Electromagnetic compatibility, EMC
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Solution to EMC Problems - Electromagnetic Shielding (or Screening) - 2

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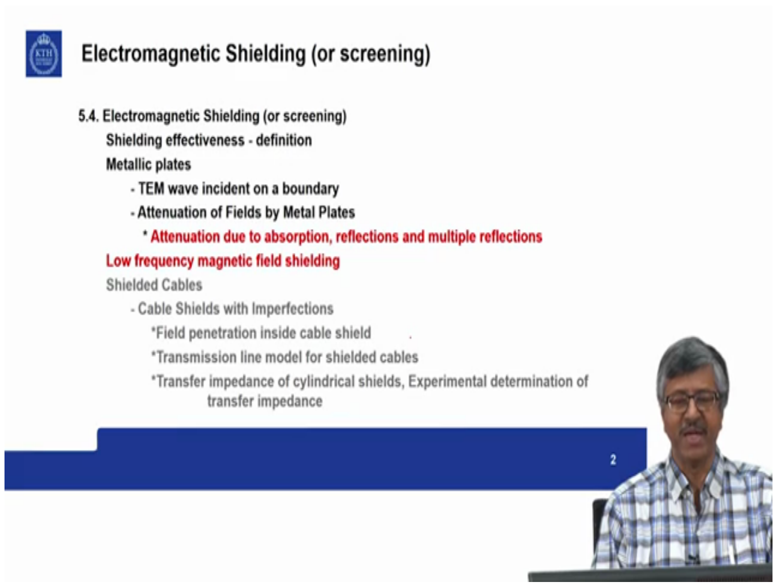

So we continue with electromagnetic shielding. So attenuation due to absorption, reflections and multiple reflections, the details we will see and low frequency magnetic shielding.

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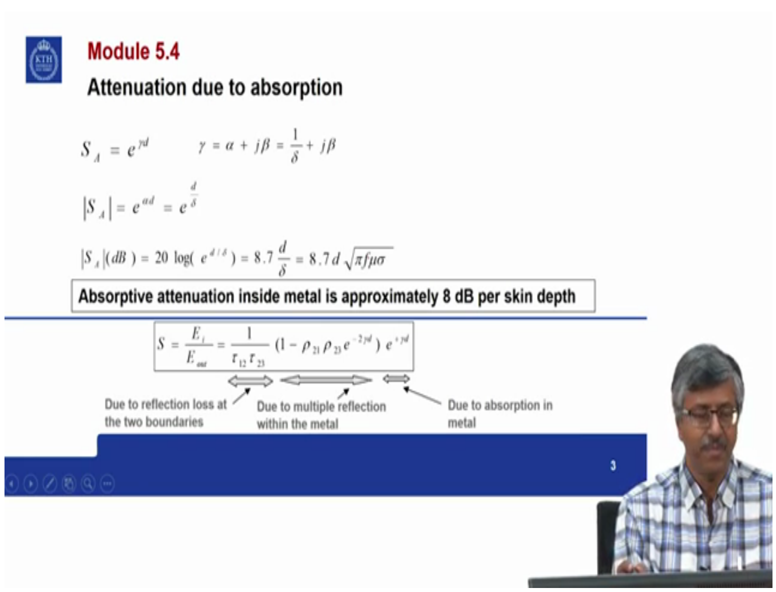

So previously we have already seen this equation. Total shielding effectiveness is composed of three factors. One factor due to reflection loss at the two boundaries and one factor due to absorption in the metal and one factor due to multiple reflection within metal. Now let us look at the details of that. So shielding absorption that is equal to e to power of gamma d, where we have seen gamma equal to alpha plus+ j beta and that is nothing but 1 by delta, which is the skin depth plus j beta for metals.

So from this we can write, SA equal to, so if you take the real part of it, because it is real part that is contributing to the attenuation, the imaginary part is only contributing to the phase. So if you take the real part of it, e to power of alpha d equal to e to power of d by delta. So in decibels 20 log e to the power of d by delta is nothing but 8.7 d by delta. d is the thickness of the shield. That is equal to 8.7 times d, square root of pi f mu sigma. That is, the shielding effectiveness due to absorption phenomena is proportional to the thickness.

More thickness means that more absorption and it is also proportional to the square root of frequency higher frequency, more absorption; higher magnetic permeability, more absorption, higher conductivity, more absorption. So this is the attenuation due to absorption. Now just understanding this formula, also suggest methods on how we can have design effective shields. Say for example, by using thicker material, by using high permeability materials like iron compared to aluminum, by using high conductivity material. So here there is a conflict because usually high conductivity material like copper are non-magnetic. So the product mu sigma, it becomes that, and high frequencies.

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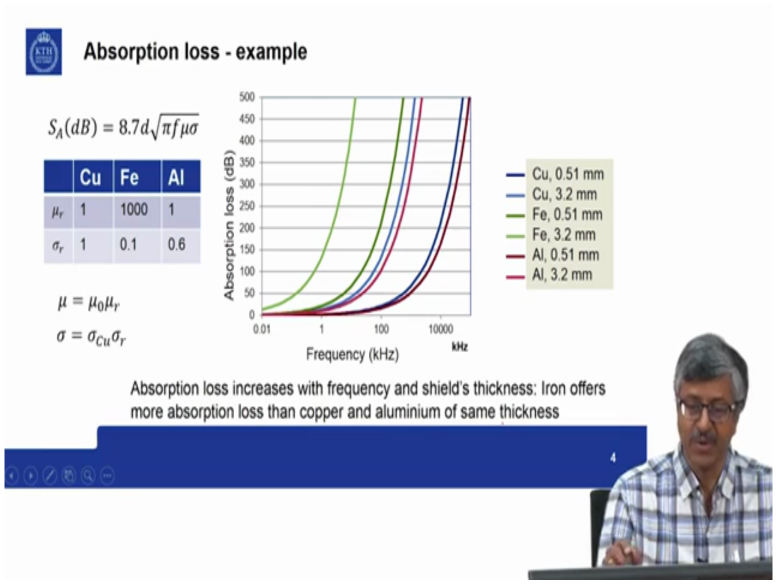

So in this graph, absorption loss is plotted against frequency for many common materials and two different thicknesses. We have selected copper, 0.51 millimeter thickness and thicker one 3.2 millimeter thickness, then same thicknesses but for iron and aluminum also is taken. And the properties of those materials are given. Relative permeability is 1 for copper and aluminum, conductivity is 1 for copper, relative conductivity; and aluminum, 0.6; for iron, 0.1.

Mu r is 1,000 for iron, this is what we assumed. Then you do the calculation, you can see that already at a kilohertz, iron with 3.2 millimeter thickness gives quite substantial attenuation, almost 100 dB attenuation, whereas for copper and other materials, it is not visible. This is mainly due to the term mu, square root of mu coming in, square root of 1,000 coming in. Now at 100 kilohertz or let us say 1 megahertz, almost any thickness of this material gives fairly good attenuation, even 0.51 or aluminum or copper. Everyone, all of them will give fairly good attenuation.

So for good absorption loss at high frequencies and the plane waves, you only need a thin foil to have good shielding, purely based on absorption loss. Absorption loss increases with frequency and shield thickness. Iron offers more absorption loss than copper and aluminum of same thickness. So this is a conclusion we can arrive.

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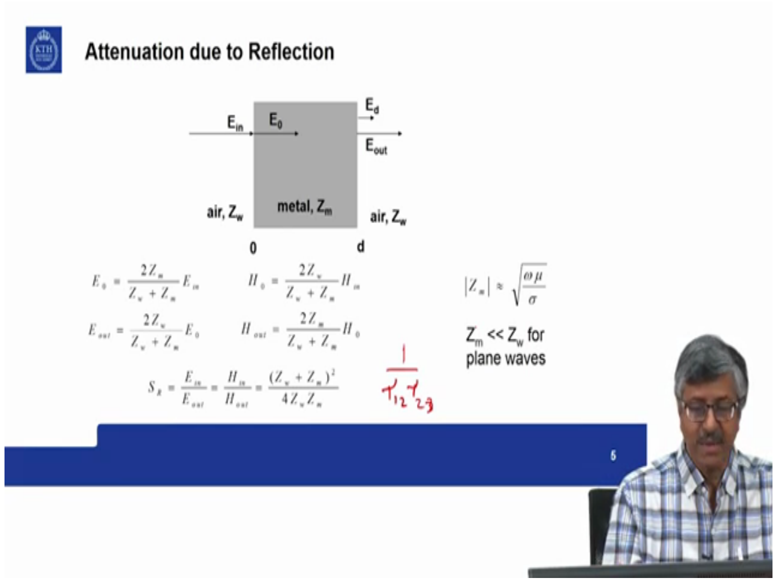

Now attenuation due to reflection E input, then E output, this is air, this is metal and this is out again air. Now you can write the transmission coefficients here, tau, previously we have seen it as tau 1, 2 and E out, tau 2, 3 it is equal to that. That we write here. Similarly for H field, tau 1, 2 and tau 2, 3 we can see the difference in the formula also. Then reflection coefficient is written as E input by E output, and you can write this.

So this is nothing but what we have seen before. Now 1 by tau 1, 2, tau 2, 3 that we have seen before we know that for metal impedance is square root of omega mu by sigma which is very small compared to the free space impedance for plane waves now due to this we can make some approximations.

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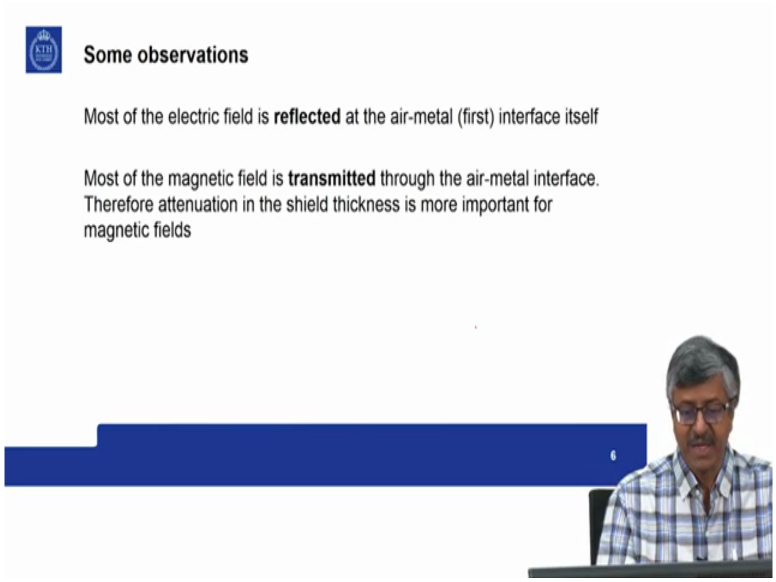

Most of the electric field is reflected at the air-metal interface itself. And most of the magnetic field is transmitted through the air-metal interface.

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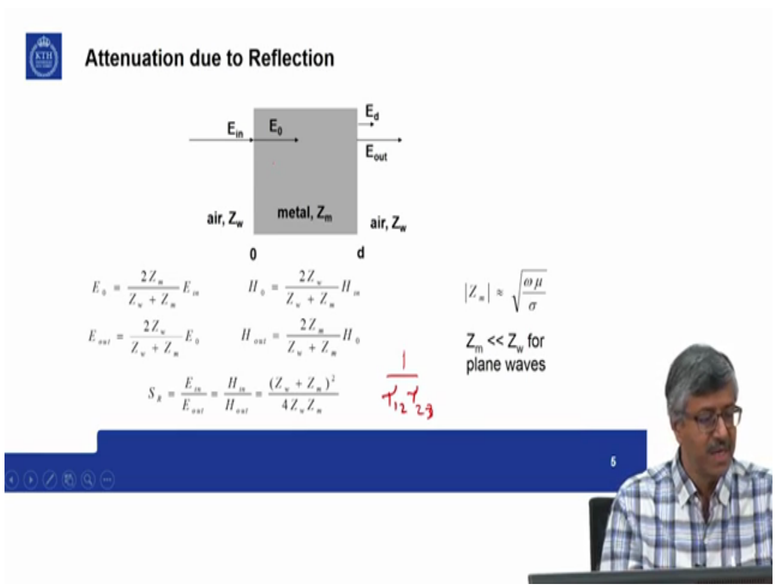

So this observation we can see from this coefficients. So this is the magnetic field, H0 is the magnetic field, so Zw is large value whereas Zm is a very small value. So you have quite low electric field falling here. But most of the field, magnetic field is falling inside.

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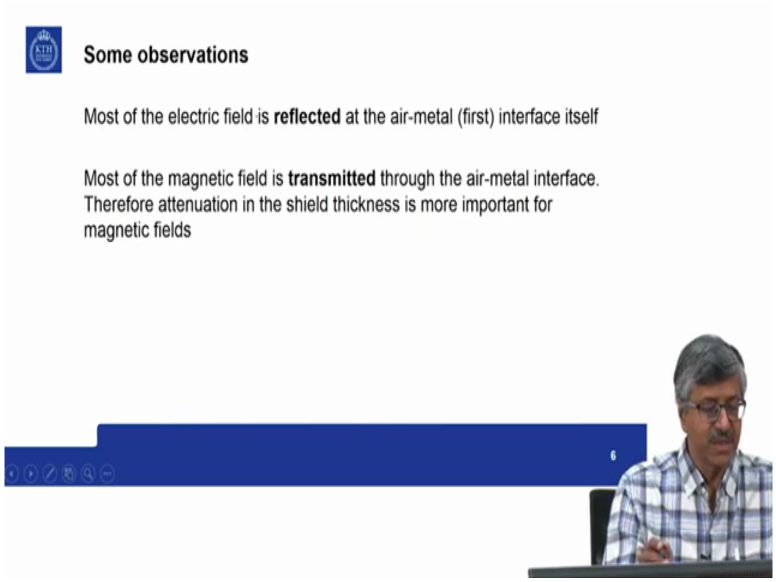

So that is the meaning of these two statements. Now since most of the magnetic field is transmitted through the air-metal interface, attenuation in the shield thickness is more important for magnetic fields, whereas for electric field already reflection is quite large.

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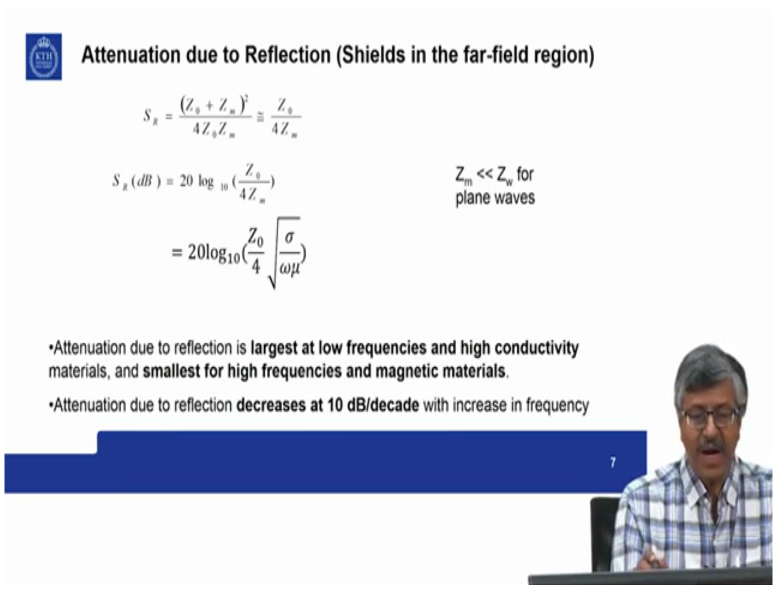

So let us look at some details of attenuation due to reflection. This is the expression and for plane waves since Zm is very small compared to Z0, SR can be written as Z0 by 4 Zm. And in decibels you can write it like this: 20 log free space impedance divided by 4 square root of conductivity divided by angular frequency times permeability, magnetic permeability. So attenuation due to reflection is largest at low frequencies because if frequency is low, this becomes very small and high conductivity materials. If conductivity is large, attenuation is large also and small as for high frequencies and magnetic materials. So it is kind of opposite effect.

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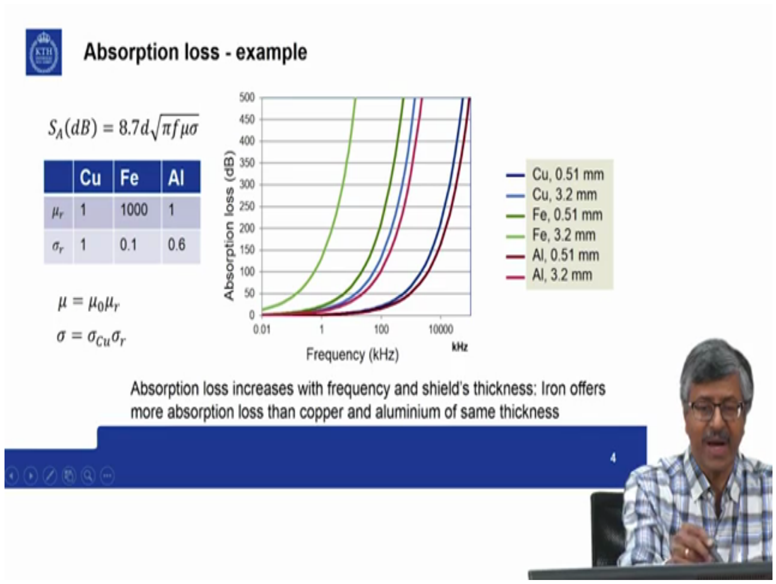

For absorption if you have high frequency, high conductivity and high magnetic materials, you have higher absorption loss.

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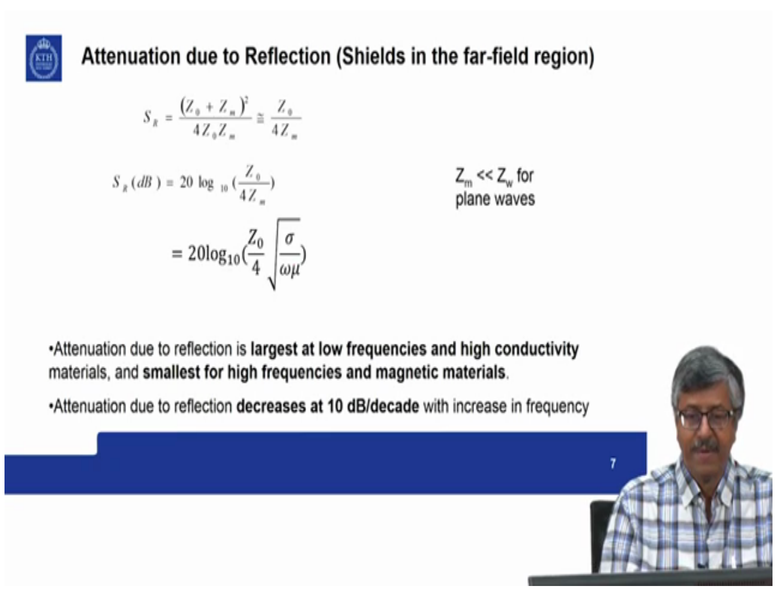

But for reflection, a high conductivity reflection is quite good. That is fine, there is no change in that. But high frequency and high permeability, the trend is opposite. So since always reflection and absorption they are coming together, what will be the final product it will be hard to predict.

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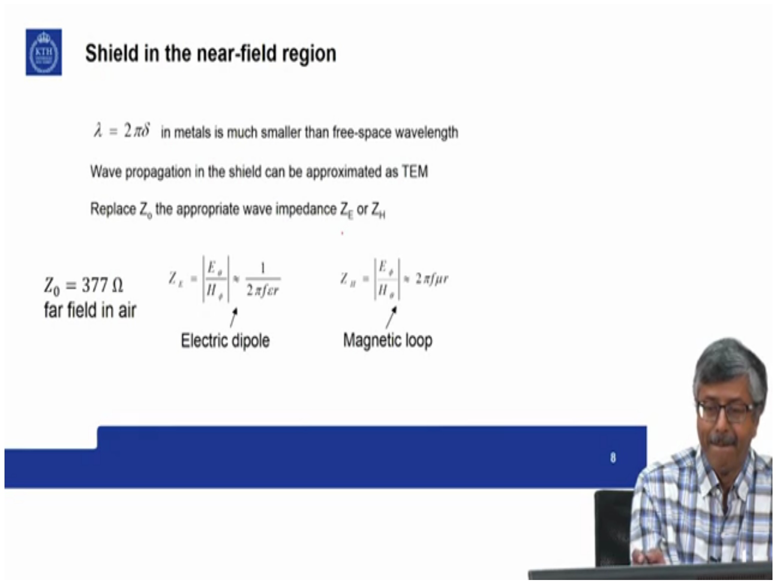

Shield in the near-field region. So in the near-field region, lambda equal to 2 pi delta in metals and it is much smaller than free-space wavelength. So wave propagation in the shield can still be approximated as TEM because the still that thickness can be radically long. So we replace Z0 with the appropriate that is in the free-space impedance we replace with appropriate wave impedance, ZE or ZH.

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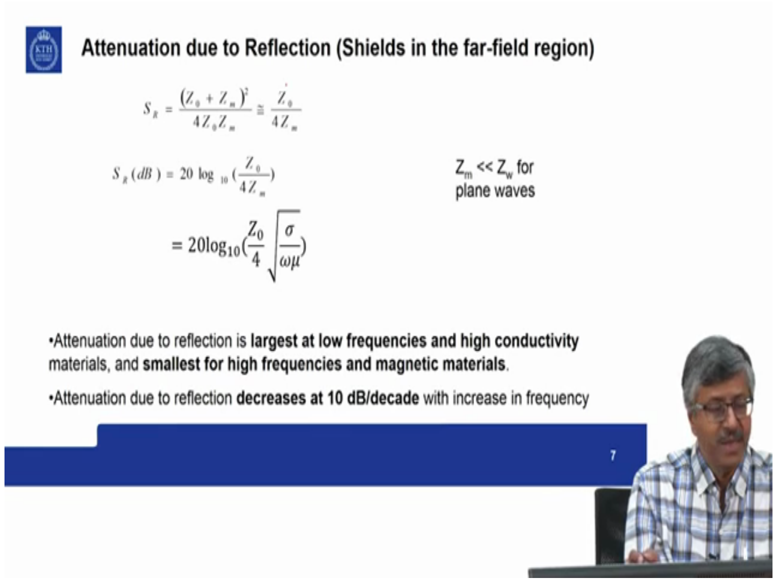

So in previous expressions over here Z0 will be replaced by either…

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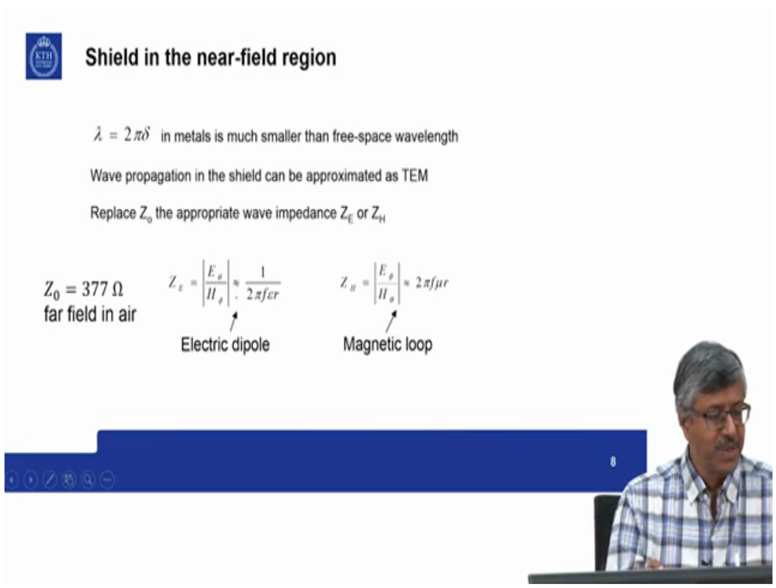

…impedance, near-field impedance for electric field or near-field impedance for the magnetic field and that is given from chapter 1 module 4, as 1 by 2 pi f epsilon r for electric dipole and 2 pi f mu r for magnetic loop and Z0 equal to 337 ohm far field in air, so let us substitute this and see what will happen.

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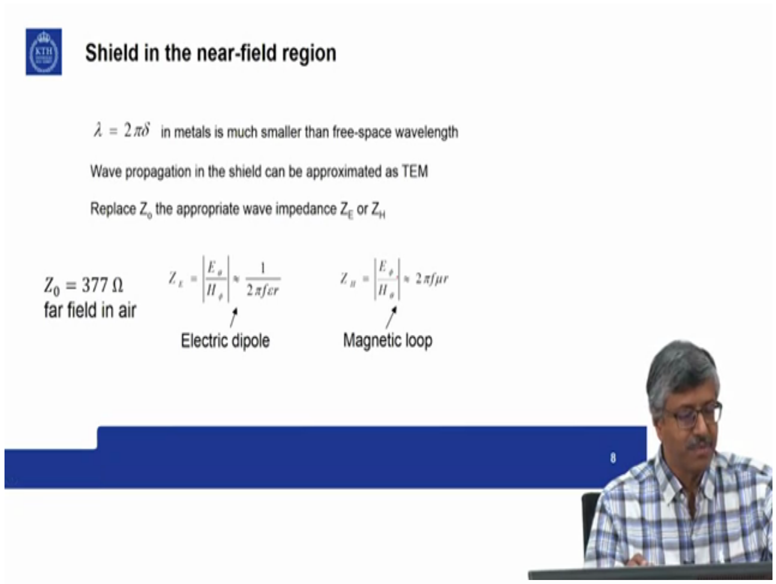

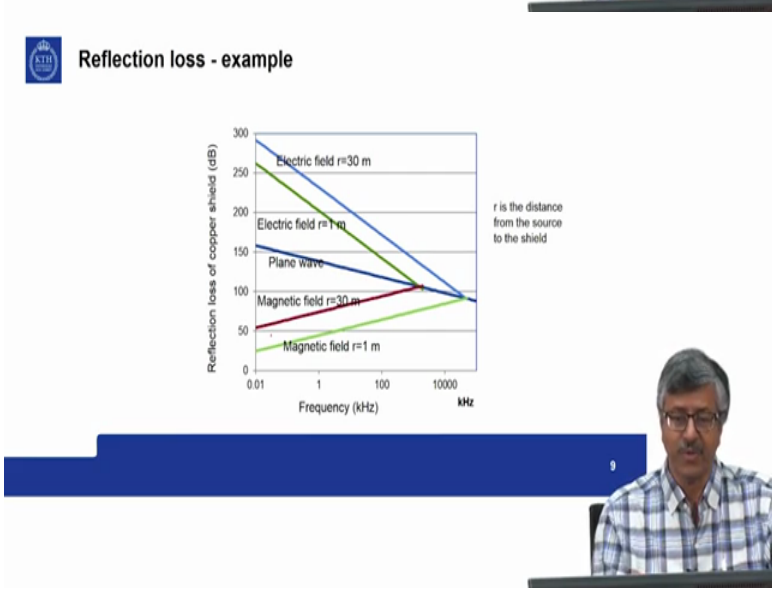

So if you do the calculation with these substitutions for free-space impedance for electric dipole this formula, for magnetic dipole this formula into the reflection loss formula, for electric field at r equal to 30 meters, you get a curve like this. So reflection loss in copper steel is very high and this is the iron shield. And this is for reference, the plane wave, whereas for the magnetic field reflection loss is quite low. Still there is a reflection loss but it is quite low compared to the electric field.

But at very high frequencies they approaches plane wave reflection loss. So this is the result of the calculation. So low frequency magnetic field, you cannot use reflection as much for shielding away the magnetic field. But for electric field even a thin foil will help, even close to the source.

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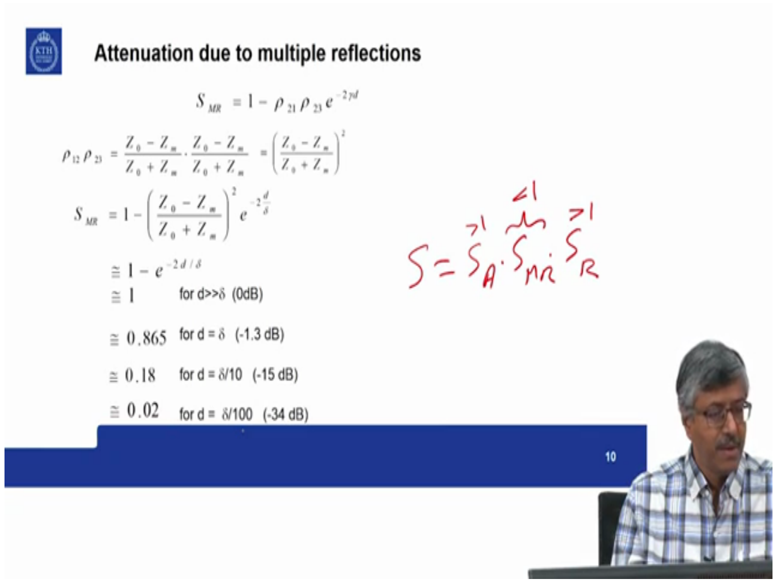

Now attenuation due to multiple reflection. Here it is 1 minus- row 21 row 23 e to the power of minus- 2 gamma d. So these are the reflection coefficients at the two boundaries from left to right. Then if you rewrite it in this particular way, and since Zm is very small, you can approximate it by this expression. And if delta, if d is far greater than delta, that is if you are, if you are at very high frequencies, then SMR equal to almost 1. You do not have, at high frequencies delta is very small, so d is very large. So SMR equal to 1. So you do not have any effect of multiple reflections basically whereas when d equal to delta, already multiple reflection is 0.865.

So your total reflection S equal to SA times SMR times S Reflection. So this is greater than 1, this is greater than 1 and this factor become less than 1. So overall there is a reduction in shielding effectiveness. In dB it will be, since it is less than 1, it will appear as minus- 1.3 dB whereas this is positive. And for delta, for d equal to delta by 100 for extremely low frequencies, multiple reflection is destroying the, compensating for the reflection quite a lot.

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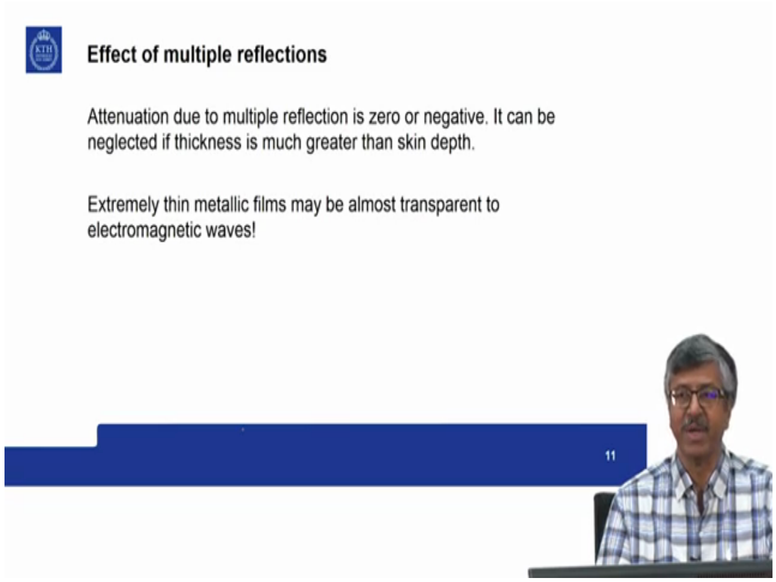

Effect of multiple reflections attenuation due to multiple reflection is zero or negative. It can be neglected if thickness is much greater than skin depth. Extremely thin metallic films may be almost transparent to electromagnetic waves. This is one effect. So previously we have seen that if you just look at the reflection or absorption, even a very thin shield is very effective. But if you include the phenomena of multiple reflection, you find that it destroy the many of the beneficial effect of reflections and very thin films may be even almost transparent to electromagnetic waves.

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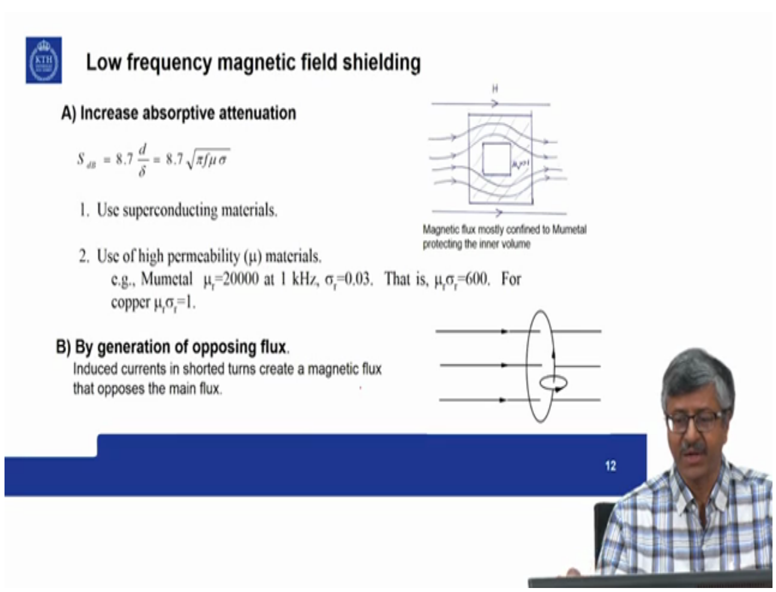

Low frequency magnetic field shielding, so we have seen that low frequency magnetic field shielding is a challenge or we have also seen that the absorption, absorptive attenuation is proportional to square root of permeability mu, therefore you can use high permeability materials for shielding. So in high permeability materials shown here, most of the magnetic field is confined to this material. For example, mu-metal, so this will protect the inner volume for magnetic fields.

Then instead of mu-metal we can use super-conducting materials. You increase the conductivity, you manipulate the conductivity. So these are the two methods that you can use to increase the absorptive attenuation. Now there is another way also. That is by generation of opposing flux. So we know that if we have a (())(19:00) inside, induced currents in shorter terms create a magnetic flux that will be opposing the main flux. So that way also if you have a mesh like structure, you can create those shorter turns and you can create opposing flux and try to reduce the magnetic field penetrating inside. So this finishes this particular module.