Code: 23EC6501

PVP 23

III B.Tech - I Semester - Honors Examinations - NOVEMBER 2025

EMI / EMC
(HONORS in ELECTRONICS & COMMUNICATION ENGINEERING)

Duration: 3 hours   Max. Marks: 70

Note: 1. This question paper contains two Parts A and B.
2. Part-A contains 10 short answer questions. Each Question carries 2 Marks.
3. Part-B contains 5 essay questions with an internal choice from each unit. Each Question carries 10 marks.
4. All parts of Question paper must be answered in one place.

BL – Blooms Level   CO – Course Outcome

PART – A

		BL	CO
1.a)	Define Electromagnetic Interference.	L1	CO1
1.b)	List any two biological effects of EMI.	L1	CO1
1.c)	Define Electrostatic Discharge.	L1	CO2
1.d)	Explain the need for frequency spectrum conservation.	L2	CO1
1.e)	Differentiate between radiation coupling and conduction coupling.	L2	CO2
1.f)	Demonstrate any two methods of EMI elimination.	L2	CO2
1.g)	Describe an anechoic chamber.	L1	CO3
1.h)	Identify two precautions in open area test sites.	L2	CO3
1.i)	Define power line filter.	L1	CO4
1.j)	List any two characteristics of EMI filters.	L1	CO4

PART – B

			BL	CO	Max. Marks
		UNIT-I			
2	a)	Illustrate the concept of EMI/EMC with suitable examples.	L3	CO1	5 M
	b)	Explain frequency spectrum conservation and its importance.	L2	CO1	5 M
		OR			
3	a)	Analyze practical experiences and concerns in EMI.	L4	CO1	5 M
	b)	Discuss methods of EMI testing.	L3	CO1	5 M
		UNIT-II			
4	a)	Interpret various sources of natural electromagnetic noise.	L2	CO2	5 M
	b)	Explain how EM fields are produced by lightning discharge.	L2	CO2	5 M
		OR			
5	a)	Sketch and explain the equivalent circuit model for Electrostatic Discharge.	L3	CO2	5 M
	b)	Write short notes on EMP-induced voltage.	L3	CO2	5 M
		UNIT-III			
6	a)	Analyze the characteristics of noise produced by switches.	L4	CO3	5 M
	b)	Explain EMI in power supply lines with suitable examples.	L3	CO3	5 M

		OR			
7	a)	Demonstrate the equivalent circuit of a relay/switch circuit model.	L3	CO3	5 M
	b)	Interpret various types of radiation coupling in EMI.	L3	CO3	5 M
		UNIT-IV			
8	a)	Discriminate between TEM cell and GTEM cell.	L4	CO3	5 M
	b)	Sketch & explain a reverberating chamber.	L3	CO3	5 M
		OR			
9	a)	Illustrate the working principle of a TEM cell.	L3	CO3	5 M
	b)	Demonstrate Electro Magnetic Compatibility (EMC) evaluation using GTEM cell.	L3	CO3	5 M
		UNIT-V			
10	a)	Explain conducted EMI from equipment with examples.	L2	CO4	5 M
	b)	Analyze the effects of EMI noise on power lines.	L4	CO4	5 M
		OR			
11	a)	Explain the characterization of conduction voltages.	L3	CO4	5 M
	b)	Appraise EMI filters and their role in power line interference.	L4	CO4	5 M

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EMI / EMC

(HONORS in ELECTRONICS & COMMUNICATIONS ENGINEERING)

PART — A

		Marks
1.a	Define Electromagnetic Interference **Definition / Explanation**	2M
1.b	List any two biological effects of EMI **Explanation**	2M
1.c	Define Electrostatic Discharge **Definition / Explanation**	2M
1.d	Explain the need for frequency spectrum conservation **Explanation**	2M
1.e	Differentiate between radiation coupling and conduction coupling **Definitions and Differences**	2M
1.f	Demonstrate any two methods of EMI elimination **Elimination Methods**	2M
1.g	Describe an anechoic chamber **Explanation**	2M
1.h	Identify two precautions in open area test sites **Precautions with Explanation**	2M
1.i	Define power line filter **Definition for power line filter and usage**	2M
1.j	List any two characteristics of EMI filters **Characteristics of EMI filters**	2M

Part-B

2 (a)	Illustrate the concept of EMI / EMC with suitable examples **Concepts of EMI /EMC and examples**	3M+2M=5M
2(b)	Explain frequency spectrum conservation and its importance **Explanation for Frequency spectrum conservation and Importance**	5M
3(a)	Analyse practical experiences and concerns in EMI **Explanation for Impacts of EMI and practical experiences and concerns**	5M

3(b)	Discuss methods of EMI testing **Explanation for methods of EMI testing**	3M+2M=5M
4(a)	Interpret various sources of natural electromagnetic noise **List of sources of natural electromagnetic noise**	2M+3M=5M
4(b)	Explain how EM fields are produced by lightening discharge **Explanation for lightening discharge and EM fields formulas (if any)**	5M
5(a)	Sketch and explain the equivalent circuit for electrostatic discharge **Explanation for ESD and Circuit diagram**	2M+3M=5M
5(b)	Write short notes on EMP induced voltage **Explanation for EMP induced voltage**	5M
6(a)	Analyze the characteristics of noise produced by switches **Explanation of characteristics of noise produced by switches**	3M+2M=5M
6(b)	Explain EMI in power supply lines with suitable examples. **Explanation for EMI in power supply lines and examples**	2M+3M=5M
7(a)	Demonstrate the equivalent circuit of a relay / switch circuit model **Explanation and Circuit diagram**	2M+3M=5M
7(b)	Interpret various types of radiation coupling in EMI **Explanation for types of radiation coupling**	2M+3M=5M
8(a)	Discriminate between TEM cell and GTEM cell **Comparison table / explanation between TEM and GTEM cells**	2.5M+2.5M=5M
8(b)	Sketch and explain a reverberating chamber **Explanation and diagram**	5M
9(a)	Illustrate the working principle of a TEM cell **Working principle & Explanation for TEM Cell**	5M
9(b)	Demonstrate Electromagnetic compatibility (EMC) Evaluation using GTEM cell **Explanation for GTEM Cell**	5M
10(a)	Explain conducted EMI from equipment with examples **Explanation for conducted EMI with examples**	5M
10(b)	Analyze the effects of EMI noise on power lines **Explanation for effects of EMI noise on power lines**	5M
11(a)	Explain the characterization of Conduction Voltages **Explanation for characterization of conduction voltages**	2M+3M=5M
11(b)	Appraise EMI filters and their role in power line interference. **Explanation for EMI filters in power line interference.**	5M

PART — A

		Marks
1.a	Define Electromagnetic Interference	2M
	Electromagnetic Interference ["EMI"] describes the phenomenon that results from allowing conducted and radiated electrical signals to reach destinations where their presence is undesirable.	
1.b	List any two biological effects of EMI	2M
	The effects of electric and magnetic fields on biological systems and human beings is a subject of considerable concern and investigation. There are two types of concerns about the exposure of humans to high intensity electromagnetic fields. One of these related to the steady state current induced in the human body as a result of its exposure to electromagnetic fields for a long period of time. Exposure to electric, magnetic and electromagnetic fields (EMF), if they are strong enough, can lead to short term health effects. Exposure to low frequency fields that are strong enough can lead to dizziness, seeing light flashes and feeling tingling or pain through stimulation of nerves. Exposure to radiofrequency fields that are strong enough can lead to heating of body tissue, and result in damage to tissues and organs. For both low frequency and radiofrequency fields exposure limits have been set below which these acute effects do not occur.	
1.c	Define Electrostatic Discharge	2M
	Electrostatic discharge (ESD) is the sudden flow of static electricity between two objects with different charges, often felt as a small shock when touching a metal doorknob after walking on a carpet. While harmless to humans in small doses, ESD can cause significant and sometimes hidden damage to sensitive electronic components, leading to immediate failure or latent defects.	
1.d	Explain the need for frequency spectrum conservation	2M
	The need for frequency spectrum conservation stems from the fact that the radio spectrum is a **finite natural resource** that is in extremely high demand by an increasing number of wireless communication services. The ever-growing need for wireless connectivity, from mobile phones and Wi-Fi to satellite communications and scientific research, means that available frequencies are becoming highly congested.	
1.e	Differentiate between radiation coupling and conduction coupling	2M
	conduction coupling requires direct physical or electrical contact via a material medium, whereas **radiation coupling** transfers energy through electromagnetic waves that can travel through air or even a vacuum without physical contact.	

1.f	Demonstrate any two methods of EMI elimination	2M
	Two common methods for eliminating electromagnetic interference (EMI) are shielding and grounding, which are often used in combination with filtering Other methods include filtering, isolation **Filtering:** Inserting filters into power or signal lines can suppress high-frequency noise. **Isolation:** Physically separating sensitive components or using different power supplies for noisy and sensitive parts can reduce interference.	
1.g	Describe an anechoic chamber	2M
	An anechoic chamber in the EMC context is a **shielded, non-reflective enclosure** designed to **absorb electromagnetic waves (or radio waves)** and **eliminate reflections** from walls, ceiling, and floor. The design parameters for chambers intended to test small- to medium-sized antennas over certain frequency bands. For example, for a microwave-frequency chamber intended for antenna measurements (e.g. 2–18 GHz), recommended chamber dimensions and layout (range length, width, absorber arrangement)	
1.h	Identify two precautions in open area test sites	2M
	In open area test sites one should Ensure the test area is a clear, obstruction-free environment to minimize unwanted electromagnetic reflections and interference from nearby structures, trees, or underground objects that could skew test results. A metallic ground plane is often used to establish a uniform test environment.	
1.i	Define power line filter	2M
	A power line EMI filter is an electronic filter designed to attenuate conducted electromagnetic interference (EMI) or radio frequency interference (RFI) present in the power line. The conducted EMI or high-frequency noise is caused by various man-made sources such as switching power supplies, electric motors, radio frequency (RF) transmitters, and other electronic devices, as well as due to natural events, such as lightning, electrical storms, and solar radiation.	
1.j	List any two characteristics of EMI filters	2M
	EMI filters are defined by their capacity to obstruct undesirable electromagnetic interference (EMI) from entering or exiting an electronic equipment, while permitting the passage of intended signals. Key characteristics include a wide operating frequency range, specific electrical ratings (rated voltage, current, isolation), and performance metrics like insertion loss, which quantifies their attenuation capabilities.	

2 (a)	Illustrate the concept of EMI / EMC with suitable examples	3M+2M=5 M

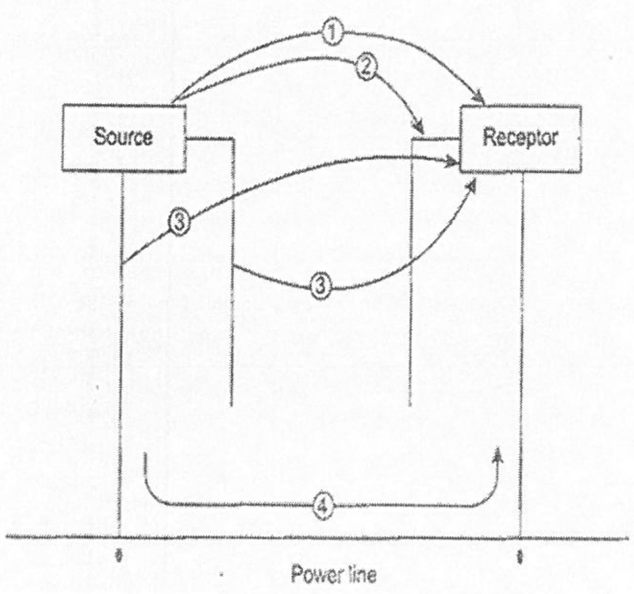
Electromagnetic Interference is unwanted interference caused in an electrical path or electrical device due to an external source. Electromagnetic Interference causes degradation in the performance of electrical devices. EMI is the coupling of signals from one system to another. This external source can be both natural and man-made source.

Electromagnetic Compatibility (EMC) is the ability of electronic devices and systems to function as intended in their shared electromagnetic environment without introducing intolerable **electromagnetic interference (EMI)** to other equipment, and without being adversely affected by external interference themselves. It is a critical engineering discipline ensuring reliability, safety, and regulatory compliance for electronic products.

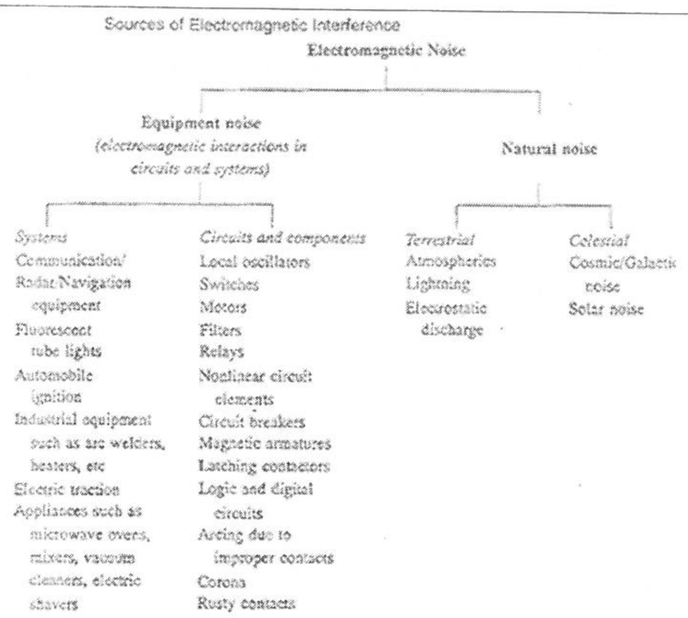
An electromagnetic disturbance is any electromagnetic phenomenon which may degrade the performance of a device, or an equipment, or a system. The electromagnetic disturbance can be in the nature of an electromagnetic noise, or an unwanted signal, or a change in the propagation medium itself.

Electromagnetic interference is the degradation in the performance of a device, or an equipment, or a system caused by an electromagnetic disturbance. The words *electromagnetic interference* and *radiofrequency interference (RFI)* are sometimes used interchangeably. This is not exactly correct. Radiofrequency interference is the degradation in the reception of a wanted signal caused by radio frequency disturbance, which is an electromagnetic disturbance having components in the radio frequency range

- direct radiation from source to receptor (path 1)
- direct radiation from source picked up by the electrical power cables or the signal/control cables connected to the receptor, which reaches the receptor via conduction (path 2)
- electromagnetic interference radiated by the electrical power, signal, or control cables of the source (path 3)
- electromagnetic interference directly conducted from its source to the receptor via common electrical power supply lines, or via common signal/control cables (path 4)
- the electromagnetic interference carried by various power/signal/control cables connected to the source, which gets coupled to the power/signal/control cables of the receptor, especially when cable harnesses are bundled (such interference



2(b)	Explain frequency spectrum conservation and its importance	5M
	Frequency slots are constantly in demand for providing various broadcast, communication, navigation, and other services. Such a demand from newer services has multiplied during the past three decades, and this demand continues to increase. Yet the electromagnetic spectrum is a limited natural resource. As a result of the increasing needs and demands, various agencies and services are forced to share the frequency spectrum with other users. No user enjoys a monopoly any longer. Electromagnetic compatibility in this situation is of paramount importance.	
3(a)	Analyse practical experiences and concerns in EMI	5M
	Today we use a greater variety and number of apparatus and appliances which generate EMI than was the case fifty years ago. The variety and the numbers are ever increasing. These apparatus, appliances, and systems are also the victims of EMI. The density of deployment of these has mushroomed during this time. Also, the use of semiconductor devices and very large-scale integrated circuit technologies have enabled us to design and operate circuits and systems using low power levels and very low signal levels. These devices and circuits have much lower tolerance levels to electromagnetic interferences, being susceptible to malfunction or burnout. some of the practical experiences and concerns can be described with respect to transmission lines, mains power supply, relays, switches, telephone equipment and radio astronomy	
3(b)	Discuss methods of EMI testing	3M+2M=5 M
	Electromagnetic Interference (EMI) testing is broadly categorized into two main types: **emissions testing** (measuring the noise generated by a device) and **susceptibility/immunity testing** (measuring a device's ability to operate when exposed to noise). **Emissions Testing** These tests ensure that the electromagnetic noise generated by an electronic device during normal operation is below the limits defined by relevant standards. • **Conducted Emissions:** This method evaluates the amount of unwanted electromagnetic energy that is conducted along power, signal, or telecommunication cables connected to the device. • **Radiated Emissions:** This test determines the strength of the RF noise that a device generates and radiates through the air. This is often performed in specialized facilities like anechoic chambers or open-area test sites (OATS) to ensure accurate measurements.	
4(a)	Interpret various sources of natural electromagnetic noise	2M+3M=5 M
	primary sources of **natural electromagnetic noise** are large-scale atmospheric and extraterrestrial phenomena, including **lightning**, **solar activity**, and **cosmic radiation**. **Sources**	



4(b)	Explain how EM fields are produced by lightening discharge	5M
	An evaluation of the exact field intensity resulting from lightning discharge is complex. We do not have any control over the nature of the electromagnetic interference waveform generated by natural sources such as lightning. Mathematical models are based on approximations. These cannot be used for exact quantitative evaluation of the effects produced. However, some approximate idea about the nature of the waveforms and their spatial distribution will be helpful in understanding the nature of associated electromagnetic interferences, and to some extent in evolving the laboratory test procedures and waveforms to evaluate their influences on receptor equipment. In the following we develop a model for the EM fields produced by lightning.	

For a model of this type, the electromagnetic fields are evaluated by first deriving the value of $\bar{A}$, and then using equations (2.1) to (2.3) to arrive at values for E and H fields. A complete mathematical derivation of this is available in the literature [4, 5]. For our present treatment, we note these results. Thus

$$\bar{E}(\bar{p}, t) = \bar{U}_r \frac{dl}{2\pi\varepsilon_0} \frac{\rho x}{D^2} \left\{ \frac{3I}{D^3} + \frac{3i}{cD^2} + \frac{1}{c^2 D} \frac{\partial i}{\partial t} \right\}$$

$$+ \bar{U}_X \frac{dl}{2\pi\varepsilon_0} \left\{ \left[\frac{3x^2}{D^2} - 1 \right] \left(\frac{I}{D^3} + \frac{i}{cD^2} \right) + \left(\frac{x^2}{D^2} - 1 \right) \frac{1}{c^2 D} \frac{\partial i}{\partial t} \right\} \quad (2.4)$$

$$\bar{H}(\bar{p}, t) = \bar{U}_\theta \frac{dl}{2\pi} \frac{\rho}{D} \left\{ \frac{i}{D^2} + \frac{1}{cD} \frac{\partial i}{\partial t} \right\} \quad (2.5)$$

where

$$I = I\left(x', t - \frac{D'}{c}\right)$$

$$= \int_0^t i(t' - D'/c)\,dt' \quad (2.6)$$

and

$$D' = (x^2 + D^2)^{1/2} \quad (2.7)$$

$\bar{U}_r$, $\bar{U}_\theta$ and $\bar{U}_X$ are the unit vectors in the cylindrical coordinate system.

Note that $D' \to D$ as $x \to 0$, that is, the dipole is located close to the ground screen.

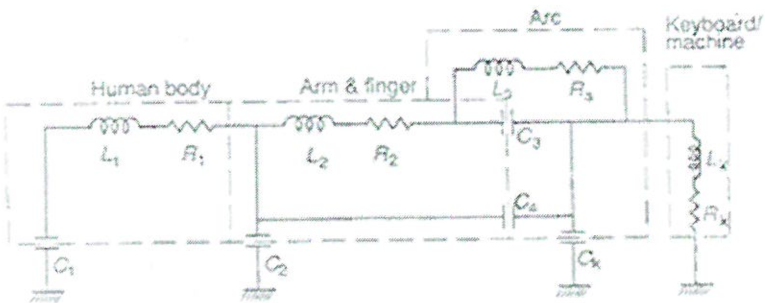
2-3-3-2 Lightning Discharge. For the purpose of modeling, the cloud-to-ground lightning discharge is considered as a vertical column of current. The discharge between two clouds is modeled as a straight horizontal column of current. In both cases, the cross-section of the current column is considered to be very small for convenience in calculating the field intensity. With these simplifications, equations (2.4) and (2.5) lead to the following results.

1. In the far-zone (ie., $D \gg dl$), all terms in equation (2.4) become negligible except the last term. Thus equation (2.4) becomes

$$\bar{E}(\bar{p}, t) = -\bar{U}_X \frac{dl}{2\pi\varepsilon_0} \frac{1}{c^2 D} \frac{\partial i}{\partial t} \quad (2.8)$$

5(a)	Sketch and explain the equivalent circuit for electrostatic discharge	2M+3M=5 M

The path of an ESD involving a human body (its forearm and finger) and an object through which discharge takes place may be represented as an equivalent electrical circuit [11] as shown in Figure 2-6. When the finger approaches very close to an object the large electrostatic field intensity may cause dielectric breakdown and result in an arc formation. Here, L_1 and R_1 are the inductance and resistance of the human body and C_1 is its capacitance to ground. L_2 and R_2 represent the inductance and resistance of the arm



Equivalent circuit model for electrostatic discharge and finger, and they appear in series with L_1 and R_1. C_2 is the capacitance of the arm and finger to the ground. L_k and R_k represent the inductance and resistance of the object being approached. C_k represents the capacitance of object to the ground. The presence of C_3 and C_4 in the circuit indicates that the object does not have a direct DC electrical connection with the forearm and the finger. While the charged body/finger is approaching an object, a strong electric field is created in the gap between the finger and the object. This strong field gives rise to an electric arc. When arcing is taking place, C_3 is shunted by the arc and the resistance and inductance appearing in the discharge path are represented by L_s and R_s. Typical values for $L_1 + L_2$, $R_1 + R_2$, and $C_1 + C_2$ are 0.7 μH, 1 to 30 kΩ and 150 pF respectively. The rise time of the pulse is decided by the ratio $(L_1 + L_2)/(R_1 + R_2)$ and the pulse width depends upon the time constant, $(R_1 + R_2) \times (C_1 + C_2)$.

5(b) Write short notes on EMP induced voltage — **5M**

A nuclear explosion results in the generation of an electromagnetic pulse which is highly intense compared to any natural source. The saying "it is more intense than one thousand lightnings" is indeed an apt description. Nuclear electromagnetic pulse (NEMP) leads to the generation of electromagnetic interference (EMI) in its most severe form. Two broad phenomena of EMI generation are associated with nuclear explosions. When equipment or a system is located in the close proximity of a nuclear burst, the weapon's X-rays or γ-rays (the incident photons) interact with different materials of the system and lead to uncontrolled emission of electrons. Motion of these electrons creates electromagnetic fields, which may cause upset or burnout of system electronics. This is the system generated electromagnetic pulse (SGEMP)

6(a) Analyze the characteristics of noise produced by switches — **5M**

Most types of relays used in electrical and electronics circuits are basically electromechanical switches. Their operation involves making or breaking electrical contacts. This process results in the generation of transient electrical current which is dependant on the circuit parameters, as well as on the materials used in the electrical contacts

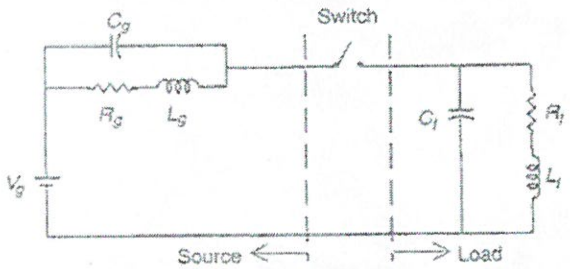
In general, the electromagnetic noise produced by switches has the following characteristics [4]:

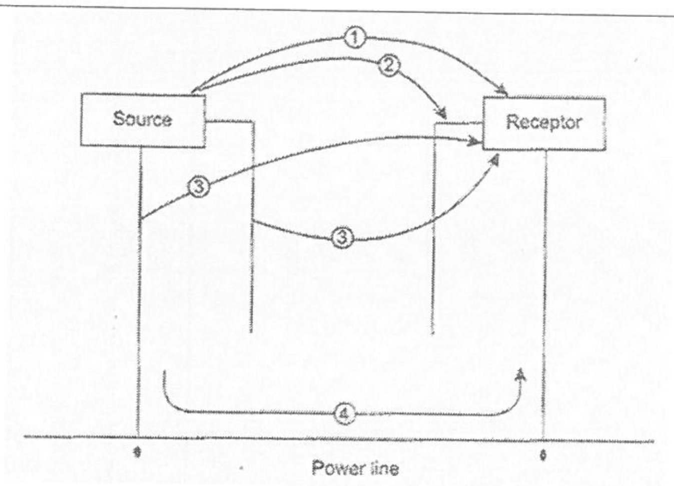
1. Switching noise is not completely random; its frequencies and amplitudes can be analyzed at least partially.
2. Significant noise is produced by the intermittent discharges.
3. Noise produced by continuous discharges is insignificant.
4. An electrical break in noninductive circuit produces a steady arc, which depends on the composition of contact material. A break in reactive circuits produces showering arc, which also depends on the composition of the contact material.
5. Relaxation oscillation is a saw-tooth wave covering a spectrum from 10 kHz to 10 MHz with each switch operation. Peak to peak voltage may vary from 100 V to several kilovolts during each switch operation, with durations ranging from 0.1 ms to several milliseconds.
6. A ringing waveform is applied to the lines connected to both sides (load and source) of the relay (or switch) for each break or make of the switch. The frequency of this ringing wave depends upon the total inductance and capacitance of the circuit, and it ranges from 10 MHz to 1000 MHz.

6(b) Explain EMI in power supply lines with suitable examples. — **5M**

Electromagnetic Interference (EMI) in power supply lines is the corruption of an electrical signal or circuit by an external source of electromagnetic energy, traveling along the conductors. This "noise" can disrupt the proper functioning of electronic devices, leading to performance degradation, errors, or complete system failure.

EMI in power lines is primarily a form of **conducted EMI**, where the interference propagates through physical contact with the power conductors.

	It involves three key elements: a noise **source**, a **coupling path** (the power line), and a susceptible **receiver** (the device being powered). Examples of Common sources of EMI that can couple into power supply lines include: • **Switching Power Supplies (SMPS):** The rapid switching of currents and voltages in SMPS circuits is a major source of high-frequency noise and harmonics. • **Electric Motors and Generators:** Sparks and brush operation in motors generate significant broadband EMI. • **Industrial Machinery:** Arc welders, relays, and other heavy equipment can produce strong, impulsive noise. • **Natural Phenomena:** Lightning strikes can induce high-voltage surges and transients into power lines.	
7(a)	Demonstrate the equivalent circuit of a relay / switch circuit model	5M
	For illustration, here we examine the switching of a telephone relay. An equivalent circuit representation of the telephone relay is shown in Figure R_g, L_g, and C_g are the resistance, inductance, and capacitance of the source side, and R_l, L_l, C_l represent the load impedance. When the relay switch is closed (i.e., contact made), current flows through C_g and C_l. The initial current rises very rapidly to a high peak value, and then gradually decays to the normal load current after undergoing a damped oscillation at a frequency  	
7(b)	Interpret various types of radiation coupling in EMI	5M
	The undesired or unintentional coupling of electromagnetic energy from one equipment (called emitter) to another equipment (called receptor) is the electromagnetic interference. The various methods of electromagnetic interference coupling between an emitter and a receptor are illustrated We will briefly describe these in the following. The radiation coupling between an emitter and a receptor results from a transfer of electromagnetic energy through a radiation path. Various types of radiation coupling are: ■ Coupling of natural and similar electromagnetic environment to the receptor, such as a power line. The power transmission line here acts as a receiving antenna. A receptor may also receive electromagnetic environmental noise or interference through exposed connectors (or connections) and from exposed signal or other lines in the equipment or circuit. ■ Coupling of electromagnetic energy from nearby equipment via direct radiation.	



8(a) Discriminate between TEM cell and GTEM cell — 5M

Parameter	TEM Cell	GTEM Cell
Frequency Range	DC to 1 GHz (typically)	DC to 20 GHz
Test Volume	Compact, restricted (small)	Medium, expandable
Field Type	Tranverse EM (plane wave)	Enhanced TEM (plane wave, extended range)
Capital Cost	Low ($20-50K)	Medium-High ($80-150K)
Operating Cost	Low	Medium
Testing Time	Fast (pre-compliance)	Fast to Standard
Portability	Portable/Mobile	Portable models available
Device Size	Small to medium devices only	Small to medium devices
Primary Use	Pre-compliance, emissions testing	Pre-compliance, emissions/immunity
Key Advantage	Cost-effective, fast	Extended frequency range, compact

8(b)	Sketch and explain a reverberating chamber	5M

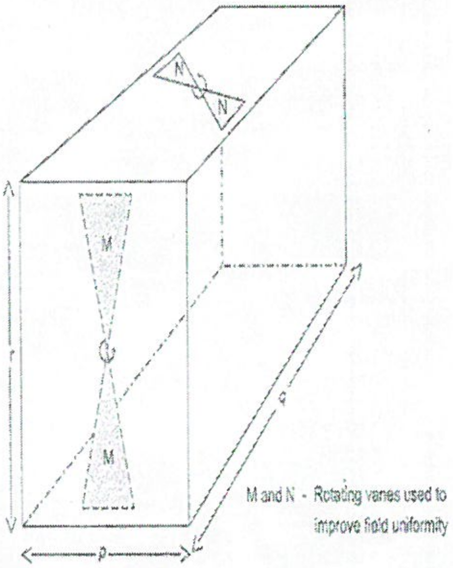
A reverberating enclosure is shown in Figure It consists of a rectangular chamber with walls, whose losses are sufficient enough to facilitate a smooth coupling of the various modes to each other, but not so high as to set up standing waves inside the chamber. An approximation to the total possible number of modes N inside a rectangular chamber is given by

$$N = \frac{8\pi}{3} pqr \frac{f^3}{c^3} - (p + q + r)\frac{f}{c} + \frac{1}{2}$$

where p, q, r are the dimensions in meters shown in Figure
f is the frequency of operation in Hertz
c is the velocity of wave propagation in meters per second

Degenerate modes are created when any two or all three sides of the chamber are of equal dimension. Thus the number of distinct modes at a given frequency of operation increases when the three walls of the chamber are of unequal dimension.

A reverberating enclosure produces an environment in which the field is uniform, except in the proximity of the enclosure walls, as a result of the presence of several modes sufficiently close to one another. A simple rectangular chamber does not produce a uniform internal field at different points inside the chamber in all directions. Two large rectangular metallic vanes are introduced in adjacent walls, as shown in Figure and rotated at different speeds around an axis perpendicular to the wall. Time variation of the chamber geometry, resulting from the rotation of the vanes, leads to a continuous variation of mode mixing with the same statistical distribution of fields. This variation is independent of the location except in the proximity of the chamber walls or the surfaces of metallic objects placed inside the chamber. This situation results in the creation of a uniformly random field environment (i.e., the magnitude of each component of the field at each point when sampled over a period of time can be characterized by approximately the same maximum, minimum, and average) within the chamber. The concept was tested by practically measuring the field strength with a test dipole inside a chamber. The results shown in Figure 6-21 for a chamber approximately 2 m per side indicate uniformity of field component to within ± 0.5 dB up to about 8 cm from the metallic walls of the enclosure.



The use of reverberating chambers for RS or RE testing has advantages because the chamber provides good isolation from the external electromagnetic environment. Reverberating chambers are also relatively inexpensive to build. They are capable of yielding efficient field conversion, thus making it possible to conduct RS testing at high field strength. On the other hand, there is difficulty in relating the measurements made in a reverberating chamber to actual operating conditions, and polarization properties are not preserved.

Reverberating chambers essentially simulate free-space conditions using the process of mode stirring in an enclosed volume (inside the shielded chamber). Reverberating chambers tend to be data intensive and low-frequency limited (generally used above 200 MHz).

9(a)	Illustrate the working principle of a TEM cell	5M

Another commonly used laboratory approach for EMI/EMC measurements makes use of the transverse electromagnetic (TEM) cell [3–7]. A photograph of a typical TEM cell is shown in Figure 6-8(a). The size of a TEM cell is limited by the upper frequency, up to which it can be used. Higher order modes start appearing in the TEM cell outside this limit. On account of this consideration, the permissible cell size becomes smaller at higher frequencies. Further, the maximum size of an EUT inside a TEM cell is limited based on the requirement that any change in the TEM cell characteristic impedance resulting from an EUT placement should be minimum. These limitations are examined in Section 6-3-3. Laboratory EMI/EMC measurement techniques using a TEM cell have both advantages and limitations, thus making this particular approach more suitable in specific applications.

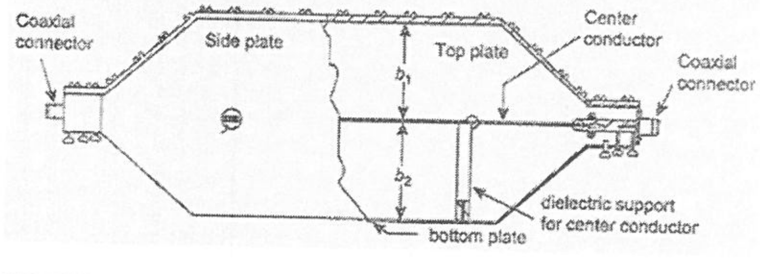
Constructional details of a typical TEM cell are shown in Figure 6-8(b). A TEM cell is a rectangular coaxial transmission line, resembling a stripline, with outer conductors closed and joined together. The rectangular section is tapered at both ends and matched to a 50-Ω coaxial transmission line. The center conductor and an outer conductor (formed by top and bottom plates and the two side plates, which are all joined together) facilitate the propagation of electromagnetic energy from one end of the cell to the other end in TEM mode. The center conductor is firmly held in position by a number of dielectric supports. The EUT is placed in the rectangular part of the transmission line between the bottom plate and the center conductor, or between the center conductor and the top plate. A dielectric material spacer (with dielectric constant as close to unity as possible) is used to electrically isolate the EUT from outer and inner conductors of the transmission line.

Note that the presence of a closed outer conductor serves as an effective shield to isolate the electromagnetic environment inside a TEM cell from the electromagnetic environment outside of the cell. This ensures that the external electromagnetic environment will not affect the measurements made inside the cell. Likewise any high-intensity fields generated during tests will be confined to the interior of the cell. Although Figure 6-8 shows a rectangular cross-section with the center conductor centrally placed (i.e., $b_1 = b_2$) between the top and bottom plates, TEM cells may also be designed with other cross-sections, such as a square cross-section (i.e., $a = b$) or an asymmetric rectangular cross-section (i.e., offset center conductor with $b_1 \neq b_2$).

For a rectangular coaxial transmission line of the type shown in Figure 6-8, with $b_1 = b_2 = b$, the characteristic impedance Z_0 is approximately given [1, 3, 8] by the expression

$$Z_0 = \frac{\sqrt{\mu_0 \epsilon_0}}{C_0} = \frac{\eta_0 \epsilon_0}{C_0} \qquad (6.3)$$

where μ_0 and ε_0 are the magnetic permeability and dielectric permittivity,
η_0 is the free-space intrinsic impedance = 120π Ω
C_0 is the distributed capacitance per unit length in farads per meter.

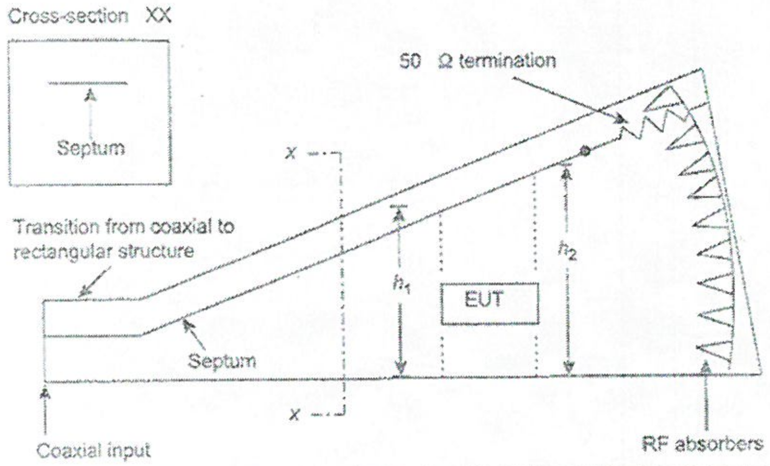


9(b)	Demonstrate Electromagnetic compatibility (EMC) Evaluation using GTEM cell	5M

The GTEM cell (see Figure 6-24) is a 50-Ω tapered rectangular coaxial transmission line with an offset center conductor (septum). The rectangular section couples at one end into a 50-Ω coaxial conductor, and the center conductor cross-section is smoothly transformed from a flat wide strip into a circular shape. The transition from asymmetric rectangular section to standard 50-Ω coaxial line is precision crafted. The far end of the taper section is terminated in a distributed matched load comprised of pyramid-shaped microwave absorbing material. The center conductor of the rectangular transmission line is also terminated in a 50-Ω load made up of several hundred carbon resistors. The distribution of resistance values matches the current distribution in the center conductor. The resistive load into which the center conductor is terminated is equivalent to a current termination, whereas the distributed load into which the flared section is terminated is analogous to a matched termination for the propagating electromagnetic waves. Thus,

the GTEM cell provides a broadband termination from DC to several GHz. Flare angle of the tapered section is usually kept small (say about 15°) so that the field pattern set up by the propagating TEM wave has a spherical symmetry with a large radius (see Figure 6-25). The propagating wave can be approximately considered to be a plane-wave for practical measurement purposes. Length of the flared section determines the size of available test volume, and therefore size of the test samples that can be evaluated for radiated emissions or radiation susceptibility.

The tapered rectangular waveguide section of the GTEM cell, which is terminated in a coaxial connector at the apex end, acts as a waveguide below cut-off for waves that tend to propagate toward the apex. Waves propagating toward the far end of the GTEM cell, which is terminated in a matched termination, are absorbed. Thus, the geometry of a GTEM cell does not permit standing waves produced by electromagnetic fields generated in the GTEM cell to be sustained. The field strength inside a GTEM cell is a function of the input power, as well as location along the longitudinal axis or septum height. The GTEM cell can be used for both CW (continuous wave) and pulse-mode



	Radiation Susceptibility Testing. The equipment under test whose radiation susceptibility is to be evaluated is placed inside the GTEM cell in a volume between the bottom of the GTEM cell and the septum. The useful test volume is bound by the height $h_1/3$ and $h_2/3$ from the bottom of the GTEM cell, as shown in Figure 6-24. In this volume, the field strength uniformity is within about ±1 dB. An appropriate signal source, in conjunction with an amplifier when higher power levels are required, is connected to the coaxial connector. The source and the amplifier are set for the desired frequency and power levels. A power monitoring mechanism is included between the output of the amplifier and the coaxial input of the GTEM cell so that input power level can be precisely measured. Field strength at the EUT position may be calculated based on the geometry of the GTEM cell and input power level. Alternately, the GTEM cell can be augmented with additional instrumentation to enable precise field strength measurement at the EUT location. When radiation susceptibility measurements must be done over a band of frequencies and a swept signal source is used for this purpose, care should be exercised to see that the sweep frequency rate is lower than the response time required by the EUT to settle down and respond with reliable performance data. As in the case of measurements using a TEM cell, where necessary the EUT may be subjected to radiation susceptibility for different angles of polarization of the equipment to ensure that the equipment is tested for maximum coupling of interference RF power to the EUT.	
10(a)	Explain conducted EMI from equipment with examples	5M
	From the foregoing discussion, it is clear that there are a number of precautions and steps to be observed in measuring conducted EMI from an equipment under test (EUT). First, incoming electromagnetic noise and other disturbances from power lines will need to be carefully isolated so that these do not affect the measured conducted EMI from an EUT. Second, the EUT may also emit noise, which is conducted by the signal lines. Third, the EUT-generated electromagnetic noise could appear either as a common-mode noise or as a differential-mode noise. It is, therefore, necessary to devise an experimental set-up carefully so that the desired conducted emission component is measured.	
10(b)	Analyze the effects of EMI noise on power lines	5M
	Low voltage (up to 1000 V) electric power supply lines in several countries are three-wire lines. In North America, for example, the three wires are the line (or phase), neutral, and safety ground conductors. The neutral and ground conductors are bonded together at each service entrance. The distance between the equipment/apparatus connected to the power supply line, and the actual location of electrical earth is thus limited, or small. In this situation, common-mode surges, and interference, would be smaller than the differential-mode interferences. In power distribution systems with two-wire lines, the bond between neutral and earth is located remotely, or far away, from the service entrance to the building. In this case, the common-mode interferences would predominate over the differential-mode interferences.	
11(a)	Explain the characterization of Conduction Voltages	5M

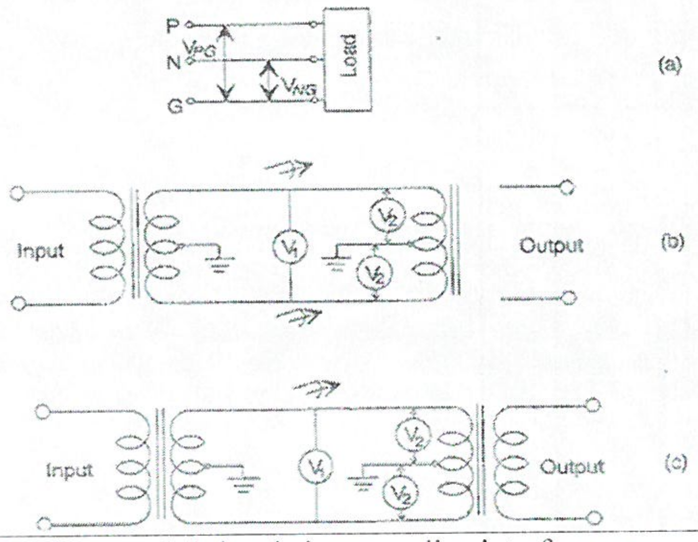
The electromagnetic disturbances carried by electrical power supply lines are classified into two categories, common-mode currents/voltages and differential-mode (or normal mode) currents/voltages. The common-mode (CM) interferences are defined as the unwanted electrical potential differences between any (or all) current-carrying conductor(s) and the reference ground. The differential-mode (DM) interferences are defined as the unwanted potential differences between any two current-carrying conductors. Thus with reference to the three conductor lines shown in Figure 7-1(a), the common-mode voltage V_c and the differential-mode voltage V_d are given by:

$$V_c = (V_{PG} + V_{NG})/2 \quad (7.1)$$

$$V_d = (V_{PG} - V_{NG})/2 \quad (7.2)$$

where V_{PG} and V_{NG} are the voltages between phase and ground wires, and neutral and ground wires, respectively. In terms of currents, the CM interference current exits from the source via the phase and neutral conductors, and returns from the load via the ground conductor. The DM interference current exits from the source via the phase conductor and returns from the load via the neutral conductor, or vice-versa.

To illustrate the concept, Figure 7-1(b) shows a balanced circuit. The sender and the receiver transformer windings have a grounded center tap. No metallic conductor is used to connect the two grounded terminals. If an interference voltage is simultaneously coupled to the two conductors, the voltmeter V_1 will not read a voltage difference,



11(b)	Appraise EMI filters and their role in power line interference.	5M

EMI (electromagnetic interference) filters are electronic circuits that use passive components like capacitors and inductors to block high-frequency noise on power lines while allowing the low-frequency AC power to pass through. Their role is to suppress electromagnetic interference, which can come from devices like motors, switches, or other electronics, ensuring clean and reliable power for sensitive equipment, preventing malfunctions, and helping devices comply with regulatory standards. Role of EMI filters in power line interface include

- **Protection for sensitive electronics:** They are crucial for protecting devices like medical equipment (e.g., MRI, ECG), industrial automation systems, and household appliances from the harmful effects of EMI.
- **Preventing interference propagation:** They prevent noise generated by one device from interfering with other devices on the same power line or the wider grid.

	• **Improving reliability and performance:** By ensuring a stable and clean power supply, EMI filters improve the reliability and performance of electronic systems and help extend their lifespan. • **Meeting compliance standards:** They are essential for helping manufacturers meet electromagnetic compatibility (EMC) and radio frequency interference (RFI) standards mandated by regulatory bodies.	