Collaborative Spectrum Sharing Lab

Lab Handout

Your Name: ______________________________________

Part 1: Getting to Know Audio Frequencies: Visualizing Sounds of Tuning Forks

Visualizing the Data (Time Domain)

Question 1.1: Does anyone know what this type of signal or function is called?

Comparing Audio Signals for Tuning Forks with Different Tunings

QUESTION 1.2: How would you describe the relation between the "Beethoven A" and "UF E" waves?

QUESTION 1.3: What is different between the plots shown of the "Beethoven A" and "UF E" waves?

Question 1.4: Ignoring the small fluctuations in the recording, what do you notice that is different about the two plots of individual cycles of the "Beethoven A" and "UF E" waves?

Making Waves

Question 1.5: Circle the appropriate relation in each sentence: * Beethoven's tuning fork sounded **higher / lower** than the UF E tuning fork.

- For a fixed observation time of 0.01 s, we observed that Beethoven's tuning had **more / fewer** cycles than the UF E tuning fork.

- One cycle of the Beethoven's tuning fork took **more / less** time than one cycle of the UF E tuning fork.

Question 1.6: How does the `cycle_rate` parameter effect the pitch of the audio signal?

Part 2: Getting to Know Audio Frequencies: Defining Frequency and Visualizing Frequencies of Signals

Frequency

Question 2.1: What do you think the word *frequency* means? In what contexts have you heard that term?

What frequencies can you hear?

Activity 2.2: 1. Write down the lowest frequency that you can hear. 1. Write down the lowest frequency that still sounds like a musical note to you.

Activity 2.3: Write down the highest frequency that you can hear. Compare with the other students in the lab. Compare with the lab instructor.

Richer Audio: Guitar

Question 2.4: What do you observe? How is this similar to, and different from, the tuning fork signals?

Question 2.5: Recall that the E note is at about 330 Hz. How do the other components in this plot relate to that frequency?

Activity 2.6: Write down the number of harmonics you feel are needed for the resulting signal to like the original guitar.

Analyzing Voice Data

Activity 2.7: How many harmonics are needed before this sounds like a voice?

Activity 2.8 (Optional, requires recording): Go back and record human speech and repeat all the voice data analysis. How is the time signal different than for singing a note? How is the frequency signal different than for singing a note?

Part 3: Frequency Multiplexing: Transmitting Multiple Voice Signals

Frequency Multiplexing: Part 1 – Low Pass Filtering

Question 3.1: How do the filtered signals sound in comparison to the original signals?

Frequency Multiplexing: Part 2 – Frequency Shifting and Combining

Question 3.2: Describe how the frequency-shifted signal sounds compared to the original signal.

Question 3.3: How does the plot of the frequency-shifted signal compare to the plot of the original signal?

Activity 3.4: Listen to the combined signal. Can you hear the different messages? Propose an explanation for what you have heard.

Frequency Demultiplexing

Questions 3.5: Do you hear any differences between the demultiplexed signals and the filtered signals? Why do you think you did/did not?

Review

- Frequency-division multiplexing is a way to put multiple signals on different, non-overlapping frequency bands
- The FFT and IFFT are techniques to transform signals into frequency representations, where filtering out frequencies or shifting frequencies are easily done
- Demultiplexing is the process of recovering the individual signals that have been multiplexed together.

Part 4: Scanning the Radio Spectrum

FM Radio

Activity 4.1 Identify at least two other strong radio signals. Find out the four-letter ID and type of radio station.

Cellular Band

Activity 4.2 Estimate the center frequency and the bandwidth (the amount of frequency spanned by the signal) for several of the signals observed.

Part 5. Digital Modulation

On-Off Keying

Question 5.1 What problems might there be with using On-Off Keying to send information? How might you avoid those problems?

Activity 5.2: Adjust the `noise_variance` parameter above to see how it affects the performance of this system.

- How high can `noise_variance` be before you start to see a large number of errors.

- Is one type of error more prevalent than another? Why do you think that is the case?

- Can you think of any way to improve the performance of this detector when the noise is large?

- Try to modify the code to improve the performance when the noise is large. Were you successful? If so, what did you do and why?

Activity 5.3: For the where you listen to a modulated message that consists of a 1 followed by 5 random bits, write down your record as:

correct / # tries

(like 3/5)

International Morse Code

1. The length of a dot is one unit.
2. A dash is three units.
3. The space between parts of the same letter is one unit.
4. The space between letters is three units.
5. The space between words is seven units.

A	• —	U	• • —
B	— • • •	V	• • • —
C	— • — •	W	• — —
D	— • •	X	— • • —
E	•	Y	— • — —
F	• • — •	Z	— — • •
G	— — •		
H	• • • •		
I	• •		
J	• — — —		
K	— • —	1	• — — — —
L	• — • •	2	• • — — —
M	— —	3	• • • — —
N	— •	4	• • • • —
O	— — —	5	• • • • •
P	• — — •	6	— • • • •
Q	— — • —	7	— — • • •
R	• — •	8	— — — • •
S	• • •	9	— — — — •
T	—	0	— — — — —

Activity 5.4: The Morse Code activity uses a parameter called `dit_duration`. Try setting `dit_duration` to a smaller value, such as 0.05. Write down the smallest value of `dit_durration` at which you can still reliably decode the message.

Review

- *Modulation* is the process by information is encoded for transmission on a channel.
- In *on-off keying*, an information stream is conveyed by turning a carrier on and off.
- *Demodulation* is the process of taking a modulated signal and recovering the information.
- *Morse Code* is a way to efficiently modulate English letters and numbers as a sequence of tones of varying lengths.

Part 6. Spectrum Sharing

Activity 6.1: Volume Normalization

Write down your team number:

Spectrum Sharing with Fixed Assignments 1

Activity 6.2: Simultaneous Transmission Fixed Frequencies

If you team is transmitting during the following tests, write down the message that was guessed by the human receivers and the actual message transmitted.** 1. Teams 1 and 3 run the block below simultaneously.

2. Teams 2 and 4 run the block below simultaneously.

3. Teams 1, 2, and 4 run the block below simultaneously.

4. Teams 1, 3, and 4 run the block below simultaneously.

5. All teams run the block below simultaneously.

Spectrum Sharing with Fixed Assignments 2

Activity 6.3: Using a Tuned Receiver

Sketch what the output of the tuned receiver looks like.

Dynamic Spectrum Sharing Experiment 1: Three Teams

Activity 6.4: Dynamic Spectrum Sharing with Three Teams, Round 1

We are now ready to carry out our first dynamic spectrum sharing experiment. If you have 4 teams, choose one to sit out the first time this experiment is run. The remaining 3 teams will try to find a set of frequencies to use that allow each team to receive the signal sent by their team's transmitter. (The team that sits out this round will participate in a second run of this experiment.)

IMPORTANT: Teams are not allowed *any* communication with the other teams during this experiment. We will allow limited communication in later experiments.

Each experiment consists of a number of rounds. Repeat the following until all teams are able to accurately determine the message sent by their team's transmitter:

1. Each team chooses one member to operate their team's transmitter. All other team members will work at the receiver.
2. Each team picks a frequency index from 1 to 4. Teams are not allowed to use their team number in the first 2 rounds. If a team was able to recover their message in the previous round, they should generally reuse the same frequency index as in the previous round. Teams that experienced interference and were not able to recover the transmitted message may decide to switch or not switch because if two teams that were using the same frequency both switch, then they both may switch to the same frequency and cause interference again.
3. At a signal from the lab leader, the participating teams will run their transmitters and receivers.
4. At the receivers, the team members will study the plots and try to decode the Morse-coded words. The members will then tell the team member that is working the transmitter what they think the message was.
5. At each transmitter, the team member will use the message specified by the receiver team to answer the question about which message was transmitted. The transmitter will then tell the receiver team whether the message was correctly decoded or not.
6. If all teams have recovered their messages correctly, the experiment is complete. Otherwise, the next round begins at step 2 above.

Questions: What is the final list of frequencies used by each team? How many rounds were required?

Activity 6.5: Dynamic Spectrum Sharing with Three Teams, Round 1

If there are four teams, repeat Activity 6.4 with 3 different teams. For reference, here is the procedure. Note that teams are not allowed to use their team_number or their frequency index from experiment 1 in the first 2 rounds.

Questions: What is the final list of frequencies used by each team? How many rounds were required?

Activity 6.6: Dynamic Spectrum Sharing with Four Teams, Sequential

In practice, it is unlikely that all of the users of a system would start accessing the channel at the same time. In this experiment, teams will begin transmitting one by one.

1. Run the cell below to choose a random order for the teams to begin transmitting. The first team listed will transmit beginning in the first round and every round thereafter, the second team listed will transmit beginning in the second round and every round thereafter, etc.
2. When a team is not transmitting, that team can still run the receive() function in order to see which channels have power in them.
3. When a team begins transmitting, it should use a transmission frequency that it believes is not being used by any other team. This can determine by listening to the tones being sent or by looking at the plot of power distribution by frequency. Once a team transmits on a frequency, it should continue to use that same frequency provided that they were able to recover the transmitted signal. The team member at the transmitter should tell the team members at the receiver which frequency it is transmitting on.
4. During a round, the team members at the receiver will tell the team member at the transmitter which animal (i.e., message) they have decoded. The team member at the transmitter should then inform the team members at the receiver whether they were correct or not. If the team chose a frequency that was already used by another team and were not able to recover their signal because of interference, then that team should choose another frequency in the next round.
5. Ideally, every team should have a unique frequency after 4 rounds, and every team should be able to recover their message in round 4. If not, continue with additional rounds until all teams can recover their message.

Questions: What is the final list of frequencies used by each team? How many rounds were required? If it was more than 4, try this experiment again and use the plots of power distribution across frequency to try to determine which frequencies are being used in previous rounds. Be sure to select a transmission frequency that is not already being used by another team.

If another round is required, answer here:

Collaborative Spectrum Sharing

Activity 6.7: Collaborative Spectrum Sharing with Sufficient Channels

In collaborative spectrum sharing, users a channel share information about their use of the available frequencies to enable the teams to use the spectrum efficiently. This information is sometimes exchanged over a special *collaboration channel*. In this experiment, team members will use voice communication for the collaboration channel.

1. The lab leader should run the cell directly below to choose the team order. This is the order in which teams will announce their planned channel usage.
2. At the beginning of each round, teams will take turns announcing their planned frequency use. The order in which teams announce their planned frequency will be specified by the lab leader (according to the random order selected in step 1).
3. At a signal from the lab leader, the participating teams will run their transmitters and receivers.
4. At the receivers, the team members will study the plots and try to decode the Morse-coded words. The members will then tell the team member that is working the transmitter what they think the message was.
5. At each transmitter, the team member will use the message specified by the receiver team to answer the question about which message was transmitted. The transmitter will then tell the receiver team whether the message was correctly decoded or not.
6. If all teams have recovered their messages correctly, the experiment is complete. Otherwise, the next round begins at step 2 above.

Questions: How many rounds were required? If more than 1 round was required, conduct the experiment again. How does this approach compares to the approach in Experiment 3 in terms of using the available frequencies efficiently?

If another round is required, answer here:

Activity 6.8: Collaborative Spectrum Sharing with Insufficient Channels

Repeat experiment 4, but only use the frequencies 1, 2, and 3. Teams do not all have to transmit in a round, but the goal is for each team to deliver 3 messages over a series of 4 rounds.

1. The lab leader should run the cell directly below to choose the team order. This is the order in which teams will announce which frequency they plan to use or whether they will not transmit.
2. At the beginning of each round, teams will take turns announcing their planned frequency use (or if they will not transmit). The order in which teams announce their planned frequency will be specified by the lab leader (according to the random order selected in step 1).
3. At a signal from the lab leader, the participating teams will run their transmitters and receivers.
4. At the receivers, the team members will study the plots and try to decode the Morse-coded words. The members will then tell the team member that is working the transmitter what they think the message was.
5. At each transmitter, the team member will use the message specified by the receiver team to answer the question about which message was transmitted. The transmitter will then tell the receiver team whether the message was correctly decoded or not.
6. If this is the fourth round, then the experiment is complete. Otherwise, start another round by going to step 2.

Questions:

- What rounds did each team transmit in?

- How many messages were delivered by each team?

- What was the total number of messages delivered?

If each team did not deliver 3 messages, have the teams discuss how they can achieve the desired goal. Then run the experiment again.

If another round was required: * What rounds did each team transmit in?

- How many messages were delivered by each team?

- What was the total number of messages delivered?

Activity 6.8: Collaborative Spectrum Sharing with Insufficient Channels

Repeat experiment 5, using only frequency indices 1, 2, and 3. Tell teams that they do not all have to transmit, but each team has the goal of getting their own message through **4 times** in 4 rounds.

1. The lab leader should run the cell directly below to choose the team order. This is the order in which teams will announce which frequency they plan to use or whether they will not transmit.
2. At the beginning of each round, teams will take turns announcing their planned frequency use (or if they will not transmit). The order in which teams announce their planned frequency will be specified by the lab leader (according to the random order selected in step 1).
3. At a signal from the lab leader, the participating teams will run their transmitters and receivers.
4. At the receivers, the team members will study the plots and try to decode the Morse-coded words. The members will then tell the team member that is working the transmitter what they think the message was.
5. At each transmitter, the team member will use the message specified by the receiver team

to answer the question about which message was transmitted. The transmitter will then tell the receiver team whether the message was correctly decoded or not.

6. If this is the fourth round, then the experiment is complete. Otherwise, start another round by going to step 2.

Questions:

- What rounds did each team transmit in?

- How many messages were delivered by each team?

- What was the total number of messages delivered?

- How did the total number of messages delivered compare to the last experiment?

- Which of Activity 6.7 and Activity 6.8 are most like a real system?

- How could real systems be incentivized to behave like those in Activity 6.7 instead of those in Activity 6.8?

Review

- Most current communication systems use *fixed channel assignment* in which each system is assigned a particular frequency band (in some area) that no one else is allowed to use.
- Fixed channel assignments are wasteful when the assigned user doesn't use the band continuously.
- In *dynamic spectrum access*, users choose channels and try to avoid disrupting each other's communications.
- In *collaborative spectrum sharing*, users exchange information to help do a better job at dynamic spectrum access.
- Methods are needed to incentivize cooperation when there are fewer channels available then there is systems that want to use those channels.

Part 7. Conclusions

Discuss the following questions and write down the best responses: * What are the potential advantages of dynamic spectrum sharing versus a fixed channel allocation?

- What are the challenges of dynamic spectrum sharing in comparison to a fixed channel allocation?

- How can a collaboration channel help with dynamic spectrum sharing? What are potential disadvantages of using a collaboration channel?

- What happens when their are more users or systems than their are available channel resources (i.e., frequencies to transmit on). How can these users or systems be incentivized to share the available frequencies and not interfere with each other?

- Which way do you think is better for future wireless communication systems: fixed channel allocation or dynamic spectrum access? Why do you say that?