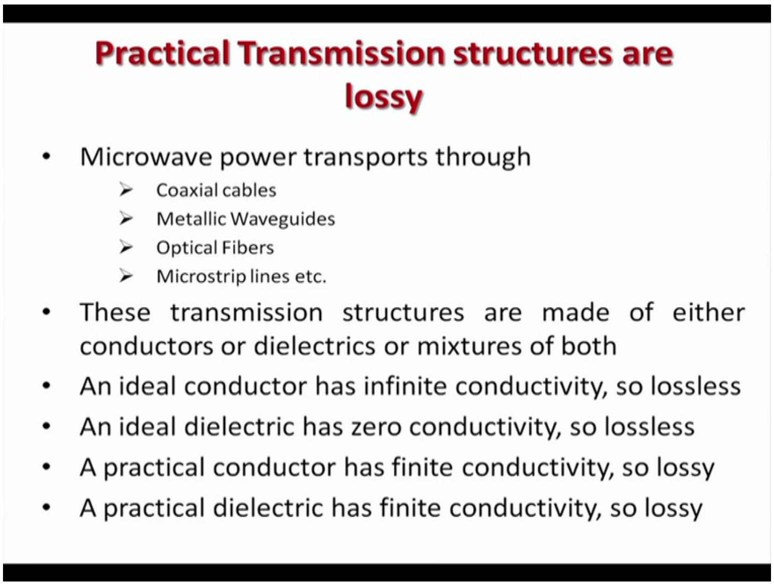
Basic Building Blocks of Microwave Engineering
Prof. Amitabha Bhattacharya
Department of Electronics and Communication Engineering
Indian Institute of Technology, Kharagpur

Lecture - 05
Losses Associated with Microwave Transmission

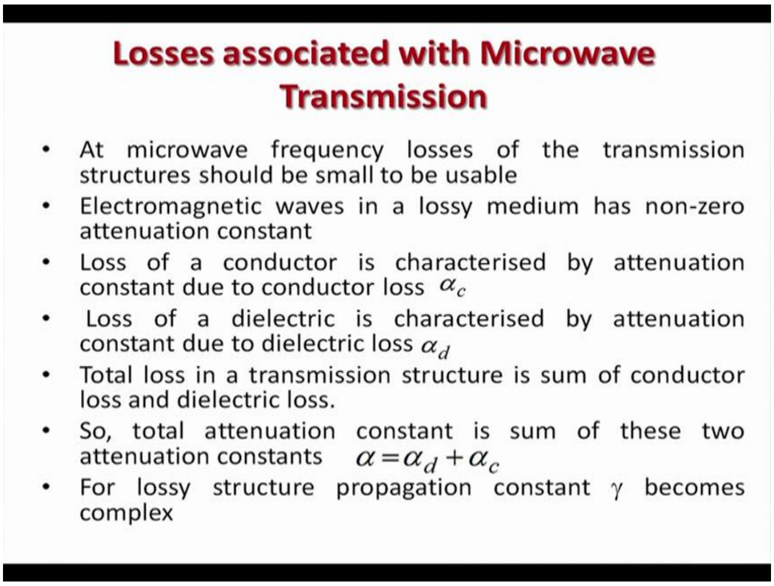
Welcome to the 5th lecture Losses Associated with Microwave Transmission. As we said that till now we have done with only lossless assumptions, but now any finite conductivity or departure from the ideal case that will give loss.

(Refer Slide Time: 00:47)



So, how to tackle and quantify that loss will be discussed in this lecture. Practical transmission structures are lossy, Microwave power transports through that is in Coaxial cable, Metallic waveguides, Optical fibers, Microstrip lines etc. This transmission structures are made up either conductors or dielectrics or mixture of both like coaxial cable you can have the two conductors that means, metals or conductors and then there are a R which is nothing but between the two conductors that is dielectric. Also, they are sometimes very precise coaxial cables they are made with dielectric cables. Sometimes, an ideal conductor has infinite conductivity so, lossless and ideal dielectric has zero conductivity but a practical conductor has finite conductivity, the practical dielectric has finite conductivity.

(Refer Slide Time: 02:00)

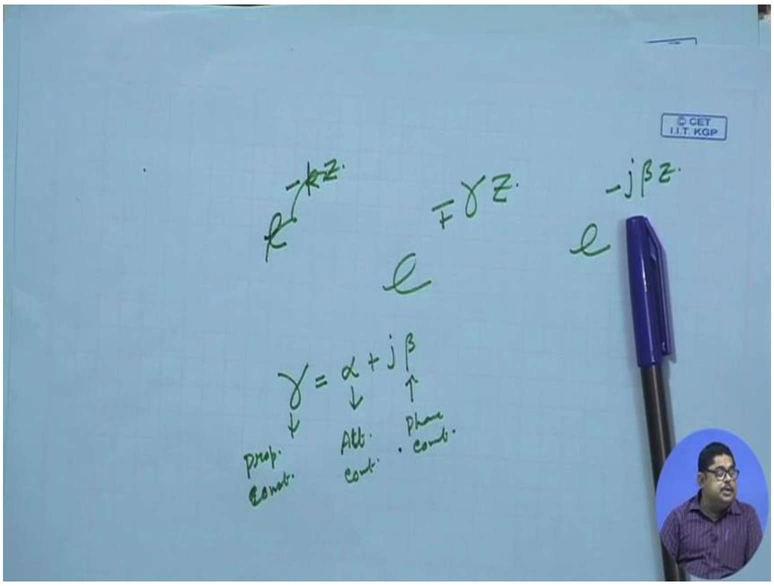


Obviously, at microwave frequency we choose transmission structures which have small loss, but now you see that day by day technology moves with higher frequency and all the applications like in earlier days satellite communication they were using some 4 and 6 gigahertz, but since the space becomes full they go to kehuband which is 18 gigahertz 16 14 and 16 gigahertz they used then they went to know still the thing got fields, so they went to bands where ka bands which is 20 gigahertz 30 gigahertz and now they are going to have w. So, as frequency is more you require this transmission structures and at higher and higher frequency then again which was quite easily used in our frequency and now at higher frequency if you go, the loss increases because we have seen that or we will see that this all things depends on frequency.

So, at microwave frequency you need to choose the transmission structure which gives you very small loss because microwave power etc those are very costly and you cannot afford to lose that power due to the loss. So, you need some mechanism to characterize or find out what is the loss and you see that our model that we have developed that we will we can find out fields in the any microwave transmissions structure or increase space and microwave transmission is taking place we know because all the signals they will be sum up either this TMT or TEM modes. We know the fields' structure.

So, from fields structure how we can find this losses that we will try to find here and electromagnetic waves in a lossy medium has non-zero attenuation constant because we know the generally we call any wave.

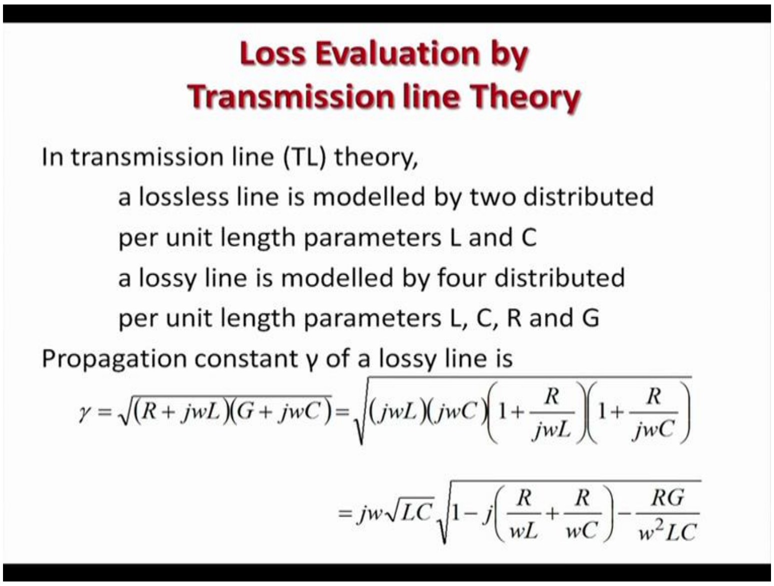
(Refer Slide Time: 04:25)



When it goes it has a variation called e to the power minus gamma z, if it is moving in plus z direction. So, we can write minus plus direction and now this gamma actually is alpha plus j beta, gamma is a complex quantity and for lossless case we know this alpha is called attenuation constant beta is phase constant, this is attenuation constant and this is phase constant and these are all (Refer Time: 5:08) theory classic we have seen and this is called propagation constant. Today, we have seen propagation vector k, this is propagation constant gamma and now in lossless case this alpha is 0. So, j beta that is why this you see in all our cases we have taken the field variation as the z variation of the wave the minus j beta z.

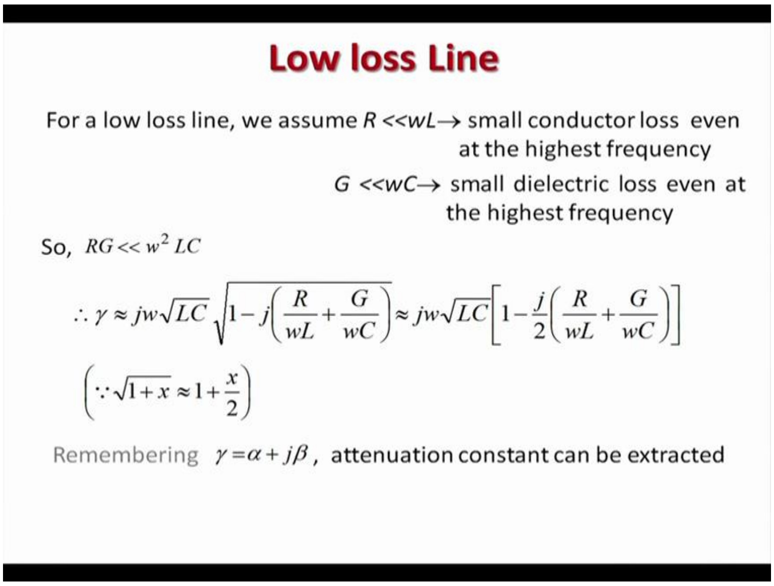
We have not anyway taken gamma, but if loss is present then we have attenuation constant and this attenuation constant for conductors we call that attenuation constant is alpha C and for dielectrics we call that alpha d and total loss in a transmission structure is sum of conductor power loss. So, power loss in conductor plus power loss in dielectric then attenuation constant also it is sum of two attenuation constants, one is alpha d another is alpha C for lossy structure propagation constant becomes complex that we have already seen.

(Refer Slide Time: 06:33)



Now, in transmission line theory we have learnt how to model a lossless line which is in a transmission line theory that means, where TMy will propagate, it is not valid for non TEM ohms, but there we have seen that you can have two distributed per unit and parameters L and C or you can say small L and C that means, some induct inspirers. So, you know that what is a transmission and model of that. Now, lossy line is modeled by four distributed per length parameter that means, two more in addition to a L and C you require and those are R and G and G is in shunt, R is in series with L, so A L and R together and G and C together.

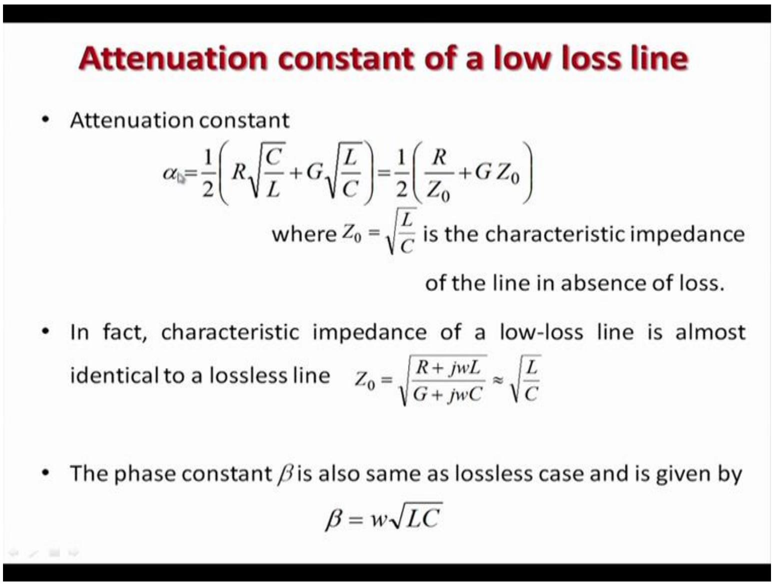
(Refer Slide Time: 07:48)



So, propagation constant gamma of a lossy line will become like this and we have seen in your transmission line classes that R plus omega L also like that if you do it becomes this. Now, for a low loss line because we will have to use it so, in our use it will be low loss line means small conductor loss even at the highest frequency.

So, omega if you take for highest frequency then R will be much smaller than omega L and with condition you will have to satisfy for a low loss line otherwise, it cannot be used. Similarly, small dielectric loss even at the highest frequency then G should be much lower than omega C to be usable that is why we will see that this coaxial lines they have when we will discuss connectors etc that the various coaxial lines they have certain frequency range. Above that this equation, this approximation does not hold good. So, we say that loss is too much, do not use that line, but up to the usable frequency this approximation will have to apply that loss is small compared to the actual work which is impudent should be omega L. So, we say that R should be much less than omega L, G should be much less than omega C. So, R G is how much? Putting that you see that the propagation constant becomes this and now this if you remember this gamma because of the loss, since we are assuming loss.

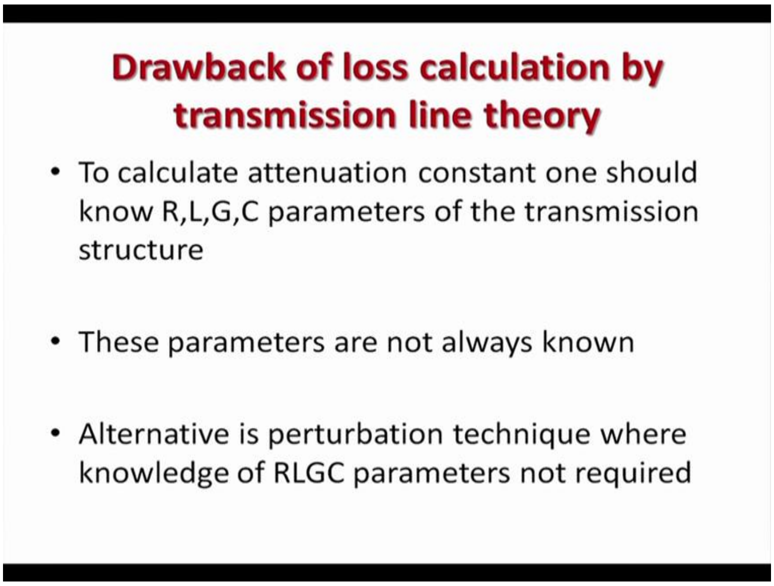
(Refer Slide Time: 09:42)



Alpha is the real part of this complex number. So, you see that here you will get a real part because this j and this j they will give you a (Refer Time: 09:39) and this part is the loss and that you can find out that alpha from that equation this is the loss. So, that is nothing but half R by Z naught plus this.

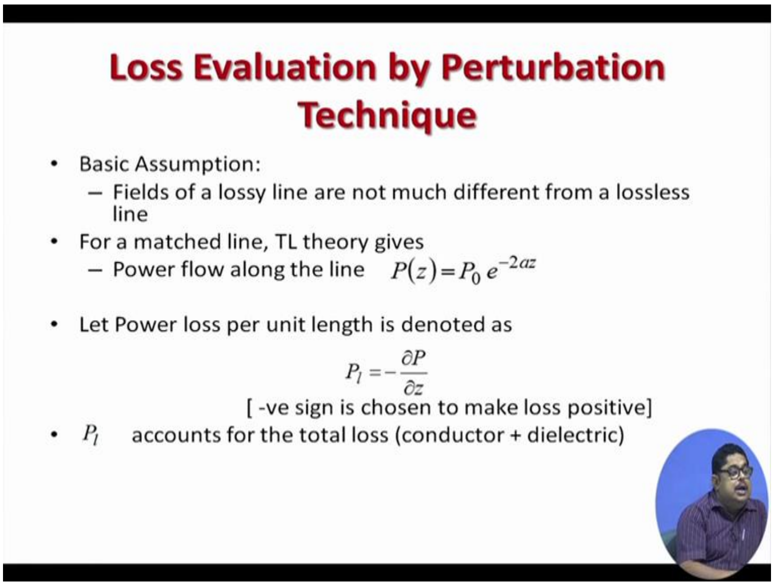
By this you can find that means if you know the R L G C parameter of the transmission line then simply you can find the attenuation constant of that, also you see that characteristic impedance of a line is almost identical to a lossless line. So, this is an important part, the second bullet it says that lossy line have an attenuation constant, but the impedance does not depend much on low loss lossy line. So, impedance is almost same that is why you see that with this approximation which you can show that lossless case we know this is the characteristic impedance and in a lossy case also it is same. Another fundamental quantity phase constant also same as lossless case and is given by this, you see L C that does not change with a. So, where from beta comes, remember where from alpha came, beta also came from the same source that gamma is equal to alpha plus j beta so, this part that means, an imaginary part is the beta phase constant.

(Refer Slide Time: 11:46)



So, this beta etc they determine again the impedance etc. So, phase constant also in the lossless case and lossy case are same, characteristic impedance are same and attenuation constant you can find and this is an easier route if you know R, L, G, C, but always this R, L, G, C are not known, distributed parameters are not always known. So, you need to find out a way to know this R L G C, you do this because this did not need any calculation of the fields, but if it is not known then we as an engineer should be able to still calculate the attenuation from the field equation because we know at least the fields and that technique is called Perturbation Technique.

(Refer Slide Time: 12:24)

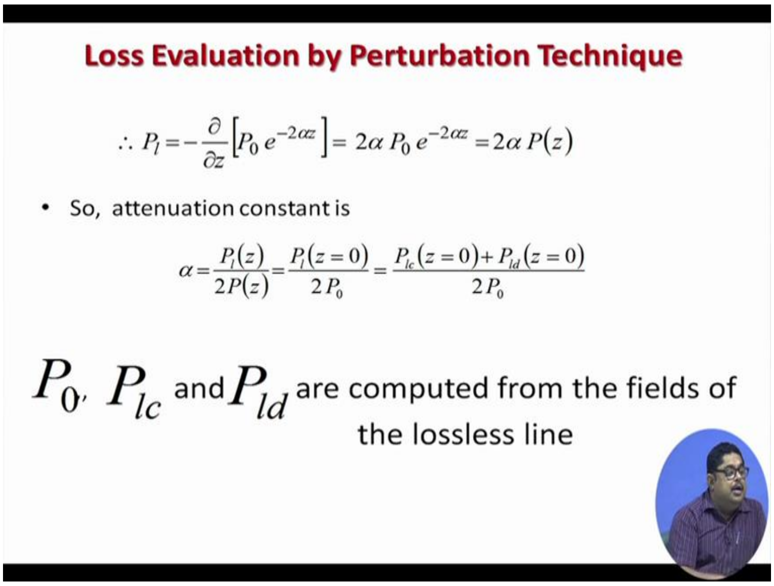


So, let us see that loss evaluation and basic assumption of perturbation means from the whatever we have seen we can gaze that fields of a lossy line are not much different from a lossless line because you see we have seen the fundamental parameters are not changing much, also we know that our main thing is the propagation of wave. So, loss we will have to keep they are minimum, also at such high frequency you see that impedance etc they are so high that to have some loss R G etc that will always be less because our frequency is very high and that is why microwave itself the lossy is quite small compared to other low thing, but still since very precisely if we want to see there are losses, but one thing we can say that the field is not much different and people have experimented and found that the fields they do not change much with loss, only some energy goes.

Now, with this assumption if we proceed we can calculate very accurately the loss that is taking place. For a impedance match line, in transmission line classes you have learnt that power flow along the line is given by P z power flow that e cross s star d s integration surface integration that is the power flow that has a z variation and if at z is equal to 0, the power is P naught then we have seen that it indicates exponentially with distance power flow and that is e to the power minus 2az and 2 alpha z, alpha is the attenuation constant, also that was power flow in a match lossless line and now we say that power loss in an lossy line per unit length let us call that Pl and obviously it should be defined as this del P by del z that is the loss.

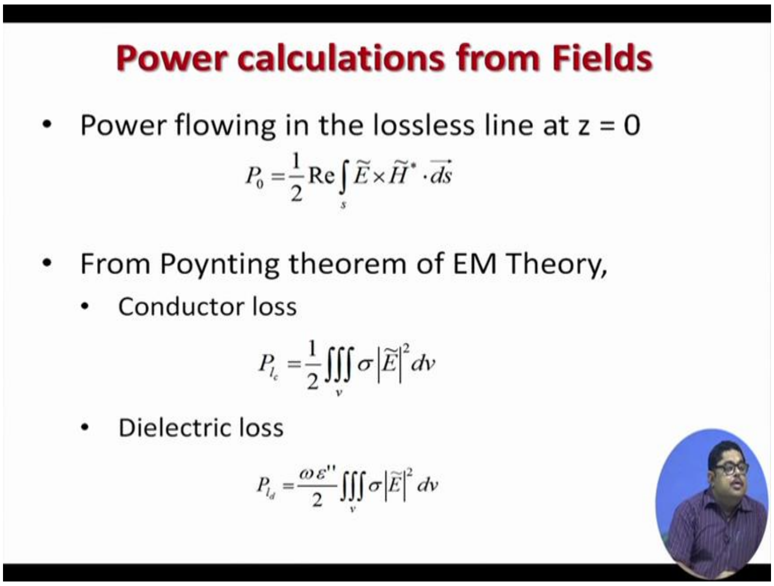
So, this Pl power loss, that is why we are not using any L subscript here, this Pz is the power flow and this is the power loss del P del z and this minus sign is chosen because you see that when we will take this minus will come because with this positive distance the power falls away obviously, because some loss is taking place. So, that is why this is minus and this Pl accounts for total loss that means, contributed by both conductor and dielectric. So, later this Pl will say that Pl will be sum of P L C conductor power loss plus P L D the dielectric power loss.

(Refer Slide Time: 15:59)



Let us put this del P del z, if we do that we get the alpha and alpha is nothing but Pl z by 2 P z. Now you see Pl z is equal to 0 by P z. So, this ratio we are taking specializing at z is equal to 0 then P L z 0 and P z z 0 already is 2 P0 and Pl again we are breaking into Plc plus Pld. So, if we can find the expression of this Plc Pld and P0 from the knowledge of our fields of the lossless line then alpha we can accurately calculate. This is according to perturbation theory which says the field does not change. Since, we have already evaluated fields we can find out P naught Plc and Pld and then put in this equation that will give us alpha that will be characterization of loss thus this done.

(Refer Slide Time: 17:07)



So, power flowing in the lossless line and z is equal to 0 is given by the Poynting vector and then surface integration. Now, this is Poynting vector and in EM theory there is a Poynting theorem, but it is actually we have given the derivation of Poynting theorem also from Maxwell's equation in our notes it is for your reference and we do not expect that you should know Poynting theorem, but if any later time you can refer it here, but from that Poynting theorem of EM theory, we will put it into notes from that you can see that we have shown that conductor loss is nothing but this expression that this conductivity as in the culprit for loss and then electric field fezzared E square that should be volume integrated that means, over the volume the loss is taking place if there is an electric field over the volume that can be found as conductor loss.

Similarly, dielectric loss is you see that this is the imaginary part of the complex dielectric constant actually this imaginary part of the complex dielectric constant that contains this culprit conductivity because E give raise to this so, omega into this and then sigma. So, dielectric loss is given by this and if we can evaluate this, it is easily said then we can find out alpha. So, we will do this that once we know the fields of any structure we will find the poynting vector then will take the surface integration of that with the one cross section surface and then take the real part of that and for time harmonic fields this half comes because of timer harmony cosines certain variation.

So, that we not will be evaluating conductor loss you see all the cases we are getting a half, this half is physically is coming because of our time harmonic field variation that means, time variation is half. So, over power is integration over time and that cosine always gives you over a time period it gives you half that is why all this are half and all this you see here we from electric field we can find the Plc, but this electric field remember it should be inside conductor.

Now, tell me an conductor generally we know that it does not have any electric field, but if there is a finite conductivity that electric field it percolates to a particular depth that is called skin depth, there is a field that field is called diffusion field in EM theory you have come across that. So, while evaluating this we need to find out this is not the field between the two conductors etc between the two or one conductor that means, in the dielectric not the field, it is a field that is going inside the conductor that is creating the eating and that is producing the loss. So, this field is the diffusion field because up to skin depth only and lower it is there, but we approximate that it as add down to 1 by e up to skin depth and that is why while evaluating this which is a tough job you will have to find the diffusion field starting from the exact field distribution there you will have to find what is diffusion field and find this loss.

Now, this loss finding is easy because this exist in the between the two conductors on the dielectric or if there is the whole structure is dielectric now through its volume the field is known. So, you need to volume integrate that and find out this field. So, and then this when you have a material dielectric you know its epsilon double prime which is nothing but coming from tan delta specification or loss tangent, you know loss tangent is nothing but epsilon double prime by epsilon prime and so that means, you know epsilon double prime omega is known, sigma is known and then you can find e square.

So, we will see this example in a tutorial class in tenth lecture we will try to do that. There we will have a tutorial where we will solve this problem for a coax that how to find this alpha because this is an important thing and we will see based on that when you use coaxial conductors you need to use or which conductor you will use. So, there will be various actually as higher and higher frequency needs to be supported by a coaxial line, nowadays you see we need to see various high frequencies to coaxial cables even suppose I want to see a pulse which is having a rise time of 20 30 picoseconds now 20 30 picoseconds means you know that it will have a very high frequency component.

So, I need to pass and see it in Oscilloscope. So, oscilloscope scope cable should be like that. Now, we will have to find that at such high frequency the gigahertz several gigahertz where 30, 40 gigahertz frequency what cable will use and what will be its loss. So, I need to characterize that. So, that unless and until I solve this case for a coaxial line I cannot evaluate this loss, based on that people are coming out with newer and newer coaxial cables which are going even the most modern coaxial cables are going up to 110 gigahertz. We will see that which is a interesting story that though we have saying that loss is small, though we are having perturbation theory, but that loss is not very small. So, at higher frequency if I go higher and higher frequency you have substantial loss then the cable cannot be used.

So, that is why people are bringing more sophisticated things and that is the importance of this designs and this formulas otherwise, this formulas mostly you do not know, but an engineer should know because he when today's technology will move to 110 gigahertz technology, he should know how to design a coaxial cable. So, that I can put power loss even to this they are minimum, what will be that attenuation constant for that what will structure I will choose. So, all this will help him there that is why that this power calculation from fields, once you know this you can put it into that this equation and this will be your thing. So, we will calculate the Plc, Pld, etcetera and then will see what the various connectors etc that will be using are.

Thank you.