SNS COLLEGE OF TECHNOLOGY

Coimbatore-35
An Autonomous Institution

Accredited by NBA – AICTE and Accredited by NAAC – UGC with 'A+' Grade
Approved by AICTE, New Delhi & Affiliated to Anna University, Chennai

DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGINEERING

19ECT211 – ELECTROMAGNETIC FIELDS

II YEAR/ IV SEMESTER

UNIT 1 – STATIC ELECTRIC FIELD

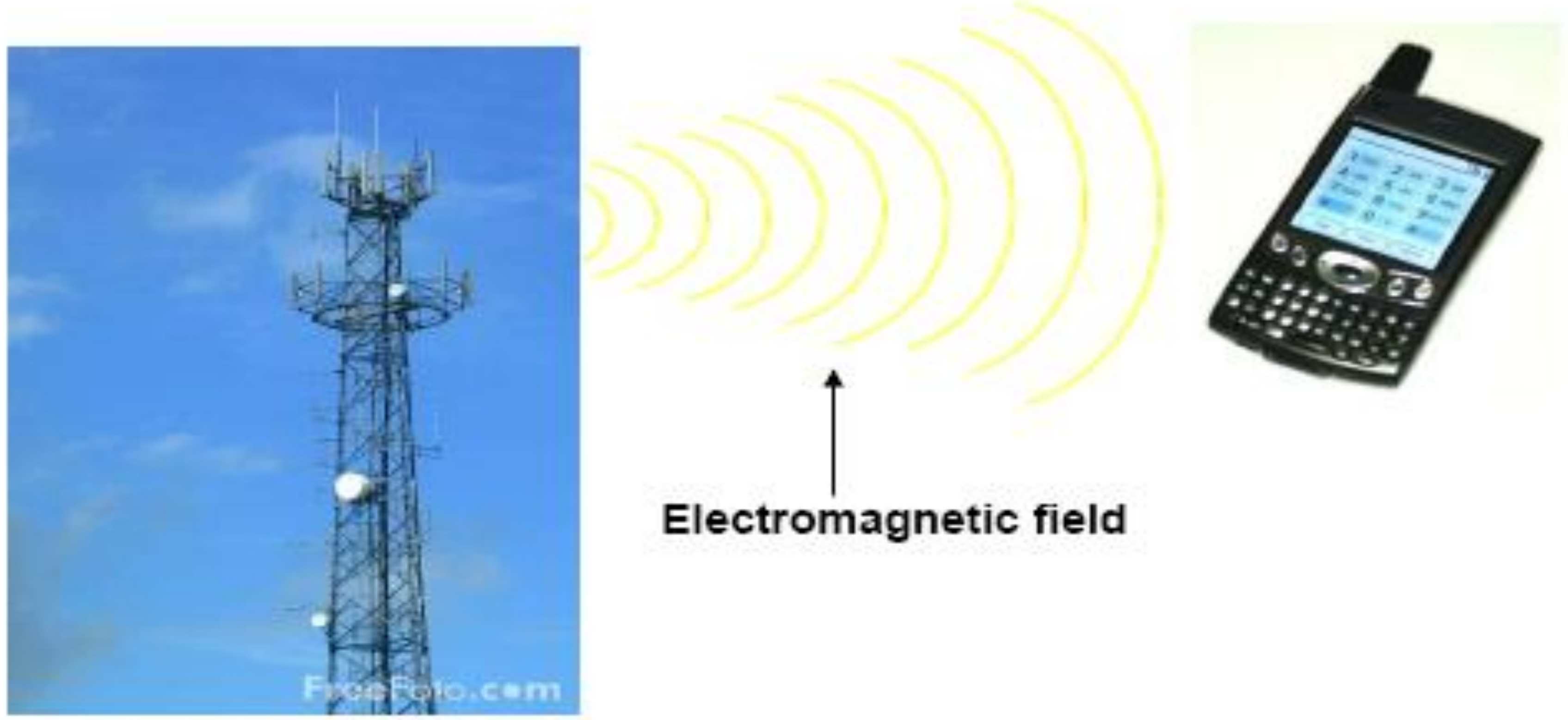
TOPIC 1 – VECTOR ANALYSIS

INTRODUCTION TO ELECTROMAGNETIC FIELDS

- Electromagnetics embraces electricity, magnetism, electric fields, magnetic fields and electromagnetic waves
- In electromagnetics the emphasis is on the space between the conductors and the electric and magnetic fields in this space
- The field approach of electromagnetics is essential for an understanding of waveguides, antennas, waves in space and particle field interactions
- Electromagnetics is also provides a basic insight to the operation of basic circuit elements as capacitors, resistors and inductors
- Electromagnetics is fundamental to the advancement of electric and computer technology

EXAMPLES OF ELECTROMAGNETIC APPLICATIONS

Communication Technology



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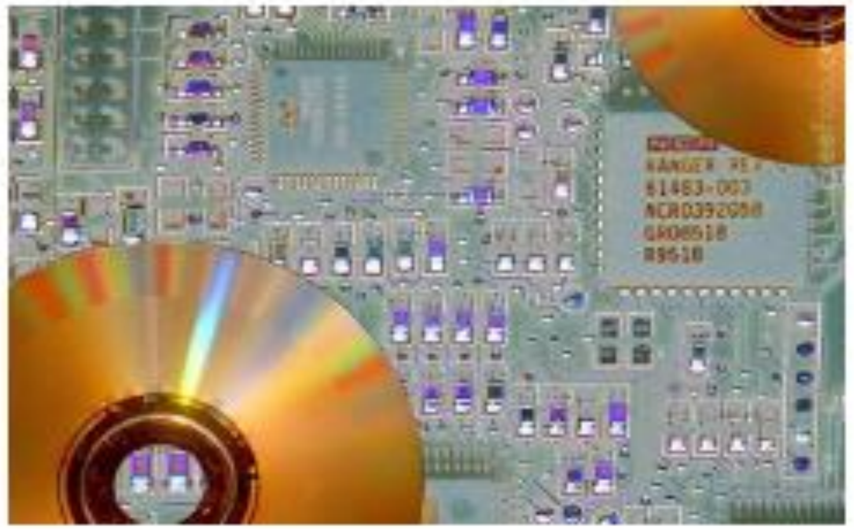
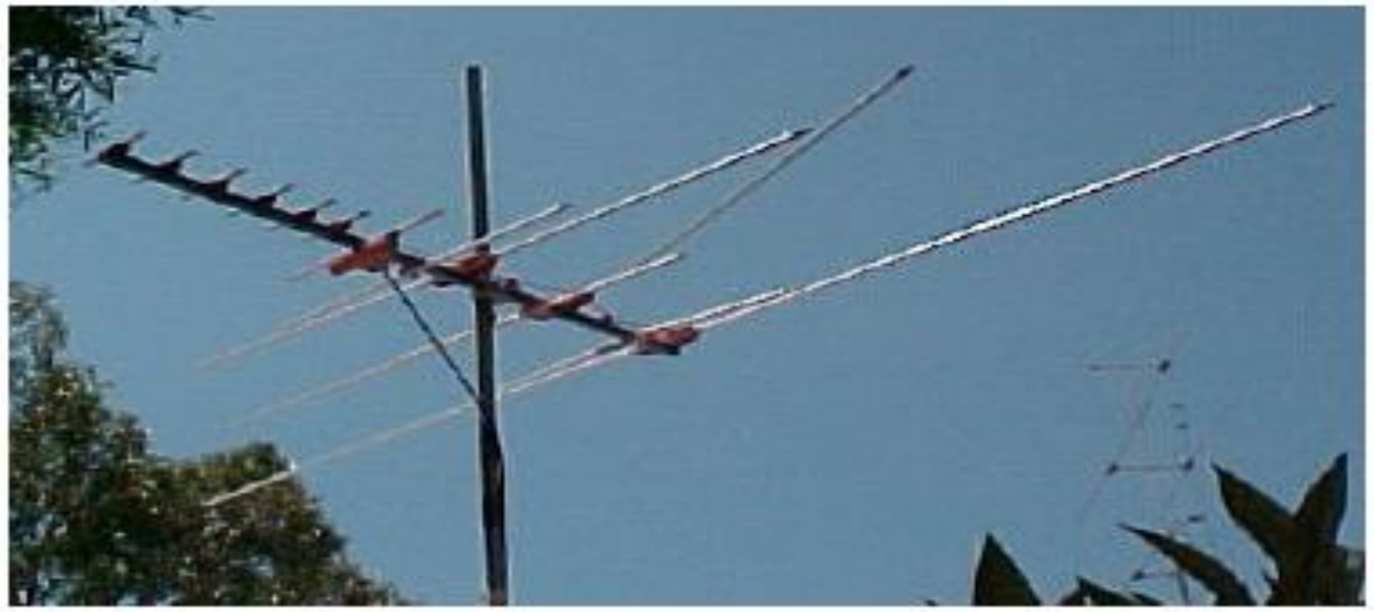
EXAMPLES OF ELECTROMAGNETIC APPLICATIONS

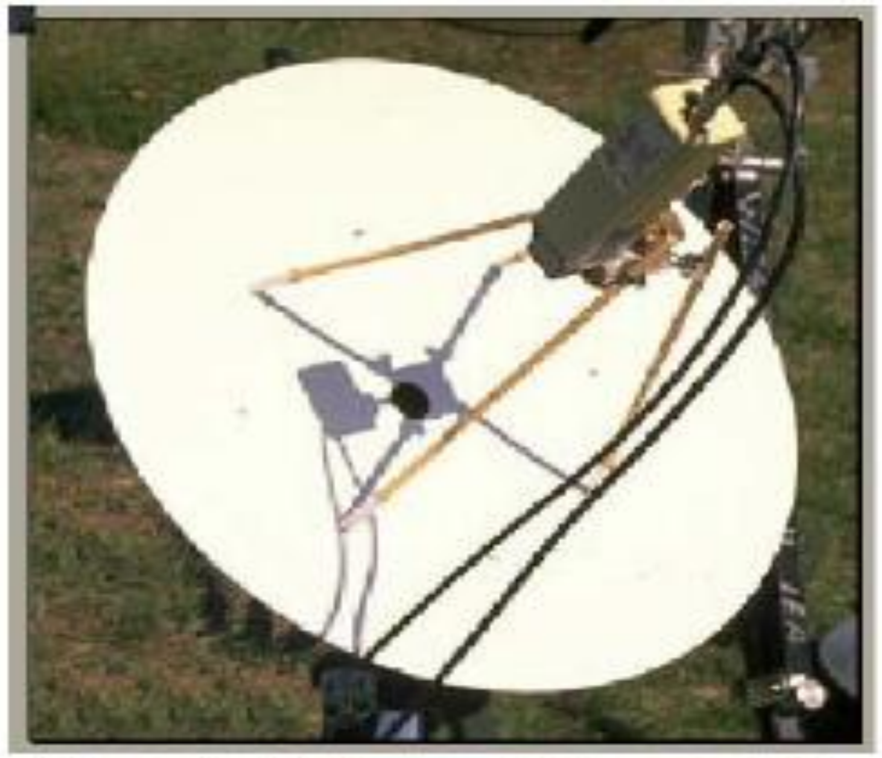
Computer Technology

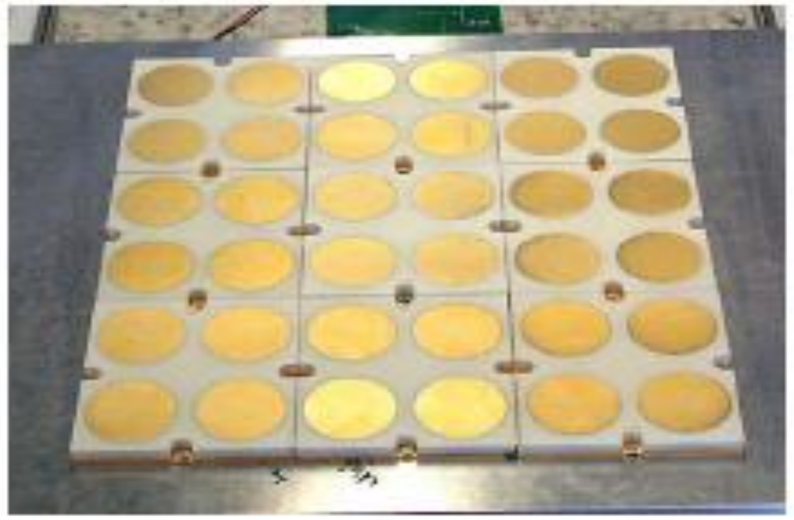


EXAMPLES OF ELECTROMAGNETIC APPLICATIONS

Antenna Technology

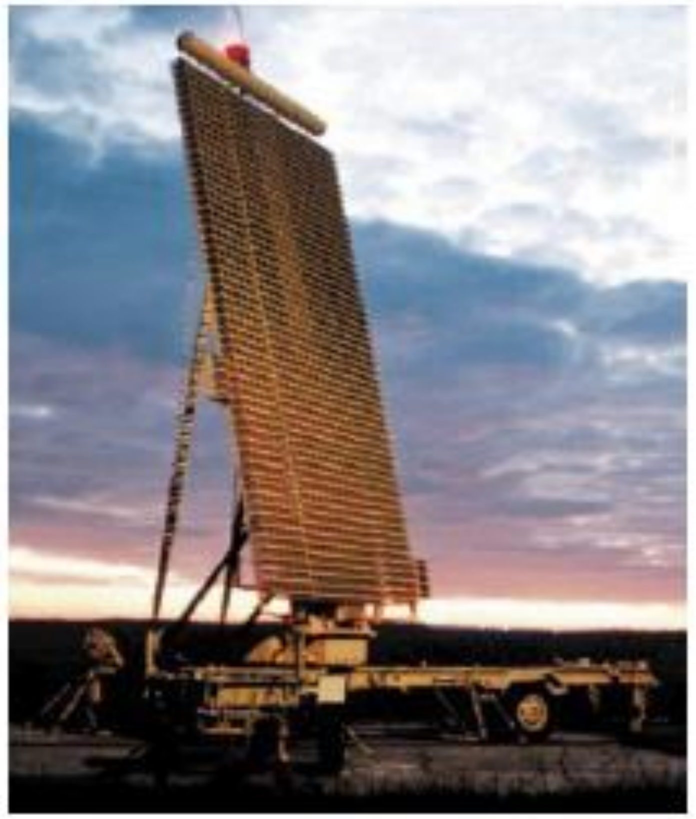




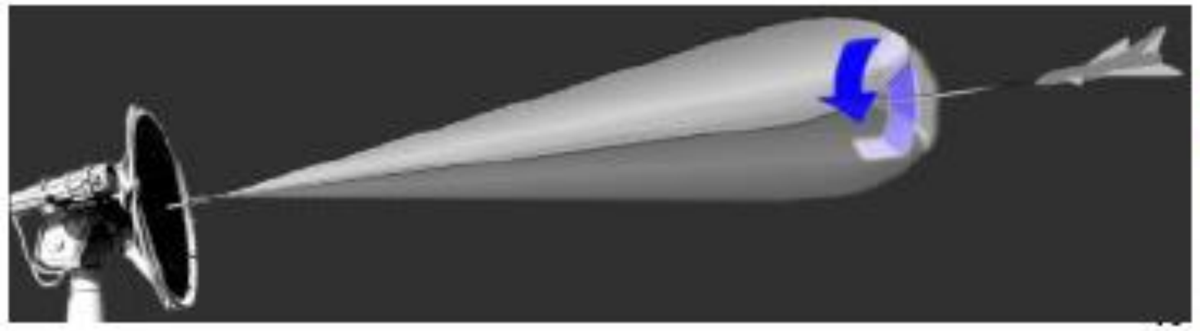


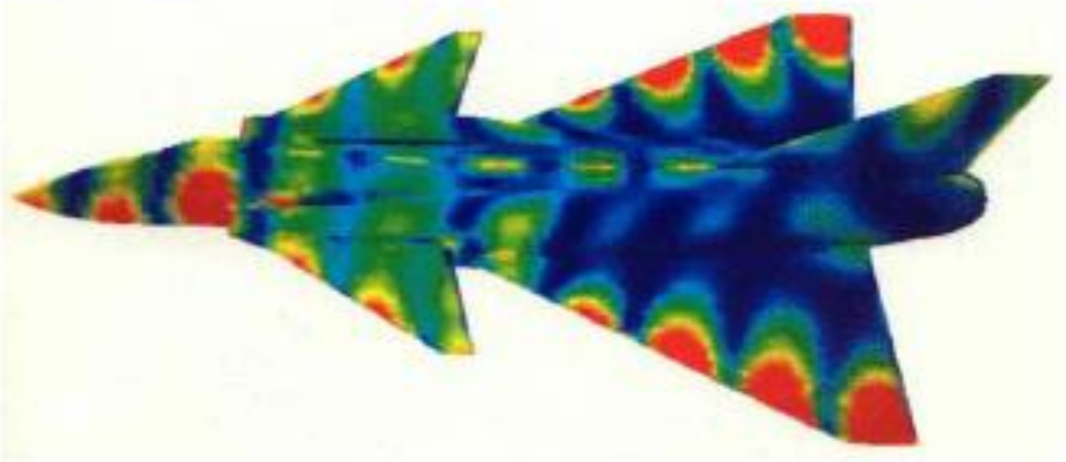
EXAMPLES OF ELECTROMAGNETIC APPLICATIONS

Military Defense Applications



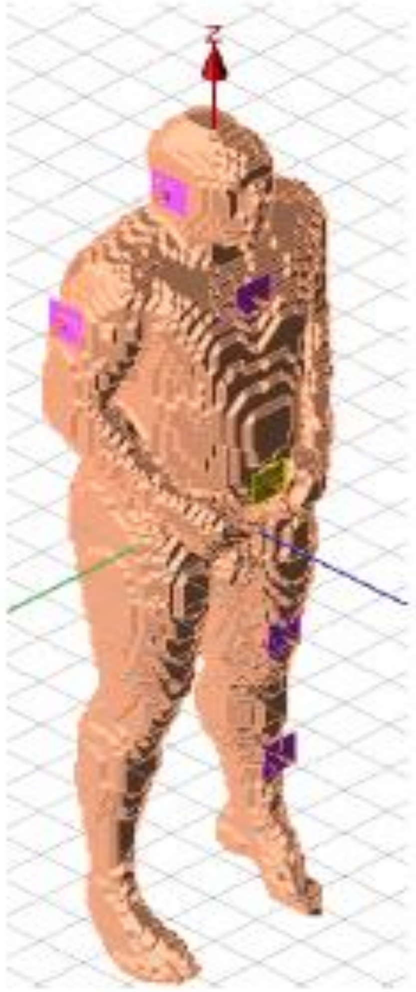
Radars

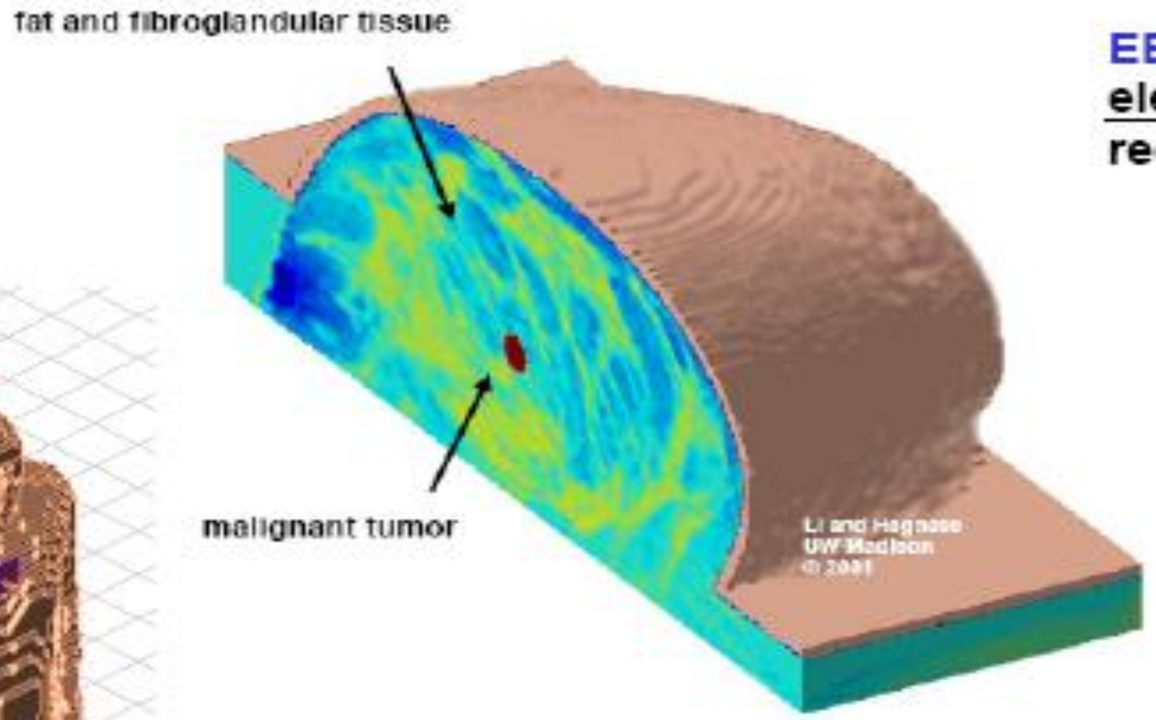




EXAMPLES OF ELECTROMAGNETIC APPLICATIONS

Biomedical Applications





EEG (Electroencephalography) measures the electrical activity produced by the brain as recorded from electrodes placed on the scalp.

Person wearing electrodes for EEG

ECG (electrocardiogram) records the electrical activity of the heart over time.

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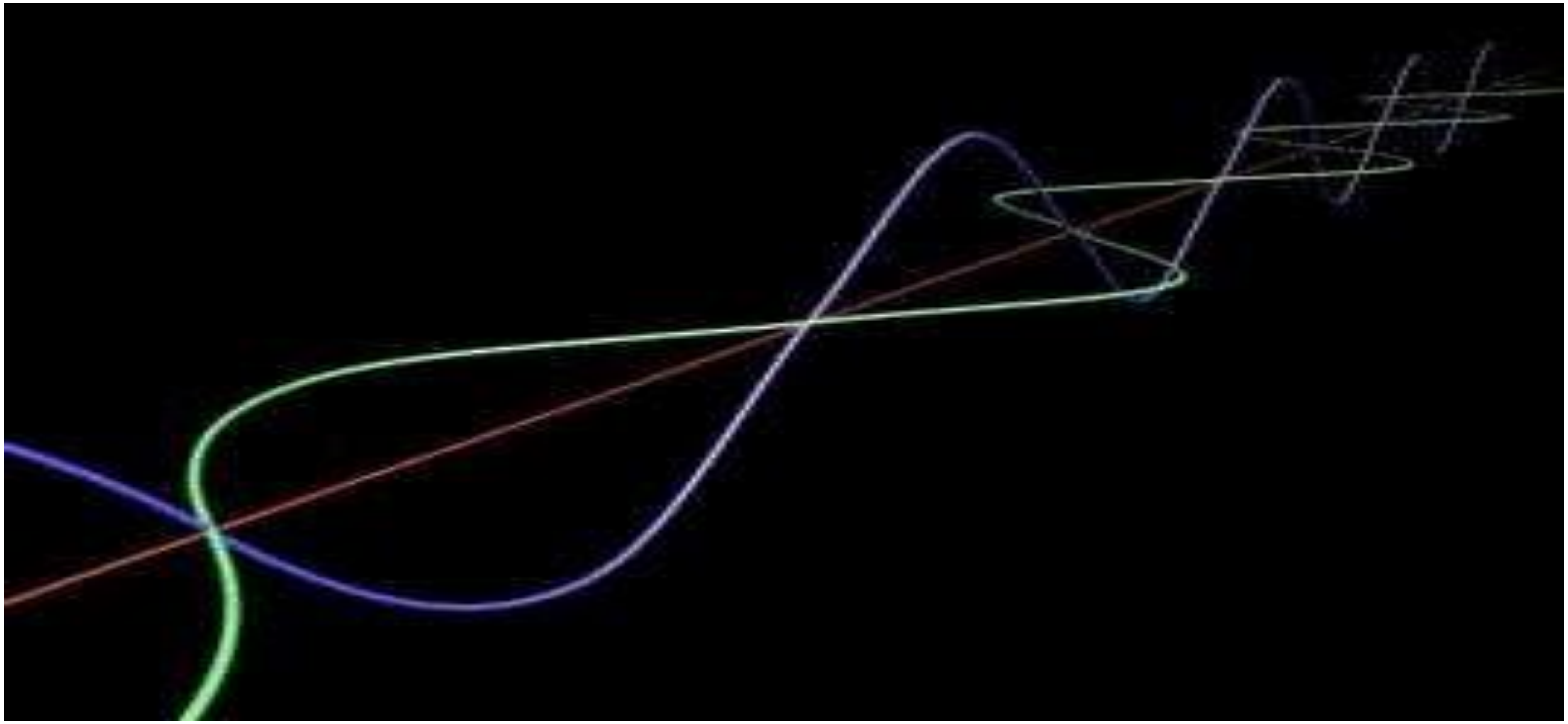
RESEARCH AREAS OF ELECTROMAGNETICS

- Antennas
- Microwaves
- Computational Electromagnetics
- Electromagnetic Scattering
- Electromagnetic Propagation
- Radars
- Optics
- etc ...

INTRODUCTION TO ELECTROMAGNETIC FIELDS

Electromagnetic is the study of the effects of charges at rest and charges in motion



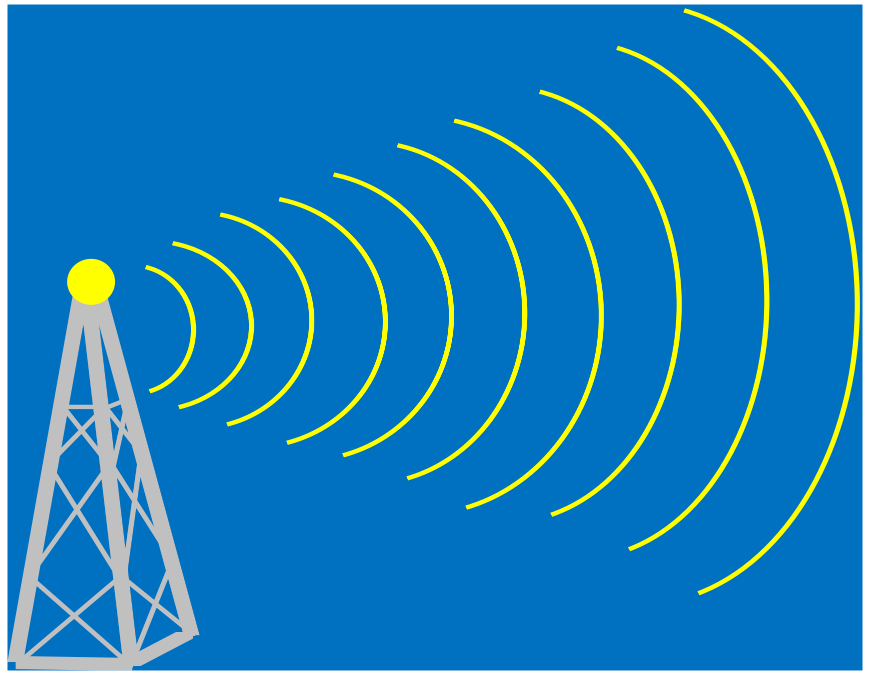
INTRODUCTION TO ELECTROMAGNETIC FIELDS

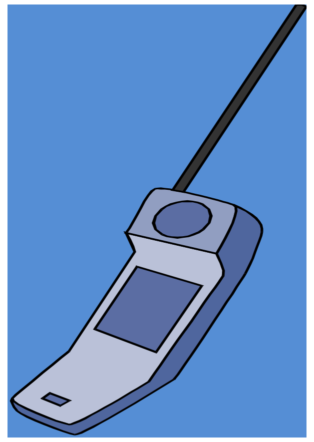
- Some special cases of electromagnetics:
  - Electrostatics: charges at rest
  - Magnetostatics: charges in steady motion
  - Electromagnetic waves: waves excited by charges in time-varying motion

WHY IS ELECTROMAGNETIC DIFFICULT ?

- Electric and magnetic fields are
  - 3 dimensional
  - vectors
  - vary in space as well as time
  - governed by PDEs
- Solution of Electromagnetic problem requires a high level of abstract thinking
- Mathematics is a powerful tool

INTRODUCTION TO ELECTROMAGNETIC FIELDS





- Transmitter and receiver are connected by a "field"

INTRODUCTION TO ELECTROMAGNETIC FIELDS

- When an event in one place has an effect on something at a different location, we talk about the events as being connected by a "field"
- A field is a spatial distribution of a quantity; in general, it can be either scalar or vector in nature

INTRODUCTION TO ELECTROMAGNETIC FIELDS

- Electric and magnetic fields:
  - Are vector fields with three spatial components
  - Vary as a function of position in 3D space as well as time
  - Are governed by partial differential equations derived from Maxwell's equations

INTRODUCTION TO ELECTROMAGNETIC FIELDS

- A scalar is a quantity having only an amplitude (and possibly phase)
- Examples: voltage, current, charge, energy, temperature
- A vector is a quantity having direction in addition to amplitude (and possibly phase)
- Examples: velocity, acceleration, force

INTRODUCTION TO ELECTROMAGNETIC FIELDS

- Fundamental vector field quantities in electromagnetics:

- Electric field intensity (E)
- units = volts per meter ($V/m = kg\ m/A/s3$)

- Electric flux density (electric displacement)
- units = coulombs per square meter ($C/m2 = A\ s\ /m2$)

INTRODUCTION TO ELECTROMAGNETIC FIELDS

- Magnetic field intensity
- units = amps per meter (A/m)

- Magnetic flux density
- units = teslas = webers per square meter (T = Wb/ m2)

FUNDAMENTAL ELECTROMAGNETIC FIELD QUANTITIES

	Field Quantity	Symbol	Unit
Electric	Electric field intensity	E	V/m
	Electric flux density	D	C/m^2
Magnetic	Magnetic flux density	B	T
	Magnetic field intensity	H	A/m

V/m = kg m/A/s^3

C/m^2 = A s /m^2

T (tesla) = Wb / m^2 = kg/A/s^3

A field is a spatial distribution of a quantity.
It can be either *scalar* or *vector* in nature.

THREE UNIVERSAL CONSTANTS

Velocity of an electromagnetic wave (e.g., light) in free-space (perfect vacuum)

$$c_0 \cong 3 \times 10^8 \quad \text{(m/s)}$$

Permittivity of free-space

Permittivity is a physical quantity that describes how an electric field affects and is affected by a dielectric medium.

Permittivity relates to a material's ability to transmit (or "permit") an electric field.

In a capacitor, an increased permittivity allows the same charge to be stored with a smaller electric field (or voltage), leading to an increased capacitance.

$$\varepsilon_0 \cong 8.854 \times 10^{-12} \quad \text{(F/m)}$$

Permeability of free-space

Permeability is the degree of magnetization of a material that responds linearly to an applied magnetic field.

Permeability is a material property that describes the ease with which a magnetic flux is established in a component

$$\mu_0 \cong 4\pi \times 10^{-7} \quad \text{(H/m)}$$

FUNDAMENTAL RELATIONSHIPS

$$c_0 = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$

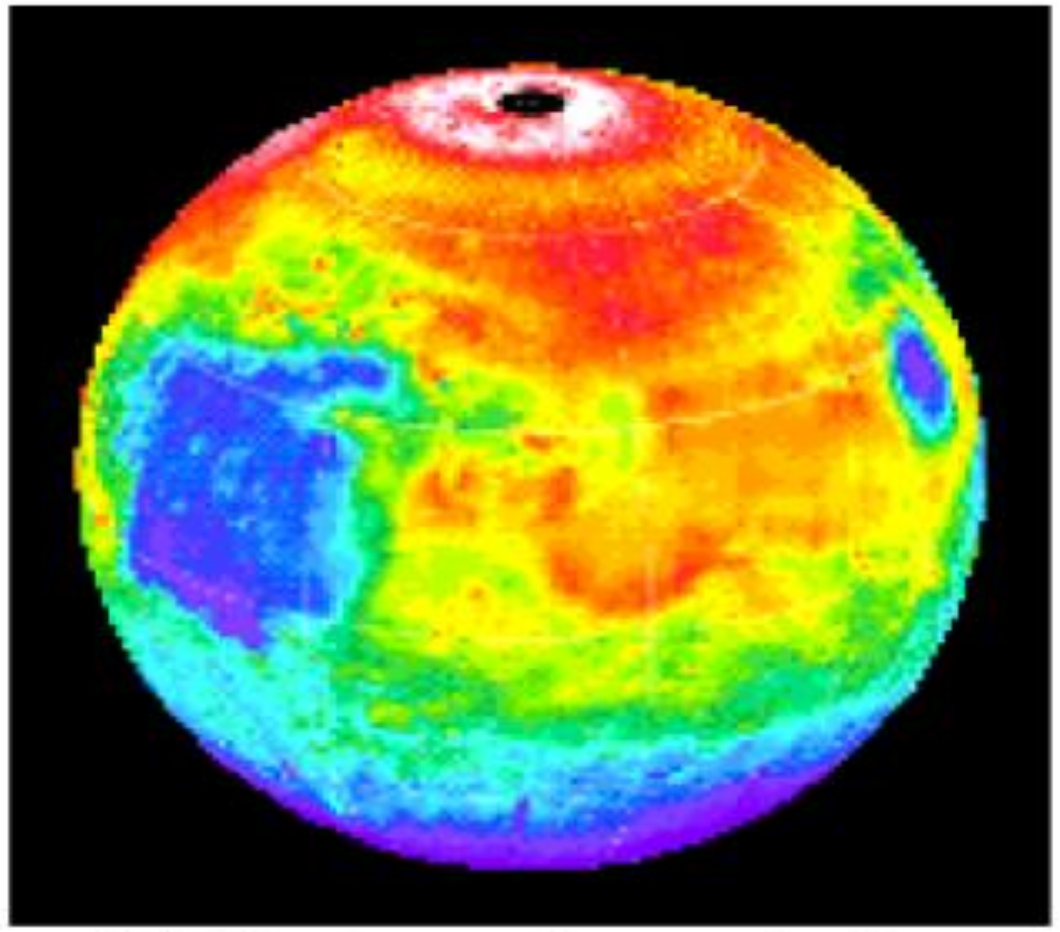
$$\left.\begin{aligned} \mathbf{D} &= \varepsilon_0 \mathbf{E} \\ \mathbf{B} &= \mu_0 \mathbf{H} \end{aligned}\right\} \quad \text{Constitutive Relations}$$

SCALAR AND VECTOR FIELDS

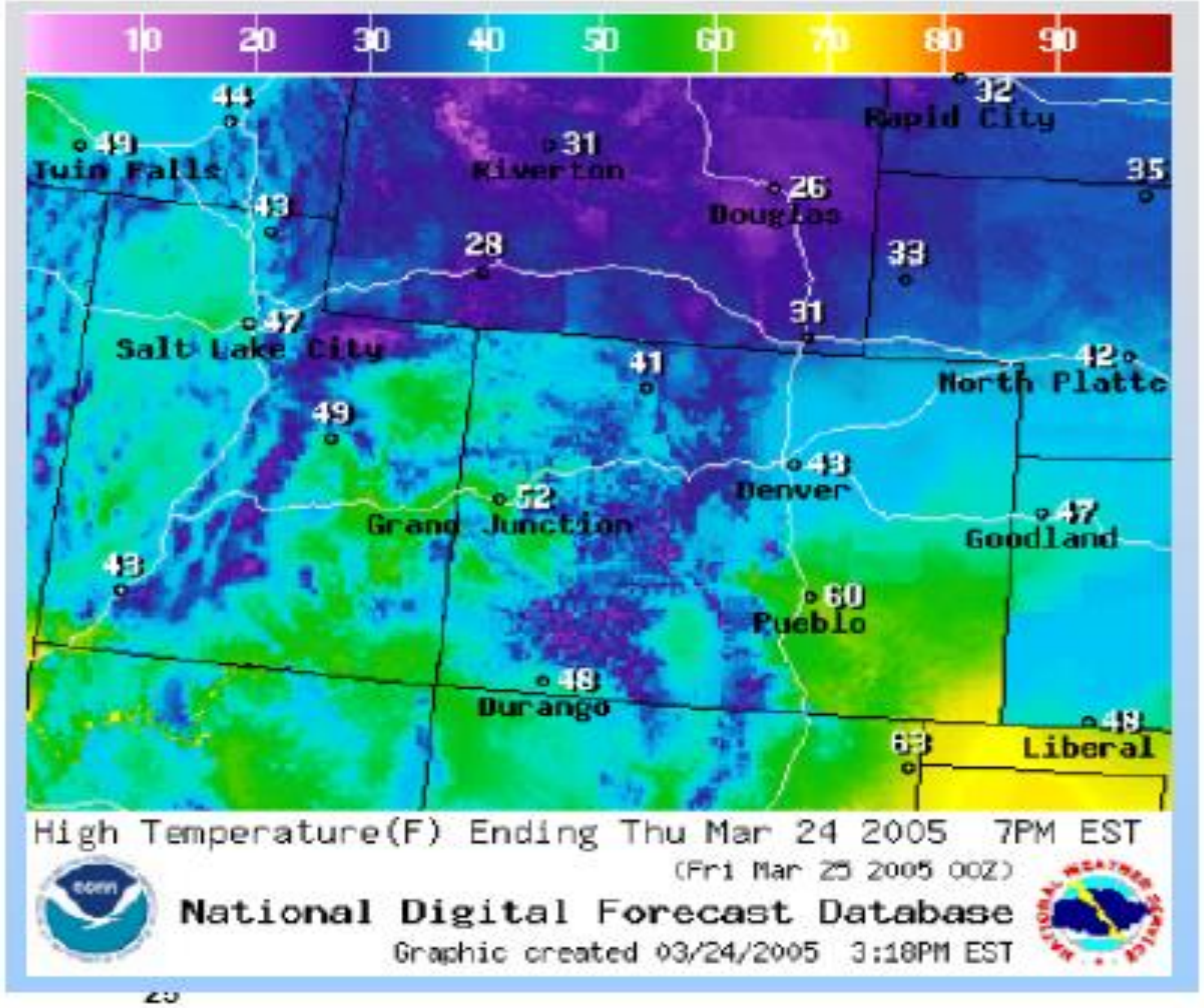
- A scalar field is a function that gives us a single value of some variable for every point in space.
- Examples: voltage, current, energy, temperature
- A vector is a quantity which has both a magnitude and a direction in space.
- Examples: velocity, momentum, acceleration and force

EXAMPLE OF A SCALAR FIELD

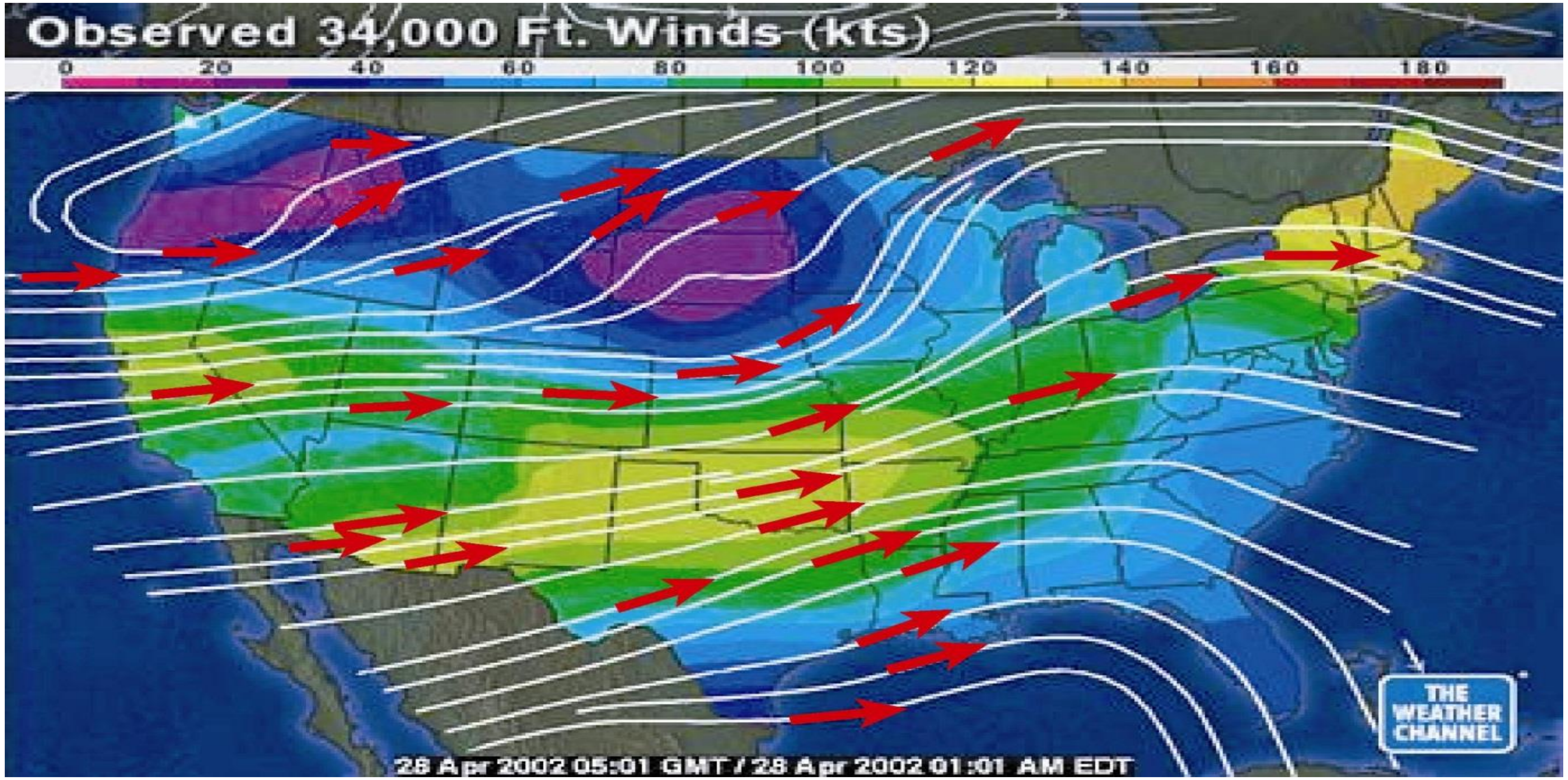
Temperature: Every location has associated value (number with units)



Nighttime temperature map for Mars



EXAMPLE OF A VECTOR FIELD



Example: Velocity vector field - jet stream

CO-ORDINATE SYSTEMS

3 PRIMARY COORDINATE SYSTEMS

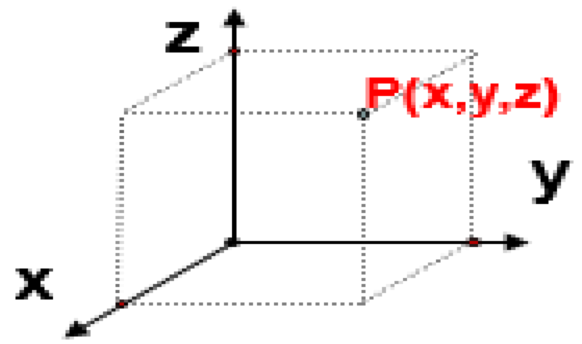
Rectangular
Cylindrical
Spherical

Choice is based on symmetry of problem

Examples:
Sheets - Rectangular
Wires/Cables - Cylindrical
Spheres – Spherical

ORTHOGONAL CO-ORDINATE SYSTEMS

Cartesian Coordinates

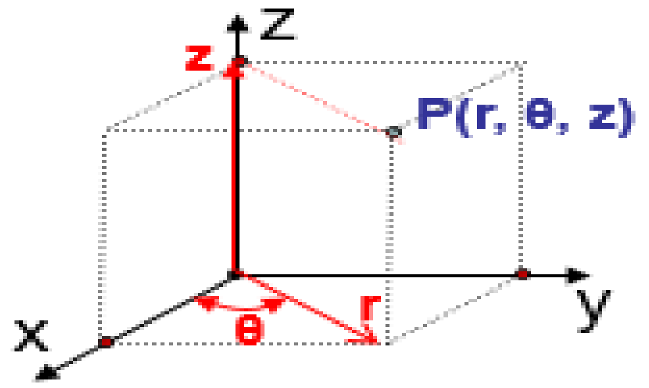


Rectangular Coordinates

P (x,y,z)

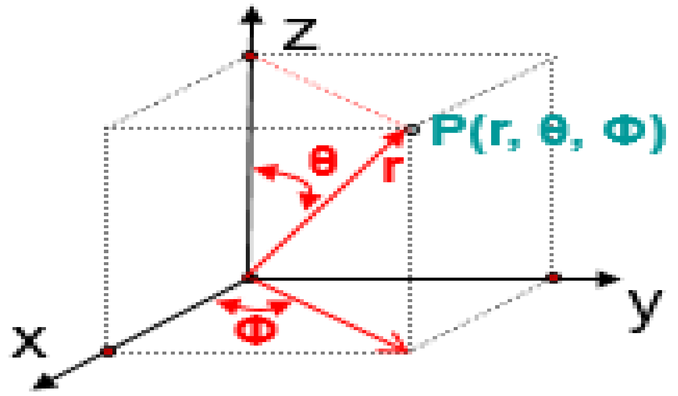
Cylindrical Coordinates

P (r, Θ, z)

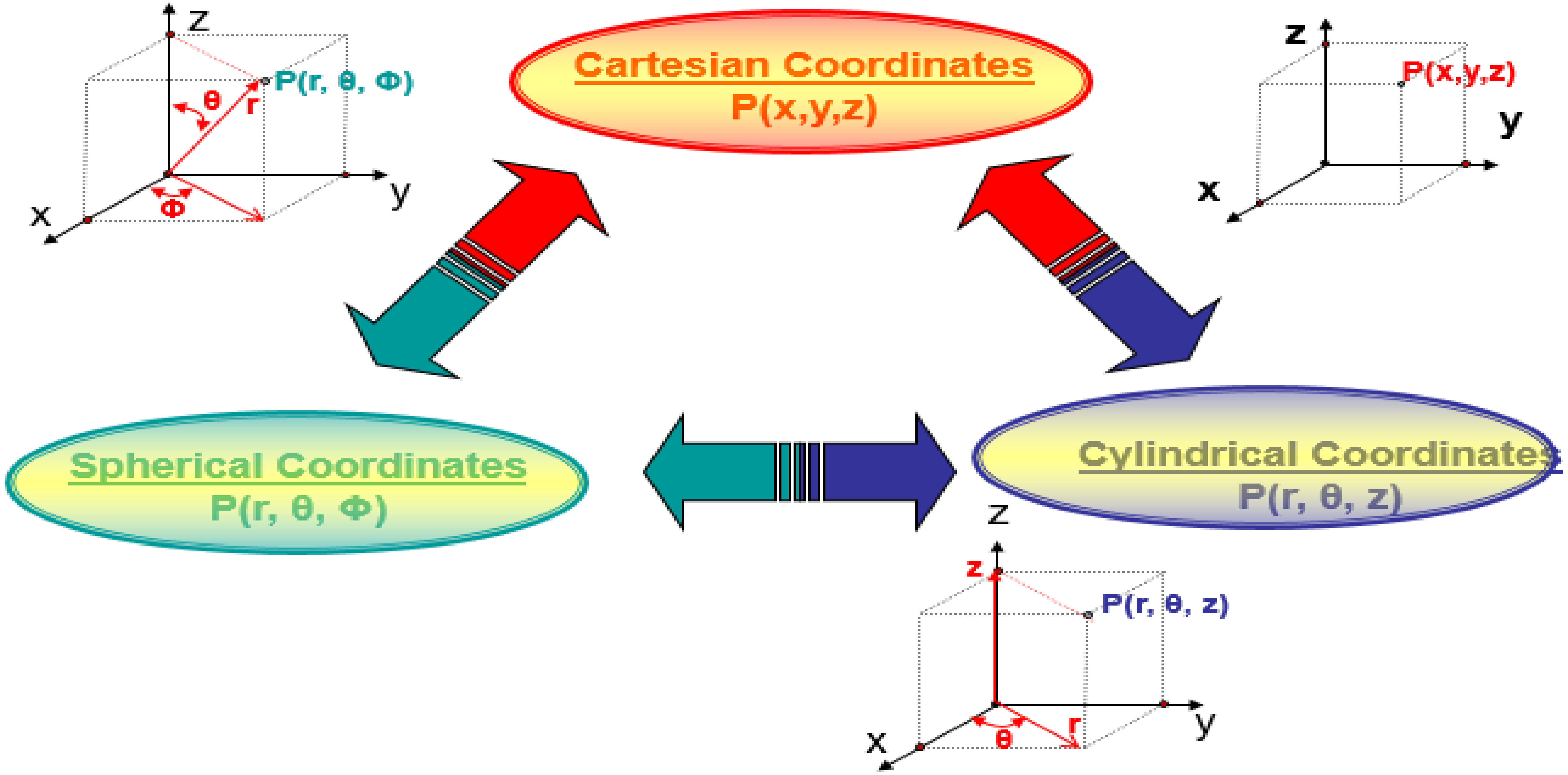


Spherical Coordinates

P (r, Θ, Φ)



CO-ORDINATE TRANSFORMATION



CO-ORDINATE TRANSFORMATION

- Cartesian to Cylindrical

(x, *y, z) to* (r,θ,Φ)

$$\rho = \sqrt{x^2 + y^2}, \qquad \phi = \tan^{-1}\frac{y}{x}, \qquad z = z$$

(r,θ,Φ) *to* (x, *y, z)*

$$x = \rho\cos\phi, \qquad y = \rho\sin\phi, \qquad z = z$$

CO-ORDINATE TRANSFORMATION

- Cartesian to Cylindrical

Vectoral Transformation

$$\begin{bmatrix} A_\rho \\ A_\phi \\ A_z \end{bmatrix} = \begin{bmatrix} \cos\phi & \sin\phi & 0 \\ -\sin\phi & \cos\phi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} A_x \\ A_y \\ A_z \end{bmatrix}$$

$$\begin{bmatrix} A_x \\ A_y \\ A_z \end{bmatrix} = \begin{bmatrix} \cos\phi & -\sin\phi & 0 \\ \sin\phi & \cos\phi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} A_\rho \\ A_\phi \\ A_z \end{bmatrix}$$

CO-ORDINATE TRANSFORMATION

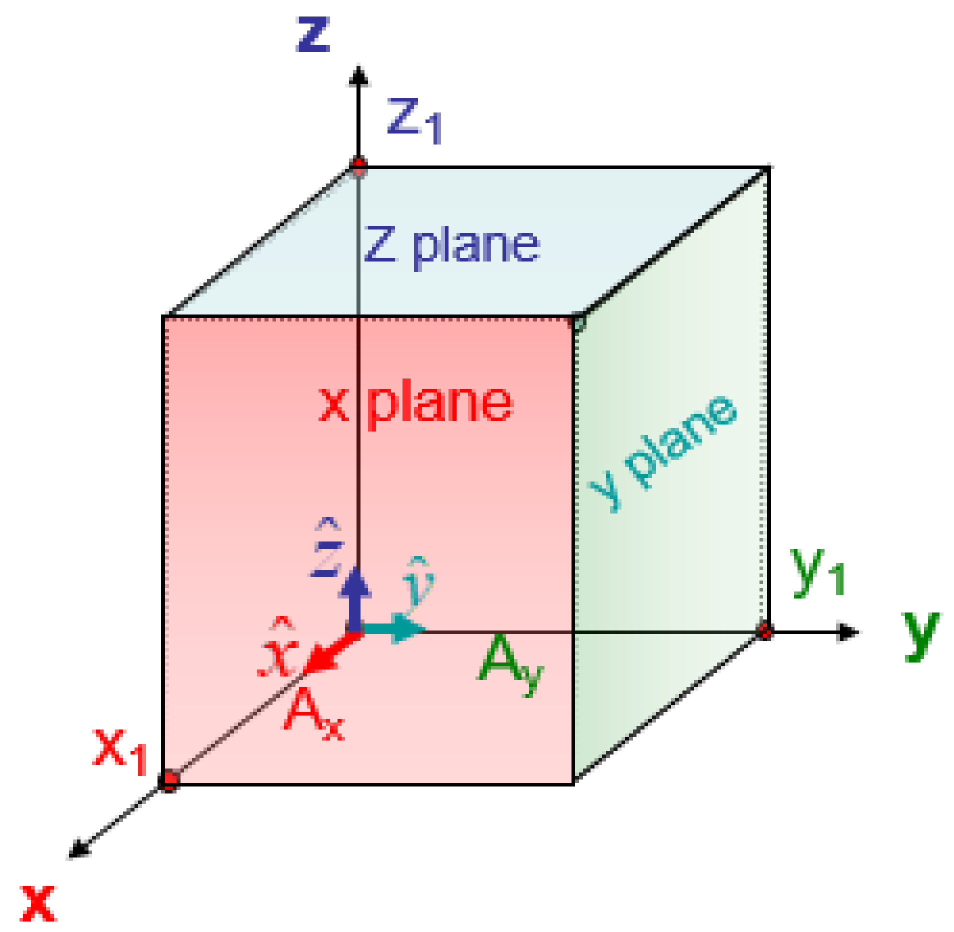
- Cartesian to Spherical

Vectoral Transformation

$$\begin{bmatrix} A_r \\ A_\theta \\ A_\phi \end{bmatrix} = \begin{bmatrix} \sin\theta\cos\phi & \sin\theta\sin\phi & \cos\theta \\ -\cos\theta\cos\phi & \cos\theta\sin\phi & -\sin\theta \\ -\sin\phi & \cos\phi & 0 \end{bmatrix} \begin{bmatrix} A_x \\ A_y \\ A_z \end{bmatrix}$$

$$\begin{bmatrix} A_x \\ A_y \\ A_z \end{bmatrix} = \begin{bmatrix} \sin\theta\cos\phi & \cos\theta\cos\phi & -\sin\phi \\ \sin\theta\sin\phi & \cos\theta\sin\phi & \cos\phi \\ \cos\theta & -\sin\theta & 0 \end{bmatrix} \begin{bmatrix} A_r \\ A_\theta \\ A_\phi \end{bmatrix}$$

VECTOR REPRESENTATİON



Unit (Base) vectors

A unit vector a_A along A is a vector whose magnitude is unity

$$\vec{a} = \frac{\vec{A}}{|\vec{A}|}$$

Unit vector properties

$$\hat{x} \cdot \hat{x} = \hat{y} \cdot \hat{y} = \hat{z} \cdot \hat{z} = 1$$

$$\hat{x} \cdot \hat{y} = \hat{y} \cdot \hat{z} = \hat{z} \cdot \hat{x} = 0$$

$$\hat{x} \times \hat{y} = \hat{z}$$

$$\hat{y} \times \hat{z} = \hat{x}$$

$$\hat{z} \times \hat{x} = \hat{y}$$

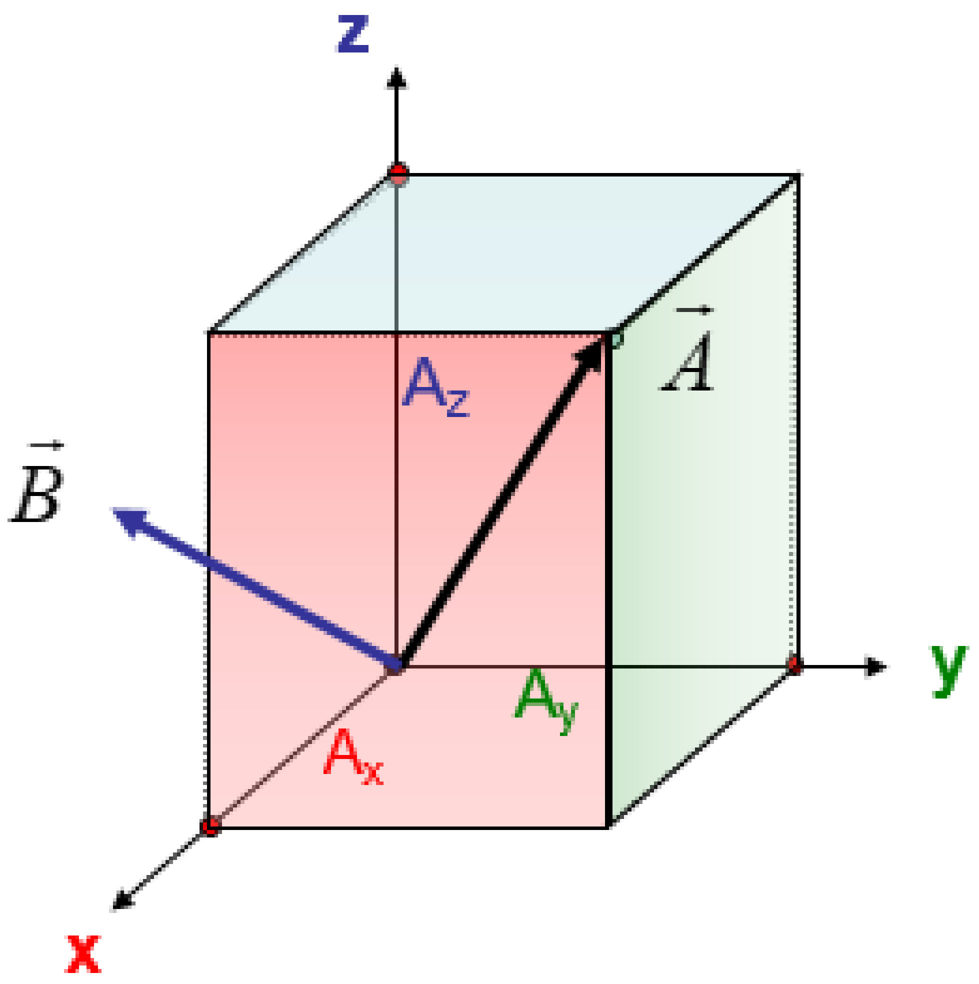
CARTESIAN COORDINATES

Dot product:

$$\vec{A}\cdot\vec{B} = A_x B_x + A_y B_y + A_z B_z$$

Cross product:

$$\vec{A}\times\vec{B} = \begin{vmatrix} \hat{x} & \hat{y} & \hat{z} \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{vmatrix}$$



MULTIPLICATION OF VECTORS

- Two different interactions (what's the difference?)
  - Scalar or dot product :
    - the calculation giving the work done by a force during a displacement
    - work and hence energy are scalar quantities which arise from the multiplication of two vectors

MULTIPLICATION OF VECTORS

- if A·B = 0
  - The vector A is zero
  - The vector B is zero
  - $\theta = 90^\circ$

LAWS

Commutative law :

$$A \cdot B = B \cdot A$$

$$A \times B = -B \times A$$

Distribution law :

$$A \cdot (B + C) = A \cdot B + A \cdot C$$

$$A \times (B + C) = A \times B + A \times C$$

Associative law :

$$A \cdot BC \cdot D = (A \cdot B)(C \cdot D)$$

$$A \cdot BC = (A \cdot B)C$$

$$A \times B \cdot C = (A \times B) \cdot C$$

$$A \times (B \times C) \neq (A \times B) \times C$$

UNIT VECTOR RELATIONSHIPS

- It is frequently useful to resolve vectors into components along the axial directions in terms of the unit vectors *i*, *j*, and *k*.

$$i \cdot j = j \cdot k = k \cdot i = 0$$
$$i \cdot i = j \cdot j = k \cdot k = 1$$

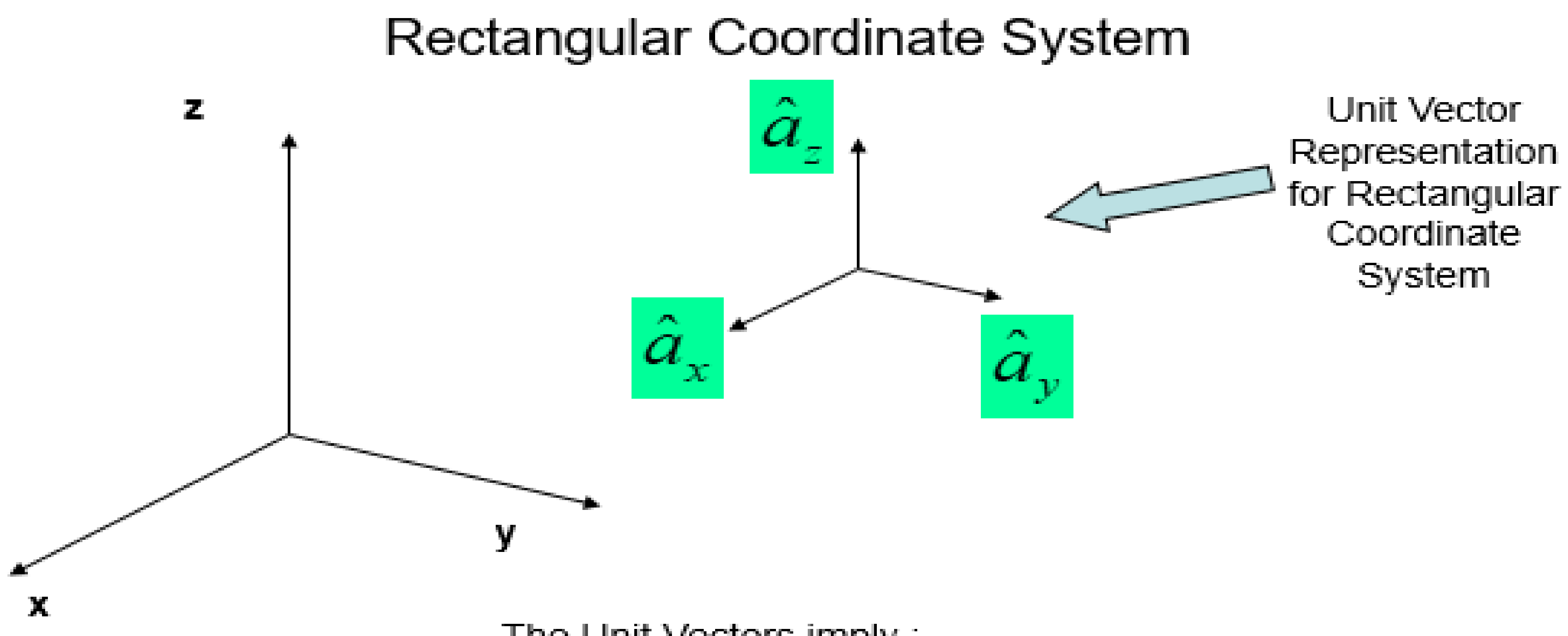
$$i \times i = j \times j = k \times k = 0$$
$$i \times j = k$$
$$j \times k = i$$
$$k \times i = j$$

$$A = A_x i + A_y j + A_z k$$
$$B = B_x i + B_y j + B_z k$$

$$A \cdot B = A_x B_x + A_y B_y + A_z B_z$$

$$A \times B = \begin{vmatrix} i & j & k \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{vmatrix}$$

VECTOR REPRESENTATION: UNIT VECTORS



The Unit Vectors imply :

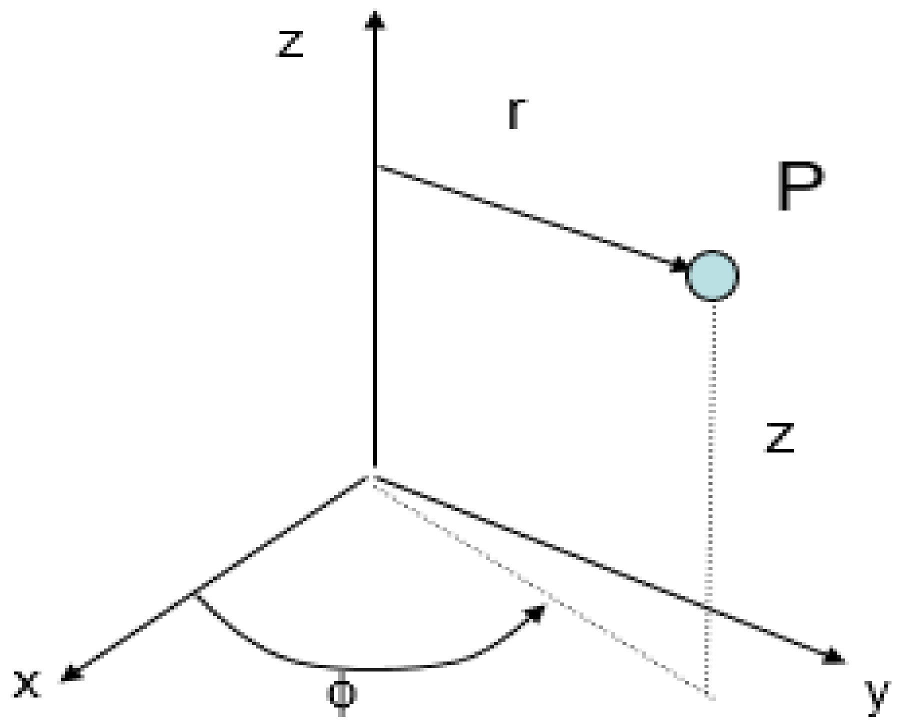
$\hat{a}_x$ ⇒ Points in the direction of increasing **x**

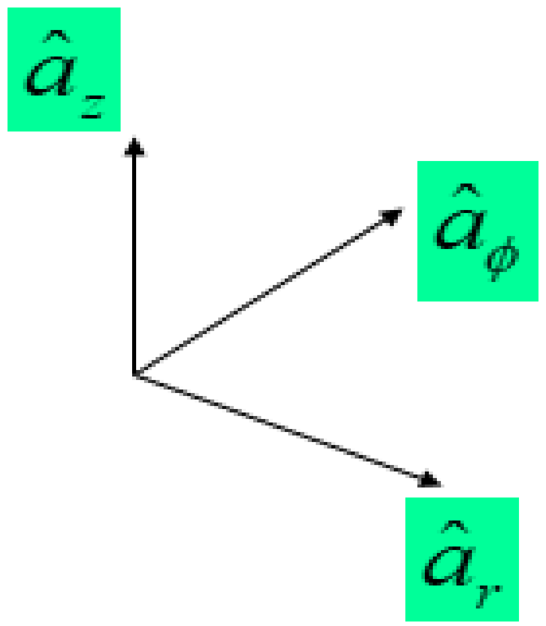
$\hat{a}_y$ ⇒ Points in the direction of increasing **y**

$\hat{a}_z$ ⇒ Points in the direction of increasing **z**

VECTOR REPRESENTATION: UNIT VECTORS

Cylindrical Coordinate System



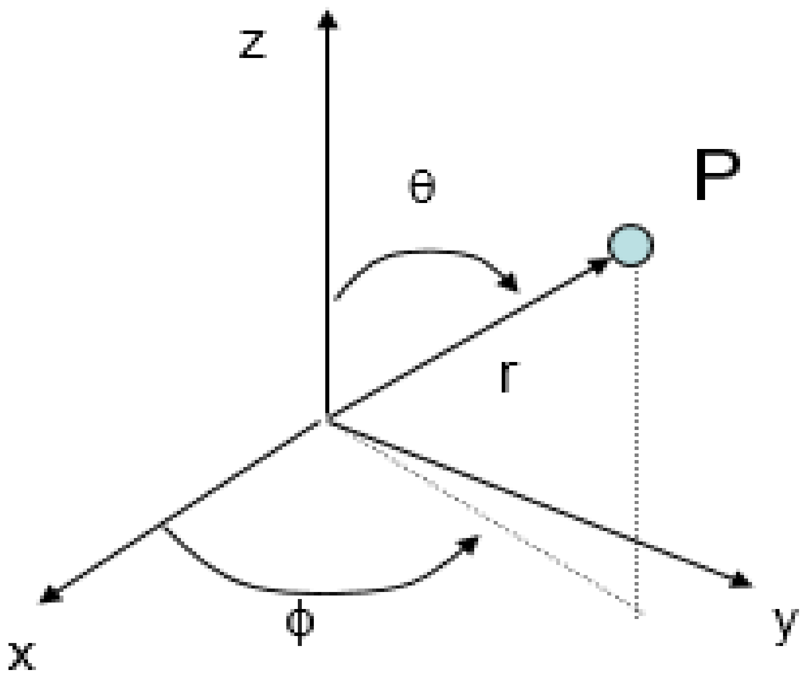


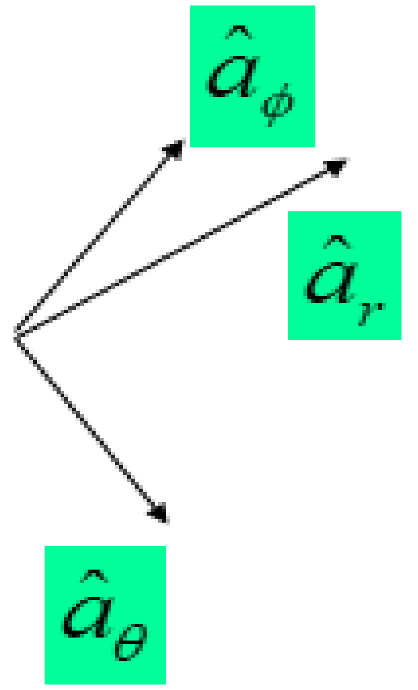
The Unit Vectors imply :

- $\hat{a}_r$ ⇨ Points in the direction of increasing **r**
- $\hat{a}_\phi$ ⇨ Points in the direction of increasing **φ**
- $\hat{a}_z$ ⇨ Points in the direction of increasing **z**

VECTOR REPRESENTATION: UNIT VECTORS

Spherical Coordinate System





The Unit Vectors imply :

$\hat{a}_r$ ⇒ Points in the direction of increasing **r**

$\hat{a}_\theta$ ⇒ Points in the direction of increasing **θ**

$\hat{a}_\phi$ ⇒ Points in the direction of increasing **φ**

REFERENCES

- John.D.Kraus , “ Electromagnetics “,5th Edition , Tata McGraw Hill, 2010
- W. H.Hayt & J A Buck: “Engineering Electromagnetics” Tata McGraw-Hill, 7th Edition 2007

THANK YOU