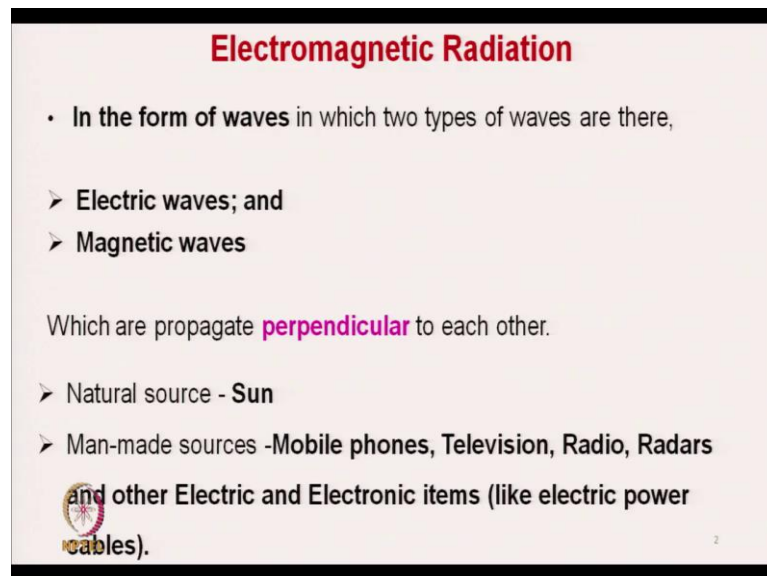


Testing of Functional & Technical Textiles
Prof. Apurba Das
Department of Textile Technology
Indian Institute of Technology, Delhi

Lecture – 24
Testing of Electromagnetic Shielding Textiles

Hello everyone. So, we have reached almost at the end of this course, today we will discuss the last topic of the course Testing of Functional and Technical Textiles. The topic we will discuss today is Testing of Electromagnetic Shielding Textiles. So, first we will try to understand what is electromagnetic shielding and why do use textile materials.

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Electromagnetic Radiation

- In the form of waves in which two types of waves are there,
 - Electric waves; and
 - Magnetic waves

Which are propagate **perpendicular** to each other.

- Natural source - Sun
- Man-made sources - Mobile phones, Television, Radio, Radars and other Electric and Electronic items (like electric power cables).

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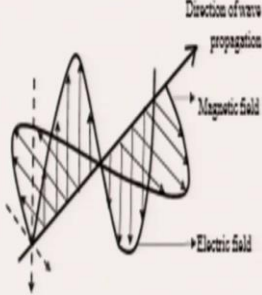
So, electromagnetic radiation it is in the form of wave in which there are two types of waves are there; these are electric waves and magnetic waves. And this waves propagate perpendicular to each other and also they are perpendicular to the direction of propagation. There are different sources of electromagnetic radiations like most common natural source is sun and manmade sources are like mobile phones, television, radars, radio and other electrical and electronic items like electric power cables there are many other sources.

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Electromagnetic Wave

Components

- Electric field
- Magnetic field
- The energy of electromagnetic waves is carried out by small particles called **photons**



The diagram illustrates an electromagnetic wave propagating to the right, as indicated by the arrow labeled 'Direction of wave propagation'. The electric field is represented by a vertical sine wave, and the magnetic field is represented by a horizontal sine wave, perpendicular to the electric field. The wave is shown in a 3D perspective, with the electric field oscillating in the vertical plane and the magnetic field oscillating in the horizontal plane.

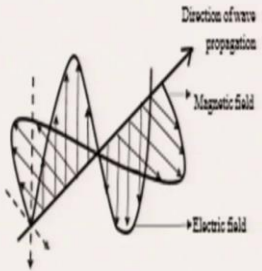
 3

So, these components are electric field and magnetic field and the energy of electromagnetic waves is carried out by small particles which are called photons, so they are carrying the energy. And here in this picture we can see here, this graph is showing electrical field and perpendicular to this graph which is showing, it is a magnetic field and these two fields are perpendicular towards the direction of propagation, this is the direction of propagation.


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Propagation of EM Waves

Electromagnetic waves perform oscillation in **Electric and Magnetic field** which are at **90 degrees** to each other and **both fields are perpendicular to the direction of propagation of waves.**

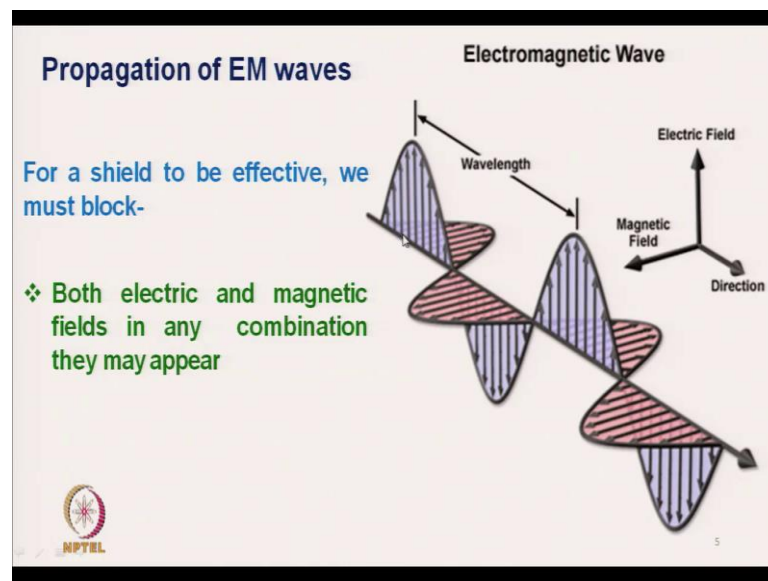


The diagram illustrates an electromagnetic wave propagating to the right, as indicated by the arrow labeled 'Direction of wave propagation'. The electric field is represented by a vertical sine wave, and the magnetic field is represented by a horizontal sine wave, perpendicular to the electric field. The wave is shown in a 3D perspective, with the electric field oscillating in the vertical plane and the magnetic field oscillating in the horizontal plane.

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So, electromagnetic waves perform oscillation in electric and magnetic field. So, this is the magnetic field oscillation and this one is electric field oscillation, which are at 90 degree to each other and both fields are perpendicular to the direction of propagation of waves so, this is the direction of propagation of waves. So, we can see here, this magnetic field is going at 90 degree angle, it is making 90 degree angle and also the electric field also it is making 90 degree angle.

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So, the propagation of electromagnetic waves are for a shield to be effective, we must block this propagation. Both electric and magnetic fields in any combination they appear, they have to be blocked. Here we can see, this blue color it is showing the electric field and a 90 degree angle this red color waves, it is showing the magnetic field and this is the direction of propagation. So, we have to block both this electric and magnetic fields.

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Effects of Electromagnetic Radiation

- When an Electromagnetic wave enters into an organism, it creates a vibration between molecules and releases heat.
- Due to this phenomenon it will obstruct the new generation of DNA and RNA in cells

 6


The effects of electromagnetic radiation are so, when an electromagnetic wave enters into an organism, it creates a vibration. So, vibration in the molecules and as the molecules vibrate, they release heat; this electromagnetic wave releases heat and due to this phenomenon it will obstruct the new generation of DNA and RNA cells in the cells, the DNA and RNA molecules they will actually obstruct.

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Effects of Electromagnetic Radiation

They hamper the technical and biological life of human and create health problems like -

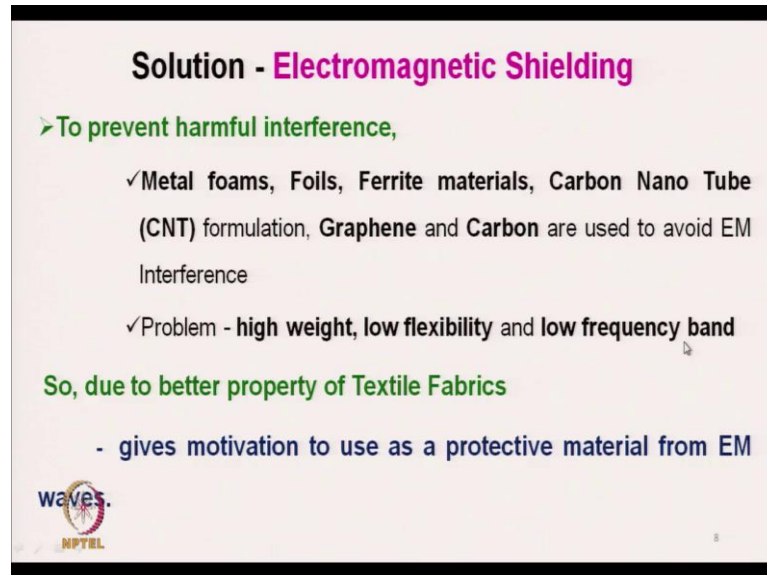
- Dizziness
- Allergies
- Leukemia
- Cancer
- Sleep disorder
- Headache
- Brain tumors
- Fatigue
- Alzheimer's disease

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So, they hamper the technical and biological life of human and create different types of health problems. So, most common health problems due to electromagnetic radiations

are dizziness, allergies, even leukemia, cancer, sleep disorder, headache, brain tumors, fatigue and Alzheimer's disease. So, these are the different types of problems which may be created due to electromagnetic radiation.

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Solution - Electromagnetic Shielding

➤ To prevent harmful interference,

- ✓ Metal foams, Foils, Ferrite materials, Carbon Nano Tube (CNT) formulation, Graphene and Carbon are used to avoid EM Interference
- ✓ Problem - high weight, low flexibility and low frequency band

So, due to better property of Textile Fabrics

- gives motivation to use as a protective material from EM

waves.
NPTTEL

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So, what are the solutions? The best solution is that to shield all this electromagnetic radiation. So, to prevent harmful interference of this electromagnetic radiations so, metal foams, foils, ferrite materials, carbon nano tube formulations, graphene, carbons are used to avoid this interference, but main problem with this materials are they are heavier in weight and they are not flexible and they work in low frequency band.

So, best alternative is that, due to better property of textile fabrics, people try to use textile material to protect themselves from electromagnetic radiations.

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Advantages of Textiles as Electromagnetic Shielding Material

- Light in weight
- Flexible
- Lower cost compare to shields made of metal sheets and wire mesh
- Possibility of elastic shaping
- Permeability to air




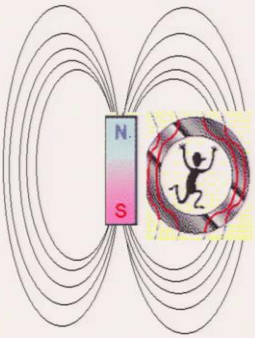
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So, basic advantages of textiles as electromagnetic shielding materials are, they are lighter in weight, they are very flexible. So, that this can be used in different applications they are moldable, low cost as compared to other shielding materials, possibility of elastic shaping so, they can be shaped, they can be covered different complex instruments; complex means, instruments of complex shape, even we can wear a fabrics made of electromagnetic shielding material and they are permeable in nature. So, that proper comfort can be imparted.

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What is electromagnetic shielding ?

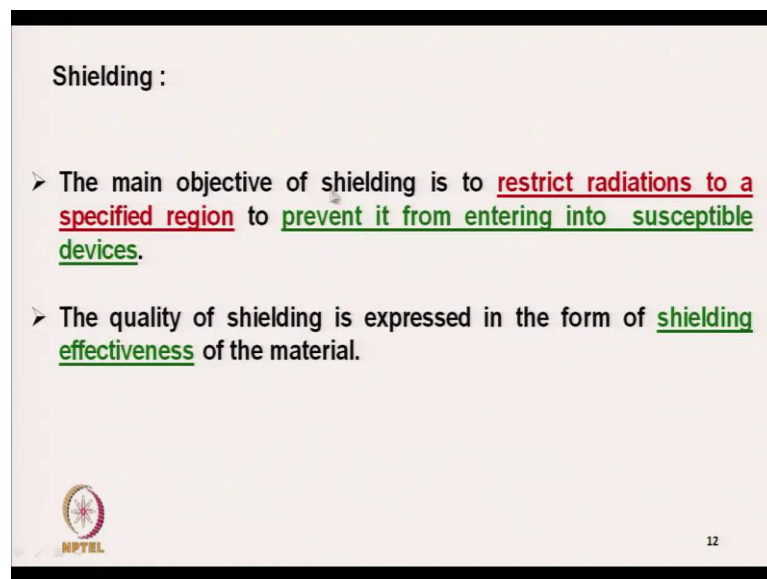
Electromagnetic shielding is the practice of reducing the electromagnetic field in a space by blocking the field with barriers made of **conductive** or **magnetic** materials.



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Now, let us try to understand the process of shielding. How do we shield by using shielding materials; basically, electromagnetic shielding is the practice of reducing the electromagnetic field in space, this is the electromagnetic field in space by blocking the field with a barrier material of conductive or magnetic materials. So, magnetic materials or conductive material, if we use we can block this radiation and that is the main function of shielding material.

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Shielding :

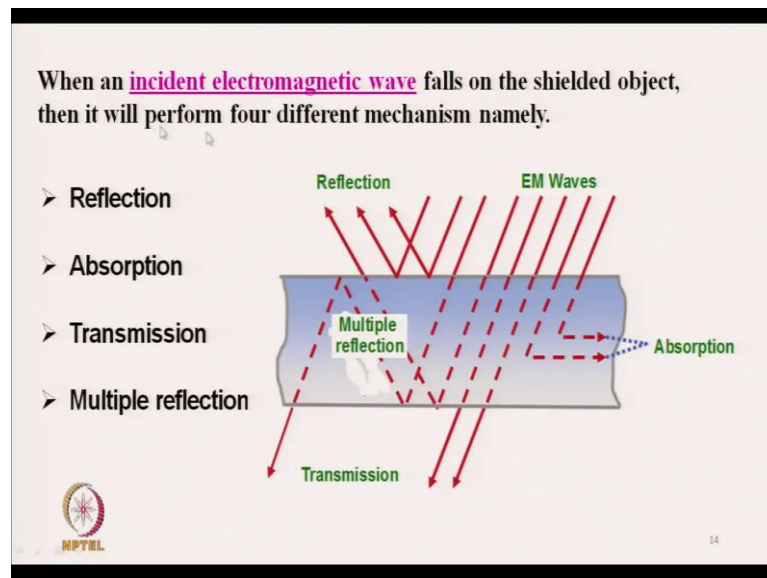
- The main objective of shielding is to restrict radiations to a specified region to prevent it from entering into susceptible devices.
- The quality of shielding is expressed in the form of shielding effectiveness of the material.

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So, the main objective of shielding is to restrict radiations to a specified region. So, we cannot restrict, we cannot stop the radiation entirely, but if we want, we can restrict the radiation in a specified place, to prevent it from entering into the susceptible devices. So, we can prevent this radiation in a particular place where we do not want this radiations to come.

The quality of shielding is expressed in terms of shielding effectiveness. The shielding effectiveness of material, if we can measure, it is expressed in terms of decibel; higher decibel value means higher shielding effectiveness.

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Now, mechanism of shielding; so, this is the electromagnetic wave. So, when an incident electromagnetic wave falls on a shielded object, this is the shielded object. Then, it will perform four different mechanisms, these mechanisms are reflection so, this wave may get reflected and it is not coming on the other side, this is the shield material and this wave may get absorbed by this material, they may be getting transmitted. So, there will be definitely some transmission ideally for perfect shielding material, transmission should be 0 and also multiple reflection.

(Refer Slide Time: 11:41)

All mechanism can be determined by an equation –

$$P_{in} = P_{abs} + P_{ref} + P_{trans} + P_{mref}$$

Where, P_{in} = Incident Power
 P_{abs} = Absorbent Power
 P_{ref} = Reflective Power
 P_{trans} = Transmission Power
 P_{mref} = Multiple Reflection Power

NPTEL

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So, all mechanism can be determined by the equations so, total incident power of the electromagnetic wave is the summation

$$P_{in} = P_{abs} + P_{ref} + P_{trans} + P_{mref}$$

of absorbent power, reflective power, transmission power and multiple reflection power.


So, if we add all this, we will get the incident power.

(Refer Slide Time: 12:11)

Shielded materials block the electromagnetic waves by three mechanisms which is explained by an equation -

$$SE = L_{abs} + L_{ref} + L_{mref}$$

Where, SE = Shielding Effectiveness,
L_{abs} = absorption loss, in dB
L_{ref} = reflection loss, in dB
L_{mref} = multiple reflection loss. in dB



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And shielded materials block the electromagnetic waves by three mechanisms as I have already just mentioned, these are absorption loss this absorption loss, reflection loss and multiple reflection loss. So, if we add this losses that will show that, shielding effectiveness. So, higher shielding effectiveness means higher absorption, reflection and multiple reflection loss.

(Refer Slide Time: 12:55)

Reflectivity R

- ✓ Fraction of energy of the electromagnetic radiation that is reflected by the shield.
- ✓ Multiple reflection occurs if thickness of shielded material is very high compared to depth of skin.

Absorptivity A

- ✓ Fraction of the energy of the electromagnetic radiation that is absorbed by the shield.
- ✓ Due to interaction of electromagnetic radiation with the electric/magnetic dipoles and electrons in the shield, absorption occurs

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So, that the terms which we can use is one of this is reflectivity which is expressed by R, that is fraction of energy of electromagnetic radiation that is reflected by the shield material that is called reflectivity of the shield material and it may include the multiple reflection also; that is multiple reflection occurs, if thickness of the shielded material is very high compared to depth of the skin. So, there will be multiple reflection.

Next term is absorptivity which is expressed in terms of A that is a fraction of energy of electromagnetic radiation that is absorbed by the shield material. So, that we can get the absorptivity of the material so, the due to interaction of electromagnetic radiation with the electric and magnetic dipoles and electrons in the shield, the absorption occurs; so, absorptivity we can measure.

(Refer Slide Time: 14:17)

Transmissivity T

- ✓ Fraction of the energy of the electromagnetic radiation that is transmitted by the shield
- ✓ The transmitted portion is the portion that has not been absorbed or reflected

$R + A + T = 1$

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Third term is transmissivity, the transmissivity is that fraction of energy of electromagnetic radiation that is transmitted by the shield. The transmitted portion is the portion that has not been absorbed or reflected. The value of transmissivity will show the effectiveness of a shield material, a very good shield material will have least transmissivity. So, if we add all three will be unit value, R plus A plus T equal to 1. So, how to measure, you have understood the shielding mechanisms; and now we will discuss the measurement techniques. .

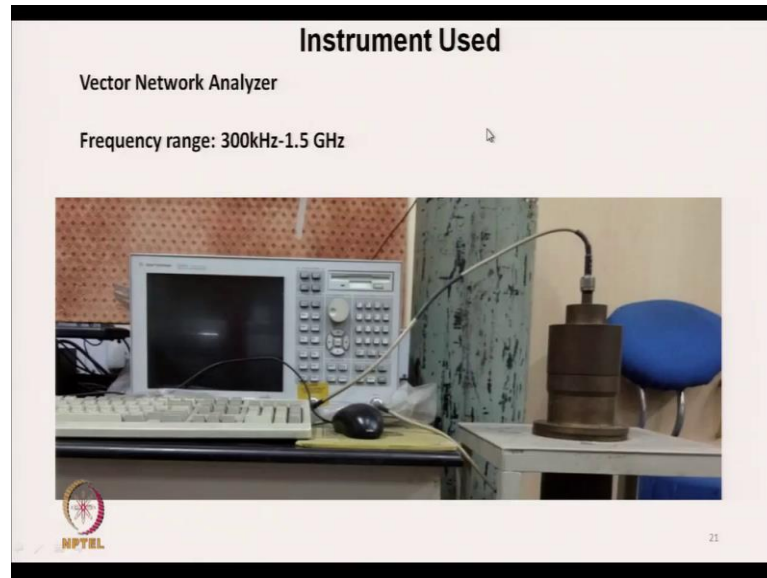
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- ✓ MIL-STD-285
- ✓ The Coaxial Holder Method
- ✓ Time Domain Method
- ✓ Dual TEM Cell Method

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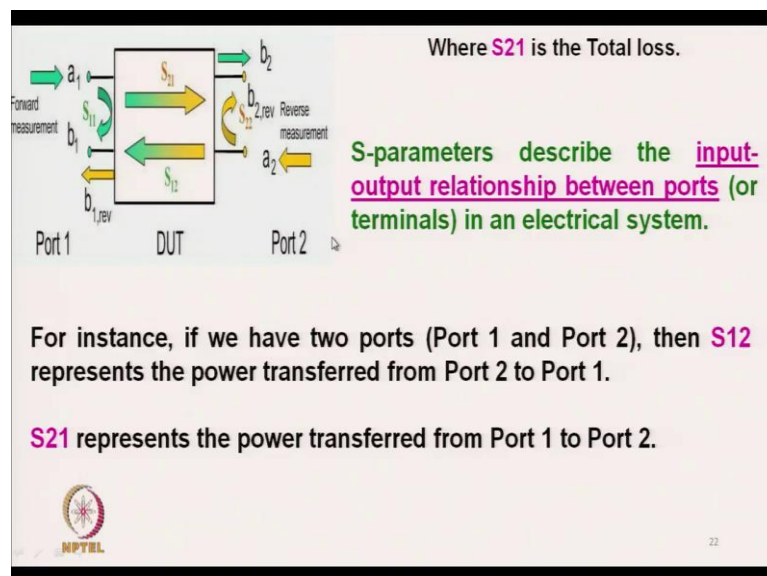
So, there are different techniques available MIL standard 285 which is military standard, we can use coaxial holder method, time domain method, dual TEM cell method; so, this methods are very commonly used.

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Now, the instrument which is normally used it is a vector network analyzer. This instrument is used for measuring the shielding effectiveness of textile material also it works in the frequency range of 300 kilohertz to 1.5 gigahertz.

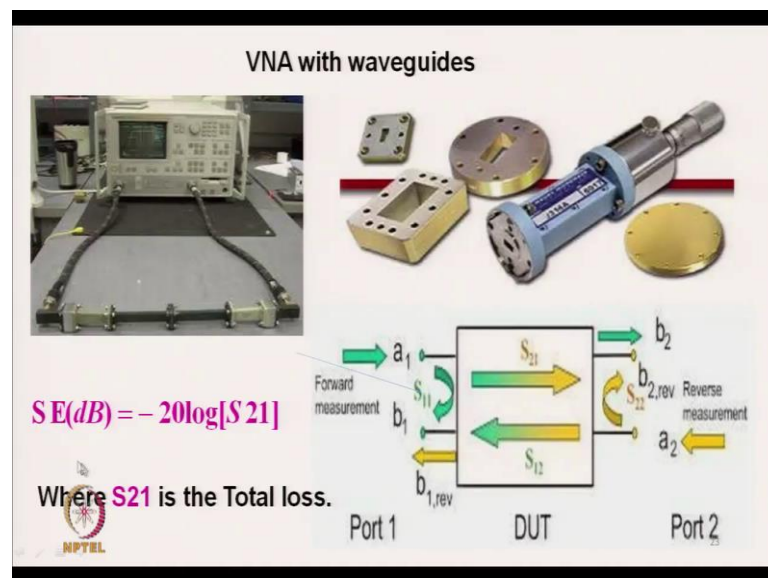
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So, first let us try to understand, what is S-parameter? S-parameters describe the input-output relationship between the ports, that these are the two ports or terminals in an electrical system. So, this S-parameter, it shows the relationship between input and output ports. For example, if we have two ports; port 1 and port 2, then S_{12} ; S_{12} represent the power transmitted from port 2 to port 1 and S_{21} represent the power transmitted from port 1 to port 2.

So, if the power is coming from port 1, then S_{21} shows the power which is getting transmitted from port 1 to port 2 through the shielding material. So, for measurement of shielding effectiveness S_{21} is used.

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So, S_{21} if we take the log so, shielding effectiveness in decibel equal to minus 20 log S_{21} , this is the common formula by which we measure the shielding effectiveness. So, S_{21} is total loss.

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Shielding effectiveness (Se) :

It is defined as the ratio of incident power to transmitted power.

$$Se \text{ (dB)} \equiv 10 \log \frac{W_i}{W_t}$$

For electric fields, we have

$$Se \text{ (dB)} \equiv 20 \log \frac{E_i}{E_t}$$

For magnetic fields, $Se \text{ (dB)} \equiv 20 \log \frac{H_i}{H_t}$

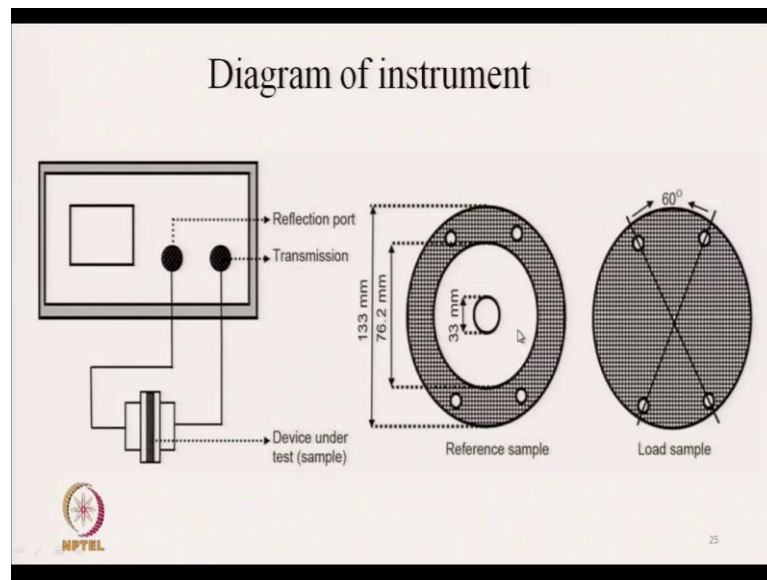
- The shielding materials can be solids, screens and braids.
- They can be in the form of boxes, partitions, cables and connectors

NPTEL 24

And shielding effectiveness for electrical field and magnetic field we can measure separately. So, shielding effectiveness for electrical field is minus, it is $20 \log E_i$ by E_t . So, initial and transmitted so, incidents and transmitted energy.

Similarly, for magnetic field, it is also $20 \log H_i$ by H_t ok. The shielding effectiveness can be measured the total shielding effectiveness, it is a $10 \log W$ incident and W transmitted ok, that is power incidence and transmitted power. The shielding material can be solid, can be screen or can be braids. And if we talk about their forms, they can be in box form, may be in partition form, may be cable form or connectors form. So, there are different forms of shielding materials.

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So, for measurement we have two ports, this is called a reflection port and one is transmission port ok. And here, the device which is under test, this may be a textile fabric also; and there are two types of samples, this sample annular ring and also small circular sample, this is called reference sample which we need to measure the effectiveness and another is load sample. So, if we take the difference, we will get the shielding effectiveness.

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Measurement Procedure

The shielding behaviors of fabric and composite specimens are measured by,

- Using [Coaxial Transmission Line Holder](#) for Low frequency range; and
- [Using Waveguide method](#) for C Band frequency range.

The Reference and Load samples are prepared as shown in Figure according to ASTM D4935 for Low frequency testing.

Using the following equation, Shielding Effectiveness of samples are calculated.

$$SE(\text{dB}) = -20 \log(S_{21})$$

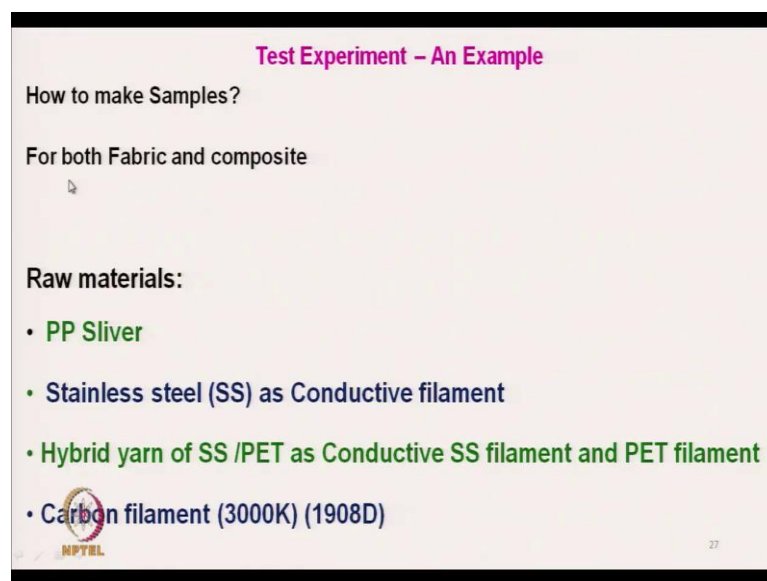
Where S_{21} is the Total loss.

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The shielding behavior of fabric and composite specimens are measured by, one is using coaxial transmission line holder which is used for low frequency range and another for C band frequency range; so, C band frequency range we can use the waveguide method. The reference and load samples as, I have just mentioned are prepared as shown in figure as per ASTM D4935 and it is used for low frequency range.

So, this formula $SE = -20 \log S_{21}$ is used to measure the shielding effectiveness of sample.

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Test Experiment - An Example

How to make Samples?

For both Fabric and composite

Raw materials:

- PP Sliver
- Stainless steel (SS) as Conductive filament
- Hybrid yarn of SS /PET as Conductive SS filament and PET filament
- Carbon filament (3000K) (1908D)

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So, both textile fabrics and textile reinforced composites can be tested. The raw materials were for the experiment which has been conducted was polypropylene sliver was used, stainless steel filament which is conductive in nature, hybrid yarn stainless steel and polyester hybrid yarns were used and carbon filament was used which is conductive in nature.

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Sample Preparation

✓ **Yarn preparation:** By DREF-3 PROCESS

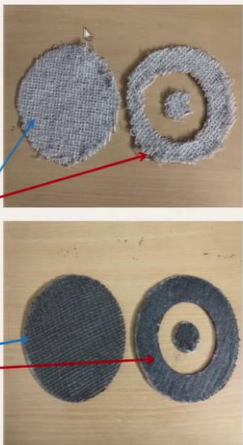
- **Conductive filament used as core** and PP as sheath

✓ **For Knitting** - Using Crochet Knitting Machine

✓ **For Composite** - Using Compression Molding Machine

Knitted fabric: **Reference sample** and Load Sample

Composite fabric: **Reference sample** and Load Sample




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Now this is the specimen. So, two types of specimens were used, one is knitted fabric another is composite fabric; composite means, fabric reinforced composite. So, knitting was done using crochet knitting machine and composite was made using compression molding machine. So, this is load sample circular and reference sample is annular ring and also a small circular portion which is for the centre. And composite fabric was of similar shape this is for load sample, another is for reference sample.

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Measurement Procedure of Fabric



- No Sample Mounting
- Air data is taken

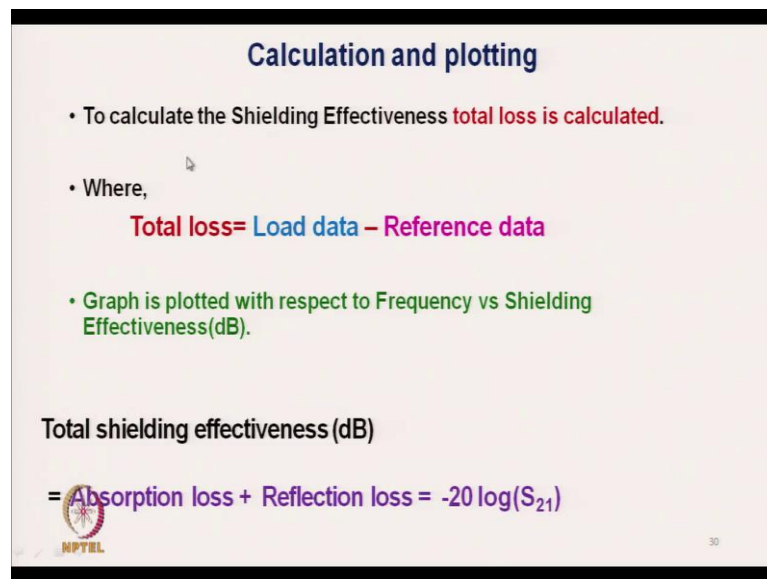
- Mounting of load Sample
- Measurement is taken

- Mounting of **Reference Sample**
- Measurement is taken

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So, here the measurement procedure is, this is the basic instrument where no sample was mounted and here only air data was taken. This instrument without any sample, the electromagnetic wave passing through air was calculated for reference. Here then sample was mounted, this is the load sample was mounted and measurement was taken and third is that, reference sample was mounted on the instrument, this is the annular ring, here it was placed and at the centre the sample circular, small circular sample was placed and measurement was taken.

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Calculation and plotting

- To calculate the Shielding Effectiveness **total loss is calculated.**
- Where,
Total loss= Load data – Reference data
- Graph is plotted with respect to Frequency vs Shielding Effectiveness(dB).

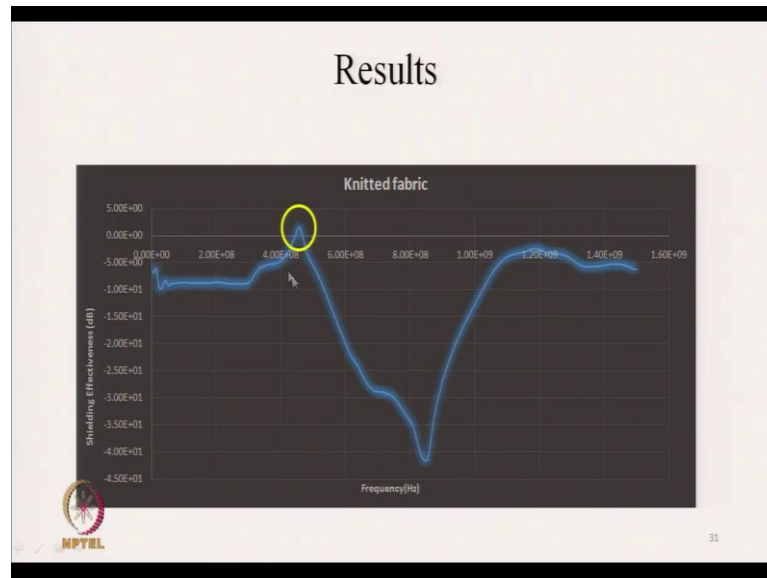
Total shielding effectiveness (dB)

= Absorption loss + Reflection loss = $-20 \log(S_{21})$

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So, three readings were taken and to calculate the shielding effectiveness the total loss is calculated; so, total loss is equal to load data minus reference data. And then graphs were plotted where in x-axis the frequency was there and in y axis shielding effectiveness in decibel was reported. So, total shielding effectiveness in decibel is equal to absorption loss plus reflection loss. So, that is expressed by minus 20 log S21 so, total loss we can calculate. So, absorption loss plus reflection loss is calculated by load data minus reference data.

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This is the typical plot where at this zone; we can see it is a maximum shielding ok.

(Refer Slide Time: 25:09)




And this is for composite material.

(Refer Slide Time: 25:11)

EMS Textiles: Classifications

| Type | Grade | Shielding effectiveness (dB) | Classification | Percentage of electromagnetic Shielding (%) |
|--------------------------|-------|------------------------------|----------------|---|
| Class I Professional use | AAAAA | SE > 60 dB | Excellent | ES > 99.9999% |
| | AAAA | 60 dB ≥ SE > 50 dB | Very good | 99.9999% ≥ ES > 99.999% |
| | AAA | 50 dB ≥ SE > 40 dB | Good | 99.999% ≥ ES > 99.99% |
| | AA | 40 dB ≥ SE > 30 dB | Moderate | 99.99% ≥ ES > 99.9% |
| | A | 30 dB ≥ SE > 20 dB | Fair | 99.9% ≥ ES > 99.0% |
| Class II General use | AAAAA | SE > 30 dB | Excellent | ES > 99.9% |
| | AAAA | 30 dB ≥ SE > 20 dB | Very good | 99.9% ≥ ES > 99.0% |
| | AAA | 20 dB ≥ SE > 10 dB | Good | 99.0% ≥ ES > 90% |
| | AA | 10 dB ≥ SE > 7 dB | Moderate | 90% ≥ ES > 80% |
| | A | 7 dB ≥ SE > 5 dB | Fair | 80% ≥ ES > 70% |



And these are the typical data for electromagnetic shielding textile materials. There are two types of cases, case one for professional use high end technical use and case 2 is for general application. So, if we want to have high end application for excellent result for excellent, we will get the decibel which is more than 60. So, if the shielding effectiveness is more than 60, then we can call it as excellent shielding where the percentage electromagnetic wave which is being blocked which is more than 99.99 percent.

On the other hand for normal application, if the shielding effectiveness is more than 30 decibel, we can call it as excellent ok.

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EMI shielding materials

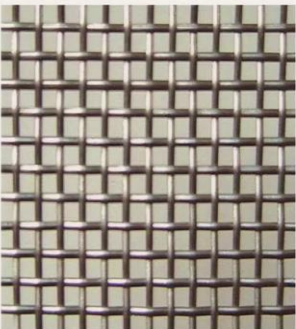
(i) Metals and alloys

Common metal: **Mu-metal**

- 14% iron,
- 5% copper,
- 1.5% chromium, and
- 79.5% nickel

Limitations:

- Heavy
- Expensive
- Rigid
- Easily prone to metal oxidation/corrosion



Metal mesh

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So, there are different types of materials available for shielding of electromagnetic radiation very common material is metal and alloys. So, common material is Mu metal. So, Mu metal is basically nickel, iron, alloy, but main problem with this metal is that they are heavy, expensive, rigid and it is prone to metal oxidation or corrosion. So, these are the problems, but still we can use this metals and alloys.


(Refer Slide Time: 27:29)

EMI shielding materials

(ii) Metal coated fabrics

Advantages

- Good shielding level
- Resistance to corrosion
- Light weight compare to metals



Nickel/Copper plated polyester fabric

Limitations

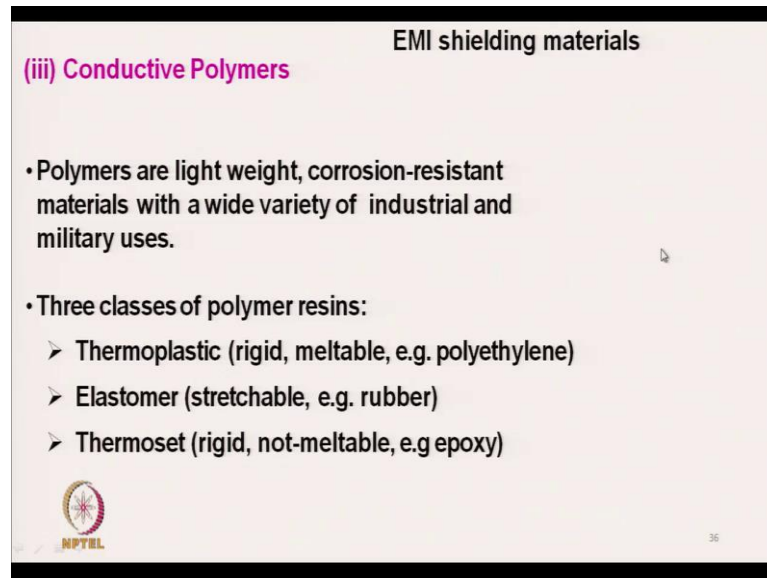
- Poor wear and scratch resistance
- Low mechanical properties and fabric flexibility

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Next is that metal coated fabrics. So, they have very good shielding effectiveness, very common product is nickel, copper plated polyester fabric; so, these are the nickel copper

plated fabric. So, they have high resistance to corrosion, light weight as compared to metals because only plating is there, but rest other material is polyester fabric. So, the problem of this type of material is they are poor wear and scratch resistance and low mechanical properties and fabric flexibility due to coating or plating the flexibility is reduced.


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EMI shielding materials

(iii) Conductive Polymers

- Polymers are light weight, corrosion-resistant materials with a wide variety of industrial and military uses.
- Three classes of polymer resins:
 - Thermoplastic (rigid, meltable, e.g. polyethylene)
 - Elastomer (stretchable, e.g. rubber)
 - Thermoset (rigid, not-meltable, e.g. epoxy)

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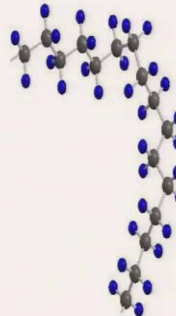
Next product is that conductive polymers. So, polymers are normally used for the lightweight corrosion resistance ok. So, they are used widely for industrial and military applications. There are different classes like thermoplastic which is meltable like polyethylene, elastomer which are stretchable material, we can use rubber, thermoset a rigid material, they are not meltable like epoxy. So, these are the normal polymers, but if we can make them conductive, this materials can be used as electromagnetic shielding material. So, these are the structure; this is the structure of conductive polymer.

(Refer Slide Time: 29:39)

EMI shielding materials

(iii) Conductive Polymers

- ❖ Polymers are generally NOT good conductors of electricity
- ❖ However, electrical conductivity is desired in various polymer applications:
 - Electrostatic discharge,
 - Electrostatic painting,
 - EMI shielding,
 - Lightning strike protection, etc.



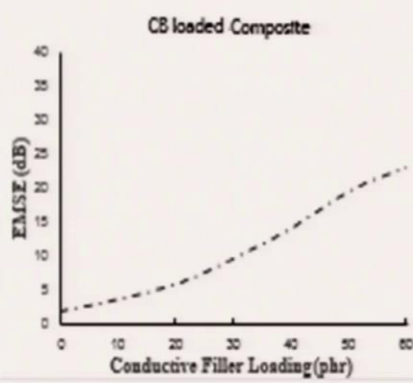
So, polymers are not good conductors; however, electrical conductivity is desired in various polymer application. So, this if we can make the polymers conductive, we can use in various applications like electromagnetic shielding ok, electrostatic discharge. So, there are different applications like lightning strike operation protection; so, we can use this material, but we have to first make the polymers conductive.

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EMI shielding materials

(iv) Conductive fillers

- Carbon black, metal particles etc..
- Mutual contact between filler particles
- Percolation points



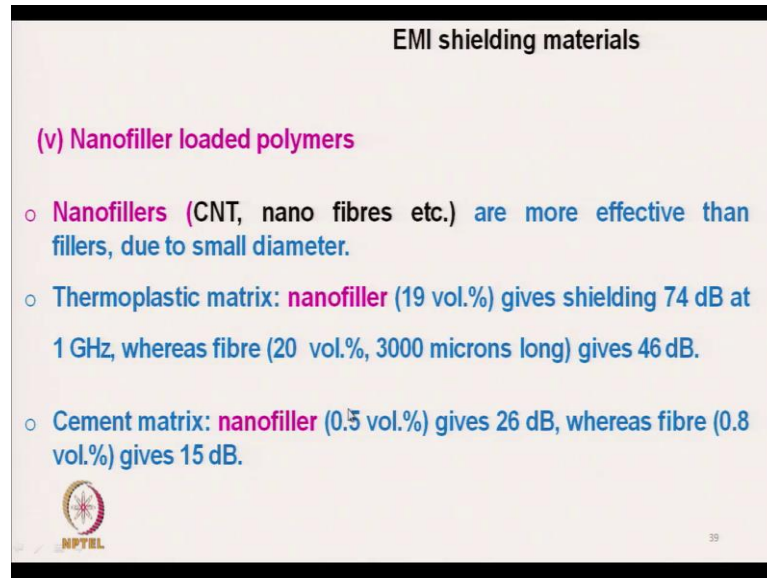
| Conductive Filler Loading (phr) | EMISE (dB) |
|---------------------------------|------------|
| 0 | 0 |
| 10 | 2 |
| 20 | 5 |
| 30 | 10 |
| 40 | 18 |
| 50 | 28 |
| 60 | 40 |



Fourth one is conductive fillers. So, like carbon black, metal particles if we can incorporate in the polymers, we can make them conductive; so, the electromagnetic

shielding effectiveness increases. So, these are the in x-axis it is a conductive filler loading is shown and as the loading increases, electromagnetic shielding effectiveness increases. So, this is due to mutual contact between filler particles.

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The slide is titled "EMI shielding materials" and contains the following text:

(v) Nanofiller loaded polymers

- Nanofillers (CNT, nano fibres etc.) are more effective than fillers, due to small diameter.
- Thermoplastic matrix: nanofiller (19 vol.%) gives shielding 74 dB at 1 GHz, whereas fibre (20 vol.%, 3000 microns long) gives 46 dB.
- Cement matrix: nanofiller (0.5 vol.%) gives 26 dB, whereas fibre (0.8 vol.%) gives 15 dB.

The slide also features the NPTEL logo in the bottom left corner and the number 39 in the bottom right corner.

So, that those were the normal macro particles, we can have nanofiller loaded polymers also. So, nanofiller loaded polymers like carbon nanotube, nano fibres this type of particles, if we can load within the polymers, these are more effective than normal fillers due to smaller size.

So, thermoplastic matrix, if we use and if we use nanofiller within that. So, 19 percent by volume will give shielding effectiveness of 74 decibel at 1 gigahertz frequency, whereas for with 20 percent of normal micron level particle will give only 46 decibel effectiveness. Similarly, cement matrix with nanofiller 0.5 percent by volume, if we give it will give 26 decibel effectiveness and for normal fibre with even higher volume for fraction 0.8 percent volume fraction, the shielding effectiveness will be dropped to around 15 decibel. So, we can see if we use nanofiller then we can enhance the shielding effectiveness.

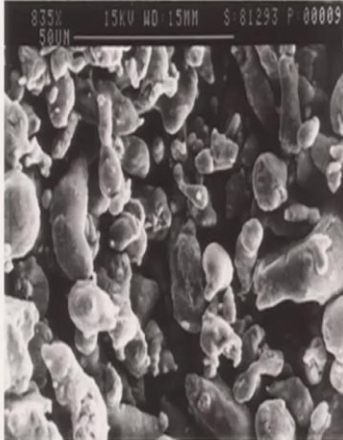
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EMI shielding materials

(v) Nanofiller loaded polymers

Limitations

- Mechanical and chemical modifications
- Dispersibility of fillers
- Poor long term stability; and
- Lack of processing methods



The SEM image shows a dense field of irregular, rounded nanofiller particles. Technical data at the top of the image reads: 8.35kV 15kV WD 1.5MM S-81293 P 00009. The NPTEL logo is in the bottom left corner, and the number 40 is in the bottom right corner.

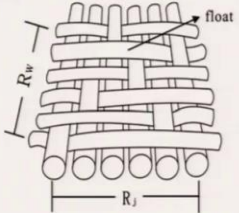
But main disadvantages of this nanofiller loaded polymers are mechanical and chemical modifications are there and dispersibility of this fillers. They are not dispersed easily, agglomeration may take place that part once you take care, poor long term stability and lack of processing methods; so, these are the problems.

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EMI shielding materials

(vi) Conductive fabrics

Conductive filament woven fabrics/Composites



The diagram illustrates a woven fabric structure with vertical and horizontal threads. Labels include 'float' pointing to a horizontal thread, R_{iv} for vertical thread spacing, R_j for horizontal thread spacing, and 'Woven fabric' below the diagram.

- Conductive yarns (like thin wire) can be laid vertical to each other which belongs to the class of small aperture metals.
- Continuous conductive network can be formed
- Tailorable shielding structures with better mechanical strength.
- Desirable fabric grid size and aspect ratio can be formed

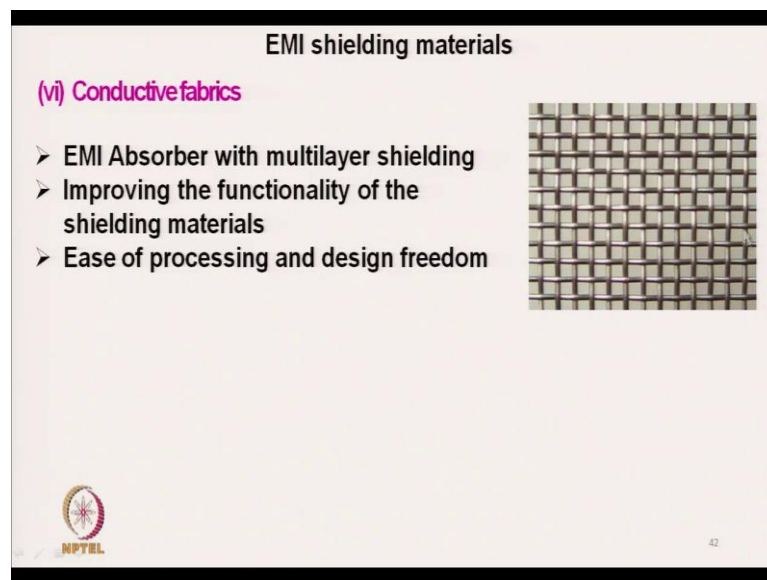
The NPTEL logo is in the bottom left corner, and the number 41 is in the bottom right corner.

And then it is a conductive fabrics which is the best solution, because this fabrics are flexible in nature. So, conductive filament woven fabrics or composites are used, the

conductive yarns like thin wire can be laid vertical to each other which belongs to the class of small aperture so, it will create small apertures.

So, continuous conductive network can be formed. So, these are the continuous conductive networks will be formed, tailorable shielding structure with better mechanical strength, we can tailor any fabric for any structure and they will have better mechanical strength, lighter weight they will be flexible, desirable fabric grids so, this grid size we can design we can actually engineer the grid size and the aspect ratio of this grids, we can create as per our requirement.

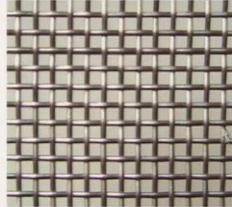
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EMI shielding materials

(vi) Conductive fabrics

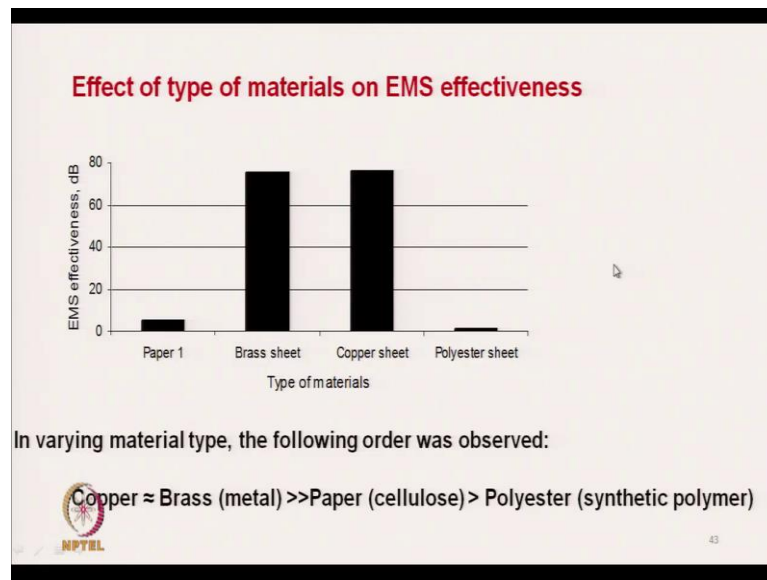
- EMI Absorber with multilayer shielding
- Improving the functionality of the shielding materials
- Ease of processing and design freedom



 NPTEL 42

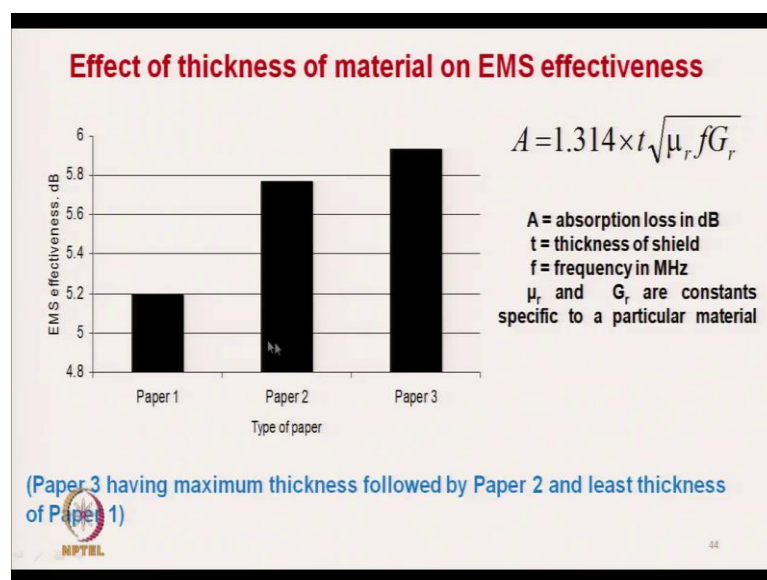
So, EMI absorber with multilayer shielding, improving the functionality of the shielding materials, ease of processing and design freedom; so, all this are the advantages of conductive fabrics.

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Now, we will discuss few factors which affect the electromagnetic shielding effectiveness. First if we see the type of material, here paper is used which is cellulose material then brass sheet is used, copper sheet is used, polyester sheet is used and it is very clear that metallic sheet they are giving very high electromagnetic shielding effectiveness as compared to the cellulosic or polyester sheet ok.

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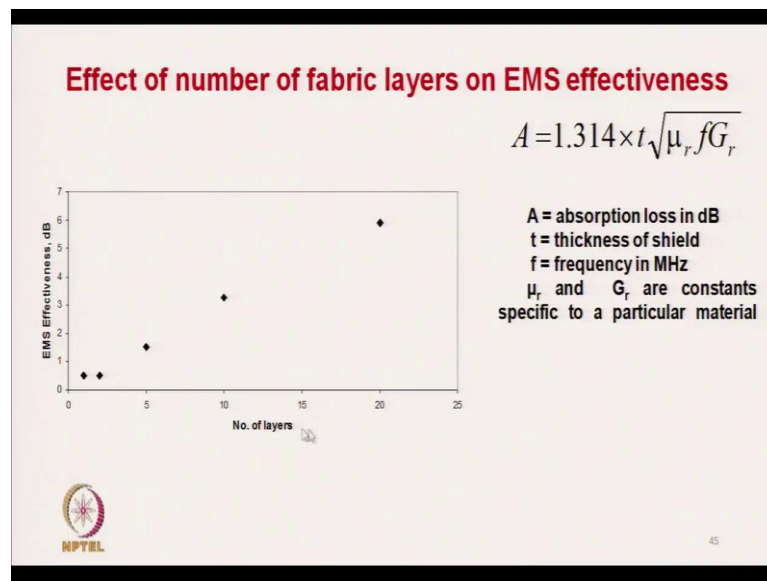


This diagram show the effect of thickness of the material. So, the paper 1, paper 2, paper 3 these are the different types of papers are being used with different GSM, Grams per

Square Meter and different thickness and paper 3 is having maximum thickness and paper 2 is having minimum thickness.

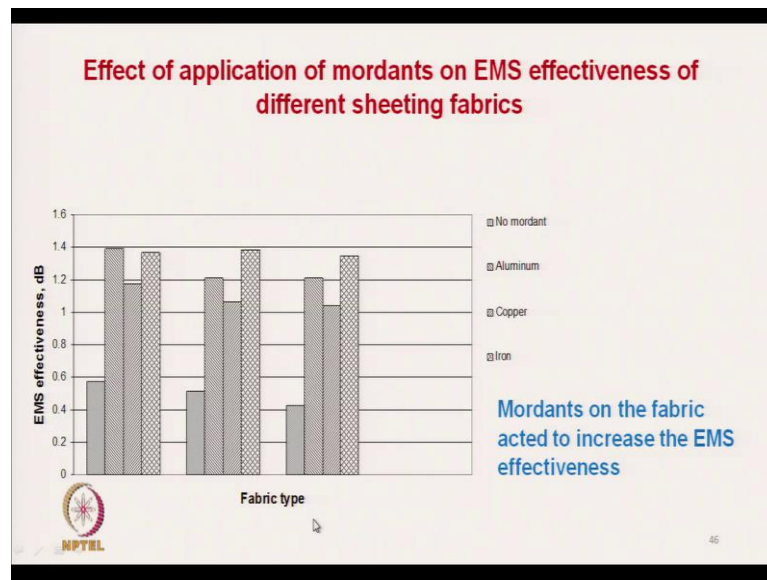
As per this equation, the absorption loss in decibel A is proportional to the thickness of the shield material, where if we keep the frequency and other parameters constant. So, as thickness increases, absorption loss also increases and here almost similar observations.

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What we have done? We have increased the number of layers of fabrics. So, number of fabric layer as we increase the number of fabric layer, thickness of the layers increases so, effectiveness also increases; so, shielding effectiveness in decibel increases gradually.

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And last part we have reached here, the effect of mordant on cotton fabric has been studied. So, first portion; first bar is showing the fabric without any mordant and other bars are showing the aluminum as mordant, copper as mordant and iron as mordant. So, if we see all this graphs, the use of mordant increases the shielding effectiveness significantly, the reason being as the mordants are metallic in nature, they will enhance the conductive nature of the fabric. So, these are the few parameters.

If you want to learn more about this, there are materials available in the literature, there are standard books available, but here what we have tried? We have tried to understand basic principles of measurement of shielding effectiveness of textile materials. So, we have reached to the end of this course, hope you have enjoyed this course, we will stop here.

Thank you, thank you for your patience.