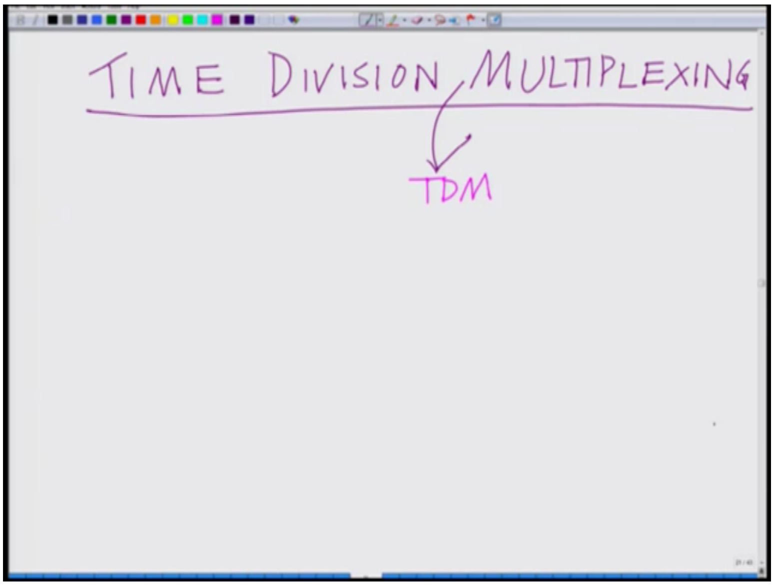
Course on Principles of Communication Systems-Part 1
Professor Aditya K. Jagannatham
Department of Electrical Engineering
Indian Institute of Technology Kanpur
Lecture 52
Module 8
Bandwidth requirements of Time Division Multiplexing (TDM), The T1 TDM System: A Case Study

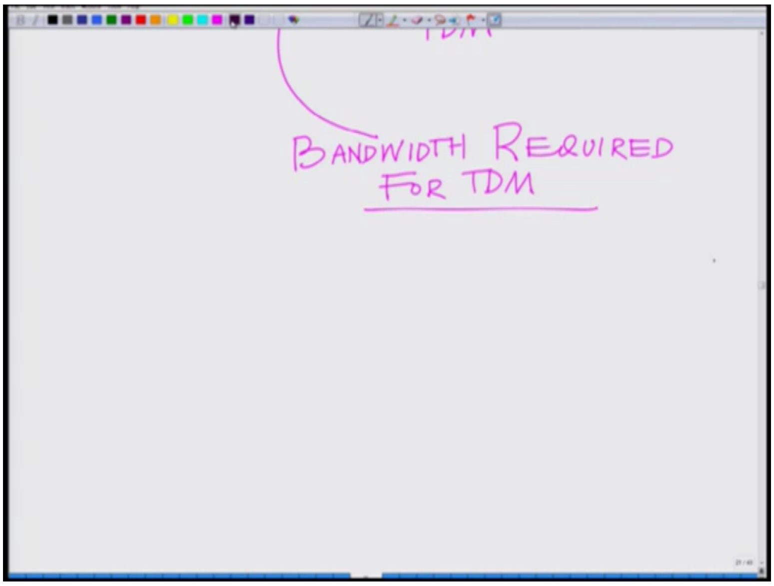
Hello, welcome to another module in this massive open online course alright. so we are looking at Time Division Multiplexing alright, so let us look at other aspects of Time Division Multiplexing in this module, ok.

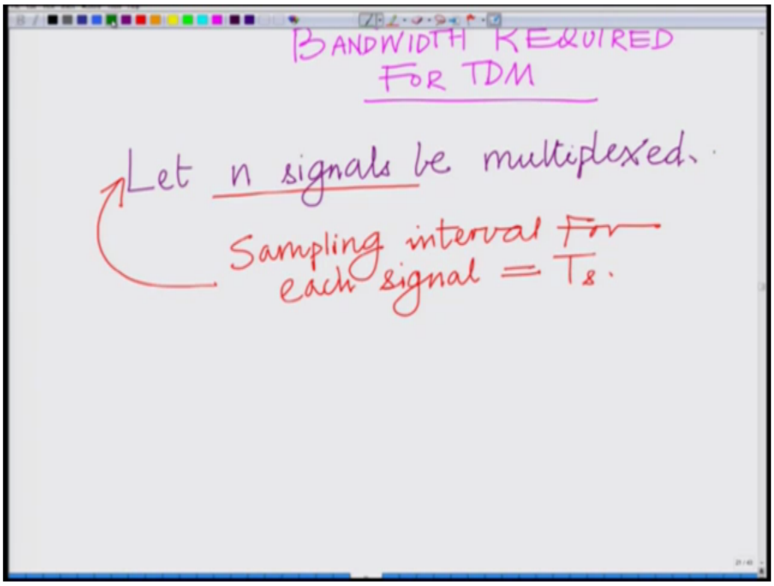
(Refer Slide Time: 0:27)



So we are looking at Time Division Multiplexing that is TDM technology to multiplex several signals over a single channel for transmission ok. So this is your Time Division Multiplexing technology.

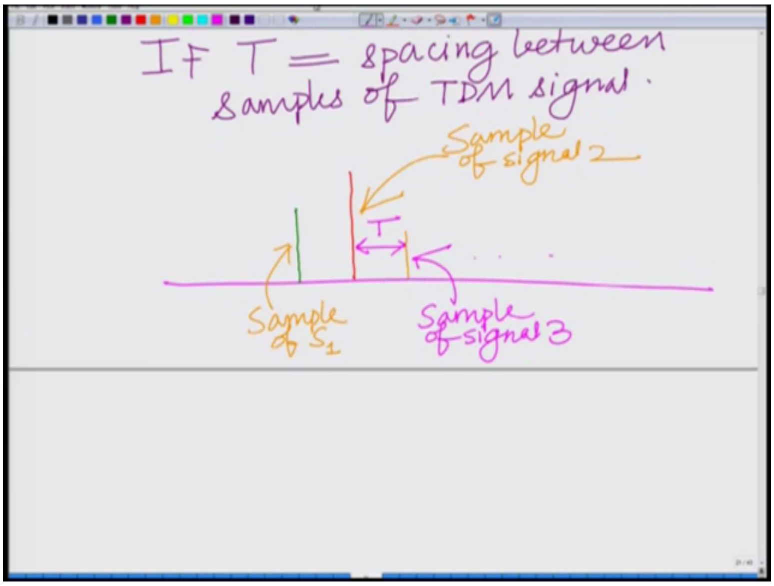
(Refer Slide Time: 1:06)





Now let us start by looking the bandwidth required for TDM, so what we want to look at is first we want to answer the question what is the bandwidth what is the bandwidth required for TDM. Now if you look at this for instance let us say let there be n signals so let us say we are multiplexing n signals using Time Division Multiplexing, so let n signals be multiplexed and they are sampled with all are sampled with at equal intervals Ts so sampling interval for each signal equals Ts, ok. So there are n signals and the sampling interval for each signal is Ts.

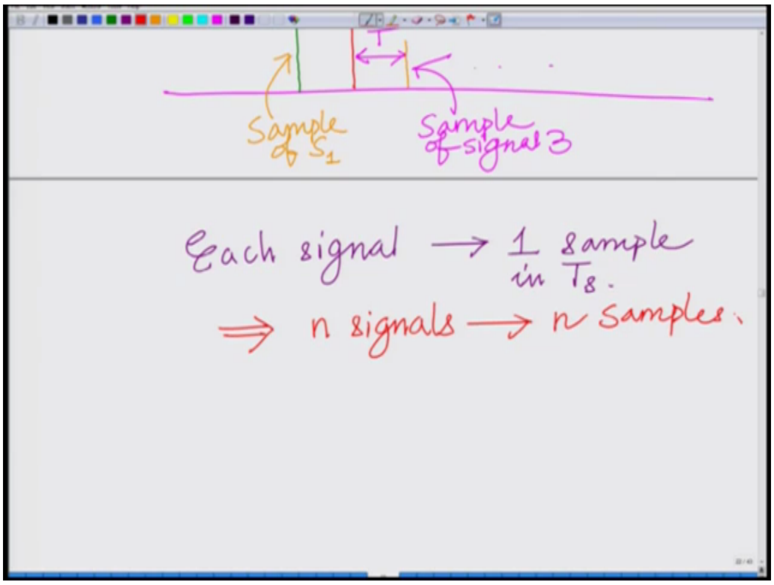
(Refer Slide Time: 2:36)

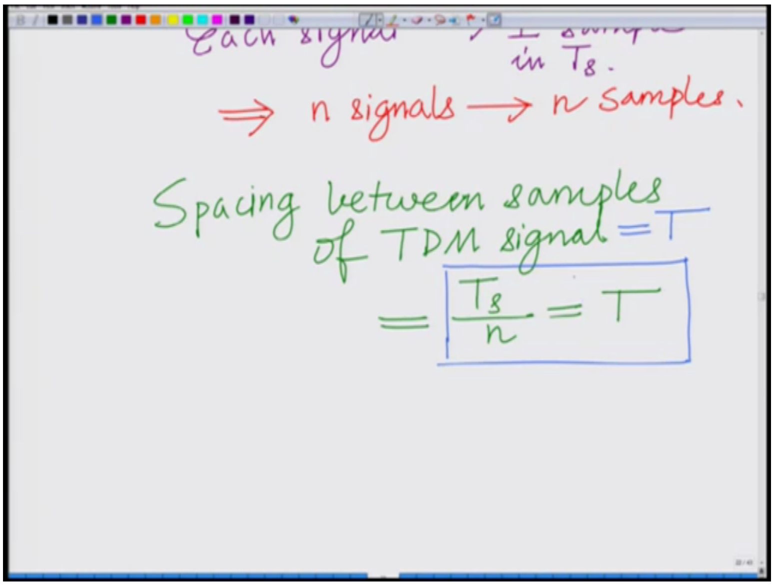


Now if T is the spacing between the samples if T equal to the denotes the spacing between samples of your TDM signal that is if you look at your TDM signal correct and let say we look at the samples of the multiplex signals. So this is sample of signal 1, sample of signal 2, sample of so this is sample of signal this is samples of the multiplex signal. So sample of signal 1, sample of signal 2, this is sample of signal 3, sample of signal 3, so on and so forth and if this duration the duration between samples is T.

Now we have to note that the sampling duration of each signal is uniformed that is Ts, which means every signal has a single sample in Ts. Therefore n signals will have n samples in the interval Ts, right.

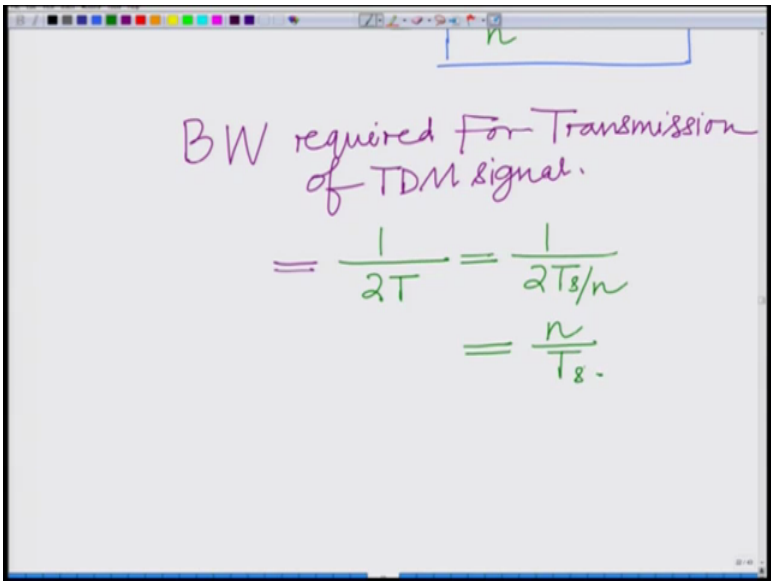
(Refer Slide Time: 4:11)

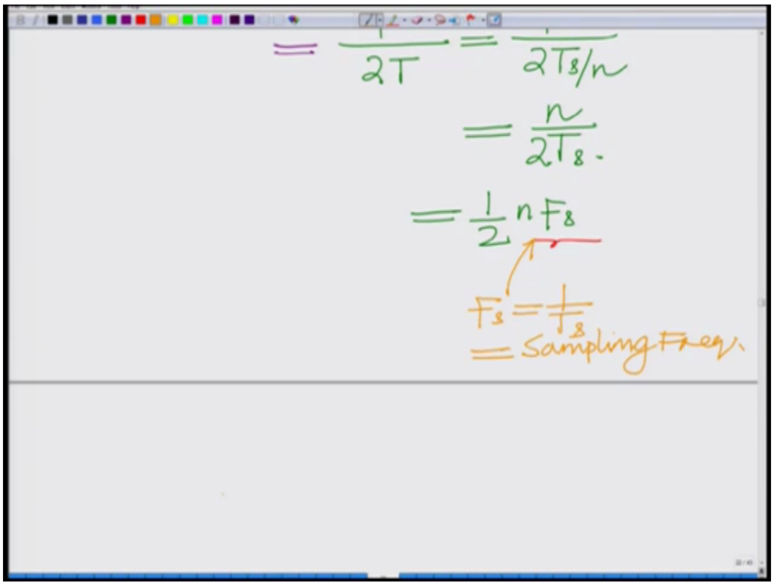




So each signal contributes 1 sample in Ts, implies when you look at n signals. So naturally they are going to give n samples, therefore distance between therefore the spacing between samples spacing between samples, since in Ts there are n samples spacing between samples of your TDM signal equals Ts divided by n that is equal to T. So sample spacing equals spacing between samples equals of TDM signal equals T and we have T equal to Ts divided by n.

(Refer Slide Time: 5:30)

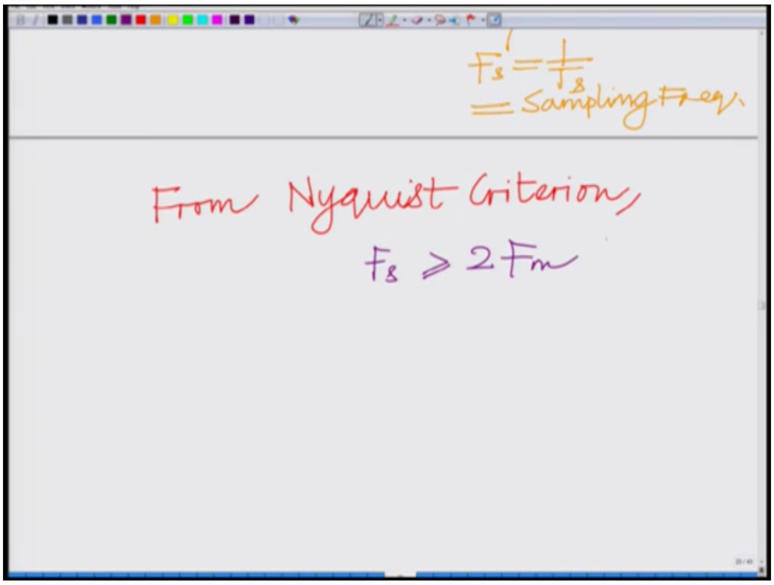


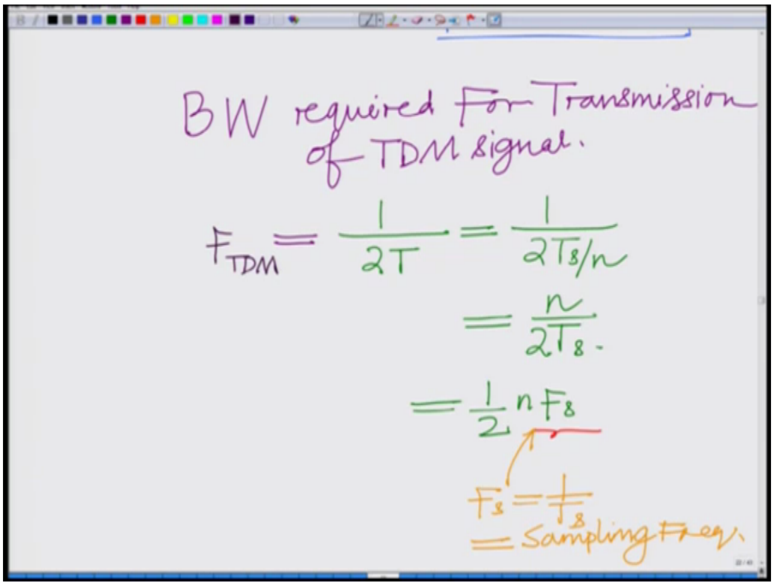


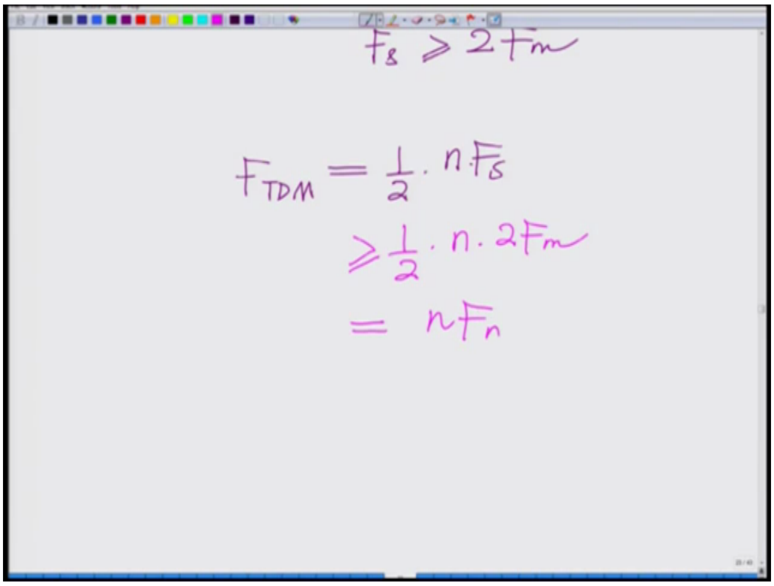
Now bandwidth that is required for transmission of TDM signal bandwidth required for transmission of TDM signal this is equal to well the bandwidth is 1 over 2T which is equal to well we have seen T equals Ts divided by n, so this is 1 over 2Ts divided by n, which is n over Ts, now n sorry this is n over twice Ts which is half nFs where Fs equals the sampling frequency Fs equals 1 over Ts equals the sampling frequency, ok so Fs equals 1 over Ts which is equal to the sampling frequency.

Now if we sample at the Nyquist rate then if we sample the signals at the Nyquist rate, right by the Nyquist Criterion the sampling ray the sampling frequency Fs has to be greater than atleast 2Fm where Fm is the maximum frequency of each signal, ok.

(Refer Slide Time: 7:08)

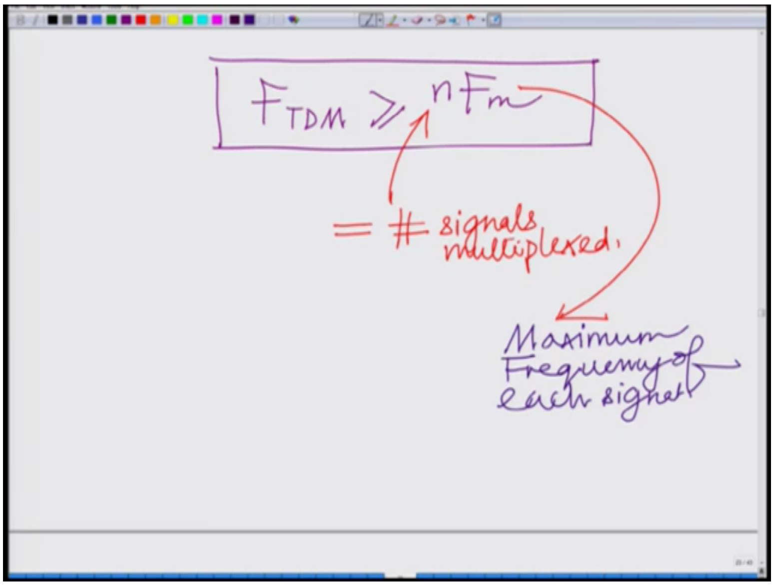






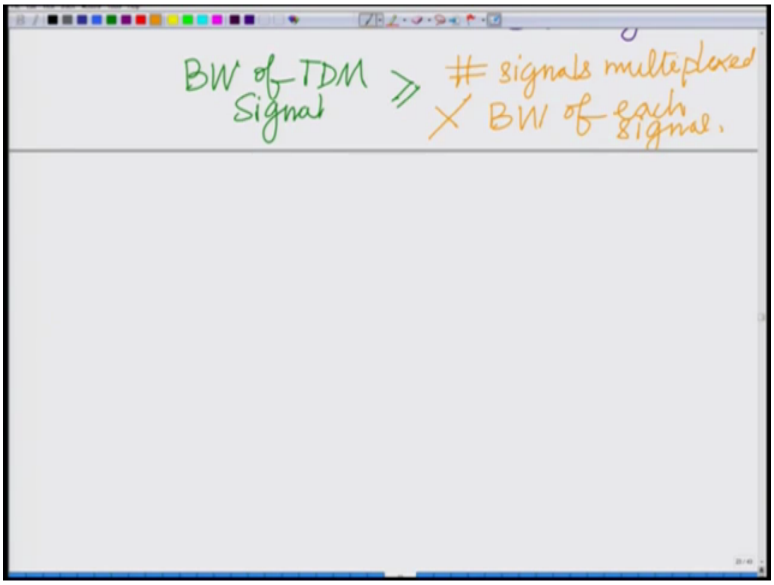
So by Nyquist Criterion or from Nyquist Criterion from the Nyquist Criterion we need Fs greater or equal to 2Fm which means bandwidth, therefore if we call this bandwidth required for transmission as F of TDM we need F of TDM F of TDM equals well half n into Fs but Fs greater than equal to 2Fm, therefore this is greater than the half n into twice Fm which is equal to n times Fm.

(Refer Slide Time: 8:20)



Therefore we need the bandwidth of the Time Division Multiplexed signal to be greater than equal to n times Fm, where Fm is the well so Fm so this is n, this is equal to number of signals multiplexed and Fm is the maximum frequency of the multiplex signals, this is equal to maximum frequency component of each signal, ok maximum frequency component of each signal, ok.

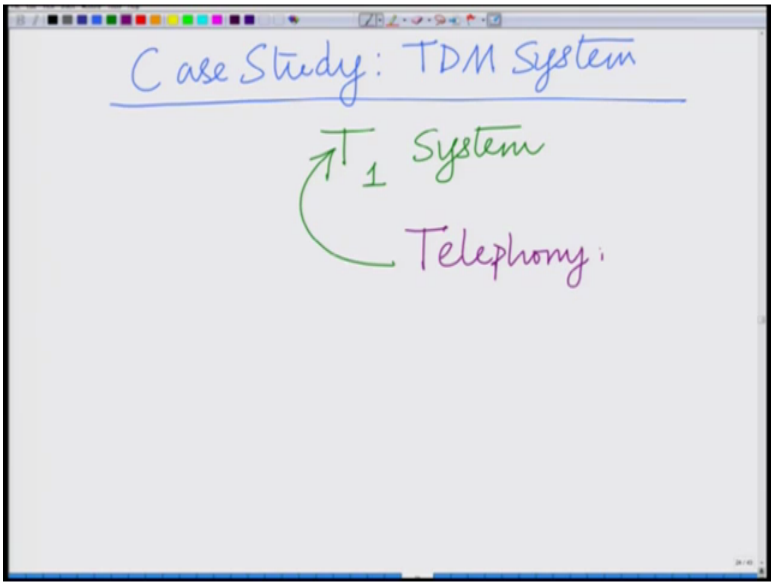
(Refer Slide Time: 9:14)



So basically the bandwidth of you can say bandwidth of TDM signal is greater than or equal to number of signals multiplexed the product of number of signals multiplexed into maximum frequency, that is or you can say bandwidth of each signal times times the bandwidth of each signal. So that is the relation that we have for the bandwidth of TDM signals. So the TDM signal ofcourse naturally since it is multiplexing a large number of signals we required a large bandwidth, right. This bandwidth is related to the sampling frequency which is in tern related to the bandwidth from the Nyquist Criterion related to the bandwidth of each signal.

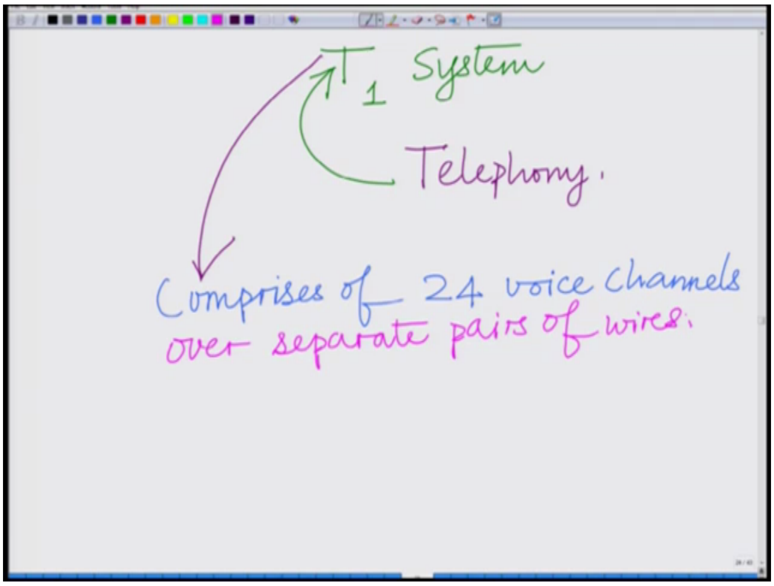
So what we have shown is the bandwidth FTDM of this Time Division Multiplex signal has to be atleast n times the bandwidth of the signals being multiplexed, ok. So it requires a large bandwidth for transmission, ok. Now let us do a simple look at a simple case study to understand that construction and working of a typical TDM signal that is a typical TDM system that is a Time Division Multiplex system also known as a T1 system, ok.

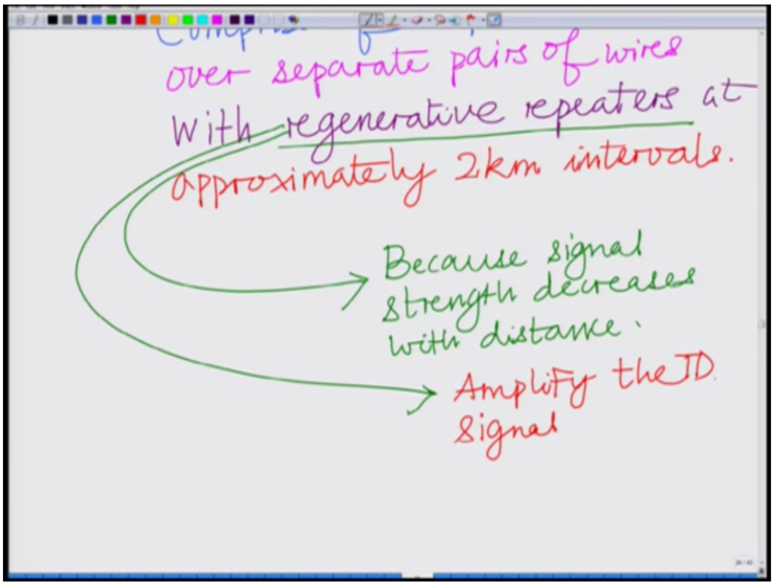
(Refer Slide Time: 10:45)

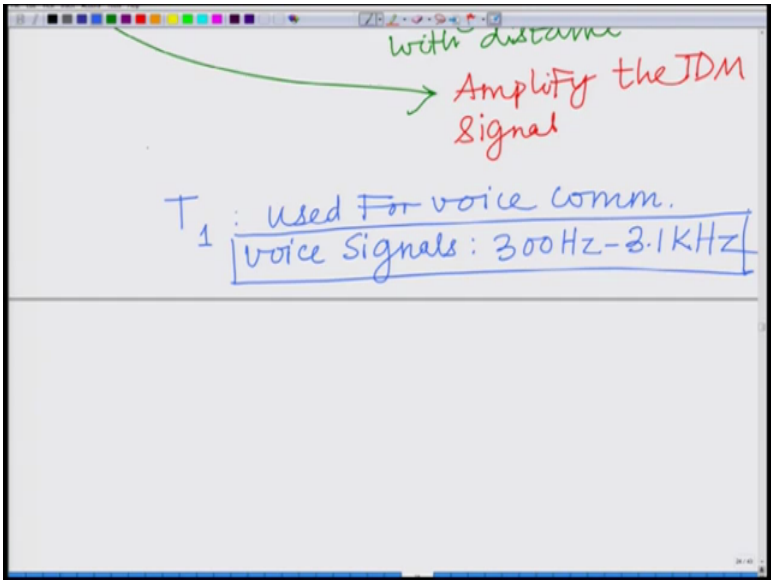


So now what we want to do is we want to do a case study for TDM system in particular we want to consider one particular TDM system that is the that is the T1 system that is used to a telephone. This is used to a voice communication voice telephone, ok so this is used for telephone, ok.

(Refer Slide Time: 11:29)



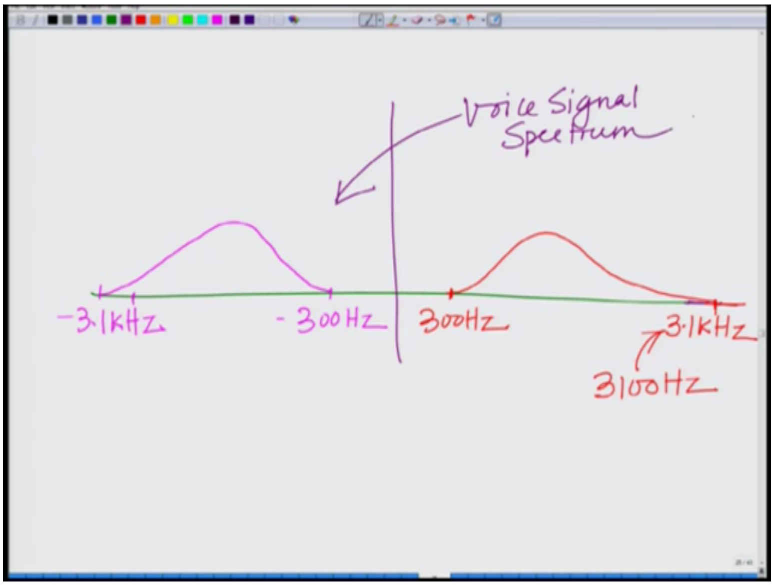




The TDM system this comprises of 24, now the T1 system is comprises of 24 is comprises of 24 comprises of 24 voice channels over separate pairs of wires over over separate pairs of wires with regenerated repeaters because the signal dies down with distance separate pairs of wires which basically amplify with regenerative repeaters at approximately 2 kilometer intervals, ok and why do we need this regenerative repeaters we need the regenerative repeaters to repeat the signal because signal strength decreases with distance because the signal strength decreases with distance, ok.

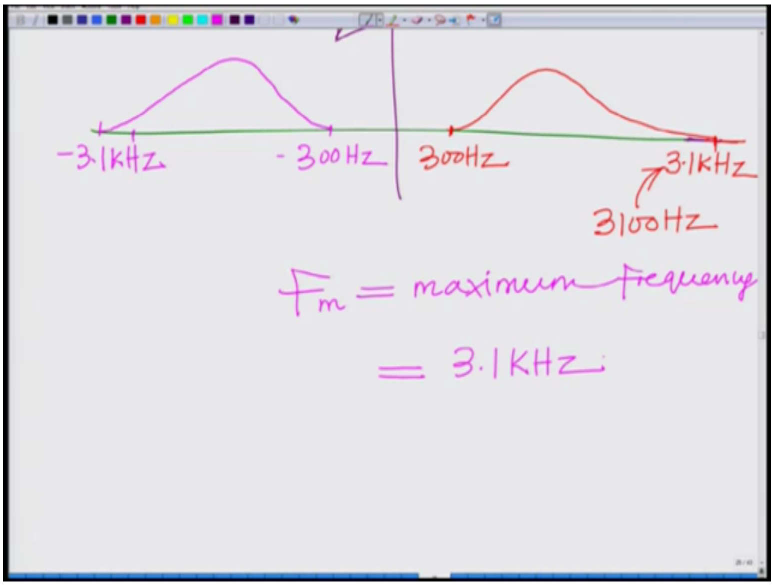
So these regenerative repeaters what they do is they amplify the signal regenerate that is prevent the signal from dying down see they amplify the the signal amplify the TDM signal, ok. So this regenerative repeaters amplify the TDM signal and this is used for voice T1 used for voice communication and voice signals have a frequency range that is 300 hertz to so the voice signal frequency band is 300 hertz to 3.1 kilohertz, ok.

(Refer Slide Time: 14:20)



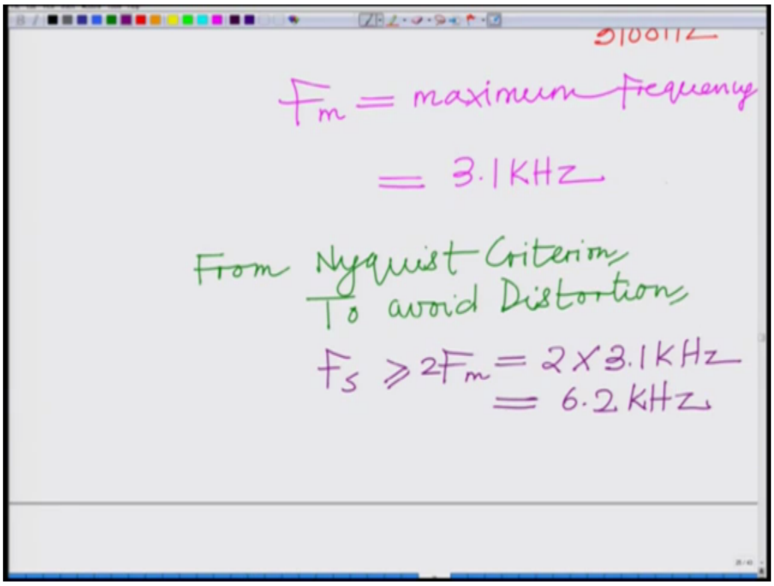
So what you have is basically you have a voice spectrum that looks something like you have a voice spectrum that looks something like this so it is the start set your 300 hertz ended something like start set 300 hertz and goes upto 3.1 kilohertz that is 3100 hertz. Similarly if you can look at this it starts with this and goes upto well right. So this is your voice spectrum is typically starts at your minus ok. So this is your voice spectrum so it start minus (300) minus 3.1 kilohertz to minus 300 hertz, this is your how your typical voice spectrum looks like or voice signal this is the spectrum of the voice signal, ok.

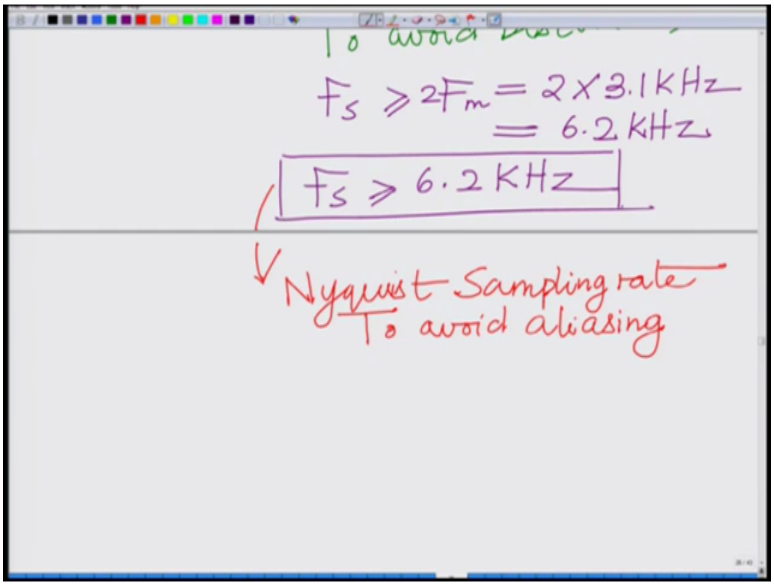
(Refer Slide Time: 15:58)



Now therefore you can see the maximum frequency Fm that is your maximum frequency in this case study of the voice signal we are consider as the multiplexing of 24 voice signal, maximum frequency equals well that is 3.1 kilohertz that is the human frequency maximum frequency of human voice signal is 3.1 kilohertz, ok.

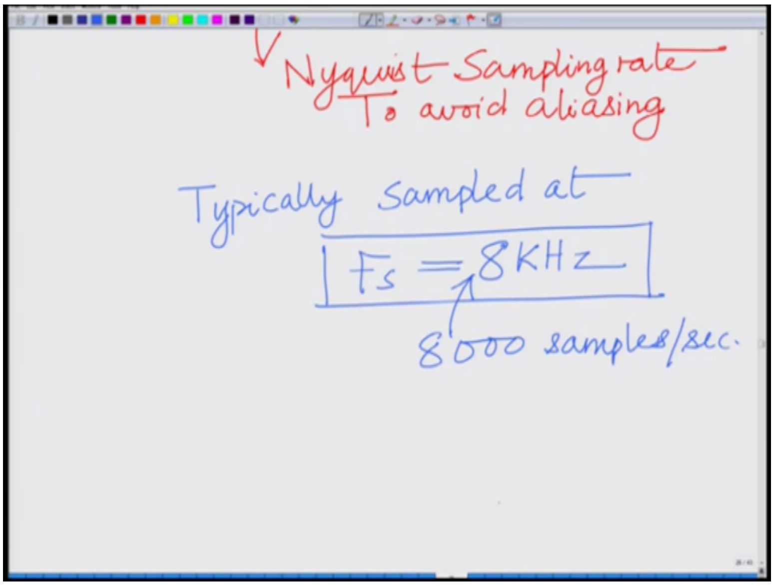
(Refer Slide Time: 16:34)





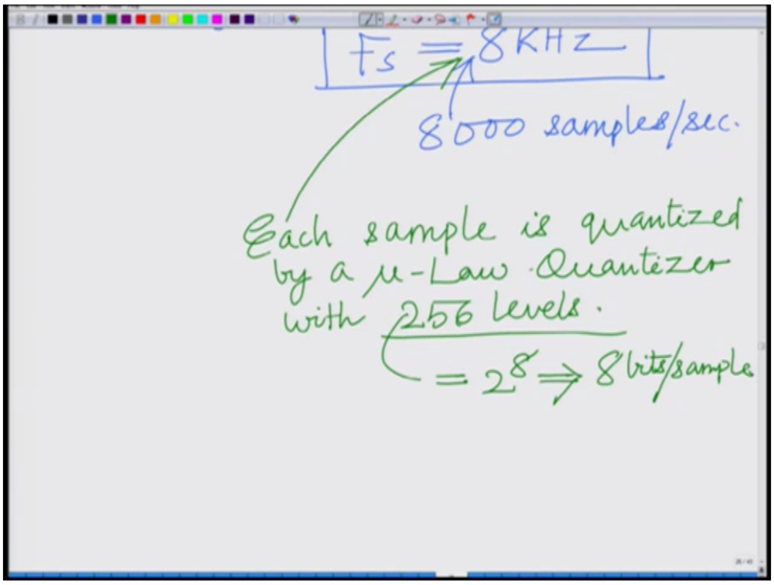
Now therefore the sampling frequency Fs from Nyquist Criterion so from Nyquist Criterion to avoid distortion to avoid distortion we need Fs greater than or equal to twice Fm which is twice into 3.1 kilohertz that is equal to 6.2 kilohertz, ok. So we need 6.2 kilohertz. However Fs greater than or equal to so we need minimum Fs is basically 6.2 kilohertz that is to avoid aliasing we know this right, this is basically the Nyquist Nyquist sampling rate minimum required sampling rate this is Nyquist sampling rate to avoid to avoid aliasing, ok.

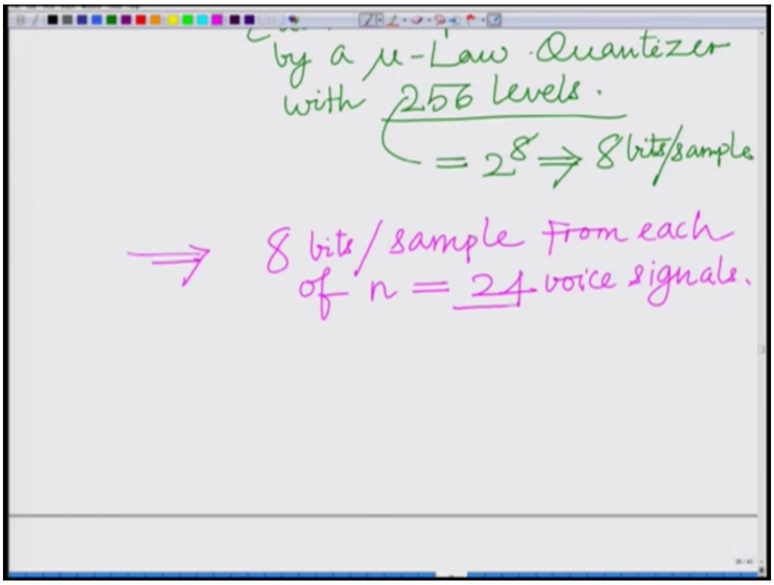
(Refer Slide Time: 18:09)



Now this is quantized with a mu law quantizer, however it is typical. So even though 6.2 kilohertz is sufficient it is typically sampled at 8 kilohertz at Fs equal to 8 kilohertz that is 8 kilo samples per second ok 8 kilo sampled at 8 kilohertz means 8 or 8000, 8 kilo means 8000 samples per second. So even though the minimum required sampling rate is 6.2 kilohertz, it is over sampled right it is sampled at a slightly higher rate it is sampled at 8 kilohertz that is 8 kilo samples or 8000 samples per second.

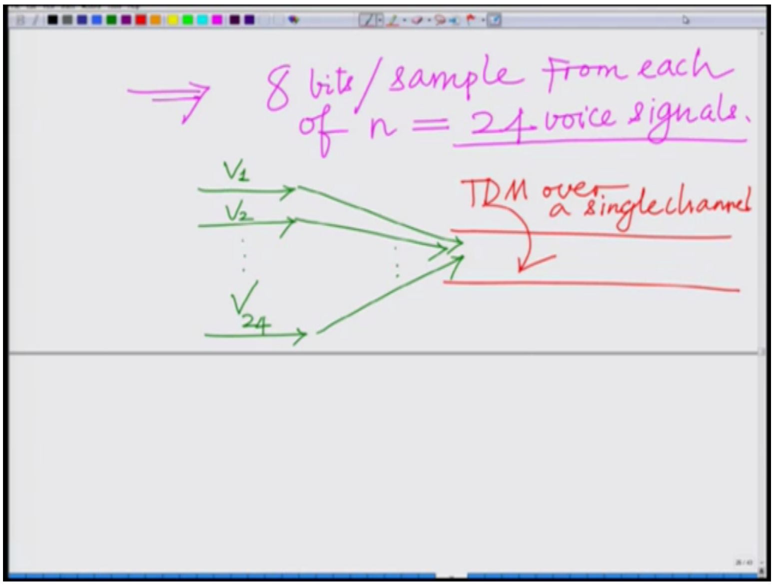
(Refer Slide Time: 19:02)





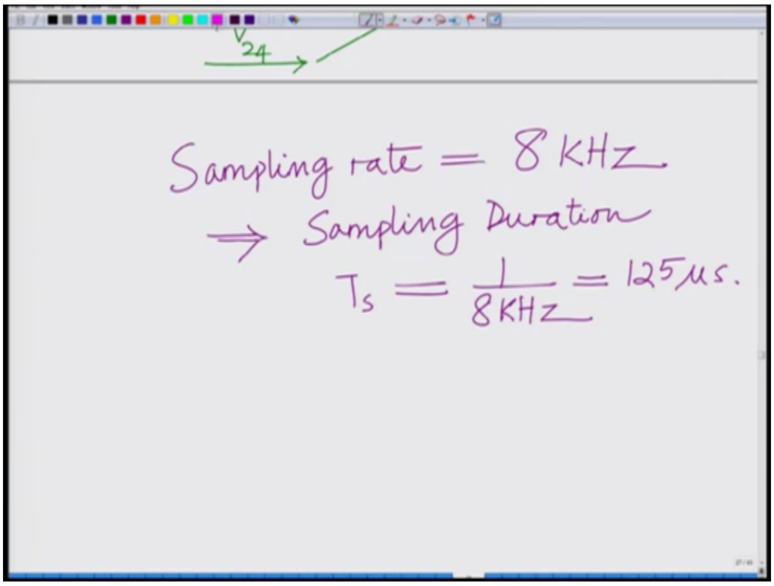
Now each sample is quantized using 8 bits alright so we have well what do we have we have each sample is quantized by a mu law quantizer using 8 bits, ok with 8 bits mu law quantizer with 256 levels where 256 equals 2 to the power of 8 implies 8 bits per sample this implies 8 bits per sample therefore we have 24 voice signals right 8 kilohertz sampling rate so net system we have is 8 bits per sample from each of n equal to 24 n equal to 24 voice signals that is your T1 system.

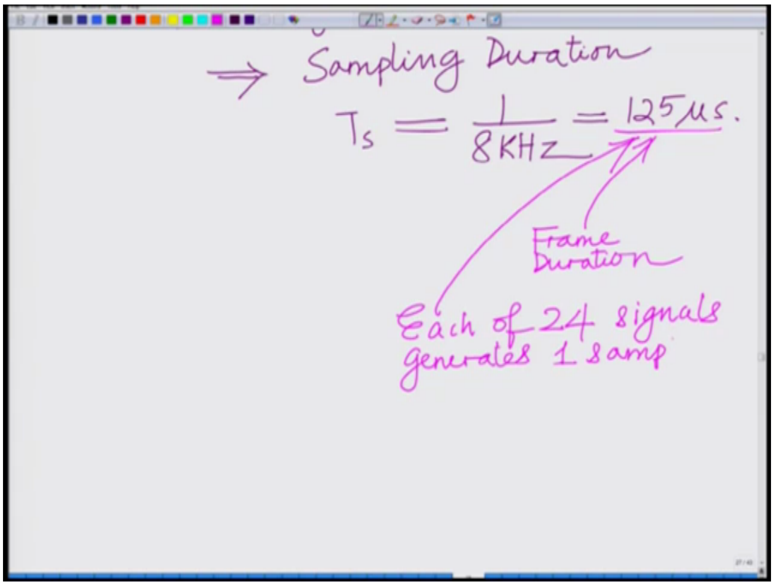
(Refer Slide Time: 20:37)



So what you have in your T1 system is basically if you look at this you have well you have signal 1, signal 2 24 so you have V1, V2, so on upto V24 all these are multiplexed over a single channel. So all these are TDM Time Division Multiplex over a over a single channel, ok.

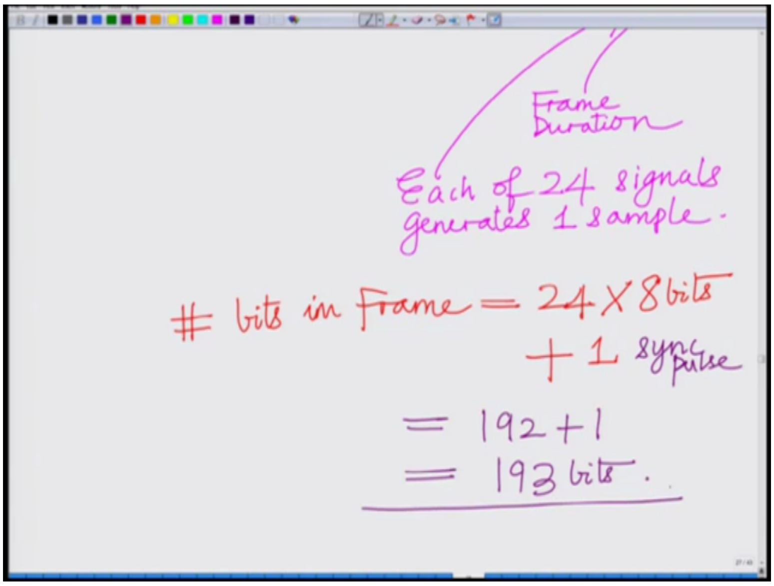
(Refer Slide Time: 21:19)





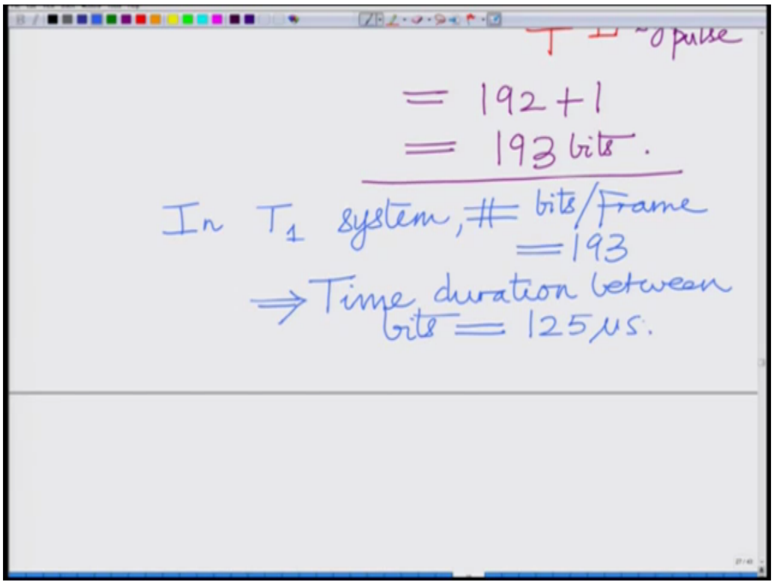
So naturally what is the well sampling rate equal to 8 kilohertz 8 kilohertz implies sampling duration equals well 1 over 8 kilohertz Ts equal to 1 over 8 kilohertz that is equal to 125 micro seconds, ok. Now each now this we can also call this as frame duration we can also call this as frame duration, ok. In this basically each signal generates so in this each signal generates 1 sample, each of the 24 signals generates 1 sample in a frame duration each of 24 signals generates 1 sample 1 sample each sample is quantized suing 24 bits.

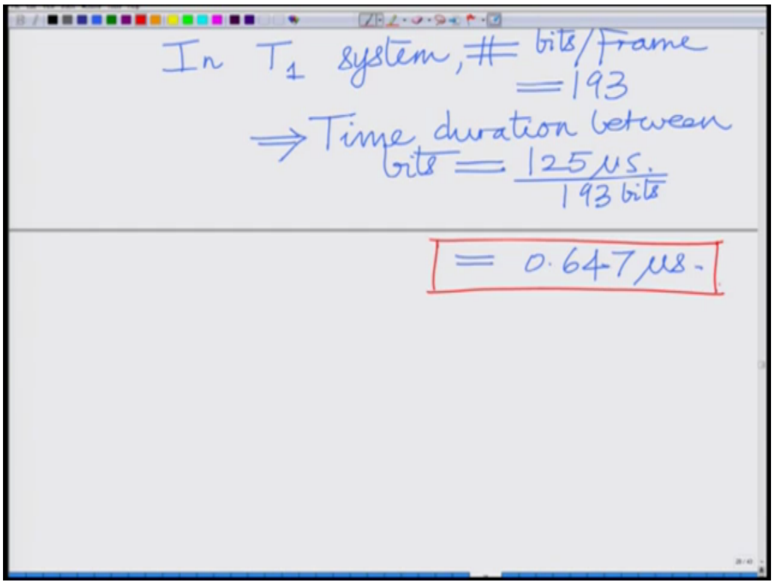
(Refer Slide Time: 22:35)



So in a frame duration you have that is number of samples in frame or you can say number of bits in frame equals well 24 number of signals into well 1 sample per signal into 8 bits per sample. So 8 bits from the (24) so 24 signals each generates a sample with 8 bits. So 24 into 8 plus 1 synchronization pulse or synchronization bit. So that is equal to 24 into 8 so 192 plus 1 synchronization 1 synch bit that is equal to 193 bits, total bits per frame equals 193.

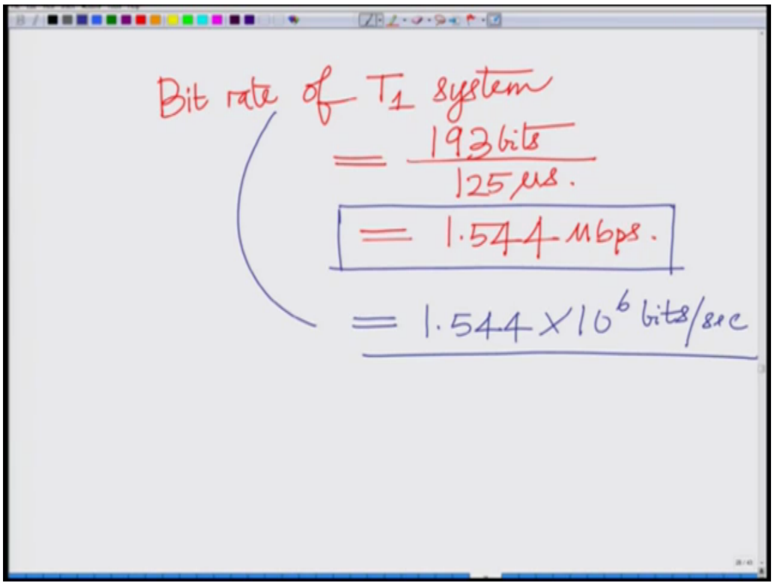
(Refer Slide Time: 23:39)

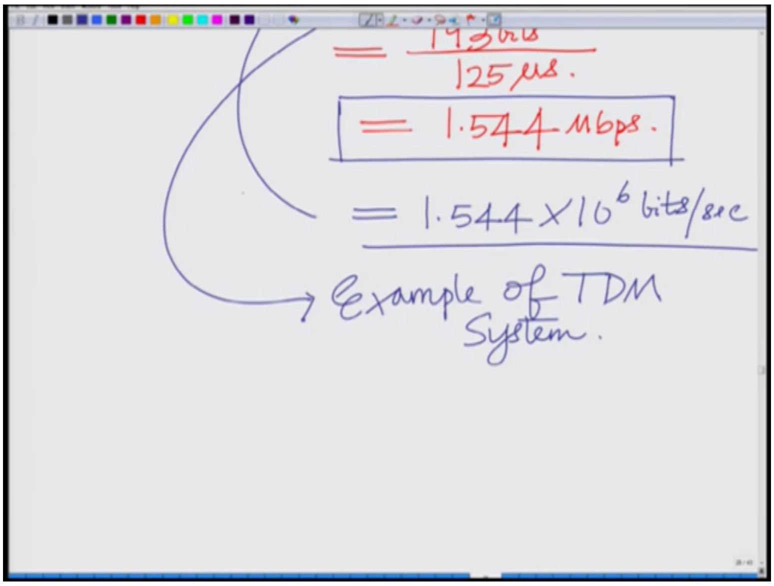




So in this TDM T1 system you can see in the TDM system in the case study that we are doing number of bits per frame equal to 193, which implies well duration of each bit or time interval between bits frame duration is 125 micro seconds, time duration between bits equals 125 micro seconds, ok. The time duration between bits is 125 micro seconds divided by well 193 bits 193 bits that is equal to well 0.647 micro seconds.

(Refer Slide Time: 24:45)





And bit rate of the T1 system bit rate of the T1 system is basically 193 bits divided by 125 micro seconds that is equal to well 1.544 megabits per second. So this is basically the bit rate of the T1 system if you calculate that that is a huge bit rate that is equal to 1.544 megabits that is into 10 to the power of 6 bits per second that is your bit rate of the T1 system, ok. And the T1 system is a classic example of a Time Division Multiplexing, this is a classic example of a TDM system therefore what we have is what we have seen in this module is you have seen some important aspects of the TDM system that is what are the bandwidth requirements of the TDM system also we have done a case study of a classic example of a TDM system that is the T1 system which combines 24 digital voice channels into a single system right and we have seen that this has a huge bit rate of 1.544 approximate 1.544 megabits per second, alright so we will stop this module here thank you.