Indian Institute of Technology Kanpur
National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Applied Electromagnetics for Engineers

Module – 23
Why Electromagnetics?

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Hello and welcome to NPTEL mook can applied electromagnetics for engineer so far we have spoken of you know as we complete the first part of our course droughty one third into the total course duration we have talked about transmission line we have understood how to you know calculate the voltage at different points on the transmission line, we know what happens when a transmission line is excited by a voltage pulse or a stepped voltage we know how to match a transmission line to the given node or match the transmission line to a generator.

We know how sinusoidal waves propagate on the transmission line leading to the effects of phase standing when, when there is a miss match we have calculated input impedance as seen from the source using derived impedance transformation formula we have talked about reflection coefficient, we have talked about standing wave ratio we have talked about the lot of term, however if I remember correctly we have not really talked or introduced word such as electricity magnetism charge density.

Current density modes we have not talked about these words right or we have not talked about columns log Gaussian law faradize law Maxwell's equation, boundaries conditions these are the terms that you would normally associate with an electromagnetic course when we talk of an electromagnetic course these are the words that come natural to your mind and it could be very strange, that they have gone roughly one third into the course and we have no other mentioned these words before.

Now there was a very good recent while we did so, because the goal of this course is to teach you topics that are very relevant which can be immediately applied that is completely practical and something that you would all appreciate whether you are you know higher interest is in understanding the electromagnetics fields or whatever right, so most of you are familiar with computers micro controller FPGA is digital hardware some of you might be for you know going into specializing in.

Analog circuit design at very high frequencies so keeping this in mind and the fact that these effects are much more interior to observe air more very relevant not that others are not relevant but I am talking about a common platform for all the engineers so we decided that transmission line theory be the introduction to this course, however transmission line theory is not electromagnetics it assumes that someone has calculated by some means the primary constant of a transmission lines.

Such as RNC and G once the constants are given to you then it is your job to find the secondary constants, it is your job to find how the voltages are changing how the current is changing and then to analyze all kind of behavior of a transmission line, so at the transmission line theory when you are applying you do not actually get to know how the quantity such as L and C R and G are defined and in fact you do not even get to know what is definition of the except telling you that L is a circuit element.

Which we call as am inductor which maintains a certain relationship between a voltage across it is terminals and a current through it is terminals of course that is essentially what the transmission line theory is mass that is completely mass asking the physical picture of the inductor or a transmission line and that is kind of presenting to you an abstract picture in which the quantities are LCG are the only interested quantities for example, if I go back this quack see a line that we got to a quack CL line.

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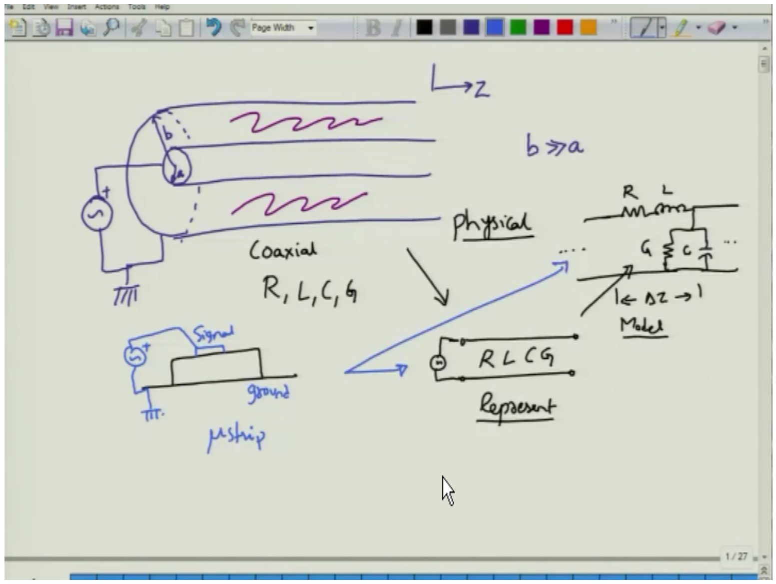

Let me go to a quack axial line and draw the quack axial line for you right so this is how the co axial line would look very, very inner conductor of some radius and there is an outer conductor of larger radius okay, so there is an inner conductor and on outer conductor of radius is and then this inner conductor and outer conductor assuming that they are quite uniform along this line can be considered to be extending along a particular line which we conventionally have denoted to be the z axis right.

So I ground the outer conductor because outer conductor is easier to ground compared to the inner conductor and if I want to apply a voltage you know I will apply a voltage by connecting the positive terminal of the voltage or the signal generator to the inner conductor, okay you can assume that the radius of the inner conductor which we can denote by A and the radius of the outer conductor which we denote by b are related in the sense that d is much, much larger than A so in reality if you look at.

A practical co axial line your essentially looking like you know a very, very thin kind of a wire inside and the surrounded by a fairly large diameter conductor, you can even fill the material inside the conductors with material of your choice this filling of the material accomplishes two things one it gives a protection mechanical protection to this system you know it gives the mechanical protection to this system, you know it gives the mechanical strength so that you can use the cable.

Connected to different points on your circuit and to it allows you to modify the speed with which this voltage is and currents are travelling inside the co axial line but you do not really get to see all this right so the moment we say co axial line and then we say okay this is what it is you will immediately ask based on whatever we have studied in the previous modules right, you will ask what is the RLC and G and if someone calculates this values to you then you replace this one so this is the actual physical picture right.

this is how a co axial cable would like more or less I am not looking at the micro surface roughness but I am just looking at a big picture kind of a thing when a macroscopic scale this is how it would like sp to you it simply looks like a finite length transmission line with values of R,L,C and G given to you right the model that you have in your mind so this is how you would represent so this is how you would represent this line.

So this is actually a quaxial cable but to you in the problem where you want to solve find out the voltage of the output given the voltage at the input you replace this quaxial line physical picture by this two straight lines which you think of a wires okay of course we are assuming that everything is uniform along the Z axis and the model you would have obtained RLCG from where you would obtain from this one which will be something like this

So there is inductiveness per net scale then your series conduct per unit itself and shell capacitor for a unit shell so this is the kind of a picture that you would have right so this picture of course continuous all the way to infinity this unit shell is a plenty Δz which eventually goes off to 0 therefore this parameters RLG and C are per unit length parameter for so this is the model that you propose where there as this is the physical picture and this is the representation on a piece of paper how do you represent a quaxial cable.

If replace a quaxial cable with the micro strip conductor or a micro strip line you would have essentially rep[resent a micro strip line okay so this is the ground plane for a micro strip and this is the signal layer here obviously I have to connect any voltage source in thus way so that the ground terminally is grounded and the positive potential or the positive terminal of the signal generator is connected to the signal layer of the micro strip line.

So regardless of whether you are considering the quaxial cable or a micro strip line your representation of that would be the same so you would still represent that one with two axis of lines which are suppose to represent the two conductor transmission line one for ground one for signal and the picture of RLGC theses values will be different.

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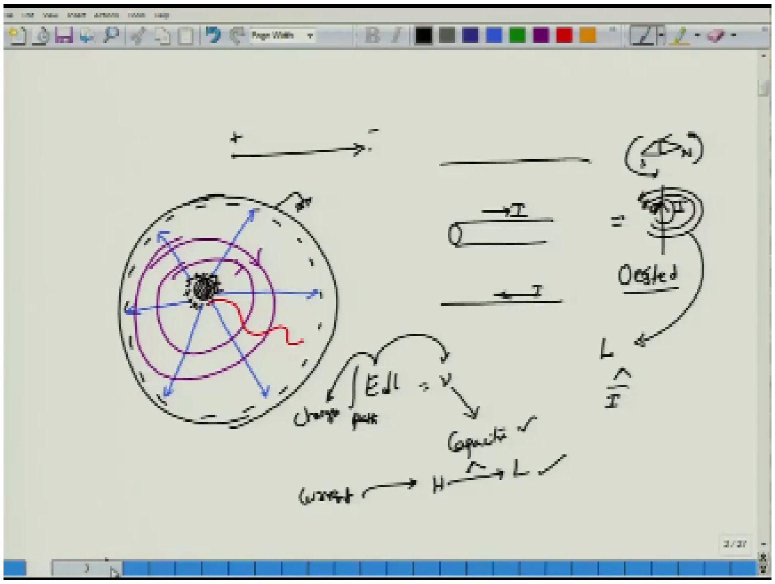

But the picture of RLGC will remind the same now of course it is not complete story because if you recall from your earlier physics courses suppose there is a charge right and there is another charge which let us say suppose it is directed there is something called as an electric field between them.

Why am I talking to you about this electric field and using this arrow and a length some were because if I look at the quaxial cable this is the quaxial cable which is made out of a conductor and it is the propagate of the conductor that there are an excess number of electrons in the conductor right surrounding this is a outer conductor which is also a conductor.

So for our case I m considering that this conductors are actually you know ideal round kind of cases but interactive there is not be there can be different but you have a connected a certain voltage to the inner conductor and the outer conductor is grounded which immediately causes a certain charge to be develop this charge will not be presented at the outside layer of the inner conductor.

But it would be rather regarding just below the inner conductor and there will be negative charges spread all over for a quaxial cable not to act or generate charges on its own the amount of total charges that are present on the outer conductor will be equal to the charges present in the inner conductor okay.

So this is what for someone how is coming from the physics background the corresponding cross section of the quaxial cable would look like and immediately for that person there will be electric field lines which would all eliminate okay from a positive charge and terminates on a negative charge correct so this is the picture that you would have also for someone realizes that this quaxial cable is carrying a current the outer conductor is carrying a return current.

But for now let us not worry about the outer conductor let us only worry about the inner conductor so if there is current I that is been carried assume that this cross section of the inner conductor is so small that I can replace this one by a straight wire carrying a current I okay so this current I could be dc current or it could be ac current.

Whether it is ac or dc current you know that surrounding that current carrying wire there will be a magnetic field right how do you know that because if you remember about 200 to 300 years ago or may be 250 years ago a person called oestard very interesting discovery he was presenting this in the class and then he had a magnetic compare some were and then he connected a current through a momentally a small amount of current through the wires.

And that cause the reflection in the magnetic compare so the magnetic compare that was present that was deflected so this deflection actually a very important thing right so this magnetic field was deflector indicating and we know that magnetic field exist because compares reactive magnetic fields so if there north and south pole of a magnetic compares got deflected. Then there must have been a magnetic field surrounding it and this magnetic field could have only come from the current that is being carried by this wire.

Because there was no other magnetic source is which had kept on the experimental table so he made this discovery which was later formulated into several norms according to hamper and then modified later by Maxwell but the critical point is that whenever there is a current carrying conductor there will be a magnetic feels of course this magnetic field will be related to a inductor because inductor is nothing but flex linkage associated with the current this are all concepts that you are familiar with your physics background and then if you look at the magnetic field lines the fields lines would be surrounding and they would be I know going in the direction that is given by the right hand thumb rule.

What is the right hand thumb rule suppose this is the way the current is carried okay, along the direction of pen then if you rap your thumb around a pen and then you are going around when your thumb is pointing in this direction then this is the direction of the current being propagated, and this is the direction in which the magnetic fields like this.

So if you look from the top then you are essentially looking at the top okay, in the form of a circle and then are this circular lines right, which form the magnetic field, so you have magnetic field around a current carrying wire you have electric field lines as we would call between the inner conductor and the outer conductor, so if you super impose this, this is how the magnetic field lines would look there should be circles the direction being given by the direction of the current that would I test, okay.

So this is what a picture for someone who has studied physics would physic and studied electrostatics and magneto statics and a little bit of concepts such as inductance and capacitance would look like. So we have talked of inductance capacitance is also sitting in this structure because I know that this electric field if I integrate alone any particular path let us say this is the path along which I integrate go from one point to another point.

I know that the integral of this electric field over that particular path will give me the total voltage change along that path, we will develop all this relationships are derived this relationship so discuss this relationships later on. But for now just understand that electric field gives you voltage okay, and of course electric field itself is caused by the charges and voltage to charge ratio is the capacitor.

Similarly you have current which act as the source to generate the magnetic field because integral of h dl will be the current that would be encompassed by that particular path and this magnetic field will be related to the flux linkages, why are the flux linkages you will get to the concept of so my current magnetic field and then it would related to the concept of inductance, right.

So you at least are able to find to two circuit elements, capacitor and inductor by going into this picture and provide this as inputs to the transmission line. Observe the way this electric field lines and the circles are arranged, the electric field lines are all going in this direction so they are all going radically like this okay, so they are all going radially and for each radius or for each direction you have actually surrounded them with the circle.

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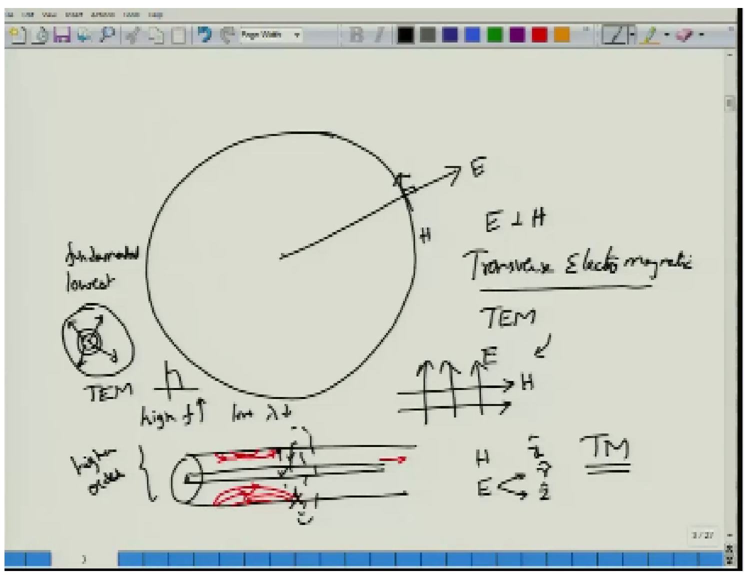

And the nature is that if I consider a circle here okay, and then I have a line which is radially emanating from that one at this point the corresponding vector we will talk about all this in just a few minutes, so there will be a corresponding vector here and there will be a 90^0 between any radial line that you would consider and the circle. So in other words, the direction of the electric field and the magnetic field are perpendicular to each other, okay.

At any point if you look at this one, at any point around the path that you take the direction of the electric field will be perpendicular to the direction of the magnetic field, okay. So such configuration in which each perpendicular to H is called as the transverse electromagnetic, so what we really have on a quaxial cable is not really a voltage and a current, but in the form of electric field and magnetic fields and these fields are what is called as transverse electromagnetic because electric field is perpendicular to the magnetic field, okay.

Another way or another pattern that we can call as TEM or TEM would be this thing right, so here you have electric and magnetic fields which are straight lines not straight and circle kind of a thing, this configuration is also TEM simply because electric field is perpendicular to the magnetic field at all points this is essentially true. If I go back to the quaxial cable and then operate this quaxial cable at very, very high frequencies essentially at very low wavelength so at high frequencies or low wavelength you would see that the electric field pattern does not remain you know radial but actually develops a certain XCL component to it.

XCL meaning the direction of the voltage propagation which was along the z axis that we have taken, the electric field lines will actually develop a certain one component along the path in which the voltage of the current is propagating, okay. Whereas the magnetic field still lies perpendicular to it, so you can imagine at the magnetic field lines are all coming out like this and then going in okay, so the magnetic field lines are all perpendicular to it.

Whereas the electric field line corresponds to a component along z axis, okay such a mode or such a pattern in which H is along the direction of the current which is along the direction z, whereas the electric field consists of two components one along the z axis and the other one which was the radial direction we will talk about all this directions in a moment. So this kind of a configuration is called as TM mode, TM standing for transverse magnetic, if we so of course this is not the one that would actually get excited first when you connect a voltage generator.

The lowest mode which gets excited when you connect a voltage source to the quaxial cable if till this radial and the circular combination are though so called transverse electromagnetic mode, okay. The one pattern that would be excited as soon as you connect a voltage source with minimal effort is called as the lowest or the fundamental mode of the particular structure and the fundamental mode of the structure for the quaxial cable is the em and all the other modes as called as the higher modes.

These are generated not yet without any effort but you have put a little bit of an effort. Example you have increase the frequency to the large values in order to observe this transfers magnetic mode in a quaxial cable. This mode takes out a little bit of energy, therefore corresponds to little bit the loss of the total energy that you have supplied. In fact the presence of the higher order mode is not desirable for a quaxial cable and it is the point which is what we call as the band width of the quaxial cable.

Any frequency below this band width will only excite the fundamental mode, the moment you go beyond this one you will start exciting the higher order modes. Once you excite the higher order modes, they will eat away a part of your energy and contribute to loss. So this is the TM of picture, that a person who has studied physics and the person who has experimented would probably see this okay.

So it is important to go back to the picture that we drew earlier right, the 1st picture we drew of this quaxial cable this is the physical cable that you have, there is no picture there is quaxial cable, which consist of inner conductor and outer conductor. You ground the outer conductor connects the signal source to the inner conductor. However a person who is looking at the quaxial cable or micro step plan a type of structure the corresponding way on which you look at will be to extract RLCG values.

And then consider no matter what kind of transmission line you are considering but represent that one by 2 pairs of line okay, which are space a small distance apart but the mental picture that they have in mind when they write this y axis that offers RLGC in the series under shunt admit ant configuration okay. so this is the picture no matter what type of physical transmission line that, we have consider whether it is or quaxial cable but for someone who has studied electromagnetic the picture will be different.

For them there are patterns of electric field there are patterns of magnetic field and these patterns electric field there are patterns of magnetic field cannot be arbitrated really, they cannot be arbitrated they have to follow Maxwell's equation and these patterns what we call as modes okay. It is just the geometric arrangement of electric field the magnetic field given these constrains of the problem. For example you do not expect the direction of electric field to be radial, simply because there is no circular conductor are there.

The conductor is plane and therefore electric fields lines will be slightly different okay, however as long as these electric field lines and magnetic field lines are perpendicular to each other in this fashion okay then the particular arrangement of fields is called as the transfers electromagnetic mode. In some modes of operations, in some range of operations electric field and magnetic field will develop an amount of axial component, which corresponds to the higher order modes and they can go into the name of transfers electric field lines and magnetic field mode.

In general when the structure has no symmetry when the structure in very general kind of nature, you will have combination, you will have a hybrid which both magnetic field will have a component and electric field and analysis of those structures and how to understand those, if the subject that is we are going to talk about now okay. Along this way about 20minutes of introduction, I have also spoken about certain things like vectors and I called certain vectors perpendicular to each other.

Certain vectors are not perpendicular to each other, what do I mean by all that is something I would like to begin now. So we will first talk about a vector very briefly a scalar, talk about how to represent those using coordinate systems and then spend couple of modules talking about the vector calculus or the vector field calculus okay. so refresh your memory.

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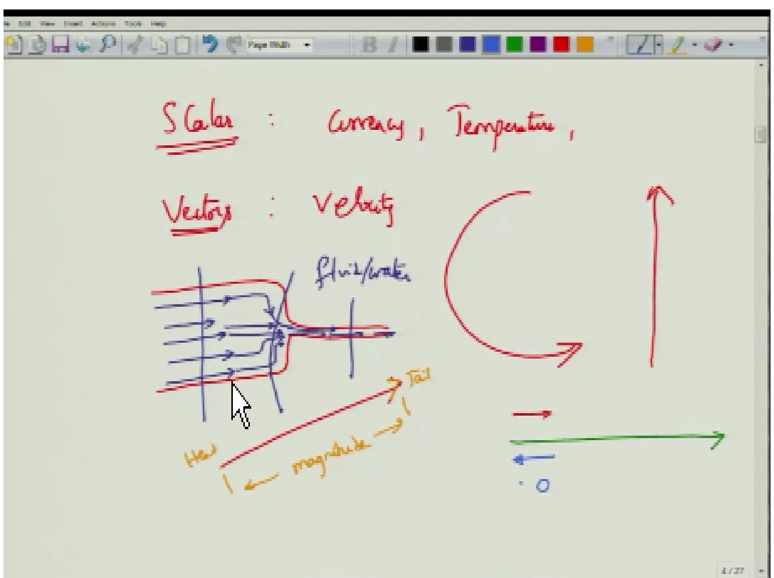

What is a scalar? Currency of a country is the scalar, why do I call currency of the country to be a scalar? Because when I buy something when I give money to this person I'm paying money okay, I'm paying let us say 20rs or 30rs. I'm not paying in the direction of north and I'm not paying in the direction of south, west. There is no direction associated with this currency, similarly when doctors take measurement of the temperature of the body they say temperature is about 100^0 faranite. They do not say 100^0 faranite along the direction 30^0 from the horizontal axis there is not direction or essence of direction associated to this quantities right. So in when you talk of these quantities which have no sense of direction but they can only this specified the numbers right.

Those quantities are called scalars, there are of course in addition to scalars a large body of quantity is which demand not only to specify the number okay that also to be specifying the direction. I say the speed of the car is 30m/s so that is no problem with it, however if say the velocity of the car is 30mper hour or 30m per s then you will immediately ask me what is the direction of this car.

Because I can have a car moving in the circle or I can have a car moving along the direction you know in a straight line or it can be moving from south to north or north to west east to west all kinds of probabilities are present right. So one example of a vector quantity is velocity okay, velocity has both sense of direction as well as the number that needs to be associated. Consider this kind of an arrangement kind of a funnel or something and let us say we fill it with water and water starts to flow.

So initially water is all flowing along this path in a very nice manner okay, but will it comes to the valves it has to change direction because it has to go to the valve and of course cannot go in the same direction, so it changes it direction so all these lines will similarly change direction and then they would propagate. You notice that the velocity of the lines here would be different the velocity of the lines here are different the velocity of the lines here are different. Not only the numbers are different but also the sense of direction in which the water of the fluid is flowing itself is different.

So there is sense of direction to the fluid or water movement inside a pipe and that forms another example of a vector okay, geometrically we represent a vector by the straight line so we represent the vector by a straight line the length of this vector gives you the magnitude of the vector okay. So the magnitude of vector gives you the length of the vector or in this case that essentially the same and the orientation specified by the arrow okay, arrow being the tail and this being the head of the vector this will tell you in which direction this particular vector is arranged okay.

For example this would be the direction of a vector it is vector whose magnitude a small whereas along the same direction this is the vector whose magnitude is large okay, this is as vector whose direction is opposite to the direction of the red one okay, and this is a vector which is a point vector or a 0 vector okay.

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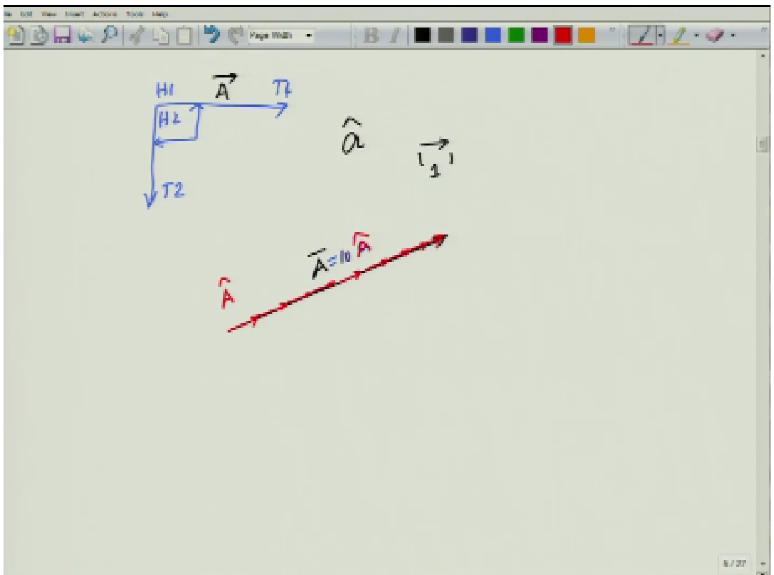

We say two vectors are perpendicular to each other because geometrically when you look at them those two vectors and arrange them in the fashion such that head of the first vector tail of the first vector head of the second vector goes in to the head of the first vector and the tail of the second vector is at this point. If the arrangement geometrically looks like this with the angle between the two vectors then these two vectors are called perpendicular vectors.

The further denote a vector by a capital vector or a small vector but then there will be a arrow on top of it in order to describe that this is the vector you can also sometimes see else writing a hat on top of it this hat signifies that there is a vector whose magnitude is equal to one unit okay and direction is in a particular given direction.

Any vector can be thought of has been composed of this unit vector because we can actually describe a unit vector along the direction of the vector so if the big vector was label as A and I use another notation to denote a vector I do not use an arrow but I just put a bar over top of it okay. Additional notation are to put an under bar you know there are lot of notations but I am going to use the notation which is slightly simpler I just put a bar in order to denote a vector okay.

And then I have this hat to denote a unit vector the unit vector will be denoted call the u it vector that I have denoted here is in the same direction as the big vector A and you can very easily convince yourself that the big vector A can be written as some number times the unit vector right, so it could be written as say ten times the unit vector because I can fit ten such unit vectors along this okay.

The number did not come out as ten but just imagine whatever the number that comes out will be the numbers that I am going to put okay. So this completes are extremely brief introduction to vectors okay from the next module we will actually discuss coordinate systems and then go back to vectors or vectors calculus okay. Thank you very much.

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