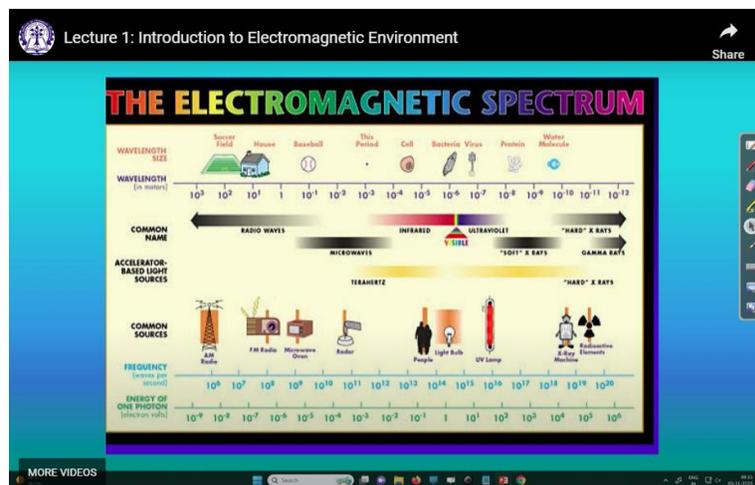


Course name: EMI /EMC and Signal Integrity: Principles, Techniques and Applications.
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Institute name: IIT Kharagpur
Week :01
Lecture 1: Introduction to Electromagnetic Environment

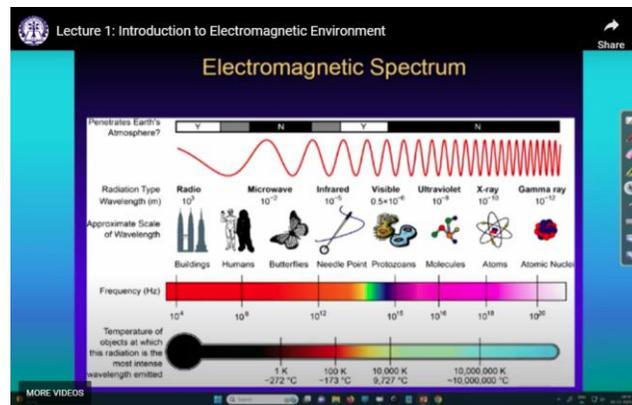
Welcome to the course on EMI EMC and Signal Integrity Principles Techniques and Applications. This is a system level course. So, this course will cover the high frequency effects that come into place when any signal or any subsystem any component in the subsystem of an electronic system is susceptible to high frequency effects. You know that at low frequency whatever happens the ball game completely changes when we go to high frequency because at high frequency various parasitic effects, various other radiation effects etcetera come into picture and so, many of the systems they get failures due to this high frequency effects. Suppose you have designed the circuit you have not thought about this high frequency effects and ultimately your design may not work even if it become it was a very innovative design, but the design may not work if you have not considered this high frequency effect. So, in this course we will try to address that effect and the first we will start today or this week with the introduction to electromagnetic environment.

Actually first we will have to know that what is the environment in which we are staying. Now when people talk about environment generally people mean that what is the habitat, what is the air, what is the water, what are the flora and fauna, but no one thinks that there is also an electromagnetic environment in which we live. So, let us see that I think all of you know that this is the electromagnetic spectrum electromagnetic spectrum. So, you can see that the it starts with if you think of wavelength it starts with even a soccer field type of thing the wavelength to house, baseball etcetera that means, from in meters if you think it is 1 kilometer and it can end into 1 picometer.



So, all these covers the electromagnetic spectrum in terms of frequency you can see that roughly you can think that it is actually it starts from 50 hertz, but roughly you can say that we can think of some kilo hertz to 10 to the power 20 hertz is the electromagnetic spectrum. Now there are common names given to the spectrum some portion of the spectrum. So, you can see that roughly there are radio waves which goes up to let us say 1 gigahertz and then from 1 gigahertz we generally have microwaves and after microwaves that means, after roughly you can say 1000 gigahertz you start with infrared then you have your visible light which is roughly from 10^{14} to 10^{15} hertz and then you have higher than that if you have frequency that is called ultraviolet then after that there are x rays and finally, there are gamma rays. So, you can the common sources of this spectrum or this electromagnetic waves they are you can think of radio waves. So, AM radio, FM radio then in every household there is microwave oven then if you go higher in microwave range there are radars in then we the next ones we do not think generally that we that means, a human being he also emits the wave that is generally infrared wave actually this is the technique by which in night you can detect a person by infrared sensing then light bulbs they emit visible light then you have UV lamp ultraviolet lamp which is used for various heating effects also then you are familiar with x ray machines. x ray machines are used for medical purposes, but also for various non destructive testing various industrial applications they are used then you have radioactive elements they are used you know in medical they use are used for cancer therapy and they also have various industrial effects. Now in terms of energy of photon it is also given that you can the AM or radio waves they have quite low amount of energy. So, they are roughly 10^{-9} to 10^{-6} electron volt for every photon actually you know that the wave and particle actually wave have dual electromagnetic waves they have dual nature wave nature and also particle nature. So, this is if the one photon what is the energy that gives you an idea that how much the electromagnetic wave is carrying that energy. So, these are that means, low energy things this radio waves, microwaves etcetera that is why when people say that microwave is dangerous for health it is a actually very wrong idea because it is energy is not much. So, it cannot ionize our body and that is why it is quite safe till now though still research is going on whether there is any harm, but actually it does not cause any harm because it cannot produce ionization in our body because it does not have that much energy only it produces some heat that heat is same as the heat that if you go outside in sunlight and the heat to which you are exposed if you are irradiated by microwave also the heat is not more than that. Now, if you go higher in frequency then your energy starts increasing. So, people that means, we emit the wave we emit in that it is roughly 0.1 electron volt then light bulbs they are 1 electron volt and you know that more higher you go in x ray, gamma ray they are huge waves they have 10^4 electron volts that means, 10 kilo electron volt or 100 kilo electron volt. So, that is dangerous. So, that is why it you should be minimally exposed to this high frequency a high power waves.

high power right side the left side is low power similarly in frequency the left side is low frequency right side of this spectrum is high frequency and wavelength wise the left side is large wavelength right side is small wavelength. So, this is the electromagnetic spectrum. An interesting thing is this electromagnetic spectrum so that means, this type of waves- does it penetrate earth's atmosphere? Now, there are two sides of it one is if the dangerous wave comes from outside then that will harm us fortunately you see that after visible light there is in the right side of the spectrum it cannot penetrate earth's atmosphere that is why the ultraviolet rays , x rays, gamma rays etcetera they do not penetrate earth's atmosphere. Fortunately there is you see again in the low frequency side there is microwaves etcetera they also cannot penetrate earth.



Fortunately in between them there is a window which is the visible light or infrared lights window there from it can penetrate earth's atmosphere. Now that is why we get light if this was not possible that means, if this window was not available we would not have got sunlight also in the low frequency you can see that it can also penetrate earth's atmosphere. So, this is one side of the story another side of the story is if we want to send some wave can we do that? fortunately yes. that in lower frequencies you can see that there is a window available in which we can send by some techniques. So, that you can get the satellite communication etcetera possible and you can see that this already the approximate scale of wavelength already has been seen that radio waves largely you can see that a building size is the wavelength size. So, that means, the one building almost the height of a building that covers the wavelength of radio wave whereas, microwave you can think that it is something like a size of a butterfly and infrared the wavelength is very small like a needle point then visible light it is like protozoa which we cannot see by our eyes ultraviolet etcetera their wavelength is like molecules x rays are like atoms none of these we can see by our eyes gamma ray that is like atomic

nucleus which is further smaller . And temperature of objects at which this radiation is the most intense there, there the interesting thing is you see we humans we emit what is our temperature our temperature is less than 1 Kelvin that means, very cold at which we emit something and actually there was a study one scientist he got Nobel Prize due to these that the ambient microwave radiation that is present in the atmosphere is 4 degree Kelvin. So, similarly you can see that as you go higher in frequency the temperature at which that emission takes place that increases and finally, in x ray etcetera it is almost 10^8 degree centigrade type of thing so, very hot. Now, this is you see that source of electromagnetic radiation this is extraterrestrial- you see galaxies, you see various systems that means, various star systems all that emits electromagnetic wave may be gamma rays, may be various x rays may be microwaves, may be radio waves so, all sorts of these are emitted. So, from outside earth extraterrestrial there from we also get radiation. this is another that extraterrestrial various stars distance stars various galactic waves they also have these. Now, another very important extraterrestrial source of electromagnetic waves is sun.



So, solar flare it produces a huge magnetosphere that means, a huge magnetic field and when the solar flare comes actually all the satellite etcetera their communication stops. So, this all satellite companies satellite service provider they keep a calendar of the solar

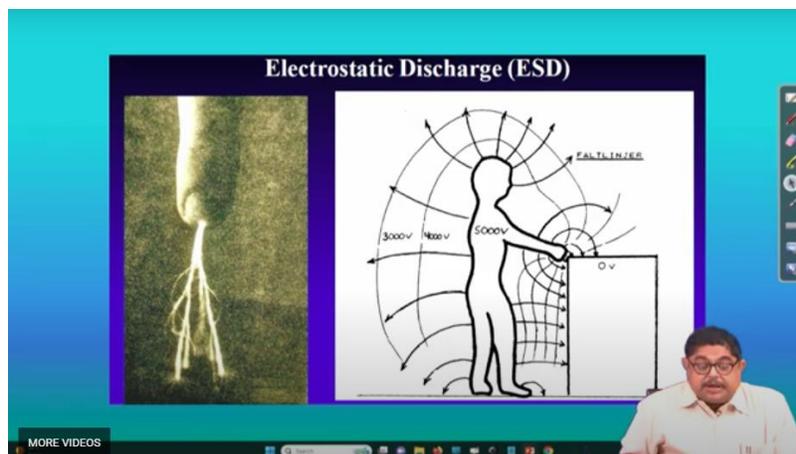


flare actually people have studied this solar flare and know that when it will be coming so, in that extra precaution is taken to have the communication etcetera disruption how to handle that. Then you this is a familiar thing you see that terrestrial so, lightning. So, lightning we see often that is also a very very important source of electromagnetic radiation all of these are familiar with this source then you see the telecommunication centre. So, this is a cellular centre you can see you can see that lightning you can see a cellular phone that also emits then the power transmission line that also is doing that subscriber premises where you have your telephone you have your teleprinter all these emits electromagnetic waves.

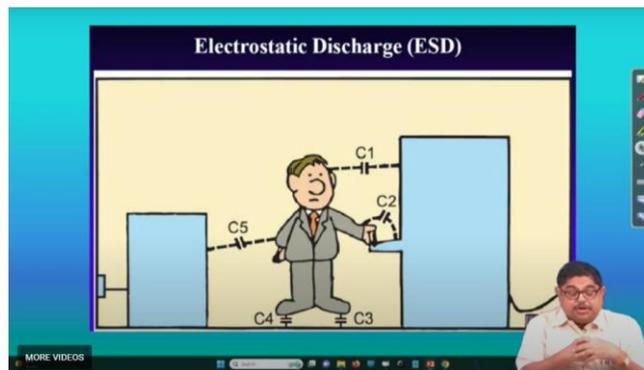


Now, this is another thing that electrostatic discharge. So, it is not electromagnetic, but all of us since you see that our body is an insulator. So, but inside our body there may be even if we do not touch any charged body we have a huge potential and so, our body is charged. Now whereas, earth it is a very good conductor now suppose you see this lady she is touching this a charged body a charged sphere actually this is for some experiments this type of charge is generated. Now, the charge generator Van de Graaff generator etcetera and the moment she is charging it you see that her hairs they are all get straighten up because there is an opposite charge here and they are repelling here.

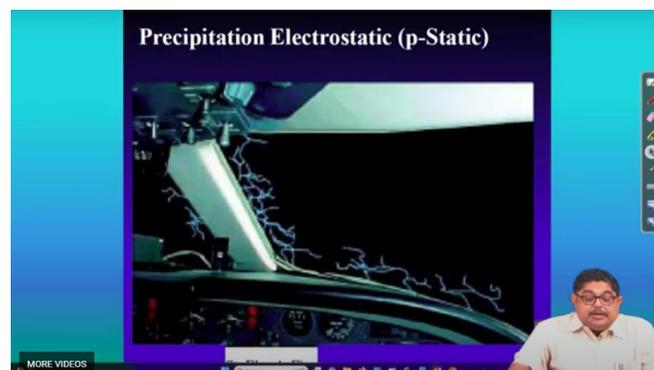
Similarly, suppose you are touching a some electronic devices you have charged here your fingers they are sharp that is why they also have charge. So, sometimes between them there may be an arcing possible in printed circuit boards there are currents etcetera flowing. So, between them there may be some charge and that potential may disturb them that is why the electrostatic discharge is also a source of electromagnetic radiation when the discharge take place. Otherwise when it is in the static electricity form it is not a problem, but when the discharge take place it discharges through the air and that time it produces an electromagnetic wave that will see what is a type of thing we will discuss electromagnetic electrostatic discharge in a later class. So, you see that a human body this is a model of a human body and you see we are charged to 5000 volt some parts of us are 4000 volt that means, 5 kilo volt you are charged and suppose you have a metallic object let us say refrigerator, refrigerator is grounded.



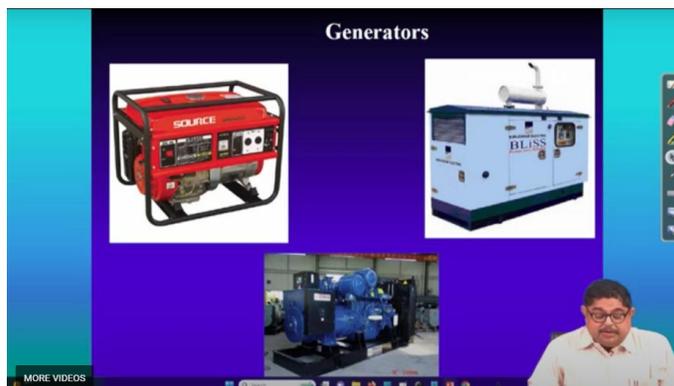
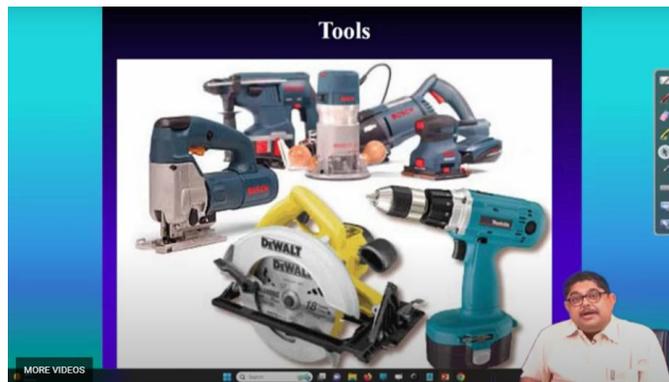
So, it is 0 volt now sometimes if your this charge in your body is sufficient you suppose you have come from outside you have taken your woolen sweater and that time there is a friction of that woolen sweater with your undergarments or your body and so, there will be charge accumulated. Now you go and touch after that the refrigerator you will get a shock you think that the refrigerator has some problem, but no refrigerator is perfectly ok the moment you are touching it it is giving those charges inside you a conducting path and that is why you are getting a shock. So, all these problems need to be analyzed need to be understood so, that you can try to live in this environment. So, this is another model that if you are charged and this one is uncharged. So, there are actually capacitance between you.



So, how you can model that? So, you can find out all these values of these C 1, C 2, C 4 and this is an engineering way of solving the electrostatic problem. The previous problem that you have seen that you are getting a charge, but then you need to calculate that whether I will get that shock or not. So, you can calculate by this way we will see this thing later. Then there is also another interesting effect in initial days it was not understood by people actually there are some fire in the in a aircraft that is when the air flows over the aircrafts wings that time some electrostatic discharge takes place. Now that if it gets a path it gives rise to some some hazards that is called precipitation electrostatic p static.



Actually many of the earlier days satellites their malfunction is nowadays attributed to these actually whenever a malfunction takes place the satellite companies or aviation companies they does an investigation and for years that investigation goes and finally, people later came to know many years after that this is due to p static. So, now how to prevent p static or how to ah make your system not susceptible to p static that is a art. So, engineers EMC engineers should know how to do that. So, these are also I am just will now go through some slides to show you that we do not think, but suppose you are running a drill machine you are getting electromagnetic wave, you are putting on a generator running a generator etcetera you are getting wave, you electrical power is getting transmitted you are getting electromagnetic wave same thing electrical power is generated transmitted etcetera. Then you see your your fridge is working your washing machine is working your various electronic gadgets your electrical oven is working your dishwasher is working you are getting electromagnetic waves calculator, camera etcetera etcetera. your computer is running, your printer is running , your keyboard is running, heavy vehicles ,ships all produce electromagnetic wave because they all have some electrical systems and they are producing these engines.



Electrical Power

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A collection of consumer electronics products including a blender, rice cooker, coffee maker, and various mobile devices like smartphones and MP3 players.

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A collection of computer hardware products including desktop towers, monitors, printers, and laptops.

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Vehicles



Four images showing large industrial vehicles and structures: a red gantry crane, an offshore oil rig, a yellow offshore platform, and a bridge.

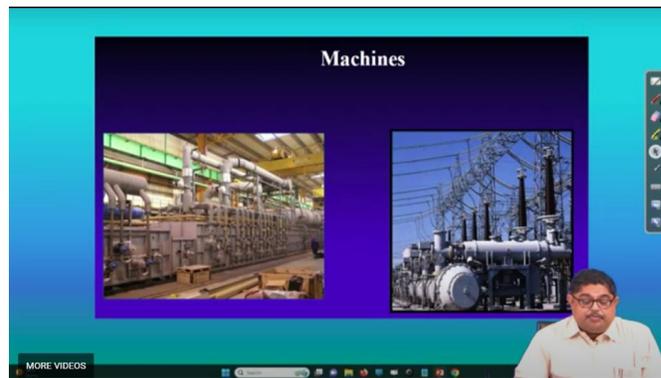
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Engines

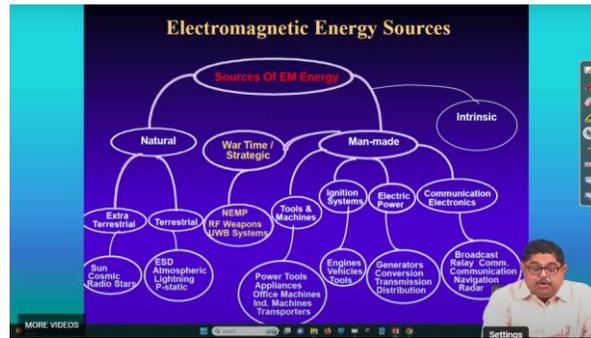


Three images of engines: a car engine, a truck engine, and a large industrial engine.

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Obviously, when they are moving they are rotating magnetic field electric field. So, they will produce machines satellites satellites do lot of communication. So, they also produce to the earth they are giving some electromagnetic wave also from the earth some electromagnetic wave is going to satellites to give its command to communicate with it. So, all that gives you. So, now we can categorize that what are the typical sources of or what are the categories of electromagnetic energy. You see broadly there are 4 types : one is natural as we have seen that these extra terrestrial terrestrial sun cosmic waves radio stars all are natural sources of electromagnetic energy. So, in natural there are terrestrial sources as we have seen and then ESD electrostatic discharge atmospheric lightning, P static all of these are natural. Then come to manmade you see most of the previous diagrams I have shown you they are manmade electromagnetic energy sources like tools and machines, power tools appliances, office machines transporters etcetera. Another manmade group is ignition systems, engines vehicles, tools then electrical power generators conversion transmission of electrical power distribution of electrical power all these are manmade. Another manmade is communication electronics broadcast, relay, navigation, radar etcetera.



Now another variety you see that intrinsic. intrinsic means it is you cannot avoid that if you have a resistor, if you have an inductor, if you have a transistor, or if you have a diode—all these will produce electromagnetic energy why because they have inside them electrons they have inside them protons. So, there is a charge difference now electrons and protons electrons are moving. So, or in case of semiconductor electrons and holes they are moving. So, any movement and they are also accelerating. So, they will produce electromagnetic energy. So, intrinsic it is part of manmade, but it always comes. So, we have seen natural we have seen manmade we have seen intrinsic. Then from manmade another variety which is made here is that it is not so required one day probably society will not have this type of sources, but now you see war everywhere and in what time or strategic thing you have this various electromagnetic energies are deliberately produced and they are dangerous. One of them is we will discuss this nuclear electromagnetic pulse, dangerous RF weapons nowadays this weapons are coming up which are this radio frequency based, microwave based or even higher frequency based then various UWB system. So, all these produces electromagnetic energy.

So, intrinsic that I was saying there is a slide on it. So, you see that any thermal noise that time you are getting an electromagnetic energy emitted. In any active device you have short noise any flicker scintillation you have low frequency emitted any in any active devices as I was saying there are delay or recombination. So, you have high frequencies.

Intrinsic

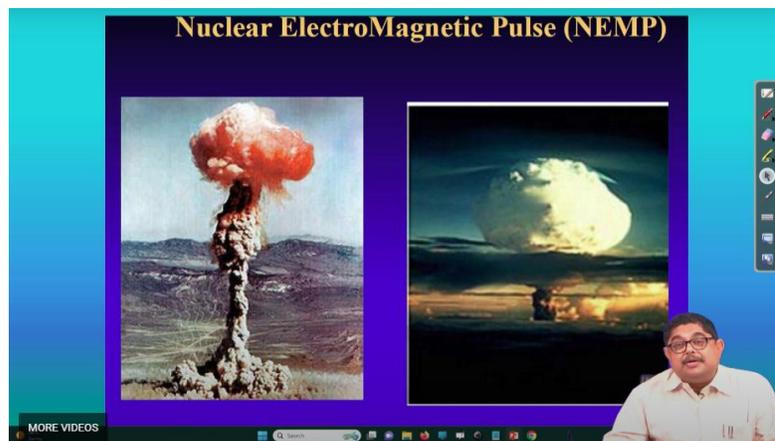
1. Thermal – passive – resistors
2. Schottky (Shot) - active
3. Scintillation (Flicker) - low frequencies
4. Delay or re-combination - active devices - high frequencies

Now there is slide on that what time strategic.

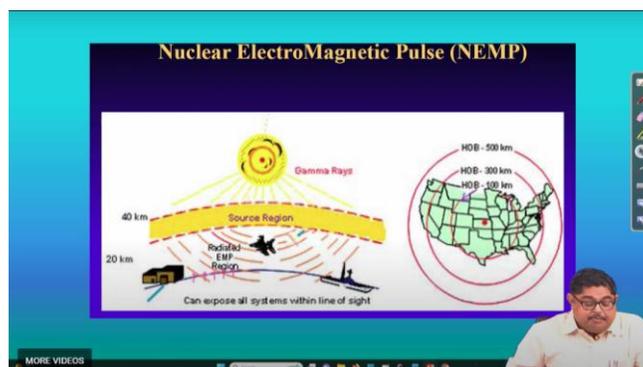


So, there are nuclear electromagnetic pulse then ultra wide band systems then tempest. Tempest is an interesting phenomena that you know that if you have if you are typing here suppose some secret thing is being typed that keyboard. So, those buttons in the keyboard the keys in the keyboard they you are pressing some key that has a signature. So, can you detect from a distance that signature. So, that means, definitely there is an electromagnetic source when you are pressing a key in the keyboard and that or you are printing something now different letters they have some different signatures can you find out what is that. So, that is called tempest and RF weapons as I was saying that suppose you want to disburse a crowd. So, you put microwaves to them. So, for some time they would they would not be able to see what is coming, but there will be due to the heat etcetera of RF weapons you will find that there will be very you will be feeling very uncomfortable there will be maybe that you are getting dehydrated. So, people go away then high power microwaves that is also another area by which this susceptibility to various systems get tested also there are those are used as weapons etcetera. So, these are the military forces these things are talked about lot they research they you pour a huge money on this. So, this is also is a very nowadays becoming very high or very substantial amount of energy is coming out from this wartime strategic electromagnetic sources.

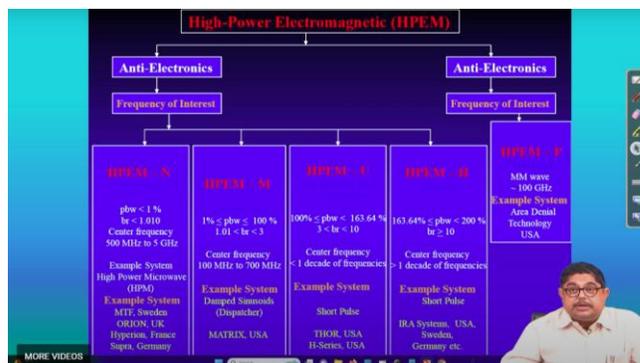
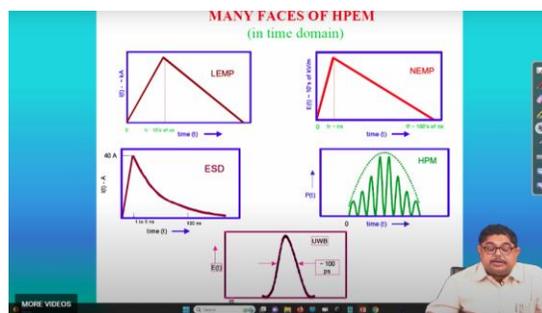
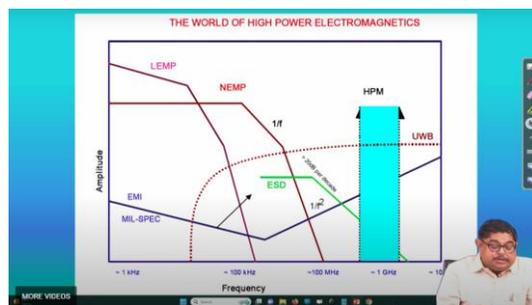
So, NEMP- what is NEMP it is nuclear electromagnetic pulse actually if there is a nuclear explosion then particularly in the atmosphere then the wave that comes down that energy that comes down. So, in the atmosphere they ionize the thing and from gamma ray a pulse called nuclear electromagnetic pulse get produced whose frequency is something like microwave and when it comes to earth any electronic system that becomes non functional to it. it is not that it gets destroyed after sometime it recovers, but for sometime it gets non functional. So, that is a very a thing that for sometime if you your electronic systems do not work the whole thing there the electronic system would not work it will be in today's civilization it is dangerous. So, people will have to have mitigation for these.



So, that saying radiated EMP region you can see and so can exposed all systems within line of sight.



So, this is I am saying that frequency wise you can see that this first is LEMP that is lightning, lightning has high value at very low frequency, but it comes down and after 100 kilohertz it does not have any effect. NEMP is also high value, but after 100 megahertz etcetera it goes down, but the dangerous thing is this high power microwave measurement. Because at microwave range it has huge amplitude and also this UWBC system, ESD is in between. So, this is and in time domain if you want to see you see that rise time of a lightning pulse is tens of micro seconds per second, but the time is very high.



So, the rise time of a lightning pulse is tens of micro second for NEMP it is of the order of nano second for high power microwaves you see it is for a lot of time it is there for UWB half power time is 100 picosecond and for ESD it is 100 micro seconds. So, for ESD the rise time is 1 to 5 nano second why I am talking rise time because you know rise time will determine how much high frequency effect it has ok I think time is up. So, we will discuss some more in the next lecture.