THE SCIENCE OF MUSIC (HSI2013)
End-of-Term Class Test, Semester 2, 2023/24

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 science or technology in music?

   (a) An oboe player performing on a new type of oboe whose mouthpiece contains an electronic chip to monitor the player's breath.

   (b) A viola player playing a viola with a viola bow which is made of a new type of material using both wood and metal.

   (c) A brass instrument maker inventing a new type of brass instrument which can produce both brass and woodwind sounds by changing the mouthpiece.

   (d) A trumpet player rehearsing on a new type of trumpet whose valves are activated electronically rather than physically.

   Answer: (c) The oboe player, viola player and trumpet player are performing essentially musical activities. The brass instrument maker is the only one performing an essentially technological activity.

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

   (a) $(\sqrt[12]{2})^{24}$.

   (b) $(\sqrt[12]{2})^{25}$.

   (c) $(\sqrt[12]{2})^{27}$.

   (d) None of the above.

   Answer: (d) Since the key signature of the piano piece has five flats, this means that all the notes named B, E, A, D and G in the piano piece must be played as B flat, E flat, A flat, D flat and G flat respectively. The lowest line of the lower staff is the note G2 which should be played as Gflat2, and the second lowest space of the upper staff is the note A4, which should be played as Aflat4. The interval from Gflat2 to Gflat4 is two octaves or 24 equal-tempered semitones, and the interval from Gflat4 to Aflat4 is 2 equal-tempered semitones. Thus the interval from Gflat2 to Aflat4 is 24 plus 2 i.e. 26 Equal-tempered semitones, which means that the ratio of the interval between these two notes is equal to $(\sqrt[12]{2})^{26}$.

3. A flute player strolling in a park plays a musical note on her flute. A man nearby then plays a note on his bassoon which is four octaves and a Just fourth below the flute's note. A woman who is just passing by hears the bassoon's note and sings a note which is three octaves and a Just second above the bassoon's note. If the note played by the flute player has a frequency of 1,768 Hz, which of the following gives the frequency of the note sung by the woman?

(a) 745.875 Hz.
(b) 828.75 Hz.
(c) 1,491.75 Hz.
(d) None of the above.

Answer: (a) Since the flute player's note has a frequency of 1,768 Hz, the frequency of the note four octaves below is equal to 1,768 Hz divided by 2 four times i.e. 110.5 Hz. Therefore the frequency of the bassoon's note which is a Just fourth below 110.5 Hz is given by 110.5 Hz times $\frac{3}{4}$ i.e. 82.875 Hz. The note three octaves above the note played by the bassoon thus has a frequency given by 82.875 Hz times 2 three times which gives 663 Hz. The woman's note is higher than 663 Hz by a Just second so its frequency is given by 663 Hz times $\frac{9}{8}$ i.e. 745.875 Hz.

4. The time signature at the beginning of a piece of music for solo voice is 24/8, and a particular bar in the piece starts with 3 dotted quavers and ends with a crotchet and 6 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) 10 quavers and 16 demisemiquavers.
   (b) 2 dotted crotchets, 4 quavers and 18 demisemiquavers.
   (c) A dotted minim, 6 quavers and 12 demisemiquavers.
   (d) None of the above.

   Answer: (b) The time signature of the piece is 24/8, so each bar of the piece requires the duration equivalent of 24 quavers or 48 semiquavers. At the beginning of the bar there are 3 dotted quavers equivalent to 9 semiquavers, and at the end of the bar there is a crotchet equivalent to 4 semiquavers and 6 semiquavers. Therefore the bar already has the equivalent of 19 semiquavers, and hence the middle of the bar requires the equivalent of 29 semiquavers. Two dotted crotchets are equivalent to 12 semiquavers, 4 quavers are equivalent to 8 semiquavers, and together with 18 demisemiquavers which are equivalent to 9 semiquavers make up a total of 29 semiquavers.

5. An open pipe labelled A is sliced into 8 short open pipes of equal length labelled A1, A2, A3, A4, A5, A6, A7 and A8. A6, A7 and A8 are joined up and one end closed up to make a closed pipe labelled B and A1, A2, A3, A4 and A5 are joined up to make an open pipe labelled C. Which of the following statements concerning the wavelengths generated by B and C 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 3 nodes between its two ends?

   (a) The wavelength of the note from C is 2 times shorter than that from B.
   (b) The wavelength of the note from C is 2 times longer than that from B.
   (c) The wavelength of the note from C is 2.5 times longer than that from B.
   (d) None of the above.

   Answer: (c)Let the fundamental frequency of A be f Hz and let its length be p cm. The fundamental frequency of an open pipe which is three-eighths the length of A is equal to f Hz times $\frac{8p}{3p}$ i.e. $\frac{8f}{3}$ Hz. The fundamental frequency of the closed pipe B of the same length will thus be half of this i.e. $\frac{8f}{6}$ Hz or $\frac{4f}{3}$ Hz. If B vibrates with 4 nodes it will be at its 9th harmonic and its frequency will be equal to $\frac{4f}{3}$ Hz times 9 i.e. $12f$ Hz. The fundamental frequency of C which is an open pipe five-eighths the length of A is equal to f Hz times $\frac{8p}{5p}$ i.e. $\frac{8f}{5}$ Hz. If

C vibrates with 3 nodes it will be at its 3rd harmonic and its frequency will be equal to $\frac{8f}{5}$ Hz times 3 i.e. $\frac{24f}{5}$ Hz. The ratio of the frequencies of the notes from B and C is thus $12f$ divided by $\frac{24f}{5}$ i.e. $\frac{5}{2}$. Since frequency is inversely proportional to wavelength, the ratio of the wavelengths of the notes from B and C is thus $\frac{2}{5}$ i.e. the wavelength of the note from C is 2.5 times longer than the note from B . Therefore statement (c) is true.

6. A closed pipe which has 6 nodes between its two ends (not counting the node at one end) is vibrating at a frequency of 2,600 Hz. When the closed pipe vibrates with 4 nodes between its two ends (not counting the node at one end), its frequency is the same as that of an open pipe vibrating with 5 nodes between its two ends. Calculate the frequency of the 12th line from the left in the spectrum of the open pipe when it vibrates at its fundamental frequency. (The spectrum shows the fundamental frequency and harmonics of the open pipe as vertical lines with the frequency increasing from left to right.)

   (a) 1,440 Hz.
   (b) 3,360 Hz.
   (c) 4,320 Hz.
   (d) None of the above.

   Answer: (c) The closed pipe must be vibrating at its 13th harmonic since it has 6 nodes. Therefore its fundamental frequency is equal to 2,600 Hz divided by 13 i.e. 200 Hz, and when the closed pipe vibrates with 4 nodes it is at its 9th harmonic. The closed pipe's frequency is therefore given by 200 Hz times 9 i.e. 1,800 Hz. Since the open pipe has 5 nodes, it is at its 5th harmonic. Therefore its fundamental frequency is given by 1,800 Hz divided by 5 i.e. 360 Hz. The 12th line from the left in the spectrum of the open pipe when it is vibrating at its fundamental frequency is its 12th harmonic, so the frequency of the 12th line is equal to 360 Hz times 12 i.e. 4,320 Hz.

7. An open pipe which has a fundamental frequency of 140 Hz is vibrating with 6 nodes between its two ends. The open pipe is vibrating with the same frequency as that of a closed pipe vibrating with 3 nodes between its two ends (not counting the node at one end). When the closed pipe vibrates with 4 nodes between its two ends, beats of 12 Hz are produced when it combines with a string 27.5 cm long vibrating at its fundamental frequency. When the string is slightly shortened, the beat frequency decreases (without passing through zero Hz). If the string is shortened to 26.7 cm, what is the beat frequency when the string's fundamental frequency combines with the note from the closed pipe which is still vibrating with 4 nodes?

   (a) 20 Hz.
   (b) 32 Hz.
   (c) 45 Hz.
   (d) None of the above.

   Answer: (a) The open pipe has 6 nodes, so it is vibrating at its 6th harmonic with a frequency equal to 140 Hz times 6 i.e. 840 Hz. Since the closed pipe has 3 nodes, it is at its 7th harmonic and its fundamental frequency is thus given by 840 Hz divided by 7 i.e. 120 Hz. When the closed pipe vibrates with 4 nodes, it must be at its 9th harmonic and its frequency must be equal to 120 Hz times 9 i.e. 1,080 Hz. Since the beat frequency is 12 Hz, the frequency of the string is either 1,080 Hz minus 12 Hz i.e. 1,068 Hz, or 1,080 Hz plus 12 Hz i.e. 1,092 Hz. On shortening the string, its frequency will increase so if the beat frequency decreases, the string's frequency must have been less than 1,080 Hz, so the string's frequency was equal to 1,068 Hz. If the string is shortened from 27.5 cm to 26.7 cm, its fundamental frequency will become 1,068

Hz times $\frac{27.5}{26.7}$ i.e. 1,100 Hz. The beat frequency will thus become 1,100 Hz minus 1,080 Hz i.e. 20 Hz.

8. With the aid of an electronic tuner producing a musical note with a frequency of 220 Hz, a 'cello player is tuning the A string of her 'cello by using her bow to set the string into vibration. The note from the open A string of the 'cello combines with the note from the electronic tuner to produce beats of 2 Hz. When the 'cello player loosens the A string of her 'cello while she is still playing the A string with her bow, the frequency of the beats increases to 3 Hz (without passing through 0 Hz). Of the following frequencies, which one is closest to the frequency of the open G 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) 98.67 Hz.
   (b) 97.78 Hz.
   (c) 96.89 Hz.
   (d) 95.11 Hz.

   Answer: (c) Since the beat frequency was 2 Hz, 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. On loosening the A string, its frequency would have decreased. Therefore its frequency must have been lower than 220 Hz since the beat frequency increased to 3 Hz, and hence the A string's frequency was equal to 218 Hz. Since the 'cello's G string's frequency is two Just fifths below the frequency of its A string, the G string's frequency is given by 218 Hz divided by $\frac{3}{2}$ two times i.e. approximately 96.889 Hz.

9. A grand piano has all its strings tuned relative to each other in accordance with the Equal-tempered scale. However, the piano is very slightly flat. The A string of a violin is tuned to 440 Hz, and its four strings are tuned relative to each other in Just fifths as is normal for a violin. When a pianist plays the Csharp7 key of the piano, the Csharp7 note produced combines with the fifth harmonic of the note from the violin's A string to produce beats of 3 Hz. Of the following frequencies, which is closest to the fundamental frequency of the G6 note on the piano? (Assume that the Equal-tempered semitone has a ratio equal to 1.05946.)

   (a) 1,553.54 Hz.
   (b) 1,557.78 Hz.
   (c) 1,645.91 Hz.
   (d) 1,650.41 Hz.

   Answer: (a) The violin's A string has a frequency of 440 Hz, which means that the frequency of its fifth harmonic is equal to 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 is most likely to be 2,197 Hz. The note G6 is 6 semitones below Csharp7, so its frequency is equal to 2,197 Hz divided by 1.05946 six times i.e.approximately 1,553.54 Hz.

10. Consonance or dissonance between two different notes played together is sometimes explained by the degree to which the harmonics of one note coincide with the harmonics of the other note. If we consider only the first 10 harmonics of a note of fundamental frequency 48 Hz, how many of these harmonics are coincident with those of a note which is a Just sixth higher than 48 Hz?

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

Answer: (a) The first 10 harmonics of the 48 Hz note are as follows: 48 Hz, 96 Hz, 144 Hz, 192 Hz, 240 Hz, 288 Hz, 336 Hz, 384 Hz, 432 Hz and 480 Hz. The frequency of the note which is a Just sixth higher than 48 Hz is equal to 48 Hz times $\frac{5}{3}$ i.e. 80 Hz. The first 6 harmonics of the 80 Hz note are: 80 Hz, 160 Hz, 240 Hz, 320 Hz, 400 Hz and 480 Hz. Therefore just two harmonics coincide at 240 Hz and 480 Hz.

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

(a) MIDI instrument.
(b) Keyboard instrument.
(c) Electronic instrument.
(d) Wind instrument.

Answer: (b) As a piano player uses a keyboard, the piano can be described as a keyboard instrument. It is however not a MIDI nor an electronic instrument, as a piano does not use electricity. It is also not a wind instrument, as no blowing is involved in the production of its sounds.

12. The action of a particular 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 5.4 times respectively. When this key is struck with a downwards speed of 5.4 cm per second, the first, second and third levers of this key will act together, causing the corresponding hammer to move upwards with a speed of 58.32 cm per second. A modification is then made to the third lever such that it multiplies the distance moved by 5 times instead of 5.4 times. Calculate the new downwards speed of the key which is required in order to maintain the same upwards speed of the hammer as before.

(a) 2.916 cm per second.
(b) 4.860 cm per second.
(c) 5.832 cm per second.
(d) None of the above.

Answer: (c) The speed of the hammer divided by the speed of the key is equal to 58.32 cm per second divided by 5.4 cm per second i.e. 10.8 times. Hence the three levers together have a combined multiplication factor of 10.8 times, and the second lever by itself has a multiplication factor given by 10.8 times divided by 5.4 i.e. 2 times. After the third lever has been modified so that it has a multiplication of 5 times instead of 5.4 times, the combined multiplication factor for the three levers acting together will become 2 times 5 i.e. 10 times. For the hammer to move upwards at the same speed as before i.e. 58.32 cm per second, the downwards speed of the key will be given by 58.32 cm per second divided by 10 i.e. 5.832 cm per second.

13. The soft pedal on the left, sostenuto pedal in the middle and the sustain or loud pedal on the right are all functioning as usual on a grand piano. A pianist plays a couple of notes on the keyboard by depressing the appropriate keys together. She also presses 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 keys, then depresses the sustain pedal and then releases the keys as well as the sustain pedal.

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

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

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

Answer: (d)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, but the sustain pedal must remain depressed. The soft pedal does not affect the dampers of the piano. If the sostenuto pedal is depressed after the keys are depressed, the dampers will be kept lifted off the corresponding strings 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, the dampers will not be lifted and the notes will not be sustained.

14. MIDI messages are sent and received by a notebook computer through a MIDI interface box which has a MIDI in IX and a MIDI out OX. An electronic keyboard with 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 piece into the computer. The song, when completed, 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 songwriter to compose and then perform the song as described above?

(a) OX to IK

(b) OK to IR.

(c) TR to IK.

(d) OR to IK.

Answer: (c) 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. For the song to be performed as described, MIDI messages should be sent out by the notebook computer through OX first to the electronic organ's MIDI in IR, and then the same MIDI messagess should be sent out of the electronic organ's MIDI thru TR to the electronic keyboard's MIDI in IK. The electronic keyboard cannot directly receive the MIDI messages from the MIDI interface box. This is because, not having a MIDI thru, it is unable to pass on the MIDI messages to the electronic organ.

15. An electronic synthesizer is to receive a MIDI message telling the synthesizer to turn on the musical note A6 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, 81, 127.

(b) 9, 15, 93, 127.

(c) 8, 0, 93, 127.

(d) None of the above.

Answer: (d) The first number (in decimal) of this MIDI message should be 9, which tells the electronic synthesizer to turn on a note; the second number should be 0, which tells the electronic synthesizer that the MIDI message is for the lowest numbered MIDI channel; the third number should be 93, telling the electronic synthesizer that the note to be turned on is A6; and the fourth number should be 127, which tells the electronic synthesizer to turn on the note as quickly as possible.

16. A closed pipe produces a note which has a spectrum whose 7th line from the left has a frequency of 2,028 Hz. A high pass filter removes all the harmonics of the note below the frequency 2,030 Hz, and a low pass filter removes all the harmonics above the frequency 2,962 Hz. After the note has passed through both the low pass and high pass filters, which lines will remain in the spectrum?

    (a) Only the 7th and 8th lines lines from the left.
    (b) Only the 7th, 8th and 9th lines from the left.
    (c) Only the 8th and 9th lines from the left.
    (d) None of the above.

    Answer: (c) Since the closed pipe's note has only odd harmonics in its spectrum the 7th line from the left in its spectrum will be its 13th harmonic. The note's fundamental frequency is thus given by 2,028 Hz divided by 13 i.e. 156 Hz. The spectrum of the note will have as its first 12 lines 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 : 156 Hz, 468 Hz, 780 Hz, 1,092 Hz, 1,404 Hz, 1,716 Hz, 2,028 Hz, 2,340 Hz, 2,652 Hz, 2,964 Hz, 3,276 Hz and 3,588 Hz. The high pass filter removes all the frequencies which are below 2,030 Hz, so only the 15th and higher harmonics remain in the spectrum. The low pass filter removes all the harmonics above 2,962 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 particular technique for the generation or synthesis of sound waveforms starts with a waveform which is rich in harmonics. Some of these harmonics are then reduced in the right proportions or even removed to obtain the required waveform. Give the usual name for this method of synthesizing a waveform.

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

    Answer: (a) This technique reduces or removes some of the required harmonics, so it is generally known as subtractive synthesis.

18. The sound of a certain musical instrument is to be synthesised using the FM synthesis method. The modulator waveform has a frequency of 865 Hz and the carrier waveform has a frequency of 17,500 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) 9,715 Hz.
    (b) 15,775 Hz.
    (c) 18,345 Hz.
    (d) 23,550 Hz.

Answer: (a) Since the FM synthesis modulator frequency is 865 Hz and the carrier frequency is 17,500 Hz, the harmonics of the FM spectrum will be spread out from the carrier frequency by intervals which are multiples of 865 Hz. The 10 harmonics which are just above 17,500 Hz are: 18,365 Hz, 19,230 Hz, 20,095 Hz, 20,960 Hz, 21,825 Hz, 22,690 Hz, 23,555 Hz, 24,420, 25,285 Hz and 26,150 Hz. The 10 harmonics just below 17,500 Hz are 16,635 Hz, 15,770 Hz, 14,905 Hz, 14,040 Hz, 13,175 Hz, 12,310 Hz, 11,445 Hz, 10,580 Hz, 9,715 Hz and 8,850 Hz. Hence only the frequency 9,715 Hz is a valid frequency of one of the harmonics in the FM spectrum of this waveform.

19. A digital transmission of a concert by the NUS Symphony Orchestra is being broadcast over the Internet, with a sampling rate of 41,224 samples per second. Calculate the highest frequency which can be preserved in this digital transmission, as stated by the Nyquist criterion.

 (a) 10,306 Hz.
 (b) 20,612 Hz.
 (c) 41,224 Hz.
 (d) None of the above.

 Answer: (b) The Nyquist theorem or criterion says that the sampling frequency or rate of the transmission has to be double that of the highest frequency to be preserved in the transmission. Since the sampling rate of the digital transmission is 41,224 samples per second, the highest frequency which will be preserved in this digital transmission is half of 41,224 samples per second i.e. 20,612 Hz.

20. A jazz concert is being digitally recorded with a signal-to noise 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) 16,384.
 (b) 8,192.
 (c) 4,096.
 (d) None of the above.

 Answer: (a) The jazz concert has a S/N ratio of 84 dB, so the number of bits is 84 divided by 6 i.e. 14 bits. Since 2^{14} is equal to 16,384, the number of quantisation levels in the digital recording is 16,384.

21. The highest frequency to be preserved in the digital recording of a symphony concert is 19,600 Hz. If the digital recording equipment doing the recording can support no more than 1,240,000 bits per second, calculate the best signal-to-noise (S/N) ratio which is possible with 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) 90 dB.
 (c) 96 dB.
 (d) None of the above.

 Answer: (b) Since the highest frequency to be preserved is 19,600 Hz, the sampling rate should be double this i.e. 39,200 samples per second. The digital recording is limited to not more than 1,240,000 bits per second, so for each of the two stereo channels the bit rate is half of this i.e. 620,000 bits per second. The number of bits per sample for each channel is thus given by 620,000 bits per second divided by 39,200 samples per second i.e. approximately 15.82 bits. Since bit length must be an integer, the bit length must be 15 bits, as for a bit length of 16 bits the allowed bit rate would be exceeded. A bit length of 15 bits gives a S/N ratio of 6 dB times 15 bits i.e. 90 dB.

22. The highest frequency to be preserved in the digital recording of a pop concert is 15,700 Hz and the signal-to-noise or S/N ratio is 66 dB. What is the bit rate of this digital recording of the concert? (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) 345,400 bits per second.
    (b) 690,800 bits per second.
    (c) 1,381,600 bits per second.
    (d) None of the above.

    Answer: (b) According to the Nyquist criterion, the sampling rate for a digital recording should be double the highest frequency to be preserved. Hence the sampling rate for the recording is equal to 15,700 Hz times 2 i.e. 31,400 samples per second. Since the signal-to-noise or S/N ratio is 66 dB, the bit length of the digital samples is given by 66 dB divided by 6 dB i.e. 11 bits. Therefore the bit rate for each stereo channel is 31,400 samples per second times 11 bits, i.e. 345,400 bits per second. For two stereo channels the bit rate is double this i.e. 690,800 bits per second.

23. The highest frequency to be preserved in the digital recording of a choral concert is 18,450 Hz and the signal-to-noise (S/N) ratio of the recording is 78 dB. The resultant bit rate is the maximum possible bit rate of the digital recording equipment used for the recording. A brass band concert is digitally recorded at the same venue the next evening using the same digital equipment with the same maximum bit rate. What is the highest signal-to-noise (S/N) ratio which is possible for the digital recording of the brass band concert if the highest frequency to be preserved in the brass band concert is 16,900 Hz? (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) 76 dB.
    (d) None of the above.

    Answer: (b) By the Nyquist criterion, the sampling rate for the choral concert is given by 18,450 Hz times 2 i.e. 36,900 samples per second. Since the bit length of the digital samples is equal to 78 divided by 6 i.e. 13 bits, the bit rate for a single audio channel is equal to 36,900 samples per second times 13 bits i.e. 479,700 bits per second. This is also the maximum bit rate for each channel for the digital equipment being used for the brass band concert, whose sampling rate is equal to 16,900 Hz times 2 i.e. 33,800 samples per second. Therefore the bit length for the brass band concert is equal to 479,700 bits per second divided by 33,800 samples per second i.e. approximately 14.19 bits. However, bit length must be an integer so the bit length is 14 bits, since a bit length of 15 bits would give a bit rate exceeding the maximum possible bit rate. A bit length of 14 bits gives 14 times 6 dB i.e. 84 dB as the S/N ratio for the brass band concert.

24. You intend to digitally record the radio broadcast of a string quartet concert lasting 48 minutes on the hard disk of your desktop computer, and the highest frequency to be preserved in the digital recording is 17,200 Hz. If the signal-to-noise (S/N) ratio for the recording is to be equal to 96 dB, calculate the number of bytes needed on your computer's hard disk to record the entire 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) 198,144,000 bytes.
    (b) 396,288,000 bytes.
    (c) 3,170,304,000 bytes.
    (d) None of the above.

    Answer: (b) Using the Nyquist criterion, the sampling frequency of the digital recording should be double 17,200 Hz, i.e. 34,400 samples per second. For a signal-to-noise (S/N) ratio of 96 dB, the number of bits for each sample is 96 divided by 6 i.e. 16 bits. Therefore for each channel, the number of bits per second is equal to 34,400 samples per second times 16 bits i.e. 550,400 bits per second and for two stereo channels the bitrate is double this i.e. 1,100,800 bits per second. For 48 minutes to be recorded on the computer, the amount of memory needed is given by 1,100,800 bits per second times 60 seconds per minute times 48 minutes i.e. 3,170,304,000 bits. In terms of bytes, this is divided by 8 to give 396,288,000 bytes.

25. The highest frequency to be preserved in the original digital recording of a Chinese orchestra concert was 17,000 Hz. The MP3 file of this digital recording has a bit rate of 128,000 bits per second and a signal-to-noise (S/N) ratio of 84 dB. Calculate the compression ratio of the conversion from the uncompressed file of the original digital recording to the compressed MP3 file. (Assume that the concert was being 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) 3,71875 to 1.
    (b) 7.4375to 1.
    (c) 14.875 to 1.
    (d) None of the above.

    Answer: (b) The highest frequency to be preserved was 17,000 Hz, so the sampling rate was double this i.e. 34,000 samples per second, and the bit length of the samples is given by 84 dB divided by 6 dB i.e. 14 bits. Therefore the bit rate of the uncompressed file is given by 34,000 samples per second times 14 bits i.e. 476,000 bits per second, and for two stereo channels the bit rate is double this i.e. 952,000 bits per second. The compression ratio from the uncompressed file to the MP3 file is thus equal to 952,000 bits per second divided by 128,000 bits per second i.e. 7.4375 to 1.

END OF TEST PAPER