Course name: EMI /EMC and Signal Integrity: Principles, Techniques and Applications.
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Week :11
Lecture 53: Shielding for Nearfield Source

Welcome to the lecture of the course on EMI, EMC and Signal Integrity Principles, Techniques and Applications. In the last class we are discussing shielding for near field sources, we have seen the wave impedance. So, how it behaves in the near field, obviously we know the wave impedance in the far field. So, that variation we have seen for both electric sources and magnetic sources. Now, today we will see the reflection loss for that. So, the basic mechanism is same as far field sources only the wave impedance should be put in place of the intrinsic impedance of free space. Now, if you see the expression of absorption loss there is no intrinsic impedance expression there, no impedance expression is there. So, absorption loss does not get affected whether the source is in the far field or near field. So, it is always same that means, whatever we have discussed for absorption loss there is no further discussion needed, but reflection loss needs to be changed. So, that we will see in the next slide. So, this is again to recapitulate that this was the wave impedance variation for high impedance field that means, for electric type of sources.



Wave Impedance variation with Distance
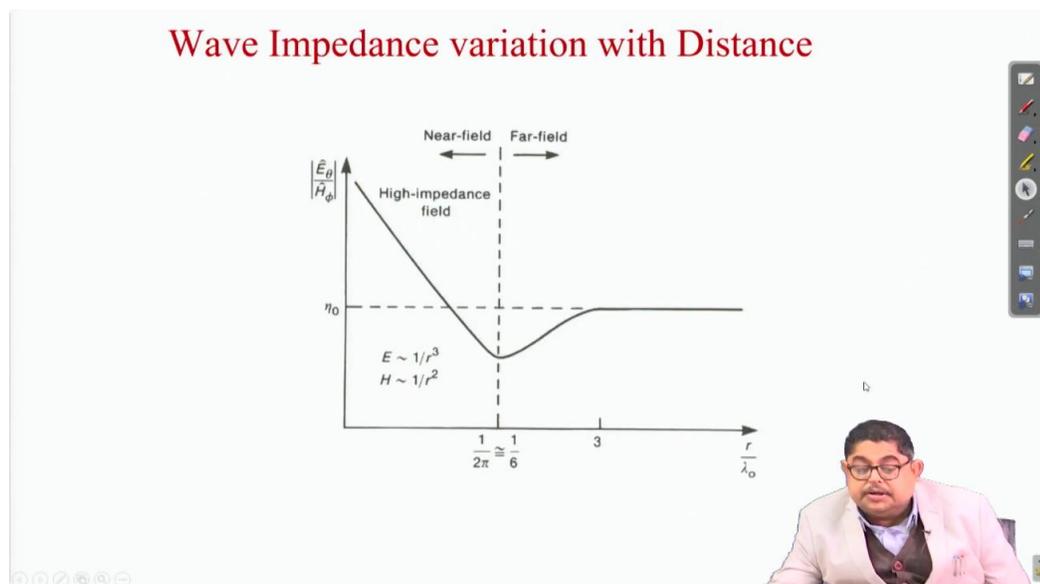
So, replace eta naught by z naught in loss terms of far field case.



**Shielding Effectiveness for Near field Sources**

- Replace $\eta_0$ by $Z_w$ in loss terms of plane wave case.
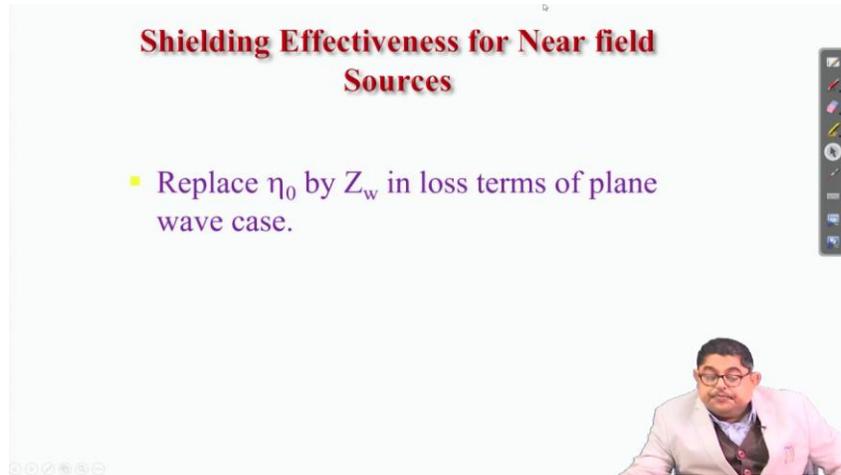
So, absorption loss unaffected I already said that. Now, you see the this reflection loss if you see the expression earlier it was eta naught plus eta by 4 eta naught eta. Now, in that place you just put z wave. So, with this since z wave is a high impedance field you can neglect the impedance of the shield eta with respect to it. So, it becomes z omega by 4. Now, z w that expression we have derived in the last class. So, just put it and eta expression already you know from the far field time. So, you put it. So, what we will get is if we collect all the unknown terms separately then it becomes 322 actually 321.7, but that we have taken as 322 plus 10 log 10 sigma r relative permeability frequency to the power 3 and separation distance between the source and the field that square.



**Electric Sources**

- Absorption loss unaffected by the type of source

$$R_{dB} = 20 \log_{10} \left| \frac{(\hat{Z}_w + \hat{\eta})^2}{4 \hat{Z}_w \hat{\eta}} \right| \cong 20 \log_{10} \left| \frac{\hat{Z}_w}{4 \hat{\eta}} \right|$$

$$= 20 \log_{10} \left| \frac{\frac{1}{2\pi f \epsilon_0 r}}{4 \sqrt{\frac{2\pi f \mu_r}{\sigma_r}}} \right| == 322 + 10 \log_{10} \left( \frac{\sigma_r}{\mu_r f^3 r^2} \right)$$
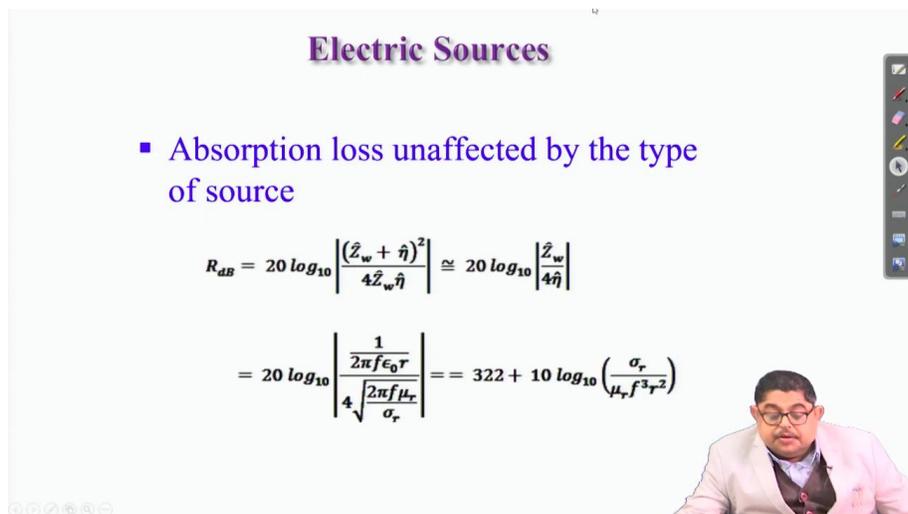
So, this if we plot as a frequency response then we will get fields why this straight  lines will come if you see the previous expression you see that suppose if we take a copper shield  then copper shield means sigma r will be 1 and for that mu r also will be 1.  So, now it is an expression that minus 30 log 10 f with some value fixed value of r.  So, basically it is a straight line with a slope of minus 30 dB per decade.  So, that is what you are getting here.  So, you see we have taken electric field if it is that means r is equal to 1 meter.  So, this is the curve r is equal to 30 meter this is the this one I am showing as my curves  that is the curve.  Now for plane wave that means for far field case this was the value.  Similarly we will see later, but plot is here that for magnetic type of source you will  get a straight line like this there it is some other frequency variation, but that also will show that it is a linear variation in dB scale. So, you see that roughly both are touching at some 3 megahertz sort of thing.  So, the point to be noted is the reflection loss is higher than far field case you see  the for electric sources it is higher we are discussing electric source do not now see  this later portion, but concentrate on this.  So, throughout you see almost up to 100 megahertz it is higher than the far field case.  Now smaller is the distance higher is the loss you see the compared to 30 meter if you  have r is equal to 1 meter distance you have higher loss that is roughly by 20 dB, 20 dB  sort of higher due to.  So, this is the thing you can take from this graph then let us come to magnetic source.



Frequency Response of Nearfield Reflection Loss

- Higher than far field
- Smaller distance, higher reflection loss
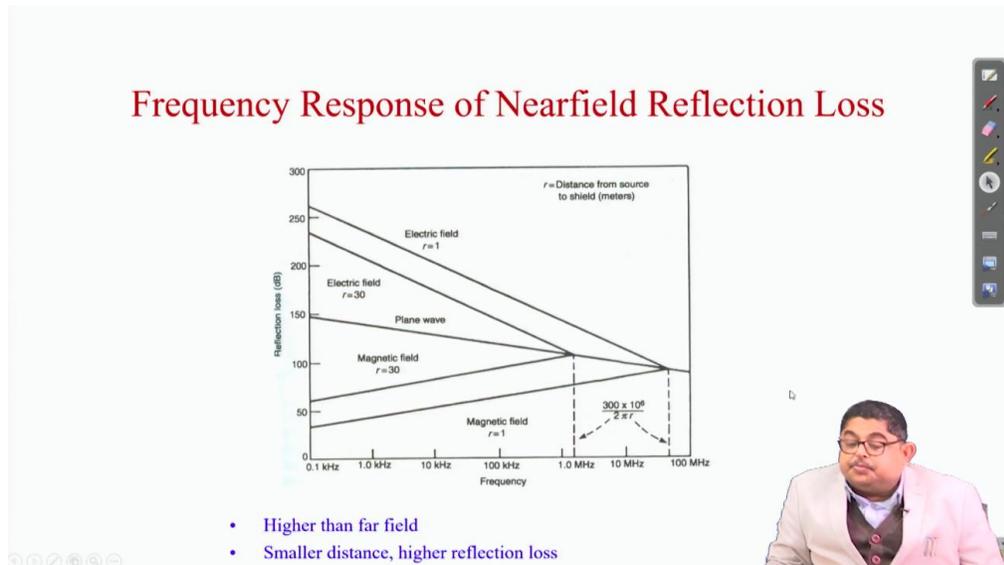
So, for magnetic source r dB is 20 log 10 the same expression Z omega m by 2.  So, just m has come in place of e. So, this is, but these values are different J w m that  will be 2 pi f mu naught r and 4 eta you can write as 4 root over omega mu by sigma.  So, then you can put those thing omega will give you the f thing. So, ultimately you will  get 10 5 7 plus 10 log 10 f r square sigma r by mu r. So, that expression I have written  here that then that is actually plotted already that in this graph.





So, from the graph you  can note that reflection loss decreases for decreasing frequency you see or you can say  that it increases for increasing frequency and reflection loss is less than the plane  wave reflection loss or far field case. Now, this you see if you think carefully there  is a problem at lower frequency for this magnetic type of sources at lower

frequency the reflection loss is quite small you see not like electric source for magnetic source reflection loss is quite small. So, who will predominate then absorption loss will predominate, but at lower frequency absorption loss is also very small. If you remember yesterday's discussion that at lower frequency absorption loss is small their reflection loss predominates, but for magnetic source we are seeing that its value is also less. So, that means, the at lower frequency magnetic for magnetic source near field magnetic source this type of shielding by a conductor is not very effective. So, it is useless. So, then we will have to think that how to do a thing. Now, this is a summary that for far field source reflection loss predominant shielding mechanism at lower frequency absorption loss predominant shielding mechanism at higher frequency near field electric source same type of frequency response behavior same does not mean that it is same, but it shows that frequency response behavior is same as far field source, but near field magnetic source absorption loss is predominant at all frequencies, but that loss is very small.

So, you need to have new methods to have low frequency shielding. So, the first case is case 1 diversion of magnetic flux with high permeability material. Here you see that actually this rectangular box that is a high permeability thing in the shield. That means, the whole thing is the shield now there as the conducting shield there there is a portion where you have a high permeability material. So, what will happen the due to this high permeability the magnetic flux they will try to concentrate basically they will try to concentrate all to the outer side. So, inside there will be a place where you will get that there is no flux by that you will get this shielding that there is this portion will be very much shielded.



**Low Frequency Magnetic Field Shielding**

Case I → Diversion of magnetic flux with high permeability materials
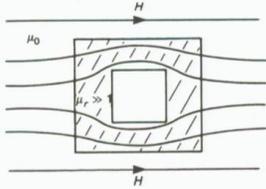
Flux passes through low reduction (high $\mu_r$) material.

Another method is called shorted turn method here you place a copper strip so that the around the shield conducting shield so that the magnetic flux cut it. Now obviously, some electromagnetic induction will takes place. So, there will be a inductive current now from Lenz's law you know that the this induced this induced current no before Lenz's law that this induced current will generate a again a magnetic flux. Now Lenz's law says that this induced magnetic flux will oppose the original flux. So, the flux value will be reduced that was your aim that you reduce the flux value so that you get good shielding.

**Low Frequency Magnetic Field Shielding (Contd.)**

Case II → Generation of opposing flux via Faraday's law.

Shorted – turn Method
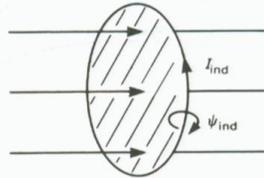
But this both this methods have their drawback that you see the one thing is permeability of for the first point is for the first case permeability of ferromagnetic materials they decreases with increasing frequency. So, those high mu r material their frequency response is not flat that actually comes down roughly after 10 20 kilohertz they fall down and also the permeability of ferromagnetic materials decreases with increasing magnetic field strength. Actually the those ferromagnetic materials they get saturated easily. So, after some time if you go on increasing magnetic field strength after some time you will see the flux is going to fall. So, this is the that picture frequency dependent.



**Drawback of Magnetic Shielding**

- Permeability of ferromagnetic materials decreases with increasing frequency.
- Permeability of ferromagnetic materials decreases with increasing magnetic field strength.

So, mu metal is a very very popular very good high permeability material. So, you see that roughly up to let us say 1 kilohertz after 1 kilohertz its relative permeability is falling. Otherwise at lower frequency up to 1 kilohertz it is its mu r is stable and that is roughly 13000. Similarly for nickel steel it is roughly 6000 for old rolled steel it is roughly 1000. So, these are good, but you see that nickel steel that is falling again roughly after 1 kilohertz mu metal is falling. So, perm alloy another one which has 15000 at the lower frequency its permeability, but they are also falling roughly after 1 kilohertz. So, you can have good shielding up to 1 kilohertz, but beyond that this with this ferromagnetic materials you cannot have.
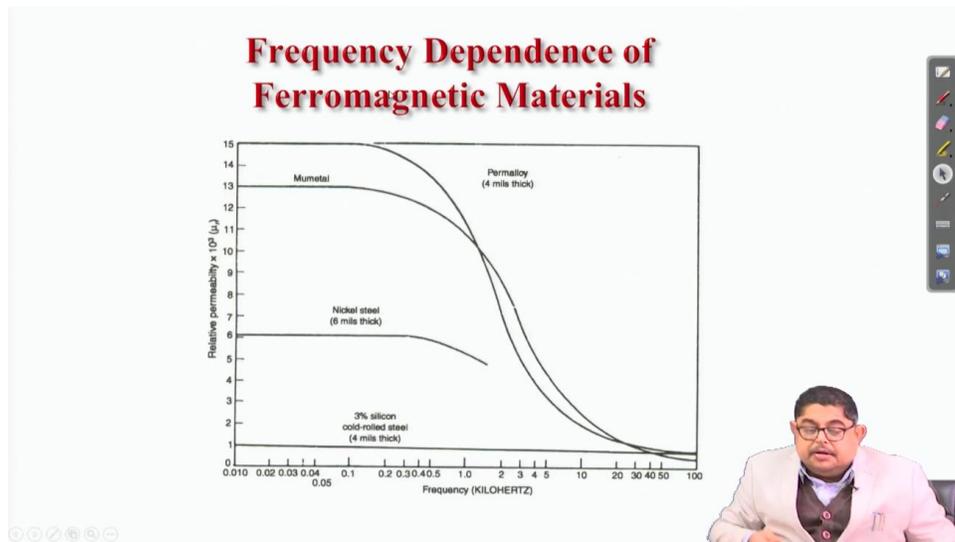


Now, our SMPS etcetera they are operates above kilohertz range 15 kilohertz 20 kilohertz etcetera. So, for them this case 1 or case 2 they are not appropriate we will have to again look for some new concepts. So, above 20 kilohertz mu metal mu metal no better than old rolled steel we have seen that or you can again see that 20 kilohertz you see 20 kilohertz mu metal and old rolled steel almost they are getting same old rolled steel nickel steel all are roughly coming to old rolled steel.Then shielding enclosures for SMPS are made of generally steel because you need to have the regulations says that for SMPS switching more power supplies which are there in all computers in many digital equipments they are used. So, they are their range for which they should comply that is 20 to 100 kilohertz. So, you cannot use mu metal or other. So, that is about low

frequency, but we are seeking an answer low frequency means for them it is 1 kilohertz or so, but we are interested to get shielding from 20 to 100 kilohertz.
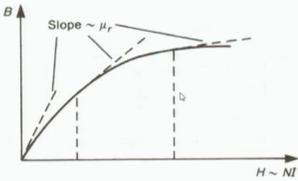


So, our problem is still not solved let us see also what happens to power supply because 50 hertz power supply that is the thing the from that we from to that supply we connect our all equipments. So, is that have the electromagnetic immunity magnetic field should not be high. So, that the shield gets saturated this slope is nothing, but mu r slope of the B H graph. So, usually for characterizing any magnetic material we use the B H graph and from which we know that it is not exactly reversible. So, that is why you have to have the written journey also here that is not shown. So, anywhere that B by mu B by H or you can say d B by d H that will be mu r B by H you can say average mu r again slope represents mu r.

Now, this is the answer for our that thing that how do we do a S M P S shielding. So, here what is done instead of 1 2 magnetic shield is used. So, the first one is having low permeability and high saturation and second one have high mu r and low saturation. Low saturation is coming because the mu metal etcetera they get saturated easily if the magnetic field is a bit high. So, that part. So, what is the job of this part this part is no problem you can have low mu r high saturation things those are available. So, you pass the coming wave through them. So, what will happen the intensity of the wave will reduce that means it is H or B flux density that will reduce the moment that is reduced now it is passed to these. So, it would not saturate the second shield, but that shield has a high mu r. So, it will give you good very very good shielding.
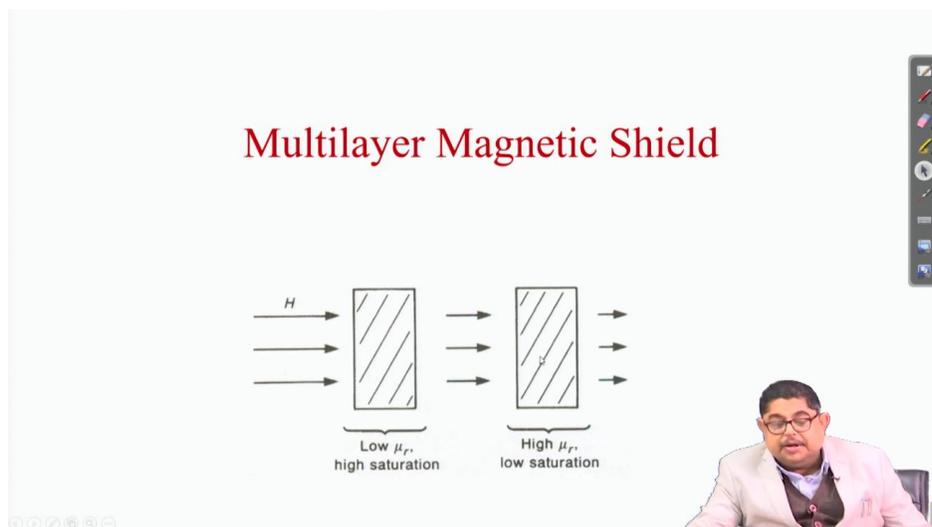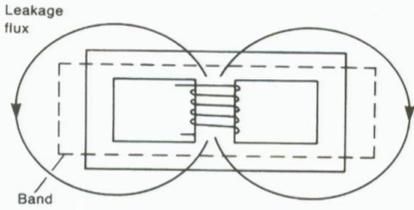


So, that is what is summarized here the first shield has a low mu r and low susceptibility to saturation reduces incident magnetic field below saturation limit of second shield first layer adds reflection loss for electric field.

Now, another technique for this type of SSC is transform in SMPS there is also not only the signal that is which is switching, but there is a transformer. So, that transformer will also give you lot of magnetic field that needs to be shielded. So, what is done you see that there is a tape here this rectangle. So, that tape a copper strip that is put at the outside of the transformer this is the front view. So, if you see the side view there also you will see that there is a strip. So, actually it is a strip around the more or less circular transformer body you can say core. So, this is the leakage flux and this is the band this copper tape is also sometime called band not bond band B A N D.
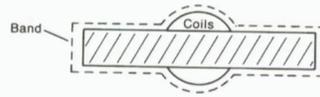


Band reduces the leakage magnetic flux of the transformer surface is bounded by surface bounded by loop should be perpendicular to the leakage flux to make it work because in perpendicular it will cut the maximum flux transformer core is frequently gap to the transformer. So, this is the band and this is the band to reduce flux level and saturation as I said that if you give a gap in the core then also the magnetic field will decrease, but you will have to take care. So, that people does not get affected. So, that is why transformer core is frequently gap and then this band is produced. Now, if required if you are seeing that the leakage is taking place not only in one direction that means suppose the here we have shown the leakage like this, but in a 3 D view the leakage can come from the this board also. So, for that time you apply 2 orthogonal bands. So, that both of them should be. So, 2 orthogonal bands may be required.

**Shorted Turn Shielding (Contd.)**

- Band reduces the leakage magnetic flux of the transformer.
- Surface bounded by loop should be perpendicular to the leakage flux.
- Transformer core is frequently gapped to reduce flux level and saturation.
- Two orthogonal bands may be required

Then what will be the shielding material selection for electric source and plane wave electric source and plane wave we are discussing together electric source means for near field electric source and plane wave means for far field. So, there more or less same. So, now there we know that it primarily depends the selection will depend on reflection loss. So, there we can say as a rule of thumb sorry the high conductivity materials are preferred obviously, because with high conductivity only we are doing the shielding and thickness of the material thickness of the sheet material we should say should be greater than skin depth at the highest frequency of operation, because skin depth will be changing at different frequency, but at highest frequency of operation we should ensure that thickness of the material that means the shield material thickness that should be greater.



**SHIELDING MATERIAL SELECTION FOR ELECTRIC SOURCE &PLANE WAVE**

**PRIMARILY DEPENDS ON REFLECTION LOSS**

- High Conductivity Materials Are Preferred

- Thickness of the Material > Skin Depth ( $\delta$ ) at the highest frequency of operation

Then use of shielding material here you can see that at the top is given the material various material which are used. So, you can see mu metal iron steel silver copper gold aluminum zinc brass phosphor bronze monad. Now, we have seen that the material is used  this here it is given what is the relative conductivity what is the relative permeability.  So, you see mu metal that has there we have seen 13000, but here it is given for this  particular variety what they have given that has 80000 is the relative permeability. Now,  this is used for shielding wall similarly iron is used steel is used steel is almost  like the permeability is one, but still it is used for shielding wall because relative  conductivity is also high means like typically like other ones. So, now obviously, copper  gold aluminum they are very good, but if you can if you have good pocket large pocket  you can do that they are also make and silver you see the let us see an interesting thing  silver is silver is 1.05, but no one will make a shielding wall with silver that will be too costly, but for contact plating when you want to have two contacts they you want to shield. So, that time it is used because that expenditure  is not much similarly in some connectors also there is silver is used gold is also if you  can afford gold can also be used for that aluminum is again shielding wall zinc is also  used for sheet plate plating brass is used for flanges in the wave guide which are also  to shield one of the activities is to shield phosphor bronze is spring contacts monel.  So, they are used. So, to make gaskets we will try to cover gaskets in a later one. So, there this monel type of thing will be coming. So, that is about the near field shielding  now some of the system aspects or some aspects of shielding that we have not covered that  we will cover in the next class. Thank you.

**USE OF SHIELDING MATERIALS**

$\sigma$ of Cu $= 5.8 \times 10^7$ mho/m
$\mu$ of Air $= 4\pi \times 10^{-7}$ H/m

| Material | Relative $\sigma_r$ with respect to Cu | Relative $\mu_r$ with respect to Air | Application |
|---|---|---|---|
| Mu – metal | 0.03 | 80,000 | Shielding wall |
| Iron | 0.17 | 1,000 | Shielding wall |
| Steel | 0.10 | 1.00 | Shielding wall |
| Silver | 1.05 | 1 | Contact plating |
| Copper | 1.0 | 1 | Shielding wall |
| Gold | 0.70 | 1 | Contact plating |
| Aluminum | 0.61 | 1 | Shielding wall |
| Zinc | 0.29 | 1 | Sheet plating |
| Brass | 0.26 | 1 | Flanges |
| Phosphor Bronze | 0.18 | 1 | Spring contacts |
| Monel | 0.04 | 1 | Gaskets |