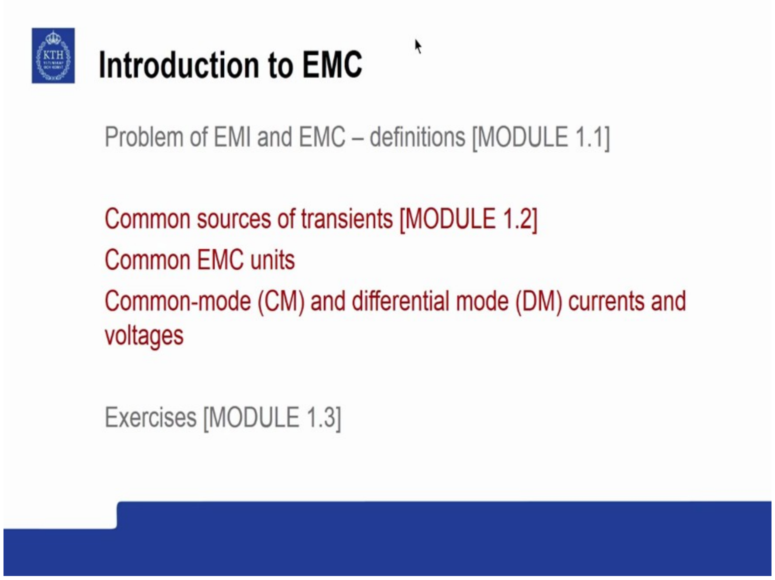
Electromagnetic Compatibility
Professor Rajeev Thottappillil, Daniel Månsson
KTH Royal Institute of Technology, Sweden
Module 1.2
Introduction to EMC - Sources, units, etc

So now we are still in the introduction. We go to module 2 of chapter 1. The numbering is like this, module 2 in chapter 1 will be designated as module 1.2, 1.3, like that. If it is chapter 2, it will be module 2.1, 2.2, like that. The first number is the chapter and the second number is the module, after the point.

(Refer Slide Time: 0:46)



Introduction to EMC

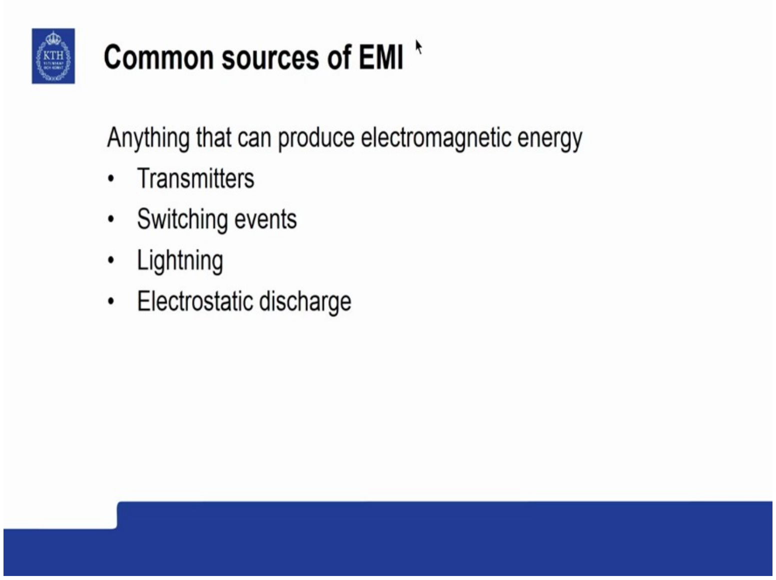
Problem of EMI and EMC – definitions [MODULE 1.1]

Common sources of transients [MODULE 1.2]
Common EMC units
Common-mode (CM) and differential mode (DM) currents and voltages

Exercises [MODULE 1.3]

We introduced the concept of EMI and EMC in module 1. In this module, we will go through common sources of transients, common EMC units and also the concept of common mode as well as differential mode currents and voltages.

(Refer Slide Time: 1:10)



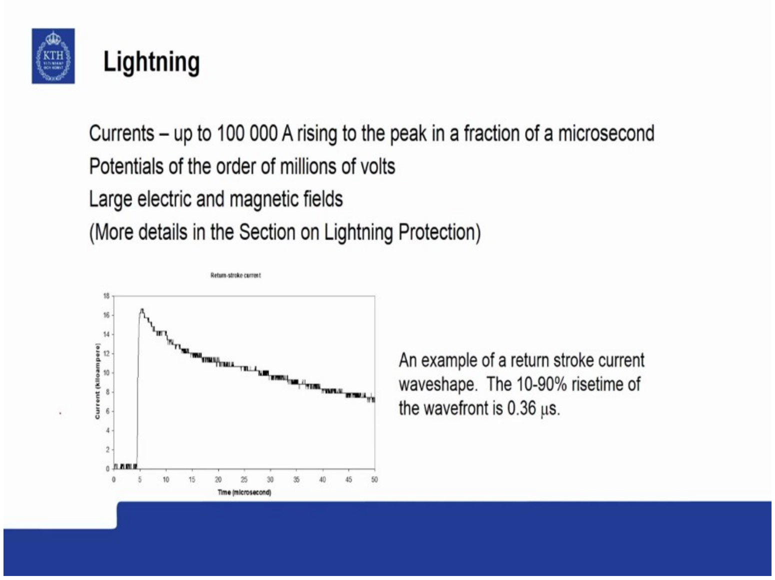
Common sources of EMI

Anything that can produce electromagnetic energy
- Transmitters
- Switching events
- Lightning
- Electrostatic discharge

Anything that can produce electromagnetic energy is a source, a noise. It can be any kind of transmitter producing electromagnetic energy, it can be mobile phones or it can be radio transmitters, radar or anything. And any switching events can potentially produce noise, if you just switch on the lights, the sparking at the switch can produce noise, both conducted as well as radiated with certain frequency content in it. The natural phenomena like lightning is a severe source of EMI problems.

Then we have electrostatic discharge from rubbing two materials together or from human body when you pick up some components or something. Now there can be discharge happening between the body and that object. So that also is a source of EMC and can potentially harmful to electronics.

(Refer Slide Time: 2:27)



Lightning

Currents – up to 100 000 A rising to the peak in a fraction of a microsecond

Potentials of the order of millions of volts

Large electric and magnetic fields

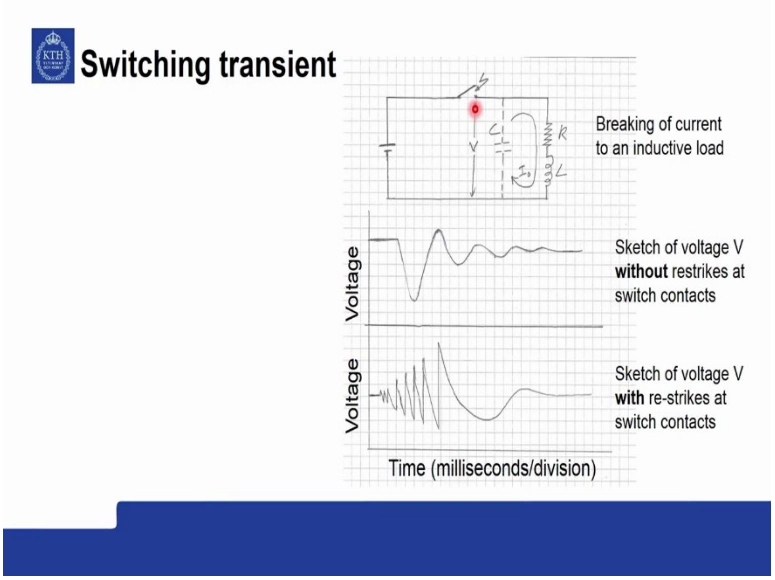
(More details in the Section on Lightning Protection)

An example of a return stroke current waveshape. The 10-90% risetime of the wavefront is 0.36 μs.

Now let us look at lightning. What is shown here is a small portion of a lightning current waveform. It is called a lightning return stroke. We will see more details of lightning when we discuss lightning protection. So here on x-axis is the time. So the time-base is in microseconds. So the total time is 50 microseconds here, the whole lightning flash may last up to one second with several events in it. So this current, this peak current for this particular return-stroke impulse, it is in terms of kiloampere, 16 or 18 kiloampere.

So this is an example of return stroke wave shape. The 10 to 90% rise time of the wave-front is 0.36 microseconds. So the currents up to 100,000 amperes and rising to the peak in a fraction of microsecond can be produced by lightning return strokes, and the potentials can be of the order of millions of volts and this produces very large electric and magnetic fields. Very close to the lightning, you can have fields of the order of 100 kilo volts per metre. That is extremely high electric fields. So more details we can see in the lightning protection.

(Refer Slide Time: 4:42)



Switching transient

Breaking of current to an inductive load

Sketch of voltage V **without** restrikes at switch contacts

Sketch of voltage V **with** re-strikes at switch contacts

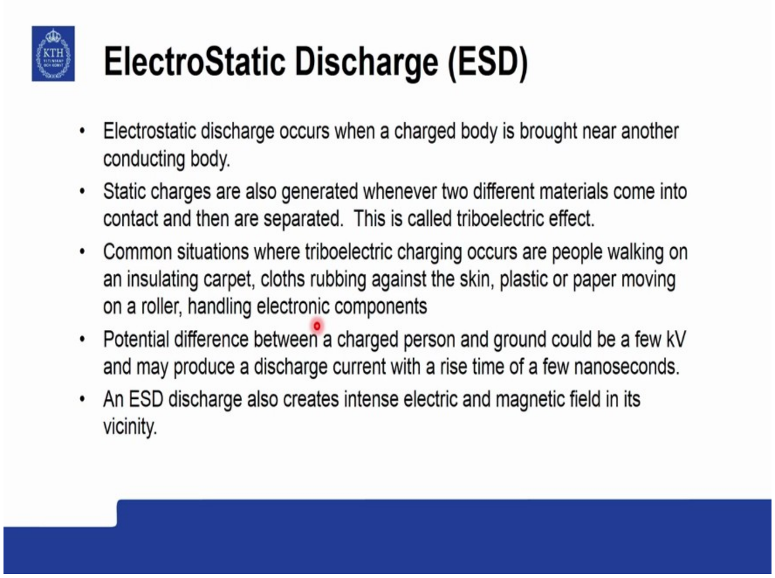
Now switching transients. Switching transients are very common, a common day occurrence, whenever you switch any device or light. Here a battery is shown and a switch, a mechanical switch that is closed and open. And your load may be in the form of resistance and inductance. Inductance is a storing element. It can store electromagnetic energy and you can have parasitic capacitance here because if you have two metal pieces across the switch contacts, you can have a capacitance across it.

It may be in Pico Farads but still, there is a capacitance. So this inductance and capacitance together, inductance of the load and parasitic capacitance together can form a resonating circuit, and this coupled with the breaking and closing of the switch can create noise. Say for example, across the switch, you have a potential difference between these two terminals and when this switch is open, this potential difference will create an arc sometimes. So you can have switching with arcing and without arcing. And with arcing it will have more severe noise issue, EMI issue.

For example, see the sketch of a voltage without restrikes. Restrikes are arcing at a switch contacts. Since voltage across switch contacts may be time varying because of this resonance phenomena and without arcing you can have a damped sinusoidal waveform across the switch. But with arcing, you can have several restrikes and finally it comes to a steady state. A sketch of voltage V with restrike at switch contacts is shown. Time scale is in milliseconds per division. So you can see that there are high-frequency content in this arcing.

So depending upon the design of your circuit and the switch, it can produce devices that produce lot of noise or less noise.

(Refer Slide Time: 7:42)



ElectroStatic Discharge (ESD)

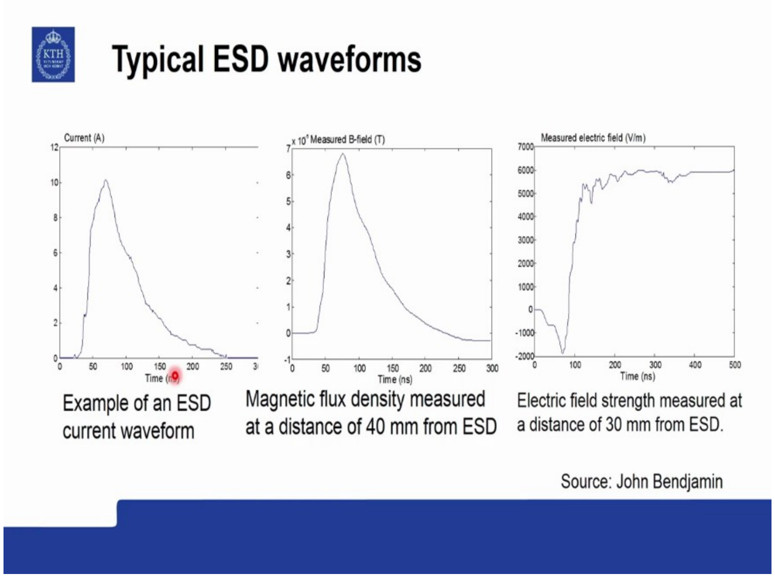
- Electrostatic discharge occurs when a charged body is brought near another conducting body.
- Static charges are also generated whenever two different materials come into contact and then are separated. This is called triboelectric effect.
- Common situations where triboelectric charging occurs are people walking on an insulating carpet, cloths rubbing against the skin, plastic or paper moving on a roller, handling electronic components
- Potential difference between a charged person and ground could be a few kV and may produce a discharge current with a rise time of a few nanoseconds.
- An ESD discharge also creates intense electric and magnetic field in its vicinity.

Electrostatic discharge: Electrostatic discharge occurs when a charged body is brought near another conducting body, and the static charges are generated whenever two different types of materials come into contact and are then separated. This is called triboelectric effect. The common situations where triboelectric charging occurs are when people are walking on an insulating mat or carpet, clothes rubbing against the skin, plastic or paper moving on a roller in industrial processes, handling of electronic components.

ESD is a big problem in paper industry and plastic industry, whenever you have situations of material passing over rollers, because, it can produce micro dimensional pinholes into the materials. So they have to control electrostatic discharge at any cost. While handling electronics, we use straps on the wrist, then grounded to reduce the danger of your body getting charged and damaging the components. The potential difference between a charged person and ground could be a few kilo volts and may produce discharge with a rise time of a few nanoseconds.

A few nanoseconds rise time means that you are talking of frequencies of several hundreds of megahertz and close to gigahertz. Then within electronic components, ESD also creates intense electric and magnetic fields in its close vicinity. This can couple to other adjacent printer circuit tracks and create problems.

(Refer Slide Time: 10:00)



Typical ESD waveforms

Example of an ESD current waveform

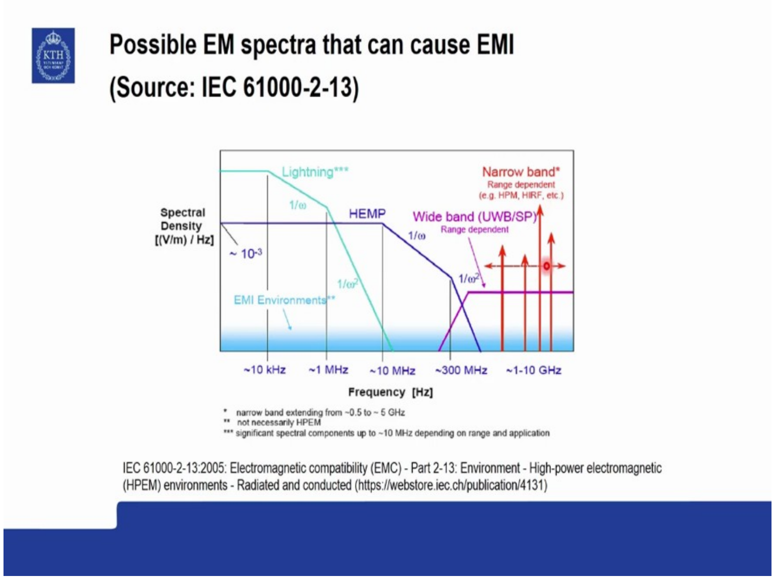
Magnetic flux density measured at a distance of 40 mm from ESD

Electric field strength measured at a distance of 30 mm from ESD.

Source: John Bendjamin

What is shown here are some typical ESD waveforms. Left is an example of a current waveform, time in nanoseconds and current in amperes. So this typically represents a human body type of ESD, arising between human body and some metallic objects. Middle one shows the magnetic flux from that type of currents and right one shows the electric field strength measured around a few centimetres away from the discharges.

(Refer Slide Time: 10:48)



Possible EM spectra that can cause EMI (Source: IEC 61000-2-13)

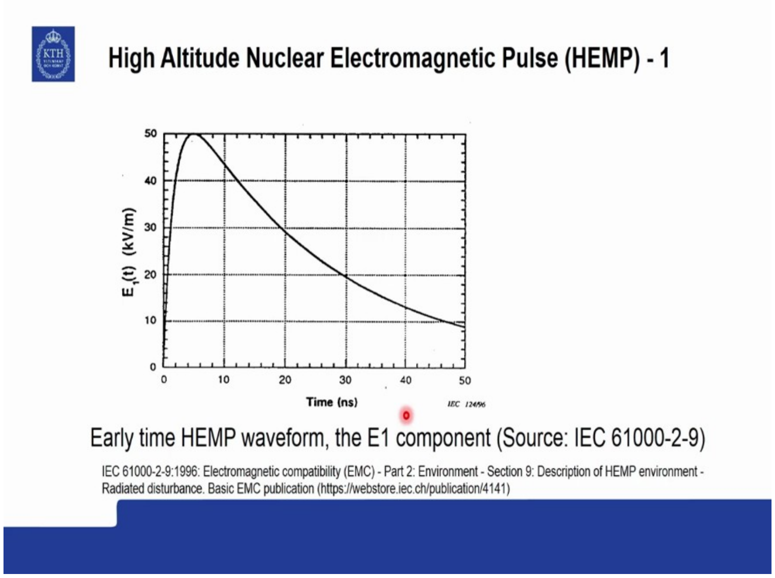
* narrow band extending from ~0.5 to ~ 5 GHz
** not necessarily HPEM
*** significant spectral components up to ~10 MHz depending on range and application

IEC 61000-2-13:2005: Electromagnetic compatibility (EMC) - Part 2-13: Environment - High-power electromagnetic (HPEM) environments - Radiated and conducted (https://webstore.iec.ch/publication/4131)

Now what could be the possible spectra that can cause EMI. In fact, it can be any known spectra of radio frequencies and low-frequency waves. This graph is taken from the International electro technical commission standard 61000. The details of the standard is given here. Electromagnetic compatibility part 2-13 while defining the high-power electromagnetic environment - radiated and conducted. So this is the website but even though this particular standard is talking of high-power electromagnetic interference, the spectrum here covers the complete frequency spectrum of radio waves and vertical axis is spectral density.

See below 10 kilo hertz. So we are in the power line harmonics, 50 hertz harmonics are somewhere here. Then switching transients maybe somewhere over here at 10-1000 kHz and also lightning, it has got very high energy at lower frequencies. High-power letter magnetic pulse from nuclear explosions and all, it has got much wider bandwidth, up to 300-400 megahertz. Then narrowband high-power microwaves, high-intensity radiated frequency, et cetera, that they come here in small narrow bands or very wide band, single narrow pulses can come over 300 MHz. Cellphones are operating in sub-GHz to GHz range where they can be susceptible for this type of frequencies. So basically as far as noise is concerned, the whole spectrum starting from sub 50 hertz even DC to several gigahertz are possible candidates for EMI problems.

(Refer Slide Time: 13:09)



High Altitude Nuclear Electromagnetic Pulse (HEMP) - 1

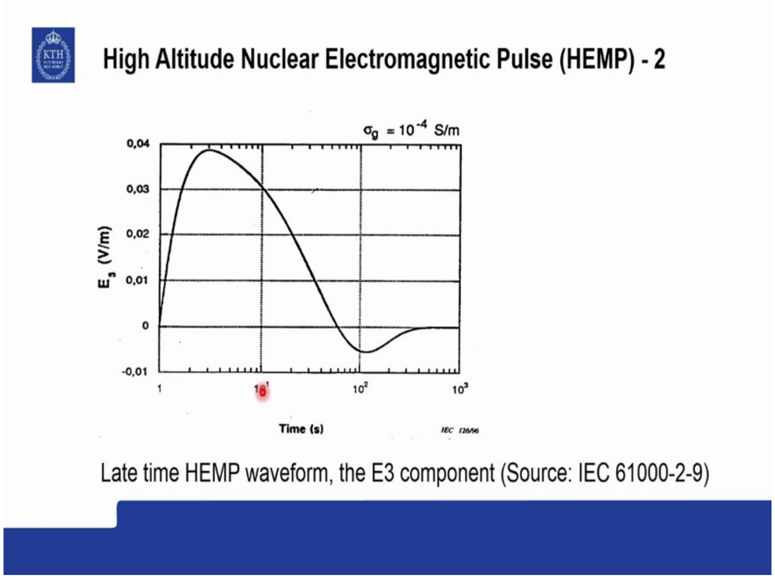
Early time HEMP waveform, the E1 component (Source: IEC 61000-2-9)

IEC 61000-2-9:1996: Electromagnetic compatibility (EMC) - Part 2: Environment - Section 9: Description of HEMP environment - Radiated disturbance. Basic EMC publication (https://webstore.iec.ch/publication/4141)

Now some examples from IEC standards are taken to show the waveforms of not very common sources of EMI issues, but if it happens, that becomes severe because it can affect the whole cities or whole countries. For example, high altitude nuclear electromagnetic pulse HEMP. Many of the critical systems in several countries are designed to withstand high altitude nuclear electromagnetic pulse, critical command and control systems of military and civilian systems in some cases.

For example, early time or E1 component of the HEMP waveform is shown here, timescale is nanosecond and vertical axis is in kilo volts per metre. So if it is decided that a system should withstand HEMP, then this is the type of waveform that are considered in civilian systems.

(Refer Slide Time: 14:17)

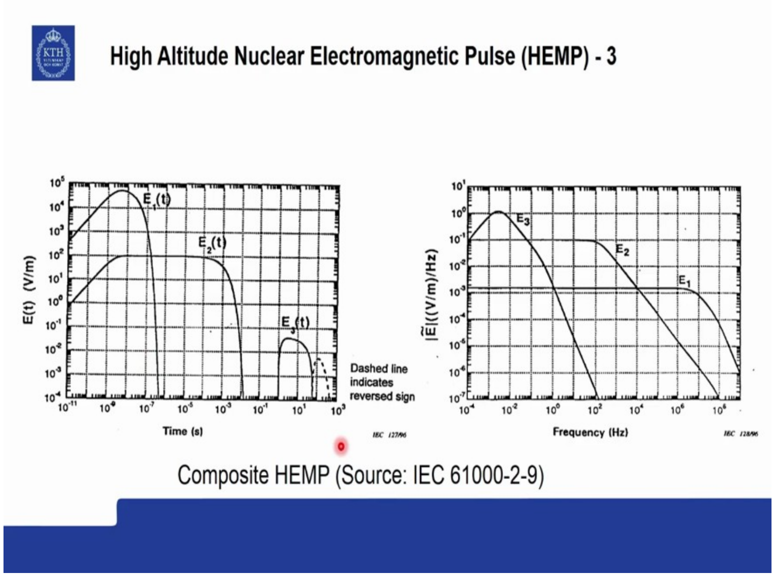


High Altitude Nuclear Electromagnetic Pulse (HEMP) - 2

Late time HEMP waveform, the E3 component (Source: IEC 61000-2-9)

And the E3 or late time component of the HEMP waveform, is shown here. Here the time is in seconds. So 10 seconds, 100 seconds etc. So high altitude nuclear EMP, E3 component has got lot of energy but amplitudes are much smaller, but it can produce problems with very long transmission lines, very long pipelines, et cetera by inducing slowly varying dc offset voltages and currents driving power transformers into saturation.

(Refer Slide Time: 14:57)

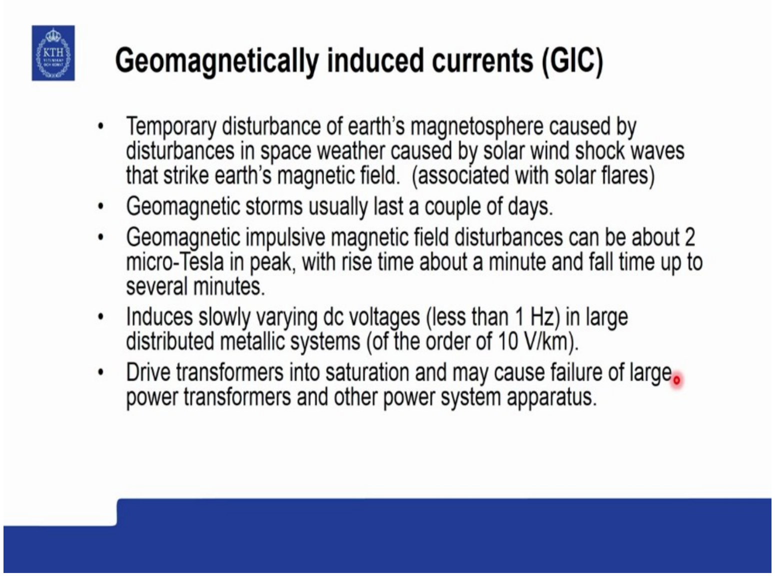


High Altitude Nuclear Electromagnetic Pulse (HEMP) - 3

Composite HEMP (Source: IEC 61000-2-9)

So this is a kind of a composite waveform showing E1 component, E2 component and E3 components. And the left graph is in timescale and right graph is in the frequency spectrum. So this is the kind of source that one has to design the critical systems against.

(Refer Slide Time: 15:20)

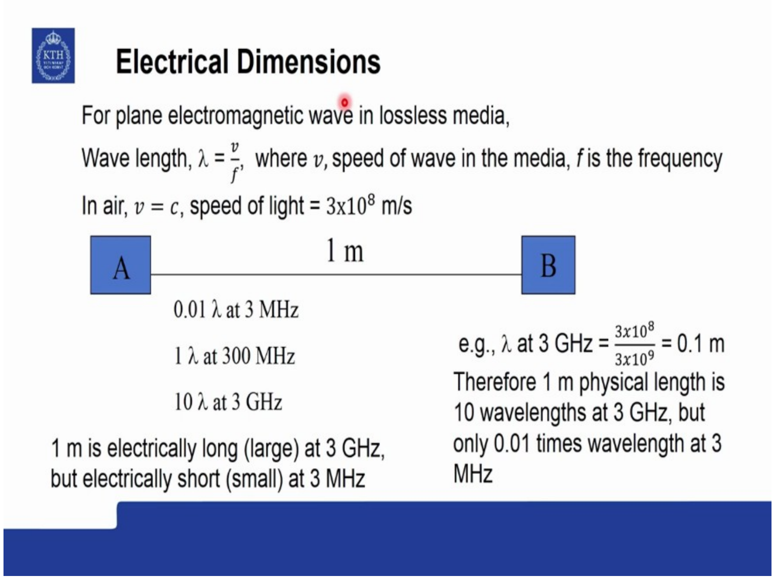


Geomagnetically induced currents (GIC)

- Temporary disturbance of earth's magnetosphere caused by disturbances in space weather caused by solar wind shock waves that strike earth's magnetic field. (associated with solar flares)
- Geomagnetic storms usually last a couple of days.
- Geomagnetic impulsive magnetic field disturbances can be about 2 micro-Tesla in peak, with rise time about a minute and fall time up to several minutes.
- Induces slowly varying dc voltages (less than 1 Hz) in large distributed metallic systems (of the order of 10 V/km).
- Drive transformers into saturation and may cause failure of large power transformers and other power system apparatus.

We also have geomagnetically induced currents. Now you have solar flares, which is part of the solar weather systems. When solar flares come, charged particles are getting injected into Earth's magnetosphere and this cause a disturbance in the Earth magnetic field and it can last several days. So this magnetic field disturbances are very small, only of the order of 2 micro tesla in peak. It is quite small which can have a rise time of about a minute and fall time up to several minutes. So in terms of waveforms, it is more compatible with the E3 component of the nuclear EMP. But this induces a slowly varying DC voltages of less than 1 hertz in large distributed metallic systems, creating voltages of the order of 10 KV per kilometre. Even though this may look very small, this can drive power transformers into saturation and power transformers in the power network are extremely rare pieces, specialized components and you do not have many spare devices around the world - huge power transformers of several MVA in rating. So when a couple of them are destroyed, it can create blackouts over large portions of the land. So solar flares and geomagnetically induced currents are quite a threat. And this has happened in northern Canada several years ago and it can happen depending upon the space weather. This is more of a threat in the higher latitudes than towards the Tropics.

(Refer Slide Time: 17:45)



Electrical Dimensions

For plane electromagnetic wave in lossless media,

Wave length, $\lambda = \frac{v}{f}$, where v, speed of wave in the media, f is the frequency

In air, $v = c$, speed of light = $3x10^8$ m/s

0.01 λ at 3 MHz

1 λ at 300 MHz

10 λ at 3 GHz

e.g., λ at 3 GHz = $\frac{3x10^8}{3x10^9}$ = 0.1 m

Therefore 1 m physical length is 10 wavelengths at 3 GHz, but only 0.01 times wavelength at 3 MHz

1 m is electrically long (large) at 3 GHz, but electrically short (small) at 3 MHz

Now we will go through some of the concepts used in EMC as we have finished with some of the description of the sources. One concept is idea of electrical dimensions. We have physical dimensions, say 1 metre, how much it is, we know. 10 metre, we have an idea in the mind. But when we, in electrical engineering, whenever we have alternating currents or electromagnetics, even though spatial distances has some meaning but more meaning is attached to electrical distances. So that is what we will define here.

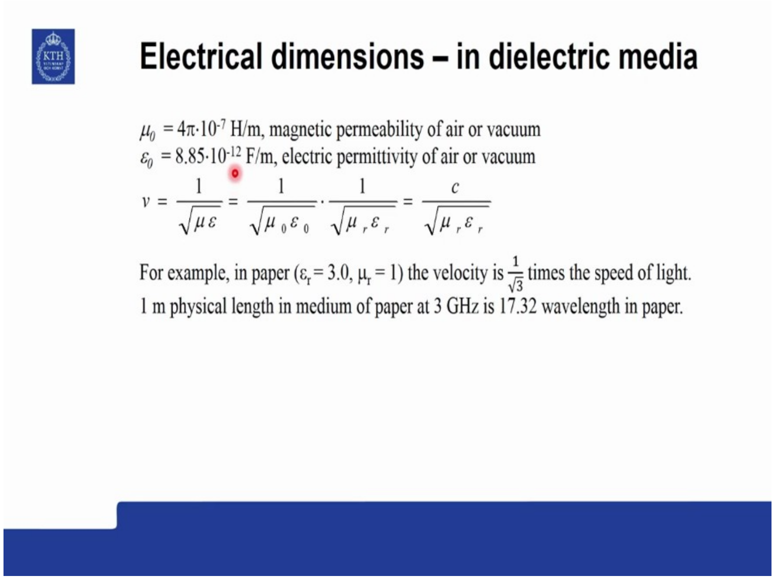
For example, for a plain electromagnetic wave in a lossless media, we have the wavelength given by the speed divided by the frequency ($\lambda = \frac{v}{f}$). Speed of the wave in the media in m/s and the frequency in Hz. So in air, v is the speed of light, 3×10^8 m/s, and frequency is number of cycles per second. So you can see that the wavelength is given in metres. Now let us see what does that mean by 1 metre distance between the system A and system B?

Let us say there is a cable in between system A and B. We see that this cable has a physical length 1 metre. So what does that mean? If you have a signal from here to here and that signal centre frequency is 3 MHz, it means it is 0.01 wavelength long only. Because, at 300 MHz the wavelength is 1 metre. So that is the speed 3×10^8 divided by the frequency, 300 MHz that will give you 1 metre. So this is one wavelength at 300 MHz.

But if it is one in 100th of the frequency at 3 MHz, this is already 0.01 wavelength only because the wavelength at 3 MHz is 100 metres. So it is one in 100th of the metre. And say for example wavelength at 3 GHz, we have 3×10^8 divided by 3 into 10 raised to 9. So wavelength is 0.1 metre only. So 1 metre will become 10 times wavelength at 3 GHz. Therefore 1 metre of physical length is 10 wavelength long at 3 GHz but only 0.01 wavelength long at 3 MHz.

So one metre is electrically long at 3 GHz. So we will introduce the concept of **electrically long** and **electrically short**. Often we will use these terms. Then if we say that 1 metre is electrically long, say it will be electrically long if it is at 3 gigahertz because it means that 10 times wavelength at 3 GHz. So it is several wavelengths long at 3 GHz. Whereas, at 3 MHz, it is covering only a portion of a wavelength. So it will be electrically short. The same distance, the same cable will be electrically short or electrically small at 3 MHz and electrically long or electrically large at 3 GHz. hese concepts we will be using very often.

(Refer Slide Time: 22:48)



Electrical dimensions – in dielectric media

$\mu_0 = 4\pi\cdot10^{-7}$ H/m, magnetic permeability of air or vacuum

$\varepsilon_0 = 8.85\cdot10^{-12}$ F/m, electric permittivity of air or vacuum

$$v = \frac{1}{\sqrt{\mu\varepsilon}} = \frac{1}{\sqrt{\mu_0\varepsilon_0}}\cdot\frac{1}{\sqrt{\mu_r\varepsilon_r}} = \frac{c}{\sqrt{\mu_r\varepsilon_r}}$$

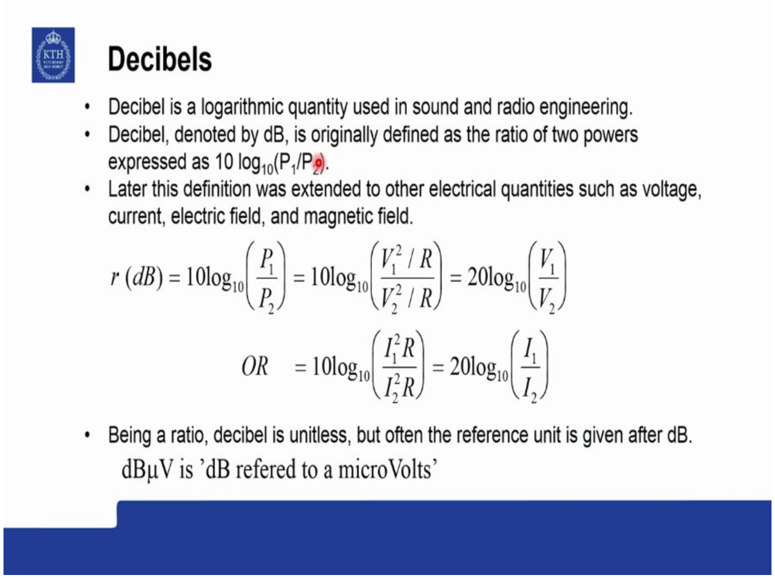
For example, in paper ($\varepsilon_r = 3.0$, $\mu_r = 1$) the velocity is $\frac{1}{\sqrt{3}}$ times the speed of light.

1 m physical length in medium of paper at 3 GHz is 17.32 wavelength in paper.

Now in other dielectric media the speed of electromagnetic waves are different from that in vacuum or air. While discussing the fundamentals of electromagnetics, we will review this. We have magnetic permeability of air or vacuum given by μ_0 ¿$4\pi . 10^{-7}$ H/m, electric permittivity of air or vacuum is given by ϵ_0=8.85x10^{-12} F/m. So $v = \sqrt{\frac{1}{\mu_0\varepsilon_0}} \;.\; \sqrt{\frac{1}{\mu_r\varepsilon_r}} \;=\; c.\sqrt{\frac{1}{\mu_0\varepsilon_0}}$.

So if we separate it out, we can write it as the speed of light c, 1 by square root of $\mu_0\epsilon_0$, multiplied by 1 by square root of relative permittivity and permeability. For example, in paper μ_r is 1 and ϵ_r is 3. So the velocity is 1 by square root of 3 of the speed of light. So one metre of physical length in the medium of paper at 3 GHz is 17.32 wavelength in paper, whereas it was 10 in air. So depending upon the medium, again electrical dimensions can change.

(Refer Slide Time: 24:44)



Decibels

- Decibel is a logarithmic quantity used in sound and radio engineering.
- Decibel, denoted by dB, is originally defined as the ratio of two powers expressed as 10 $\log_{10}(P_1/P_2)$.
- Later this definition was extended to other electrical quantities such as voltage, current, electric field, and magnetic field.

$$r\,(dB) = 10\log_{10}\left(\frac{P_1}{P_2}\right) = 10\log_{10}\left(\frac{V_1^2/R}{V_2^2/R}\right) = 20\log_{10}\left(\frac{V_1}{V_2}\right)$$

$$OR \quad = 10\log_{10}\left(\frac{I_1^2 R}{I_2^2 R}\right) = 20\log_{10}\left(\frac{I_1}{I_2}\right)$$

- Being a ratio, decibel is unitless, but often the reference unit is given after dB.

dBμV is 'dB refered to a microVolts'

Another concept that we frequently use in EMC studies is decibel. It comes from sound engineering to measure the amplification of the sound. But then later, it was used in other areas including electrical engineering and the electromagnetics. So decibel is a logarithmic quantity used in sound and radio engineering and it is denoted by d and capital B, dB, small d and capital B. So it is originally defined as ratio of 2 powers expressed as

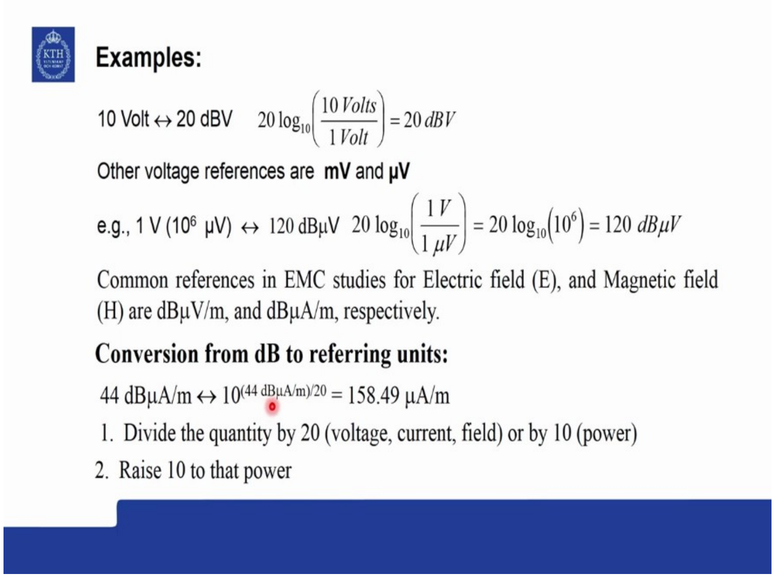
$$10\log_{10}\left(\frac{P_1}{P_2}\right)$$

P1 and P2 are two powers. One power may be from the signal source and another power maybe after amplification.

So you can see what gain is. So it is P1 by P2, I mean this is some ratio of powers you can define, 10 times log to the base 10 of the power ratio. The reason for defining decimals is that often in EMC studies or electromagnetics, you deal with magnitudes that are several orders, 10 to the power of 8, 10 to the power of 10 like that. So you cannot disperse it on linear scale 1 to 10^{10}. It is very difficult in a linear graph. It is very difficult but if you are expressing it logarithmically, in 10 divisions, you can express, 10 to the power of 1, 10 to the power of 2, 10 to the power of 3, like that. Then you multiply it by 10 arbitrarily, it is defined like that. So P1/P2 ratio in dB is $10\log_{10}\left(\frac{P_1}{P_2}\right)$. So it is a unitless number because power is watt divided by watt, so it is unit less. But at the same time, you want to know what are the reference units being used. It makes a difference whether this is watt or milliwatt in the final number. So to denote that, you will add the unit you used beside dB even though dB is a unitless number.

Now later, the concept of dB is extended to voltages and currents, electric fields and magnetic fields, et cetera. Then there you define it as 20 log ratio of voltages. The reason for that is, say for example power is given by voltage squared by R where R is the resistance or I square R, I is the current. So here we can see V squared and here we can see I squared. Then this 2 is taken over here to become $20\log_{10}\left(\frac{V_1}{V_2}\right)$ or $20\log_{10}\left(\frac{I_1}{I_2}\right)$. Being a ratio, decibel is unitless but we refer to it as dB microvolts dB referred to a microvolt or dB watt, dB refer to a watt or dBM, dB referred to milliwatt or millivolt and things like that. And if it is voltage or current, we define it as 20 log of the ratio. If it is power, 10 log of the ratio.

(Refer Slide Time: 28:57)



Examples:

10 Volt ↔ 20 dBV $20\log_{10}\left(\frac{10\,Volts}{1\,Volt}\right) = 20\,dBV$

Other voltage references are **mV** and **μV**

e.g., 1 V (10^6 μV) ↔ 120 dBμV $20\log_{10}\left(\frac{1\,V}{1\,\mu V}\right) = 20\log_{10}\left(10^6\right) = 120\,dB\mu V$

Common references in EMC studies for Electric field (E), and Magnetic field (H) are dBμV/m, and dBμA/m, respectively.

Conversion from dB to referring units:

44 dBμA/m ↔ $10^{(44\,\text{dB}\mu\text{A/m})/20}$ = 158.49 μA/m

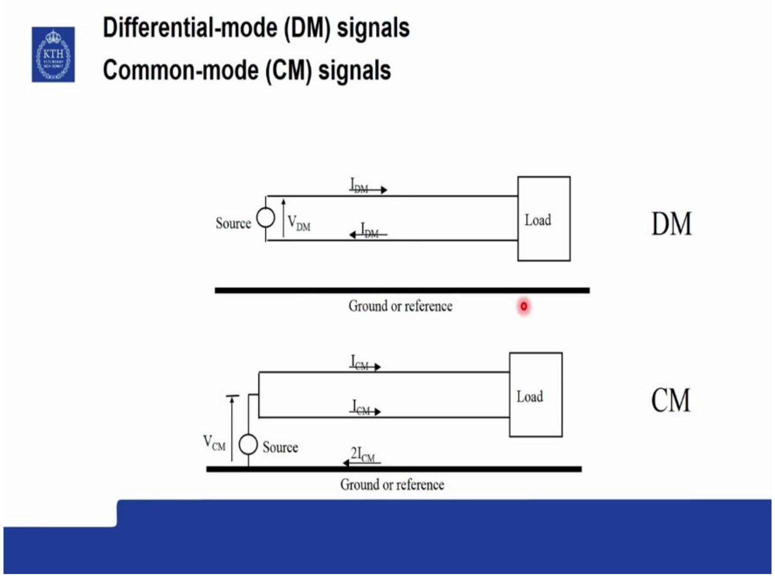
1. Divide the quantity by 20 (voltage, current, field) or by 10 (power)
2. Raise 10 to that power

Now some examples are given here. Say 10 volt is equal to 20 dB volt. How do we get that? 20 log to the base 10, 10 volts and your reference is 1 volt. Then log 10 is 1, so you get 20 dB volt. See you can express instead of volts, in terms of millivolt or microvolt. So if you take 1 volt which is equivalent to 10 to the power 6 microvolt, that will be 120 dB microvolt. Say 20 log 1 volt divided by 1 microvolt equal to 20 log 10 to the power of 6 is equal to 120 dB microvolt. So, units in EMC studies for electric field and magnetic field are dB micro-volts per metre and dB microampere per meter respectively.

That also comes from the same relationship. It will be 20 log ratio of electric fields or 20 log ratio of magnetic fields. So from that, this can come. Now we can convert from dB to the referring units, to the opposite. For example 44 dB µA/m, suppose we want to convert it into microamperes per metre or amperes per metre let us say. So how do we do that? So from this, presence of microampere per metre, we know that the base is microampere per metre for the magnetic field intensity.

So we do the reverse of this. It is 10 to the power of 44 dB microampere per metre. Since it is a magnetic field, we know that by definition it is 20 log. So that divided by 20, 10 to the power of that will give you 158.49 µA/m. So this you can further convert it into say 0.15849 mA/m or 158.49 x 10^{-6} A/m, like that you can write. So the process is, divide the quantity by 20 if it is voltage, current or field or by 10 if it is power. Then raise 10 to the power. So this is the procedure for converting from dB to the referring units.

(Refer Slide Time: 32:21)



Differential-mode (DM) signals

Common-mode (CM) signals

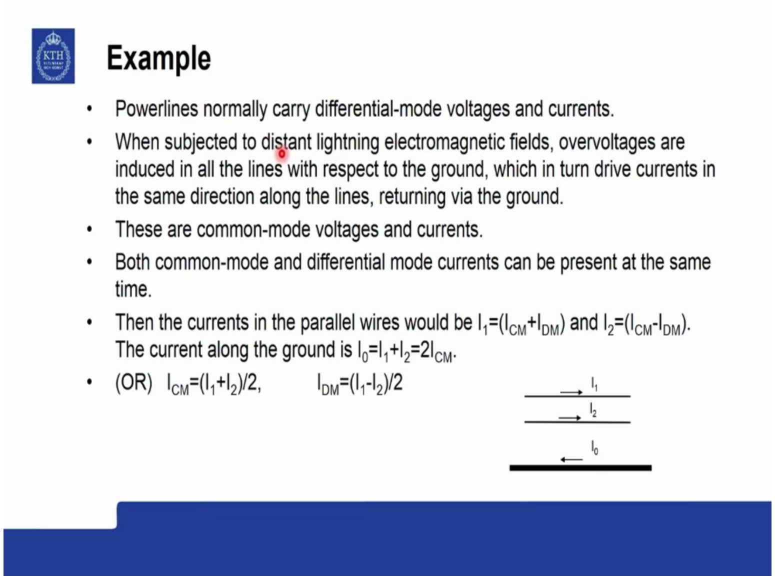
Now another concept which we will see very often and which has got great significance in EMC is differential mode signals and the common mode signals. Say in the first picture over here, you have a source, then you have a load. So the source is producing some voltage, it can be alternating current or DC. These arrows of current shows directions at an instant of time. So you have a current flow to the right and a return current of equal magnitude to the left. So both currents are the same but opposite in direction.

So this is called a differential mode. So normal signals are all differential mode signals. And there can be some noise, EMI also circulating in the differential modes. For example, some other switching noise or some other electronic noise. So this is a ground plate but it could also happen that you have some fields, electromagnetic fields coming from some other direction and it is falling on this circuit over here, then you create a potential difference between your lines and the ground because of the interaction of the electric and magnetic fields.

And that will drive some net currents, it can have parasitic elements, parasitic capacitance here or some other connections and it can drive some currents through these lines, through the ground and back into the line. So it is as if, you have some source here on the left of bottom picture, this is a fictitious source here. I mean, this action of the electric and magnetic fields can be modelled as a fictitious source that is driving a current, common mode current, through this line and back through the ground. So this is I subscript CM and this would be the total common mode current flowing back.

So if you just take this part of the circuit alone, just the lines, what you experience is just currents in the same direction and same magnitude. So this is called the common mode currents. So this basic decomposition can be done, most of the lines will have both differential mode and common mode currents even though common mode currents are usually quite small.

(Refer Slide Time: 35:11)



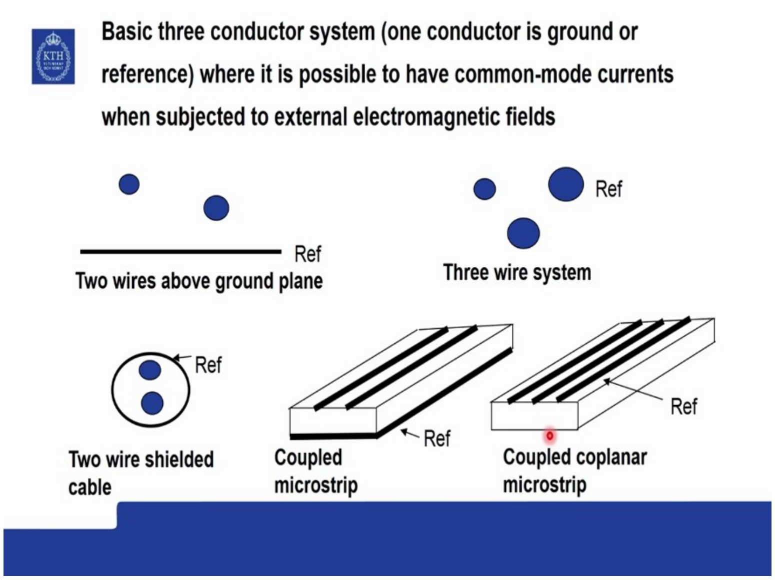
Example

- Powerlines normally carry differential-mode voltages and currents.
- When subjected to distant lightning electromagnetic fields, overvoltages are induced in all the lines with respect to the ground, which in turn drive currents in the same direction along the lines, returning via the ground.
- These are common-mode voltages and currents.
- Both common-mode and differential mode currents can be present at the same time.
- Then the currents in the parallel wires would be $I_1=(I_{CM}+I_{DM})$ and $I_2=(I_{CM}-I_{DM})$. The current along the ground is $I_0=I_1+I_2=2I_{CM}$.
- (OR) $I_{CM}=(I_1+I_2)/2$, $I_{DM}=(I_1-I_2)/2$

For example, a power lines normally carry differential mode voltages and currents. When subjected to distant lightning electromagnetic fields, over voltages are induced in all the lines with respect to the ground. This in turn produce currents in the same direction along the line via the returning ground. So this is one example of common mode currents in power lines. And you can have both common mode currents and differential mode currents at the same time. So why common mode and differential mode currents are important in terms of radiation, radiated disturbance?

You can see it over here. Say for example, if there are currents into parallel wires, I1 and I2, then I1 is I common mode plus I differential mode and I2 will be, since differential mode direction is changing, I common mode minus I differential mode. Then the current along the ground is I1 plus I2 or 2 times ICM. Or you can define differential mode currents as sum of these currents divided by 2 because differential mode currents are cancelling each other and differential mode currents are difference in these 2 currents, I1 and I2 divided by 2 because common mode currents are cancelling each other. Since common mode currents are in the same direction, it can produce quite large fields at a distance even with a small current. Whereas if it is a differential mode, these 2 currents are opposing each other, so it will not produce as much fields, far from it.

(Refer Slide Time: 37:23)



Basic three conductor system (one conductor is ground or reference) where it is possible to have common-mode currents when subjected to external electromagnetic fields

Now these type of common mode currents can be produced in any 3 conductor system when subjected to external fields. So they are very common. For example, two wires above a ground plane, a three wire conductor system, it can be a two wire shielded cable or a coupled strip or a couple coplanar micro strip. All kinds of three conductor system or even more conductor systems you can find and there will be some common mode currents because in EMC, even microamperes can create disturbances. So you will always encounter some common mode currents in all these type of systems. So that ends module 2.