EE1 and ISE1 Communications I

Pier Luigi Dragotti

Lecture ten

Lecture Aims

- To examine Full AM process
- AM signal and its envelope
- Sideband carrier power
- Generation of AM signals
- Demodulation of AM signals

Double Sideband Suppressed Carrier

- A receiver must generate a carrier in frequency and phase synchronism with the carrier at the transmitter
- This calls for sophisticated receiver and could be quite costly
- An alternative is for the transmitter to transmit the carrier along with the modulated signal.
- In this case the transmitter needs to transmit much larger power.

Amplitude Modulation

- **Carrier** $A \cos(\omega_c t + \theta_c)$
  - **Phase is constant** $\theta_c = 0$
  - **Frequency is constant.**
- **Modulating signal** $m(t)$
- **With amplitude spectrum** $m(t) \Longleftrightarrow M(\omega)$
- **Full AM signal is**

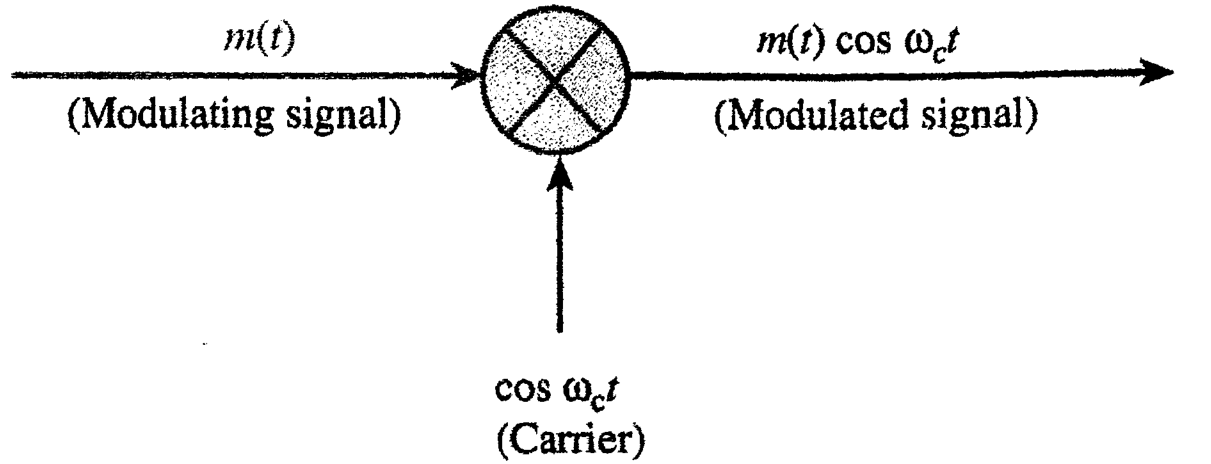
$$\varphi_{AM}(t) = A\cos\omega_c t + m(t)\cos\omega_c t$$
$$= [A + m(t)]\cos\omega_c t$$

- **Spectrum of Full AM signal**

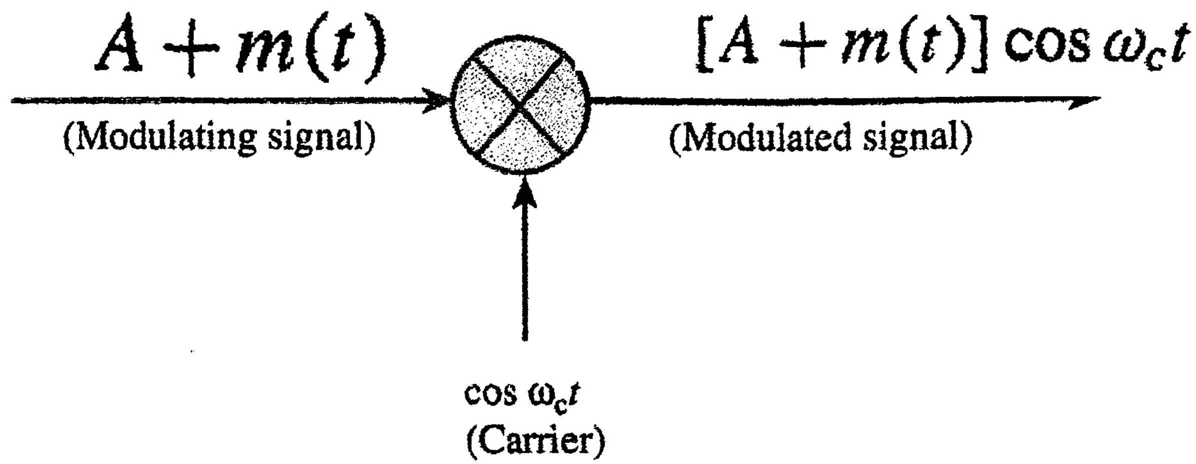
$$\varphi_{AM}(t) \Longleftrightarrow \frac{1}{2}[M(\omega+\omega_c) + M(\omega-\omega_c)] + \pi A[\delta(\omega+\omega_c) + \delta(\omega-\omega_c)]$$

Full AM Modulated signal

- **DSB Modulated signal:**



- **Full AM signal**



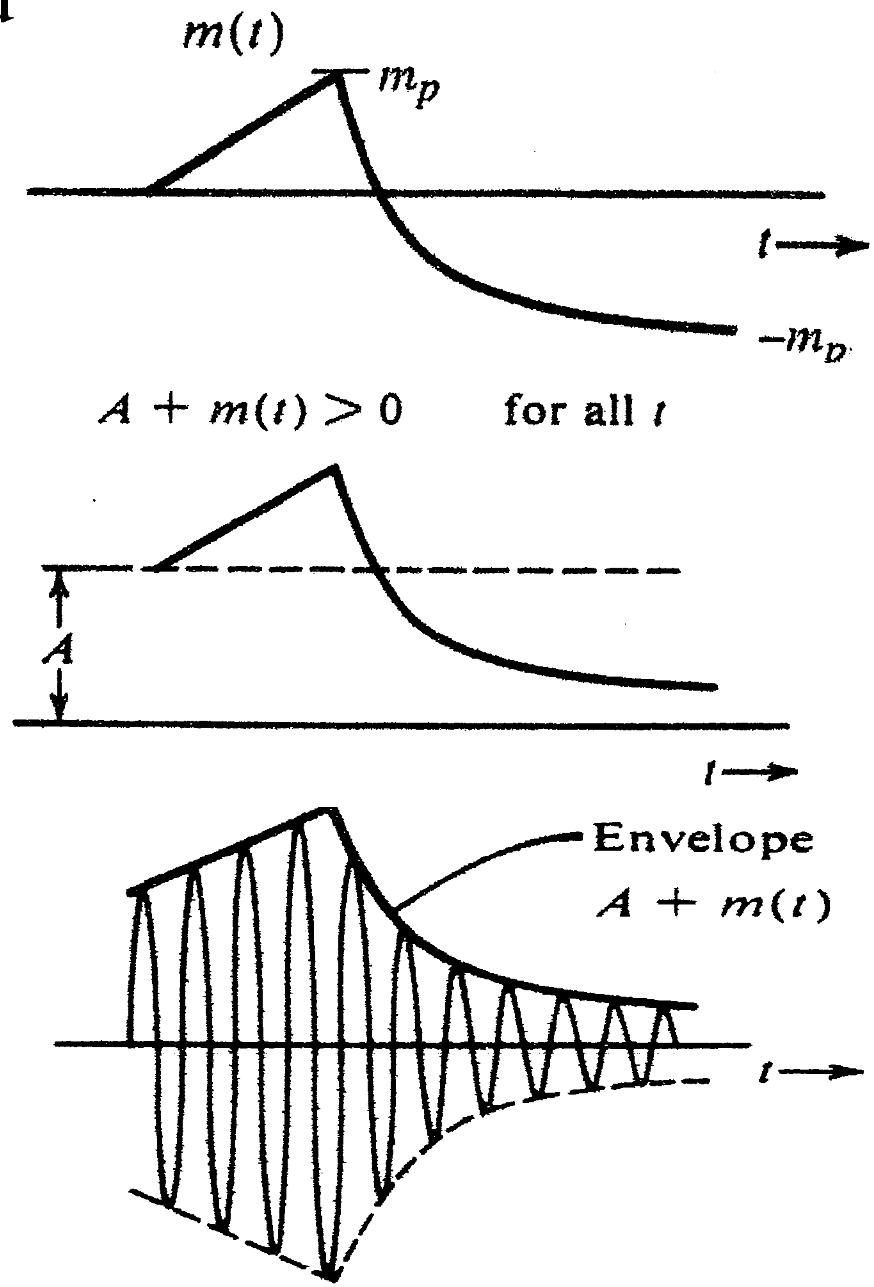
- FULL AM Modulated signal

- **Signal**

- **Modulating signal**

- **Modulated signal:**

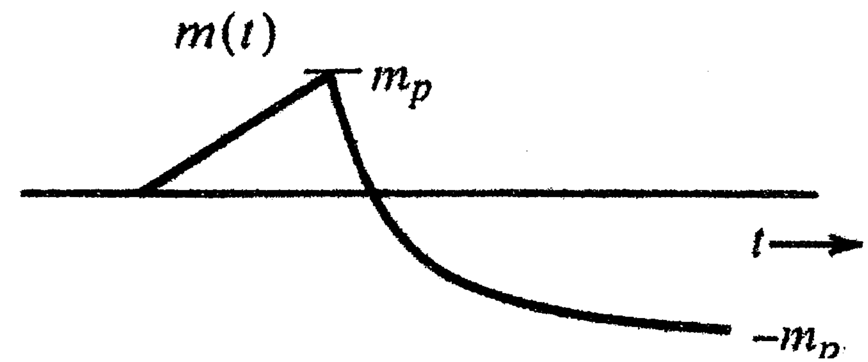
  $[A + m(t)] \cos \omega_c t$



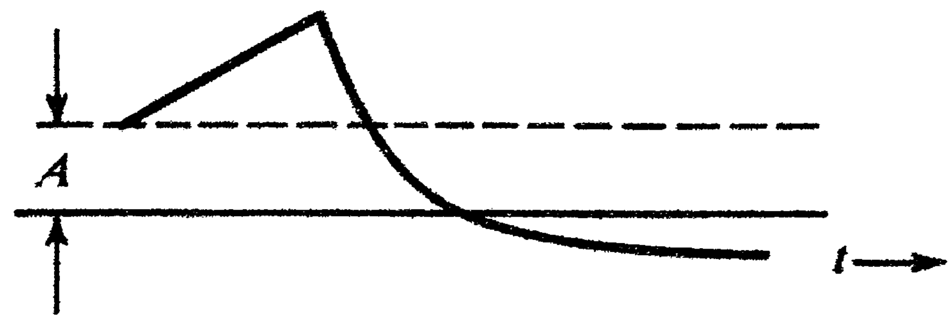
- Envelope detection is not possible when

$A + m(t) \ngtr 0$ for all t

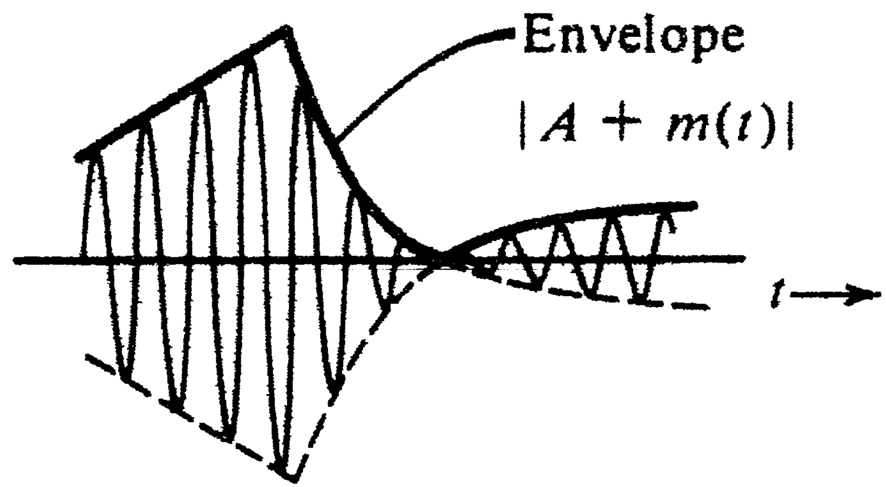
- **Signal**



- **Modulating signal**



- **Modulated signal:**
  $[A + m(t)] \cos \omega_c t$



Envelope Detection condition

- Detection condition $A + m(t) \geq 0$
- Let m_p be the absolute peak amplitude of $m(t)$. This means that $m(t) \geq -m_p$.
- When we have $A \geq m_p$, we can use envelope detector.
- The parameter $\mu = \frac{m_p}{A}$ is called the modulation index.
- When $0 \leq \mu \leq 1$, we can use an envelope detector

Envelope detection example

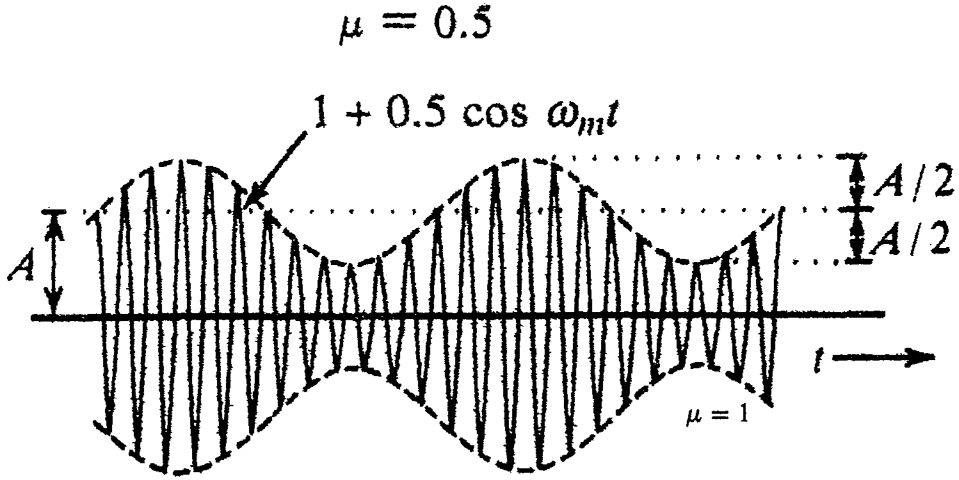
- **Modulating signal** $m(t) = B\cos\omega_m t$
- **Modulating signal amplitude is** $m_p = B$
- **Hence** $\mu = \frac{B}{A}$ **and** $B = \mu A$
- **Modulating and modulated signals are**

$$m(t) = B\cos\omega_m t = \mu A\cos\omega_m t$$

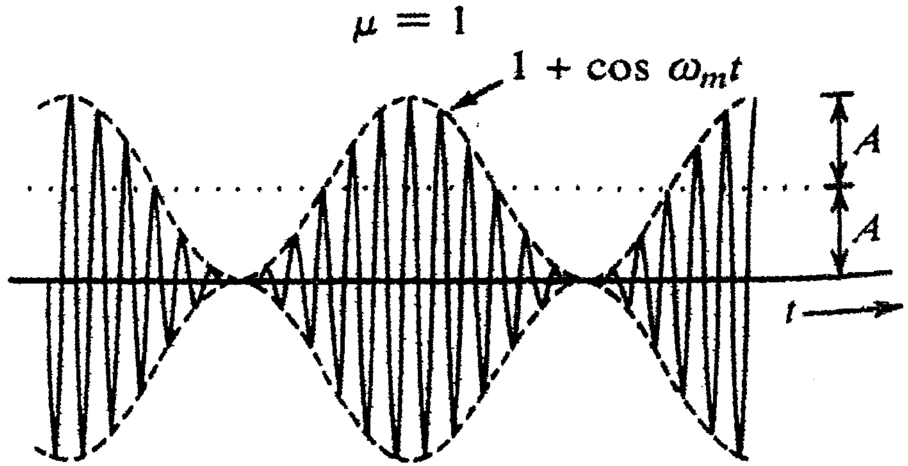
$$\varphi_{\mathrm{AM}}(t) = [A + m(t)]\cos\omega_c t = A[1 + \mu\cos\omega_m t]\cos\omega_c t$$

Demodulation of DSB signal

- **Consider modulation index to be** $\mu = 0.5$



- **For modulation index** $\mu = 1$



Sideband and Carrier power

- **Consider Full AM signal**

$$\varphi_{\text{AM}}(t) = \underbrace{A\cos\omega_c t}_{\text{carrier}} + \underbrace{m(t)\cos\omega_c t}_{\text{sidebands}}$$

- **Power** P_c **of the carrier** $A\cos\omega_c t$

$$A^2/2$$

- **Power** P_s **of the sideband signals**

$$0.5\,\widetilde{m^2(t)}$$

- **Power efficiency**

$$\eta = \frac{\text{useful power}}{\text{total power}} = \frac{P_s}{P_c + P_s} = \frac{\widetilde{m^2(t)}}{A^2 + \widetilde{m^2(t)}}100\%$$

Maximum power efficiency of Full AM

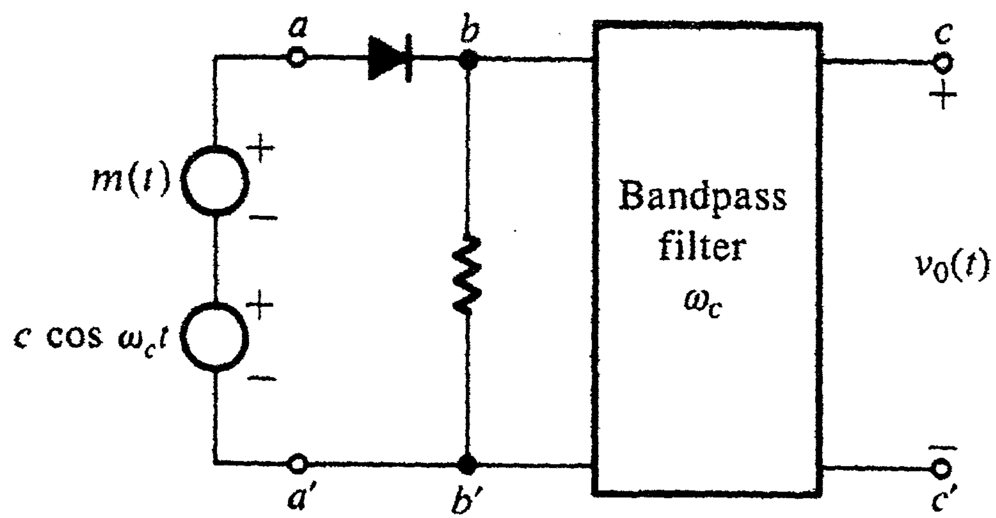
- **When we have** $m(t) = \mu A \cos \omega_m t$
- **Signal power is** $\overline{m^2(t)} = \frac{(\mu A)^2}{2}$
- **When** $0 \leq \mu \leq 1$
- **When modulation index is unity, the efficiency is**

  $\eta_{max} = 33\%$
- **When** $\mu = 0.3$ **the efficiency is**

$$\eta = \frac{(0.3)^2}{2 + (0.3)^2} 100\% = 4.3\%$$

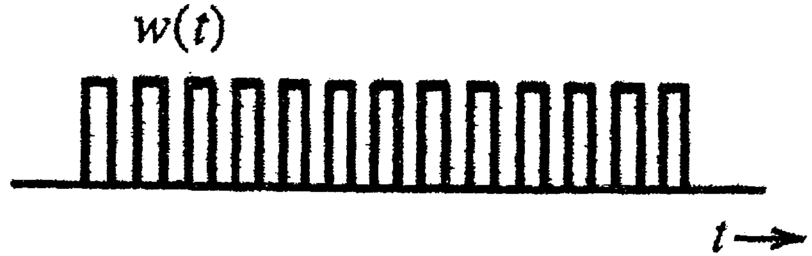
Generation of AM signals

- **Full AM signals can be generated using DSB-SC modulators.**
- **But we do not need to suppress the carrier at the output of the modulator, hence we do not need a balanced modulators**
- **Use a simple diode**



Simple diode modulator design

- **Input signal** $c\cos\omega_c t + m(t)$
- **Consider the case** $c \gg m(t)$
- **Switching action of the diode is controlled by** $c\cos\omega_c t$
- **A switching waveform**



- **is generated. The diode open and shorts periodically with** $w(t)$
- **The signal is generated**

$$v_{bb'}(t) = [c\cos\omega_c t + m(t)]w(t)$$

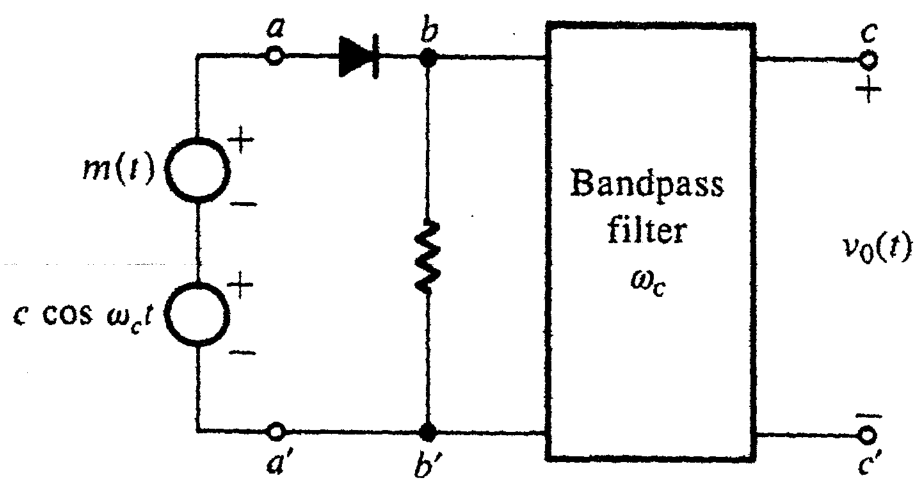
Diode Modulator

- **Diode acts as a multiplier**

$$v_{bb'}(t) = [c\cos\omega_c t + m(t)]w(t)$$

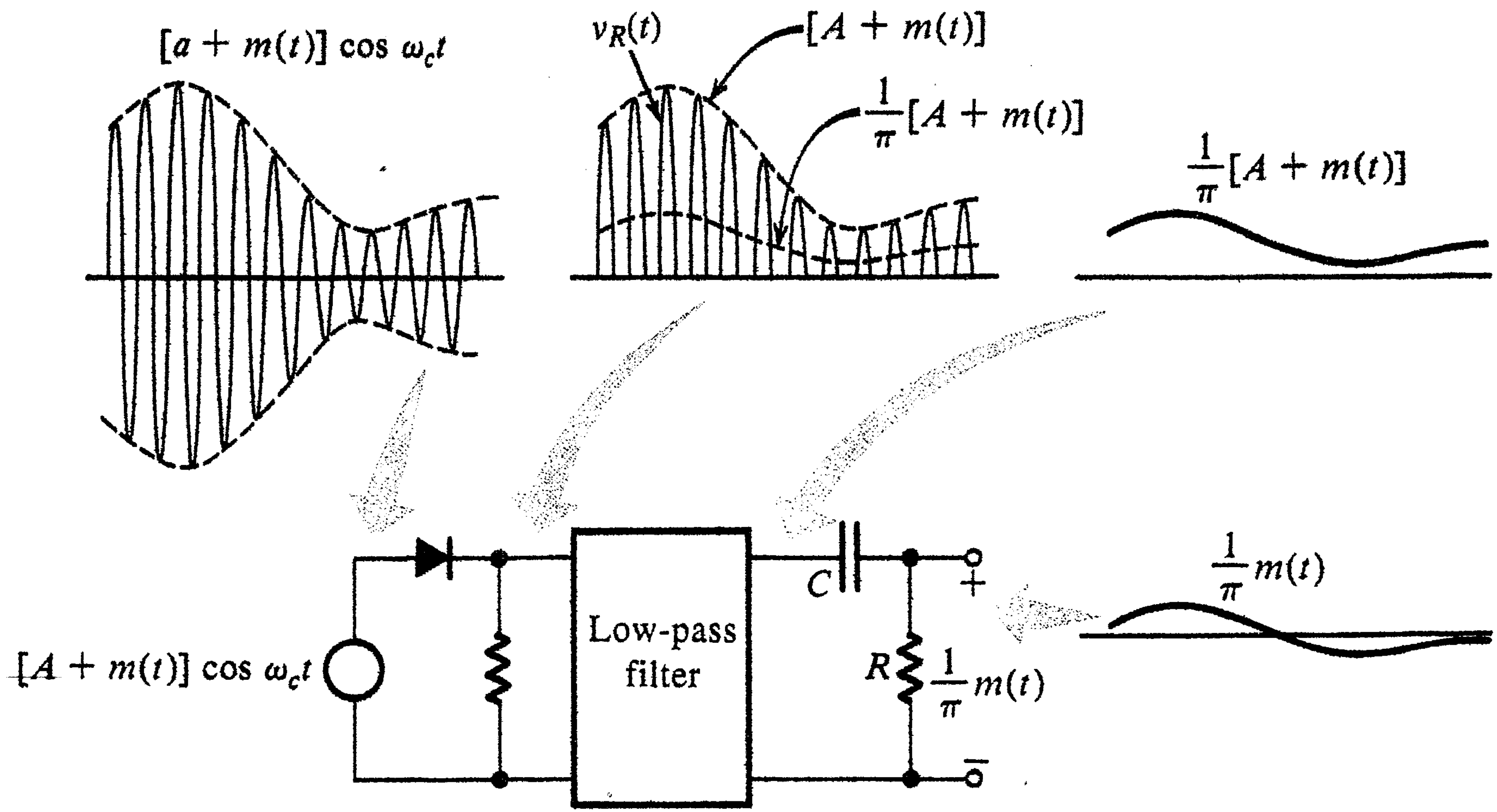
$$= [c\cos\omega_c t + m(t)]\left[\frac{1}{2} + \frac{2}{\pi}\left(\cos\omega_c t - \frac{1}{3}\cos 3\omega_c t + \frac{1}{5}\cos 5\omega_c t - \cdots\right)\right]$$

$$= \underbrace{\frac{c}{2}\cos\omega_c t + \frac{2}{\pi}m(t)\cos\omega_c t}_{\text{AM}} + \underbrace{\text{other terms}}_{\substack{\text{suppressed by} \\ \text{bandpass filter}}}$$



Demodulation of AM signals

- **Rectifier detector**



Demodulation of AM signals

- **Half wave rectified signal** v_R **is given by**

$$v_R = \{[A + m(t)] \cos \omega_c t\} \, w(t)$$

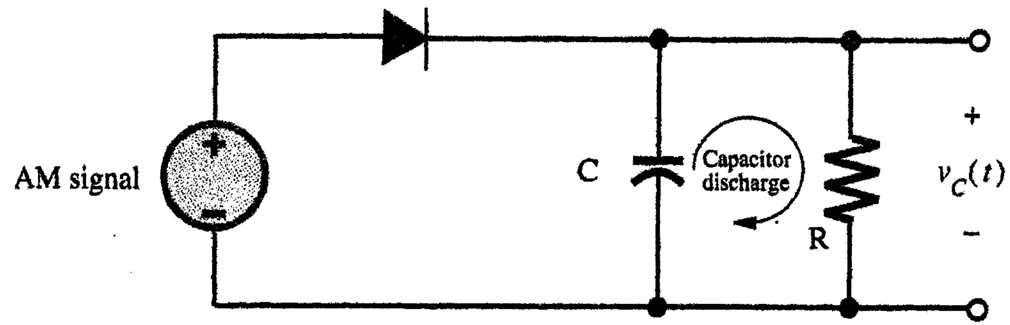
- **Where** $w(t)$

$$v_R = [A + m(t)] \cos \omega_c t \left[\frac{1}{2} + \frac{2}{\pi} \left(\cos \omega_c t - \frac{1}{3} \cos 3\omega_c t + \frac{1}{5} \cos 5\omega_c t - \cdots \right) \right]$$

$$= \frac{1}{\pi} [A + m(t)] + \text{other terms of higher frequencies}$$

Demodulation of AM signals using an envelope detector

- **Simple detector**



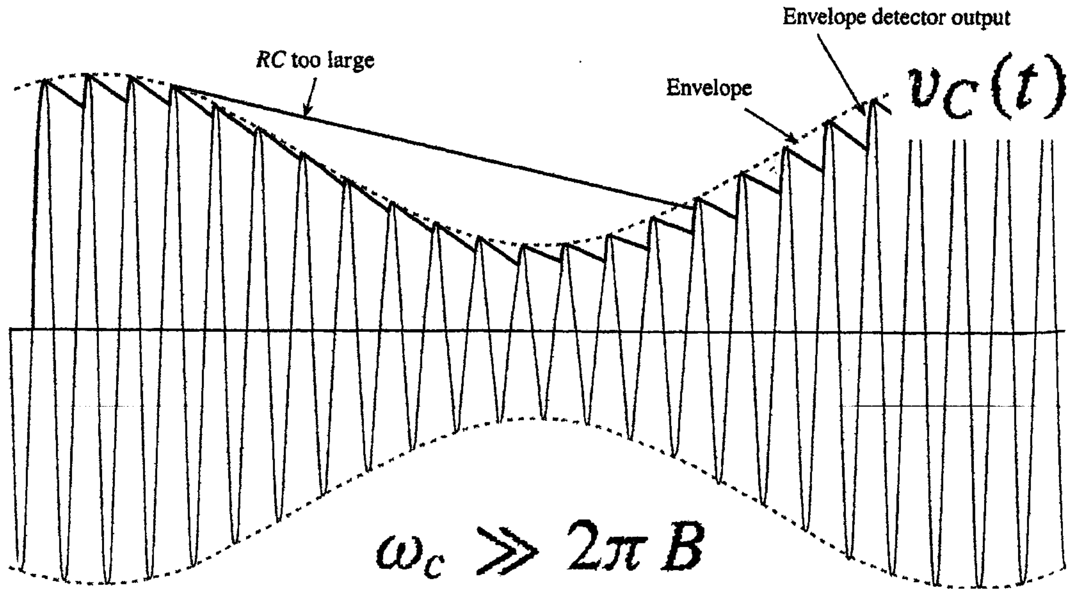
Large

$RC \gg 1/\omega_c$

But smaller than

$1/2\pi B$

- **Detector operation**

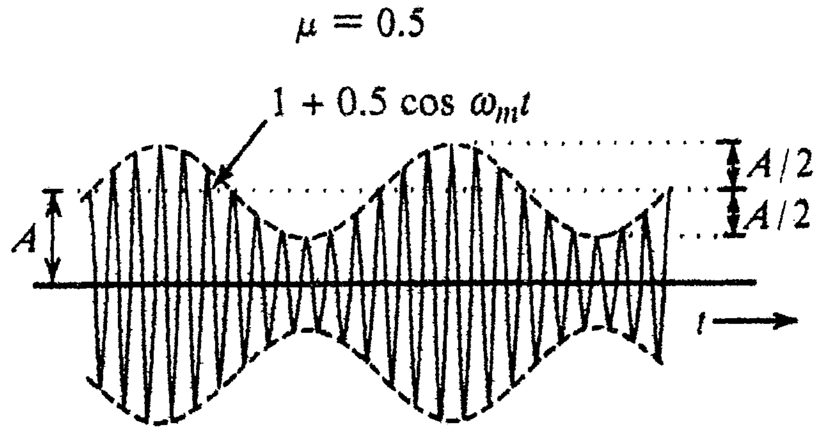


$v_C(t) = A + m(t)$

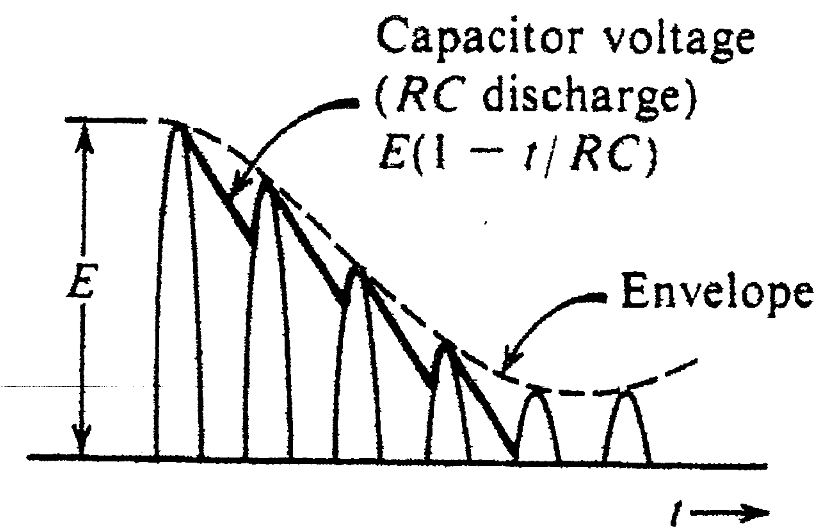
$\omega_c \gg 2\pi B$

Envelope detector example

- **For the single tone**



- **Design an envelope detector**



$$v_C = Ee^{-t/RC}$$

$$v_C \simeq E\left(1 - \frac{t}{RC}\right)$$

Conclusions

- Examined full AM
- Sideband and carrier powers
- AM modulators
- AM demodulators