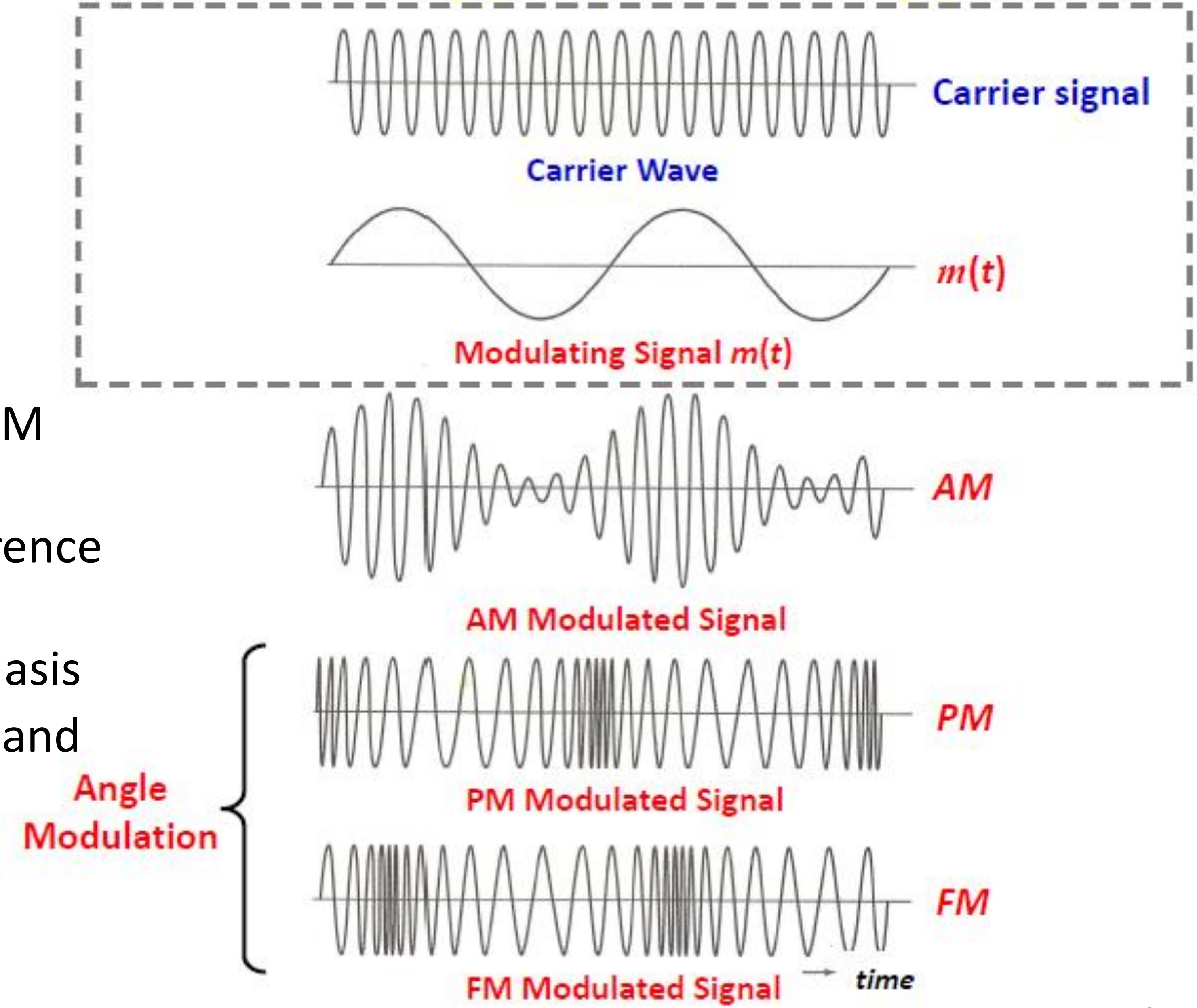
EE 361
Communication Theory

Chapter 4
Angle Modulation
Part 13

- Previously
  - Demodulation of FM

- Today
  - Effect of Non-linearity on FM signals
  - Effect of Noise and Interference on FM signals
  - Preemphasis and De-emphasis
  - Stereophonic FM Transmit and Receiver

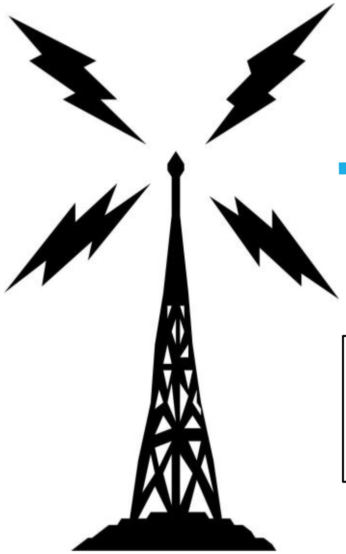
Illustrating AM, PM and FM Signals

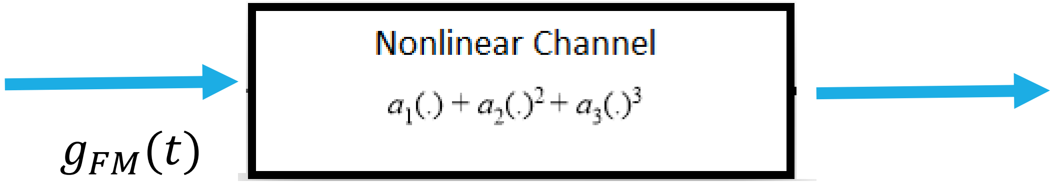


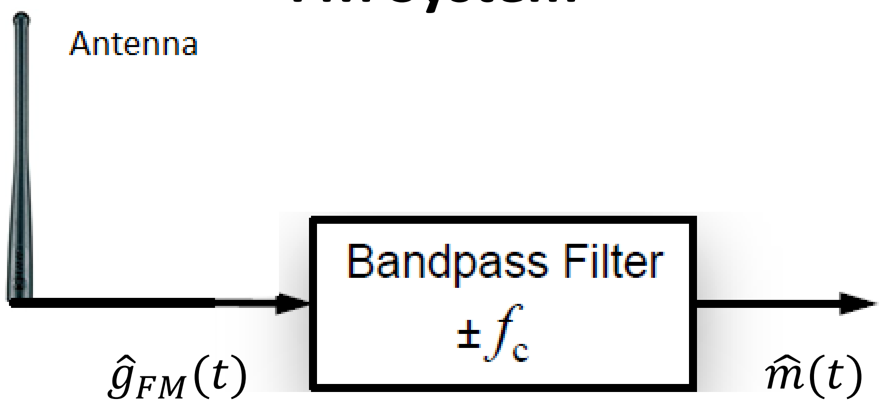
[Haykin and Moher, 2006]

Effect of Non–Linearity: FM Versus AM

FM System







$$g_{FM}(t) = A\cos\left(\omega_c t + k_f\int_{-\infty}^{\infty} m(\alpha)d\alpha\right)$$

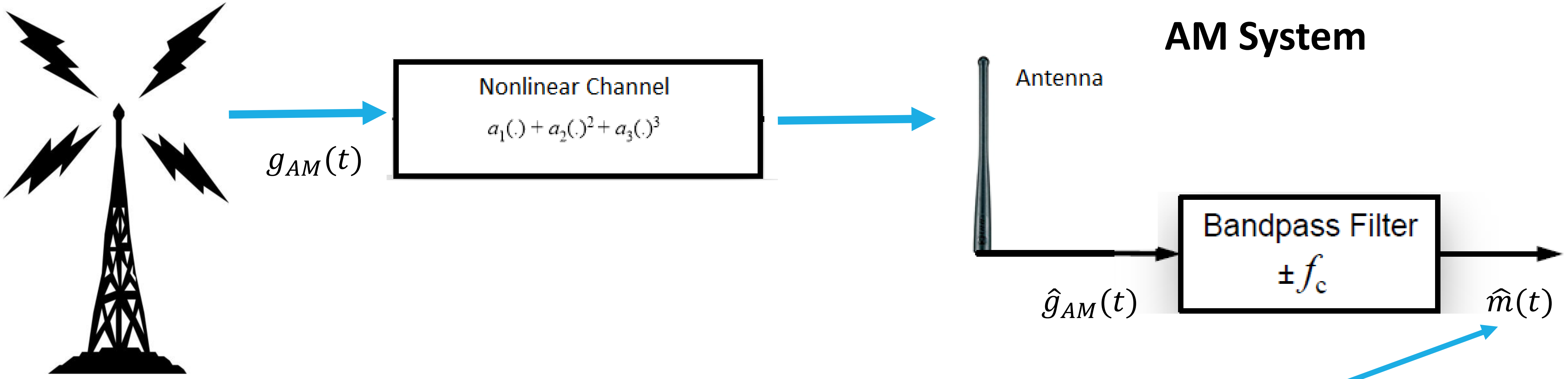
$$\hat{g}_{FM}(t) = a_1 A\cos\left(\omega_c t + k_f\int_{-\infty}^{\infty} m(\alpha)d\alpha\right) + a_2\left[A\cos\left(\omega_c t + k_f\int_{-\infty}^{\infty} m(\alpha)d\alpha\right)\right]^2 + a_3\left[A\cos\left(\omega_c t + k_f\int_{-\infty}^{\infty} m(\alpha)d\alpha\right)\right]^3$$

$$= a_1 A\cos\left(\omega_c t + k_f\int_{-\infty}^{\infty} m(\alpha)d\alpha\right) + \frac{a_2 A}{2}\left[1+\cos\left(2\omega_c t + 2k_f\int_{-\infty}^{\infty} m(\alpha)d\alpha\right)\right] + \frac{a_3 A}{2}\left[1+\cos\left(2\omega_c t + 2k_f\int_{-\infty}^{\infty} m(\alpha)d\alpha\right)\right]\cos\left(\omega_c t + k_f\int_{-\infty}^{\infty} m(\alpha)d\alpha\right)$$

$$= \underbrace{\frac{a_2 A}{2}}_{DC} + \boxed{\underbrace{\left[a_1 A + \frac{3a_3 A}{4}\right]\cos\left(\omega_c t + k_f\int_{-\infty}^{\infty} m(\alpha)d\alpha\right)}_{\text{Around } \omega_c \text{ with } k_f' = k_f}} + \underbrace{\frac{a_2 A}{2}\cos\left(2\omega_c t + 2k_f\int_{-\infty}^{\infty} m(\alpha)d\alpha\right)}_{\text{Around } 2\omega_c \text{ with } k_f' = 2k_f} + \underbrace{\frac{a_3 A}{4}\cos\left(3\omega_c t + 3k_f\int_{-\infty}^{\infty} m(\alpha)d\alpha\right)}_{\text{Around } 3\omega_c \text{ with } k_f' = 3k_f}$$

Effect of Non–Linearity: FM Versus AM

AM System

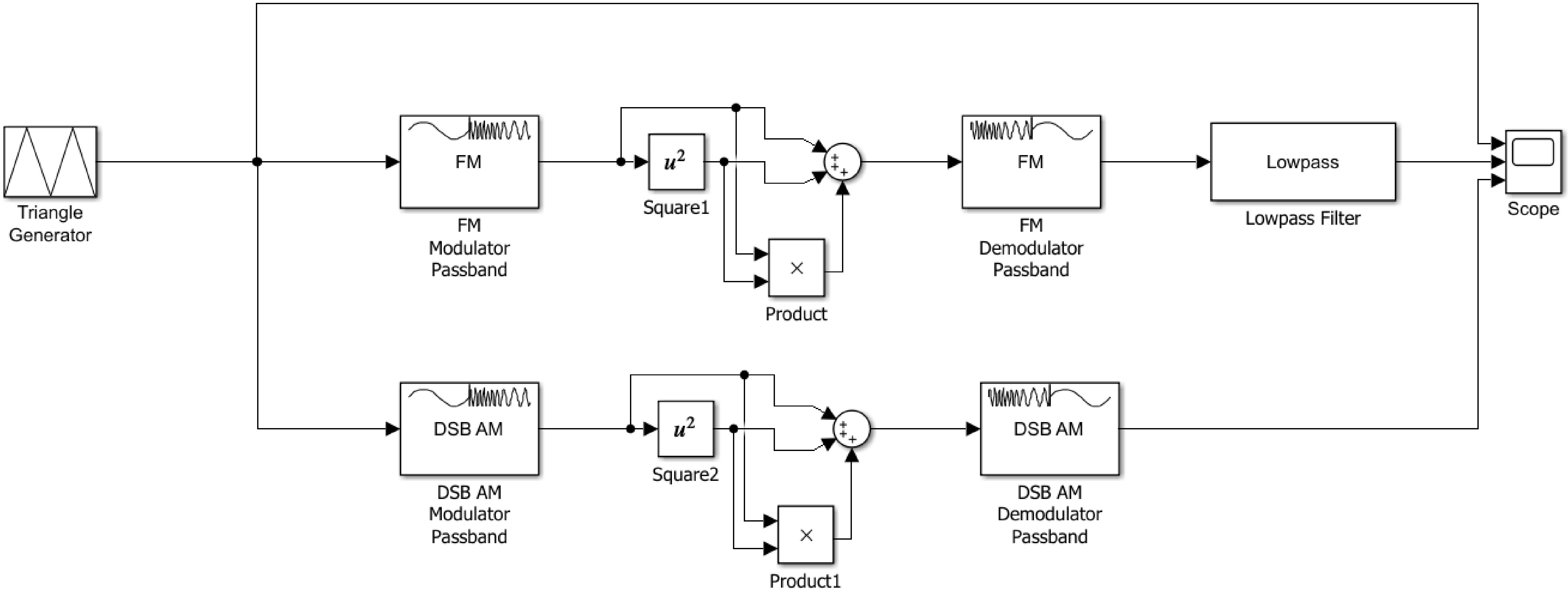


$$\hat{g}_{AM}(t) = a_1 m(t)\cdot\cos(\omega_c t) + a_2\left[m(t)\cdot\cos(\omega_c t)\right]^2 + a_3\left[m(t)\cdot\cos(\omega_c t)\right]^3$$

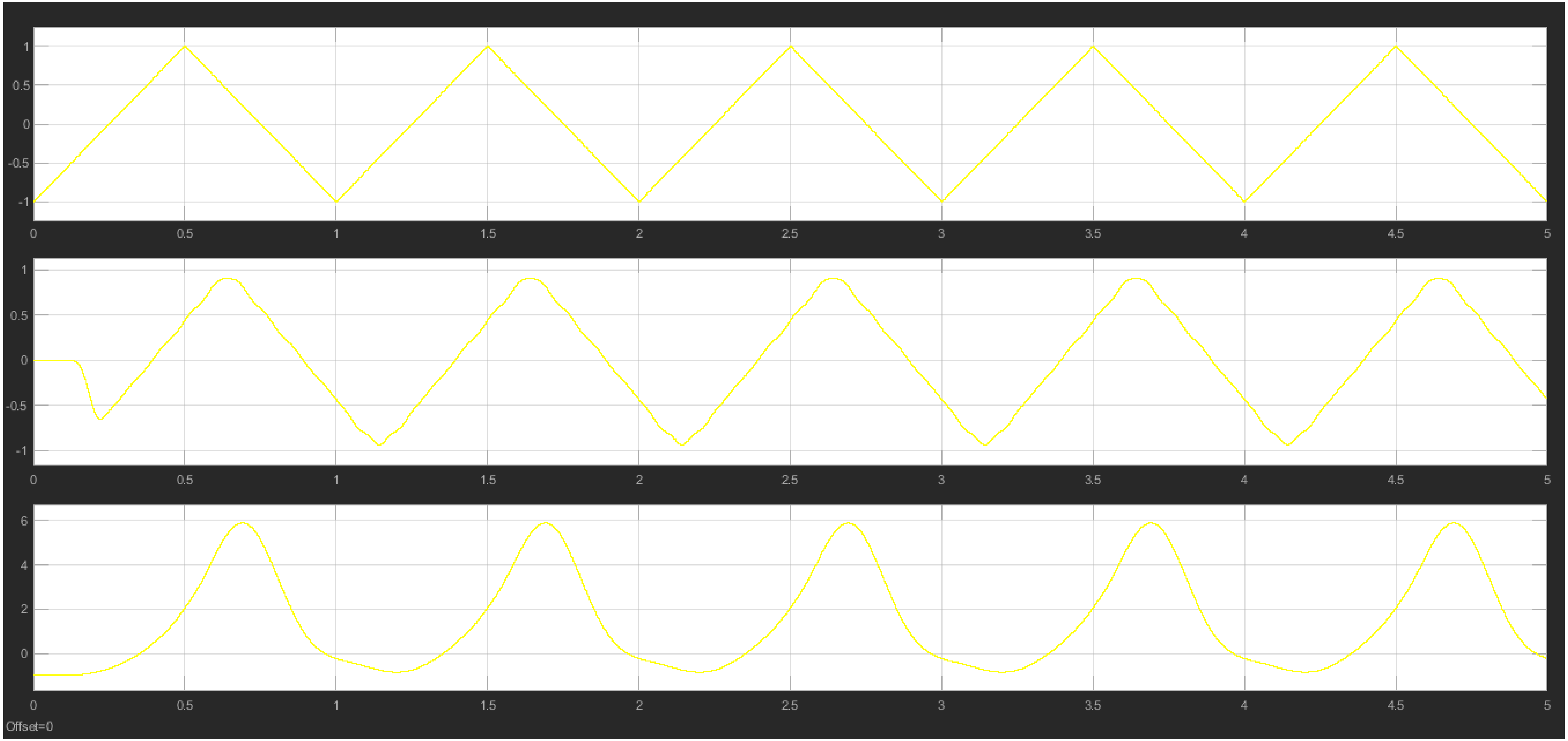
$$= a_1 m(t)\cdot\cos(\omega_c t) + \frac{a_2 m^2(t)}{2}\left[1+\cos(2\omega_c t)\right] + \frac{a_3 m^3(t)}{2}\cdot\cos(\omega_c t)\left[1+\cos(2\omega_c t)\right]$$

$$= \underbrace{\frac{a_2 m^2(t)}{2}}_{\text{Around } 0} + \boxed{\underbrace{\left[a_1 m(t) + \frac{3a_3 m^3(t)}{4}\right]\cdot\cos(\omega_c t)}_{\text{Around } \omega_c}} + \underbrace{\frac{a_2 m^2(t)}{2}\cos(2\omega_c t)}_{\text{Around } 2\omega_c} + \underbrace{\frac{a_3 m^3(t)}{4}\cdot\cos(3\omega_c t)}_{\text{Around } 3\omega_c}$$

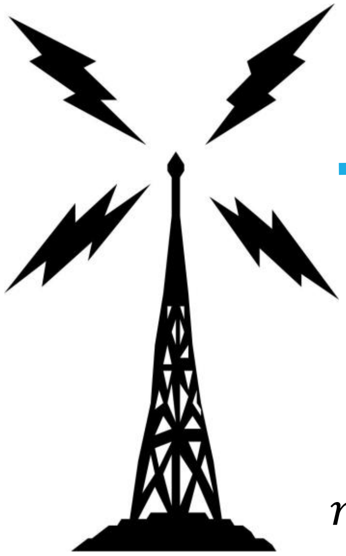
Effect of Non–Linearity: FM Versus AM

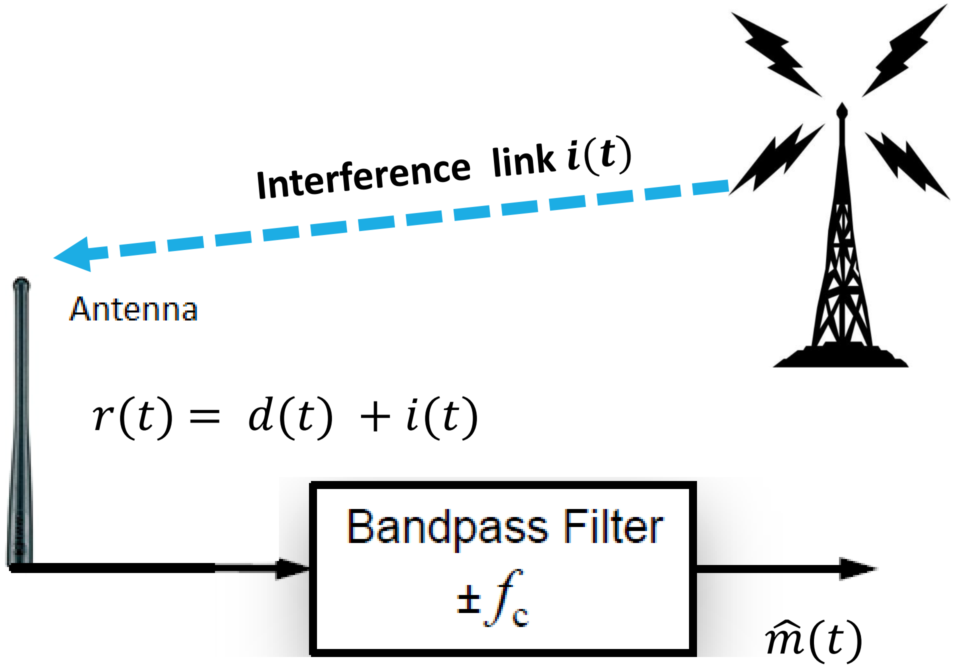


Effect of Non–Linearity: FM Versus AM



Effect of Interference on FM System





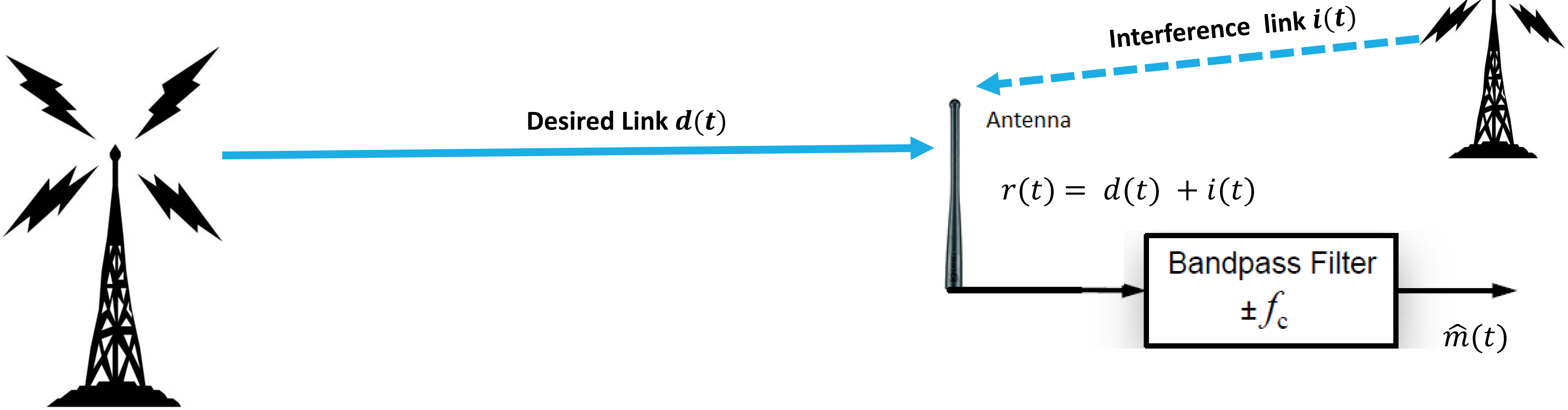
$$d(t) = A\cos(\omega_c t)\,;$$
$$i(t) = I\cos\big((\omega_c + \omega)t\big)$$

$$\begin{aligned} r(t) &= A\cos(\omega_c t) + I\cos\big((\omega_c+\omega)t\big) \\ &= \mathrm{A}\cos(\omega_c t) + \mathrm{I}\cos(\omega_c t)\cos(\omega t) - I\sin(\omega_c t)\sin(\omega t) \\ &= (A + I\cos(\omega t))\cos(\omega_c t) - I\sin(\omega t)\sin(\omega_c t) \\ &= E(t)\cos\big(\omega_c t + \Phi(t)\big) \end{aligned}$$

$$E(t) = \sqrt{(A + I\cos(\omega t))^2 + (I\sin(\omega t))^2}$$ % Envelop

$$\Phi(t) = \tan^{-1}\left(\frac{I\sin(\omega t)}{A + I\cos(\omega t)}\right)$$ % Phase

Effect of Interference on PM and FM System



Considering that Interference signal is weak as compared to desired signal, i.e., $I \ll A,\ then$

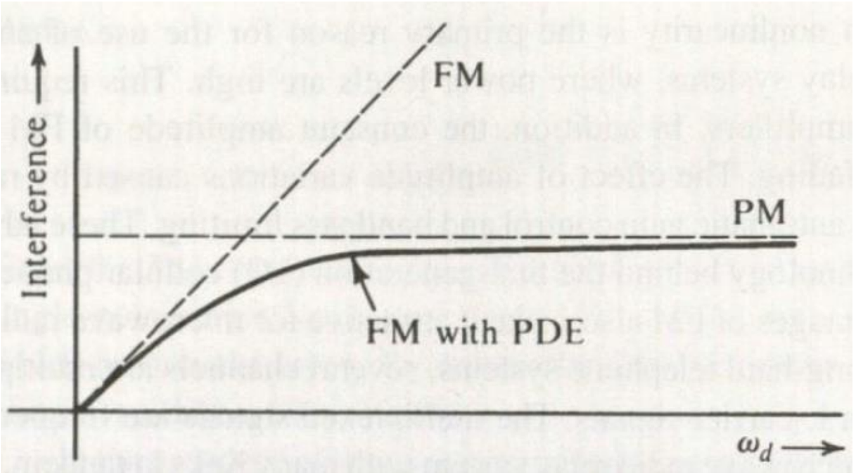
$$\Phi(t) = \tan^{-1}\left(\frac{I\sin(\omega t)}{A + I\cos(\omega t)}\right)$$

$$\approx \frac{I}{A}\sin(\omega t) \qquad \tan^{-1}x = x - \frac{x^3}{3} + \frac{x^5}{5} - \frac{x^7}{7} + \cdots \overset{|x|\ll 1}{\simeq} x$$

Therefore;

$$\hat{g}_{PM}(t) \approx \cos\left(\omega_c t + \frac{I}{A}\sin(\omega t)\right) \qquad \text{\% For PM direct use } \Phi(t)$$

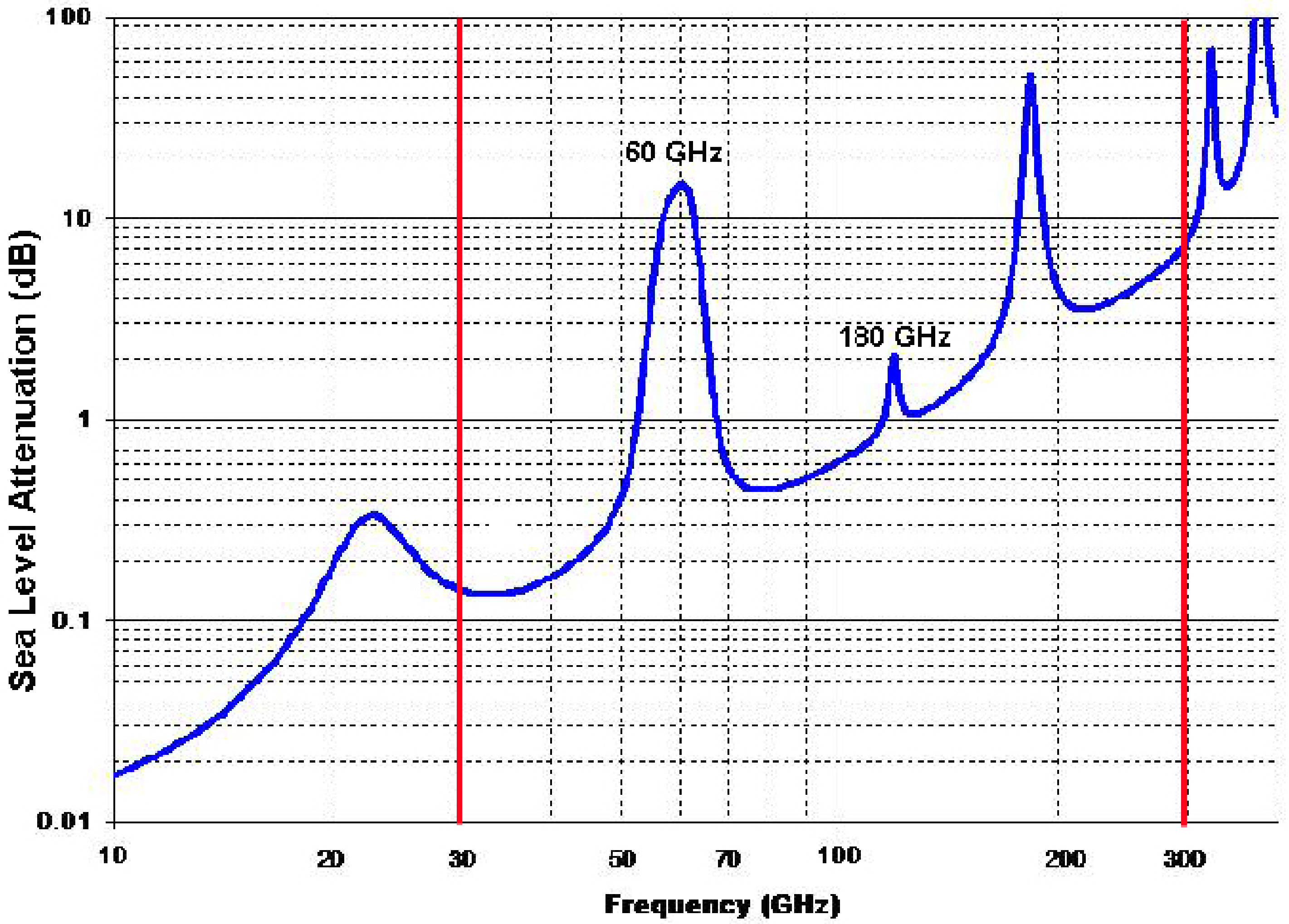
$$\hat{g}_{FM}(t) \approx \cos\left(\omega_c t + \frac{I\omega}{A}\cos(\omega t)\right) \qquad \text{\% For FM use } \frac{\mathrm{d}}{\mathrm{dt}}\Phi(t)$$



Lathi, B. P., & Ding, Z. (2009). Modern digital and analog communication systems (4th ed.). Oxford, UK: Oxford University Press.

FM Broadcast Preemphasis and Deemphasis filtering

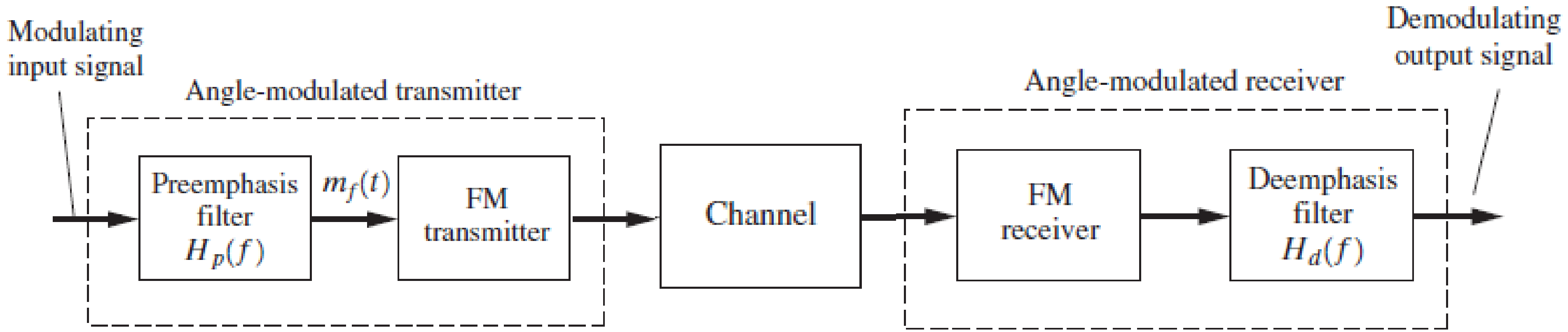
Rational of Use: Noise power non-linearly increase with frequency

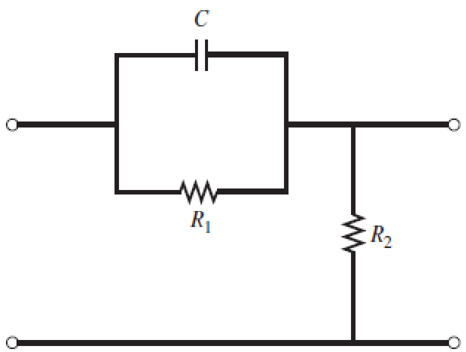


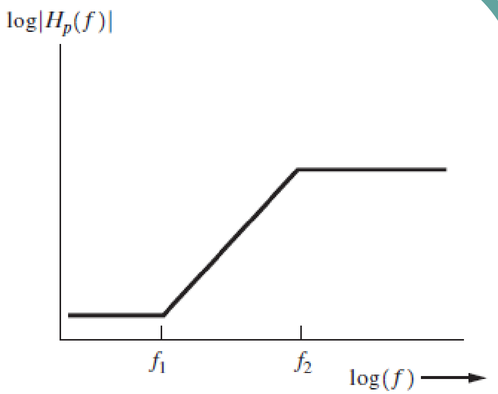
In angle-modulated systems, the signal-to-noise ratio at the output of the receiver can be improved if the level of the modulation is

- boosted at the top end of the (e.g., audio) spectrum (at the transmitter); this is called preemphasis, and
- attenuated at high frequencies on the receiver output—called deemphasis.

FM Broadcast Preemphasis and Deemphasis filtering





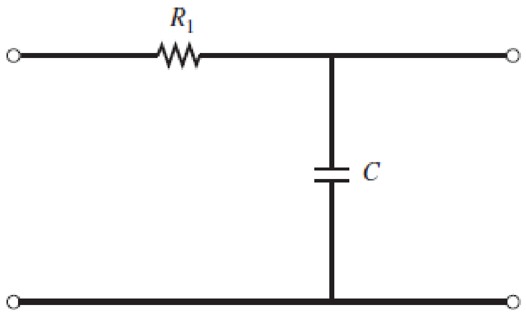


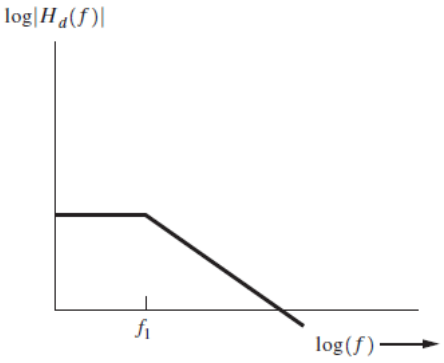
Preemphasis Filter

$$H_p(f) = K\frac{1 + j(f/f_1)}{1 + j(f/f_2)}$$

$$\text{where } f_1 = \frac{1}{2\pi\tau_1} = \frac{1}{2\tau R_1 C},$$

$$f_2 = \frac{1}{2\pi\tau_2} = \frac{R_1 + R_2}{2\tau R_1 R_2 C}$$





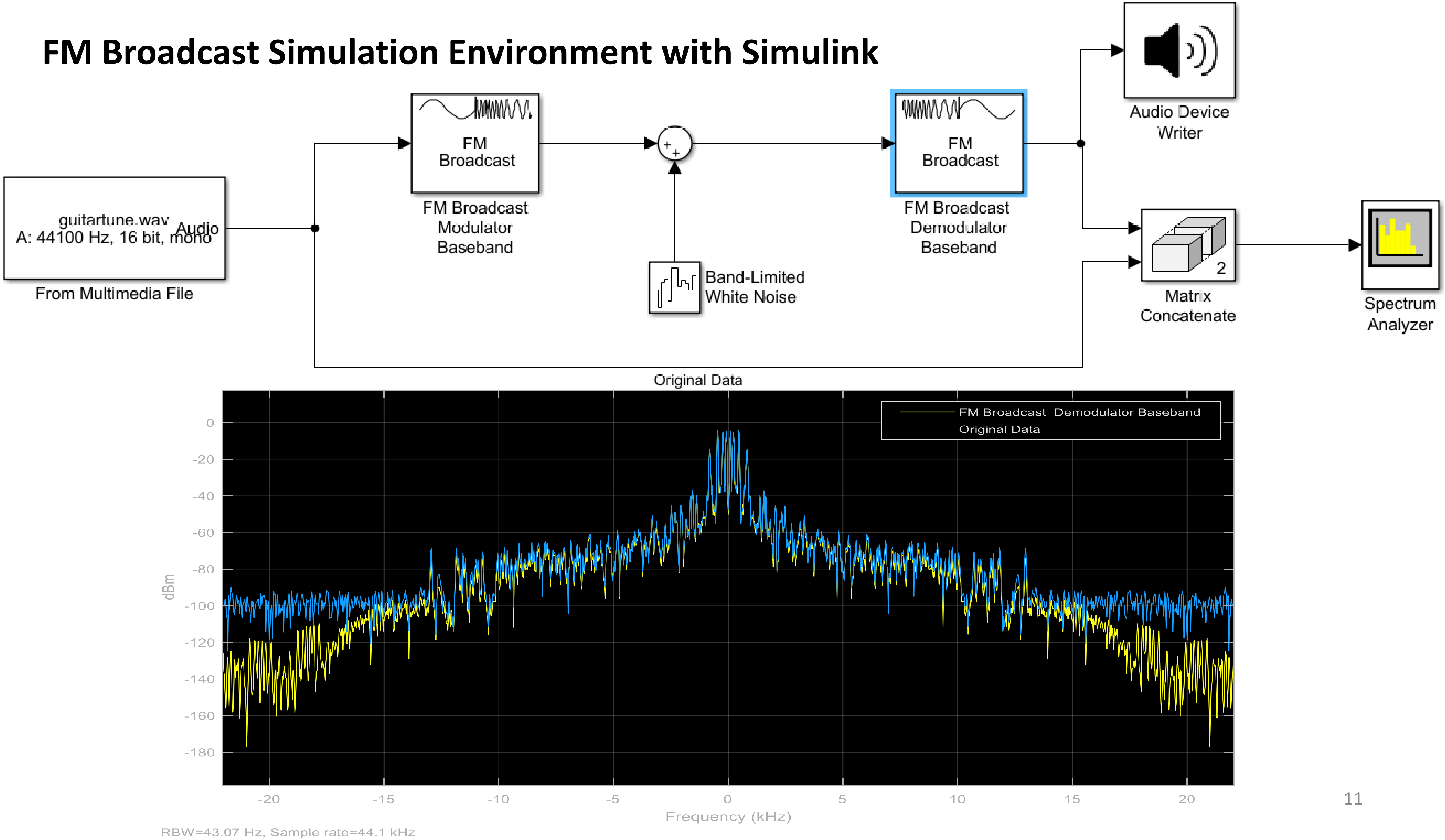
Deemphasis Filter

$$H_p(f) = \frac{1}{1 + j(f/f_1)}$$

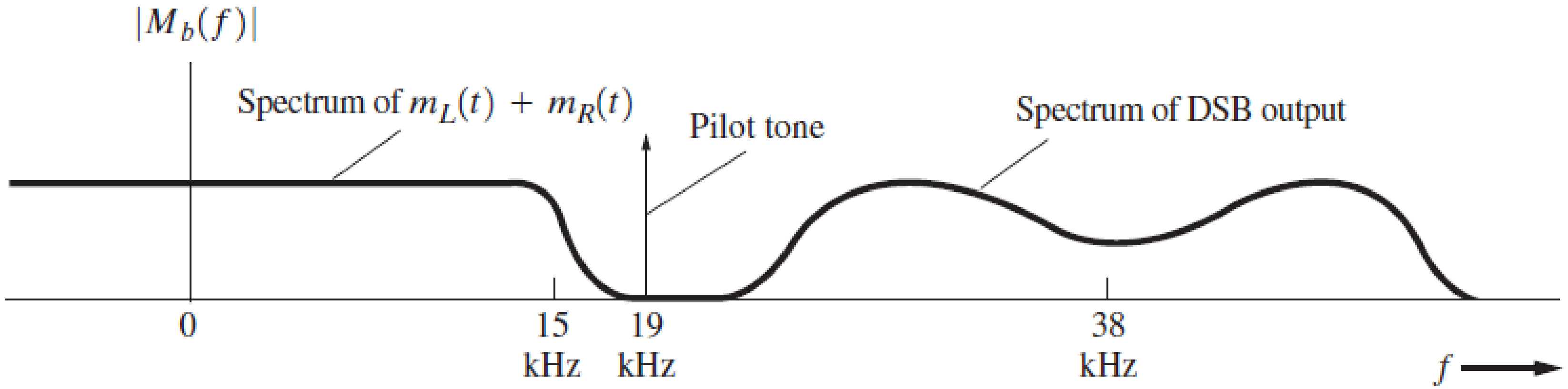
$$\text{where } f_1 = \frac{1}{2\pi\tau_1} = \frac{1}{2\tau R_1 C}$$

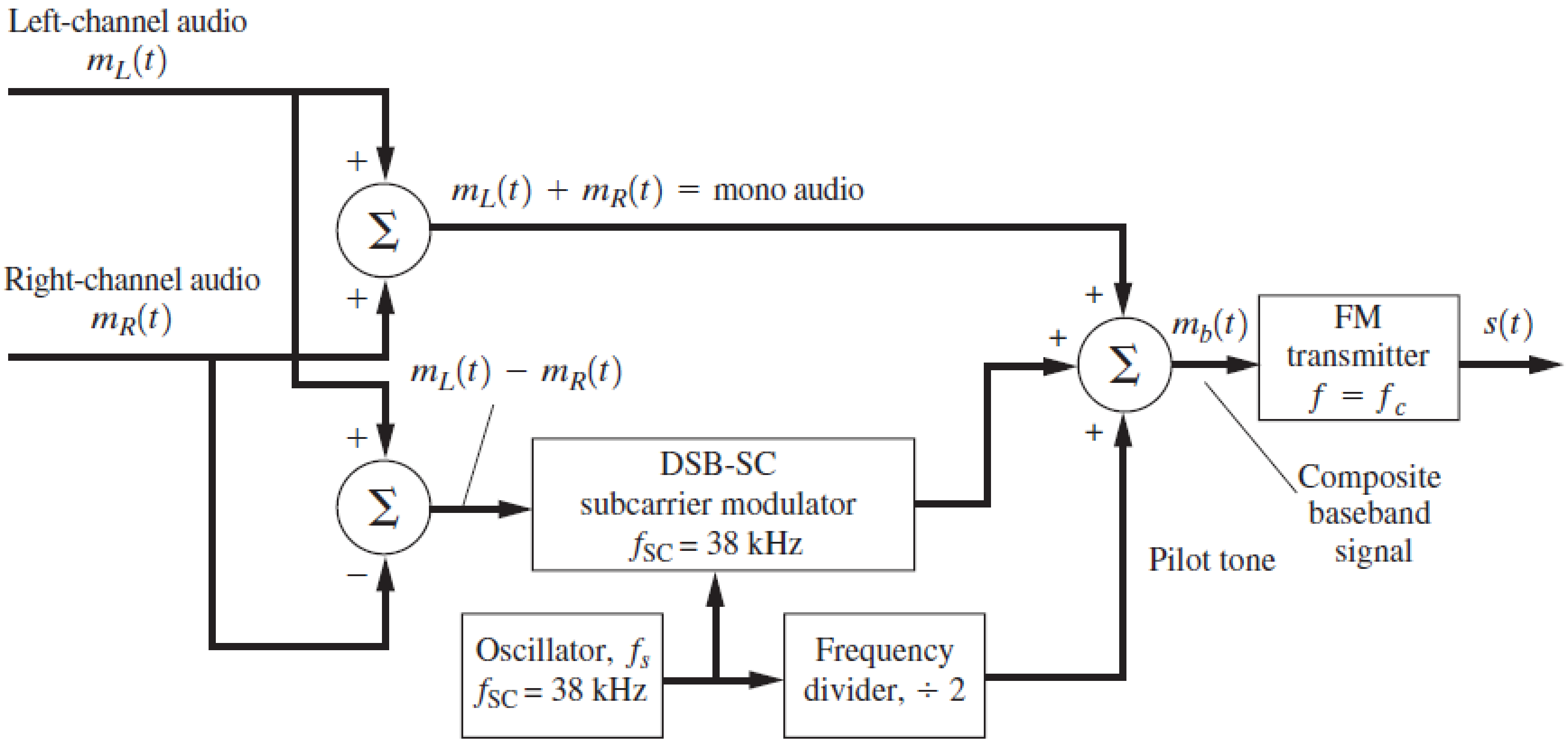
Couch, L. W., Shao, H., Li, X., & Liu, L. (2012). Digital and analog communication systems (8th ed.). Upper Saddle River, NJ: Prentice Hall.

FM Broadcast Simulation Environment with Simulink



FM Stereo Transmitter





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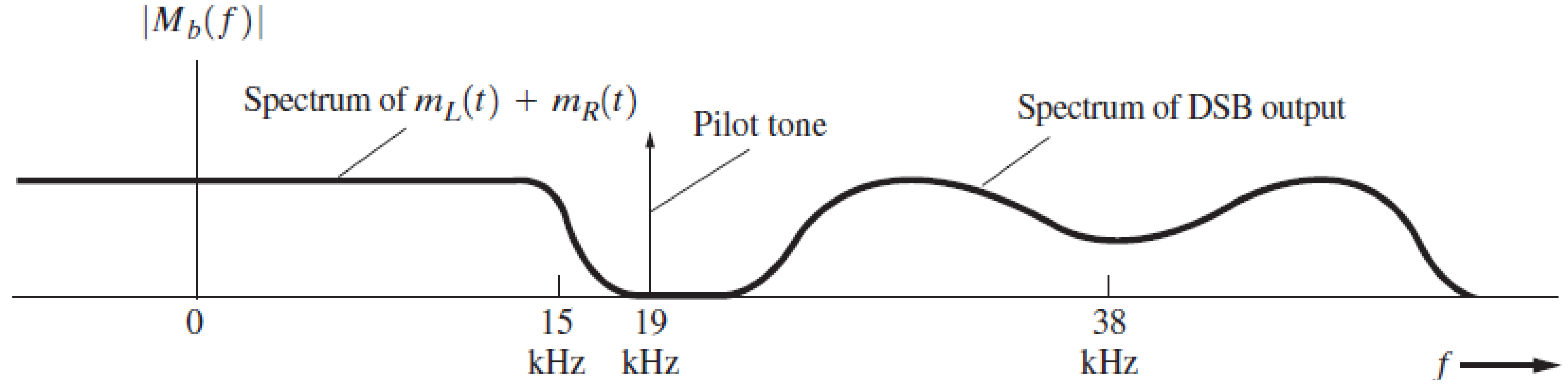
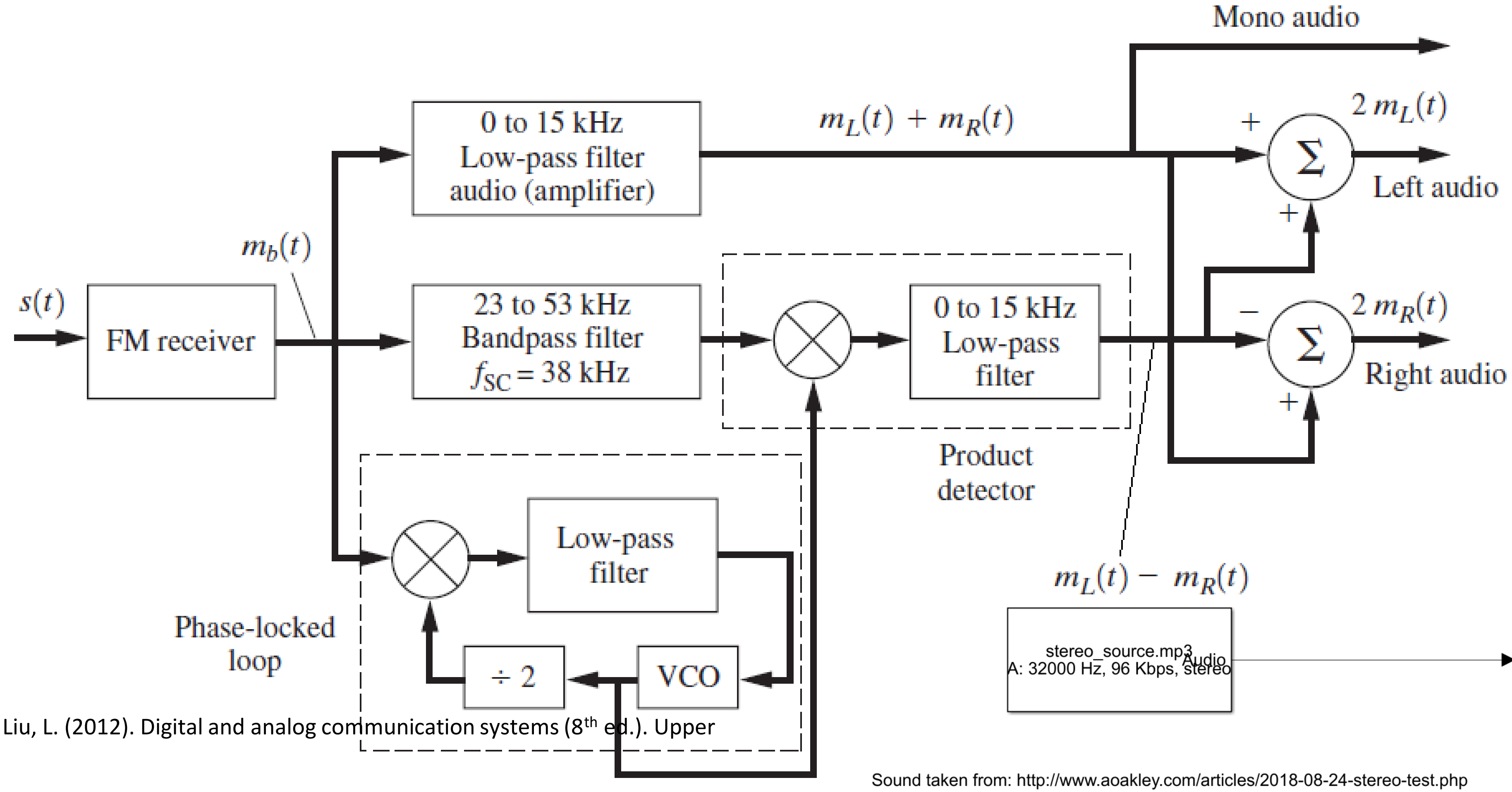
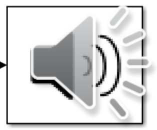
FM Stereo Receiver







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Sound taken from: http://www.aoakley.com/articles/2018-08-24-stereo-test.php

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