THE SCIENCE OF MUSIC (HSI2013)
End-of-Term Class Test, Semester 2, 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. A woman walking in a shopping mall sings a musical note, and a double bassoon player nearby then plays a note on his double bassoon which is two octaves and a Just sixth below the woman's note. A clarinet player standing a short distance away then plays a note on her clarinet which is five octaves and a Pythagorean sixth above the double bassoon's note. If the woman's note has a frequency of 275 Hz, calculate the frequency of the note played by the clarinet player.

   (a) 2,200 Hz.
   (b) 2,227.5 Hz.
   (c) 4,400 Hz.
   (d) None of the above.

   Answer: (b) The woman's note has a frequency of 275 Hz, so the frequency of the note two octaves below is given by 275 Hz divided by 2 two times i.e. 68.75 Hz. The double bassoon's note is a Just sixth below 68.75 Hz so its frequency is equal to 68.75 Hz times $\frac{3}{5}$ i.e. 41.25 Hz. Therefore the note five octaves above the note played by the double bassoon has a frequency equal to 41.25 Hz multiplied by 2 five times i.e. 1,320 Hz. The clarinet's note is higher than 1,320 Hz by a Pythagorean sixth so its frequency is equal to 1,320 Hz times $\frac{27}{16}$ i.e. 2,227.5 Hz.

2. A piano piece has a musical score whose upper staff starts with a treble clef and lower staff starts with a bass clef. The key signature at the beginning of the score has four flats on each staff. A certain chord in this score has its lowest note written on the lowest space of the four spaces of the lower staff, and its highest note written on the middle line of the five lines 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 a piano which is tuned correctly to the Equal-tempered scale.)

   (a) $(\sqrt[12]{2})^{26}$.
   (b) $(\sqrt[12]{2})^{24}$.
   (c) $(\sqrt[12]{2})^{20}$.
   (d) None of the above.

   Answer: (a) Since the key signature of the piano piece has four flats, all the notes named B, E, A and D in the piece should be played as B flat, E flat, A flat and D flat respectively. The lowest space of the lower staff is the note A2 which should be played as Aflat2, and the middle line of the upper staff is the note B4 which should be played as Bflat4. The interval from Aflat2 to Aflat4 is two octaves or 24 equal-tempered semitones, and the interval from Aflat4 to Bflat4 is 2 equal-tempered semitones. The interval from Aflat2 to Bflat4 is thus 24 plus 2 i.e. 26 equal-tempered semitones, so the ratio of the interval between these two notes is equal to $(\sqrt[12]{2})^{26}$.

3. A musical score of a piece for solo voice has a time signature of 34/8 at its beginning. One particular bar in this piece starts with 3 dotted quavers and ends with 6 quavers and 8 semiquavers. Of the following combinations of notes, which one would fit exactly into the middle of this bar in accordance 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) A dotted semibreve, 2 dotted crotchets and 2 quavers.
   (b) A dotted minim, 5 dotted quavers and 20 demisemiquavers.
   (c) 3 dotted crotchets, 5 quavers and 22 demisemiquavers.
   (d) 2 dotted minims, 3 dotted quavers and 10 demisemiquavers.

   Answer: (c) The time signature of the piece is 34/8 which means that each bar of the piece must contain the duration equivalent of 34 quavers or 68 semiquavers. The beginning of the bar already has 3 dotted quavers equivalent to 9 semiquavers, and the end of the bar has 6 quavers equivalent to 12 semiquavers and 8 semiquavers, so the bar already has the equivalent of 29 semiquavers. Therefore the middle of the bar requires the equivalent of 39 semiquavers. 3 dotted crotchets are equivalent to 18 semiquavers, 5 quavers are equivalent to 10 semiquavers, and together with 22 demisemiquavers which are equivalent to 11 semiquavers make up a total of 39 semiquavers.

4. An open pipe labelled A is sliced into 3 short open pipes of equal lengths. Two of these pipes are joined up and one end closed up to make a closed pipe labelled B. The remaining pipe is labelled C. Which of the following statements concerning pipes A, B and C are true?
   (i) Assuming the fundamental frequency of pipe A is f Hz, the beat frequency formed between pipes A and C vibrating at their fundamental frequencies is 2f Hz.
   (ii) The ratio of the number of antinodes produced by pipe B vibrating in its fifth harmonic (not counting the antinode at one end) to that produced by pipe C vibrating in its third harmonic (not counting the antinodes at both ends) is 2:3.
   (iii) The frequency produced by pipe A vibrating with 3 nodes between its two ends is halved that produced by pipe C vibrating with 1 antinode (not counting the antinodes at both ends).
   (iv) The ratio of the wavelength of the sound wave produced by pipe A vibrating with 2 antinodes (not counting the antinodes at both ends) to that produced by pipe B vibrating with 1 node (not counting the node at one end) is 3:4.

   (a) Only statements (i) and (iii) are true.
   (b) Only statements (ii) and (iv) are true.
   (c) Statements (i), (iii) and (iv) are true.
   (d) All statements are true.

   Answer: (c) Since the fundamental frequency of pipe A is f Hz, the fundamental frequency of pipe C which is one third shorter will be $3f$ Hz. An open pipe the same length as pipe B will have fundamental frequency of $\frac{3f}{2}$ Hz. Pipe B being a closed pipe will therefore have a fundamental frequency of $\frac{3f}{4}$ Hz. The beat frequency when pipes A and C are vibrating at their fundamental frequencies is therefore $2f$ Hz. Statement (i) is true. When pipe B vibrates in its fifth harmonic, it will have two antinodes. When pipe C vibrates in its third harmonic, it will have two antinodes as well. So the ratio of the antinodes is 1:1. Statement (ii) is false. The frequency produced by pipe A vibrating with 3 nodes or 3rd harmonic is $3f$. That produced by pipe C vibrating with 1 antinode or 2nd harmonic is $6f$. So statement (iii) is true. The frequency of the sound wave produced by pipe A vibrating with 2 antinodes or 3rd harmonic is $3f$ Hz. That produced by pipe B vibrating with 1 node or 3rd harmonic is $\frac{9f}{4}$ Hz. The ratio of the frequencies is hence 3:$\frac{9}{4}$ or 4:3. Since wavelength is inversely proportional to frequency, the ratio of the wavelengths is therefore 3:4. Statement (iv) is true. So statements (i), (iii) and (iv) are true.

5. A closed pipe vibrating with 4 antinodes between its two ends (not counting the antinode at one end) has the same frequency as that of a string vibrating with 4 nodes (not counting the nodes at both ends). When the closed pipe vibrates at its fundamental frequency, the 8th line from the left in its spectrum has the frequency corresponding to a sound wave of exactly 0.20 m in wavelength. What is the fundamental frequency of the string? (Assume the velocity of sound in air is 330 m/s.)

   (a) 154 Hz.
   (b) 198 Hz.
   (c) 242 Hz.
   (d) None of the above.

   Answer: (b) The 8th line in the spectrum of the closed pipe vibrating at its fundamental frequency is its 15th harmonic which has a frequency equal to $\frac{330}{0.20}$ Hz i.e. 1,650 Hz. The fundamental frequency of the closed pipe is therefore equal to 1,650 Hz divided by 15 i.e. 110 Hz, and if the closed pipe vibrates with 4 antinodes it is at its 9th harmonic, and its frequency will be equal to 110 Hz times 9 i.e. 990 Hz. The string has 4 nodes and therefore 5 antinodes so it is vibrating at its 5th harmonic, and its fundamental frequency is therefore equal to 990 Hz divided by 5 i.e. 198 Hz.

6. An open pipe which has a fundamental frequency of 150 Hz is vibrating with 6 nodes between its two ends. This is the same frequency as that of a closed pipe vibrating with 4 nodes between its two ends (not counting the node at one end). When the closed pipe vibrates with 7 nodes between its two ends (not counting the node at one end), beats of 15 Hz are heard when it combines with a string 61 cm long vibrating at its fundamental frequency. On shortening the string slightly, the beat frequency decreases (without passing through zero Hz). If the string is shortened to 59.4 cm, what would be the beat frequency between the string's fundamental frequency and the note from the closed pipe which is still vibrating with 7 nodes?

   (a) 0 Hz.
   (b) 50 Hz.
   (c) 55.8 Hz.
   (d) None of the above.

   Answer: (d) The open pipe has 6 nodes so it is vibrating at its 6th harmonic at a frequency equal to 150 Hz times 6 i.e. 900 Hz. Since the closed pipe is vibrating with 4 nodes, it is at its 9th harmonic and its fundamental frequency is equal to 900 Hz divided by 9 i.e. 100 Hz. When the closed pipe has 7 nodes it is at its 15th harmonic, and therefore its frequency is then equal to 100 Hz times 15 i.e. 1,500 Hz. The beat frequency is 15 Hz, so the frequency of the string is either 1,500 Hz minus 15 Hz i.e. 1,485 Hz, or 1,500 Hz plus 15 Hz i.e. 1,515 Hz. On shortening the string, its frequency will increase so if the beat frequency decreases, the string's frequency must have been less than 1,500 Hz, i.e. its frequency was equal to 1,485 Hz. If the string was shortened from 61 cm to 59.4 cm, its fundamental frequency would then be equal to 1,485 times $\frac{61}{59.4}$ i.e. 1,525 Hz, and the beat frequency would thus be equal to 1,525 Hz minus 1,500 Hz i.e. 25 Hz.

7. A violinist tunes the A string of his violin by bowing it and then listens to the beats formed with the aid of an electronic tuner which produces a musical note with a frequency of 440 Hz.

The note from the open A string of the violin produces beats of 1 Hz when it combines with the note from the electronic tuner. He then loosens the A string of the violin, and as a result the beat frequency decreases (without passing through 0 Hz). Calculate the frequency of the open G string of the violin when the beat frequency was 1 Hz. (Assume that all the strings of the violin are tuned in relation to each other as is normal for a violin, when the beat frequency was 1 Hz.)

(a) 196 Hz.
(b) 195.56 Hz.
(c) 195.11 Hz.
(d) 194.67 Hz.

Answer: (a) Since the beat frequency was 1 Hz, the violin's A string's frequency was either 440 Hz minus 1 Hz i.e. 439 Hz, or 440 Hz plus 1 Hz i.e. 441 Hz. When the A string was loosened, the A string's frequency would have decreased, so its frequency must have been higher than 440 Hz i.e. it was at 441 Hz as the beat frequency had then decreased. The violin's G string's frequency is two Just fifths below the frequency of its A string, so the G string's frequency is equal to 441 Hz divided by $\frac{9}{4}$ i.e. 196 Hz.

8. A cello has its A string tuned to 220 Hz, and all its four strings are tuned relative to each other in Just fifths as is usual for a 'cello. An 88-key grand piano which is very slightly flat has all its strings tuned relative to each other in accordance with the Equal-tempered scale. When the A5 key of the piano is played, the A5 note combines with the fourth harmonic of the note from the 'cello's A string to produce beats of 3 Hz. Find the frequency of the highest note on the piano. (Assume that the Equal-tempered semitone has a ratio equal to 1.05946.)

   (a) 4,200.24 Hz.
   (b) 4,185.97 Hz.
   (c) 4,171.70 Hz.
   (d) None of the above.

   Answer: (c) or (d) The 'cello's A string has a frequency of 220 Hz, so the frequency of its fourth harmonic is equal to 220 Hz times 4 i.e. 880 Hz. Since the piano's A5 note produces 3 Hz beats on combining with this 4th harmonic, the frequency of the piano's A5 note is either 880 Hz minus 3 Hz i.e. 877 Hz, or 880 Hz plus 3 Hz i.e. 883 Hz. The piano is very slightly flat, so the frequency of the A5 note on the piano is equal to 877 Hz. The highest note on the piano is the note C8 which is two and one-quarter octaves above the A5 note. So its frequency is given by 877 Hz multiplied by 4 and multiplied by 1.05946 three times i.e. 4,171.70 Hz. It is not incorrect to start from 877 Hz and move up 27 semitones by multiplying 877 Hz by the ratio of a semitone 27 times. If we use a value of 1.05946 (as specified) for this procedure we obtain 4,171.41 Hz. Hence (d) is not incorrect using this method of calculating the frequency of C8.

9. According to a theory of consonance or dissonance between two different notes played together, 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. Considering just the first 12 harmonics of a note of fundamental frequency 40 Hz, how many of these harmonics are coincident with those of a note which is a Just third higher than 40 Hz?

   (a) Four harmonics.
   (b) Three harmonics.
   (c) Two harmonics.

(d) One harmonic.

Answer: (c) The first 12 harmonics of the 40 Hz note are as follows: 40 Hz, 80 Hz, 120 Hz, 160 Hz, 200 Hz, 240 Hz, 280 Hz, 320 Hz, 360 Hz, 400 Hz, 440 Hz and 480 Hz. We can obtain the frequency of the note a Just third higher than 40 Hz by multiplying 40 Hz by $\frac{5}{4}$ i.e. 50 Hz. The first 10 harmonics of the 50 Hz note are: 50 Hz, 100 Hz, 150 Hz, 200 Hz, 250 Hz, 300 Hz, 350 Hz, 400 Hz, 450 Hz and 500 Hz. Therefore two harmonics coincide at 200 Hz and 400 Hz.

10. Which of the following is the most appropriate description of a piano?

(a) Wind instrument.

(b) MIDI instrument.

(c) Electronic instrument.

(d) Percussion instrument.

Answer: (d) The piano produces its notes by causing hammers to beat on strings, so the piano can also be described as a percussion instrument. However, it is not a wind instrument, as no blowing is involved in the production of its sounds. It does not use electricity so it cannot be a MIDI or an electronic instrument.

11. The first and third levers of the action of a particular key on a Cristofori piano multiply the distance moved by the effort by factors of 1 and 4.8 times respectively. When this key is struck 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 40.8 cm/s. After the third lever is modified so that it multiplies the distance moved by 5.0 times instead of 4.8 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) 3.84 cm per second.

(b) 4 cm per second.

(c) 4.5 cm per second.

(d) None of the above.

Answer: (a) Acting together, the three levers have a combined multiplication factor equal to the speed of the hammer divided by the speed of the key i.e. 40.8 cm/s divided by 4 cm/s i.e. 10.2 times. The second lever by itself would therefore have a multiplication factor given by 10.2 times divided by 4.8 i.e. 2.125 times. After the third lever is modified to have a multiplication factor of 5.0 times instead of 4.8 times, the new combined multiplication factor for the three levers acting together will be equal to 2.125 times 5.0 i.e. 10.625 times. If the hammer is to move upwards at the same speed as before i.e. 40.8 cm per second, the downwards speed of the key must be equal to 40.8 cm per second divided by 10.625 i.e. 3.84 cm per second.

12. The soft pedal on the left, the sostenuto pedal in the middle and the sustain or loud pedal on the right on a certain grand piano are all functioning as normal. A pianist then plays a chord on the keyboard by depressing the appropriate keys simultaneously, and also by depressing one of these three pedals. Which of the following sequence of actions would 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 soft pedal and then releases the keys, and keeps the soft pedal depressed.

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

Answer: (b) 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 be sustained even when the keys have been released, but only as long as the sustain pedal remains depressed. The soft pedal when depressed has no effect on the sustaining of the notes played.

13. MIDI messages are sent to and from a notebook computer through a MIDI interface box which has a MIDI in IX and a MIDI out OX. An electronic keyboard which has only a MIDI in IK and a MIDI out OK is used by a songwriter to write a song by inputting the notes of the song into the notebook computer. After the song has been completed, it is to be performed on the electronic keyboard and an electronic organ which has a MIDI in IR, a MIDI out OR and a MIDI thru TR. Of the following connections, which one is a proper connection for the notebook computer, electronic keyboard and electronic organ to enable the song to be composed and performed as desired?

    (a) OR to IX.

    (b) OX to IK.

    (c) OK to IR.

    (d) TR to IK.

    Answer: (d) MIDI messages should be received by the notebook computer from the MIDI out OK of the electronic keyboard through the MIDI in IX of the MIDI interface box. In order for the completed piece of music to be performed, MIDI messages should be sent out by the notebook computer through OX to the electronic organ's MIDI in IR, and the same MIDI messages should be sent out of the electronic organ's MIDI thru TR to the electronic keyboard's MIDI in IK. It is not possible for the MIDI messages from the MIDI interface box to be sent directly to the electronic keyboard's MIDI in IK. This is due to the fact that the electronic keyboard does not have a MIDI thru to pass on the MIDI messages to the electronic organ.

14. The notes of a song are sent to an electronic synthesiser to be played. What is the correct sequence of numbers (in decimal form) for the program change MIDI message if the notes are to be played on the harmonica MIDI instrument using the highest numbered MIDI channel? (The program number for the harmonica in the GM instrument list is 23.)

    (a) 12, 0, 22.

    (b) 12, 15, 22.

    (c) 12, 15, 23.

    (d) None of the above.

    Answer: (b) The number in the first message is the number 12 for a MIDI program change; the second number is 15 for the highest MIDI channel; and the third number is 22 for the harmonica in the GM set.

15. An electronic synthesiser receives a MIDI message which tells it to turn on the musical note Gflat2 in the lowest numbered MIDI channel as quickly as possible. Which of the following is the correct sequence of numbers (in decimal form) for this MIDI message?

    (a) 9, 0, 30, 0.
    (b) 8, 0, 30, 127.
    (c) 9, 0, 42, 127.
    (d) None of the above.

    Answer: (c) For this MIDI message, the first number (in decimal) should be 9 to tell the electronic synthesizer to turn on a note; the second number should be 0 to tell the electronic synthesizer that the MIDI message is for the lowest numbered MIDI channel; the third number should be 42 to tell the electronic synthesizer that the note to be turned on is Gflat2; and the fourth number should be 127 to tell the electronic synthesizer to turn on the note as quickly as possible.

16. In the spectrum of the fundamental frequency of a closed pipe, the 6th line from the left has a frequency of 1,980 Hz. After a high pass filter removes all the harmonics of this note below the frequency 1,970 Hz, and a low pass filter removes all the harmonics above the frequency 2,690 Hz, which lines will remain in the spectrum?

    (a) Only the 6th and 7th lines from the left.
    (b) Only the 6th, 7th and 8th lines from the left.
    (c) Only the 4th, 5th and 6th lines from the left.
    (d) None of the above.

    Answer: (a) Since the note from the closed pipe has only odd harmonics in its spectrum, the 6th line from the left in its spectrum is its 11th harmonic, and the note's fundamental frequency is therefore equal to 1,980 Hz divided by 11 i.e. 180 Hz. The first 12 lines of the spectrum of this note will thus be its fundamental frequency and its 3rd, 5th, 7th, 9th, 11th, 13th, 15th, 17th, 19th, 21st and 23rd harmonics. The respective frequencies of these harmonics are: 180 Hz, 540 Hz, 900 Hz, 1,260 Hz, 1,620 Hz, 1,980 Hz, 2,340 Hz, 2,700 Hz, 3,060 Hz, 3,420 Hz, 3,780 Hz and 4,140 Hz. The high pass filter removes all the harmonics below 1,970 Hz leaving only the 11th and higher harmonics. The low pass filter removes all the frequencies which are above 2,690 Hz, so only the 11th and 13th harmonics i.e. the 6th and 7th lines from the left will remain in the spectrum of the note.

17. In one particular method for the synthesis of musical sounds, a musical waveform rich in harmonics is first generated. A number of these harmonics are then either removed or reduced in amplitude, so that what remains conforms to the relative proportions of the required harmonics in the musical sound to be synthesised. Give the usual name for this method of waveform synthesis.

    (a) Additive synthesis.
    (b) Subtractive synthesis.
    (c) Amplitude Modulation synthesis.
    (d) Frequency Modulation synthesis.

    Answer: (b) This method removes or subtracts all or a portion of the harmonics. Hence this method of synthesis is usually known as subtractive synthesis.

18. The musical sound of a particular musical instrument is being synthesised by the FM synthesis method. For this synthesis process, the frequency of the carrier waveform is 32,560 Hz and the frequency of the modulator waveform is 485 Hz. Of the following frequencies, which one is a valid frequency of one of the harmonics in the spectrum of the musical sound being generated?

    (a) 36,445 Hz.
    (b) 34,985 Hz.
    (c) 29,640 Hz.
    (d) 28,185 Hz.

    Answer: (b) Since the FM synthesis carrier frequency is 32,560 Hz and the modulator frequency is 485 Hz, the FM spectrum of the musical sound will have its harmonics separated from the carrier frequency by multiples of 485 Hz. The 10 harmonics which are just above 32,560 Hz are: 33,045 Hz, 33,530 Hz, 34,015 Hz, 34,500 Hz, 34,985 Hz, 35,470 Hz, 35,955 Hz, 36,440, 36,925 Hz and 37,410 Hz. The 10 harmonics just below 32,560 Hz are 32,075 Hz, 31,590 Hz, 31,105 Hz, 30,620 Hz, 30,135 Hz, 29,650 Hz, 29,165 Hz, 28,680 Hz, 28,195 Hz and 27,710 Hz. The frequency 34,985 Hz is thus the only valid frequency of one of the harmonics in the FM spectrum of this waveform.

19. The sampling rate of the digital recording of a concert by the NUS Chinese Orchestra is 38,386 samples per second. By the Nyquist criterion, what is the highest frequency of the concert which can be preserved by this digital recording?

    (a) 76,772 Hz.
    (b) 38,386 Hz.
    (c) 19,193 Hz.
    (d) None of the above.

    Answer: (c) By the Nyquist theorem or criterion, the sampling frequency or rate of the digital recording should be double that of the highest frequency to be preserved in the digital recording. The sampling rate of the digital recording is 38,386 samples per second, so the highest frequency to be preserved in the digital recording is half of this i.e. 19,193 Hz.

20. The number of quantization levels in the digital Internet telecast of a symphony orchestra concert is 16,384 levels. What is the signal to noise (S/N) ratio of this digital Internet telecast? (Assume that each bit of the sample bit length contributes 6 dB to the S/N ratio.)

    (a) 72 dB.
    (b) 78 dB.
    (c) 84 dB.
    (d) None of the above.

    Answer: (c) The symphony orchestra concert has 16,384 quantisation levels. Since 2^{14} is equal to 16,384, the number of bits in each digital sample of the digital telecast is 14 bits. Hence the S/N ratio is given by 14 bits times 6 i.e. 84 dB.

21. For the digital transmission of a jazz concert, the highest frequency to be preserved is 18,350 Hz, and the digital broadcasting equipment can support a digital transmission of at most 720,000 bits per second. Calculate the maximum possible bit length used for this digital transmission. (Assume that the digital recording is in stereo sound, with two audio channels of equal bit rates in the recording.)

    (a) 9 bits.

(b) 10 bits.
(c) 11 bits.
(d) None of the above.

Answer: (a) The sampling rate of the digital transmission must be double the highest frequency to be preserved which is 18,350 Hz i.e. 36,700 samples per second. Since the equipment for the digital transmission can support at most 720,000 bits per second, for each of the two stereo channels the bit rate is half of this i.e. 360,000 bits per second. Therefore the number of bits per sample for each channel is equal to 360,000 bits per second divided by 36,700 samples per second i.e. approximately 9.81 bits. However, the bit length has to be an integer so it is equal to 9 bits. A bit length of 10 bits would give a bit rate exceeding the maximum possible so the bit length is 9 bits.

22. The signal-to-noise or S/N ratio in the digital recording of an Indian orchestra concert is 72 dB. If highest frequency to be preserved in the digital recording is 19,450 Hz, what would be 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) 116,700 bits per second.
(b) 233,400 bits per second.
(c) 466,800 bits per second.
(d) None of the above.

Answer: (d) The Nyquist criterion says that the sampling rate for a digital recording has to be double the highest frequency to be preserved. Hence for the digital recording, the sampling rate is given by 19,450 Hz times 2 i.e. 38,900 samples per second. A signal-to-noise or S/N ratio of 72 dB means that the bit length of the digital samples is given by 72 dB divided by 6 dB i.e. 12 bits. Therefore the bit rate for each stereo channel is given by 38,900 samples per second times 12 bits, i.e. 466,800 bits per second. For two stereo channels the bit rate is double this i.e. 933,600 bits per second.

23. The highest frequency to be preserved in the digital recording of a pop concert is 17,355 Hz, and the signal-to-noise (S/N) ratio of the recording is to be 90 dB. It turns out that the resultant bit rate also happens to be the maximum possible bit rate of the digital recording equipment being used for the recording. The following evening, a folk music concert is digitally recorded at the same place, using the same digital recording equipment used for the pop concert. If the highest frequency to be preserved in the folk music concert is 19,240 Hz, what would be the highest signal-to-noise (S/N) ratio which is possible for the digital recording of the folk 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) 78 dB.
(c) 72 dB.
(d) None of the above.

Answer: (b) The sampling rate for the pop concert by the Nyquist criterion is double 17,355 Hz i.e. 34,710 samples per second. Since the bit length of the digital samples is equal to 90 dB divided by 6 dB i.e. 15 bits, the bit rate for a single audio channel is given by 34,710 samples per second times 15 bits i.e. 520,650 bits per second. This is also the maximum bit rate for each channel for the digital recording equipment, and for the folk music concert the sampling rate is equal to 19,240 Hz times 2 i.e. 38,480 samples per second. Therefore the bit length for the folk music concert is given by 520,650 bits per second divided by 38,480 samples per second i.e. approximately 13.53 bits. Since bit length must be an integer, the bit length is 13 bits since a bit length of 14 bits would result in a bit rate greater than the maximum possible bit rate. For a bit length of 13 bits the S/N ratio is given by 13 times 6 dB i.e. 78 dB.

24. You intend to digitally record on the hard disk of your notebook computer the broadcast of a symphony concert. The signal-to-noise (S/N) ratio of the digital recording is to be 78 dB, and the highest frequency to be preserved in the digital recording is 16,950 Hz. If the number of bytes available for recording on your computer's hard disk is 370,188,000 bytes, calculate how long the recording can be. (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) 56 miinutes.
    (b) 84 minutes.
    (c) 112 minutes.
    (d) None of the above.

    Answer: (a) By the Nyquist criterion, the sampling frequency of the digital recording is double 16,950 Hz, i.e. 33,900 samples per second. The number of bits for each sample for a signal-to-noise (S/N) ratio of 78 dB is equal to 78 dB divided by 6 dB i.e. 13 bits. Therefore for each audio channel, the number of bits per second is given by 33,900 samples per second times 13 bits i.e. 440,700 bits per second. The bit rate for two stereo channels is double this i.e. 881,400 bits per second. Therefore the length of time of the recording is given by 370,188,000 times 8 bits divided by 881,440 bits per second i.e. 3,360 seconds or 56 minutes.

25. The digital recording of a K-pop concert has its recording compressed into an MP3 file which has a bit rate of 128,000 bits per second and a signal-to-noise (S/N) ratio of 84 dB. If the highest frequency preserved in the original digital recording is 20,000 Hz, calculate the compression ratio for the compression of the original 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 digital recording.)

    (a) 4.375 to 1.
    (b) 8.75 to 1.
    (c) 17.5 to 1.
    (d) None of the above.

    Answer: (b) The sampling rate by the Nyquist criterion should be double the highest frequency 20,000 Hz to be preserved, i.e. 40,000 samples per second. Since the bit length of the samples is equal to 84 dB divided by 6 dB i.e. 14 bits, the bit rate of the uncompressed file was equal to 40,000 samples per second times 14 bits i.e. 560,000 bits per second. The bit rate is double this for two stereo channels i.e. 1,120,000 bits per second. The compression ratio is thus given by 1,120,000 bits per second to 128,000 bits per second i.e. 8.75 to 1.

END OF TEST PAPER