Digital Circuits

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Lecture - 01
Introduction

Welcome to this course on Digital Circuits. So, if you look into this VLSI design process or VLSI industrial development where this I integrated circuit chips are being manufactured. So, you will see that most of the designs that we have so, they are digit al in nature.

So, the basis of all these developments are on these type of circuits where we consider the digital circuits as the building block.

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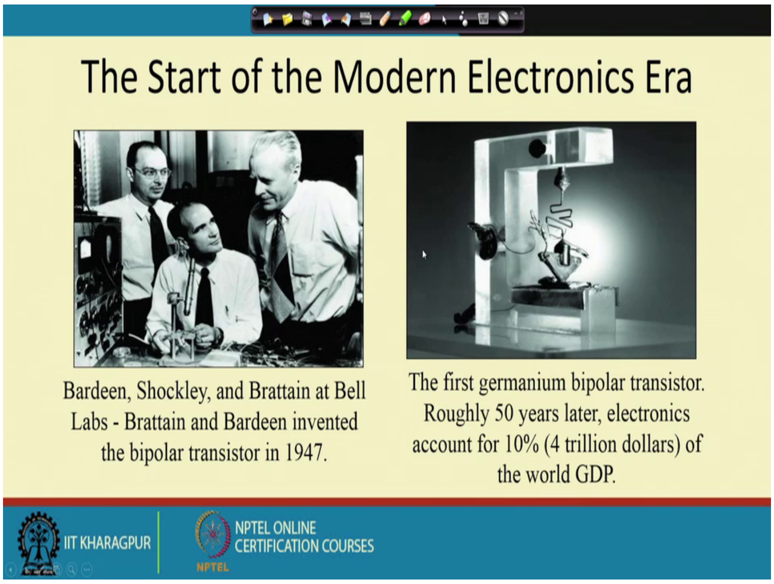

So, the start of this modern electronics era if you look back in to the history so, we will see that it started around the revolution started in 1947, where a group of a scientist at bell labs they invented the bipolar transistors in 1947. So, 1947 is a very important year for India as well we got freedom, and similarly the on the electronics industry. So, this is another land mark that we had achieved in 1947.

So, from that point onwards the electronics design it has advanced a lot. And today we are at a stage where this the complexity of systems and their performance have gone up by leaps and bounds. And now it is it is almost whatever functionality we think about so, we will look for an integrated circuit chip which can do that one. And majority of them are digital in nature.

So, we will why this has happened. So, if you look into the this slides on the next in the right side it shows the first germanium bipolar transistor. So, this left side. So, this was silicon, based on silicon. So, this is the bipolar transistor based germanium. So, 50 years later so, this electronics account for about 10 percent of the world's total GDP.

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So, this is the milestones that we have in the electronics industry. In the 1874 Braun invented the solid state rectifier. Then 1906 Defros for deforest invented triode vacuum tube. So, that way this the whole development has taken place. So, started with solid state rectifier then the vacuum tube diode the triodes, then the radio circuits then field effect devices the patent was filled in 1925.

1947 as we already said so, there is a bipolar transistor was invented. Then 1952 Texas instruments they started making these bipolar transistors commercially. 1956 that there was a Nobel Prize given to Bardeen Brattain and Shockley. So, they receive the Nobel Prize for this transistor.

Then IC was developed in 1958 by Kelby and Noyce, and then the first commercial IC came from the Fairchild semiconductor in 1961. So, as this industry was advancing so, so the scientists also started doing lots of research works, and there was an institution of engineers IE which was formed IEEE so, electrical and electronics engineers.

So, that was found by merger or ire and AIEE. So, IEEE is one of the very popular or societies now that we have and they apart from just bringing pears close to each other. They make a lot of standards for the new devices and systems that are coming up, and that way they are helping in the electronics industry.

So, whenever we are looking for some development of some device or system, we normally look for some standards and that standardization is generally done by IEEE whatever we have today. The operational amplifier; so, this is the analog part. So, though we will not discuss much about the analog revolution, but this analog part also has started be getting developed from 1968.

So, first operational amplifier IC came up in 1968. The other important part that we have in it is system digital system; so, apart from a during computation. So, you need to store lot of information and in that direction the memory chips. So, they are the main part that we have. So, they so, transistors are again are used for making the memory chips. So, this dynamic ram that we see in almost all the computer systems today. So, they are they were invented in 1970 at IBM by Dennard.

So, in the involution process as this computations and computations and memory storage. So, they went on improving over the generations. So, this computational module. So, they were club together into a structure called microprocessor, where it can do some set of operations in taking help of some registers are may be taking executing some stored program, which it can access through some address and data lines. So, that microprocessor came in 2 1971. So, it was Intel 4004 microprocessor.

So, and now you see that after that it has gone a long way, and today we have got this Pentium processors and other risk machines and all so, they are all very advanced versions of this microprocessors. So, this is another digital component that has involved a lot. Then this commercially memory chips they started coming in 2 1978. So, first one kilo bit memory chip was available in 1978. 1974 another very popular microprocessor 8080 came up.

So, this is one of the I should say with the one of the first well known microprocessor 8080 of the again from Intel. And that so, based on this microprocessor there has been they lot of developments and all this later microprocessors that are available; so, they are actually developed from this microprocessor architecture.

We will see one such microprocessor in this particular codes which is 8085. So, it has it is bit improved version over 8080. In 1984 we have got mega bit memory chip that was introduced so, memory capacity went up. So, this was a because of because of this we could we can now stored lots of memory and today storage is not a problem. Because this memory chips they have advanced so much like even this tiniest devices that we have in our day to day life electronic devices. So, they have got large amount of memory that we can have in the system. So, they can store lots of information.

So, that is the, that is the point so, we this memory chip development that is also digital in nature. So, this digital circuits so, they helped us in developing this memory chips to get the functionality implemented by the systems. Then the, this another Nobel prize came up in 2000, by to Alf, Alferov, Kelby and Kromer. So, they have got another Nobel Prize for this memory and all.

So, this way this electronic industry came. So, after 2000 so, we do not have the information here, but as you are all familiar. So, lots of development are taking place every day where this electronics industry is advancing towards better and better processors with higher and higher capabilities, and better and higher memory storage capacities.

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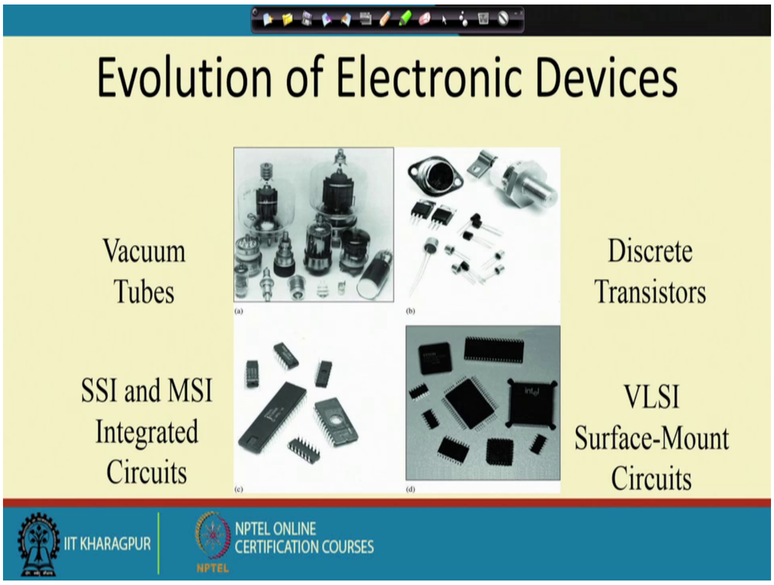

So, if pictorially so, this shows that. So, this is the first generation where we have got this is the vacuum tube diode triodes and all. Then they came that discrete transistors. So, you see the volumes or size of the devices. So, that has decreased price so much you see. So, this is a power m power transistor so, this is a another transistor. So, these are some diode some transistors and all so, they are all discrete transistors.

Then after that came this one. So, where we have got this small scale integrated circuits and medium scale integrated circuits, MSI and SSI. So, they are actually this IC chips started coming. So, they do not have large number of transistors in them, SSI chips they will have about 10 transistors, MSI will have about thousand 100 transistors. ULSI will have thousand transistors, and then VLSI is going beyond that.

So, that way we have got large number of transistors. So, today this we have got even further terms like ULSI and all so, that is actually having larger and larger number of transistors in them. And now this is not a limitation; like, if we want to pack large number of transistors on a single chip that is possible because of the technology advancement. So, we can have transistor size is very small so, we can pack large number of transistors on a silicon flour.

So, that way size is not a problem, but the difficulty comes in terms of power consumption in terms of heat generation and all. So, those are of course, not part of this course discussion. So, they will go to some course on VLSI design.

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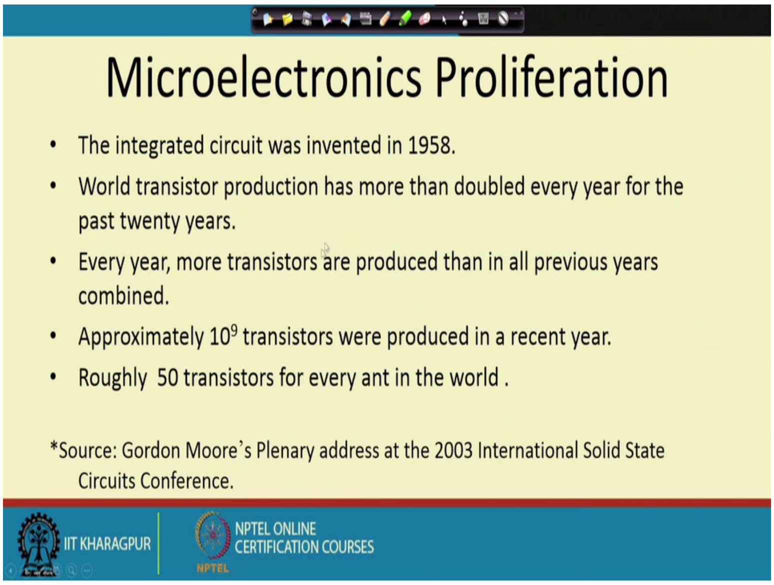

So, integrated circuit it was invented in 1958, then this world transistor production has more than doubled every year for the past 20 years. So, every year so, total transistor productions so, it has doubled. So, you can imagine the amount of functionality that is becoming digital every year, digital or electronic going to electronic components every year.

So, more transistors are produced every year more transistors are produced which is more than all the previous year previous years combined. So, if you some up are all the transistors that are produced till last year. So, this year it is going to be double of that some. So, that is an exponential growth in terms of transistor production you can say.

So, approximately 10 to the power 9 transistors were produced can be some recent year. So, though it is not mentioned which year. So, it is around that. So, we can and roughly 50 transistors for every ant in the world. So, this is another statistical information. So, if you think about all the ants that are available in the world. So, each of them that multiplied by 50 so, that give the total number of transistors in the world, this is just a speculation of course.

So, this is obtained from 2003 source so, so, you all this figures. So, they have gone up significantly by the time today.

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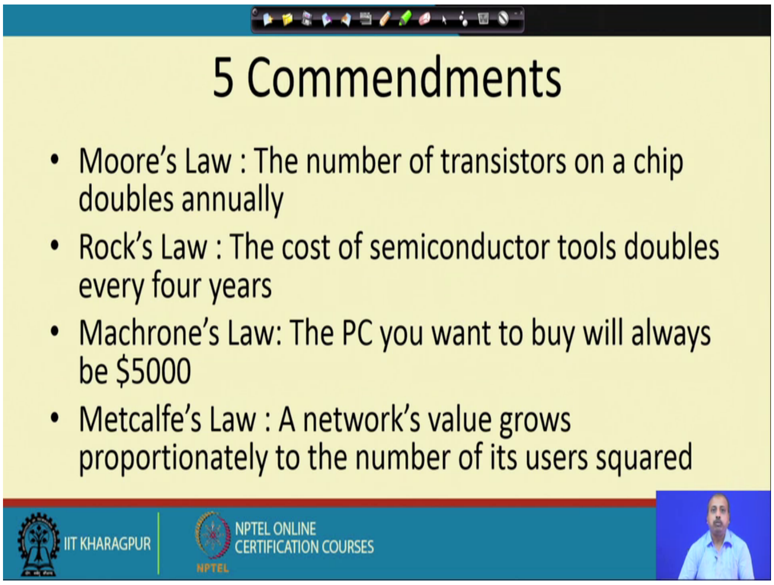

So, there are a few laws which actually predicted the growth of this electronic industry. So, first one is the Moore's law, it says that the number of transistors on a chip doubles annually. So, this is a prediction and more or less it has been followed, then there is a rocks law it says that the cost of semiconductor tools doubles every 4 years.

So, this is another problem because as the complexity of the system is going up so, you cannot think about designing the system by hand. So, you cannot just take draw say 10 12 transistors, connect them in some fashion and get your circuit design. So, that is not possible so, we have to take help of these semiconductor tools; that may be based on, that maybe for this design specification, that maybe for simulation, that maybe for synthesis, that maybe for testing.

But the costs are going up for every 4 years. Because the complexity of this systems are going up, complexity of this chips are going up. So, testing them the corresponding testing and implementing them the corresponding tools so, they are also becoming very complex, and the cost is going up significantly.

Then there is another law due to Machrone, which says that the pc you want to buy will always be dollar 5000. So, what does it mean it means 2 things, first of all it says that the cost will not go up significantly, because of the advancement in the semiconductor industry. So, the cost of production will go down so, that way it is going like this. So, you can say the cost are producing a transistor is coming down. So, that way it is it will in some sense say.

So, it will balance the cost increase in the in the in the tools that we have, in the cost of the semiconductor tools that we have so, that that will get balanced. So, if we say on the other side that your cost of this manufacturing has gone down, but what has gone up is the cost of the software. So, software's are becoming more and more complex, as a result this the pc will always be a more or less the same price so, if you look at any point of time.

Then there is a mat Metcalfe's law which says that the a networks value grows proportionately to the number of users of it is users squared so, that you know very well. Today in the in the era of this mobile networks so, you know so, if they are as the number of subscribers to the network increase we value that network further because that gives the connectivity both in our day today life and social life.

So, that way this is another law which says that if you if you are making the network complex, and you can accommodate more number of users. So, you are going to be paid back at a square rate. So, that is also very important thing.

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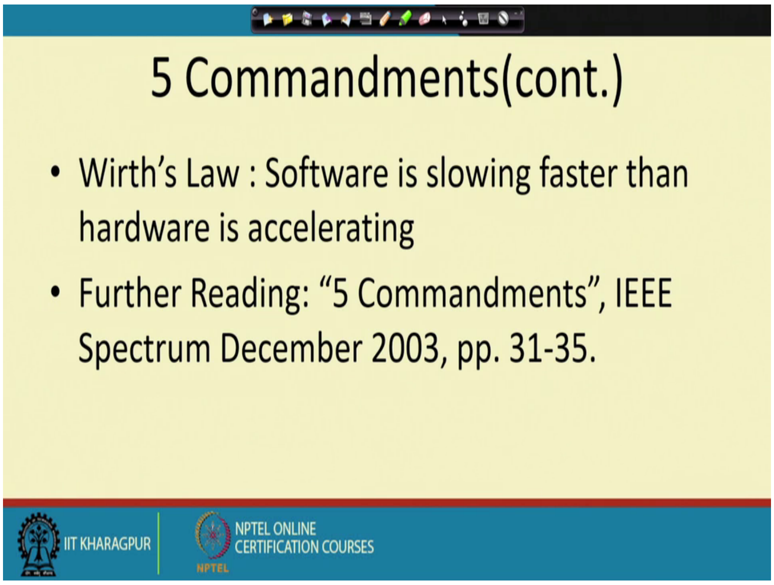

Then there is a Wirth's law it is say that software is slowing faster than hardware is accelerating. So, this is another important issue which says that the software is slowing.

So,, why because the computational power is increasing. So, as a software designer people think that we can pushing lot of functionalities into it, and when we do that, the overall software speed that is coming down. So, so, essentially again there are research which will try to make that software faster.

So, hardware engineer they come up with some assisted tools by which you can make this hardware faster to run those operating system and software modules, but it is actually the software which is pooling back the developments in hardware, the speed advancement in hardware to a limit so that you can always you will always have the more or less the similar type of speed if you are if you are using if you are not using very advance software.

So, this is a reference that talks about these commandments further.

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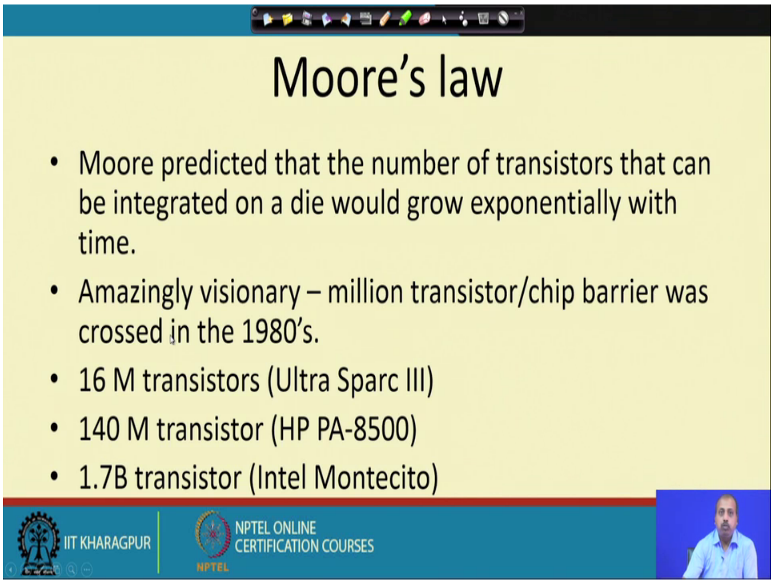

So, if you look into the Moore's law; so, Moore predicted that the number of transistors that can be integrated on a silicon on a on a die so that would grow exponentially with time. So, it is says that it will double every year every 2 years or.

So, what was happened is a it is amazingly visionary law that Moore has predicted. So, you see that million transistor per chip barrier was crossed in the 1980s. So, and then I mean ultra sparc 3 had 16 mega mega transistors 16 million transistors, then HP's PA

8500 140 million transistors. So, that way the number of transistors that we have so that is more or less following the Moore's law.

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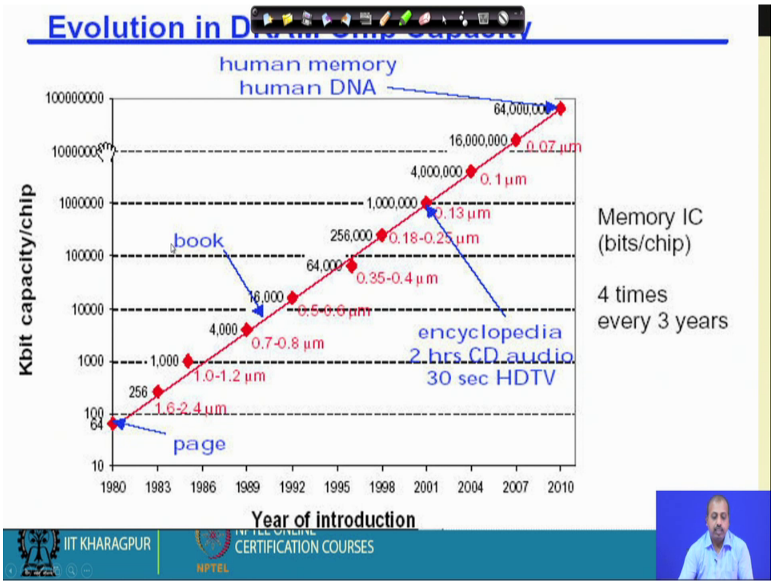

So, this is the evolutions if you see that this is a. So, from 1980 to above 2010. So, you we if we just look into this dram capacity. So, dram how this dram capacity is growing so, you see that this is it was about say 64 kilo bit per chip in the around 19 in the year around 1980 so, which was sufficient for holding say one page of information.

Then around 1989 1990 around that time we have got the capacity which us sufficient for a book. Then in the year 2001, it reached to support suppose as a it can hold the entire encyclopedia. So, 2 hours of CD audio or 30 second of HDTV, high definition television high definition television signals.

Then this then in 2010. So, the capacity has increased so much that even the total human memory or human DNA, we can store in that chip. So, memory IC is it is a becoming 4 times every 3 years. The capacity of the memory chips are it is becoming 4 times every 3 years roughly. So, that way it is memory capacity is going to increase.

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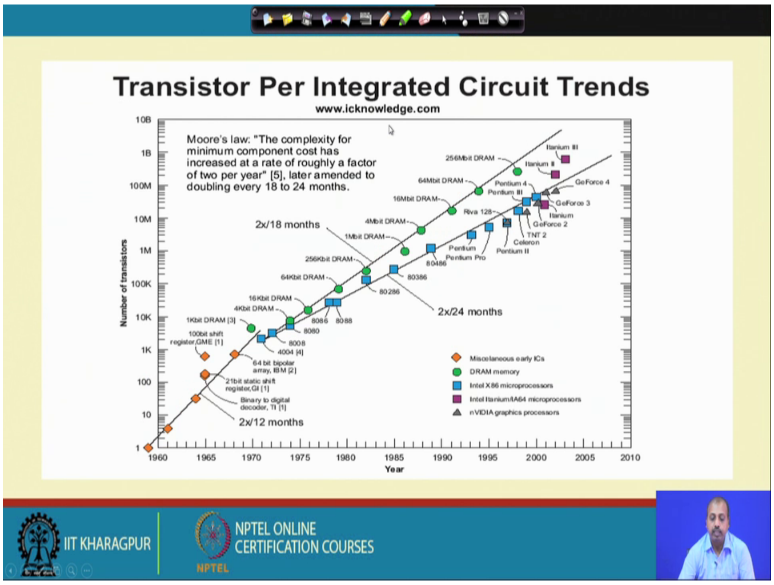

If you plot the number of transistors per integrated circuit so the trend is like this. So, it is started in 1960 so, if you say that it just started then it has gone up.

So, this Moore's law, which says that the complexity for minimum component cost has increased at a rate of a roughly a factor of 2 per year. So, it was later amended to 80 18 to 24 months ok. So, this is a 2 year so, this was shortened further. So, if this was a brought down to 18 months also.

So, this way where is the transistor per integrated circuit so, number transistor so, it has increased following Moore's law and that is going on, and as the technology is advancing further and further. So, whenever it comes to a saturation point you see that the technology advances is advances it to the next state, next stage and this Moore's law still continue to hold in the next generation.

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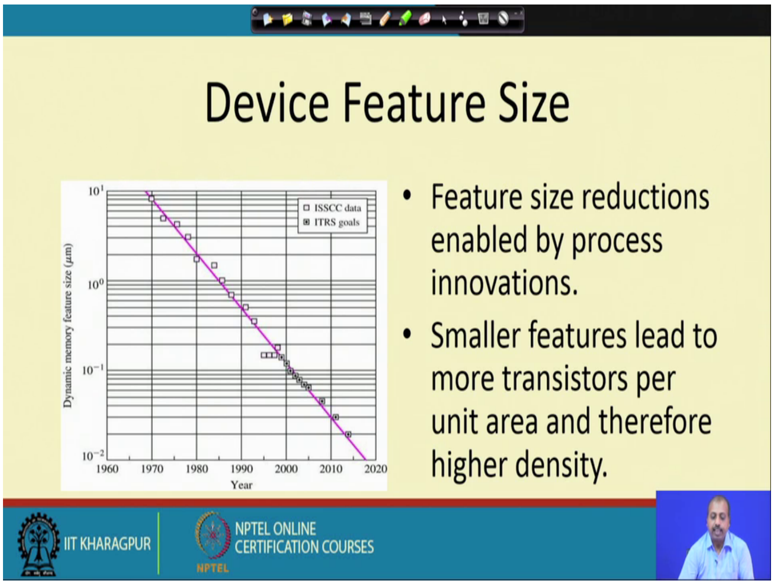

Feature size or device size so, feature size feature, when you say feature so, it is a size of a transistor you can say. So, that is the feature size in the VLSI terminology so, this feature size is reducing that will enable by process innovations. So, you we in the VLSI manufacturing process so, it is advancing so, we can process a smaller and smaller sized devices transistors.

So, you can have say some something like say 16 nano meter designs now. So, that way it is a big advantage that we have so, the feature size is reducing so, overall size of the system is coming down so on the same silicon flour so, you can put in lot of transistors.

So, they put more transistors per unit area and therefore, we can have higher density. So, this is a plot till 2000 predicted up to 2020. So, after 2005 so, these are the goals that is said up to this much this was fine and then it is so, it is dynamic memory inter feature size in micron so that has come down significantly.

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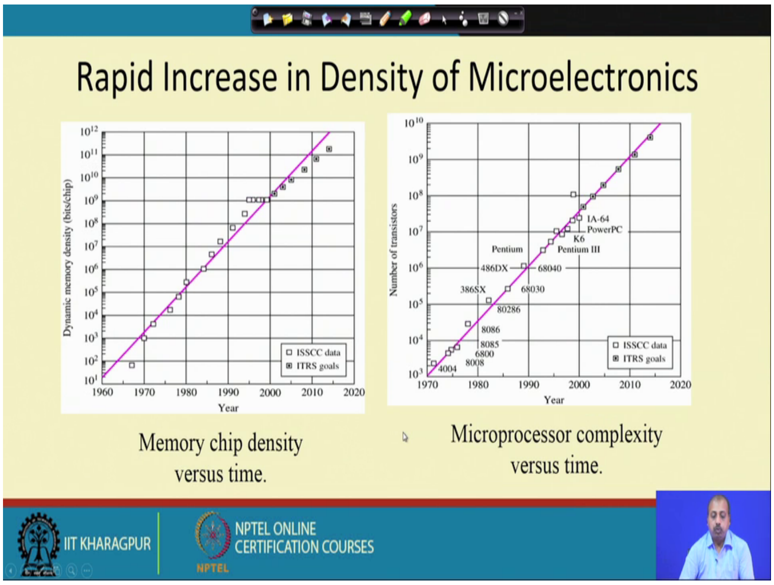

So, if you look in to this memory chip density versus time so, that is also density is also increasing significantly, as you say see over the year. So, that is following a more or less an exponential development and this microprocessor complexity. So, over this if you measure in terms of number of transistor so, that is also going up exponentially.

So, you see that from 1970's where we have we if you just start around 1975 or so, this 4004, Intel 4004 was introduced, then 1980 this 800 is, was introduced so, like that it went. So, there are lots of developments that are taking place and they more or less following this Moore's law in the rate of increase of this device density and this computational power.

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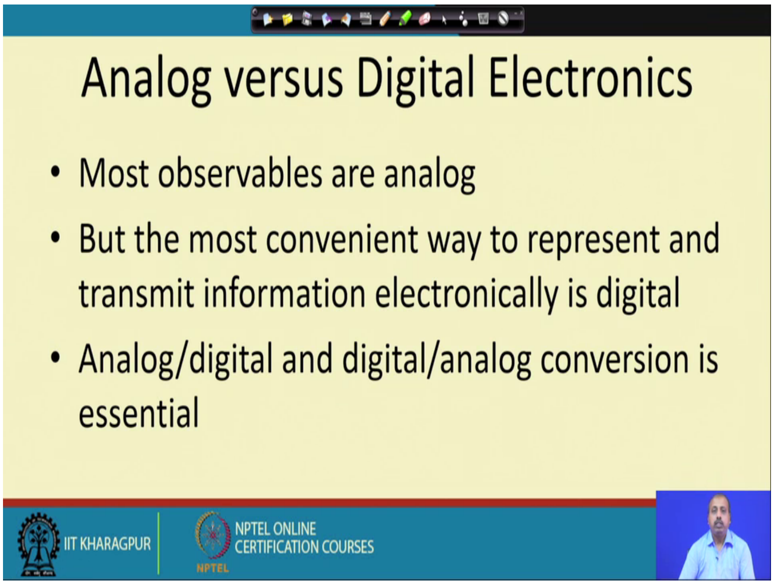

So, if you look into these developments in the electronics industry so, you find development both in the analog domain and in digital domain. So, to on the analog domain it is mainly the operational amplifier introduction of operational amplifier and circuit development around that, so, which is which has got the momentum on the digital domain of course, we have got different type of logic families that are being developed and we can realized some switching circuitry based on those logic on those logic elements, and accordingly we can have some digital design implemented in the IC.

So, if you just try compare bet between analog and digital electronics so, most observables are analog in nature. So, why do I say so, because nature is analogs so, there is nothing digital in nature. So, if you look into the temperature. So, it is not the temperature is the digital quantity, if you look into the amount of light so; it is never a digital quantity. So, that way it is a most of the observables that we have. So, they are analog in nature so, weight of some person so, that is also an.

So, that is also analog in the sense that. So, if you measure the weights of different people. So, they will be you cannot always say that after say 75 kg. So, next weight will definitely be 76 kg or 78 kg. So, in between you can get number of other values.

So, they are observe there will be a values are analog in nature, most of the; but most convenient weight to represent and transmit information electronically is digital. So, we will see why so, once we have got it in digital format. So, we know that with the transmission becomes easy from our say if this our devices the electronic devices that we are handling. So, we are nor normally going for digital design so, why this digital? So, that will try to explain in the part of this course.

So, all the processing job that we do so, they are digital in nature whereas, the nature the environment is inherently analog. So, what is required is that if we are trying to process something in the analog in the something related to the environment. So, we should have this interface, which will convert the analog input signal into digital and again that after processing the actuation should be done in terms of digital values, which should be converted to analog value, for controlling the environment.

So, this way we have got analog to digital conversion on the input side of this digital processors and on the output side will we may have a digital to analog conversion. So, which will convert these digital values to analog actuation signals.

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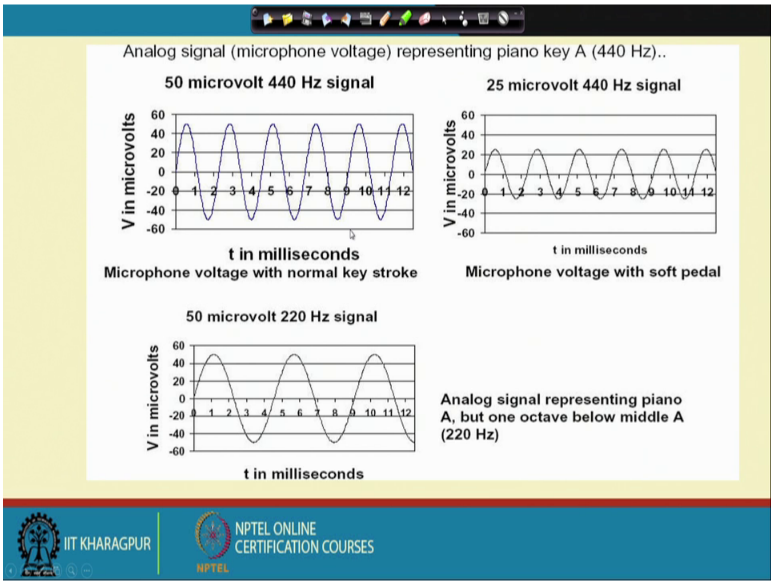

So, thus to have a understanding so, this analog signal; so, suppose we are using this piano and thus this key a is place so, that is the 44 hertz. So, if you so, you can represent it in terms of a sinusoidal signals sinusoidal voltage signal which has got a maximum volt of 50 maximum peak of around 50 microvolt, so, this 44 hertz 50 microvolt sinusoidal signal may be like this. So, in this side if you plot the time in milliseconds and this side if you plot the volt voltage in microvolts, the signal generated from the piano key A so, it may be like this.

So, on the same time, if you say that if you are using microphone voltage with soft pedal, then this is 20, it is a 25 microvolt signal, frequency may remain same. So, it is 25 microvolt peak to peak, and 25 microvolt peak and we have got 44 hertz signal. Or you can have this piano A, but one octave bellow the middle A so, that is about 220 hertz so, frequency is less. So, this is the peak value is 55 50 microvolt and this frequency is going to be 220 hertz. So, this way we can have the analog signals which are coming from the instrument.

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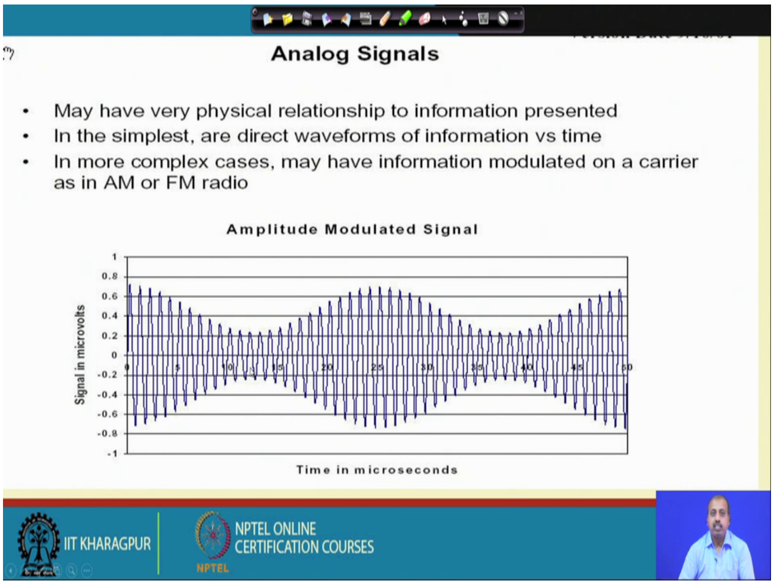

Now, this analog signals that we are talking about. So, they may have a very physical relationship to information presented. So, naturally this the direct signal that we have so they are information versus time. So, the so, this is basically the wave form the, that is generated is in terms of that is giving a some information in terms of the different time instance. So, in, but it is a normally what is done is that we never have this analog signals transmitted or analog signals processed directly. So, we convert it into some other form, which is known as the process of modulation.

So, we with the information that we want to send. So, that or we that we want to transmit. So, it is modulated on a carrier, such as a in amplitude modulation or this frequency modulation the AM radio or FM radio that we have.

So, what is happening? So, this is an example of this amplitude modulated signal. So, here these high frequency signal that we have here so, that is basically the carrier signal.

So, we have got this high frequency, this blue colored so, this is the high frequency carrier signal. And so, this is used for transmitting a relatively low frequency sinusoidal signal. So, if you look into this signal so, this high frequency signal so, this it frequency is much higher. Whereas, this low frequency signals so, it is time period is pretty high.

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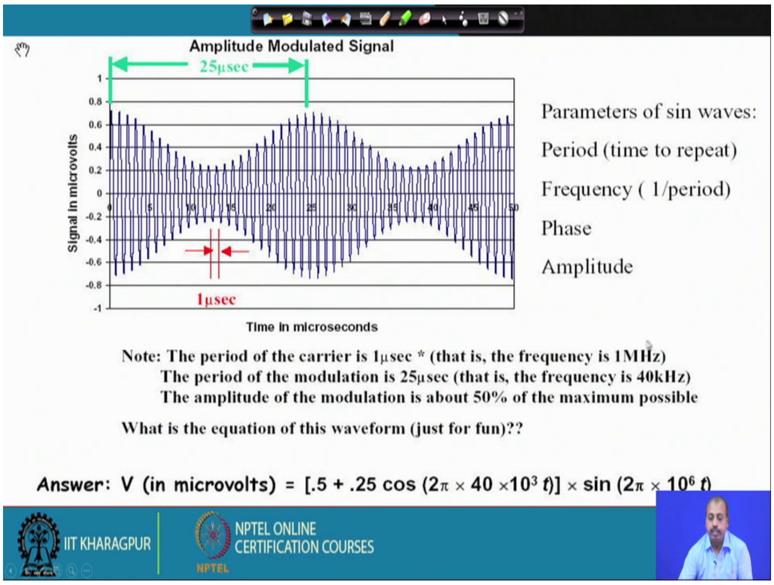

So, accordingly so, this if this high frequency carrier signal is multiplied by this low frequency sinusoidal signal. So, we will get some wave form like this. So, this is the amplitude modulated signal.

So, this the diagram it shows the parameters like see this is the; so, this parameters of the sin waves like period time to repeat then frequency. So, these are the parameters for any sin wave so, we can have so, in this case. So, this is the 25 micro second. So, this is the period of the modulating signal that we have. So, thus the information that we want to transmit so, that is the, that is that period is 25 microsecond whereas, the frequency sin wave. So, it is time period is one microsecond so, this is high frequency.

So, the period of the carrier is one microsecond that is the frequency is one megahertz, and the period of the modulation is 25 microseconds. So, the sinusoidal signal that we want to transmits so, that periodicity is 25 microsecond. So, it is frequency is 40 kilohertz, much lesser than this one megahertz signal.

Then so, this amplitude so what so, amplitude of this carrier signal is getting modulated by this. So, this amplitude of the modulation is about 50 percent of the maximum possible value. So, you can just do some mathematics and try to figure out, say like what is the corresponding equation for this ultimate output signal. So, this is going to be an expression like this ok.

So, this way we can have this amplitude modulated signal which will be which will be used for this analog communication purpose.

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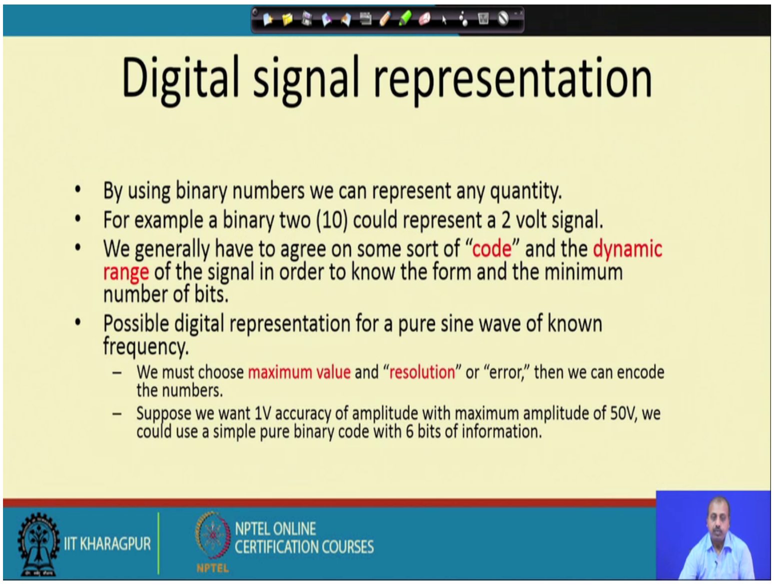

On the other hand, when we go for digital signal processing so, we normally use this binary representation. So, this will help us in making the system much more robust. So, we will see it in the next class.