Basics of Noise and Its Measurements
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Lecture – 40
Octave Band Analysis

Hello, welcome to Basics of Noise and its Measurement. This is the 4th lecture of the current week that is the 7th week of this particular MOOC course, and our last 3 lectures we have discussed some of the practical elements in a related to noise measurement.

We have discussed how to measure impedance of materials using 2 microphone methods, how to quickly design reasonably good impedance tube, and in the first lecture we had looked at some of the important considerations we should be careful about, as and when we are taking noise related measurements.

So, what we will discuss today and also in the next lecture, will be about octave bands and octave band analysis. To give you overview, as to why we are taking about these is that a lot of times whenever we report results related to noise on the frequency spectrum, people would are typically interested in having some sort of a standard format for reporting these results. So, if I have to report my results in different octave bands then, there are some industry and trade specific standards which we have to subscribe to. So, that whenever I share my results in the largest scientific and industrial community, then they can understand those results and they can compare these are my numbers with their numbers in a consistent way, if we are following the same rules of the game.

So, that is the fundamental thinking behind defining industry stand and noise community specific standard octave bands, because otherwise an octave bands could be anything, it could an octave band could be a 3 to 6 hertz, 6 to 12 hertz, 12 to 24 hertz. These are all octaves and mathematically the definitions of all these octaves are fine, but if I am having my results in 3 to 6, 6 to 12, 12 to 24 hertz and so on and so forth.

Another person is taking measurements and reporting results in a different set of octave bands, may be 2 to 4, 4 to 8, 8 to 16 and so on and so forth. Then we cannot compare our results because, his octave bands and my octave bands are different. So, that is the first thing I will discuss and the definition of octave bands. And then, we will discuss something beyond that; that how do we synthesis and compress data into octave bands and report a single number specific to a particular octave bands.

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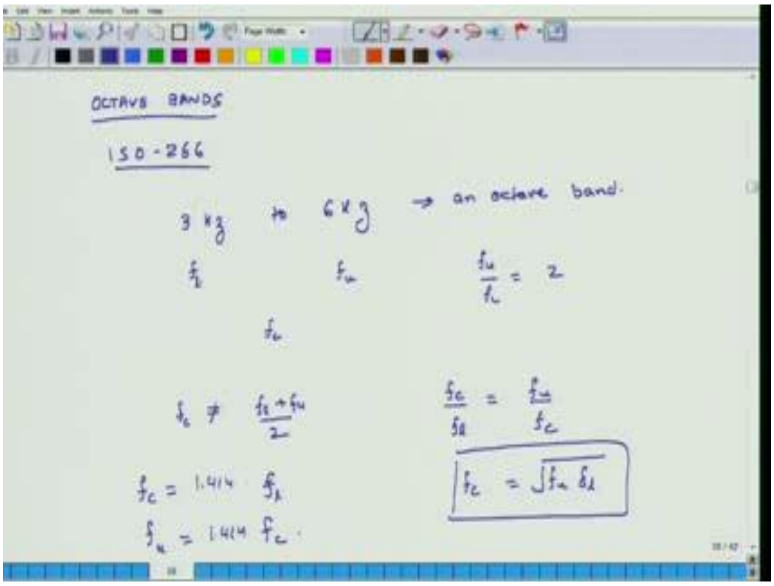

Whenever we are talking about standards, we will either refer to ISO or ASTM or some well known standard. So, for octave bands, whatever discussion we are having it will be in context of an industry standard and that is ISO 266. So, this is a document you can go on and purchase it on line, it has been done at by international standards organization and the number is 266 and this actually defines all you know industry standard octave bands, but before I explain what are these bands, we I will define 2 other things.

So, any octave bands let us say 3 hertz to 6 hertz, this is an octave band. Now this is not an industry standard octave, but I just wanted to make couple of concepts clear, it has a lower frequency limit f l and it has a higher frequency limit f u. So, an octave band has a lower frequency limit and a higher frequency limit and the ratio of the f u over f l equals 2 and then there is also a center frequency f c. So, it is not you know. So, there is a lower frequency limit there is an upper frequency limit, and there is a center frequency.

Now center frequency f c is not equal to f l plus f u over 2 you do not take the average of these 2 rather, what you do is that the proportion of f c f l and f u and f c has to be same. So, f c over f l should be same as f u over f c. So, in the same proportion the value has to go up. So, what the way says that f c square equals f u times f l square root of that. So, there should be a square sign here. So, this is how you calculate the center frequency of an octave band.

And, if you do the math you will find, that f c equals 1.414 times f u and f; no excuse me, this will be f l and f u is equal to 1.414 times f c.

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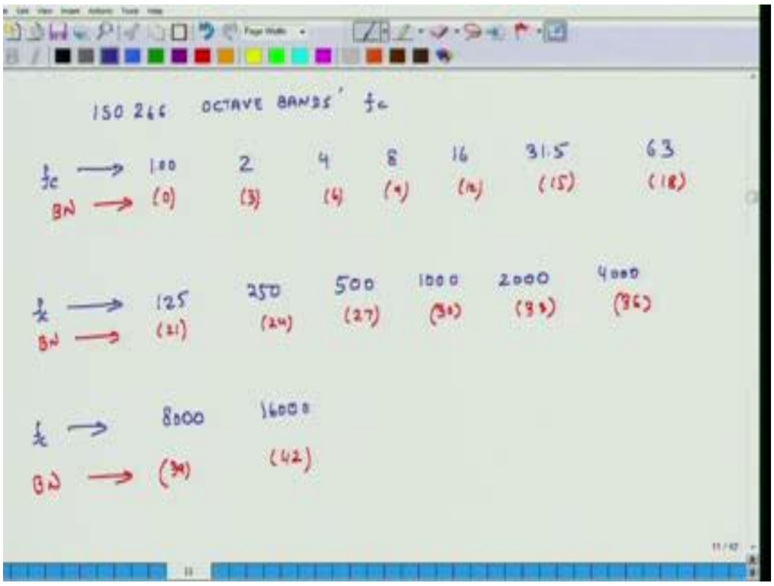

So, now I am going to specify different octave bands, each octave band I am only going to specify it is center frequency. Then for that octave band if I specify the center frequency you can calculate using the relations we discussed earlier, it is upper frequency element and the lower frequency element, so 266 octave bands. So, I am going to just specific their well use of f c. So, the first octave bands center frequency is 1 hertz, and then 2, 4, 8, 16, 31.5 that is a little difference here - 63, 125, 250, 500, 1000, 2000, 4000, 8000 and 16,000.

So, these are all center frequencies. So, and each of this band also has a band number. So, the band number of this guy is zero. What is the meaning of this band number we will see it later, but for the movement, just remember that it has a band number; the band number for this second octave band which has a center frequency of 2. So, this is 3, this is 6, this is 9, this is 12, this is 15, this is 18 and I am going to complete this series. So, this is my center frequency this is my band number this is band number this is band number and these are center frequencies.

So, lot of times in the industry or in scientific literature you will be expected to produce your results related to noise measurements and initially, you will have a time series data then you may f f t it and then, the expectation will be that you further change the form of that frequency doming data. You report data at these specific center frequencies, only because then you can see more you know clear information, they will not be 20,000 you know lot of points that will be cleaner information and people can compare your results with their results. How you do that? We will discuss that later, but right now this is what I wanted to discuss.

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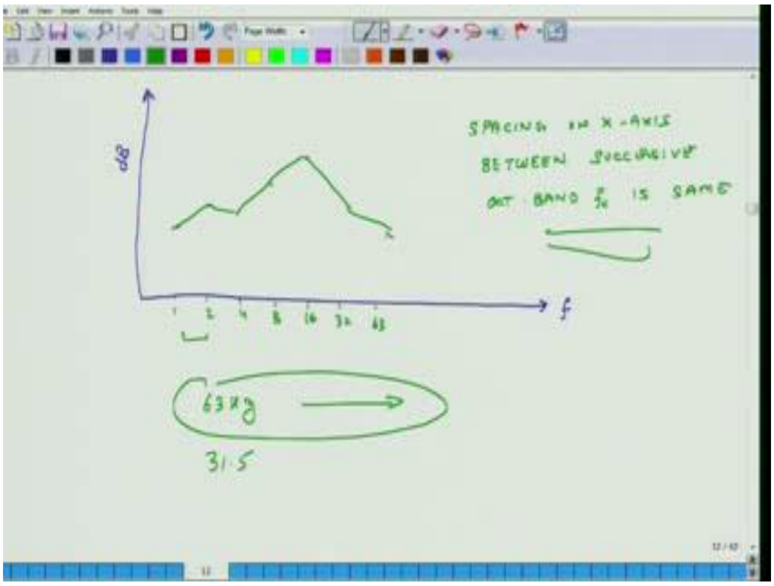

Now, suppose you want to report the results. So, how do you report the results on graph? So, on the x axis again you will have frequency and on the lefts on the y axis, you want to plot decibels you want to plot decibels and suppose, you want to report results for all these octave bands. So, what you do is, you can first list them. So, this is 1, 2, 4, 8, 16, 32, I was 31.5. So, I am going to round off here, but it should be actually 32, 31.5, 63 and. so on and so forth. And then, whatever is the s p l corresponding to these frequencies.

Now this s p l is not the value of pressure at that particular frequency, but it is the pressure due to all the energy which is contained in this octave band corresponding to 1 hertz band. That is the number we are going to put when you do f f t you will get some value at 1 hertz, that is what the valuable to put on this graph. Rather you will see what is the total energy in this octave band, there will some s p l corresponding to that and that s p l you are going to put it here, how will you will calculate? It will discuss that later, but the point what I am trying to make is that this value is not directly taken from the f f t of the signal it will require further processing. So, you will write different values. So, you can plot these and then you can collect them so on and so forth.

Couple of things when we are making this kind of a graph, look at the spaces between different center frequencies, spacing on x axis between successive octave bands; band central frequencies is same, essentially what; that means, is this is a logarithmic scale, the space spacing between the one and 2 is not double half of that between 2 and 4 and so on and so forth is the same thing. So, this is the important to note.

Typically, a lot of times; so these are industry standard octave bands a lot of times when we report data on noise most of the times, we start from 63 hertz and then we go up to 5, 10000 hertz or so, something like that, where there is no frequency noise most of the times we cannot listen in some cases. We may also start from 31.5 hertz, in most of the times we are worried from 63 hertz an upwards. So, this is the other thing, understood. This is what octave bands, have then now; in octave band the center frequencies are space bio-factor of 2. Now, people can say that oh this resolution of between frequencies is very large I want finer information.

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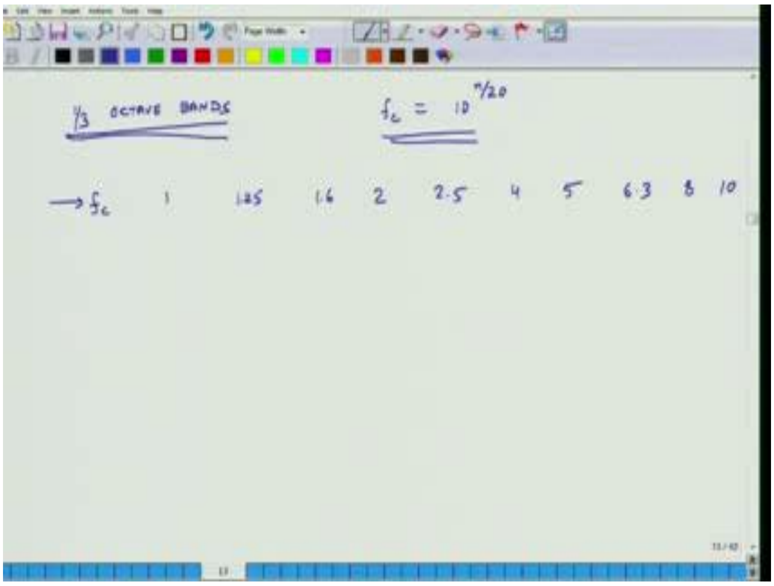

So, then there are one-third octave bands. So, how do you calculate these one-third octave bands their center frequencies you again start from 1 hertz that is the first center frequency. So, so this row is f c first is 1 hertz and there is a formula for it. Why it is one-third we will talk about it later, but the formula is that f c is equal to 10 to the power of n over 20. So, you use this formula.

When n is equal to 0s is 1. When n is equal to 2 this thing is, 1.25. When n is equal to 3 this is 1.6. n is equal to 4 this is 2. So, I will write down these values. So, 2; 2.5 can be writing down approximate values 4, 5, 6.38. When n is equal to 10, you know it becomes 10 hertz. Excuse me! when n is equal to 20, then 20 over 20 is one this becomes 10. So, you use this relation to calculate these frequencies now you would take.

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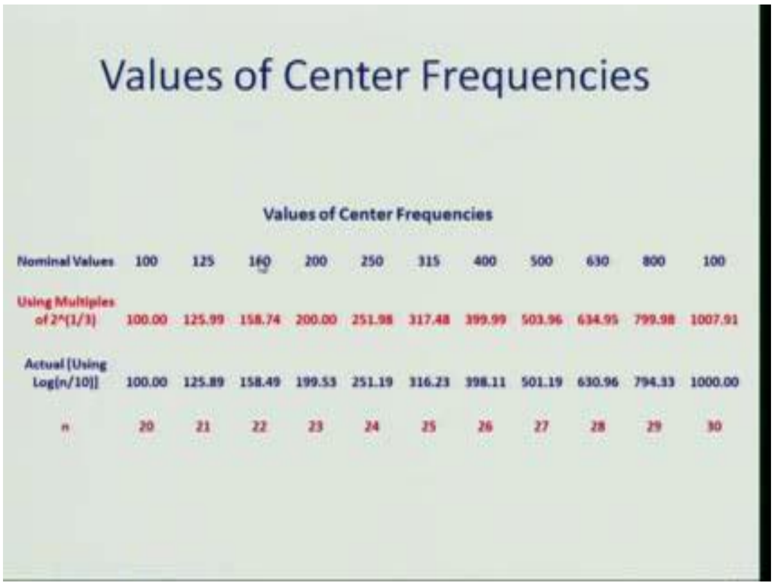

Values of Center Frequencies

Values of Center Frequencies

Nominal Values	100	125	160	200	250	315	400	500	630	800	100
Using Multiples of 2^(1/3)	100.00	125.99	158.74	200.00	251.98	317.48	399.99	503.96	634.95	799.98	1007.91
Actual [Using Log(n/10)]	100.00	125.89	158.49	199.53	251.19	316.23	398.11	501.19	630.96	794.33	1000.00
n	20	21	22	23	24	25	26	27	28	29	30

So, actually let me show you a graph. So, these are, what I am shown here are different values of center frequencies. So, let us look at this blue line this is log. So, I am sorry it should be log n over not 20; it should be n over 10. I do not know - I was wrong that is why it was not matching. Let us say n is equal to 20, you start from n is equal to 20.

Then 20 over 10 is 2; 10 to the power of. So, this is 100 this should be 10 to the power of, I have to correct this 10 to the power of yeah. So, when n is equal to 20 - I get 100 hertz. When n is equal to 30 I get 1000 hertz and all the intermediate frequencies, I will get like this these are the mathematically correct values of frequencies 100, 125.89, 158.49, 199 and so on and so forth.

But you do not use these long numbers for practical considerations. So, you basically put some num. So, these are the exact values generated the standards and then says, you do not have to worry about 125.89 hertz you can be happy with 125. So, these are the nominal values is specified by. So, this is also in blue.

So, these are the values of center frequencies, there is also a red line we will talk about it later - 100, 125, 160, 200, 250, 350, 400, 500, 630. So, what does that mean that every time n goes up by a factor of 10, I move out one decade? Here n is to 20 here n is 30. So, n has drawn up by a factor of 10 n I have gone by one decade of frequencies. Now, interestingly enough, when we look at the mathematics if you multiple this starting frequency 100 by 2 to the power of 1 by 3. What is the number you get 125.99 this is what now, you when you do this - 158.74, 200, 251.98, 317.48, 400 this should be actually exactly 400 and so on and so forth.

So, these frequencies in red and blue they are pretty close for practical considerations, and that is why this is known as one-third octave band. Because if you have (Refer Time: 19:21) one-third octave band you will have to multiple 2 to the power of 1 by 3. When the values, which you get at the pretty close to these values, and then you make sure that where series the other end. You have then round it off to 1000 and then you again start the next cycle that is what, one-third octave bands central frequencies. This is how they are calculated based on this 10 to the power of n over 10 formula and then you round it off to get their nominal values.

Last thing you look at these ns n equals 20, 21, 22, 23 24, 24 these ns are called band numbers. So, in the last, earlier one I was discussing, octave bands - I had just mentioned that each band is associated with the number. So, these are the band numbers. So, whenever my frequency goes up by a factor of 2, see this is 100 hertz this is 200 hertz n goes up by factor of 3. Not 3 by 3; again when I go to 400 it goes up again by difference of 3 and so on and so forth. So, you understand this?

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Third-Octave and Octave Passbands

Band No.	Nominal center frequency (Hz)	1/3 Octave Passbands (Hz)	Octave Passbands (Hz)	Band No.	Nominal center frequency (Hz)	1/3 Octave Passbands (Hz)	Octave Passbands (Hz)
1	1.25	1.12-1.41		11	12.5	11.2-14.1	
2	1.6	1.41-1.78		12	16	14.1-17.8	11.2-22.4
3	2	1.78-2.24	1.41-2.82	13	20	17.8-22.4	
4	2.5	2.24-2.82		14	25	22.4-28.2	
5	3.15	2.82-3.55		15	31.5	28.2-35.5	22.4-44.7
6	4	3.55-4.47	2.82-5.62	16	40	35.5-44.7	
7	5	4.47-5.62		17	50	44.7-56.2	
8	6.3	5.62-7.08		18	63	56.2-70.8	44.7-89.1
9	8	7.08-8.91	5.62-11.2	19	80	70.8-89.1	
10	10	8.91-11.2		20	100	89.1-112	

So, these are the industries standard octave bands. The band numbers of octave bands are same as if you calculate using one-third octave formula. So, band number 1 is 1.25, 0 was 1 hertz, 1 is 1.25, and this is the range of frequencies. This is the upper where lower frequency limit upper frequency limit for the center octave band. This is the second one-third octave band not. So, band numbers 2 and this is band number 3 and this 2 also happens to be the center frequency of this octave band. So, this is an octave band these are all one-third octave bands.

So, this is the frequency range for this octave band then, we have one some more 2 more octave band, one-third octave band, then you may get the second; third another octave band. Then you have some more one-third octave bands and so on and so forth. So, this is. So, it starts band number starts from once. So, once you have the band number actually, you can calculate the center frequency upper frequency all that stuff very easily. So, so band number is all what you want.

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Band No.	Nominal center frequency (Hz)	1/3 Octave Passbands (Hz)	Octave Passbands (Hz)
21	125	112-141	89.1-178
22	160	141-178	
23	200	178-224	
24	250	224-282	178-355
25	315	282-355	
26	400	355-447	
27	500	447-562	355-708
28	630	562-708	
29	800	708-891	
30	1000	891-1120	708-1.41k

Band No.	Nominal center frequency (Hz)	1/3 Octave Passbands (Hz)	Octave Passbands (Hz)
31	1250	1120-1410	
32	1600	1410-1780	
33	2000	1780-2240	1.41k-2.82k
34	2500	2240-2820	
35	3150	2820-3550	
36	4000	3550-4470	2.82k-5.62k
37	5000	4470-5620	
38	6300	5620-7080	
39	8000	7080-8910	5.62k-11.2k
40	10k	8910-11200	
41	12.5k	11.2k-14.1k	
42	16k	14.1-17.8k	11.2k-22.4k
43	20k	17.8-22.4k	

Then you can calculate everything in this table and then of course, you have to round it off to meet some you know practicality considerations. So, you can go up till 12,000 hertz and you will have. So, their total of 43 plus the first of one-third octave band was number zero. So, total of 44, one-third octave bands in the whole system. So, here we started from 1.25 you should have started from 0. So, this is how it goes. So, understand that?

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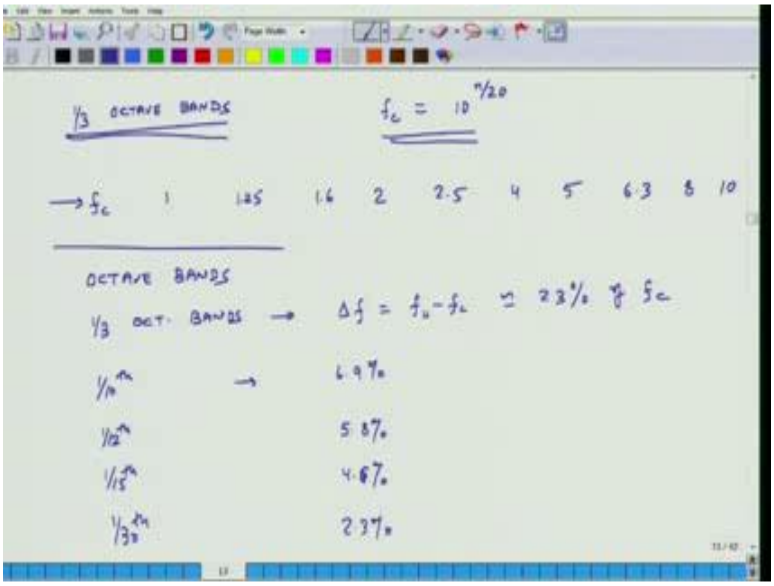

Now, last point, so we have talked about octave bands then we have talked about one-third octave bands and. So, this is your final resolution. Then there are final bands also, there is one-tenth band, here then we have one-twelfth, then you have one-fifteenth, and you have one-thirtieth.

Now in one-third octave band, delta f; what is delta f? The difference between f u minus f c that is delta f, this is approximately equal to 23 percent of f c. If you do the calculation you will find that it is about 23 percent of f c, for one-tenth band this number is about 6.9e percent. For one-tenth band this number is finer, 5.8 percent then we have one-fifteenth it is 4.6 percent and then, one-thirtieth band is 2.3 percent, I have to write this clearly. So, this is one-thirtieth band.

And then there is also a one percent band where, this delta f is one percent of the band width and you can calculate. So, it is not that there are only 2 types of bands octave bands and one-third octave band there lots of bands, but most of times in industry you will see octave and one-third octave, but if you really want to (Refer Time: 24:40) and take a final look at the results, you can go to final resolutions also. So, this is what I wanted to discuss in this class, in the next class what we will discuss is how to generate results for these octave bands using our time series analysis.

Thank you.