UNIV 213 Science & Engineering of Music & Sound Spring 2020

Homework Assignment #2 – due in BRKI 368 at 5:00 pm on Monday, Feb. 17, 2020

***Instructions, notes, and hints*:**

Provide the details of all solutions, including important intermediate steps. You will not receive credit if you do not show your work. If you justify any approximations you make, you will be given full credit for such answers.

***Assignment*:**

Note that the first three problems below are marked "not graded." You do not have to submit them with the rest of the problems. However, you should work through them and compare your answers to the posted answers. The ungraded problems are meant to help you prepare for the exam and to provide practice to help you solve the graded problems.

1. **[not graded]** The expression below mathematically represents the case of a forward (subscript *fwd*) traveling wave and a reflected traveling wave (subscript *ref*) with the same amplitude A propagating at the same time along a string tied between two points. Note that the waves on a string are transverse waves, which means that the displacement (motion) y of the string is perpendicular to the direction in which the waves are moving. The string is aligned along the x-axis, and the variable t is time.

$$y(x,t) = y_{fwd}(x,t) + y_{ref}(x,t) = A\cos(kx - \omega t) + A\cos(kx + \omega t),$$

where k is the wavenumber ($k = 2\pi/\lambda$) and ω is the so-called radian frequency ($\omega = 2\pi f$). The variables λ and f are the wavelength in meters and frequency in hertz, respectively. Using the trigonometric identity

$$\cos(a-b) + \cos(a+b) = 2\cos(a)\cos(b)$$

with the subsitutions $a = kx$ and $b = \omega t$, the expression for the total displacement y can be rewritten as

$$y(x,t) = 2A\cos(kx)\cos(\omega t) = 2A\cos(\omega t)\cos(kx).$$

This is the mathematical representation of a standing wave. Thus, a standing wave can be thought of as two counter-propagating traveling waves added together. That concept helps to explain why standing waves (which represent vibrations) appear on strings and inside tubes.

Suppose that a certain string is 50 cm long and is vibrating at the first resonant frequency of 500 Hz. The maximum amplitude of the vibration (the greatest possible displacement) is 0.20 mm. Sketch the displacement of the full string (i.e., plot y vs. x) at the instances in time given by t = 0 ms, 0.25 ms, 0.50 ms, 0.75 ms, and 1.00 ms.

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2. **[not graded]** Express the following power, intensity, or pressure increases or decreases in terms of the appropriate dB units:

   a. Power increase from 1.2 nW to 4.8 mW (increase by a factor of 4×10^6)
   b. Power decrease from 15 W to 300 mW (decrease by a factor of 1/50 or 0.02)
   c. Intensity increase from 4.4 μW/m^2 to 35.2 μW/m^2 (increase by a factor of 8)
   d. Pressure increase from 2.3 nPa to 12.65 μPa (increase by a factor of 5,500)
   e. Sound pressure level (SPL) decrease from 58.3 dB to 34.2 dB

3. **[not graded]** Express the following absolute quantities in terms of dB units:

   a. For a power of 1.2 nW, find the equivalent power level (L_W).
   b. For an intensity of 5.4 nW/m^2, find the equivalent intensity level (L_I).
   c. For a sound that creates a pressure change of 0.42 mPa above or below the average air pressure, find the equivalent sound pressure level (L_p or SPL).
   d. For a sound that creates a pressure change of 3.7 μPa above or below the average air pressure, find the equivalent sound pressure level (L_p or SPL).

4. When a person walks toward a certain loud 1500 Hz noise source, the sound pressure level (SPL) rises from 25 dB to 82 dB. For this case:

   a. Find the factor by which the sound pressure increases and by which the corresponding intensity increases.
   b. Find the sound pressure expressed in pascals that corresponds to an SPL of 82 dB.
   c. Find the intensity expressed in W/m^2 that corresponds to an SPL of 82 dB.

5. Suppose that a jackhammer is operating outside your building. An occupational safety official measures an SPL value of 94 dBA one meter away from the jack hammer. The jack hammer is 13 m away from the nearest wall of the building you are in, and you are right next to the same wall inside the building. The building wall attenuates outside sounds by 35 dB (i.e., sounds just outside the wall are 35 dB stronger than just inside the wall). Assuming that the decrease in sound intensity follows the ideal hemispherical behavior described in Sec. 6.2 of the textbook (Rossing, Moore, and Wheeler, 3rd. ed.) find the SPL of the jackhammer noise that you would experience.

6. Some radio stations like the time standard station WWV encode information using low-frequency tones that are at such a low level that listeners cannot hear them. If a station were to transmit subaudible tones at 100 Hz, find the maximum sound pressure level that the tones could have at a distance of 1 m or more from the radio and not be heard by most people.

7. Find the sound pressure level (SPL) that a 60 Hz tone would have to have to be perceived as loud as a 2000 Hz tone with an SPL of 20 dB.

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8. An acoustics engineer is trying to determine the source of a low-frequency rumble-like noise in a workroom that is irritating several of the employees. The engineer takes measurements in the room when no one is there and the room is completely quiet except for the rumble. The SPL measured using a sound level meter set to the A-weighting scale is 20 dB. However, the reading using the Z-weighting scale is 50 dB. What is the approximate frequency of the noise? *Hint*: Refer to the frequency weighting diagram available at the "Sound Level Meter" Wikipedia page.

9. A certain composite sound is made up of partials at the frequencies 720 Hz, 900 Hz, 1080 Hz, and 1260 Hz. Find the perceived pitch that a listener would be likely to experience.

10. The pitch standards to which musical instruments are tuned have risen considerably over the past few centuries. In the time of George Frideric Handel, the musical note of A above middle C was around 422 Hz. It is now 440 Hz. The change puts antique stringed instruments at risk of breakage because of the increased tension in their strings when tuned to modern standards. Referring to Sec. 4.3 in the textbook (Rossing, Moore, and Wheeler, 3rd, ed.), find the amount (the multiplying factor) by which the tension in a violin's A string must be increased to change the tuning from 422 Hz to 440 Hz. A violin has four strings, so the total increase in tension (and therefore the increase in the net force experienced by the instrument's neck) is roughly four times the value you calculate for the A string. However, for this problem find only the increase in the A string's tension. (Tension is the force transmitted through a string, so, like force, it is measured in newtons.)