Mechatronics
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Lecture - 03
Electric Circuits and Components

Welcome you all in NPTEL online certification course on Mechatronics. Today, we are going to discuss about Electric Circuits and Components. Electric circuit and components, they are very vital part of any mechatronics system. As the mechatronics system consists of many electrical components and their connections. So, today we are going to see some basics about electric circuits and components, which are useful from the mechatronics perspective.

Electric circuit and components as I said, they are important in design of discrete circuit for signal conditioning and interfacing purpose. So, as we have seen the basic block diagram for any mechatronics system, we have actuators, sensors and then, we have the signal conditioning and interfacing unit. So, this study is very important from that perspective.

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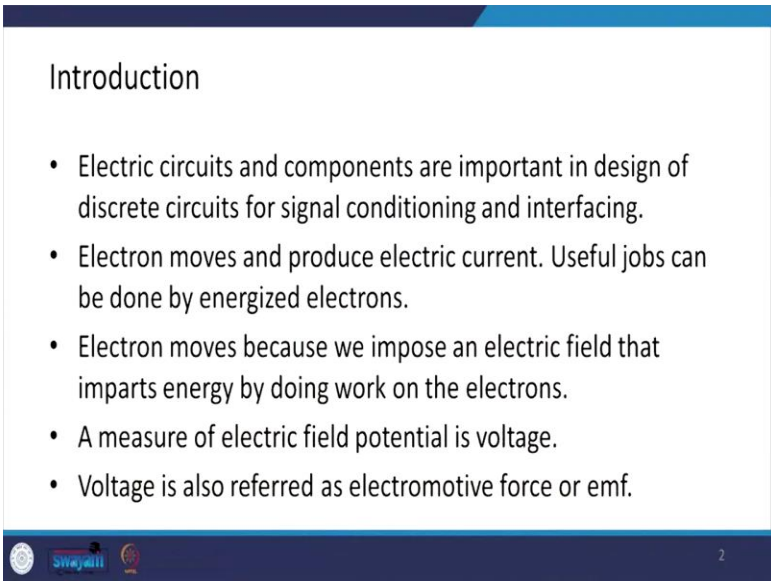

Now, we all know from our basic knowledge of physics that electron moves and produce electric current and useful job can be done by these inner energized electrons. And why does the electron move? The electron moves because we impose an electric field and that electric field imparts energy by doing work on the electrons. A measure of this electric field potential is the voltage, as we know and this voltage is also referred to as electro motive force or in short, we write as emf.

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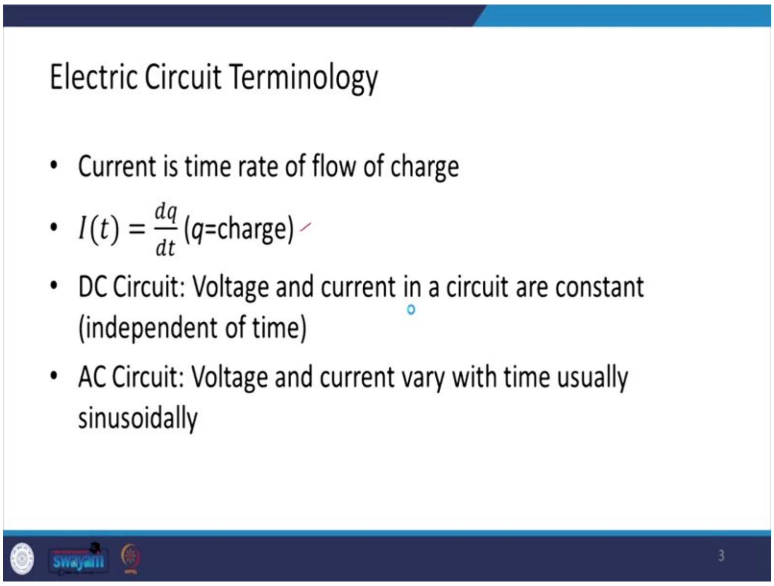

Current as we know that, its time rate of flow of charge. So, the current which is function of time, this is actually a given by,

$$I(t) = \frac{dq}{dt}$$

where, q are the charges. Now, we come across the two types of circuits that are the DC circuit, direct current circuit and alternative current circuit, AC circuit.

So, DC circuits are the circuit, where voltage and current in a circuit are constant. That is they are independent of time; whereas, in case of AC circuits voltage and currents varies with time usually, in a sinusoidal way.

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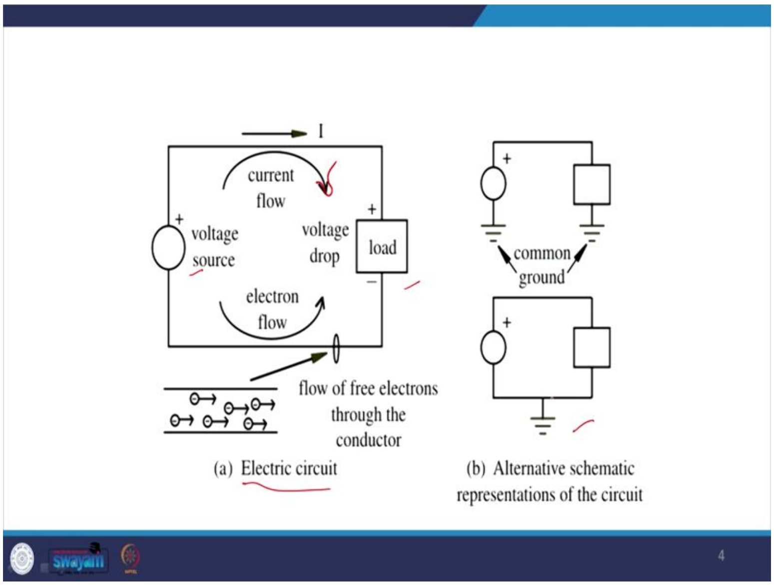

So, if we look at this figure basically this figure depicts the electric circuit. And here, you can see that in this figure, we have a voltage source and there is a load and this is the direction of the flow of electron flow through the conductor and the conventional way of the current flow is taken opposite to the sense of the electron flow. So, we have this direction as the current flow direction.

And there is a voltage drop across the load. So, this is how an electric circuit looks like. There could be an alternate way of representing these circuits. Here say we have a source and we have a load here and one end is grounded here. So, or it could be represented in this way, a way where rather than the separate ground, we have a common ground.

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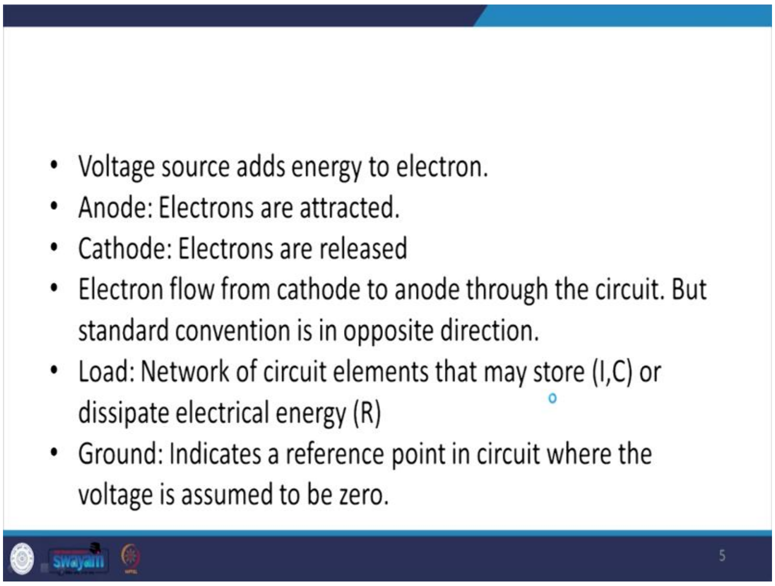

Now, as I said these voltage sources adds energy to the electrons and at anode, electrons are attracted at cathode, electrons are released. These are all basic preliminaries which you study in case of cells also ok. So, we will be just going through these. Now, electrons flow from cathode to anode through the circuit; but extended convention as I said, it is in the opposite direction and load basically consists of network of circuit element that may either store in energy or that may dissipate energy.

So, there are two storing energy storing elements which we call as the inductor and capacitor and the dissipative element is basically resistor in case of electrical circuit and the ground indicates a reference point in a circuit, where voltage assumed to be 0 or so, it’s basically a reference.

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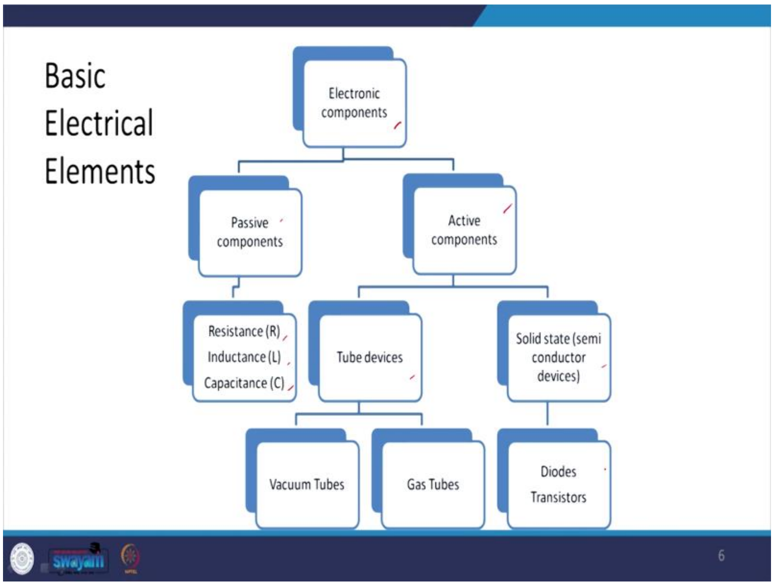

Now, coming to the basic electrical elements, I just said our purpose of this lecture is to study the elements which we come across in a mechatronics system. So, the basic electro elements are the passive elements or passive components and active components. So, as the name indicates that in passive component, these component do not require additional source of power basically. So, these components are resistance, inductance and capacitance.

And if you come to the active components, these are the components which require additional source of power and these could be either the tube type of devices, which were used earlier in the electronic circuits or they could be the solid state devices, which are basically the semiconductor devices.

So, in tube type devices, we have the vacuum tube and say gas tube and in solid state devices, we have diodes, transistors and so on. So, this is the basic classification of the electric elements.

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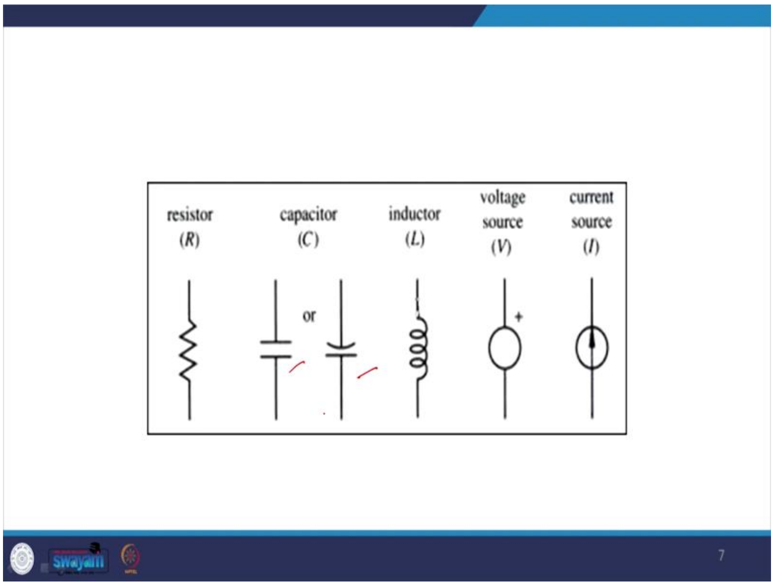

As I said the passive elements, we have a resistor, capacitor (here there are two notations of the capacitor, they can be represented either way) and the inductor. Resistor is an energy dissipating element; whereas, the capacitor and inductor are the energy storing element. And then, there are the two sources; the voltage source and the current source. So, these are the representation of the two sources. Current source, you can see that inside the circle, we represent an arrow and that basically tells us the direction of flow of current.

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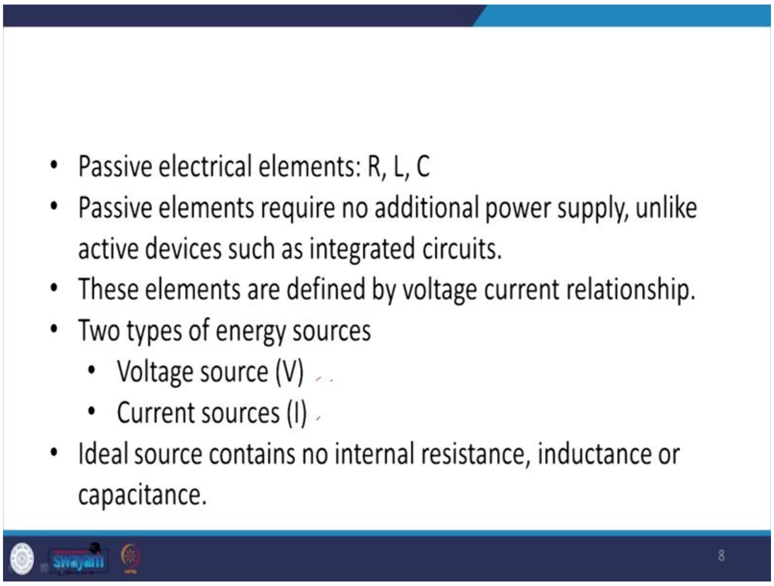

So, as I said passive electrical elements are resistor, inductor and capacitor. Resistors is indicated by R; inductance is indicated by L and the capacitance is indicated by C. And as I said passive elements require no additional power supply unlike active elements such as integrated circuits. I have talked about diode and the transistor also as the active elements.

These elements are defined mathematically while the voltage current relationship. And as I said there are two types of energy sources that is the voltage source and current source and the ideal sources, we assume that although there is no ideal source; but to simplify our analysis, we assume that the ideal sources contains no internal resistance, inductance or capacitance.

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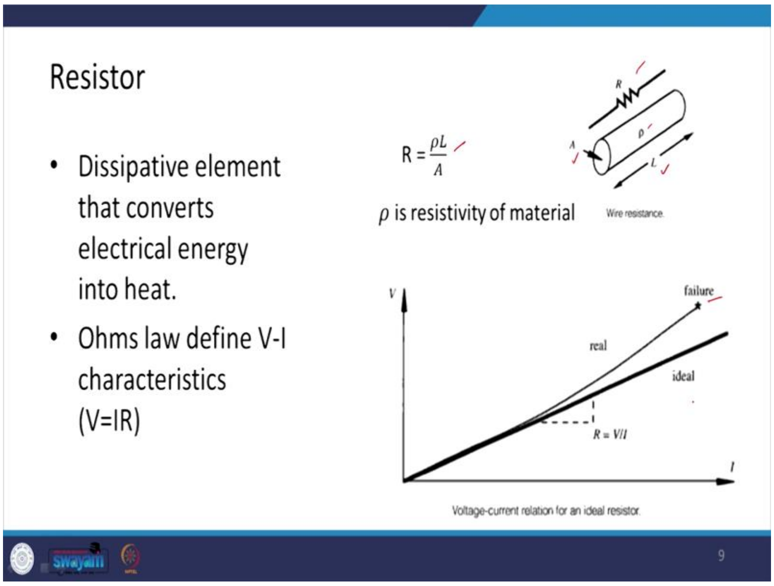

So, let us begin with the first passive element that is the resistor. So, resistor we can see that it is a dissipative element that converts electrical energy into heat and the heat is dissipated to the universe or atmosphere. And thus, if suppose, I have a wire resistance conductor of say length L and area of cross section A and resistivity of the material is ρ, then

$$R = \frac{\rho L}{A}$$

And this is the notation basically how it is represented in an electrical circuit. Do not confuse this type of notation with the spring notation which will be are talking later. And so, Ohms law defines V-I characteristic voltage and current characteristic of a resistor and we all are very well familiar with the Ohms law which says that V = I R.

So, here is a plot which gives the voltage current relation for an ideal resistor. So, the ideal one, we can see that (V = I R). So, the resistance can be found out as (V/ I) that is the slope of this curve will be giving us the resistance; whereas, in case of the ideal you can see that this relationship is linear; whereas, in case of the actual resistor, the relationship will real resistor the relationship with not be linear.

And after a certain amount of current or once the current value exceeds a certain value, the resistor will fail. So, this is where the failure is indicated.

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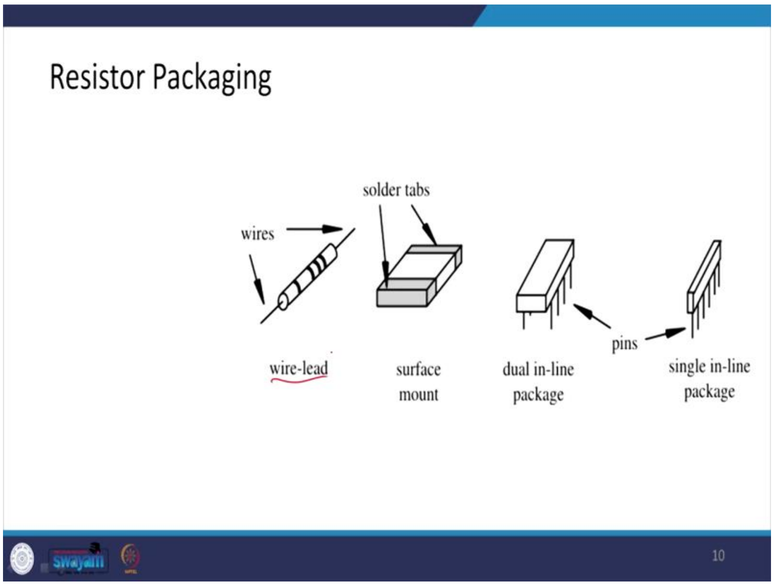

Now, these resistors are available in the market in various form of packaging. Our aim as a mechatronics engineer to make different circuits, different components to be used in a mechatronics system. So, we need to know that what type of resistor or what is the packing which is commercially available in the market for procuring the resistor.

So, it could be wire lead type here. You can see here, there are various bands. I will be talking about these bands little later. Then, we have a surface mount resistor, where at the ends, you can see that there are solder tabs and there is dual inline packaging, where you have the two lines. Here as you can see, two line of pins are there and commercially, they are also available in the form of single inline packaging, where you can see that there is a single line.

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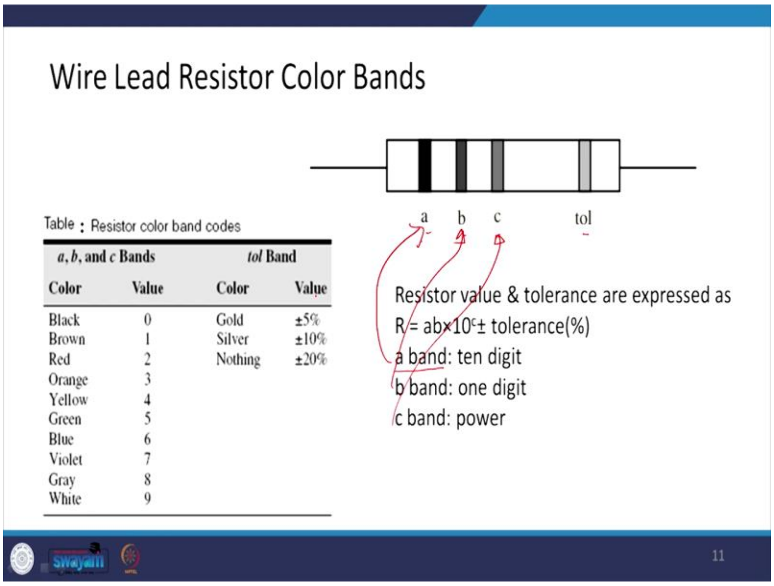

So, this way, we can go and get them in the market. Coming back to the first case which I was talking to you that is the wire lead type, so if you look at the wire lead resistor there are different color bands actually in it. You can see a, b, c and then, there is an after a gap, there is another band which we call as the tolerance band.

So, here basically the resistor value with this help of color band, you can measure the value of the resistor, which we measure in terms of the Ohms (Ω). And this value of resistor, you can also measure with the help of multimeter; but if you know this color coding without help of multimeter, you can see what value of resistance this resistor will be providing.

So, resistor value and tolerance these are expressed as,

$$R = ab \times 10^c \pm tolerance(\%)$$

where basically **a** band indicates the ten digit and **b** band indicates the one digit and **c** band basically indicates the power and these values of a, b and c band are actually given based on the color code.

For example, here you can see the for black, there is 0 value, brown 1, red 2 and so on. Similarly, for the tolerance band depending on the color, we have the tolerance values. So, this way, we can identify the resistor value.

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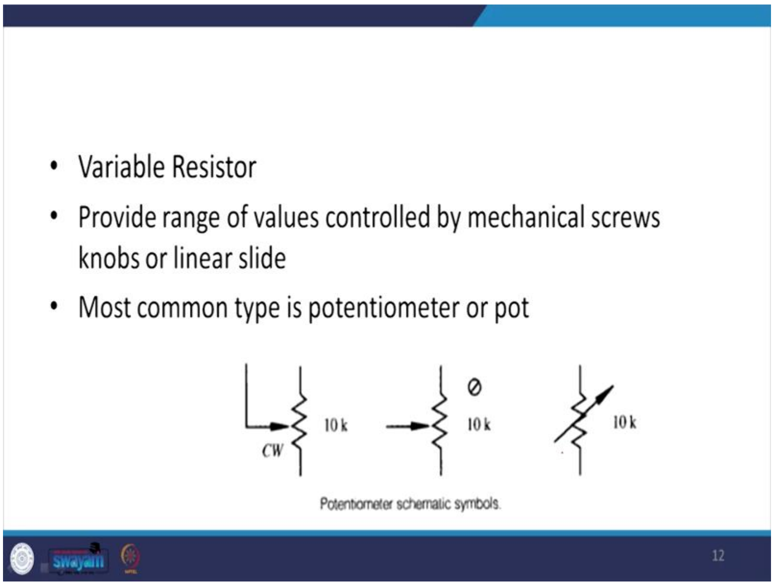

Then, we also require many times the variable resistor, especially in a device call potentiometer or in short, it is called as POT, we often require the variable resistor and these variable resistors provide range of values and these values could be controlled by say some mechanical screw now or some linear slide.

So, if you have a linear slide and that slide is moving, the resistance value is moving. So, that type of arrangement could be there and so, here is the notation basically 10 k, you can see the either it could be represented like this.

The variable resistor, where an arrow is touching here, there is a symbol provided which means that you can change this value through the screw knob or it could be a simple one, this way the variable resistor can be indicated.

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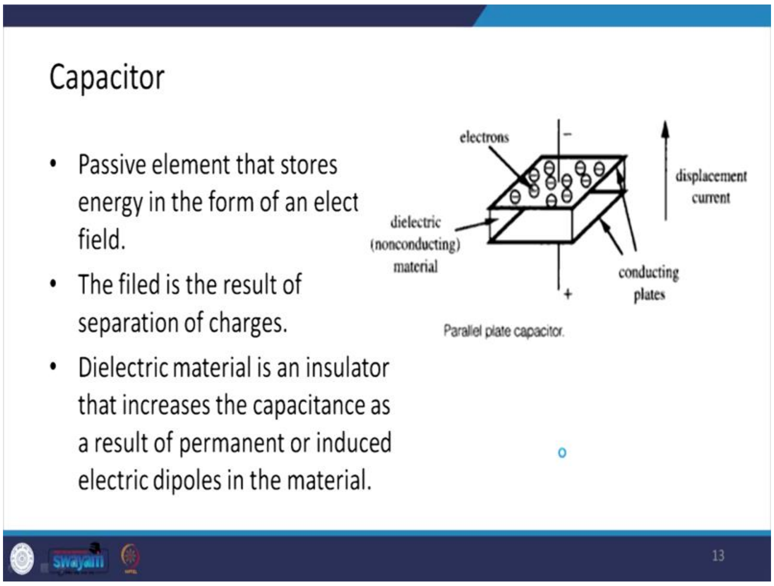

Then, next passive component is the capacitor and it is a passive element that it stores energy in the form of electric field. So, here you can see that a parallel plate capacitor has been shown in this figure and there are two terminals; the positive terminal, negative terminal for that and basically there are two parallel plates and in between the parallel plate, there is a dielectric material which is a non-conducting material.

So, the field is the result of the separation of charges here, we can see the dielectric material is an insulator basically that increases the capacitance as a result of permanent or induced dipole in the material. Strictly speaking the DC current does not flow through the capacitor and charges are displaced through the circuit.

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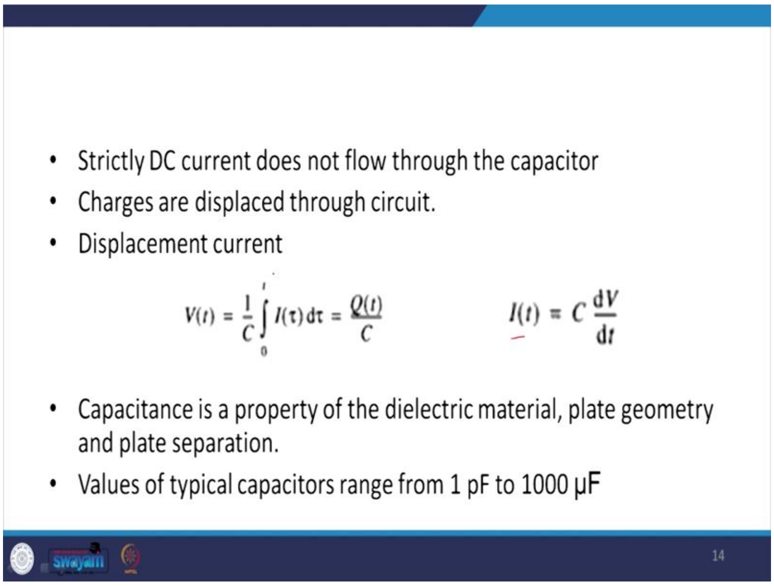

And there is a current what we call it as the displacement current which is defined for capacitor,

$$V(t) = \frac{1}{C}\int_0^t I(t)d\tau = \frac{Q(t)}{C}; \qquad I(t) = C\frac{dV}{dt}$$

So, we can see that capacitance is a property or the dielectric material, plate geometry and the plate separation. I am not going much details of these things.

You must have studied in your 12th class, all these basic concepts. My emphasis is here rather on just reviewing this concept from the mechatronics point of view. So, the values of typical capacitor ranges from 1 Pico Farad to the 1000 micro Farad. So, this we have to keep in mind, while selecting them for our component in our mechatronics system. Next important mechatronic component is the inductor. So, inductor again as I said it is a passive element that stores energy in the form of a magnetic field.

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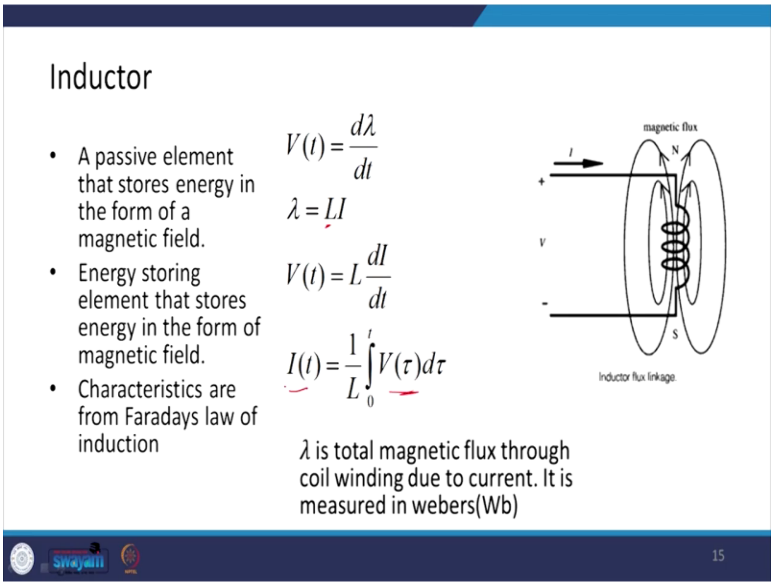

An energy storing elements stores energy in the form of magnetic field and characteristics are from the Faradays law of induction. So, Faradays law of induction says that,

$$V(t) = \frac{d\lambda}{dt}$$

$$\lambda = LI$$

And this magnetic flux is proportional to the current and if I remove that proportionality symbol with a constant, we define inductance of the material that is L. So, we have,

$$V(t) = L\frac{dI}{dt}$$

I can evaluate,

$$I = \frac{1}{L}\int_0^t V(\tau)d\tau$$

where, λ is basically a dummy variable in order to integrate the voltage. And this magnetic flux is measured in terms of the weber and this is how you can see that the flow of current causes the magnetic field.

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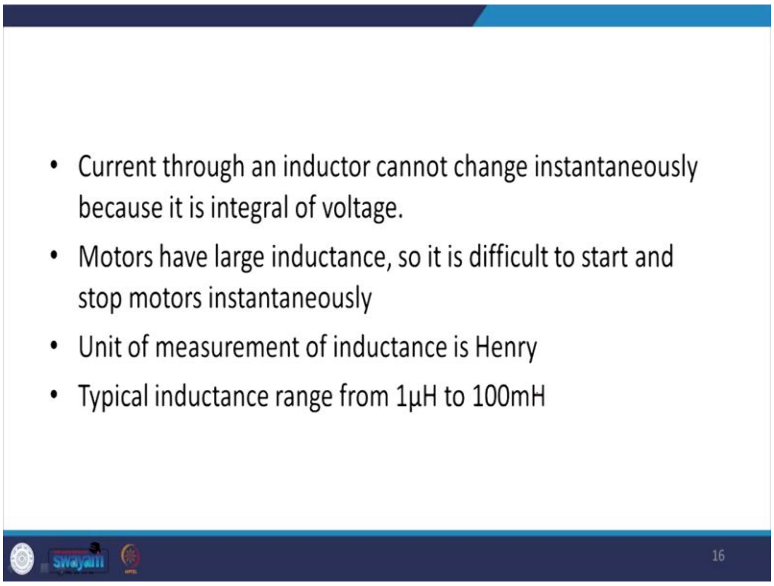

So, the current through an inductor cannot change instantaneously because it is integral of the voltage. So, here you can see that this current is integral of the voltage. So, this cannot be changed instantaneously and because of this, we have to look for a component which have high value of inductances and which are used in the mechatronics system; motor is one of such components.

So, if your motor has got large inductances, it is difficult to start and stop motor instantaneously and the unit for measurement of inductance is Henry and the typical or inductance range is 1 micro Henry to 100 milli Henry. So, these are the values.

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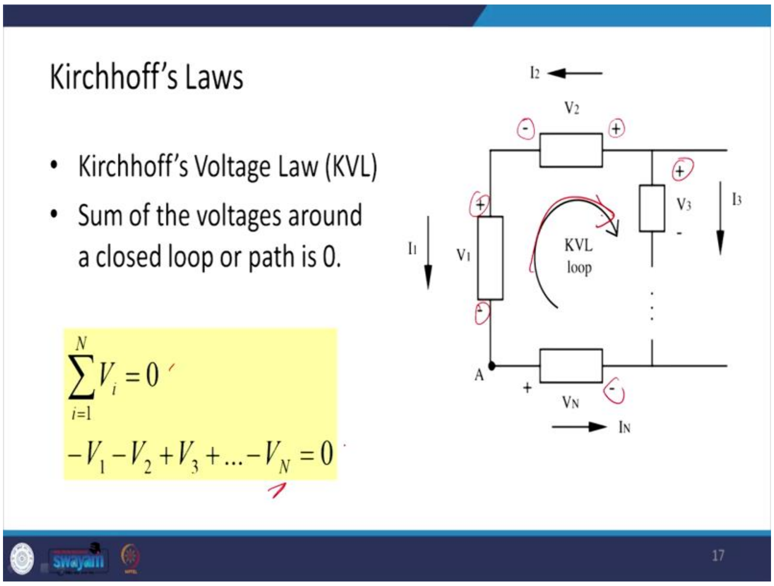

Next important thing is that how do we analyze our electric circuit? As I said we will be using these components to make our mechatronics system. Then, if we want to analyze this mechatronics system, say if you want to find out the voltage across some element or say we want to find out the current through some element, then how could we do that?

So, Kirchhoff's laws are very useful for this. There are two Kirchhoff's laws; Kirchhoff's voltage law which in short is called KVL and Kirchhoff's current law. So, we will see both of these. So, suppose I have got an electric circuit like this, now in this electric circuit basically what we do is that, we assume a direction of current and whatever elements comes across in that current direction, we can have the voltage drop.

So, we have a positive and negative here. There is a drop of voltage across these elements in the direction of current we can see over here and we can form a loop through all these components and then, we can write the Kirchhoff's voltage law which says that sum of the voltages across a closed loop or path is 0. So, if we have n components here, so

$$\sum_{i=1}^{N} V_i = 0$$

Now, how do we take care of the signs here? So, we can say here we can start from one of the component. So, here you have a negative sign. So, this is my loop direction basically. So,

$$-V_1 - V_2 + -V_3 + \ldots - V_N = 0$$

So, this way we can write the Kirchhoff's Voltage Law, KVL.

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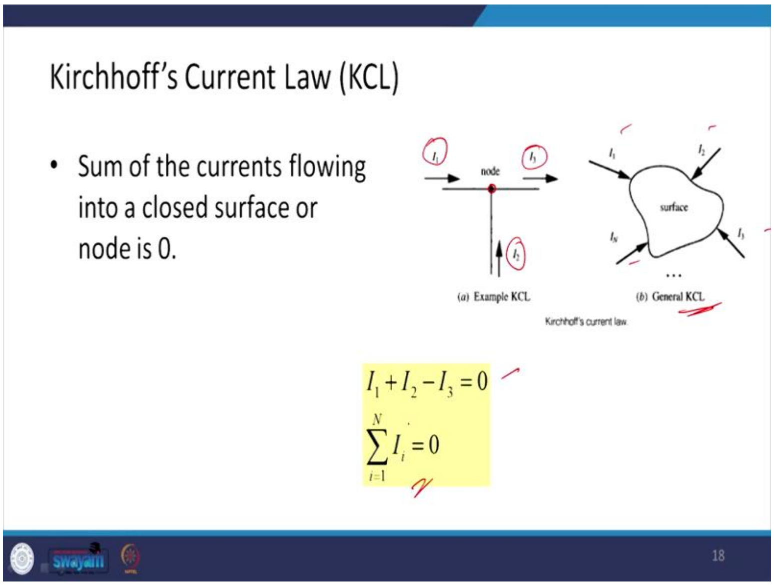

Similarly, the Kirchhoff's Current Law can be written as this, that is sum of the currents flowing into a closed surface or node is 0. So, suppose you have a node here and there is a current I 1 in, I 2 in and I 3 going. So, we can take the in value as positive and outgoing value as negative and we can write that Kirchhoff's current law.

So, for this node:

$$I_1 + I_2 - I_3 = 0$$

I am putting minus sign here because this is going out of the node and plus sign for these two because these current are into this node. So, this is there. So, if I have to write a general expression across a surface, various currents I_1, I_2, I_3 and I_N,

I can just write it like this,

$$\sum_{i=1}^{N} I_i = 0$$

So, this way we can analyze a circuit.

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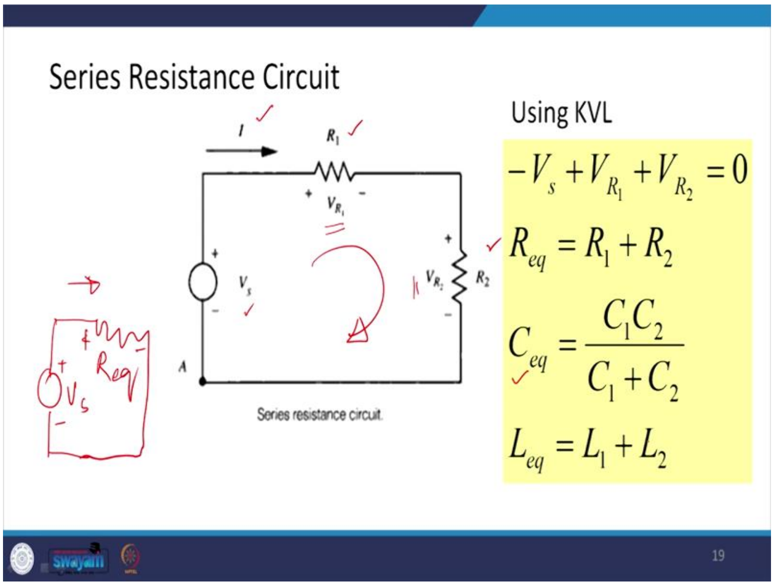

Now, if we have a series resistance circuit, consisting of say two resistors here say resistor arriving values R_1 and R_2. If we assume this direction of current, here say this is a voltage source. Then, voltage drop here is $V_{R_1}$and V_{R_2}. So, if I write the Kirchhoff's voltage law here, then you see minus V_s plus V_{R_1}, if I take this as the loop.

So,

$$-V_s + V_{R_1}+V_{R_2}=0$$

Now, if I substitute for these voltages V_{R_1} and V_{R_2}, I can find out an equivalent resistance which will be going to be,

$$R_{eq} = R_1 + R_2$$

That is, I will have a voltage source here and I will have equal equivalent resistance for this which I can say this is R equivalent and this is my voltage source. So, this way, this is my direction of current; so, this is my positive and this is my negative. So, this way I can write.

Similarly, if in this series circuit instead of resistance, I have the capacitance capacitor with the capacitance C_1 and C_2; I can derive this, ,

$$C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$$

and if I have in series the two inductors that is then I can write,

$$L_{eq} = L_1 + L_2$$

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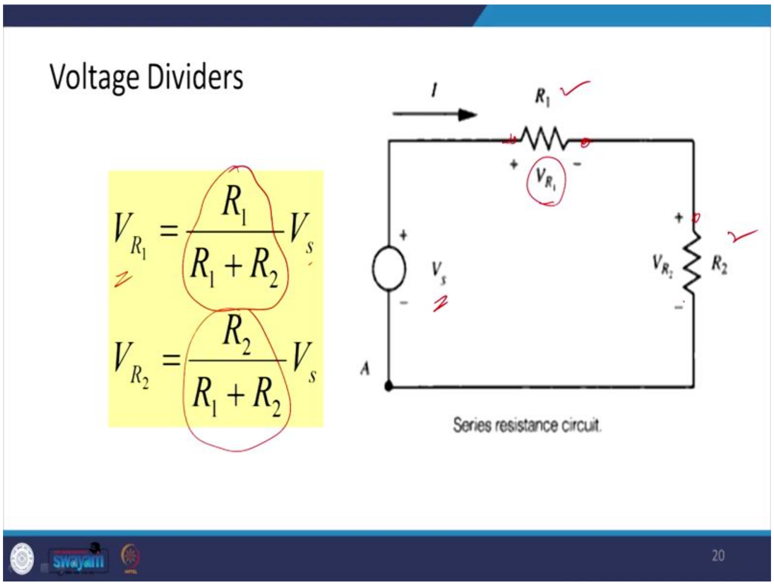

Similarly, I can use this concept in the voltage divider and that is very helpful especially in mechatronics system, if we have to take the power from, say across a resistor. So, in this voltage divider basically these register could be used as the elements which divide your source voltage. So, for example, the voltage across this,

$$V_{R_1} = \frac{R_1}{R_1 + R_2} V_S$$

Similarly,

$$V_{R_2} = \frac{R_2}{R_1 + R_2} V_S$$

So, again through Kirchhoff's law, I can use that and this basically means that I can tap a voltage from this one which is not V_S, which is multiple of V_S or fraction of V_S. Similarly, I can a take some voltage from here which is again a fraction of V_S.

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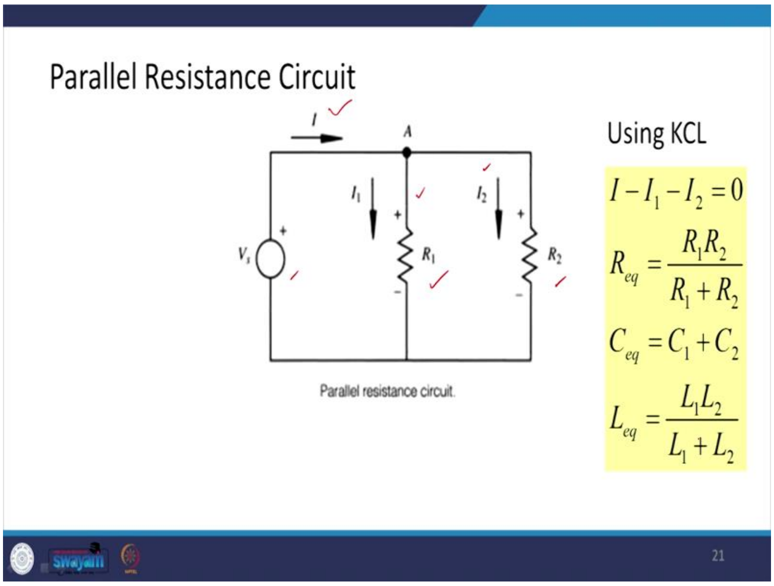

Similarly, we can find out the equivalent for the parallel resistance circuit. Here you have shown a parallel resistor circuit with say consisting of the two resistances R_1 and R_2. Let these resistors are connected across a voltage source here and let current through this circuit is I and this current is slit up in the two parts a current through resistor R_1 is I_1 and through R_2 it is I_2.

Then, if we apply the Kirchhoff's current law here, then we can see that I is in and I_1 and I_2 are out. So,

$$I - I_I - I_2 = 0$$

Now, if I apply Ohms law across R_1 and R_2, then I can find out the equivalent resistance for this one. So,

$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2}$$

And if I replace this resistor by capacitors,

$$C_{eq} = C_1 + C_2$$

And similarly, if I replace this with inductance, then I can find out the,

$$L_{eq} = \frac{L_1 L_2}{L_1 + L_2}$$

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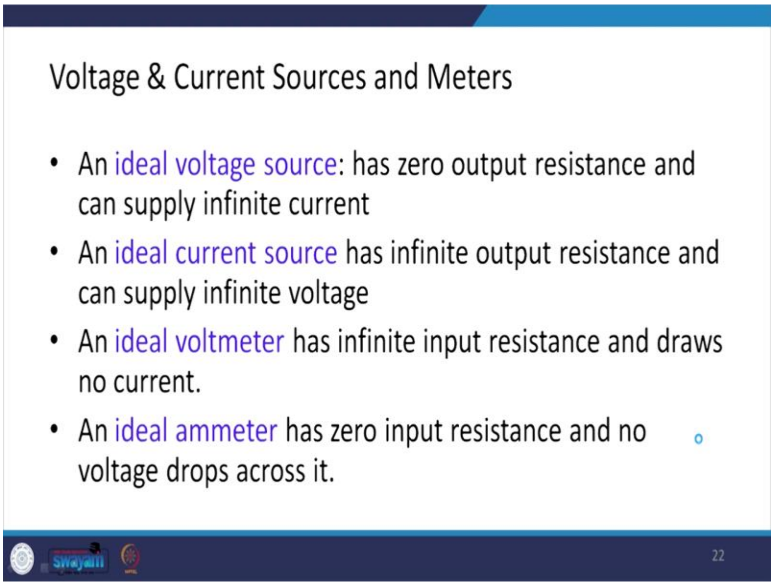

Now, we come across the voltage and current sources and meters in mechatronic systems. So, it is very important for us to understand some of the basics of these voltage and current sources and voltage meter and current meter. So, an ideal voltage source has zero output resistance and it can supply infinite current. Similarly, an ideal current source has infinite output resistance and can supply infinite voltage. These are assumptions basically and ideal volt meter has infinite input resistance and draws no current.

It draws no current so that there is no voltage drop. And similarly, an ideal ammeter has zero input resistance and no voltage drop across, it has zero input resistance and no voltage drop across it.

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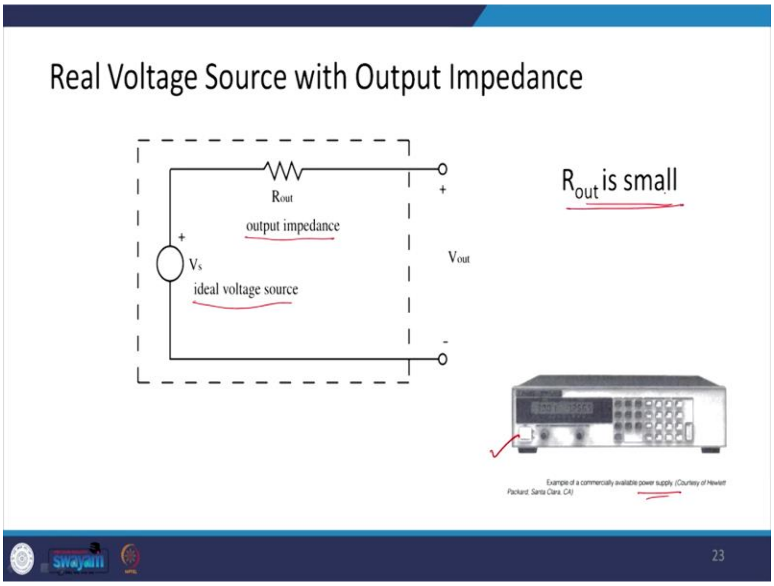

So, the real voltage source and output impedance, you can see. An example of the voltage source here commercially available power supply by HP is shown over here. So, the real voltage source can be represented by an ideal voltage source plus a output impedance, where we consider this output impedance to be small.

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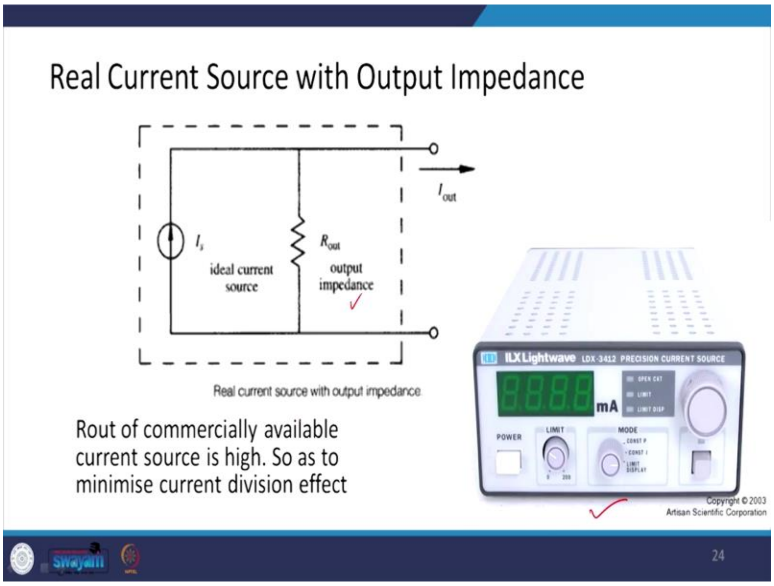

Similarly, the real current source say we have a real current source over here and with output impedance. So, this is how it can be represented by, and this R out of commercially available current source is very high to minimize the current division effect.

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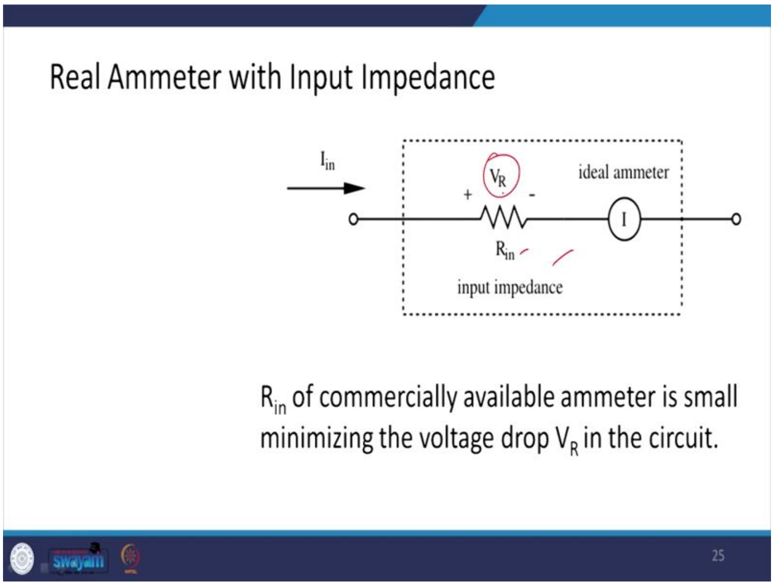

Similarly, the real ammeter with input impedance. So, we can see that the real ammeter is here and R in this real commercial available ammeter is a small for minimizing the voltage drop, V_R in the circuit.

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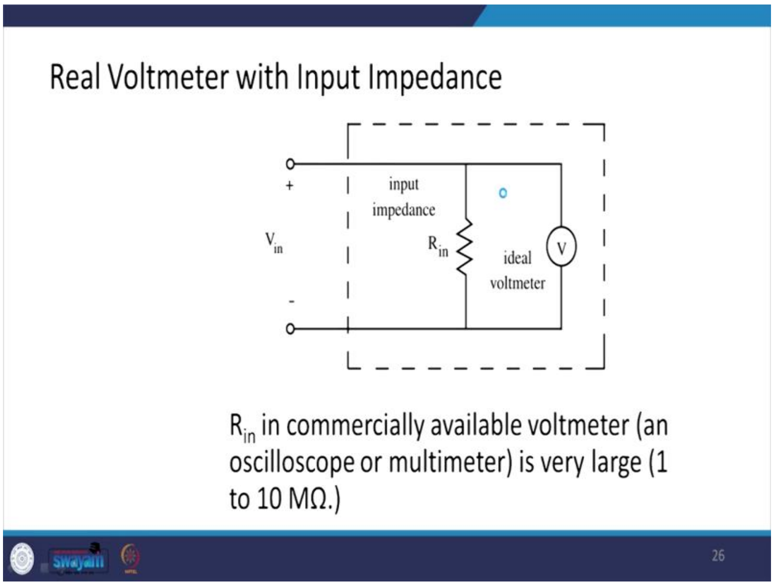

And we define real voltmeter here, ideal voltmeter with input impedance and this R_{in} of commercially available voltmeter is very large.

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So, these are some of the commercially available multimeters which can be used for the various purposes such as current measurement, voltage measurement, resistance measurement and so on.

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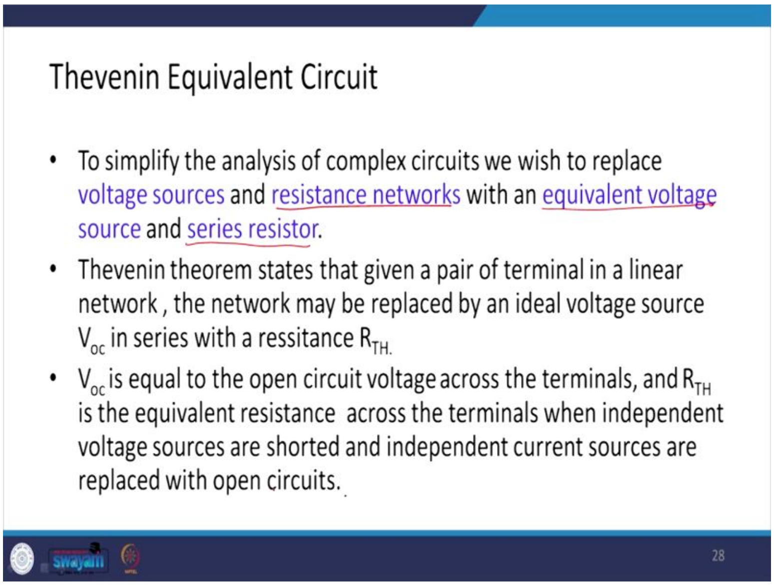

Now, to analyze the electrical circuit there are two more theorems which helped us in this analysis that we will be looking at; one is the Thevenin equivalent circuit and another one is the Norton one. So, let us see that. So, to simplify and analysis of complex circuit we wish to replace the voltage source and the resistance network with an equivalent voltage and the series resistor. So, along with the equivalent voltage, we put the series resistor. So, this resistance network is basically replaced by the series resistor.

So, the Thevenin theorem states that given a pair of terminal in a linear network, the network may be replaced by an ideal voltage source in series with a resistor. So, here V_{oc} is equal to the open circuit voltage across the terminal and $R_{th}$is the equivalent resistor's resistance across the terminal, when the independent voltage source are shorted and the independent current source are replaced with the open circuit.

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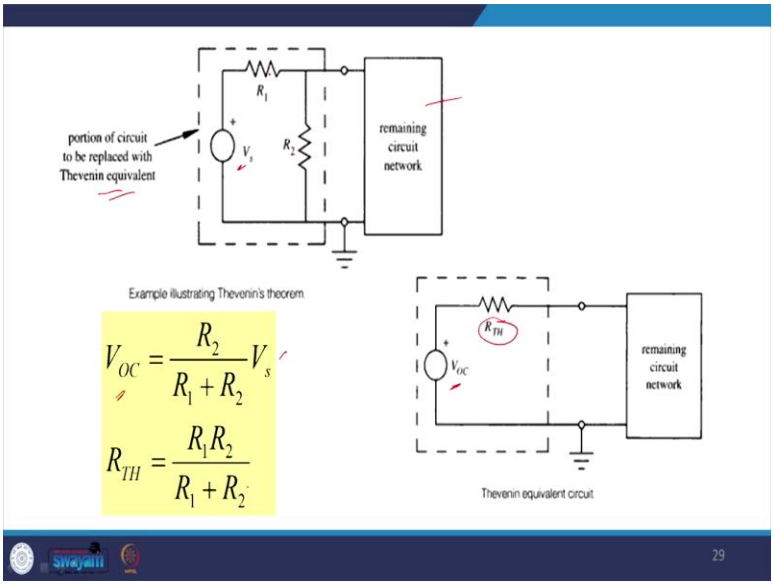

So, here we can see that suppose I have a source and there are two resistors, I want to replace this portion with the Thevenin equivalent. So, what we do is that we replace this with a voltage source V_{oc} and the Thevenin equivalent resistance. This V_{oc} can be given,

$$V_{oc} = \frac{R_2}{R_1 + R_2}V_s$$

, and

$$R_{TH} = \frac{R_1 R_2}{R_1 + R_2}$$

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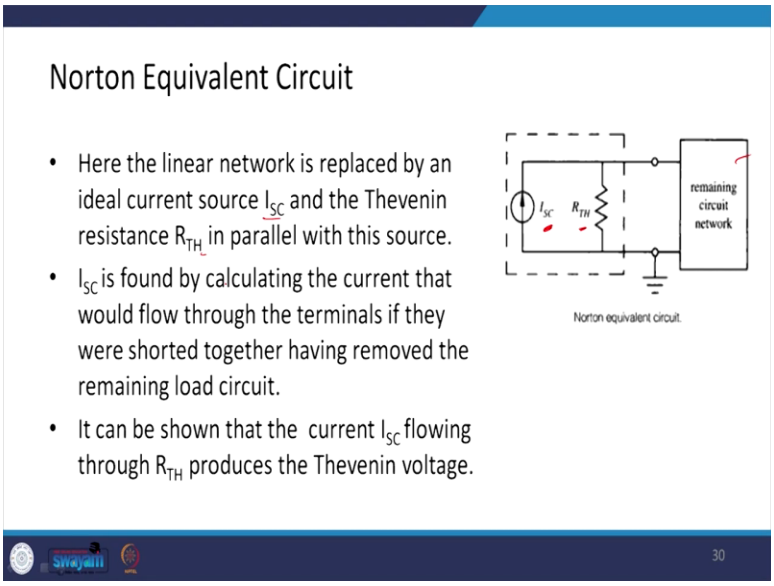

Coming to the Norton equivalent circuit, here the linear network is replaced by an ideal current source and the Thevenin resistance in parallel with source. So, Norton equivalent circuit will have the ideal current source and the Thevenin resistance in parallel with the source and here, you will be having rest of the circuit.

So, how this ideal current source is found? It is found by calculating the current that would flow through the terminal, if they were shorted together having remove the remaining of the load circuit and it can be shown that the current flowing through the Thevenin produces the Thevenin voltage. So, I am not going into all those details.

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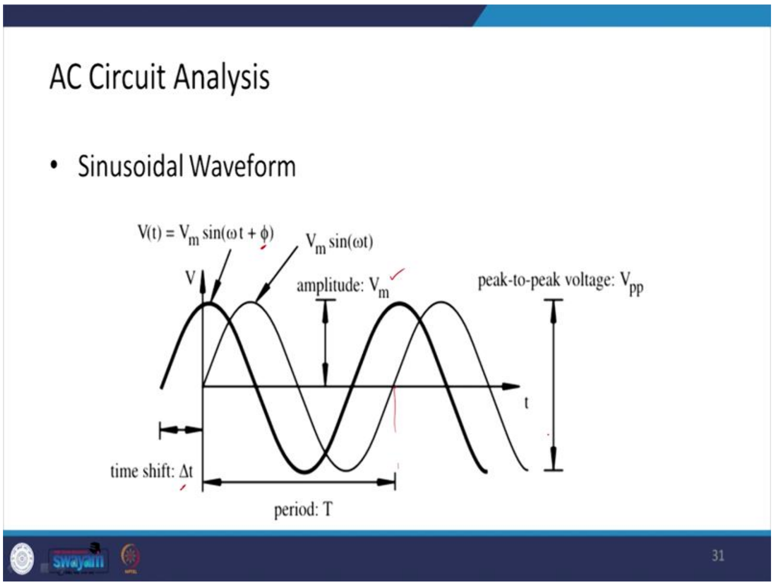

Next I will just talk little about AC circuit analysis and to this, I will be just talking about the sinusoidal waveform here. So, there are the two signals here and they are replaced with some phase shift say time shift Δt is there and the phase angle ϕ is there, then here the term is the peak, which we define from a horizontal axis to the maximum value is defined as peak and this is defined as the time for this one time period and there is a peak-to-peak voltage is there.

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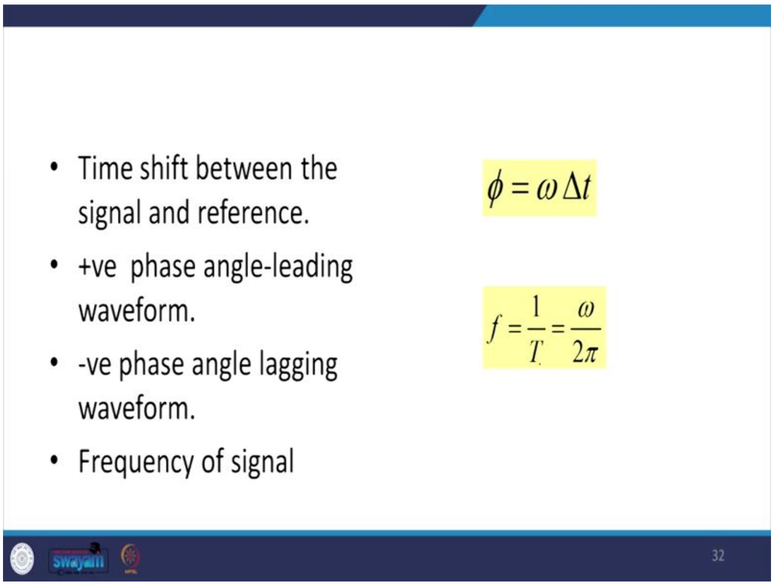

And the time shift between the signal and say reference, one of the signal could be reference signal that is basically $\omega\Delta t$ and the positive phase angle is what we call it as it is there in the leading waveform and the negative phase angle is there in the lagging waveform and this frequency of signal is given,

$$f = \frac{1}{T} = \frac{\omega}{2\pi}.$$

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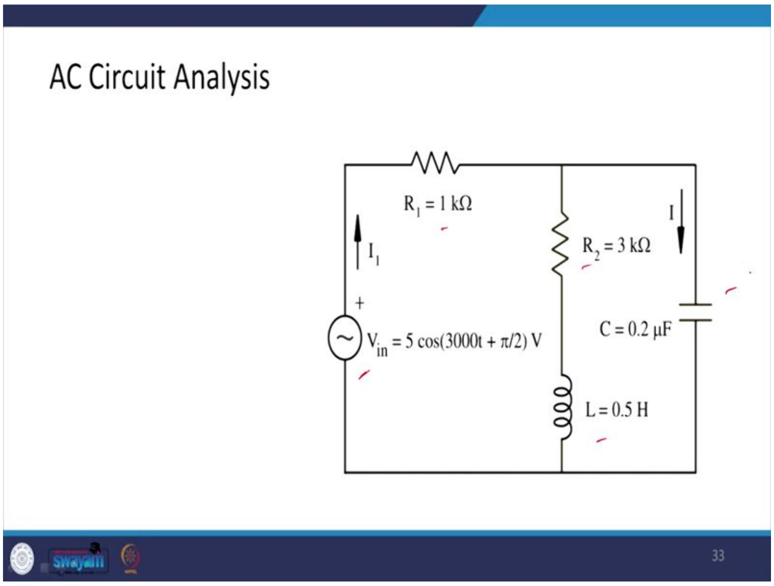

So, and our AC circuit analysis could consist of say a source here, then they have resistor, inductor, capacitor; so, all these type of elements could be there. So, we can carry out the say AC circuit analysis. There is concept of impedances which has to be looked into, which I am not taking it here.

Please have a look at it. In AC circuit, we have the concept of impedances comes which are analogous to the resistances in the DC circuit. So, that thing is to be taken care and then, this analysis could be carried out.

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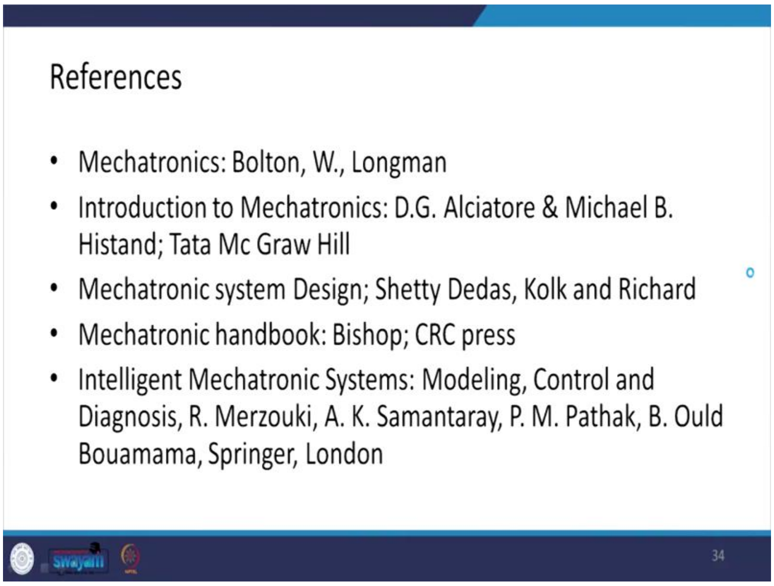

So, with this, I would like to give you a references. So, again these are the some of the common reference; the standard Mechatronics books, which you can look for further study. So, wish you good luck and thank you for listening to this lecture.

Thank you.