Acoustics and Noise Control
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Module – 15
Lecture – 20
Db Arithmetic

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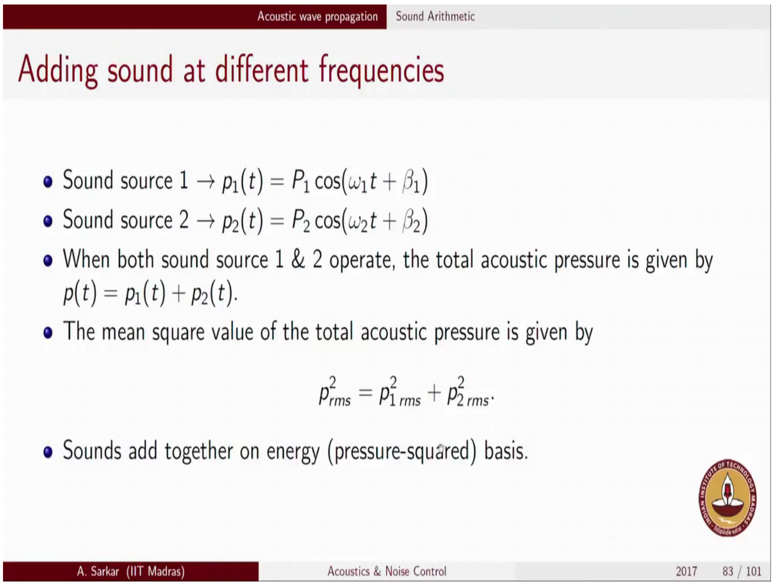

In the last class we had talked about how to add sound or different frequencies, and we had got this very important relation that, it is in the mean square sense that the addition is valid that is if you have 2 sound sources one emanating and acoustic pressure of P 1, the other emanating and acoustic pressure of P 2 it is the mean square associated with P 1and the mean square associated with P 2, that gets added up to give the mean square of the total combination. That was true for different frequencies because omega 1 and omega 2 were chosen to be different.

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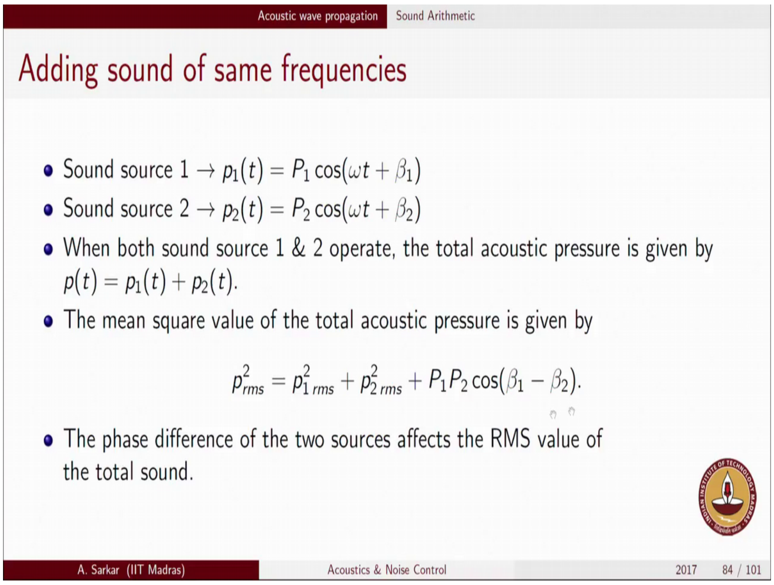

Now, let us just turn back once and see what happens if we choose omega 1 and omega 2 to be same.

So, this time we are adding sound of 2 from 2 different sources which are emanating at the same frequency. So, here you can expect that the above formula will not hold and the reason for that is can we understood from this derivation itself.

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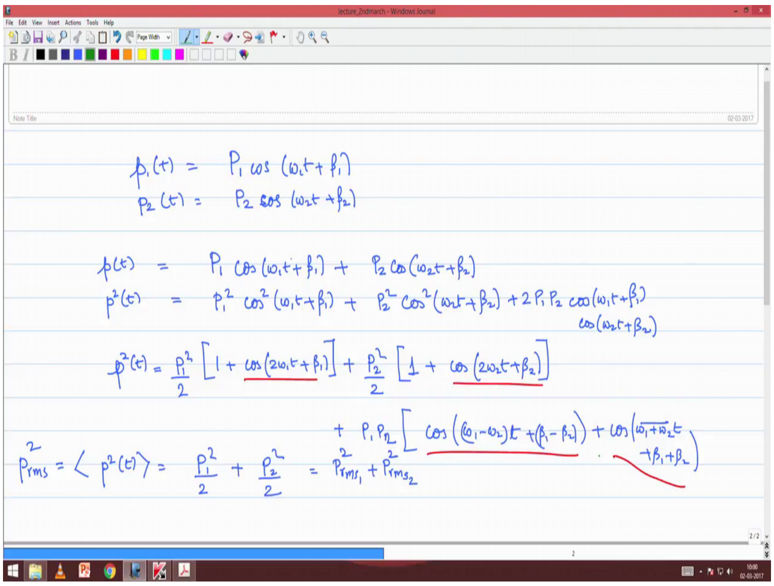

So, this was the derivation that we did in the last lecture for the case of omega 1 and omega 2 be in different, here you will see that this term leaves to say the light of the day this term which is omega 1 minus omega 2 will now give a 0 right. So, this underlined term is no longer going to be of the form, which has 0 mean because there will be a cos beta 1 minus beta 2 which remains which is dependent upon the phase difference between the 2 sound sources is going to be just constant right, but all other parts of the derivation is going to be identically same you will get this term associated with the average value of this quantity, this quantity is again not going to contribute to the average value.

This quantity is not going to contribute to the average value. So, you will have P 1square by 2 and P 2 square by 2 as usual, just in this term where both of these trigonometric terms were shown to have a 0 average effect that is not going to be true only the second term is going to have a 0 average effect, but this first term where in you have omega 1 minus omega 2 that will be having an average effect associated with P 1 P 2 cos beta 1 minus beta 2, which is the cosine of the phase difference between the 2 signals multiplied by the product of the 2 so that part is clear.

So, therefore, what you will get is something like this. So, here as we see that the mean square addition is not exactly valid because together with a some of the mean squares you get another term which is just dependent on the cosine of the phase difference between these 2 sources. So, we will keep this note and we will say that the phase difference of the 2 sources will definitely affect the rms value of the total sound. So, that is when you have 2 sources which are emitting sound at the same frequency, and even from the concept of phasor this fact that there is that the issue of phase difference between the sources does affect can be understood in a slightly different prospective may be I will do that.

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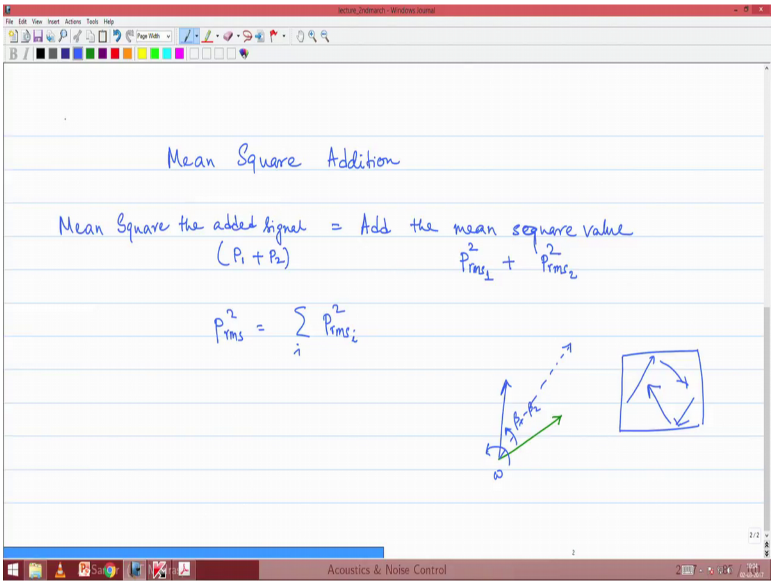

So, if you look back at the phasor concept, let say there are associated with each source we are giving a phasor representation. So, 2 sources I will draw 2 phasors, which are having a phase difference of beta 1 minus beta 2 both of them are going to rotate at the angular frequency.

The addition of these 2 is just going to be a vector addition of the 2 phasors, which is going to rotate. So, as you know the vector addition of the 2 vectors depend upon the angle subtended by the 2 vectors. So, therefore, the resultant phasor will depend upon the cosine of the face difference. So, therefore, the mean square addition from we would sort of fail I would not say fail rather it will sort will sort of is limited, I would say to the case of only where the frequencies are different. If the frequencies are same then the mean square addition should include a phase factor related contribution.

But then a times we tend to ignore this phase factor related contribution, but the reason form for ignoring this phase factor related contribution has to be completely justify.

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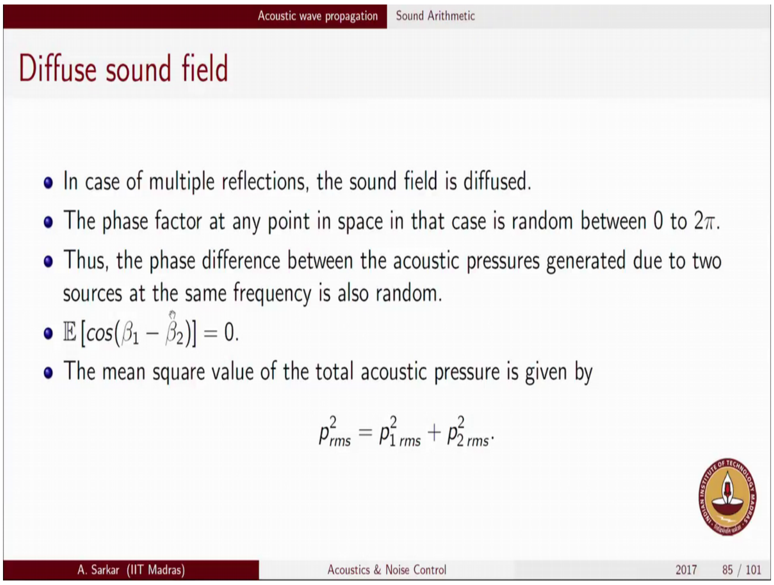

We can ignore this phase factor related contribution if we are making a further assumption that the sound field is diffused.

What does that mean, what happens in an inclusion problem such as you know this room or any other similar rooms you as we understand associated with the boundaries of your acoustic domain you will get reflection, and since you already has 6 boundaries and in a cubicle room of this sort you will get multiple reflections and each reflected wave will intern produce further reflection something like this to illustrate if you have I can only draw 2 D plot here. So, if you have an enclosure of this sort if there is an incident wave, it will get reflected and this reflected wave will further get reflected and this reflected wave will further get reflected. So, each reflection intern will induce additional reflections and in totality it is a standing wave that we understand, but the standing wave is actually a resultant of multiple reflections that is what we have seen, even in the case of one d acoustics which is nice and simple in terms of it is analytics, but extrapolating those observations we can understand that any three dimensional cavity will induce multiple such reflections and further another complication associated with these reflections is the fact that at times or realistically speaking these boundaries are not particularly plainer may be it does not affect so much significantly, but at times these irregularities in the boundary can cause further issues and further complications definitely with relate with regards to a computational process.

But once there is a multiple reflection associated with each reflection you can understand that there will be a phase change and therefore, the phase at any point rather is the phase difference beta 1 minus beta 2 that factor could be anything between 0 to 2 pi because just like as I showed in the schematic drawing, there are multiple reflections and these reflections can happening in a every it is very difficult in order to predict these reflections. So, has to say and therefore, the associated phase change is induced by these reflections are almost like a random quantity between 0 to 2 pi

So, therefore, we say that the cos of these random quantity which fluctuates between 0 to 2 pi, can be anywhere between minus 1 to plus 1, but the expected value of it will be between these 2 and mean value. So, as to say is going to be 0.

So, the phase difference between the acoustic pressure generated due to 2 sources at the at the same frequency under this diffuse sound field assumption is therefore, going to be random between 0 to 2 pi, and once you invoke these assumption then you can say that the expected value expectation in the sense of the theory of random variables of this factor which is the factor which was sort of playing a (Refer Time: 08:11) for the mean square addition law, that factor can now be killed 2 0. So, it is only under a diffuse sound field assumption that this phase factor can be kill to 0, and thereby we get back even for the case of sources emitting acoustic waves of the same frequency that the mean square addition will still hold because this phase factor is now getting killed because of this diffuse sound field assumption.

So, the moral of the story is thus that if you have sources emitting different frequencies go ahead with your mean square addition law, if the 2 sources are there or multiple sources are there and so, happens that the phase factor the mean square addition will not hold in it is totality, rather than there will be an additional term associated with the phase difference between these 2 sources. So, that is the idealistic view point, but then if you in cases of mostly cavity acoustic and interior acoustics where in there are multiple reflections expected and each reflection will bring about it is phase difference. So, as a result you can expect that the expected value associated with this phase factor quantity would be nullified to 0.

In such cases again the mean square addition will hold even for the same frequency case. The reason why I have iterating this is because of the next formula which is pretty well-known in by the field engineers in acoustics and envisage groups, but probably it is not very well appreciated under what conditions this dB addition formula holds.

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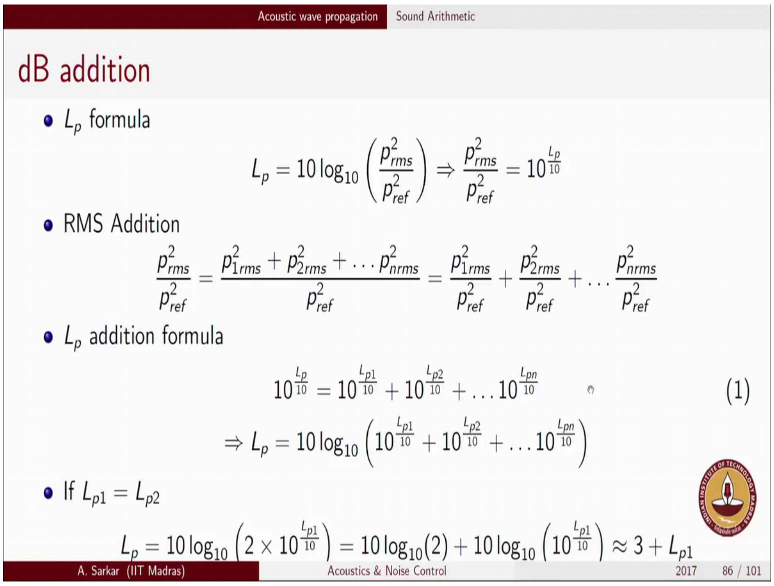

So, let us make take a look at the dB addition formula it is a very handy formula for the noise control engineer in the field. So, as we understand that acoustics is linear which means that the sound pressure created due to one source and the sound pressure created due to the other source can always be added up, but then we realize that it is not possibly what talking in terms of sound pressure in Pascal's, we shifted our units from that of Pascal's to that of a decimal scale which is a logarithmic scale. And just to recall the formula for sound pressure level is pl are abbreviated as L p is l underscore p that is l subscript p I should say that L p term is given by 10 logarithmic with a base 10.

The rms square of the pressure divided by P the difference rms value which is taken as 20 micro Pascal and square of it. So, this is the sound pressure level formula that we had seen even in the last class. So, we will we could turn this round and look at it in this form that P r ms square by p reference square is going to be 10 to the power Lp by 10. So, Lp by 10 and 10 to the power of that is going to give this bracketed quantity.

So, Prms square is we know how to calculate the mean square of the pressure by now that formula is also discussed we discuss this with particular reference to both sounds at different frequency as well as sound at the same frequency. So, in either way the you know how to calculate Prms square so that part is clear. Now the question is if you have the multiple sources what we have seen and let us say multiple sources emanating sound at different frequencies, then we understand that the mean square of the total sound pressure is going to be the addition of the mean square of the sound pressures emitted by individual sources. So, if you have n such sources which of them emanating P 1, P 2, P 3 and P n then the in totality the mean square of the total sound pressure is going to be the sum of the mean squares of the constituent the acoustic pressure mean square of the acoustic pressures emitted by each of those individual constituents.

So, this is just the mean square addition formula that we have derive in the previous class if you wish to look back at it, this is the mean square addition formula that the we had derived. So, we are applying that we are appealing to that formula and thereby making this step ahead and when we just simplify it in this form which is nice and fine and now we take 10, we refer to this part of the formula where we where we realize that the ratio of the mean square with reference to the reference square is going to be 10 to the power L p by 10. So, 10 to the power L p by 10 is going to be 10 to the power Lp 1 by 10 which is P 1rms square by Pref square and so on. So, therefore, this is the addition formula in terms of Lp you could make it look better by taking a log on both the sides and multiplying with 10 again. So, that would mean that the decimal addition formula or the decimal level of the total sound which is created is going to be 10 log 10 of this quantity on the right hand side which is appearing in the bracket right, this is not an arithmetic addition this is the formula for logarithmic addition. So, here in we must understand that if you have sound from one source to be let us say 80 dB and the other source to be let us say 82 dB, then it does not add up following the arithmetic law of addition that is 80 plus 82 does not give you 162 rather it gives you as per this formula right. So, this is the dB addition formula and a very special case of this which is sort of very counter intuitive at first go is this let us consider that there are just 2 sources and each of them are sort of equal in the decimal level in the sound pressure level that is been emitted.

So, if each of them are emitting the same sound pressure level and there are just 2 of these sources we can easily reduce this formula as Lp 1 equals to Lp 2, and since both of these quantities are going to be same we might as well write it as 2 into 10 to the power Lp 1 by 10. And using the fact that logarithmic of a product is sum of the logarithms so, therefore, we take this as 10 times log of 2 base 10 plus 10 times log base 10 of 10 to the power Lp 1 by 10. So, that second term is log of 10 to the power Lp by 10 is Lp by 10 and you have a multiplicating factor sitting of 10 here. So, therefore, this party is Lp 1 and logoff 2 is roughly 0.3 4 0 or something like that. So, 0.3 multiplied by 10 is going to be roughly 3.

There are some additional disable points here which is why this is an approximation. So, roughly what it means that if you have 2 sound sources which are emitting the same sound pressure level then the total sound pressure level is not the arithmetic addition, but just 3 dB over and above the individual levels right. So, this is obviously, in these days we can easily code this up into to a nice disable calculator and you can do that as a part of your assignments for sure this is nothing is not a very big complicated program by in the sense you can have dB calculators.

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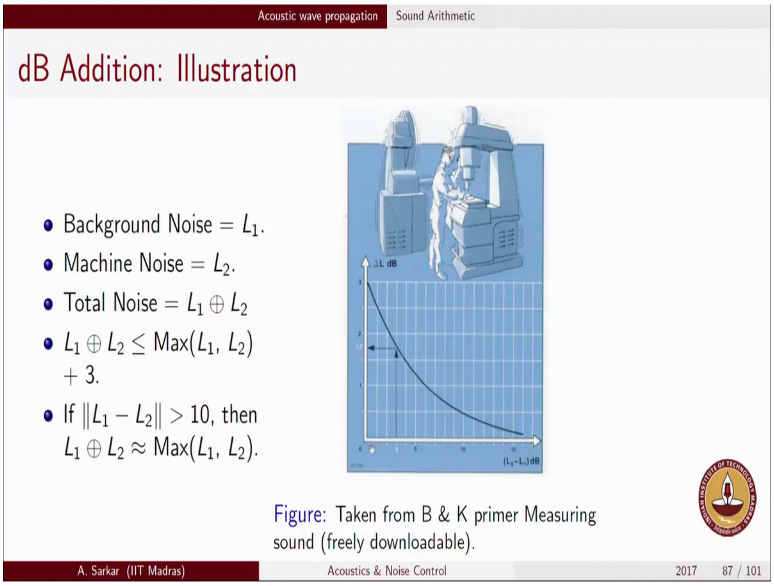

But at least in classical even computers were not so, very well available. So, this was represented in a chart the dB addition kind of a formula.

And the way it is this dB addition formula comes in handy is in the following fashion. Let us say I am the manufacturer of this machine I code that this machine is going to emanate a sound of let say L 2 dB right, but then this machine emanate sound of L 2 d B under a perfectly quiet conditions. When there are no other sounds there right in a standalone fashion this the machine manufacturer quotes that this machine is supposed to emanate a certain decibel level.

But then when this machine is planted in to the factory, then this machine is there together with several other machines which produce sound some of them may be the same machine also right. So, the question that the factory installation people would like to know and the safety inspector of the factory would like to know is that, if these additional machine now comes and sits into the way of the factory then what is the new sound pressure level that is expected and what is the sound pressure level which the factory workers will be exposed to.

So, of the quick calculation for this is that first we measure the background noise. The background noise means what is the sound pressure level in absence of this machine right. So, that comes out as let us a l d B, and will probably in the next class look at how to do sound measurements also will there is instruments such as sound level meter which can quickly give us this sound pressure level in decimals. So, let say that measurement can be done and that is L 1 dB and then the machine noise is L 2 dB. So, therefore, the total noise is L 1 addition, but this addition is strange addition it is logarithmic addition it is not the usual arithmetic addition and to stress this fact I have used a different symbol for addition.

The plus sign coming within a circle. So, this is just (Refer Time: 18:14) notation for a logarithmic addition as suppose to arithmetic addition. So, L 1 logarithmic edition of L 2 is the total noise that is expected and that can be easily determine through this kind of a formula or maybe in the shop floor where things have to be done fast, and sometimes without a computer also. We have this kind of charts which really tells us that if the arithmetic difference of L 2 and L 1 is known this is L 2 and this is L 1 this L 2 minus L 1 simple arithmetic difference where we have learnt it in our kindergarten. So, we do not need to worry about it.

So, whatever is the difference with that, we need to add this value for it. For example, if the difference is 3 dB then we need to arithmetically add 1.7 dB right and that will give us that total loss. So, this is this sort of a chart is very useful to convert this logarithmic addition formula to a very useful handy formula and you will also note that if L 2 and L 1 are just identical which means that L 2 minus L 1 the arithmetic subtraction is 0, then you need to add 3 dB to the component which is at the higher level.

So, you have to the formula goes this way that logarithm addition of L 1 and L 2 is max of L 1 L 2 plus three and that is the maximum thing that you will get. The actual value has to be quoted from this sort of a graph, the actual value of L 1 plus L 2 will be max of L 1 and L 2 plus the value which you will rid of from this graph right. So, and also please note that this graph has a very sharp decaying characteristics. So, if L 1 minus L 2 is less than 10. So, you can see that there is hardly any addition that you need to make.

So, at the level of 10 possibly you need to make a 0.5 addition, but at the level of fifteen there is hardly any addition that you need to make. So, which means that if there are 2 sound sources and the sound pressure level between these 2 sound sources differs arithmetically by 10 dB or more, then you are not exactly going to contribute anything to the to much to the total sound right.

Another way in which this formula should be very handy towards for practicing engineer is this, suppose you are going to in a certain vehicle or in a certain component you are going to add one extra component to that machine, and you are worried whether the addition of that component is going to affect the overall sound pressure level of this entire machine. Let us say as an example you have a vehicle and let us say the vehicle initially was without the ac or without the edge back system, now you wish to add this edge back system to this vehicle.

So, the question is by addition of this edge back system will the interiors increase if it increases how much and preferably it should not increased. The most of the times of these are some ancillary units let us say you want to change the fuel pump of an engine assembly. So, the engine; obviously, makes noise in itself, but the fuel pump in addition will make noise and in totality it will contribute to the total noise emanated by the engine.

So, as an engine manufacturer I would like to choose a well pump for this engine which possibly is already at the level of 10 dB or lower. If I am sure that the fuel pump in isolation without the engine just as a pump if it is working, it is making noise which is less than 10 dB then I am quite sure that when this fuel pump works together with my engine then the total sound is going to be almost negligible due to the addition of this extra ancillary unit additional noise making unit right. So, this will be a very important formula as far as your selection of vendors for these ancillary units will be considered.

This is what you should demand you should demand that you are the additional unit that is being procured from the vendor should have noise levels perceptively lower much lower and how much lower you can look from this chart if you cross this 10 dB limit you are quite sure that this is not going to affect right ok.

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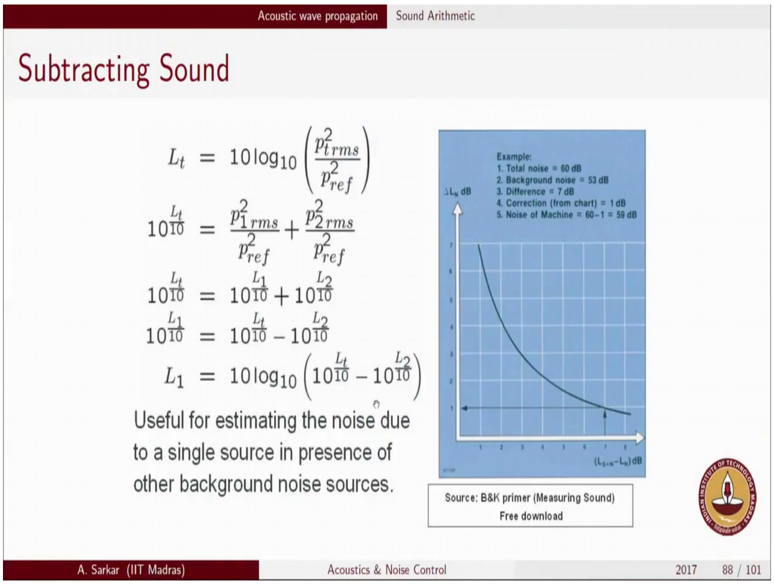

So, if we know addition subtraction should not be too difficult, the subtraction formula I will just run through it quickly. So, now, it is the other way round let us say in the shop floor kind of environment where there are many different machines, and it is very difficult to shut down all the machines and measure out the sound emanated by one particular machine right. Suppose for some reason you are thinking that a particular machine is not working correctly and you need to have to know just like you know our human ear can possibly get a custom to the sound of it, and if we hear a different sound when we write our bicycle every morning then we are almost sure that it needs certain overall overhauling and some oiling is required.

So, similar things do happen in condition monitoring of machines also, but again in a factory environment you are not expected to switch down switch off all the machines and take the measurement of one particular machine in isolation. You have to do it in a more efficient fashion. So, the way it is done is that you measure the total noise and then you shut down only one machine the machine associated with the one that you are investigate right; and using the subtraction formula you can recover what is the noise emanated by this machine in isolation right. So, that is how this formula will be applicable in the field.

So, the total sound which is abbreviated as L subscript t is given as 10 log 10 the P the mean square of the total sound divided by the reference square. So, that could be turn around and written as 10 to the power L t by 10 is this total sound which is p Ptrms square by P ref square, and we already know that the total rms is P 1rms square and P 2 rms square just simply added. So, therefore, we know that 10 to the power L t by 10 is 10 to the power l by 10 plus 10 to the power L 2 by 10 we just turn this around and write it in this following form, but 10 to the power L 1 by t is L 1 by 10 is 10 to the power lt by 10 minus 10 to the power L 2 by 10 right.

So, there L 1 can be written as if you take logarithmic of it and multiply by 10, you will get 10 log 10 to the power L t by 10 minus 10 to the power L 2 by 10. So, this is the formula by which if you know the total sound and if you know the sound of the sound obtain with one machine switched off, you could actually recover the sound associated with the machine under investigation that is typically the case which will be used in different shop floor kinds of in environment. Also another way in which this formula comes handy is with regards to noise source banking I think I will talk about noise source ranking in little more details in few slides down the light. So, I will refrain myself to talk about noise source ranking.

So, here is another example using of using this sort of a chart. So, here we had a total noise of 60 dB, that is the background noise together with the machine is 60 dB the background noise was measured as 53 dB, the difference which is just the arithmetic difference turns out therefore, to be 7 dB. So, 7 in dB intern means through this collection chart we get that we have to subtract just 1 dB. So, therefore, the noise of the machine under investigation is 59 dB, in other words 59 dB plus 53 dB should given us 60 dB right 59 dB plus 63 dB added logarithmically is going to give was total sound of 60 decibels ok.

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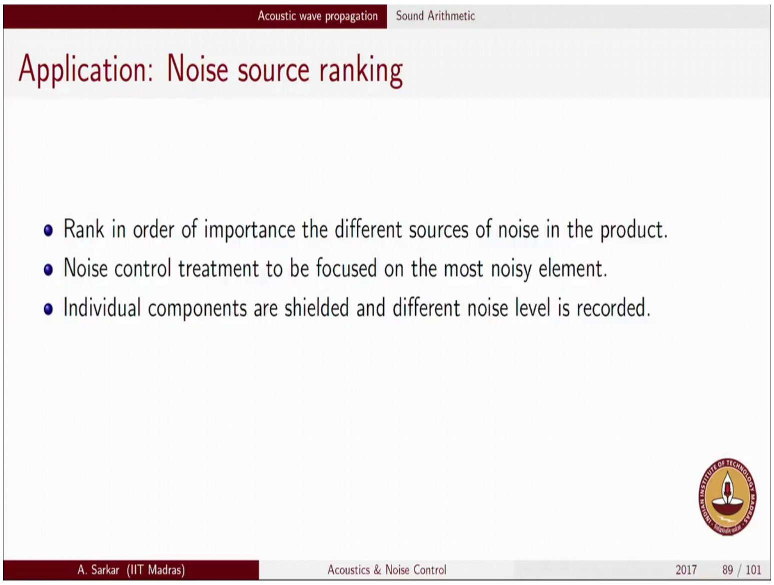

So, here we are about noise source ranking, as I said that the subtraction formula is very useful for the exercise of noise source ranking. Whenever you as a in which engineer you have to the first job rather of an in which engineer would possibly be to identify which is the most noisiest component of your product right this is very important because what the dB addition and dB subtraction formula. In fact, tells you is that that unless you target the nosiest component of your machine you will not be able to make any substantial gain in the total noise. Suppose you have in your machine 2 components, and both of the components let us say engine and the transmission, both of the components are noise makers in isolation, but the point is at the vehicle level when both the components are working you should be able to identify which is the most noisiest source.

If it so, happened that you know the noisiest source is the engine and you and just to give you some example numbers let us say the engine is at 90 dB and the transmission is at 84 dB, then it will actually not help much I mean vary marginal help gains on almost no perceptible gains in terms of the sound levels will be obtained, if you concentrate your efforts to silence the in the transmission rather than the engine right because just from this dB level itself you can understand that you know if that 84 dB even if you reduce to 80 dB nothing much will happen, if 90 plus 84 is adding up to something then 90 plus 80 will add up to almost the same number right.

So, you will not be able to get any gains in as far as the total noise is concerned, unless you target the right source of sound and there is a that is why the importance of noise source ranking is very important for the life of an nvh engineer. So, usually for a any machine let us say something like a vehicle or even something like an air conditioning example, you will have lots of components which are potential noisemakers. You must have a well-defined procedure by which you can rank these different sources of noise and then concentrate your analysis towards improving the noise characteristics of the noisiest source rather than trying to dedicate your efforts to our each and every component you should attack right at the source of the noise and only if you are able to mitigate the primary source, will you achieve any substantial gains towards the total noise of your component.

So, ranking in order of importance of different sources of noise in the product is extremely important because unless you do so, you are not be able to translate or get any substantial gains as far as the total noise of the product is concerned. So, noise control treatment therefore, has to be focused on the most noisy element and you have to identify that that in a particular process which is what I would elaborate to you in a moment. So, there are different components just like for example, that we are talking about let us talk about the vehicle. So, in a vehicle as you know the engine is a noise source, the exhaust is a noise source, the intake is a noise source, the road noise is a matter of concern transmission is a noise source, air condition is a noise source.

So, the question is how will you in a sort of feasible and economical fashion rank each of the source in terms of it is importance. The idea is actually pretty simple we have something called noise absorbers which are like fibrous material. So, if each of these noise sources are sort of covered with these absorbers, it is expected that the noise emanated from these machines will substantially reduce, but then you cannot sell a vehicle where your engine as well as a gearbox and everything gets (Refer Time: 31:15) with this 5 plus materials, because usually the longevity of this fibrous material is not very high. So, be specially because of the temperature effects and the dust effects they tend to get spoil. The ones which are like more reliable and more durable are extremely costly. So, the process by which the noise from individual sources of the vehicle will be estimated is the following.

So, first we take a measurement of the total vehicle noise that is we call it as measurement one and second time we repeat the same experiment, but this time we (Refer Time: 31:54) the product of our interest rates in the engine with this absorbing materials as was discussed. So, this will be called as measurement 2. So, using the dB subtraction rule we will subtract measurement 2 from measurement 1 and as a result what we will get is the noise produced by the engine. So, in this fashion we can construction we can estimate the noise due to each and every product within the vehicle.

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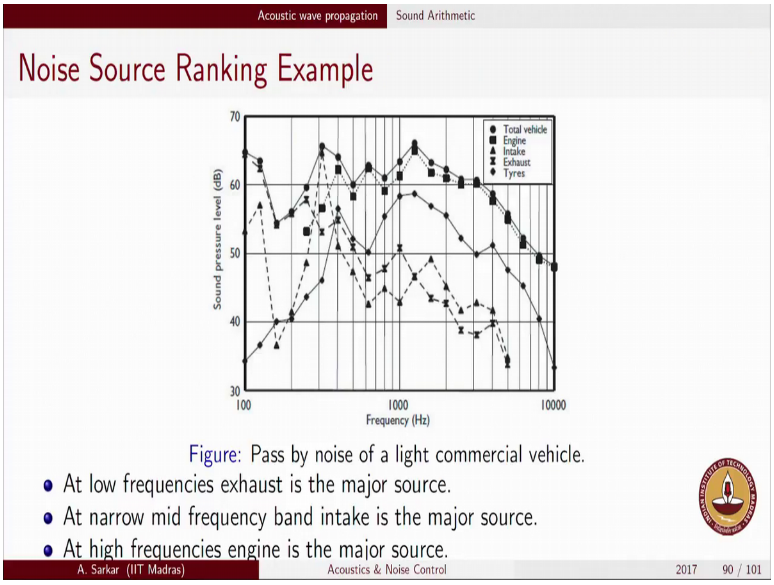

So, here is an example where we employ the dB subtraction role as was explained in the previous slide. So, here in practical applications such as using vehicle we know that there are lots of noise sources. So, typically in a vehicle we will find the engine, the transmission, the intake the exhaust the tires all of them contributing to the total noise. As a vehicle manufacturer one needs to have a clear idea that which of these components are important noisemakers, and accordingly target those components rather than a grappling in the dark and trying to act random or trying to control the noise of any of these individual products. So, what is usually done is the following; measurement of the total noise is taken and that is what you see as a total vehicle noise which is plotted in solid line along with circular dots, then followed by that for example, if you are interested to find out what is the engine noise in isolation.

Then the engine is sort of coward with noise absorbing materials and another reading is taken. This reading is subtracted from the first reading then what you get to is the engine noise. So, the noise that was already in that was obtained when the engine was showed properly with acoustic absorber, in that noise reading the effect of engine noise would possibly have been struck off and as a result that measurement will include the measurement of all noise other than the engine, and then from the total vehicle noise if you subtract that noise the noise due to all other components excepting the engine, then you will end up with the noise from the engine in isolation.

So, using this procedure of dB subtraction between these 2 measurements which I have just talk, you will be able to recover the engine noise in isolation. This exercise is very important from the application point of view as I said that the noise source ranking is an important exercise in industrial application, because only through noise source ranking in industrial applications can you really zoom in to the source of noise and then take appropriate corrective actions for the refinement of the noise.

Coming back to the result shown in this slide what you see here is not only the engine noise insulation, but also the intake and exhaust noise and also (Refer Time: 35:01). So, when your superpose all these noise in reading that have been taken through the appropriate measurement procedure as discussed and overlay these graphs together, then we have get a very informative picture of different components of noise that are being contributed by the different products within this assembly. For example, in the low frequency zone between 100 to 300, 400 possibly what you see is that the exhaust noise which is shown in dotted lines together with a marker which looks like an hour glass, and that is contributing to the total vehicle noise

So, if you wish to get any reduction of the low frequency noise, then one has to target the exhaust possibly design better muffler. Similarly the intake noise has a peek at a single frequency you can observe a district in possibly the third vertical line, but again on the high frequency side it is the engine noise which dominantly (Refer Time: 36:02) on to the total vehicle noise.

So, in the high frequency slides if you want to get any benefit, then what has to do for major refinements in the engine structure and try to bring down the engine noise. If engine noise is brought down at the high frequency region that the total vehicles in the high frequency will also be control, but having said that we must realize that the overall s p l is contributed by all these components and their overall s p l actress the frequency or the overall dB level, here will be reduced if one can control the either the low frequency noise to the exhaust or the high frequency noise which is happening just around 1000 (Refer Time: 36:45).

So, looking at this chart as a acoustician I would like to recommend that one has to take care that near about 1000 hertz the engine noise must be reduced and near about 100 hertz, the exhaust noise must be reduced. So, design a muffler for this vehicle such that the performance at 100 hertz comes down, we must do something and even at the intake noise such that the frequency corresponding to that third grade line which is possibly like 500 words or so, should come down and the engine structure must be redesign such that the frequency peak again corresponding to 1000 hertz comes down.

You will note that each of these frequencies are like the bounds of the total vehicle noise curve and therefore, if you want to bring down the total vehicle noise these are the design changes that you must do to your vehicle, but so as to manifest considerable noise improvement in the noise performance.

So, I think we will stop here and will care take it out from here in next class.