# **Direction Finding**

Introduction
W2MIL
ORMOND BEACH RADIO CLUB
Spectrum Monitoring

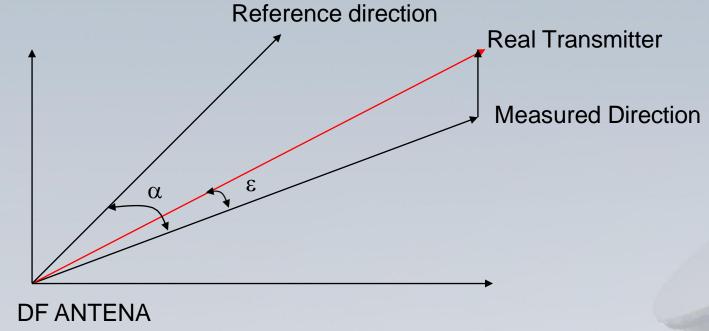


#### Outline

- Definition of Direction Finding.
- Tasks of radio Direction Finding.
- Direction Finding Techniques.
- Requirements on DF system.
- Components of a DF system.
- DF Antennas.
- Classic DF Methods.
- Locating the Transmitter Source
- Single Site Location
- DF Measurement



## Definition Of Direction Finding



 Direction finding refers to the use of specialized instruments, antennas, and methodologies to determine the physical location of a source of RF energy or "targets"



## Tasks of radio Direction Finding

#### • DF purposes:

- location of a transmitter in a distress situation.
- · location of an unauthorized transmitter.
- location of an interfering transmitter which cannot be identified by other means.
- determination of the site of a source of harmful interference of reception.
- identification of transmitters, both known and unknown.

## Direction Finding Techniques

- DF techniques are roughly grouped in three categories:
  - amplitude sensitive.
  - phase sensitive.
  - combined phase and amplitude sensitive.

## Requirements on DF system

- High accuracy
  - Within about 1° to 3°.
- High sensitivity
- Sufficient large-signal (adjacent signals) immunity
- Immunity to multipath propagation
- Immunity to polarization errors

#### Requirements on DF system

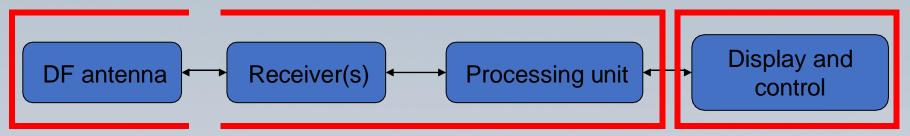
- Determination of elevation in shortwave range
- Stable response in case of non-coherent co-channel interferers
- DF of short-duration signals
- Scanning direction finders: high scanning speed and probability of intercept (POI)

#### Error sources

- The DF accuracy is affected by a number of influences:
  - Wave propagation (usually disturbed by obstacles)
  - Signals radiated by the emitters are modulated, limited in time and their carrier frequency is often unknown
  - Received field is additionally superimposed by noise, co-channel interferers
  - Tolerances and noise in the DF system



## Components of a DF system



- Antenna
  - Design usually specific to a given DF methodology
- Receiver(s) and processing unit
  - One or more receive channels with analog-to-digital conversion
  - Integrated or separate digital signal processing
- User interface
  - Software for display and control
  - Position fix and map display software



#### DF Antennas

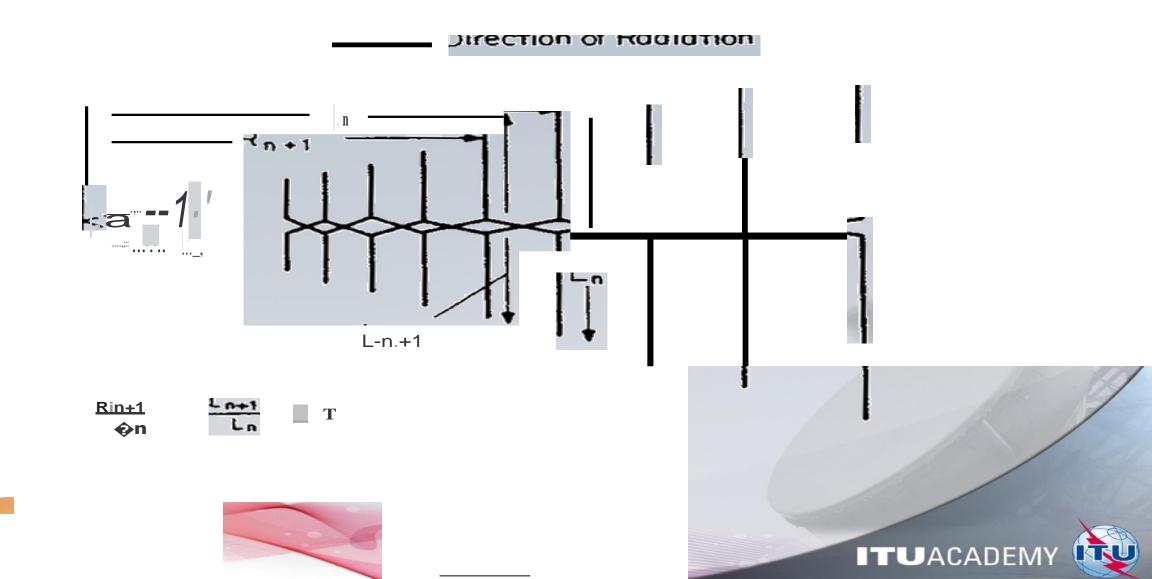
- Beam/Yagi Antenna.
- Log-Period Antenna.
- Loop Antenna.
- Ferrite Rod Antennas.
- Phased Arrays and Adcocks.

## Beam/Yagi

- Very accurate bearings
- Tune to null (sharper than gain)
- Front to back ratio > 50 db
- Can use front to help find weaker signals but with reduced bearing accuracy



## Log-Period Antenna



## Log-Period Antenna

- Antennas where characteristics repeat according to logarithm of frequency
  - 7.5 dBi typical gain in free space
  - Good directivity: 14 dB typical front-to-back ratio
  - Uniform pattern over up to 10:1 frequency range
- Radiating elements are fed by central transmission line
- Individual elements are repeated at intervals constant with logarithm of frequency

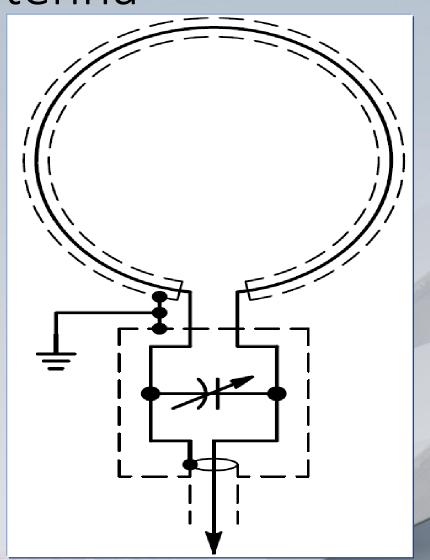
## Loop Antenna

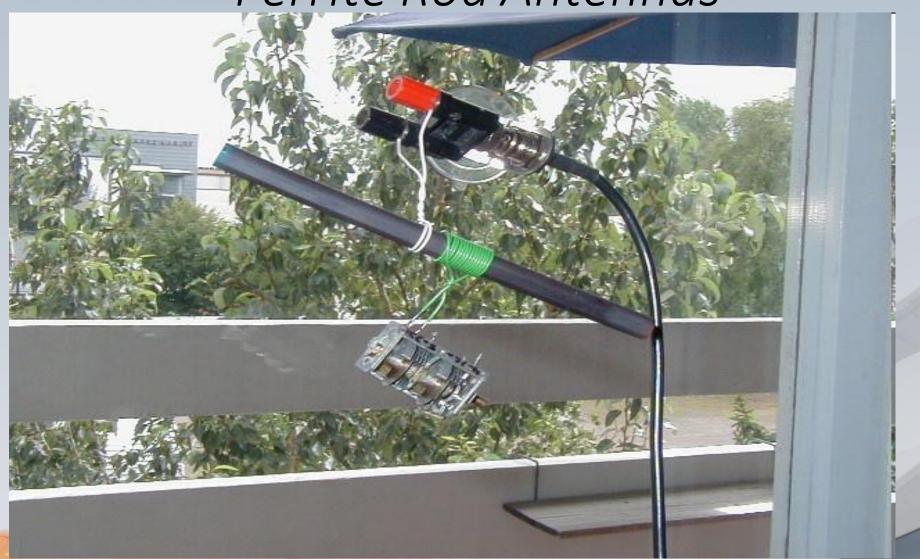
- The loop antenna acts much the same as the secondary winding of a transformer.
- The voltage at the output is proportional to the amount of flux passing through it and the number of turns.
- To obtain the most accurate bearings, the loop must be balanced electrostatically with respect to ground.
- Otherwise, the loop will exhibit two modes of operation, One is the mode of a true loop, The second mode is called the *antenna effect*.

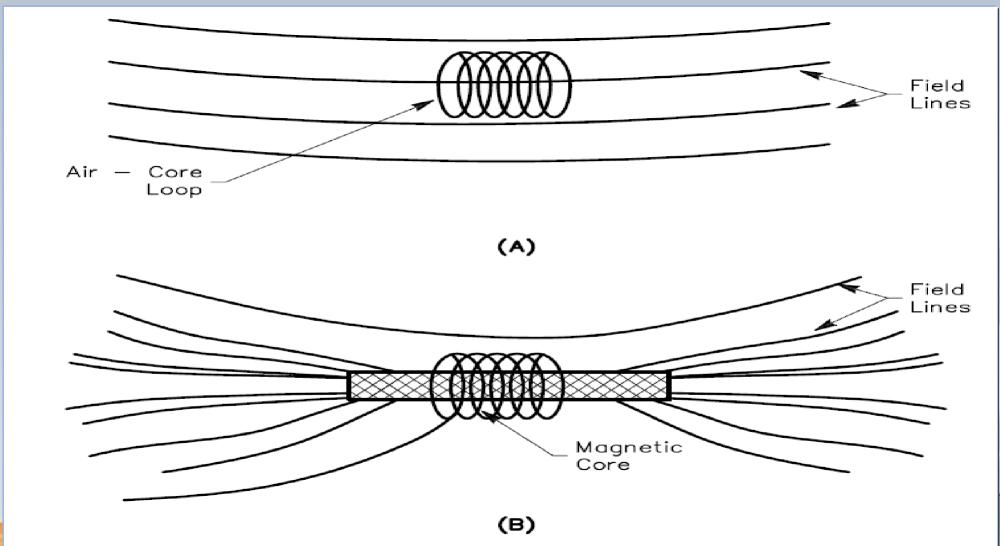


Loop Antenna

- More common on HF frequencies
- Very compact
- Tune to the null
- Bearings not very precise
- Has 180 degree ambiguity.





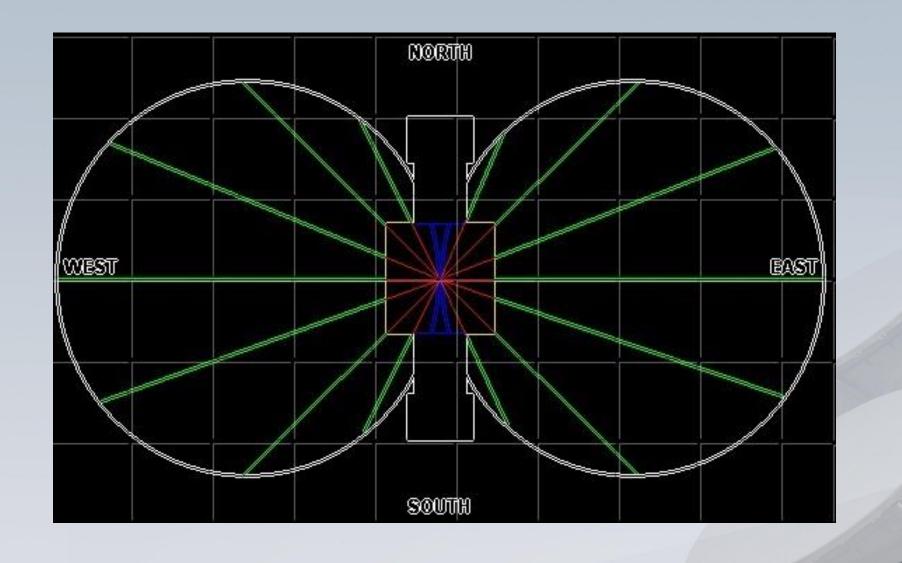


(loopstick antennas)

- The true loop antenna responds to the magnetic field of the radio wave, and not to the electrical field.
- The voltage delivered by the loop is proportional to the amount of magnetic flux passing through the coil, and to the number of turns in the coil.

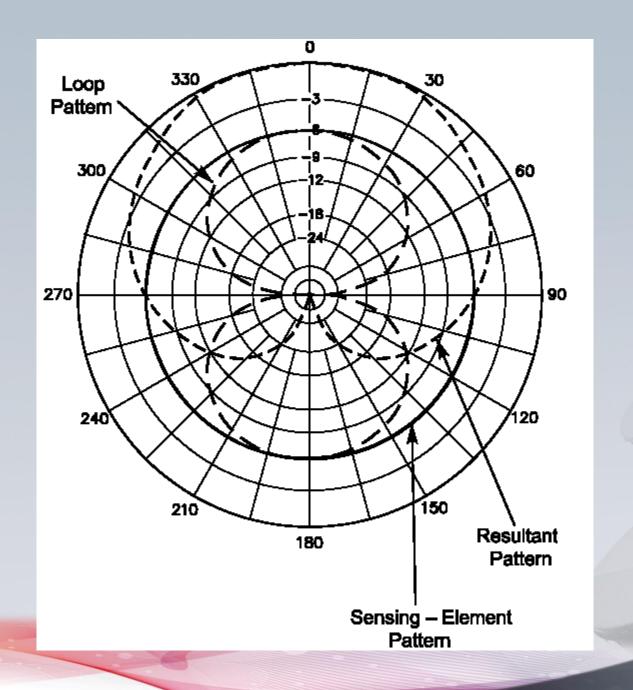
(loopstick antennas)

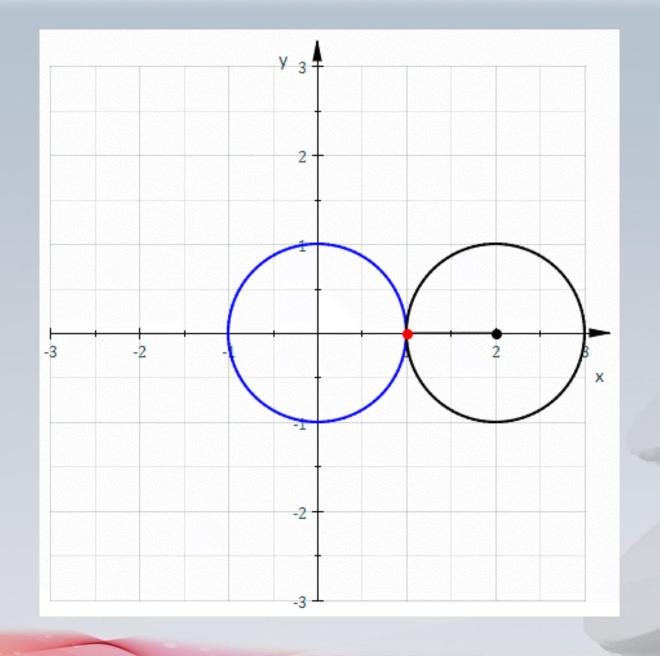
- If an air-core loop is placed in a field, in essence it cuts the lines of flux without disturbing them (A), On the other hand, when a ferrite (magnetic) core is placed in the field, the nearby field lines are redirected into the loop (B).
- To get higher loop output is to increase the permeability of the medium by winding a coil of wire around a form made of high permeability material, such as ferrite rod, much greater flux is obtained in the coil without increasing the crosssectional area.



#### Sense Antennas

- There is ambiguity as to which null indicates the true direction of the target station.
- Modify a loop or loopstick antenna pattern to have a single null by adding a second antenna element.
- It senses the phase of the signal wavefront for comparison with the phase of the loop output signal.



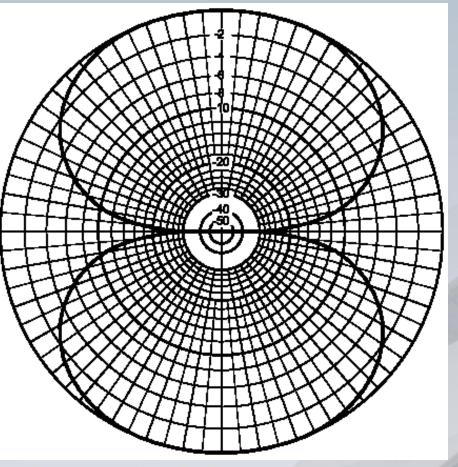


## Phased Arrays and Adcock

- The field radiated from a linear (straight) element, such as a dipole or vertical monopole, is proportional to the sum of the elementary currents flowing in each part of the antenna element.
- Many directional patterns are possible depending on the spacing and phasing of the elements.
- The directional frequency range of this antenna is limited to one band, because of the critical length of the phasing lines.

# **Adcock Antenna**

#### **Adcock Antenna Pattern**



#### LOOPS VERSUS PHASED ARRAYS

- loops can be made smaller than suitable phased arrays for the same frequency of operation.
- sharper nulls can be obtained with phased arrays.
- Loops are not as useful for skywave RDF work because of random polarization of the received signal.
- Phased arrays are somewhat less sensitive to propagation effects, probably because they are larger for the same frequency of operation and therefore offer some space diversity.



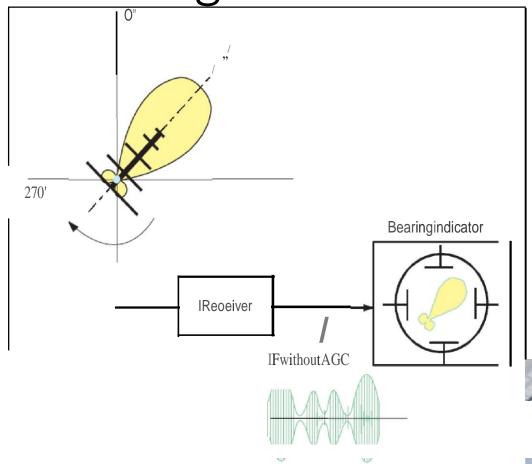
### Classic DF methods

- Manual Direction Finding.
- Doppler direction finder.
- Watson-Watt principle.
- AOA (Angle of Arrival)
- Interferometer.
- TDOA (Time Difference Of Arrival)
- Correlative Interferometry



# Manual Direction Finding







## Manual Direction Finding

- Evaluating the receive voltage is the simplest way of direction finding.
- Manual direction finding involves the use of a receiver and hand-held directional antenna: usually some type of yagi / log-periodic.
- The antenna is moved / rotated until the point of maximum signal strength is determined.
- Rotation can also be performed using an antenna mounted on a rotor or swivel.

## Manual Direction Finding

- Benefits of this DF method:
  - High sensitivity due to the directivity
  - Simple and Low-cost, no need for dedicated DF receiver or complex antennas
  - Same antenna can be used for direction finding and monitoring
  - Effectiveness depends strongly on the skill level of the operator.

## Doppler DF Concept

- Typically four to eight antennas are arranged in a circular array and are RF combined in a way that simulates rotation.
- As we move closer to a signal, the received frequency will shift upwards (or vice-versa). This shift can be detected and used to determine if we are moving in the right direction.

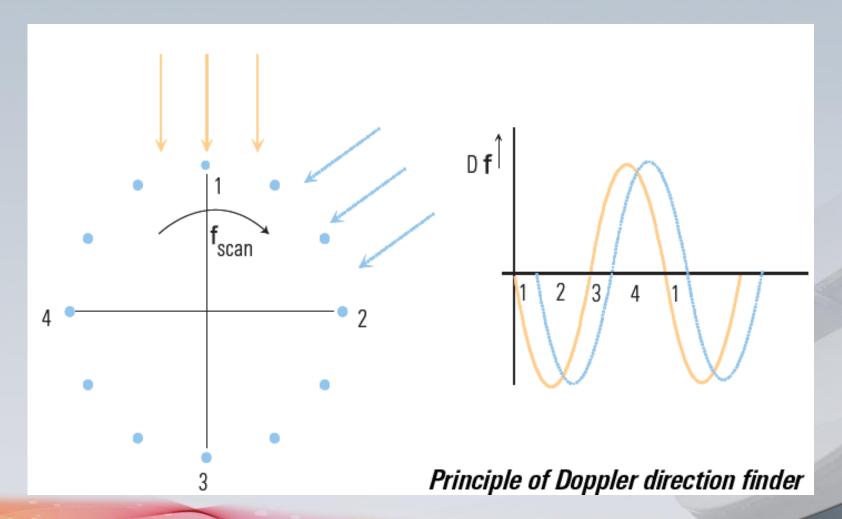
# Doppler DF Concept







## Bearing Calculation



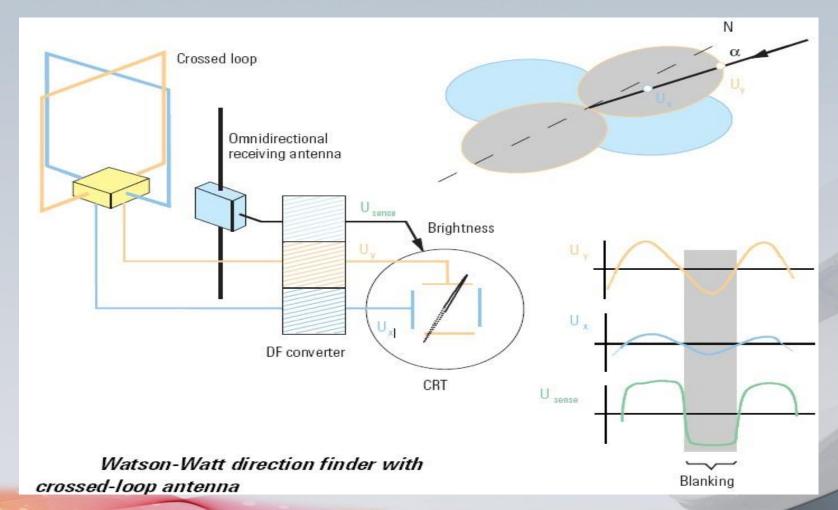
## Doppler Direction Finder

- Low cost compared to other DF systems .
- Cannot handle multiple signals.
- Require a constant (CW) type signal.
- Antenna sensitivity: Low.
- Works while stationary or when moving.
- Normally works best on VHF/UHF frequencies (< 1 GHz).</li>
- Doesn't work well for horizontally polarized signals (Doppler antennas

#### Watson-Watt DF Principle

- This DF method is based on two directional antennas pairs and one omnidirectional antenna
- The response of the two pairs are proportional to sine and cosine of the arrival signal.
- Watson-Watt DF consists of three phase-matched receivers and displays angle of arrival in terms of sine and cosine functions utilizing third omni-directional channel to solve ambiguity.

## Watson-Watt principle



## Watson-Watt principle

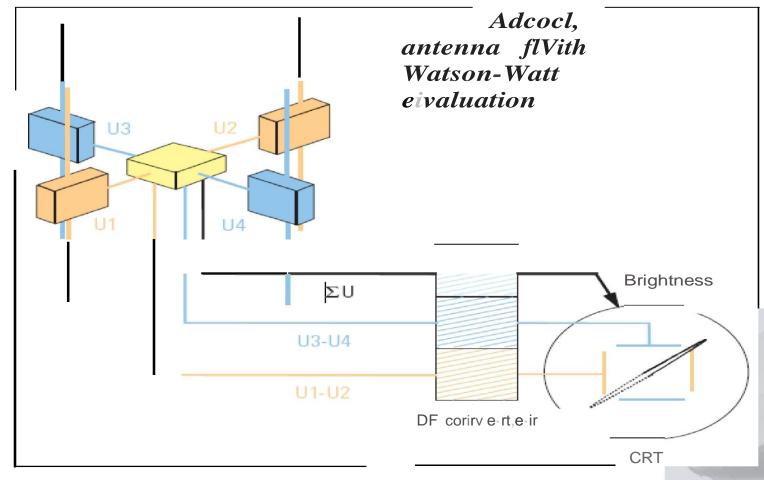
#### • Benefits:

- minimum signal duration is sufficient.
- simple implementation.
- Little space required (small aperture antenna array).

#### • Drawback:

- Small aperture system (D/ $\lambda$ <0.2) leading to errors in case of multipath propagation.
- large DF errors in case of skywaves with steep elevation angles

# Watson-Watt principle



# Watson-Watt principle

- advantages :
  - Improved error tolerances for skywave reception
  - Implementation of wider apertures to avoid errors in case of multipath reception

# Angle of Arrival

- AOA simply measures the angle(s) at which a signal arrives at an antenna array : not the phase or time differences of the signal at different elements.
- To determine if a signal is "arriving" at an antenna, we make a determination of the power of the incoming signal at one or more antennas, so AOA is sometimes also called "power of arrival" (POA).
- AOA antennas are typically circular array of (somewhat) directional antennas.
- Resolution / bearing accuracy is increased with an increasing number of antenna faces.

# Interferometer



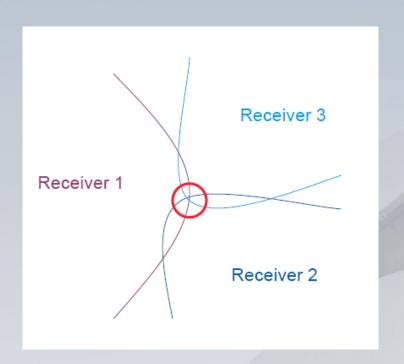


#### Interferometer Based DF

- This concept is based on phase measurement between a subset of possible pairs of antennas with minimum of two coherent receiver channels
- Phase measurement for a specific pair can be used for arrival angle determination, based on knowledge of relative antenna distance
- When more then one pair is used elevation calculation is possible
- Antenna sensitivity: low
- Azimuth accuracy:  $\sigma = 1.5^{\circ} -3^{\circ}$

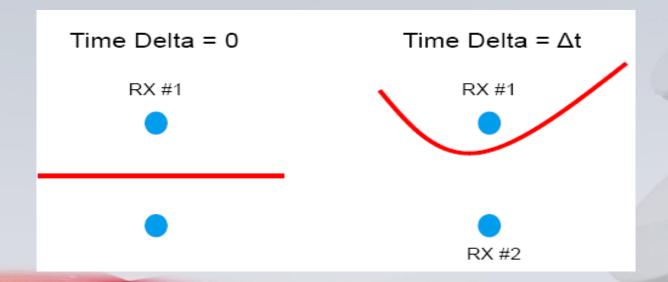
# Time Difference of Arrival (TDOA)

- Three or more receivers at different locations receive a signal from the target.
- Usually the paths between the transmitter and the receivers are of different length, so there are differences in the time of arrival at the different receiver locations.
- The time differences can be represented as hyperbolae which cross at the location of the transmitter of interest.



# Time Difference of Arrival (TDOA)

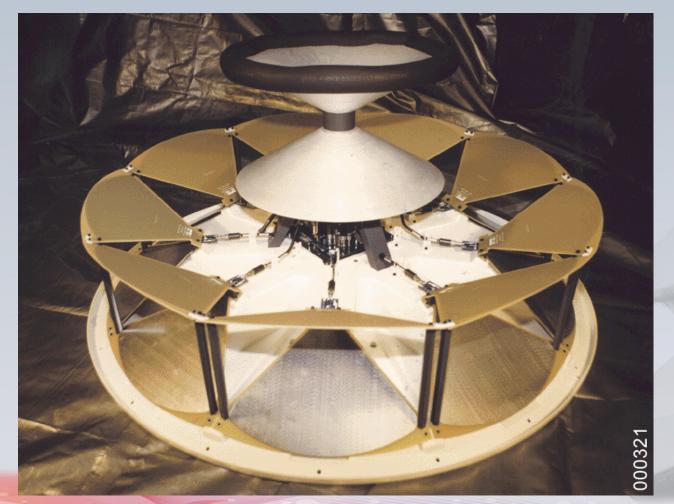
- Once we have computed the time difference,  $\Delta t$ , between the times the signal was received at two stations, we can then compute / plot a hyperbola representing this distance between them.
- The intersection of multiple hyperbolae yields the estimated target location.



# Time Difference of Arrival (TDOA)

- Requires small aperture antenna array
- Requires single-channel receiver
- Cannot handle multiple signals
- Antenna sensitivity: low
- Azimuth accuracy:  $\sigma = 3^{\circ}$
- DF data collection time: 1 S

# Correlative Interferometry Technique



# Correlative Interferometry

- Can use any multi-port antenna array
- Requires two or more receiver channels
- Minimizes effect of signal modulation and fading
- Measures amplitude and phase
- Can solve multimode interference with two-channel receiver

# Correlative Interferometry

- Can handle multiple signals with multiple receiver channels
- Antenna Sensitivity: high
- Azimuth Accuracy:  $\sigma = 1^{\circ} -2^{\circ}$
- Data Collection Time: fast; depends on number of receiver channels

### Locating the Transmitter source

- Steps of detection of the Location:
  - 1. Monitoring (Frequency B.W Modulation)
  - 2. DF (Fixed Stations)
  - 3. Detection of location (2 fixed stations one fixed and one mobile SSL)
  - 4. Homing using Mobile.
  - 5. Portable receivers (inside building)

# Single Site Location

 When a propagation path of no more than one reflection at the ionosphere can be assumed, position of an HF emitter can be determined by a single observing site using vertical triangulation, provided that the height of the ionosphere at the point where the radio wave is reflected, can be determined.

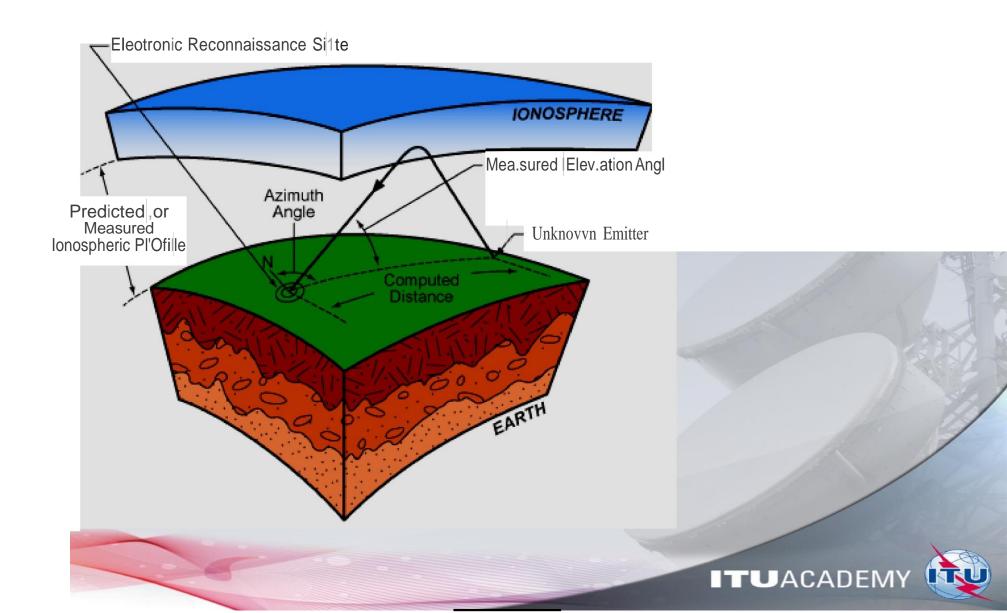


## Single Site Location

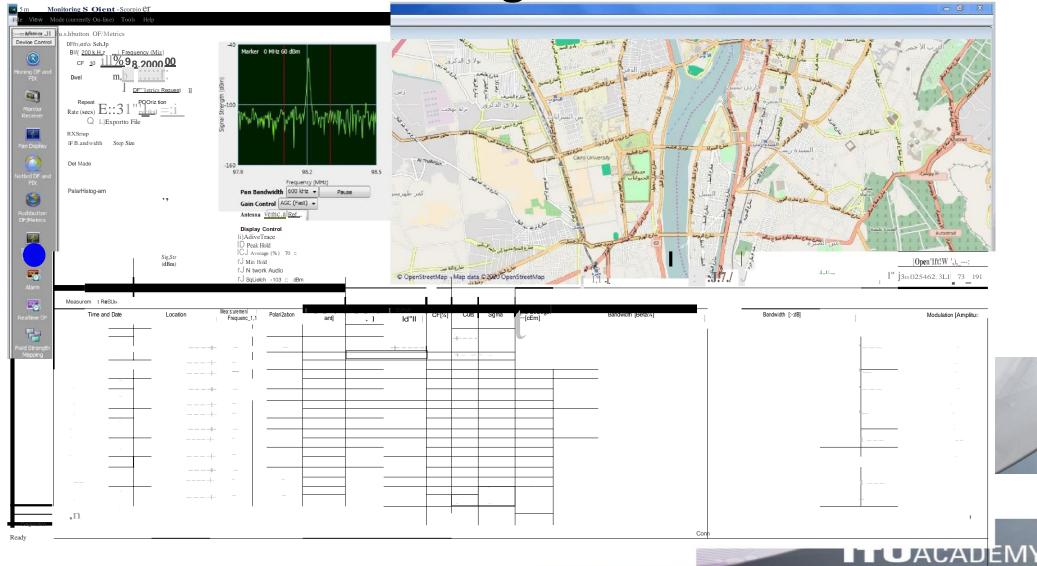
- Determination of distance to target transmitter:
  - Elevation angle of arrival is measured by HFDF system
  - Electron density profile of the ionosphere is measured by ionospheric sounder
  - The path of the electromagnetic wave through the ionosphere can be reconstructed using a ray tracing algorithm
  - The distance to target transmitter can be calculated based on Martyn's Theorem (with correction terms)

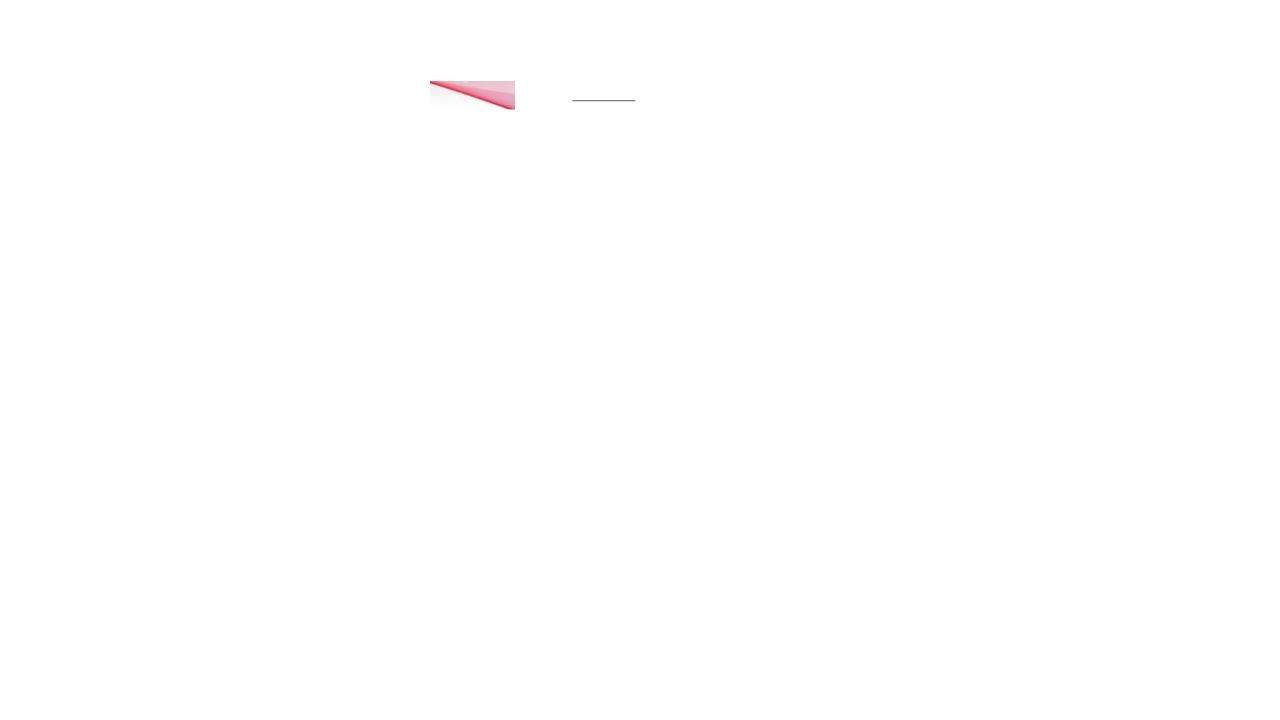


### SSL Distance Calculation

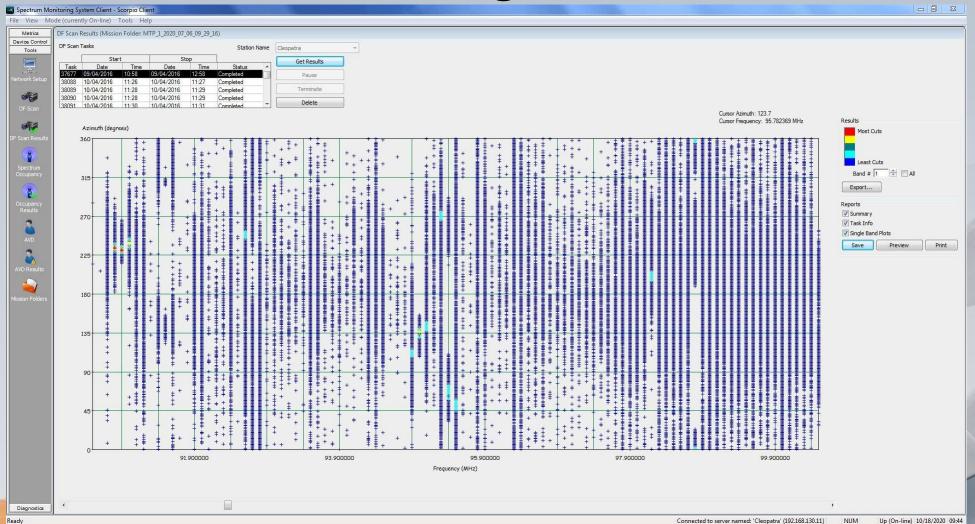


Direction Finding Measurement





# Direction Finding Measurement



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# Direction Finding Measurement

