THE SCIENCE OF MUSIC (HSI2013)
End-of-Term Class Test, Semester 2, 2024/25

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 least appropriate example of a scientific or technological activity?

   (a) A flute player finding out how flute sounds from flutes made of different metal alloys differ in tone.

   (b) A clarinet player practising on a clarinet whose body is made of a new type of synthetic material.

   (c) An organist inventing a new type of organ pedal which is electronically activated.

   (d) A timpani player investigating how different types of drum skins affect the sound of his timpani.

   Answer: (b) The flute player, organist and timpani player are all performing essentially scientific or technological activities. The clarinet player is the only one performing an essentially musical activity.

2. The upper staff of a musical score of a piano piece starts with a treble clef and its lower staff starts with a bass clef. The key signature at the beginning of the score has three 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 of the chord written on the highest space of the four spaces of the upper staff. Of the following, which one is 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) $(\sqrt[12]{2})^{19}$.

   (b) $(\sqrt[12]{2})^{30}$.

   (c) $(\sqrt[12]{2})^{31}$.

   (d) None of the above.

   Answer: (c) Since the key signature of the piano piece has three flats, this means that all the notes named B, E and A in the piece should be played as B flat, E flat and A flat respectively. The lowest space of the lower staff is the note A2 which should be played as Aflat2, and the highest space of the upper staff is the note E5 which should be played as Eflat5. The interval from Aflat2 to Aflat4 is two octaves or 24 equal-tempered semitones, and the interval from Aflat4 to Eflat5 is 7 equal-tempered semitones. Hence the interval from Aflat2 to Eflat5 is 24 plus 7 i.e. 31 equal-tempered semitones, so the ratio of the interval between these two notes is equal to $(\sqrt[12]{2})^{31}$.

3. A girl walking in a park sings a musical note, and a man nearby then plays a note on his bassoon which is two octaves and a Just fifth below the girl's note. A soprano singer who is not far away hears the bassoon's note and sings a note which is four octaves and a Just third above the bassoon's note. If the soprano singer's note has a frequency of 1,760 Hz, what is the frequency of the note sung by the girl?

   (a) 736.875 Hz.

(b) 528 Hz.
(c) 165 Hz.
(d) None of the above.

Answer: (b) Since the soprano singer's note has a frequency of 1,760 Hz, the frequency of the note four octaves below is given by 1,760 Hz divided by 2 four times i.e. 110 Hz. The bassoon's note which is a Just third below 110 Hz is equal to 110 Hz times $\frac{4}{5}$ i.e. 88 Hz. The note two octaves above the note played by the bassoon therefore has a frequency equal to 88 Hz times 2 twice i.e. 352 Hz. The girl's note is higher than 352 Hz by a Just fifth so its frequency is equal to 352 Hz times $\frac{3}{2}$ i.e. 528 Hz.

4. The score of a piece of music for solo oboe has a time signature of 32/8 at the beginning, and a certain bar in this piece starts with three dotted crotchets and ends with 4 quavers and 8 semiquavers. Of the following combinations of notes, which one 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) 3 dotted quavers, 14 semiquavers and 10 demisemiquavers.
   (b) 2 crotchets, 18 demisemiquavers and 7 quavers.
   (c) A dotted minim, 8 quavers and 4 demisemiquavers.
   (d) 3 dotted crotchets, a minim and 5 semiquavers

   Answer: (c) The time signature of the piece is 32/8 so each bar of the piece must have the duration equivalent of 32 quavers or 64 semiquavers. The start of the bar has three dotted crotchets equivalent to 18 semiquavers, and the end of the bar has 4 quavers equivalent to 8 semiquavers and 8 semiquavers. Therefore the bar already has the equivalent of 34 semiquavers so the middle of the bar requires the equivalent of 30 semiquavers. A dotted minim is equivalent to 12 semiquavers, 8 quavers are equivalent to 16 semiquavers, and together with 4 demisemiquavers which are equivalent to 2 semiquavers make up a total of 30 semiquavers.

5. An open pipe labelled A is sliced into 7 short open pipes of equal length labelled A1, A2, A3, A4, A5, A6 and A7. A1, A2 and A3 are joined up and one end closed up to make a closed pipe labelled B. The short pipes A4, A5, A6 and A7 are joined up to make an open pipe labelled C. Of the following statements regarding the wavelengths of the notes generated by B and C, which one is true when B is vibrating with 4 nodes between its two ends (not counting the node at one end) and C is vibrating with 6 nodes between its two ends?

   (a) The wavelength of the note from B is 2 times longer than that from C.
   (b) The wavelength of the note from B is 2 times shorter than that from C.
   (c) The wavelength of the note from B is 3 times shorter than that from C.
   (d) None of the above.

   Answer: (d) Let the length of A be p cm and its fundamental frequency be f Hz. The fundamental frequency of an open pipe which is three-sevenths the length of A is given by f Hz times $\frac{7p}{3p}$ i.e. $\frac{7f}{3}$ Hz. Therefore the fundamental frequency of a closed pipe B of the same length will be half of this i.e. $\frac{7f}{6}$ Hz, and if B vibrates with 4 nodes it will be at its 9th harmonic. Its frequency will hence be equal to $\frac{7f}{6}$ Hz times 9 i.e. $\frac{63f}{6}$ Hz or $\frac{21f}{2}$ Hz. Since C is an open pipe four-sevenths the length of A, its fundamental frequency is equal to f Hz times $\frac{7p}{4p}$ i.e. $\frac{7f}{4}$ Hz, and when C vibrates with 6 nodes it will be at its 6th harmonic. Its frequency will thus be given by $\frac{7f}{4}$ Hz times 6 i.e. $\frac{21f}{2}$ Hz. The ratio of the frequencies of the notes from

B and C is thus equal to $\frac{21f}{2}$ Hz divided by $\frac{21f}{2}$ Hz i.e. 1 to 1. Since frequency is inversely proportional to wavelength, the ratio of the wavelengths of the notes from B and C is thus 1 to 1 i.e. the wavelength of the note from B is the same as that from C.

6. A closed pipe vibrating with 3 antinodes (not counting the antinode at one end) has the same frequency as that of a string vibrating with 5 nodes between its two ends (not counting the nodes at both ends). When the closed pipe is vibrating at its fundamental frequency, the 3rd line from the left in its spectrum corresponds to a frequency from a sound wave in the air with a wavelength of exactly 1.1 metres. What is the fundamental frequency of the string? (Assume the velocity of sound in air is 330 m/s.)

   (a) 60 Hz.
   (b) 70 Hz.
   (c) 600 Hz.
   (d) None of the above.

   Answer: (b) The frequency corresponding to the 3rd line or 5th harmonic in the spectrum of the closed pipe vibrating at its fundamental frequency has a value given by $\frac{330}{1.1}$ i.e. 300 Hz. The fundamental frequency of the closed pipe is therefore equal to 300 Hz divided by 5 i.e. 60 Hz. When the closed pipe vibrates with 3 antinodes it is at its 7th harmonic, and its frequency will be 60 Hz times 7 i.e. 420 Hz. The string has 5 nodes and 6 antinodes and is thus vibrating at its 6th harmonic, so its fundamental frequency is given by 420 Hz divided by 6 i.e. 70 Hz.

7. An open pipe has a fundamental frequency of 300 Hz. When it vibrates with 6 nodes between its two ends, it has the same frequency as that of a closed pipe vibrating with 7 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 14 Hz are produced when it combines with a string 43 cm long vibrating at its fundamental frequency. When the string is shortened slightly, the beat frequency decreases (without passing through zero Hz). If the string is shortened to 41.3 cm, what would be the beat frequency when the string's fundamental frequency combines with the note from the closed pipe which is still vibrating with 3 nodes?

   (a) 20 Hz.
   (b) 24 Hz.
   (c) 48 Hz.
   (d) None of the above.

   Answer: (a) The open pipe has 6 nodes so it is vibrating at its 6th harmonic, and hence its frequency is given by 300 Hz times 6 i.e. 1,800 Hz. Since the closed pipe is vibrating with 7 nodes, it is at its 15th harmonic and its fundamental frequency must be given by 1,800 Hz divided by 15 i.e. 120 Hz. When the closed pipe has 3 nodes it is at its 7th harmonic and its frequency must then be equal to 120 Hz times 7 i.e. 840 Hz. As the beat frequency is 14 Hz, the frequency of the string is either 840 Hz minus 14 Hz i.e. 826 Hz, or 840 Hz plus 14 Hz i.e. 854 Hz. If the string is shortened, its frequency will increase so if the beat frequency decreases, the string's frequency must have been less than 840 Hz. Hence its frequency was equal to 826 Hz. If the string was shortened from 43 cm to 41.3 cm, its fundamental frequency would become 826 times $\frac{43}{41.3}$ i.e. 860 Hz. The beat frequency will thus become 860 Hz minus 840 Hz i.e. 20 Hz.

8. A violin player tunes the A string of his violin by using his bow to set the string into vibration, aided by an electronic tuner producing a musical note with a frequency of 440 Hz. When the note from the open A string of the violin combines with the note from the electronic tuner,

beats of 4 Hz are produced. When the A string of the violin is loosened while the A string was still being played with the bow, the beat frequency increases (without passing through 0 Hz). Of the following frequencies, which one is closest to the frequency of the open E string of the violin when the beat frequency was 4 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 4 Hz.)

(a) 672 Hz.

(b) 664 Hz.

(c) 660 Hz.

(d) 654 Hz.

Answer: (d) Since the beat frequency was 4 Hz, the violin's A string's frequency was either 440 Hz minus 4 Hz i.e. 436 Hz, or 440 Hz plus 4 Hz i.e. 444 Hz. The string's frequency would have decreased when the A string was loosened, so its frequency must have been lower than 440 Hz i.e. at 436 Hz as the beat frequency had then increased. The violin's E string's frequency is a Just fifth above the frequency of its A string, so the E string's frequency is given by 436 Hz multiplied by $\frac{3}{2}$ i.e. 654 Hz.

9. A grand piano has all its strings tuned relative to each other in accordance with the Equal-tempered scale, but the piano is very slightly flat. The A string of a violin is tuned to 440 Hz, and all its four strings are tuned relative to each other in Just fifths as is normal for a violin. An organist plays the Csharp7 key of the piano, and the Csharp7 note combines with the fifth harmonic of the note from the violin's A string to produce beats of 3 Hz. Which of the following frequencies is closest to the fundamental frequency of the E7 note on the piano? (Assume that the Equal-tempered semitone has a ratio equal to 1.05946.)

   (a) 2,768.0 Hz.

   (b) 2,619.8 Hz.

   (c) 2,612.7 Hz.

   (d) 2,472.8 Hz.

   Answer: (c) The violin's A string has a frequency of 440 Hz so the frequency of its fifth harmonic is given by 440 Hz times 5 i.e. 2,200 Hz. Since the piano's Csharp7 note produces 3 Hz beats on combining with this 5th harmonic, the frequency of the piano's Csharp7 note is either 2,200 Hz minus 3 Hz i.e. 2,197 Hz, or 2,200 Hz plus 3 Hz i.e. 2,203 Hz. Since the piano is very slightly flat, the frequency of the Csharp7 note on the piano must be 2,197 Hz. The note E7 is 3 semitones above Csharp7, so its frequency is given by 2,197 Hz multiplied by 1.05946 three times i.e. approximately 2,612.7 Hz.

10. A theory of consonance or dissonance between two different notes played together explains that it 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 75 Hz, how many of these harmonics are coincident with those of a note which is a Just sixth higher than 75 Hz?

    (a) One harmonic.

    (b) Two harmonics.

    (c) Three harmonics.

    (d) Four harmonics.

Answer: (b) The first 12 harmonics of the 75 Hz note are as follows: 75 Hz, 150 Hz, 225 Hz, 300 Hz, 375 Hz, 450 Hz, 525 Hz, 600 Hz, 675 Hz, 750 Hz, 825 Hz and 900 Hz. Going up a Just sixth higher than 75 Hz means multiplying 75 Hz by $\frac{5}{3}$ i.e. 125 Hz. The first 8 harmonics of the 125 Hz note are: 125 Hz, 250 Hz, 375 Hz, 500 Hz, 625 Hz, 750 Hz, 875 Hz and 1,000 Hz. Therefore two harmonics coincide at 375 Hz and 750 Hz.

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

    (a) Keyboard instrument.

    (b) Wind instrument.

    (c) MIDI instrument.

    (d) Instrument using a mouthpiece.

    Answer: (a) As a piano player uses a keyboard, the piano can be described as a keyboard instrument. However, it is not a wind instrument, as no blowing is involved in the production of its sounds, and it certainly does not use a mouthpiece. It is also not an electronic or MIDI instrument.

12. The action of a certain Cristofori piano has the first and third levers of a particular key on the keyboard multiplying the distance moved by the effort by factors of 1 and 4.5 times respectively. When this key is struck with a downwards speed of 5 cm per second, the first, second and third levers of this key will cause the corresponding hammer to move upwards with a speed of 54 cm per second. The third lever is then changed such that it multiplies the distance moved by 5.0 times instead of 4.5 times. Calculate the new downwards speed of the key required to enable the hammer to move upwards with the same speed as before.

    (a) 5.0 cm per second.

    (b) 4.5 cm per second.

    (c) 4.2 cm per second.

    (d) None of the above.

    Answer: (b) The speed of the hammer divided by the speed of the key is 54 cm per second divided by 5 cm per second i.e. 10.8 times, so the three levers together have a combined multiplication factor of 10.8 times. The second lever by itself would thus have a multiplication factor equal to 10.8 times divided by 4.5 i.e. 2.4 times. After the third lever has been modified to have a multiplication factor of 5.0 times instead of 4.5 times, the combined multiplication factor for the three levers acting together will be equal to 2.4 times 5.0 i.e. 12 times. For the hammer to move upwards at the same speed as before i.e. 54 cm per second, the downwards speed of the key must be equal to 54 cm per second divided by 12 i.e. 4.5 cm per second.

13. The soft pedal on the left, the sostenuto pedal in the middle and the sustain or loud pedal on the right on a particular grand piano are functioning normally. When a pianist plays a chord on the keyboard by depressing the appropriate keys simultaneously, she also depresses 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 depressing the sostenuto pedal.

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

    (c) The pianist depresses the keys, then depresses the sostenuto pedal and then releases the keys, and keeps depressing the sostenuto pedal.

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

Answer: (c) 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 and the notes will thus be sustained even when the keys have been released, as long as the sustain pedal remains depressed.

14. A MIDI interface box which has a MIDI in IX and a MIDI out OX enables a notebook computer to send and receive MIDI messages. A songwriter uses an electronic keyboard with only a MIDI in IK and a MIDI out OK to write a song by inputting the notes of the song into the computer. When the song is 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. Which of the following connections is a proper connection for the notebook computer, electronic keyboard and electronic organ to enable the composer to compose and then perform the song as desired?

(a) OR to IX.

(b) OX to IK.

(c) OR to IK.

(d) TR to IK.

Answer: (d) MIDI messages are received by the notebook computer from the MIDI out OK of the electronic keyboard through the MIDI in IX of the MIDI interface box. For the completed song to be performed, MIDI messages should be sent out by the notebook computer through OX to the electronic organ's MIDI in IR, and then 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 because the electronic keyboard does not have a MIDI thru to pass on the MIDI messages to the electronic organ.

15. An electronic keyboard receives a MIDI message telling the keyboard to turn on the musical note D5 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, 74, 127.

(b) 9, 15, 74, 127.

(c) 9, 0, 62, 127.

(d) None of the above.

Answer: (a) For this MIDI message, the first number (in decimal) should be 9 which tells the electronic keyboard to turn on a note; the second number should be 0 which tells the electronic keyboard that the MIDI message is for the lowest numbered MIDI channel; the third number should be 74 which tells the electronic keyboard that the note to be turned on is D5; and the fourth number which tells the electronic keyboard to turn on the note as quickly as possible should be 127.

16. In the spectrum of the fundamental frequency produced by a closed pipe, the 6th line from the left has a frequency of 1,430 Hz. If a low pass filter removes all the harmonics of this note above the frequency 2,720 Hz, and a high pass filter removes all the harmonics below the frequency 1,695 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 9th and 10th lines from the left.
(b) Only the 9th, 10th and 11th lines from the left.
(c) Only the 7th, 8th and 9th lines from the left.
(d) None of the above.

Answer: (d) Since the note from the closed pipe has only odd harmonics in its spectrum, the 6th line from the left in its spectrum will be its 11th harmonic, and hence the note's fundamental frequency is given by 1,430 Hz divided by 11 i.e. 130 Hz. The first 13 lines of the spectrum of the note will be its fundamental frequency and its 3rd, 5th, 7th, 9th, 11th, 13th, 15th, 17th 19th, 21st, 23rd and 25th harmonics, whose respective frequencies are: 130 Hz, 390 Hz, 650 Hz, 910 Hz, 1,170 Hz, 1,430 Hz, 1,690 Hz, 1,950 Hz, 2,210 Hz, 2,470 Hz, 2,730 Hz, 2,990 Hz and 3,250 Hz. The low pass filter removes all the harmonics above 2,720 Hz, so only the 19th and lower harmonics remain. The high pass filter removes all the frequencies which are below 1,695 Hz, so only the 15th, 17th and 19th harmonics i.e. the 8th, 9th and 10th lines from the left will remain in the spectrum of the note.

17. One particular method for the generation or synthesis of musical sounds first generates a waveform which is rich in harmonics. Some of the harmonics are then reduced or removed to create a spectrum similar to that of the desired waveform. Which of the following is the usual name for this method of waveform generation?

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

Answer: (b) This method reduces or removes some of the required harmonics of a waveform rich in harmonics, so this method of generation or synthesis is known as subtractive synthesis.

18. The musical sound of a certain musical instrument is being synthesised using the FM synthesis method. For this synthesis, the carrier waveform has a frequency of 18,900 Hz and the modulator waveform has a frequency of 455 Hz. Of the following frequencies, which one is a valid frequency of one of the harmonics in the spectrum of the waveform being generated?

(a) 14,805 Hz.
(b) 18,455 Hz.
(c) 20,260 Hz.
(d) 22,985 Hz.

Answer: (a) Since the FM synthesis carrier frequency is 18,900 Hz and the modulator frequency is 455 Hz, the harmonics of the FM spectrum will differ from the carrier frequency by multiples of 455 Hz. The 10 harmonics which are just above 18,900 Hz are: 19,355 Hz, 19,810 Hz, 20,265 Hz, 20,720 Hz, 21,175 Hz, 21,630 Hz, 22,085 Hz, 22,540, 22,995 Hz and 23,450 Hz. The 10 harmonics just below 18,900 Hz are 18,445 Hz, 17,990 Hz, 17,535 Hz, 17,080 Hz, 16,625 Hz, 16,170 Hz, 15,715 Hz, 15,260 Hz, 14,805 Hz and 14,350 Hz. Therefore only the frequency 14,805 Hz is a valid frequency of one of the harmonics in the FM spectrum of this waveform.

19. In the digital telecast of a concert by the Singapore Symphony Orchestra over the Internet, the highest frequency of the concert to be preserved of the digital broadcast is 17,885 Hz. Calculate the sampling rate of this digital transmission by the Nyquist criterion.

(a) 8,942.5 samples per second.

(b) 17,800 samples per second.
(c) 35,770 samples per second.
(d) None of the above.

Answer: (c) By the Nyquist theorem or criterion, the sampling frequency or rate of the transmission should be double that of the highest frequency to be preserved in the transmission. Therefore since the highest frequency in the concert to be preserved is 17,885 Hz, the sampling rate is double this i.e. 35,770 samples per second.

20. A Chinese orchestra concert is being digitally broadcast with a signal to noise (S/N) ratio of 84 dB. Calculate the number of quantization levels in this digital recording. (Assume that each bit of the sample bit length contributes 6 dB to the S/N ratio.)

(a) 32,768.
(b) 16,384.
(c) 8,192.
(d) None of the above.

Answer: (b) The Chinese orchestra concert has a S/N ratio of 84 dB, so the number of bits in each sample is 84 divided by 6 i.e. 14 bits. Since 2^{14} is equal to 16,384, there must be 16,384 quantization levels in the digital recording.

21. 17,350 Hz is the highest frequency to be preserved in the digital recording of a symphony concert and the digital recording equipment on which the recording is being made can support at most 780,000 bits per second. What is the best 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) 84 dB.
(b) 78 dB.
(c) 72 dB.
(d) None of the above.

Answer: (d) The highest frequency to be preserved in the recording is 17,350 Hz, so the sampling rate is double this i.e. 34,700 samples per second. Since the digital recording can support no more than 780,000 bits per second, for each of the two stereo channels the bit rate is half of this i.e. 390,000 bits per second. Therefore the number of bits per sample for each channel is equal to 390,000 bits per second divided by 34,700 samples per second i.e. approximately 11.24 bits. However, the bit length has to be 11 bits because a bit length of 12 bits would give a bit rate greater than 390,000 bits per second. For a bit length of 11 bits, the S/N ratio is equal to 6 dB times 11 bits i.e. 66 dB.

22. If the highest frequency to be preserved in the digital recording of a jazz concert is 18,255 Hz and the signal-to-noise or S/N ratio is 72 dB, what is the bit rate of this 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) 438,120 bits per second.
(b) 803,220 bits per second.
(c) 876,240 bits per second.

(d) None of the above.

Answer: (c) The Nyquist criterion says that the sampling rate for a digital recording is double the highest frequency to be preserved. The sampling rate for the digital recording is thus equal to 18,255 Hz times 2 i.e. 36,510 samples per second. Since the signal-to-noise or S/N ratio is 72 dB, the bit length of the digital samples is equal to 72 dB divided by 6 dB i.e. 12 bits. Therefore the bit rate for each stereo channel is given by 36,510 samples per second times 12 bits, i.e. 438,120 bits per second. For two stereo channels the bit rate is double this i.e. 876,240 bits per second.

23. The highest frequency to be preserved in the digital recording of a jazz music concert is 18,650 Hz, and the signal-to-noise (S/N) ratio of the recording is to be 84 dB. The resultant bit rate is also the maximum possible bit rate of the digital recording equipment used for the recording. The next evening, a folk music concert is digitally recorded at the same place using the same digital recording equipment used for the jazz music concert. If the highest frequency to be preserved in the folk music concert is 17,150 Hz, what is 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) 90 dB.
    (b) 84 dB.
    (c) 78 dB.
    (d) None of the above.

    Answer: (a) The sampling rate by the Nyquist criterion is double 18,650 Hz i.e. 37,300 samples per second. Since the bit length of the digital samples is equal to 84 dB divided by 6 dB i.e. 14 bits, the bit rate for a single audio channel is given by 37,300 samples per second times 14 bits i.e. 522,200 bits per second. This is also the maximum bit rate for each channel for the digital recording equipment. For the folk music concert the sampling rate is equal to 17,150 Hz times 2 i.e. 34,300 samples per second. Therefore the bit length for the folk music concert is given by 522,200 bits per second divided by 34,300 samples per second i.e. approximately 15.22 bits. However, bit length must be an integer, so the bit length is 15 bits, as a bit length of 16 bits would give a bit rate greater than the maximum possible bit rate. For a bit length of 15 bits we obtain a S/N ratio equal to 15 times 6 dB i.e. 90 dB for the folk music concert.

24. The performance of a symphony concert which is 35 minutes long is to be recorded digitally on the hard disk of your desktop computer, and the highest frequency to be preserved in the digital recording is 15,600 Hz. If the signal-to-noise (S/N) ratio for the recording is to be 78 dB, calculate 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) 26,617,500 bytes.
    (b) 212,940,000 bytes.
    (c) 1,703,520,000 bytes.
    (d) None of the above.

    Answer: (b) Using the Nyquist criterion, the sampling frequency of the digital recording is double 15,600 Hz, i.e. 31,200 samples per second. Since the signal-to-noise (S/N) ratio is 78 dB, the number of bits for each sample is given by 78 dB divided by 6 i.e. 13 bits. Therefore for each audio channel, the number of bits per second is equal to 31,200 samples per second times 13 bits i.e. 405,600 bits per second, and for two stereo channels the bit rate is double this i.e. 811,200 bits per second. To record 35 minutes on the computer, the amount of memory needed is given by 811,200 bits per second times 60 seconds per minute times 35 minutes i.e. 1,703,520,000 bits, which after division by 8 is equal to 212,940,000 bytes.

25. The digital recording of a jazz concert is compressed into an MP3 file which has a bit rate of 128,000 bits per second. Its signal-to-noise (S/N) ratio is 72 dB, and the highest frequency preserved in the original digital recording is 16,800 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 rate, 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) 12.6 to 1.
    (b) 7.5 to 1.
    (c) 6.3 to 1.
    (d) None of the above.

    Answer: (c) The highest frequency to be preserved is 16,800 Hz, so the sampling rate must be double this i.e. 33,600 samples per second. Since the bit length of the samples is 72 dB divided by 6 dB i.e. 12 bits, the bit rate of the uncompressed file is 33,600 samples per second times 12 bits i.e. 403,200 bits per second. For two stereo channels the bit rate is double this i.e. 806,400 bits per second. The compression ratio is therefore given by 806,400 bits per second to 128,000 bits per second i.e. 6.3 to 1.

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