

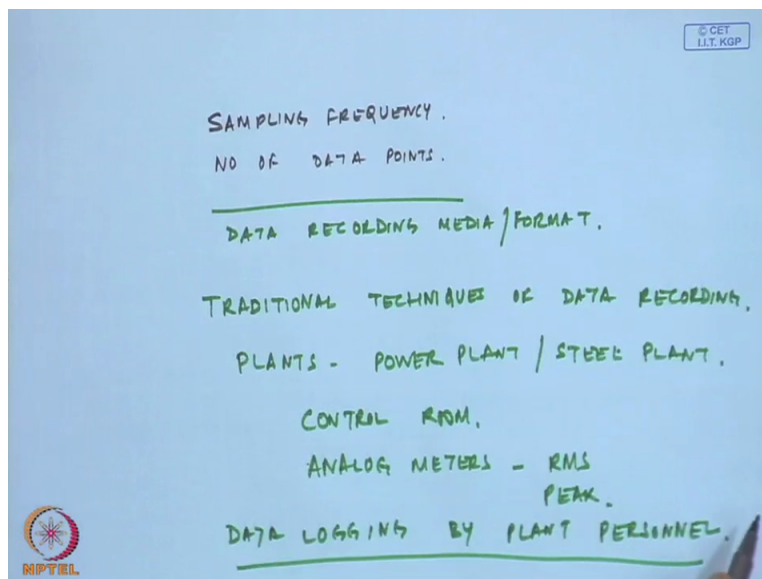
Machinery Fault Diagnosis and Signal Processing
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Lecture -18
Data Recording and Transmission

This lecture is on data recording and signal transmission. As you know in machinery condition monitoring, it is very important that we get the data out of this machine and then, record it so that we can do these signal analysis on it. Well, so what is the format of recording is what we are going to discuss in this class.

What are the methods to record certain signal and then, how do you do the analysis? You all recall that in computer aided data acquisition.

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We notice the importance of sampling frequency. And then, the number of data points; this plays an important role in the selection of the, data recording media or format. Well, before we come to this idea, I would like to tell you something about the traditional techniques of data recording. Well, you all must have visited certain plants would be a power plant, could be a steel plant.

So, they have a control room in which, I am talking about things in the industry about you know, 3 to 4 decades ago. And then, all they had, where lot of analog meters, essentially, RMS for peak

meters. And data logging was done by planned personnel. This was the format of data recording, maybe a couple of decades ago.

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DATE	(HOURS) TIME	CURRENT	TEMP	SUPPLY VOLTAGE
	0:30			
	1:00		0	0
	1:30		INCREASING	

HUMAN BEINGS.

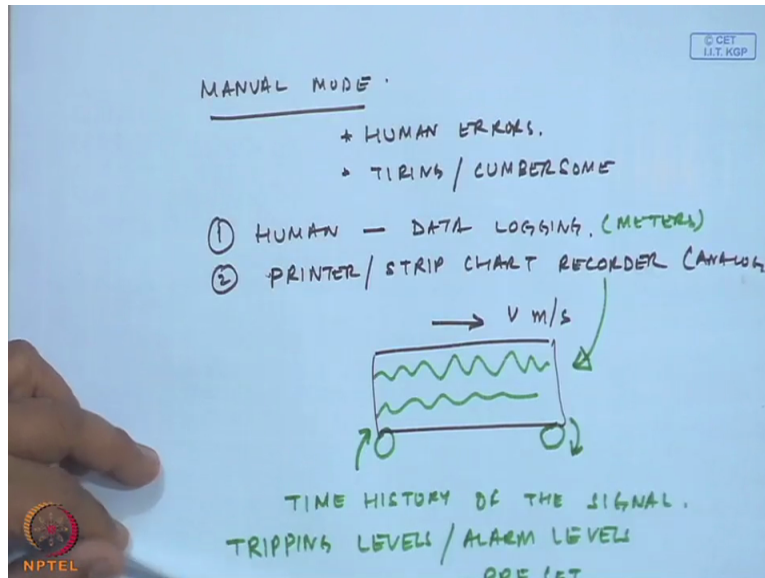
LOG SHEETS.

But now, what they were doing is, as there is as a function of time, they would note down the parameters like the current drawn by motor, maybe the temperature of the bearing, maybe the supply voltage, okay. And this time, mind you, maybe, you know, every maybe, every 30 minutes in hours. So, and this was being done by a human being.

And if there was not and this is the, this should be the log sheets, they would essentially form the log sheets. and then, and this were available in the plant room; and then, if there was an abnormality at certain conditions, people would go back to a certain date and look into the log sheet of the plant; and then try to come to a conclusion like what went wrong and so on.

Or suddenly, if in the plant, operator notices that the temperature is suddenly rising, is increasing then, they would certain alarm condition. And then, people would take precautionary measure moments as to how to reduce this kind of abnormal behaviour of the machine; or how to control them. But there are lot of problems with this. This was a completely manual mode, okay.

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There are problems in which human errors could creep in because of wrong recording or wrong writing, wrong reading. This was one possible; and another was, it was tiring and cumbersome because, you know; usually you have to read all the meters in the control room. And, and the control rooms could be know, panels of meters and so on.

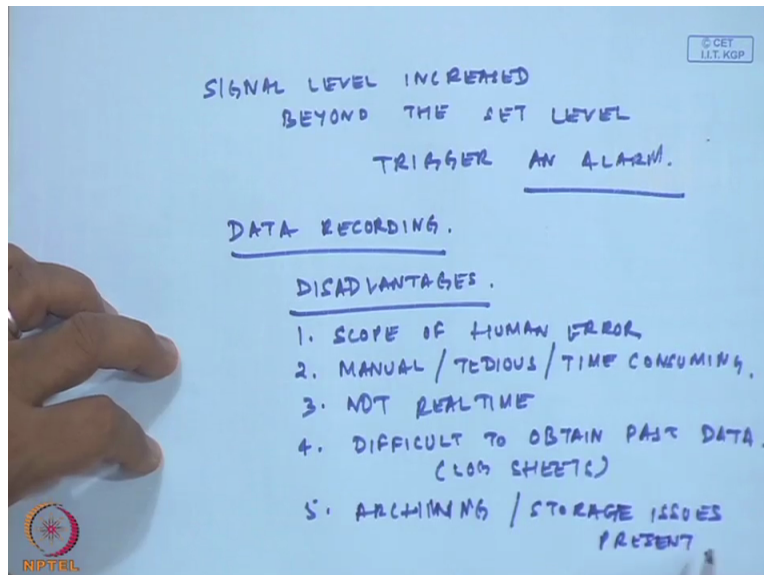
And this was a very cumbersome and tedious process. And then, there are a lot of chances by which errors could creep in. And you know, there are been instances where people have reported that because of a wrong reading recorded by person. The interpretation was wrong and then, the analysis of the prognosis was not correct.

Well, another method was you know, there were, other than writing. So, the first one was a human intervention with physical data logging. But closely, with this is, using a either a printer or a strip chart recorder. These are the analog, okay and wherein there will be just a voltage signal coming out, because of the parameter.

And then with time, basically there will be a paper roll, okay which will be moving at a certain speed V meters per second. And then, there will be pens on this and they will be writing the, or plotting the parameters. And this would be on the roll, okay, okay. And this is essentially, what is a strip chart recorder.

And then people used to have such large rolls of data wherein, we can look into the problem and then find out get basically a time history of the signal, by looking at the strip chart recorder. And some of these data logging meters used to have trip set, tripping levels or alarm levels set, reset.

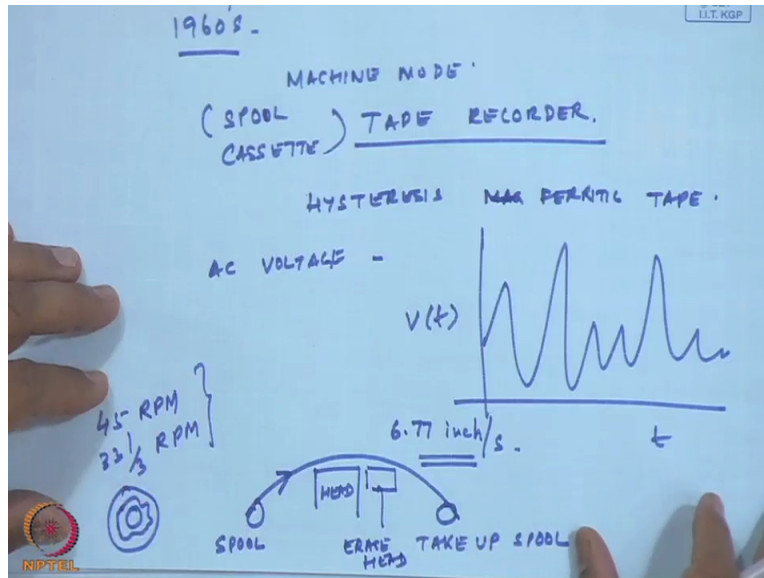
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That means, when the alarm level increased or the signal level increased, beyond the set level it would trigger an alarm. This was, what the traditional method of, I would say, data recording. But, as you can see, the problem with this kind of data recording is fostered; list down, one was a lot of scope of human error. It is manual thus tedious time consuming; it is not real time, it is difficult to obtain past data.

Because then, one has to physically pull out the log sheets and that would be cumbersome. And then because of larger amount of writings archiving or storage issues present, okay.

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Now, because of this, disadvantages, since the sixties, people have started to use other means of recording. And that was the machine mode. And first would be a tape recorder, okay like, like the spool or the cassette. Of course, cassette came much later under the stool, a spool type tape recorder, okay. Now, we will look into these different types of tape recorders. And then, what is the present format of tape recorder and how we do the digital recording in such tape recorders?

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Data Recording

Machinery Fault Diagnosis & Signal Processing

- Analog
 - Direct Recording
 - FM Recording
 - PCM Recording
 - DAT Recording
- Digital
 - CD, DVD
 - RAM

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So, if I was to look into the different formats of data recording relevant today, one could be with the analog recording or the digital recording. What happens in the analog recording? We still have the direct recording method wherein, on a cassette or a tape recorder or a spool type tape

recorder, the data was stored because of the hysteresis in the Ferritic tape because the signal would be converted.

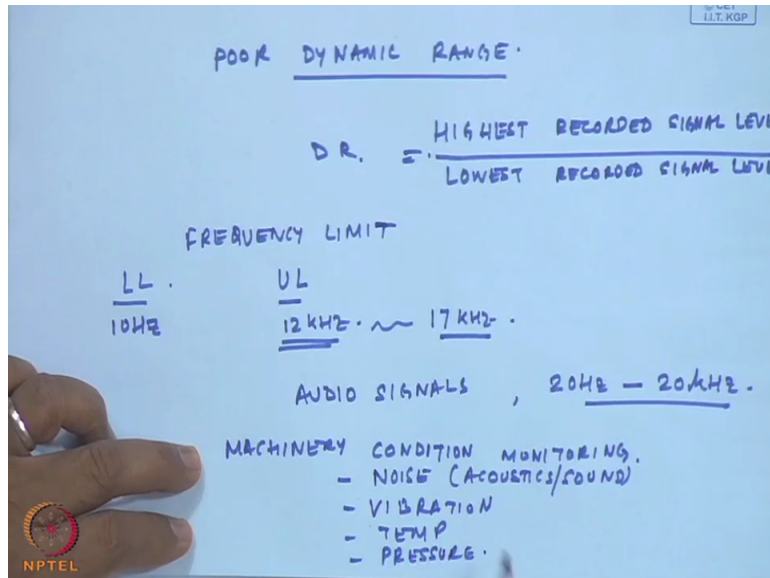
Basically, essentially, we have a voltage signal which is time varying or an AC voltage. This could be my voltage signal which has to be recorded. Now, because of this varying voltage, there will be an magnetic flux created, when the signal is recorded through the head of the tape recorder. So, we have a magnetic head and then the tape is made to go at a particular speed, okay.

And the take up spool and the home spool and they go at a particular speed. And some of them go to 6.77 inch per second. And this is the value of the industry format. Then, it was in the inch per second speed, linear speed. And this is dependent on the rpm, you know, we used to have the old LPs at 45 rpm or 33 and one third rpm, etcetera. So, these are the particular speed at which these things used to run.

Of course, I am not talking about the LP spools, because in LP spools what happens? The data once stored, cannot be erased or changed, okay. But we are not talking about the LP spools in this case. We are talking about in head wherein because of the magnetism in the, introduced in the variety tape, the data could be stored.

And then, of course, we also had the possibility of having an erase head. If the erase head is there, you could demagnetize it and then the tip the information stored in the tape could be removed. But the advantages or disadvantages of this kind of systems are:

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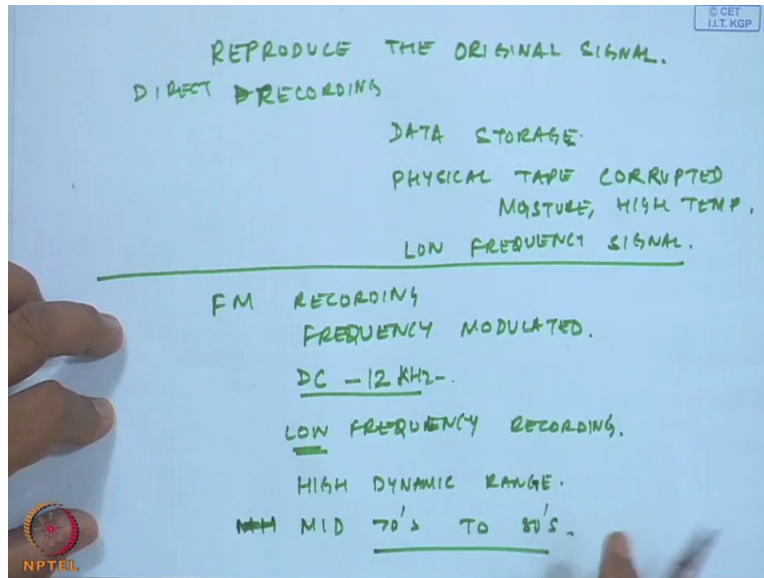


This had a very poor dynamic range, by dynamic range are different as the highest recorded signal level to the lowest recorded signal level. And they were also having a frequency limit, like an upper limit or a lower limit. And traditionally, these, these magnetic tapes had a very, very low upper limit could be as low as 10 Hertz and maybe as high as maybe 12 kilo hertz, so on.

And this later on improved with the type of tapes, you know, there were metal tapes, chromium tapes, etcetera wherein, this could be go up to maybe a 70, 17 kilo Hertz. But traditionally, this direct recording tape recorders were used miss mostly, for recording audio signals. And as you know, the audio signals are in the range of 20 Hertz to 20 kilohertz.

And these recorders did a good job in recording such audio signals or for that matter, any signals, which had, which are in this frequency range. So, when you are talking about machinery condition monitoring, we could be recording signals from noise or acoustic signals, vibration signals and maybe temperature signals or certain process parameters like pressure, etcetera.

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And our requirement is that with each device, we have to either reproduce the original signal; but the problem is this direct recording was data storage; because once we store it in a magnetic media, there is every possibility possible chance that in a magnetic environment, they may deteriorate; the physical tape may get corrupted, because of moisture, high temperature, etcetera.

You must have seen if you are at home if you store your old tape, if you ever have your old-spool tapes or cassette tapes stored elsewhere, you will see if you do not care about the moisture around, you know, and there will be a lot of fungi formation on those tapes. And then, there will be, you will lose the signal quality, etcetera and these are the problems.

And of course, from a signal processing point of view, the major problem is, it cannot record the low frequency signal. But in these early 70s or late 60s, this pool type direct recording tape recorders were quite popular and because that was the only technology available. Then, and they were doing fairly a good job with recording audio signals, particularly, no music, music recordings, etcetera.

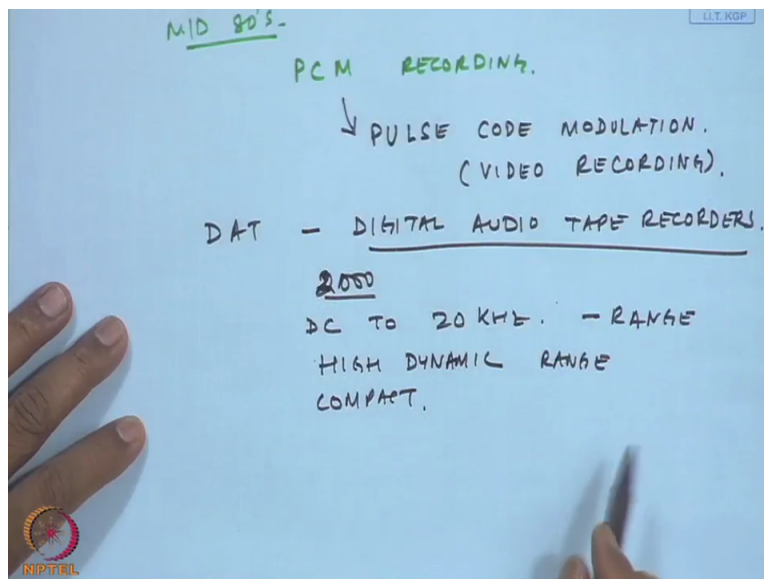
Of course, if you want to then have a permanent recording in the media, people use this, the record, record player in the record, the LP record, the EP records, etcetera wherein, permanently, the song tracks could be cast and kept in those vinyl discs, okay. But we are not talking about,

you know, we obviously cannot store data because data has to be recovered for an analysis; and we do not want to record it permanently in recording media.

So, that the provision of erasing was not possible in the LP records, of the EP records. But in the direct recording, by having the serious head with have always erase the data recorded. Then, they coming back to the next format of recording, that is the FM recording that is the frequency modulated recording, the FM recordings are very popular and convenient because they can measure as low as DC and then can go higher than 12 kilo Hertz, etcetera.

So, low frequency, low frequency recording are possible by the FM according. Of course, the recording media could again, again be a spool or a cassette tape and so on. But the advantages the low frequency recording could be done and it has a relatively high dynamic range. So, this was a popular from the, maybe from the seventies to the, maybe, maybe mid 80s. People used to use this FM recording for recording the signals. This is from mid 70's to 80's; people were doing the FM recording.

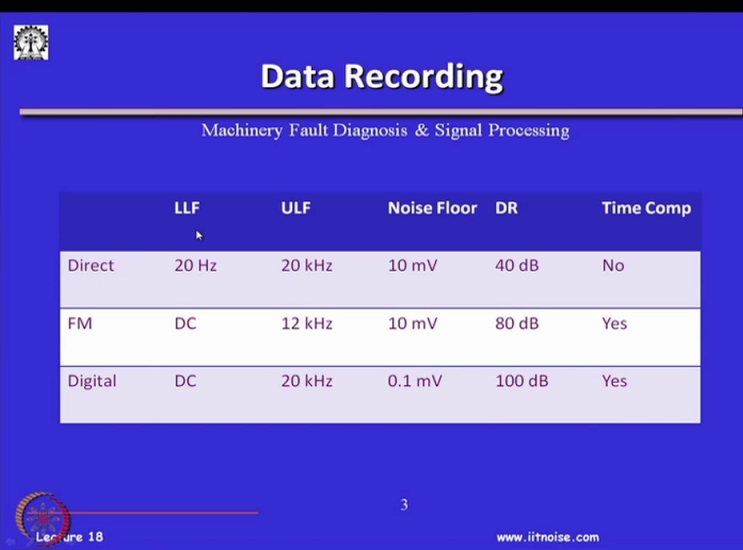
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But then, this later on from mid 80s, we have come up with this format of pulse code modulation recording, which we are, essentially have high frequency recording, used in the, you know, in the video recording. People use the same pulse code modulation technique which is using video recording for recording audio signals.

And people then use them in DAT recorders or digital audio tape recorders. And these are quite popular till very recently maybe, maybe till about late or maybe outside, till the year 2000. They were very popular; digital DAT recorders, okay. And the advantages of these DAT recorders are: They are DC to about 20 kilos hertz, high dynamic range, compact and so on.

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	LLF	ULF	Noise Floor	DR	Time Comp
Direct	20 Hz	20 kHz	10 mV	40 dB	No
FM	DC	12 kHz	10 mV	80 dB	Yes
Digital	DC	20 kHz	0.1 mV	100 dB	Yes

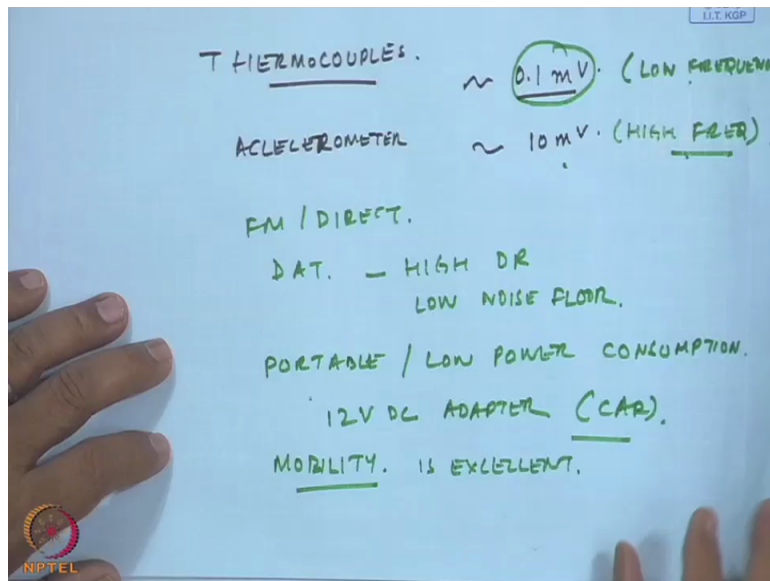
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If you see here, I have just made a comparison in this slide, on the data recording methods, by the direct recording, the frequency modulated recording, the digital recording; the lower frequency limit in direct recordings is over 20 Hertz; upper limit is 20 kilo Hertz; noise floor 10 millivolts. That means, you cannot record any signal less than 10 millivolts.

Dynamic range is very poor, 40 decibels and time compensation is not available; whereas in frequency modulation recording; I can go as low as DC or 0.1 Hertz to about 12 kilo Hertz. Of course, this has improved lately. Again, noise floor is 10 millivolt um but then, we can have a very, very high dynamic range of 80 decibels and time compensation is possible.

The digital audio recording or the DAT format which we use can have a low frequency limit of DC and then, the high limit, high frequency limit is 20 kilo Hertz, noise floor is 0.1 millivolt and 100 decibels. But the advantage of the digital recording over the other recording is that the noise floor being very, very low, we can have signals from devices like thermocouples.

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As you know, thermocouples give a very, very low millivolt signal, okay as opposed to, maybe an accelerometer, maybe 10 millivolt, okay. And if I was to, for a good comparison, these are basically low frequency signals. And these are relatively high frequency signals, okay. Now, having a signal less than or around .1 millivolt, it will be very difficult to measure either by FM or Direct recording.

But, if you have a digital audio tape, you could record such low signals and low frequency as well as high values and at high frequencies; because they have a high dynamic range and then low noise floor. But all these three types of tape recorders are available in the market. I mean, of course, you know, it will be very difficult for you to find a digital sorry, direct recorder or an FM tape recorder with spool or the cassette nowadays.

But even finding a DAT recorder could be difficult at times, because you know nowadays people are using the DVD recorders are totally recording in a flash card or a compact media; even writing it straight to the hard disk of the device. But the advantages of these recorders are: They are portable, low power consumption; some of these recorders can be even powered from the 12-volt DC adapter given in your car.

So, the mobility of such recorders is excellent, okay because, why do we have these data recorders in the first place?

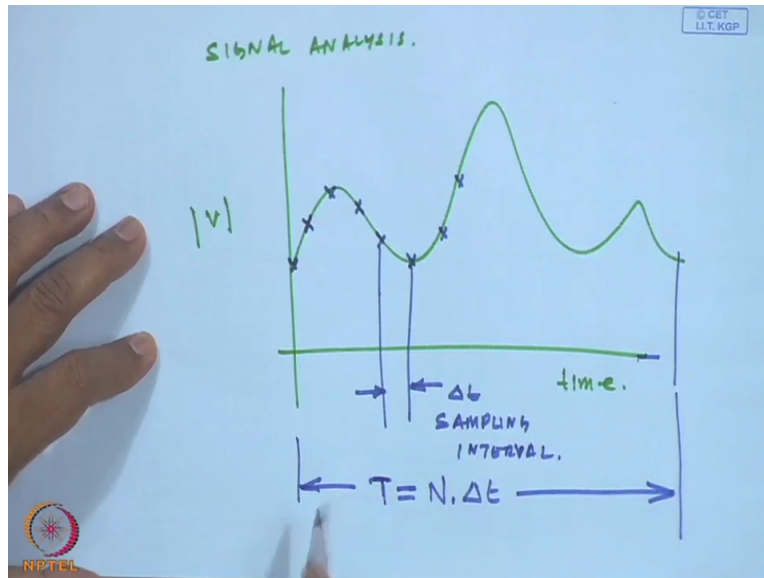
We have these data recorders because we cannot possibly go to the plant, maybe the plant is a coal mine, a very dusty environment. We cannot go and sit next to a crusher or a grinding mill and do the vibration analysis as to find out the remaining useful life of this crusher or the grinding mill. Rather have the transducers mounted around the grinding wheel or the crusher and then, record the signal on a tape recorder.

And then, this tape recorder obviously has to be portable, has to be lightweight, could be powered by any source and then, once we have recorded it in a particular media, we can bring this tape recorder back to our laboratory, wherein we can do these signal analysis and try to find out the condition of this machine. It is not that the tape recorder is fixed or tape recorder is always there in the lab.

No, this is not the objective of our recording here. Our recording in condition based maintenance or monitoring is to be, have a big steel plant for that matter, next to you, sitting in your analysis office, okay. Obviously, I cannot bring a steel plant to my office. But if I have recorded the signals in a tape recorder, which reproduces the signals as they were recorded or as they were measured, right at the steel plant, my job is done.

And with that objective, actually, we are recording these signals. And then, we will see, what are the advantages of using a portable recorder, with high dynamic range where the data can be stored for long, long of time? So, right in the beginning of this class, I told you about the importance of two factors: one is the sampling frequency and other is the number of data points, ok.

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If you will recall, because all you need to do is, signal analysis. That means, if I have a signal like this, some signal, this has to be sampled at a fixed interval. This has to be fixed at the sampling interval and the total time of this data, total time is $T = N$ times Δt .

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$T = N \cdot \Delta t$

↓

Number of Data Points.

x x ← SAMPLED DIGITAL DATA.

STORAGE MEMORY REQUIREMENT.

DIGITAL RECORDING.

DATA — 16 bits (2 bytes) of MEMORY SPACE.

$F_s = 100 \text{ kHz}$

$\Delta t = \frac{1}{100 \times 1000} = 10^{-5} \text{ s}.$

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This $T = N$ times Δt , where N is the number of data points. In the previous diagram, all those crosses I have done were actually the locations of the sampled digital data. So, in terms of the storage memory requirement, because this digital data has to be stored in some memory location in the digital recording.

Now, if every data requires 16 bits or 2 bytes of memory space, suppose, I am sampling at F_s is equal to, maybe 100 kilohertz, okay; that is, ΔT is equal to 1 by 100 kilohertz multiplied by thousand is 10 to the power minus 5 seconds is my sampling interval.

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$$T = N \cdot \Delta t$$

$$N = \frac{T}{\Delta t}$$

16 bits, 10 MINUTES OF DATA, $f_s = 100 \text{ kHz}$.

$$N = 10 \times 60 \times \frac{1}{10^{-5}} = 600 \times 10^5 \text{ DATA points.}$$

$$N = 2 \text{ BYTES.}$$

$$\text{MEMORY REQD.} = 2 \times 600 \times 10^5 \text{ BYTES}$$

$$1 \text{ KB} = 1024 \text{ bytes.} \approx 10^3 \text{ bytes}$$

And if I was to find out the total time is equal to N times Δt ; N is equal to the total time by ΔT , ok. Now, if I want to record 10 minutes of data at a sampling frequency of 100 kilohertz, my number of data which has to be stored is 10 minutes, 10 into 60 seconds into 1 by Δt , which is a 1 by 10 to the power -5. That is 600 into 10 to power 5 data points.

Now, if every data point requires 2 bytes, I require the memory required to store 10 minutes of data sampled at 100 kilohertz, in a 16-bit recorder would be, 2 into 600 into 10 to the power 5 bytes, okay. I would, though, no, one kilobyte is equal to 1024 bytes. If I approximate it, as I know, maybe, for the sake of discussions, maybe, 10 to the power 3 bytes.

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MEMORY READ

$$= 2 \times 60 \times 10^5$$

$$= 120 \times 10^6$$

$$\approx 120 \text{ MBYTES.}$$

1 KB $\approx$ 1000 BYTES
 ≈ 1024 B

10 MINUTES OF DATA, SAMPLED
 AT 100 KHZ, IN A 16 BIT DIGITAL RECORDER
 APPROXIMATELY NEED 120 MB OF DIGITAL
 MEMORY.

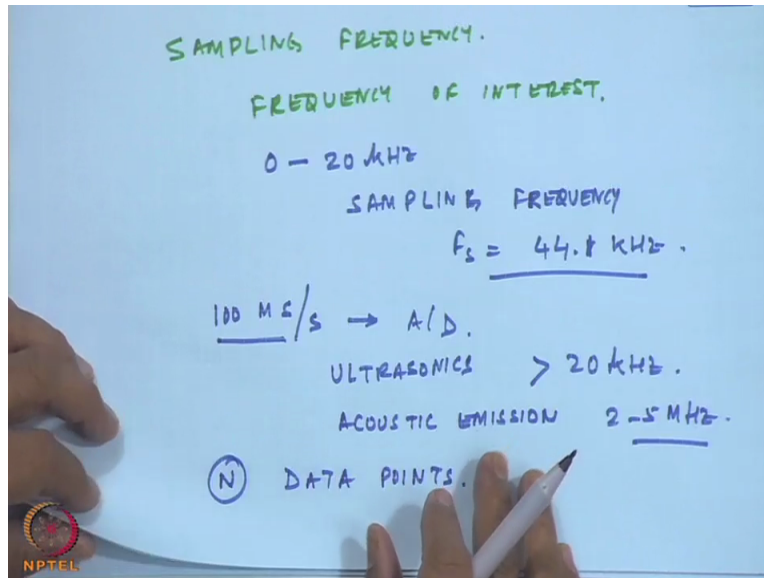
$$N = \frac{T}{\Delta t} = T \cdot f_s$$

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So, the memory required would be 2 into 600 into 10 to the power 5. That is equal to about 12, 120 into 10 to power 6 approximately 120 megabytes MB. Though, I have used an approximate that, 1 kilobyte is thousand bytes. That is not quite right. But just for the sake of this discussion is actually 1024 bytes. So, approximately the, to summarize, to store 10 minutes of data sampled at 100 kilohertz in a 16-bit digital recorder, would require approximately 100, 120 megabyte of digital memory, okay.

Now, you can now multiply if you want to instead of 10 minutes you want to make it 100 minutes another extra 0 coming here. Still if you want to sample at still higher frequencies, you know, your, the, because N is equal to T by T by delta t or T times fs, ok. If your sampling frequency is increased and node increased, if your time is increased, node is increased. So, depending on that, you can do a calculation and then, try to understand, what is the amount of memory required?

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But in digital recording, the most limiting factor is the sampling frequency. In digital recorders, depending on our frequency of interest, we can have this hybrid frequency decided from the Shannon sampling theorem. Now, suppose, we are talking about the mechanical signals basically, in the audio range from 0 to 20 kilohertz maybe, we sample at sampling frequency, f_s is equal to 44.1 one kilohertz.

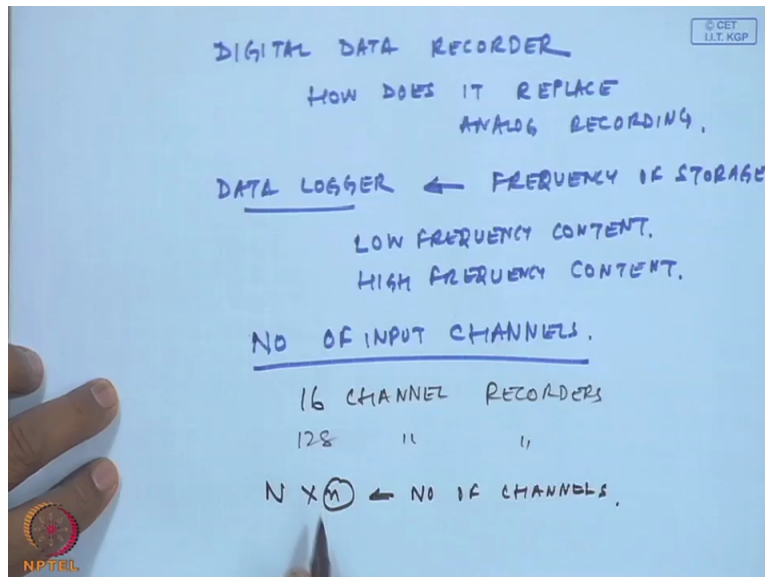
And this is a set sampling frequency and then, we can record as much as you want, provided, we have the memory space. But nowadays, there are very, very high sampling devices which can sample at a 100 mega samples per second, okay. And this is the present state of the art. We can have A to D systems, A to D card which can sample at about 100 samples per second.

And then, these high samplings are actually used for studying ultrasonic's. Ultrasonic's occur at frequencies below or greater than 20 kilohertz or you want to study about acoustic emission which occur from anywhere from 2 to 5 mega Hertz. So, if I was to record any ultrasonic signals or capture any acoustic emission phenomena, I have to be sampling at very, very high frequencies could be you know 100 mega Hertz and so on.

And these A to D cards are very costly, very difficult to find at times, nevertheless, nowadays systems are coming in with such sampling devices are there. And then, we eventually, we have to store this data in data recorder or data points. And from the previous example, we just saw that

by playing around with the number of data points, sorry, by playing around with the sampling frequency and the time data time, which you require to record, we can increase the number of data points.

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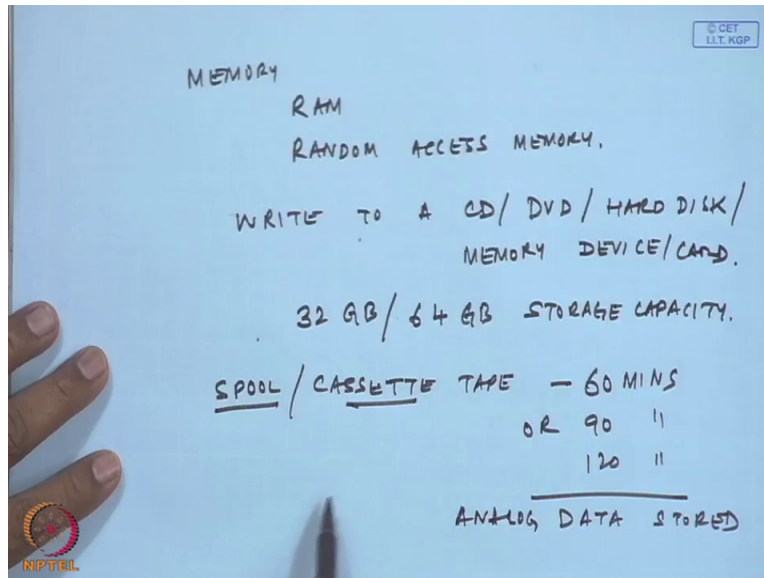


Now, so, how do such digital data recorder replace the conventional recall, the analog data recording people are doing by hand, how does it replace analog recording? So, in this data logger which we call, I can decide frequency of storage may be continuously. And imagine, I have a signal which is low frequency content and another which has high frequency content, like the case of the thermocouple and the accelerometer.

So, depending on my interest, low frequency content could be sample at a low frequency, high frequency content could be sample at a higher frequency. In the same data logger, the number of input channels is also a very important characteristic; For example, there are 16 channel recorders, even there are 128 channel recorders and so on, okay. That depends on suppose, of course, with all the previous examples.

If we are done with one channel if simultaneously, I want to record 16 channels of data, or 128 channels of data, I need to also record them and multiply the number of data points by the smaller number of channels.

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And these data points have to be stored in a memory which is RAM memory may be which could be raised. And then, if you want to have a permanent record, you can write to a CD/DVD okay or even put it in your hard disk or maybe also in a memory card or a device. Nowadays, you know you get cameras and flash cards within a 32Gb or 64Gb storage capacity, okay.

And these are traditionally, you know, compared to the data recording facilities we had in the sixties, wherein a typical spool or a cassette tape, utmost have, you know, 60 minutes or 90 or 120 minutes of data could be stored, okay. This was the duration of this spool, cassette type. Obviously, we cannot do continuous data recording over months, when such recording because of the limitation of the storage space.

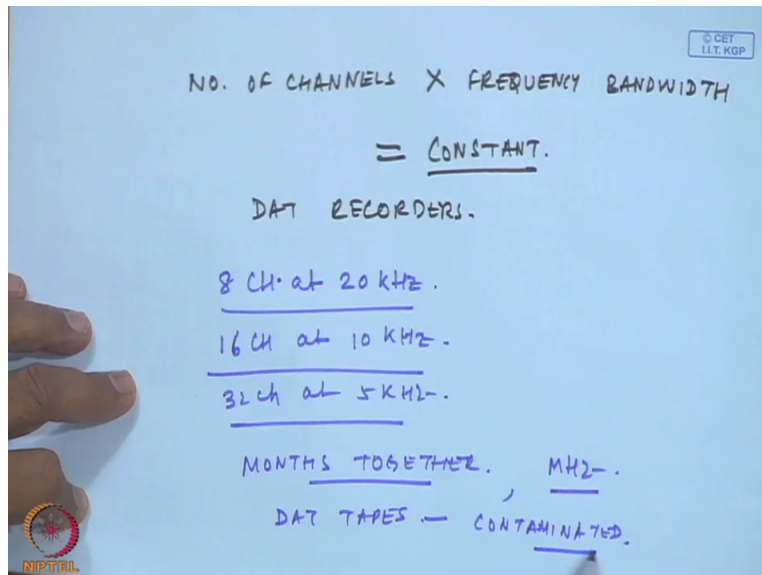
But nowadays, with such compact memory cards, with capacity of 32 or 64 GB, you know; 64 GB would last, you what maybe, you know, just to show in an example that the data recorder, how this can be stored?

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So, come back here this is a typical data channel recorder which we have in our laboratory. This is a this is where the digital cassette tape goes in and if you will see here there are 8 channels of input and 8 output channels and then you can record about 120 minutes of data in each tape at a maximum frequency of 20 kilohertz in each of the eight channels okay.

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So, the number of channels times the frequency bandwidth is a constant in this kind of and recorders. So, it is 8 channels at 20 kilohertz okay and then you could be, if you want a more make more channels if you want to make 16 channels it has to be sampled at 10 kilohertz and so on okay. So, this option can be there are 32 channels at 5 kilohertz okay.

But the limitations of such dat recorders are I obviously cannot record months together recorder is not possible and then I obviously cannot record at very, very high frequencies maybe in megahertz okay. And then of course again this has to be stored in dat tapes which could be contaminated.

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So, off recently quite you know in the last maybe 5 or 6 years people are using this digital dat recorder like you see one which we have in our laboratory here you can have 16 channels of record and then you can given signals. And for such a recorder we can have very, very high sampling frequencies and then we can record a lot of data points.

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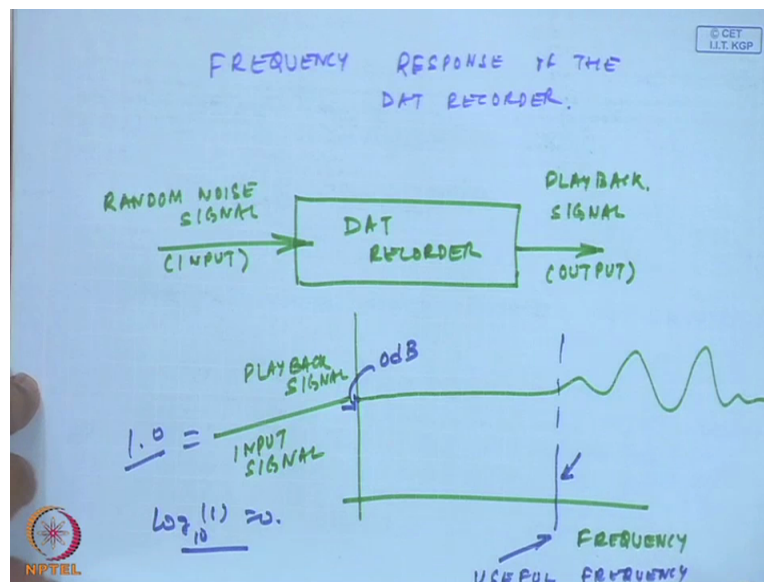
Digital Data Recording with 2 Gpoint Memory		
Machinery Fault Diagnosis & Signal Processing		
Sample Rate	With 1 Ch	With 16 Ch
100 MS/s	20 s	2 sec (using 8 Ch)
10 MS/s	3 min. 20 s	10 s
1 MS/s	30 min	1 min. 40 s
100 KS/s	5 hour	10 min
10 KS/s	50 hour	2 hour 30 min
200 S/s	30 days	50 hours
20 S/s	30 days*	30 days

Just give an example for this digital data recording with about two Giga point of a memory space there is a provision of changing the sampling rate okay 100 mega samples per second or 10 mega samples per second with single channel I can be recording at 20 seconds of data 100 mega samples you know like the Hertz per second.

So, very, very high sampling rate whereas you know even know, we were happy with 5 kilohertz samples per second. Even if you for a mechanical signal if you sample at 100 kilo samples per second with single channel you can record 5 hours of data okay. And if you are running a very, very slow phenomena like monitoring temperatures, 200 samples per second that itself is very, very high while monitoring temperature.

He could be recording with single device for about days without worrying about your memory space about the reproducibility of such signals and so on. A very important point comes in this recorders is the how do you determine the frequency response of the DAT recorder, he could also try this with the digital recorder a simple way to do this is.

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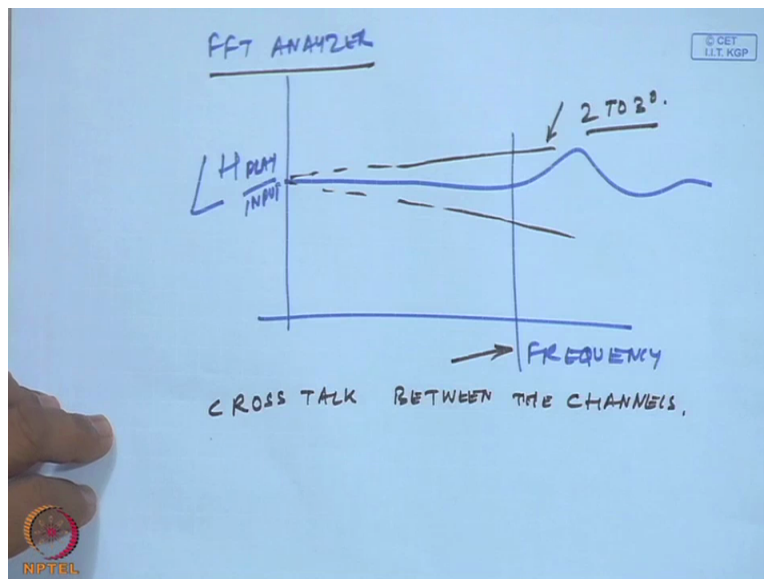


Suppose we have a dat recorder all you have to do is record random noise single at the input and then play back the signal output signal okay. And then simultaneously plot this as a function of frequency playback signal by the input signal. And you will see a frequency because the

playback has to be of the same level as the random noise signal and if you have recorded a random noise of a particular bandwidth you will see okay.

In a dB scale this should be 0 dB this value because a $\log$ of $1 = 0$, so if playback is at the same level as the input signal it will be 1 so it will be 0 decibels. So, this is the useful frequency limit of the signal okay.

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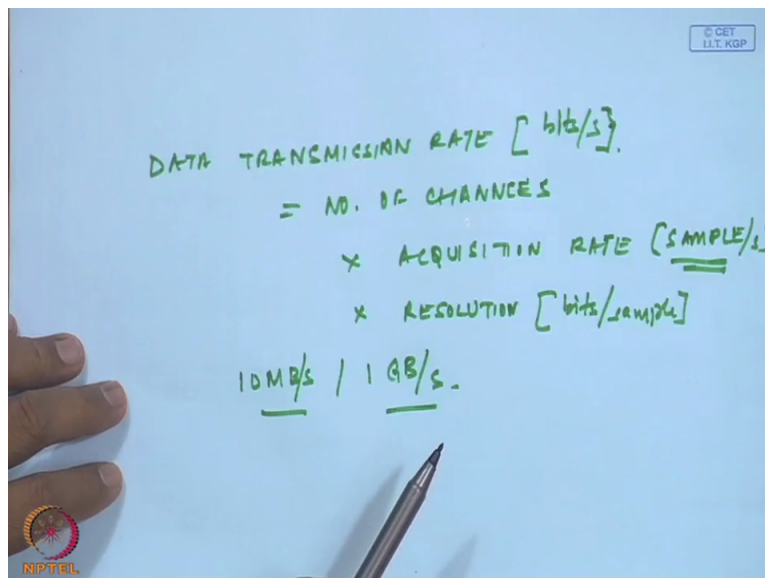
This check in a research it actually does this but it is a good idea to check it out if you have an FFT analyzer you can also see the if you have an FFT analyzer you can also see the phase response. So, the phase of the transfer function between the playback and the input okay and this phase angle should also not vary and this is usually this phase angles typically are they of the order of 2 to 3 degrees.

So, then you can see the frequency limit of the signal okay. So, the upper frequency limit is decided by doing such a small test using random noise dat recorder and you could use that same technique in a digital recorder as well. And there should not be any crosstalk between the channels okay.

Now once we have recorded this signal we also need to transfer the signals and usually the transmission rate of the signal or signal transmission rate depends on the number of channels

multiplied by the acquisition rate and the resolution. So, the data transfer rate even if it is given in bits per second and acquisition and rate in samples per second resolution in bits per second.

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A photograph of a hand holding a pen, writing a formula on a blue surface. The formula is: DATA TRANSMISSION RATE [bits/s] = NO. OF CHANNELS x ACQUISITION RATE [SAMPLE/s] x RESOLUTION [bits/sample]. Below the formula, the units 10MB/s and 1GB/s are written and underlined. In the bottom left corner, there is a logo for NIPTEIL. In the top right corner, there is a small logo for CET I.I.T. KGP.

$$\begin{aligned} \text{DATA TRANSMISSION RATE [bits/s]} \\ &= \text{NO. OF CHANNELS} \\ &\times \text{ACQUISITION RATE [SAMPLE/s]} \\ &\times \text{RESOLUTION [bits/sample]} \\ \hline &10\text{MB/s} / 1\text{GB/s} \end{aligned}$$

So, the data rate, the data transfer rate, transfer or transmission rate is the number of channels multiplied by the acquisition rate multiplied by the resolution an acquisition rate it is the unit of samples per second and resolution is bits per sample and the units of data transmission rate is bits per sample sorry bits per second.

And usually when we use wireless for data transmission rate we have about the maximum level of 10 Mbps or 1 GB okay. So, we can decide what would be the sampling rate and this is the limitation of the present day data transmission by signal by wireless transmission as to the maximum data transfer rate available to us and which is about 10 Mbps or 1 Gbps and then this depends on the number of channels or data you are transferring.

The acquisition rate and resolution typically the resolutions nowadays people use is about 16 samples per second or 24 samples per second and the sampling rate for a low frequency signal it is easier to transfer by wireless. But when we are talking about high frequency signals you know you want to sample or send and 10 channels of vibration data over the wireless.

The data transmission rate of the present wireless technology is limiting these levels of data transfer. And so, that would conclude our discussions on the signal recording in the analog digital domain and the signal transfer by; in the by the wireless, thank you.