Assignment 6
Physics of Music - 2016
Physics 341

1 a)I attended the Marriage of Figaro a few years ago, and found that hearing the bass while he was singing his lower notes was much more difficult than hearing the tenors and the women. Could there be some Physics reason for this? What is it?

for a bass, the frequencies are very low, much lower than the knee frequency of the mouth. (the mouth diameter is about 5cm which would give a knee frequency of about 340m/s / .1m = 3.4KHz. A bass singer will sing down around 100Hz, which is 5 octaves below the knee frequency. Ie, this corresponds to an efficiency of -30dB. Compare this to a soprano who sings at around 800Hz for her fundamental, which is only two octaves below the knee frequency for an efficiency of -12dB, 18dB higher than for the bass. Of course this is not the whole story. The ear is also more sensitive around 1kHz than around 100Hz at the sound levels likely to be heard in an opera.

b) Why is an (unpowered) megaphone useful (consider the size of the radiating area)? Why do singers tend to sing with their mouths wide open? (It is not for the looks!)

In both cases the purpose is to lower the knee frequency and thus increase the efficiency of the sound radiated from the mouth. Note that the megaphone makes no difference to the energy created at the mouth or at the mouth of the megaphone (the energy goes as Area x velocity^2, and that product will be the same at the mouth and at the opening to the megaphone. Although the total energy goes as the area, the total energy coming out of the mouth is spread out over the area of whole area. However the efficiency of converting that sound energy near the mouth to sound far away is higher the larger the radiating diameter. Since the megaphone opening is probably around 50cm for a large megaphone, and the mouth has diamater around 2cm, the mouth's knee frequency will be around 340m/s / 2x.02m = 8500Kz, while the megaphone's would be about 340m/s / 2 x .5m= 340Hz. So, for the megaphone the sound would escape with unit efficienty for all frequencies about 340 Hz, vs falling at 6dB per octave for the mouth. Ie, at 340Hz, which is about 5 1/2 octaves below 8500Hz, or about 33dB quiter than from the megaphone.

c) Why, when you scream for help, do you open your mouth wide and scream at a high pitch?

Again, efficiency. The wider open the mouth, the lower the knee frequency (as in the last item, the knee freq for an open mouth is about 8KHz, and higher than that for a partially closed mouth.) Also since the efficiency increases as the pitch gets higher (6dB/octave), a high pitched sound will get out with higher intensity than a low pitched sound.

2. Figures 1 and 2 are the polar plot of the sound radiation intensity given off by a vibrating diaphram in a wall, at various frequencies. what is the the relative

intestity both as a ratio to straight ahead and as dB (relative to straight ahead) of the sound given off at 40 degrees for a frequency of twice the knee frequency? At 70 degrees? What are the relative intensities (compared to straight ahead) of the sound given off at 5 degrees and at 30 degrees for a frequency of eight times the knee frequency.

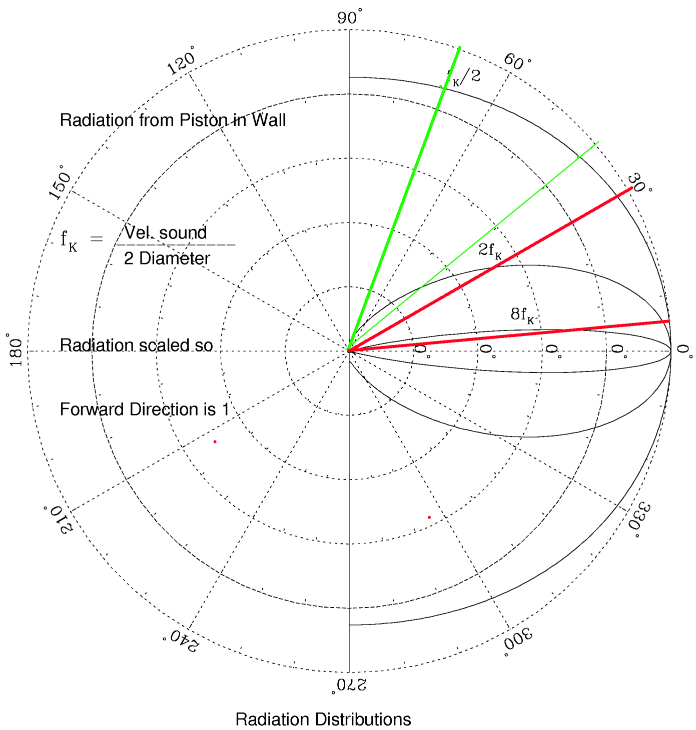

Figure 1

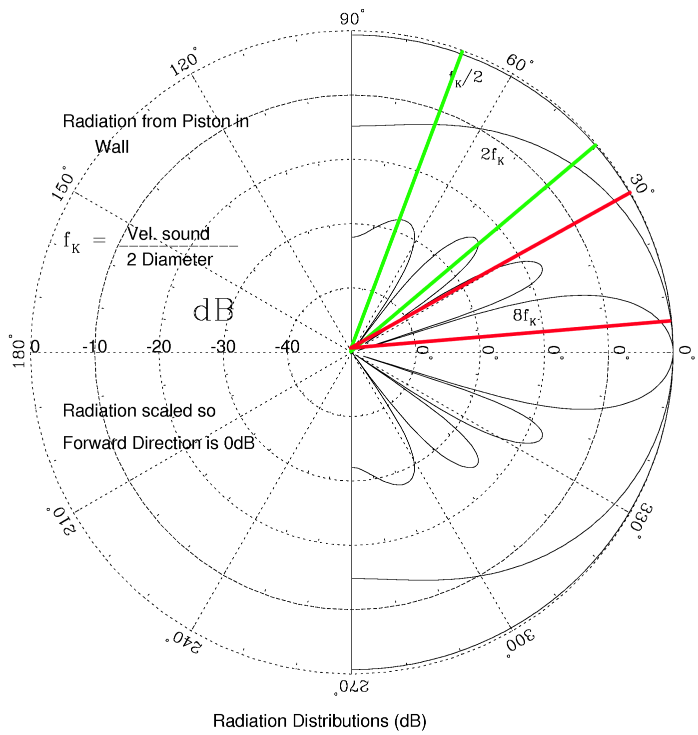

Figure 2

The green lines in the plots are at 40 degrees and 70 degrees for the twice knee freq, and the red lines are at 5 degrees and 30 degrees for 8 times.

40deg: from the (reletive intensity) first graph, The intersection with the $2f_k$ curve occurs at a radius of roughly .35. At 70 degrees, the intersection is very near the center, with perhaps something like .05, but it is hard to estimate. However, lookin at the green line at 30 degrees on the dB graph, apporx. -5dB. (which would be a fractional ratio of .32 which is close enough to the .35 read of from the fraction graph).

At 70 degrees it is essentially impossible to read it off from the fractioal graph, since it is too close to 0. From the dB graph, we get approx -12dB, which would be four powers of 2 (12=4x3, and 3dB is a factor of 2) so that would be 1/16 (1/(2x2x2x2))=.0625– no wonder it is hard to read off from the fraction graph.

For the $8f_k$ curve, at 5 degrees, from the fractional graph, I get about .75 as the fractional intensity. For 30 degrees, it is again totally impossible to read off from the first graph. From the second graph, I get about -23dB (each step from one circle to the next is 10dB) which is about .005 (3dB-¿ factor of 2 less than -20dB which is 1/100=.01. So 23dB-¿ .01/2=.005) which would be totally impossible to read off from the first graph.

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3. Why, when you take off your earphone and lay them on the table, do you suddenly stop hearing the bass, and all you hear is a very tinny high pitched sound?

Again, knee frequency. The earphones lying free have a very high knee frequency (the speaker is of the order of cm in size so the knee frequency is above 10KHz). On the ear, the phones directly drive the eardrum, so their effiency is unity all across the band. On the table the efficiency of such a small speaker falls at 6-12dB/octave(depending on how well the osund from the back of the phones is aborbed) and thus only the high frequencies get radiated.

4. A loudspeaker has a free air (ie outside of any box) resonance of 100 Hz. What would you expect to happen to that resonance if you mounted the speaker in a box enclosure. How would you expect that frequency to depend on the size of the box? Why is it it impossible to get good bass response from a small box?

When the speaker is in the box, its compresses and rarifies the air inside the box as it vibrates. This compression of the air increases the stiffness of the vibration of the cone, which increases the frequency of resonance of the cone. Thus even if the speaker has virtually no natural stiffness (a very loose mounting) this air stiffness will make sure that the resonance of the cone will be at a fairly high frequency. In the 1950 a speaker manufacturer, Acoustic Research (AR) developed a line of speakers called air suspension speakers where the natural stiffness was very low, and almost all of the restoring force (stiffness) came from this air compression, in order to get the lowest possible frequency from their speakers. The smaller the box, the stiffer the air suspension would be, making it very difficult to get a low frequency from a speaker. Thus good bass (down to say 50 Hz) requires a box at least 20 litres or more in size, and to get even lower bass, a bigger box (the frequency goes as the square root of the box size, to get down to 25Hz would require about 100 litres of box volume)

5. How much louder would a loudspeaker with 4 speaker cones vibrating be than a loudspeaker with just one of those same speakers? What would happen if you miswired one of them so that the motion was out of phase with the other three? How about if you put stacked 20 of them all wired with the same phase? (recall what you know about adding sounds together.)

Recall that it is the amplitudes that add, not the intensities if all the speakers are "in phase" (as they would be if properly wired up and fed from the same source.) Thus the amplitude would be 4 times as large, and the intensity would be 4x4=16 times as large. Since each factor of 2 is 3dB, 16, which is 2x2x2x2 would be 12 dB louder.

If you miswired one of the speakers out of phase, it would cancel with one of the neighbours, meaning that the sound would only be 2 the amplitude of 6dB louder.

If you stacked 20 the amplitude would be 20 ties as large, and the intensity would be 400 times larger. 400=2x2x10x10 ==¿ 3+3+10+10 dB= 26dB louder. That is a lot.

Note that one would have to be located such that the time difference to your ear from the various speakers is the same (or is less than about 1/4 of a period different) so that the travel time from the speakers to your ear did not produce a phase shift. This would certainly be true for the bass frequencies, which have a long period and large wavelength. For the higher frequencies, this woould no longer be true. The higher frequencies would tend to beam, for the same reason that the high frequencies from a single speaker would tend to beam. Ie, the people right in front of the speakers would get a higher intensity of high frequency sound than people off axis. The size of the array would play the role of determining the "knee frequency" for purposes of beaming.

6. Since people like bass sounds, some loudspeakers are designed so that one can use the sound from inside the box to augment the sound from the speaker at low frequencies. This is done by cutting hole into the box, and either inserting carefully constructed length of tubing into the hole (Bass Reflex loudspeaker). This gives the air in the box a "coke bottle" resonance. What would lengthening or shortening the length of the tube do? What is the phase of the motion of air in the tube with respect to the air in the front of the speaker i) at frequencies well below resonance, ii) at resonance iii) well above resonance. HOw would the sound from the air in the hole combine with the sound from the front of the speaker in these three cases.

The "bass reflex" hole acts like the sound hole in the guitar or violin. As the speaker moves back and forth, it increases and decreases the pressure inside the box. The hole in the box acts like the neck of a coke bottle, and the air in the hole has a natural frequency of vibration. Below that resonant frequency, the air in the hole will move out and in in phase with the motion of the back of the speaker. That is out of phase with the air coming from the front of the speaker, cancelling out the sound (because the hole is almost always smaller than cone, the efficiency will mean that the cancellation is not complete). As one gets to the natural frequency, the air in the hole is 90 degrees out of phase with the motion of the front of the speaker, and will thus no longer cancel, and will augment the sound from the front. If the Q is high (higher than about 1 or 2) this vibration will dominate over the sound from the speaker itself. As one gets above the natural frequency the air in the hole will now go into phase with the motion of the front of the speaker, adding to it. However the amplitude of the osciallion will fall. If one designes everything just right one can extend the frequency response of the whole system by about an octave, or just a bit less. A well built bass reflex can thus produce more bass. A poorly constructed one will however tend to produce a "boomy" bass with a one bass frequency strongly accentuated by the resonance and near by frequencies not very much. Listening will sound like it has "lots of bass" but it will get very tiring quickly, because the pitch of that bass is always the same (that of the "coke bottle" resonance of that hole in the box).