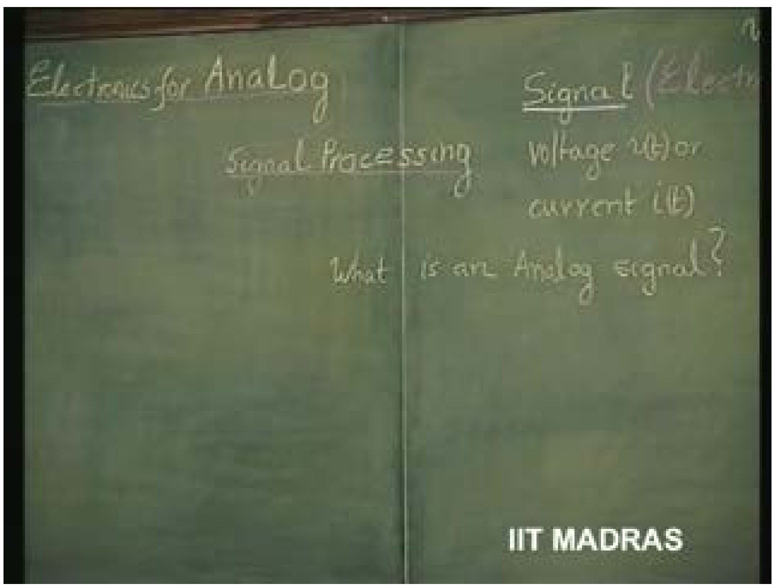
Electronics for Analog Signal Processing

By
Prof .K.Radhakrishna Rao
Department of Electrical Engineering
Indian Institute of Technology Madras

Lecture - 1
Introduction

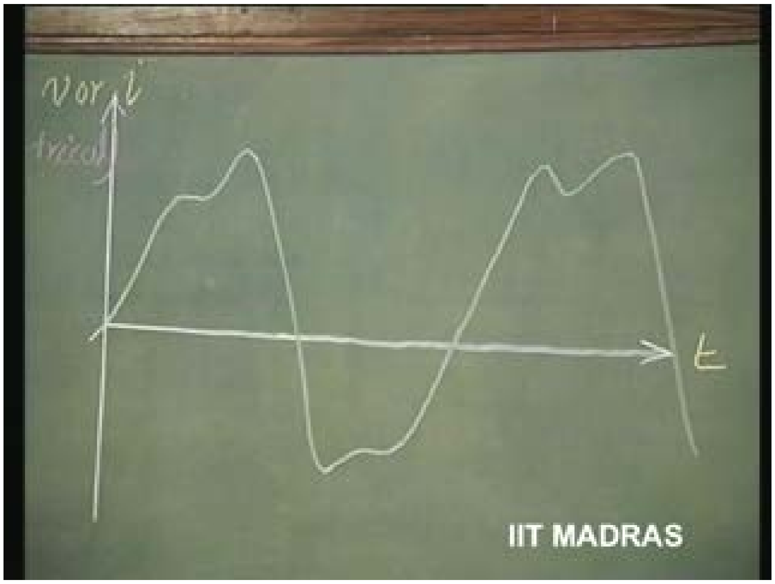
Basic electronics is what we are going to, sort of study it now. In basic electronics currently it is meaning that we are going to discuss analog circuits and that is what has been going on for years but the way we approach this basic electronics is going to be slightly different from the conventional approach. Let us therefore see what this basic electronics comprises, it comprises electronics for analog signal processing, so in this we should know what is analog, what is an analog signal that we have to understand.

(Refer Slide Time: 02:15)



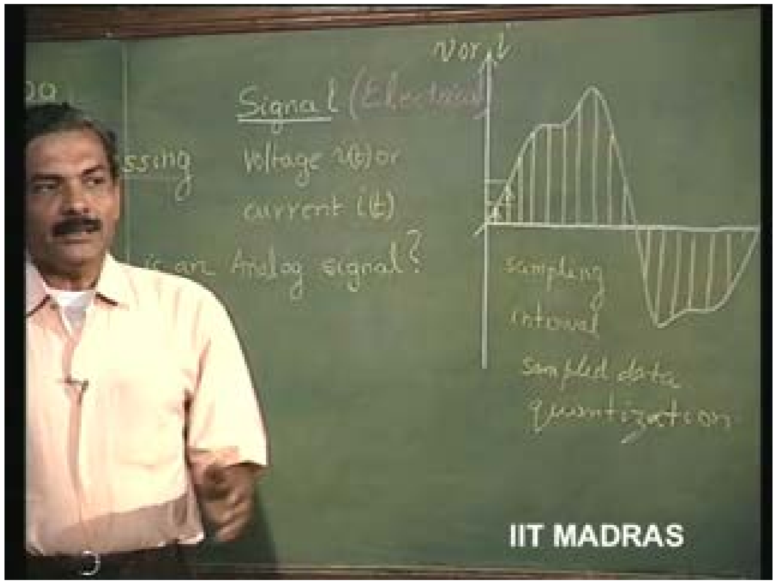
Signal in electrical engineering simply means either voltage v as a function of time or current as a function of time, this is the general definition of the signal in electrical engineering and the analog signal typically represented something like this, some analog signal arbitrary time varying.

(Refer Slide Time: 02:58)



This analog signal is continuous in its amplitude in the sense at any given time the amplitude can lie may be between some point and some other point, any value, that means there can be infinite number of levels at which the amplitude can remain at any given instant of time that is continuous analog signal, continuous with respect to time as well as with respect to values. This is the analog signal which we deal with in analog signal processing, further you might also like to know what is not an analog signal? One might like to sample this not at all times but at regular intervals of time, let us say if the interval is regular, at definite intervals of time I am going to sample the signal, let us say this is the sampling interval and at those intervals of time whatever amplitude occurs for the analog signal I am interested in only those, I am not interested in the rest of the amplitude.

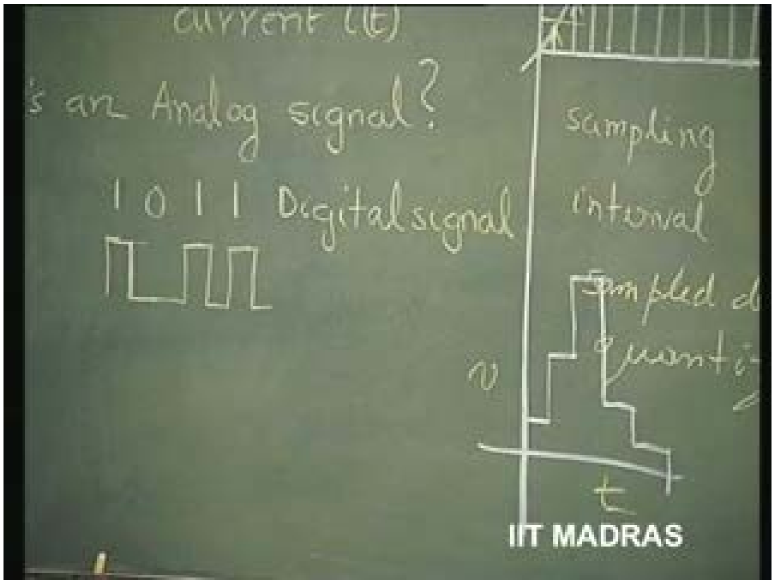
(Refer Slide Time: 05:47)



This is called sample data, where the time is discontinuous not continuous it is occurring at regular intervals whereas the amplitude could be any continuous value but taken only during these intervals of time, so this is the sample data. We can do a sort of processing for sample data that is called sample data processing; it also belongs to a certain extent to another analog signal processing. Then we would also not be interested in any amplitude, we are going to be in some cases interested in specific intervals of time and specific values of analog signal, let us say analog signal at this level is of interest; anything less than this is going to be considered as belonging to this if it is half way above as belonging to this level, if it is less than half way.

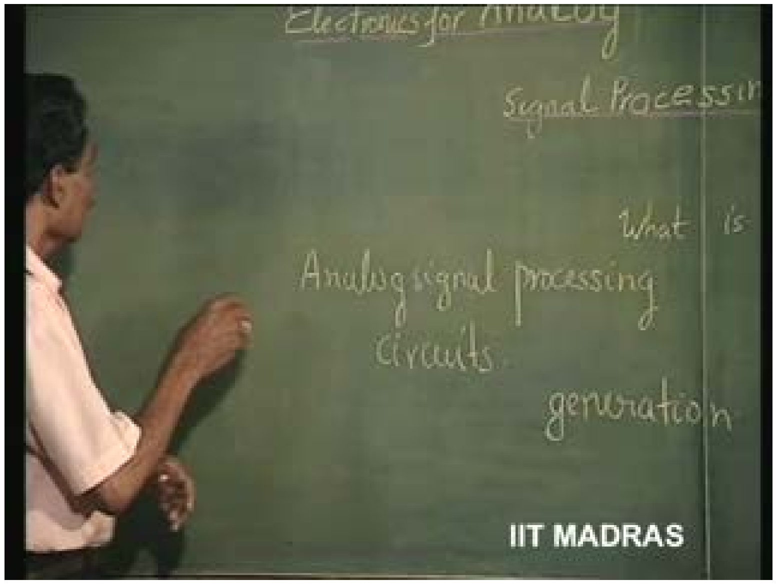
Similarly anything let us say between this and this, if it is in between this can be considered as this; if it is here, it can be considered as this that is called quantization of signal that means I am going to categorize this signal, if it is between this and this it is going to be considered approximated as this, between this and this it could be considered as this. It is like let us say population of a country, comparing populations of countries; we would say, we are going to be rounding off the population to so many lakhs right? Se are not going to be interested in anything less than a lakh, so we will round it off to the nearest lakh that is there as far as population is concerned that kind of quantization. So we would like to compare population only in terms of lakhs, so we are not going to be interested in the intermediate continuous values, this is called quantization. Once you quantize the data, the data is going to appear as, let us say something like this, during this time interval this one, during this time interval this one, like this so on.

(Refer Slide Time: 08:56)



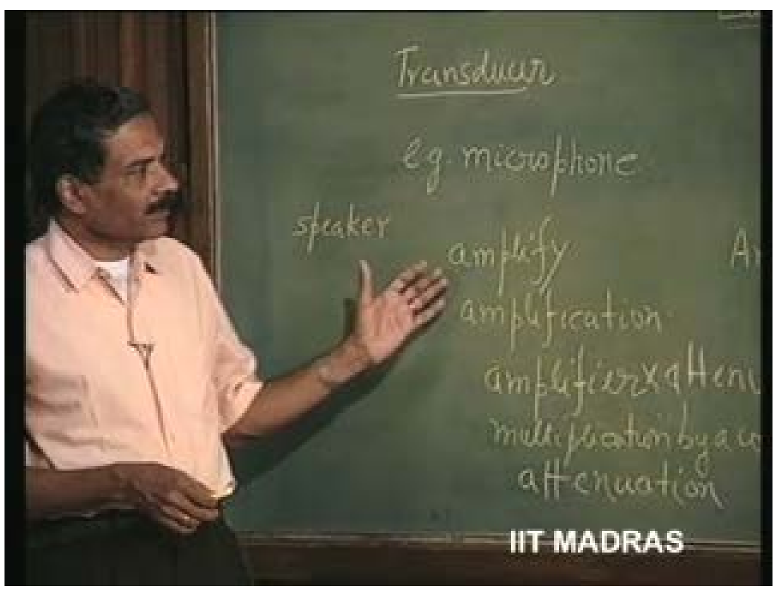
So these are the allowed levels, let us say in this kind of signal with respect to time and these levels, these discrete levels can be represented in terms of a digital world. So we can encode, code this particular level properly so that it is appearing as a stream of existence of a pulse which is called 1, non existence of a pulse which is called 0 that means we will therefore, therefore represent this for example as 1 0 1 1 or something like that, that is the digital world it may be 1 0 1 1 that is the amplitude of this signal, so this is called a digital signal or digital word. So I suppose you have understood that we have continuous time signal with amplitude being continuous and time being continuous then we have sample data signals where the amplitude is continuous whereas the time interval is discrete then we have quantized this signal to specific time interval as well as specific signal levels and converted into some kind of signal which is called digital signal. Where the two levels that are important are the 1's and 0's, 0 means that is say 0 level, 1 means some 5 volts or some voltage, so existence of 5 volts indicates 1, exist non-existence of 5 volts indicates, 0 volts indicates 0, this is one way of, sort of indicating the digital signal. This is a digital word; it is this digital signal which is also processed in digital signal processing that is going to be taken up separately in digital circuit analysis or digital signal processing. Our interest mainly is going to be concentrated on analog signal processing circuits, so we are going to concentrate on analog signal processing circuits. What are those circuits or hardware that will become necessary to process this analog signal?

(Refer Slide Time: 10:03)



What do you mean by processing? We would like to know what are the processing steps, first of all we would like to know how the signal gets generated, so generation, so that the signal exists before it is processed. The signal of this type can occur in what is called a transducer, which converts one type of energy into another type of energy, Transducer, let us say transducer.

(Refer Slide Time: 13:53)

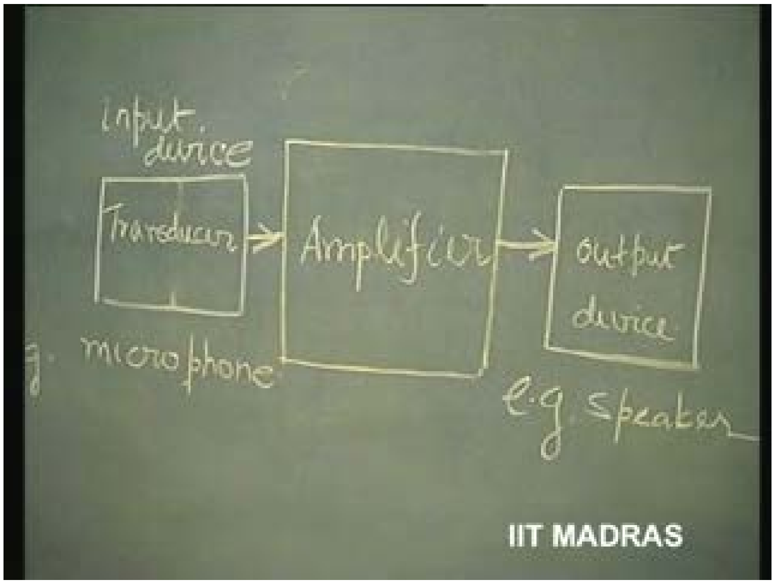


In this we can convert, for example pressure transducer, pressure gets converted, mechanical pressure gets converted into electrical signal or acoustic signal gets again pressure, gets converted into electrical signal. An example of this is a microphone, most of you know about this microphone, you speak into it and immediately, because of the pressure fluctuations you can generate at the terminal of the microphone a voltage signal, so this kind of generation of signal is possible with transducers. Now after the generation of the signal with the help of, for example one typical transducer, we would like to process it; what would you like to do? You would, the signal strength is very low, it is occurring at very low voltage level or very low power level; we would like to therefore amplify it. So amplification that means the signal is simply increased in its amplitude both in terms of voltage and current so that its power level is higher. So amplify, amplific, this is called amplification the operation and the device that does this is called an amplifier.

So we would like to amplify and that action is called amplification and that is done by a device called amplifier. This is nothing but multiplication of voltage and current or voltage or current by a constant factor. Mathematically it is equivalent to multiplication by a constant factor which is greater than 1 so that is called amplification. Multiplication by a factor, constant factor which is less than 1 is called opposite of amplification, is called attenuation. A signal voltage or current can be amplified by an amplifier or attenuated by an attenuator. So amplifier opposite of this is attenuator, amplification opposite of that is attenuation. So this is one of the device which will process a signal and if you can bring out this amplification at a fairly high power level, I would like to sort of output this, convert this electrical signal into audio signal by applying it to what is called a speaker, again all of you are aware of this speaker system. You can output so many watts of power at the speaker end by suitably driving the speaker by means of a power amplifier.

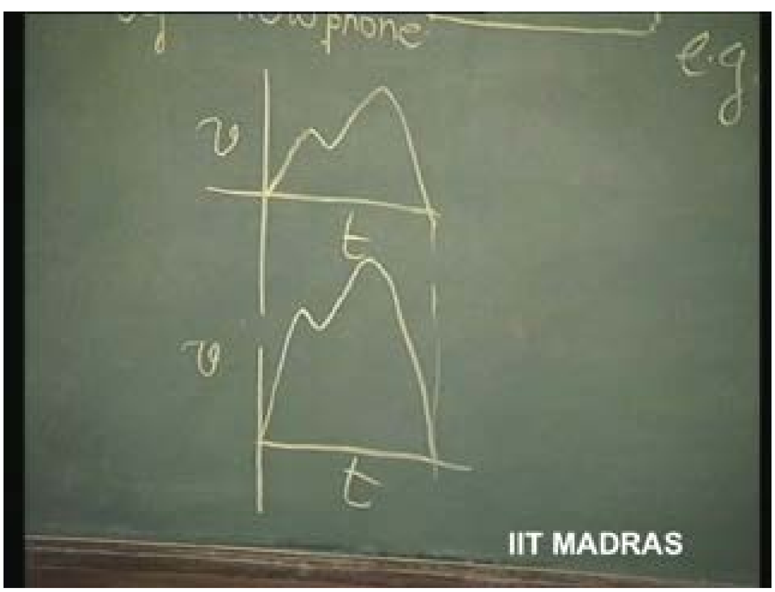
So this is one way of analog signal processing, this is what is going to be learnt by us in the course of our discussion in these series of lecture. So let us put what we have learnt so far in our analog signal processing in terms of what is called block diagram. This is an input device, in our case now we said this is the transducer, example microphone; so this is going to be converting whatever form of energy you have mechanical, temperature or anything pressure into electrical energy here which is a voltage or current form and that is going to be amplified as a voltage amplifier or current amplifier or in general it is called a power amplifier here, to the level that we require so as to drive an output device, in this case it could be a display device or for example it could be a speaker.

(Refer Slide Time: 15:22)



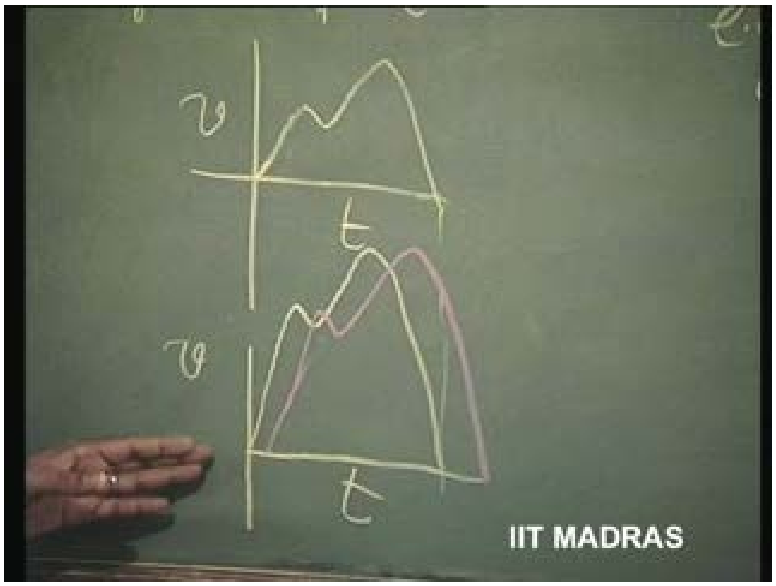
So it is getting converted here from again electrical back to sound energy in this case of a speaker or if it is say an oscilloscope, display device it will be coming in the form of a waveform. So this is the part that we are going to concentrate on as to how we should design an amplifier, what are devices involved, what is the mechanism of amplification etc. Amplification for example I just told you is a multiplication by a constant factor that means if I have a signal with respect to time, let us say something like this, let us say voltage, I will amplify this so that this is going to be over the same time interval, going to have a larger amplitude, but it is going to retain the shape, shape in the same fashion as this, the shape is going to be the exact replica of this.

(Refer Slide Time: 16:36)



Then we said to amplify this signal without distortion, so we said no distortion is occurring if I am able to produce a replica of this with increased amplitude for the same time duration. Suppose I am able to produce this replica of the signal but it is sort of shifted in time then we say there is certain amount of delay, so let us we are going to produce the same thing but with some amount of delay, so this signal and this signal look almost alike but it is going to be delayed by a certain time interval.

(Refer Slide Time: 17:08)

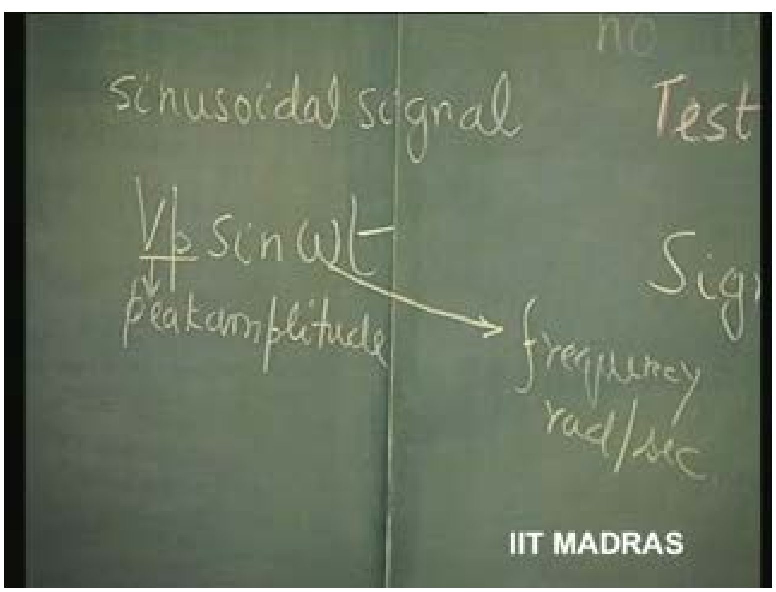


So this is said to be a delayed signal with respect to time but in some cases this delay is not going to matter at all. So as long as amplitude distortion does not occur we are able to say that it is the same signal as this. So this is one way of signal processing, we will learn more about how to prevent distortion, how to reduce the delay etcetera, in our design of amplifiers. Next we can think of wave generation, in order to test my amplifier I need not always produce this signal from a transducer.

(Refer Slide Time: 18:32)

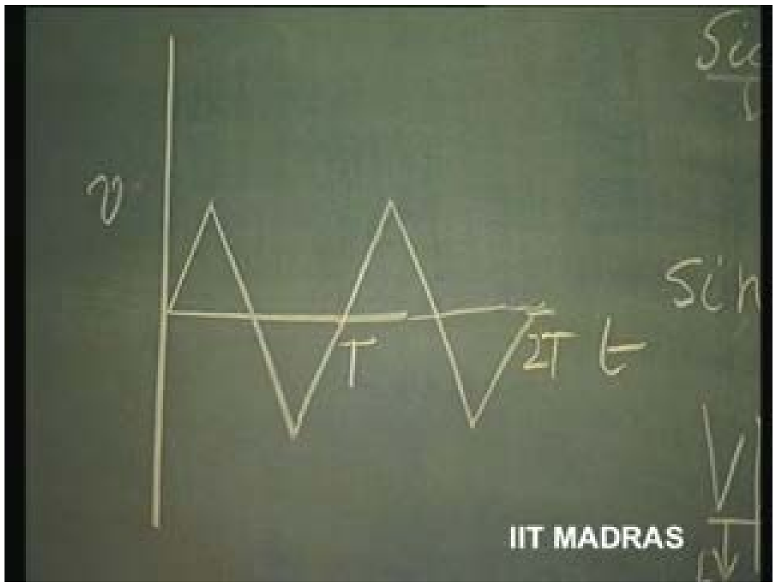
I would like to test, so for test signal that is the circuits which I am using for signal generation in order to test these, for test signals I would like to have my own signal generators, signal generators. Here I would like to dwell for some time, what are the signals of importance? So for signal generators I would like to have first of all a sinusoidal signal mathematically represented by Vp sin omega t.

(Refer Slide Time: 19:40)



Vp is the peak amplitude of the signal, omega is the frequency of the signal, this is called the peak amplitude and this is the frequency in terms of radians per second. So all of this you have learnt in your earlier course on networks. Vp is the peak amplitude of signal and omega is the frequency of the signal and I would like a signal generator which can produce sinusoidal signal. What are the circuits that will sort of generate these sinusoidal signals that can also be a topic of discussion. We know that the sinusoidal signal is very important because you know that any periodic signal, according can be written, any periodic signal, what is a periodic signal? Let us say we have some signal like this, is getting repeated after a certain time, this is called the time period t, so if it is getting repeated exactly after a certain time in the same fashion that is said to be a periodic signal.

(Refer Slide Time: 20:27)



So any periodic signal can be represented as a summation of several sinusoids, this will have a fundamental component which is of the same frequency as this and may be its harmonics. This again you have leant in your networks course, so it is therefore interesting to observe how it is going to respond to a sine wave so that I can predict the performance of my amplifier or any other block that I am going to design as to exactly how it behaves using this test signal from a signal generator which is a sinusoidal signal. Apart from the sinusoidal signal for example what I have drawn here is a triangular waveform, so this also is going to be of interest and other waveforms which are going to be of interest will be a square wave form in the sense it is going to have, let us say plus a and minus a amplitude, for the same interval of time the negative as well as positive durations would be exactly same and it is going to get repeated, so this is called a square wave.

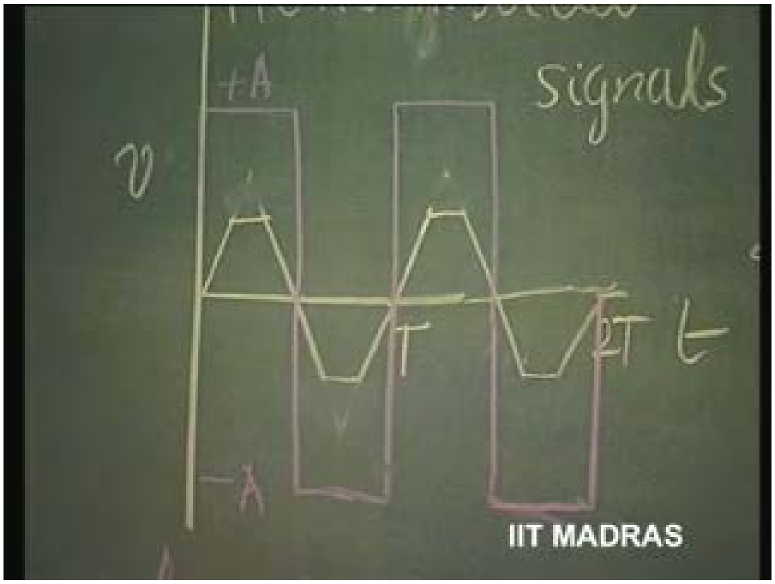
(Refer Slide Time: 22:06)

So we have triangular waves and square waves apart from sine waves which are going to be of interest to us. Apart from this we would like to also have sharp spikes, this is going to be very important in what is called time markers, I would know exactly how much time has elapsed and at that time I would like to have an indication, these are called trigger pulses.

(Refer Slide Time: 23:03)

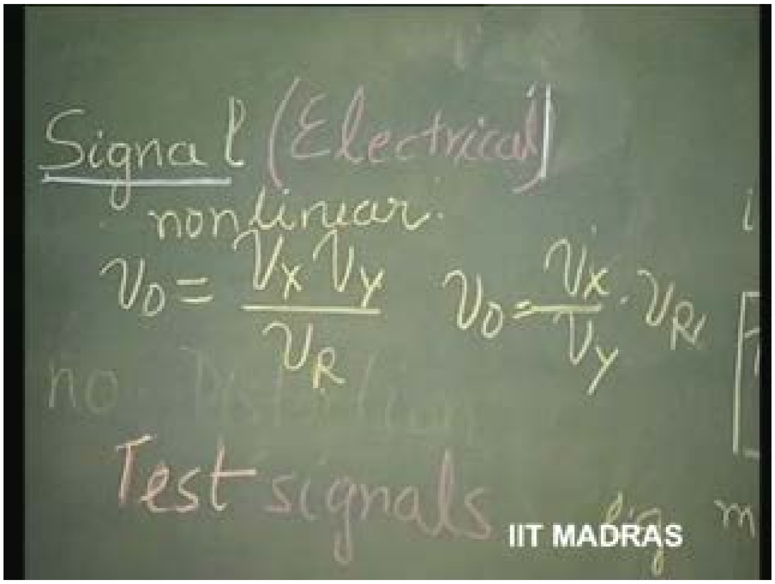
So exactly after t interval we get a, let us say a trigger pulse so I know periodically these trigger pulse will come and sort of indicate that this much time has elapsed. So to generate this trigger pulses what are the circuits that we have to use. So these are the commonly used signals in analog signal processing and testing. So we would like to know what are the circuits which will generate these, so signal generator will form another topic of discussion, both sinusoidal as well as non-sinusoidal, these are called non sinusoidal signals. So we would like to generate both sinusoidal as well as non-sinusoidal signals. Then we would like to further shape signals, how to cut chop the top portion and the bottom portion.

(Refer Slide Time: 24:24)



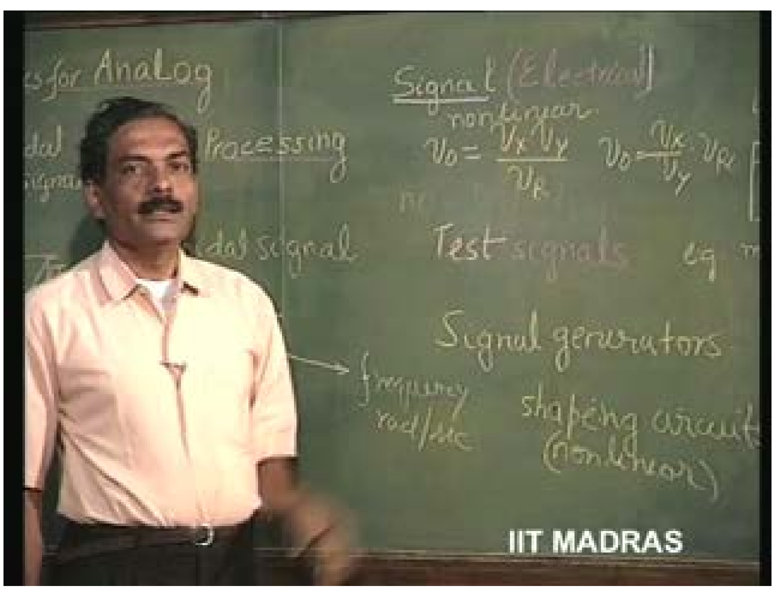
Look at this, I would like to chop this and this and formulate. So if I chop of the head of this triangular waveform to the extent I need then I get what is called a trapezoidal waveform. So signal shaping circuits converting a triangle into a trapezoid, converting a triangle into a sine wave, these are the shaping circuits. Then we would like to also discuss about how to multiply two signals, so multiplier that means multiply one voltage with another voltage, for example output voltage is going to be v_x into v_y divided by v_r, so output since it is a voltage I can multiply v_x by another voltage v_y divided by v_r so that the dimension of this is again a voltage, so this can form a multiplier

(Refer Slide Time: 26:05)



Or if this is v_x and this is v_y and that is v_r that is a divider. So v_x is divided by v_y this is called non linear operation, this amplification is a linear operation whereas multiplication is a non linear operation, signal shaping also is a non linear operation, you are chopping off some portion, so these are all non linear operations which are important, multiplication is also a non linear operation which is important.

(Refer Slide Time: 26:26)



This comes about in communication circuits, what is multiplication? Actually speaking when I multiply I get, for example A sine omega t is one signal multiplied by B sine omega$_1$ t omega$_2$ t divided by let us say V_R, DC let us say.

(Refer Slide Time: 28:58)

So you get AB by V_R into a component which is going to be $omega_1$ minus $omega_2$ and another component which is going to be $omega_1$ plus $omega_2$, [sine $omega_1$ t into sine $omega_2$ t]. So this is the amplitude of this signal, you can say that this is the modulating frequency and this is the carrier, so this is called double side band modulation right, DSB. This is one way of shifting the signal from the low frequency band to high frequency, you would like to have this signal carried by something, this is called the carrier frequency; this is called the modulating frequency. So this is one way of coding the information so that it can be transmitted at very high frequency. We can have different carriers carrying different kinds of information, one might be madras radio station another may be Hyderabad, all these stations can have different carriers and then you can select the carrier which is carrying the information using what are called as tuned circuits and then sort of detect the signal that is occurring in that. So in communication this kind of operation is common, this is called some kind of modulation or more popularly mixing, you are mixing one signal with another so this operation of multiplication is adopted in what is called as mixer, modulator as well as demodulator, in order to get the information out from this I simply have to multiply this now by, if I simply multiply this by another signal.

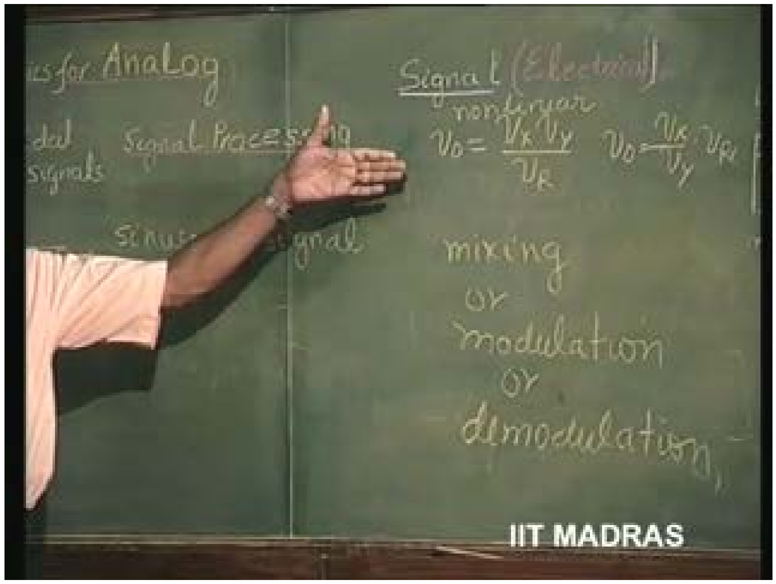
(Refer Slide Time: 29:25)

So if sine omega$_c$ t, c sine omega t, ct then you will note that sine omega$_c$ t, sine omega$_c$ t will become sine squared omega$_c$ t and I can expand it has [1 minus cos 2 omega$_c$ t] divided by 2.

(Refer Slide Time: 30:03)

So you can see that sine squared omega$_c$ t is getting converted into this kind of form and I can extract the wanted signal from this by separating this by using a simple low pass filter. This is a high frequency signal, this is the carrier frequency signal twice that and I can separate it from this composite signal by using a low pass filter. All these discussion we will be doing later on. This is a communication signal operation, so this is called, this operation is called mixing or modulation or demodulation. So this important operation of multiplication is also one of the, sort of signal processing operation that we would like to understand.

(Refer Slide Time: 30:43)

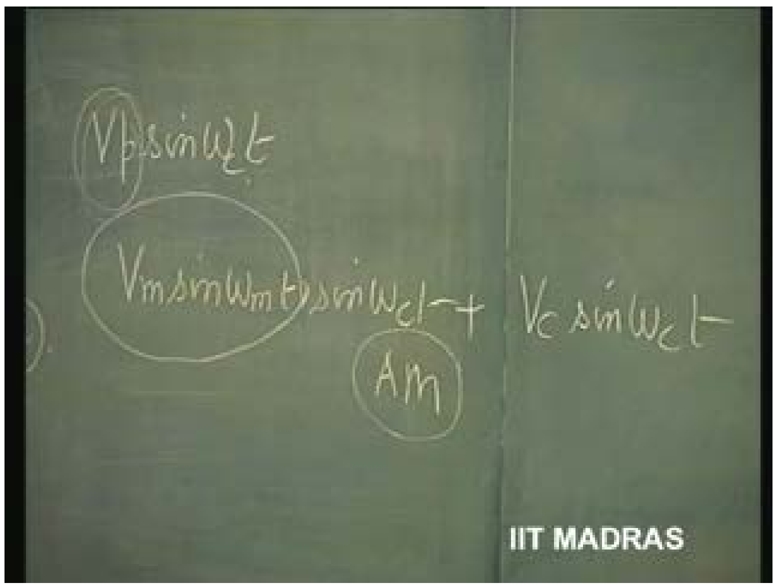


We have just now seen how amplifier simply multiplies the signal by a constant, how in testing these amplifiers etc it becomes necessary for us to generate certain signals like sinusoids, triangular waveforms or square waveforms that is also termed as oscillator.

(Refer Slide Time: 32:19)

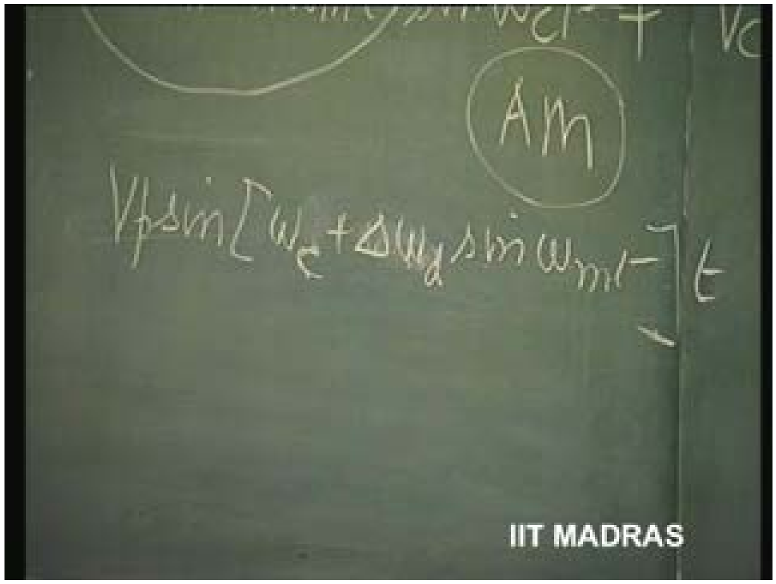
How we can multiply one voltage by another voltage, again get an output voltage by using a multiplier which do what is called coding of signal in terms of modulation, mixing. How we can also do wave shaping of these different signal waveforms to convert one waveform for example triangle to sine wave, triangle to trapezoid etc by using wave shaper circuits and further so on we can also do some kind of modulation both of amplitude and frequency. This kind of coding can be done, this is called amplitude modulation circuit, this is called FM modulation because we know that any given waveform Vp sine omega t, sine wave, we can make Vp become equal to let us say V_m sine, this is $omega_m$ t into sine $omega_c$ t that means this amplitude Vp itself is sinusoidaly varying, so we can see here this is nothing but multiplication of one modulating frequency with carrier.

(Refer Slide Time: 33:30)



This is the modulation that multiplier that we talked about. In order to identify the carrier we might also add along with this, the carrier itself so that we can at the receiving end select the carrier properly and therefore get the modulating frequency more easily that is called AM. That is after multiplying you add suitable amount of carrier power for easy selection so that this is amplitude modulation of the given waveform, Whereas if I change the frequency based on the amplitude of the modulating signals, let s say Vp sine $omega_c$ plus $omega_c$ t plus $omega_m$ that is delta $omega_d$ sine $omega_m$ t.

(Refer Slide Time: 34:29)

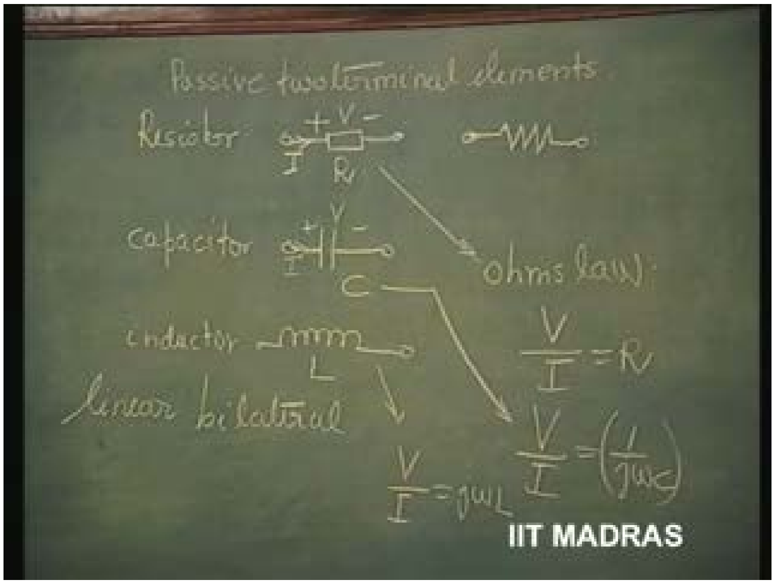


So this is called frequency modulation, this is the frequency deviation and this is called frequency modulation. So I am now changing the frequency of the signal, originally it was omega$_c$, omega$_c$ changes to plus delta omega$_d$ sine omega$_m$ t, it is changing in a manner determined by the signal, so this is called the FM. So how FM generators can be obtained by what are called voltage controlled oscillators. So this will be the topic of our discussion also.

(Refer Slide Time: 34:45)

So generation of all this waveforms will form also part and parcel of analog signal processing. Now we are coming to the basic elements involved in analog signal processing. The elements that are already familiar to you, let us consider first a resistor, resistor, which could be represented as, let us say r, the other symbol for this is this. So you have been already exposed to basic elements such as resistor, then capacitor and then inductor.

(Refer Slide Time: 38:48)



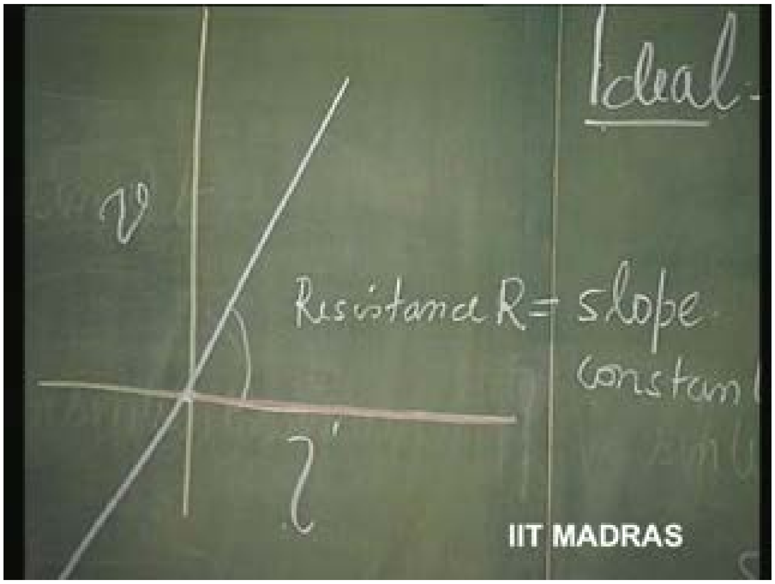
These are the passive two terminal elements, these are further, if they are ideal they are also called linear bilateral elements. We will understand what this means because there is certain volt ampere relationship for each one of these elements which you have already studied earlier in your network course, for example the current and the voltage in all these three cases will be linearly related. So for example let us take ohms law which has been studied by you as V divided by I equal to R, voltage divided by current is a constant this is what is called ohms law. On this is the resistance value, if you plot this, let us say this is the voltage V and the current in this is I so V by I is equal to R. In this case also if I at a certain frequency consider its impedance, the impedance of this is going to be 1 over j omega c that is going to be equal to V by I at a certain frequency now, at a given frequency that is equal to the impedance one over j omega c in this case, this also is known.

Here this V over I in this case is nothing but j omega L, this is connected with this; this is connected with this; this is connected with this. What it indicates is that impedance in this case is proportional to frequency of the applied signal, impedance here is inversely proportional to the frequency of the applied signal so this and there is a fixed lag of 90 degree between the current and the voltage, there is phase lead of 90 degree between the current and voltage that is all. But basically all these elements are linear, absolutely linear that is voltage to current relationship is linear so these are called linear bilateral. It does not matter in which direction the voltage is applied, the current is going to flow in suitably in that direction with the same law that is being followed. So direction is of course consequence, therefore they are bilateral. So these basic elements are known to you in electrical engineering and we are going to make use of these basic elements for our analog signal processing apart from this, for electronics this is needed for electrical signal processing and for electronics we would like to use other elements. Out of these other elements the most important two terminal element of interest to us in electronics is called diode. This is a terminal element so symbol is this, this V and I indicate instantaneous value of voltage at any given time.

(Refer Slide Time: 41:15)

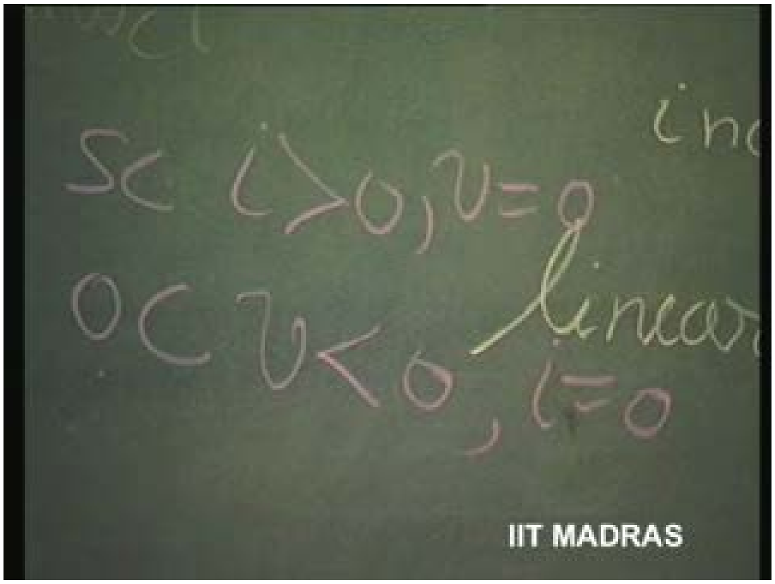
This V and this I indicate, this capital letters here indicate either DC or the RMS value at a given frequency. So in this particular case this is a non linear device unlike this device, these devices which are all linear devices, this is a non-linear device what does it mean? If you apply a voltage in direction it has zero resistance in this case, it is a short circuit. If therefore actually current is to flow in this direction only, this is the arrow direction that means this arrow indicates that it is permitting the current flow only in this direction, so current flow is possible only in this direction. If I apply a voltage in the opposite direction that is if this is made positive and this is made negative then there is no current flow, it is an open circuit. So depending upon the direction of current or voltage this is going to change its property, so it is not linear, it is nonlinear. Now let us see how its characteristic will look like, let us compare this characteristic with that of the linear elements. For example let us take the characteristic of a resistor. This is a linear characteristic of a resistor, this slope of this, V divided by I is going to give me the resistance value.

(Refer Slide Time: 43:56)



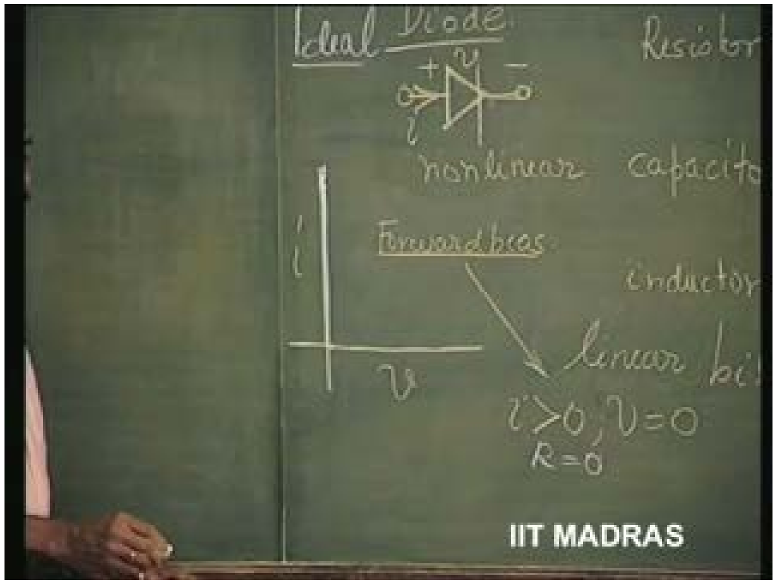
So I can even take this slope that is slope is constant and that is equal to the resistance value so this is the characteristic of a resistance. If you plot this, this is nothing but V is equal to I into R, you can see that. So V is equal to I into R is nothing but a linear characteristic like this. If you have to draw I mean if the resistance value is very high, the slope is going to be high. The resistance value is very low; the slope is going to be low. Now how will the characteristic of a diode, ideal diode look like, let us say it will permit current flow of any magnitude in this direction and the resistance is going to be 0 that means it is going to be a short circuit in this direction of current that means the resistance is going to be 0 for this right? And as far as, and it will permit any value of current and it will sustain 0 voltage there. This is the characteristic in this direction and in the opposite direction whatever be the value of voltage I apply in the opposite direction, this is going to be an open circuit that means for I greater than 0 it is a short circuit, for V less than 0 it is an open circuit. This is an important statement here.

(Refer Slide Time: 44:42)



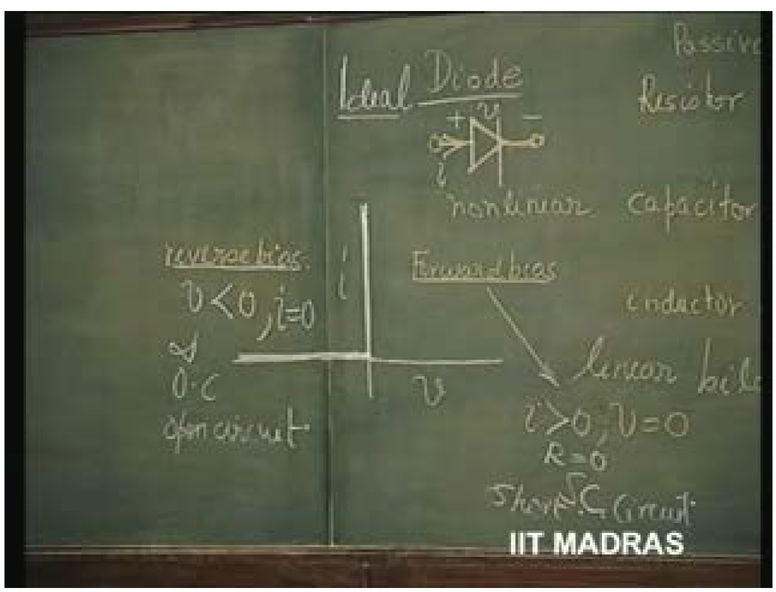
I less than, I greater than 0 it is a short circuit that means voltage across it is 0. V greater than, V less than 0 it is an open circuit or current through that is equal to 0. So open circuit or I is equal to 0, here V is equal to 0. So this is important, when I is greater than 0 voltage across it is maintained 0, throughout whatever be the value of current. When V is less than 0, I is equal, V is less than 0 is this, I is going to be maintained 0 throughout, so this is the characteristic of an ideal diode. So we will see how this ideal diode can be used in variety of applications in the next class. Apart from that we would also like to see how in practice we have availability of such a diode in the form of what is called semiconductor diode. So we have just seen in the case of a diode how it can be represented, now I am going to change the axis, I will put I here, V here, earlier we had put V here and I here so that we can see that, as far as the what is forward bias region is concerned this is called forward bias region.

(Refer Slide Time: 46:48)



What is it? In fact when I is greater than 0 it is called forward bias. So when I is flowing this way it is called forward bias and V at that time, in the case of an ideal diode is 0, so this is called forward bias in the diode. At that point of time we saw that the characteristic looks something like this, I is going to be anything but V is going to be 0. So in this forward bias region, this is the characteristic of the diode. Resistance is going to be 0 so R is going to be 0 in this region. And we have reverse bias, where is it? When V is less than 0, I is going to be 0 that means in this direction of V we have the I becoming equal to 0, this is called reverse bias of the diode.

(Refer Slide Time: 48:36)



So this is called biasing the diode, that if I want a bias the diode in the forward direction I must make I greater than 0. I must be forced into the diode in this direction then automatically V becomes equal to 0 for this and resistance of the diode is 0. Here for V less than 0, I is 0 right? So if V less than 0, I is 0, resistance there is going to be equal to infinity because we can say V over I is equal to R, I is equal to 0, R becomes infinity. Here in the forward direction V is equal to 0 for any value of I, so R is equal to 0. So from this we can conclude that it is piece wise linear. In this direction it is linear and resistance is going to be 0, in this direction it is again linear and resistance is going to be infinity or it is going to be a short circuit here and an open circuit here, so this is a short circuit and this is an open circuit.

Let us therefore in the next class see how this kind of ideal diode characteristic is going to be imitated by a practical diode called semiconductor diode. What is its characteristic? How closely it is going to represent our ideal diode and what are the various applications of this diode, in the form of wave shaping, clamping, clipping, rectification, a sort of multiplexing, so this are the variety of application for which these diodes can be used, all of which we are going to start discussing from the next class.