THE SCIENCE OF MUSIC (HSI2013)
End-of-Term Class Test, Semester 1, 2025/26

This is an open book test. The test is one hour long.

Give your answers to ALL 25 questions on the computer-readable sheet provided, using a soft (2B) pencil to shade the appropriate choice for each question.

1. Which of the following is the most appropriate example of a scientific or technological activity?

   (a) A clarinet player rehearsing on a clarinet whose mouthpiece has been shaped differently using new acoustical principles.

   (b) A trumpet player practising on a trumpet whose body is made of a new type of metal alloy.

   (c) A pianist inventing a new type of piano pedal which changes the tone quality of the piano note being played.

   (d) A bassoon player playing on a bassoon whose reeds in its mouthpiece are made from a new type of plastic.

   Answer: (c) The clarinet player, trumpet player and bassoon player are all performing essentially musical activities. The pianist is the only one performing an essentially technological activity.

2. The musical score of an organ piece has its upper staff starting with a treble clef and its lower staff starting with a bass clef, and the key signature at the beginning of the score has four sharps on each staff. One particular chord in this score has its lowest note written on the second lowest space of the four spaces of the lower staff, and its highest note written on the second lowest space of the four spaces of the upper staff. Which of the following gives the ratio of the interval between the lowest note and the highest note of this chord? (Assume that the chord is played on an organ which is tuned correctly to the Equal-tempered scale.)

   (a) $(\sqrt[12]{2})^{19}$.

   (b) $(\sqrt[12]{2})^{20}$.

   (c) $(\sqrt[12]{2})^{32}$.

   (d) None of the above.

   Answer: (b) The key signature of the organ piece has four sharps, so all the notes named F, C, G and D in the piece should be played as Fsharp, Csharp, Gsharp and Dsharp respectively. The second lowest space of the lower staff is the note C3 which should be played as Csharp3, and the second lowest space of the upper staff is the note A4. The interval from Csharp3 to Csharp4 is one octave or 12 equal-tempered semitones, and the interval from Csharp4 to A4 is 8 equal-tempered semitones. Therefore the interval from Csharp3 to A4 is 12 plus 8 i.e. 20 equal-tempered semitones, which means that the ratio of the interval between these two notes is equal to $(\sqrt[12]{2})^{20}$.

3. A tuba player walking in a park plays a musical note on his tuba, and a flute player nearby then plays a note on her flute which is four octaves and a Just third above the tuba's note. A bass singer who is not far away hears the flute's note and sings a note which is three octaves and a Pythagorean seventh below the flute's note. If the bass singer's note has a frequency of 64 Hz, what is the frequency of the note played by the tuba player?

(a) 48.6 Hz.

(b) 64 Hz.

(c) 81 Hz.

(d) None of the above.

Answer: (a) Since the bass singer's note has a frequency of 64 Hz, the frequency of the note three octaves above is given by 64 Hz multiplied by 2 three times i.e. 512 Hz. The flute's note which is a Pythagorean seventh above 512 Hz is equal to 512 Hz times $\frac{243}{128}$ i.e. 972 Hz. The note four octaves below the note played by the flute therefore has a frequency equal to 972 Hz divided by 2 four times i.e. 60.75 Hz. The tuba's note is lower than 60.75 Hz by a Just third so its frequency is equal to 60.75 Hz times $\frac{4}{5}$ i.e. 48.6 Hz.

4. A piece for solo clarinet has a score with a time signature of 30/8 at the beginning. A certain bar in this piece starts with a dotted minim and ends with 8 quavers and 10 semiquavers. Which of the following combinations of notes would fit exactly into the middle of this bar in agreement with the time signature of the piece? (A demisemiquaver is half the duration of a semiquaver. A note or rest which has a dot has its duration value increased by 50%.)

(a) 4 dotted quavers and 18 demisemiquavers.

(b) 3 crotchets, 4 quavers and 4 demisemiquavers.

(c) A dotted minim and 22 demisemiquavers.

(d) A semibreve and a minim.

Answer: (b) Since the time signature of the piece is 30/8, each bar of the piece should have the duration equivalent of 30 quavers or 60 semiquavers. Since the start of the bar has a dotted minim equivalent to 12 semiquavers, and the end of the bar has 8 quavers equivalent to 16 semiquavers and 10 semiquavers, the bar already has the equivalent of 38 semiquavers so the middle of the bar requires the equivalent of 22 semiquavers. Three crotchets are equivalent to 12 semiquavers, 4 quavers are equivalent to 8 semiquavers, and together with 4 demisemiquavers which are equivalent to 2 semiquavers make up a total of 22 semiquavers.

5. An open pipe labelled E is sliced into 8 short open pipes of equal length labelled E1, E2, E3, E4, E5, E6, E7 and E8. E1, E2, E3, E4 and E5 are joined up and one end closed up to make a closed pipe labelled F. The short pipes E6, E7 and E8 are joined up to make an open pipe labelled G. When F is vibrating with 4 nodes between its two ends (not counting the node at one end) and G is also vibrating with 4 nodes between its two ends, the ratio of the wavelength of the sound wave from F to that from G is *m:n*. Determine the ratio *m:n*.

(a) 27:10

(b) 27:20.

(c) 27:40.

(d) None of the above.

Answer: (d) Let the length of E be d cm and its fundamental frequency be f Hz. Therefore the fundamental frequency of an open pipe which is five-eighths the length of E is equal to f Hz times $\frac{8d}{5d}$ i.e. $\frac{8f}{5}$ Hz. The fundamental frequency of the closed pipe F will therefore be half of this i.e. $\frac{4f}{5}$ Hz. When F vibrates with 4 nodes it will be at its 9th harmonic and its frequency will be given by $\frac{4f}{5}$ Hz times 9 i.e. $\frac{36f}{5}$ Hz. The pipe G is an open pipe three-eighths the length of E, so its fundamental frequency is given by f Hz times $\frac{8d}{3d}$ i.e. $\frac{8f}{3}$ Hz. When G vibrates with 4 nodes it will be at its 4th harmonic and its frequency will be equal to $\frac{8f}{3}$ Hz times 4 i.e. $\frac{32f}{3}$ Hz. Therefore the ratio of the frequencies of the notes from F and G is given by $\frac{36f}{5}$ Hz divided by $\frac{32f}{3}$ Hz i.e. $\frac{27}{40}$. Since frequency is inversely proportional to wavelength, the ratio of the wavelength from F to that from G expressed as m:n is thus 40:27.

6. A string vibrating with 7 nodes between its two ends (not counting the nodes at both ends) has the same frequency as that of a closed pipe vibrating with 7 antinodes (not counting the antinode at one end). When the closed pipe vibrates at its fundamental frequency, the 6th line from the left in its spectrum corresponds to the frequency of a sound wave in air of exactly 0.15 m in wavelength. Calculate the fundamental frequency of the string. (Assume the velocity of sound in air is 330 m/s.)

   (a) 375 Hz.
   (b) 325 Hz.
   (c) 275 Hz.
   (d) None of the above.

   Answer: (a) In the spectrum of the closed pipe vibrating at its fundamental frequency, the 6th line in its spectrum i.e. its 11th harmonic has a frequency given by $\frac{330}{0.15}$ Hz i.e. 2,200 Hz. Therefore the fundamental frequency of the closed pipe is given by 2,200 Hz divided by 11 i.e. 200 Hz. If the closed pipe vibrates with 7 antinodes it is at its 15th harmonic, and its frequency will be equal to 200 Hz times 15 i.e. 3,000 Hz. Since the string has 7 nodes and 8 antinodes, it is vibrating at its 8th harmonic. Its fundamental frequency is thus equal to 3,000 Hz divided by 8 i.e. 375 Hz.

7. An open pipe which has a fundamental frequency of 250 Hz is vibrating with 7 nodes between its two ends. Its frequency is the same as that of a closed pipe vibrating with 2 nodes between its two ends (not counting the node at one end). When the closed pipe vibrates with 3 nodes between its two ends (not counting the node at one end), beats of 20 Hz are produced when it combines with a string 50 cm long vibrating at its fundamental frequency. When the string is shortened slightly, the beat frequency increases (without passing through zero Hz). If the string is shortened to 49.4 cm, calculate the beat frequency if the string's fundamental frequency then combines with the note from the closed pipe which is still vibrating with 3 nodes.

   (a) 25 Hz.
   (b) 52 Hz.
   (c) 80 Hz.
   (d) None of the above.

   Answer: (d) Since the open pipe has 7 nodes, it is vibrating at its 7th harmonic, and hence its frequency is equal to 250 Hz times 7 i.e. 1,750 Hz. The closed pipe is vibrating with 2 nodes so it is at its 5th harmonic and its fundamental frequency is equal to 1,750 Hz divided by 5 i.e. 350 Hz. If the closed pipe has 3 nodes it is at its 7th harmonic and its frequency must then be equal to 350 Hz times 7 i.e. 2,450 Hz. As the beat frequency is 20 Hz, the frequency of the string is either 2,450 Hz minus 20 Hz i.e. 2,430 Hz, or 2,450 Hz plus 20 Hz i.e. 2,470 Hz. When the string is shortened, its frequency will increase so if the beat frequency increases, the string's frequency must have been greater than 2,450 Hz, i.e. its frequency was equal to 2,470 Hz. If the string was shortened from 50 cm to 49.4 cm, its fundamental frequency would become 2,470 times $\frac{50}{49.4}$ i.e. 2,500 Hz. The beat frequency will thus become 2,500 Hz minus 2,450 Hz i.e. 50 Hz.

8. A 'cellist is tuning the A string of her 'cello by using her bow to make the string vibrate. She uses an electronic tuner that produces a musical note with a frequency of 220 Hz to help her. The note from the open A string of her 'cello produces beats of 2 Hz when it combines with

the note from the electronic tuner. When the A string of the 'cello is tightened while it is still being played with the bow, the beat frequency increases (without passing through 0 Hz). Which of the following frequencies is the frequency of the open D string of the 'cello when the beat frequency was 2 Hz? (Assume that all the strings of the 'cello are tuned in relation to each other as is normal for a 'cello, when the beat frequency was 2 Hz.)

(a) 166.5 Hz.

(b) 148 Hz.

(c) 146.67 Hz.

(d) 145.33 Hz.

Answer: (b) The beat frequency was 2 Hz, so the 'cello's A string's frequency was either 220 Hz minus 2 Hz i.e. 218 Hz, or 220 Hz plus 2 Hz i.e. 222 Hz. Since the A string's frequency would have increased when the A string was tightened, its frequency must have been higher than 220 Hz i.e. it was at 222 Hz as the beat frequency had then increased. The 'cello's D string's frequency is a Just fifth below the frequency of its A string, so the D string's frequency is given by 222 Hz divided by $\frac{3}{2}$ i.e. 148 Hz.

9. The A string of a viola is tuned to 440 Hz, and all its four strings are tuned relative to each other in Just fifths as is normal for a viola. An upright piano which is very slightly sharp has all its strings tuned relative to each other in accordance with the Equal-tempered scale. A pianist plays the E6 key of the piano, and the E6 note combines with the third harmonic of the note from the viola's A string to produce beats of 2 Hz. Of the following frequencies, which one is closest to the fundamental frequency of the Bflat6 note on the piano? (Assume that the Equal-tempered semitone has a ratio equal to 1.05946.)

   (a) 1,869.6 Hz.

   (b) 1,866.7 Hz.

   (c) 1,863.9 Hz.

   (d) 1,764.6 Hz.

   Answer: (a) Since the viola's A string has a frequency of 440 Hz, the frequency of its third harmonic is equal to 440 Hz times 3 i.e. 1,320 Hz. The piano's E6 note produces 2 Hz beats on combining with this 3rd harmonic, so the frequency of the piano's E6 note is either 1,320 Hz minus 2 Hz i.e. 1,318 Hz, or 1,320 Hz plus 2 Hz i.e. 1,322 Hz. The piano is very slightly sharp, so the frequency of the E6 note on the piano is equal to 1,322 Hz. The note Bflat6 is 6 semitones above E6, so its frequency is equal to 1,322 Hz multiplied by 1.05946 six times i.e. approximately 1,869.56 Hz.

10. A theory of consonance or dissonance between two different notes played together explains that the degree of consonance or dissonance is due to the degree with which the harmonics of one note coincide with the harmonics of the other note. If we consider just the first 12 harmonics of a note of fundamental frequency 60 Hz, how many of these harmonics are coincident with those of a note which is a Just fourth higher than 60 Hz?

    (a) One harmonic.

    (b) Two harmonics.

    (c) Three harmonics.

    (d) Four harmonics.

Answer: (c) The first 12 harmonics of the 60 Hz note are as follows: 60 Hz, 120 Hz, 180 Hz, 240 Hz, 300 Hz, 360 Hz, 420 Hz, 480 Hz, 540 Hz, 600 Hz, 660 Hz and 720 Hz. The note a Just fourth higher than 60 Hz is obtained by multiplying 60 Hz by $\frac{4}{3}$ i.e. 80 Hz. The first 10 harmonics of the 80 Hz note are: 80 Hz, 160 Hz, 240 Hz, 320 Hz, 400 Hz, 480 Hz, 560 Hz, 640 Hz, 720 Hz and 800 Hz. Therefore three harmonics coincide at 240 Hz, 480 Hz and 720 Hz.

11. Which of the following is the least appropriate description of a piano?

    (a) Keyboard instrument.

    (b) String instrument.

    (c) Percussion instrument.

    (d) Wind instrument.

    Answer: (d) Since a keyboard is used by the piano player to play the piano's notes, the piano can be described as a keyboard instrument. The notes are produced by hammers beating on strings, so the piano can also be described as a percussion instrument or a string instrument. However, it is not a wind instrument, as no blowing is involved in the production of its sounds.

12. A particular Cristofori piano has an action of which the first and third levers of a certain key on the keyboard multiply the distance moved by the effort by factors of 1 and 5.6 times respectively. On striking this key with a downwards speed of 4 cm/s, the first, second and third levers of this key cause the corresponding hammer to move upwards with a speed of 44.8 cm/s. After the third lever is then changed so that it multiplies the distance moved by 5.0 times instead of 5.6 times, what would the new downwards speed of the key have to be in order to enable the hammer to move upwards with the same speed as before?

    (a) 5.6 cm per second.

    (b) 5 cm per second.

    (c) 4.8 cm per second.

    (d) None of the above.

    Answer: (d) The three levers together have a combined multiplication factor given by the speed of the hammer divided by the speed of the key i.e. 44.8 cm/s divided by 4 cm/s i.e. 11.2 times. Hence the second lever by itself would have a multiplication factor given by 11.2 times divided by 5.6 i.e. 2.0 times. The third lever is then modified to have a multiplication factor of 5 times instead of 5.6 times, so the new combined multiplication factor for the three levers acting together will be equal to 2.0 times 5.0 i.e. 10 times. In order for the hammer to move upwards at the same speed as before i.e. 44.8 cm per second, the downwards speed of the key is given by 44.8 cm per second divided by 10 i.e. 4.48 cm per second.

13. On a certain grand piano, the soft pedal on the left, the sostenuto pedal in the middle and the sustain or loud pedal on the right are all functioning normally. A pianist then plays a chord on the keyboard by depressing the appropriate keys simultaneously, and also depressing one of these three pedals. Of the following sequence of actions, which one would not successfully sustain the sound of the notes played?

    (a) The pianist depresses the sostenuto pedal, then depresses the keys and then releases the keys, and keeps the sostenuto pedal depressed.

    (b) The pianist depresses the keys, then depresses the sostenuto pedal and then releases the keys, and keeps the sostenuto pedal depressed.

    (c) The pianist depresses the keys, then depresses the sustain pedal and then releases the keys, and keeps the sustain pedal depressed.

(d) The pianist depresses the sustain pedal, then depresses the keys and then releases the keys, and keeps the sustain pedal depressed.

Answer: (a) If the sostenuto pedal is depressed after the keys have been depressed, the notes of the corresponding strings will be kept sustained even after the keys have been released, as long as the sostenuto pedal is kept depressed. If the sostenuto pedal is depressed before the keys are depressed, this will not happen. The sustain pedal lifts all the dampers of the piano off the strings, so the notes will thus be sustained even when the keys have been released, as long as the sustain pedal remains depressed. If the sustain pedal is depressed after the keys have been depressed, the notes will also be sustained after the keys have been released since the sustain pedal keeps all the hammers up.

14. A desktop computer sends MIDI messages in and out through a MIDI interface box which has a MIDI in IB and a MIDI out OB. A composer uses an electronic piano which has only a MIDI in IP and a MIDI out OP to write a piece of music by inputting the notes of the piece into the computer. The completed piece is to be performed on the electronic piano and an electronic synthesizer which has a MIDI in IS, a MIDI out OS and a MIDI thru TS. Which of the following connections is not a proper connection for the desktop computer, electronic piano and electronic synthesizer to enable the composer to compose and perform the piece of music as desired?

(a) OP to IB.

(b) OB to IS.

(c) OS to IP.

(d) TS to IP.

Answer: (c) The desktop computer should receive MIDI messages from the MIDI out OP of the electronic piano through the MIDI in IB of the MIDI interface box. To perform the completed piece of music, MIDI messages should be sent out by the desktop computer through OB to the electronic synthesizer's MIDI in IS, and the same MIDI messages should be sent out of the electronic synthesizer's MIDI thru TS to the electronic piano's MIDI in IP. The MIDI messages from the MIDI interface box cannot be sent directly to the electronic piano's MIDI in IP, as the electronic piano does not have a MIDI thru to pass on the MIDI messages to the electronic synthesizer.

15. A MIDI message is sent to an electronic organ telling the organ to turn on the musical note B2 in the highest numbered MIDI channel as quickly as possible. Of the following sequences of numbers, which is the correct sequence of numbers (in decimal form) for this MIDI message?

(a) 9, 0, 47, 127.

(b) 9, 15, 47, 127.

(c) 9, 15, 35, 127.

(d) None of the above.

Answer: (b) The first number for this MIDI message (in decimal) should be 9 to tell the electronic organ to turn on a note; the second number should be 15 to tell the electronic organ that the MIDI message is for the highest numbered MIDI channel; the third number should be 47 to tell the electronic organ that the note to be turned on is B2; and the fourth number should be 127 to tell the electronic organ to turn on the note as quickly as possible.

16. The fundamental frequency produced by a closed pipe has a spectrum in which the 8th line from the left has a frequency of 2,475 Hz. A low pass filter then removes all the harmonics of this note above the frequency 3,130 Hz, and a high pass filter removes all the harmonics below

the frequency 2,155 Hz. Which lines will remain in the spectrum after the note has passed through both the low pass and high pass filters?

(a) Only the 8th and 9th lines from the left.

(b) Only the 8th, 9th and 10th lines from the left.

(c) Only the 9th and 10th lines from the left.

(d) None of the above.

Answer: (a) The note from the closed pipe has only odd harmonics in its spectrum, so the 8th line from the left in its spectrum is its 15th harmonic. Therefore the note's fundamental frequency is equal to 2,475 Hz divided by 15 i.e. 165 Hz. For this note, the first 12 lines of its spectrum will be its fundamental frequency and its 3rd, 5th, 7th, 9th, 11th, 13th, 15th, 17th, 19th, 21st and 23rd harmonics. Their respective frequencies are: 165 Hz, 495 Hz, 825 Hz, 1,155 Hz, 1,485 Hz, 1,815 Hz, 2,145 Hz, 2,475 Hz, 2,805 Hz, 3,135 Hz, 3,465 Hz and 3,795 Hz. Since the low pass filter removes all the harmonics above 3,130 Hz, only the 17th and lower harmonics remain. The high pass filter removes all the frequencies which are below 2,155 Hz, so only the 15th and 17th harmonics i.e. the 8th and 9th lines from the left will remain in the spectrum of the note.

17. A certain method for the synthesis of musical sounds first generates the waveforms of all the harmonics required. These harmonics are then added up, but modified in magnitude to conform to the relative proportions of the required harmonics in the musical sound to be synthesised. What is the usual name for this method of waveform generation?

(a) Amplitude Modulation synthesis.

(b) Frequency Modulation synthesis.

(c) Additive synthesis.

(d) Subtractive synthesis.

Answer: (c) Since this method adds up all of the required harmonics of the musical sound in the correct proportions, this method of synthesis is usually known as additive synthesis.

18. The FM synthesis method is being used to synthesise the musical sound of a certain musical instrument. The frequency of the carrier waveform for this synthesis process is 24,550 Hz and the frequency of the modulator waveform is 395 Hz. Which of the following frequencies is not a valid frequency of one of the harmonics in the spectrum of the musical sound being generated?

(a) 20,995 Hz.

(b) 24,155 Hz.

(c) 25,745 Hz.

(d) 27,710 Hz.

Answer: (c) The FM synthesis carrier frequency is 24,550 Hz and the modulator frequency is 395 Hz, so the harmonics of the FM spectrum of the musical sound will be separated from the carrier frequency by multiples of 395 Hz. Therefore the 10 harmonics which are just above 24,550 Hz are: 24,945 Hz, 25,340 Hz, 25,735 Hz, 26,130 Hz, 26,525 Hz, 26,920 Hz, 27,315 Hz, 27,710, 28,105 Hz and 28,500 Hz. The 10 harmonics just below 24,550 Hz are 24,155 Hz, 23,760 Hz, 23,365 Hz, 22,970 Hz, 22,575 Hz, 22,180 Hz, 21,785 Hz, 21,390 Hz, 20,995 Hz and 20,600 Hz. Therefore only the frequency 25,745 Hz is not a valid frequency of one of the harmonics in the FM spectrum of this waveform.

19. A concert by the NUS Symphony Orchestra is being digitally telecast over the Internet. If the sampling rate of the digital telecast of the concert is 40,580 samples per second, what is the highest frequency of the concert which can be preserved by this digital telecast, by the Nyquist criterion?

    (a) 81,160 Hz.
    (b) 40,580 Hz.
    (c) 10,145 Hz.
    (d) None of the above.

    Answer: (d) The Nyquist theorem or criterion says that the sampling frequency or rate of the transmission has to be be double that of the highest frequency to be preserved in the digital telecast. Since the sampling rate of the digital telecast is 40,580 samples per second, the highest frequency to be preserved in the digital telecast is half of this i.e. 20,290 Hz.

20. The digital broadcast of a jazz band concert has a signal to noise (S/N) ratio of 90 dB. What is the number of quantization levels in this digital broadcast? (Assume that each bit of the sample bit length contributes 6 dB to the S/N ratio.)

    (a) 65,536.
    (b) 32,768.
    (c) 16,384.
    (d) None of the above.

    Answer: (b) Since the jazz band concert has a S/N ratio of 90 dB, the number of bits in each sample is 90 divided by 6 i.e. 15 bits. 2^{15} is equal to 32,768, so there must be 32,768 quantization levels in the digital recording.

21. The highest frequency to be preserved in the digital recording of a pop concert is 17,680 Hz. If the digital recording equipment on which the recording is being made can support at most 750,000 bits per second, what is the highest signal-to-noise (S/N) ratio which is possible for this digital recording? (Assume that the digital recording is in stereo sound, with two audio channels of equal bit rates in the recording. Assume also that each bit of the sample bit length contributes 6 dB to the S/N ratio.)

    (a) 60 dB.
    (b) 66 dB.
    (c) 72 dB.
    (d) None of the above.

    Answer: (a) Since the highest frequency to be preserved in the recording is 17,680 Hz, the sampling rate of the recording must be double this i.e. 35,360 samples per second. The equipment for the digital recording can support at most 750,000 bits per second, so for each of the two stereo channels the bit rate is half of this i.e. 375,000 bits per second. The number of bits per sample for each channel is thus given by 375,000 bits per second divided by 35,360 samples per second i.e. approximately 10.61 bits. The bit length has to be an integer so it is equal to 10 bits because a bit length of 11 bits would give a bit rate greater than 375,000 bits per second. A bit length of 10 bits would result in a S/N ratio equal to 6 dB times 10 bits i.e. 60 dB.

22. The highest frequency to be preserved in the digital recording of a folk music concert is 16,385 Hz. If the signal-to-noise or S/N ratio of the recording is 66 dB, calculate the bit rate of the digital recording. (Assume that the digital transmission of the concert is in stereo sound, with two audio channels of equal bit rates. Assume also that each bit of the sample bit length contributes 6 dB to the S/N ratio.)

    (a) 180,235 bits per second.
    (b) 360,470 bits per second.
    (c) 720,940 bits per second.
    (d) None of the above.

    Answer: (c) By the Nyquist criterion, the sampling rate for a digital recording should be double the highest frequency to be preserved. Therefore the sampling rate for the digital recording is given by 16,385 Hz times 2 i.e. 32,770 samples per second. For a signal-to-noise or S/N ratio of 66 dB, the bit length of the digital samples is equal to 66 dB divided by 6 dB i.e. 11 bits. The bit rate for each stereo channel is thus equal to 32,770 samples per second times 11 bits, i.e. 360,470 bits per second, and for two stereo channels the bit rate is double this i.e. 720,940 bits per second.

23. For the digital recording of a symphony concert, the highest frequency to be preserved is 20,450 Hz, and the signal-to-noise (S/N) ratio of the recording is to be 78 dB. The resultant bit rate also happens to be the maximum possible bit rate of the digital recording equipment being used for the recording. A pop music concert is digitally recorded at the same place the following evening, using the same digital recording equipment used for the symphony concert. The highest frequency to be preserved in the pop music concert is 15,850 Hz. Calculate the highest signal-to-noise (S/N) ratio which is possible for the digital recording of the pop music concert. (Assume that both concerts are being recorded in stereo sound i.e. with two audio channels of equal bit rates. Assume also that each bit of the sample bit length contributes 6 dB to the S/N ratio.)

    (a) 84 dB.
    (b) 90 dB.
    (c) 96 dB.
    (d) None of the above.

    Answer: (c) Using the Nyquist criterion, the sampling rate for the symphony concert is double 20,450 Hz i.e. 40,900 samples per second. The bit length of the digital samples is given by 78 dB divided by 6 dB i.e. 13 bits, so the bit rate for a single audio channel is equal to 40,900 samples per second times 13 bits i.e. 531,700 bits per second which is also the maximum bit rate for each channel for the digital recording equipment. For the pop music concert the sampling rate is given by 15,850 Hz times 2 i.e. 31,700 samples per second. The bit length for the pop music concert is thus equal to 531,700 bits per second divided by 31,700 samples per second i.e. approximately 16.77 bits. The bit length is 16 bits, as bit length must be an integer and a bit length of 17 bits would result in a bit rate greater than the maximum possible bit rate. For a bit length of 16 bits the S/N ratio is given by 16 times 6 dB i.e. 96 dB.

24. A jazz concert which is 42 minutes long is to be digitally recorded on the hard disk of your notebook computer. The highest frequency to be preserved in the digital recording is 17,500 Hz and the signal-to-noise (S/N) ratio for the recording is to be 66 dB. What is the number of bytes needed on your computer's hard disk to record the whole concert? (Assume the recording is in stereo i.e. there are two audio channels to be recorded, and that each audio channel has the same bit rate. Assume also that each bit of the sample bit length contributes 6 dB to the S/N ratio.)

(a) 121,275,000 bytes.
(b) 242,550,000 bytes.
(c) 485,100,000 bytes.
(d) None of the above.

Answer: (b) The sampling frequency of the digital recording by the Nyquist criterion is double 17,500 Hz, i.e. 35,000 samples per second. For a signal-to-noise (S/N) ratio of 66 dB, the number of bits for each sample is equal to 66 dB divided by 6 dB i.e. 11 bits. For each audio channel, the number of bits per second is thus equal to 35,000 samples per second times 11 bits i.e. 385,000 bits per second. For two stereo channels the bit rate is double this i.e. 770,000 bits per second. Hence the amount of memory needed to record 42 minutes on the computer is given by 770,000 bits per second times 60 seconds per minute times 42 minutes i.e. 1,940,400,000 bits, which is equal to 242,550,000 bytes.

25. A Chinese orchestra concert which has been digitally recorded has its recording compressed into an MP3 file which has a bit rate of 192,000 bits per second and a signal-to-noise (S/N) ratio of 90 dB. If the highest frequency preserved in the original digital recording is 18,000 Hz, what is the compression ratio for the compression of the original uncompressed digital recording to the MP3 file? (Assume that the concert is recorded in stereo with two audio channels of equal bit rates, and assume also that each bit of the sample bit length contributes 6 dB to the S/N ratio. The S/N ratio and the highest frequency to be preserved are the same for the MP3 file and the original uncompressed file.)

(a) 5.25 to 1.
(b) 6 to 1.
(c) 10.5 to 1.
(d) None of the above.

Answer: (d) Since the highest frequency to be preserved is 18,000 Hz, the sampling rate by the Nyquist criterion must be double this i.e. 36,000 samples per second. The bit length of the samples is equal to 90 dB divided by 6 dB i.e. 15 bits, so the bit rate of the uncompressed file is 36,000 samples per second times 15 bits i.e. 540,000 bits per second. For two stereo channels the bit rate is double this i.e. 1,080,000 bits per second. Therefore the compression ratio is equal to 1,080,000 bits per second to 192,000 bits per second i.e. 5.625 to 1.

END OF TEST PAPER