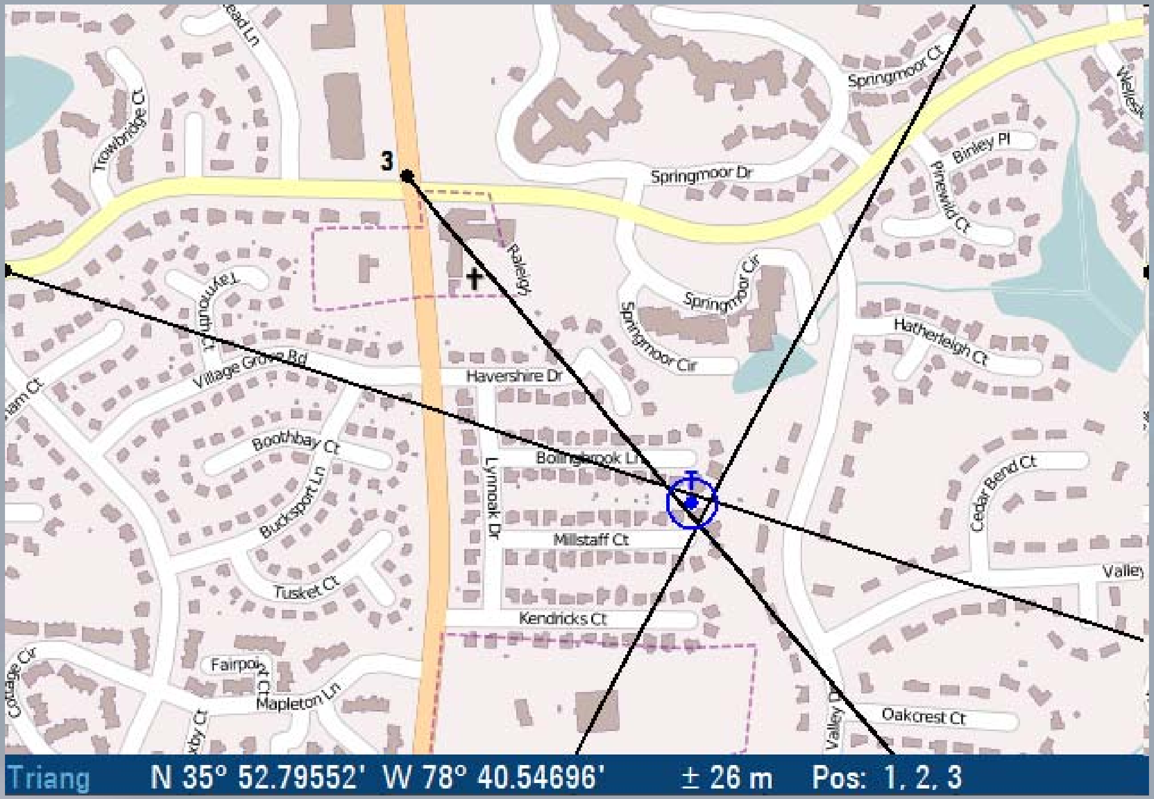
A comparison of radio direction-finding technologies



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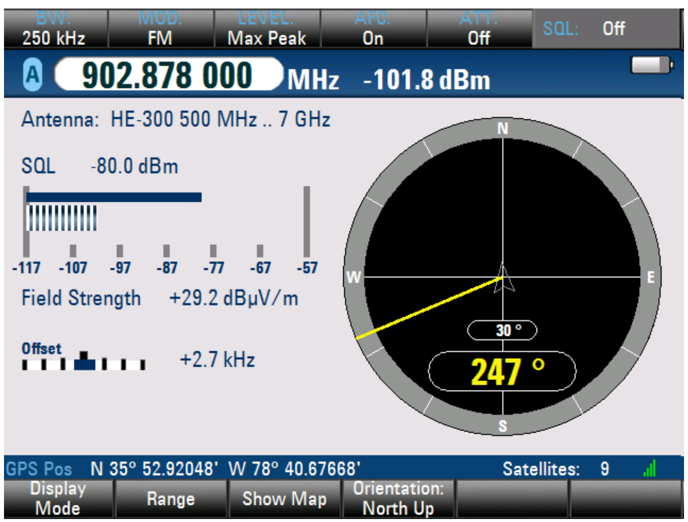
Topics

- General introduction to radiolocation
- Manual DF techniques
- Doppler DF
- Time difference of arrival
- Watson-Watt
- Correlative interferometry



General introduction to radiolocation

- Spectrum is becoming more and more crowded.
- More transmitters means more potential interference.
- More mobile devices – stationary transmitters are no longer the norm.
- Spectrum clearing not always 100% effective.
- Radiolocation / direction finding is used to determine the geographical location of a signal.
- If an interfering signal cannot be identified via demodulation or signal analysis, radiolocation may be the only way to identify it.

Manual techniques

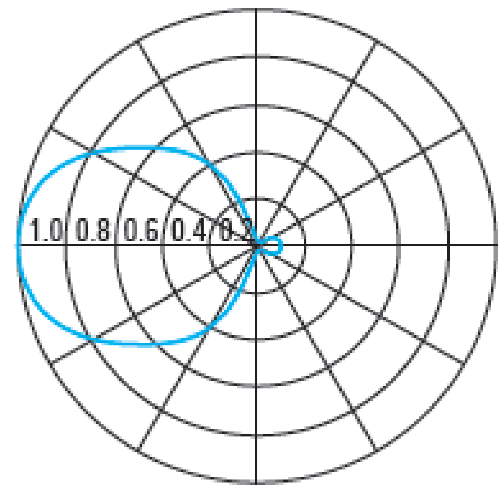
- Manual direction finding involves the use of a receiver and hand-held directional antenna : usually some type of yagi / log-periodic.
- The antenna is moved / rotated until the point of maximum signal strength is determined, most often based on received signal amplitude.
- Rotation can also be performed using an antenna mounted on a rotor or swivel.
- Accuracy decreases rapidly as distance to source increases.

Manual DF methodologies

- Two main ways in which manual DF is used
  - Bearing lines : antenna is used to determine a line of bearing to the signal source. Multiple lines are plotted and used to triangulate the transmitter's location
  - Final approach : when the source has been narrowed down to ~100 meters, manual DF is often the most effective (or only) way to find the precise location. Antenna is used to sweep or test possible locations in the suspect area.

Practical considerations

- Low-cost, no need for dedicated DF receiver.
- Portable, can be done in almost any location (rooftops, in buildings, etc.) with minimal setup time.
- Effectiveness depends strongly on the skill level of the operator.
- Difficult when dealing with short duration or frequency-agile signals.
- Accuracy may be poor for objects more than several hundred meters away.
- Important to have an antenna with both sufficient directivity and acceptable bandwidth.



Typical gain pattern of a handheld DF antenna – note the directivity

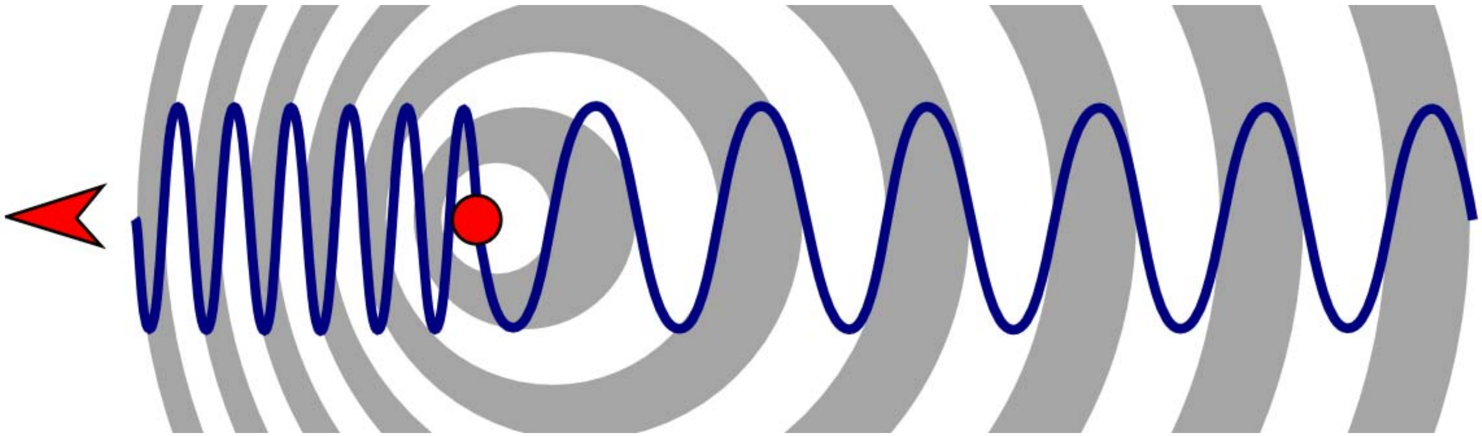
A Doppler Shift refresher

Christian Doppler (1803-1853)

- The Doppler shift or Doppler effect is named after Christian Doppler, who described it in 1842.
- Doppler shift is a type of frequency modulation.
- Relative motion of objects towards each other causes the observed frequency to increase. Relative motion away from each other causes a decrease in frequency.
- Doppler shift can be observed in the audio frequency domain (a passing train) and the visible energy domain (red shift of stars moving away from Earth).
- In the radio frequency domain it can be used for direction finding.

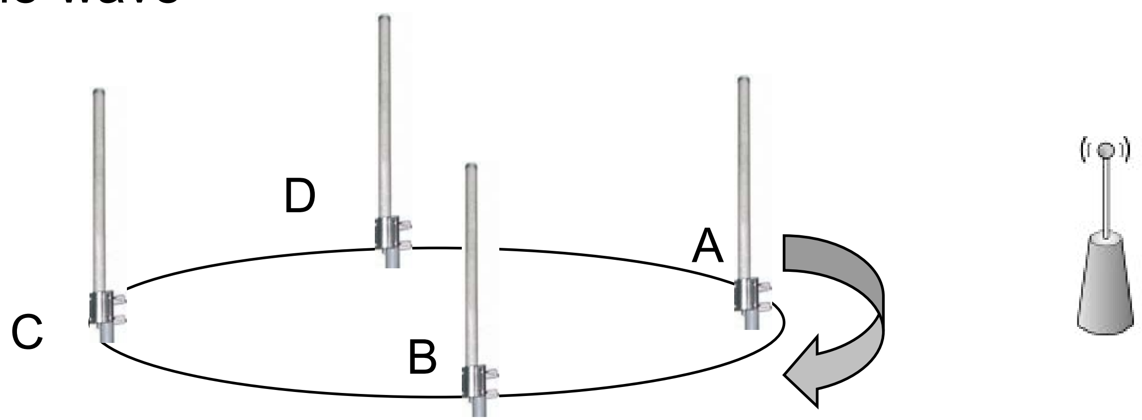
Using Doppler shift for DF

- 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.
- What we want is a method for moving the DF receiver relative to the transmitter so that we can measure the Doppler shift.
- But how do we do this if the DF receiver is not in motion?



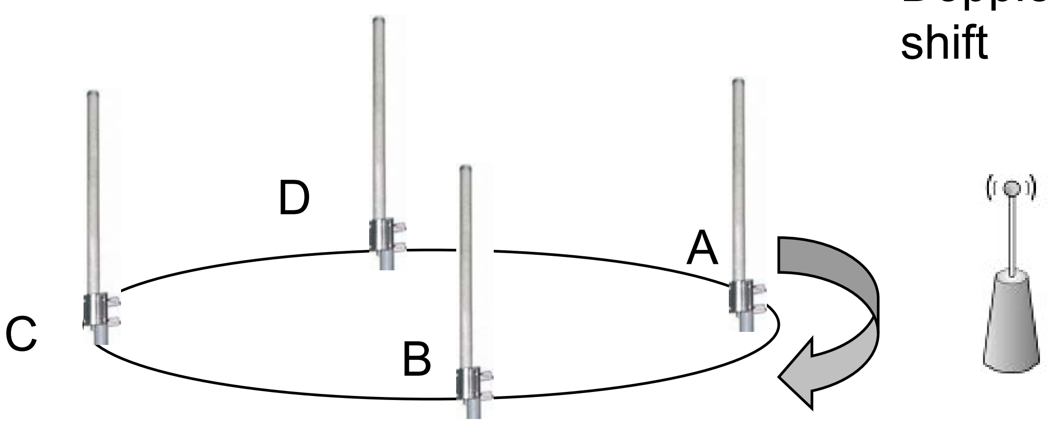
Simple rotating antenna

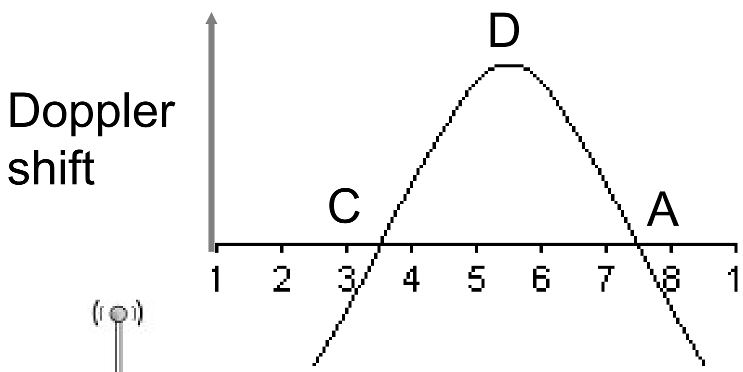
- Imagine we have a single antenna mounted on a rotating disk.
- As this disk is rotated, the antenna will move closer to and then further away from the transmitter.
- At positions A and C, the antenna is stationary relative to the transmitter, so Doppler shift = 0
- At position B (moving away) and D (moving towards), Doppler shift will be maximum.
- Continuous measurements of Doppler shift will yield a so-called Doppler sine-wave



Doppler sine wave

- By making frequency shift measurements as we go around the wheel (so to speak), we get a Doppler sine wave with two zero crossings at A and C, i.e. where there is no Doppler shift.
- The second zero crossing (downwards slope) is the point closest to the transmitter.
- This sine wave has the same frequency as the rotational frequency (ω) of the antenna.





Implementing the antenna

- An antenna on a rotating disk is not practical (required rotational speed is far too high).
- To simulate a rotating disk, Doppler DF switches sequentially between a set of 4 or 8 antennas
- Each antenna generates a series of Doppler pulses and the system uses them to synthesize the Doppler sine wave.
- To produce sufficient Doppler shift, the switching between the antennas must be very fast.

Displaying the results

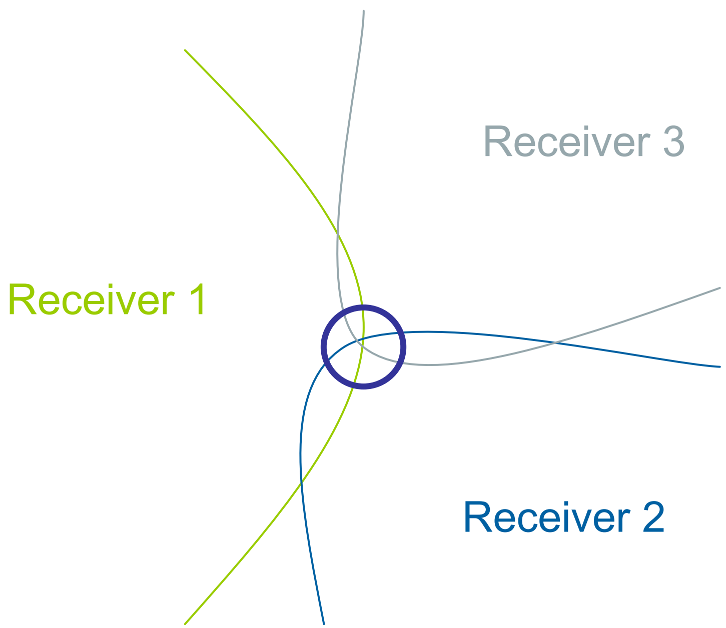
- A Doppler DF display usually consists of a circle of LED's which show the relative bearing to the signal source. It may also output a numeric bearing.

Practical considerations

- Low cost compared to other DF systems.
- Uses commercial, off-the-shelf receivers (e.g. Icom, AOR).
- Require a constant (CW) type signal. Not suitable for intermittent signals or broadband noise.
- Works while stationary or when moving.
- Best suited for VHF/UHF frequencies (< 1 GHz). Doesn't work well for horizontally polarized signals.

Time Difference of Arrival (TDOA)

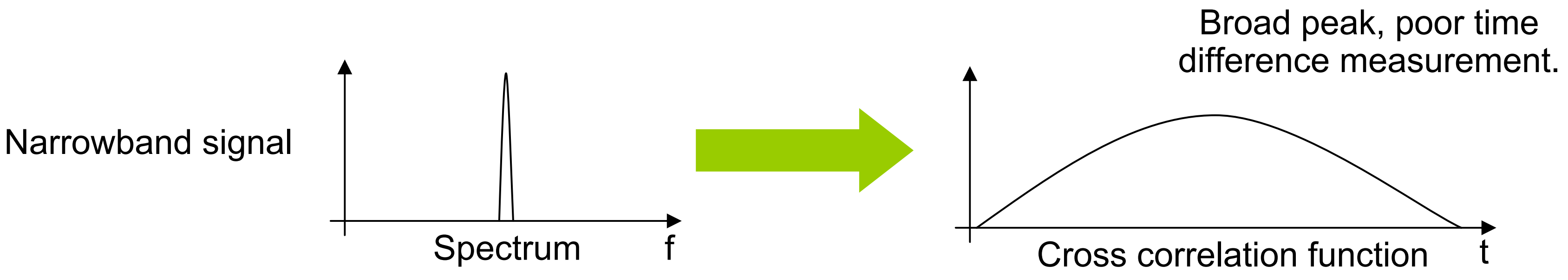
- Three or more receivers at different locations receive a signal from a transmitter of interest.
- Usually the paths between the transmitter and the receivers are of different length, so there are differences in the time of arrival at the different receiver locations.
- These differences can be measured by means of an accurate time reference (GPS).
- The time differences can be represented as hyperbolas which cross at the location of the transmitter of interest.



Intersection of hyperbolas gives estimated transmitter location

How TDOA works

- Digitized IF (IQ data) from all receive stations is transferred over data links to a master station (computer).
- Once the master station receives IF data from all receive stations a cross-correlation function for all stations is calculated.
- The time differences are thus used to calculate transmitter location.
- Note that TDOA does not work well with narrowband signals because the broad peak in the cross correlation function does not allow for an accurate time difference measurement.



TDOA Equipment

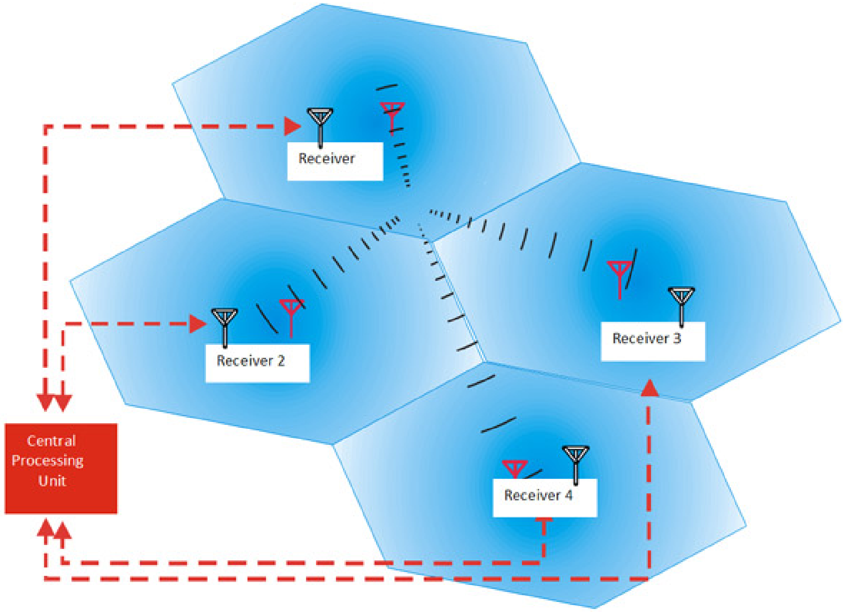
- Sensors can be used in a fixed (more common) or movable configuration.
- TDOA sensors are normally purpose-built devices : cannot normally be used as stand-alone receivers without the control computer.
- Sensors require network, power and GPS connections. Typically weatherized.
- TDOA sensors tend to be inexpensive, which means lower RF performance.

Location coverage and accuracy

- In practice good TDOA results typically are accurate to within several hundred meters.
- Outside the area surrounded by the TDOA receive stations the location accuracy can be very poor.
- In the diagram to the left, transmitter A is within the covered area of sensors Rx 1-3, whereas transmitter B is not within the covered area.
- Some pre-knowledge of the transmitter location is therefore essential when positioning TDOA sensors.

Practical considerations

- Simple stations : just a receiver and a standard antenna. Low profile.
- Relatively low cost, although setup time can be high.
- Accuracy is commonly on the order of a few hundred meters.
- A network of at least 3-4 stations is required .
- Most TDOA sensors are optimized for reduced size and price so they have limited RF performance and low immunity to strong signals.
- Poor location accuracy for narrowband signals.

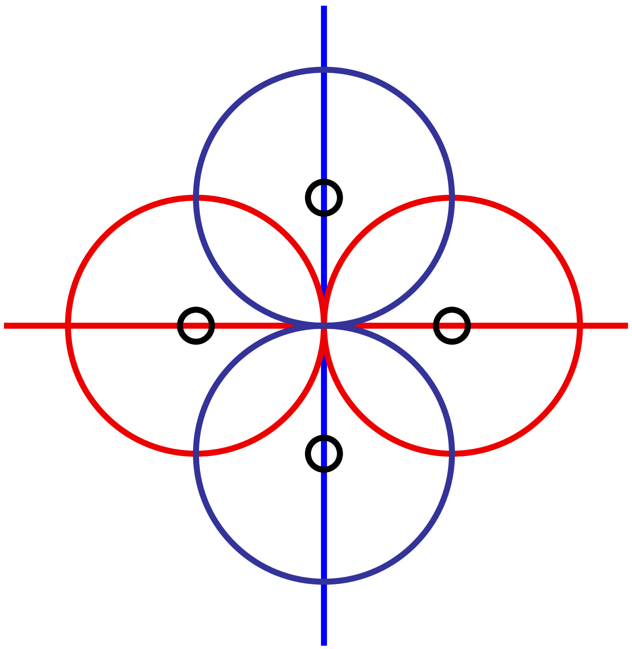


Overview of Watson-Watt

- Originally developed shortly after World War I and named after Sir Robert Alexander Watson-Watt, one of the inventors of radar.
- Watson-Watt is an amplitude comparison DF system. It uses Adcock (or crossed loop) antennas to compare the level of the signal received at each antenna. It then computes bearing based on the differences between them.
- Watson-watt describes the method of processing information obtained from an Adcock antenna.

Adcock antenna theory

- An Adcock antenna has four equally-spaced vertical elements. These four antennas (N, S, E, and W aerials) are arranged in pairs : the North-South axis and the East-West axis
- The results is two figure-eight shaped lobes, with maximum sensitivity along the axis and nulls perpendicular to the axis
- This creates a unique set of magnitudes for every direction due to the antenna pattern.
- An omnidirectional sense antenna can be used to resolve 180º ambiguities

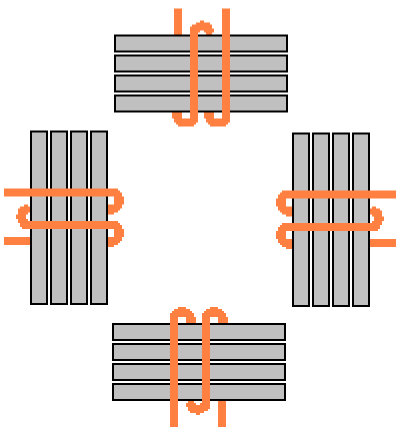


Adcock antenna implementation

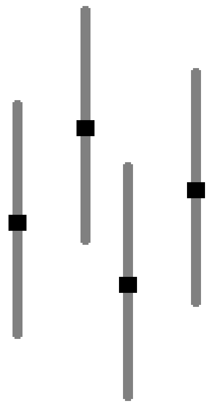
- Adcock antennas are typically be monopoles (where a ground plane is present, e.g. a vehicle roof) or dipoles (for pole/tower mounted applications).
- Spacing between aerials is a compromise between accuracy (closer together is better) and sensitivity (farther apart is better).
- In some cases, additional Adcock pairs can be used to lessen the effect of these constraints.

Many ways of making pairs

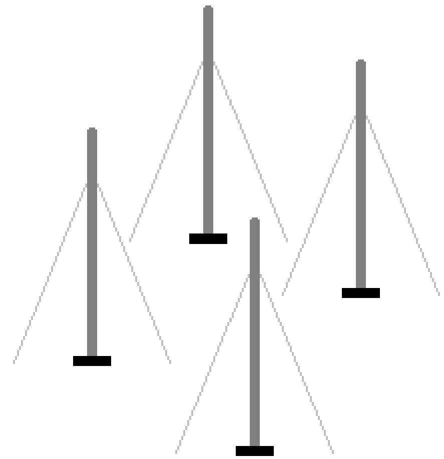
- Depending on size and frequency requirements, the Adcock pairs may be implemented in a variety of ways.



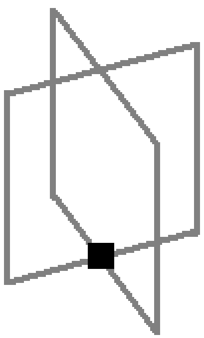
Crossed ferrite loops



Crossed dipole elements



Crossed monopole elements



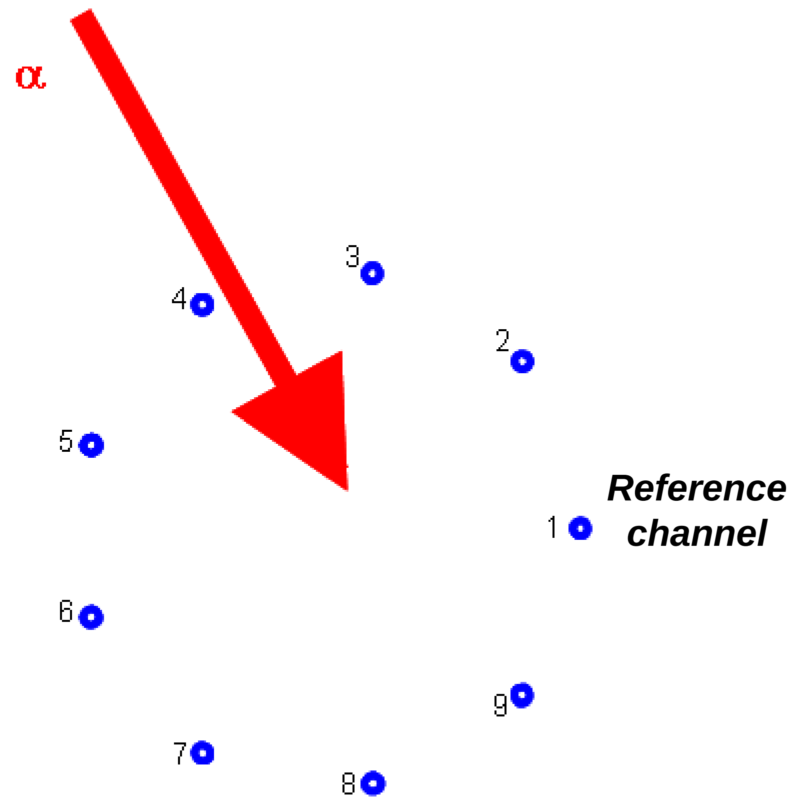
Crossed loops

Practical considerations

- Fast response time.
- High accuracy and sensitivity.
- Allows for small antennas, especially in the HF range.
- Narrow frequency range.
- Accuracy depends on the circularity of the antenna pattern.
- No measurement of elevation possible, and decreasing azimuth accuracy as transmitter elevation increases.

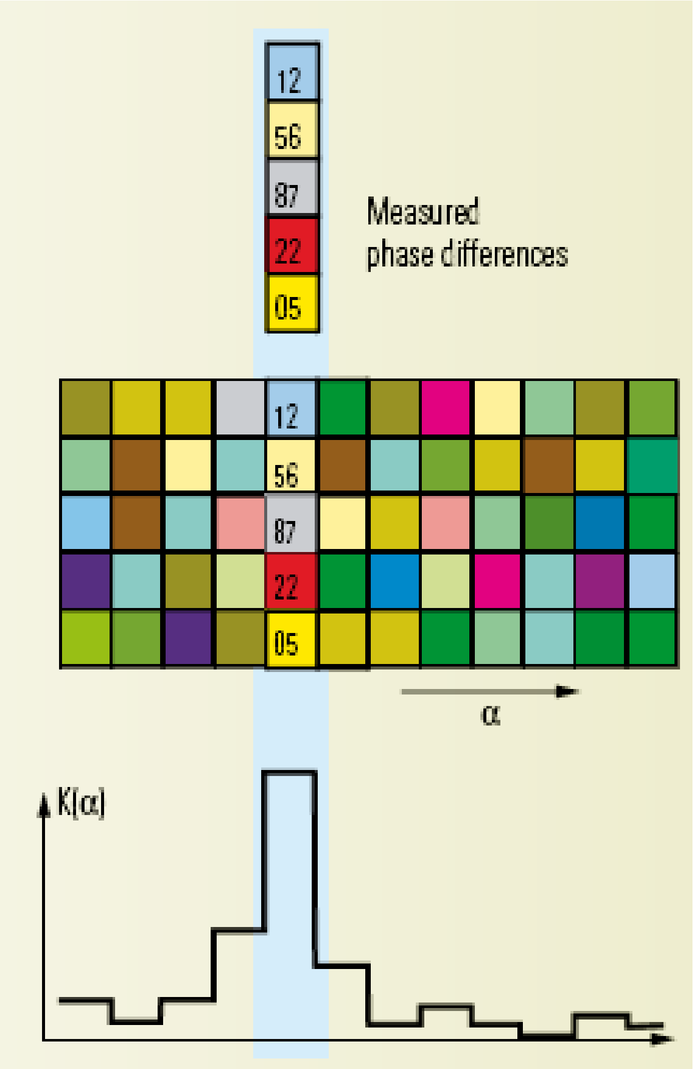
Correlative Interferometry

- Interferometry was first used in radio astronomy.
- Interferometers calculate bearings based on phase differences of the signal received at multiple co-located antenna elements.
- These antennas are normally arranged in a circular pattern with one antenna element serving as a reference channel.
- For each antenna element the phase difference relative to a reference element is calculated. This is typically done for each reference angle (0º to 360º) in increments of 1º.



Computing correlation

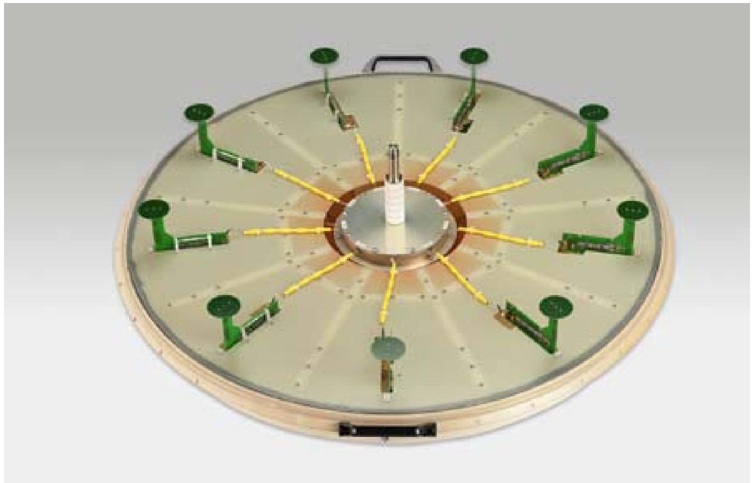
- In correlative interferometry we compare the *measured* phase differences with *reference* phase differences for the DF antenna at each wave angle.
- We move our column of measured phase angles through our matrix of reference phase angles and look for the value at which maximum correlation occurs.
- This value corresponds to the angle (α) of the incoming signal.



Implementation of CI antennas

- The number of elements in a CI antenna can vary, although commonly 5-9 elements are used.
- Elements are typically enclosed in a radome.
- Often incorporate a GPS/electronic compass for mobile use.

Practical consideration



Inside the radome of a 9-element correlative interferometer antenna

- Very high accuracy : less than 1º is typical.
- Higher immunity to reflections compared to other DF techniques.
- Measurement of elevation possible.
- For HF and low VHF, large antenna arrays needed to get a reasonable phase difference, therefore CI systems often incorporate Watson-Watt for lower frequency DF.
- Circular arrays can cover very large frequency ranges (> 1 GHz).

Concluding observations

- Effective use of a DF technology requires an understanding of its strengths and weaknesses.
- Need to balance sensitivity, accuracy, speed, bandwidth, complexity, and cost.
- In practical direction finding, more than one technology may be required, e.g. rough fix vs. last 100 meters.
- Integration with GPS, mapping, and other location technologies greatly reduces time and effort.

Questions / Discussion