2. The bandwidth of a speech signal is from 50 Hz through to 10 kHz and that of a music signal is from 15Hz through to 20Khz. You want to digitize these signals using the Nyquist criterion.

- What is the bit rate produced for the speech signal if 12 bits are used per sample?
- Perform the same for the music signal when 16 bits per sample are used.

• How many mega bytes of storage do you need for 10 minutes of stereophonic music?

Speech signal must be sampled at 20 kHz. Therefore its bit rate = 12 * 20 = 240 Kbps Music signal must be sampled at 40 kHz. Therefore its bit rate = 16 * 40 = 640 Kbps 10 minute of mono music requires 10*60*640K = 384 Mbits = 48 Mbytes For stereophonic music, space required = 48*2 = 96 Mbytes

5. The high-frequency limit of human hearing extends to approximately 20 kHz, but studies have shown that intelligible speech requires frequencies only up to 4kHz.

• Justify why the sampling rate for an audio Compact Disc (CD) is 44.1 kHz. What is the Nyquist rate for reliable speech communications?

• Why do you think people sound different on the phone from in person?

• Suppose intelligible speech requires 7 bits per sample. If the phone system is designed to precisely meet the requirements for speech (which is the case), what is the maximum bit rate allowable over telephone lines?

• CDs use 16 bits per sample. What is the bit rate of music coming off a CD? Is a modem connection fast enough to support streamed CD quality audio?

The ear is the ultimate receptor of the rendered digital audio. Since it can hear frequencies no more than 20KHz, the original signal must be sampled at at least 40 KHz to capture all the 20KHz frequencies. With some additional room for higher ranges, the CD audio is sampled at 44.1 KHz. The reliable sampling rate for speech communication is 2*4kHz=8kHz.

People's voice are sampled and reconstructed through the telephone lines, which cause loss of high frequencies. That's why it will be sound different from in person. Max bit rate over telephone lines = 2x4x7 = 56Kbps.

Bit rate of CD sound = $44.1 \times 16 = 705.6$ Kbps for mono, 1.411 Mbps for stereo.

Broad band to most homes is getting to a point where this can be supported, but still for practical efficiency, the CD audio streams are compressed using a psychoacoustic audio compression scheme, such as mp3 or AAC.

9. You are asked to design anti-aliasing filters for i)FM Radio, ii) CD Recording and ii) Telephone System. The corresponding sampling rates are given in a table located in the text. What will be typical filter design requirements for these applications?

For those devices, the f_s is fixed. If $f_s < 2f_M$, aliasing will occur. So the pre-filter should cut off the high frequency of the original signal to control f'_M , and make $f'_M \ll f_s/2$.

Thus, for FM Radio, the pre-filter should cut off frequencies higher than 11kHz; CD 22.05kHz; Telephone 4kHz (for speech) or 8kHz (for teleconferencing)