University of Pennsylvania
Department of Electrical and System Engineering
Digital Audio Basics

ESE150, Spring 2020 Midterm Wednesday, March 4

- Exam ends at 5:50PM; begin as instructed (target 4:35PM)
- Do not open exam until instructed to begin exam.
- Problems weighted as shown.
- Calculators allowed.
- Closed book = No text or notes allowed.
- Provided reference materials on next to last page.
- Show work for partial credit consideration.
- Unless otherwise noted, answers to two significant figures are sufficient.
- Sign Code of Academic Integrity statement (see last page for code).

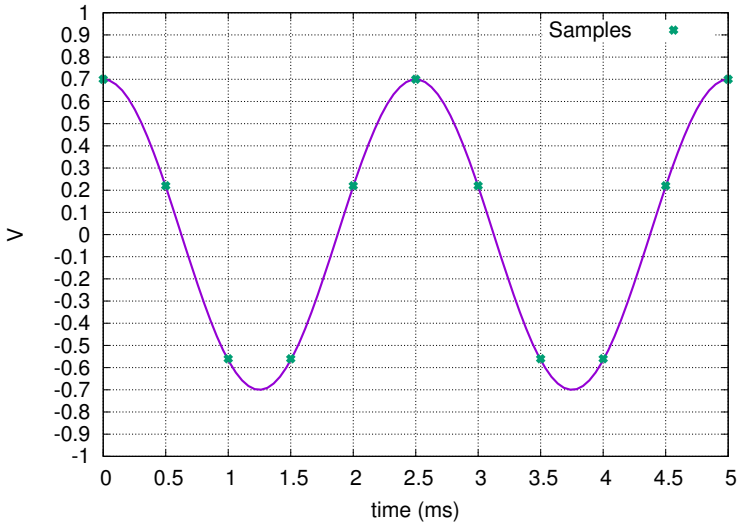
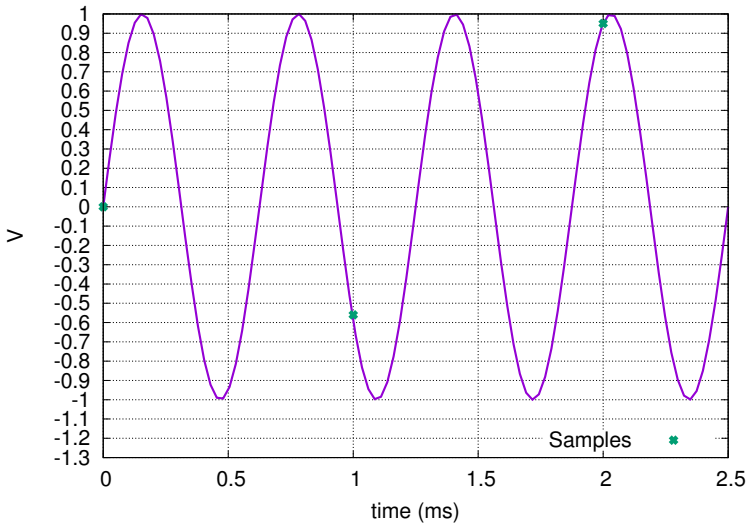
I certify that I have complied with the University of Pennsylvania's Code of Academic Integrity in completing this exam.

Name:

1	2			3					4	5			
	a	b	c	a	b	c	d	e		a	b	c.i	c.ii
10	4	3	3	2	2	2	2	2	10	2	3	2	3

6	7				8					**Total**
	a	b	c	d	a	b	c	d		
10	5	5	5	5	6	4	3	7		100

1. Consider the following sampling cases, complete the table entries.

Waveform and Sample	Waveform Frequency (Hz)	Sample Frequency (Hz)	Inferred Frequency (Hz) from Samples	Properly Sampled?
				
				

2. Telephone digital voice uses PCM encoding with 8KHz sample rate and 8b amplitude quantization.

   (a) What is the maximum frequency this sample rate can accurately capture?

   (b) What is the sample period (length of time between samples)?

   (c) How many bits does this scheme require to record a 15 second voice-mail message?

3. Consider the following quote from Lt. Cmd. Vindman:

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
T	h	i	s		i	s		A	m	e	r	i	c	a	.	

17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
H	e	r	e	,		r	i	g	h	t		m	a	t	t	e	r	s	.

This has 37 symbols from a set of 16 unique symbols.

symbol	A	H	T	.	,		a	c	e	g	h	i	m	r	s	t	**sum**
count	1	1	1	2	1	5	2	1	4	1	2	4	2	4	3	3	37

(a) How many bits to encode this using a uniform encoding where each symbol is encoded using the same number of bits?

(b) Is this likely to be compressible with a variable-length symbol encoding? Why? Illustrate with specific symbols.

(c) What is the Shannon Entropy lower bound for for this quote?

$$\text{Lower Bound} = -\sum_i \log_2(P(c[i])) \tag{1}$$

Hint: there are only 5 different counts, so 5 different P(c[i]) values to calculate.

(d) Consider the following set of variable-length binary encodings. Assign each symbol to an encoding to minimize the encoded length.

encode	000	0010	0011	0100	01010	01011	0110	0111
symbol								

encode	10000	10001	1001	101	11000	11001	1101	111
symbol								

(e) For the above assignment, how many bits are required to encode the quote?

4. While watching a movie, which sounds are likely to annoy you (interfere with your preception and enjoyment...) during each of two scenes: (a) piano recital (25–4200 Hz) at 40–80dB, (b) 100dB explosion (broad spectrum 20–8,000 Hz) ?

   Classify each as: (U)nnoticeable, (H)ighly annoying, (L)ightly annoying

	piano	explosion
70dB, 45KHz squeak		
60dB, 2-3 KHz child cry		
20dB, 100-300 Hz whisper		
40dB, 5Hz mechanical vibration		
50dB, 11KHz electronic whine		

5. Assume for simplicity in this problem that each band has 30 discernable frequencies. We allocate 180b to encode each band. Assume 16b quantization is essentially perfect (zero error). The error for a frequency is a value between 0 and 1 equal to

$$Error(f) = \frac{|\text{ActualFrequency} - \text{EncodedFrequency}|}{2^{16}} \tag{2}$$

Encoding to k-bit quantization means an encoded value of e will be interpreted as an EncodedFrequency of $e \times 2^{16-k}$.

(a) If we assign equal quantization to every frequency in the band, how many bits can we use to represent the amplitude of each frequency?

(b) Ignoring masking, what is the maximum possible total error across the entire band? (sum up the errors across all frequencies in the band.)

(c) Assuming anything with amplitude 20% below the maximum frequency in the band is masked and contributes no subjective error. Assume frequencies within the 20% bound contribute a subjective error equal to the full Error(f) stated above. Assume for simplicity omitted frequencies do not cost encoding bits.

i. What is the maximum number of loud (amplitude within 20% of maximum amplitude frequency in the band) frequencies that a band can have and achieve a zero subjective error encoding?

ii. What is the maximum possible subjective error when there are 15 loud frequencies (amplitude within 20% of maximum amplitude frequency in the band) and you assign equal quantization to these loud frequencies.

6. Given: $f(t) = 0.3\cos(2\pi \cdot 400t) + \sin(2\pi \cdot 600t) + 0.2\sin(2\pi \cdot 700t)$
give the second, tenth, and twenty-third time-sample values of $f(t)$ for a 4KHz sample rate.

sample	2	10	23
time (t)			
value $f(t)$			
$\cos(2\pi \cdot 400t)$			
$\sin(2\pi \cdot 600t)$			
$\sin(2\pi \cdot 700t)$			

You only need to complete the **value** row. Other rows are likely useful to assembling your solution and showing your work for partial credit.

7. Early telephones used DTMF (dual-tone, multiple frequency)-signalling to send signals including phone number digits. They used pairs of frequencies (the dual tone) to represent each symbol. The table below shows how pairs formed from 2 sets of 4 frequencies were used to represent 16 symbols:

	1209 Hz	**1336 Hz**	**1477 Hz**	**1633 Hz**
697 Hz	**1**	**2**	**3**	**A**
770 Hz	**4**	**5**	**6**	**B**
852 Hz	**7**	**8**	**9**	**C**
941 Hz	*****	**0**	**#**	**D**

Assume a tone must be present for at least 100 ms to be registered as a symbol and an absence of dual tone must occur for at least 20 ms to denote the separation between one symbol and the next.

(a) How would DTMF symbol detection and extraction work for a modern time-sampled digital system listening to an analog line from an analog phone producing DTMF signals?

(b) If we just wanted a system to decode DTMF signals:

i. What is the minimum sample rate required for our time-sampled digital system?

ii. What analog filtering would be needed to support operation at this sample rate?

(c) If you had an MP3 of a phone conversation where someone inadvertantly pushed a button on the phone that generated one or more DTMF signals, how could you clean it up? (produce a better MP3 that removed the audible DTMF tones)

(d) Assume you can place a digital processor between the microphone and analog output line on a phone (and similarly between the analog input line and the speaker). For legacy signalling over an analog line, how could you insert DTMF tones on the originating end and remove them at the destination so that the humans never heard them?

8. Corporate sonic branding creates short audio snippets intended to identify the specific brand. For simplicity let's model the space of potential sounds as composed of four 100 ms chords, where each chord is composed of up to 3 frequencies.

   - Assume at most 30 distinguishable frequencies per critical band.
   - Restrict to the 20 bands from 2–21 to assure most people can hear the frequencies.

   (a) Assuming we want to avoid masking in the design of the brand snippet, what restrictions should we place on the frequencies composing each chord (composition of 3 frequencies composed in each of the four 100 ms segments)?

   (b) Given this restriction, and assuming you don't want to differentiate brand snippets only by the amplitude of frequencies, how many potential 400 ms audio snippets are there?

   (c) How many bits of information does this represent?

   (d) Assuming 25 ms sample windows, 4b amplitude quantization, and that you can model the MP3 as encoding the present frequencies and their associated amplitudes in each 25 ms window, how large (in bits) will the MP3s be to respresent these audio snippets?

Human auditory critical bands:

Band Number	Low	High
1	20	100
2	100	200
3	200	300
4	300	400
5	400	510
6	510	630
7	630	720
8	720	920
9	920	1080
10	1080	1370
11	1270	1480
12	1480	1720
13	1720	2000
14	2000	2320
15	2320	2700
16	2700	3150
17	3150	3700
18	3700	4400
19	4400	5300
20	5300	6400
21	6400	7700
22	7700	9500
23	9500	12000
24	12000	15500

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B. Plagiarism Using the ideas, data, or language of another without specific or proper acknowledgment. Example: copying another persons paper, article, or computer work and submitting it for an assignment, cloning someone elses ideas without attribution, failing to use quotation marks where appropriate, etc.

C. Fabrication Submitting contrived or altered information in any academic exercise. Example: making up data for an experiment, fudging data, citing nonexistent articles, contriving sources, etc.

D. Multiple Submissions Multiple submissions: submitting, without prior permission, any work submitted to fulfill another academic requirement.

E. Misrepresentation of academic records Misrepresentation of academic records: misrepresenting or tampering with or attempting to tamper with any portion of a students transcripts or academic record, either before or after coming to the University of Pennsylvania. Example: forging a change of grade slip, tampering with computer records, falsifying academic information on ones resume, etc.

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G. Unfair Advantage Attempting to gain unauthorized advantage over fellow students in an academic exercise. Example: gaining or providing unauthorized access to examination materials, obstructing or interfering with another students efforts in an academic exercise, lying about a need for an extension for an exam or paper, continuing to write even when time is up during an exam, destroying or keeping library materials for ones own use., etc.

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