Phonetics and Phonology: A broad Overview
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Lecture 11
Acoustic Analysis 4

Hello, and this is a continuation of the lecture on formants and we are continuing with the course NPTEL MOOC course, Phonetics and Phonology: A Broad Overview.

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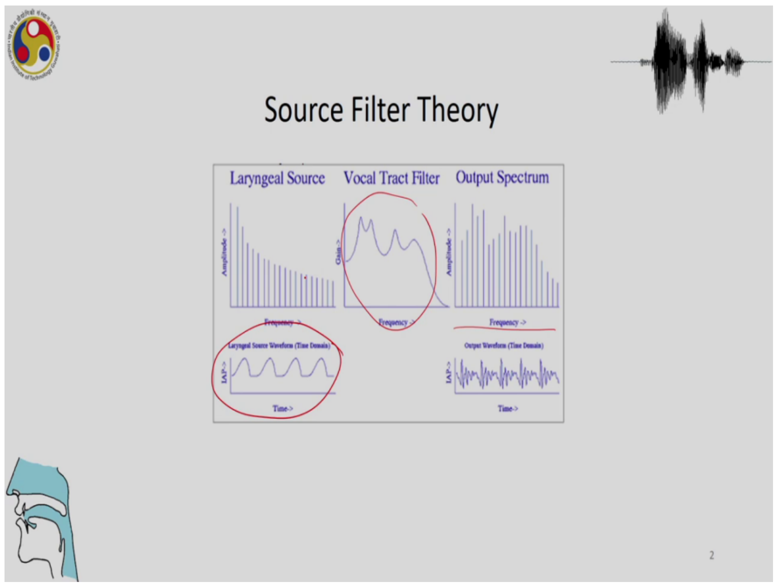

So, we have learned that the glottal source has sinusoidal components, and we saw that these sinusoidal components then go through the filter, and as a result we have the output spectrum. And this is a laryngeal source. And with the sinusoidal components, which undergoes through the vocal tract filtering, which has the vocal tract with its own resonances filter, the sinusoidal components, as a result, we have the output spectrum, which has properties of both the filter and the source.

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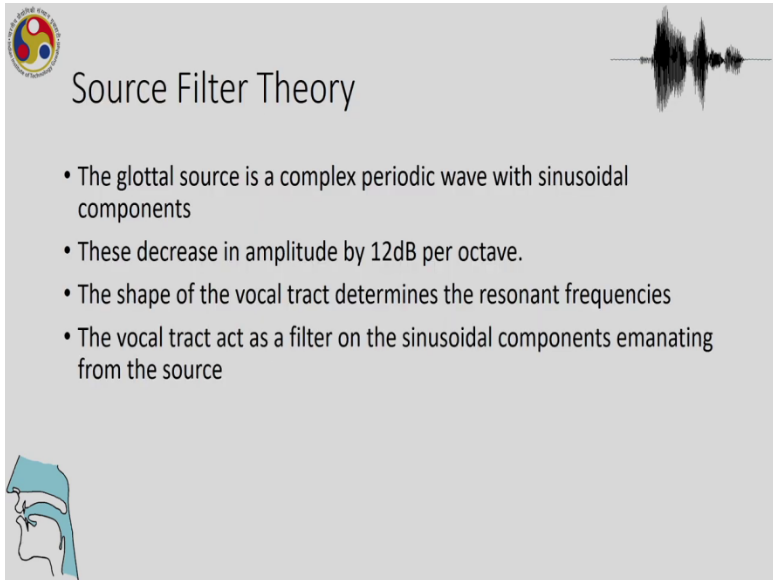

So far, we saw when we were looking at source filter theory, and the components decrease in amplitude over by 12 decibels per octave. And the shape of the vocal tract determines the resonant frequencies, which you already know. And the vocal tract act as a filter of the sinusoidal components emanating from the source.

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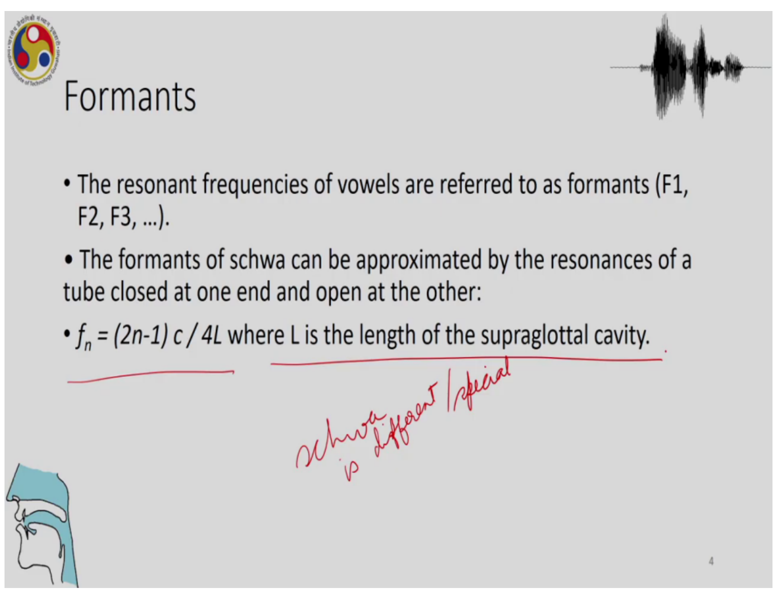

And we also know that the resonant frequencies of vowels are referred to as formants. And it is F1, F2, F3 and so on. And where F1 and F2 are generally considered the most important for the analysis or the quantification or finding out the most relevant formant frequencies of vowels. The formants of schwa can be approximated by the resonances of a tube closed at one end and open at the other. So, the schwa is sort of different, schwa is special, because it can tell you about the length of the vocal tract.

So, the formants of the schwa can be approximated by the resonance effective closed at one end open and the other and which is not relevant for all the other vowels. So, we see a formula here, which says fn is equal 2n minus 1 multiplied by c divided by 4L, where L is the length of the supraglottal level cavity.

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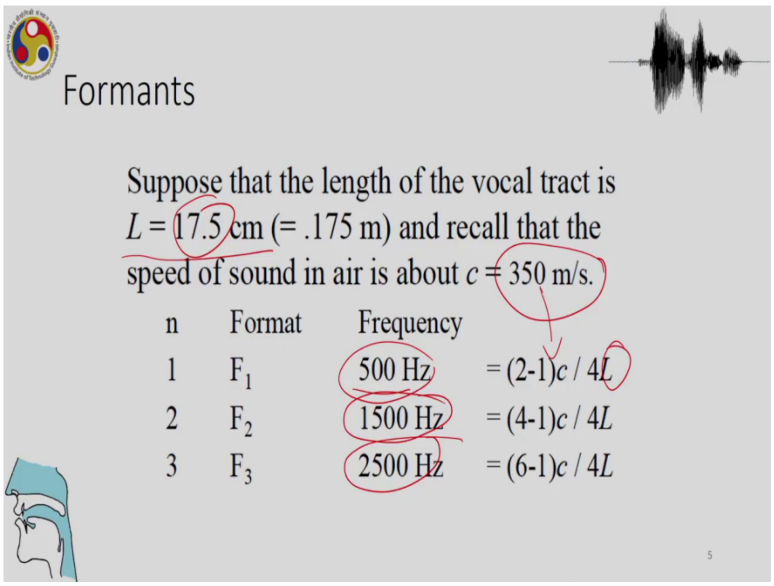

So, suppose that the length of the vocal tract is 17.5 centimeter, and we have to recall that the speed of sound in air is about 350. Suppose, we take into account these 2 values, and put the values irrelevant values here, so this value for c and this value for L.

And then as a result, what are the frequencies that we will get, so if you use these values, you will find that, the first formant will be 500 hertz, the second formant and will be 1500 hertz, and the third formant will be 2500 hertz, and we are talking about the schwa. So, this is good to remember that the idealized values for the frequencies of a schwa will be at the most neutral state of the vocal tract will be 500, 1500, 2500 hertz.

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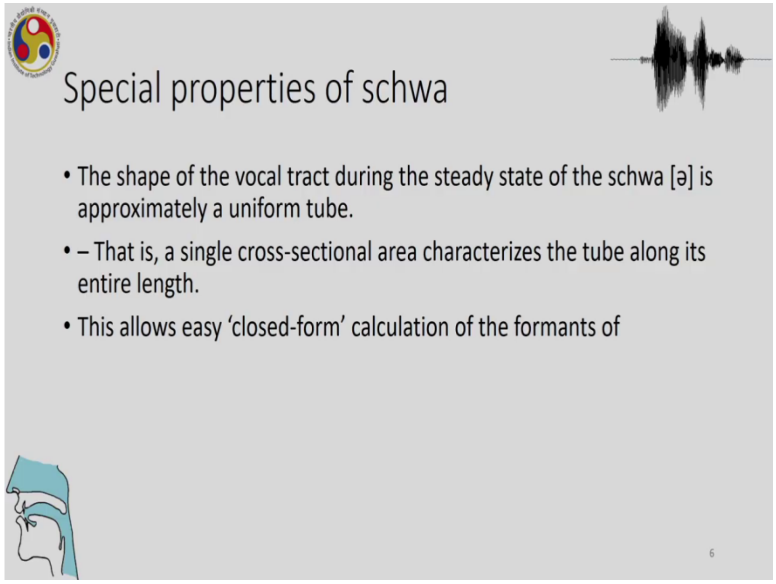

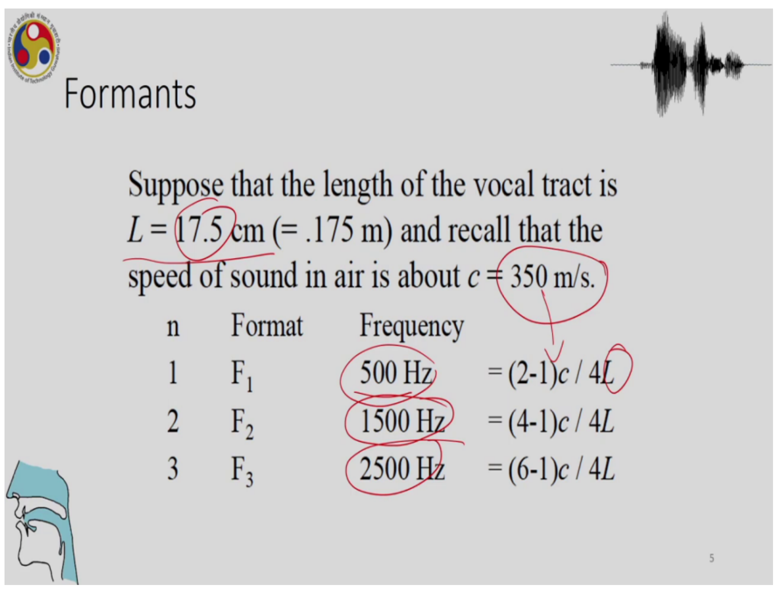

And these are, as I have been saying that the schwa has special properties. And therefore, the shape of the vocal tract during the steady state of the schwa is approximately a uniform tube, which cannot be said for the other vowels. That is a single cross sectional area that characterizes tube along with its entire length.

So, it is a single area, and we will see that it cannot be said for the other vowels, and we need more cross sectional area that we will talk about when we talk about the other vowels. So, this allows for a closed form calculation of formants of the schwa. And as a result, these are the predicted values of a schwa, that this is 500, 1500, 2500 hertz.

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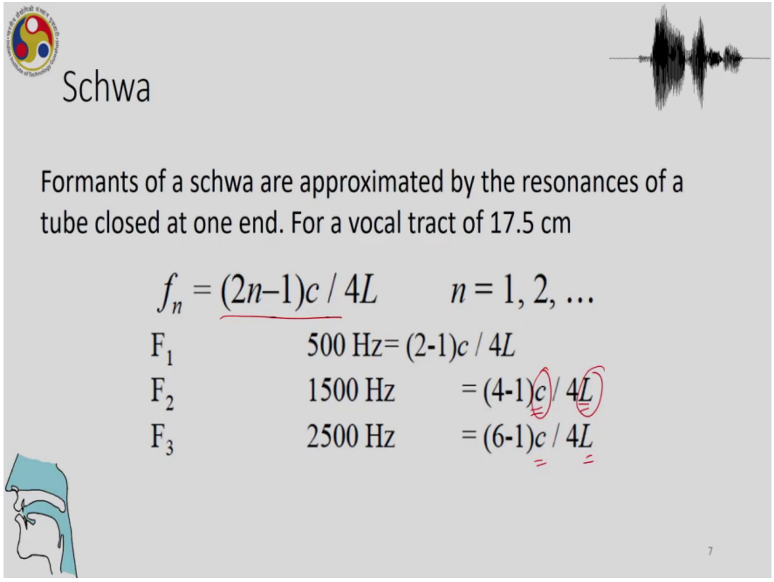

So, as we have been saying, formants of shwa are approximated by the resonances of a clear tube close at one end. And for vocal tract of 17.5 centimeter, we have these values for the schwa again. So, where we use the speed of sound here and the length of the vocal tract for the values, for value of c we used a value the speed of sound, value for L we use the value for the length of the vocal tract.

And so, this is our formula, where 2n minus 1 is multiplied by c and just divided by 4L. And this formula is actually used for the calculation of the formants, where the tube is closed at one end, as we will see. But then, the model of formant calculation that we are talking about is a tube model, assumes more than one tube for most of the vowels.

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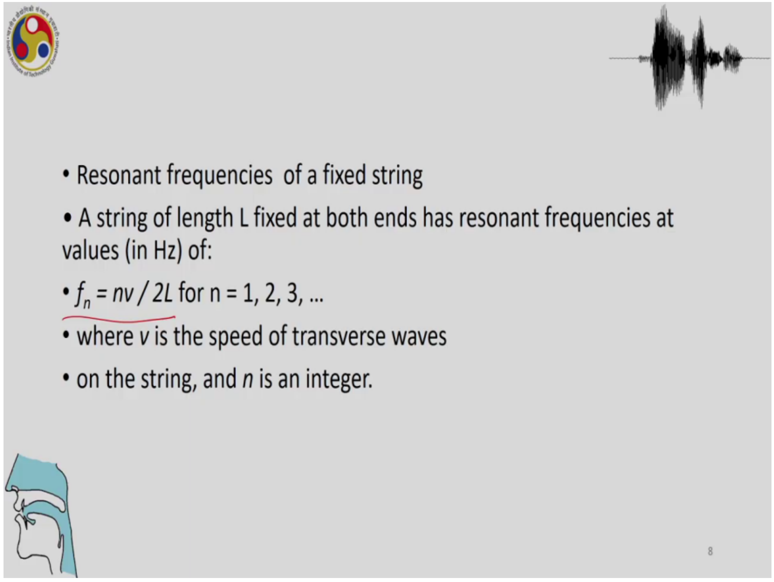

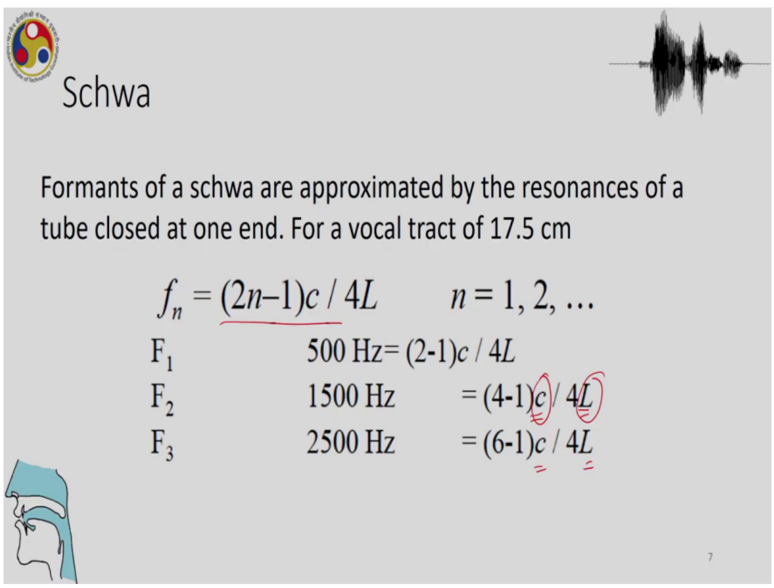

So, another thing that we have to remember when we are talking about formants standard, whereas we saw that this is the formula which is used for the calculation of, of the schwa, that is 2n minus 1 multiplied by c divided by 4L. And that is the formula which is used for a tube closed at one end. But when we are talking about resonant frequencies of a fixed string, that is, both ends are close.

So, this is the formula that we use at fn is equal to nv by 2L. And where v is the speed of the transverse waves on the string and n is an integer multiple, which is, which could be 1, 2, or 3.

And so, this is the difference between a tube closed at one end, and a tube, which is closed on both ends like a fixed string.

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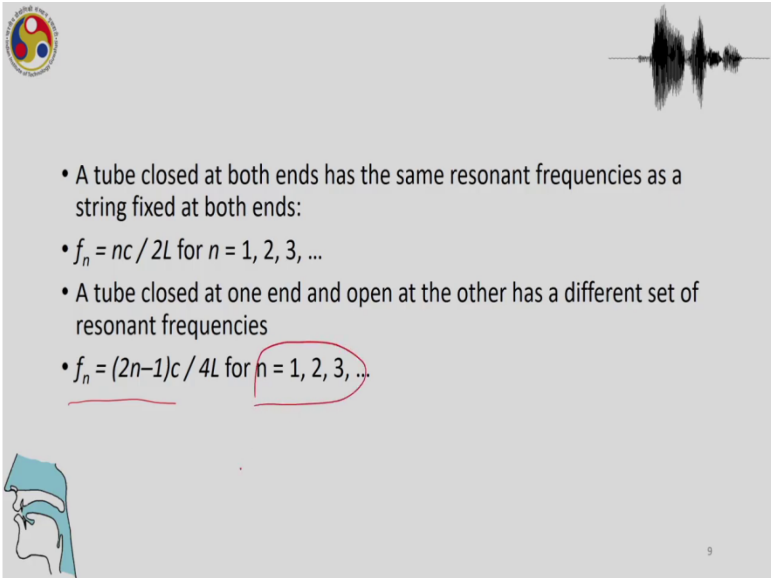

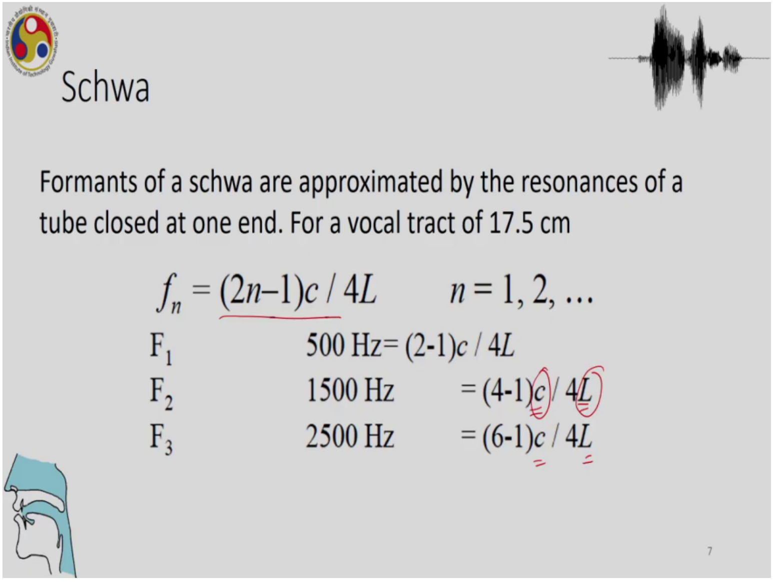

So, as we have just mentioned, a tube closed at both ends has the same resonance frequencies as a string fixed at both ends. And a tube close at one end, and open at the other has a different set of resonant frequencies. So, if n equals 2n minus 1 multiplied by c divided by 4, divided by 4L, where n is equal to 1, 2, 3, etc. This was, what was used for the calculation of the formants of the schwa, as you can see, and again, that is use for all the vowels, where tube is closed at one end.

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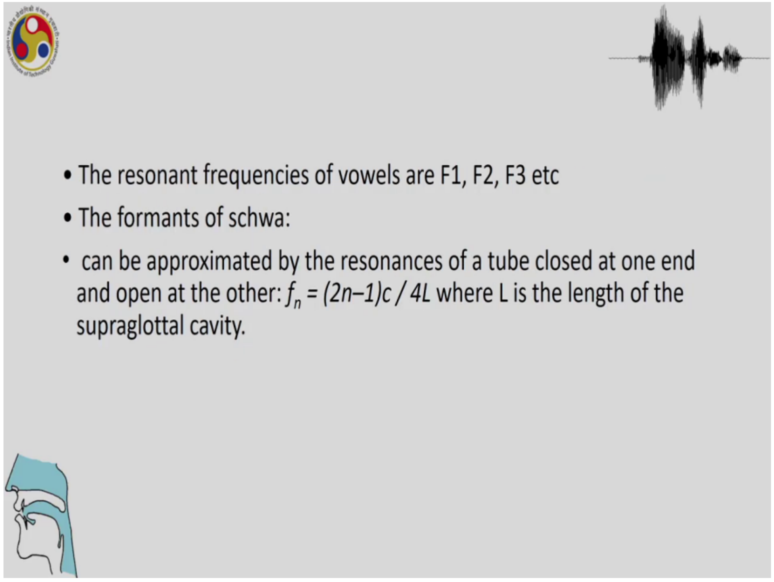

So, the resonant frequencies of vowels are F1, F2, F3, etc. And the formants of the schwa can be approximated by the resonances of a tube, close at one end and open another, where L is the length of the supraglottal cavity.

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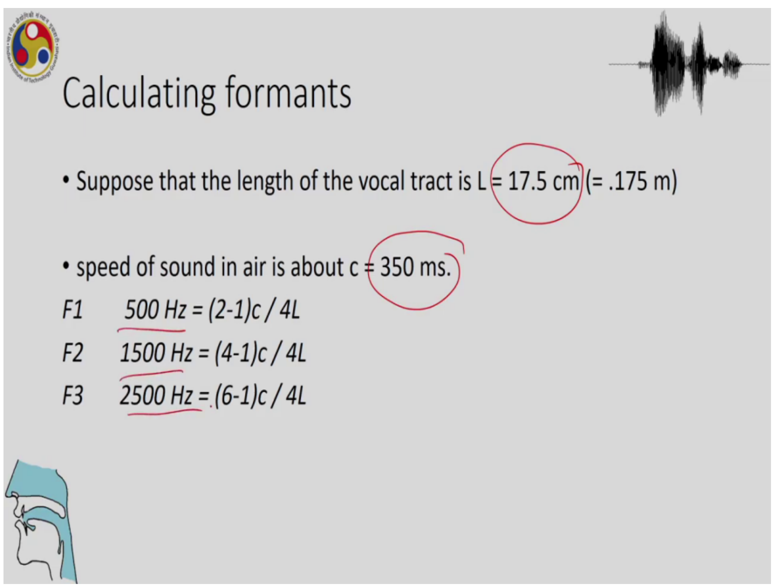

And that is repeating what we saw a while ago, that if we assume that this system of speed of sound in air, and this is the length of vocal track, then these are the values that we get for the schwa.

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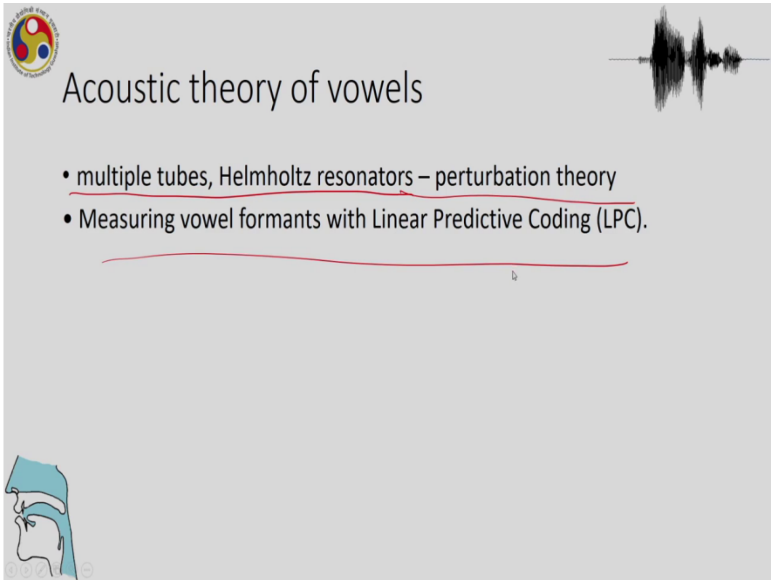

So, the general acoustic theory of vowels is more complex than that. We assume multiple tubes, Helmholtz resonators, and perturbation theory etc. So, and apart from that, measuring vowel formants with linear predictive coding. So multiple tubes is one Helmholtz resonators, something which we will talk about now. And measuring vowel formants with linear predictive coding is not a part of this lecture.

So, the thing to remember is that the tube models that we will talk about now predicts the kind of formants that you will find in different vowels. And, measuring a vowel formant with linear predictive coding is actually how formants are measured.

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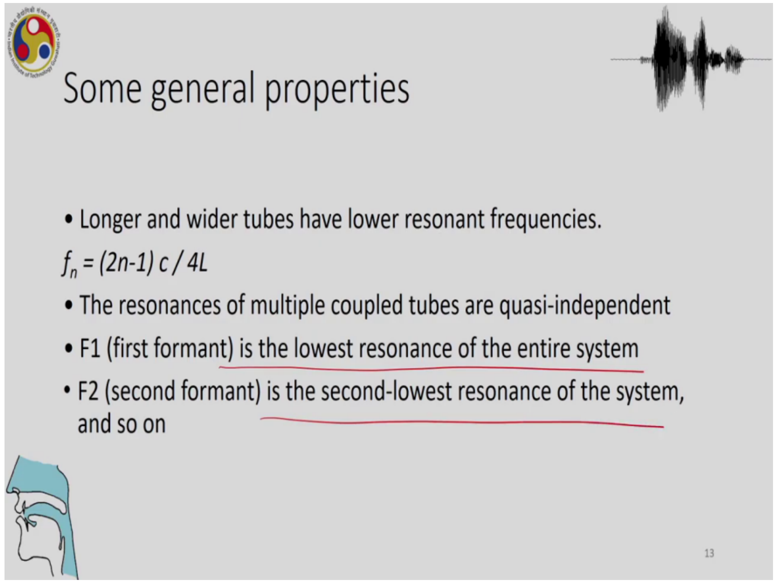

So longer and wider tubes have lower resonant frequencies. And that is why the integer multiples 1, 2 and 3 are used for the different formants. And the resonance is a multiple couple tubes are quasi independent. So, and the first formant and is the lowest resonance of the entire system, and the second lowest resonance of the system and so on. So, this is a general property, let us just assume that lowest F1 is the lowest resonance of the entire system. Now, what does that mean, we will see that gradually in this lecture.

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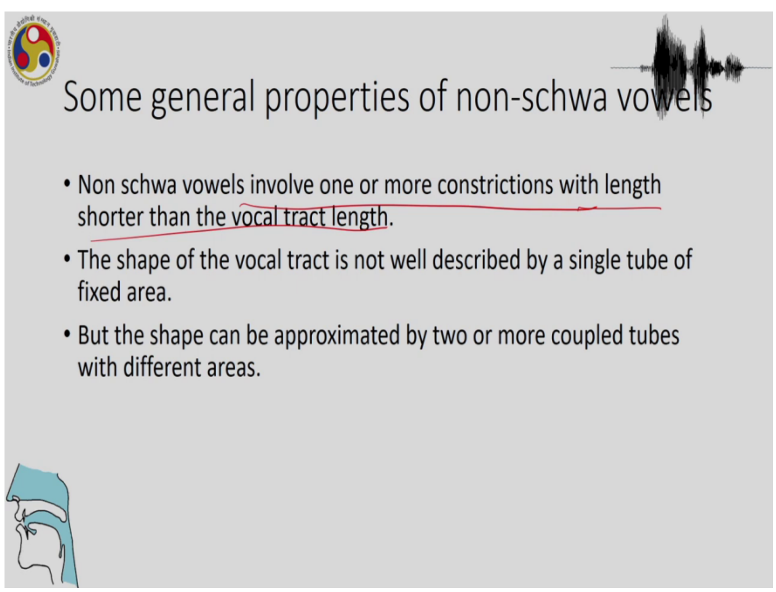

Non schwa vowels involve a one or more constructions with length shorter than the vocal tract length. And the shape of the vocal tract is not well described by single tube of fixed area, but the shape can be approximated by two or more couple tubes with different areas. So, as we just mentioned, that non schwa vowels involve more constriction. So remember, the cross sectional area that we talked about the schwa was uniform, it is the most neutral state of the vocal tract, but the things could be more complex for other vowels.

So, and that is why they involve one or more constrictions with length, short shorter than the vocal tract length. And the shape of the vocal tract is not well described by single tube of fixed area. So it is, remember that to calculate the formants of the schwa, we just took into account the length of the vocal tract. What we are going to show now is that we cannot do that for all the vowels, because, as we have just mentioned, for the production of the schwa, we have the most neutral state of the vocal tract and the entire vocal tract, the length of the entire vocal tract can be taken into consideration for the calculation formants.

However, it is not so for the other vowels, and they involve more constrictions with lengths which are different and mostly shorter than the vocal tract length. And that is why they are different from the schwa. And the shape of the vocal tract is not well described by single tube of fixed area, the shape can be approximated by 2 or more couple tubes with different areas.

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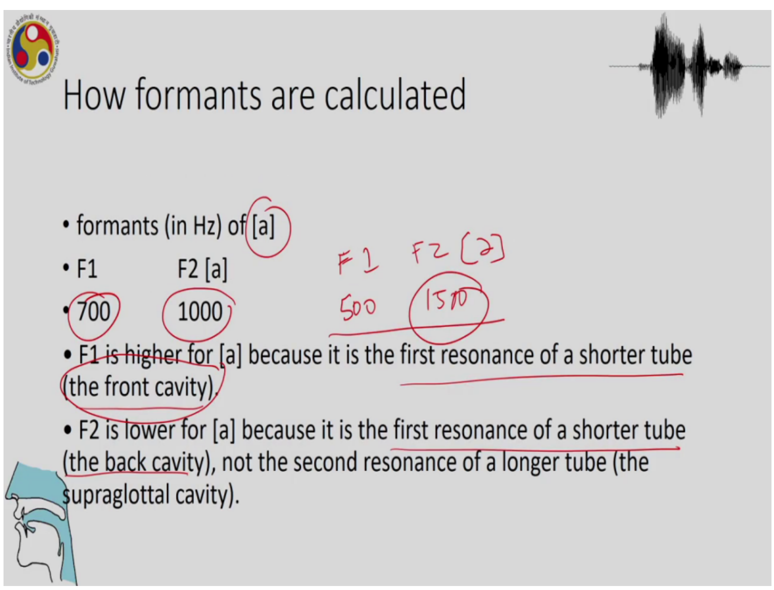

And let us talk about other vowels now, and if we compare suppose the formants of r with the formants of the schwa. So, F1, F2, or schwa would be 500 and 1500 hertz, compare this to the formant frequencies of the vowel r. So F1 is higher for r because it is the first resonance of a shorter tube and which is the front cavity. So, recall when we studied articulatory phonetics, that these are different cavities, which are involved in the production of the different vowels and F2 is lower for r because it is a first resonance of the lower than the schwa.

So, while F2 for r is 1000 F2 for schwa a is 1500. And again, 1 is higher, and F2 is lower. F1 is higher, because it is the first resonance shorter, much shorter to than the vocal tract. And F2 is lower for r because it is the first resonance of a shorter tube of the back cavity and not the second resonance of a longer tube. Now, these values are therefore the schwa because these are the result of the same tube, because this is the first resonance and second resonance of a long tube 500 and 1500.

But suppose we take into consideration a vowel like r the formant frequencies of this vowel is going to be different, because this is the resonance of a shorter tube and first resonance of a shorter tube and first resonance of a shorter tube of the back cavity and this is the front cavity. So, the two cavities are involved in the production of the vowel r unlike the schwa.

So, this is how a tube model predicts formant frequencies of different vowels based on the different tubes, which are involved in the production of the vowels their resonant frequencies.

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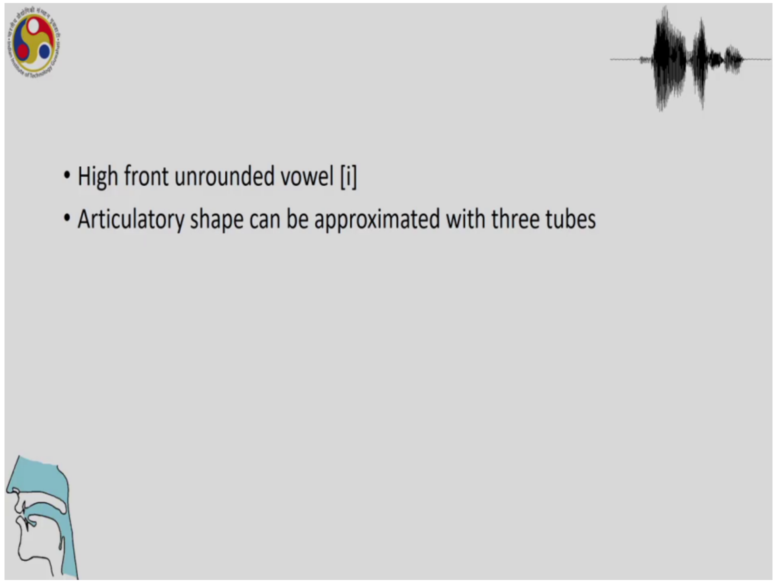

So, suppose the high front unrounded i. And here we can actually talk about 3 tubes, the resonant properties of the vowel i can be approximated with 3 tubes.

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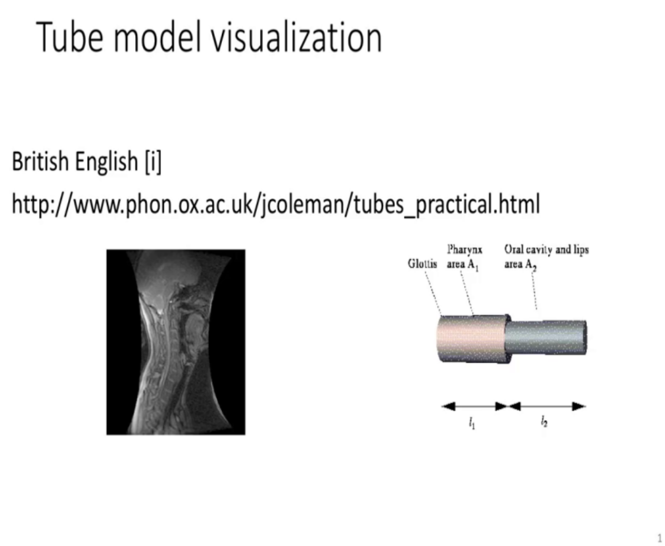

So, this is a visualization of i and we can see that this is a British English production of i. So, this is aware this is been taken from so, if it is a i vowel, then the different cavities which are used the front cavity, the back cavity, and also the glottal. So, we have the pharyngeal area, we have the oral cavity and lips and all these different parts of the production of the i will be relevant that their resonant frequencies will be relevant in the approximation of the formants for this vowel.

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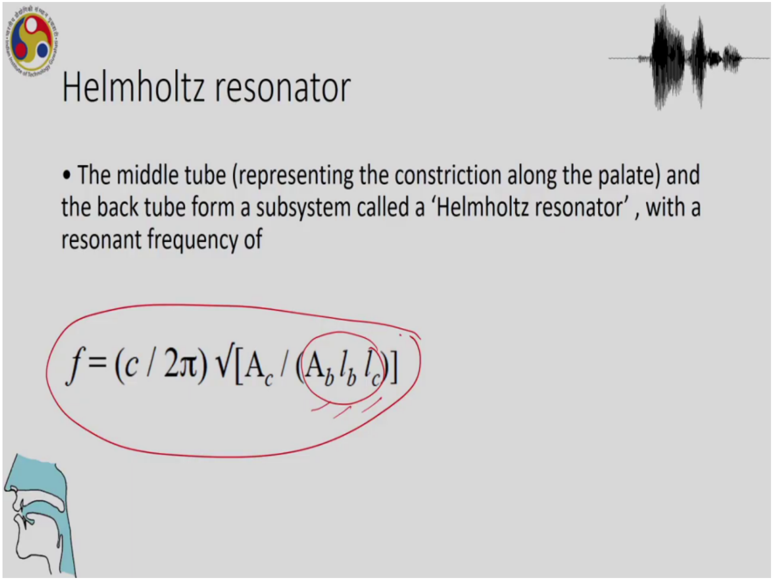

So, importantly, now, we come to an important part of this which is called the Helmholtz resonator. So, there is a middle tube in the production of i, which is representing the constriction along the palate and the back tube form a subsystem called the Helmholtz resonator, where this formula is used for the calculation of that resonant frequencies. So, recall that we are talking about 3 tubes here and the length of the 3 tubes will be relevant in the calculation of the resonant frequency of the Helmholtz resonant.

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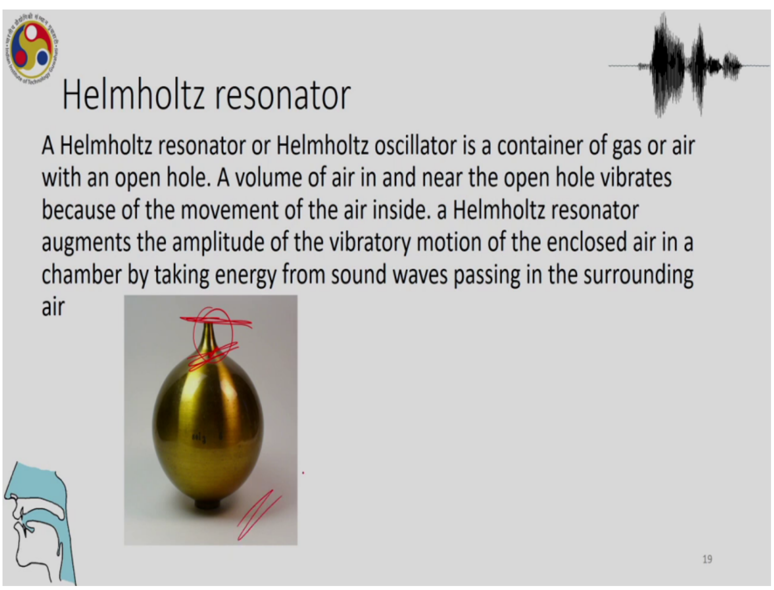

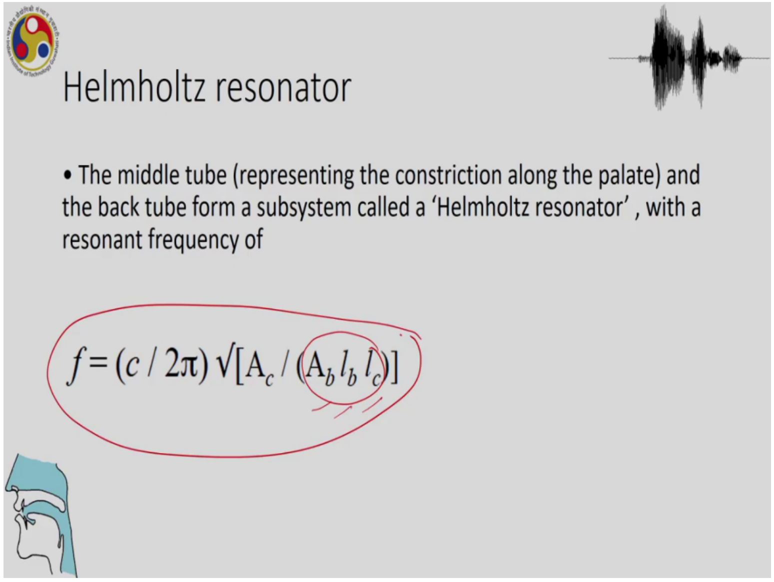

Now what is a Helmholtz resonator? So it is actually not something which was originally meant for the description of formants. So, this is something attributed to Helmholtz and Helmholtz resonator or Helmholtz oscillator is a container of gas with an open hole like this and the volume of air in a near the hole vibrates because movement of the air inside.

And it is said that the Helmholtz resonator augments, which is increases the amplitude of the vibratory motion of air enclosed, of enclosed air in the chamber, this one increases here by taking energy from sound waves passing in the surrounding air. So basically, there is a, there is a springiness in the air trapped in this resonator. So, this is what Helmholtz resonator actually looks like. And, the middle tube of the production of the vowel i, is supposed to approximate a Helmholtz resonator. And this technically, this is what a Helmholtz resonator is.

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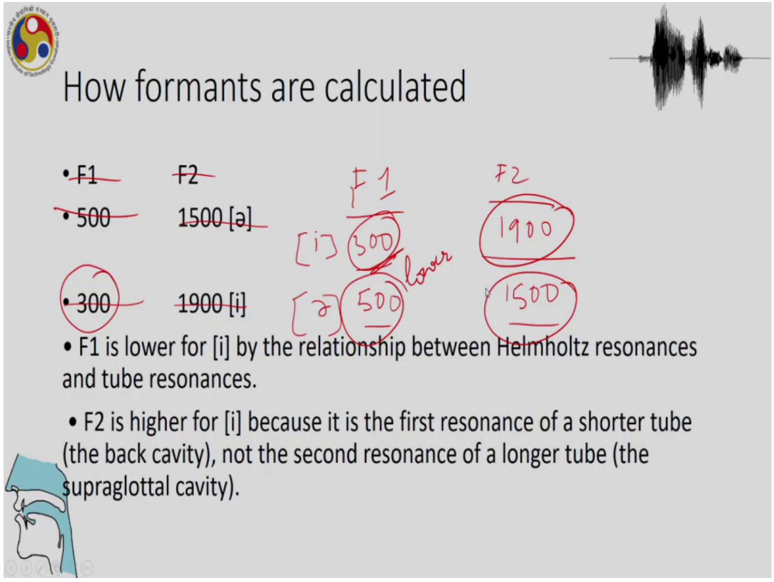

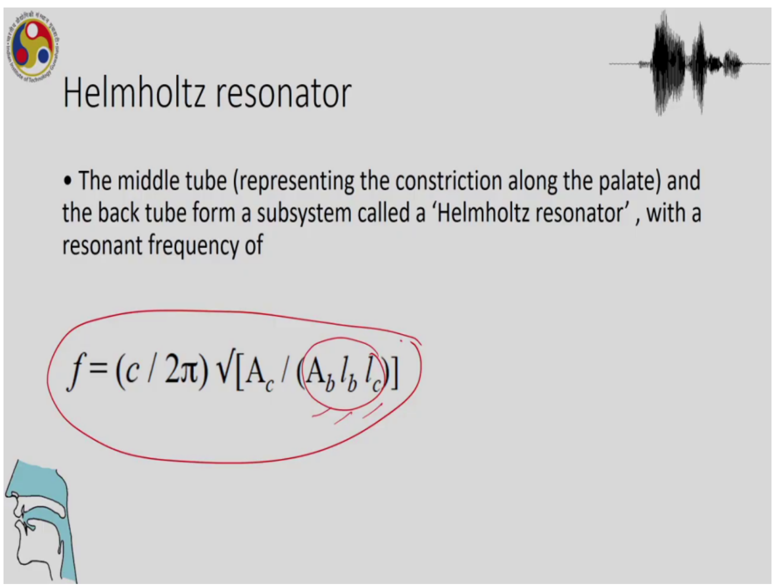

So, as you can imagine that the additional tube that appears in the vowel i is a bit more complex than the formula that we had seen for the calculation of the other two vowels schwa and a. And so F1 is lower for i by the relationship between Helmholtz resonances and tube resonances. And that is why always we will find that the F1 for the vowel i is always much lower. So, I beg your pardon, there is a mistake here. So, the F1 and F2, so F1 for i is 300 hertz, and F1 for schwa, as we already know, is 500 hertz.

So, this is E, this is schwa and F2 for i, the vowel i is much higher at 1900. And it is lower for the vowel schwa, at 1500. So, these two vowels we have i, he has these two formant frequencies and schwa has 500 and 1500. So F1 is lower, as we can see, this one is only 500 for a and only 300 for i. So, this is lower, I has lower F1 but I has much higher F2 with 1900 because it is the first resonance of a shorter tube, the back cavity and not the second resonance for longer tube.

So, like the supra glottal cavity of the schwa. So, the reason why F1 is very low for a high front vowel like i is because of the complicated relationship between Helmholtz resonances, and tube resonances.

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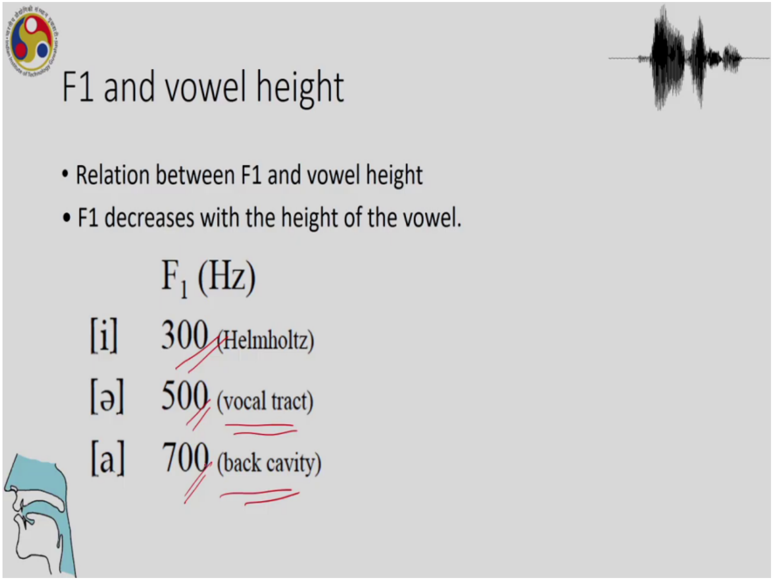

And relation between F1 and vowel height F1 decreases with the height of the vowel. And as we can see, because of Helmholtz resonator, the i has always a very high F1. Then the schwa, which is the vocal tract is responsible for the F1 of the schwa. And the bat cavity is responsible for the higher F1 for the vowel a.

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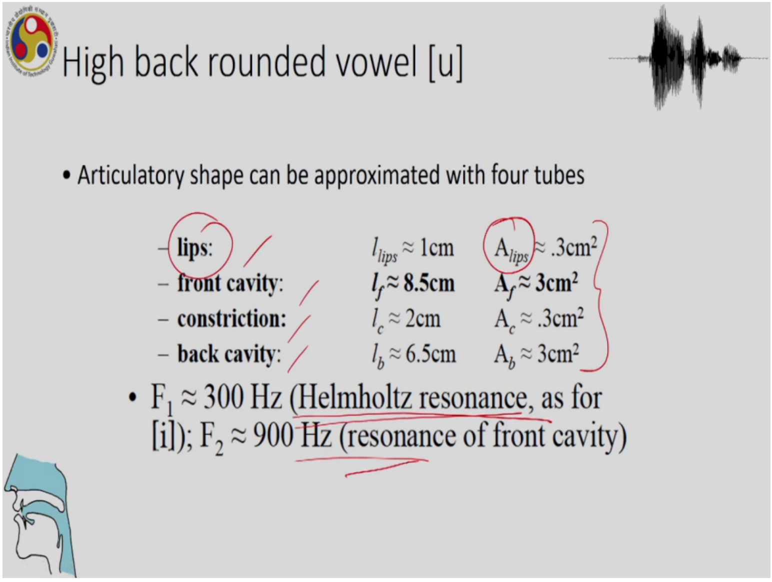

So, now when we talk about the high back, rounded vowel, u. So the articulatory shape can be approximated with 4 tubes. So, we have the lips, the front cavity, the constriction and the back cavity. So, the initial property of the lips is relevant here, because u, is a rounded vowel. And so, we have the front cavity, the constriction and the back cavity.

Now, for F1, like i, which produces a very low F1, like 300 hertz because Helmholtz resonance and F2 around 900 hertz, the resonance of the front cavity. And if we talk about u, then comparatively, now we have to take into account the lips, again, which is another tube, because the lips give additional shape to a vowel like u.

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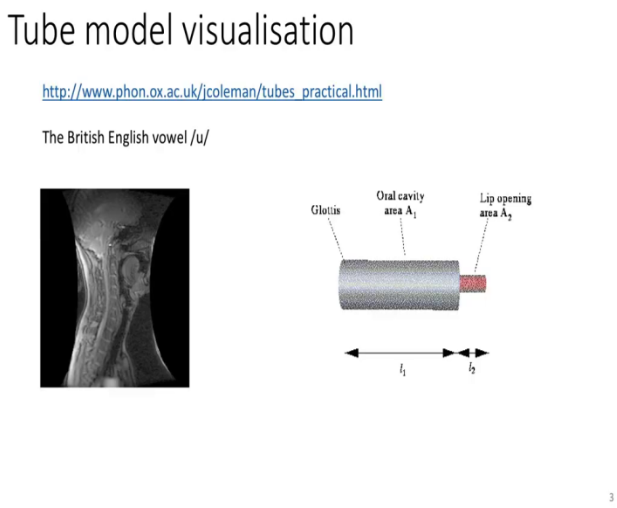

So again, for a while, like u, recall that we have the lips as additional tubes. So, we have the oral cavity, the pharyngeal with the glottis. So, we have all these tubes responsible for the production of the British English u.

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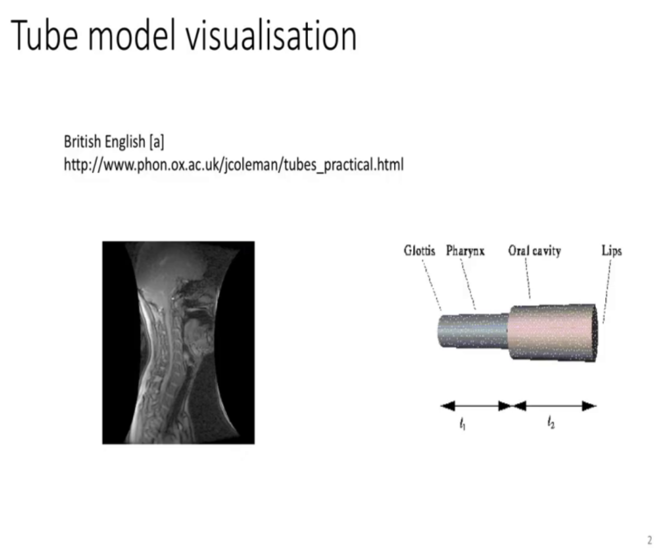

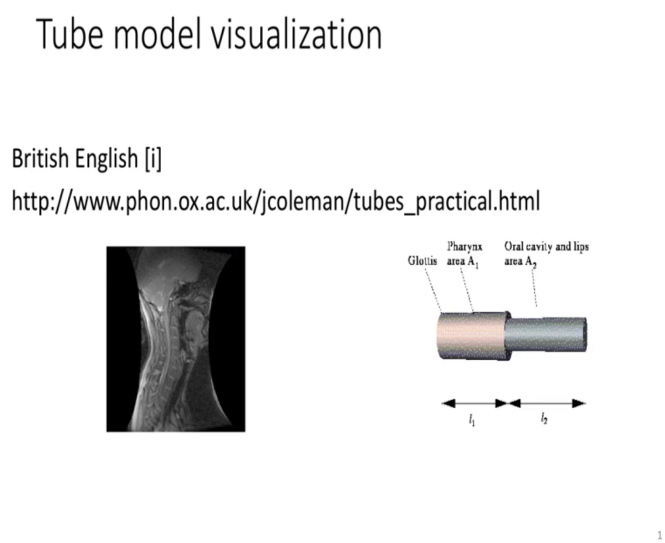

And this is something that we would use for the production of British English a, so notice that there is a difference in the x rays that you see alongside the tubes for the production of these vowels. So, we have r, so when the jaw goes down, and we have the back cavity there and unlike this one, where I, so there is a striking difference between the i and the r, where the back of t is more prominent.

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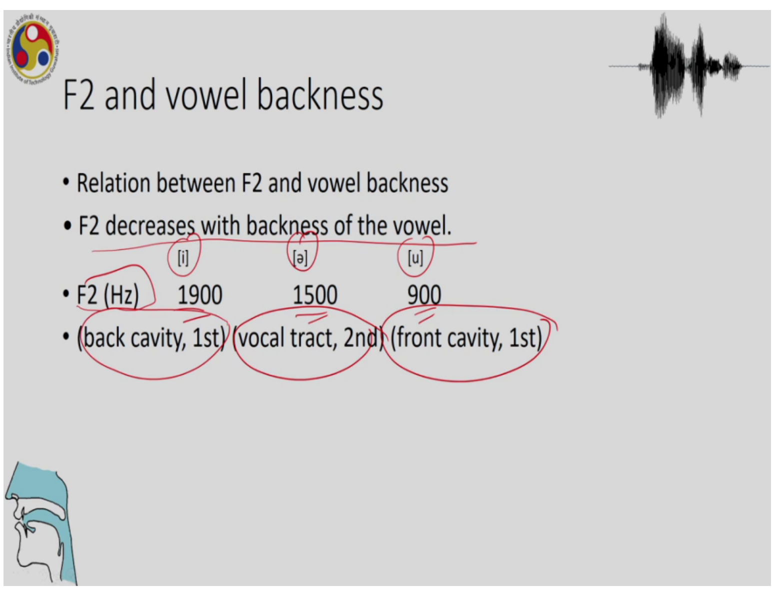

And the relation between F2 and vowel backness F2 decreases with the backness of the vowel. And these are the F2 values of the 3 vowels here e, a and u. And so, we have 1900 hertz, we have 1500 hertz, as we already know, and u at 900 hertz. So, now we note that u has a much lower F2.

And now it is important to note that, and we have already noted that this in all the other previous lectures, that the F2 the formant frequency the second formant frequency decreases with the backness of the vowel.

So here, this is for the production of the vowel u, the F2 decreases the backness of the vowel because it is the first resonance of the front cavity. And for e, it is the first resonance of the back cavity. And for the vocal tract, and for schwa, this is a second resonance of the vocal tract, supraglottal.

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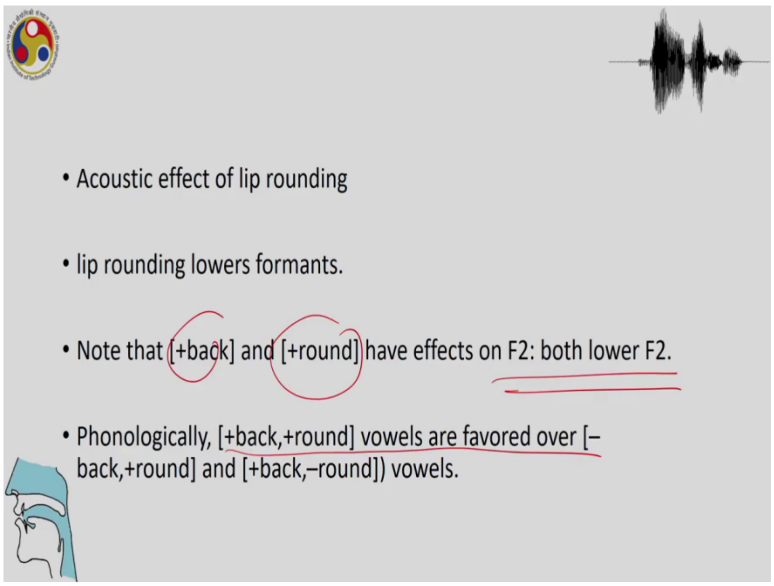

So, acoustic effect of lip rounding, lip rounding lowers formants. Note that the features plus back and plus round have effects on F2 both lower the second formant. So, not phonologically, again, when we look at phonology, we will again see that plus back plus round vowels are favored over, minus back vowels which are not back but round, and plus back and minus round vowels and also back vowels which are not rounded. So basically, the features back and round go together, and the features front and unrounded go together.

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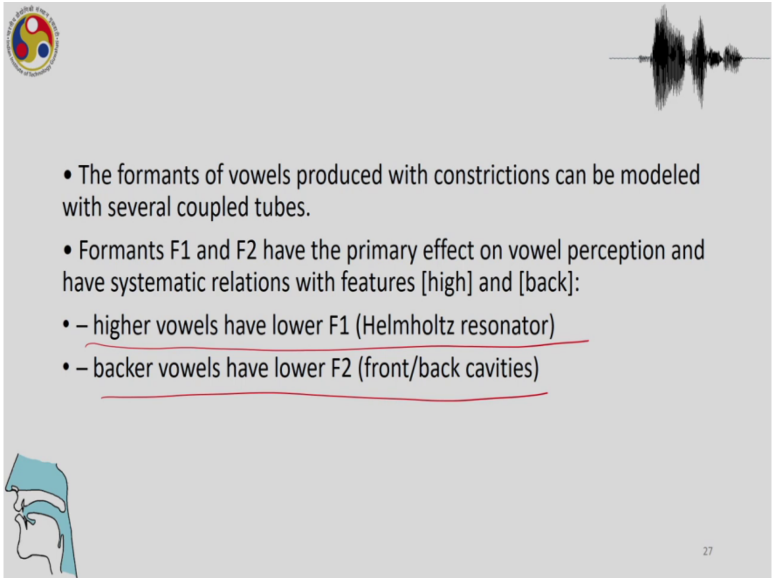

And that is related to again, the behavior of the tubes where one augments the other. So, the formants of vowels produce it constrictions can be modeled with several couple tubes, as we already know. And formants F1 and F2 have the primary effect on vowel perception and have systematic relations with features high and back which we will study in phonology. But, something that we will again, emphasize here again is that higher vowels have lower F1 and backer vowels have lower F2 because of the different cavities front and back cavity.

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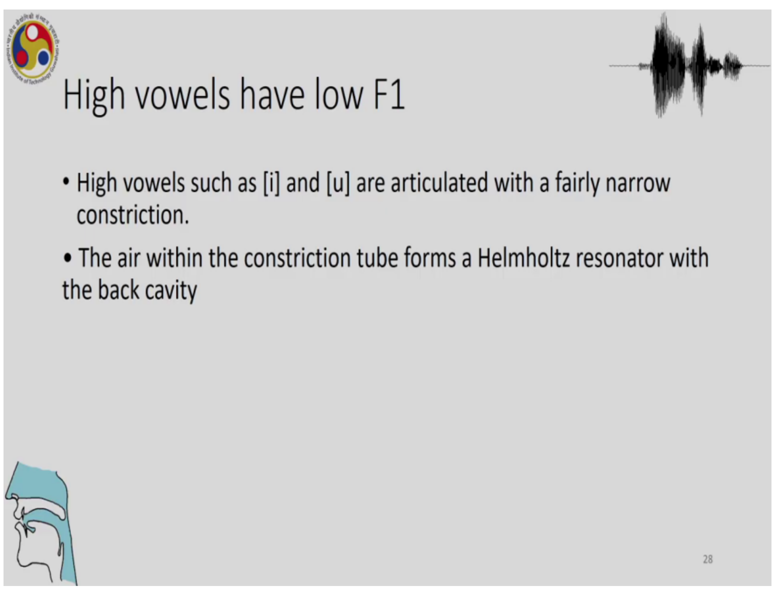

And high vowels have low F1 because high vowels are just i and u, articulated with a fairly narrow constriction and the air within the constriction tubes forms the Helmholtz resonator with the back cavity.

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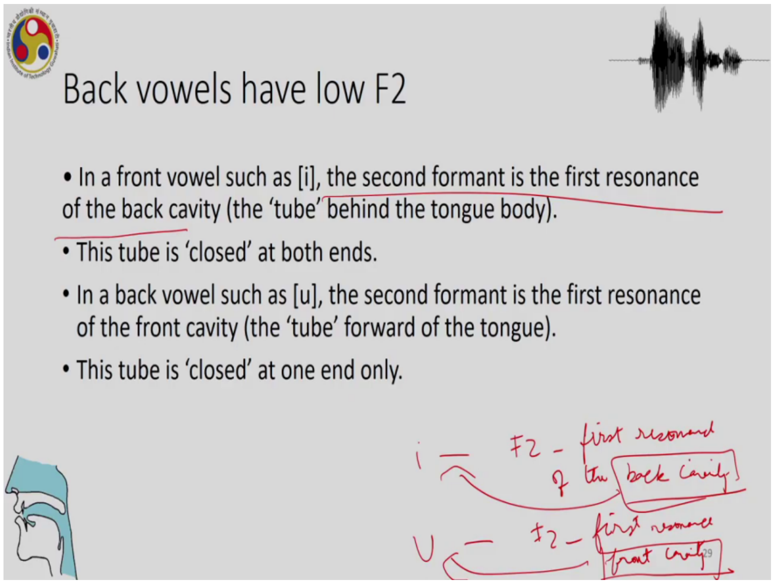

In front vowels, which is e the second formant is the first resonance of the back cavity, and that is the tube behind the tongue body. So, that results in the second formant and it is the first resonance of the back cavity which we had seen earlier. And this tube is closed at both ends. So, we know the formula for the tube closed and both ends. And in aback vowel, which is u, the second format is the first resonance of the front cavity. So, this is altered for u, it is the first resonance F2 is the first resonance of the front cavity that is, the tube forward of before the tongue.

And again, for a vowel like e, F2 is the, so for a vowel like e, F2 is the first resonance of the front cavity for a vowel like u, F2 is the first resonance, first resonance of the front cavity. We are doing this again just to see that the two cavities are different for the two vowels for u it is the first resonance of the front cavity for e it is the first resonance of the back cavity. So, the two are altered for u which is a back vowel F2 is the resonance of the front cavity. For e which is a front vowel F2 is the first resonance of the back cavity. So those things are altered.

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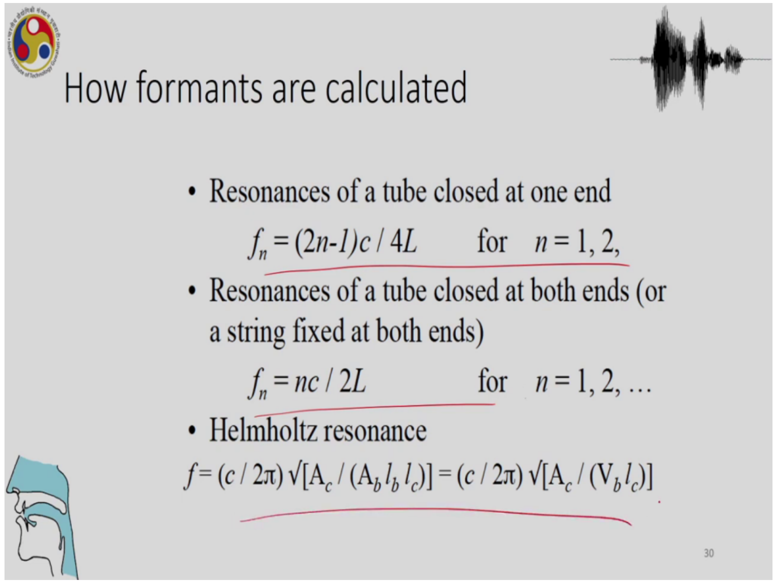

And we again repeat the different formulas which are used for the different tubes. So, tube closed at one end the system, formula for a tube closed, or a string, fixed at both ends is the formula and for the Helmholtz resonators, this is the formula.

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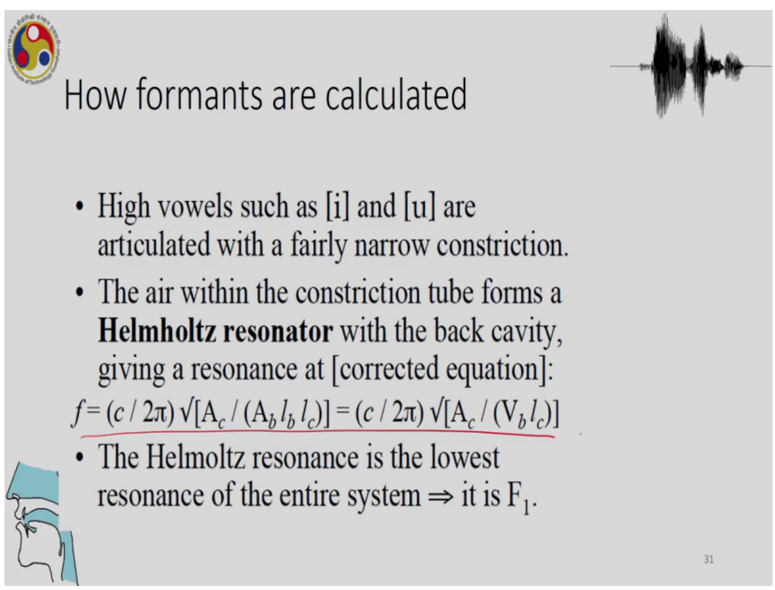

And again, high vowels such as i and u are articulated with a fairly narrow constriction which we saw. And the air within the constriction tube forms a Helmholtz resonator with the back cavity giving a resonance of where we have this formula which will not go into, because it will involve some explanation, it is just enough to know that there is a Helmholtz resonator, which is responsible for the low frequencies of the high vowels. The Helmholtz resonance is the lowest resonance of the entire system, it is to F1.

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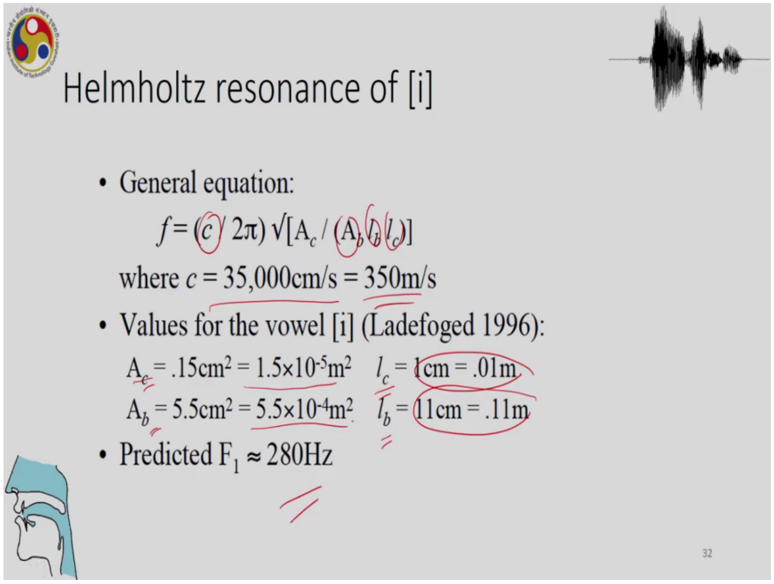

And again, we know that this is the value of speed of air, so 350 minutes per second. And so, you we have the values for the vowel e, so this is the length of the different tubes. And these lengths are calculated based on the length of the tubes. And then if we take into account all of these different lengths, and which we see in this formula, and we put them in the formula, then we get a predicted F1 for e at 200 hertz.

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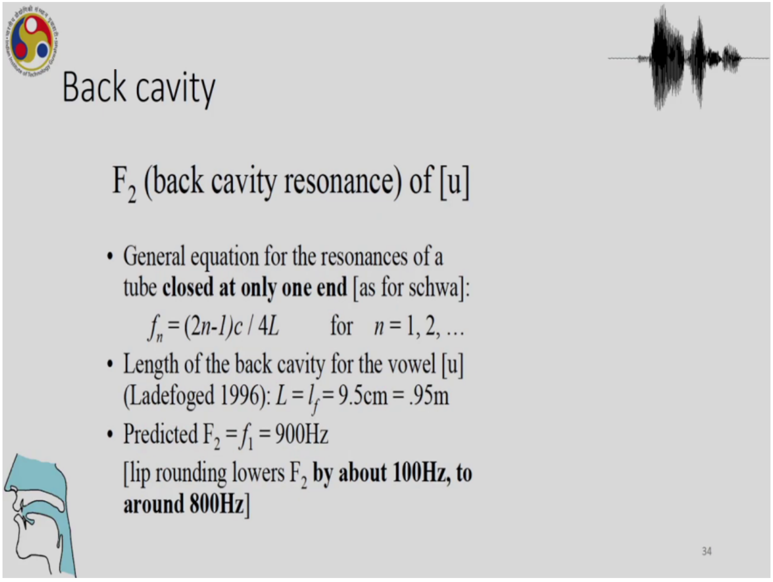

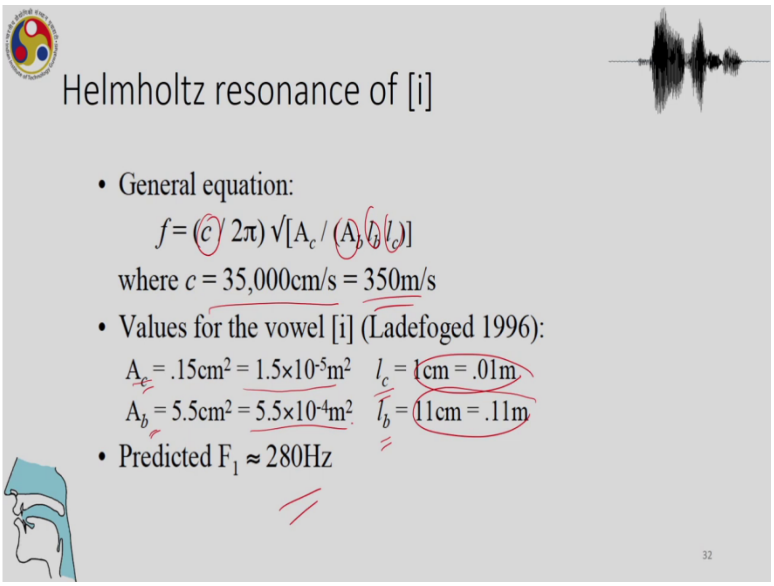

And similarly, for the F2 a back resonance of e. So, the general equation for the resonance of tube close at both ends. So, this is the formula. And then the length of the back cavity for the vowel e, so these are from Ladefoged, so we can see that this is the point, it is 11 cm is point 11 meters, and then this is a predicted f1 is 1600 hertz using this formula.

So that is how we get to different formats. So, this is the formula for the Helmholtz resonator, we get to 280 hertz, for the predicted F2 for which as you recall, we use the back cavity. And then if we use the length of the back cavity and put it in L, and remember that the back cavity is closed at both ends. And so that is why this formula will be used. And that is why we will get this F2.

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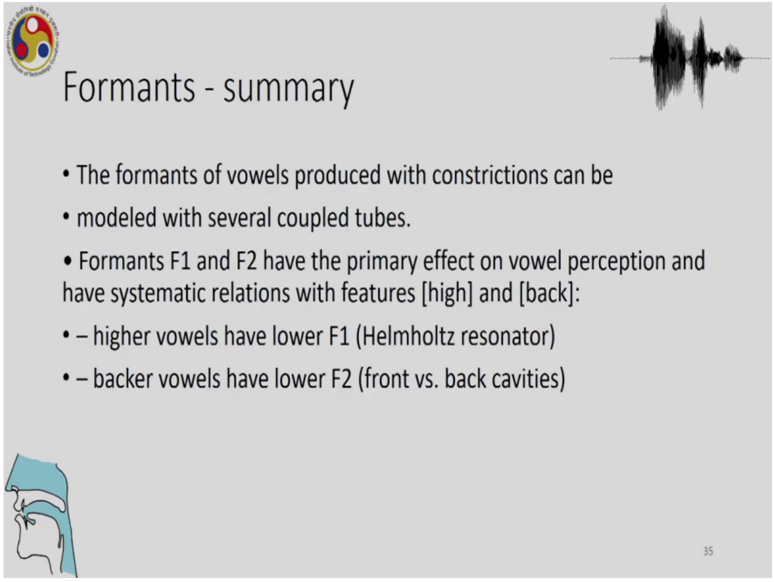

And F2 back cavity and back cavity resonance of u. So, again, general equation for the resonance tube close at only one end where, remember recall that this is a formula we used for the calculation for schwa, the resonances of schwa. So, if we use it again for the calculation F2 of u, then it is 900 hertz. So, lip rounding, again, recall rounding generally decreases formants and lip rounding lowers F2 by 100 hertz to around 800 hertz.

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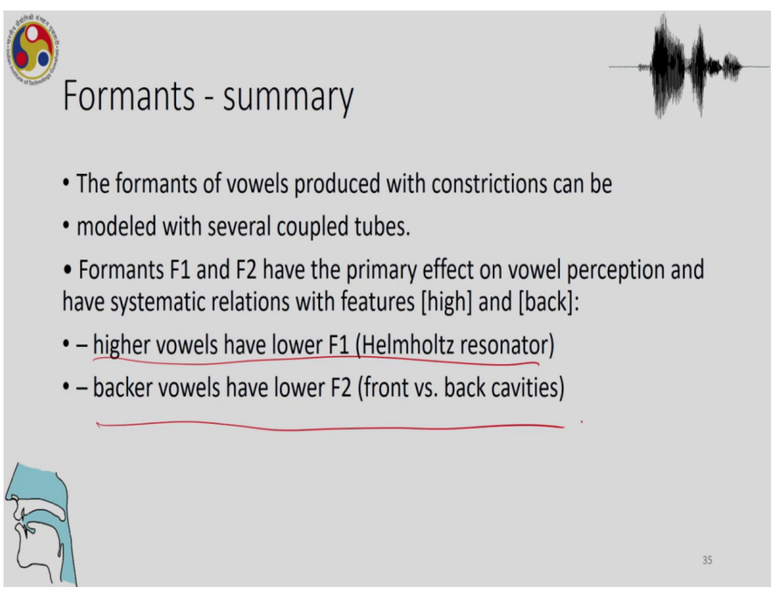

So, we are coming to the end of this part on the formant calculation using tube models. The formants of vowels produced with constrictions can be modeled with several tubes and formants

F1 and F2 have the effect on vowel perception and have systematic relations with what we call high and back in the phonology, higher vowels of lower F1 and backer vowels have lower F2.

So, summary of this lecture that, higher vowels, why higher vowels are lower F1 and why backer vowels have lower F2 can be predicted with the help of the tube bottles. Thank you for listening. And this brings us to the end of our lecture on formants. Thank you