Computational Electromagnetics
CEM:An Overview
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CEM: An Overview
Lecture – 2.3
Different ways of solving them

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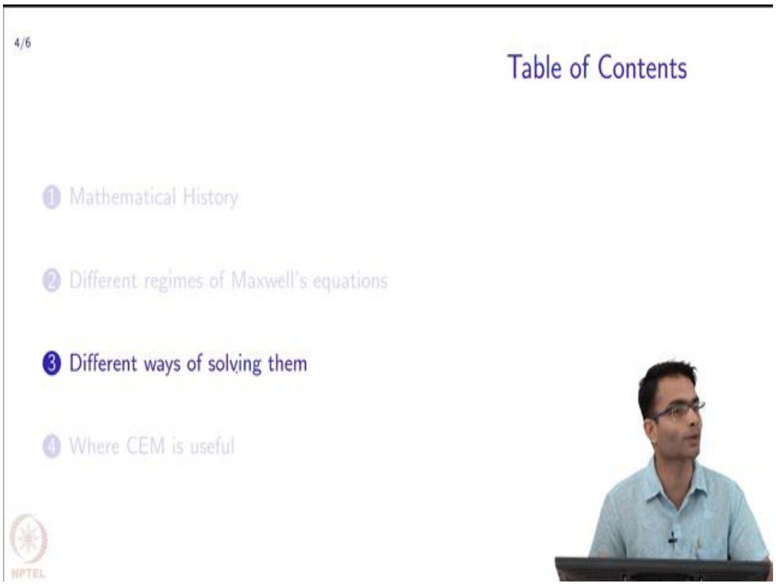

So, now let us look at the different ways of solving them.

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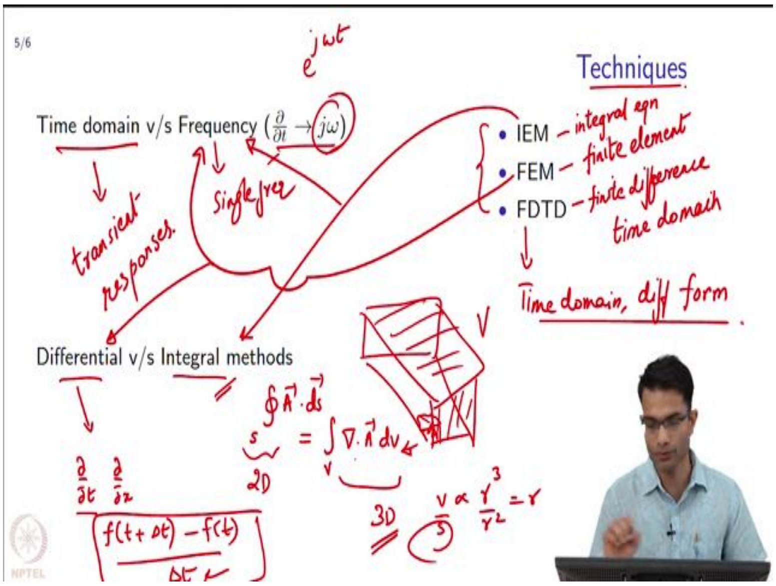

So, these are what we will call techniques ok. So, now, there are looking at the equations of Maxwell, you could solve them in let us say either the time domain or if you use Fourier ideas, you could solve them in the frequency domain ok. So, we will see what these are as we as we go along. So, the other way of solving them is by looking at what form in which Maxwell's equations are written. The form which I showed you at the start of the lecture was which form? Differential form right; they were partial differential equations ok. So, I can solve them directly in partial in that differential form.

There is another version of Maxwell's equations which is in integral form right. So, we can convert it to integral form and solve it that way as well right. So now which method to use when? This is really very important and hopefully at the end of this course, you will know which method to apply when. If you do not know that, then life becomes like that person who has a hammer; you know if you have a hammer everything, you see looks like a nail right. So, you learn one technique and you have not studied other techniques, so, you applied everywhere we do not want to do that.

So I will give you a simple example. Let us say I have a radar ok. Now, typically radars, they send a single frequency wave right its sending a single frequency, let us say our air traffic control radar. It is sending a wave is hitting the plane and coming back and by calculating let us say time lag or something to find out how far it is, but it is sending a single frequency. If it is sending a single frequency, then if I substitute you know the time dependence of this form, then d by dt becomes j omega. Then all my equations have only spatial derivatives, the time derivatives have gone. Since the time derivatives have gone, my pro life has become easier.

I do not have to worry about time derivatives. It is just become a constant number j omega so; I have to deal only with the space derivatives. So in that case so single frequency case, it is better for me to work with a frequency domain way of solving these problems; why make life more complicated. On the other hand; let us say you have a situation, where there is some transient response that you are interested in then you turn some switch on the some transient thing that happens over there. There what happens when I have a very short lived signaling time, what is the frequency content? Very large; it is spread out in frequency.

So, if I wanted to solve this problem in frequency domain, I have to solve for various omegas; then take the inverse Fourier transform and get the time response. So, that is like holding your nose this way. So, time domain methods would be better for that. Let us say circuit simulation you turn a signal on and you want to see how the wave spreads and things like that right. So, there we will work directly in the time domain ok. So, this is for example, transient responses ok.

Now so that is two different ways of looking at time versus frequency; the other aspect is differential versus integral. Now this may not seem very clear to you in this class, but it will become clear as we go along, but there are there are a few hints that I can give you. So, when we look at let us say the differential form, there is let us say for example, d/dt is everywhere and d/dt is everywhere ok. So, if you were to solve this numerically, what would you do intuitively? If there is a derivative and time and you want to solve it numerically you would.

Student: (Refer Time: 04:10).

No well because I am solving it on the computer, I cannot you calculate these derivatives analytically. So, I will represent a derivative and time by something like $(f(t+\Delta t)-f(t-\Delta t))/\Delta t$; finite differences that is how I will implement a derivative, similarly for the spatial derivative. So, when I do this chopping up off space and time into discrete things what happens is that, as a wave travels on a discrete grid it begins to disperse; you want the wave. So, physically I send away from here to the end of this room it goes like a wave, but when I want to solve it numerically I have to discretize chop up space and time of this finite segments. I cannot make it infinitely small otherwise the memory requirement will go to infinity. So, I take some finite distance.

And when I propagate this field, we will see in this course that that field begins to mathematically disperse,; physically its going in one direction, but mathematically because of this discretization it begins to disperse which we do not want. So, that would be an example where a differential method is not suitable. On the other hand, integral methods have a very beautiful theory within them which we will study which do not allow the wave to disperse.

Student: (Refer Time: 05:30).

So, if I have propagation over long distances, over there I say I should switch to integral equation methods. Now those of you who saw the review lecture on a vector calculus, there were two very important theorems. For example, the divergence theorem and Stokes theorem right; so, let us just write down divergence theorem. So, divergence theorem said that the flux of a vector field is equal to the divergence of I mean the volume integral of this right so closed surface this.

Now when I use integral equation methods; let us look at this over here, and let us say I have some volume v over here ok. So, some volume V. Now if I want to solve the system of this system of equations numerically as I said, we must do this chopping up into small dx dy dz dt. So, on the right hand side, I have to chop up this entire volume into small cubes right. That is what will happen.

So this is a 3D problem, but the same thing on the left hand side over here is only over the outer surface. So, this is a 2D problem over here ok. So, from a computational point of view, the advantage is that in an integral equation method what I can use theorems like this, to convert a volume integral into a surface integral. And you can imagine that for a given volume, the number of small small volume elements will become much larger than the elements that are on the surface right; surface area versus volume which one grows surface remains smaller than volume right.

So, let us look at what is the volume of a let us say take a sphere what is the volume of a sphere proportional to?

Student: r^3.

Proportional to r^3, what is the surface area proportional to?

Student: Square.

Square right. So as r increases, as I go to a larger and larger object which number is becoming larger volume is growing larger. So, this the cost of doing this is going to become more and more, because now a little cubes that make up that volume are increasing at a much higher rate than the surface area right. So, these kinds of tricks, they help us to save a lot of computational time right. At the end of the day you may have a very good method, but you want a solution that comes to within reasonable time you do not want to say, I have coded it I have, I will come back after one month and usually what happens after 1 month is you discover the coding mistake.

So, that is not what we want. So, that is why you will take use these integral equation methods ok. So, we will talk about all four different kinds of methods in this course and after you are familiar with all four, then you can choose for a given problem what is the best candidate. So, these are broadly the three methods that we will cover in this course ok. So, what is IEM? Its integral equation methods. So, integral equation methods; obviously, you can see that they are integral methods and usually formulated in the frequency domain ok. Then you come to FEM. FEM is?

Student: Finite element.

Finite element; so this is finite element ok. Any guesses, is it time or frequency? Those of you who are familiar with it is actually frequency domain again. So, it is frequency domain and it is a differential or integral. At least the TAs should be able to answer, differential it is in the differential form. And finally we have FDTD so that is finite difference time domain. Basically using this idea finite differences right; so, this as the word almost gives it away, this is going to be in time domain and differential form ok. So, depending on whatever is the problem at hand, we are going to use one or the other ok.

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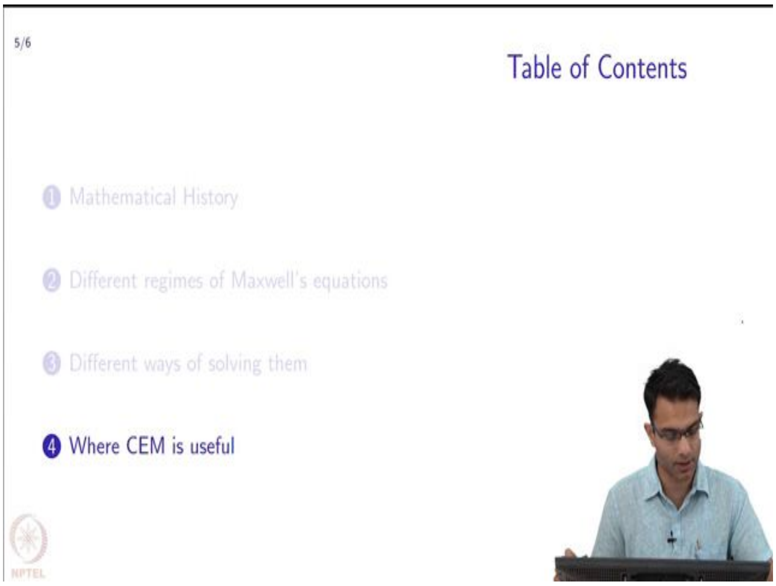

So, that sort of brings us to where is computational electromagnetics actually used where we you know where is it useful.

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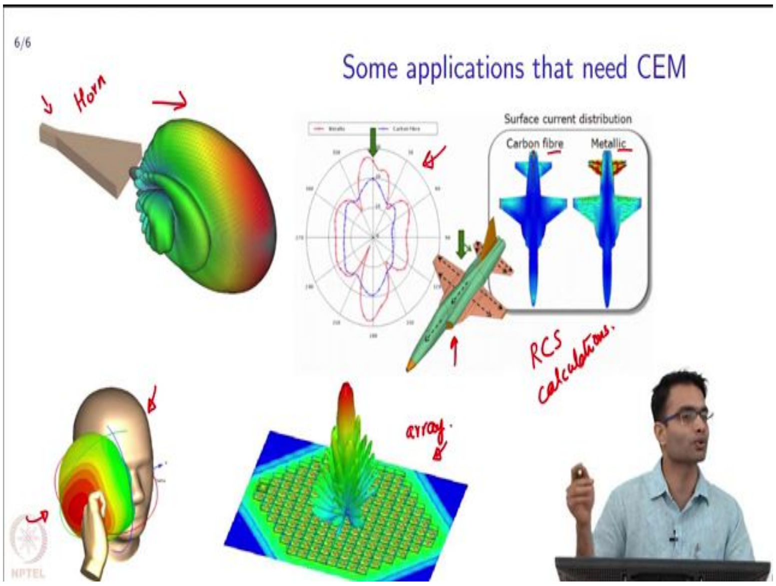

So, I have just put a few simple equations of pictures over here to show you simulation results. The credits page has gone from here these are taken from commercial software like CST, microwave and HFSS. So, for example, the first thing over here, this is can anyone tell me what is this; this structure over here?

Student: (Refer Time: 10:40).

It is a horn antenna right. And what is coming out of this is how is the electromagnetic field that is shooting out of a horn antenna what does it look like ok. So now, this is a simulation which was done to find out what the field looks like ok. So, now horn antenna is known but now let us say tomorrow for your particular application you build some other antenna. And, you want to know how does the field look like now you will be interested in how the field looks like, because let us say you know you have a communication problem I want to communicate from here to let us say that point and I want to make sure that no field goes to some eavesdropper on one side.

So, I have to make sure that this like this big beam over here is only in one direction not in the other direction. So, how will you know it? You have to solve Maxwell's equations numerically and get this ok. So, that is an example of an antenna pattern. Then here is another interesting example which in technology these days is becoming very important.

So, this is a collection of many many antennas. So, it is called an antenna array ok. So, any of you who are in working or interested in 5G, people will be using antenna arrays, instead of just a single antenna there will be an array of antennas which will be used to do beam forming MIMO and all of these things. So, how do you again same problem I want to you know send a beam here, but not that all of those things.

So, calculate the radiation pattern of on the antenna array, so you would use CEM techniques. The other thing for example, we hear about a lot is cell phone radiation damage to let us say biological tissue, is it true is it not true well, it is not fully clear. But at least one way to scientifically study it, is to build a, let us say, a model of human tissue. And then simulate a mobile phone radiation and then you can see: what is the maximum field generated can. So, scientifically you can say look so much field is generated if it is used for so much time. So, much it will be generated there may or may not be tissue damage.

So, that is one scientific way of doing it. So, this is a very active area of research. Lot of cell phone companies that is why employ computational EM people; because before they put a product in the market, they have to certify this produces so much radiation things like that. And then there are large amount of military applications so when computational EM started in the 60s, one of the major driving forces were military applications, that you want to make a stealth aircraft it should not be detectable by radar.

Now, if know that is the goal, but how do I make sure that it is not detectable? I simulate and show that the radar cross section is less or more. So, in this simple example what they have done is they have taken a aircraft and either made it out of carbon fiber or a metallic frame. And this simulation is showing you the electric fields on the surface.

So, they are different and therefore, the radar cross section is going to be different. So, this can be used for aircraft, ships any other such play missiles where it is needed to know: what is the radar cross section. So, this is RCS calculations ok. These are just some of the applications and we will look at more towards the end of the course when you look at applications of RCS.