2016-17
B. Tech. IV Semester (Electronics Engineering) Examination
Electromagnetics
AP-204

Maximum Marks: 60
Credits: 4
Duration: Two Hours

Answer all the questions.

Symbols have their usual meanings, use appropriate notations wherever required.

1(a) Sketch a spherical coordinate system showing all the coordinates and unit vectors. [3.0]
Obtain an expression for the gradient of a scalar field in this coordinate system.

1(b) By solving Laplace's equation in cylindrical coordinates, discuss the variation of the
potentials and electric fields with \( \rho, \varphi \) and \( z \) using proper boundary condition.

1(c) Three infinite uniform sheets of charge are located in free space as follows: [5.0]

3 nC/m² at \( z = -4 \), 6 nC/m² at \( z = 1 \), and -8 nC/m² at \( z = 4 \). Find \( \vec{E} \) and \( \vec{D} \) fields at the
points A(2,5,-5); B(4, 2, -3), C(-1,-5,2) and D(-2,4,5).

1(d) Verify the Divergence theorem for the function \( A = r^2 \hat{a}_r + r \sin \theta \cos \phi \hat{a}_\varphi \) over the
surface of a quarter of a hemisphere defined by \( 0 < r < 3 \), \( 0 < \phi < \frac{\pi}{2} \) and \( 0 < \theta < \frac{\pi}{2} \).

2(a) An infinite long filamentary wire along the z-axis carries current 20A along \( \hat{a}_z \). [4.0]
i) If \( V_m = 0 \) at \( (2, 0^0, 5) \), find \( V_m \) at \( (6, \pi/4, 0) \)
ii) If \( V_m = 1 \)A at \( (0,7,10) \), calculate \( V_m \) at \( (-3, 4, 0) \)

2(b) Apply Ampere's circuital law to find the magnetic field intensity due to an infinite sheet
of negligible thickness carrying surface current. [4.0]

OR

2(b') Define \( \vec{H}, \vec{B} \) and \( \vec{M} \). How these vectors are related with each other? Discuss magnetic
boundary conditions at the interface of two linear-homogeneous -isotropic media.

2(c) Give an account of various magnetic materials. [3.0]

2(d) What is transmission line? Obtain expressions for magnetic flux, magnetic flux density
and scalar magnetic potential due to an infinite transmission line in all the region of
interests.

cont'd...2.
3(a) Find the expressions for induced emf for the following cases
   (a) a stationary loop in a time-varying magnetic field
   (b) a time-varying loop area in a static magnetic field
   (c) a time-varying loop area in a time-varying magnetic field.

3(b) What was the idea of Maxwell to modify Ampere's law? Obtain an expression for the
     modified Ampere's law and discuss the physical significance of displacement current.

3(c) The electric and magnetic fields in free space are given by
     \[ E = \frac{50}{\rho} \sin (10^8 t + \beta z) \, \hat{a}_x \text{ V/m} \]
     \[ H = \frac{H_0}{\rho} \sin (10^8 t + \beta z) \, \hat{a}_\rho \text{ A/m} \]
     Express these in phasor form and determine the constants \( H_0 \) and \( \beta \) such that these fields
     satisfy the Maxwell's equations.

4(a) Explain the propagation of plane electromagnetic waves in free space, and calculate the
     intrinsic impedance of free space.

OR

4(a') A lossy dielectric has an intrinsic impedance of 200 \( \angle 30^\circ \) \( \Omega \) at a particular frequency \( \omega \).
If at this frequency, the plane wave propagating through the dielectric has the magnetic
field component
     \[ H = 10 e^{-ax} \cos(\omega t - \frac{1}{2} x) \, \hat{a}_y \text{ A/m} \]
find \( E \), \( \alpha \), skin depth (d) and wave polarization.

4(b) Obtain the expressions for reflection and transmission coefficient for normal incidence
     of a plane electromagnetic wave. Also, discuss the case for which medium 1 is perfect
     insulator and medium 2 is perfect conductor.

4(c) Discuss the propagation of radio waves through the ionosphere.
2016-2017  
B.TECH. (Winter Semester) Examination  
Branch: Electronics Engineering 2nd Year  
Course : Electrical Engineering  
COURSE CODE: EE-202N  

Maximum Marks: 60  
Credits: 04  
Duration: Two Hours

Answer all the questions.  
Assume suitable data if missing.  
Notations used have their usual meaning.

<table>
<thead>
<tr>
<th>Q.No.</th>
<th>Question</th>
<th>M.M. 60</th>
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</thead>
<tbody>
<tr>
<td>Q1 (a)</td>
<td>Explain how the speed of a dc motor can be controlled by the variation of field flux. Draw the speed- Torque characteristics both for series and shunt motors.</td>
<td>06</td>
</tr>
<tr>
<td>Q1 (b)</td>
<td>Explain the principle of operation of dc motors. How back emf is produce in dc motor?</td>
<td>06</td>
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<td>OR</td>
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<tr>
<td>Q1 (b')</td>
<td>What is the necessity of using starter for dc motors? Draw a labeled diagram of three point starter and explain its function of various parts</td>
<td>06</td>
</tr>
<tr>
<td>Q2 (a)</td>
<td>Develop the equivalent circuit of a 3-phase induction motor and List the features of the induction motor starter.</td>
<td>08</td>
</tr>
<tr>
<td>Q2 (b)</td>
<td>Draw and explain the torque-slip characteristics of a 3 phase induction motor. Why induction motor cannot run at synchronous speed.</td>
<td>04</td>
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<td>OR</td>
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</table>
| Q2 (b') | A 480V, 60 Hz, 50-hp, three phase induction motor is drawing 60A at 0.85 PF lagging. The stator copper losses are 2 kW, and the rotor copper losses are 700 W. The friction and windage losses are 600 W, the core losses are 1800 W, and the stray losses are negligible. Find the following quantities:  
   a) The air-gap power $P_{AG}$.  
   b) The power converted $P_{conv}$.  
   c) The output power $P_{out}$.  
   d) The efficiency of the motor. | 04 |
| Q3 (a) | A 3-phase, 50 Hz, star connected salient pole alternator has 216 slots with 5 conductors per slot. All the conductors of each phase are connected in series; the winding is distributed and full pitched. The flux per pole is 30 mwb and the alternator runs at 250 rpm. Determine the phase and line voltages of emf | 04 |

cont'd...
induced. Assuming, Pitch factor(Kp) = 1 and distribution factor(Kd) = 0.9597.

Q3 (b) Why synchronous motor is not self starting? Name different techniques by which synchronous motor can be made self starting and explain any one of them.

OR

Q3 (b') What are the main features of stepper motor? Explain with the help of a diagram the working of a stepper motor.

Q4 (a) Discuss the Classification and representation of different types of transmission lines.

Q4 (b) Why the HVDC link is used? Also write the advantages and disadvantages of HVDC transmission system.

OR

Q4 (b') Find the A, B, C, D constants for a nominal-T configuration of a medium transmission line.

Q5 (a) What is electric lamp? Discuss any two types of luminescent lamp with the help of a diagram.

Q5 (b) Differentiate between any one of the following

(a) Feeder, distributor and service mains
(b) Radial, Ring main and interconnected system.

----- END -----
Maximum Marks: 60  Credits: 04  Duration: Two Hours

Answer all the questions. Assume suitable data, if missing. Notations used have their usual meanings.

Q. No. Question M. M. CO

1 (a) With a suitable circuit diagram, explain the operation Large-Signal of a BJT-based Differential Amplifier with Active Loads. [9] CO-1

OR

1 (a’) With a suitable circuit diagram, explain the operation Large-Signal of a MOS-based Differential Amplifier with Active Loads. [9] CO-1

1 (b) An npn differential amplifier with $I = 0.5 \text{ mA}$, $V_{CC} = +2.5 \text{ V}$, $V_{EE} = -2.5 \text{ V}$, and $R_C = 8 \text{ K\Omega}$ utilizes BJTs with $\beta = 100$ and $v_{BE} = 0.7 \text{ V}$ at $i_C = 1 \text{ mA}$. Assuming that the bias current is obtained by a simple current source and that all transistors require a minimum $v_{CE}$ of 0.3 V for operation in the active mode, find the input common-mode range. [6] CO-1

OR

1 (b’) An NMOS differential amplifier utilizes a bias current of 400 $\mu$A. The devices have $V_t = 0.5 \text{ V}$, $W = 20 \mu$m, and $L = 0.5 \mu$m, in a technology for which $\mu_nC_{ox} = 200 \mu\text{ A/V}^2$. Find $V_{GS}$, and $g_m$ in the equilibrium state. Also find the value of $v_{id}$ for full-current switching. To what value should the bias current be changed in order to double the value of $v_{id}$ for full-current switching? [6] CO-1
2 (a) Perform small-signal analysis on the Gain stage of the IC-741 opamp, the circuit of which is shown in Fig. 2(a).

OR

2 (a') Perform small-signal analysis on the Output stage of the IC-741 opamp, the circuit of which is shown in Fig. 2(a').

2 (b) Explain the operation of a 'Push-Pull' type Class-B output stage.

3 (a) Consider the circuit shown in Fig. 3(a). Discuss the operation of the circuit for the following two cases:
   i. When the input voltage $V_{in}$ is equal to 3V DC
   ii. When input voltage $V_{in}$ is a 1 KHz sinusoid with ±3V amplitude

3 (b) Explain the operation of an operational amplifier based Instrumentation Amplifier. Tabulate its significant advantages over a typical opamp-based difference amplifier.

4 (a) Design a Monostable Multivibrator circuit using the 555 Timer IC capable of producing at its output a single voltage pulse of amplitude equal to −5 Volts with pulse width equal to 1 microsecond. After the pulse duration is over, the circuit should return to its stable state of voltage amplitude +5 Volts.

4 (b) Draw the internal circuit schematic of the RC4200 Analog Multiplier IC and explain its working. Thereafter, explain how the RC4200 may be configured as a Four-Quadrant Analog Multiplier.

contd...
Q.No. Question M.M.
1(a) In the following control system, if \( r(t) = tu(t) \). Find \( e(t) \). [CO1] [07]

1(b) The introduction of the feedback is mainly motivated by the incompleteness of the knowledge of the system to be controlled and effects of external disturbances. More strictly, the use of feedback can be regarded as unreasonable if there is no uncertainty in the system. Describe this concept with the help of control system where temperature in a room need to be maintained (room heating system). [CO1] [05]

OR

1(b') For a tachometer, if \( \theta(t) \) is the rotor displacement in radians, \( e(t) \) is the output voltage and \( K_e \) is the tachometer constant is V/rad/sec, then determine the transfer function \( \frac{E(s)}{\theta(s)} \). [CO1] [5]

2(a) The asymptotic approximation of the log-magnitude vs frequency plot of a system containing only real poles and zeros is shown below. Determine the transfer function of the system. Comment on the stability of the system. [CO2] [6+1=7]
2(a') A unity feedback closed-loop system has the characteristic function

\[(s^2 - 4)(s + 1) + K(s - 1) = 0\]

Plot its root-locus against K and find the range(s) of K for the system to be stable.

[CO2]

2(b) The frequency response of a linear system \(G(j\omega)\) is given in the tabular form below.

| \(|G(j\omega)|\) | 1.3 | 1.2 | 1.0 | 0.8 | 0.5 | 0.3 |
|------------------|-----|-----|-----|-----|-----|-----|
| \(\angle G(j\omega)\) | -130° | -140° | -150° | -160° | -180° | -200° |

Determine the gain margin (in dB) and phase margin (in Degrees) for the system.

[CO2]

3(a) Find the steady state error for unity feedback control system having \(G(s) = \frac{100}{s(s+2)}\) with an input signal \(r(t) = 5 + 2t\).

[CO3]

3(b) Design a phase-lead compensator using Bode plot for a unity feedback control system with open-loop transfer function \(G(s) = \frac{k}{s(1+0.1s)(1+0.001s)}\). The compensated system should full fill the following specifications:

a) Phase margin \(\geq 45°\)  
b) Velocity constant \(K_v = 1000\) sec\(^{-1}\)

[CO3]

3(b') Figure below shows a PD controller used for a system. Design the controller (find \(T_d\)) so that the system is critically damped. Also calculate its settling time.

[CO3]

4(a) The state variable description of an LTI system is given by

\[
\begin{pmatrix}
\dot{x}_1 \\
\dot{x}_2 \\
\dot{x}_3
\end{pmatrix} =
\begin{pmatrix}
0 & a_1 & 0 \\
0 & 0 & a_2 \\
a_3 & 0 & 0
\end{pmatrix}
\begin{pmatrix}
x_1 \\
x_2 \\
x_3
\end{pmatrix} +
\begin{pmatrix} 0 \end{pmatrix} u
\]

\[
y =
\begin{pmatrix}
1 & 0 & 0
\end{pmatrix}
\begin{pmatrix}
x_1 \\
x_2 \\
x_3
\end{pmatrix}
\]

[06]

contd...
Where $y$ is the output and $u$ is the input. Determine all possible values (or intervals) of $a_1$, $a_2$ and $a_3$ for which system is controllable. [CO4]

4(b) Find the state space representation of the system describe by the following equations

$$\frac{dx_1(t)}{dt} = -3x_1(t) + x_2(t) + 2u(t),$$

$$\frac{dx_2(t)}{dt} = -2x_2(t) + u(t)$$

and $y(t) = x_1(t)$

Where $u(t)$ is the input and $y(t)$ is the output. [CO4]

OR

4(b') Determine the state transition matrix and the state transition equation of the state variable system given below

$$\dot{x}(t) = \begin{bmatrix} 0 & 1 \\ 0 & -3 \end{bmatrix} x(t) + \begin{bmatrix} 1 \\ 0 \end{bmatrix} u(t)$$

with initial condition $x(0) = [-1 \ 3]^T$

and the unit step input $u(t)$ is applied.

Symbol "T" in the superscript indicates transpose. [CO4]

5(a) Determine the stability of the system shown in figure below [CO2]
2016-17
B.TECH. (WINTER SEMESTER) EXAMINATION
ELECTRONICS ENGINEERING
LOGIC CIRCUITS
EL-231

Maximum Marks: 60 Credits: 04 Duration: Two Hours

Answer all the questions.
Assume suitable data if missing.
Notations used have their usual meaning.

Q.No. Question M.M.
1(a) Convert hexadecimal 2AC5.D to decimal, octal and binary number system. (CO3) [04]
1(b) What is the range of unsigned & signed decimal values that can be represented in a byte? (CO3)
1(c) Show how a two input XOR and XNOR gate can be constructed from two input NAND gates only. (CO1) [07]

2 (a) Simplify the following Boolean function: \( F(A,B,C,D) = \sum (0,1,2,5,8,9,10) \) in (CO4) [07]
    (i) Sum of products and (ii) Product of sums.
2 (b) Draw the logic diagram of a 2-line-to-4 line decoder/demultiplexer using NOR gates only. (CO4) [08]

OR

2'(a) With the help of block diagram, differentiate between Multiplexers and De-Multiplexers. Also Implement the following function:
    \( F(A,B,C,D) = \sum (0,1,3,4,8,9,15) \) with the help of a 8 Input Multiplexer. (CO4)
2'(b) Design a 4 line to 2 line priority encoder. Include an output \( E \) to indicate that at least one input is a 1. (CO4) [08]

3(a) Explain the operation of a NAND Latch with the help of a logic diagram. (CO5) [07]
3(b) Design a synchronous counter, using J-K Flip Flops that has the following sequence: 000, 001, 010, 011, 100 and repeat. The undesired states must always go to 000 on the NEXT clock pulse.

OR

3'(a) Discuss the operation of clocked T Flip Flop with the help of detailed gate level logic diagram. Also determine its characteristic table and characteristic equation.

3'(b) What are shift registers? With the help of detailed logic diagrams explain the operations of shift left and shift right.

4(a) Implement a 1-bit Full Adder with the help of 1-bit Half Adders.

4(b) Design a combinational circuit that accepts a three bit binary number and generates an output binary number equal to the square of input number.
2016-17
B.TECH. (WINTER SEMESTER) EXAMINATION
ELECTRONICS ENGINEERING
Principles of Communication Engineering
EL-242

Maximum Marks: 60 Credits: 04 Duration: Two Hours

Answer all the questions.
Assume suitable data if missing.
Notations and symbols used have their usual meaning.

Questions

1 (a) A SSB AM signal is generated by modulating an 800-kHz carrier by the signal \( m(t) = \cos(2000\pi t) + 2\sin(2000\pi t) \). The amplitude of the carrier is \( A_c = 100 \).
   i. Determine the signal \( n(t) \).
   ii. Determine the (time domain) expression for the lower sideband of the SSB AM signal.
   iii. Determine the magnitude spectrum of the lower sideband SSB signal.  [CO1]

1 (b) Explain the considerations that are to be accounted during the design of designing an envelope detector for successful demodulation of an AM signal. [CO2]

1 (c) The carrier \( c(t) = A\cos(2\pi 10^6 t) \) is angle modulated (PM or FM) by the sinusoidal signal \( m(t) = 2\cos(2000\pi t) \). The deviation constants are \( k_p = 1.5 \text{ rad/V} \) and \( k_f = 3000 \text{ Hz/V} \).
   i. Determine the modulation index for PM and FM signals.
   ii. Determine the bandwidth in each case using Carson’s rule.  [CO1]

OR

1* (a) In a superheterodyne radio receiver the mixer translates the carrier frequency \( f_c \) to a fixed IF of 455kHz by using a local oscillator of frequency \( f_{LO} \). The broadcast-band frequencies range from 540kHz to 1600kHz. Determine the range of tuning that must be provided in the local oscillator when:
   (i) \( f_{LO} \) is higher than \( f_c \)
   (ii) \( f_{LO} \) is lower than \( f_c \).  [CO1, CO2]
1' (b) A sinusoidally modulated AM signal \( f(t) \) is applied to the square-law device, such that the output voltage \( e_0(t) = f(t)^2 \). Show that the ratio of the second harmonic to the first harmonic in \( e_0(t) \) is equal to \( \mu/4 \). [CO1, CO2] 

2 (a) With the help of the block diagram explain the generation scheme of Pulse Width Modulated signal. [CO2, CO3] 

2 (b) For a low-pass signal with a bandwidth of 6000 Hz, what is the minimum sampling frequency for perfect reconstruction of the signal? What is the minimum required sampling frequency if a guard band of 2000 Hz is required? [CO2] 

2 (c) Discuss the need of line coding in a communication system. An ASCII code '1011001' is transmitted using line coding. Draw the waveform and calculate the DC content if: 
   i) Unipolar coding is used. 
   ii) Manchester coding is used. [CO3] 

3 (a) In a broadcasting communication system the transmitter power is 40 KW, the channel attenuation is 80 dB, and the noise power-spectral density is \( 10^{-10} \) W/Hz. The message signal has a bandwidth of \( 10^4 \) Hz. Find the output SNR if the modulation is SSB. [CO4] 

3 (b) Derive the Figure of Merit of a FM receiver and analyse the effect of signal power on its performance. [CO4] 

OR 

3'(b) What is the resulting signal to quantization noise ratio for a signal uniformly distributed on \([-1, 1]\) when uniform PCM with 256 levels is employed. [CO4] 

3 (c) Explain companding and analyse its effect on the performance of a PCM communication system. [CO3] 

4 A pulse transmission system uses matched filter approach for signal detection. Design a detector that maximizes the output signal to noise ratio assuming that the pulse amplitude of \(-A\) and \(+A\) represents the two symbols 0 and 1 respectively. Also prove that the average probability of symbol error in a binary symmetric channel depends solely on the ratio of the transmitted signal energy per bit to the noise spectral density. [CO2, CO3, CO4]
1 (a) Find the electric field intensity at a point P(0,0,z) due to a circular ring of radius 'a', carrying a total charge Q, distributed uniformly along the ring. Neglect the thickness of the ring and consider point P along the axis of the ring at a distance z from its center.

OR

(a') A dipole having a moment \( p = 3a_x - 5a_y + 10a_z \) nC.m is located at (1, 2, -4) in free space. Find \( V \) at \( P(2, 3, 4) \).

(b) State and explain the Gauss’s law. Deduce the Coulomb’s law from the Gauss’s law thereby affirming that Gauss’s law is an alternative statement of Coulomb’s law and that Coulomb’s law is implicit in Maxwell’s equation \( \nabla \cdot \mathbf{D} = \rho_f \).

2 (a) Two homogeneous, isotropic dielectrics with relative permittivities \( \varepsilon_{r1} = 2 \) and \( \varepsilon_{r2} = 8 \) are separated by the surface \( x-2y+2z=5 \). The origin lies in region 1. If \( E_1 = 20a_x - 10a_y + 50a_z \) V/m. Find \( E_2 \).

OR

(a') State and explain Ampere's circuital law. A hollow conducting cylinder has inner radius 'a' and outer radius 'b' carries current \( I \) along the positive z-axis. Find \( \mathbf{H} \) everywhere.

(b) A conducting current strip carrying \( K = 12a_x \) A/m lies in the x=0 plane between \( y=0.5 \) and \( y=1.5 \) m. There is also a current filament of \( I = 5A \) in the \( a_x \) direction along the z-axis. Find the force exerted on the filament by the current strip.

OR
(b') Two co-axial conducting cylinders of radius 2 cm and 4 cm have a length of 1 m. The region between the cylinders contains a layer of dielectric from \( r = 2 \) cm to \( r = 3 \) cm with \( \varepsilon_r = 4 \) and rest of the region between cylinders is filled with free space. Find the capacitance between two cylinders.

3. (a) A conducting rod moves with a constant velocity of \( 3a_z \) m/sec parallel to a long straight wire carrying current 15 A as shown in Fig. 1. Calculate the emf induced in the rod and state which end is at higher potential.

(b) What is the significance of displacement current? Derive the point form of continuity equation and discuss its significance.

4. (a) In a non-magnetic medium

\[
E = 4\sin(2\pi 10^7 t - 0.8x) a_z \text{ V/m,}
\]

Find relative permittivity, intrinsic impedance and time averaged power per unit area carried by the wave.

OR

(a') Calculate the skin depth and velocity of propagation for a uniform plane wave at frequency 6 MHz traveling in polyvinylchloride (\( \mu_r = 1 \), \( \varepsilon_r = 4 \), dissipation factor=7x10^-2).

(b) Derive the wave equations for \( E \) and \( H \) for a sinusoidal wave in a lossy conducting medium.

5. (a) What is quarter wave transformer matching? A thin wire half-wave dipole antenna has an input impedance of \( Z_L = 73 + j42.50\Omega \). Design a quarter wave transformer to match this antenna to a transmission line with characteristic impedance \( Z_0 = 100\Omega \).

(b) Explain how transmission lines can be used as reactive circuit elements at high frequencies. Give the equivalent reactive components represented by transmission lines of various lengths under open and short circuit conditions.
Differential Operators in various co-ordinate Systems

**DIVERGENCE**

**CARTESIAN** \[ \nabla \cdot \mathbf{D} = \frac{\partial D_x}{\partial x} + \frac{\partial D_y}{\partial y} + \frac{\partial D_z}{\partial z} \]

**CYLINDRICAL** \[ \nabla \cdot \mathbf{D} = \frac{1}{\rho} \frac{\partial}{\partial \rho} (\rho D_\rho) + \frac{1}{\rho} \frac{\partial D_\phi}{\partial \phi} + \frac{\partial D_z}{\partial z} \]

**SPHERICAL** \[ \nabla \cdot \mathbf{D} = \frac{1}{r^2} \frac{\partial}{\partial r} (r^2 D_r) + \frac{1}{r \sin \theta} \frac{\partial}{\partial \theta} (D_\theta \sin \theta) + \frac{1}{r \sin \theta \partial \phi} \frac{\partial D_\phi}{\partial \phi} \]

**GRADIENT**

**CARTESIAN** \[ \nabla \mathbf{V} = \frac{\partial V}{\partial x} \mathbf{a}_x + \frac{\partial V}{\partial y} \mathbf{a}_y + \frac{\partial V}{\partial z} \mathbf{a}_z \]

**CYLINDRICAL** \[ \nabla \mathbf{V} = \frac{\partial V}{\partial \rho} \mathbf{a}_\rho + \frac{1}{\rho} \left( \frac{\partial V}{\partial \phi} \right) \mathbf{a}_\phi + \frac{\partial V}{\partial z} \mathbf{a}_z \]

**SPHERICAL** \[ \nabla \mathbf{V} = \frac{\partial V}{\partial r} \mathbf{a}_r + \frac{1}{r \sin \theta} \frac{\partial V}{\partial \theta} \mathbf{a}_\theta + \frac{1}{r \sin \theta \partial \phi} \frac{\partial V}{\partial \phi} \mathbf{a}_\phi \]

**CURL**

**CARTESIAN** \[ \nabla \times \mathbf{H} = \left( \frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z} \right) \mathbf{a}_x + \left( \frac{\partial H_x}{\partial z} - \frac{\partial H_z}{\partial x} \right) \mathbf{a}_y + \left( \frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} \right) \mathbf{a}_z \]

**CYLINDRICAL** \[ \nabla \times \mathbf{H} = \frac{1}{\rho} \left( \frac{\partial H_\phi}{\partial \rho} - \frac{\partial H_\rho}{\partial \phi} \right) \mathbf{a}_\rho + \left( \frac{\partial H_\rho}{\partial z} - \frac{\partial H_z}{\partial \rho} \right) \mathbf{a}_\phi + \frac{1}{\rho} \left[ \frac{\partial (\rho H_\phi)}{\partial \phi} - \frac{\partial H_\phi}{\partial \rho} \right] \mathbf{a}_z \]

**SPHERICAL** \[ \nabla \times \mathbf{H} = \frac{1}{r \sin \theta} \left[ \frac{\partial (H_\phi \sin \theta)}{\partial \theta} - \frac{\partial H_\theta}{\partial \phi} \right] \mathbf{a}_r + \frac{1}{r} \left[ \frac{\partial H_r}{\partial \theta} - \frac{\partial (r H_\theta)}{\partial r} \right] \mathbf{a}_\theta + \frac{1}{r} \left[ \frac{\partial (r H_\phi)}{\partial \phi} - \frac{\partial H_r}{\partial \phi} \right] \mathbf{a}_\phi \]

**LAPLACIAN**

**CARTESIAN** \[ \nabla^2 V = \frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} + \frac{\partial^2 V}{\partial z^2} \]

**CYLINDRICAL** \[ \nabla^2 V = \frac{1}{\rho} \frac{\partial}{\partial \rho} \left( \rho \frac{\partial V}{\partial \rho} \right) + \frac{1}{\rho^2} \frac{\partial^2 V}{\partial \phi^2} + \frac{\partial^2 V}{\partial z^2} \]

**SPHERICAL** \[ \nabla^2 V = \frac{1}{r^2} \frac{\partial}{\partial r} \left( r^2 \frac{\partial V}{\partial r} \right) + \frac{1}{r^2 \sin \theta} \frac{\partial}{\partial \theta} \left( \sin \theta \frac{\partial V}{\partial \theta} \right) + \frac{1}{r^2 \sin^2 \theta} \frac{\partial^2 V}{\partial \phi^2} \]

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