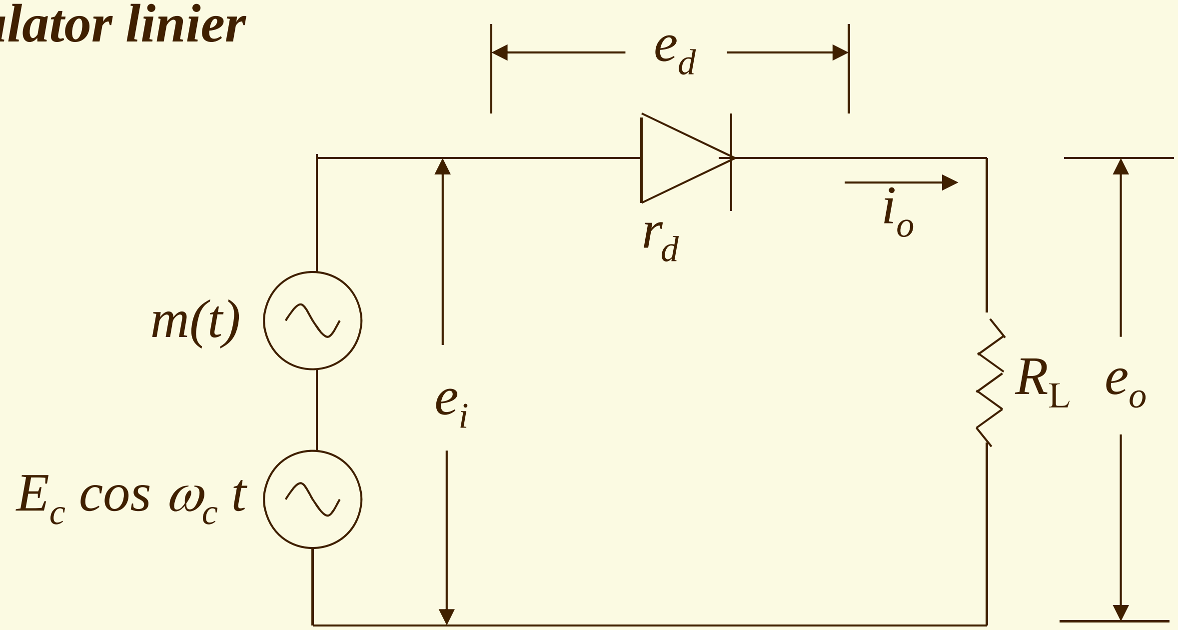


- Bentuk gelombang output

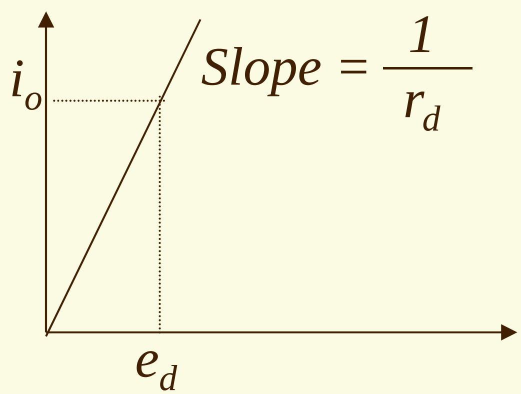
Sinyal input
f_c=200 kHz, 240 m$V_{p\text{-}p}$
f_s=3,125 kHz, 90 m$V_{p\text{-}p}$
Sinyal output T_2 1,1 $V_{p\text{-}p}$
$m \approx 40\%$



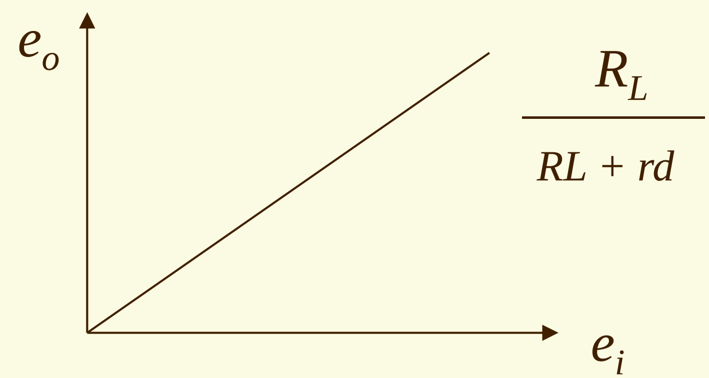
**** Modulator linier***



Karakteristik input-output diode



Karakteristik input-output modulator



- *Analisa modulator linier adalah sebagai berikut :*

Dimisalkan persamaan sinyal carrier dan sinyal pemodulasi seperti dibawah ini :

$$e_c(t) = a \cos \omega_c t$$

$$e_s(t) = m(t)$$

dimana $a > E_s$ *sinyal input modulator adalah :*

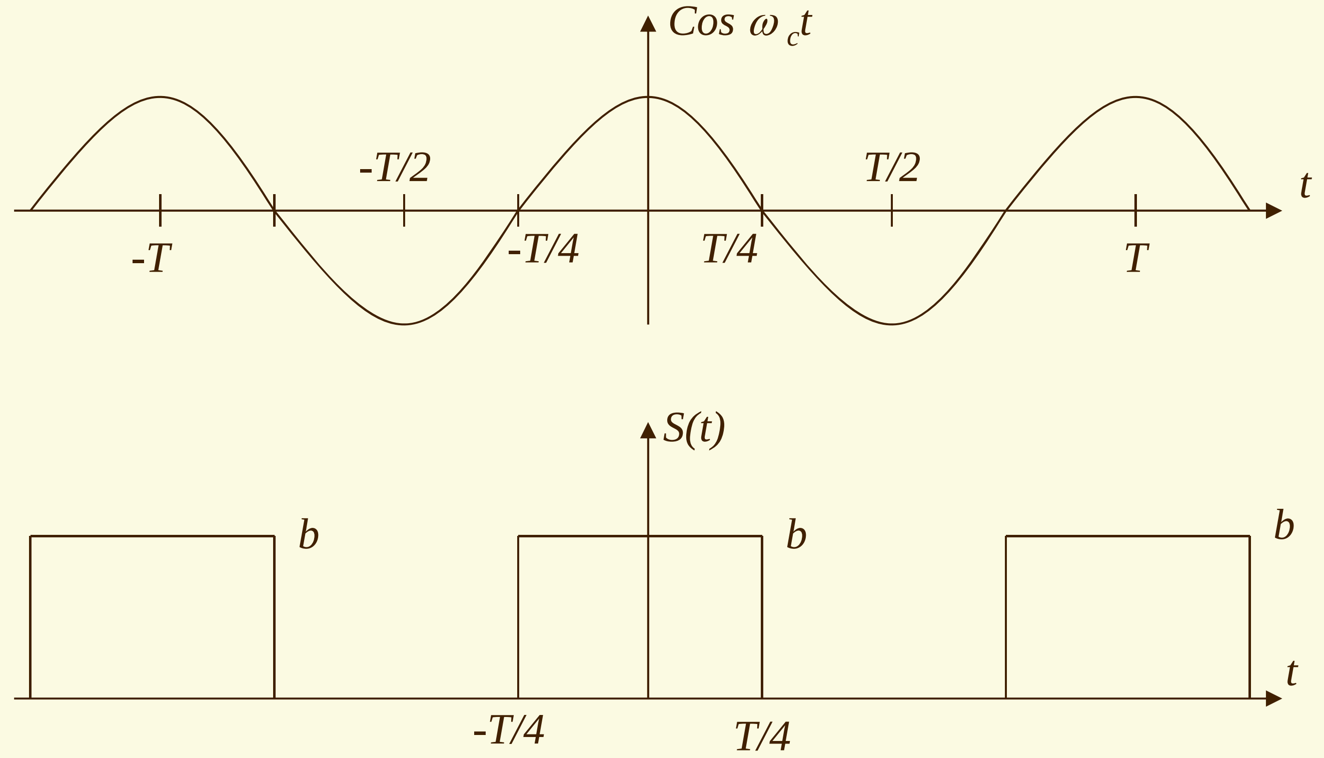
$$e_i(t) = a \cos \omega_c t + m(t)$$

arus diode mengalir hanya jika diode mendapat bias maju, maka :

$$I_o = \begin{cases} \dfrac{R_L}{R_L + r_d} \, e_i(t) = b(a \cos \omega_c t + m(t)) & (a \cos \omega_c t > 0) \\ 0 & (a \cos \omega_c t < 0 \end{cases}$$

dimana, $b = \dfrac{R_L}{R_L + r_d}$

- Tegangan output modulator yaitu dengan memanfaatkan fungsi switching S(t) seperti gambar dibawah :



- Dari gambar fungsi switching diperoleh persamaan :

$$e_o(t) = [a \cos \omega_c t + m(t)\} S(t)$$

Dimana, $S(t) = \begin{cases} b & (-T/4 < t < T/4),\ T = 1/f_c \\ 0 & \text{(untuk yang lain)} \end{cases}$

$$S(t) = b\left[\frac{1}{2} + \sum_{n=1}^{\infty} \frac{\sin(n\pi/2)}{n\pi/2} \cos n\omega_c t\right]$$

Karena itu $e_{o(t)}$ menjadi :

$$eo(t) = \{a \cos \omega ct + m(t)\} b \left[\frac{1}{2} + \frac{\sin(\pi/2)}{\pi/2} \cos \omega ct + \sum_{n=3}^{\infty} \frac{\sin(n\pi/2)}{n\pi/2} \cos n\omega ct \right]$$

$$= b \left[\frac{1}{2} m(t) + \frac{2a}{\pi} \cos^2 \omega ct + \frac{a}{2} \left[1 + \frac{4}{\pi a} m(t) \right] \cos \omega ct \right]$$

$$+ \left[\sum_{n=3}^{\infty} \frac{\sin(n\pi/2)}{n\pi/2} [\cos n\omega ct + m(t)] \cos n\omega ct \right]$$

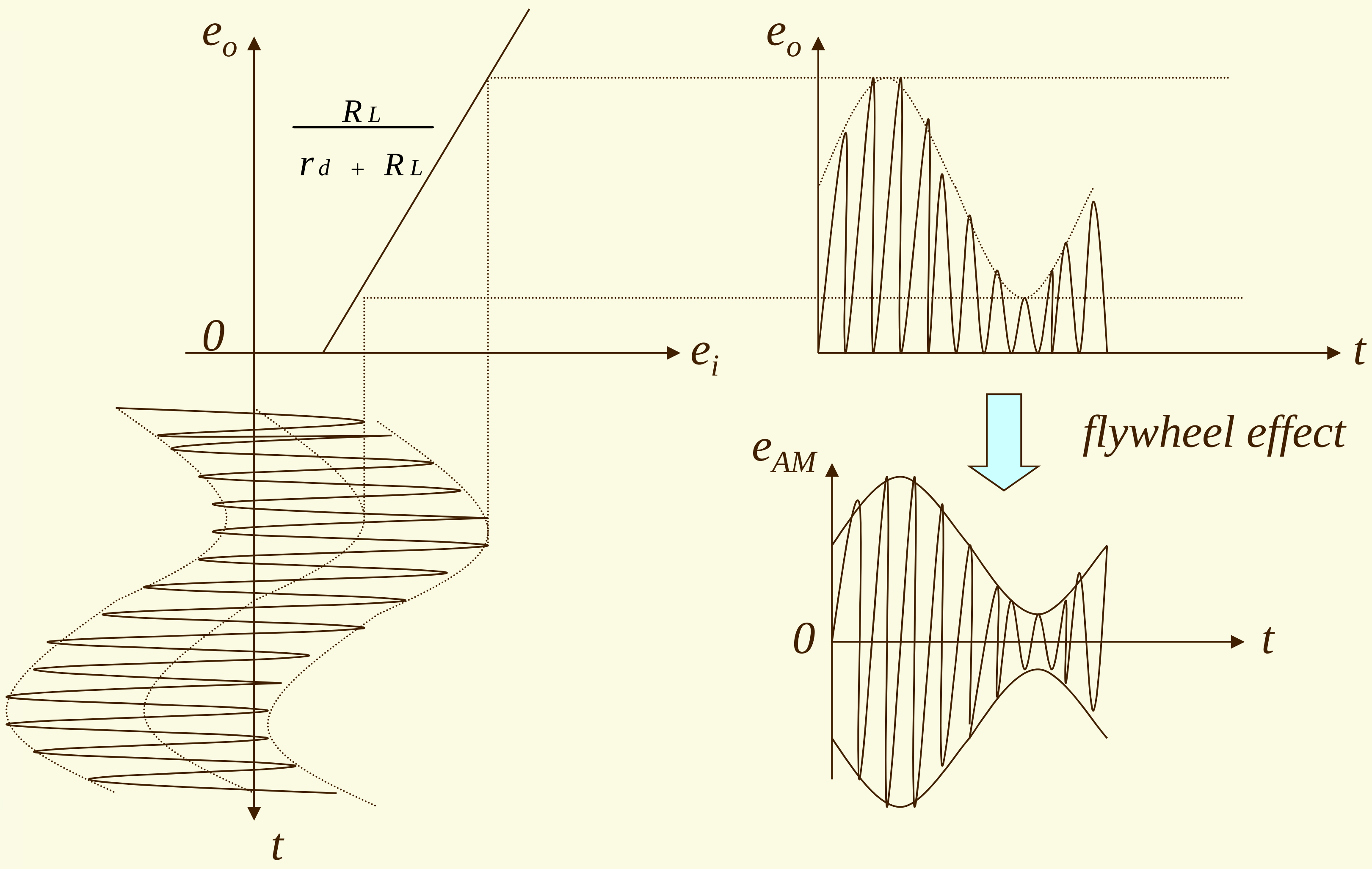
Jika $e_o(t)$ dilewatkan BPF dengan frekuensi tengah f_c maka didapat gelombang AM dengan persamaan :

$$e(t)_{AM} = \frac{ab}{2}\left[1 + \frac{4}{\pi a} m(t)\right]\cos \omega_c t$$

$$= E_c\left[1 + mm(t)\right]\cos \omega_c t$$

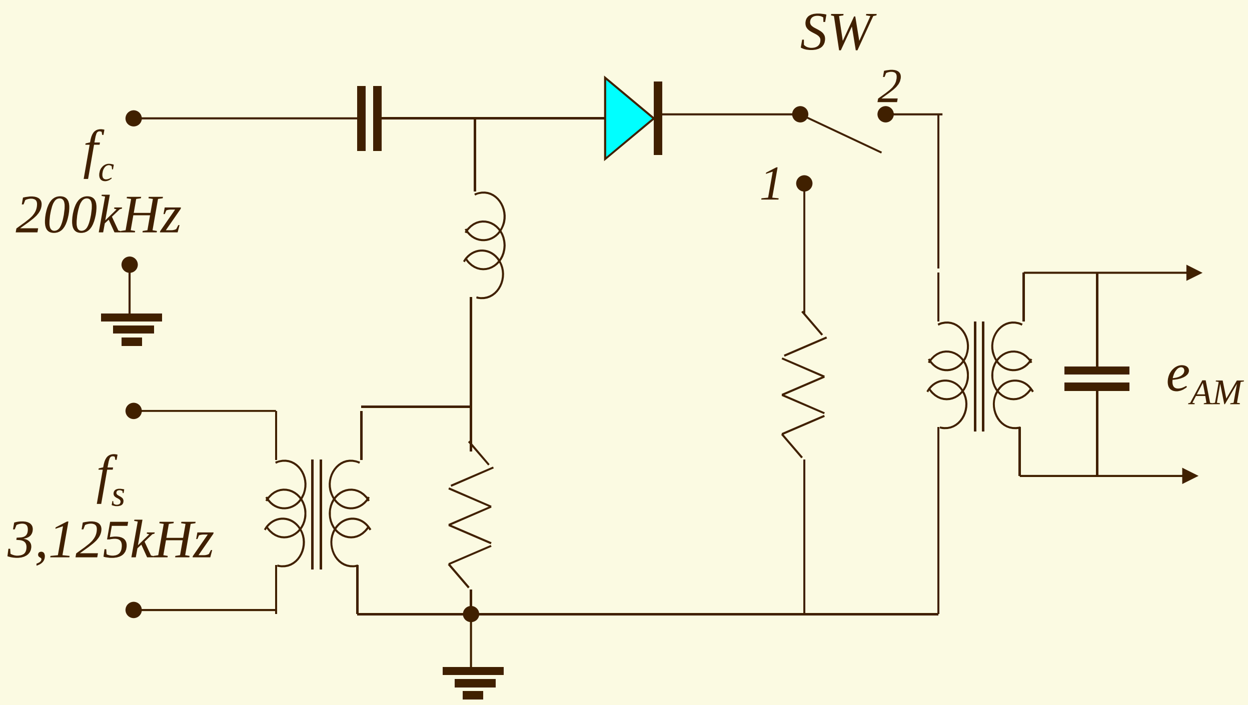
dimana, **E_c = ab/2,** **dan** **$m=4/\pi a$**

- Bentuk gelombang output modulator linier



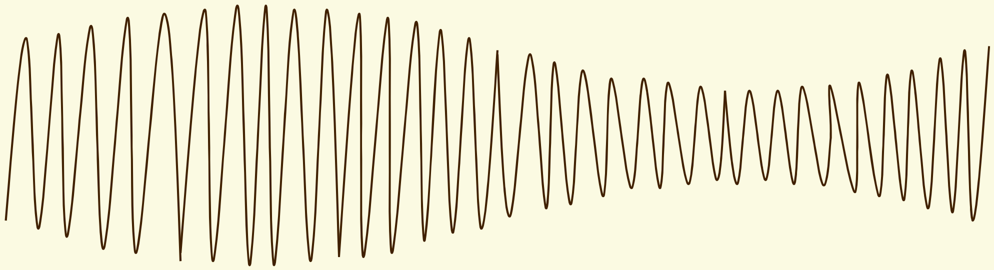
** Modulator linier diode*

- Rangkaian

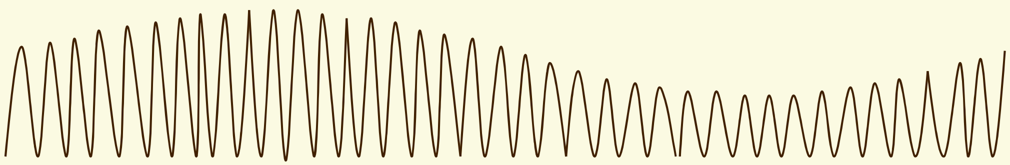


- *Bentuk gelombang*

SW-2 6,25 $V_{p\text{-}p}$, *m=35%*

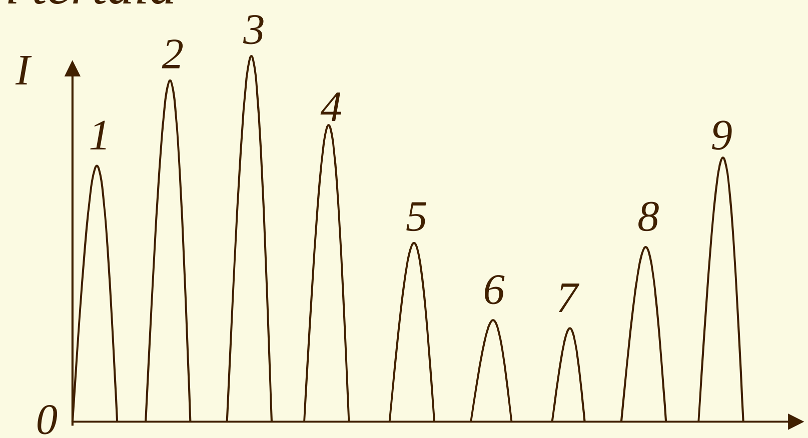


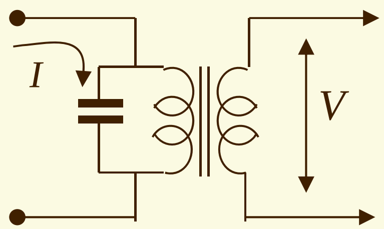
SW-1 200kHz, 0,75mA



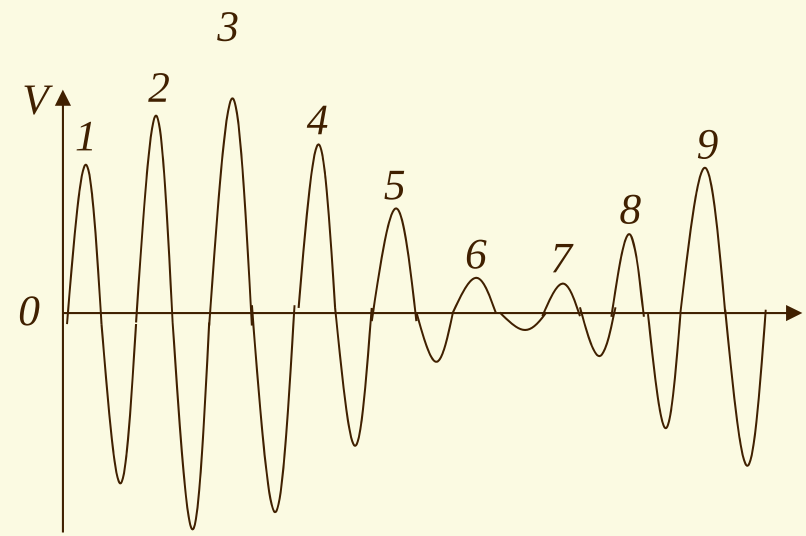
- *Prinsip kerja rangkaian tertala*

Gelombang arus ke rangkaian tertala





Output rangkaian tertala



* Metode-metode pengukuran Index modulasi

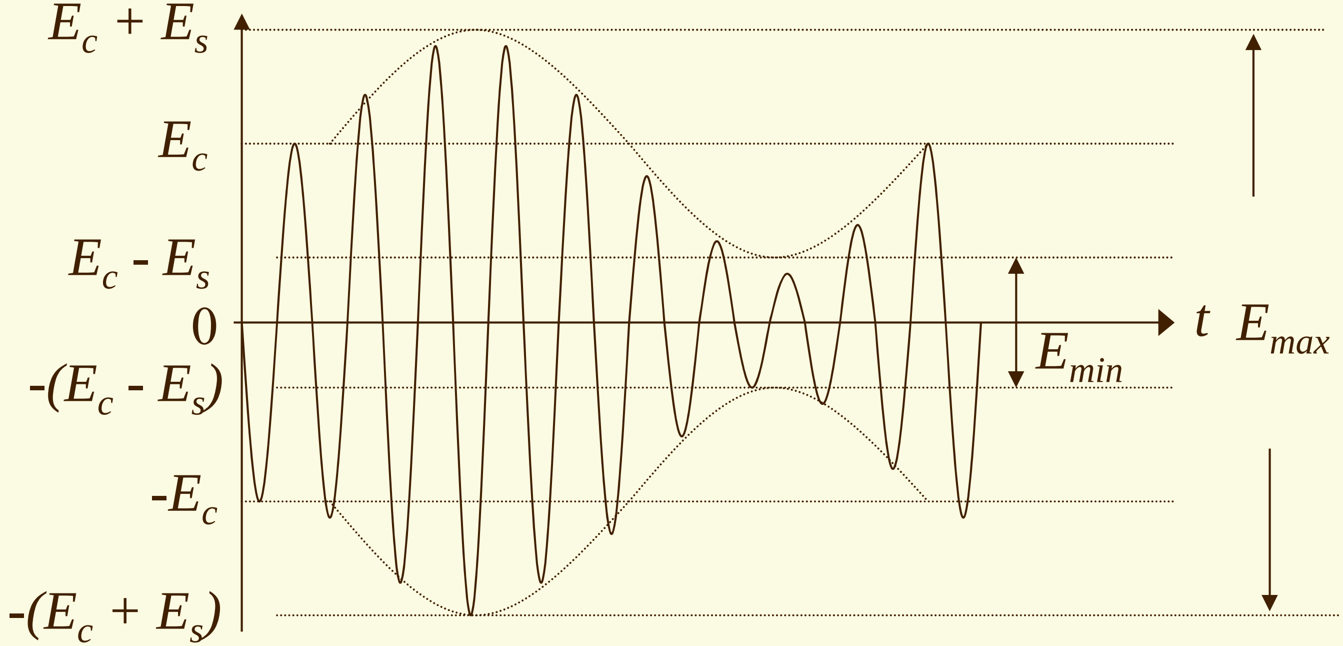
(1) *Mengukur harga peak-to peak dan minimum to minimum gelombang AM*
(2) *Metode Trapesoidal*
(3) *Metode Elliptical*
(4) *Metode spektrum analizer*

(1) Metode peak to peak dan minimum to minimum

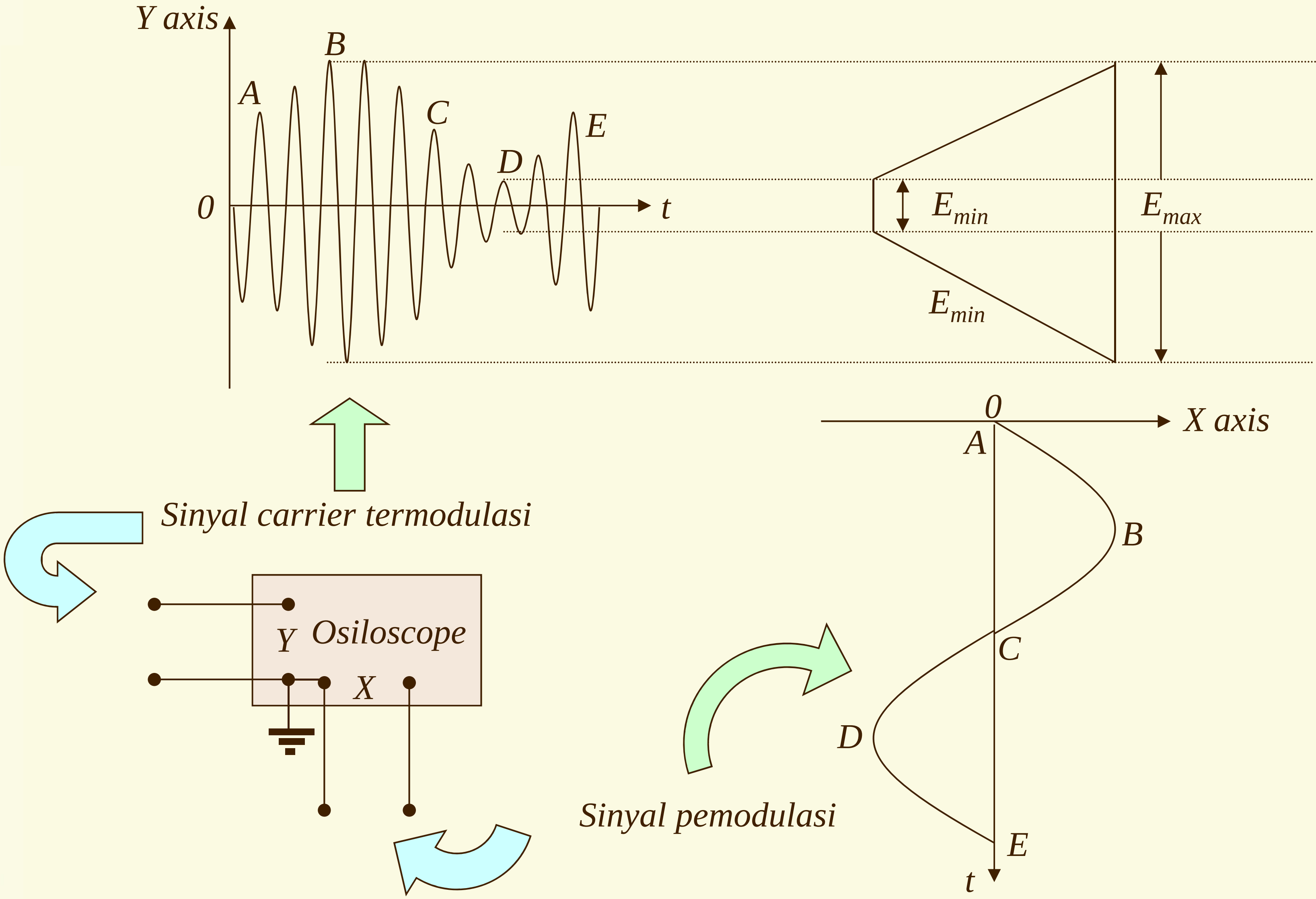
$E_{max} = 2(E_c + E_s)$

$E_{min} = 2(E_c - E_s)$

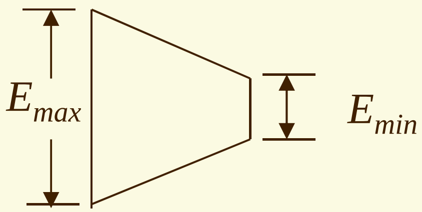
$$m = \frac{Es}{Ec} = \frac{E\max - E\min}{E\max + E\min}$$



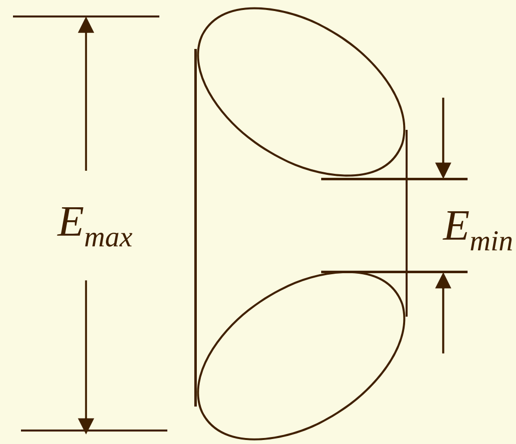
(2) Metode trapezoidal



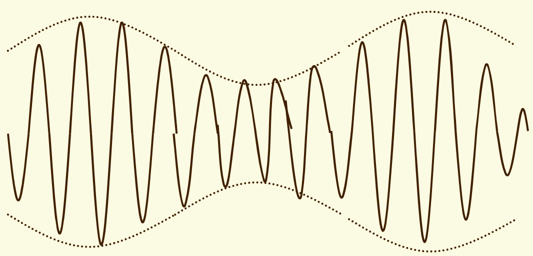
- Macam-macam pola pada trapesoidal



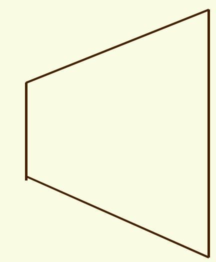
Trapesoidal phase sama

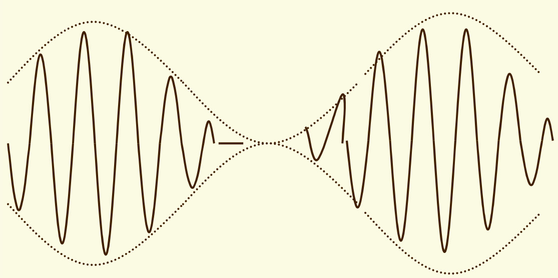


Trapesoidal berbeda phase

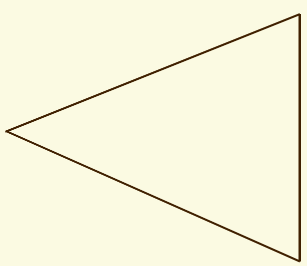


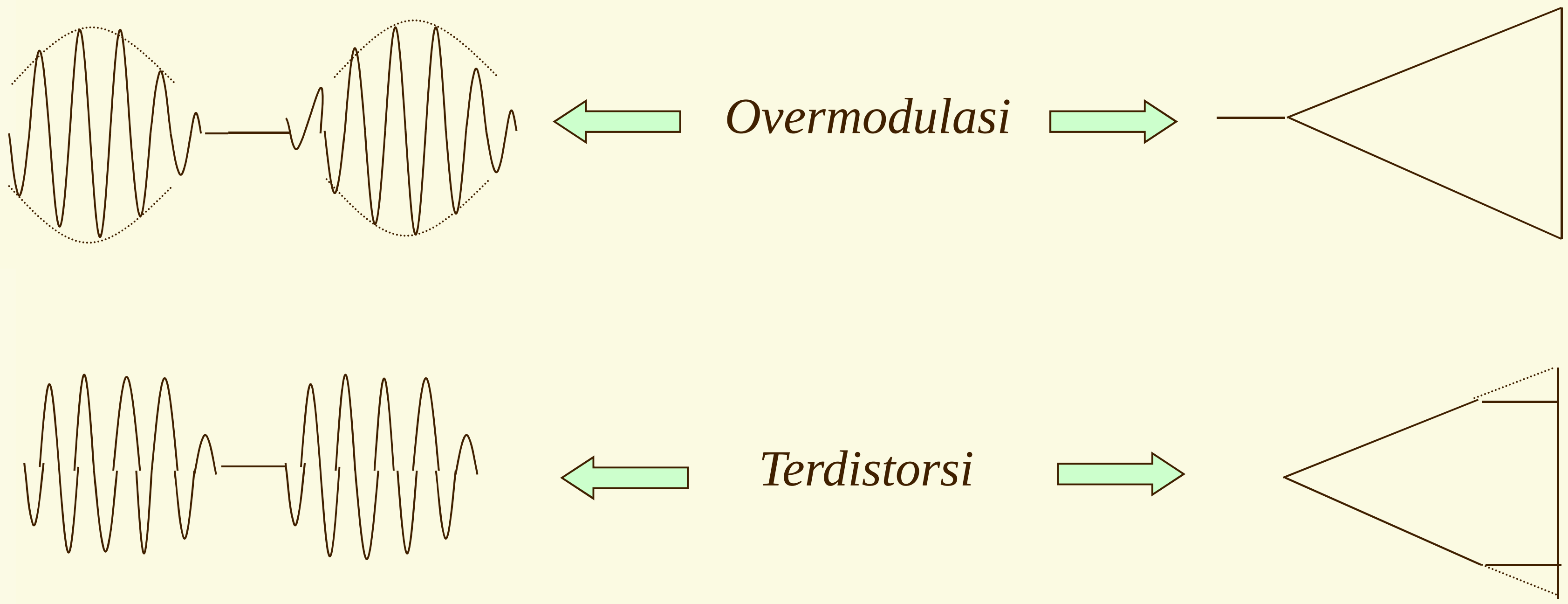
m=kira-kira 35%





m=100%





(3) Metode spektrum analyzer

$$X_c = 20 \log_{10} E_c \qquad [dB]$$

$$X_{SB} = 20 \log_{10} (mE_c/2) \qquad [dB]$$

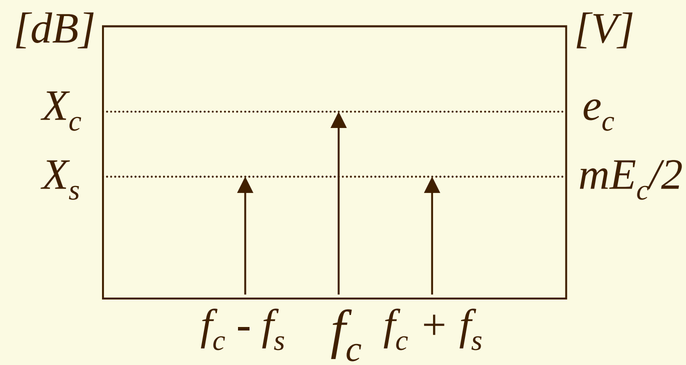
maka index modulasi m didapat :

$$m = 10^{(X_s - X_c + 20\log 2)/20}$$

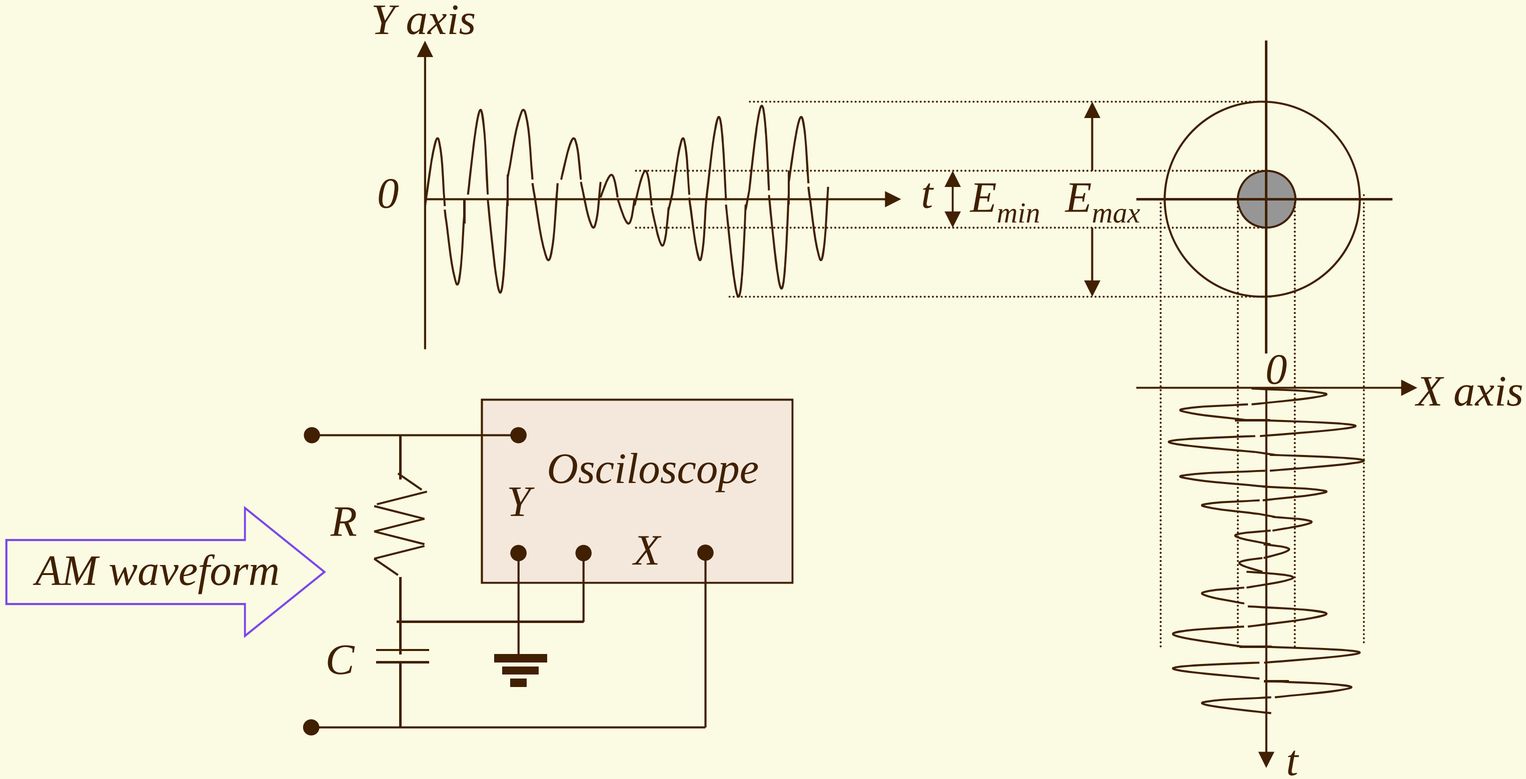
$$= 10^{(X_s - X_c + 6)/20}$$

atau,

$$m = 2 \cdot 10^{(X_s - X_c)/20}$$



(4) Metode elliptical



* Perhitungan daya pada sinyal AM

♣ Daya total :

$$P_t = P_c + P_{LSB} + P_{USB}$$

P_t = daya carrier
P_{LSB} = daya sideband bawah
P_{USB} = daya sideband atas

$$Pc = \frac{\left(Ec / \sqrt{2}\right)^2}{R}$$

$$P_{LSB} = \frac{\left(\frac{mEc}{2} / \sqrt{2}\right)^2}{R}$$

$$P_{LSB} = \frac{\left(\frac{mEc}{2} / \sqrt{2}\right)^2}{R}$$

$$Pt = \frac{Ec^2}{2R} + \frac{m^2 Ec^2}{8R} + \frac{m^2 Ec^2}{8R}$$

$$Pt = Pc + \frac{m^2}{4} Pc + \frac{m^2}{4} Pc$$

$$Pt = Pc \left(1 + \frac{m^2}{2}\right)$$

2.2.1 Sistem DSB-SC (Double Side Band Suppressed Carrier)

♠ *Persamaan* *sinyal carrier* *sinyal pemodulasi*

$e_c(t) = E_c \cos\omega_c t$

$e_s(t) = E_s \cos\omega_s t$

Output modulator DSB-SC

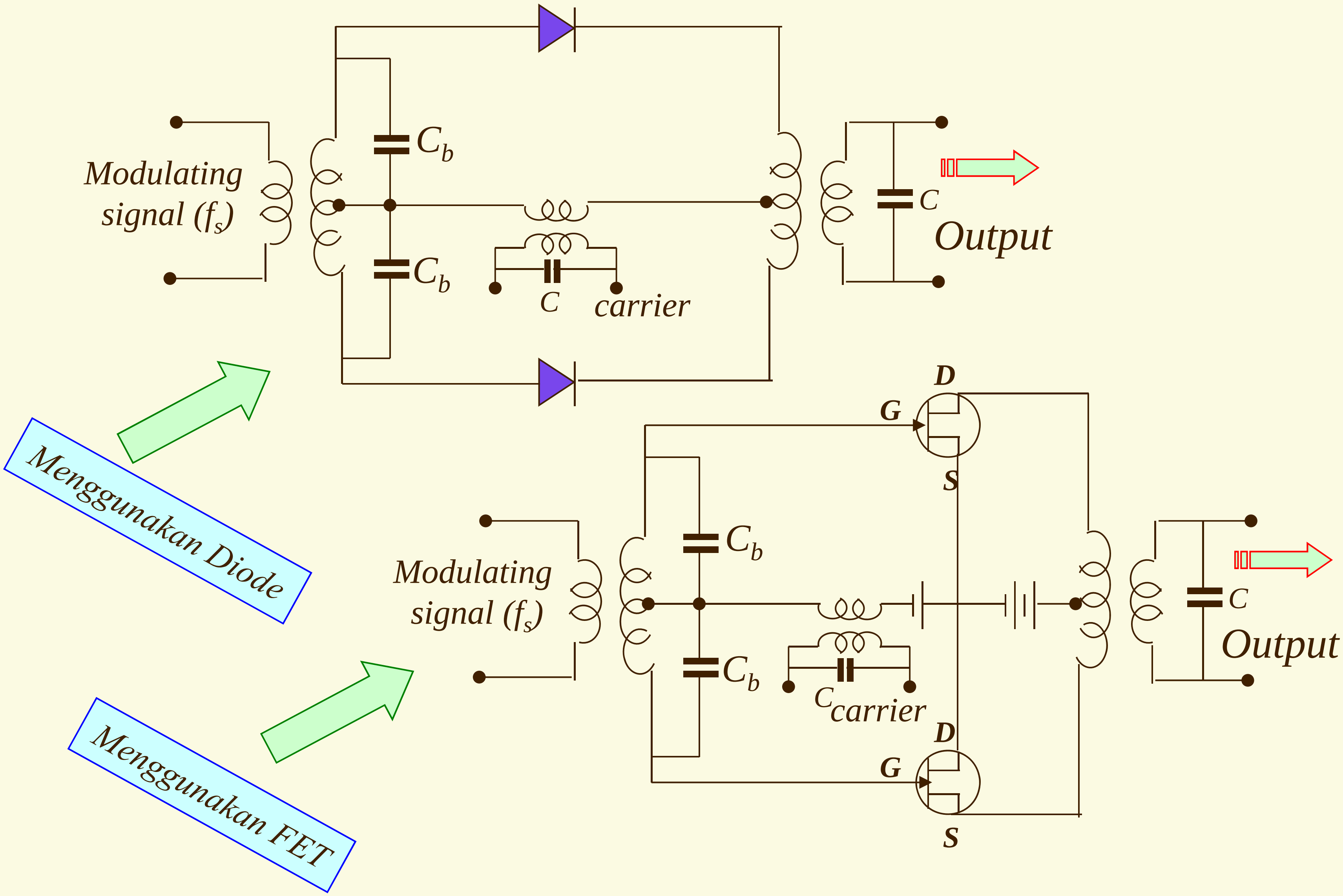
$$\begin{aligned} e_{DSB\text{-}SC}(t) &= e_c(t) \,.\, e_s(t) \\ &= E_c \cos\omega_c t \,.\, E_s \cos\omega_s t \\ &= \frac{E_c\, E_s}{2} [\cos(\omega_c + \omega_s)\, t + \cos(\omega_c - \omega_s)\, t] \end{aligned}$$

• *Tanpa carrier*

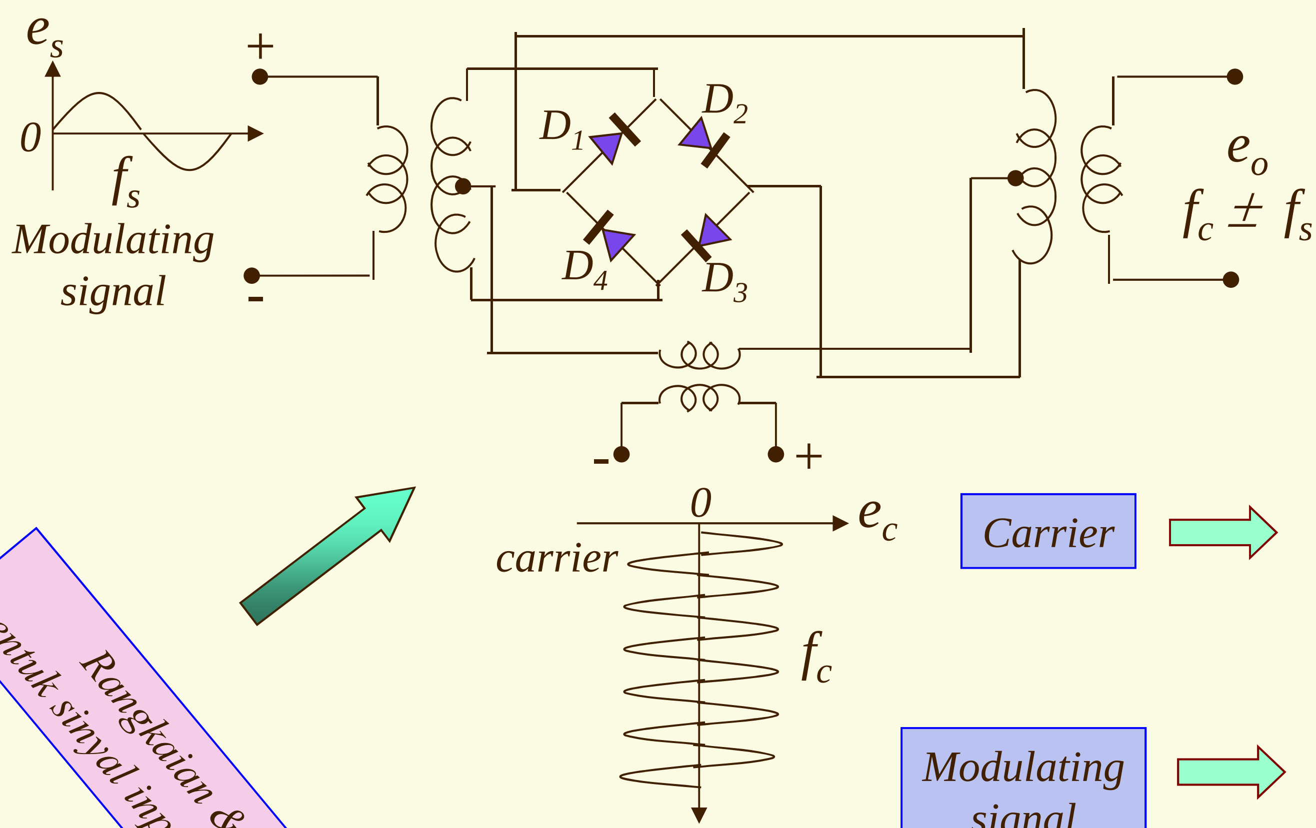
$$e_{DSB\text{-}SC}(t) = \frac{E_s}{2} \cos(\omega_c + \omega_s)\, t - \frac{E_s}{2} \cos(\omega_c - \omega_s)\, t$$

USB *LSB*

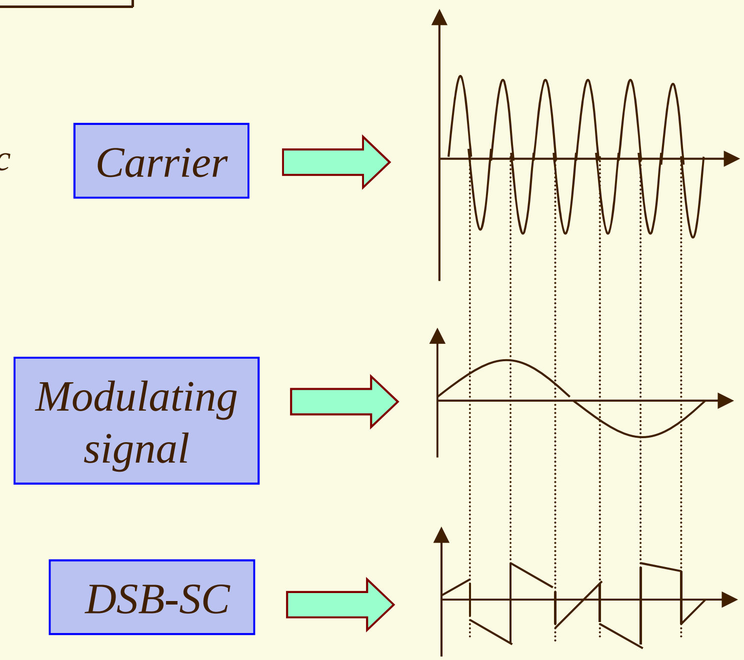
♠ *Ballans modulator (BM)*



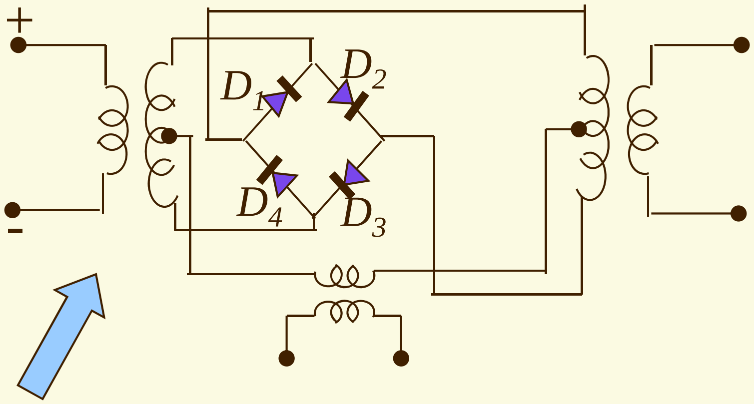
♠ Ring modulator (DBM)



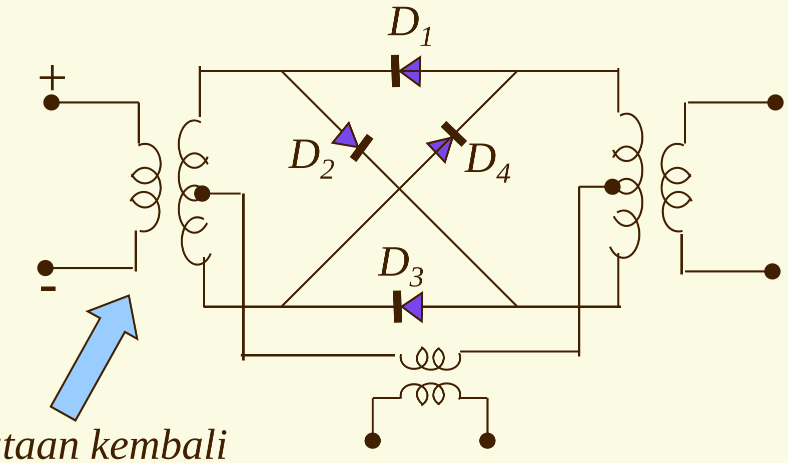
Rangkaian & bentuk sinyal input/output



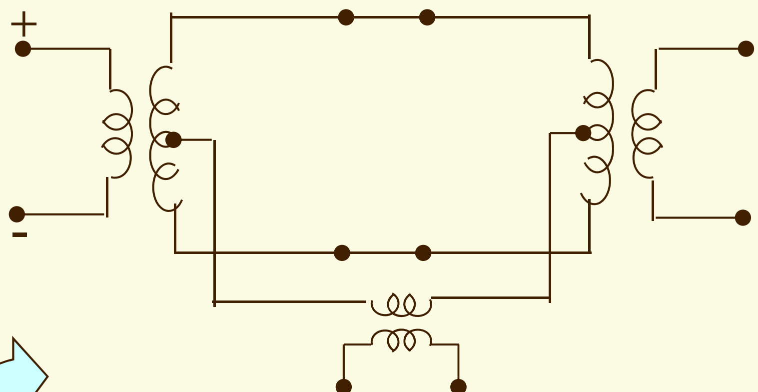
♠ *Analisa ring modulator (DBM)*

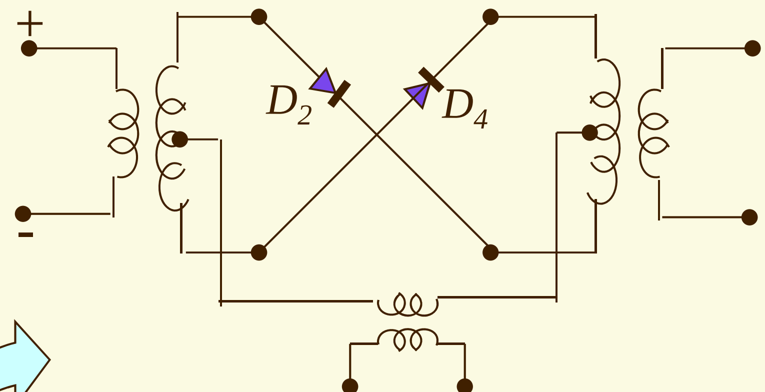


Rangkaian ring modulator



Penataan kembali rangkaian ring modulator





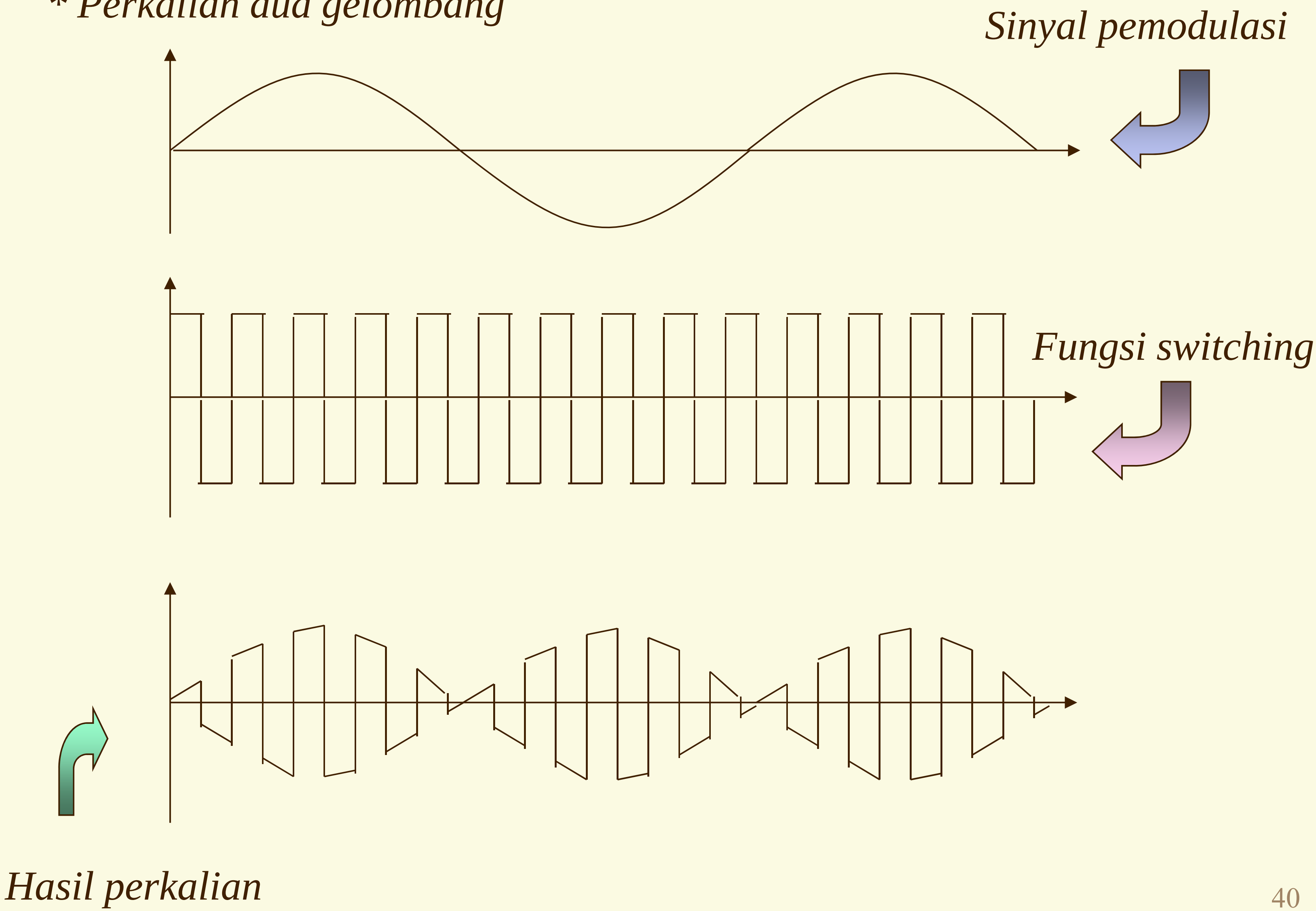
D_1 & D_3 ⟺ "ON"

D_2 & D_4 ⟺ "OFF"

D_1 & D_3 ⟺ "OFF"

D_2 & D_4 ⟺ "ON"

** Perkalian dua gelombang*



* *Perkalian dua gelombang menghasilkan bentuk gelombang seperti gambar sebelumnya dan bila dianalisa secara matematis sebagai berikut :*

$$e_s = E_s \cos \omega_s t$$

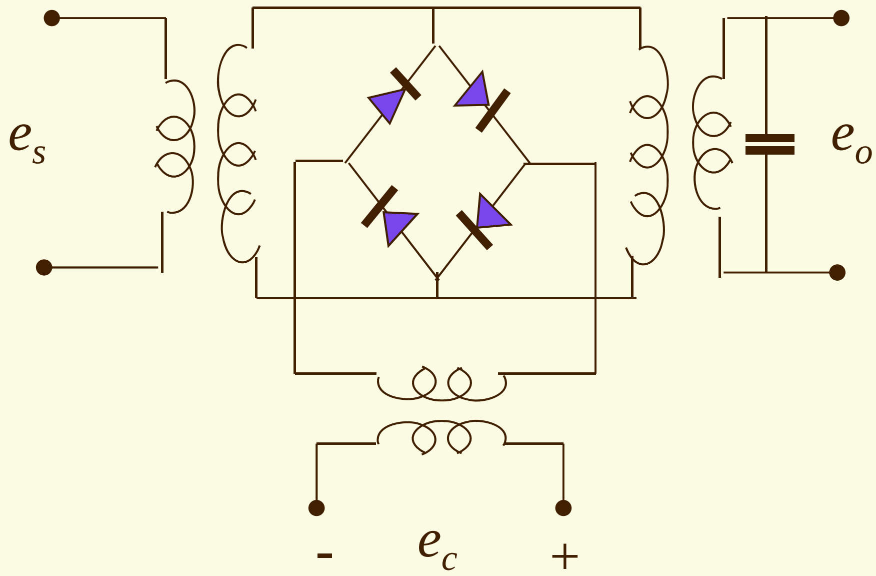
$$e_c = \sum_{n=1}^{\infty} E_n \cos \omega_c t \qquad \textit{(n = 1,3,5,....)}$$

$$e_{DBM-out} = e_c . e_s = \frac{E_s}{2} \sum_{n=1}^{\infty} E_n \left\{ \cos(n\omega_c + \omega_s)t + \cos(n\omega_c - \omega_s)t \right\}$$

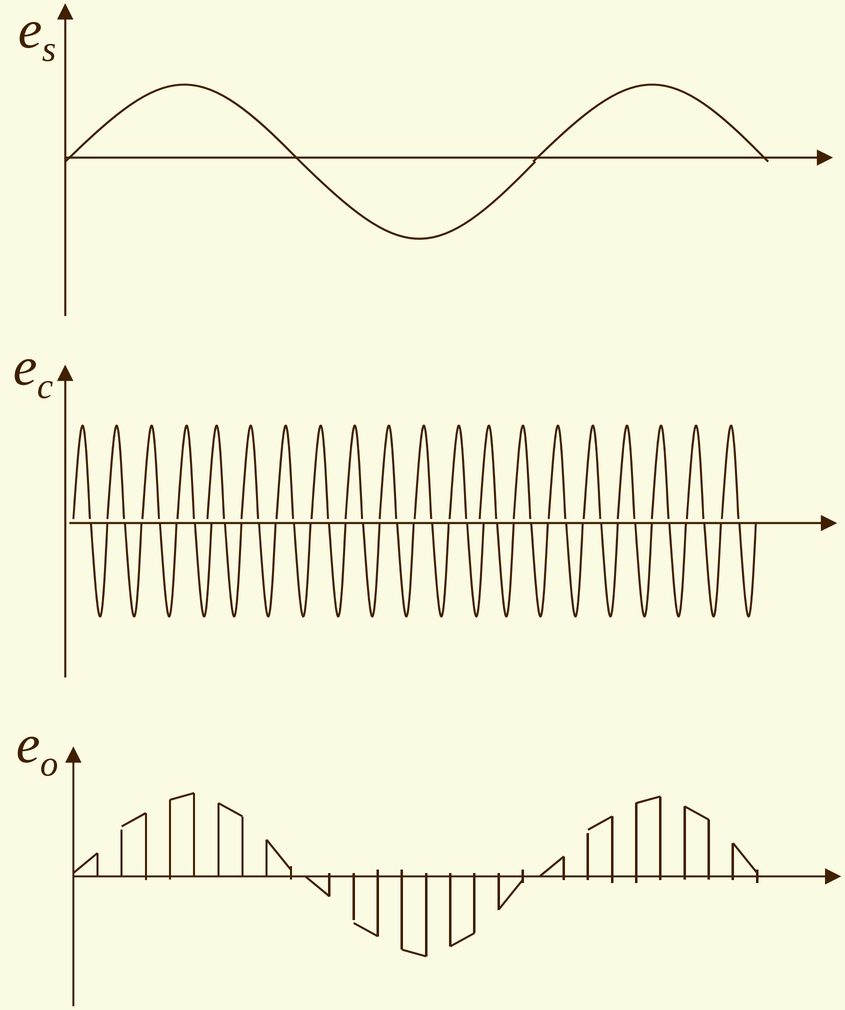
Bandpass filter pada n = 1

Menghasilkan output $f_c + f_s$ *atau* $f_c - f_s$

♠ *Shunt bridge diode modulator*



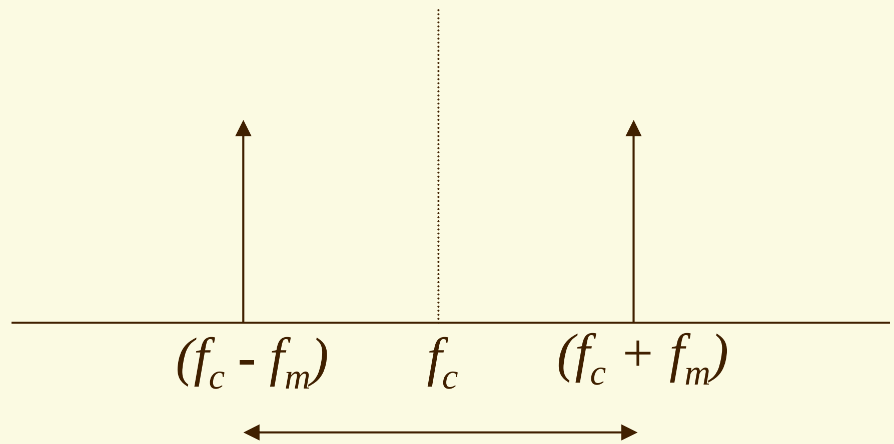
Rangkaian



Bentuk gelombang input/output

♠ *Spektrum sinyal DSB-SC*

Daya pancar $(P_t) = P_{USB} + P_{LSB}$

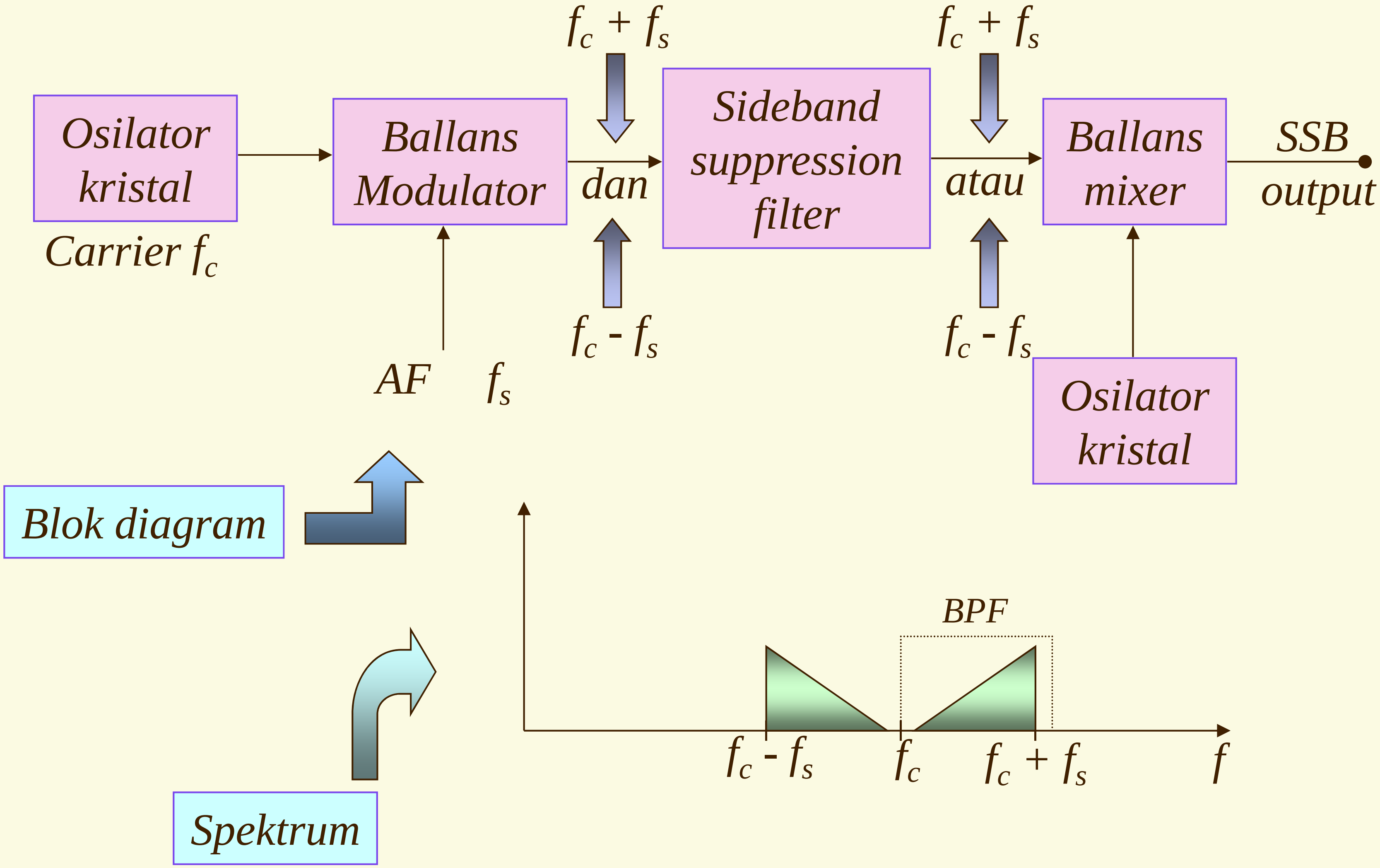


Bandwidth (BW)

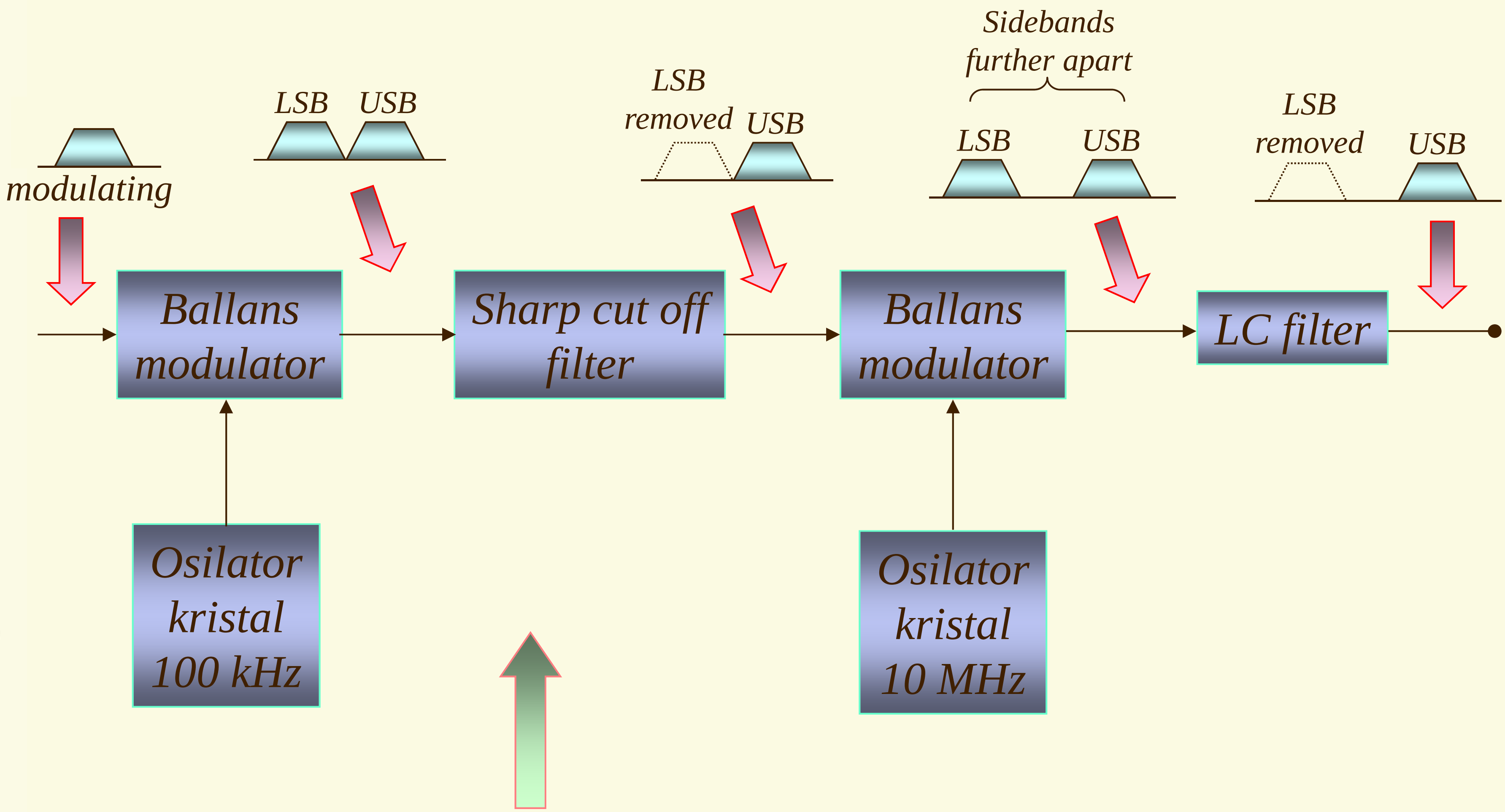
$BW = 2 \times f_s$

2.2.2 Sistem SSB (single side band)

♠ *Metode filter*

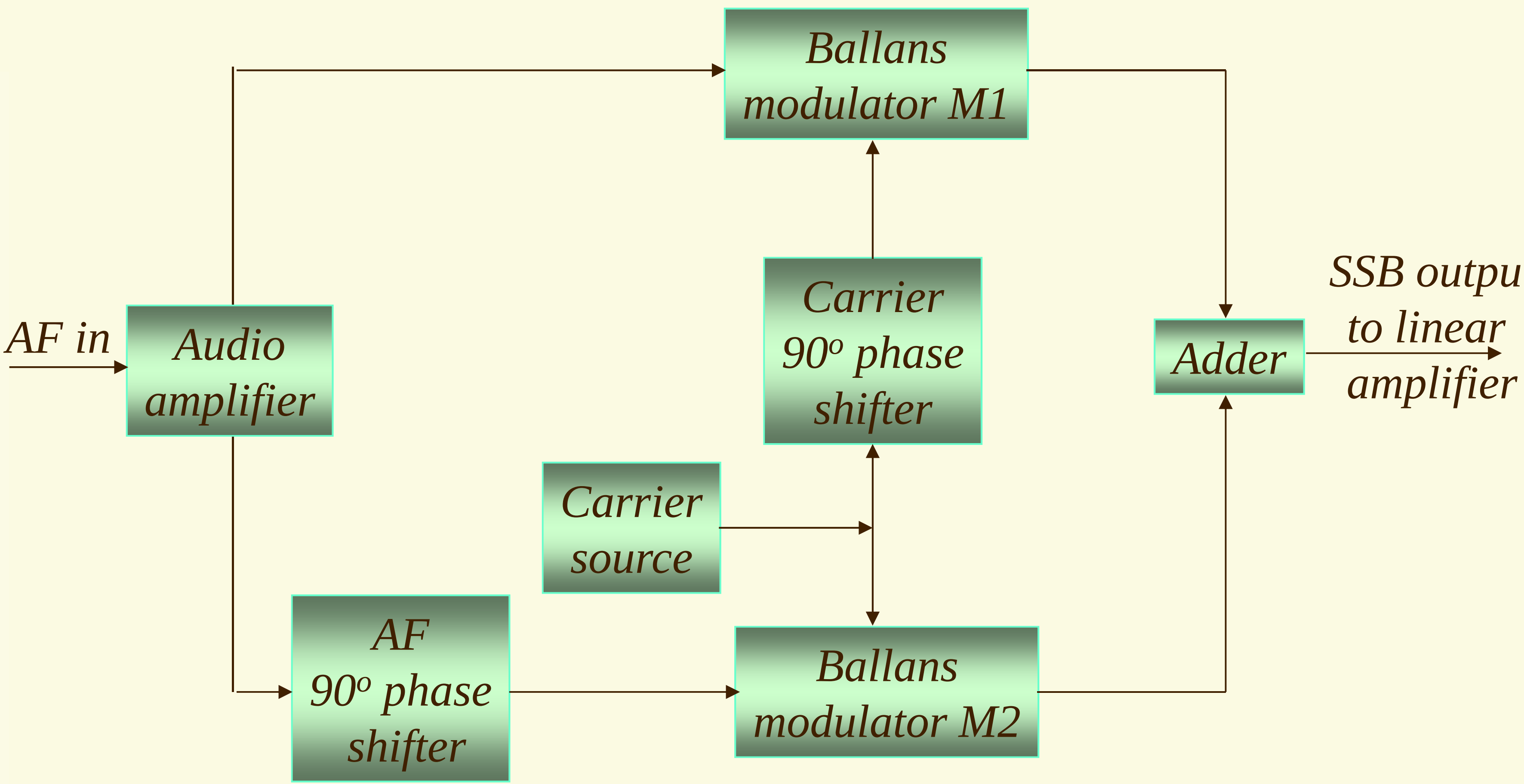


- *Modulator SSB dua tahap*

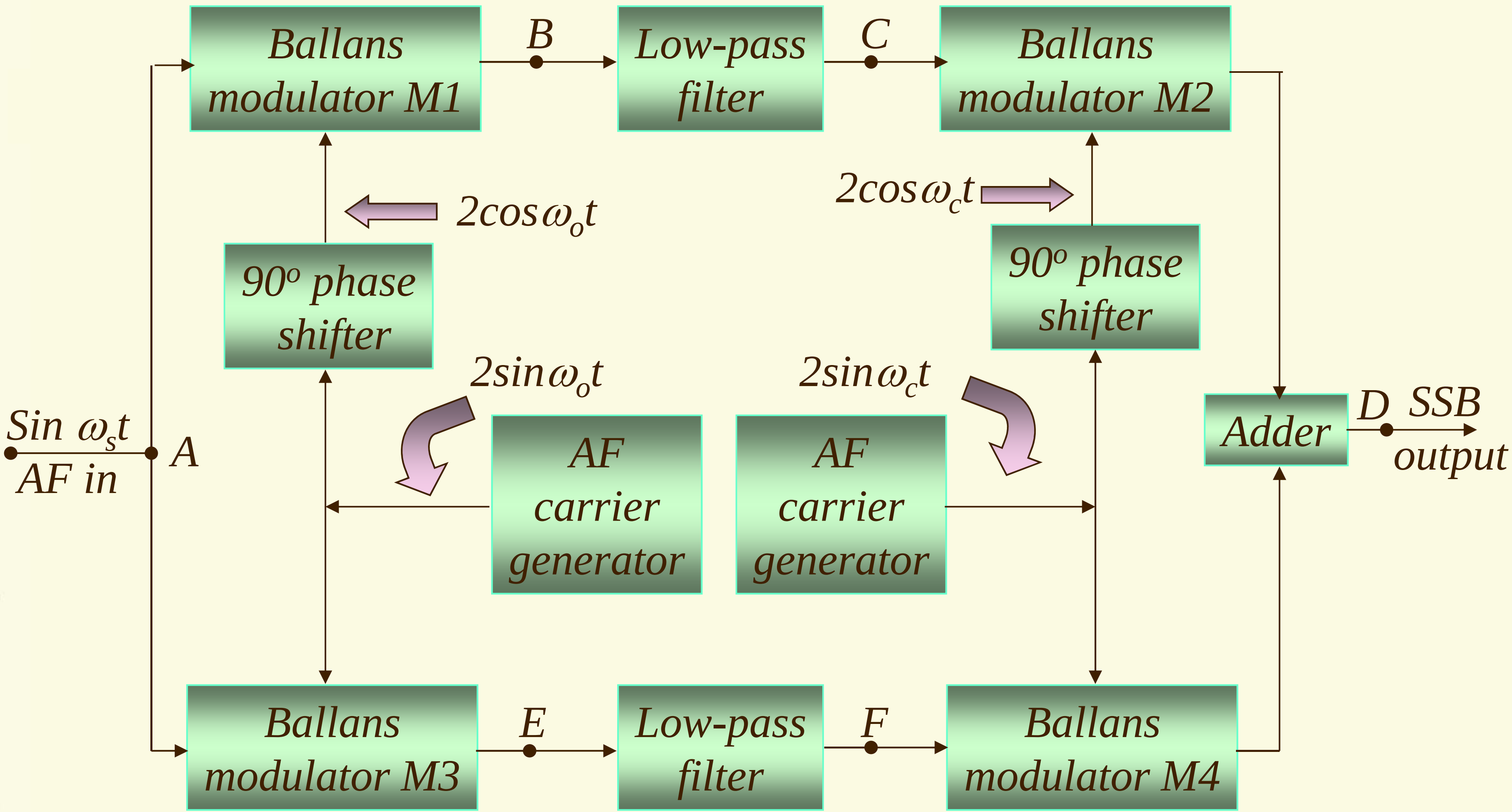


Modulator SSB dua tahap

♠ *Metode penggeser phasa*



♠ *Metode ketiga dalam pembangkit SSB*



- *Spektrum sinyal SSB*

Persamaan sinyal SSB

LSB :

$$\cos(\omega_c - \omega_s)t = \cos\omega_c t \,.\, \cos\omega_s t + \sin\omega_c t \,.\, \sin\omega_s t$$
$$= f(t)\cos\omega_c t + f'(t)\sin\omega_s t$$

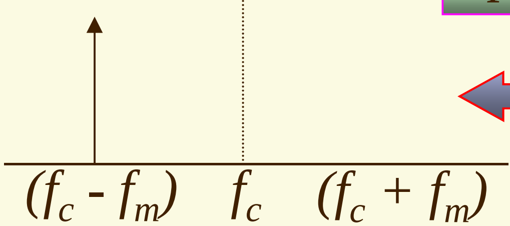
dimana :

$$f(t) = \cos\omega_s t$$
$$f'(t) = \sin\omega_s t \quad \Leftarrow \quad \text{Shift } -90^o$$

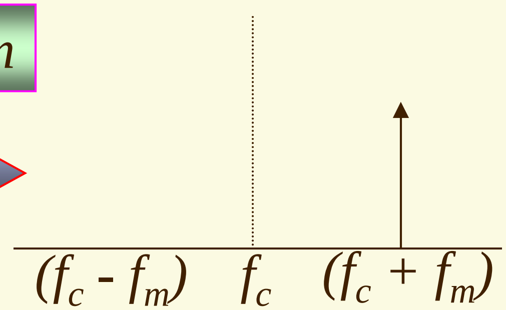
USB :

$$\cos(\omega_c + \omega_s)t = \cos\omega_c t \,.\, \cos\omega_s t - \sin\omega_c t \,.\, \sin\omega_s t$$
$$= f(t)\cos\omega_c t + f'(t)\sin\omega_s t$$

Spektrum



LSB



USB

Bandwidth = f_s
Daya pancar :
$P_t = P_{USB}$
$= P_{LSB}$

2.3 Demodulator Amplitudo

- Merupakan proses untuk mendapatkan kembali sinyal informasi.

- Informasi yang diterima berasal dari modulator amplitudo

2.3.1 Demodulator DSB-FC

A. Demodulator non linier

$$e_{AM} = E_c(1 + m\cos\omega_s t)\cos\omega_c t$$

dan sinyal input ke modulator :

$$x = A_o + e_{AM}$$

dimana : A_o *= tegangan bias*

$y=kx^2$ *= karakteristik I/O diode*

maka tegangan output pada R :

$$e_L = Ry = Rkx^2 = Rk(A_o + e_{AM})^2$$

$$= Rk(A_o^2 + 2A_o e_{AM} + e_{AM}^2)$$

$$= Rk[A_o^2 + 2A_o E_c(1 + m \cos\omega_s t) \cos\omega_c t + E_c^2(1 + m \cos\omega_s t)^2 \cos^2\omega_c t]$$

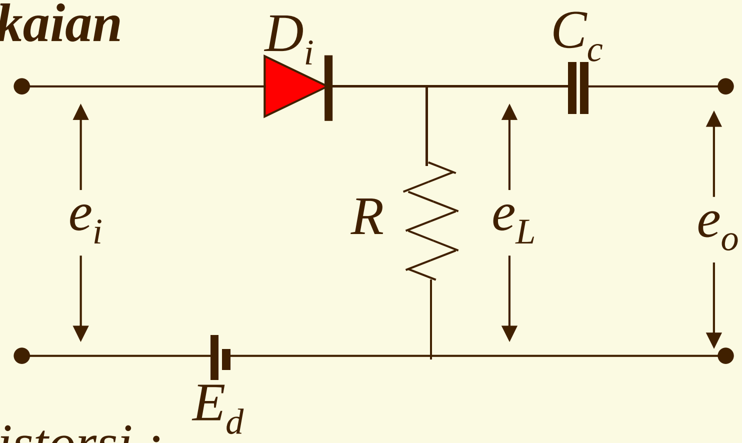
$$= Rk[A_o^2 + 2A_o E_c(\cos\omega_c t + m \cos\omega_s t \,.\, \cos\omega_c t) + \frac{Ec^2}{2} (1 + 2\, m \cos\omega_s t$$

$$+ \frac{m^2(1+\cos 2\omega_s t)}{2} (1 + 2 \cos\omega_c t)]$$

maka outputnya adalah :

$$e_o = RkE_c^2(m \cos \omega_s t + \frac{m^2}{4} \cos 2\omega_s t$$

*** Rangkaian**



Ratio distorsi :

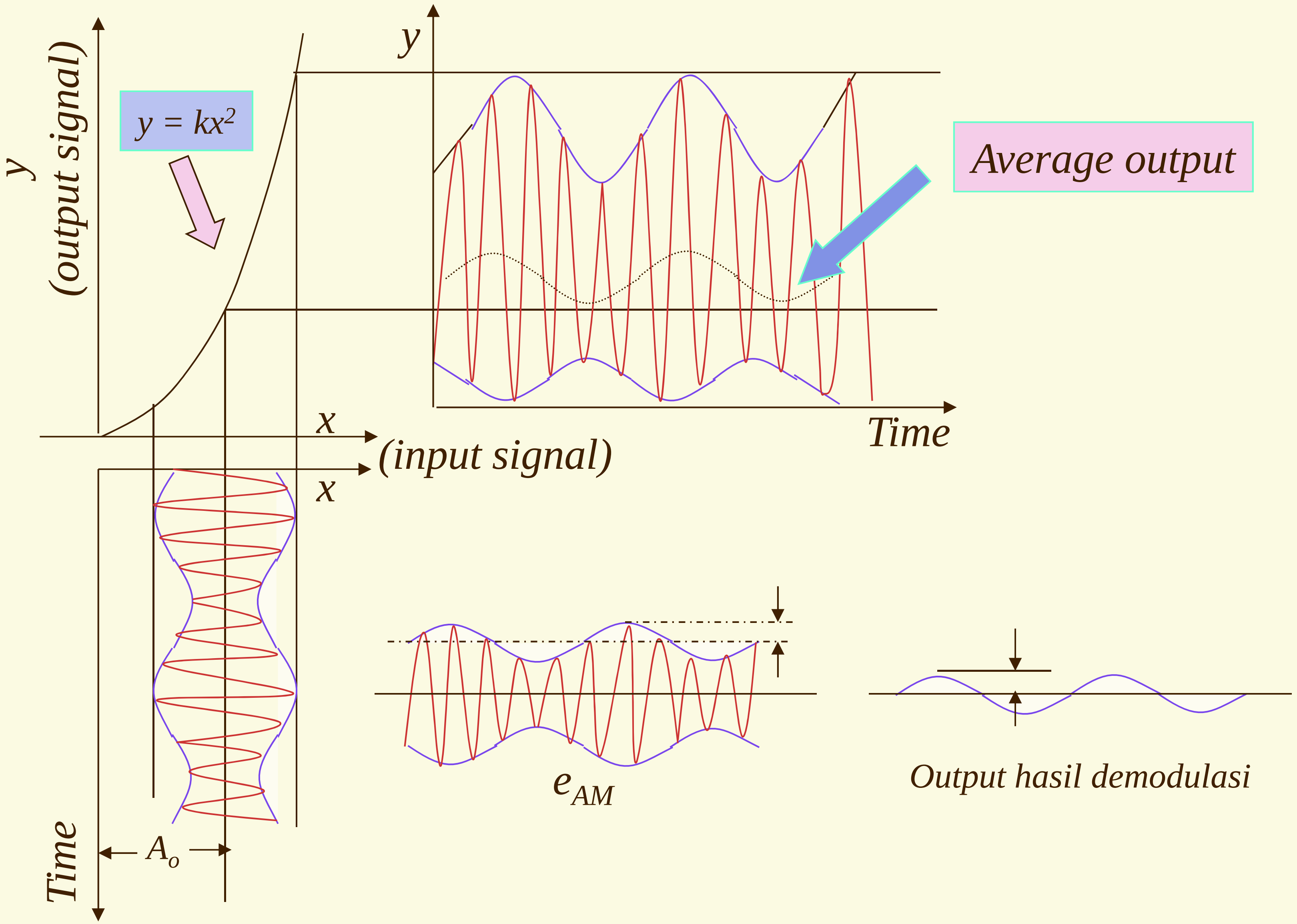
$$D = \frac{\text{harga rms dari harmonisa}}{\text{harga rms dari sinyal fundamental}} = \frac{\sqrt{E_2^2 + E_3^2 + \ \ldots \ + E_n^2}}{E_1}$$

$$D = \frac{m^2/4}{m/2} = \frac{m}{4} x100 \qquad [\%]$$

$$\mu = \frac{\text{amplitudo dari sinyal hasil demodulasi}}{\text{amplitudo dari sinyal pemodulasi pada } e_{AM}}$$

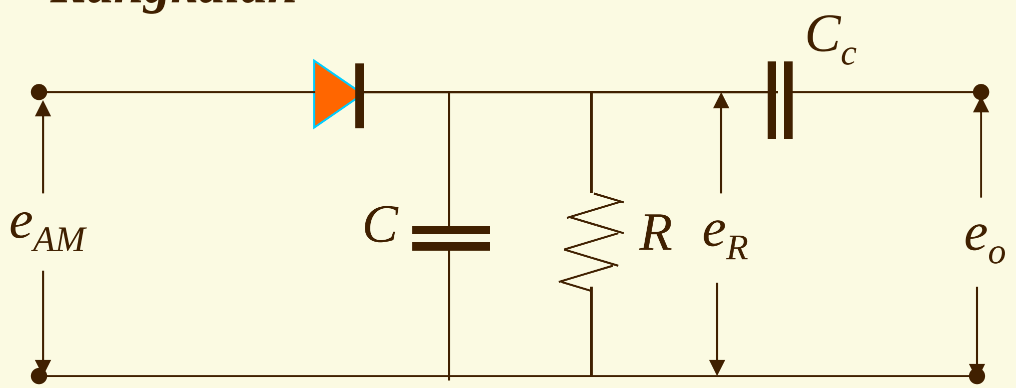
$$\mu = \frac{mRkE_c^2}{mE_c} = RkE_c \text{ x } 100\ [\%]$$

* Bentuk gelombang



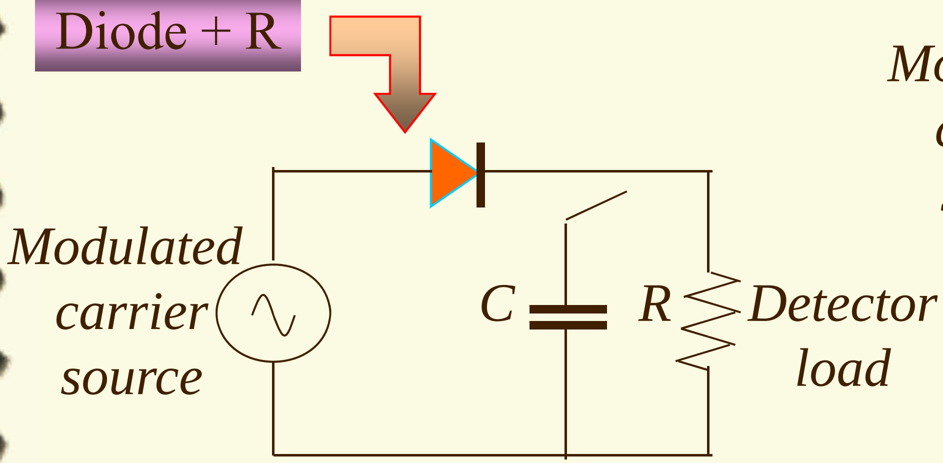
B. Detektor selubung diode

* Rangkaian

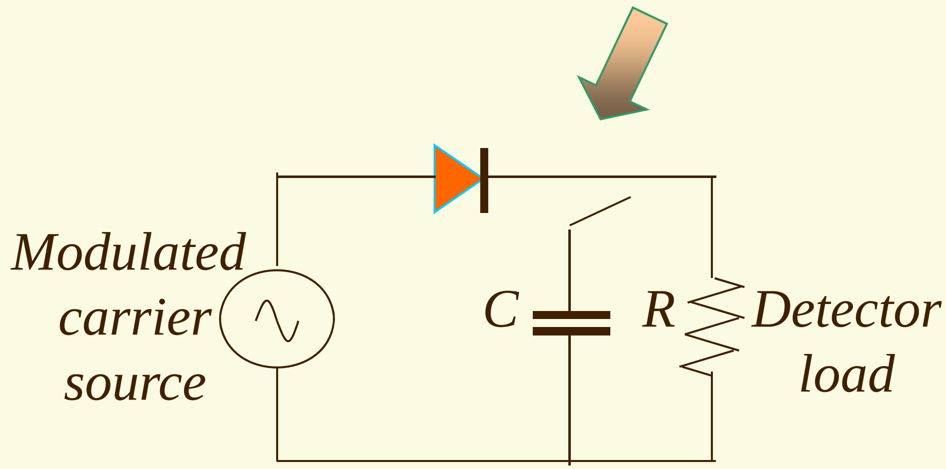


* Analisa rangkaian

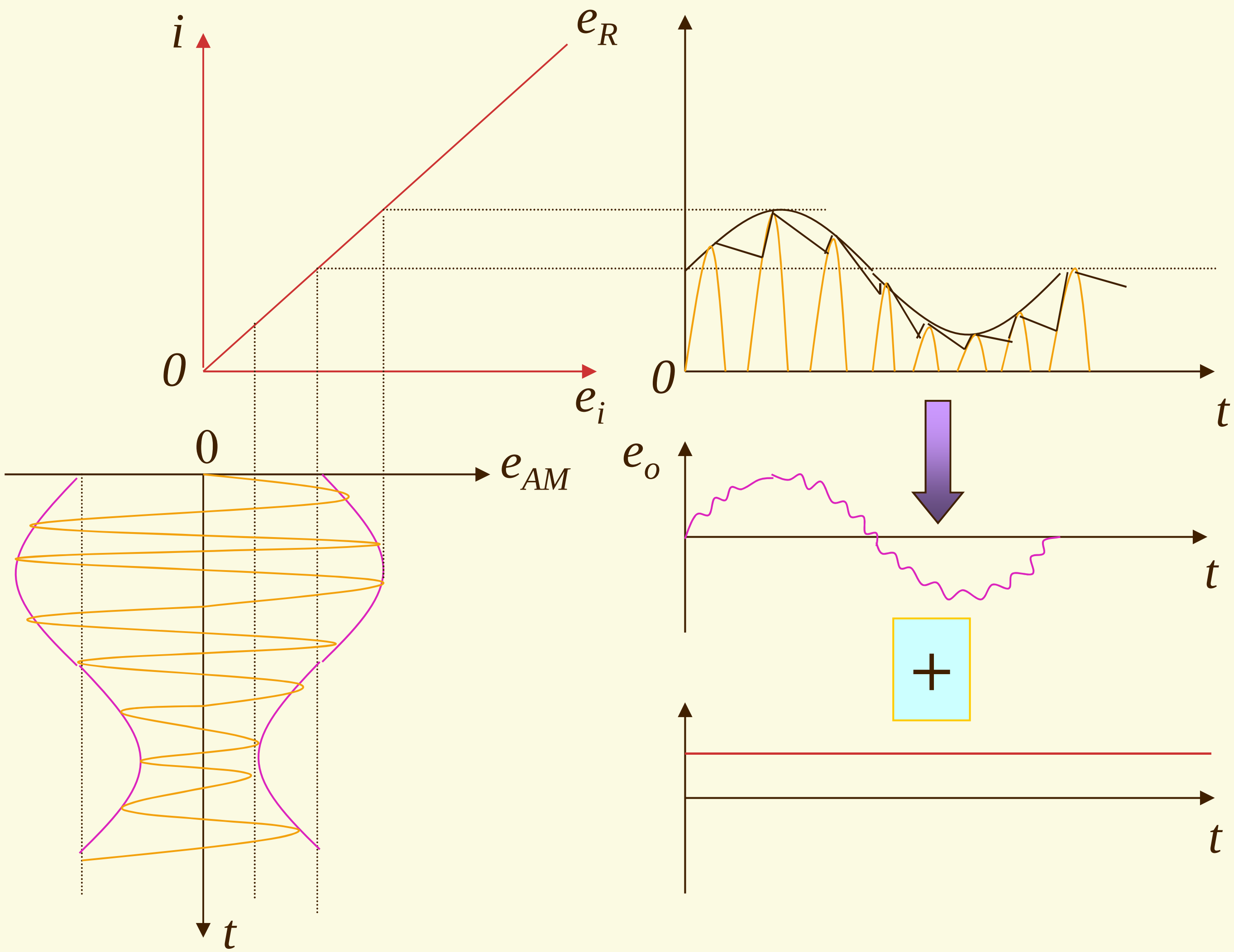
Diode + R



Diode + R + C

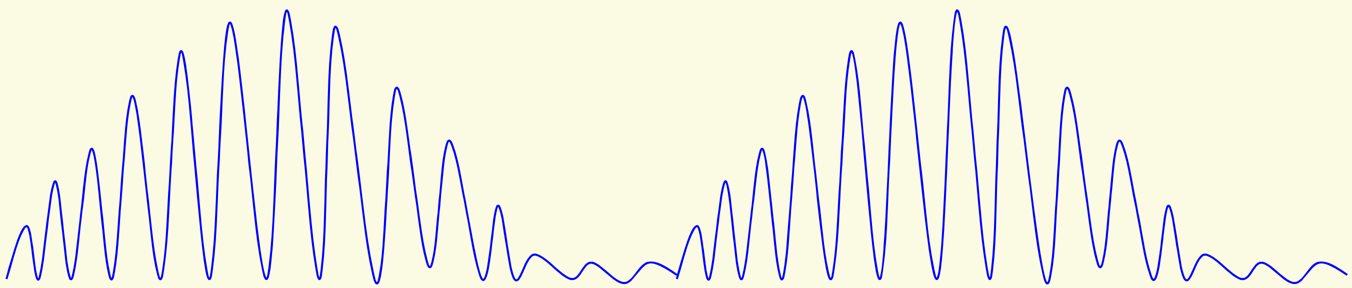


* Bentuk gelombang detektor selubung

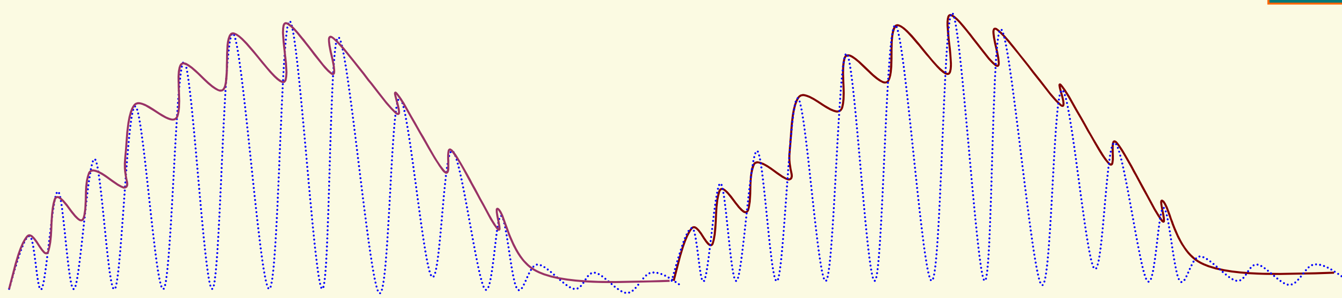


* *Bentuk gelombang hasil analisa rangkaian*

Rectified waveform

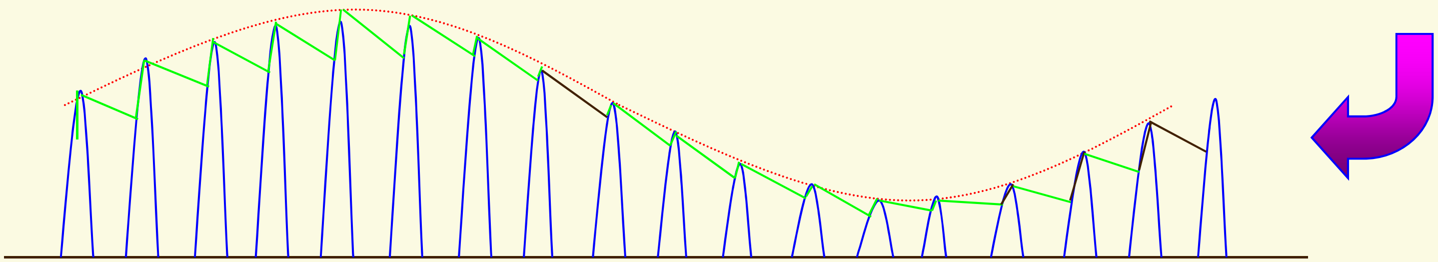


Filtered waveform

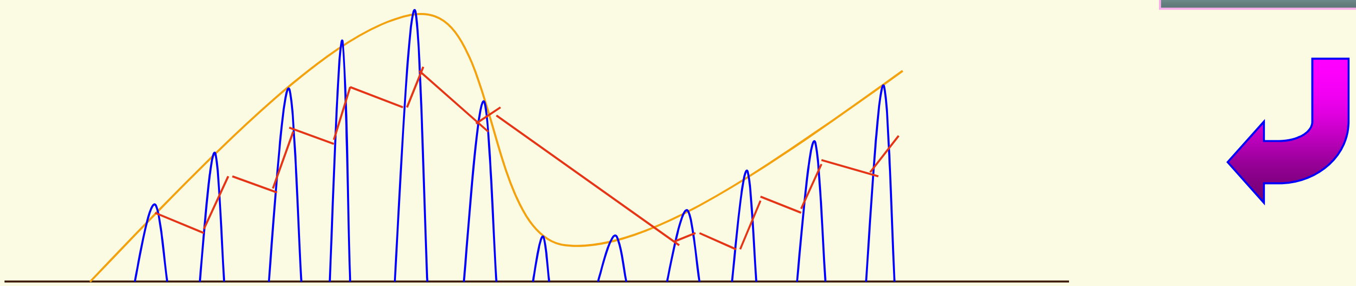


* *Diagonal clipping*

CR sesuai



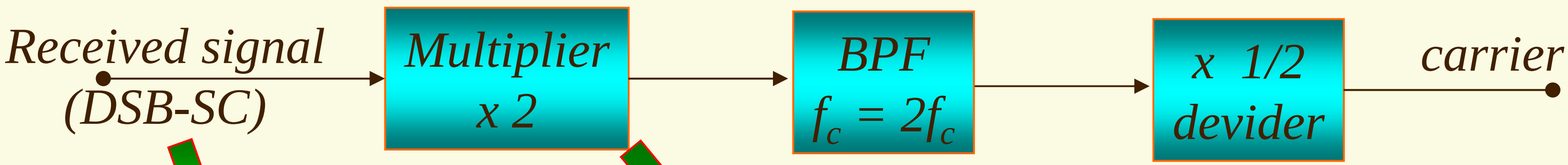
CR terlalu besar



2.3.1 Demodulator DSB-SC

- *Pembangkitan kembali sinyal carrier*
- *Demodulasi dengan menambahkan carrier*
- *Demodulasi perkalian*
- *Loop "Costas"*

A. Pembangkitan kembali sinyal carrier



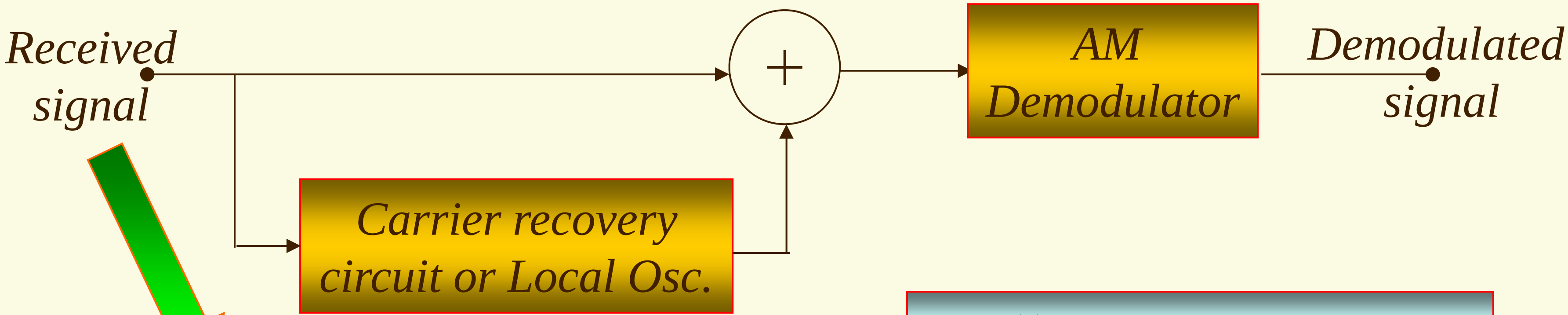
$$e_r(t) = E_r \cos \omega_s t \cos (\omega_c t + \varphi_r)$$

$$e_r^2(t) = E_r^2 \cos^2 \omega_s t \cos^2(\omega_c t + \varphi_r)$$

$$e_r^2(t) = \frac{1 + 2\sin 2\omega_s t}{2} = \frac{1 + 2\sin 2\omega_s t(\omega_c t + \varphi_r)}{2}$$

B. Demodulasi dengan menambahkan carrier

* Blok diagram



$$e_{DSB}(t) = E_s E_c \cos \omega_s t \cos \omega_c t$$

$$e_r(t) = E_r \cos \omega_s t \cos (\omega_c t + \varphi_r)$$

$$e_r(t) = S(t) \cos (\omega_c t + \varphi_r) \quad \Rightarrow \quad S(t) = E_r \cos \omega_s t$$

S(t) menggambarkan amplitudo carrier yang berubah-ubah

* Misal $C_o(t)$ = carrier yang dibangkitkan kembali
dan frekuensi $C_o(t)$ sama dengan frekuensi $e_r(t)$ tetapi phasenya berbeda

maka :

$C_o(t) = E_o \cos(\omega_c t + \phi_r)$

sinyal jumlahan dari $e_r(t)$ dan $C_o(t)$ adalah :

$$e_r(t) + C_o(t) = s(t)\cos(\omega_c t + \phi_r) + E_o \cos(\omega_c t + \phi_c)$$

$$= s(t)\{\cos\omega_c t \cos\phi_r - \sin\omega_c t \sin\phi_c\} + E_o\{\cos\omega_c t \cos\phi_r - \sin\omega_c t \sin\phi_c\}$$

$$= \{s(t)\cos\phi_r + E_o\cos\phi_c\}\cos\omega_c t - \{s(t)\sin\phi_r + E_o\sin\phi_c\}\sin\omega_c t$$

$$= \sqrt{s(t)^2 + E_o^{\,2} + 2E_o s(t)(\cos\phi_r\cos\phi_c + \sin\phi_r\sin\phi_c)}\cos(\omega_c t + \theta)$$

$$= \sqrt{s(t)^2 + E_o^{\,2} + 2E_o s(t)\cos(\phi_r - \phi_c)}\cos(\omega_c t + \theta)$$

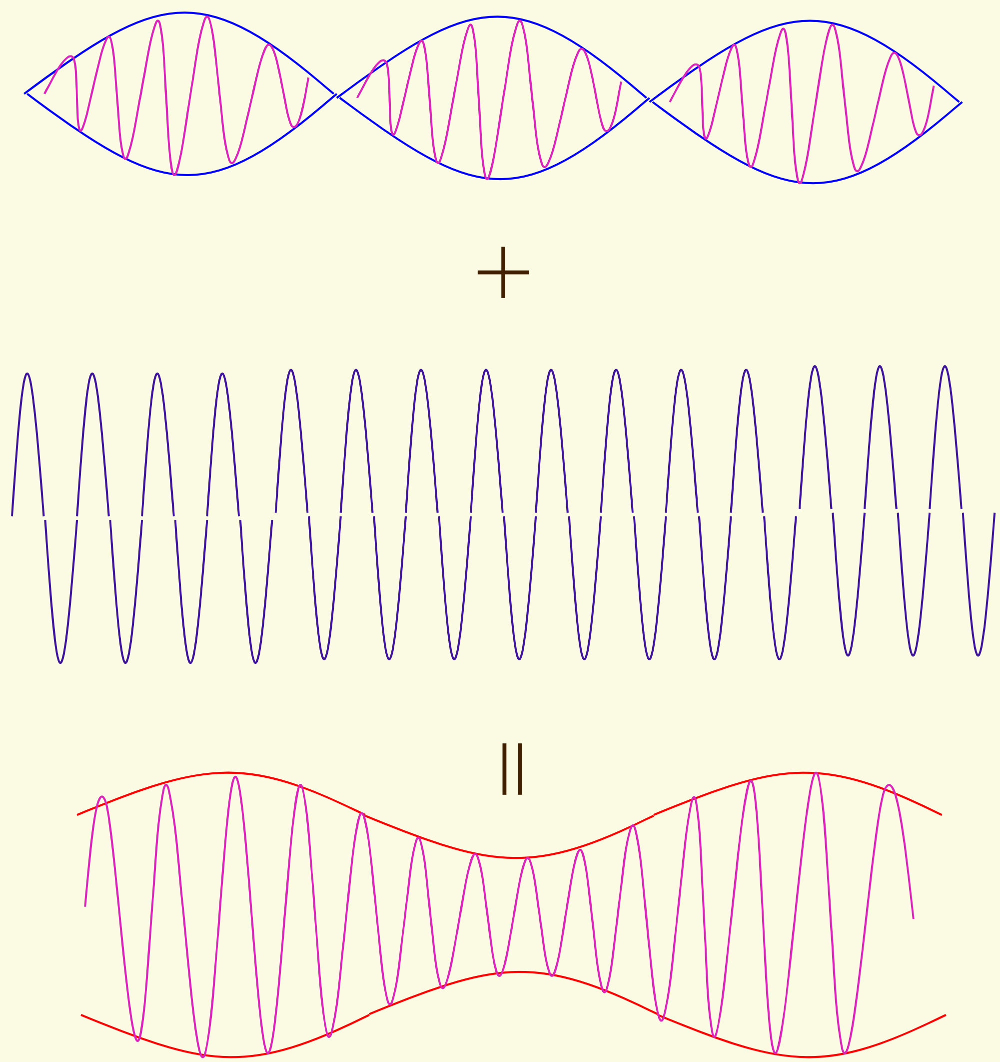
dimana $$\theta = \tan^{-1}\frac{s(t)\sin\theta_r + E_o\sin\theta_c}{s(t)\sin\theta_r + E_o\cos\theta_c}$$

*** Bentuk gelombang DSB-SC dengan cara menambah carrier**

DSB-SC signal

carrier signal

AM signal



* *Persamaan yang digunakan :*

$$A \cos x - B \sin x = \sqrt{A^2 + B^2}\ \cos(x + \theta)$$

dimana $\theta = \tan^{-1}(B/A)$

Jika $\phi_r - \phi_c \approx 0$ *maka* $\cos(\phi_r - \phi_c) \approx 1$

persamaan menjadi

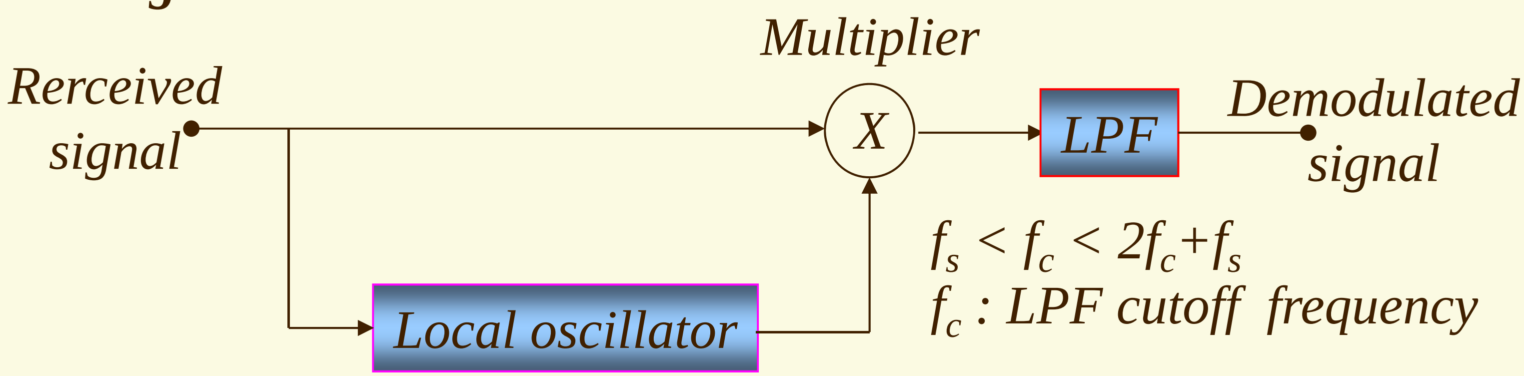
$$E_r(t) + C_o(t) \approx \{s(t) + E_o\} \cos(\omega_c t + \theta)$$

$$= E_o\{1 + s(t)/E_o\} \cos(\omega_c t + \theta)$$

≈ *persamaan AM*

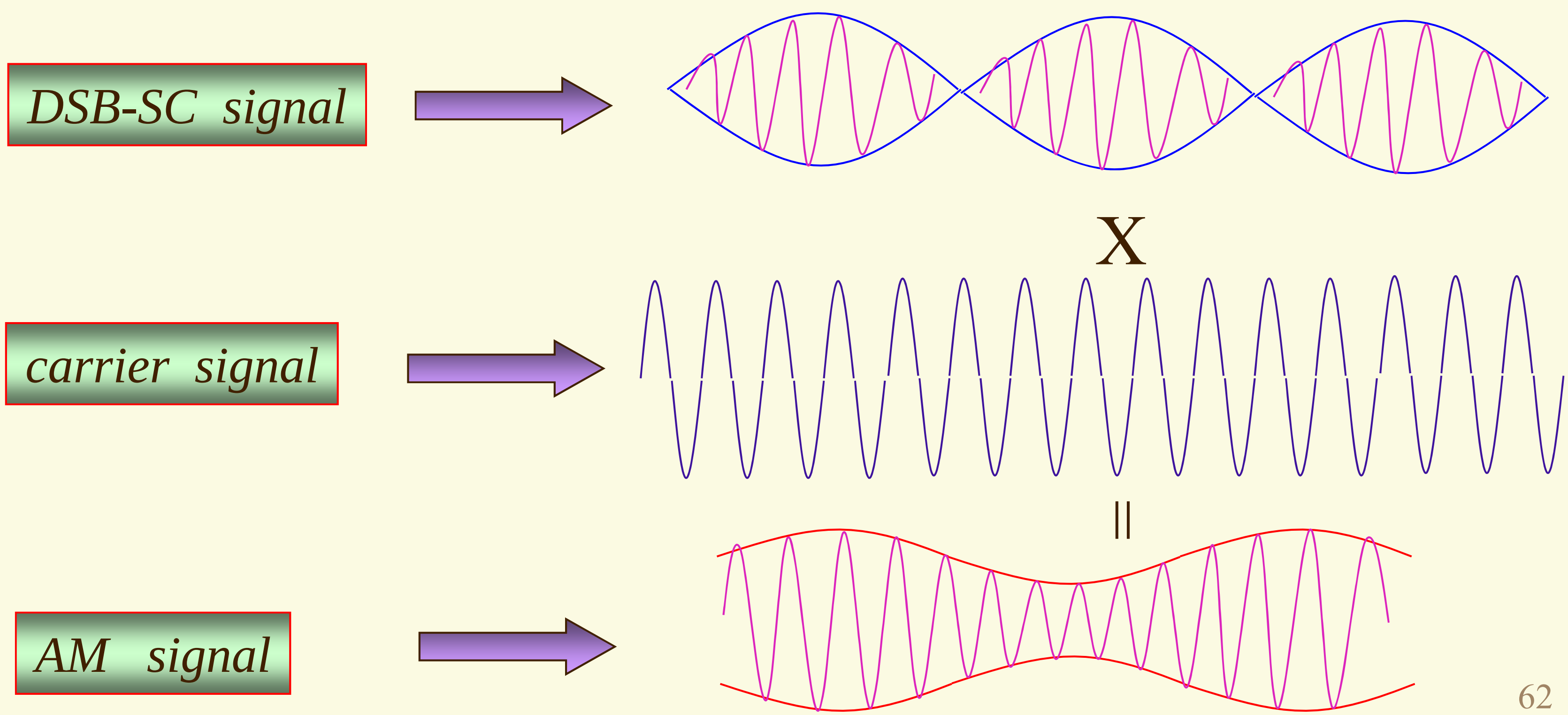
C. Demodulasi perkalian

** Blok diagram*



$f_s < f_c < 2f_c + f_s$

f_c : *LPF cutoff frequency*



**** Persamaan yang digunakan (demodulasi perkalian)***

"Misal sinyal yang diterima :"

$e_r(t) = s(t) \cos(\omega_c t + \phi_r)$ → $s(t) = E_r \cos \omega_s t$

Sinyal carrier $C_o(t) = \cos(\omega_c t + \triangle\omega + \phi_r + \triangle\phi)$

Sinyal perkalian

$$
\begin{aligned}
e_r(t).\, C_o(t) &= s(t) \cos(\omega_c t + \phi_r) \cos(\omega_c t + \triangle\omega + \phi_r + \triangle\phi) \\
&= (1/2)\, s(t) \cos\{(2\omega_c t + \triangle\omega)t + (2\phi_r + \triangle\phi)\} \\
&\quad + (1/2)\, s(t) \cos\{(\triangle\omega t + \triangle\phi)
\end{aligned}
$$

Bila $e_r(t)$ sama dengan frekuensi carrier $C_o(t)$ dan $\triangle\omega = 0$

Maka :

$$e_r(t).\ C_o(t) = (1/2)\ s(t) \cos(2\omega_c t + 2\phi_r + \triangle\phi)\} + (1/2)\ s(t) \cos\triangle\phi)$$

LPF

Jika $\triangle\phi = \pi/2 \longrightarrow 0$

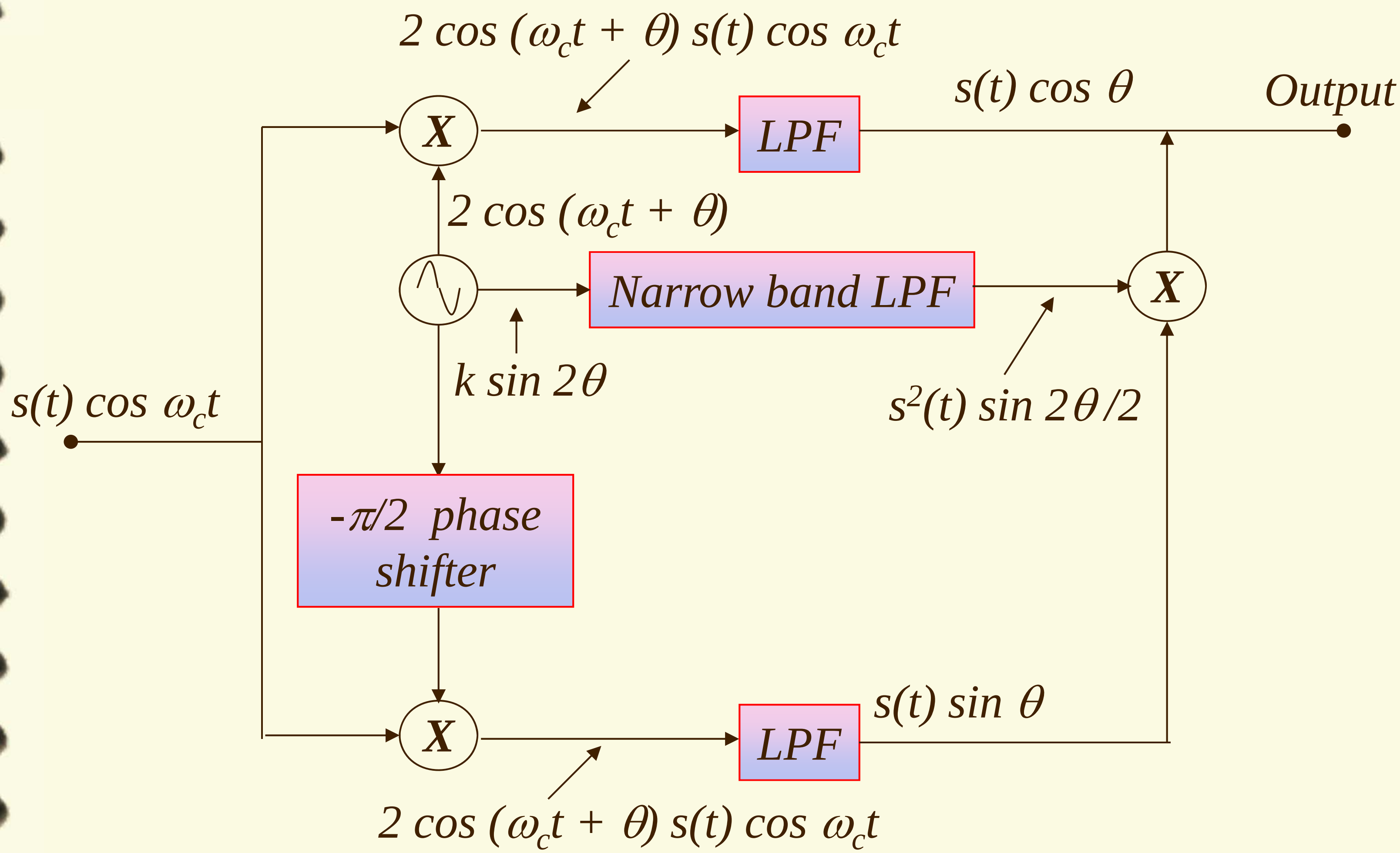
Jika $\triangle\phi = 0 \longrightarrow (1/2)\ s(t)$

$$(1/2)\ s(t) \cos\triangle\phi\ t$$

Hasil demodulasi tidak baik bila frekuensinya berbeda

D. Loop "Costas"

* Blok diagram



2.4 Modulasi sudut

- *Mempunyai sudut phase $\theta(t)$ yang berubah-ubah*
- *Perubahan tergantung pada sinyal pemodulasi*
- *Mempunyai $A(t)$ dan f_c tetap*

** Persamaan :* " $e(t) = A(t) \cos\{2\pi f_c t + \theta(t)\}$ "

** Macam-macam :*

- *Modulasi frekuensi (FM)*
- *Modulasi phase (PM)*

2.4.1 Modulasi frekuensi

* Persamaan matematis :

Sinyal carrier

$e_c = E_c \sin(\omega_c t + \theta_o)$

$\omega_c : 2\pi f_c$: frekuensi sudut carrier

θ_o : phase awal

Sinyal pemodulasi

$e_s = E_s \cos \omega_s t$

$\omega_s : 2\pi f_s$: frekuensi sudut sinyal pemodulasi

Frekuensi sesaat FM

Frekuensi carrier + perubahan frekuensi sesuai sinyal pemodulasi

$$\begin{aligned} f_i &= f_c + k_f\ e_s \\ &= f_c + k_f\ E_s \cos \omega_s t \\ &= f_c + \Delta\ f \cos \omega_s t \end{aligned}$$

$\Delta\ f = k_f E_s$ [Hz]

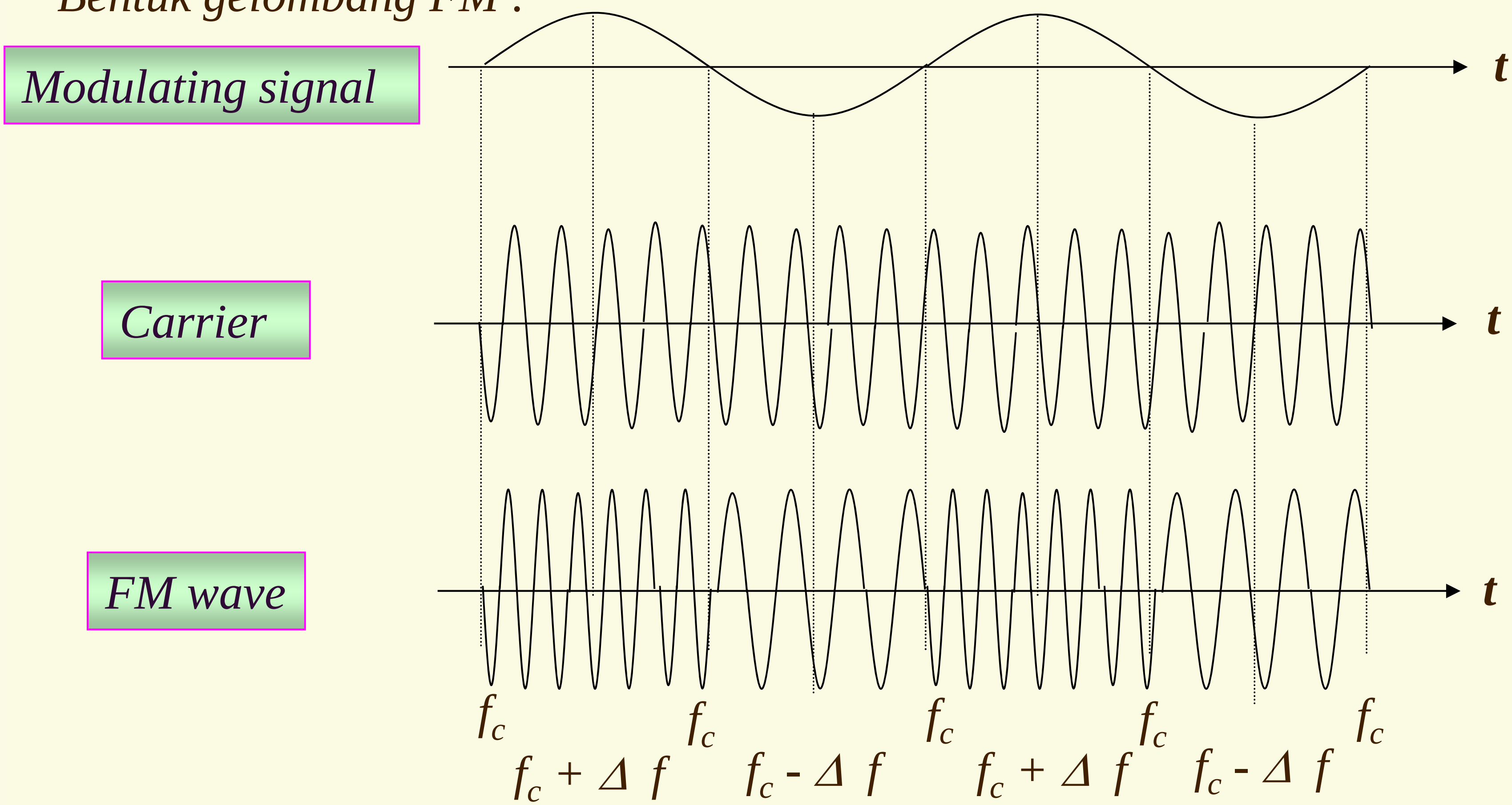
k_f = konstanta [Hz/V]

* Frekuensi sudut sesaat :

$$\begin{aligned}\omega_i &= 2\pi f_i \\ &= 2\,\pi\,(f_c + \Delta\ f\cos\,\omega_s\,t) \\ &= \omega_c + \Delta\,\omega\cos\,\omega_s\,t\end{aligned}$$

$$\Delta\,\omega = 2\pi\,\Delta\ f$$

* Bentuk gelombang FM :



* Persamaan gelombang FM

$$\theta(t) = \int_{0}^{t} \omega_i \quad dt$$

$$= \int_{0}^{t} (\omega_c + \Delta\,\omega \cos\,\omega_s\,t\,)\;\;dt$$

$$= \omega_c\,t + m_f\;\;\sin\,\omega_s\,t$$

Index modulasi FM

$$m_f = \frac{\Delta\omega}{\omega_s} = \frac{\Delta f}{f_s} \quad [radian]$$

$$e_{FM} = E_c \sin\,(\omega_c t + m_f\;\;\sin\,\omega_s\,t + \theta_o)$$

$$\theta_o = 0$$

$$e_{FM} = E_c \sin\,(\omega_c t + m_f\;\;\sin\,\omega_s\,t)$$

* Rasio deviasi & persen modulasi

Deviasi maximum

$$\delta = \frac{\Delta f}{f_{s\,\max}} \quad [radian]$$

Frek. Sinyal pemodulasi

$$\beta = \frac{\Delta f \quad sebenarnya}{\Delta f \quad \max\ imum} x100\,[\%]$$

* Spektrum gelombang FM

- *Menggunakan fungsi Bessel*

$$
\begin{aligned}
e_{FM} &= E_c \sin(\omega_c t + m_f \sin \omega_s t) \\
&= E_c[\sin \omega_c t \,.\, \cos(m_f \sin \omega_s t) + \cos \omega_s t \,.\, \sin(m_f \sin \omega_s t)] \\
&= E_c \sin \omega_c t \,\{J_o(m_f) + 2\sum_{n=1}^{\infty} J_2 n(m_f) \cos 2n\, \omega_c t \\
&\quad + E_c \cos \omega_c t \,\{2\sum_{n=0}^{\infty} J_2 n+1(m_f) \cos(2n+1)\, \omega_s t\} \\
&= E_c \{J_o(m_f) \sin \omega_c t \\
&\quad + 2J_1(m_f) \cos \omega_c t \,.\, \sin \omega_s t + 2J_2(m_f) \sin \omega_c t \,.\, \cos \omega_s t \\
&\quad + 2J_3(m_f) \cos \omega_c t \,.\, \sin 2\omega_s t + 2J_4(m_f) \sin \omega_c t \,.\, \cos 2\omega_s t \\
&\quad + 2J_5(m_f) \cos \omega_c t \,.\, \mathrm{Sin}\, 3\omega_s t + 2J_6(m_f) \sin \omega_c t \,.\, \cos 3\omega_s t \\
&\quad + \,.\,.\,.\, \}
\end{aligned}
$$

* Lanjutan

- *Menggunakan fungsi Bessel*

$$
\begin{aligned}
e_{FM} = E_c \{ J_o(m_f) \sin \omega_c t \; & \\
& + J_1(m_f) \{\sin(\omega_c + \omega_s) t - \sin(\omega_c - \omega_s) t\} \\
& + J_2(m_f) \{\sin(\omega_c + 2\omega_s) t + \sin(\omega_c - 2\omega_s) t\} \\
& + J_3(m_f) \{\sin(\omega_c + 3\omega_s) t - \sin(\omega_c - 3\omega_s) t\} \\
& + \ldots \}
\end{aligned}
$$

carrier

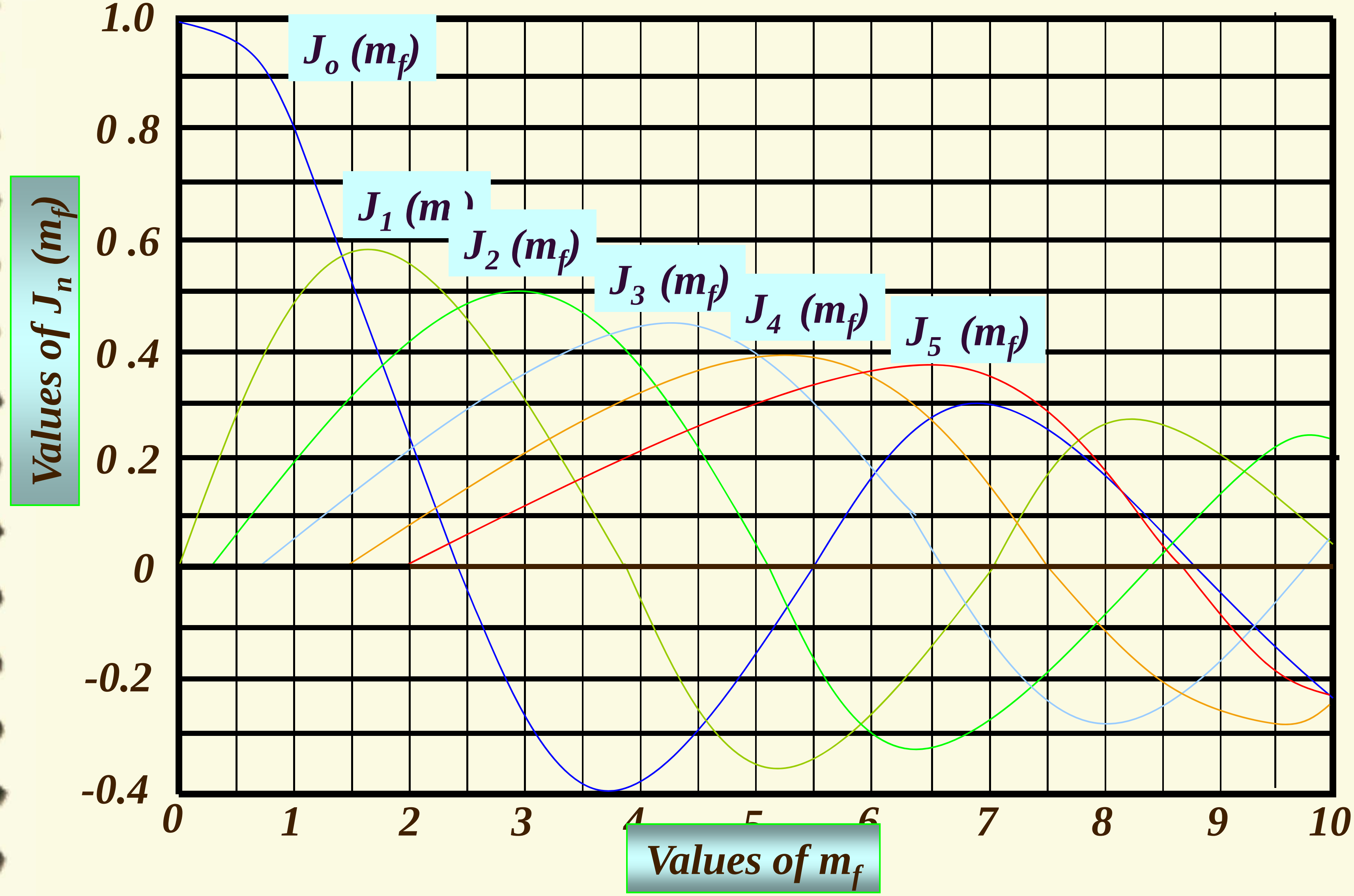
sidebands

$$
e_{FM} = E_c \left[J_o(m_f) \sin \omega_c t + 2 \sum_{n=1}^{\infty} Jn(m_f) \sin(\omega_c + n\,\omega_s)\, t \right.
$$

$$
\left. + 2 \sum_{n=1}^{\infty} (-1)^n J_n(m_f) \sin(\omega_c + n\,\omega_s)\, t \right]
$$

* Fungsi Bessel *

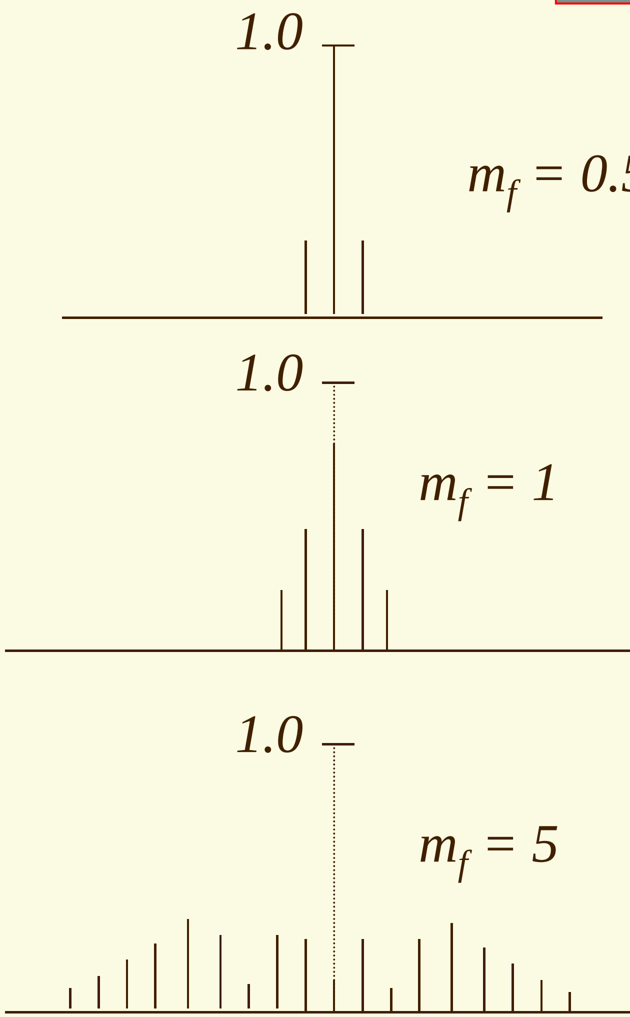
J_n (m_f) sebagai fungsi m_f untuk n = 0, 1, 2, . . . ,5



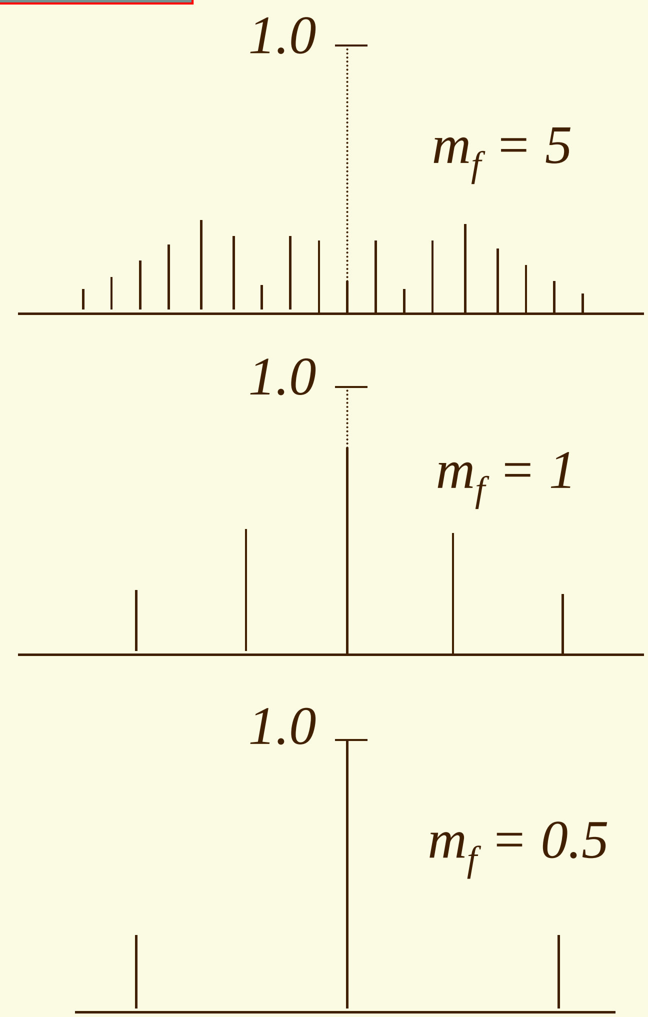
* Tabel fungsi Bessel

M_f	J_o	J_1	J_2	J_3	J_4	J_5	J_6	J_7	J_8
0.00	1.000								
0.10	0.9975	0.0499	0.0013	0.0001					
0.20	0.9900	0.0995	0.0050	0.0002	0.0001				
0.25	0.9845	0.1241	0.0078	0.0003	0.0001				
0.30	0.9776	0.1484	0.0111	0.0006	0.0001				
0.40	0.9604	0.1961	0.0197	0.0013	0.0001				
0.50	0.9385	0.2423	0.0306	0.0026	0.0002				
0.60	0.9120	0.2867	0.0437	0.0044	0.0004	0.0001			
0.70	0.8812	0.3290	0.0588	0.0069	0.0006	0.0001			
0.80	0.8463	0.3689	0.0758	0.0103	0.0011	0.0001			
0.90	0.8075	0.4060	0.0946	0.0144	0.0017	0.0002			
1.00	0.7652	0.4400	0.1150	0.0195	0.0025	0.0003	0.0001		
1.25	0.6459	0.5107	0.1711	0.0369	0.0059	0.0008	0.0001		
1.50	0.5119	0.5579	0.2321	0.0610	0.0118	0.0018	0.0003		
1.75	0.3690	0.5802	0.2940	0.0919	0.0209	0.0038	0.0006	0.0001	
2.00	0.2239	0.5767	0.3529	0.1289	0.0340	0.0070	0.0012	0.0002	
2.50	-0.0484	0.4971	0.4461	0.2166	0.0738	0.0195	0.0043	0.0008	0.0002

* Spektrum sinyal FM

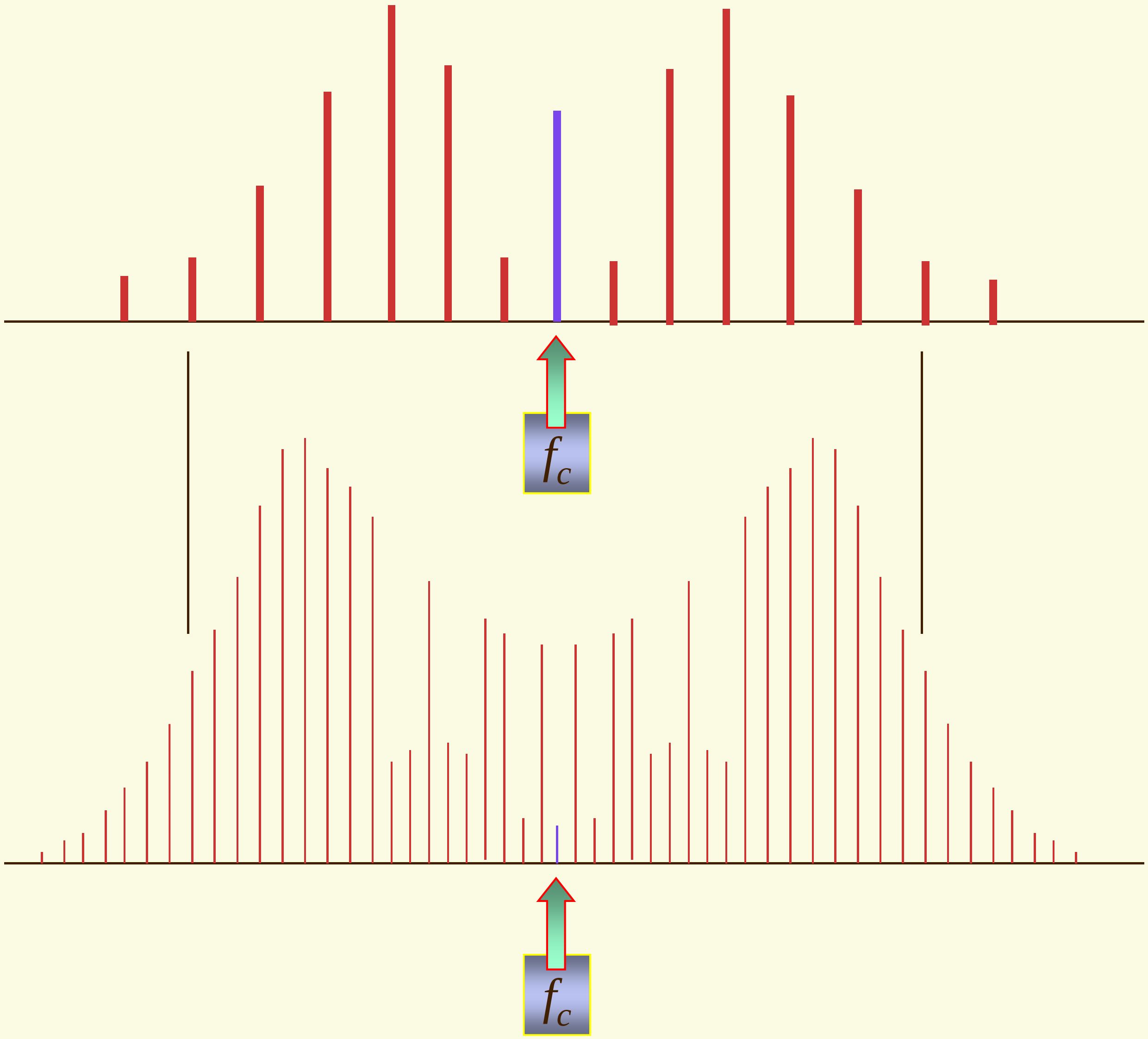


f_s :tetap, m_f : makin besar
(Δ f : makin besar)



Δ f :tetap, f_s: makin besar
(m_f : makin kecil)

* Spektrum sinyal FM



$m_f = 4,\ f_s$ besar

$\Delta\ f$ adalah sama untuk kedua contoh ini

$m_f = 20,\ f_s$ kecil

* Bandwidth FM*

Tergantung index modulasi (m_f)

$B_{FM} = 2\, f_s$; $f \ll f_s$ ⇒ $m_f \ll 1$
narrowband FM

$B_{FM} = 2(\Delta f + f_s)$; $\Delta f \ll f_s$ ⇒ $m_f \gg 1$
wideband FM

Lebih tepat ⇒
Gambar fungsi BESSEL
$B_{FM} = 2\, N\, f_s$
N = jumlah sideband

** Pengukuran index modulasi sinyal FM **

- *Membuat amplitudo carrier tak termodulasi sama dengan satu kemudian tentukan m_f dengan grafik fungsi Bessel.*
- *Dengan melihat amplitudo carrier dan amplitudo sideband berdasarkan tabel berikut :*

Beberapa harga m_f untuk mengukur index modulasi

	Carrier = 0	Sideband pertama =0	Carrier = Sideband pertama
m_f	2,40 5,52 8,65	3,83 7,02 10,17	1,44 3,11

* Daya sinyal FM *

$P_T = P_C + P_{SB}$

P_T = Daya total yang dikirimkan

P_C = Daya carrier

P_{SB} = Daya total sideband

$$P_T = \frac{E_c^{\,2}}{2R}$$

E_c = Tegangan peak carrier

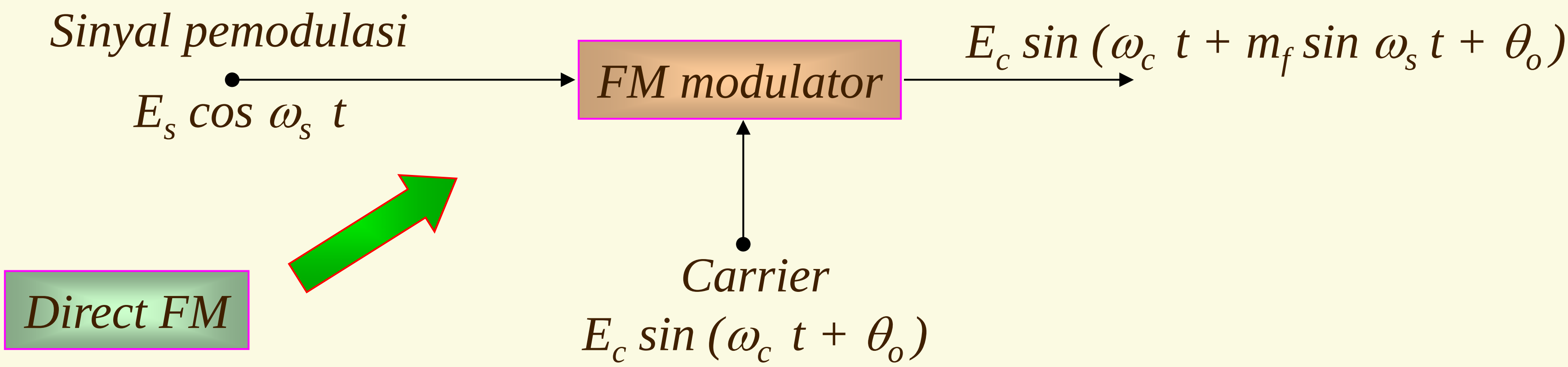
$P_C = J_o^{\,2}(m_f)\ P_T$

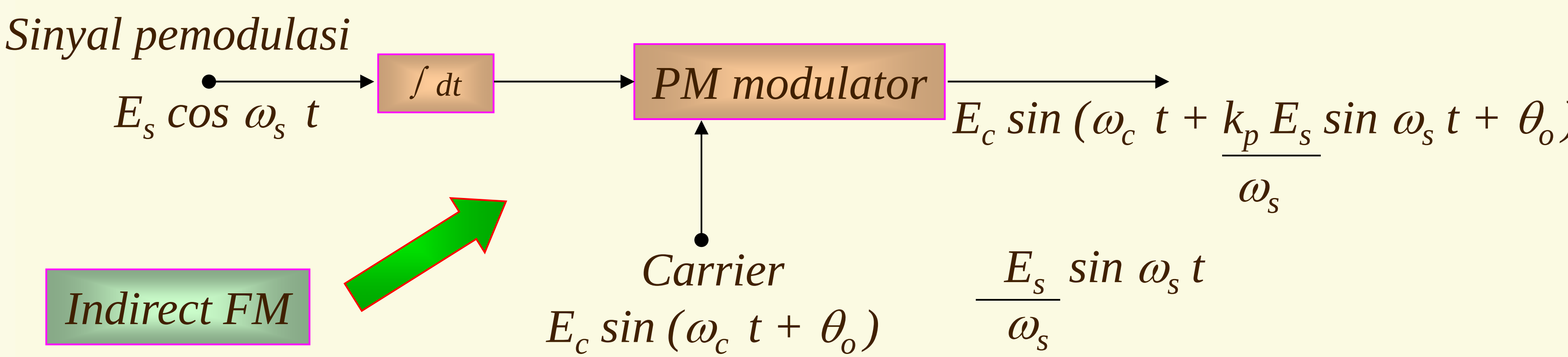
$P_{SB\ I} = 2\,J_1^{\,2}(m_f)\ P_T$

$P_{SB} = P_T - P_C$

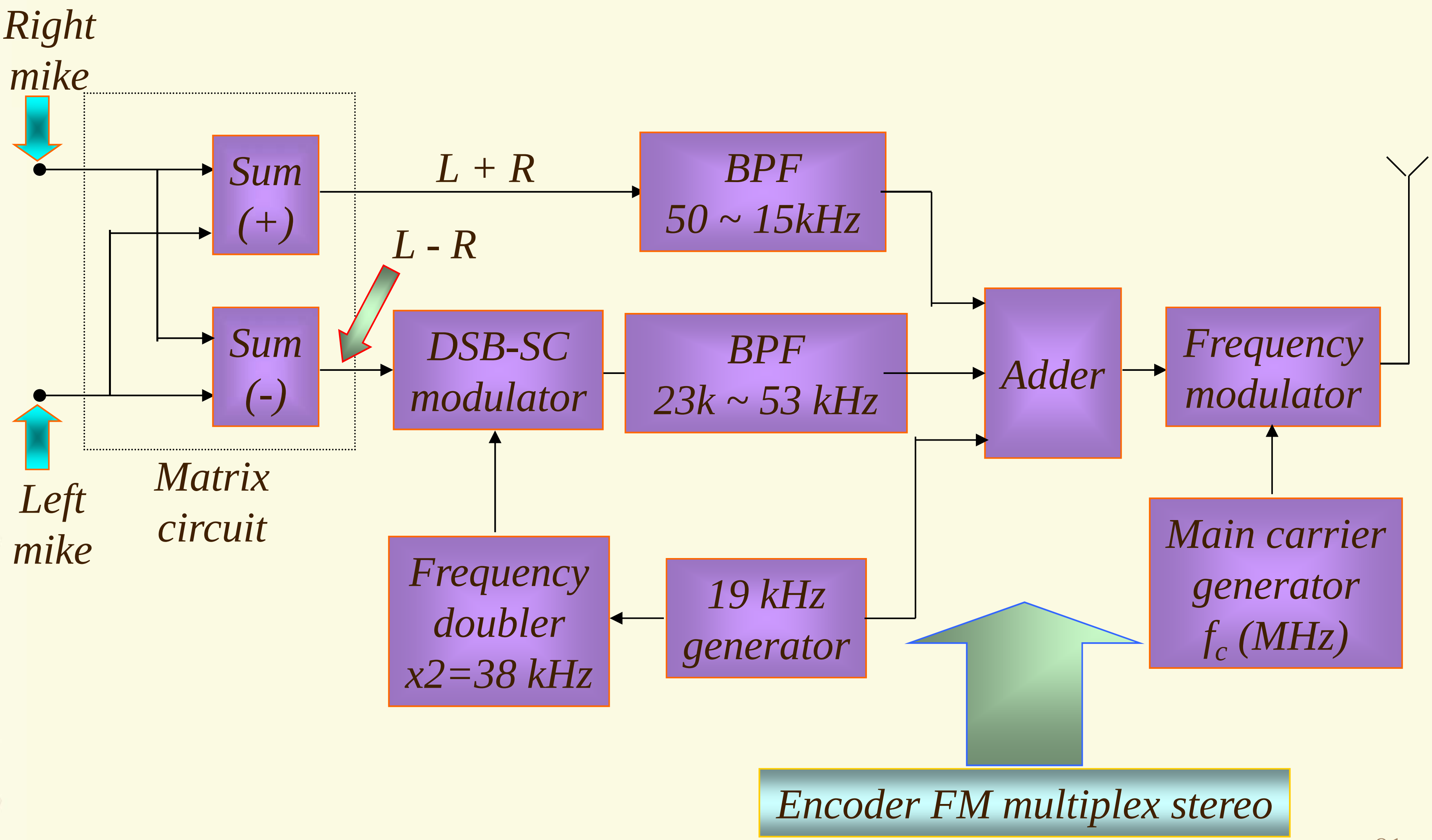
m_f = Index modulasi sinyal FM

* Pembangkitan sinyal FM *

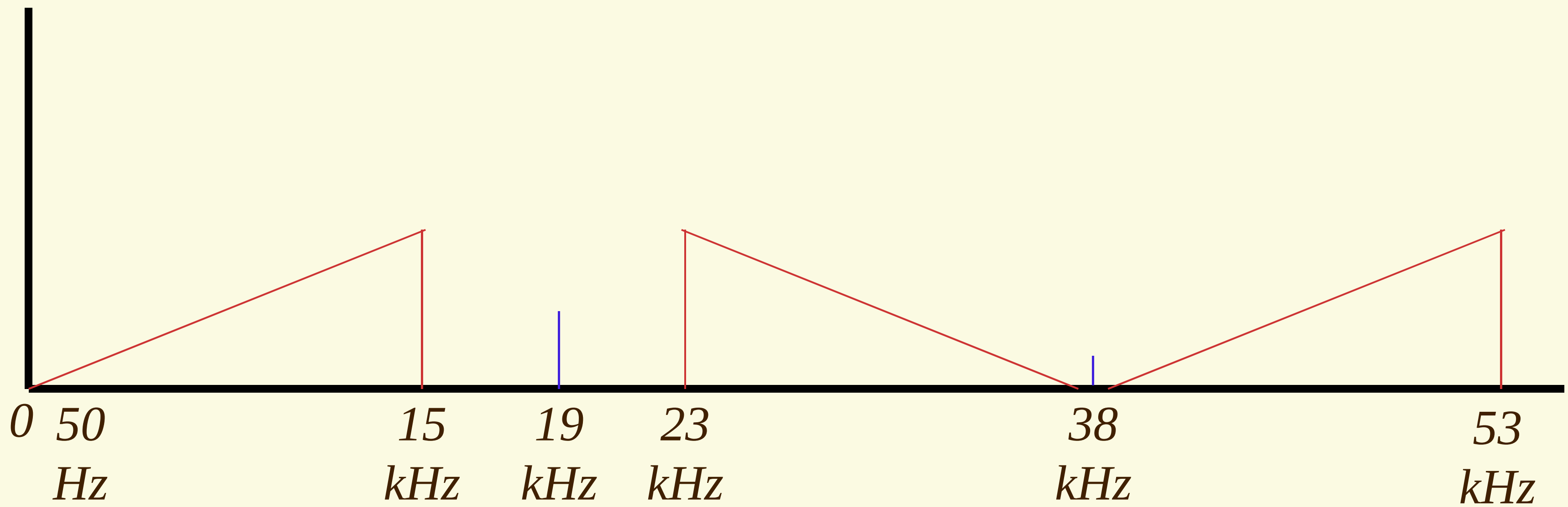




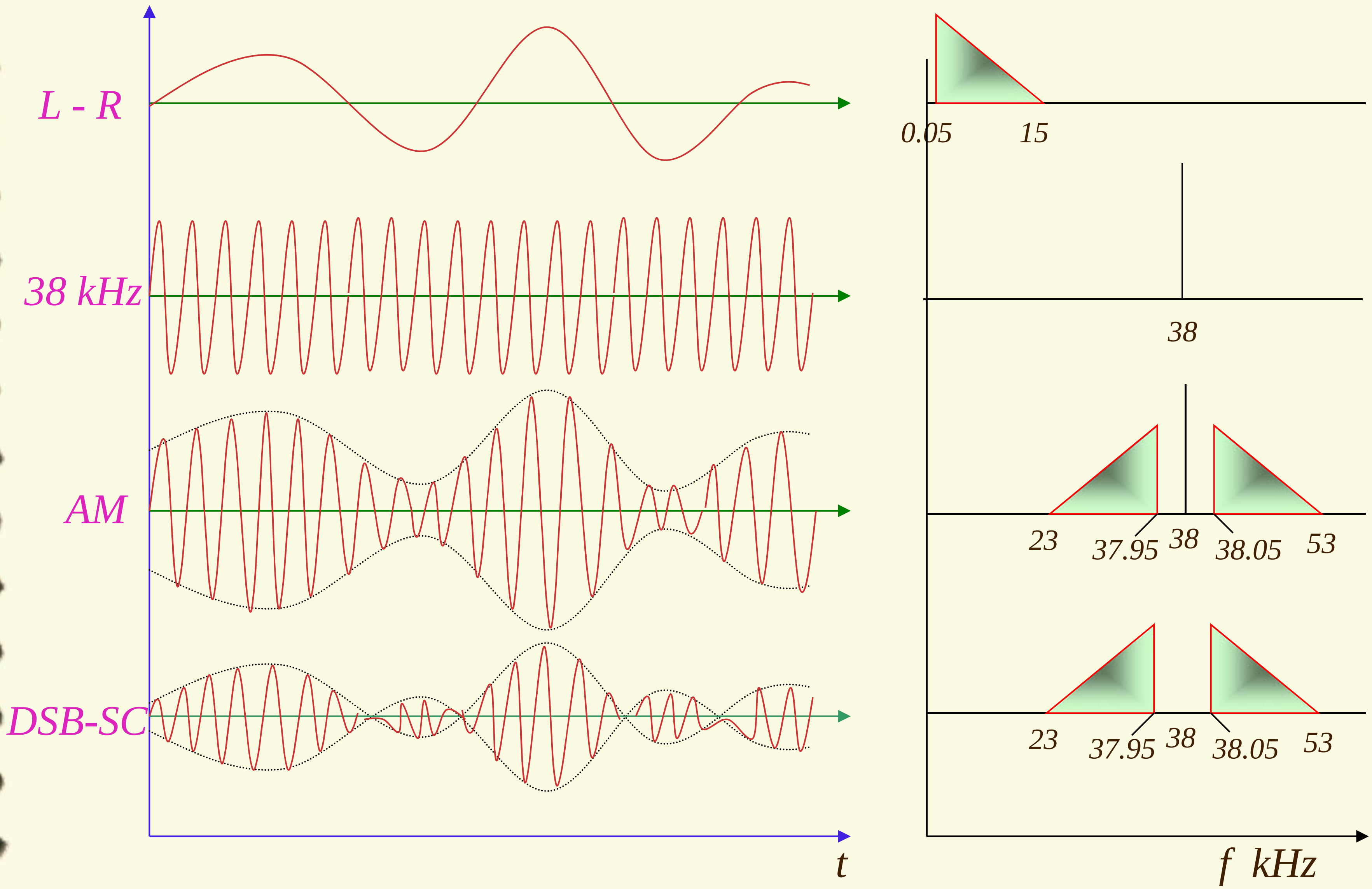
* Teknik pembangkitan FM stereo Broadcast



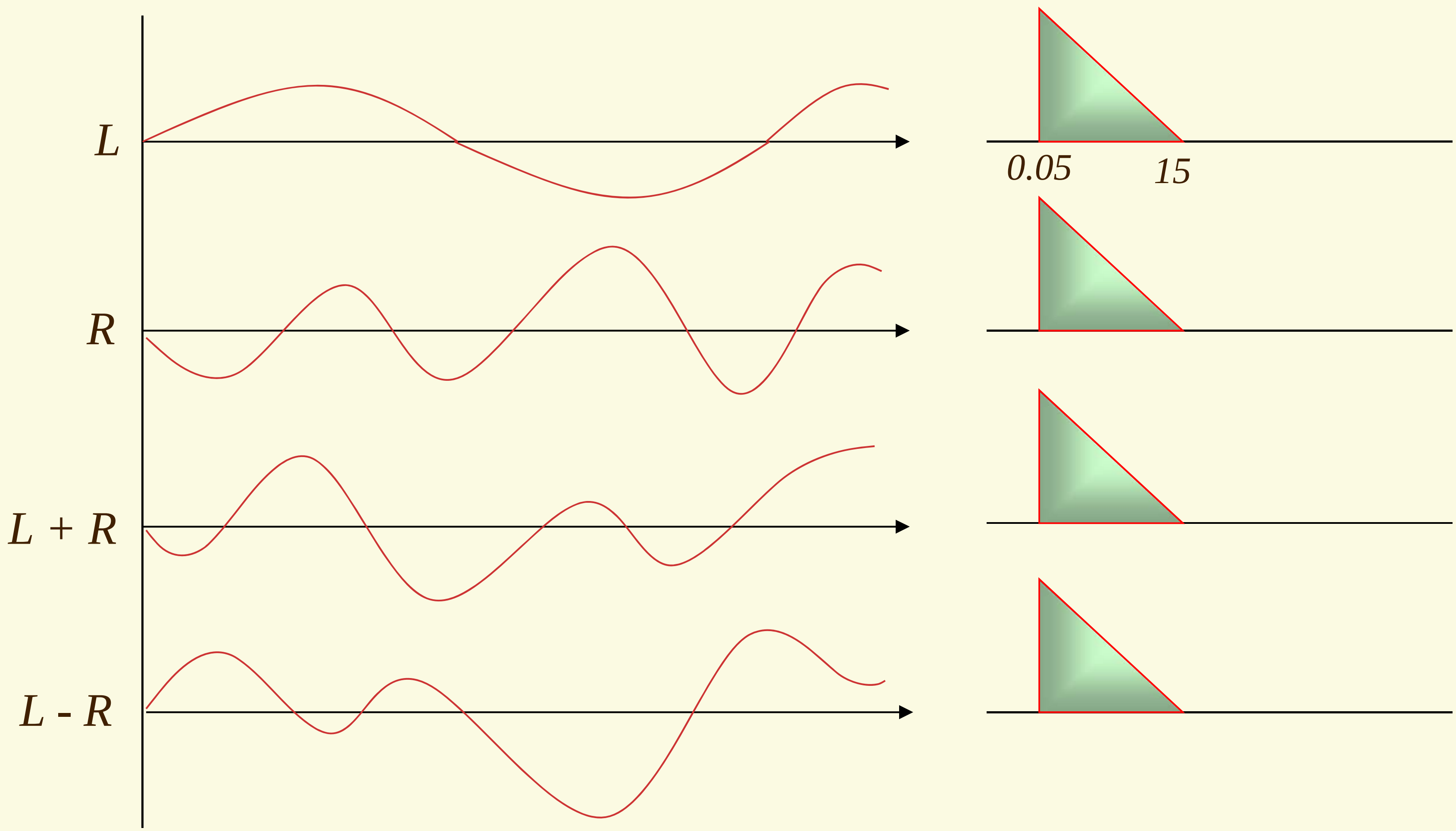
* Spektrum sinyal pemodulasi FM multiplexing stereo



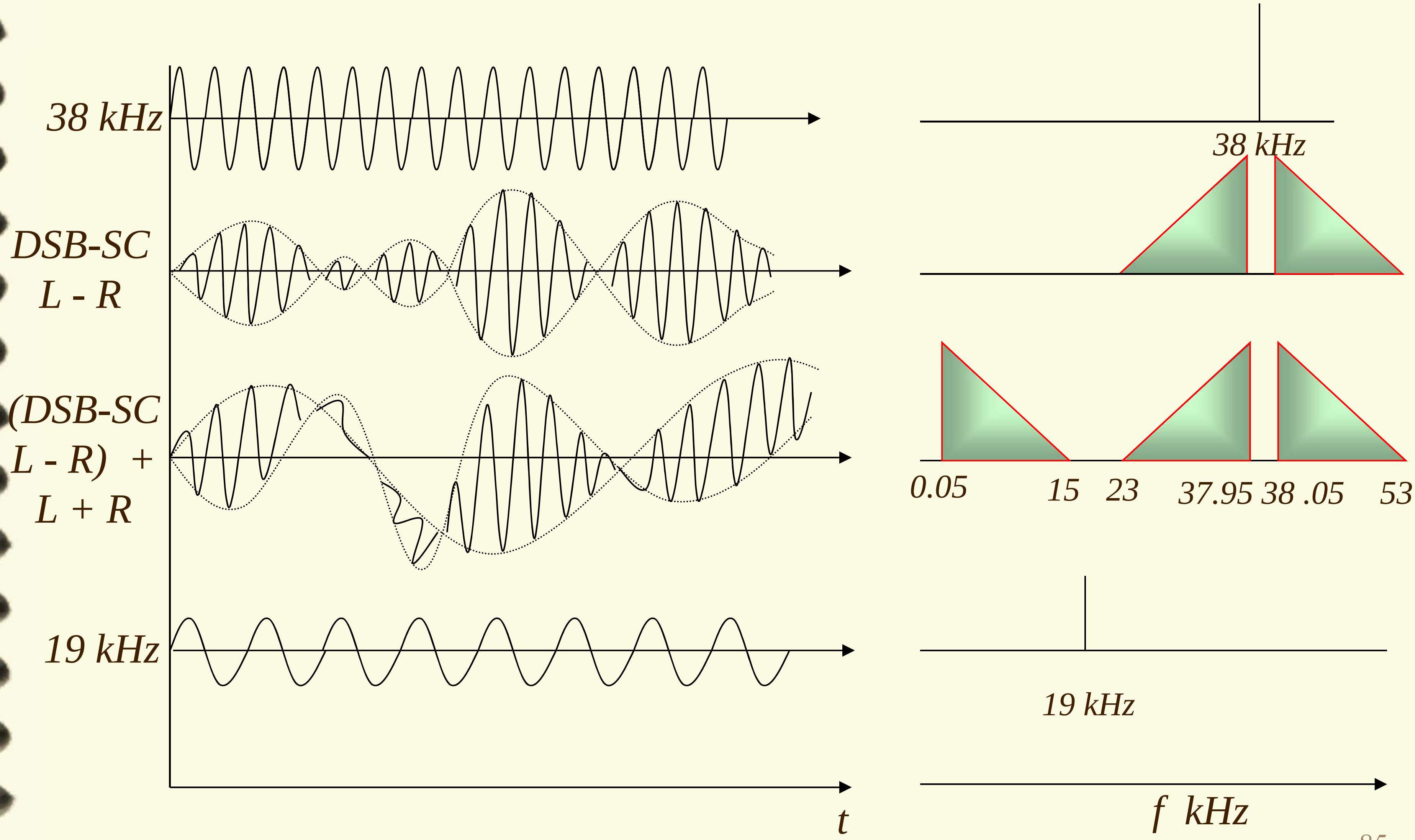
* Sinyal L - R dan spektrum frekuensi



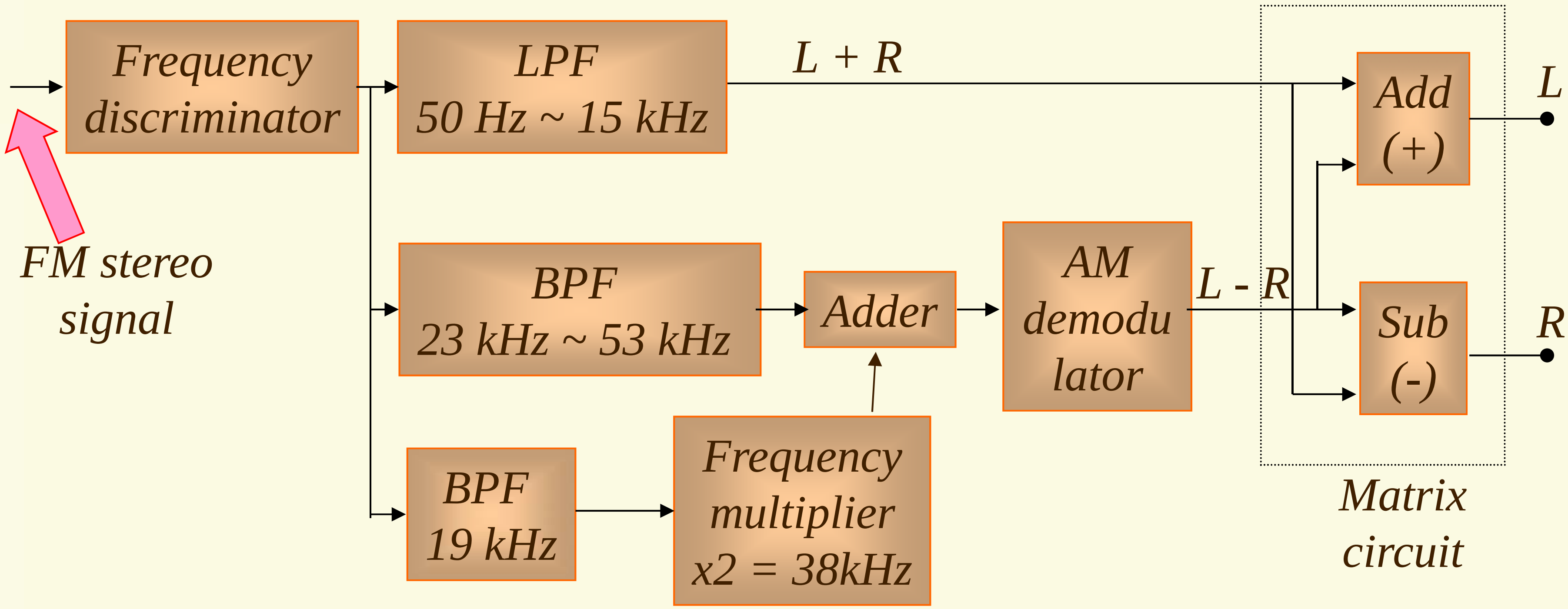
* Bentuk gelombang & spektrum transmisi FM stereo *



*** Bentuk gelombang & spektrum transmisi FM stereo ***

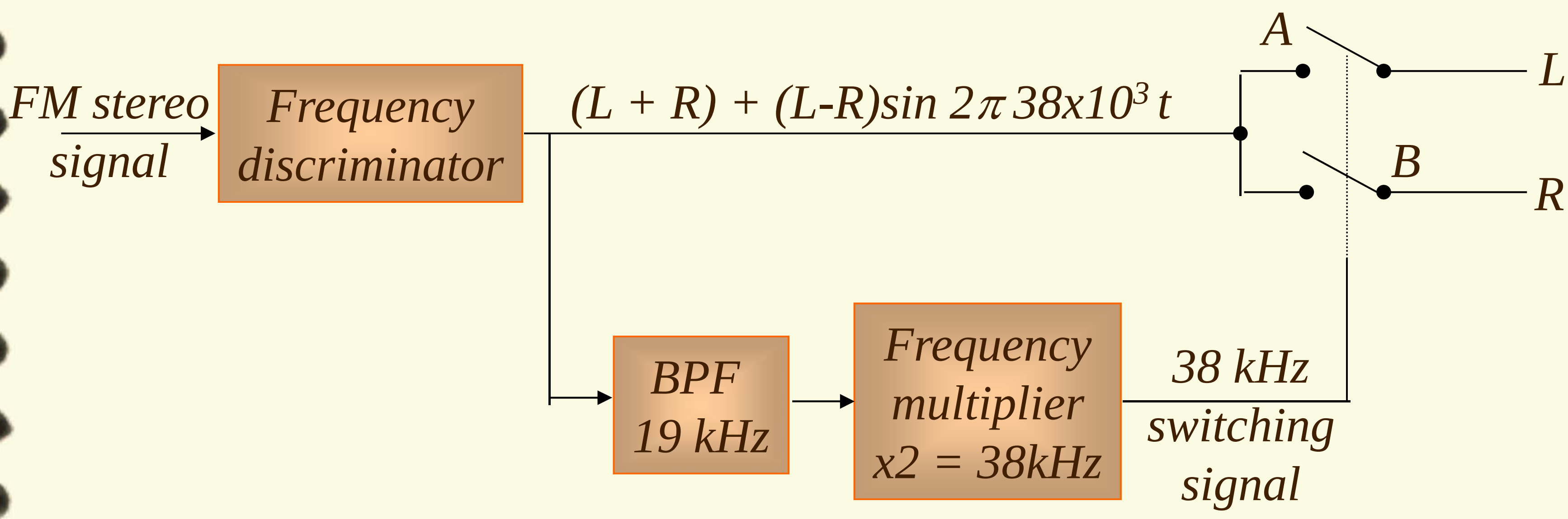


* Decoder FM stereo



Sistem Matrix

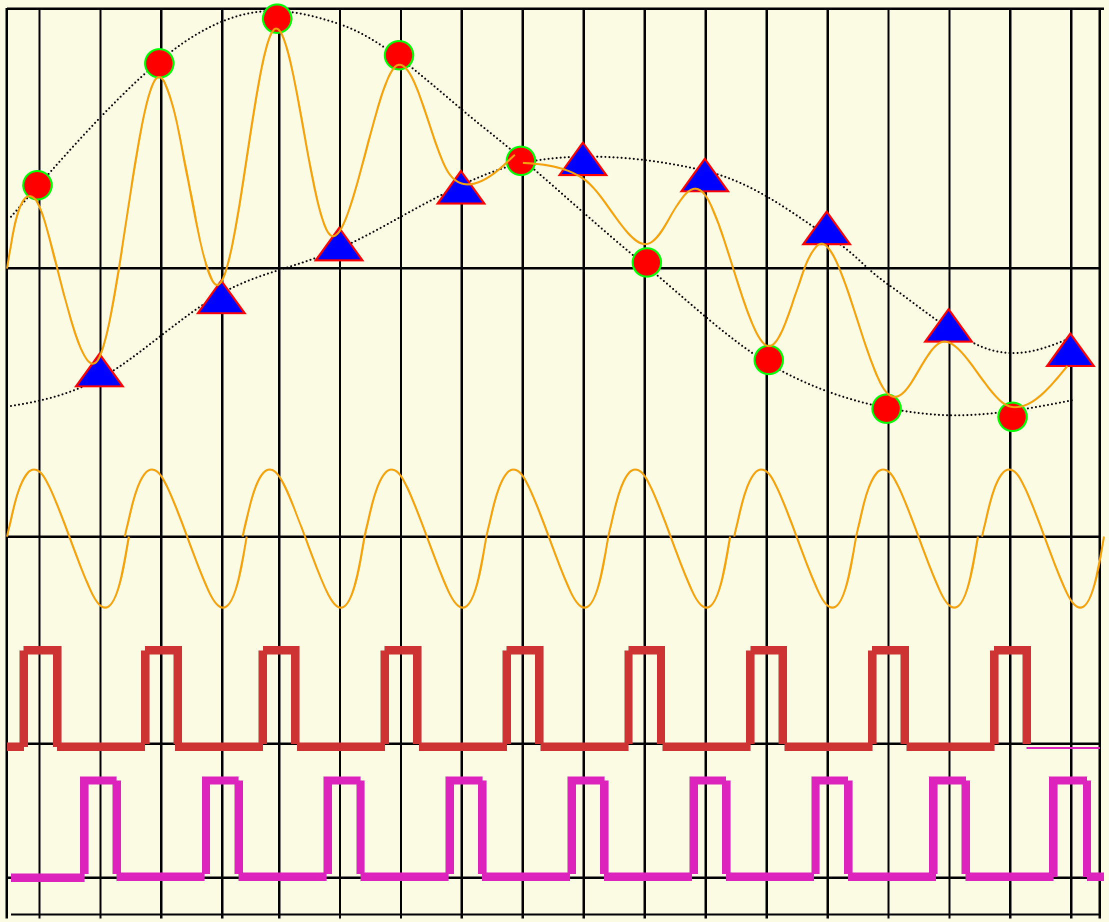
* Decoder FM stereo



Jenis switching

* Bentuk gelombang decoder FM stereo jenis switching *

(L + R) +
(L - R) sin 2π 38 x 10^3 t

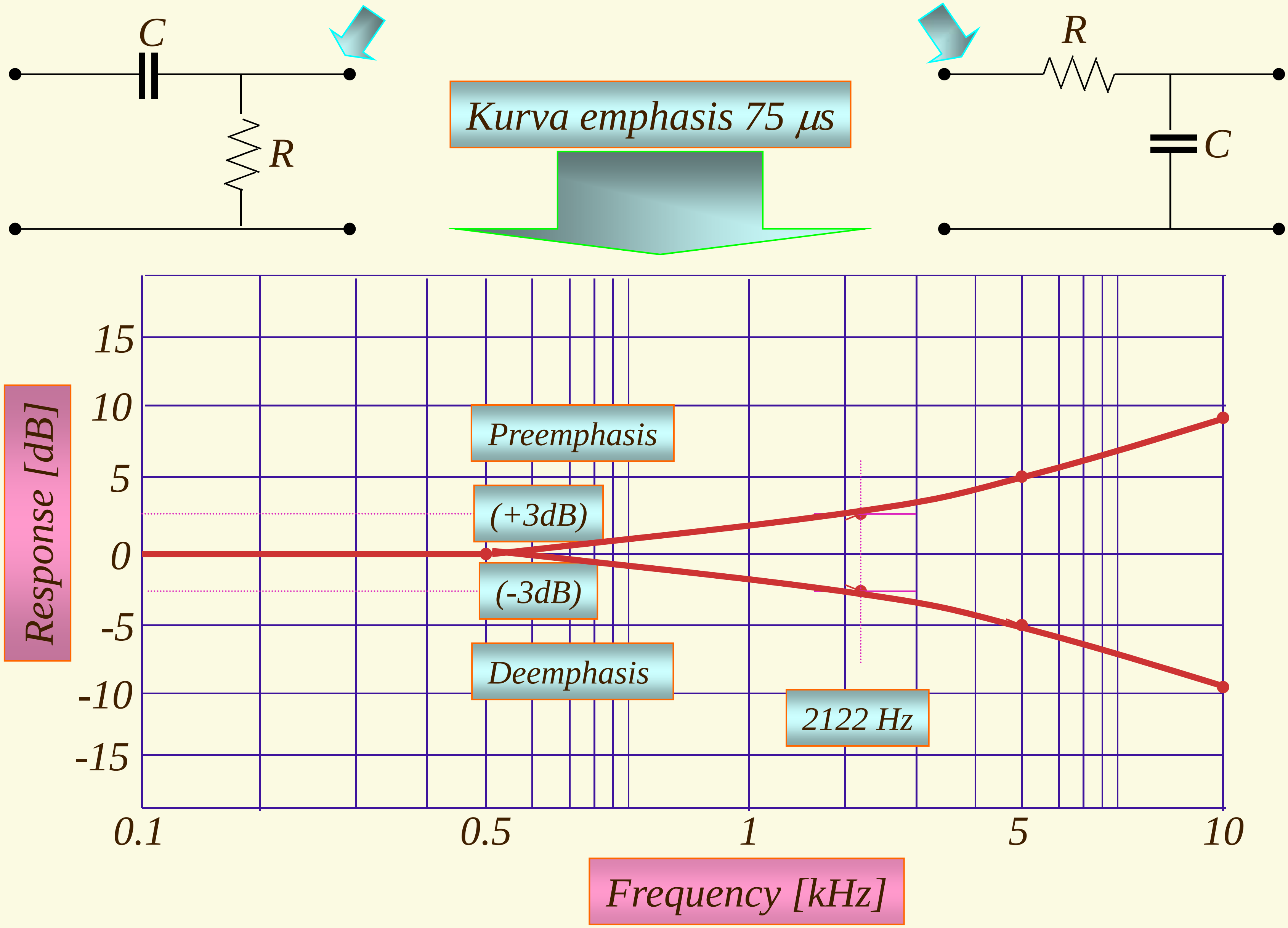


Sub-carrier

Switch A ON

Switch B ON

* Pre-emphasis & de-emphasis



* Jenis-jenis emisi FM *

- *FIA (sebelumnya F_1). : Carrier digeser frekuensinya (FSK) dan diterima dengan pendengaran*
- *FIB (sebelumnya F_1) : Carrier digeser frekuensinya (FSK) dan diterinma secara mekanis atau elektronik*
- *F2A (sebelumnya F_2) : Carrier digeser frekuensinya (FSK) dan termodulasi tone, diterima dengan pendengaran*
- *F3E (sebelumnya F_3) : Carrier termodulasi frekuensi, dimodulasi dengan suara analog atau music.*
- *F3C (sebelumnya F_4) : Carrier termodulasi frekuensi, dimodulasi dengan elemen-elemen gambar diam (faximail)*
- *F3F (sebelumnya F_5) : Carrier termodulasi frekuensi, dimodulasi dengan gambar bergerak (televisi yang digunakan pada TV satelit)*

2.4.2 Demodulator FM (diskriminator frekuensi)

Macam-macam

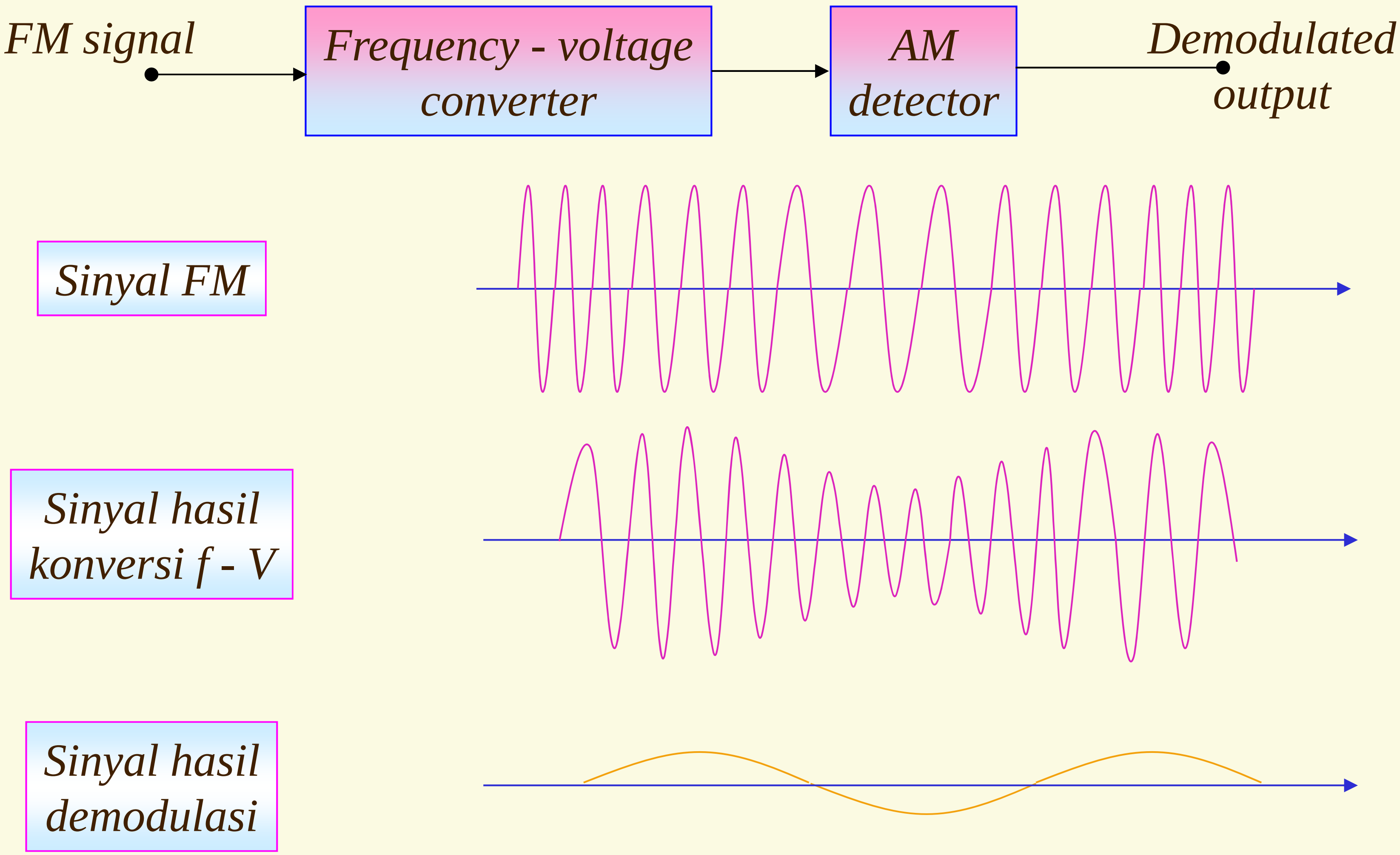
- *Slope detektor*
- *Detektor ballans*
- *Demodulator PLL*
- *Detektor Quadrature*
- *Diskriminator Foster Seeley*
- *Detektor ratio*

Konversi frekuensi ke tegangan

&

Detektor AM

Diagram blok dan bentuk sinyal konversi frekuensi ke tegangan dan detektor AM



Persamaan demodulator FM

Persamaan sinyal FM

$$e_{FM} = E_c \sin(\omega_c t + m_f \sin \omega_s t)$$

dimana,

$$m_f = \Delta\omega / \omega_s = \Delta f / f_s \,,\quad \omega_s = 2\pi f_s$$

diffrerensiasi

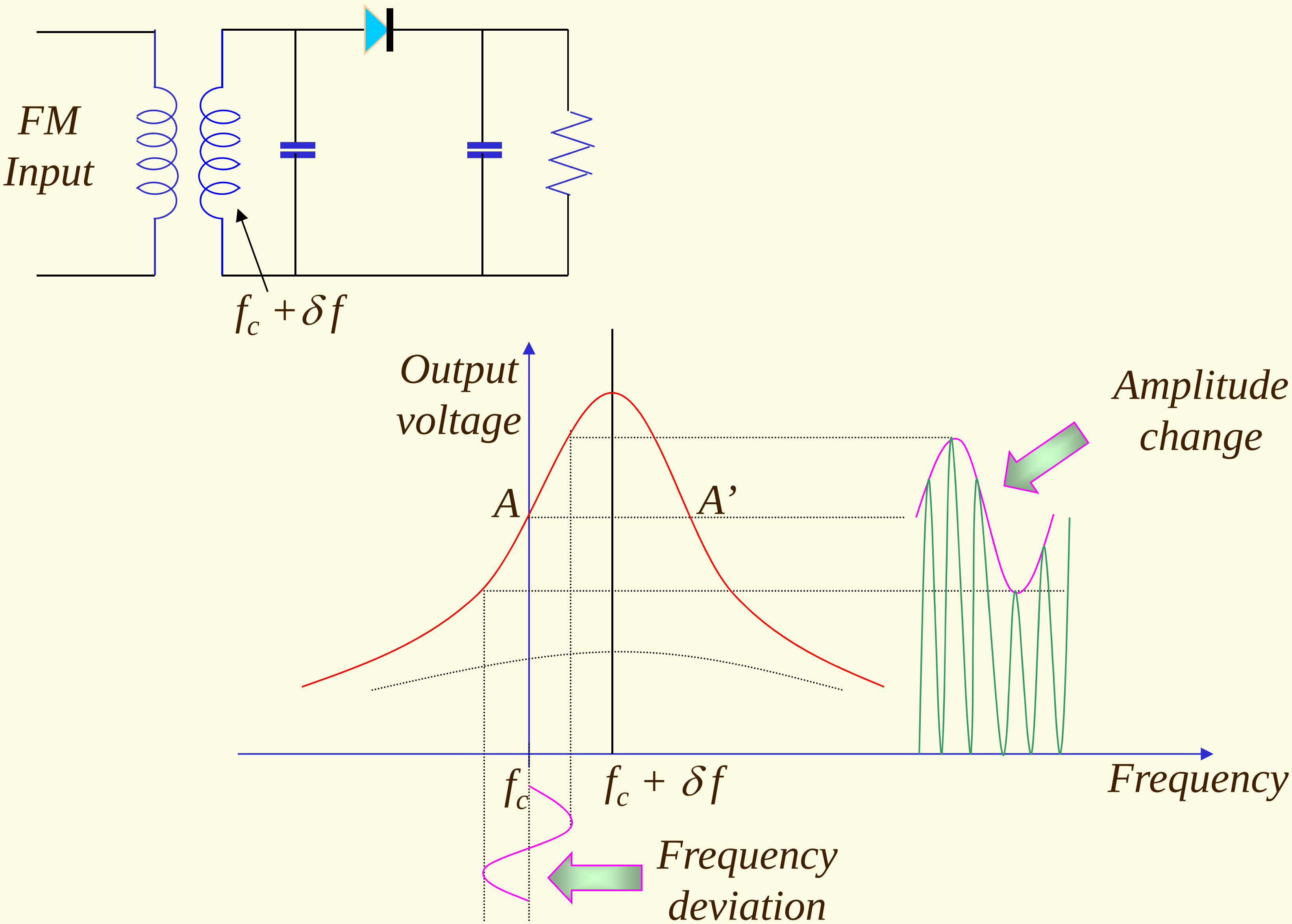
$$\begin{aligned}
e'_{FM} &= E_c(\omega_c + \omega_s m_f \sin \omega_s t)\cos(\omega_c t + m_f \sin \omega_s t) \\
&= E_c\,\omega_c\left(1 + \frac{\omega_s m_f}{\omega_c}\cos \omega_s t\right)\cos(\omega_c t + m_f \sin \omega_s t) \\
&= E_c'(1 + m \cos \omega_s t)\cos(\omega_c t + m_f \sin \omega_s t)
\end{aligned}$$

$\approx$ *pers. AM*

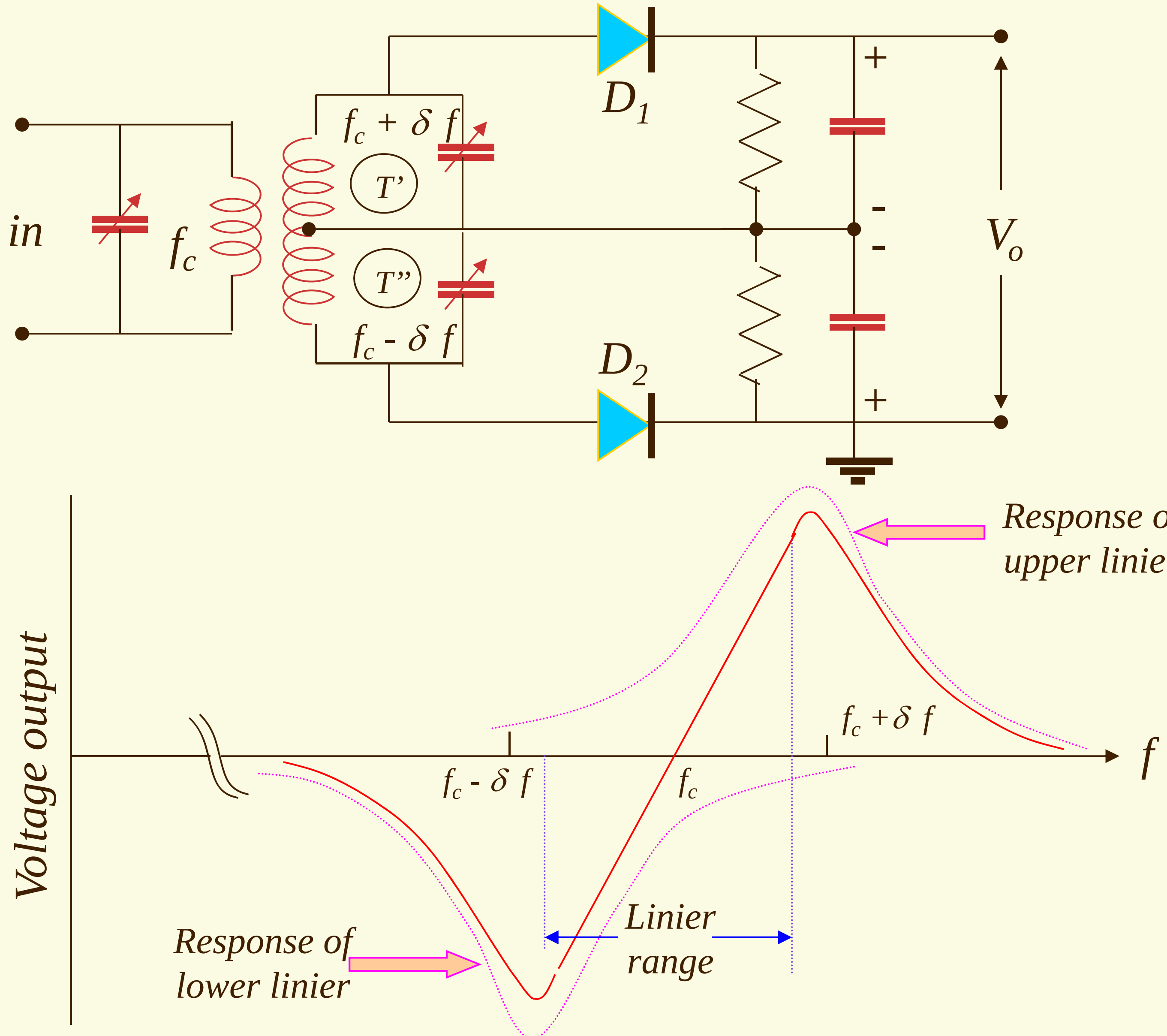
dimana,

$$E_c' = E_c\,\omega_c \quad \text{dan} \quad m = \frac{\omega_s m_f}{\omega_c} = \Delta\omega / \omega_c$$

Slope detector



Slope detector ballans



BAB III
FREQUENCY DIVISION MULTIPLEXING
[FDM]

3.1 Multiplexing

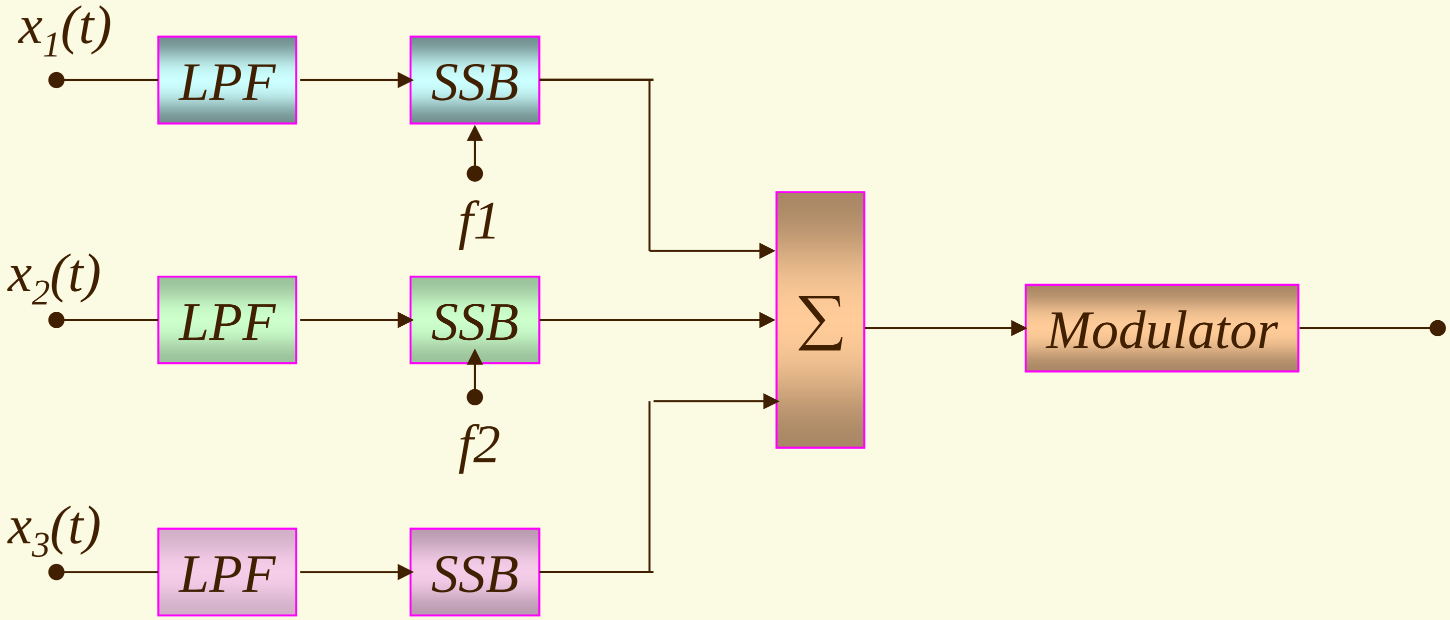
** Definisi : Suatu cara pengiriman beberapa macam informasi atau sinyal melalui sebuah saluran secara bersama-sama dengan tujuan meningkatkan effisiensi saluran*

** Jenis : - Frequency Division Multiplexing [FDM]*
- Time Division Multiplexing [TDM]

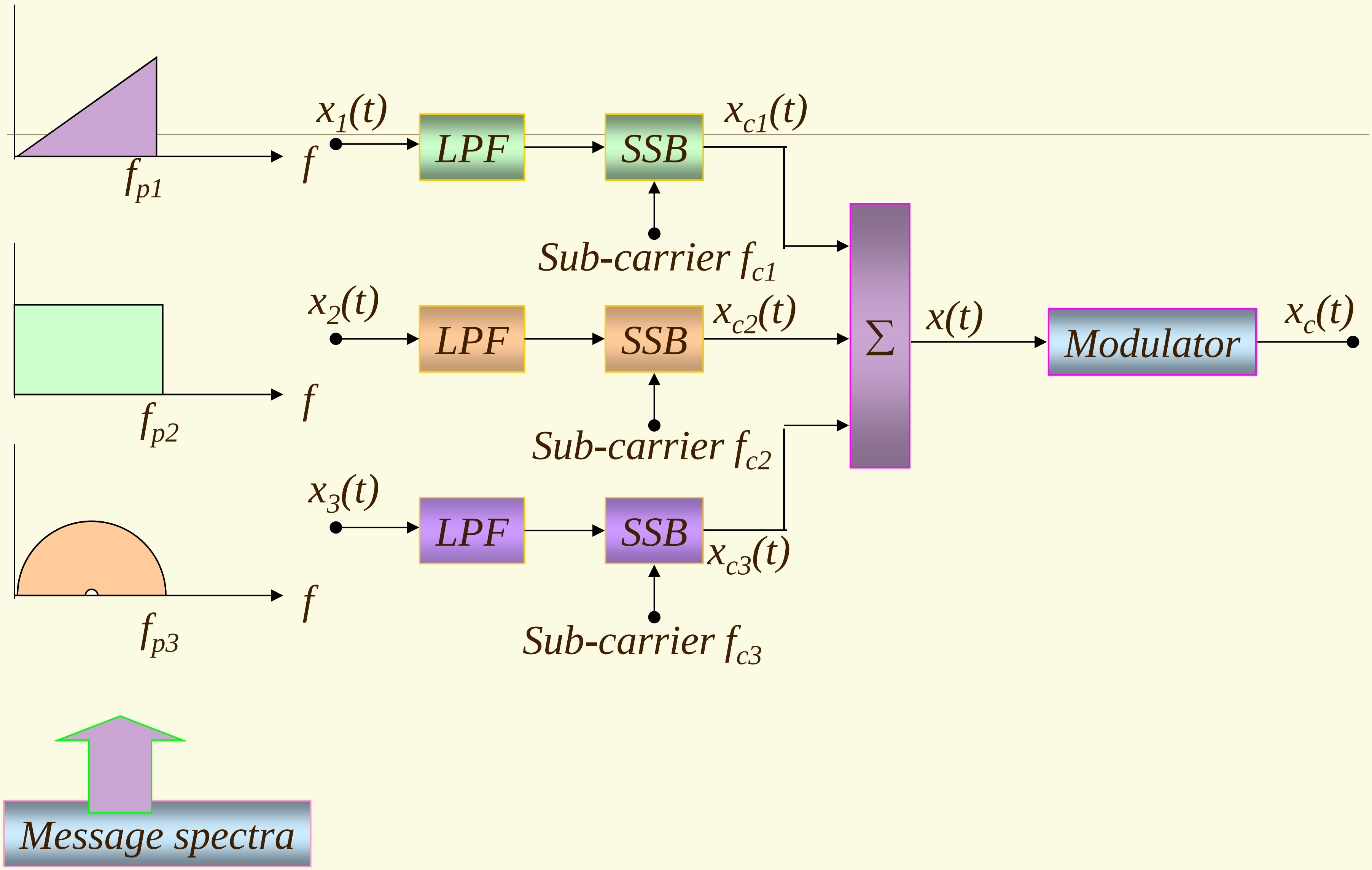
3.2 Teknik FDM

- *Beberapa informasi atau sinyal dikirim secara bersama-sama dengan menggunakan beberapa frekuensi yang berbeda*
- *Digunakan beberapa carrier (sub carrier) untuk dimodulasi dengan masing-masing sinyal informasi*

Prinsip FDM

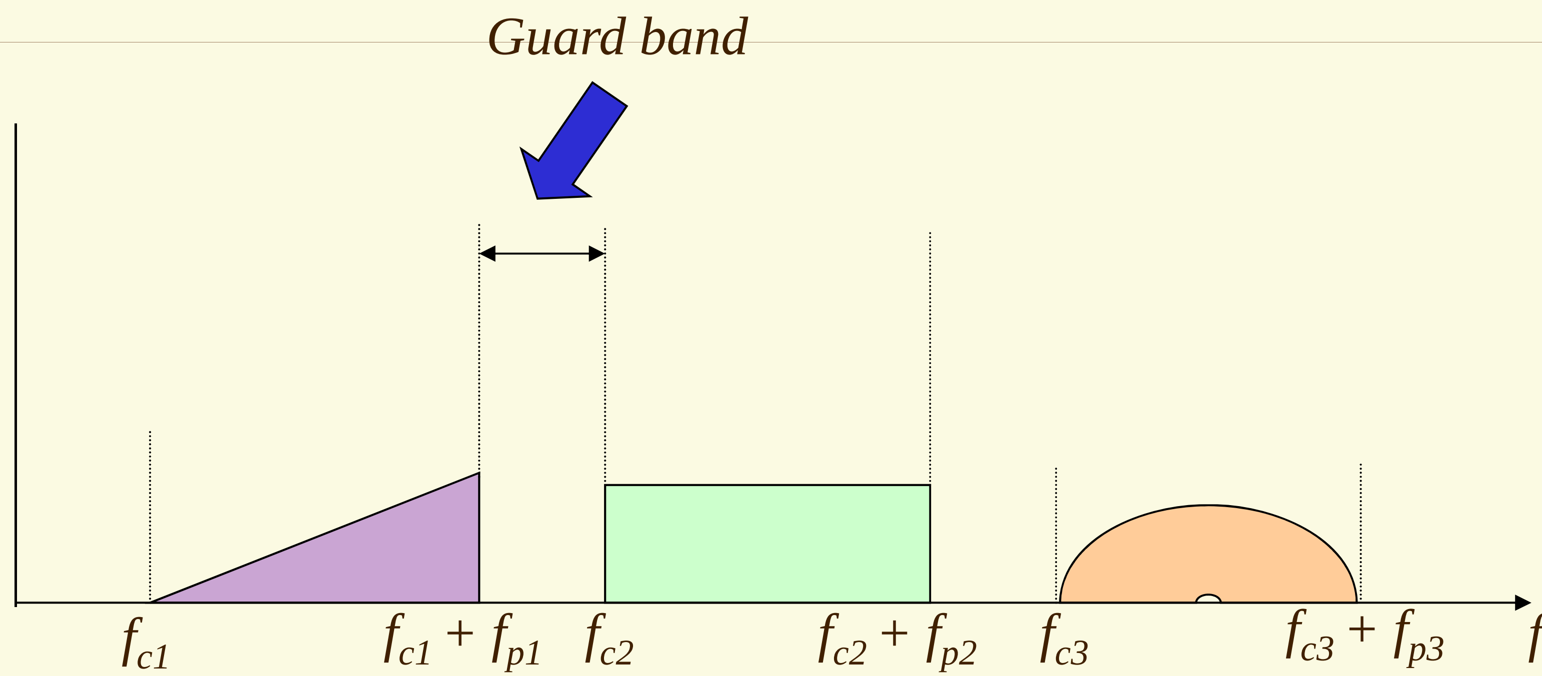


Teknik FDM

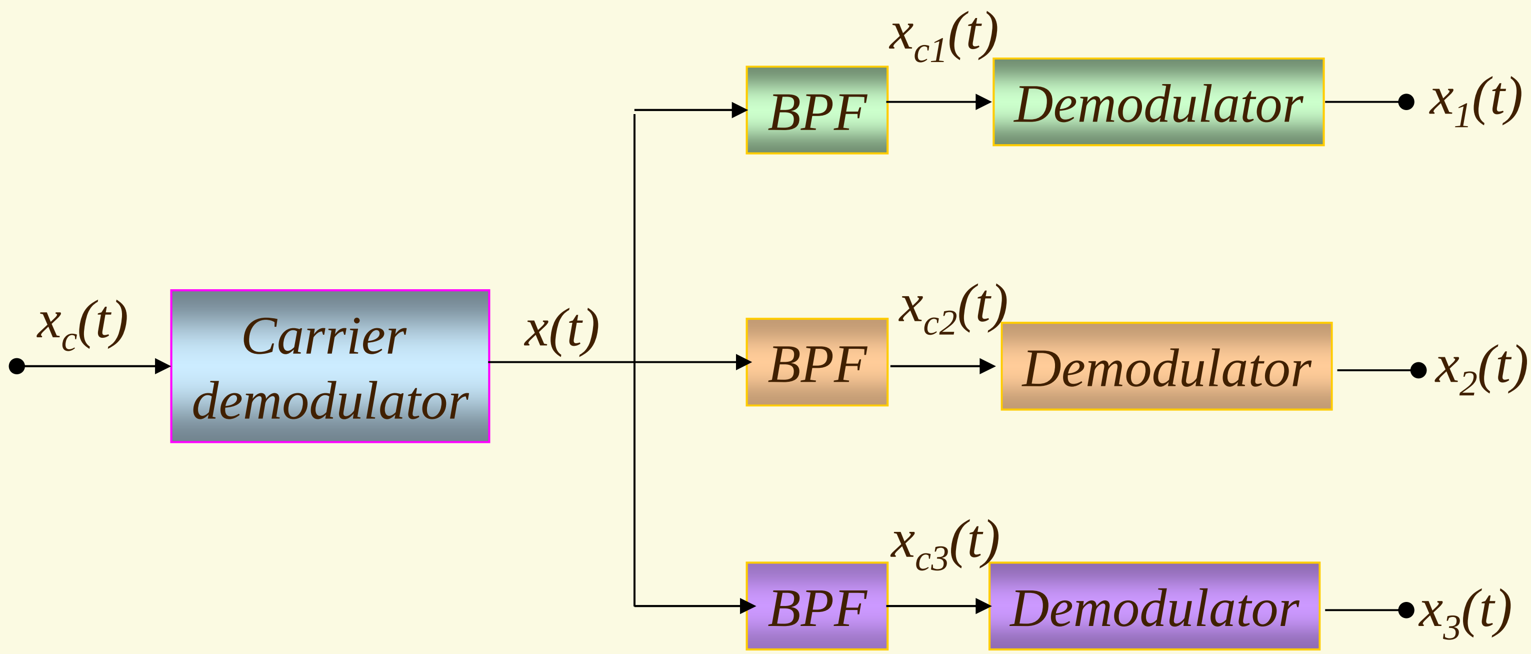


f_{p1}
f
f_{p2}
f
f_{p3}
f
$x_1(t)$
LPF
SSB
$x_{c1}(t)$
Sub-carrier f_{c1}
$x_2(t)$
LPF
SSB
$x_{c2}(t)$
Sub-carrier f_{c2}
$x_3(t)$
LPF
SSB
$x_{c3}(t)$
Sub-carrier f_{c3}
Σ
$x(t)$
Modulator
$x_c(t)$
Message spectra

Spektrum hasil multiplexing



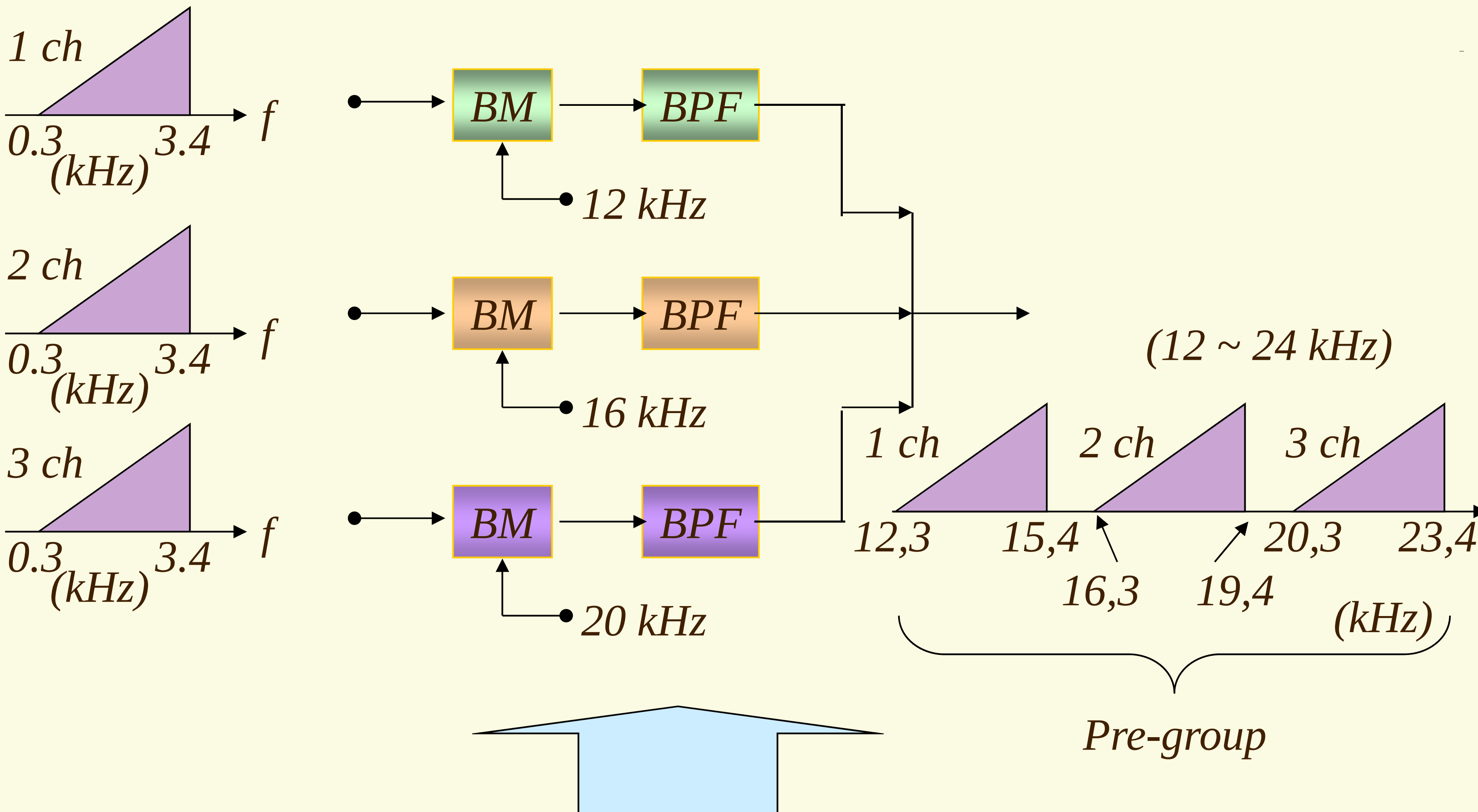
Penerima FDM



Hirarki FDM dari Bell system

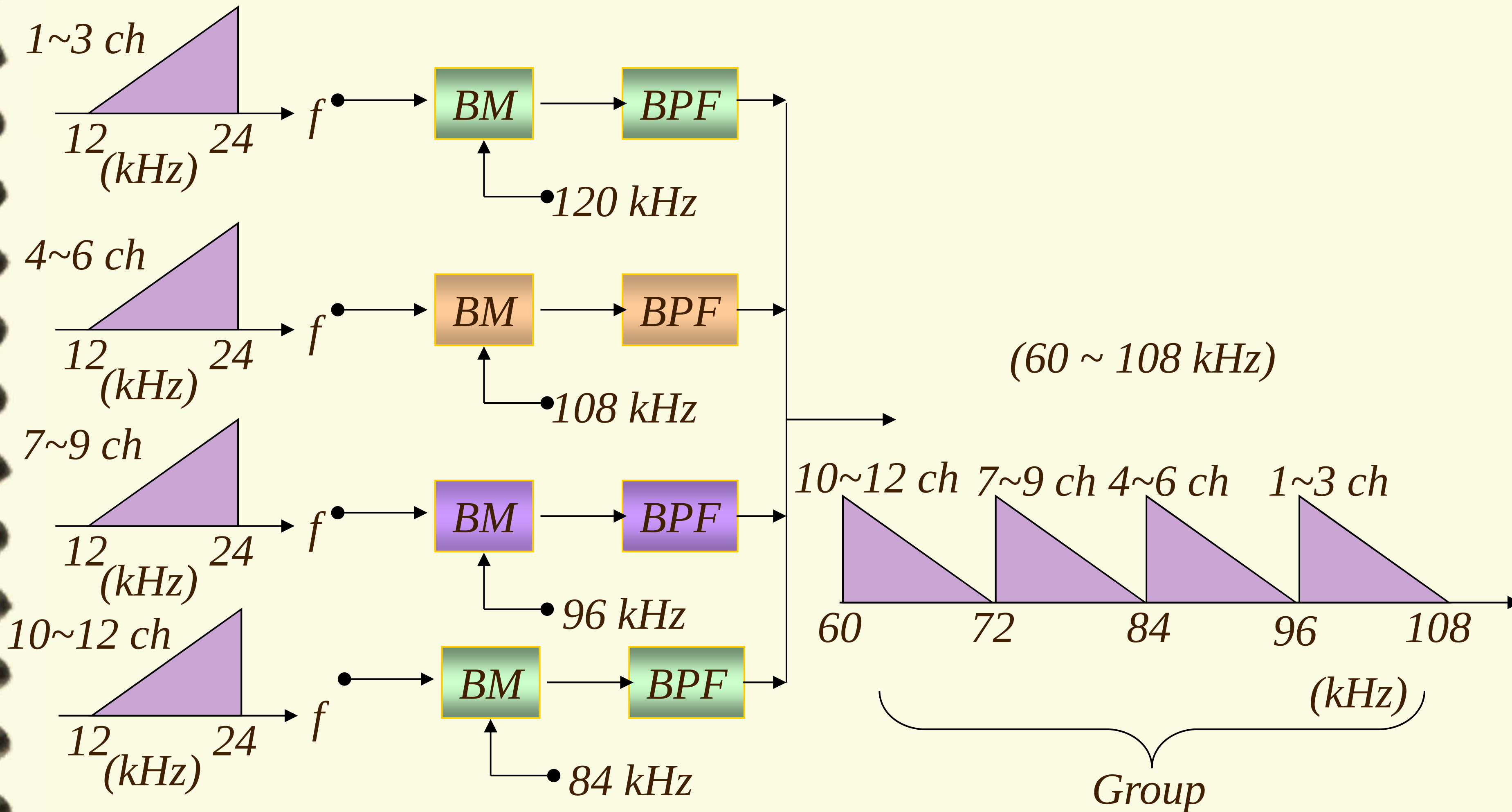
Istilah	Komposisi	Range frekuensi (kHz)	Bandwidth (kHz)	Banyaknya kanal suara
Group	12 Voice channel	60 - 108	48	12
Super group	5 Group	312 - 552	240	60
Master group	10 Super group	564 - 3084	2520	600
Super master group	6 Master group	500 - 17.500	17.500	3600

Hirarki FDM



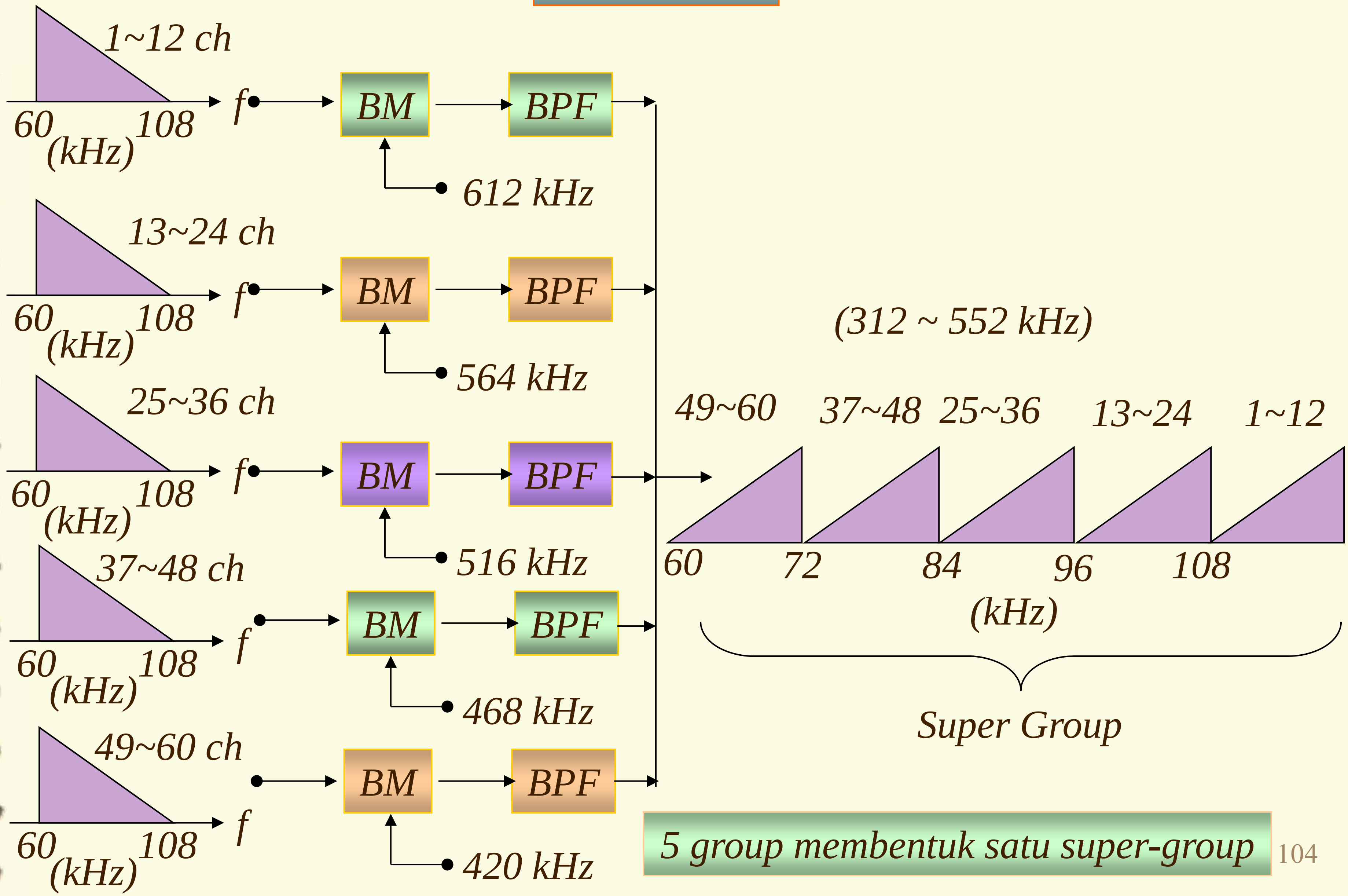
3 kanal membentuk satu pre-group

Hirarki FDM



4 pre-group membentuk satu group

Hirarki FDM



5 group membentuk satu super-group

Tabel carrier hirarki FDM

* Channel Multiplexer

Channel	Carrier frequency	LSB Frequency range
1	108 kHz	104 ~ 108 kHz
2	104 kHz	100 ~ 104 kHz
3	100 kHz	96 ~ 100 kHz
4	96 kHz	92 ~ 96 kHz
5	92 kHz	88 ~ 92 kHz
6	88 kHz	84 ~ 88 kHz
7	84 kHz	80 ~ 84 kHz
8	80 kHz	76 ~ 80 kHz
9	76 kHz	72 ~ 76 kHz
10	72 kHz	68 ~ 72 kHz
11	68 kHz	64 ~ 68 kHz
12	64 kHz	60 ~ 64 kHz

Tabel carrier hirarki FDM

** Group Multiplexer (60 Voice channel)*

Group	Carrier frequency	LSB Frequency range
1	420 kHz	312 ~ 360 kHz
2	468 kHz	360 ~ 408 kHz
3	516 kHz	408 ~ 456 kHz
4	564 kHz	456 ~ 504 kHz
5	612 kHz	504 ~ 552 kHz

Freq. Range 312 ~ 552 kHz → *Bandwidth 240 kHz*

Tabel carrier hirarki FDM

* Supergroup Multiplexer (600 Voice channel)

Channel	Carrier frequency	LSB Frequency range
1	612 kHz	60 ~ 300 kHz
2	Direct	312 ~ 552 kHz
3	1116 kHz	564 ~ 804 kHz
4	1364 kHz	812 ~ 1052 kHz
5	1612 kHz	1060 ~ 1300 kHz
6	1860 kHz	1308 ~ 1548 kHz
7	2108 kHz	1556 ~ 1796 kHz
8	2356 kHz	1804 ~ 2044 kHz
9	2604 kHz	2052 ~ 2292 kHz
10	2852 kHz	2300 ~ 2540 kHz

Freq. Range 60 ~ 2540 kHz → Bandwidth 2480 kHz

BAB IV
RANGKAIAN RESONANSI & TRANSFORMATOR

**** Proses Resonansi***

RLC
Komponen real (resisitif) + imajiner (reaktif)

↓

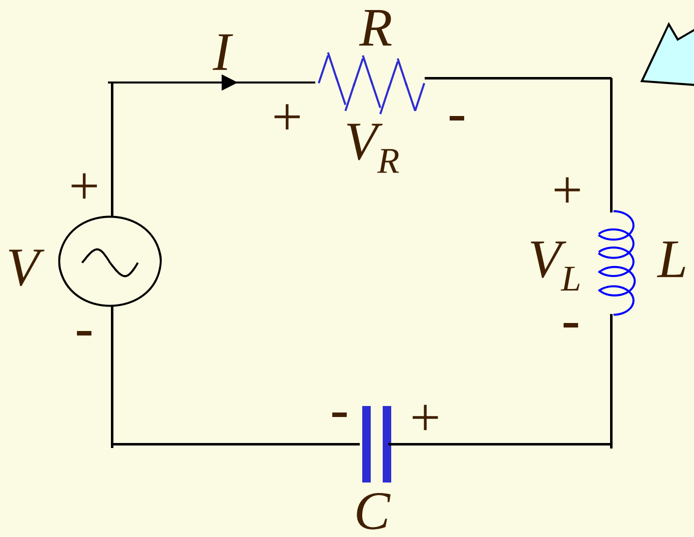
RLC
Komponen resistif (impedansi & admitansi real saja)

↓

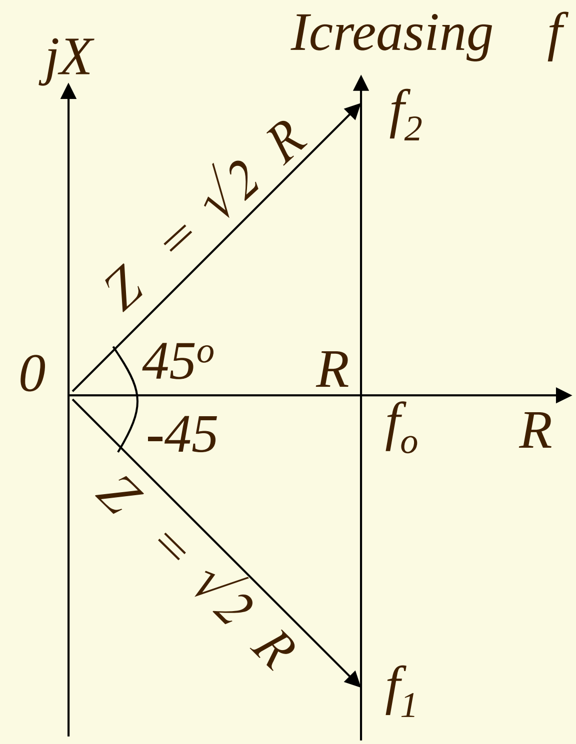
Resonansi

RLC Seri

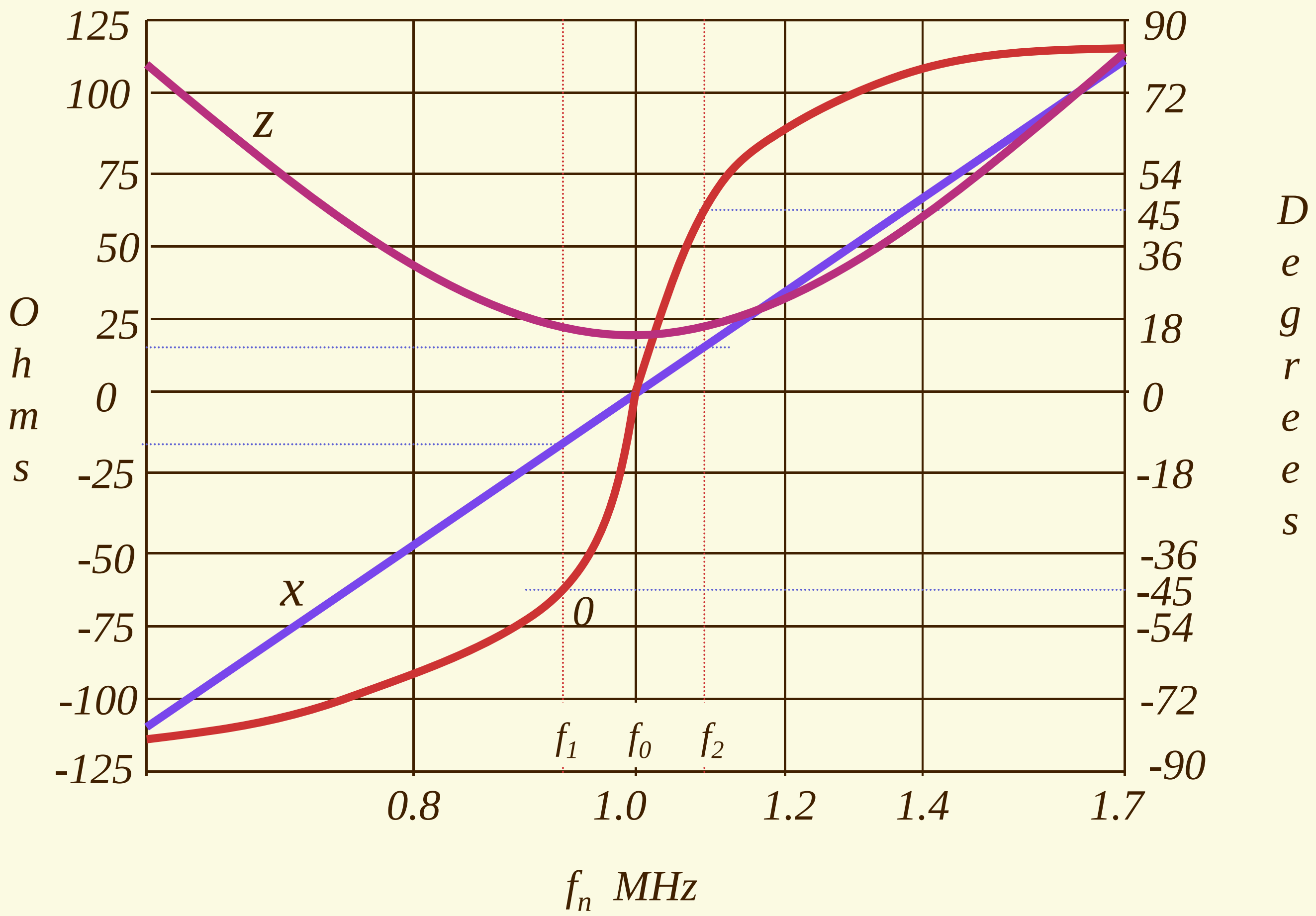
Rangkaian



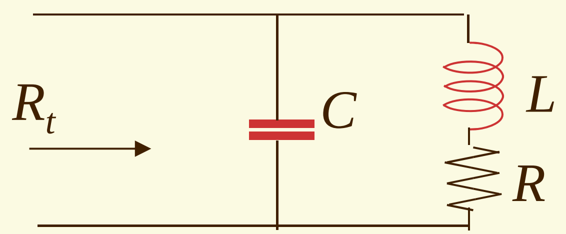
Kedudukan bidang Z



Respons frekuensi rangkaian RLC seri

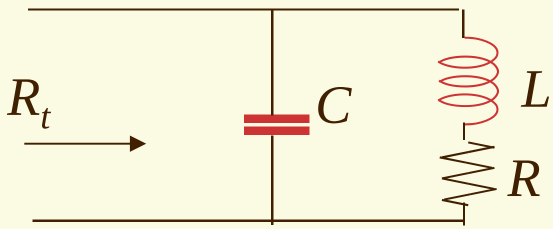


Rumus-rumus perencanaan untuk rangkaianRL//C



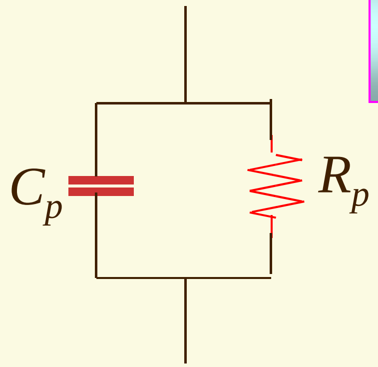
Quality	*Exact Expression*	*Unit*	*Approximate Expression* $Q_t \geq 10$
ω_o	$=\left(\dfrac{1}{LC-R^2C^2}\right)^{1/2}$	*rad/s*	$=\dfrac{1}{\sqrt{LC}}$
Q_t	$=\dfrac{1}{\omega_0 CR}=\dfrac{R_t}{\omega_0 L}$		$=\dfrac{\omega_0 L}{R}$
$\omega_0 L$	$=\dfrac{1}{\omega_0 C}\left(\dfrac{Q_t^2+1}{Q_t^2}\right)$	*ohms*	$=\dfrac{1}{\omega_0 C}$

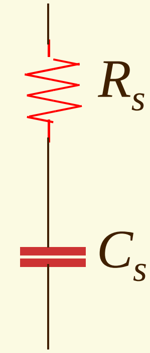
Rumus-rumus perencanaan untuk rangkaianRL//C



Quality	Exact Expression	Unit	Approximate Expression $Q_t \geq 10$
R_t	$= \left(\frac{L}{CR}\right) = \omega_0 L Q_t$	ohms	$= Q_t^2 R = \frac{Q_t}{\omega_0 C}$
	$= R\left(Q_t^2 + 1\right)$		$= \frac{\omega_0 L}{R}$
B		hertz	$= \frac{f_0}{Q_t} = \frac{1}{2\pi C R_t}$

Rumus konversi paralel-seri untuk rangkaian RC





Define : $$X_p = \frac{1}{\omega C_p}$$

Parallel Equivalent of the Series Network

$$Q_p = \frac{R_p}{X_p}$$

Define : $$X_s = \frac{1}{\omega C_s}$$

Series Equivalent of the Parallel Network

$$Q_s = \frac{X_s}{R_s}$$

Exact Formula

$$R_{pe} = R_s\left(1 + Q_s^2\right)$$

$$X_{pe} = X_s\left(\frac{Q_s^2+1}{Q_s^2}\right)$$

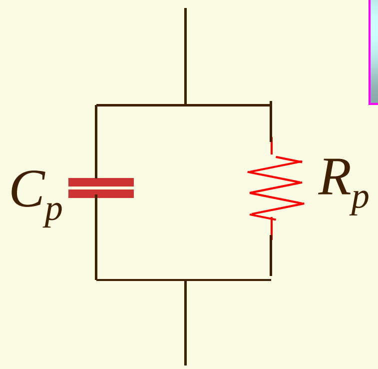
$$C_{pe} = C_s\left(\frac{Q_s^2}{Q_s^2+1}\right)$$

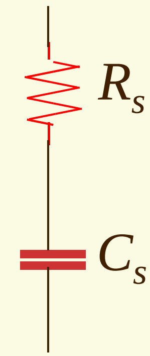
$$R_{se} = \frac{R_p}{1+Q_p^2}$$

$$X_{se} = X_p\left(\frac{Q_p^2}{Q_p^2+1}\right)$$

$$C_{se} = C_p\left(\frac{Q_p^2+1}{Q_p^2}\right)$$

Rumus konversi paralel-seri untuk rangkaian RC





Define : $$X_p = \frac{1}{\omega C_p}$$

Parallel Equivalent of the Series Network

$$Q_p = \frac{R_p}{X_p}$$

Define : $$X_s = \frac{1}{\omega C_s}$$

Series Equivalent of the Parallel Network

$$Q_s = \frac{X_s}{R_s}$$

Approximate Formulas

If $Q_s \geq 10$

$$R_{pe} = R_s Q_s^2$$

$$X_{pe} = X_s$$

$$C_{pe} = C_s$$

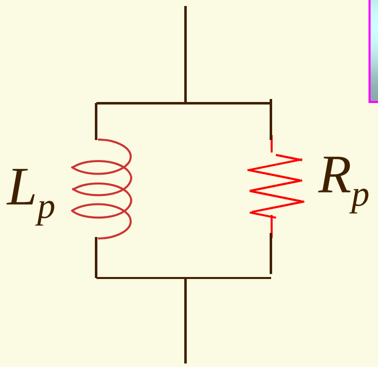
If $Q_p \geq 10$

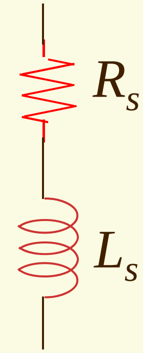
$$R_{se} = \frac{R_p}{Q_p^2}$$

$$X_{se} = X_p$$

$$C_{se} = C_p$$

Rumus konversi paralel-seri untuk rangkaian RL





Define : $X_p = \omega L_p$

Parallel Equivalent of the Series Network

$$Q_p = \frac{R_p}{X_p}$$

Define : $X_s = \omega L_s$

Series Equivalent of the Parallel Network

$$Q_s = \frac{X_s}{R_s}$$

Exact Formula

$$R_{pe} = R_s\left(1 + Q_s^2\right)$$

$$X_{pe} = X_s\left(\frac{Q_s^2+1}{Q_s^2}\right)$$

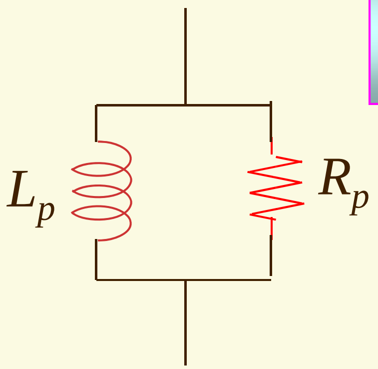
$$L_{pe} = C_s\left(\frac{Q_s^2}{Q_s^2+1}\right)$$

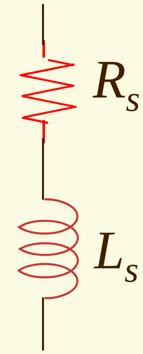
$$R_{se} = \frac{R_p}{1+Q_p^2}$$

$$X_{se} = X_p\left(\frac{Q_p^2}{Q_p^2+1}\right)$$

$$L_{se} = L_p\left(\frac{Q_p^2+1}{Q_p^2}\right)$$

Rumus konversi paralel-seri untuk rangkaian RL





Define : $X_p = \omega L_p$

Define : $X_s = \omega L_s$

Parallel Equivalent of the Series Network

$$Q_p = \frac{R_p}{X_p}$$

Series Equivalent of the Parallel Network

$$Q_s = \frac{X_s}{R_s}$$

If $Q_s \geq 10$

$$R_{pe} = R_s Q_s^2$$

$$X_{pe} = X_s$$

$$L_{pe} = L_s$$

If $Q_p \geq 10$

$$R_{se} = \frac{R_p}{Q_p^2}$$

$$X_{se} = X_p$$

$$L_{se} = L_p$$