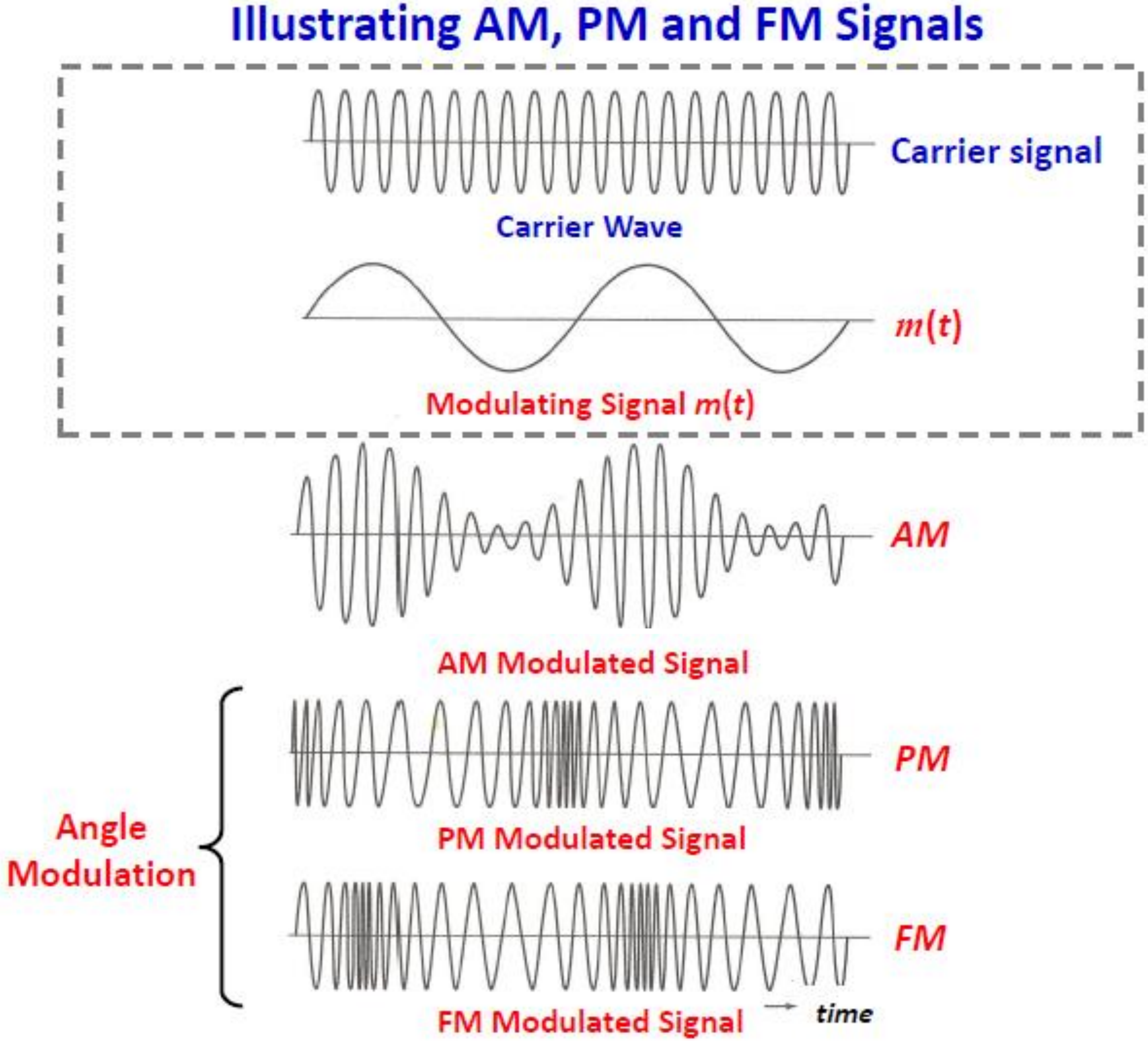
EE 361
Communication Theory

Chapter 4
Angle Modulation
Part 7

Today

- Previously,
  - **AM**
  - Linear Modulation
  - Applications:
    AM Broadcast, TV video, Aircraft radio
- Presently
  - **Angle/Exponential Modulati**
  - Non-linear Modulation
  - **FM**
  - Applications:
    FM Broadcast, TV audio, Cordless Telephone
  - **PM**
  - Applications:
    Extensively in Digital Communication including [



[Haykin and Moher, 2006]

Summary

Message signal is $m(t)$

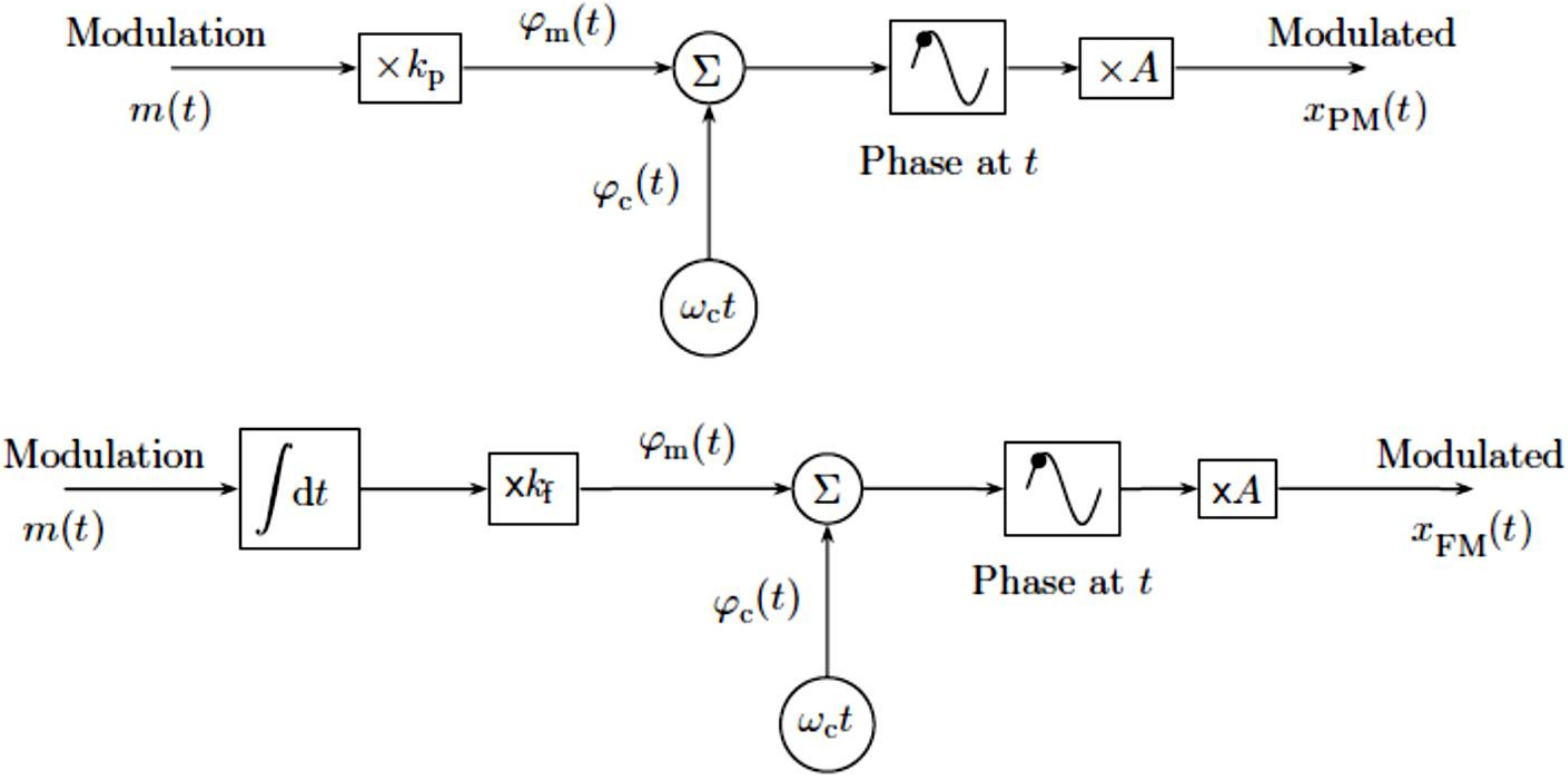
Definition: Instantaneous frequency is $\omega_i(t) = \dfrac{d\theta_i(t)}{dt}$

	Phase Modulation	Frequency Modulation
Angle	$\theta_i(t) = \omega_C t + k_p m(t)$	$\theta_i(t) = \omega_C t + k_f \int_{-\infty}^{t} m(\lambda)\, d\lambda$
Frequency	$\omega_i = \omega_C + k_p \dfrac{dm(t)}{dt}$	$\omega_i = \omega_C + k_f m(t)$

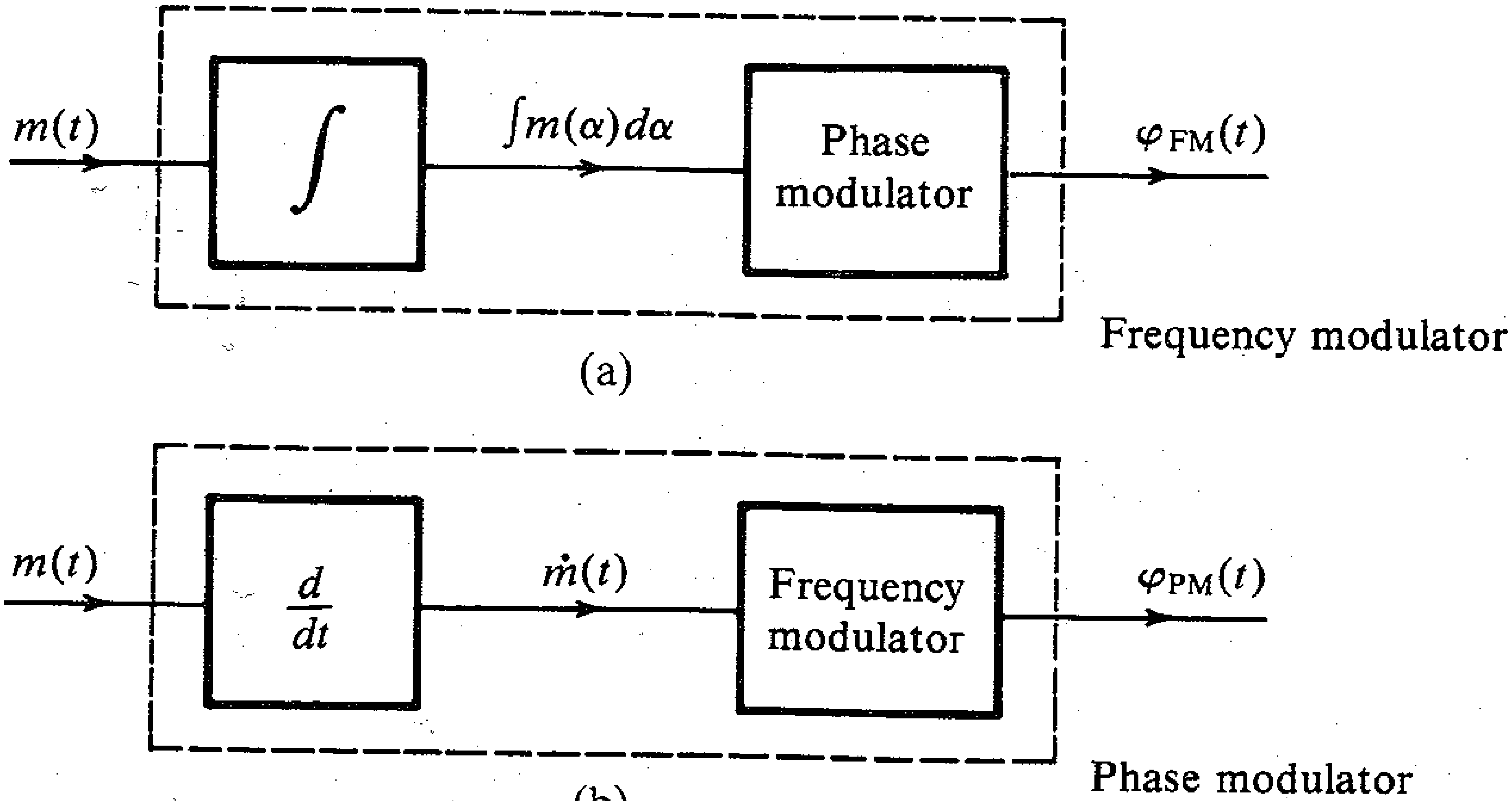
In phase modulation $m(t)$ drives the time variation of phase θ_i.

In frequency modulation $m(t)$ drives the time variation of frequency f_C.

Block diagrams of PM and FM



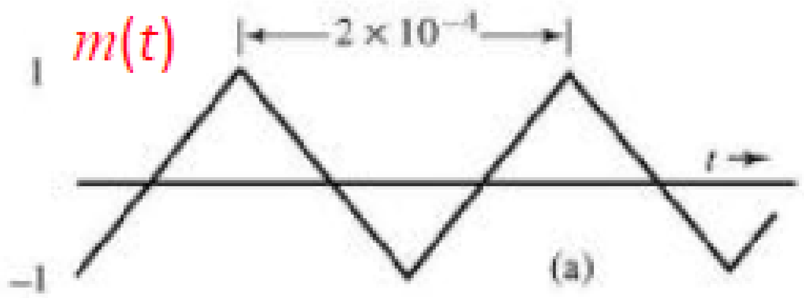
FM and PM are inseparable

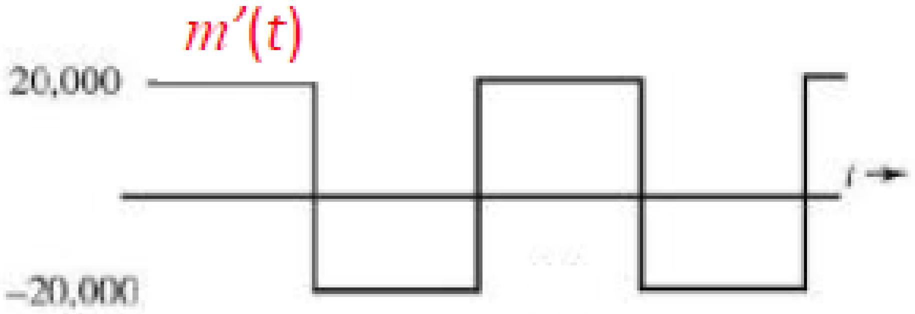


[Lathi and Ding, 2009]

FM and PM Example 5.1 (Text Book)

Sketch FM and PM waveforms for the modulating signal $m(t)$. The constants k_f and k_p are $2\pi \times 10^5$ and 10π, respectively. Carrier frequency f_c = 100 MHz.





$$f_i = f_C + \frac{k_f}{2\pi} m(t) = 1\times 10^8 + 1\times 10^5 \cdot m(t);$$

$$m_{\min} = -1 \text{ and } m_{\max} = 1$$

$$(f_i)_{\min} = 10^8 + 10^5(-1) = 99.9 \text{ MHz},$$

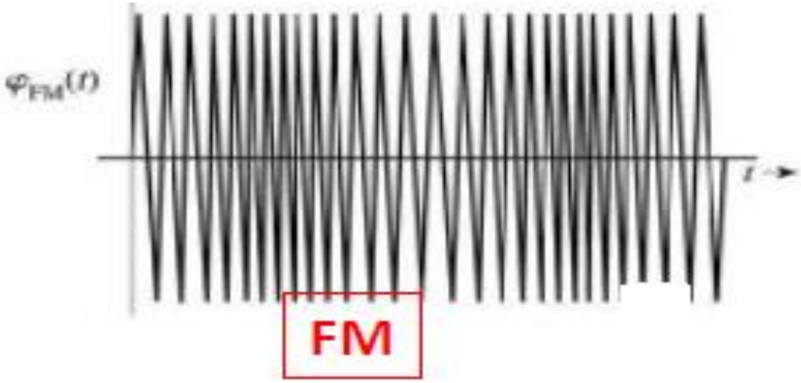
$$(f_i)_{\max} = 10^8 + 10^5(+1) = 100.1 \text{ MHz}$$

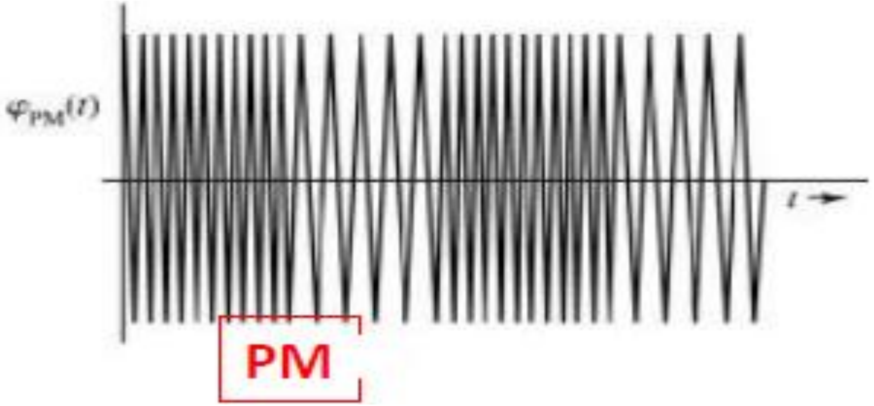
$$f_i = f_C + \frac{k_p}{2\pi} m'(t) = 1\times 10^8 + 5 \cdot m'(t);$$

$$m'_{\min} = -20{,}000 \text{ and } m'_{\max} = 20{,}000$$

$$(f_i)_{\min} = 10^8 + 5(-20{,}000) = 99.9 \text{ MHz},$$

$$(f_i)_{\max} = 10^8 + 5(+20{,}000) = 100.1 \text{ MHz}$$

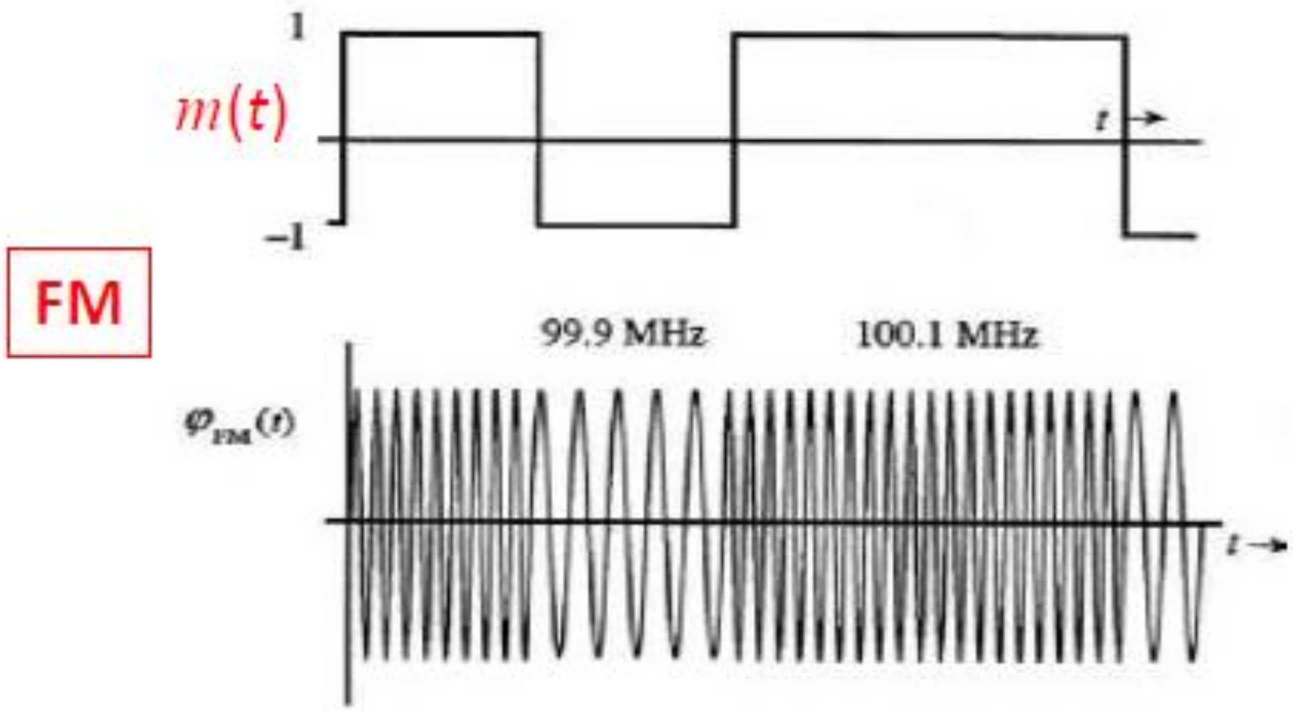




Frequency Shift Keying is Related to FM Example 5.2

(Text Book)

Sketch the FM waveform for the modulating signal $m(t)$. The constant k_f is $2\pi \times 10^5$. Carrier frequency $f_c = 100$ MHz.

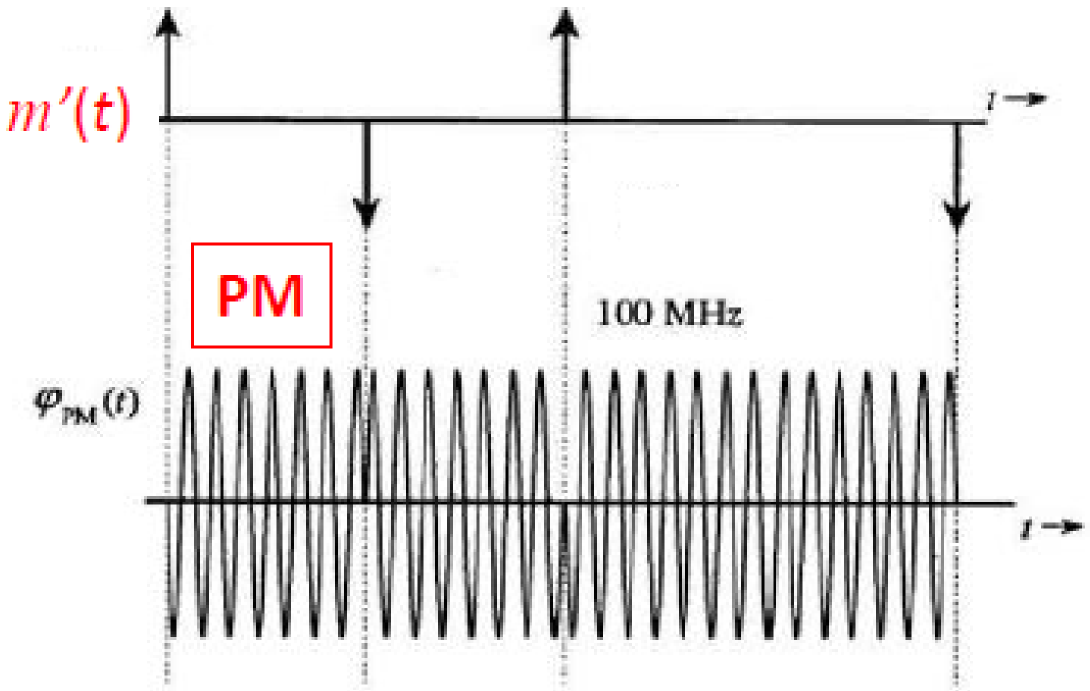


$$f_i = f_C + \frac{k_f}{2\pi} m(t) = 1\times10^8 + 1\times10^5 m(t)$$

Since $m(t)$ switches from +1 to -1 and vice versa, the FM wave frequency switches between 99.9 MHz and 100.1 MHz. This is called **Frequency Shift Keying (FSK)** and is a digital communication format.

Example – continued

Sketch the PM waveform for the modulating signal $m(t)$ from prior slide. The constant k_p equals $\pi/2$. Carrier frequency f_c = 100 MHz.



$$f_i = f_C + \frac{k_p}{2\pi} m'(t) = 1\times 10^8 + \frac{1}{4} m'(t)$$

This is carrier PM by a digital signal – it is **Phase Shift Keying (PSK)** because the digital data is represented by phase of the carrier wave.

$$\varphi_{PM}(t) = A_C \cos\left[\omega_C t + k_p m(t)\right] = A_C \cos\left[\omega_C t + \frac{\pi}{2} m(t)\right]$$

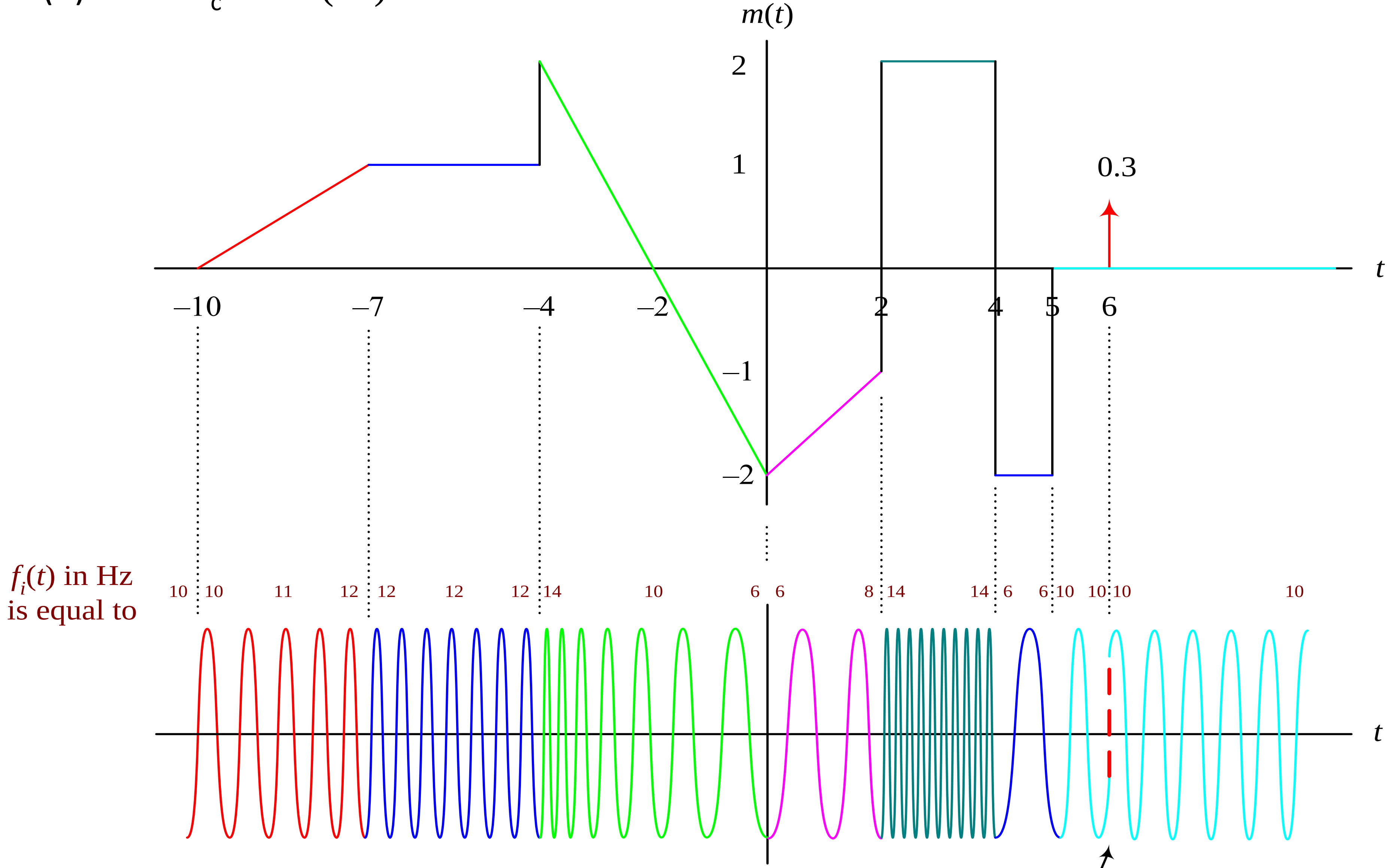
$$\varphi_{PM}(t) = A_C \sin(\omega_C t) \quad \text{when} \quad m(t) = -1$$

$$\varphi_{PM}(t) = -A_C \sin(\omega_C t) \quad \text{when} \quad m(t) = 1$$

Comparing Frequency Modulation to Phase Modulation

#	Frequency Modulation (FM)	Phase Modulation (PM)
1	Frequency deviation is proportional to modulating signal $m(t)$	Phase deviation is proportional to modulating signal $m(t)$
2	Noise immunity is superior to PM (and of course AM)	Noise immunity better than AM, but not FM
3	Signal-to-noise ratio (SNR) is better than PM (and of course AM)	Signal-to-noise ratio (SNR) is not quite as good as with FM
4	FM is widely used for commercial broadcast radio (88 MHz to 108 MHz)	PM is primarily used for mobile radio services
5	Modulation index is proportional to modulating signal $m(t)$ as well as the modulating frequency f_m	Modulation index is proportional to modulating signal $m(t)$

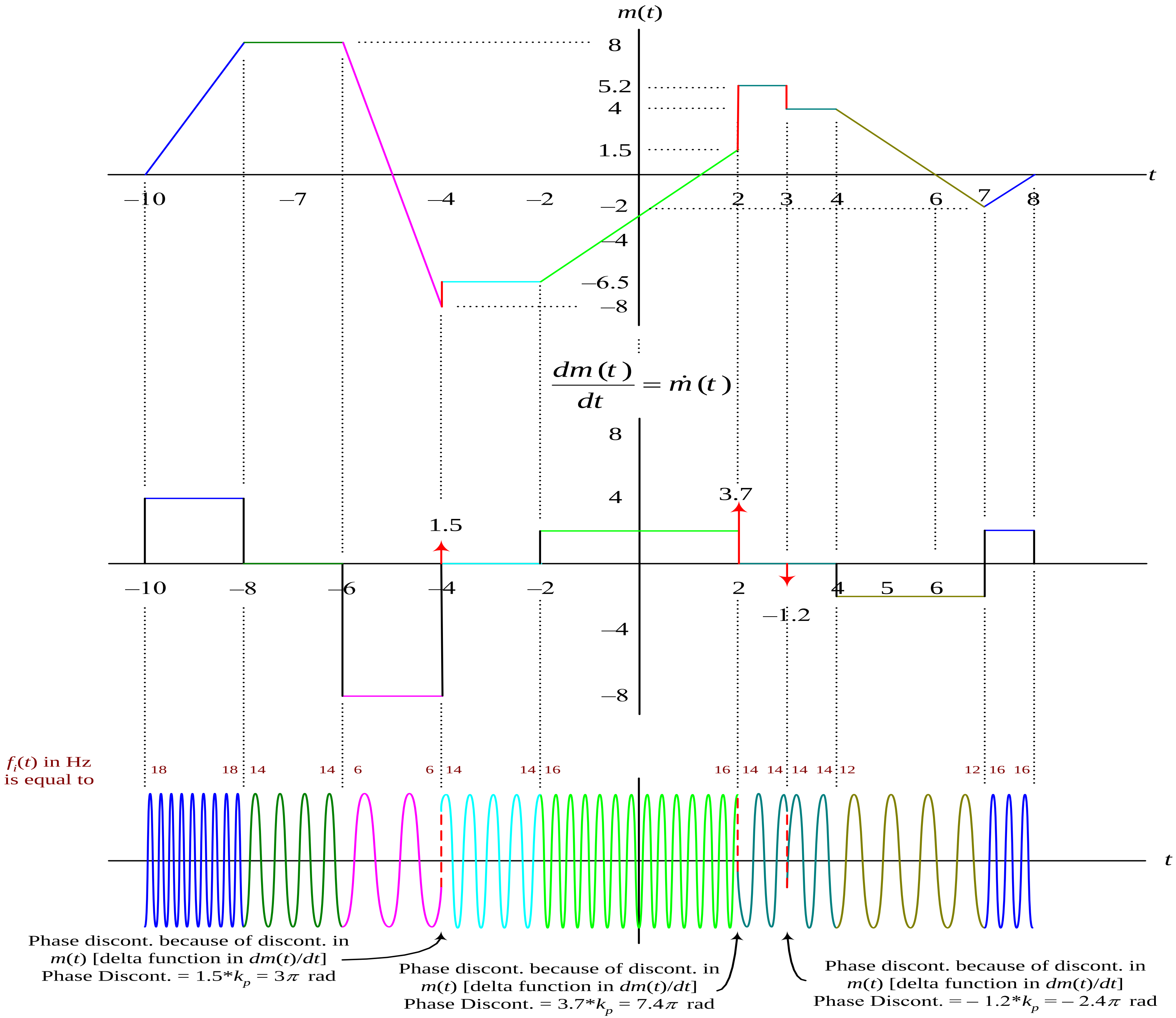
Example: Sketch the FM signal that results when modulating the message signal $m(t)$ shown below with $k_f = 2\pi(2)$ and $\omega_c = 2\pi(10)$ rad/s.



Phase Discontinuity here because of delta in $m(t)$

Phase Discont. = $0.3 * k_f = 1.2\pi$ rad

Example:
Sketch the PM signal that results when modulating the message signal $m(t)$ shown below with $k_p = 2\pi$ and $\omega_c = 2\pi(14)$ rad/s.



References

- Lathi, B. P., & Ding, Z. (2009). Modern digital and analog communication systems (4th ed.). Oxford, UK: Oxford University Press.
- Couch, L. W., Shao, H., Li, X., & Liu, L. (2012). Digital and analog communication systems (8^{th} ed.). Upper Saddle River, NJ: Prentice Hall.
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