National University of Computer and Emerging Sciences, Lahore Campus

Course:	**Analog and Digital Communications**	**Course Code:**	**EE3003**
Program:	**BS (Electrical Engineering)**	**Semester:**	**Fall 2024**
Exam:	**Assignment 1**	**Page(s):**	**3**
Chapter(s):	**1,3**	**Section:**	**ALL**
Submission Date:	**Thursday, September 12, 2024**	**CLO:**	**01**
Instructor(s):	**Dr. S. M. Sajid, Mohsin Yousuf**	**Marks:**	**50**

Question # 1 [CLO 01] [10]

Radio waves propagate in free space (and in our atmosphere) at a velocity of $v = 2.99792\ 10^{8}$ meters per second. **For this problem use $v = 3.00\ 10^{8}$ meters per second (m/sec).** An important wave parameter for electromagnetic waves is the wavelength λ which is inversely related to the wave frequency f (cycles per second in units of Hertz). The relationship is velocity equals wavelength times frequency ($v = f$).

The reason wavelength λ is important is because the wavelength is approximately the spatial resolving dimension of radar and antenna sizes scale with wavelength (*e.g.*, long wavelengths require large antennas).

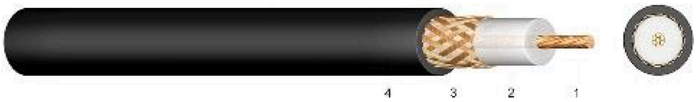
To get a feel for the size of the free space wavelength λ for various radio communication systems **fill out** the table below: [Express all **wavelengths in either meters, or millimeters** for smaller wavelengths.]

Table 1. Different frequency band along with their wavelengths

Radio Application	Frequency Band	Wavelength Range
AM broadcast radio	535 kHz to 1605 kHz	
FM broadcast radio	88 MHz to 108 MHz	
VHF Civil Aviation Band *(example)*	108 MHz to 136 MHz	2.778 meters to 2.206 meters *(example)*
GSM Cellular (Uplink)	890 MHz to 915 MHz	
GSM Cellular (Downlink)	925 MHz to 960 MHz	
Wi-Fi 802.11b/g/n	2.400 GHz to 2.497 GHz	
Wi-Fi 802.11 ac	4.915 GHz to 5.825 GHz	
X-band Police Radar	10.525 GHz (narrowband)	
Ka-band Photo-Radar	34.2 GHz to 34.4 GHz	
Wi-Fi 802.11 ad	57.05 GHz to 71.00 GHz	
Automotive Long-Range Radar	76 GHz to 77 GHz	

<u>Question # 2 [CLO 01] [10]</u>

Cable Attenuation



Attenuation (RG 213)	
Frequence	Attenuatin in dB/100m
100MHz	6,9dB
145*MHz	8,5dB
200MHz	9,8dB
400MHz	15,7dB
432*MHz	15,8dB
500MHz	16,7dB
1000MHz	25,7dB
1296MHz	30,0dB
1800MHz	37,0dB
2000MHz	41,6dB
2320*MHz	46,5dB
3000MHz	58,5dB
* amateur bands	

Transmission losses in cables (such as coaxial cables) are generally expressed in decibels per 100 feet (dB/100 ft) or decibels per 100 meters (dB/100 m) Suppose you have a 50-ohm **RG-213** coaxial cable with an attenuation per distance as a function of frequency as listed in the table:

If you input 10 milliwatts (that is, + 10 dBm) into an **RG-213** cable of 25 feet in length, **find** the output power (express it in both milliwatts and dBm) at **(a)** 100 MHz, **(b)** at 500 MHz, and **(c)** at 2320 MHz?

<u>Hint:</u>

First, we convert dB/100 meters to dB/100 feet.
Note: 3.2808 feet per meter; 25 $feet = 7.620\ meters$; so, the conversion is:

$$(dB/100\ feet) = (dB/100\ meters) \times 0.3048$$

Fill the table:

Frequency	Loss in dB/100 meters	Loss in dB/100 feet
100 MHz	6.9	2.1
500 MHz	16.7	
2,320 MHz	46.5	

At 100 MHz, we have 2.1 dB/100 feet loss, therefore

$$Total\ Loss = 25\ ft \times \frac{-2.1\ dB}{100\ ft} = -\ 0.525\ dB$$

The minus sign indicates loss.

$$Loss = 10\left(\frac{P_{out}}{P_{in}}\right) = -\ 0.525\ dB$$

(a) P_{out} is to be calculated here (both in mW and dBm).

Repeat the same procedure for part (b) and (c).

(b) At 500 MHz

(c) At 2,320 MHz

Question # 3 [CLO 01] [5+5]

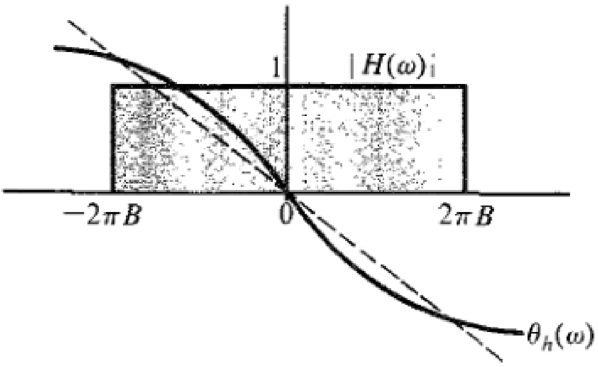
Bandwidth of a Channel

(a)	**Evaluate** the bandwidth of a channel with capacity 36,000 bits/sec and a signal-to-noise ratio of 30 dB.
(b)	**Calculate** the bandwidth required of a channel capacity of 25 kbps (kilobits/sec) when the signal-to-noise ratio is numerically 500.

Question # 4 [CLO 01] [5+5]

A certain channel has ideal amplitude, but nonideal phase response, given by

$$|H(\omega)| = 1$$
$$\theta_h(\omega) = -\omega t_0 - k \sin sin\, \omega T \qquad k \ll 1$$



a) **Find** the channel response $y(t)$ to an input pulse $g(t)$ band-limited to B Hz.

Hint: Use $e^{-jk \sin sin\, \omega T} \approx 1 - jk \sin sin\, \omega T$

b) **Discuss** how this channel will affect TDM and FDM systems from the view point of interference among the multiplexed signals.

Question # 5 [CLO 01] [10]

Show that a filter with transfer function

$$H(\omega) = \frac{4(10^5)}{\omega^2 + 10^{10}} e^{-j\omega t_0}$$

is unrealizable. Can this filter be made approximately realizable by choosing a sufficiently large t_0. Use your own (reasonable) criterion of approximate realizability to determine t_0.

Hint: Show that the impulse response is non-causal.

Q. No. 1

$\Rightarrow v = 3 \times 10^8 \ ms^{-1}$

As $v = f\lambda$

$\Rightarrow \lambda = \dfrac{v}{f}$

(a)

AM Broadcast Radio

f range: 535kHz to 1605 kHz

$\Rightarrow \lambda = \dfrac{3 \times 10^8}{535 \times 10^3}$ $\quad\quad$ $\Rightarrow \lambda = \dfrac{3 \times 10^8}{1605 \times 10^3}$

$= 560.748 \ m$ $\quad\quad$ $= 186.916 \ m$

Wavelength range: $\boxed{560.748m \text{ to } 186.916m}$

(b)

FM Broadcast Radio

Frq range : 88MHz to 108MHz

$\Rightarrow \lambda = \dfrac{3 \times 10^8}{88 \times 10^6}$ $\quad\quad$ $\Rightarrow \lambda = \dfrac{3 \times 10^8}{108 \times 10^6}$

$= 3.409 \ m$ $\quad\quad$ $= 2.778 \ m$

Wavelength Range: $\boxed{3.409m \text{ to } 2.778m}$

Date: __/__/20

(c)

GSM Cellular (Uplink)

f: 890 MHz to 915 MHz

$\Rightarrow \lambda = \frac{3\times10^8}{890\times10^6}$ $\qquad \Rightarrow \lambda = \frac{3\times10^8}{915\times10^6}$

$= 0.337\,m$ $\qquad = 0.329\,m$

Wavelength Range : $\boxed{0.337\,m \text{ to } 0.329\,m}$

(d)

GSM Cellular (Downlink)

f: 925 MHz to 960 MHz

$\Rightarrow \lambda = \frac{3\times10^8}{925\times10^6}$ $\qquad \Rightarrow \lambda = \frac{3\times10^8}{960\times10^6}$

$= 0.324\,m$ $\qquad = 0.312\,m$

Wavelength Range : $\boxed{0.324\,m \text{ to } 0.312\,m}$

(e)

Wifi 802.11 b/g/n

f: 2.400 GHz to 2.497 GHz

$\Rightarrow \lambda = \frac{3\times10^8}{2.4\times10^9}$ $\qquad \Rightarrow \lambda = \frac{3\times10^8}{2.497\times10^9}$

$= 0.125\,m$ $\qquad = 0.120\,m$

Wavelength Range : $\boxed{0.125\,m \text{ to } 0.120\,m}$

Date: __/__/20

(f)

Wifi 802.11 ac

f: 4.915 GHz to 5.825 GHz

$\Rightarrow \lambda = \frac{3\times10^8}{4.915\times10^9}$ $\Rightarrow \lambda = \frac{3\times10^8}{5.825\times10^9}$

$= 61.038$ mm $= 51.502$ mm

Wavelength range: $\boxed{61.038 \text{ mm to } 51.502 \text{ mm}}$

(g)

X-Band Police Radar

f: 10.525 GHz (narrowband)

$\Rightarrow \lambda = \frac{3\times10^8}{10.525\times10^9}$

$= 28.504$ mm

Wavelength : $\boxed{28.504 \text{ mm}}$

(h)

Ka-Band Photo Radar

f: 34.2 GHz to 34.4 GHz

$\Rightarrow \lambda = \frac{3\times10^8}{34.2\times10^9}$ $\Rightarrow \lambda = \frac{3\times10^8}{34.4\times10^9}$

$= 8.772$ mm $= 8.721$ mm

Wavelength Range: $\boxed{8.772 \text{ mm to } 8.721 \text{ mm}}$

(i)

Wifi 802.11 ad

f: 57.05 GHz to 71.00 GHz

$\Rightarrow \lambda = \frac{3 \times 10^8}{57.05 \times 10^9}$ $\Rightarrow \lambda = \frac{3 \times 10^8}{71 \times 10^9}$

$= 5.258$ mm $= 4.225$ mm

Wavelength Range: $\boxed{5.258 \text{ mm to } 4.225 \text{ mm}}$

(j)

Automotive Long-Range Radar

f: 76 GHz to 77 GHz

$\Rightarrow \lambda = \frac{3 \times 10^8}{76 \times 10^9}$ $\Rightarrow \lambda = \frac{3 \times 10^8}{77 \times 10^9}$

$= 3.947$ mm $= 3.896$ mm

Wavelength Range: $\boxed{3.947 \text{ mm to } 3.896 \text{ mm}}$

Q.No.2

$\Rightarrow P_{in} = 10\ dBm = 10\ mW$

$\Rightarrow$ As Loss in dB/100 ft = Loss in dB/100m × 0.3048

$\Rightarrow$ Total loss over 25 ft = $\dfrac{\text{Loss in dB/100ft}}{100} \times 25$

$\Rightarrow P_{out\,(dBm)} = P_{in\,(dBm)} - \text{Total loss}_{(dB)}$

$\Rightarrow P_{out\,(mW)} = 10^{\frac{P_{out}(dBm)}{10}}$

(a)

Frequency: 8100 MHz   Loss in dB/100 m: 6.9 dB

$\Rightarrow$ Loss in dB/100ft $= 6.9 \times 0.3048$

$= 2.103$ dB

$\Rightarrow$ Total loss over 25ft $= \dfrac{2.103}{100} \times 25$

$= 0.526$ dB

$\Rightarrow P_{out\,(dBm)} = 10 - 0.526$

$\boxed{P_{out\,(dBm)} = 9.474\ dBm}$

$\Rightarrow P_{out\,(mW)} = 10^{\frac{9.474}{10}}$

$= 10^{0.9474}$

$\boxed{P_{out}(mW) = 8.859\ mW}$

(b)

Frequency: 500MHz Loss in dB/100m: 16.7 d

$\Rightarrow$ Loss in dB/100 ft $= 16.7 \times 0.3048$

$= 5.090$ dB

$\Rightarrow$ Total loss over 25ft $= \frac{5.090}{100} \times 25$

$= 1.273$ dB

$\Rightarrow P_{out}$ (dBm) $= 10 - 1.273$

$\boxed{P_{out}\text{ (dBm)} = 8.727 \text{ dBm}}$

$\Rightarrow P_{out}$ (mW) $= 10^{\frac{8.727}{10}}$

$= 10^{0.8727}$

$\boxed{P_{out}\text{ (mW)} = 7.459 \text{ mW}}$

Date: __/__/20

(C)

Frequency: 2320 MHz   Loss in dB/100m: 46.5 dB

$\Rightarrow$ Loss in dB/100 ft $= 46.5 \times 0.3048$

$= 14.173$ dB

$\Rightarrow$ Total loss over 25ft $= \frac{14.173}{100} \times 25$

$= 3.543$ dB

$\Rightarrow P_{out}\,(dBm) = 10 - 3.543$

$$\boxed{P_{out}\,(dBm) = 6.457 \text{ dBm}}$$

$\Rightarrow P_{out}\,(mW) = 10^{\frac{6.457}{10}}$

$= 10^{0.6457}$

$$\boxed{P_{out}\,(mW) = 4.423 \text{ mW}}$$

Date: __/__/20

Q.No.3

(a)

$C = 36000$ bit/sec $\quad SNR_{dB} = 30\,dB$

As $SNR = 10^{\frac{SNR(dB)}{10}}$

$= 10^{\frac{30}{10}}$

$= 10^{3}$

$\Rightarrow SNR = 1000$

As $C = B \log_2(1 + SNR)$

$\Rightarrow B = \dfrac{C}{\log_2(1+SNR)}$

$= \dfrac{36000}{\log_2(1+1000)}$

$= \dfrac{36000}{\log_2(1001)}$

$= \dfrac{36000}{9.967}$

$\Rightarrow \boxed{B = 3611.919\ Hz}$

(b)

$C = 25\,kbps$ $\quad$ $SNR = 500$

As $C = B \log_2(1+SNR)$

$$\Rightarrow B = \frac{C}{\log_2(1+SNR)}$$

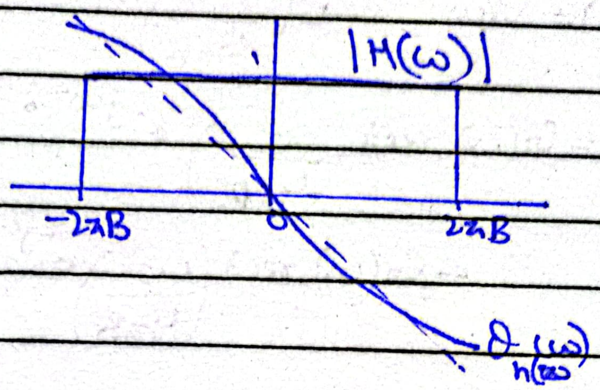
$$= \frac{25 \times 10^3}{\log_2(1+500)}$$

$$= \frac{25 \times 10^3}{\log_2(501)}$$

$$= \frac{25 \times 10^3}{8.969}$$

$$\Rightarrow \boxed{B \approx 2787.379\ Hz}$$

Q. No. 4



$|H(\omega)| = 1$ $\qquad \theta_h(\omega) = -\omega t_0 - k\sin(\omega T)$; $k \ll 1$

(a)

As $\quad g(t) \Longleftrightarrow G(\omega)$

$\quad y(t) \Longleftrightarrow Y(\omega)$

and $\quad Y(\omega) = H(\omega)\, G(\omega) \quad$ — ①

where $\quad H(\omega) = rect\left(\frac{\omega}{4\pi B}\right) e^{-j(\omega t_0 + k\sin\omega T)}$

Hence, eq(1) becomes

$$Y(\omega) = G(\omega)\, rect\left(\frac{\omega}{4\pi B}\right) e^{-j(\omega t_0 + k\sin\omega T)}$$

$$= G(\omega)\, rect\left(\frac{\omega}{4\pi B}\right) e^{-jk\sin\omega t}\, e^{-j\omega t_0}$$

As $\quad e^{-jk\sin\omega t} \simeq 1 - jk\sin\omega T \qquad$ (given)

Date: __/__/20

Hence, $Y(\omega)$ becomes

$$Y(\omega) = G(\omega)\,\text{rect}\left(\frac{\omega}{4\pi B}\right) e^{-j\omega t_0}(1 - jk\sin\omega T)$$

$$= G(\omega)\,\text{rect}\left(\frac{\omega}{4\pi B}\right) e^{-j\omega t_0}$$

$$- G(\omega)\,\text{rect}\left(\frac{\omega}{4\pi B}\right) e^{-j\omega t_0}\, jk\sin\omega T$$

As $G(\omega)$ is band limited to B Hz,

Hence,

$$G(\omega)\,\text{rect}\left(\frac{\omega}{4\pi B}\right) = G(\omega)$$

Therefore,

$$Y(\omega) = G(\omega)e^{-j\omega t_0} - G(\omega)e^{-j\omega t_0}\, jk\sin\omega T$$

$$= \left(G(\omega)e^{-j\omega t_0}\right) - k\left(G(\omega)j\sin\omega T\right)e^{-j\omega t_0} \quad \text{—(2)}$$

As $g(t-T_0) \Leftrightarrow G(\omega)e^{-j\omega T_0}$

$$\Rightarrow \quad g(t-T) - g(t+T) \Leftrightarrow G(\omega)e^{-j\omega T} - G(\omega)e^{j\omega T}$$

$$g(t-T) - g(t+T) \Leftrightarrow G(\omega)\left[e^{-j\omega T} - e^{j\omega T}\right]$$

$$g(t-T) - g(t+T) \Leftrightarrow -2G(\omega)\left[\frac{-e^{-j\omega T} + e^{j\omega T}}{2}\right]$$

$$g(t-T) - g(t+T) \Leftrightarrow -2G(\omega)(j\sin\omega T)$$

$$\frac{g(t-T) - g(t+T)}{-2} \Leftrightarrow G(\omega)\, j\sin\omega T \quad \text{—(3)}$$

$$\frac{g(t-T-t_0) - g(t+T-t_0)}{-2} \Leftrightarrow \left(G(\omega)\, j\sin\omega T\right)e^{-j\omega t_0} \quad \text{—(4)}$$

Date: __/__/20

From ②, ③ & ④

$$\Rightarrow y(t) = g(t-t_0) - k\left[\frac{g(t-T-t_0)-g(t+T-t_0)}{-2}\right]$$

$$\boxed{y(t) = g(t-t_0) + \frac{k}{2}\left[g(t-T-t_0)-g(t+T-t_0)\right]}$$

(b)

⇒ TDM (Time division multiplexing) is a data, voice and video comunication technique. The entire time interval is divided into smaller time slots.

⇒ FDM (Frequency division multiplexing) is a technique suitable for analog signals. In FDM, the entire frequency interval is divided into smaller frequency slots.

⇒ In FDM, all signals operate at same time with different frequencies, while in TDM, all signals operate ~~at~~ with same ~~time~~ frequency at different times.

⇒ This channel will not affect TDM and FDM as ~~the~~ $H(\omega) = 1$, meaning there will be a distortionless transmission.

Date: __/__/20

Q.No 0.5

$$H(\omega) = \frac{4(10^5)}{\omega^2 + 10^{10}} e^{-j\omega t_0}$$

For a physically realizable system, h(t) must be causal, i.e

$$h(t) = 0 \quad \text{for } t < 0$$

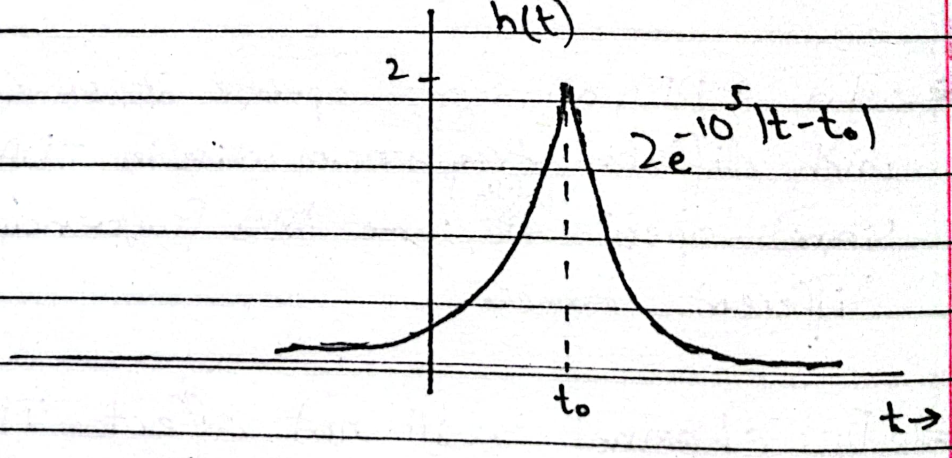
As $e^{-a|t-t_0|} \Longleftrightarrow \frac{2a}{a^2+\omega^2} e^{-j\omega t_0}$ —— ①

$$H(\omega) = \frac{4(10^5)}{\omega^2 + 10^{10}} e^{-j\omega t_0}$$

$$= 2\left[\frac{2(10^5)}{(10^5)^2 + (\omega)^2} e^{-j\omega t_0}\right] \Rightarrow a = 10^5$$

From ①

$$h(t) = 2e^{-10^5|t-t_0|}$$



As $h(t) \neq 0$ for $t < 0$, this filter with transfer function

$$H(\omega) = \frac{4(10^5)}{\omega^2 + 10^{10}} e^{-j\omega t_0}$$

is unrealizable.

Date: __/__/20

The exponential delays to 1.8% at 4 times constant.

Hence, $t_0 = \frac{4}{a}$

$= \frac{4}{10^5}$

$= 40\,\mu s$

$\Rightarrow$ $\boxed{t_0 = 40\,\mu s}$ is a reasonable choice to make this filter approximately realizable.