Antenna Theory and Design
Introduction

2023

Kamil Karaçuha

References

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Contact

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Our Motivation

Goals

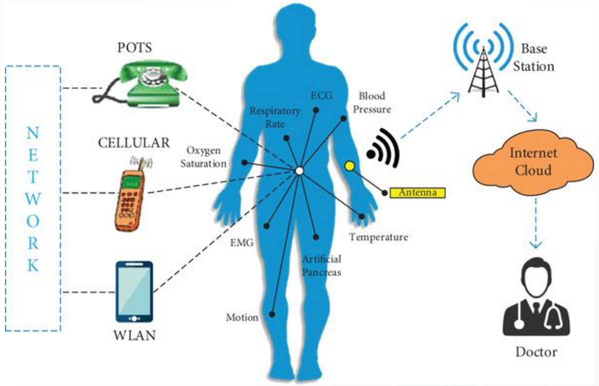
The aim is to provide you with an understanding of:
•Engineering considerations related to antenna systems used in communication, broadcasting, radar, direction finding, and navigation applications.

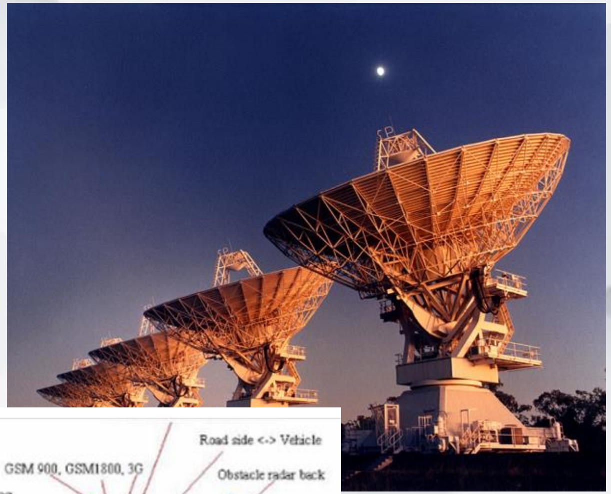
This will enable you to:
•Engage in the analysis and creation of:

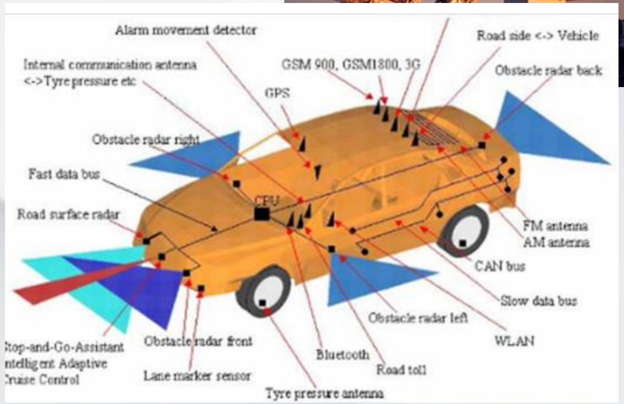
- Microstrip antennas
- Broadband antenna systems, including spiral and log periodic structures
- Parabolic reflector antennas
- Feed networks for phased arrays (beam-forming networks)
- ELF, VLF, LF, MF, HF antennas

•Integrate theoretical approaches with Computer Aided Design (CAD) tools.
•Implement systems for conducting antenna far-field and compact range measurements."

Antennas are everywhere







Content

Content From Balanis' Book

- Antennas
- Fundamental Parameters of Antennas
- Radiation Integrals and Auxiliary Potential Functions
- Linear Wire Antennas
- Loop Antennas
- Arrays: Linear, Planar, and Circular
- Aperture Antennas
- Horn Antennas
- Reflector Antennas
- Microstrip Antennas
- **Antenna Synthesis and Continuous Sources**
- **Frequency Independent Antennas, Antenna Miniaturization, and Fractal Antennas**
- **Antenna Measurements**

Suggested References

Balanis, C. A. (2016). Antenna Theory, Analysis and Design (4th ed.). John Wiley & Sons.

Stutzman, W. L., & Thiele, G. A. (1998). Antenna Theory and Design (2nd ed.). John Wiley & Sons.

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Elliot, R. S. (1981). Antenna Theory and Design. Prentice-Hall.

Kildal, P. S. (2015). Foundations of Antennas.

Collin, R. E., & Zucker, F. J. (1969). Antenna Theory Part I & II. McGraw-Hill Book Co.

Collin, R. E. (1985). Antennas and Radiowave Propagation. McGraw-Hill Book Co.

Grading

Grading will be as below:

1. Easy Midterm, questioning the fundamentals: 20%
2. Group Study with the selected topic and presentation: 20% *(3-4 students)*
3. Realization of an Antenna design published in the journals after 2013 (included) listed below with any commercial tools and preparing a report.
   (HFSS tutorial is provided to you.) (1-2 students) 20%
4. Final Examination including derivations and engineering design trade-offs 40%

Journals:

IEEE Transactions on Antennas and Propagation

IEEE Antennas and Wireless Propagation Letters

IEEE Transactions on Microwave Theory and Techniques

AEU-International Journal of Electronics and Communications

IET Microwaves, Antennas & Propagation

IEEE Access

If you need workstation, contact with me

No HW, attendance is not compulsory but encouraged.

Selected Topics in Balanis Book (3-4 students)

- **Antenna Synthesis and Continuous Sources**
- **Frequency Independent Antennas, Antenna Miniaturization, and Fractal Antennas**
- **Antenna Measurements**

Grading

Group Study with the selected topic and presentation: 20% *(3-4 students)*

- You need to use İTÜ official presentation template (*you can find it on "KURUMSAL KİMLİK" website)*
- You may even need to use the blackboard. It is encouraged to use it during derivations
- You may present it in Turkish and/or English, please do not other languages ☺
- You should learn your selected topic totally, but you will present some part of it, of course.
- The division of labor must be fair, equal, and consistent.
- There must be a consistent, comprehensive, and holistic approach to the relevant subject.
- It would be better if the scope and details of the content are done in consultation with me. It would be good to proceed with an evolutionary approach while preparing the presentation. It is important not to prepare for the last week. Development during the term is also important in grading.

Grading

Realization of an Antenna design published in the journals after 2013 (included) listed below with any commercial tools and preparing a report.

(HFSS tutorial is provided to you.) (1-2 students) 20%

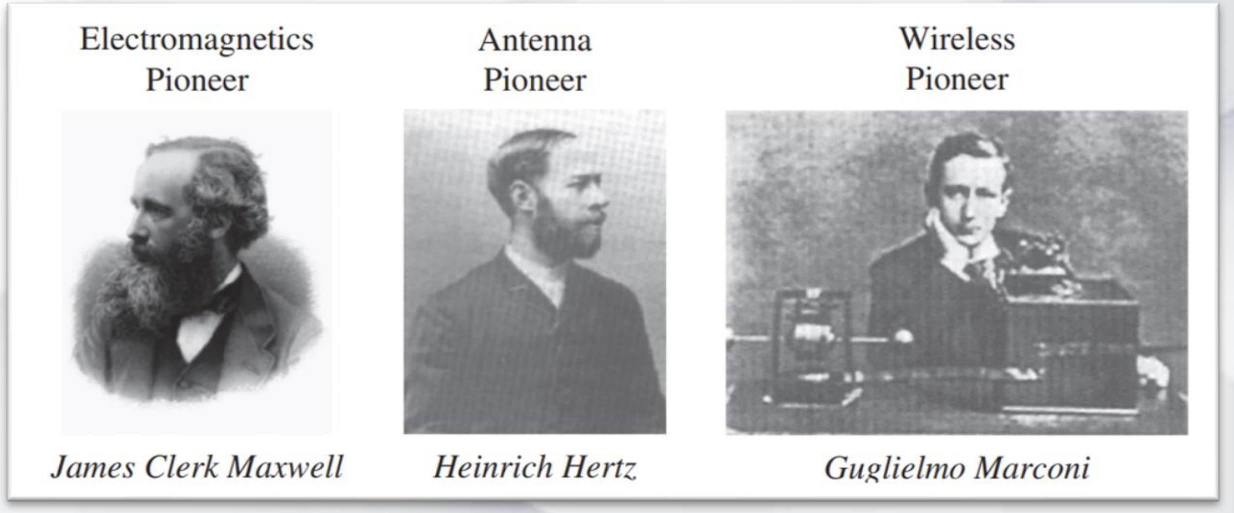
- Reporting must be done according to ITU official format. You can work alone or in groups of two. If one person is alone and the same person wants to work in a group, they can be a group of 3 people, provided that they are a single group. That group is obliged to take a more detailed approach.
- An evolutionary approach is essential in this process. It would be good to share the selected articles, progress and problems during the year with me. Communication is important for grading.

Introduction

Antennas are mainly found in communication applications, with most uses in telecommunications, which means distant communications and has roots in the Greek word “tele” meaning “at a distance.”
Telecommunication, telepathy, telescope, telemeter

Table. Timeline of Significant Events in the History of Antennas and Communications

Pre-modern civilization (up to 2 million years ago)
Optical communications: Smoke signals, flags
Acoustical communications: Drums
1844 Telegraph-The beginning of electronic communication
Samuel Morse
1864 Maxwell's equations-Principles of radio waves and the electromagnetic spectrum
James Clerk Maxwell
1866 First lasting transatlantic telegraph cable
1876 Telephone-Wireline analog communication over long distance
Alexander Bell
1887 First Antenna
Heinrich Hertz.
1897 First practical wireless (radio) systems
Guglielmo Marconi
1901 First transatlantic radio
Guglielmo Marconi
1920 First broadcast radio station
World War II Development of radar; horn, reflector, and array antennas
1950s Broadcast television in wide use
1960s Satellite communications and fiber optics
1980s Wireless reinvented with widespread use of cellular telephones

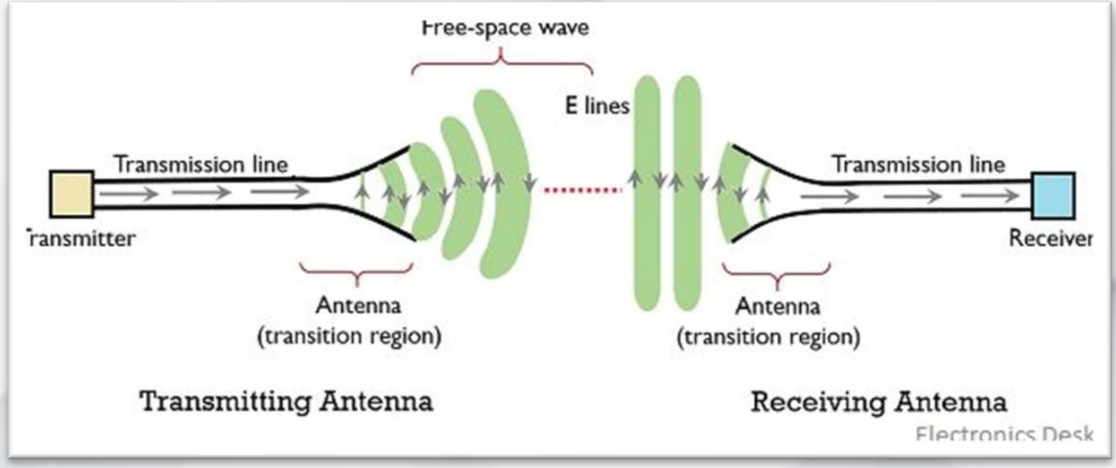


What is antenna?

An antenna is a **device** or structure designed to **transmit** or **receive** electromagnetic waves. It is a crucial component in various communication systems, including radio, television, wireless networks, radar, and satellite communication. The primary purpose of an antenna is **to convert electrical signals into electromagnetic waves for transmission, or to capture incoming electromagnetic waves and convert them into electrical signals for reception.**

- An antenna is a passive structure that serves as a transition between a transmission line and an air
- A transducer between 'free space' and transmission line
- A device for transmitting or receiving electromagnetic waves

  directional spatial filter
- It filters in frequency domain



Transmission - radiates electromagnetic energy into space

Reception – collects electromagnetic energy from space

High frequency vs. low frequency
Antenna vs. transmission line
Near range vs far range

Why antenna?

Factors that dictate the choice between transmission lines and EM radiation

Attenuation

- Path loss in transmission lines: $\propto (e^{-\alpha r})^2$ exponential,
- Path loss between two LOS antennas: algebraic, $\propto \frac{1}{r^2}$

Cost

- # of users
- Type of service
- Distances involved

Application

Ex: Mobile Commun.,
Commun. from ship to shore,
radar
satellite systems

Other factors that influence the choice of the type of transmission system include historical reasons, security, and reliability

Terrain and environmental conditions

Ex: Earthquake regions

Distance and Range:

•Transmission lines are suitable for conveying signals over relatively short distances within a system or between components. Antennas are used for long-range communication, broadcasting, and satellite links.

Directionality and Beamforming:

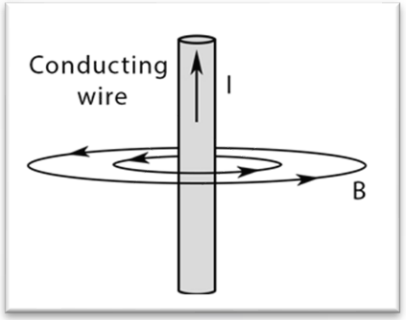
•Antennas can be engineered to have specific radiation patterns, allowing for directional transmission or reception. This is crucial in applications like radar, satellite communication, and wireless networks.

Power Handling Capability:

•Transmission lines are designed to carry high-power signals with minimal loss. For high-power applications, especially in industrial settings, transmission lines are preferred. Antennas are generally not designed to handle high power levels.

Radiation Mechanism

Any time-varying electric current can radiate electromagnetic waves in the space.



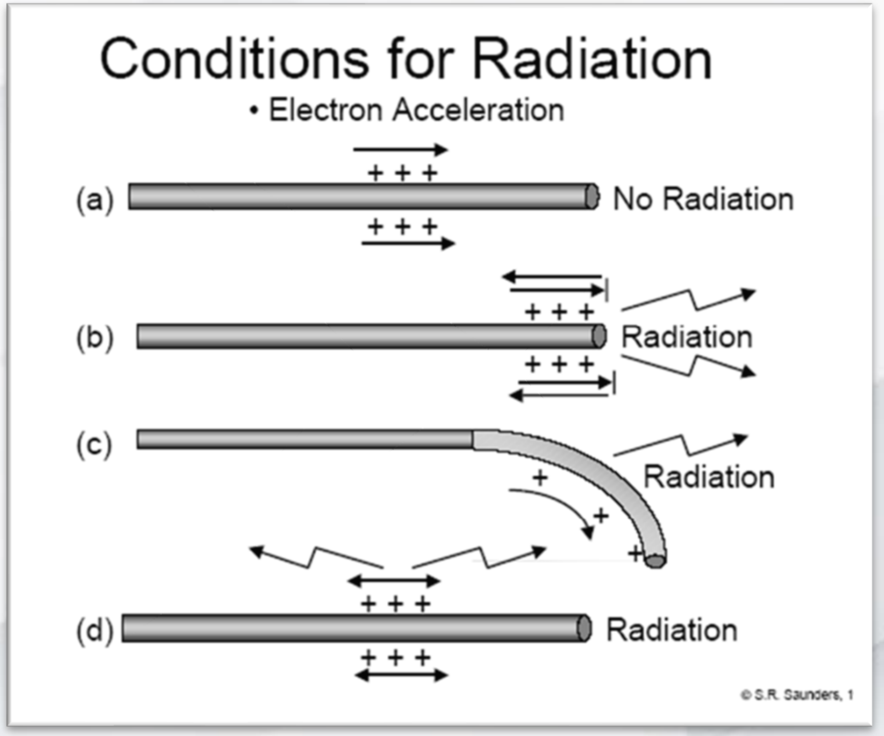
$$\nabla \times \bar{H} = \bar{J} + \varepsilon \frac{\partial \bar{E}}{\partial t}$$

Conduction current density

Displacement current density $\bar{J}_d = \varepsilon \frac{\partial \bar{E}}{\partial t}$

the waves moving across the tops of a wind-swept field of wheat while the base of the stalks remain stationary.

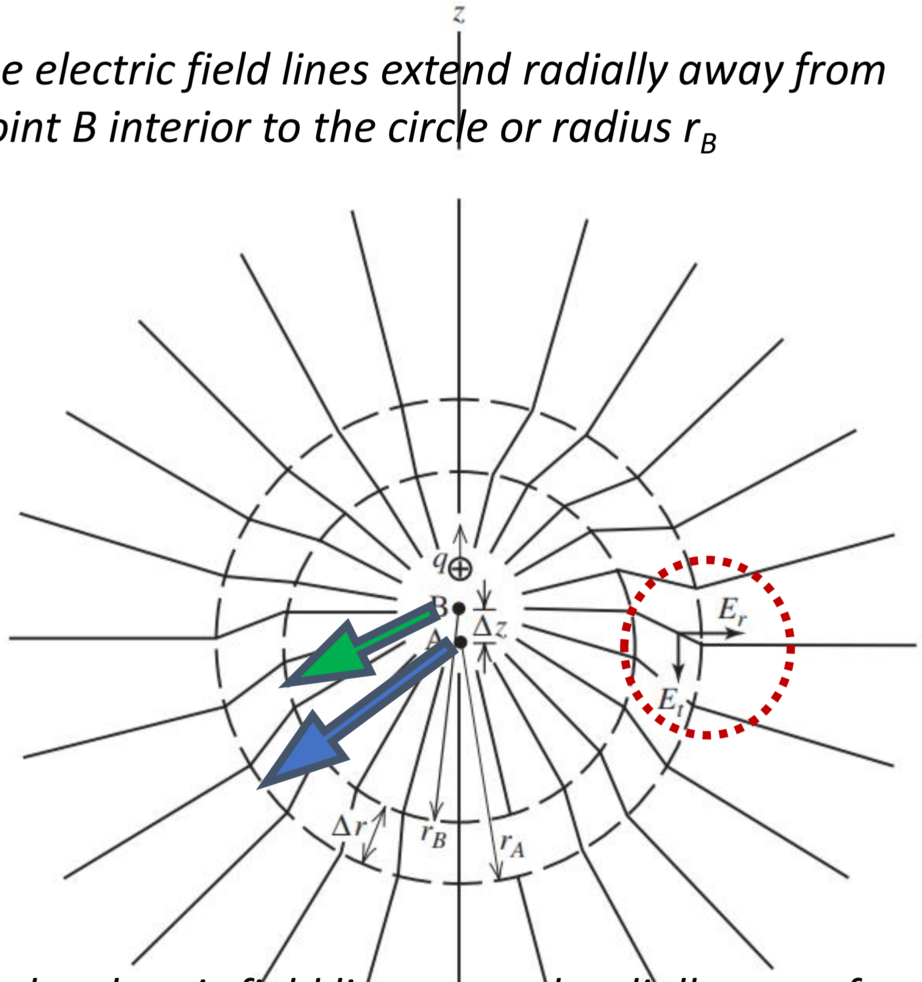
o Leonardo da Vinci (1452–1519)



The important physical principle in this example is that accelerated charges radiate. Acceleration, in general, occurs through change of speed or change of direction of a charge. For antennas the primary mechanism of radiation is via charges (i.e., charge disturbances) moving back and forth on a wire, or oscillating in response to an oscillating generator. Charge direction is reversed at the ends of the wire, which is an acceleration and results in radiation.

Radiation Mechanism

the electric field lines extend radially away from point B interior to the circle or radius r_B



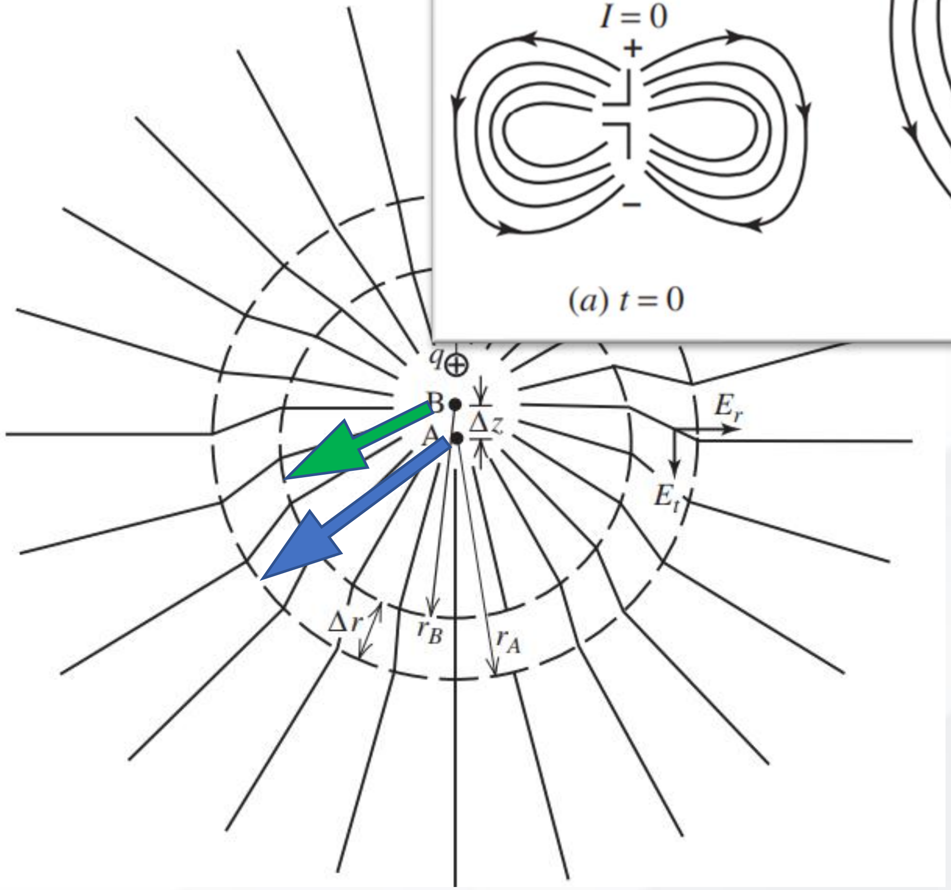
the electric field lines extend radially away from point A outer to the circle or radius r_A

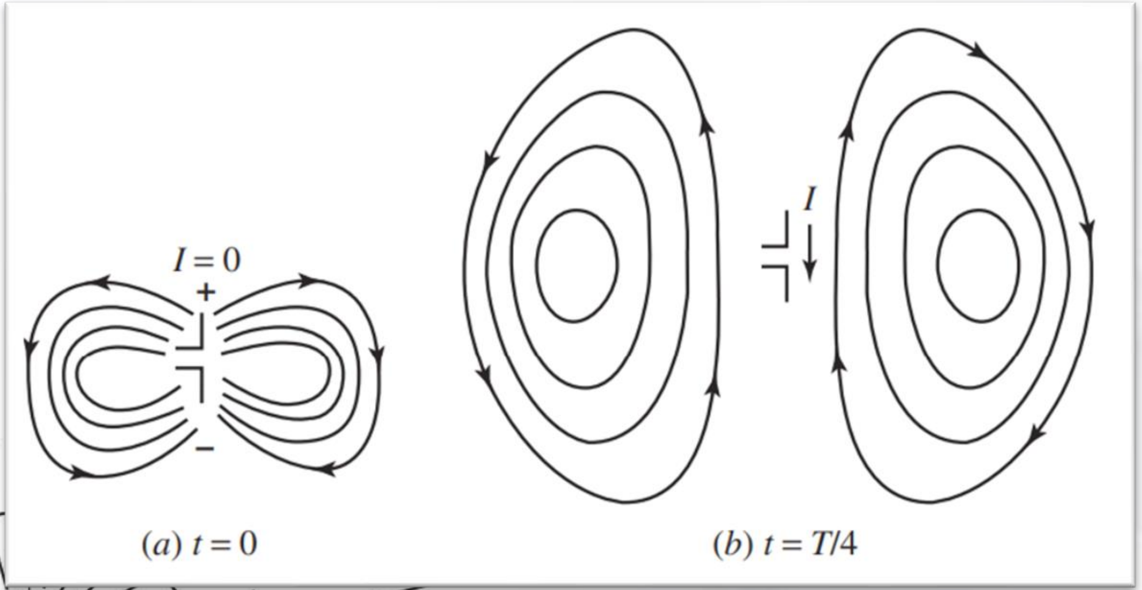
Radiation is a disturbance of the electromagnetic fields that propagates away from the source of the disturbance so that the total power in the wave does not decay with distance.

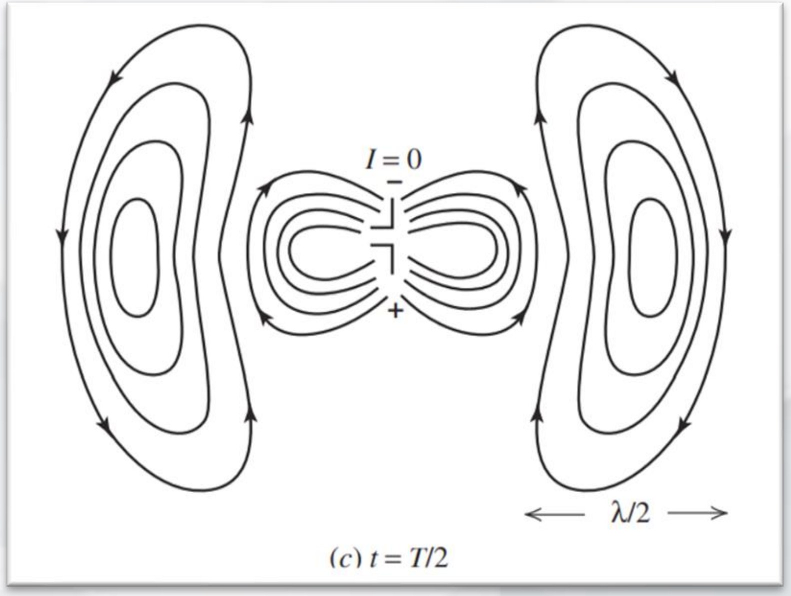
time t = 0 the charge begins to be accelerated (i.e., velocity is increased) until reaching point B at time t = Δt where it continues on at the acquired velocity for all time t > Δt

The distance between the circles is the distance light would travel in time Δt, or $\Delta r = r_B - r_A = c/\Delta t$. Because the charge moves slowly compared to the speed of light (c), $\Delta z \ll \Delta r$ and the circles are nearly concentric. The electric field lines in the Δr region are joined together because of the required continuity of electric field lines in the absence of charges. This region is obviously one of disturbed field structure and was caused by acceleration of the charge which ended a time r_B/c

Radiation Mechanism

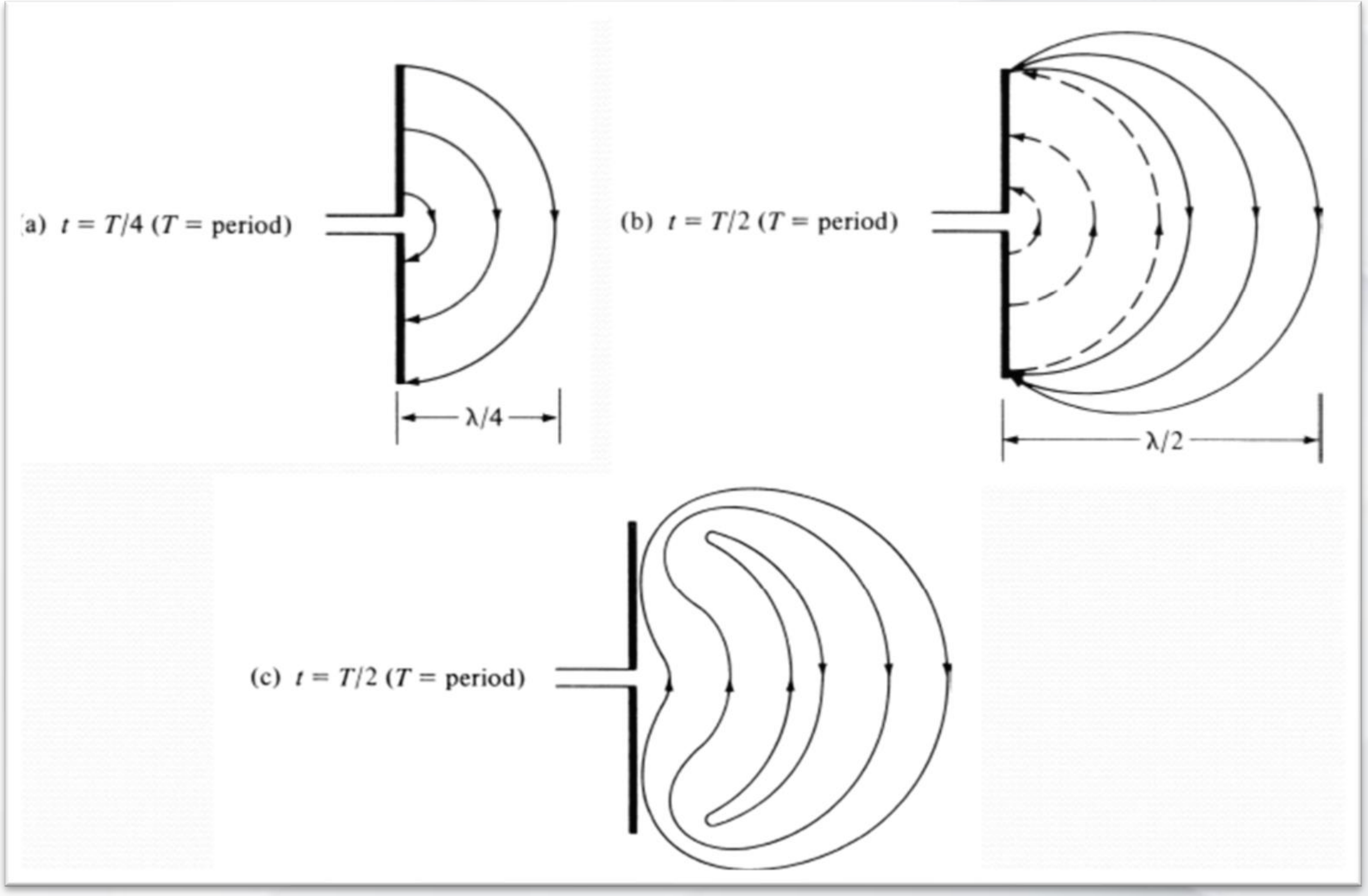






Fields of an oscillating charge dipole for various instants of time. Electric field lines are shown on one side of the dipole but exist everywhere around the dipole. The oscillations are of frequency f with a period of $T = 1/f$. The separation between the equal, opposite-sign charges is much smaller than the wavelength of the oscillations. A dipole antenna is shown to indicate that the radiation is the same as that for an ideal dipole antenna.

Formation and Detachment of E-field lines for Short Dipole Antenna excited by a sinusoidal function



Antenna Applications

- **Wireless Communication:**
  - Cellular Networks (2G, 3G, 4G, 5G)
  - Wi-Fi and WiMAX
  - Bluetooth
  - Zigbee and other IoT protocols
- **Broadcasting:**
  - Radio Broadcasting (AM and FM)
  - Television Broadcasting (VHF and UHF)
- **Satellite Communication:**
  - Satellite TV and Radio
  - Satellite Internet
- **Radar Systems:**
  - Weather Radar
  - Air Traffic Control Radar
  - Military Radar Systems
- **Navigation Systems:**
  - Global Positioning System (GPS)
  - Glonass (Russian Navigation System)
  - Galileo (European Navigation System)
- **Microwave Links:**
  - Point-to-Point Microwave Links for Data Transmission
- **RFID (Radio Frequency Identification):**
  - Asset Tracking
  - Inventory Management
- **NFC (Near Field Communication):**
  - Contactless Payment Systems
  - Access Control
- **Automotive Applications:**
  - Car Key Fobs
  - Tire Pressure Monitoring Systems (TPMS)
  - Remote Keyless Entry (RKE)
- **Aerospace and Aviation:**
  - Aircraft Communication Systems
  - Satellite Communication for In-Flight Entertainment
- **Military and Defense:**
  - Military Communication Systems
  - Radar Systems for Defense
- **Radio Astronomy:**
  - Large Parabolic Antennas for Observing Celestial Objects
- **Amateur Radio (Ham Radio):**
  - Communication among Amateur Radio Operators
- **Underwater Communication:**
  - Sonar Systems for Communication and Navigation
- **Remote Sensing:**
  - Earth Observation Satellites for Environmental Monitoring
- **Direction Finding and Location-Based Services:**
  - Antennas used in Systems for Locating Signals or Devices
- **Wireless Charging:**
  - Inductive Charging Systems for Devices like Smartphones
- **Internet of Things (IoT):**
  - Wireless Sensors and Devices for IoT Applications
- **Electronic Warfare:**
  - Jamming and Countermeasure Systems
- **RF Energy Harvesting:**
  - Harvesting RF Energy for Low-Power Devices
- **Search and Rescue:**
  - Emergency Beacon Systems (EPIRBs)
- **Space Communications:**
  - Antennas on Spacecraft for Communication with Ground Stations
- **Medical Applications:**
  - MRI Antennas
  - Wireless Medical Devices

Analysis Methods:

1. **Analytical Methods:**
    1. **Dipoles and Monopoles:** Analytical solutions exist for simple antenna geometries like dipoles and monopoles. These solutions are based on solving Maxwell's equations for specific configurations.
2. **Method of Moments (MoM):**
    1. MoM is a numerical technique used to solve electromagnetic field problems. It discretizes the antenna structure into small elements and applies the principle of equivalence between electric current distribution and induced electromagnetic fields.
3. **Finite Element Method (FEM):**
    1. FEM is a numerical technique widely used for solving complex antenna problems. It divides the structure into small, interconnected elements and solves for the electromagnetic field in each element.
4. **Finite Difference Time Domain (FDTD):**
    1. FDTD is a numerical method that discretizes both time and space, allowing for the simulation of time-varying electromagnetic fields. It is widely used for transient analysis and can handle complex geometries.
5. **Moment Method (MoM) and Physical Optics (PO):**
    1. These techniques are used for analyzing large and electrically large structures. MoM focuses on the surface currents, while PO approximates the fields reflected by the structure.
6. **Ray-Tracing and Geometrical Optics:**
    1. These methods are used for studying propagation and scattering in complex environments, taking into account reflections, refractions, and diffractions.
7. **Asymptotic Methods:**
    1. These methods simplify complex problems by considering specific asymptotic cases. Examples include the Uniform Theory of Diffraction (UTD) and Physical Theory of Diffraction (PTD).
8. **Hybrid Methods:**
    1. Combining multiple analysis techniques, such as MoM with FEM or FDTD with FEM, allows for accurate modeling of antennas in complex environments.

Units and dB

In practice we use dB or dBi, dBm

$$|A/A_{\mathrm{ref}}|_{\mathrm{dB}} = 20 \cdot \log|A/A_{\mathrm{ref}}|$$

$$|P/P_{\mathrm{ref}}|_{\mathrm{dB}} = 10 \cdot \log|P/P_{\mathrm{ref}}|$$

$$|A/A_{\mathrm{ref}}|_{\mathrm{dB}} = |P/P_{\mathrm{ref}}|_{\mathrm{dB}}$$

A-> amplitude
P -> power

dB: a logarithmic unit that indicates the ratio of a physical quantity (usually power or intensity) relative to a specified reference level.

dBi: The forward gain of an antenna compared with the hypothetical isotropic antenna.

dBm is a unit of power used in electronics and telecommunications to express power levels in decibels (dB) relative to one milliwatt (mW).

Antenna People in Türkiye

Mustafa SEÇMEN Yaşar Üniversitesi

Evren Ekmekci Süleyman Demirel üniversitesi

Gökhan APAYDIN Üsküdar Üniversitesi

Selçuk Paker İstanbul Teknik Üniversitesi

Mehmet Çayören İstanbul Teknik Üniversitesi

Gönül Turhan Sayan Orta Doğu Teknik üniversitesi

Özlem Aydın Çivi Orta Doğu Teknik üniversitesi

Sema Dumanlı Boğaziçi Üniversitesi

Ayhan Altıntaş Bilkent Üniversitesi

İrşadi Aksun Koç Üniversitesi

İbrahim Tekin Sabancı Üniversitesi

Birsen Saka Hacettepe Üniversitesi

Selçuk Helhel Akdeniz Üniversitesi

Alp Kuştepeli İYTE

Gonca Çakır Kocaeli Üniversitesi

Mehmet Çiydem Gazi Üniversitesi

Abdullah Burak Polat Yıldız Teknik Üniversitesi

The antenna is often the largest and the most expensive part of a communication system or a microwave system or a radar

- System technology
- Field theory
- Antenna theory and analysis methods
- Programming and CAD simulations
- Materials technology (also artificial materials)
- Manufacturing techniques
- Experimental development
- Measurements

Factors that are important in the selection of the antenna in communication system

frequency of operation

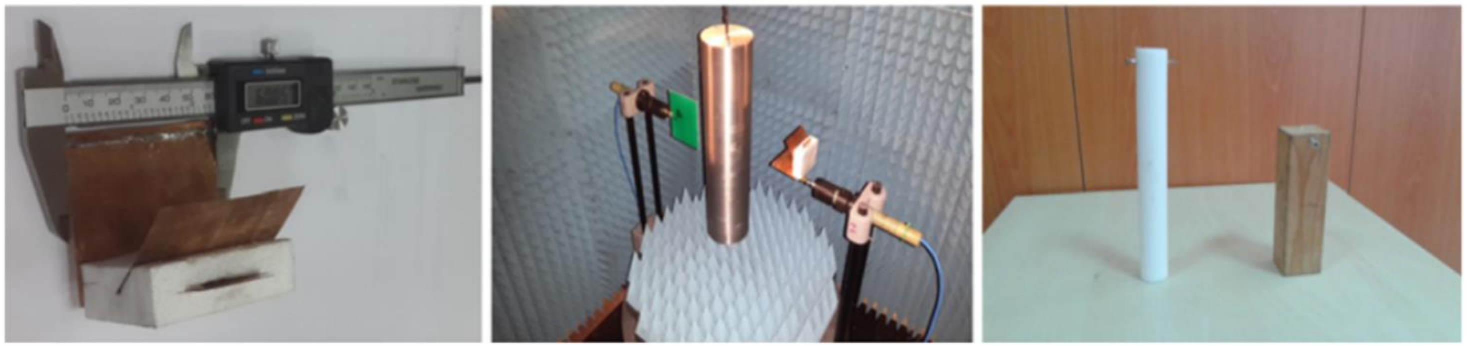
- radiation characteristics radiation pattern,

beamwidth, gain, side lobe level

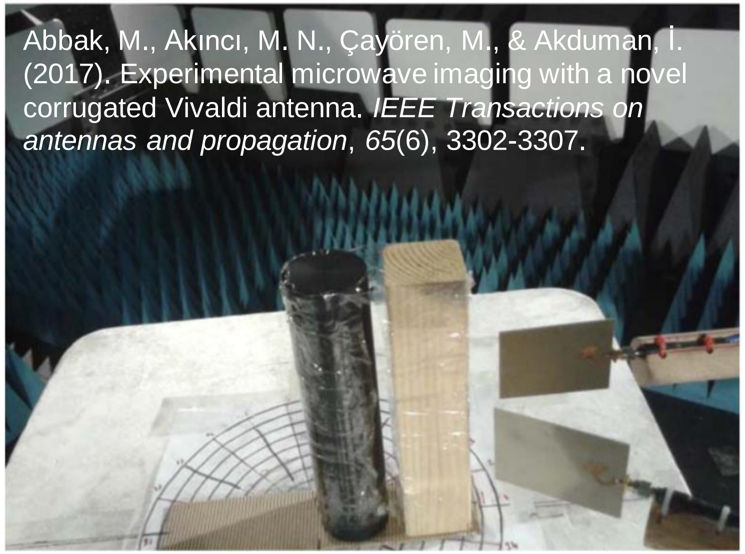
impedance characteristics

- bandwidth
- polarization (circular, linear)
- receiving or transmitting mode
- space limitation
- power handling capacity
- cost

Antenna in İTÜ

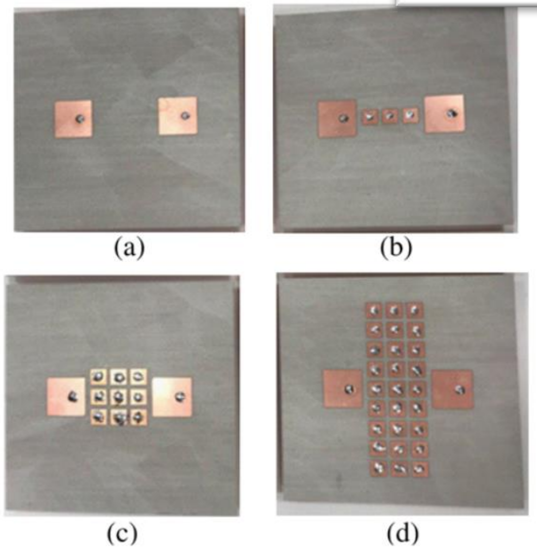


Abbak, M., Nuri Akıncı, M., Ertay, A. O., Özgür, S., Işık, C., & Akduman, İ. (2017). Wideband compact dipole antenna for microwave imaging applications. *IET Microwaves, Antennas & Propagation*, *11*(2), 265-270.



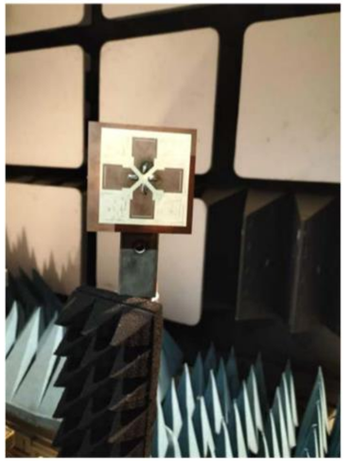
Abbak, M., Akıncı, M. N., Çayören, M., & Akduman, İ. (2017). Experimental microwave imaging with a novel corrugated Vivaldi antenna. *IEEE Transactions on antennas and propagation*, *65*(6), 3302-3307.

Yussuf, A. A., & Paker, S. (2019). Design of a compact quad-radiating element MIMO antenna for LTE/Wi-Fi application. *AEU-International Journal of Electronics and Communications*, *111*, 152893.



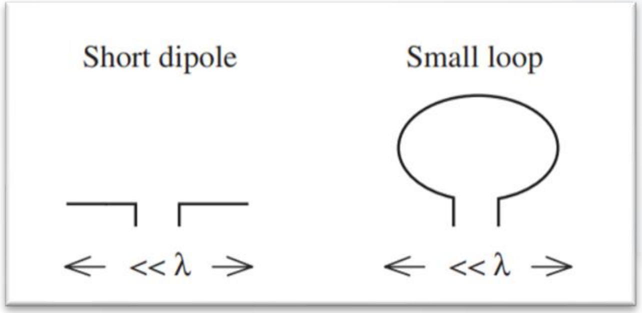
Gebesoglu, D., Ertay, A. O., & Simsek, S. (2023). Investigation of AFGSM Methods for Some Electromagnetic Bandgap Structures: From Analysis to Applied Antenna Design. *IEEE Access*.

Çelik, F. T., Joof, S., & Karaçuha, K. (2023). A Dual-Polarized Bandwidth Enhanced Filtering Dipole Antenna Design for 5G. *IEEE Access*.

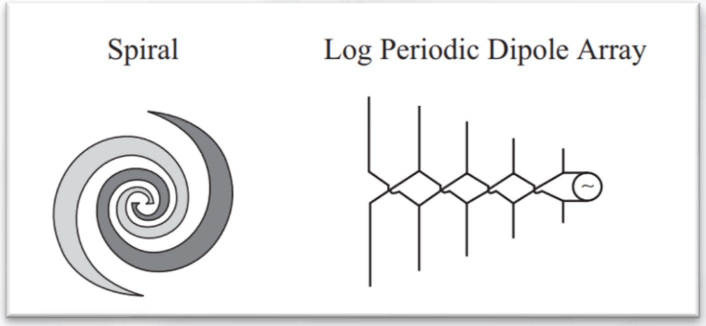


Antenna Types

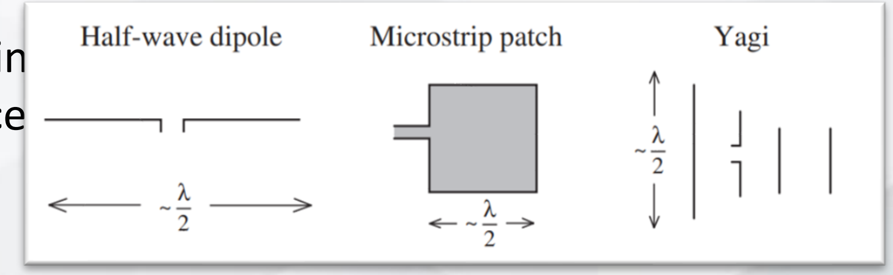
Electrically Small Antennas: The extent of the antenna structure is much less than a wavelength λ
Properties:
Low directivity
Low input resistance
High input reactance
Low radiation efficiency
Examples:



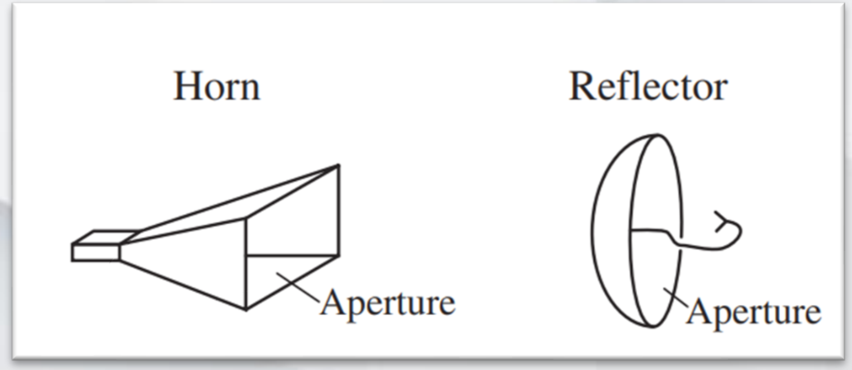
Broadband Antennas: The pattern, gain, and impedance remain acceptable and are nearly constant over a wide frequency range.
Characterized by an active region with a circumference of one wavelength or an extent of a half-wavelength, which relocates on the antenna as frequency changes.
Properties:
Low to moderate gain
Constant gain
Real input impedance
Wide bandwidth
Examples:



Resonant Antennas: The antenna operates well at a single or selected narrow frequency bands.
Properties:
Low to moderate gain
Real input impedance
Narrow bandwidth
Examples:



Aperture Antennas: Has a physical aperture (opening) through which waves flow. Properties:
High gain
Gain increases with frequency
Moderate bandwidth
Examples:



Antenna Types

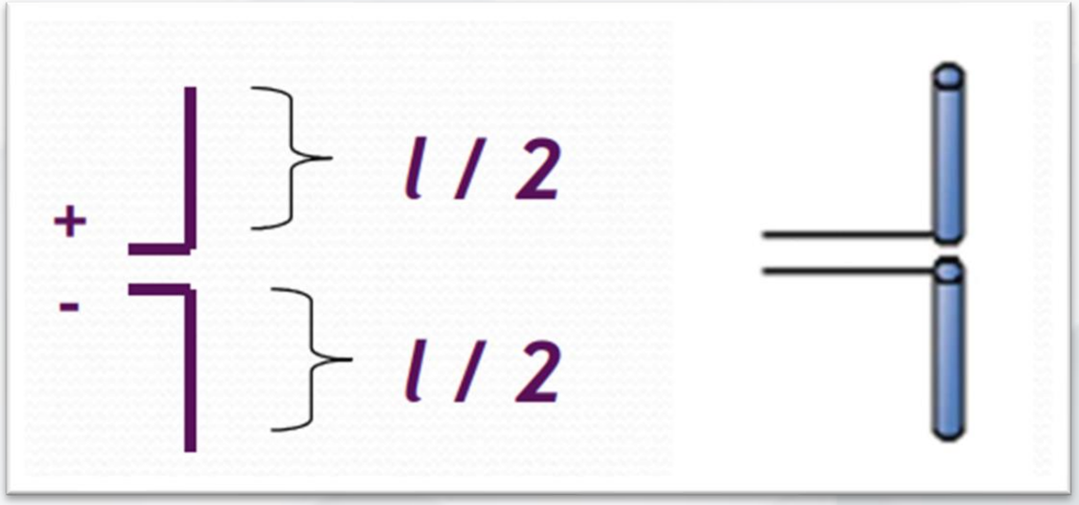
A common design situation is the search to find an antenna to achieve a desired gain value. The list below provides a guide in this selection process.

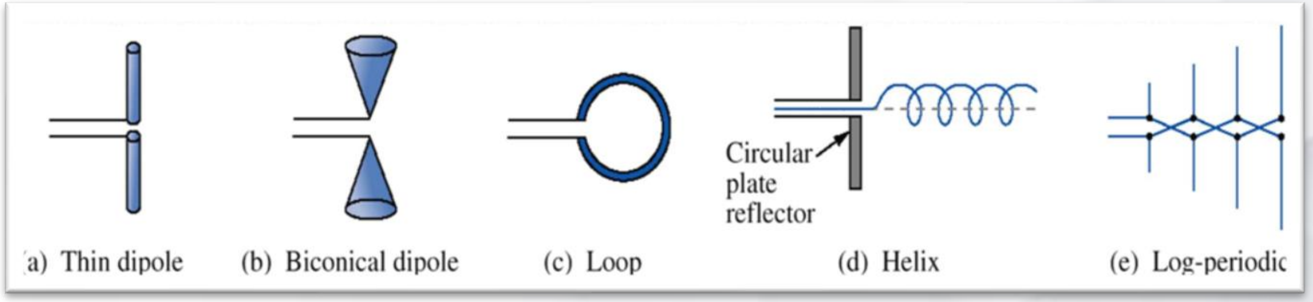
- **5 dB or less**
  Electrically small antennas
  Loops
  Dipoles/monopoles
- **5 dB to 8 dB**
  Microstrip patches
  Planar frequency-independent antennas (e.g. spirals)
- **8 dB to 15 dB**
  Yagi-Uda
  Helix (axial mode)
  Log periodic dipole array
- **15 dB and more**
  Aperture antennas
  Horns
  Reflectors

Wire Antennas

Dipole antenna is the basic antenna element (building block).

The dipole antenna is the simplest antenna, despite of not being used practically in applications, it is considered as the reference antenna. A dipole antenna consists of 2 wires. The two wires are separated by a gap and their terminals are connected to the transmitter or the receiver.





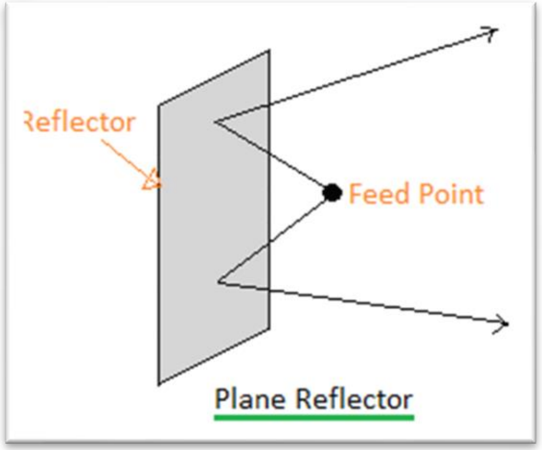
Aperture Antennas

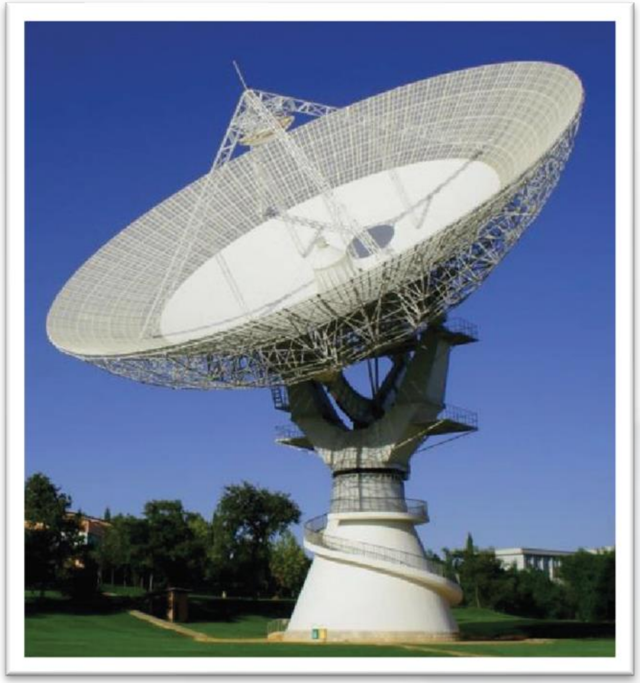
The horn is widely used as a feed element for large radio astronomy, satellite tracking, and communication dishes.

Simplicity in construction, ease of excitation, versatility, large gain, and preferred overall performance

Antenna Types

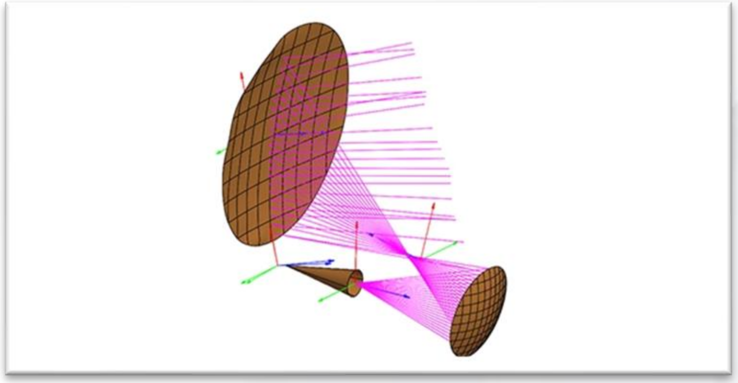
Reflector Antennas

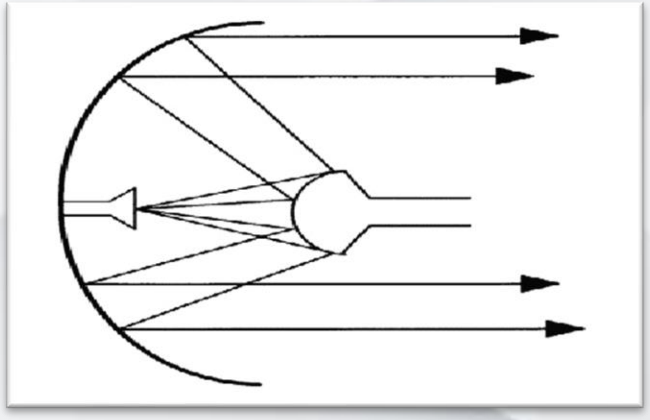




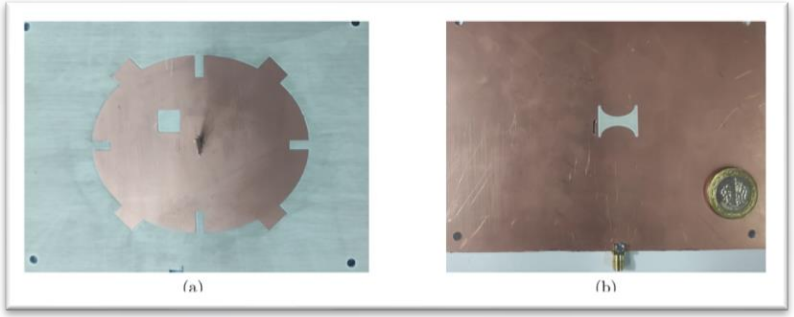
The horn is widely used as a feed element for large radio astronomy, satellite tracking, and communication dishes.

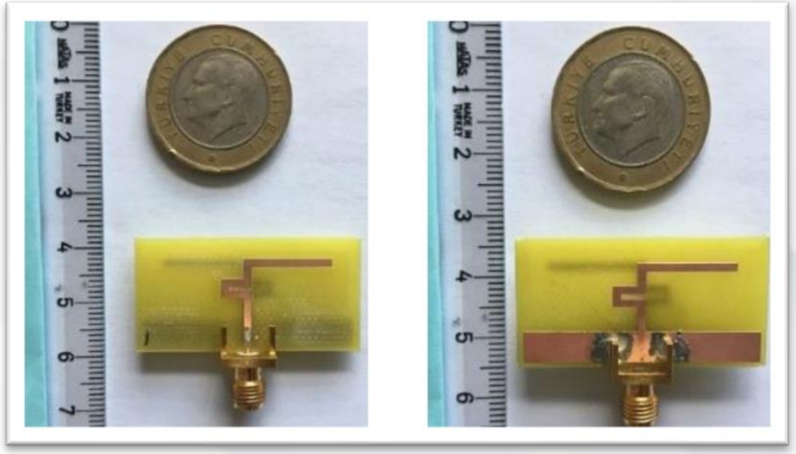
a) Primary-fed reflector antenna
b) Dual-reflector antenna

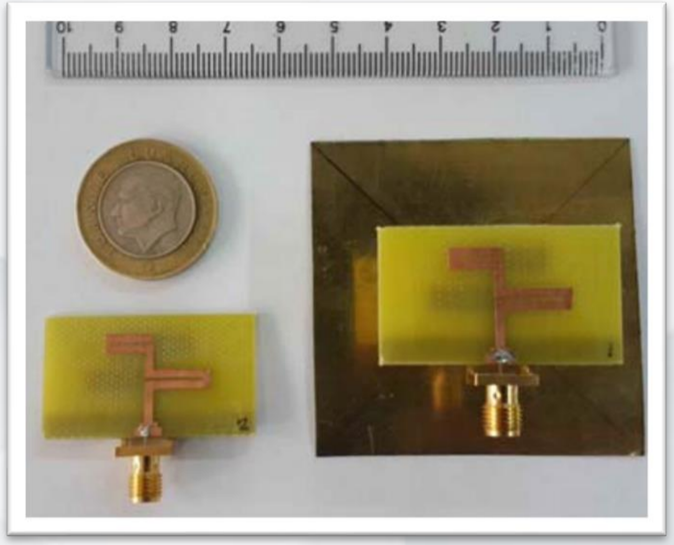




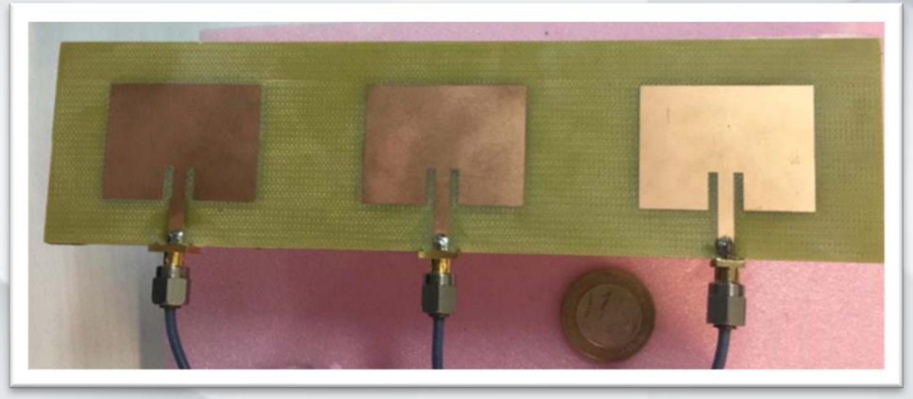
Antenna Types



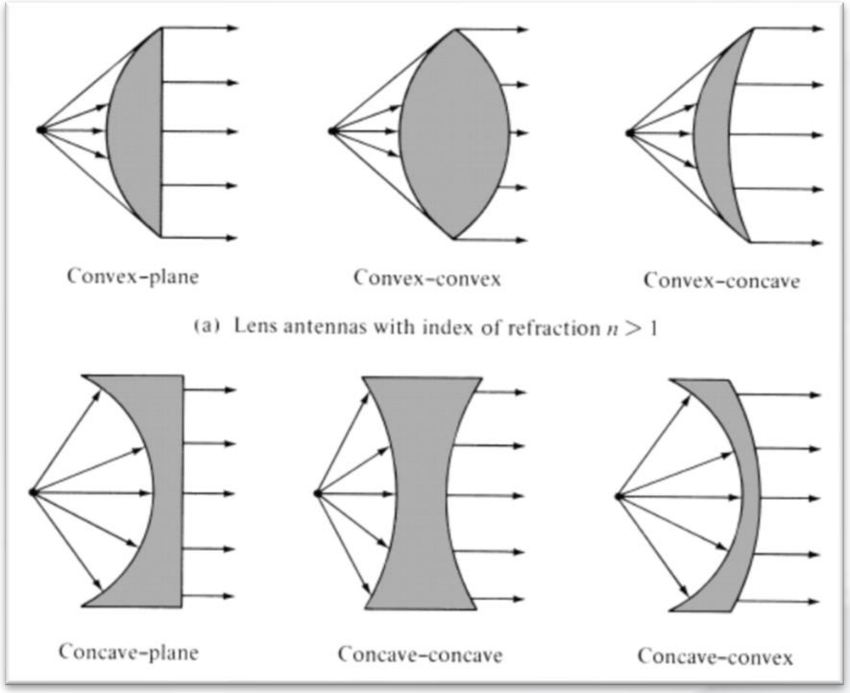


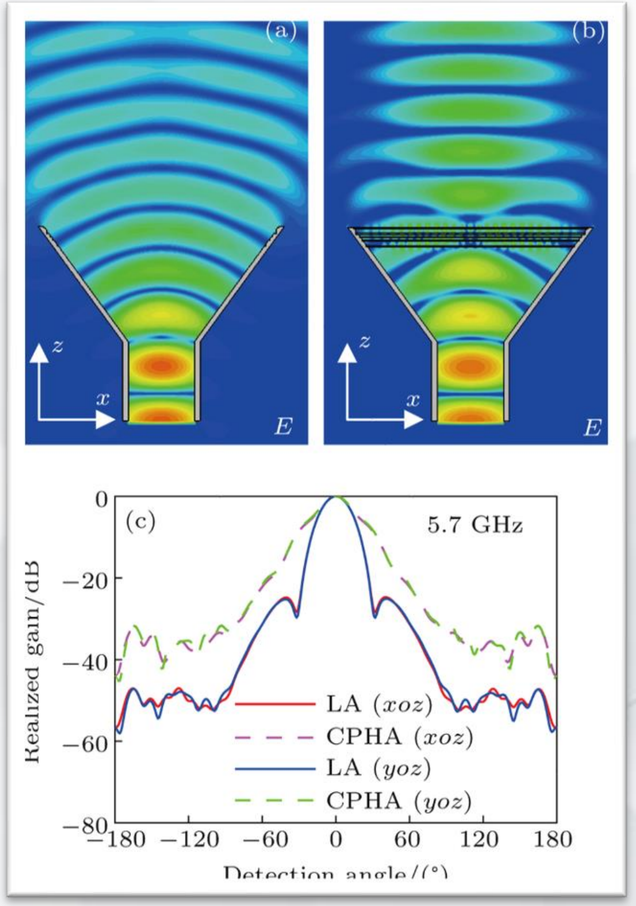


The patch (radiating element) may be circular, rectangular or any other shape . They are low-profile, conformal to planar and nonplanar surfaces, simple and inexpensive to fabricate. But, they usually have narrow bandwidth and low efficiency.



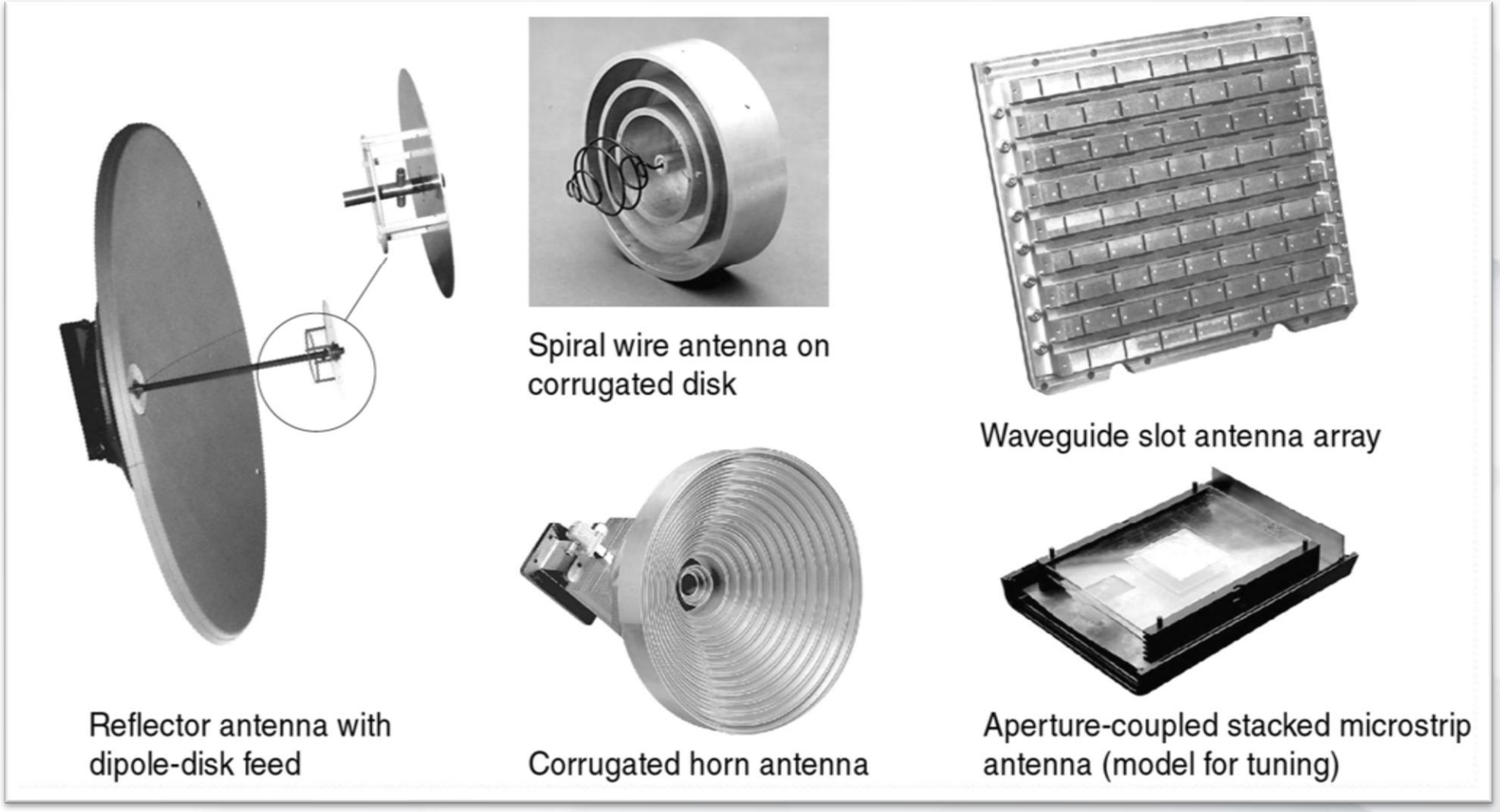
Antenna Types





Used to collimate incident divergent energy to prevent it from spreading in undesired directions. They can transform various forms of divergent energy into plane waves. Often preferred to reflectors at frequencies > 100 GHz

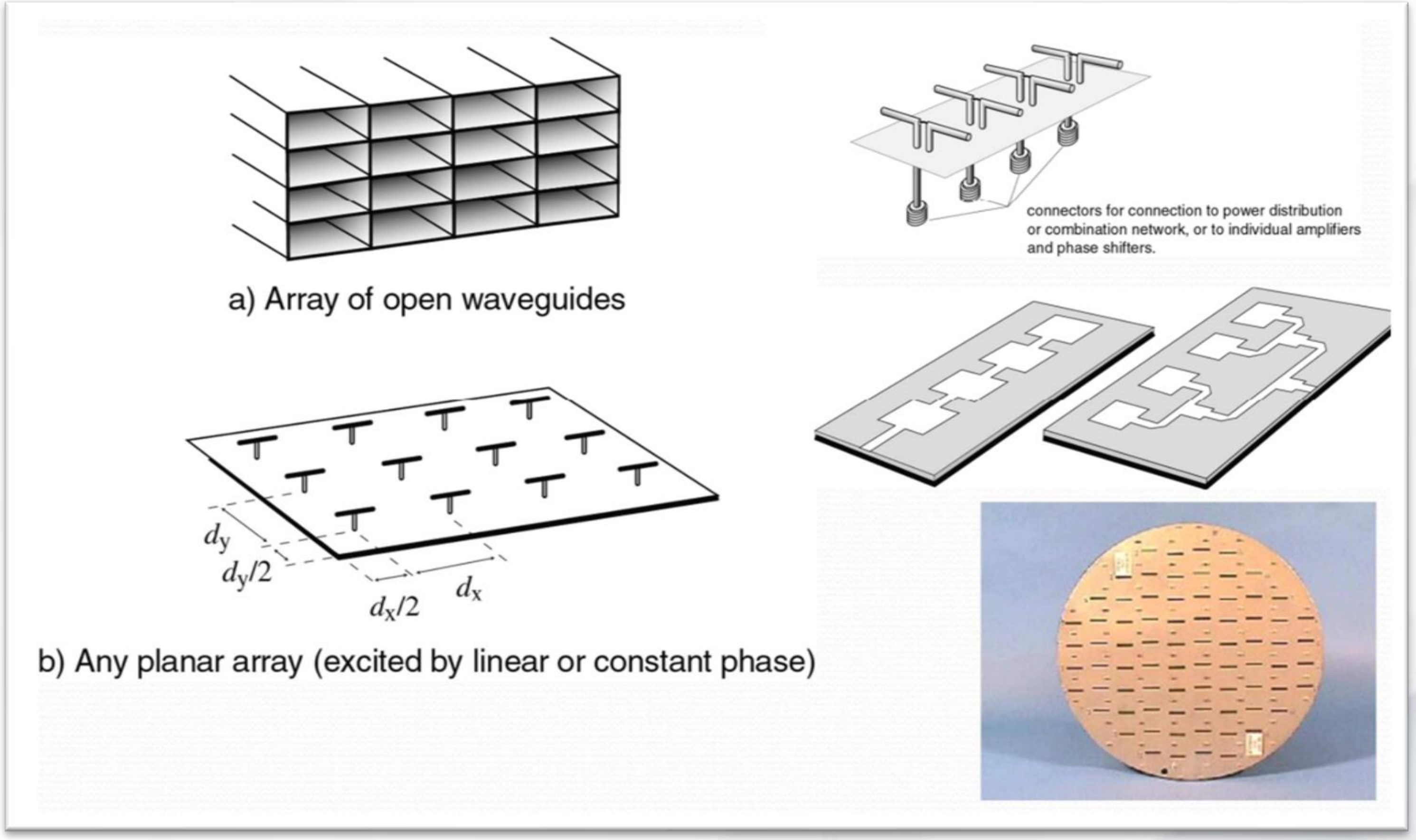
Examples of different antenna types

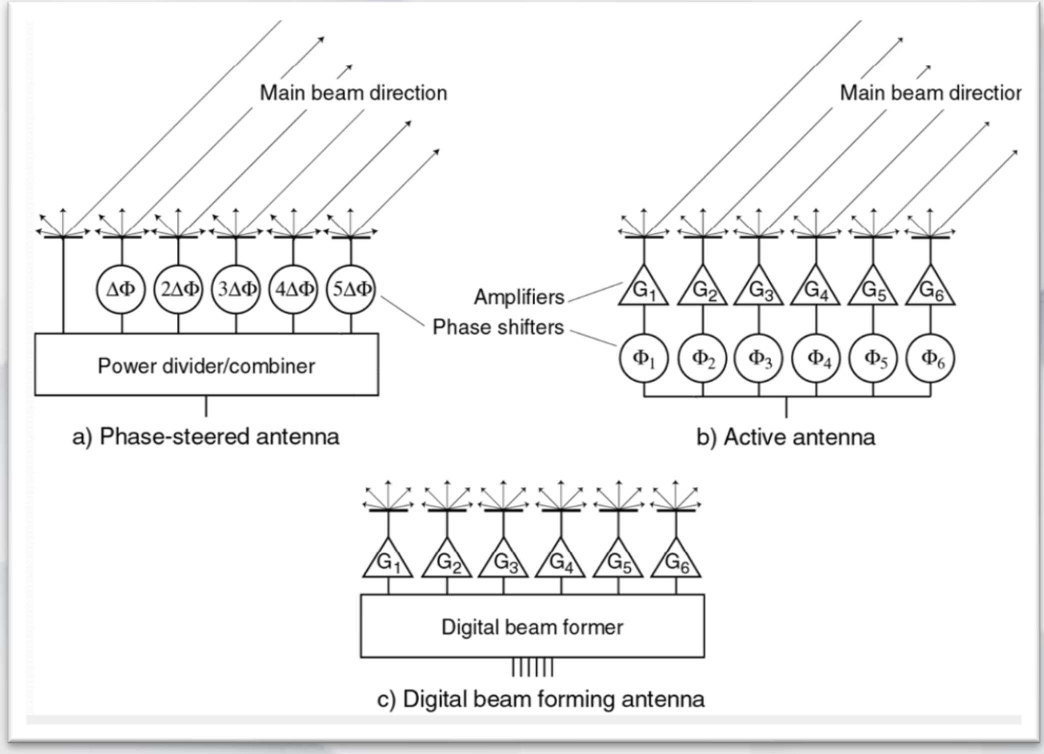


Array antenna types

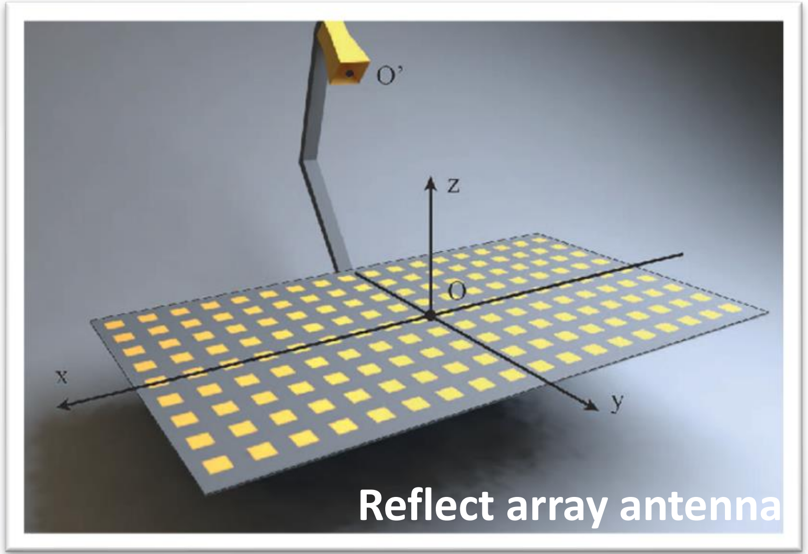
- **Uniform Linear Array (ULA):** are arranged in a straight line along a single axis. This type of array is relatively simple to implement and is used for applications like phased arrays and beamforming.
- **Uniform Circular Array (UCA):** Elements are arranged in a circular pattern. This configuration is useful for applications where azimuthal coverage is important, such as in radar systems.
- **Planar Array:** Elements are arranged in a two-dimensional plane. Planar arrays can provide both azimuthal and elevation coverage, making them suitable for tracking systems.
- **Rectangular Grid Array:** Elements are arranged in a regular grid pattern. This type of array is versatile and can be used for various applications including radar, satellite communication, and wireless networks.
- **Phased Array:** Phased arrays use variable phase shifts to control the direction of the beam without physically moving the antenna. They are widely used in radar, communication systems, and satellite tracking.
- **Adaptive Array:** Adaptive arrays dynamically adjust their beam patterns in response to changing conditions, allowing for better reception of desired signals and rejection of interference.
- **Reflectarray:** Reflectarrays use a planar array of passive elements to control the phase of incident waves, enabling beam shaping. They are used in satellite communication and radar systems.
- **Smart Antenna Array:** Smart antenna arrays use digital signal processing techniques to adaptively control the radiation pattern to maximize signal quality and minimize interference.
- **Subarray:** A subarray is a smaller array within a larger array. It is used to simplify the design and control of large arrays.
- **Circularly Symmetric Array:** Elements are arranged symmetrically around a central point. This configuration is useful for applications where omnidirectional coverage is desired.
- **Sparse Array:** Sparse arrays have fewer active elements compared to fully populated arrays. They are used to reduce cost and complexity while maintaining desired performance.

Array antenna types

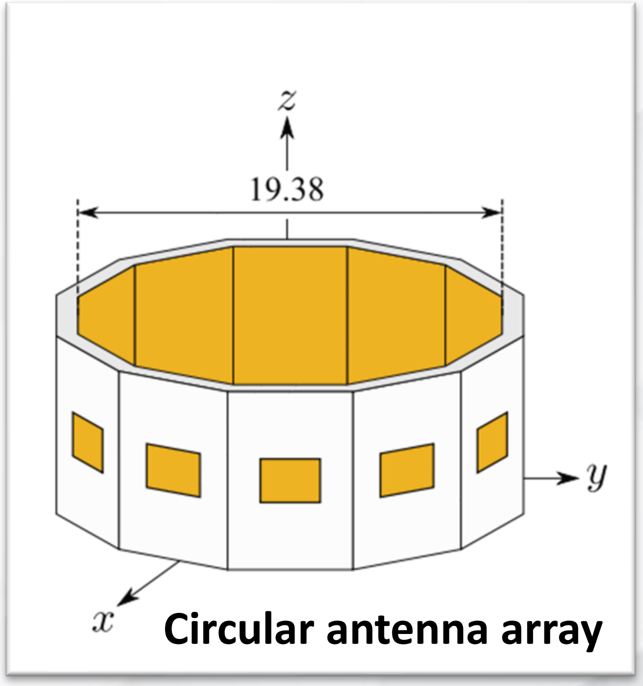




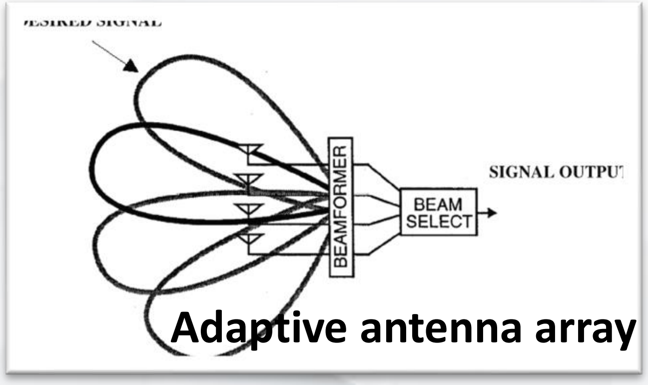
Antenna Types



Reflect array antenna

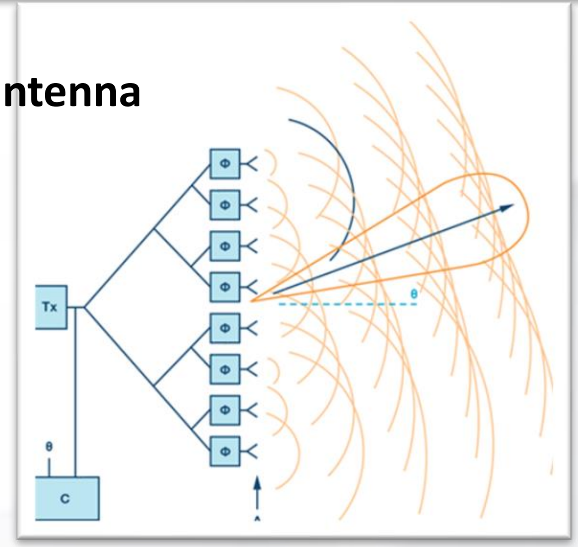


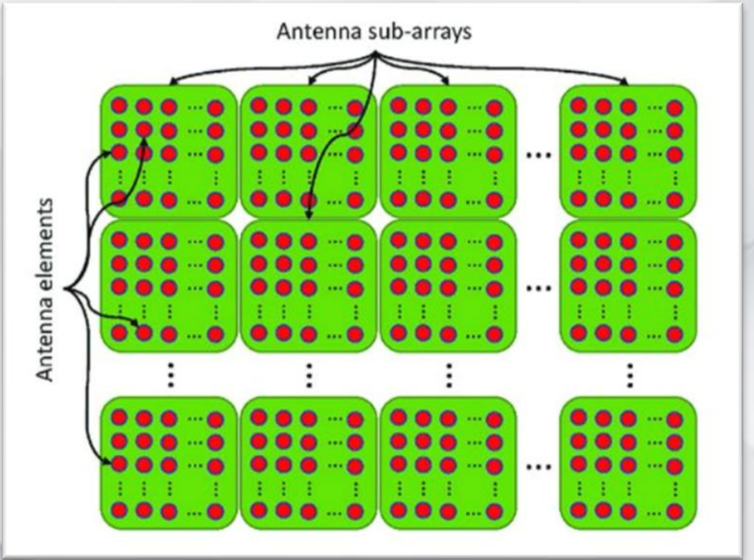
Circular antenna array



Adaptive antenna array

Phased array antenna





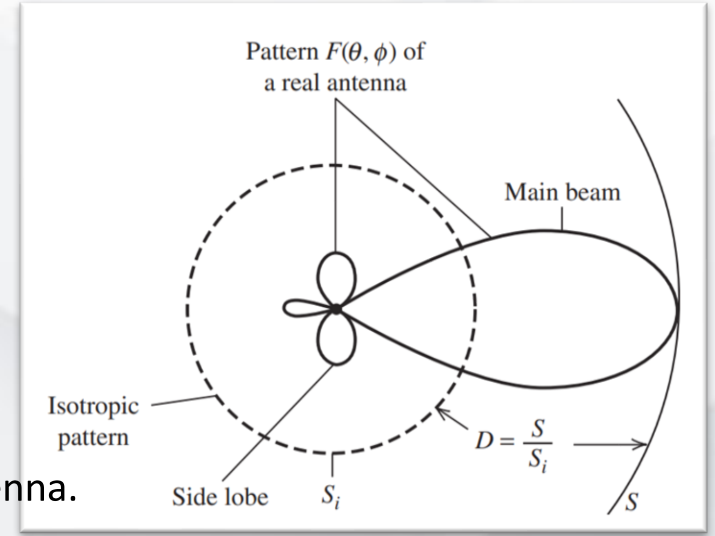
Subarray

Electromagnetic Spectrum

Band Designation	Frequency	Wavelength	Example Uses
ELF (Extremely Low Frequency)	3 to 30 Hz	100 to 10Mm	
SLF (Super Low Frequency)	30 to 300 Hz	10 to 1Mm	Power lines
ULF (Ultra Low Frequency)	300 to 3kHz	1Mm to 100 km	
VLF (Very Low Frequency)	3 to 30kHz	100 to 10 km	Submarine comm.
LF (Low Frequency)	30 to 300kHz	10 to 1 km	RFID
MF (Medium Frequency)	300kHz to 3MHz	1 km to 100 m	AM broadcast
HF (High Frequency)	3 to 30MHz	100 to 10 m	Shortwave broadcast
VHF (Very High Frequency)	30 to 300MHz	10 to 1 m	FM and TV broadcast
UHF (Ultra High Frequency)	300MHz to 3GHz	1 m to 10 cm	TV, WLAN, GPS, Microwave ovens
SHF (Super High Frequency)	3 to 30GHz	10 to 1 cm	Radar, WLAN, Satellite comm.
EHF (Extremely High Frequency)	30 to 300GHz	10 to 1 mm	Radar, Radio astronomy, Point–to–point high rate data links, Satellite comm.
Microwaves	1 to 300GHz	30 cm to 1 mm	
Millimeter waves	30 to 300GHz	10 to 1 mm	
Submillimeter waves	$>$ 300GHz	$<$ 1 mm	

Frequency-to-Wavelength Conversions
$\lambda = c/f$
$\lambda(\mathrm{m}) = 3 \times 10^8/f(\mathrm{Hz})$
$\lambda(\mathrm{m}) = 300/f(\mathrm{MHz})$

Antenna Performance Parameters



- **Radiation Pattern, $F(\theta, \phi)$** : Angular variation of radiation around the antenna, including:
  Directive single or multiple narrow beams
  Omnidirectional (uniform radiation in one plane)
  Shaped main beam
- **Directivity, D:** Ratio of power density in the direction of the pattern peak to the average power

density at the same distance from the antenna.

- **Gain, G** (or radiation efficiency e_r, where $G = e_r D$): Directivity reduced by the losses on the antenna.
- **Polarization:** The figure traced out with time by the instantaneous electric field vector associated with the radiation from an antenna when transmitting. Antenna polarizations: Linear, Circular, Elliptical
- **Impedance, Z_A :** The input impedance at the antenna terminals.
- **Bandwidth:** Range of frequencies over which important performance parameters are acceptable.
- **Scanning:** Movement of the radiation pattern in space. Scanning is accomplished by mechanical movement or by electronic means such as adjustment of antenna current phase.
- **System Considerations:** Mechanical considerations (size, weight, aerodynamics, vibration, positioning accuracy), environmental aspects (effects of wind, rain, temperature, altitude), scattering/radar cross section, esthetic appearance.
- **Special Considerations for transmitting antennas:** Power handling, intermodulation, radiation hazards.
- **Special Considerations for receiving antennas:** Noise.

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