Direction Finding

Spectrum Management Training Program

Elective Module EM1-Option 1 : Spectrum Monitoring

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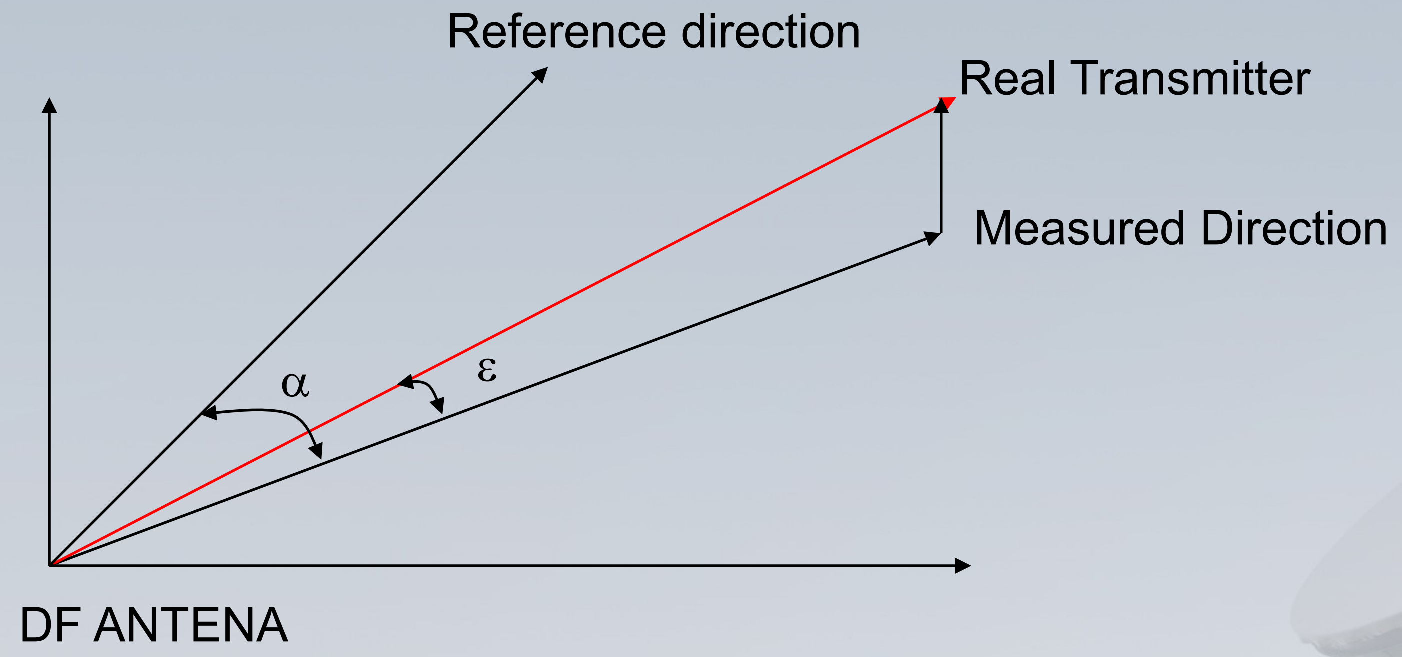
Outline

- 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

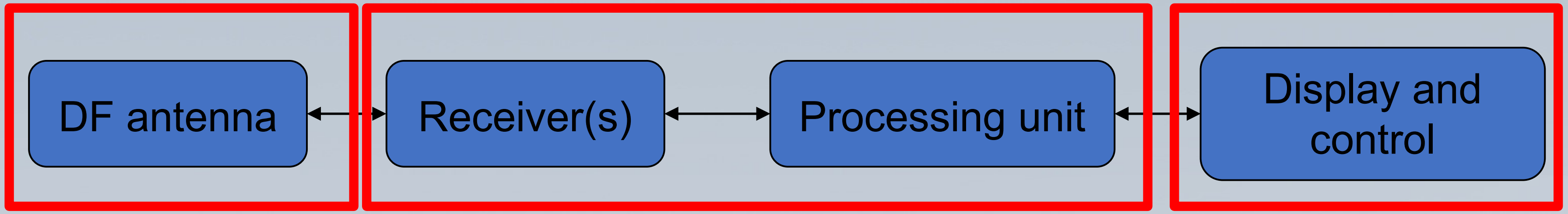
Requirements on DF system

- 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



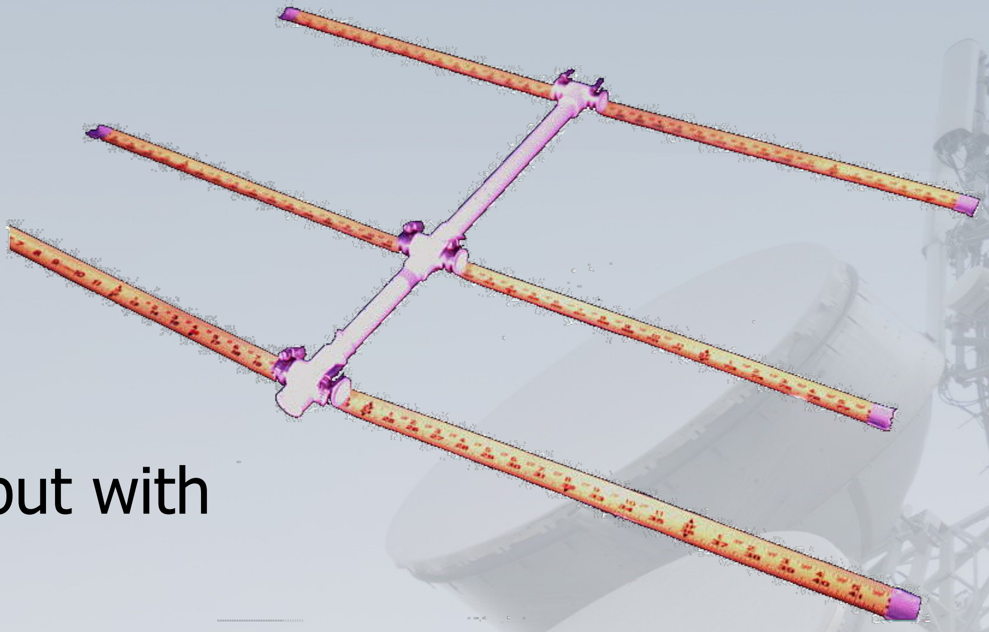
- Antenna
  - Design usually specific to a given DF methodology
- Receiver(s) and processing unit
  - One or more receive channels with analog-to-digital conversion
  - Integrated or separate digital signal processing
- User interface
  - Software for display and control
  - Position fix and map display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

DF Antennas

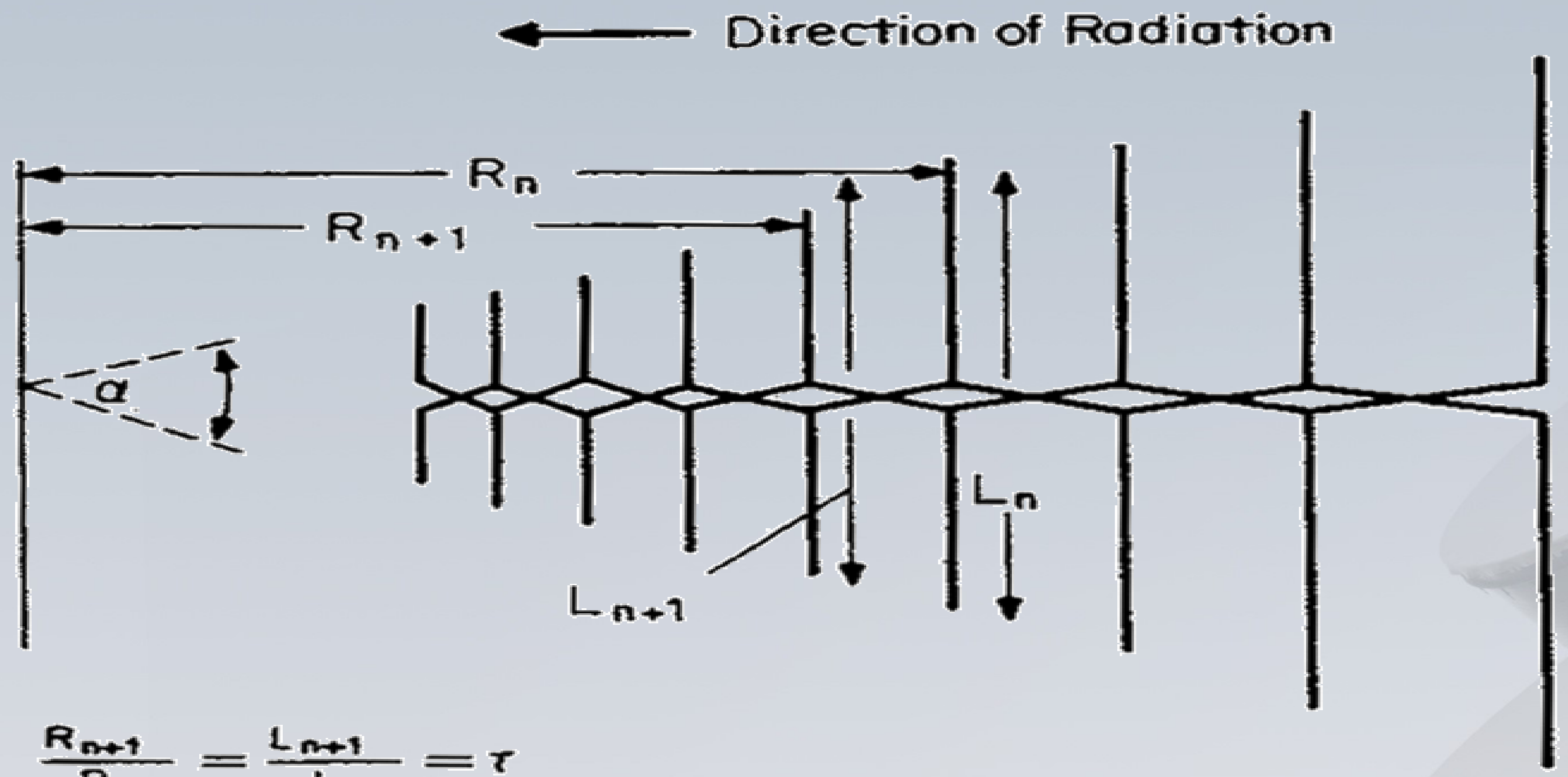
- Beam/Yagi Antenna.
- Log-Period Antenna.
- Loop Antenna.
- Ferrite Rod Antennas.
- Phased Arrays and Adcocks.

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



$$\frac{R_{n+1}}{R_n} = \frac{L_{n+1}}{L_n} = \tau$$

Log-Period Antenna

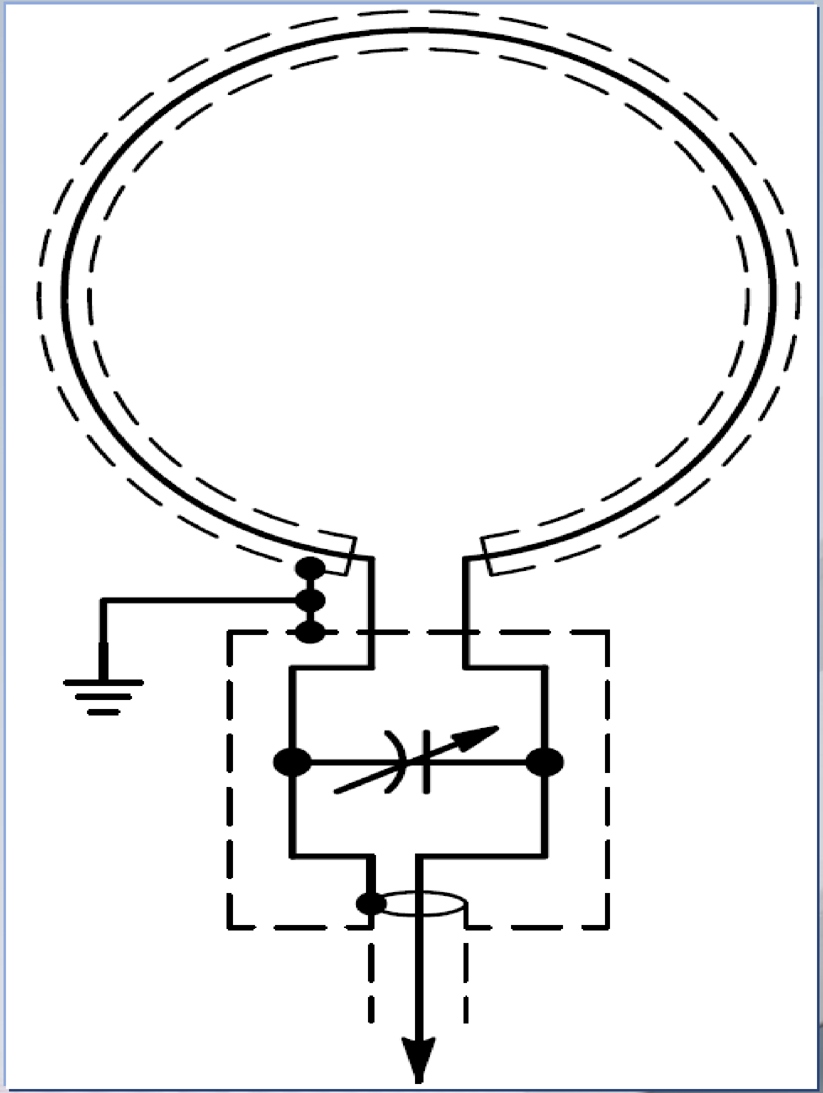
- Antennas where characteristics repeat according to logarithm of frequency
  - 7.5 dBi typical gain in free space
  - Good directivity: 14 dB typical front-to-back ratio
  - Uniform pattern over up to 10:1 frequency range
- Radiating elements are fed by central transmission line
- Individual elements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

Loop Antenna

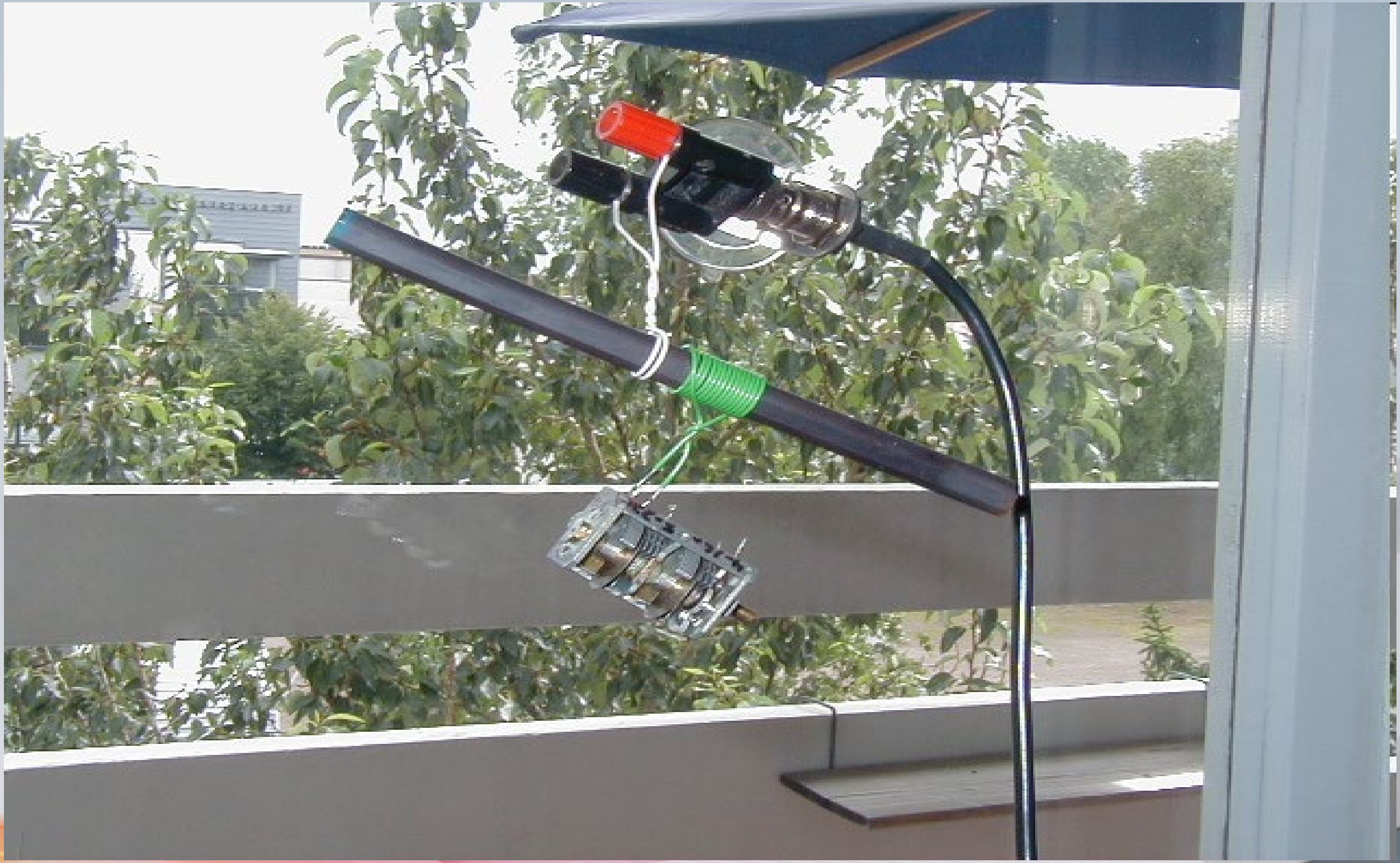
- The loop antenna acts much the same as the secondary winding of a transformer.
- The voltage at the output is proportional to the amount of flux passing through it and the number of turns.
- To obtain the most accurate bearings, the loop must be balanced electrostatically with respect to ground.
- 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

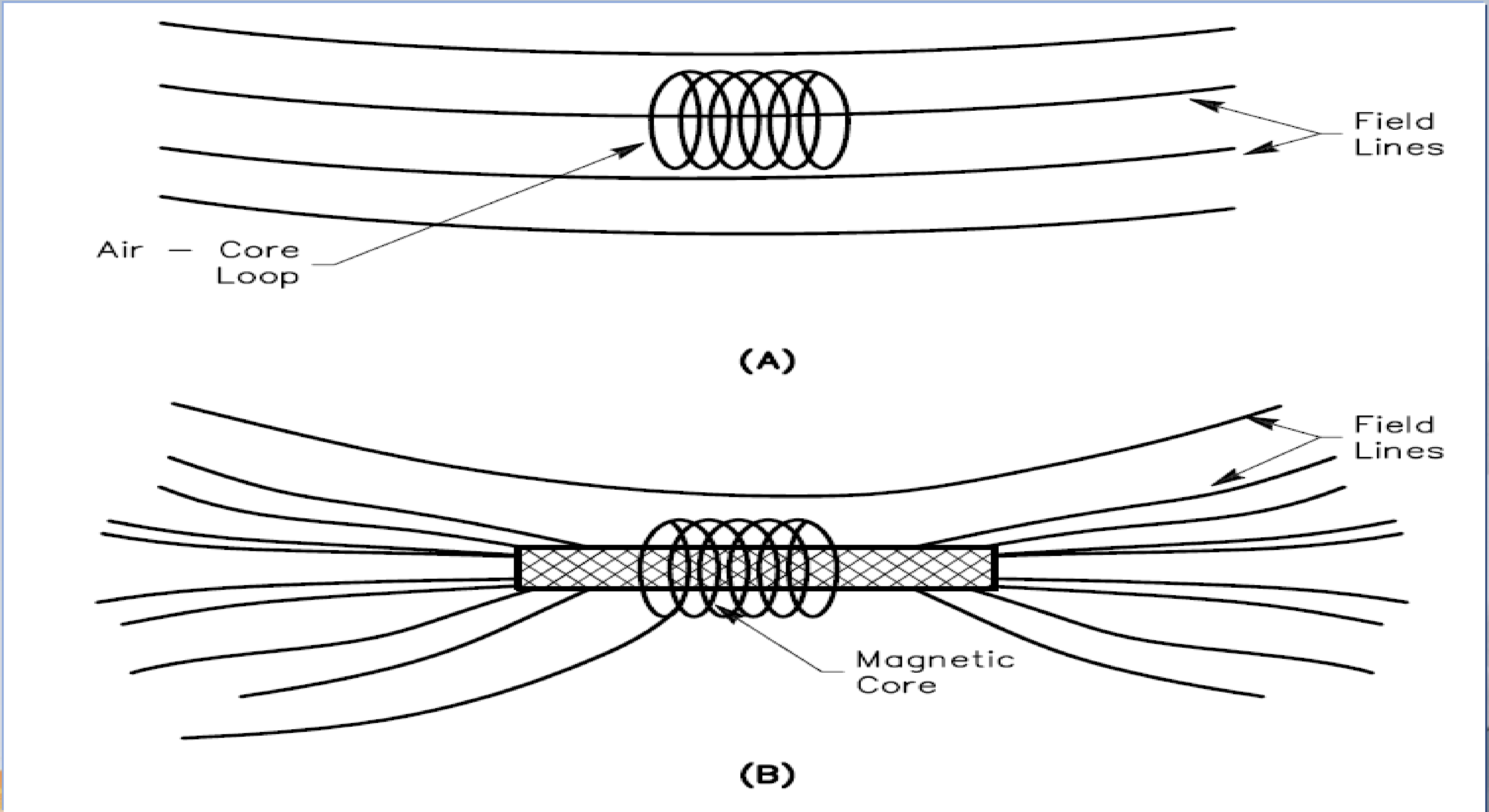
- More common on HF frequencies
- Very compact
- Tune to the null
- Bearings not very precise
- Has 180 degree ambiguity.



Ferrite Rod Antennas



Ferrite Rod Antennas



Ferrite Rod Antennas

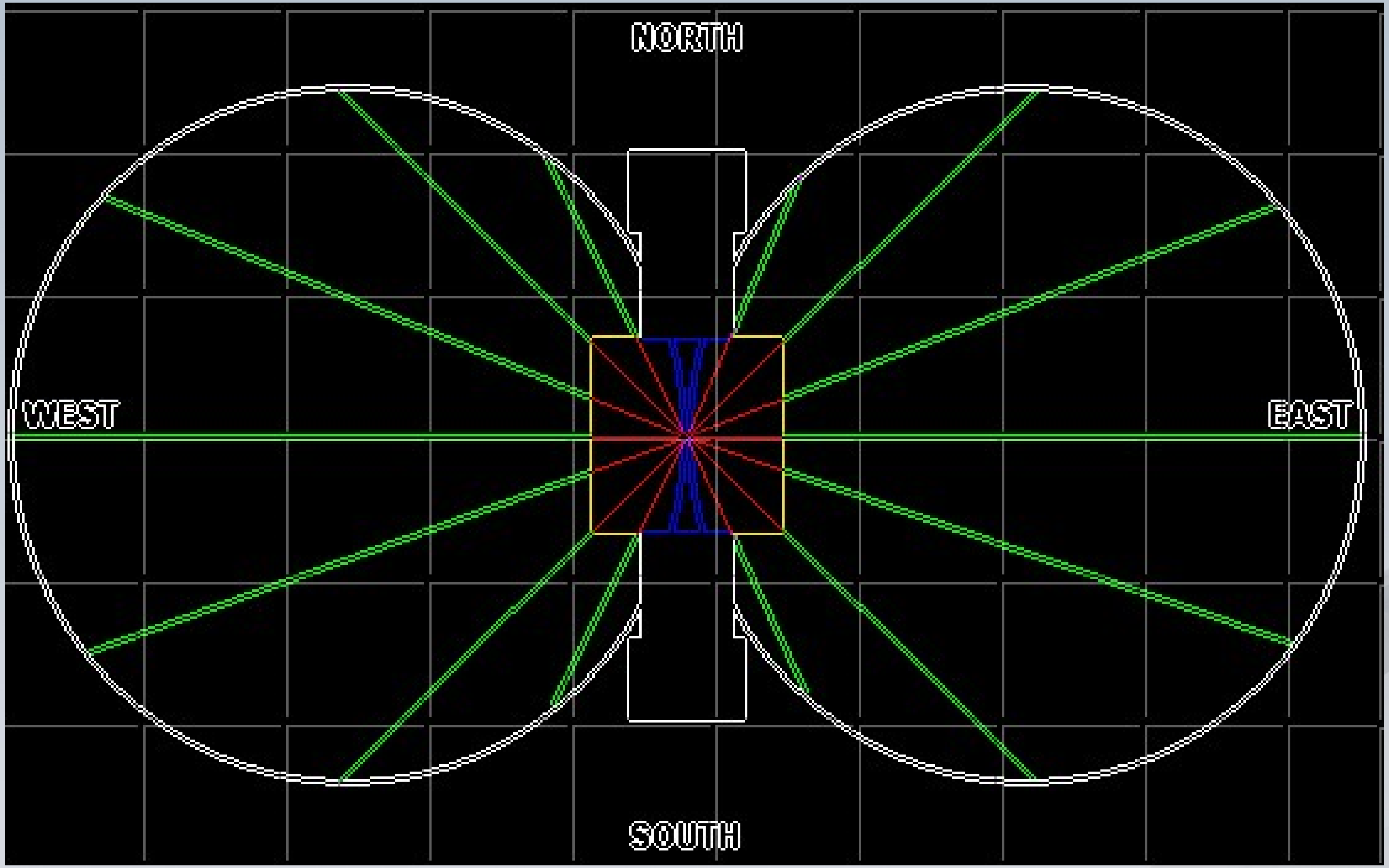
(loopstick antennas)

- 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.

Ferrite Rod Antennas

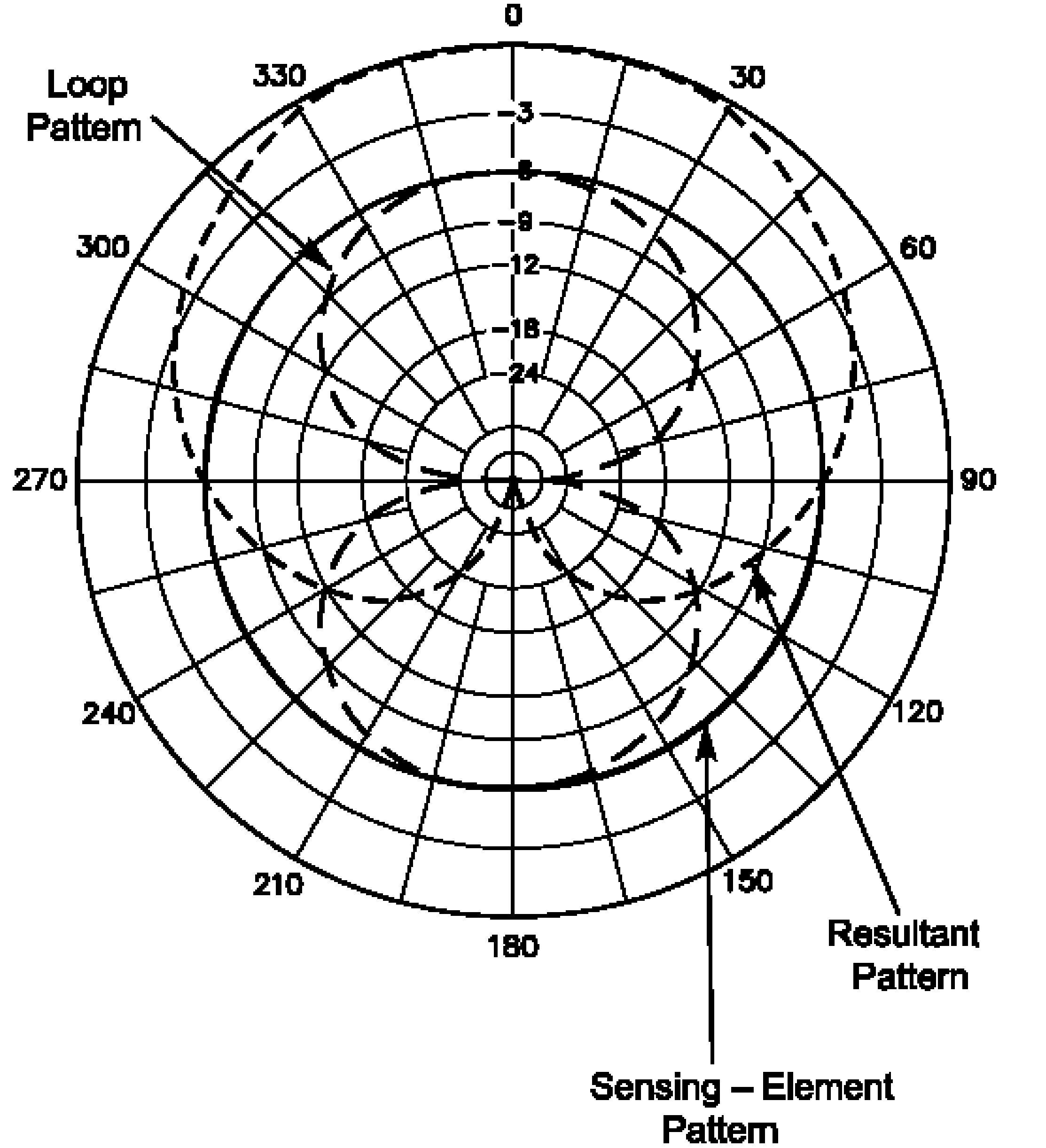
(loopstick antennas)

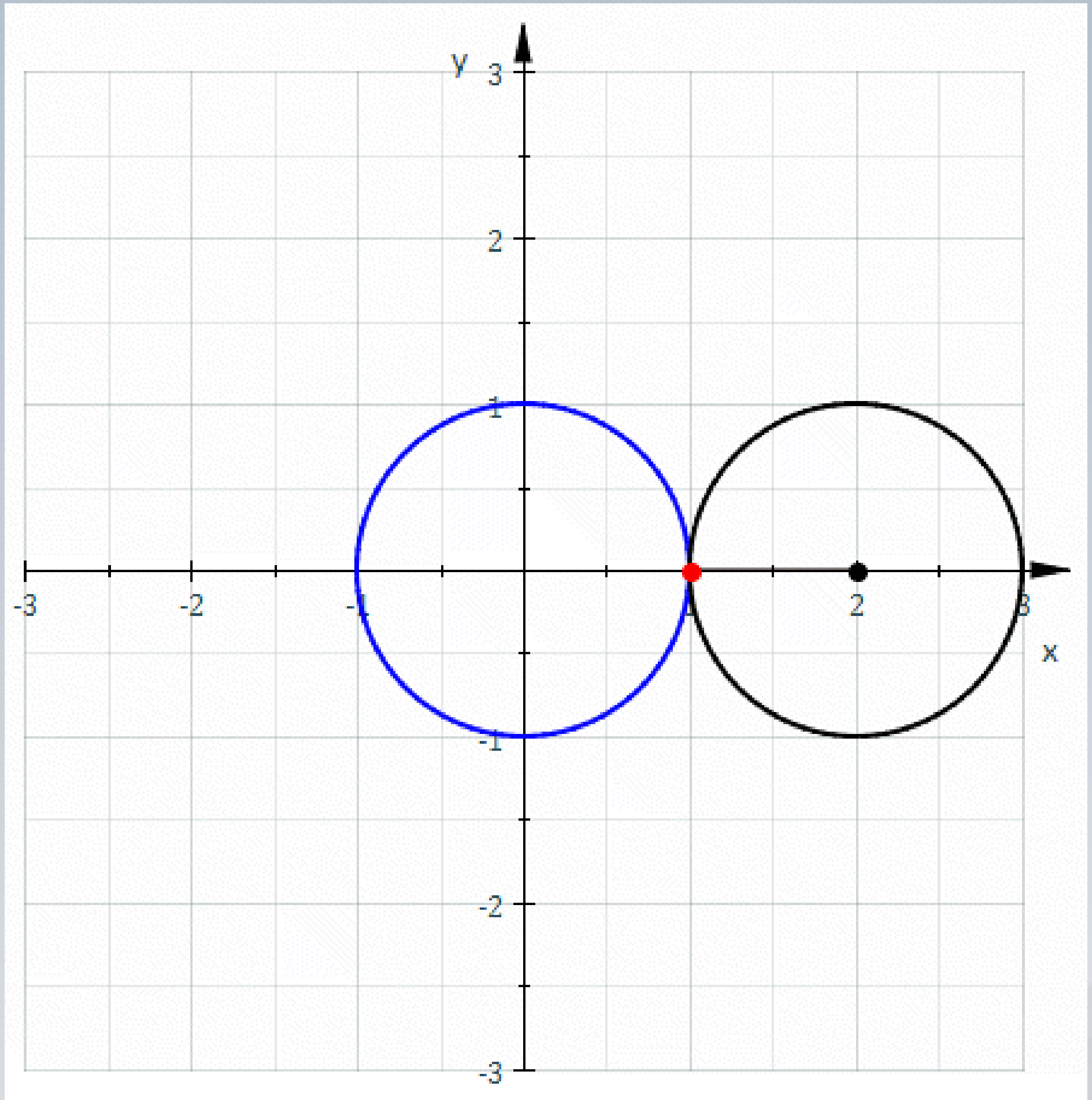
- If an air-core loop is placed in a field, in essence it cuts the lines of flux without disturbing them (A), On the other hand, when a ferrite (magnetic) core is placed in the field, the nearby field lines are redirected into the loop (B).
- To get higher loop output is to increase the permeability 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 cross-sectional area.


NORTH
WEST
EAST
SOUTH

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.


0
30
60
90
120
150
180
210
240
270
300
330
-3
-6
-9
-12
-18
-24
Loop Pattern
Resultant Pattern
Sensing – Element Pattern

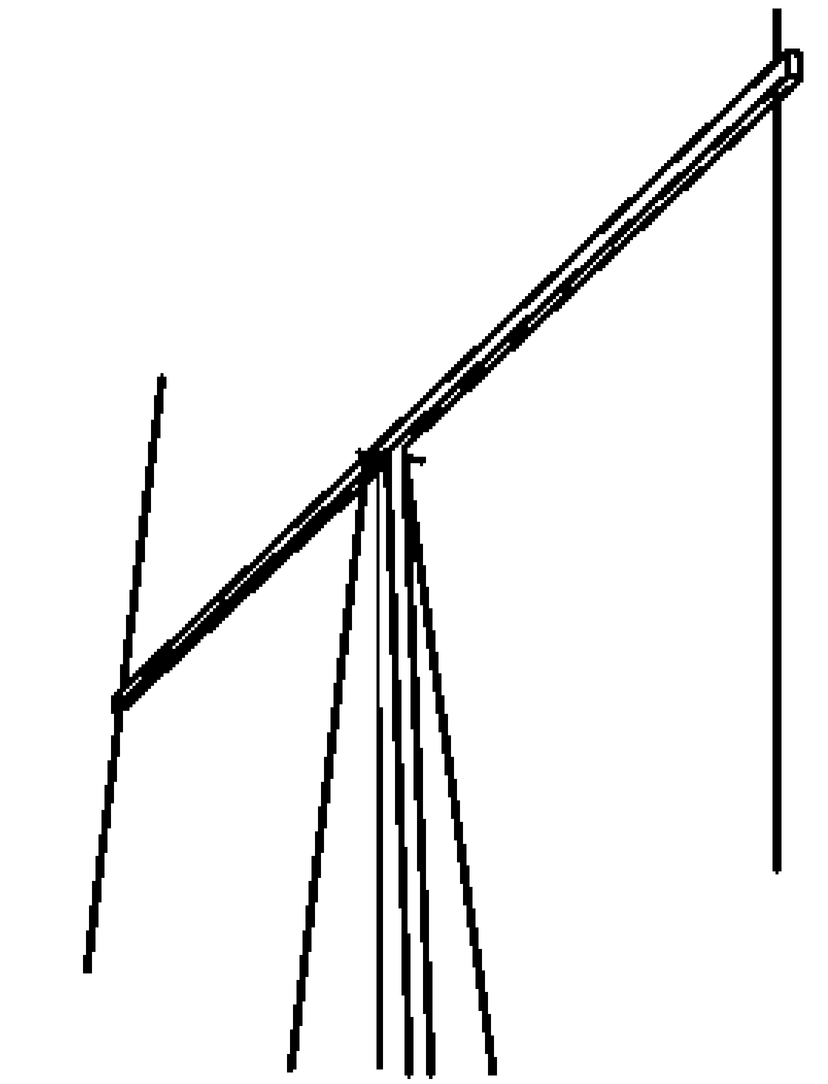


y
3
2
1
-1
-2
-3
-3
-2
-1
2
3
x

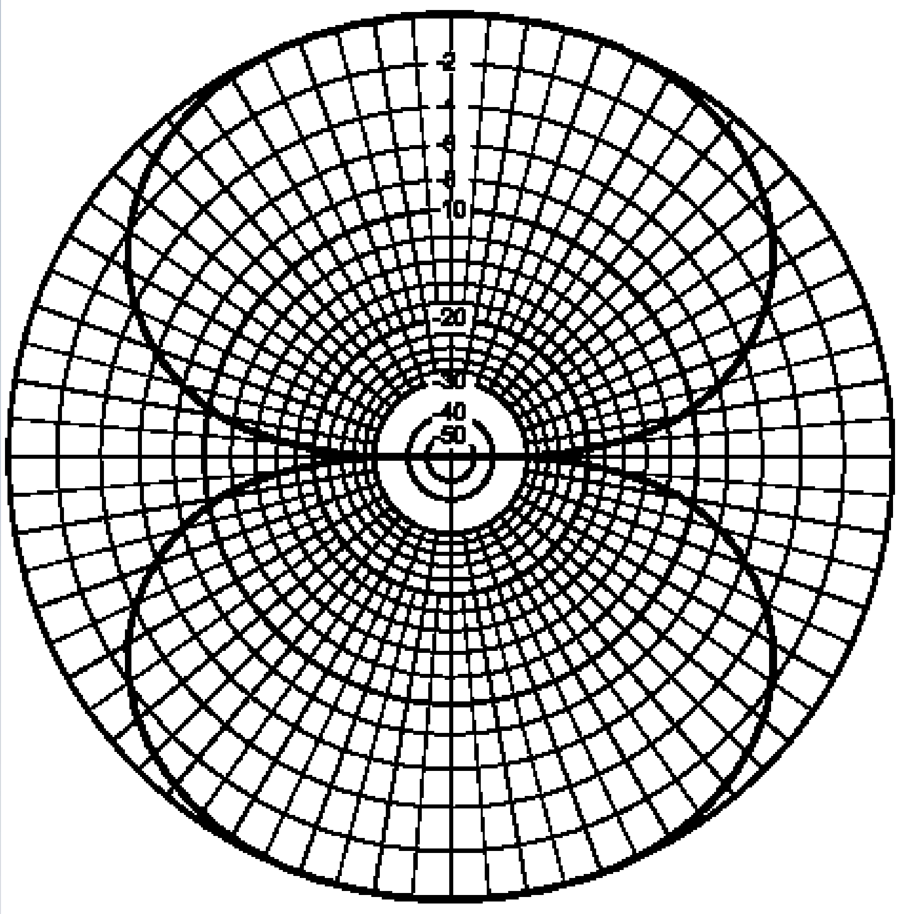
Phased Arrays and Adcock

- 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



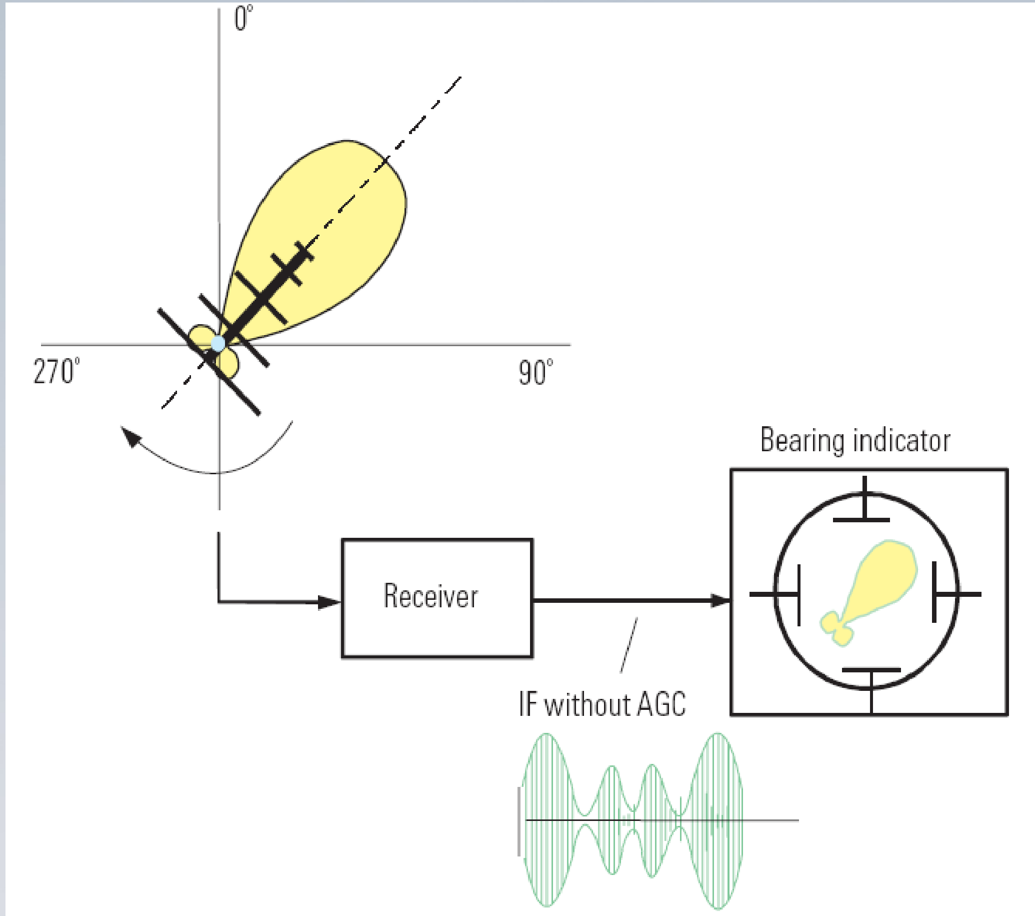
LOOPS VERSUS PHASED ARRAYS

- 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.

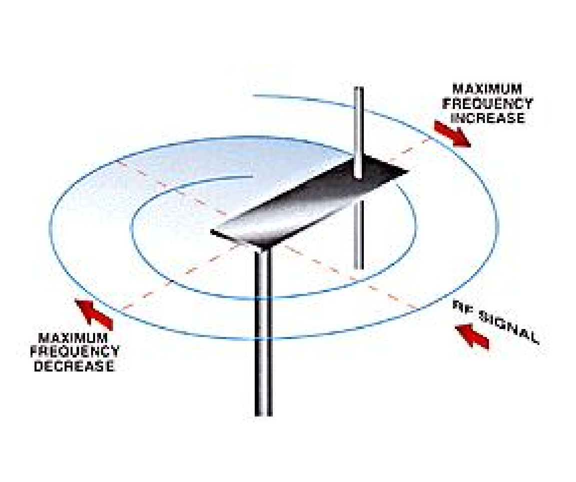
Manual Direction Finding

- 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.

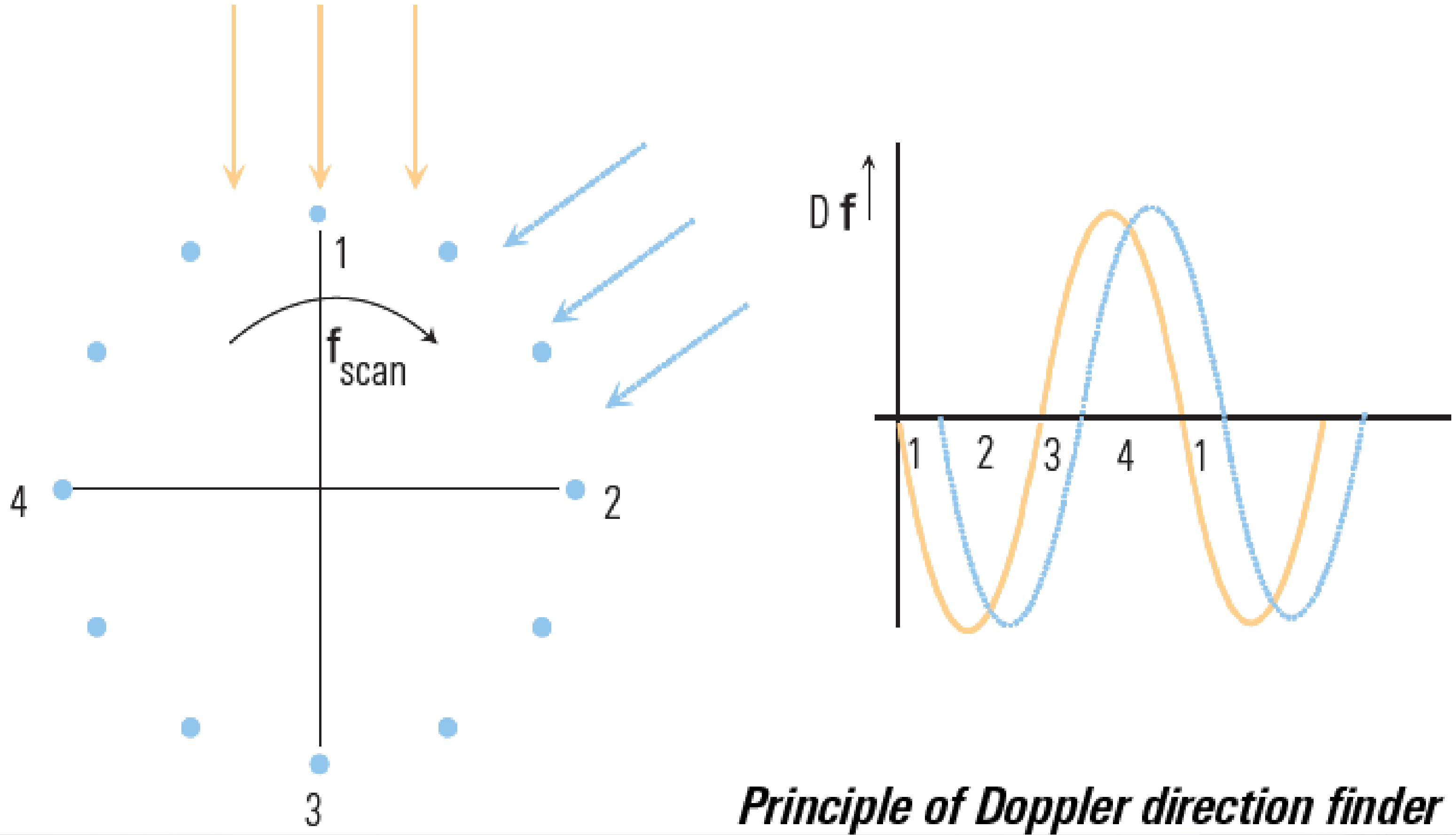
Doppler DF Concept

- 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



Principle of Doppler direction finder

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).
- Doesn’t work well for horizontally polarized signals (Doppler antennas usually vertically polarized)

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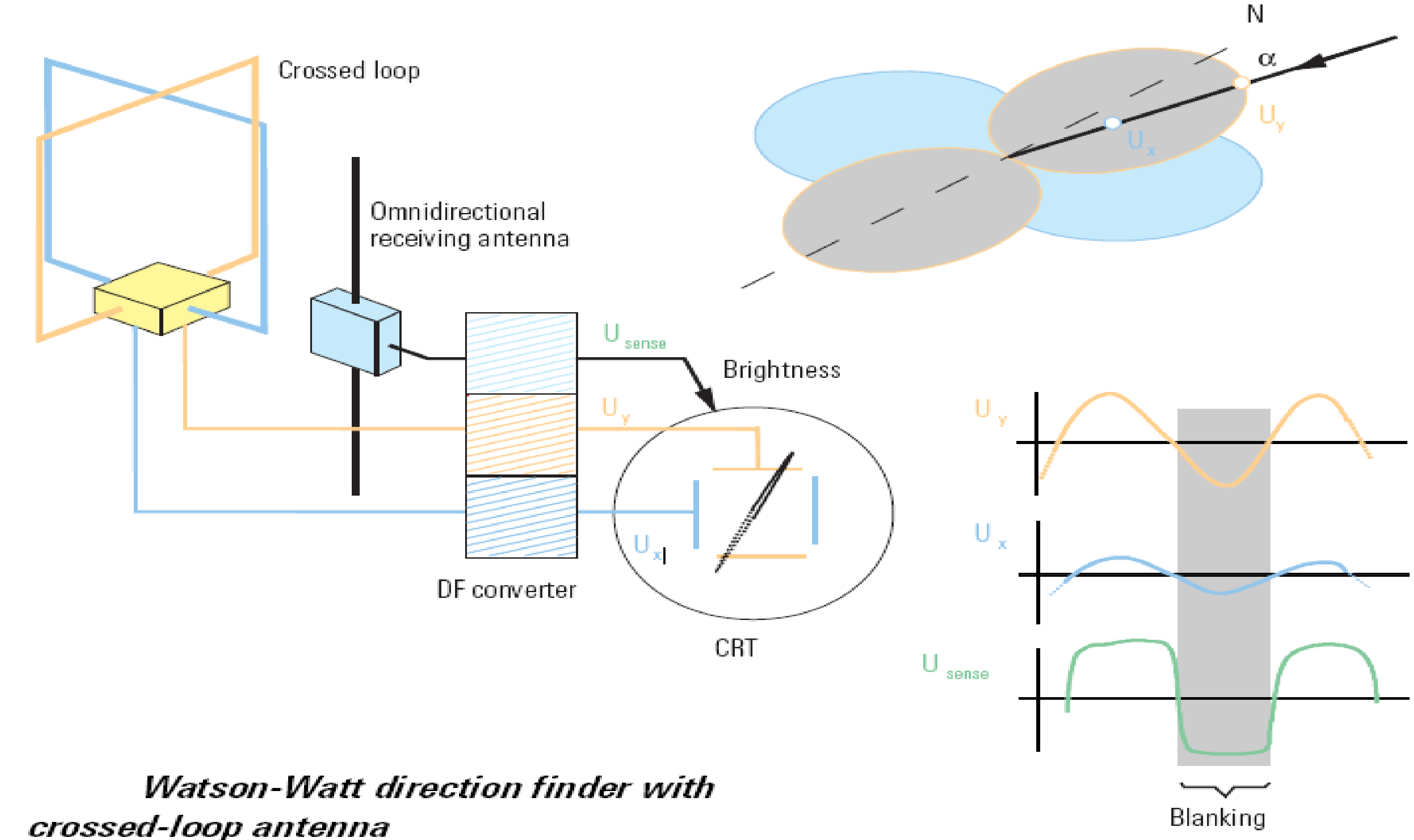
Watson-Watt DF Principle

- This DF method is based on two directional antennas pairs and one omni-directional 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

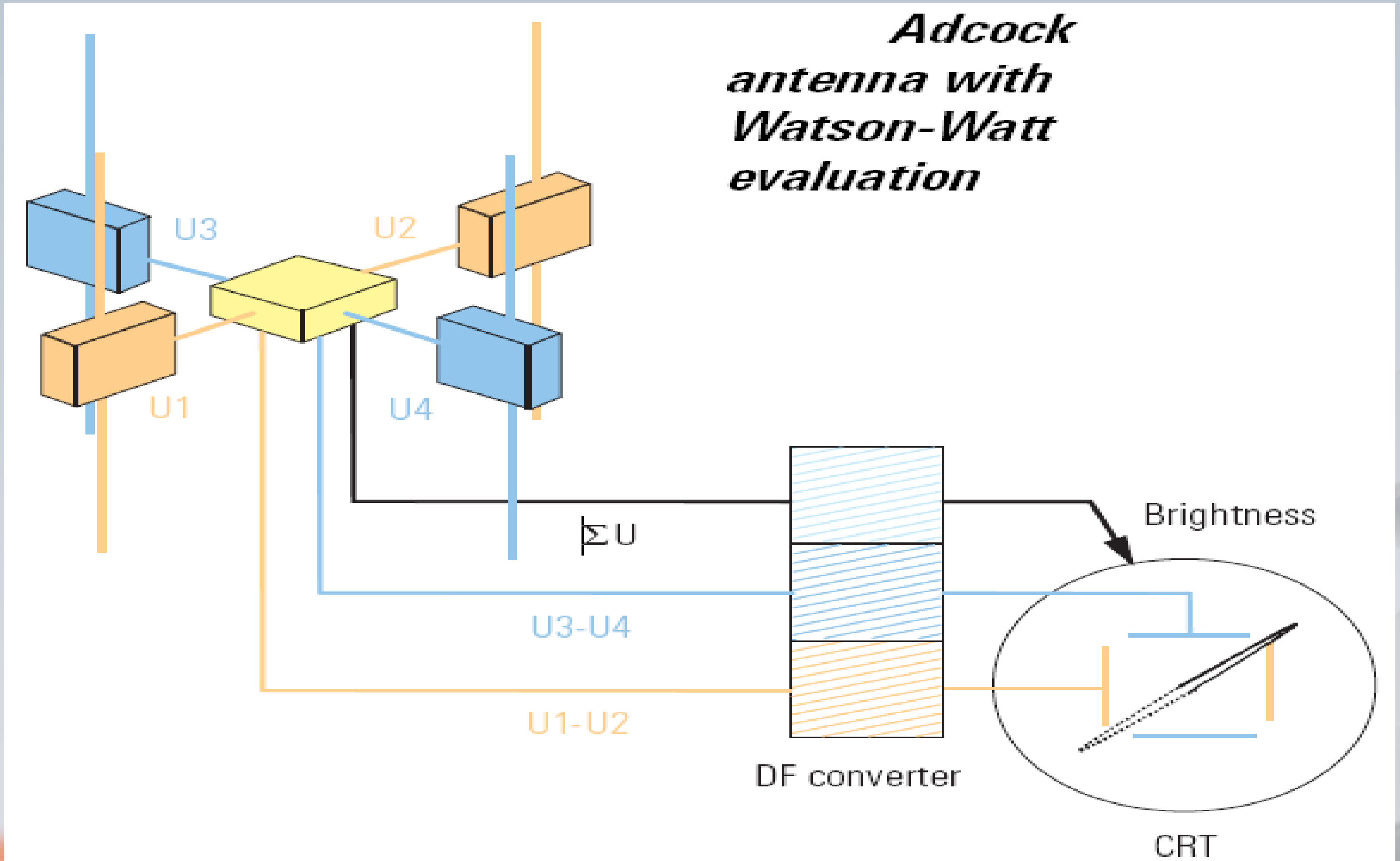


Watson-Watt direction finder with crossed-loop antenna

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.

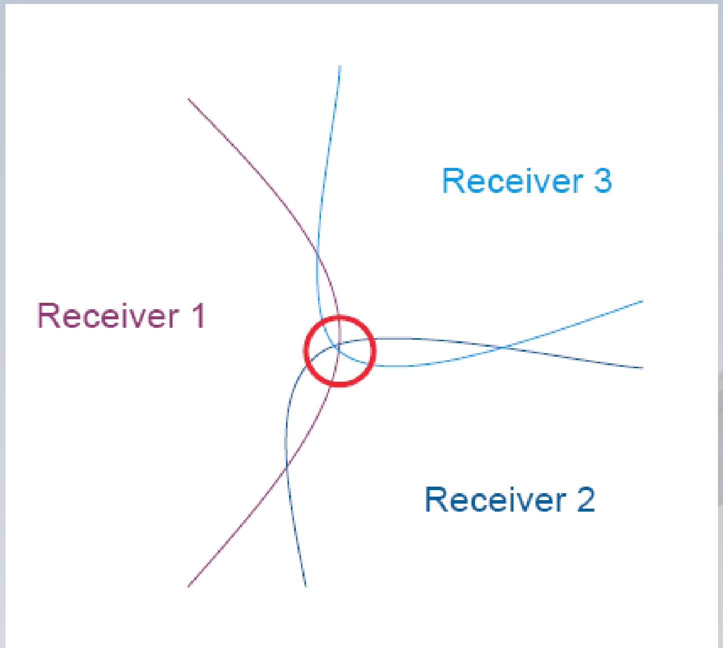
Interferometer

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: σ = $1.5^\circ - 3^\circ$

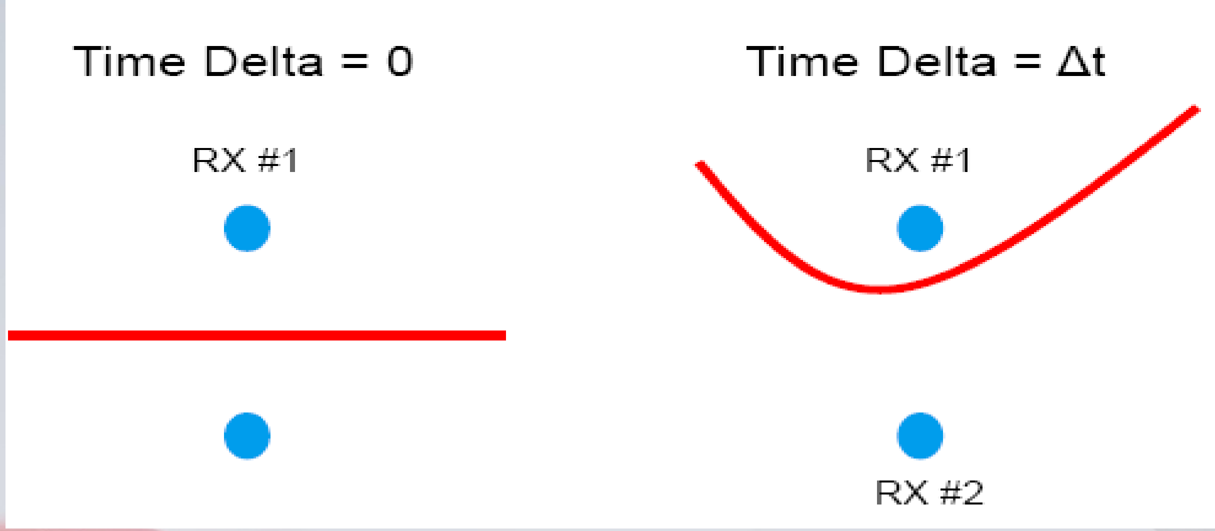
Time Difference of Arrival (TDOA)

- 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)

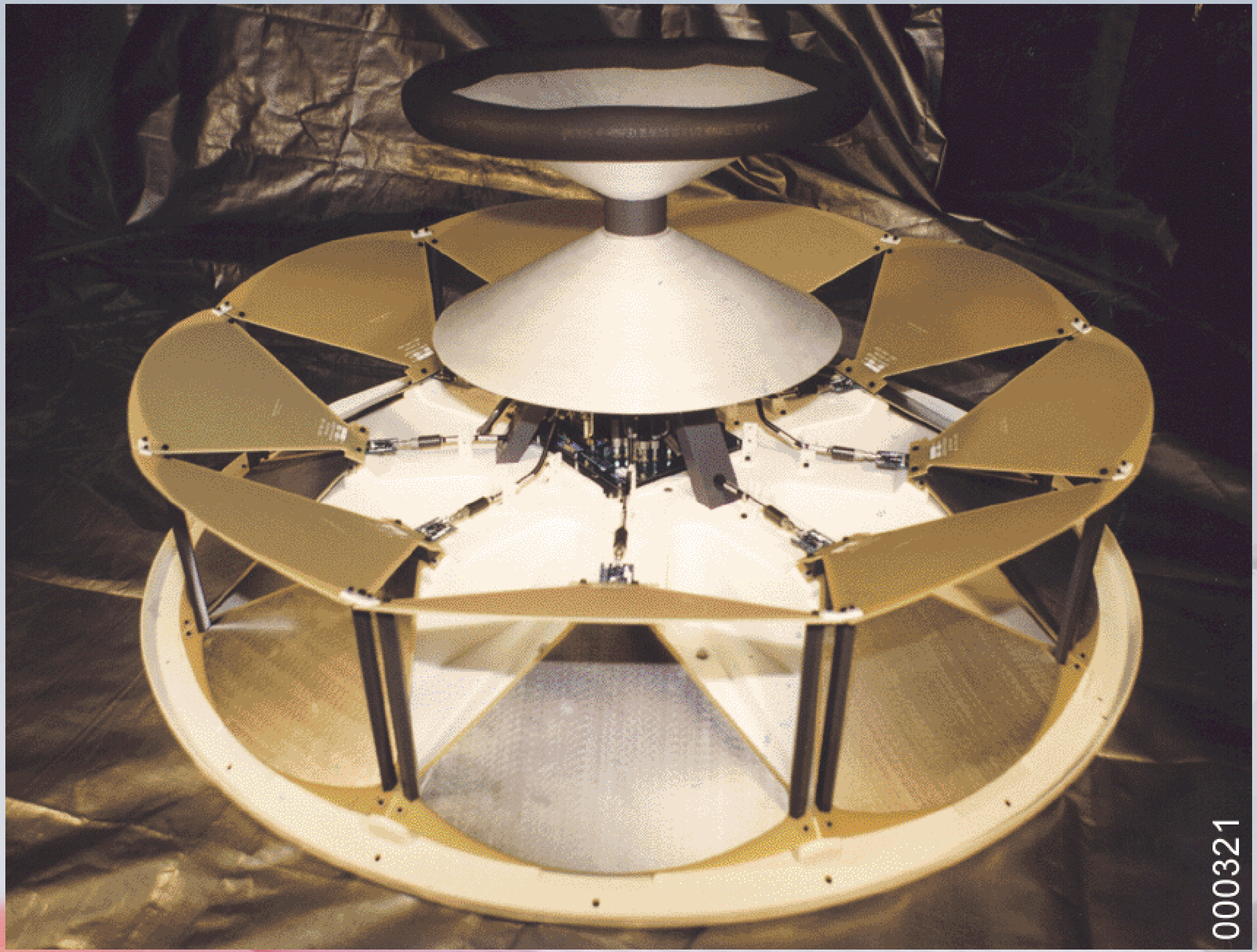
- Once we have computed the time difference, Δt, between the times the signal was received at two stations, we can then compute / plot a hyperbola representing this distance between them.
- The intersection of multiple hyperbolae yields the estimated target location.



Time Difference of Arrival (TDOA)

- Requires small aperture antenna array
- Requires single-channel receiver
- Cannot handle multiple signals
- Antenna sensitivity: low
- Azimuth accuracy: σ = 3°
- 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)

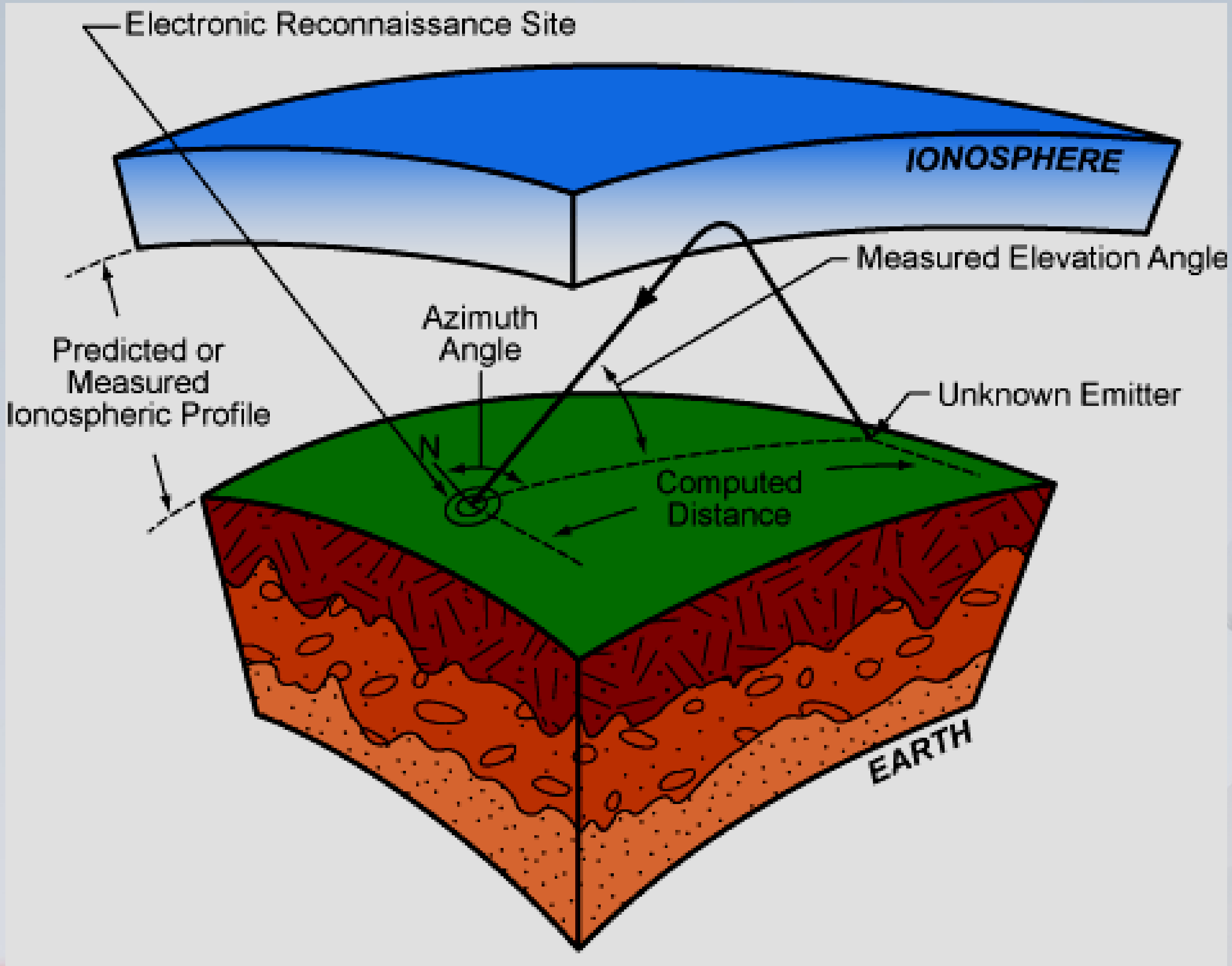
Single Site Location

- 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.

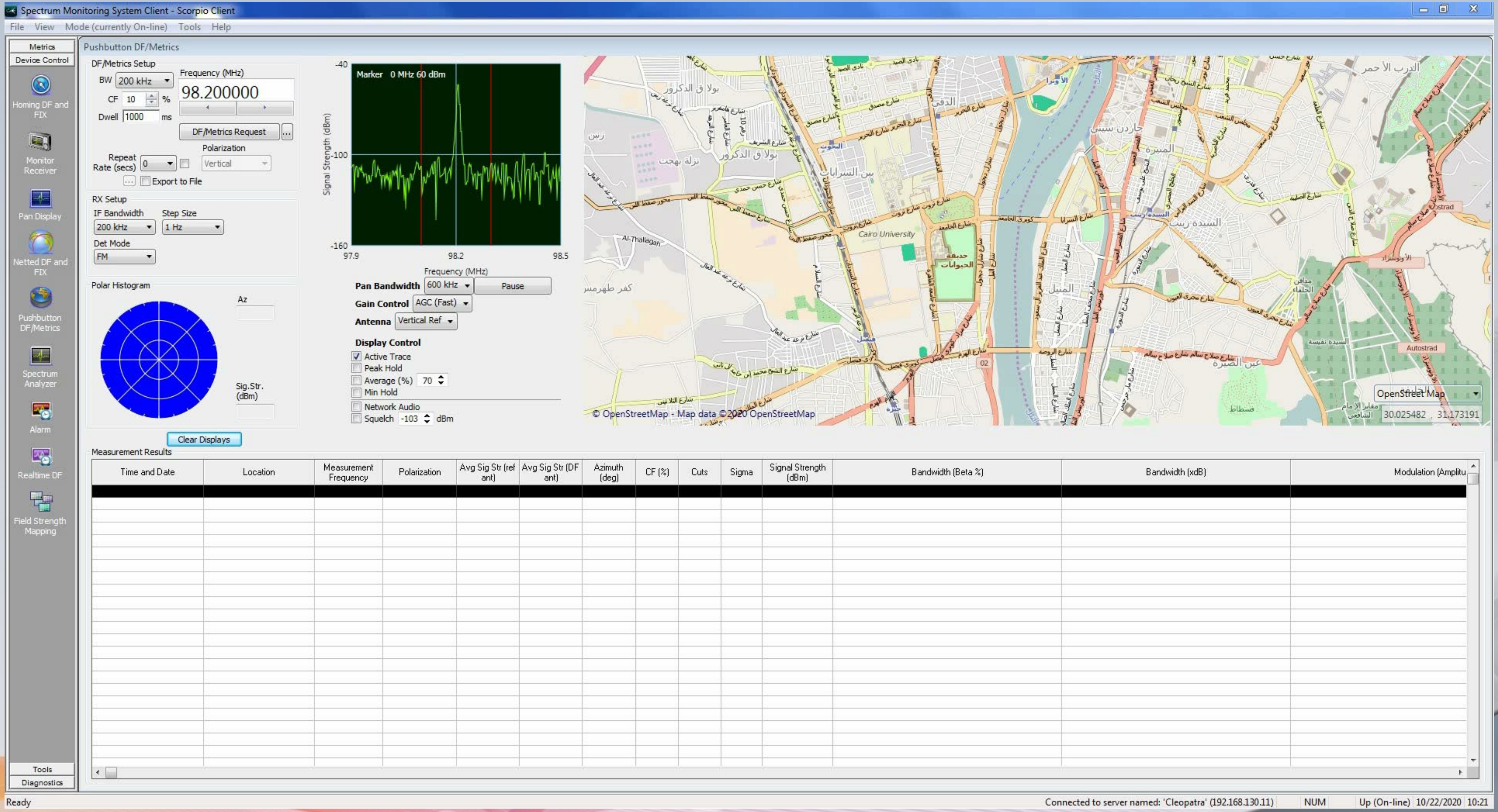
Single Site Location

- 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)

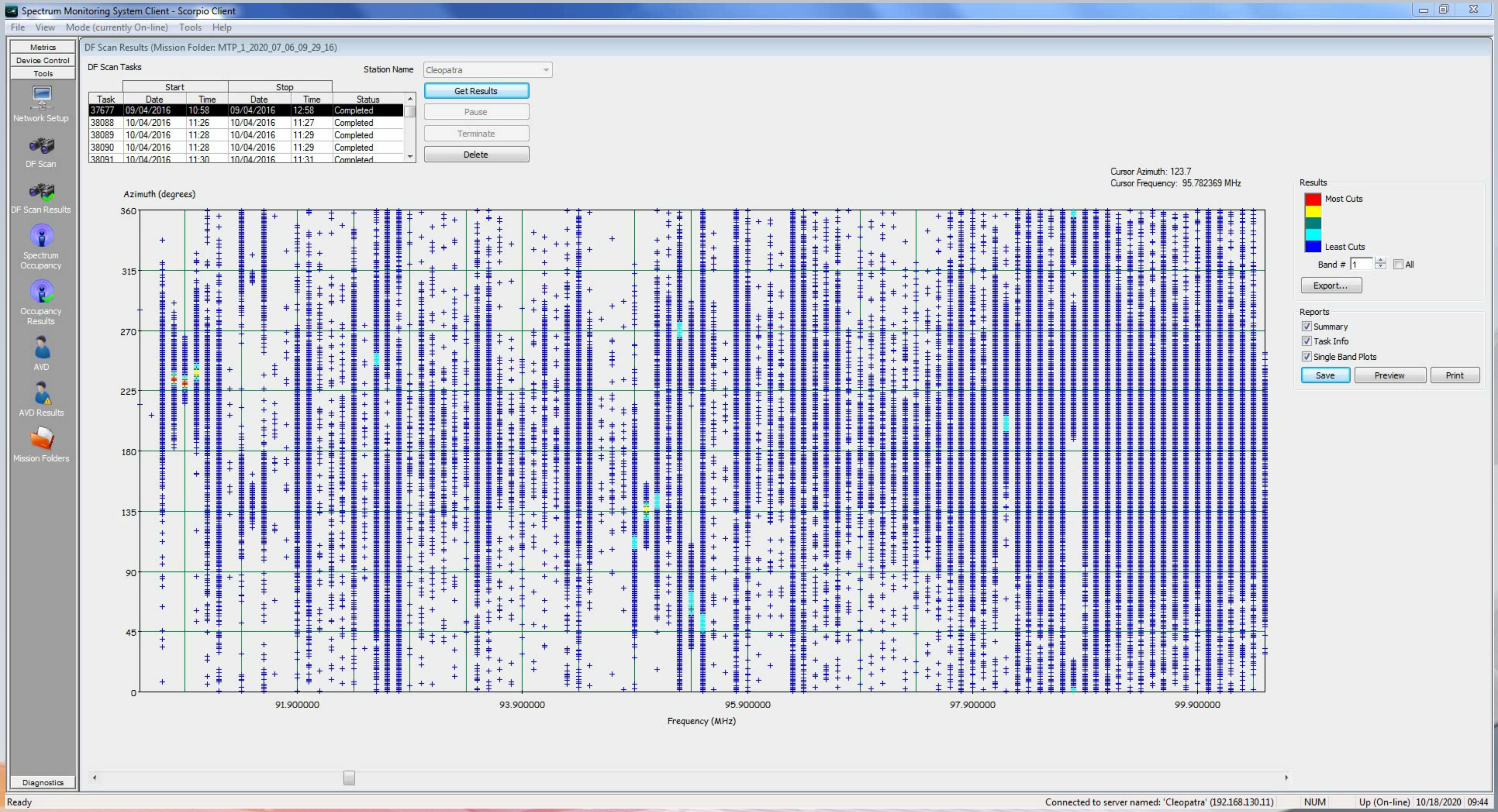
SSL Distance Calculation



Direction Finding Measurement



Direction Finding Measurement



Direction Finding Measurement

DF Scan Summary Report

Task No:	38097	Storage Interval:	15 secs
Operator ID:	TCI-WS-2	Noise Riding Threshold:	15 dB
Schedule Time:	10/4/2016 11:49:00 AM	Fixed Duration:	30 secs
Completion Time:	10/4/2016 11:49:30 AM	DF Resolution:	1 deg
Site Location:	N 30 1' 21" E 31 12' 32.1"	Azimuth Range:	0 --- 360
		All Single Band	

Chan Num	Frequency (MHz)	Total Num. Of Cuts	Cuts Used in Summary	Azimuth (Degrees)	Field Str. (dBuV/m)	Standard Deviation
1	794.000000	0	--	--	--	--
2	794.012500	0	--	--	--	--
3	794.025000	0	--	--	--	--
4	794.037500	0	--	--	--	--
5	794.050000	0	--	--	--	--
6	794.062500	0	--	--	--	--
7	794.075000	0	--	--	--	--
8	794.087500	0	--	--	--	--
9	794.100000	0	--	--	--	--
10	794.112500	0	--	--	--	--
11	794.125000	0	--	--	--	--
12	794.137500	0	--	--	--	--
13	794.150000	0	--	--	--	--
14	794.162500	0	--	--	--	--
15	794.175000	0	--	--	--	--
16	794.187500	0	--	--	--	--
17	794.200000	0	--	--	--	--
18	794.212500	0	--	--	--	--
19	794.225000	0	--	--	--	--
20	794.237500	0	--	--	--	--
21	794.250000	0	--	--	--	--
22	794.262500	0	--	--	--	--
23	794.275000	0	--	--	--	--
24	794.287500	0	--	--	--	--
25	794.300000	0	--	--	--	--
26	794.312500	0	--	--	--	--
27	794.325000	0	--	--	--	--
28	794.337500	0	--	--	--	--

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