BITS Pilani
Hyderabad Campus
Department of Electrical Engineering

EEE/ECE F311
Communication Systems
Tutorial-1

Date : 07/08/2025
12/08/25

Tutorial-1

1. Compute the energy and power of the following signals and find out whether the signal is an energy signal or power signal, or neither.

   a) $x(t) = 4\sin\left(2\pi t\right); \ -\infty < t < \infty$

   b) $x(t) = 2e^{-2|t|}; \ -\infty < t < \infty.$

   c) $x(t) = \begin{cases} 2/\sqrt{t}; & t > 1 \\ 0; & t \le 1 \end{cases}$

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Solution 1(a)

$$E=\int_{-\infty}^{\infty}\left|x(t)\right|^2 dt=\int_{-\infty}^{\infty}\left|4\sin(2\pi t)\right|^2 dt=16\int_{-\infty}^{\infty}\left[\frac{1-\cos(4\pi t)}{2}\right]dt=8\int_{-\infty}^{\infty}dt-8\int_{-\infty}^{\infty}\cos(4\pi t)\,dt=\infty$$

$$P=\lim_{T\to\infty}\frac{1}{T}\int_{-T/2}^{T/2}x^2(t)\,dt=\lim_{T\to\infty}\frac{1}{T}\int_{-T/2}^{T/2}16\sin^2(2\pi t)\,dt=8\lim_{T\to\infty}\frac{1}{T}\int_{-T/2}^{T/2}dt-16\lim_{T\to\infty}\frac{1}{T}\int_{-T/2}^{T/2}\frac{\cos(4\pi t)}{2}dt=8$$

As the energy of *x*(t) is infinite, and average power is finite. Thus *x*(t) is a power signal.

Solution 1(b)

$$E=\int_{-\infty}^{\infty}\left|x(t)\right|^2 dt=\int_{-\infty}^{\infty}\left|2e^{-2|t|}\right|^2 dt=4\int_{-\infty}^{0}e^{4t}dt+4\int_{0}^{\infty}e^{-4t}dt=2$$

$$P=\lim_{T\to\infty}\frac{1}{T}\int_{-T/2}^{T/2}x^2(t)\,dt=4\lim_{T\to\infty}\frac{1}{T}\int_{-T/2}^{0}e^{4t}dt+4\lim_{T\to\infty}\frac{1}{T}\int_{0}^{T/2}e^{-4t}dt=0$$

The energy of *x*(t) is finite, and average power is zero. Thus *x*(t) is an energy signal.

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Solution 1(c)

$$P = \lim_{T\to\infty}\frac{1}{T}\int_{-T/2}^{T/2} x^2(t)\mathrm{dt} = \lim_{T\to\infty}\frac{1}{T}\int_{1}^{T/2}\frac{4}{t}\,dt$$

$$= 4\lim_{T\to\infty}\left(\frac{1}{T}\ln\left[t\right]^{T/2}_{1}\right) = 4\lim_{T\to\infty}\left(\frac{1}{T}\ln\left[\frac{T}{2}\right] - \frac{1}{T}\ln\left[1\right]\right)$$

$$= 4\lim_{T\to\infty}\left(\frac{1}{T}\ln\left[\frac{T}{2}\right]\right)$$

$$= 4\lim_{T\to\infty}\left(\frac{\ln\left[\frac{T}{2}\right]}{T}\right)$$

Using L'Hospital's rule we have,

$$P = 4\lim_{T\to\infty}\left(\frac{\ln\left[\frac{T}{2}\right]}{T}\right) = 4\lim_{T\to\infty}\left(\frac{\frac{2}{\mathrm{T}}}{1}\right) = 0$$

$$E = \int_{-\infty}^{\infty}|x(t)|^2dt = \int_{1}^{\infty}\frac{4}{t}\,dt$$

$$= 4\ln\left[t\right]_1^{\infty}$$

$$= \infty$$

The energy of the signal is infinite & its average power is zero; x(t) is <u>neither energy signal nor power signal</u>.

Tutorial-1

2. Determine the power and RMS value of the following signal.

$$x(t) = e^{j2t} \cos(10t)$$

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Solution 2

$$x(t) = e^{j2t}\cos(10t)$$

$$= (\cos 2t + j\sin 2t)\cos(10t)$$

$$= \frac{(\cos 12t + \cos 8t)}{2} + j\frac{(\sin 12t - \sin 8t)}{2}$$

Power of the signal $= \dfrac{\left(\frac{1}{2}\right)^2}{2} + \dfrac{\left(\frac{1}{2}\right)^2}{2} + \dfrac{\left(\frac{1}{2}\right)^2}{2} + \dfrac{\left(\frac{1}{2}\right)^2}{2} = \dfrac{1}{2}$

RMS value of the signal $= \sqrt{\dfrac{1}{2}}$

$$\cos(10t) = \frac{e^{j10t} + e^{-j10t}}{2}$$

$$x(t) = e^{j2t} \cdot \frac{e^{j10t} + e^{-j10t}}{2} = \frac{1}{2}\left(e^{j(12t)} + e^{-j8t}\right)$$

$$P = \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{T} |x(t)|^2 dt$$

$$|x(t)|^2 = \left|\frac{1}{2}\left(e^{j12t} + e^{-j8t}\right)\right|^2 = \frac{1}{4}\left|e^{j12t} + e^{-j8t}\right|^2$$

$$|a+b|^2 = |a|^2 + |b|^2 + 2\mathrm{Re}(ab^*)$$

$$a = e^{j12t}, b = e^{-j8t}$$

$$|x(t)|^2 = \frac{1}{4}(1 + 1 + 2\cos(20t)) = \frac{1}{4}(2 + 2\cos(20t)) = \frac{1}{2}(1 + \cos(20t))$$

$$P = \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{T} \frac{1}{2}(1 + \cos(20t))dt$$

$$= \frac{1}{2} \lim_{T\to\infty} \left[\frac{1}{2T} \int_{-T}^{T} 1\, dt + \frac{1}{2T} \int_{-T}^{T} \cos(20t)\, dt\right]$$

$$P = \frac{1}{2}\left(\frac{2T}{2T} + 0\right) = \frac{1}{2}$$

Tutorial-1

3. Find the odd and even components of the following signal.

$$x(t) = \sin 2t + \sin 2t \cos 2t + \cos 2t$$

Tutorial-1

Solution 3

$$x(t) = \sin 2t + \sin 2t \cos 2t + \cos 2t$$

$$x(-t) = \sin(-2t) + \sin(-2t)\cos(-2t) + \cos(-2t)$$

$$= -\sin 2t - \sin 2t \cos 2t + \cos 2t$$

Therefore the odd and even components are calculated as,

$$x_e(t) = \frac{1}{2}\left[x(t) + x(-t)\right] = \cos 2t$$

$$x_o(t) = \frac{1}{2}\left[x(t) - x(-t)\right] = \sin 2t + \sin 2t \cos 2t$$

Tutorial-1

4. The energies of the two energy signals $x(t)$ and y(t) are E_x and E_y, respectively.
   a) If $x(t)$ and $y(t)$ are orthogonal, then show that the energy of the signal $x(t) \pm y(t)$ is given by E_x+E_y.

   b) The cross-energy of the two signals is defined as, $E_{xy} = \int_{-\infty}^{\infty} x(t)\,y^*(t)\,dt$

   If $z(t) = x(t) \pm y(t)$, then show that, $E_z = E_x + E_y \pm (E_{xy} + E_{yx})$

Tutorial-1

Solution 4(a)

$$\int_{-\infty}^{+\infty} \left|x(t) \pm y(t)\right|^2 dt = \int_{-\infty}^{+\infty} \left|x(t)\right|^2 dt + \int_{-\infty}^{+\infty} \left|y(t)\right|^2 dt \pm \underbrace{\int_{-\infty}^{+\infty} x(t)\, y^*(t)\, dt}_{=0} \pm \underbrace{\int_{-\infty}^{+\infty} x^*(t)\, y(t)\, dt}_{=0}$$

$$= \int_{-\infty}^{+\infty} \left|x(t)\right|^2 dt + \int_{-\infty}^{+\infty} \left|y(t)\right|^2 dt$$

$$= E_x + E_y$$

Solution 4(b)

$$\int_{-\infty}^{+\infty} \left|x(t) \pm y(t)\right|^2 dt = \int_{-\infty}^{+\infty} \left|x(t)\right|^2 dt + \int_{-\infty}^{+\infty} \left|y(t)\right|^2 dt \pm \underbrace{\int_{-\infty}^{+\infty} x(t)\, y^*(t)\, dt}_{\text{Cross Energy Component}} \pm \underbrace{\int_{-\infty}^{+\infty} x^*(t)\, y(t)\, dt}_{\text{Cross Energy Component}}$$

$$= E_x + E_y \pm \left(E_{xy} + E_{yx}\right)$$

Tutorial-1

5. Show that an exponential signal e^{-at} starting at $-\infty$ is neither energy nor a power signal for any real value of ‘a’. However, if imaginary, it is a power signal with unity power, regardless of the value of ‘a’.

Tutorial-1

Solution 5

For real 'a',

$$E_g = \int_{-\infty}^{+\infty} (e^{-at})^2 dt = \int_{-\infty}^{+\infty} e^{-2at} dt = \infty$$

$$P_g = \lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{+T/2} (e^{-at})^2 dt = \lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{T/2} e^{-2at} dt = \infty$$

Hence for real value of 'a', the signal e^{-at} starting at $-\infty$ is neither energy nor a power signal.

Consider, a is imaginary and given by $a = jx$.

$$P_g = \lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{T/2} (e^{jxt})(e^{-jxt}) dt = \lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{T/2} dt = \underline{1} \text{ (Ans)}$$

Hence the statement is proved.

In case of imaginary

$$|x(t)|^2 = x(t)\, x^*(t)$$
$$= e^{j(t)}\, e^{-jt} = e^0 = 1$$

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EEE/ECE F311
Communication Systems
Tutorial-2

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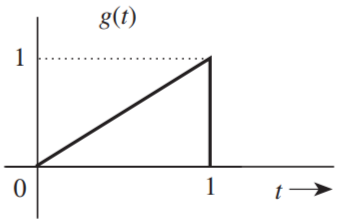
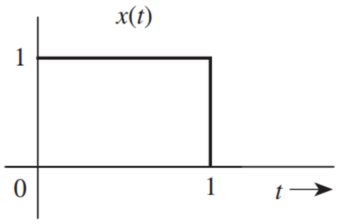
Tutorial-2

1. For the signals $g(t)$ and $x(t)$, find the component of the form $x(t)$ contained in $g(t)$. What is the resulting error signal energy?



(a)



(b)

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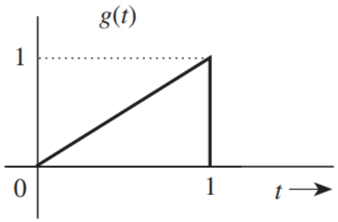
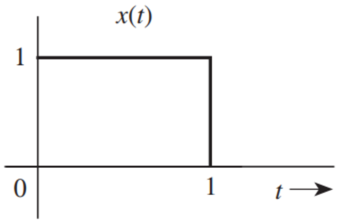
Tutorial-2

Solution 1



(a)



(b)

(a) In this case $E_x = \int_0^1 dt = 1$, and

$$c = \frac{1}{E_x}\int_0^1 g(t)x(t)\,dt = \frac{1}{1}\int_0^1 t\,dt = 0.5$$

$$e(t) = g(t) - \tfrac{1}{2}x(t) = t - \tfrac{1}{2} \text{ on } [0, 1]$$

(b) Thus, $g(t) \approx 0.5x(t)$, and the error $e(t) = t - 0.5$ over $(0 \le t \le 1)$, and zero outside this interval. Also E_g and E_e (the energy of the error) are

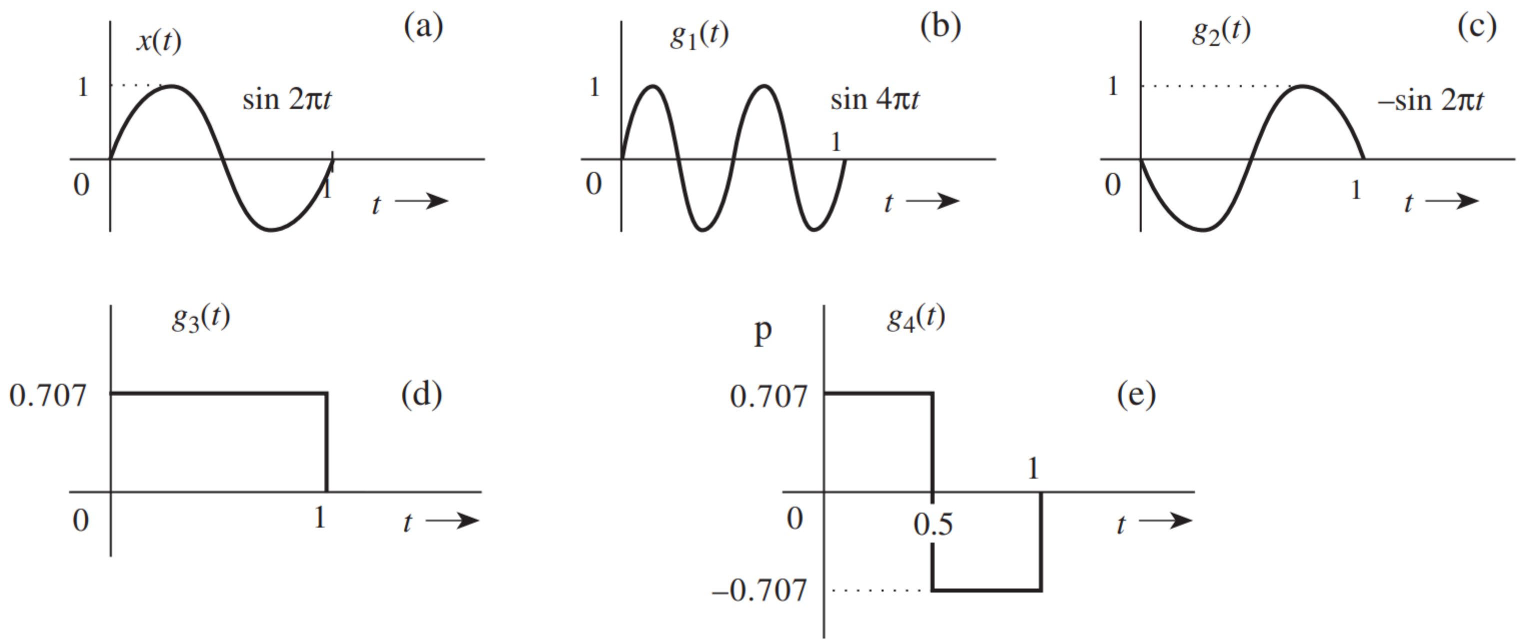
$$E_g = \int_0^1 g^2(t)\,dt = \int_0^1 t^2\,dt = 1/3 \quad \text{and} \quad E_e = \int_0^1 (t-0.5)^2\,dt = 1/12$$

The error $(t - 0.5)$ is orthogonal to $x(t)$ because

$$\int_0^1 (t-0.5)(1)\,dt = 0$$

Tutorial-2

2. Determine the correlation coefficient c_n of the signal x(t) and each of the four pulses. To provide maximum margin against the noise along the transmission path, which pair of pulses would you select for a binary communication?



Tutorial-2

Solution 2

The energy of the signal x(t): $E_x = \int_0^1 \sin^2(2\pi t)\,dt = 0.5$

Similarly, find the energy of the signals $g_1(t)$, $g_2(t)$, $g_3(t)$, and $g_4(t)$:

$$E_{g1} = E_{g2} = E_{g3} = E_{g4} = 0.5$$

(1) $\rho_n = \dfrac{1}{\sqrt{0.5\times 0.5}} \int_0^1 \sin(2\pi t)\sin(4\pi t)\,dt = 0$

(2) $\rho_n = \dfrac{1}{\sqrt{0.5\times 0.5}} \int \sin(2\pi t)\sin(-2\pi t)\,dt = -1$

(3) $\rho_n = \dfrac{1}{\sqrt{0.5\times 0.5}} \int_0^1 0.707\sin(2\pi t)\,dt = 0$

(4) $\rho_n = \dfrac{1}{\sqrt{0.5\times 0.5}} \left[\int_0^{0.5} 0.707\sin(2\pi t)\,dt - \int_{0.5}^1 0.707\sin(2\pi t)\,dt \right] = 0.9$

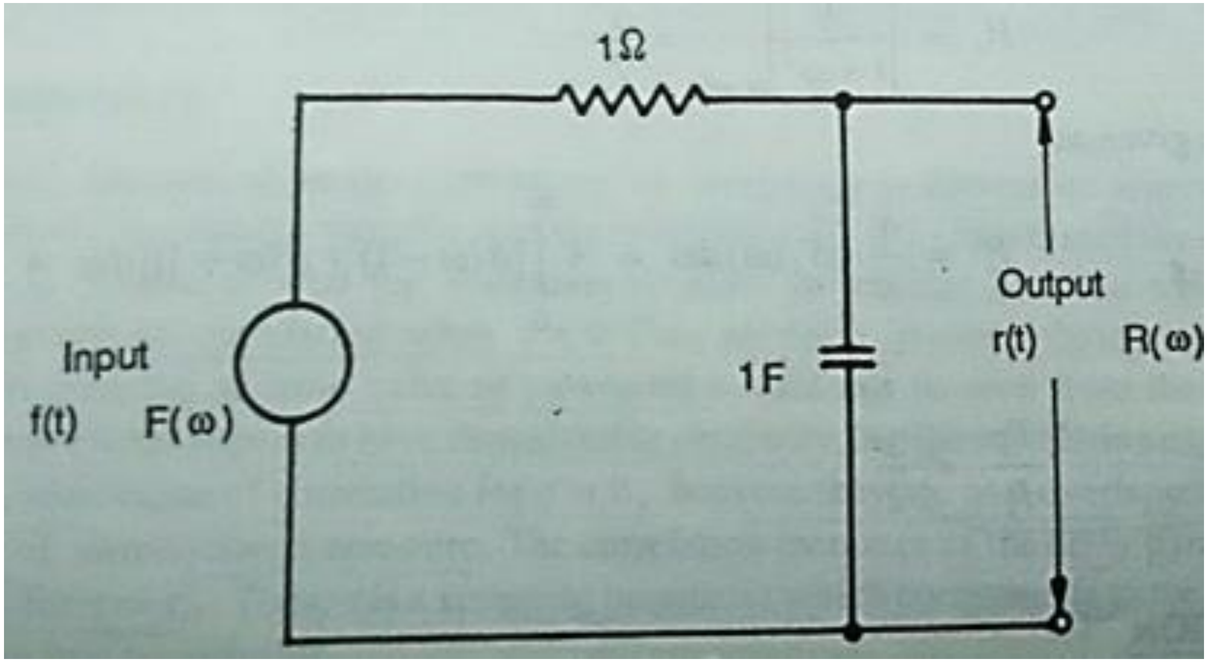
Chosen signal for binary transmission is x(t) and $g_2(t)$ as the correlation coeff. is -1

Tutorial-2

3. A signal with power spectral density

$$D_f(\omega) = A\pi\left[\delta(\omega-1)+\delta(\omega+1)\right]$$

is applied to the input of a linear system shown in figure given below . Find the ratio of average power of the response and excitation.



Solution

Transfer function $$H(j\omega) = \frac{Z_C}{R + Z_C} = \frac{1/(j\omega)}{1 + 1/(j\omega)} = \frac{1}{1 + j\omega}$$

Magnitude $$|H(j\omega)|^2 = \frac{1}{1 + \omega^2}$$

Input PSD $$S_f(\omega) = D_f(\omega) = A\pi\left[\delta(\omega - 1) + \delta(\omega + 1)\right]$$

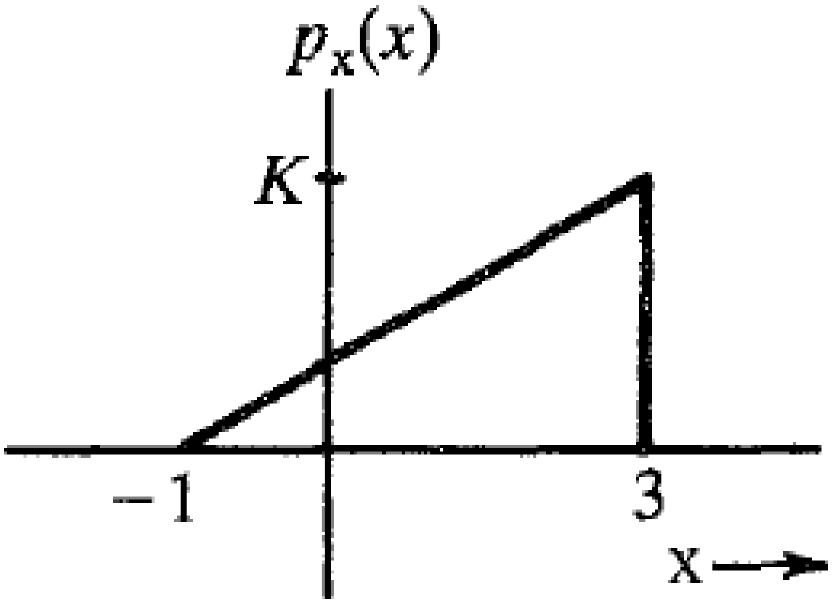
Average input power $$P_f = \frac{1}{2\pi}\int_{-\infty}^{\infty} S_f(\omega)\, d\omega = \frac{1}{2\pi}(A\pi + A\pi) = A$$

Average output power $$P_r = \frac{1}{2\pi}\int_{-\infty}^{\infty} |H(j\omega)|^2 S_f(\omega)\, d\omega = \frac{1}{2\pi} A\pi\left(|H(j1)|^2 + |H(j{-1})|^2\right) = A|H(j1)|^2$$

Power ratio $$\frac{P_r}{P_f} = |H(j1)|^2 = \frac{1}{1 + 1^2} = \boxed{\frac{1}{2}}$$

Tutorial-2

4. Find the mean, the mean square, and the variance of the RVx whose PDF is shown in figure.



K=0.5
$P_X(x)$=1/8(x+1)
Mean=5/3
Mean square=11/3
Variance=8/9

Tutorial-2

5. Find the autocorrelation function of $x(t) = A\cos(2\pi f_0 t + \varphi)$ in terms of its period, $T_0 = 1/f_0$. find the average normalized power of $x(t)$, using $P_x = R(0)$.

For a deterministic periodic signal, its autocorrelation over one period is

$$R_x(\tau) = \frac{1}{T_0}\int_0^{T_0} x(t)\,x(t+\tau)\,dt, \qquad T_0 = \frac{1}{f_0}.$$

With $x(t) = A\cos(2\pi f_0 t + \phi)$,

$$\begin{aligned}
R_x(\tau) &= \frac{A^2}{T_0}\int_0^{T_0} \cos(2\pi f_0 t + \phi)\cos(2\pi f_0 (t+\tau) + \phi)\,dt \\
&= \frac{A^2}{2T_0}\int_0^{T_0} [\cos(2\pi f_0 \tau) + \cos(4\pi f_0 t + 2\phi + 2\pi f_0 \tau)]\,dt \\
&= \frac{A^2}{2}\cos(2\pi f_0 \tau) = \frac{A^2}{2}\cos\left(\frac{2\pi\tau}{T_0}\right),
\end{aligned}$$

$$P_x = R_x(0) = \frac{A^2}{2}$$

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6. A random variable has exponential PDF given by $p_X(x) = a.e^{-b|x|}$, where a and b are constants.
Find:
(i) relationship between a and b
(ii) the CDF of X.

Tutorial-2

Sol.

$$\int_{-\infty}^{\infty} p_x(x)dx = 1$$

$$\int_{-\infty}^{\infty} ae^{-b|x|}dx = 1$$

(i) After solving the above equation, we will get b=2a

(ii) For x<0, CDF F(x)= $\int_{-\infty}^{x} f(u)du = \int_{-\infty}^{x} ae^{-bu}du$ =1/2 e^{bx}

For x>0, CDF F(x)= $\int_{-\infty}^{x} f(u)du = \int_{-\infty}^{0} ae^{bu}du + \int_{0}^{x} ae^{-bu}du$ =1- 1/2 e^{-bx}

$$F(x) = \begin{cases} \frac{1}{2}e^{bx}, & x < 0 \\ 1 - \frac{1}{2}e^{-bx}, & x > 0 \end{cases}$$

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Communication Systems
Tutorial-3

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Tutorial-3

1. For the baseband signal $m(t) = \cos(1000\pi t)$, sketch the spectrum of

   a. $m(t)$

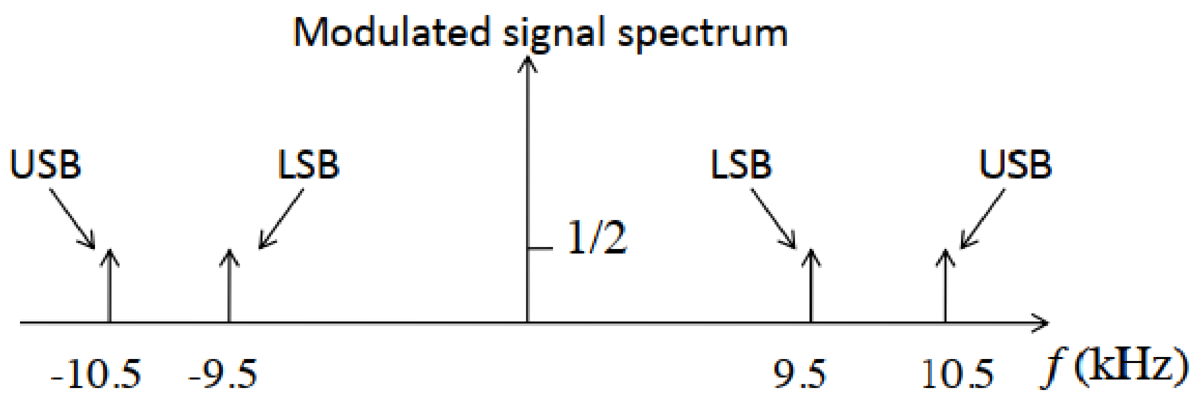
   b. $m(t)\cos(20000\pi t)$

   c. Identify the USB and LSB spectra.

   d. Identify the frequencies in the baseband and the corresponding frequencies in the DSB-SC, USB, LSB spectra.

Tutorial-3

Solution 1



Tutorial-3

2. An AM signal is generated by modulating the carrier f_c = 800 kHz by the message signal,

$$m(t) = \sin(2000\pi t) + 5\cos(4000\pi t)$$

The AM signal,

$$u(t) = 100\left[1 + m(t)\right]\cos(2\pi f_c t)$$

is fed to a 1Ω load.

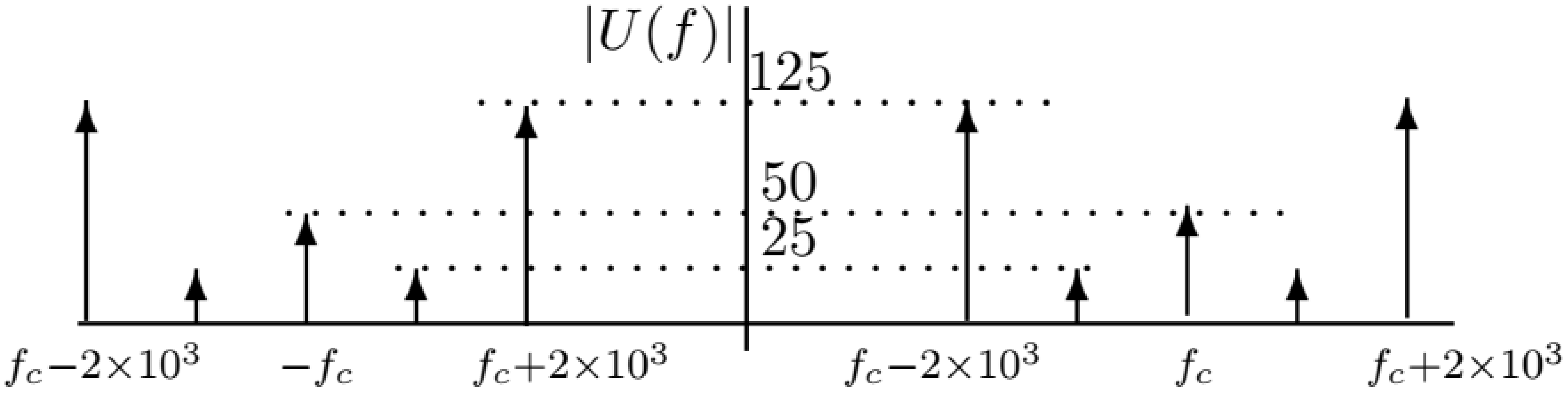
a. Determine and sketch $|U(f)|$.

b. Determine the average power in the carrier and in the sidebands.

c. What is the modulation index?

Tutorial-3

Solution 2



b. average power in the carrier = 5000 watt
average power in the sidebands= 65000 watt
c. modulation index= 5 to 6

Tutorial-3

3. An AM modulator with a tone signal input has output,

$$s\,(t) = \mathbf{A} \cos (400\pi t) + \mathbf{B} \cos (360\pi t) + \mathbf{B} \cos (440\pi t)$$

The total carrier power is 100 W and the power efficiency is 40%. Compute A, B and modulation index.

Tutorial-3

Solution 3

Carrier power, $A = \sqrt{200} = 14.14$ $\mu = 1.155$

$B = 8.165$

Tutorial-3

4. Consider a message signal $m(t) = \cos(2\pi t)$ volts, and the carrier wave $c(t) = 50\cos(100\pi t)$ volts.

   a. Give the time domain expression for the resulting conventional AM signal for 75% modulation.

   b. Find the power developed across load of 100Ω due to this AM wave.

Tutorial-3

Solution 4

$$\varphi_{AM}(t) = 50\cos(100\pi t) + 18.75\cos(102\pi t) + 18.75\cos(98\pi t)$$

Total power: $P = 16.015 \text{ watt}$

Tutorial-3

5. If $m(t) = \cos(200\pi t)$, find the transmission bandwidth and total transmitted power for AM transmission considering $A_C = 10$ and $\mu = 0.6$. Repeat the same for DSB-SC transmission.

Tutorial-3

Solution 5

transmission bandwidth=200Hz

total transmitted power for AM transmission= P_T

$$P_T = 59\ Watt$$

total transmitted power for carrier= P_C= 50 Watt

total transmitted power for DSB-SC transmission=9 Watt

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Communication Systems
Tutorial-4

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Tutorial-4

1. **The signal $x(t) = 4 \sin(\pi t/2)$ is transmitted by DSB. What range of the carrier frequencies can be used?**

Tutorial-4

Solution 1

$$10B < f_c < 100B$$

$$\left(10 \times \frac{1}{2}\right) \text{ kHz} < f_c < \left(100 \times \frac{1}{2}\right) \text{ kHz}$$

$$\boxed{5 \text{ kHz} < f_c < 50 \text{ kHz}}$$

Tutorial-4

2. An AM transmitter has a carrier power of 30 W. The percentage of modulation is 85 percent. Calculate (a) the power in DSB signal and (b) the power in SSBSC.

Tutorial-4

Solution 2

As per the definition we have Power in DSB (Double sideband with full carrier),

$$P_{DSB} = 40.8 \text{ W}$$

$$P_{DSBSC} = 10.8 \text{ W}$$

Power of the single sideband, SSB

$$P_{SSB} = 5.4 \text{ W}$$

Tutorial-4

3. An SSB transmitter has a 24-V dc supply. On voice peaks the current achieves a maximum of 9.3 A. What is the PEP? What is the average power of the transmitter?

Tutorial-4

Solution 3

Concept 1

In SSB, the transmitter output is expressed in terms of peak envelope power (PEP), the maximum power produced on voice amplitude peaks. PEP is computed by the equation $P = V^2/R$.

The PEP input power is simply the dc input power of the transmitter’s final amplifier stage at the instant of the voice envelope peak. It is the final amplifier stage dc supply voltage multiplied by the maximum amplifier current that occurs at the peak, $PEP = V_S I_{max}$

Concept 2

Note that voice amplitude peaks are produced only when very loud sounds are generated during certain speech patterns or when some word or sound is emphasized. During normal speech levels, the input and output power levels are much less than the PEP level. The average power is typically only one-fourth to one-third of the PEP value with typical human speech.

Tutorial-4

Solution 3

a. What is the PEP?

$$\text{PEP} = V_s I_m = 24(9.3) = 223.2 \text{ W}$$

b. What is the average power of the transmitter?

$$P_{\text{avg}} = \frac{\text{PEP}}{3} = \frac{223.2}{3} = 74.4 \text{ W}$$

$$P_{\text{avg}} = \frac{\text{PEP}}{4} = \frac{223.2}{4} = 55.8 \text{ W}$$

$$P_{\text{avg}} = 55.8 \text{ to } 74.4 \text{ W}$$

Tutorial-4

4. An SSB transmitter produces a peak-to-peak voltage of 178 V across a 75Ω antenna load. What is the PEP?

Tutorial-4

Solution 4

$$\text{PEP} = 52.8\ \text{W}$$

Tutorial-4

5. Find the power in each sideband of a DSB-SC signal with the carrier signal at 1 MHz and of a peak signal voltage of 100 V modulated simultaneously by three different signals. The frequencies of the modulating signals are 2 kHz, 3 kHz and 5 kHz, respectively, and peak modulating voltages are 10 V, 20 V, and 30 V, respectively. Assume a load resistance of 100 Ω.

Solution 5

Power in each sideband of a DSB-SC= P_{SB}= 1.75 W

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Tutorial-5

Date : 04/09/2025

Date : 09/09/2025

Tutorial-5

1. A transmitter transmits an AM signal with a carrier frequency of 1500 kHz. When a super heterodyne radio receiver (which has a poor selectivity in its RF-stage bandpass filter) is tuned to 1500 kHz, the signal is heard loud and clear. The same signal is also heard (not as strongly) when tuned to another carrier frequency setting within the AM range of 590-1605 kHz. State, with reasons, at what frequency you will hear this station. The IF is 455 kHz.

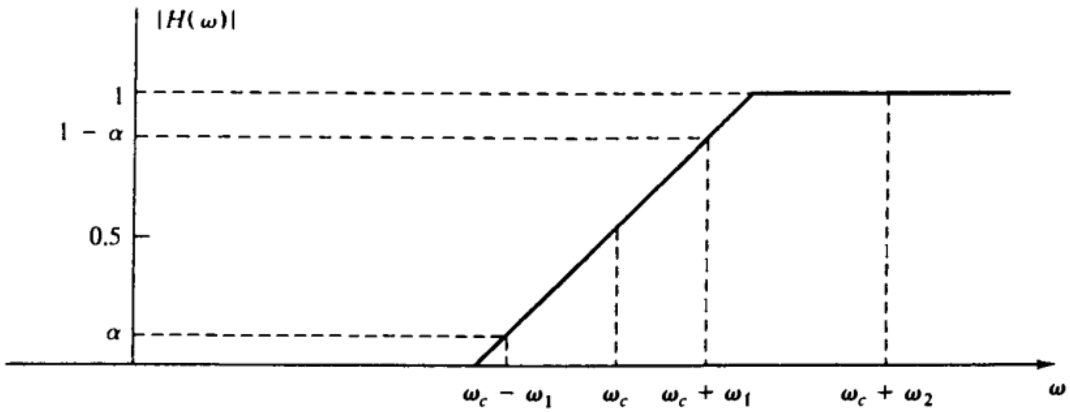
Tutorial-5

Solution 1

if the receiver is tuned to 590 kHz, the same channel will be listened.

Tutorial-5

2. The frequency response H(ω) of a VSB filter is shown below.



Find the VSB signal $x_{VSB}(t)$ when

$$m(t) = a_1 \cos \omega_1 t + a_2 \cos \omega_2 t$$

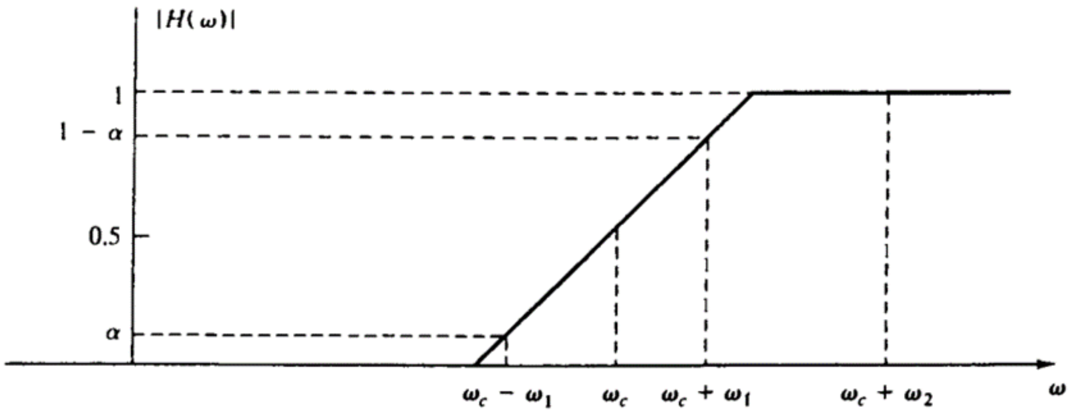
Also, show that $x_{VSB}(t)$ can be demodulated by the synchronous demodulator.

Tutorial-5

Solution 2

$$x_{\text{DSB}}(t) = m(t)\cos\omega_c t$$

Signal will be passed through the VSB filter which has gains as per the diagram.

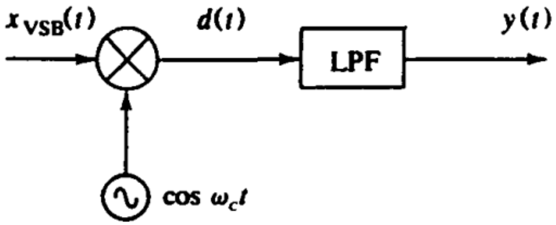


$$x_{\text{VSB}}(t) = \tfrac{1}{2}a_1\alpha\cos(\omega_c - \omega_1)t + \tfrac{1}{2}a_1(1-\alpha)\cos(\omega_c + \omega_1)t + \tfrac{1}{2}a_2\cos(\omega_c + \omega_2)t$$

Tutorial-5

Solution 2

Considering the synchronous demodulation we have,

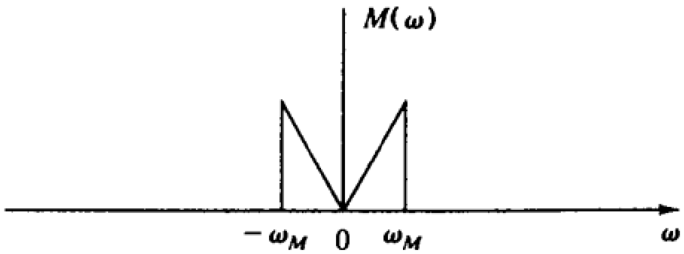


Using low-pass filtering to eliminate the double-frequency terms, we obtain

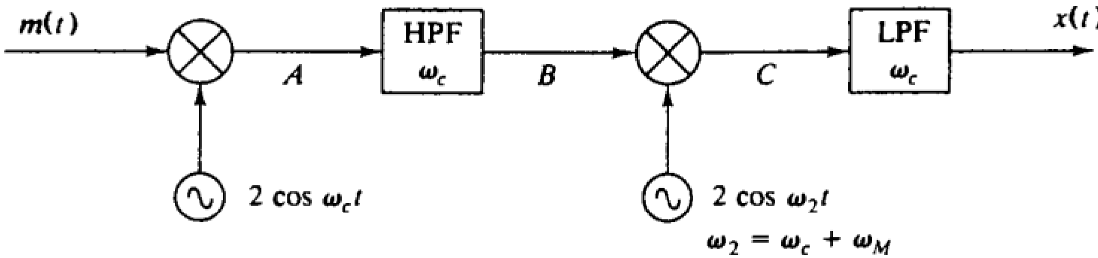
$$y(t) = \frac{1}{4}(a_1 \cos \omega_1 t + a_2 \cos \omega_2 t) = \frac{1}{4} m(t)$$

Tutorial-5

3. **The spectrum of a message signal m(t) is shown below. To ensure communication privacy, this signal is applied to a system (known as a scrambler) shown below. Analyze the system and sketch the spectrum of the output x(t).**



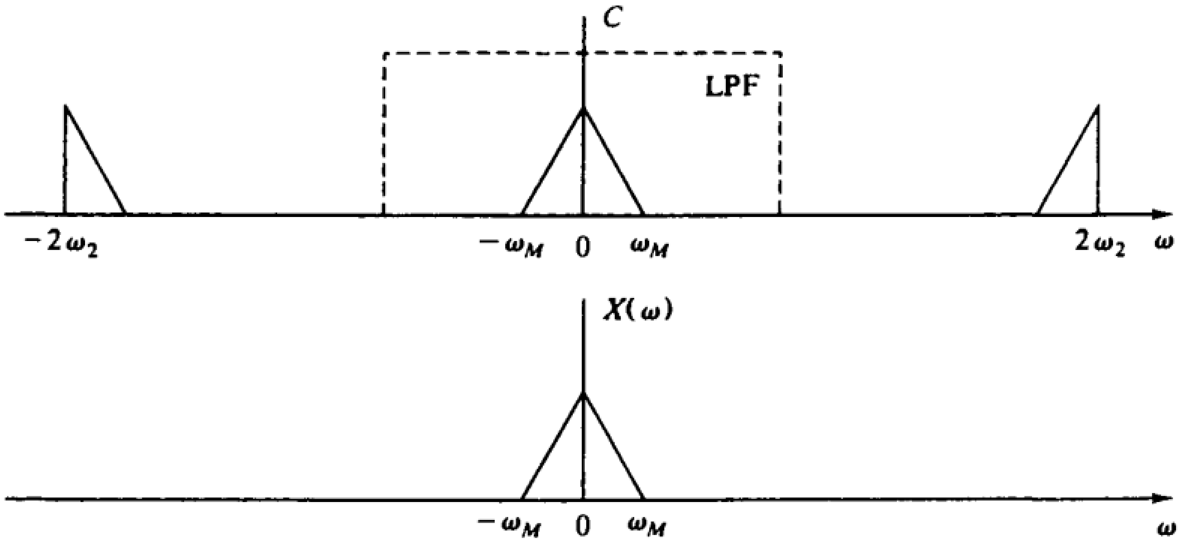
(a)



(b)

Tutorial-5

Solution 3

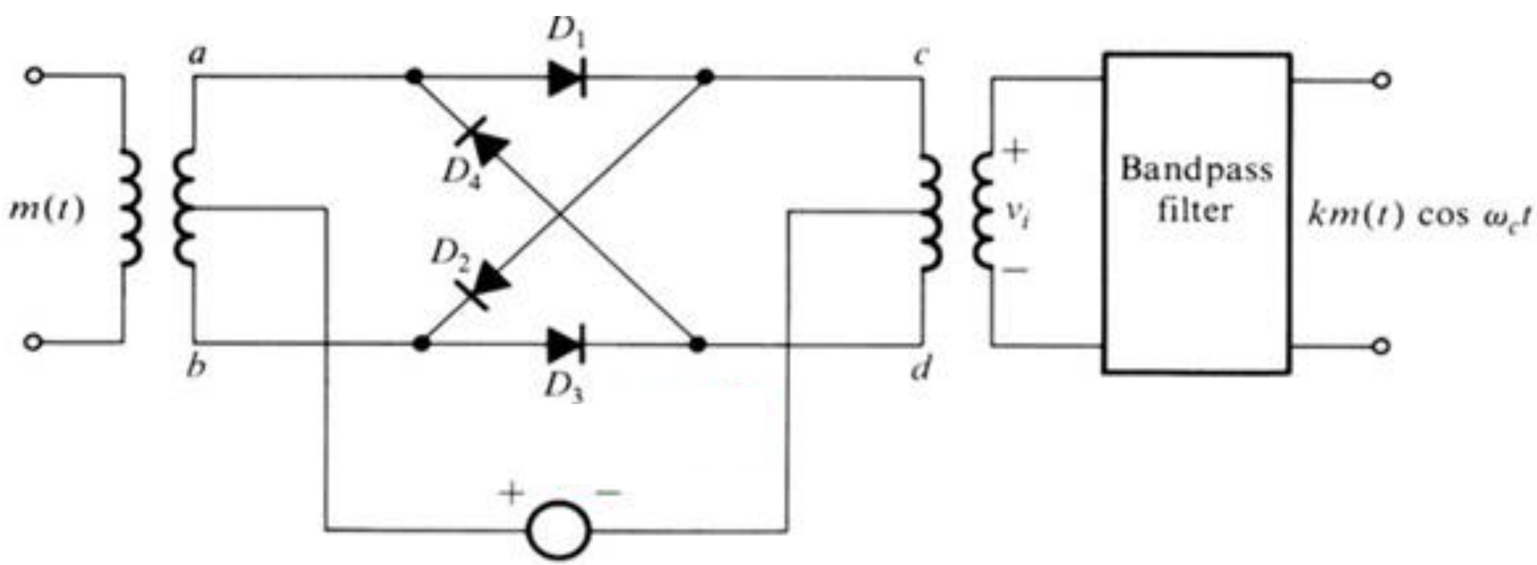


Tutorial-5

4. Design a DSBSC modulator to generate a modulated signal $km(t)\cos\omega_c t$ with the carrier frequency f_c = 300 kHz ($\omega_c = 2\pi \times 300{,}000$). The following equipment is available in the stock room: (i) a signal generator of frequency 100 kHz; (ii) a ring modulator (as shown in figure given below); (iii) a band pass filter tuned to 300 kHz.

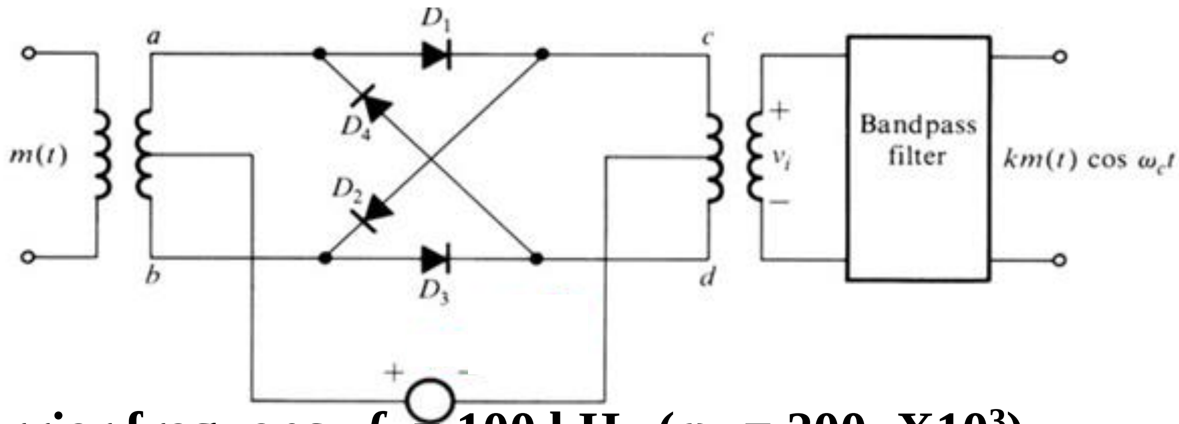
(a) Show how can you generate the desired signal.

(b) If the output of the modulator is $km(t)\cos\omega_c t$, find k.



Tutorial-5

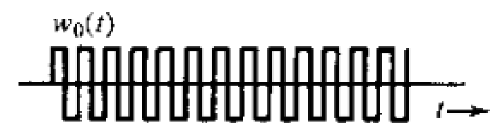
Solution 4



(a)

Given: The carrier frequency f_c = 100 kHz ($\omega_c = 200\pi X10^3$)

The output band pass filter centered at f_c = 300 kHz



The output $v_i(t)$ is found as $v_i(t) = m(t)\, w_0(t)$

$v_i(t) = 4/\pi\ [m(t) \cos \omega_c t - 1/3\ m(t) \cos 3\omega_c t + 1/5 m(t) \cos 5\omega_c t + \ldots.]$

k=- $4/3\pi$

Tutorial-5

5. In the figure given below, the input φ(t) = m(t), and the amplitude $A \geq |\phi(t)|$.

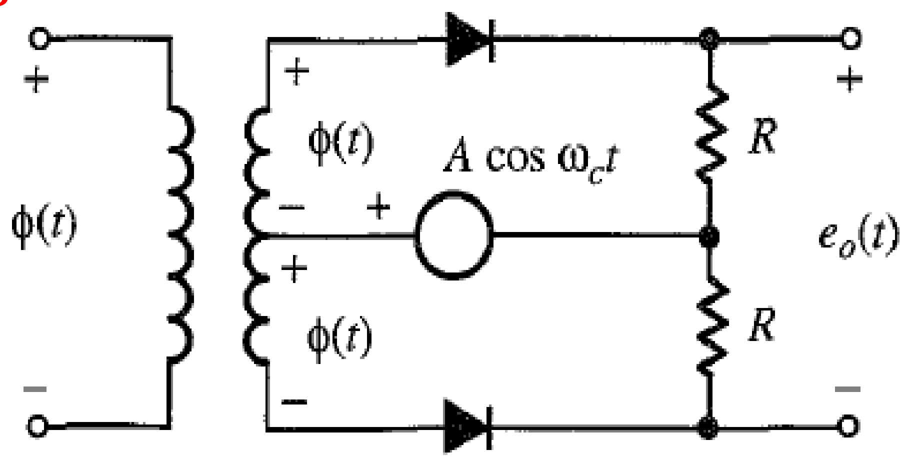
The two diodes are identical with a resistance r ohms in the conducting mode and infinite resistance in the cutoff mode. Show that the output $e_o(t)$ is given by

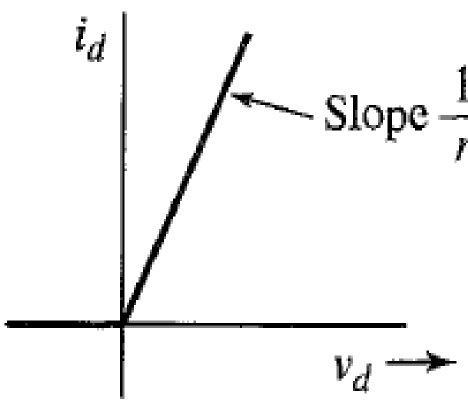
$$e_0(t) = \frac{2R}{R+r} w(t) m(t)$$

Where *w(t)* is the switching periodic signal with period $2\pi/\omega_c$ seconds.

(a) Hence, show that this circuit can be used as a DSBSC modulator.

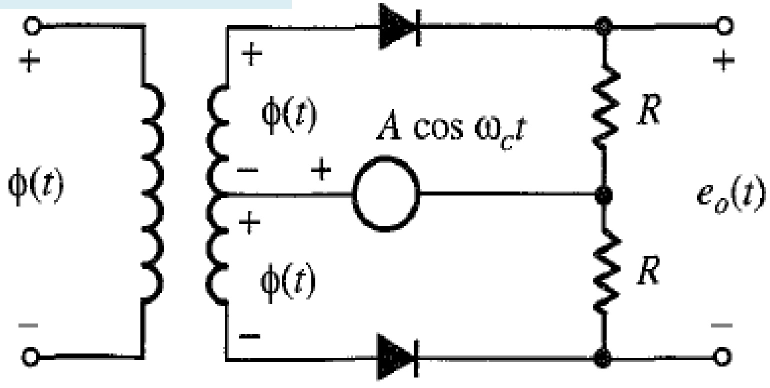
(b) How would you use this circuit as a synchronous demodulator for DSB-SC signals





Tutorial-5

Solution 5



The output is:

$$e_0(t) = \frac{2R}{R+r} w(t)m(t)$$

(a) If we pass the output $e_0(t)$ through a band pass filter (centered at ω_c),

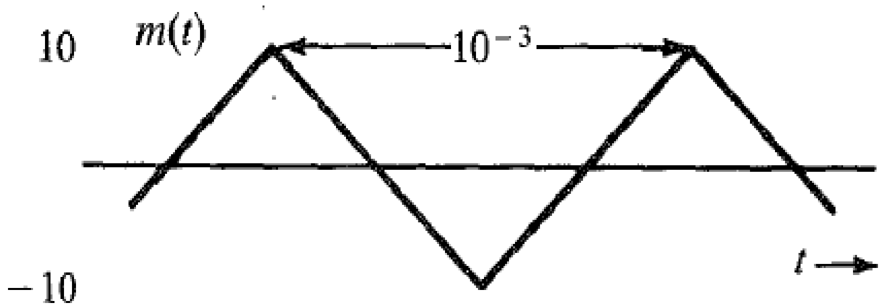
$$\frac{4R}{\pi(R+r)} m(t)\cos\omega_c t$$

At the output of demodulator

$$\frac{2R}{\pi(R+r)} m(t)$$

Tutorial-5

6. For the baseband message signal m(t) as shown in figure, an AM signal *$[A+m(t)]\cos\omega_c t$* has been generated with modulation index of 0.8.



(a) Find the amplitude and power of the carrier.
(b) Find the sideband power and the power efficiency η.

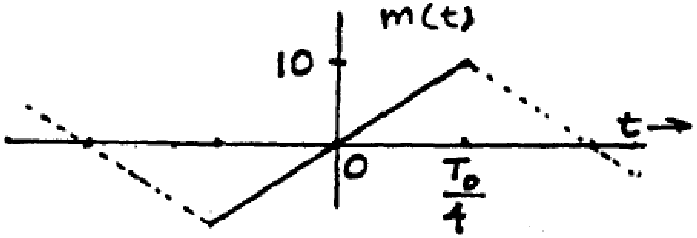
Tutorial-5

Solution 6

(a) Carrier amplitude is $A = m_p/\mu = 10/0.8 = 12.5$

The carrier power is $P_c = A^2/2 = 78.125$

(b) Sideband power is



$$P_s = \frac{1}{2}\widetilde{m^2(t)}$$

$$\widetilde{m^2(t)} = \frac{1}{T_0/4}\int_0^{T_0/4}\left[\frac{40t}{T_0}\right]^2 dt = 33.34$$

$$P_s = \frac{\widetilde{m^2(t)}}{2} = 16.67$$

$$\eta = \frac{P_s}{P_c + P_s} = \frac{16.67}{78.125 + 16.67} \times 100 = 19.66\%$$

BITS Pilani
Hyderabad Campus
Department of Electrical Engineering

EEE/ECE F311
Communication Systems
Tutorial-6

Date : 11/09/2025
Date : 16/09/2025

Tutorial-6

1. An angle-modulated signal is described by

$$x_c(t) = 10\cos\left[2\pi(10^6)t + 0.1\sin(10^3)\pi t\right]$$

(a) Considering $x_c(t)$ as a PM signal with $k_p = 10$, find $m(t)$.

(b) Considering $x_c(t)$ as an FM signal with $k_f = 10\pi$, find $m(t)$.

Tutorial-6

Solution 1(a)

$$10m(t) = 0.1\sin\left(10^3 \pi t\right)$$

$$\Rightarrow \boxed{m(t) = 0.01\sin\left(10^3 \pi t\right)}$$

Solution 1(b)

$$\therefore \boxed{m(t) = 10\cos\left(10^3 \pi t\right)}$$

Tutorial-6

2. A carrier is frequency-modulated with a sinusoidal signal of 2 kHz, resulting in a maximum frequency deviation of 5 kHz.

(a) Find the bandwidth of the modulated signal.

(b) The amplitude of the modulating sinusoid is increased by a factor of 3, and its frequency is lowered to 1 kHz. Find the maximum frequency deviation and the bandwidth of the new modulated signal.

Tutorial-6

Solution 2(a)

Bandwidth of the FM signal

$$B_T = 2f_m(\beta + 1)$$
$$= 14 \text{ kHz}$$

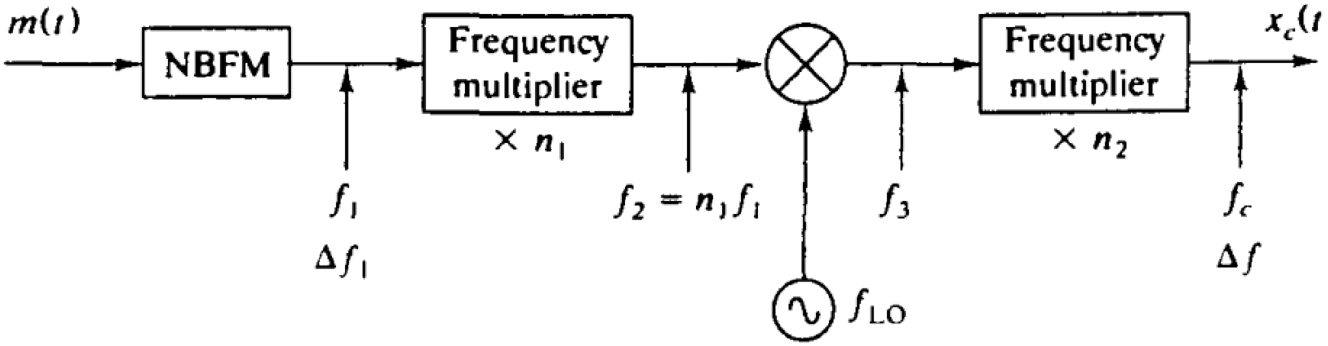
Solution 2(b)

$$\Delta f^{new} = \beta_1 f_m^{new} = 15 \text{ kHz}$$

$$B_T^{new} = 2f_m^{new}(\beta_1 + 1)$$
$$= 32 \text{ kHz}$$

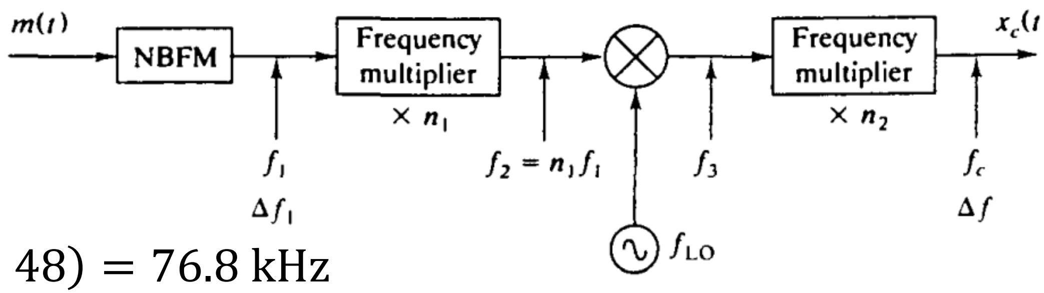
Tutorial-6

3. A block diagram of an indirect (Armstrong) FM transmitter is shown below. Compute the maximum frequency deviation Δf of the output of the FM transmitter and the carrier frequency f_c. if f_1 = 200 kHz, f_{LO} = 10.8 MHz, Δf_1 = 25 Hz, n_1 = 64, and n_2 = 48.



Tutorial-6

Solution 3



$$\Delta f = \Delta f_1 n_1 n_2 = (25 \times 64 \times 48) = 76.8 \text{ kHz}$$

$$f_c = n_2 f_3 = (48 \times 2.0) \text{ MHz} = 96 \text{ MHz}$$

Tutorial-6

4. The message signal input to a modulator is $m(t) = 4\cos(4\pi \times 10^4 t)$; $k_f = 500\pi$, and the carrier is $16\cos(2\pi \times 10^8 t)$. Verify that the modulated signal is NBFM. What should be the bandwidth of the modulated signal?

Tutorial-6

Key Concept

- To identify the nature of the FM signal, we need to find the β.
- If $\beta \leq 0.3$, then the signal is called NBFM
- If $\beta \geq 5$, then the signal is called WBFM

Solution 4

$$\begin{aligned} B_T &= 2f_m(\beta + 1) \\ &= 42 \text{ kHz} \end{aligned}$$

Tutorial-6

5. A 2 kHz sinusoidal signal phase modulates a carrier at 100 MHz with a peak phase deviation of π/4 (rad/sec). What will be the approximate BW of the signal?

Tutorial-6

Solution 5

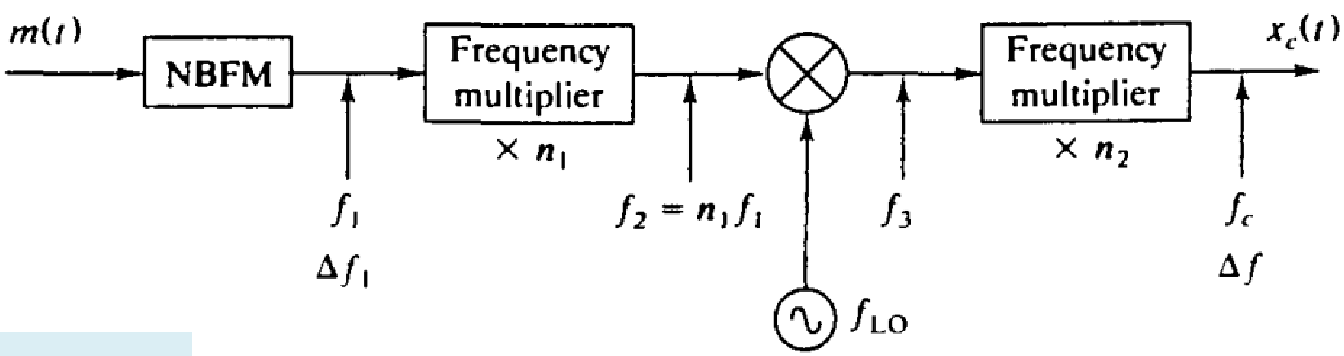
As per the problem statement, $\beta_P = \dfrac{\pi}{4} = 0.785$

Bandwidth as per the Carson's rule is given by,

$$\begin{aligned} B_T &= 2 f_m (\beta + 1) \\ &= \left[2 \times 2 \times 10^3 \times (0.785 + 1) \right] \text{ Hz} \\ &= 7.14 \text{ kHz} \end{aligned}$$

Practice Problem

Design (the block diagram with carrier frequency and frequency deviation at each point) an Armstrong indirect FM modulator to generate a Deccan Radio 107.8 MHz for Hyderabad. A NBFM generator is available at a carrier frequency of 180 KHz with frequency deviation 9.25 Hz. The available oscillator has an adjustable frequency in the range of 20 MHz to 22 MHz. There are plenty of frequency doublers are available. Designer is not allowed to use more than two frequency multiplier blocks. Each frequency multiplier block can contain only frequency doublers (≥1).



Solution

N1= 128 and N2= 64

EEE/ECE F311
Communication Systems
Tutorial-7

Date : 18/09/2025

Date : 23/09/2025

Tutorial-7

1. A signal $x_1(t)$ is bandlimited to 2 kHz while $x_2(t)$ is bandlimited to 3 kHz. Find the Nyquist sampling rate for:

(a) $x_1(2t)$

(b) $x_2(t-3)$

(c) $x_1(t) + x_2(t)$

(d) $x_1(t)x_2(t)$

Tutorial-7

Solution: $x_1(t)$ is bandlimited to 2 kHz while $x_2(t)$ is bandlimited to 3 kHz

(a) $x_1(2t)$: the Nyquist sampling rate = (2×4) kHz = 8 kHz.

(b) $x_2(t-3)$: the Nyquist sampling rate = (2×3) kHz = 6 kHz.

(c) $x_1(t) + x_2(t)$: the Nyquist sampling rate = (2×3) kHz = 6 kHz.

(d) $x_1(t)x_2(t)$: the Nyquist sampling rate = (2×5) kHz = 10 kHz.

Tutorial-7

2. Given the signal $m(t) = 10 \cos(2000\pi t) \cos(8000\pi t)$.

(a) What is the minimum sampling rate based in the low pass uniform sampling theorem?

(b) Repeat the problem based on bandpass sampling theorem.

Tutorial-7

Solution 2

Baseband or Low Pass Sampling Theorem

Nyquist sampling rate considering baseband or LP sampling theorem
$f_S = 2f_M = 10$ kHz.

Tutorial-7

Solution 2

Bandpass Sampling Theorem

Sampling rate considering bandpass sampling theorem
$f_S = (2f_U/k) = 5$ kHz.

Tutorial-7

3. A binary channel with a bit rate of 36000 bps is available for PCM voice transmission. Find the appropriate values of the sampling rate, quantization level, and number of bits level assuming $f_M = 3.2$ kHz

Tutorial-7

Solution 3

n = 5 (5 bits are required to represent the quantization levels)

No. of quantization levels L = $2^n = 2^5 = 32$.

$f_S \leq (36000 / 5) = 7.2$ kHz.

Tutorial-7

4. An audio signal $s(t) = 3\cos(2\pi \times 500t)$ is quantized using 10-bit PCM. Determine the signal-to-quantization noise ratio.

Tutorial-7

Solution 4

$$\frac{S_i}{N_q}(\text{dB}) = 10 \times \log(1.57 \times 10^6) = 62 \text{ dB}$$

Tutorial-7

5. A PCM system used for an analog signal with maximum frequency of 4 KHz. If the minimum dynamic range of the quantizer used is 46 dB, and the maximum decoded voltage at the receiver is ±2.55 V, determine the minimum sampling rate, the number of bits used in the PCM code, the step size, the maximum quantization error, and the coding efficiency.

Tutorial-7

Solution 5

For given $f_m = 4$ kHz, $f_s = 2 \times 4$ kHz $= 8$ kHz

For given DR = 46 dB, we get $n \approx 46/6 \approx 7.66$.

But for given maximum decoded voltage of ±2.55 V, one additional sign bit is required.

Hence, the minimum number of bits used in the PCM code = 9 bits

$$\Delta = 2.55\text{V}/\,(2^8 - 1) = 0.01\text{V}$$

Maximum quantization error = $\Delta/2 = 0.01$ V/2 = 0.005 V

$$\eta_{\text{PCM}}(\%) = \frac{\text{min\_bits}}{\text{actual\_bits}} \times 100$$

$$\eta_{\text{PCM}}(\%) = [(7.66 + 1 \text{ sign bit})/9 \text{ bits}] \times 100 \approx 95.9\ \%$$