Electromagnetic Compatibility, EMC
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Solution to EMC Problems - Electromagnetic Shielding (or Screening) - 1

Solution to EMC problems, electromagnetic shielding or screening, so this is module 5.3 Electromagnetic Shielding will be done in two parts, module 5.3 and 5.4.

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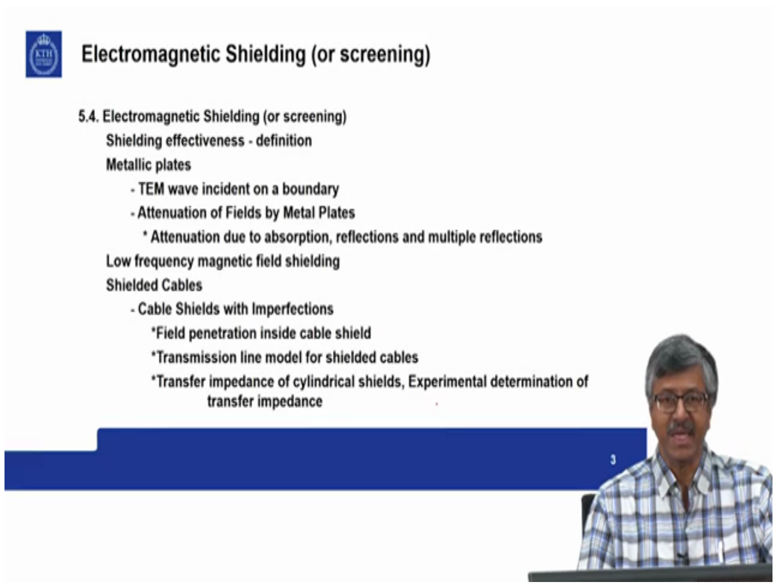

So these are the content of this particular section of the chapter: Shielding effectiveness – the definition of that concept metallic plates or TEM wave incident on a boundary. The equations will be derived then attenuation, low frequency magnetic shielding, shielded cables which are cable shields with imperfections. The concept of transfer impedance will be introduced. So let us go through the details.

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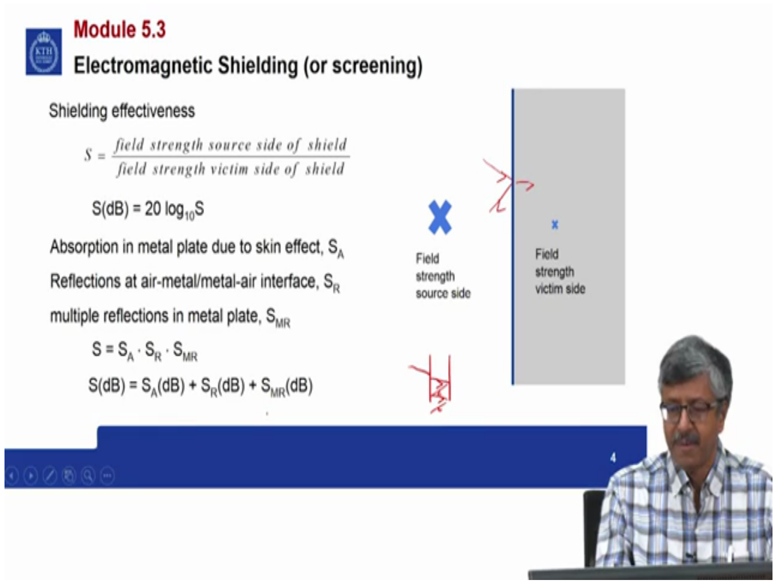

What is meant by shielding effectiveness? To cover here, so here this is a shield. Inside is the protected part. This can be part of a cabinet. So you want to reduce the field strength to a very low value compared to the field strength outside. Outside is source side and this is the victim side. Now shielding effectiveness is defined as field strength source side divided by field strength in the victim side. So if you have some shielding, then shielding effectiveness S will be always greater than 1 because on the outside it will be larger field, inside it will be smaller field.

So you want to have a number greater than 1. Logarithmically or in decimal it is defined as SDB equal to 20 log to the base 10 S. Now later it will be shown that this S is composed of three parts. One is absorption in the material of the medium of the shield. So it is over here. It is this material we are talking of, of the shield material. So that is S subscript A absorption. Then you have reflections happening from this shield.

So you can have, the wave will be indent and then it can reflect part of it and only a part will be going inside. So this reflection at air metal, metal-air interface, so that will be S subscript R. Then inside the shield, this is your thickness of the shield, you can have multiple reflections. So that part is called MR. Now SA and SR are positive whereas the one due to multiple reflection it will be negative. We will see the reason for that. So the total shielding effectiveness is SA multiplied by SR multiplied by SMR. And in decimals now this multiplications becomes plus.

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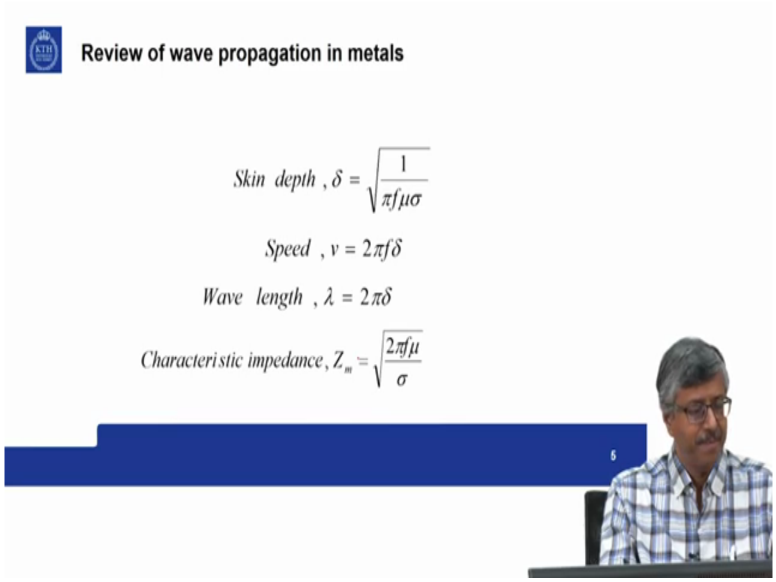

So we have seen in chapter 2 wave propagation in metals and we have introduced several concepts and those concepts will be used here. So for easiness of reference, I have reproduced some of important formulas. One is skin depth, it is square root of 1 by pi f mu sigma. So skin depth is inversely proportional to the root of frequency, inversely proportional to the root of material parameters like mu and conductivity.

mu is (permittivity) permeability, and sigma is the conductivity. Now speed of the wave inside metal is 2 pi f delta. Delta is the skin depth or omega delta. And wavelength is 2 pi delta. So you can see that when skin depth is very small for high frequencies, speed is less and wavelength is also less and skin depth is small. Then characteristic impedance of the metal is equal to square root of 2 pi f mu by sigma. So this is, higher the frequencies, you have higher characteristic impedance but still quite low value.

And here the mu and conductivity comes in numerator and denominator where both are in the denomination. So you can see that on the whole depending upon a material is magnetic or non-magnetic material or highly conducting or non-highly conducting, you get a very complex picture.

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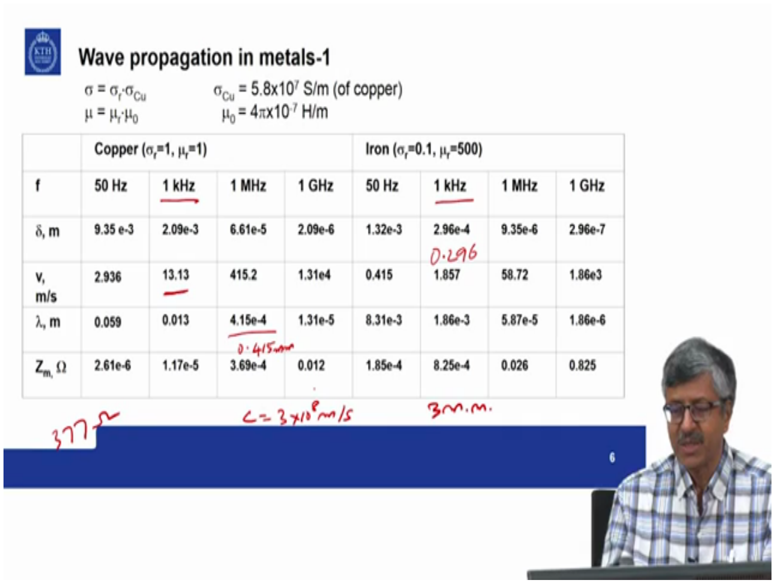

We have done this calculation also before regarding wave propagation in metals, conductivity of copper and relative permeability and you can express in terms of mu R, mu 0, mu R, mu copper. So here frequency, skin depth, velocity, wavelength and characteristic impedance of the metal are given for various frequencies for iron here and for copper here. So let us take a frequency of now 1 kilohertz. Now the skin depth is 2.09 millimeter for copper. So 1 kilohertz, we can see that skin depth is even smaller for that. It will be 0.296 only for iron.

And velocity is 13.13 meters per second. And what is the speed in air? So this versus 3 into 10 to the power of 8 meters per second. Therefore lambda is extremely small, 0.013 meters. So higher the frequencies you will have even smaller lambda. So here it will be say 0.415 meters only. Now 0.145 millimeters only so even if you have a shield of let us say 3 millimeter thick, you will have several wavelength already inside. You can see that the shield is appearing already at 1 megahertz as electrically long for these frequencies.

So for this reason we will make a big approximation, that approximation is that we can assume that the inside the shield it is almost like a TEM wave, transfer electromagnetic wave or a plane wave. And we can use that many of the concepts that we used, that we developed for the plane waves, for the shield also. The reasoning comes from this, we have extremely low value for lambda and even a resembling thickness of the shield can be electrically significantly long. The impedance is extremely small. The free space impedance is 377 ohm, compared to that it is fraction of ohms. So some of these properties we can notice.

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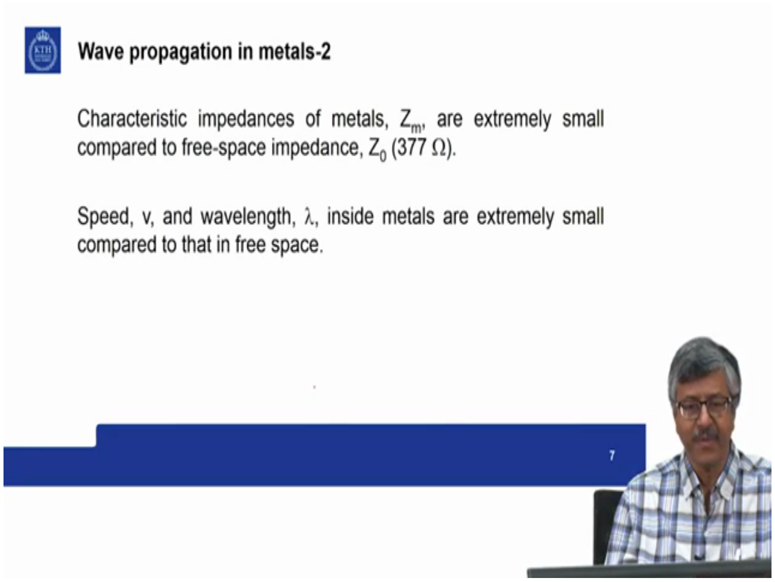

One characteristic impedance of metals are extremely small compared to free space impedance. Speed v and wavelength lambda inside metals are extremely small compared to that in free space.

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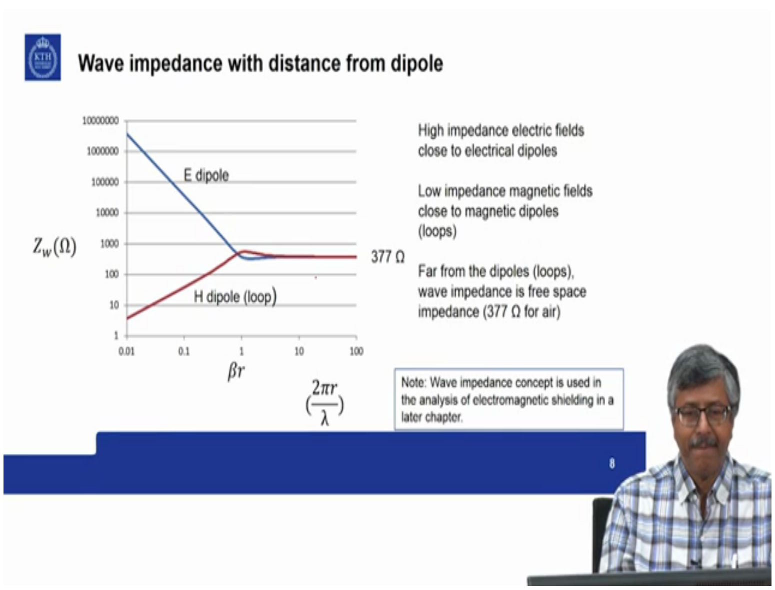

We have also seen wave impedance with distance from dipole because sometimes we can have a dipole just outside the shield for a loop. In that case we have seen how close to the loop it is high impedance electric field and close to the loop we have low impedance magnetic field. So high impedance electric field and low impedance magnetic field. So this is impedance and free space impedance will be 377 far from that. So this is in free space not in metal. So wave impedance concept is used in the analysis of electromagnetic shielding.

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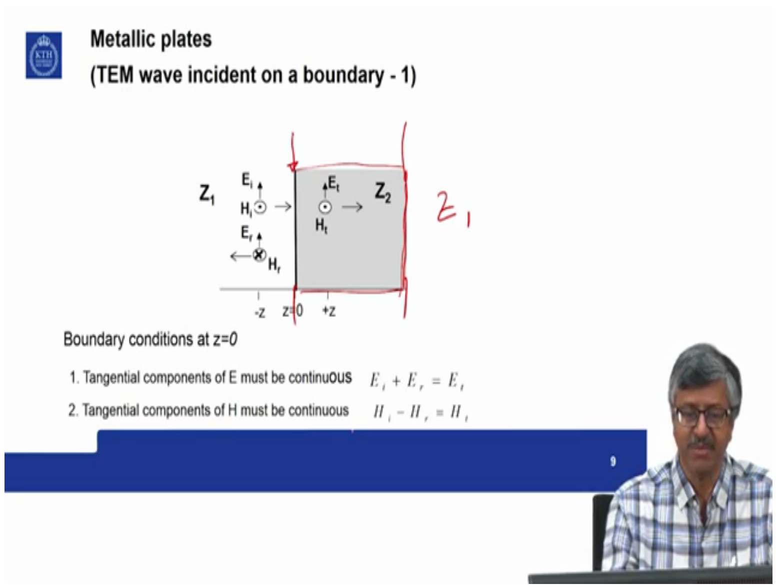

So let us look at how we can derive some of the equations. So metallic plates, this is the metal plate. So TEM wave incident on a boundary, now in a TEM wave we have seen that electric and magnetic field will be orthogonal to each other and orthogonal to the direction of propagation. So this is the direction of propagation. And for convenience, let us say E field is that up like this and H field is now coming out of the plane. Now after some part of it will be reflected at this boundary. Let us assume that reflector wave is in the same direction, ER. So this is the direction of propagation and that also is TEM.

And reflector magnetic field let us say is into the plane, opposite direction HR. And later the science will come out correctly that we will see it. Then inside this enclosure we assume a certain direction for ET, T means transmitted, I means incidence. R means reflector. So this has got an impedance set to. So then after that it goes into the other impedance. So this is the boundary of the shield.

The shield is surface, this is the shield this is just the boundary. And this is again Z1 when it is coming out. So this is the thickness of the shield. So boundary condition at z0 is tangential components of E must be continuous. It means that EI plus+ ER equal to ET. Then tangential components of H must be continuous. So based on the assumed directions, we can write HI plus+ HR, so we assume a negative direction, so minus- HR equal to HT. So these are the boundary conditions we have seen before.

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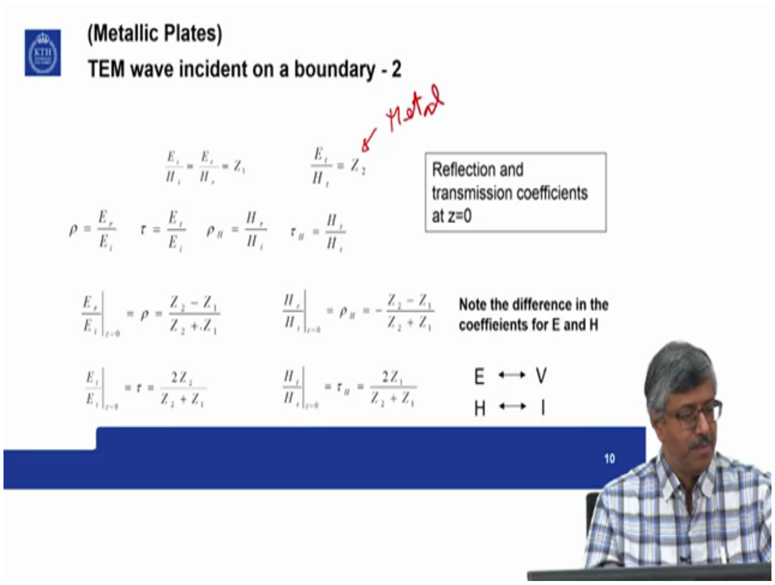

Now we can define Z1 and Z2. Z1 is the free space impedance, impedance in medium one, Z2 is impedance in medium 2. So this medium is metal. So EI by HI is Z1 and that is equal to ER by HR. So this is in medium 1. Now reflection coefficient is defined as ER by EI reflected by incident. Transmission coefficient tau is defined as ET by EI, transmitted divided by incident. And reflection coefficient for H, for magnetic field we write H to indicate that it is magnetic field. For electric field we do not use any subscript so reflected versus incident and for transmission transmitted versus incident.

So these at the very boundary ER by EI at z equal to 0, that is a reflection coefficient, you can write from the, since we assume that wave is TEM and inside the metal also it is TEM kind of wave even though it is attenuating, we can say that row equals Z2 minus- Z1 divided by Z1 plus+ Z2. That is difference in impedances divided by sum of the impedances. This is for the electric field. Already you can see that since Z2 in metal is extremely small, this is a negative number. And this will be very close to 1 also. So this will be very close to negative 1, minus- 1 but not fully like that.

Now for the magnetic field it is negative of this coefficient, difference divided by sum. Now for the transmission it is ET by EI, two times 2 by Z2 plus+ Z1. And for the magnetic field it is two times Z1 by Z2 plus+ Z1. So here the transmission coefficient is very different. Here in the numerator Z2 is a very low value compared to the denominator. And here it is Z1. Also we have a correspondent between E and V and H and I. So this correspondence is used to connect this with the theory on reflection of transmission lines that we have seen in chapter 2.

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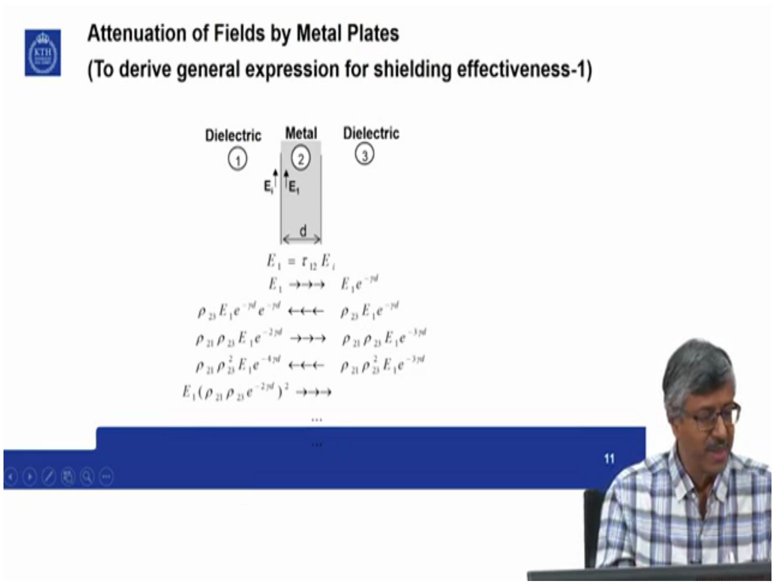

Attenuation of fields by metal plates now to derive the general expression for shielding effectiveness, let us make an attempt on that by tracing the wave all the way for several cycles and forming an infinite series and simplifying that. You can try this mathematics at home but here some of the important steps are given. So medium 1, this is dielectric, this is dielectric, and this is metal. EA is incident. Now here it is E1, D is the thickness.

Now just across this boundary, E1 this is the transmitted, after transmission this field just across the boundary, E1 will be then transmission coefficient from 1 to 2 times EI. So this comes from the definition of this transmission coefficient. Now this tau 1, 2 EI that is, or we denote it as E1 now, E1 is propagating across and as it is propagating it is getting attenuated. And by the time it reaches the left of this boundary here, you can say that it is E1 e to power of minus- gamma d, where gamma is the propagation constant.

So after this the wave will be reflected back, at least part of it. Part of it will go there and part of it will be reflected back. Let us look at what is getting reflected. Forget about what is going inside for now. That we will deal with in the end. So just look at what is getting reflected from this left boundary, sorry, right boundary but left side of the right boundary. So row 2, 3 is the reflection coefficient when a wave is moving from medium to 2 to 3, times this value, E1 e to the power minus- gamma d.

Now it is getting propagated. By the time it reaches over here, this has to be multiplied by e to power minus- gamma d because we have attenuation here. Now it is getting reflected from there. So you have to add row, the reflection coefficient is from row 2, 1. The wave is coming from boundary to getting reflected in this boundary 1. So row 2, 1 is this is multiplied with that is the wave going in this direction. So when it comes over here, again it is multiplied by e to power minus- gamma d. Now this is going back again, this is multiplied by row 2, 3, so you get square.

By the time it reaches here, you add e to power minus- gamma d. And by the time it is getting reflected, you have to multiply again by row 2, 1. Row 2, 1 here square. So the whole thing can be given in brackets and square it goes. So likewise you can follow it up like that. After that you add up all these things over here and all these things over here.

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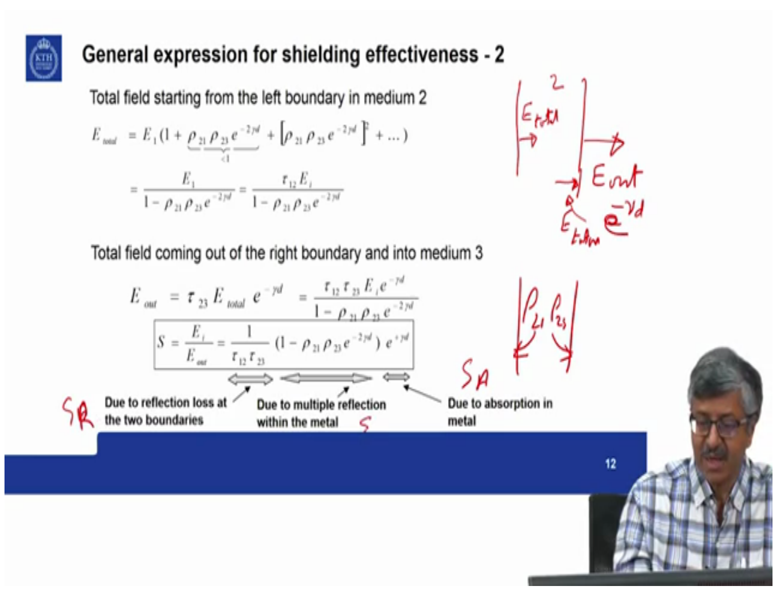

Then total field starting from the less boundary in medium 2, but finally after adding up all these things, so this field, total field, E total starting from the left boundary in medium 2, this is medium 2, can be written as E1 and this value square plus+, so likewise an infinite series you will be getting. So since row 2, 1 and row 2, 3 are less than 1, the whole thing will be multiplied by e to power minus- 2 gamma d. This will be less than 1. So you have an infinite series like this and from the tables on series you can simplify it as E1 divided by 1 minus- row 21, row 23, e to power minus- 2 gamma d. You can write it like that.

Now E1 we have seen before, is nothing but tau 12 EI, incident wave, so that you write. Then total field coming out of right boundary into medium 3, E out will be, now E total is travelling in this direction and by the time it reaches over here, it will be tau 2, 3 E total. This is what is reaching this boundary. Now this is what is coming out of this boundary but what is reaching this boundary is, remove this, E to the power of minus- gamma d.

So this is what is reaching here. Now as it is going out, it will be tau 2, 3, E total, e to power minus- gamma d. So you substitute E total from here into this, then you get this expression. So EI is appearing here. So what is your shielding effectiveness? It is EI by E out. So you get 1 by tau 1, 2, tau 2, 3 times this fraction, e to power of gamma d, because we have another gamma d over there. So you get 3 factors in the shielding effectiveness.

So the first factor involving two transmission coefficients at left boundary and right boundary. Tau 1, 2 and tau 2, 3 that is due to reflection laws of the two boundaries and this part, last part e to power of gamma d is due to absorption in the metal. And central part involving both reflection coefficients from inside 2, 1 and 2, 3. So this reflection coefficients are 2, 1, like that and 2, 3 like this. So this is due to the multiple reflection within the metals. So shielding, so this is SA that we have seen before, this is, sorry this is SA and this is SR and this is SMR. So we go to the second module.