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

ESE150, Spring 2019 Midterm Wednesday, March 13

- 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			
a	b	c	d	e		a	b	c	a	b	c	d
3	3	3	3	3	15	5	3	2	2.5	2.5	2.5	2.5

5				6	7	8				**Total**
a	b	c	d			a	b	c		
2	3	3	2	15	10	3	3	9		100

1. Cat hearing ranges from 45Hz to 64KHz. Consider performing sound capture for cats.

   (a) What is the minimum sample rate you should use to capture the full range of frequencies the cat can hear?

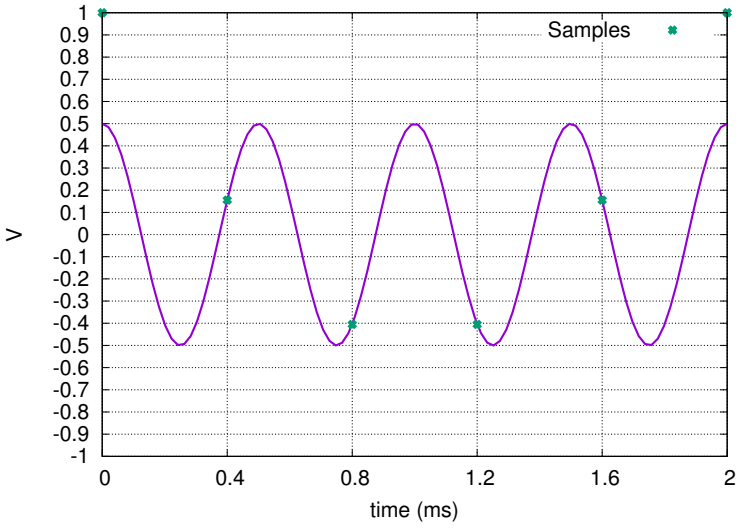
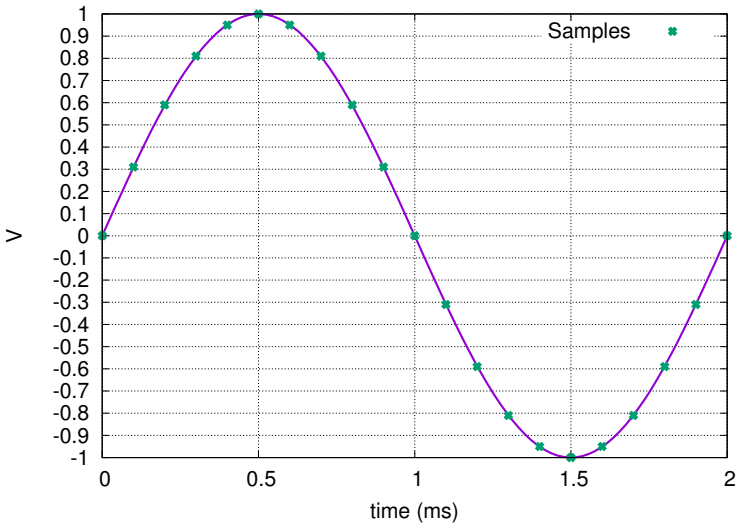
   (b) What is the minimum period between samples at this rate?

   (c) How many Bytes will it take to encode a 3-minute, single-channel (mono) "cat" song with 16b PCM samples?

   (d) Given that human hearing goes to 22KHz, how much more PCM data is required for a "cat" song than a human song? (State as a ratio.)

   (e) Staying with PCM audio, how could you compress the cat song to guarantee to achieve the same data rate (bits/second) as human PCM audio? Is this lossy or lossless compression?

2. 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?
				
				

3. While the cat can hear up to 64KHz, it likely has similar critical band limitations to humans. Consider the hypothetical band structure shown on the facing page, and make the simplifying assumption that we only need to represent the strongest 4 frequencies in each band over a 25 ms time window to 4 Hz resolution. Assume 16b amplitude quantization for each frequency. Let's determine efficient frequency-band representations for discernable cat audio.

   (a) Exploiting this structure, what do you store for each 25 ms window and how many bits does this require?

   (b) How much compression does this achieve over the PCM samples for the same 25 ms window? (State as a ratio.)

   (c) What kind of compression is this (lossless or lossy) and why?

Hypothetical cat auditory critical bands:

Band Number	Low	High
1	45	100
2	100	200
3	200	300
4	300	400
5	400	500
6	500	600
7	600	800
8	800	1200
9	1200	1500
10	1500	2000
11	2000	2500
12	2500	3000
13	3000	4000
14	4000	5000
15	5000	6000
16	7000	8500
17	8500	10000
18	10000	12000
19	12000	15000
20	15000	18000
21	18000	22000
22	22000	25000
23	25000	30000
24	30000	35000
25	35000	42000
26	42000	46000
27	46000	50000
28	50000	56000
29	56000	60000
30	60000	64000

While the cat auditory range to 64,000 Hz is real. This auditory band structure is a synthetic construct generated just for this problem and likely does not represent reality.

4. Consider the following set of sounds that occur **simultaneously**. Identify which sounds a human is likely to hear and explain why or why not. (read through all 4 sounds before starting your answers.)

   (a) Soft (25dB) cat purrs at 150 Hz

   (b) Loud (80dB) mechanical squeek at 30 KHz

   (c) Moderate (60dB) child yelling at 2200 Hz

   (d) Soft (30dB) cat meow at 2100 Hz

5. Consider the following Claude Shannon quote:

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Thus we may have knowledge of the past but cannot control it;
we may control the future but have no knowledge of it.
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Including spaces and punctuation, the quote has 116 total symbols (and 26 unique symbols).

(a) If we give every symbol the same number of bits, how many bits do we need to encode each symbol?

(b) For a variable length symbol encoding, which symbol should get the fewest bits? (and why?)

(c) For a variable length symbol encoding, which symbol could get the most bits? (and why?)

(d) Is variable length symbol encoding a lossy or lossless compression scheme? (why?)

6. Given a signal with 3 frequencies, 250 Hz (amplitude 1/2), 1400 Hz (amplitude 1/4), and 8000 Hz (amplitude 1), that can be represented as sine waves starting at $t = 0$, what is the amplitude of the temporal waveform at each of the following time points?

Time	**Amplitude**
0.02 ms	
1.00 ms	
2.37 ms	

7. A curious engineer with several cats would like to know what her cats hear (are they reacting to sounds she cannot hear? do they talk to each other above the range of her hearing?) Making the same assumptions about cat hearing from Problems 1 and 3, describe how she could build a cat-sound translator that converts the full range of cat-audible sounds into human-audible sounds.

8. Audio forensics (think Sherlock Holmes, CSI) may not find conventional MP3 encodings as useful as standard Compact-Disc (44KHz sample rate) PCM encodings or even analog recordings. [Assume the analog recording is a perfect capture of the original continuous sound waveform at the point of the recording microphone.]

   (a) Of the three, which would capture a high pitched sound (e.g. 30KHz)? For each, why or why not?

      i. MP3 encoded

      ii. PCM encoded with 44KHz samples, anti-alias input filtering

      iii. analog recording

   (b) Of the three, which might be able to recover a whispered conversation happening further from the microphone than a loud conversation? For each, why or why not?

      i. MP3 encoded

      ii. PCM encoded with 44KHz samples, anti-alias input filtering

      iii. analog recording

   (c) Assuming you are willing to store information at a variable data rate (unlike MP3s), want to preserve any potential signal up to 120 KHz, but also want to minimize bits used (equivalently, maximize the time period you can store on 1TB of storage), describe a sampling, transformation, compression, and storage strategy.

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.

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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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