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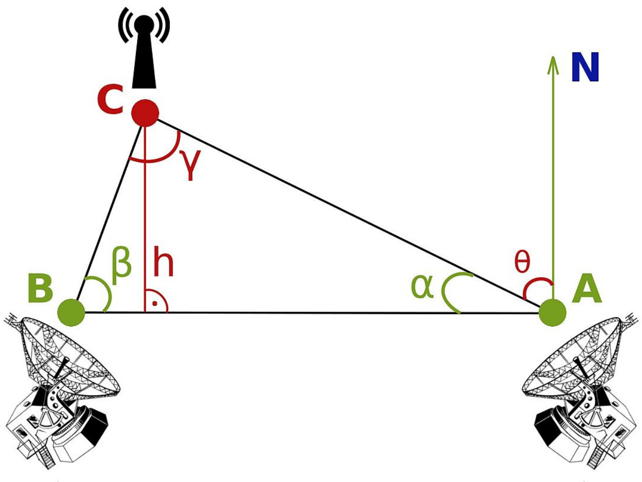
Direction finding

Direction finding (**DF**), or **radio direction finding** (**RDF**), refers to the measurement of the direction from which a received signal was transmitted. This can refer to radio or other forms of wireless communication. By combining the direction information from two or more suitably spaced receivers (or a single mobile receiver), the source of a transmission may be located in space via triangulation. Radio direction finding is used in the navigation of ships and aircraft, to locate emergency transmitters for search and rescue, for tracking wildlife, and to locate illegal or interfering transmitters.



Radiotriangulation scheme

RDF systems can be used with any radio source, although the size of the receiver antennas are a function of the wavelength of the signal - very long wavelengths (low frequencies) require very large antennas, and are generally used only on ground-based systems. These wavelengths are nevertheless very useful for marine radio navigation as they can travel very long distances "over the horizon", which is valuable for ships when the line-of-sight may be only a few tens of kilometres. For aerial use, where the horizon may extend to hundreds of kilometres, higher frequencies can be used, allowing the use of much smaller antennas. An automatic direction finder, which could be tuned to radio beacons called non-directional beacons or commercial AM radio broadcasters, was until recently, a feature of most aircraft, but is now being phased out

For the military, RDF is a key component of signals intelligence systems and methodologies. The ability to locate the position of an enemy broadcaster has been invaluable since World War I, and played a key role in World War II's Battle of the Atlantic. It is estimated that the UK's advanced "huff-duff" systems were directly or indirectly responsible for 24% of all U-Boats sunk during the war. Modern systems often used phased array antennas to allow rapid beamforming for highly accurate results, and are part of a larger electronic warfare suite.

Several distinct generations of RDF systems have been used over time, following the development of new electronics. Early systems used mechanically rotated antennas that compared signal strengths, and several electronic versions of the same concept followed. Modern systems use the comparison of phase or doppler techniques which are generally simpler to automate. Early British radar sets were referred to as RDF, which is often stated was a deception. In fact, the Chain Home systems used large RDF receivers to determine directions. Later radar systems generally used a single antenna for broadcast and reception, and determined direction from the direction the antenna was facing.

Antennas

Direction finding requires an antenna that is directional (more sensitive in certain directions than in others). Many antenna designs exhibit this property. For example, a Yagi antenna has quite pronounced directionality, so the source of a transmission can be determined simply by pointing it in the direction where the maximum signal level is obtained. However, to establish direction to great accuracy requires more sophisticated technique.

The crossed-loops DF antenna atop the mast of a tug boat

A simple form of directional antenna is the loop aerial. This consists of an open loop of wire on an insulating former, or a metal ring that forms the antenna elements itself, where the diameter of the loop is a tenth of a wavelength or smaller at the target frequency. Such an antenna will be *least* sensitive to signals that are normal to its face and *most* responsive to those meeting edge-on. This is caused by the phase output of the transmitting beacon. The phase changing phase causes a difference between the voltages induced on either side of the loop at any instant. Turning the loop face on will not induce any current flow. Simply turning the antenna to obtain minimum signal will establish two possible directions from which the signal could be emanating. The NULL is used, as small angular deflections of the loop aerial near its null positions produce larger changes in current than similar angular changes near the loops max positions. For this reason, a null position of the loop aerial is used.

To resolve the two direction possibilities, a sense antenna is used, the sense aerial has no directional properties but has the same sensitivity as the loop aerial. By adding the steady signal from the sense aerial to the alternating signal from the loop signal as it rotates, there is now only one position as the loop rotates 360° at which there is zero current. This acts as a phase ref point, allowing the correct null point to be identified, thus removing the 180° ambiguity. A dipole antenna exhibits similar properties, and is the basis for the Yagi antenna, which is familiar as the common VHF or UHF television aerial. For much higher frequencies still, parabolic antennas can be used, which are highly directional, focusing received signals from a very narrow angle to a receiving element at the centre.

More sophisticated techniques such as phased arrays are generally used for highly accurate direction finding systems called goniometers such as are used in signals intelligence (SIGINT). A helicopter based DF system was designed by ESL Incorporated for the U.S. Government as early as 1972.

See also: Radio direction finder

Single channel DF

The RDF antenna on this B-17F is located in the prominent teardrop housing under the nose.

Single-channel DF refers to the use of a multi-antenna array with a single channel radio receiver. This approach to DF obviously offers some advantages and drawbacks. Since it only uses one receiver, mobility and lower power consumption are obvious benefits but without the ability to look at each antenna simultaneously (which would be the case if one were to use multiple receivers, also known as N-channel DF) more complex operations need to occur at the antenna in order to present the signal to the receiver.

The two main categories that a single channel DF algorithm falls into are *amplitude comparison* and *phase comparison*. Some algorithms can be hybrids of the two.

Pseudo-doppler DF technique

The pseudo-doppler technique is a phase based DF method that produces a bearing estimate on the received signal by measuring the doppler shift induced on the signal by sampling around the elements of a circular array. The original method used a single antenna that physically moved in a circle but the modern approach uses a multi-antenna circular array with each antenna sampled in succession.

Watson-Watt / Adcock antenna array

Main article: Adcock antenna

The Watson-Watt technique uses two Adcock antenna pairs to perform an amplitude comparison on the incoming signal. An Adcock antenna pair is a pair of monopole or dipole antennas that takes the vector difference of the received signal at each antenna so that there is only one output from the pair of antennas. Two of these pairs are co-located but perpendicularly oriented to produce what can be referred to as the N-S (North-South) and E-W (East-West) signals that will then be passed to the receiver. In the receiver, the bearing angle can then be computed by taking the arctangent of the ratio of the N-S to E-W signal.

Correlative interferometer

The basic principle of the correlative interferometer consists in comparing the measured phase differences with the phase differences obtained for a DF antenna system of known configuration at a known wave angle (reference data set). The comparison is made for different azimuth values of the reference data set, the bearing is obtained from the data for which the correlation coefficient is at a maximum. In case the DF antenna elements have a directional antenna pattern, the amplitude may be included in the comparison.

Usage

Radio navigation

Radio direction finding, *Radio direction finder*, or *RDF* was once the primary aviation navigational aid. (*Range and Direction Finding* was the abbreviation used to describe the predecessor to Radar.) Beacons were used to mark "airways" intersections and to define departure and approach procedures. Since the signal transmitted contains no information about bearing or distance, these beacons are referred to as *non-directional beacons*, or *NDB* in the aviation world. Starting in the 1950s, these beacons were generally replaced by the VOR system, in which the bearing to the navigational aid is measured from the signal itself; therefore no specialized antenna with moving parts is required. Due to relatively low purchase, maintenance and calibration cost, NDB's are still used to mark locations of smaller aerodromes and important helicopter landing sites.

A portable, battery operated GT-302 Accumatic automatic direction finder for marine use

Further information: Non-directional beacon

Similar beacons located in coastal areas are also used for maritime radio navigation, as almost every ship is (was) equipped with a direction finder (Appleyard 1988). Very few maritime radio navigation beacons remain active today (2008) as ships have abandoned navigation via RDF in favor of GPS navigation.

In the United Kingdom a radio direction finding service is available on 121.5 MHz and 243.0 MHz to aircraft pilots who are in distress or are experiencing difficulties. The service is based on a number of radio DF units located at civil and military airports and certain HM Coastguard stations. These stations can obtain a "fix" of the aircraft and transmit it by radio to the pilot.

Location of illegal, secret or hostile transmitters - SIGINT

See also: High frequency direction finding and SIGINT

In WW2 considerable effort was expended on identifying secret transmitters in the United Kingdom (UK) by direction finding. The work was undertaken by the Radio Security Service (RSS also MI8). Initially three U Adcock HF DF stations were set up in 1939 by the General Post Office. With the declaration of war, MI5 and RSS developed this into a larger network. One of the problems with providing coverage of an area the size of the UK was installing sufficient DF stations to cover the entire area to receive skywave signals reflected back from the ionised layers in the upper atmosphere. Even with the expanded network, some areas were not adequately covered and for this reason up to 1700 voluntary interceptors (radio amateurs) were recruited to detect illicit transmissions by ground wave. In addition to the fixed stations, RSS ran a fleet of mobile DF vehicles around the UK. If a transmitter was identified by the fixed DF stations or voluntary interceptors, the mobile units were sent to the area to home in on the source. The mobile units were HF Adcock systems.

By 1941 only a couple of illicit transmitters had been identified in the UK; these were German agents that had been 'turned' and were transmitting under MI5 control. Many illicit transmissions had been logged emanating from German agents in occupied and neutral countries in Europe. The traffic became a valuable source of intelligence, so the control of RSS was subsequently passed to MI6 who were responsible for secret intelligence originating from outside the UK. The direction finding and interception operation increased in volume and importance until 1945.

The HF Adcock stations consisted of four 10m vertical antennas surrounding a small wooden operators hut containing a receiver and a radio-goniometer which was adjusted to obtain the bearing. MF stations were also used which used four guyed 30m lattice tower antennas. In 1941 RSS began experimenting with Spaced Loop direction finders, developed by the Marconi company and the UK National Physical Laboratories. These consisted of two parallel loops 1 to 2m square on the ends of a rotatable 3 to 8m beam. The angle of the beam was combined with results from a radiogoniometer to provide a bearing. The bearing obtained was considerably sharper than that obtained with the U Adcock system, but there were ambiguities which prevented the installation of 7 proposed S.L DF systems. The operator of an SL system was in a metal underground tank below the antennas. Seven underground tanks were installed, but only two SL systems were installed at Wymondham, Norfolk and Weaverthorp in Yorkshire. Problems were encountered resulting in the remaining five underground tanks being fitted with Adcock systems. The rotating SL antenna was turned by hand which meant successive measurements were a lot slower than turning the dial of a goniometer.

Another experimental spaced loop station was built near Aberdeen in 1942 for the Air Ministry with a semi-underground concrete bunker. This, too, was abandoned because of operating difficulties. By 1944 a mobile version of the spaced loop had been developed and was used by RSS in France following the D-Day invasion of Normandy.

The US military used a shore based version of the spaced loop DF in WW2 called "DAB". The loops were placed at the ends of a beam, all of which was located inside a wooden hut with the electronics in a large cabinet with cathode ray tube display at the centre of the beam and everything being supported on a central axis. The beam was rotated manually by the operator.

The Royal Navy introduced a variation on the shore based HF DF stations in 1944 to track U-boats in the North Atlantic. They built groups of five DF stations, so that bearings from individual stations in the group could be combined and a mean taken. Four such groups were built in Britain at Ford End, Essex, Goonhavern, Cornwall, Anstruther and Bowermadden in the Scottish Highlands. Groups were also built in Iceland, Nova Scotia and Jamaica. The anticipated improvements were not realised but later statistical work improved the system and the Goonhavern and Ford End groups continued to be used during the Cold War. The Royal Navy also deployed direction finding equipment on ships tasked to anti-submarine warfare in order to try to locate German submarines, e.g. Captain class frigates were fitted with a medium frequency direction finding antenna (MF/DF) (the antenna was fitted in front of the bridge) and high frequency direction finding (HF/DF, "Huffduff") Type FH 4 antenna (the antenna was fitted on top of the mainmast).[1]

Arguably the most comprehensive reference on WW2 wireless direction finding was written by Roland Keen who was head of the engineering department of RSS at Hanslope Park. The DF systems mentioned here are described in detail in his exhaustive treatment of the subject in the 1947 edition of his book "Wireless Direction Finding".

At the end of WW2 a number of RSS DF stations continued to operate into the cold war under the control of GCHQ the British SIGINT organisation.

Most direction finding effort within the UK now (2009) is directed towards locating unauthorised 'pirate' FM broadcast radio transmissions. A network of remotely operated VHF direction finders are used mainly located around the major cities. The transmissions from mobile telephone handsets are also located by a form of direction finding using the comparative signal strength at the surrounding local 'cell' receivers. This technique is often offered as evidence in UK criminal prosecutions and, almost certainly, for SIGINT purposes.

Emergency aid

Main article: Radio direction finder

There are many forms of radio transmitters designed to transmit as a beacon in the event of an emergency, which are widely deployed on civil aircraft. Modern emergency beacons transmit a unique identification signal that can aid in finding the exact location of the transmitter.

Avalanche rescue

Avalanche transceivers operate on a standard 457 kHz, and are designed to help locate people and equipment buried by avalanches. Since the power of the beacon is so low the directionality of the radio signal is dominated by small scale field effects and can be quite complicated to locate.

Wildlife tracking

Location of radio-tagged animals by triangulation is a widely applied research technique for studying the movement of animals. The technique was first used in the early 1960s, when the technology used in radio transmitters and batteries made them small enough to attach to wild animals, and is now widely deployed for a variety of wildlife studies. Most tracking of wild animals that have been affixed with radio transmitter equipment is done by a field researcher using a handheld radio direction finding device. When the researcher wants to locate a particular animal, the location of the animal can be triangulated by determining the direction to the transmitter from several locations.

Reconnaissance

Phased arrays and other advanced antenna techniques are utilized to track launches of rocket systems and their resulting trajectories. These systems can be used for defensive purposes and also to gain intelligence on operation of missiles belonging to other nations. These same techniques are used for detection and tracking of conventional aircraft.

Sport

Main article: Amateur Radio Direction Finding

Events hosted by groups and organizations that involve the use of radio direction finding skills to locate transmitters at unknown locations have been popular since the end of World War II. Many of these events were first promoted in order to practice the use of radio direction finding techniques for disaster response and civil defense purposes, or to practice locating the source of radio frequency interference. The most popular form of the sport, worldwide, is known as Amateur Radio Direction Finding or by its international abbreviation ARDF. Another form of the activity, known as "transmitter hunting", "mobile T-hunting" or "fox hunting" takes place in a larger geographic area, such as the metropolitan area of a large city, and most participants travel in motor vehicles while attempting to locate one or more radio transmitters with radio direction finding techniques.

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Notes

[1] Elliott (1972), p. 264

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Radio direction finder

Amelia Earhart's Lockheed Model 10 Electra with the circular *RDF* aerial visible above the cockpit

A **radio direction finder** (**RDF**) is a device for finding the direction to a radio source. The basic idea is to use two or more measurements of the same signal, and then use slight differences between the measurements to determine the direction of the source. Several distinct generations of RDF systems have been used over time, following the development of new electronics. Early systems used mechanically rotated antennas that compared signal strengths in different directions, and several electronic versions of the same concept followed. Modern systems use the comparison of phase or doppler techniques which are generally simpler to automate.

RDF systems can be used with any radio source, although the size of the receiver antennas are a function of the wavelength of the signal - very long wavelengths (low frequencies) require very large antennas, and are generally used only on ground-based systems. These wavelengths are nevertheless very useful for marine navigation as they can travel very long distances and "over the horizon", which is valuable for ships when the line-of-site may be only a few tens of kilometres. For aerial use, where the horizon may extend to hundreds of kilometres, higher frequencies can be used, allowing the use of much smaller antennas. An automatic direction finder, often tuned to commercial AM radio broadcasters, is a feature of almost all modern aircraft.

For the military, RDF systems are a key component of signals intelligence systems and methodologies. The ability to locate the position of an enemy broadcaster has been invaluable since World War I, and play a key role in World War II's Battle of the Atlantic. It is estimated that the UK's advanced "huff-duff" systems were directly or indirectly responsible for 24% of all U-Boats sunk during the war. Modern systems often used phased array antennas to allow rapid beam shaping for highly accurate results. These are generally integrated into a wider electronic warfare suite.

Early British radar sets were referred to as RDF, which is often stated was a deception. In fact, the Chain Home systems used separate omni-directional broadcasters and large RDF receivers - in effect, the Chain Home system was performing RDF on its own signals. Later radar systems generally used a single antenna for broadcast and reception, and determined direction from the direction the antenna was facing.

History

Early mechanical systems

The earliest experiments in RDF were carried out in 1888 when Heinrich Hertz discovered the directionality of an open loop of wire used as an antenna. When the antenna was aligned so it pointed at the signal it produced maximum gain, and produced zero signal when "face on". This meant there was always an ambiguity in the location of the signal, it would produce the same output if the signal was in front or back of the antenna. Later experimenters also used dipole antennas, which worked in the opposite sense, reaching maximum gain at right angles and zero when aligned. RDF systems using mechanically swung loop or dipole antennas were common by the turn of the 20th century. Prominent examples were patented by John Stone Stone in 1902 (U.S. Patent 716,134) and Lee de Forest in 1904 (U.S. Patent 771,819), among many other examples. These systems generally shared the limitation that they were very large, and were generally found only in ground-based installations, or short-range examples on ships.

Bellini-Tosi

A key improvement in the RDF concept was introduced by Ettore Bellini and Alessandro Tosi in 1909 (U.S. Patent 943,960). Their system used two such antennas, typically triangular loops, arranged at right angles. The signals from the antennas were sent into coils wrapped around a wooden frame about the size of a pop can, where the signals were re-created in the area between the coils. A separate loop antenna located in this area could then be used to hunt for the direction, without moving the main antennas. This made RDF so much more practical that it was soon being used for navigation on a wide scale, often as the first form of aerial navigation available, with ground stations homing in on the aircraft's radio set. Bellini-Tosi direction finders were widespread from the 1920s into the 1950s.

Early RDF systems were useful largely for long wave signals. These signals are able to travel very long distances, which made them useful for long-range navigation. However, when the same technique was being applied to higher frequencies, unexpected difficulties arose due to the reflection of high frequency signals from the ionosphere. The RDF station might now receive the same signal from two or more locations, especially during the day, which caused serious problems trying to determine the location. This led to the 1919 introduction of the Adcock antenna (UK Patent 130,490), which consisted of four separate monopole antennas instead of two loops, eliminating the horizontal components and thus filtering out the "sky waves" being reflected down from the ionosphere. Adcock antennas were widely used with Bellini-Tosi detectors from the 1920s on.

The US Army Air Corps in 1931 tested a primitive radio compass that used commercial stations as the beacon.[1]

Huff-duff

A major improvement in the RDF technique was introduced by Robert Watson-Watt as part of his experiments to locate lightning strikes as a method to indicate the direction of thunderstorms to sailors and airmen. He had long worked with conventional RDF systems, but these were difficult to use with the fleeting signals from the lightning. He had early on suggested the use of an oscilloscope to display these near instantly, but was unable to find one while working at the Met Office. When the office was moved, his new location at a radio research station provided him with both an Adcock antenna and a suitable oscilloscope, and he presented his new system in 1926.

In spite of the system being presented publicly, and widely used, its impact on the art of RDF seems to be strangely subdued. Development was limited until the mid-1930s, when the various British forces began widespread development and deployment of these "high-frequency direction finding", or "huff-duff" systems. The Germans had developed a method of broadcasting short messages under 30 seconds, less that the 60 seconds that a trained Bellini-Tosi operator would need to determine the direction. However, this was useless against huff-duff systems, which located the signal with reasonable accuracy in seconds. The Germans did not become aware of this problem until the middle of the war, and did not take any serious steps to address it until 1944. By that time huff-duff had helped in about one-quarter of all successful attacks on the U-boat fleet.

Post-war systems

Several developments in electronics during and after the war led to greatly improved methods of comparing the phase of signals. In addition, the phase-locked loop (PLL) allowed for easy tuning in of signals, which wouldn't drift. Finally, improved vacuum tubes and the introduction of the transistor allowed much higher frequencies to be used economically, with led to widespread use of VHF and UHF signals. All of these changes led to new methods of RDF, and much more widespread use.

In particular, the ability to compare the phase of signals led to phase-comparison RDF, which is perhaps the most widely used technique today. In this system the loop antenna is replaced with a single square-shaped ferrite core, with loops wound around two perpendicular sides. Signals from the loops are sent into a phase comparison circuit, who's output phase directly indicates the direction of the signal. By sending this to any manner of display, and locking the signal using PLL, the direction to the broadcaster can be continuously displayed. Operation consists solely of tuning in the station, and is so automatic that these systems are normally referred to as automatic direction finder.

Other systems have been developed where more accuracy is required. pseudo-doppler radio direction finder systems use a series of small dipole antennas arranged in a ring and use electronic switching to rapidly select pairs of dipoles to feed into the receiver. The resulting signal is processed and produces an audio tone, who's frequency is dependant on the direction of the signal. Doppler RDF systems have widely replaced the huff-duff system for location of fleeting signals, as it does not require an oscilloscope.

Operation

Radio Direction Finding works by comparing the signal strength of a directional antenna pointing in different directions. At first, this system was used by land and marine-based radio operators, using a simple rotatable loop antenna linked to a degree indicator. This system was later adopted for both ships and aircraft, and was widely used in the 1930s and 1940s. On pre-World War II aircraft, RDF antennas are easy to identify as the circular loops mounted above or below the fuselage. Later loop antenna designs were enclosed in an aerodynamic, teardrop-shaped fairing. In ships and small boats, RDF receivers first employed large metal loop antennas, similar to aircraft, but usually mounted atop a portable battery-powered receiver.

World War II US Navy high frequency radio direction finder

In use, the RDF operator would first tune the receiver to the correct frequency, then manually turn the loop, either listening or watching an S meter to determine the direction of the *null* (the direction at which a given signal is weakest) of a long wave (LW) or medium wave (AM) broadcast beacon or station (listening for the null is easier than listening for a peak signal, and normally produces a more accurate result). This null was symmetrical, and thus identified both the correct degree heading marked on the radio's compass rose as well as its 180-degree opposite. While this information provided a baseline from the station to the ship or aircraft, the navigator still needed to know beforehand if he was to the east or west of the station in order to avoid plotting a course 180-degrees in the wrong direction. By taking bearings to two or more broadcast stations and plotting the intersecting bearings, the navigator could locate the relative position of his ship or aircraft.

Later, RDF sets were equipped with rotatable ferrite loopstick antennas, which made the sets more portable and less bulky. Some were later partially automated by means of a motorized antenna (ADF). A key breakthrough was the introduction of a secondary vertical whip or 'sense' antenna that substantiated the correct bearing and allowed the navigator to avoid plotting a bearings 180 degrees opposite the actual heading. After World War II, there were many small and large firms making direction finding equipment for mariners, including Apelco, Aqua Guide, Bendix, Gladding (and its marine division, Pearce-Simpson), Ray Jefferson, Raytheon, and Sperry. By the 1960s, many of these radios were actually made by Japanese electronics manufacturers, such as Panasonic, Fuji Onkyo, and Koden Electronics Co., Ltd. In aircraft equipment, Bendix and Sperry-Rand were two of the larger manufacturers of RDF radios and navigation instruments.

Usage in maritime and aircraft navigation

Radio transmitters for air and sea navigation are known as *beacons* and are the radio equivalent to a lighthouse. The transmitter sends a Morse Code transmission on a Long wave (150 – 400 kHz) or Medium wave (520 – 1720 kHz) frequency incorporating the station's identifier that is used to confirm the station and its operational status. Since these radio signals are broadcast in all directions (omnidirectional) during the day, the signal itself does not include direction information, and these beacons are therefore referred to as non-directional beacons, or **NDBs**.

Historic advertisement for Kolster radio compass

As the commercial medium wave broadcast band lies within the frequency capability of most RDF units, these stations and their transmitters can also be used for navigational fixes. While these commercial radio stations can be useful due to their high power and location near major cities, there may be several miles between the location of the station and its transmitter, which can reduce the accuracy of the 'fix' when approaching the broadcast city. A second factor is that some AM radio stations are omnidirectional during the day, and switch to a reduced power, directional signal at night.

RDF was once the primary form of aircraft and marine navigation. Strings of beacons formed "airways" from airport to airport, while marine NDBs and commercial AM broadcast stations provided navigational assistance to small watercraft approaching a landfall. In the United States, commercial AM radio stations were required to broadcast their station identifier once per hour for use by pilots and mariners as an aid to navigation. In the 1950s, aviation NDBs were augmented by the VOR system, in which the direction to the beacon can be extracted from the signal itself, hence the distinction with non-directional beacons. Use of marine NDBs was largerly supplanted in North America by the development of LORAN in the 1970s.

Today many NDBs have been decommissioned in favor of faster and far more accurate GPS navigational systems. However the low cost of ADF and RDF systems, and the continued existence of AM broadcast stations (as well as navigational beacons in countries outside North America) has allowed these devices to continue to function, primarily for use in small boats, as an adjunct or backup to GPS.

Automatic direction finder (ADF)

An **automatic direction finder** (**ADF**) is a marine or aircraft radio-navigation instrument that automatically and continuously displays the relative bearing from the ship or aircraft to a suitable radio station. ADF receivers are normally tuned to aviation or marine NDBs operating in the LW band between 190 – 535 kHz. Like RDF units, most ADF receivers can also receive medium wave (AM) broadcast stations, though as mentioned, these are less reliable for navigational purposes.

The operator tunes the ADF receiver to the correct frequency and verifies the identity of the beacon by listening to the Morse code signal transmitted by the NDB. On marine ADF receivers, the motorized ferrite-bar antenna atop the unit (or remotely mounted on the masthead) would rotate and lock when reaching the null of the desired station. A centerline on the antenna unit moving atop a compass rose indicated in degrees the bearing of the station. On aviation ADFs, the unit automatically moves a compass-like pointer (RMI) to show the direction of the beacon. The pilot may use this pointer to *home* directly towards the beacon, or may also use the magnetic compass and calculate the direction from the beacon (the *radial*) at which their aircraft is located.

Unlike the RDF, the ADF operates without direct intervention, and continuously displays the direction of the tuned beacon. Initially, all ADF receivers, both marine and aircraft versions, contained a rotating loop or ferrite loopstick aerial driven by a motor which was controlled by the receiver. Like the RDF, a sense antenna verified the correct direction from its 180-degree opposite.

More modern aviation ADFs contain a small array of fixed aerials and use electronic sensors to deduce the direction using the strength and phase of the signals from each aerial. The electronic sensors listen for the *trough* that occurs when the antenna is at right angles to the signal, and provide the heading to the station using a direction indicator. In flight, the ADF's RMI or direction indicator will always point to the broadcast station regardless of aircraft heading, however a banked attitude can have a slight effect on the reading, the needle will still generally indicate towards the beacon, however it suffers from DIP error where the needle dips down in the direction of the turn.Wikipedia:Please clarify Such receivers can be used to determine current position, track inbound and outbound flight path, and intercept a desired bearing. These procedures are also used to execute holding patterns and non-precision instrument approaches.

Typical NDB services ranges

Class of NDB	Transmission Power	Effective Range
Locator	below 25 watts	15 NM
MH	below 50 watts	25 NM
H	50 to 1,999 watts	50 NM
HH	2,000+ watts	75 NM

Station passage

As an aircraft nears an NDB station, the ADF becomes increasingly sensitive, small lateral deviations result in large deflections of the needle which sometimes shows erratic left/right oscillations. Ideally, as the aircraft overflies the beacon, the needle swings rapidly from directly ahead to directly behind. This indicates *station passage* and provides an accurate position fix for the navigator. Less accurate station passage, passing slightly to one side or another, is shown by slower (but still rapid) swinging of the needle. The time interval from the first indications of station proximity to positive station passage varies with altitude — a few moments at low levels to several minutes at high altitude.

Homing

The ADF may be used to *home* in on a station. Homing is flying the aircraft on the heading required to keep the needle pointing directly to the 0° (straight ahead) position. To home into a station, tune the station, identify the Morse code signal, then turn the aircraft to bring the ADF azimuth needle to the 0° position. Turn to keep the ADF heading indicator pointing directly ahead. Homing is regarded as poor piloting technique because the aircraft may be blown significantly or dangerously off-course by a cross-wind, and will have to fly further and for longer than the direct track.

Tracking

The ADF may also be used to *track* a desired course using an ADF and allowing for winds aloft, winds which may blow the aircraft off-course. Good pilotage technique has the pilot calculate a correction angle that exactly balances the expected crosswind. As the flight progresses, the pilot monitors the direction to or from the NDB using the ADF, adjusts the correction as required. A direct track will yield the shortest distance and time to the ADF location.

Radio-magnetic indicator (RMI)

A **radio-magnetic indicator** (**RMI**) is an alternate ADF display providing more information than a standard ADF. While the ADF shows relative angle of the transmitter with respect to the aircraft, an RMI display incorporates a compass card, actuated by the aircraft's compass system, and permits the operator to read the magnetic bearing to or from the transmitting station, without resorting to arithmetic.

An aircraft RMI

Most RMI incorporate two direction needles. Often one needle (thin or single-barred) is connected to an ADF and the other (generally the thicker, double-barred needle) is connected to a VOR. Using multiple indicators, a navigator can accurately fix the position of their aircraft without requiring station passage. There is great variation between models, and the operator must take care that their selection displays information from the appropriate ADF and VOR.

Notes

[1] "Broadcast Station Can Guide Flyer", April 1931, Popular Science (http://books.google.com/books?id=8ycDAAAAMBAJ&pg=PA54&dq=Popular+Science+1931+plane&hl=en&ei=AQUHTY_IEtOhnQeK35jlDQ&sa=X&oi=book_result&ct=result&resnum=8&ved=0CEQQ6AEwBw#v=onepage&q=Popular Science 1931 plane&f=true)

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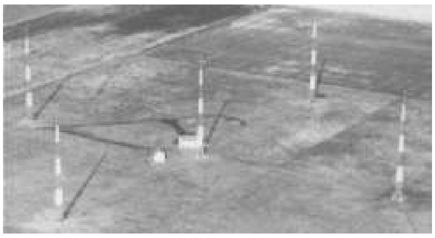
External links

- Flash based radio-magnetic indicator (RMI) simulator (http://www.luizmonteiro.com/Learning_RMI_Sim_1.aspx)

Adcock antenna

The **Adcock antenna** is an antenna (British English aerial) array consisting of four equidistant vertical elements which can be used to transmit or receive directional radio waves.



Adcock radio range ground station. Hundreds of these stations were deployed around the U.S. alone.

The Adcock array was invented and patented by British engineer Frank Adcock in 1919 as British Patent No. 130,490, and has been used for a variety of applications, both civilian and military, ever since.[1] Although originally conceived for receiving Low Frequency (LF) waves, it has also been used for transmitting, and has since been adapted for use at much higher frequencies, up to Ultra High Frequency (UHF).

In the early 1930s, the Adcock antenna (transmitting in the LF/MF bands) became a key feature of the newly created radio navigation system for aviation. The Low Frequency radio range (LFR) network, which consisted of hundreds of Adcock antenna arrays, defined the airways used by aircraft for instrument flying. The LFR remained as the main aerial navigation technology until it was replaced by the VOR system in the 1950s and 1960s.

The Adcock antenna array has been widely used commercially, and implemented in vertical antenna heights ranging from over 130 feet (40 meters) in the LFR network, to as small as 5 inches (13 cm) in tactical direction finding applications (receiving in the UHF band).

Radio direction finding

Frank Adcock originally used the antenna as a receiving antenna, to find the azmuthal direction a radio signal was coming from in order to find the location of the radio transmitter; a process called radio direction finding.

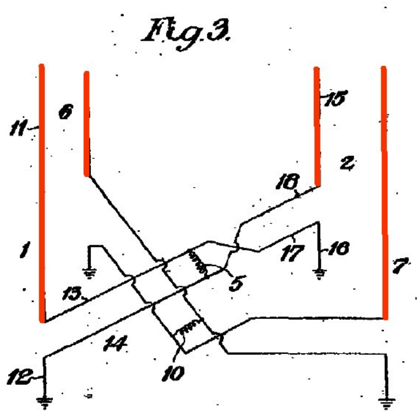


Diagram from Adcock's 1919 patent, depicting a four-element monopole antenna array; active antenna segments are marked in red.

Prior to Adcock's invention, engineers had been using loop antennas to achieve directional sensitivity. They discovered that due to atmospheric disturbances and reflections, the detected signals included significant components of electromagnetic interference and distortions: horizontally polarized radiation contaminating the signal of interest and reducing the accuracy of the measurement.

Adcock—who was serving as an Army officer in the British Expeditionary Force in wartime France at the time he filed his invention—solved this problem by replacing the loop antennas with symmetrically inter-connected pairs of vertical monopole or dipole antennas of equal length. This created the equivalent of square loops, but without their horizontal members, thus eliminating sensitivity to much of the horizontally polarized distortion. The same principles remain valid today, and the Adcock antenna array and its variants are still used for radio direction finding.

Low Frequency radio range

Main article: Low Frequency radio range

In the late 1920s, the Adcock antenna was adopted for aerial navigation, in what became known as the Low Frequency radio range (LFR), or the "Adcock radio range". Hundreds of transmitting stations, each consisting of four or five Adcock antenna towers,[2] were constructed around the U.S. and elsewhere.

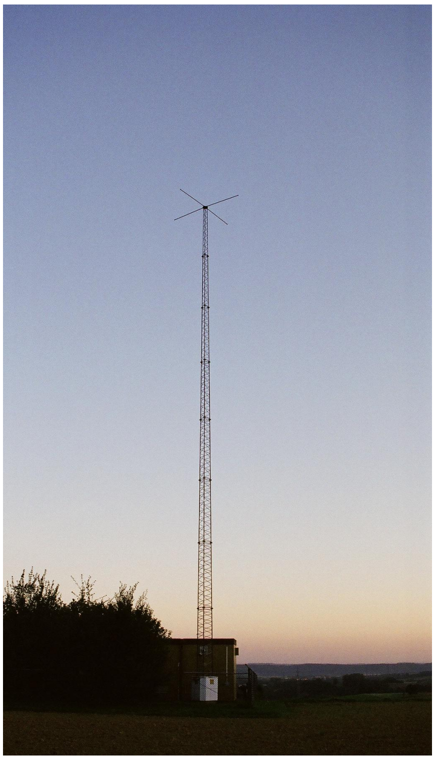
The result was a network of electronic airways, which allowed pilots to navigate at night and in poor visibility, under virtually all weather conditions. The LFR remained as the main aerial navigation system in the U.S. and other countries until the 1950s, when it was replaced by VHF-based VOR technology. By the 1980s all LFR stations were decommissioned.

References

[1] (Note: The patent lawyer's name appears as inventor, with "F. Adcock" in parentheses, since Lt. Adcock, RE was serving in wartime France at the time.)
[2] A fifth tower was often added in the center of the square for voice transmissions.

Non-directional beacon

A **non-directional (radio) beacon** (**NDB**) is a radio transmitter at a known location, used as an aviation or marine navigational aid. As the name implies, the signal transmitted does not include *inherent* directional information, in contrast to other navigational aids such as low frequency radio range, VHF omnidirectional range (VOR) and TACAN. NDB signals follow the curvature of the Earth, so they can be received at much greater distances at lower altitudes, a major advantage over VOR. However, NDB signals are also affected more by atmospheric conditions, mountainous terrain, coastal refraction and electrical storms, particularly at long range.

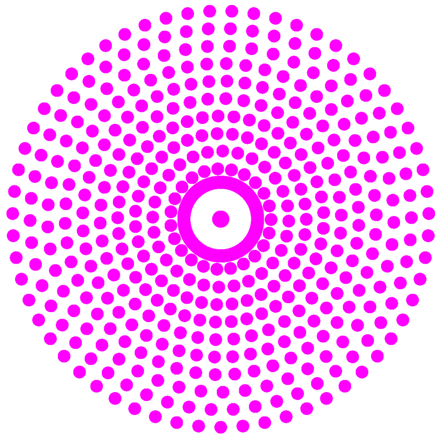


Radio Tower of NKR Leimen-Ochsenbach, Germany

NDBs used for aviation are standardised by ICAO Annex 10 which specifies that NDBs be operated on a frequency between 190 kHz and 1750 kHz, although normally all NDBs in North America operate between 190 kHz and 535 kHz. Each NDB is identified by a one, two, or three-letter Morse code callsign. In Canada, privately owned NDB identifiers consist of one letter and one number. North American NDBs are categorized by power output, with low power rated at less than 50 watts, medium from 50 W to 2,000 W and high being over 2,000 W.

Automatic direction finder equipment

NDB navigation consists of two parts — the *automatic direction finder* (or ADF) equipment on the aircraft that detects an NDB's signal, and the NDB transmitter. The ADF can also locate transmitters in the standard AM medium wave broadcast band (530 kHz to 1700 kHz at 10 kHz increments in the Americas, 531 kHz to 1602 kHz at 9 kHz increments in the rest of the world).



This symbol denotes an NDB on an aeronautical chart. A hollow square superimposed on this symbol indicates a co-located DME installation.

ADF equipment determines the direction to the NDB station relative to the aircraft. This may be displayed on a relative bearing indicator (RBI). This display looks like a compass card with a needle superimposed, except that the card is fixed with the 0 degree position corresponding to the centreline of the aircraft. In order to track toward an NDB (with no wind) the aircraft is flown so that the needle points to the 0 degree position, the aircraft will then fly directly to the NDB. Similarly, the aircraft will track directly away from the NDB if the needle is maintained on the 180 degree mark. With a crosswind, the needle must be maintained to the left or right of the 0 or 180 position by an amount corresponding to the drift due to the crosswind. (Aircraft Heading +/- ADF needle degrees off nose or tail = Bearing to or from NDB station).

The formula to determine the compass heading to an NDB station (in a no wind situation) is to take the relative bearing between the aircraft and the station, and add the magnetic heading of the aircraft; if the total is greater than 360 degrees, then 360 must be subtracted. This gives the magnetic bearing that must be flown: (RB + MH)%360 = MB.

When tracking to or from an NDB, it is also usual that the aircraft track on a specific bearing. To do this it is necessary to correlate the RBI reading with the compass heading. Having determined the drift, the aircraft must be flown so that the compass heading is the required bearing adjusted for drift at the same time as the RBI reading is 0 or 180 adjusted for drift. An NDB may also be used to locate a position along the aircraft track. When the needle reaches an RBI reading corresponding to the required bearing then the aircraft is at the position. However, using a separate RBI and compass, this requires considerable mental calculation to determine the appropriate relative bearing.

To simplify this task a compass card is added to the RBI to form a "Radio Magnetic Indicator" (RMI). The ADF needle is then referenced immediately to the aircraft heading, which reduces the necessity for mental calculation.

The principles of ADFs are not limited to NDB usage; such systems are also used to detect the locations of broadcast signals for many other purposes, such as finding emergency beacons.

Use of non-directional beacons

Airways

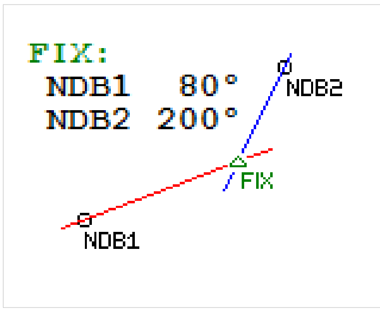
NDB transmitter at 49° 12.35' N, 2° 13.20' W. Callsign JW – 'Jersey West'. 329.0 kHz.

A bearing is a line passing through the station that points in a specific direction, such as 270 degrees (due West). NDB bearings provide a charted, consistent method for defining paths aircraft can fly. In this fashion, NDBs can, like VORs, define "airways" in the sky. Aircraft follow these pre-defined routes to complete a flight plan. Airways are numbered and standardized on charts; colored airways are used for low to medium frequency stations like the NDB and are charted in brown on sectional charts. Green and red airways are plotted east and west while amber and blue airways are plotted north and south. There is only one colored airway left in the continental United States. It is located off the coast of North Carolina and is called G13 or Green 13. Alaska is the only other state in the United States to make use of the colored airway systems. Pilots follow these routes by tracking radials across various navigation stations, and turning at some. While most airways in the United States are based on VORs, NDB airways are common elsewhere, especially in the developing world and in lightly populated areas of developed countries, like the Canadian Arctic, since they can have a long range and are much less expensive to operate than VORs.

All standard airways are plotted on aeronautical charts, such as U.S. sectional charts, issued by the National Oceanographic and Atmospheric Administration (NOAA).

Fixes

NDBs have long been used by aircraft navigators, and previously mariners, to help obtain a fix of their geographic location on the surface of the Earth. Fixes are computed by extending lines through known navigational reference points until they intersect. For visual reference points, the angles of these lines can be determined by compass; the bearings of NDB radio signals are found using RDF equipment.



Plotting fixes in this manner allow crews to determine their position. This usage is important in situations where other navigational equipment, such as VORs with distance measuring equipment (DME), have failed. In marine navigation, NDBs may still be useful should GPS reception fail.

Determining distance from an NDB station

To determine the distance in relation to an NDB station in nautical miles, the pilot uses this simple method:

1. Turns the aircraft so that the station is directly off one of the wingtips.
2. Flies that heading, timing how long it takes to cross a specific number of NDB bearings.
3. Uses the formula: Time to station = 60 x number of minutes flown / degrees of bearing change
4. Uses the flight computer to calculate the distance the aircraft is from the station; time * speed = distance

NDB approaches

A runway equipped with NDB or VOR (or both) as the only navigation aid is called a non-precision approach runway; if it is equipped with ILS it is called a precision approach runway.

Instrument landing systems

NDBs are most commonly used as markers or "locators" for an instrument landing system (ILS) approach or standard approach. NDBs may designate the starting area for an ILS approach or a path to follow for a standard terminal arrival procedure, or STAR. In the United States, an NDB is often combined with the outer marker beacon in the ILS approach (called a locator outer marker, or LOM); in Canada, low-powered NDBs have replaced marker beacons entirely. Marker beacons on ILS approaches are now being phased out worldwide with DME ranges used instead to delineate the different segments of the approach. German Navy U-boats during World War II were equipped with a Telefunken Spez 2113S homing beacon. This transmitter could operate on 100 kHz to 1500 kHz with a power of 150 W. It was used to send the submarine's location to other submarines or aircraft, which were equipped with DF receivers and loop antennas.

Technical

NDBs typically operate in the frequency range from 190 kHz to 535 kHz (although they are allocated frequencies from 190 to 1750 kHz) and transmit a carrier modulated by either 400 or 1020 Hz. NDBs can also be co-located with a DME in a similar installation for the ILS as the outer marker, only in this case, they function as the inner marker. NDB owners are mostly governmental agencies and airport authorities.

One of the wooden poles of NDB HDL at Plankstadt, Germany

NDB radiators are vertically polarised. NDB antennas are usually too short for resonance at the frequency they operate – typically perhaps 20m length compared to a wavelength around 1000m. Therefore they require a suitable matching network that may consist of an inductor and a capacitor to "tune" the antenna. Vertical NDB antennas may also have a 'top hat', which is an umbrella-like structure designed to add loading at the end and improve its radiating efficiency. Usually a ground plane or counterpoise is connected underneath the antenna.

Other information transmitted by an NDB

Apart from **Morse Code Identity** of either 400 Hz or 1020 Hz, the NDB may broadcast:

- Automatic Terminal Information Service or **ATIS**

- Automatic Weather Information Service, or **AWIS**, or, in an emergency i.e. Air-Ground-Air Communication failure, an Air Traffic Controller using a Press-To-Talk (PTT) function, may modulate the carrier with voice. The pilot uses their ADF receiver to hear instructions from the Tower.

Ferrite antenna for non-directional beacon (NDB), frequency 255 - 526.5 kHz

- Automated Weather Observation System or **AWOS**
- Automated Surface Observation System or **ASOS**
- Meteorological Information Broadcast or **VOLMET**
- Transcribed Weather Broadcast or **TWEB**
- **PIP** monitoring. If an NDB has a problem, e.g. lower than normal power output, failure of mains power or standby transmitter is in operation, the NDB may be programmed to transmit an extra 'PIP' (a Morse dot), to alert pilots and others that the beacon may be unreliable for navigation.

Common adverse effects

Navigation using an ADF to track NDBs is subject to several common effects:

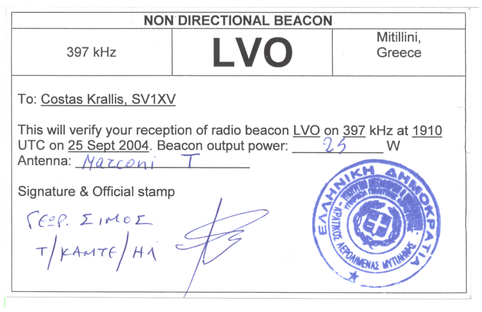
- **Night effect**: radio waves reflected back by the ionosphere can cause signal strength fluctuations 30 to 60 nautical miles (54 to 108 km) from the transmitter, especially just before sunrise and just after sunset (more common on frequencies above 350 kHz)
- **Terrain effect**: high terrain like mountains and cliffs can reflect radio waves, giving erroneous readings; magnetic deposits can also cause erroneous readings
- **Electrical effect**: electrical storms, and sometimes also electrical interference (from a ground-based source or from a source within the aircraft) can cause the ADF needle to deflect towards the electrical source
- **Shoreline effect**: low-frequency radio waves will refract or bend near a shoreline, especially if they are close to parallel to it
- **Bank effect**: when the aircraft is banked, the needle reading will be offset

While pilots study these effects during initial training, trying to compensate for them in flight is very difficult; instead, pilots generally simply choose a heading that seems to average out any fluctuations.

Radio-navigation aids must keep a certain degree of accuracy, given by international standards, FAA, ICAO, etc.; to assure this is the case, Flight inspection organizations periodically check critical parameters with properly equipped aircraft to calibrate and certify NDB precision.

Monitoring NDBs

Besides their use in aircraft navigation, NDBs are also popular with long-distance radio enthusiasts ("DXers"). Because NDBs are generally low-power (usually 25 watts, some can be up to 5 kW), they normally cannot be heard over long distances, but favorable conditions in the ionosphere can allow NDB signals to travel much farther than normal. Because of this, radio DXers interested in picking up distant signals enjoy listening to faraway NDBs. Also, since the band allocated to NDBs is free of broadcast stations and



NON DIRECTIONAL BEACON

397 kHz | LVO | Mitillini, Greece

To: Costas Krallis, SV1XV

This will verify your reception of radio beacon LVO on 397 kHz at 1910 UTC on 25 Sept 2004. Beacon output power: 25 W

Antenna: Marconi T

Signature & Official stamp

A PFC QSL card from an NDB

their associated interference, and because most NDBs do little more than transmit their Morse Code callsign, they are very easy to identify, making NDB monitoring an active niche within the DXing hobby.

In North America, the NDB band is from 190 to 435 kHz and from 510 to 530 kHz. In Europe, there is a longwave broadcasting band from 150 to 280 kHz, so the European NDB band is from 280 kHz to 530 kHz with a gap between 495 and 505 kHz because 500 kHz was the international maritime distress (emergency) frequency.

The beacons that are between 510 kHz and 530 kHz can sometimes be heard on AM radios that can tune below the beginning of the AM broadcast band. (For example, the "HEH" beacon in Newark, Ohio at 524 kHz is within the bandwidth of most AM radios, the "OS" beacon in Columbus, Ohio at 515 kHz and the "YWA" beacon in Petawawa, Ontario, Canada at 516 kHz can also be heard on some AM radios). Some beacons can also be heard on 530 kHz, although from the adjacent frequencies such as "LYQ" at 529 kHz in Manchester, Tennessee but for the most part, reception of NDBs requires a radio receiver that can receive frequencies below 530 kHz (the longwave band). A NDB in Miramichi, New Brunswick once operated at 530 kHz as "F9" but had later moved to 520 kHz. Most so-called "shortwave" radios also include mediumwave and longwave, and they can usually receive all frequencies from 150 kHz to 30 MHz, which makes them ideal for listening to NDBs. Whilst this type of receiver is adequate for reception of local beacons, specialized techniques (receiver preselectors, noise limiters and filters) are required for the reception of very weak signals from remote beacons.

The best time to hear NDBs that are very far away (i.e. that are "DX") is the last three hours before sunrise. Reception of NDBs is also usually best during the fall and winter because during the spring and summer, there is more atmospheric noise on the LF and MF bands.

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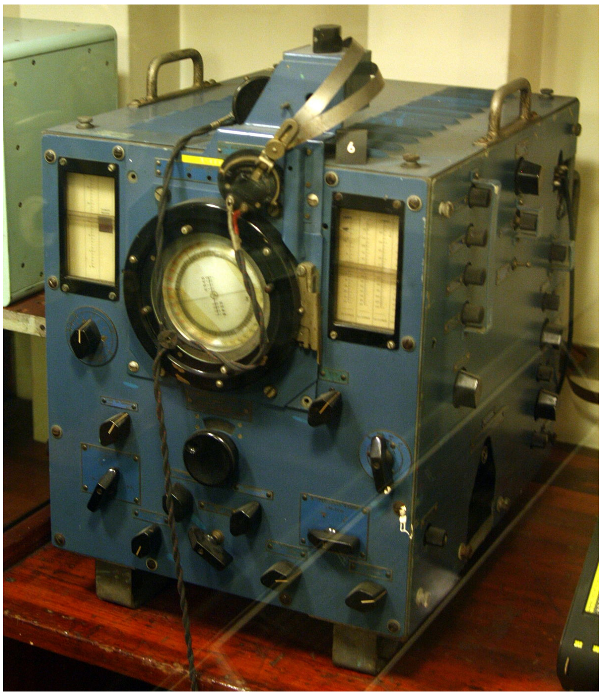
- Robert Connolly (August 2009). "NDB DXing – Understanding the basics". *Radio User* (PW Publishing Ltd) **4** (8): 40–42. ISSN 1748-8117 (http://www.worldcat.org/issn/1748-8117).
- *Instrument Procedures Handbook FAA-H-8261-1A*. FAA. 2007. pp. 5–60.

External links

- List of navigation aids from airnav.com (http://www.airnav.com/navaids/)
- A list of navigation aids with entries missing from the above (http://worldaerodata.com/)
- UK Navaids Gallery with detailed Technical Descriptions of their operation (http://www.trevord.com/navaids/)
- Flash-based ADF instrument simulator (http://www.luizmonteiro.com/Learning_ADF_Sim.aspx)
- Large selection of beacon related resources at the NDB List Website (http://www.ndblist.info/)
- The NDB List Radiobeacon Photo Gallery (http://www.ndblist.info/ndbphotos/beaconpics.htm)
- On The art of NDB DXing (http://pe2bz.philpem.me.uk/Comm/- ELF-VLF/- ELF-Theory/-Antenna-Theory/Vlf-11101-NDB-Dxing/)

High-frequency direction finding

High-frequency direction finding, usually known by its abbreviation **HF/DF** or nickname **huff-duff**, is the common name for a type of radio direction finding (RDF) employed especially during World War II. It was used primarily to catch enemy radios while they transmitted, although it was also used to locate friendly aircraft as a navigation aid. The basic technique remains in use to this day as one of the fundamental disciplines of signals intelligence, or "SIGINT", although this is typically incorporated into a larger suite of radio systems and radars instead of being a stand-alone system.



FH4 "Huff-duff" equipment on the museum ship HMS *Belfast*

The name is something of a misnomer, as the technique works at any frequency. A more accurate term would be "high-*speed* direction finding", as the primary difference between huff-duff and previous systems was its ability to locate the source of the signal almost instantly. To do this, huff-duff used a set of antennas to receive the same signal in slightly different locations or angles, and then used the slight differences in the signal to display the bearing to the transmitter on an oscilloscope display. Earlier systems used a mechanically rotated antenna (or solenoid) and an operator listening for peaks or nulls in the signal, which took considerable time to determine. Huff-duff's speed allowed it to catch fleeting signals, like those from the German U-Boat fleet.

The system was initially developed by Robert Watson-Watt starting in 1926, although many of the practical elements were not developed until the late 1930s. Huff-duff units were in very high demand, and there was considerable inter-service rivalry involved in their distribution. An early use was by the RAF Fighter Command as part of the Dowding system of interception control, and ground-based units were also widely used to feed information to the Admiralty to locate U-Boats. By 1942/43 smaller units were widely available and became common fixtures on most Royal Navy ships. It is estimated that huff-duff contributed directly or indirectly to 24% of all U-Boats sunk during the war.[1]

The basic concept is also known by several alternate names, including **Cathode-Ray Direction Finding** (CRDF), **Twin Path** DF, and for its inventor, **Watson-Watt** DF or **Adcock/Watson-Watt** when the antenna is considered.

History

Before huff-duff

Radio direction finding was a widely-used technique even before World War I, used for both naval and aerial navigation. The basic concept used a loop antenna, in its most basic form simply a circular loop of wire who's circumference is decided by the frequency range of the signals to be detected. When the loop is aligned at right angles to the signal, the signal in the two halves of the loop cancels out, producing a sudden drop in output known as a "null".

Early DF systems used a loop antenna that could be mechanically rotated. The operator would tune in a known radio station and then rotate the antenna until the signal disappeared. This meant that the antenna was now at right angles to the broadcaster, although it could be on either side of the antenna. By taking several such measurements, or using some other form of navigational information to eliminate one of the ambiguous directions, the bearing to the broadcaster could be determined.

In 1907 an improvement was introduced by Ettore Bellini and Alessandro Tosi that greatly simplified the DF system in some setups. The single loop antenna was replaced by two antennas, arranged at right angles. The output of each was sent to its own looped wire, or as they are referred to in this system, a "field coil". Two coils, one for each antenna, are arranged close together at right angles. The signals from the two antennas generated a magnetic field in the space between the coils, which was picked up by a rotating solenoid, the "search coil". The maximum signal was generated when the search coil was aligned with the magnetic field from the field coils, which was at the angle of the signal in relation to the antennas. This eliminated any need for the antennas to move. The Bellini-Tosi goniometer (B-T) was widely used on ships, although mechanical systems tended to be used on aircraft as they were normally smaller.[2]

All of these devices took time to operate. Normally the radio operator would first use conventional radio tuners to find the signal in question, either using the DF antenna(s) or on a separate non-directional antenna. Once tuned, the operator rotated the antennas or goniometer looking for peaks or nulls in the signal. This normally took some time, with the rough location being found by spinning the control rapidly, and then "hunting" for the angle with increasingly small movements. With periodic signals like Morse code, or signals on the fringe of reception, this was a difficult process. Fix times on the order of one minute were commonly quoted.[2]

Some work on automating the B-T system was carried out just prior to the opening of the war, especially by French engineers Maurice Deloraine and Henri Busignies, working in the French division of the US's ITT Corporation. Their system motorized the search coil as well as a circular display card, which rotated in sync. A lamp on the display card was tied to the output of the goniometer, and flashed whether it was in the right direction. When spinning quickly, about 120 RPM, the flashes merged into a single (wandering) dot that indicated the direction. The team left France just in time in 1940 to continue the development in the US, while destroying all of their work in the French office.[3]

Watson-Watt

It had long been known that lightning gives off radio signals due to the ionization of the air as it is heated. The signal is across many frequencies, but is particularly strong in the longwave spectrum, which was one of the primarily radio frequencies for long-range naval communications. Robert Watt (the "Watson" was not added until 1942) had demonstrated that measurements of these radio signals could be used to track thunderstorms and provide useful long-range warning for pilots and ships. In some experiments he was able to detect thunderstorms over Africa, 2,500 kilometres (1,600 mi) away.[4]

However, the lightning strikes lasted such a short time that traditional RDF systems using loop antennas could not determine the bearing before they vanished. All that could be determined was an average location the produced the best signal over a long period, incorporating the signal of many strikes.[4] In 1916 Watt proposed that a cathode ray tube (CRT) could be used as an indicating element instead of mechanical systems,[5] but did not have the ability to test this.

Watt worked at the RAF's Met Office in Aldershot, but in 1924 they decided to return the location to use for the RAF. In July 1924 Watt moved to a new location at Ditton Park near Slough. This site already hosted the National Physical Laboratory (NPL) Radio Section research site. Watt was involved in the Atmospherics branch, basic studies in the propagation of radio signals through the atmosphere, while the NPL were involved in Field Strength Measurements and Direction Finding Investigations. NPL had two devices used in these studies that would prove critical to the development of huff-duff, an Adcock antenna and a modern oscilloscope.[4]

The Adcock antenna is an arrangement of four masts that act as two loop antennas arranged at right angles. By comparing the signals received on the two virtual loops, the direction to the signal can be determined using existing RDF techniques. Researchers had set up the antenna in 1919 but had been neglecting it in favour of smaller designs. These were found to have very poor performance due to the electrical characteristics of the Slough area, which made it difficult to determine if a signal was being received on a straight line or down from the sky. Smith-Rose and Barfield turned their attention back to the Adcock antenna, which had no horizontal component and thus filtered out the "skywaves". In a series of follow-up experiments they were able to accurately determine the location of transmitters around the country.[6]

It was Watt's continuing desire to capture the location of individual lightning strikes that led to the final major developments in the basic huff-duff system. The lab had recently taken delivery of a WE-224 oscilloscope from Bell Labs, which provided easy hook-up and had a long-lasting phosphor. Working with Herd, in 1926 Watt added an amplifier to each to the two arms of the antenna, and sent those signals into the X and Y channels of the oscilloscope. As hoped, the radio signal produced a pattern on the screen that indicated the location of the strike, and the long-lasting phosphor gave the operator ample time to measure it before the display faded.[4][]

Watt and Herd wrote an extensive paper on the system in 1926, referring to it as "An instantaneous direct-reading radiogoniometer" and stating that it could be used to determine the direction of signals lasting as little as 0.001 second.[7] The paper describes the device in depth, and goes on to explain how it could be used to improve radio direction finding and navigation. In spite of this public demonstration, and films showing it being used to locate lightning, the concept apparently remained unknown outside the UK, This allowed it to be developed into practical form in secret.

Battle of Britain

Main article: Pip-squeak

During the rush to install the Chain Home (CH) radar systems prior to the Battle of Britain, CH stations were located as far forward as possible, along the shoreline, in order to provide maximum warning time. This meant that the inland areas over the British Isles did not have radar coverage, relying instead on the newly formed Royal Observer Corps (ROC) for visual tracking in this area. While the ROC were able to provide information on large raids, fighters were too small and too high to be positively identified. As the entire Dowding system of air control relied on ground direction, some solution to locating their own fighters was needed.

The expedient solution to this was the use huff-duff stations to tune in on the fighter's radios. Every Sector Control, in charge of a selection of fighter squadrons, was equipped with a huff-duff receiver, along with two other sub-stations located at distant points, about 30 miles (48 km) away. These stations would listen for broadcasts from the fighters, compare the angles to triangulate their location, and then relay that information to the control rooms.[8] Comparing the positions of the enemy reported by the ROC and the fighters from the huff-duff systems, the Sector Commanders could easily direct the fighters to intercept the enemy.

To aid in this process, a system known as "pip-squeak" was installed on some of the fighters, at least two per section (with up to four sections per squadron). Pip-squeak automatically sent out a steady tone for 14 seconds every minute, offering ample time for the huff-duff operators to track the signal.[9] It had the drawback of tying up the aircraft's radio while broadcasting its DF signal.

The need for DF sets was so acute that the Air Ministry initially was unable to supply the numbers requested by Hugh Dowding, commander of RAF Fighter Command. In simulated battles during 1938 the system was demonstrated to be so useful that the Ministry responded by providing Bellini-Tosi systems with the promise that CRT versions would replace them as soon as possible. This could be accomplished in the field, simply by connecting the existing antennas to a new receiver set. By 1940 these were in place at all 29 Fighter Command "sectors", and were a major part of the system that won the battle.

Battle of the Atlantic

"Super Duff" equipment on the museum ship HMS *Belfast*

Along with sonar ("ASDIC"), intelligence from breaking German codes and radar, "Huff-Duff" was a valuable part of the Allies' armoury in detecting German U-boats and commerce raiders during the Battle of the Atlantic.

Aware of the danger presented by normal RDF techniques, the Kriegsmarine developed a system for very short messages. This consisted of short number sequences for common terms like "weather report" and "convoy location", along with descriptions of the format of the following information so that additional descriptions would not be needed in the message. The resulting "kurzsignale" was then encoded with the Enigma machine and then transmitted as rapidly as possible, with times on the order of 20 seconds being typical.[10] This would make conventional RDF techniques essentially useless for tracking these signals accurately, but nowhere near short enough to avoid detection by huff-duff.

The ability to locate U-boats far out to sea was of immense interest to the Royal Navy, who competed with the Air Force for huff-duff sets. They developed a system to detect the high frequency radios used by the U-Boats - this is why the name contains "high-frequency". At first, the system consisted of a number of shore stations in the British Isles and North Atlantic, who would coordinate their interceptions to determine locations. One advantage of the system was that it located the boats directly, so there was no need to intercept the *content* of the message. This was important as the U-Boats encrypted the messages using an Enigma machine, which could not be deciphered at that time.

The distances involved in locating U-boats in the Atlantic from shore-based DF stations were so great that DF accuracy was relatively inefficient and in 1944 a new strategy was developed by Naval Intelligence where localized groups of 5 shore-based DF stations were built so that the bearings from each of the five stations could be averaged to gain a more reliable bearing. Four such groups were set up in Britain at Ford End in Essex, Anstruther in Fife, Bower in the Scottish Highlands and Goonhavern in Cornwall. It was intended that other groups would be set up in Iceland, Nova Scotia and Jamaica[*Confirmation needed*]. Simple averaging was found to be ineffective and later statistical methods were used. Operators were also asked to grade the reliability of their readings so that poor and variable ones were given less importance than those that appeared stable and well defined. Several of these df groups continued into the 1970s as part of the Composite Signals Organisation.

Ground-based systems were used because there were severe technical problems operating on ships, mainly due to the effects of the superstructure on the wavefront of arriving radio signals. However, these problems were overcome under the technical leadership of the Polish engineer Wacław Struszyński, working at the Admiralty Signal Establishment.[11] As ships were equipped, a complex measurement series was carried out to determine these effects, and cards were supplied to the operators to show the required corrections at various frequencies.

By 1942 the availability of the cathode ray tubes, originally limited, improved and was no longer a limit on the number of huff-duff sets that could be produced. At the same time, improved sets were introduced that included continuously motor-driven tuning, to scan the likely frequencies to pick up and sound an automatic alarm when any transmissions were detected. Operators could then rapidly fine tune the signal before it disappeared. These sets were installed on convoy escort ships, enabling them to get much more accurate triangulation fixes on U-boats transmitting from over the horizon, beyond the range of radar. This allowed hunter-killer ships and aircraft to be dispatched at high speed in the direction of the U-boat, which could be illuminated by radar if still on the surface and by ASDIC if it had dived.

Description

The basic concept of the huff-duff system is to send the signal from two aerials into the X and Y channels of an oscilloscope. Normally the Y channel would represent north/south for ground stations, or in the case of the ship, be aligned with the ship's heading fore/aft. The X channel thereby represents either east-west, or port/starboard.

The deflection of the spot on the oscilloscope display is a direct indication of the instantaneous phase and strength of the radio signal. Since radio signals consist of waves, the signal varies in phase at a very rapid rate. If one considers the signal received on one channel, say Y, the dot will move up and down, so rapidly that it would appear to be a straight vertical line, extending equal distances from the center of the display. When the second channel is added, tuned to the same signal, the dot will move in both the X and Y directions at the same time, causing the line to become diagonal. However, the radio signal has a finite wavelength, so as it travels through the antenna loops, the relative phase that meets each part of the antenna changes. This causes the line to be deflected into an ellipse or Lissajous curve, depending on the relative phases. The curve is rotated so that its major axis lies along the bearing of the signal. In the case of a signal to the north-east, the result would be an ellipse lying along the 45/225-degree line on the display.[12] Since the phase is changing while the display is drawing, the resulting displayed shape includes "blurring" that needed to be accounted for.[13]

This leaves the problem of determining whether the signal is north-east or south-west, as the ellipse is equally long on both sides of the display centre-point. To solve this problem a separate aerial, the "sense aerial", was added to this mix. This was an omnidirectional aerial located a fixed distance from the loops about 1/2 of a wavelength away. When this signal was mixed in, the opposite-phase signal from this aerial would strongly suppress the signal when the phase is in the direction of the sense aerial. This signal was sent into the brightness channel, or Z-axis, of the oscilloscope, causing the display to disappear when the signals were out of phase. By connecting the sense aerial to one of the loops, say the north-south channel, the display would be strongly suppressed when it was on the lower half of the display, indicating that the signal is somewhere to the north. At this point the only possible bearing is the north-east one.[14]

The signals received by the antennas is very small and at high frequency, so they are first individually amplified in twin radio receivers. This requires the two receivers to be extremely well calibrated in order that one does not amplify more than the other and thereby change the output signal. For instance, if the amplifier on the north/south antenna is slightly more powerful, the dot will not move along the 45 degree line, but perhaps the 30 degree line. To ensure the two amplifiers were equal, most set-ups included a "test loop" which generated a directional test signal that could be used to tune the system.[15]

For shipboard systems, the ship's superstructure presented a serious cause of interference, especially in phase, as the signals moved around the various metal obstructions. To address this, ships were anchored while a second ship broadcast a test signal from about one mile away, and the resulting signals were recorded on a calibration sheet. The broadcast ship would then move to another location and repeat the calibration. The calibration was different for different wavelengths, which required considerable amounts of work to build up a complete set of sheets for each ship.[16]

Naval units, notably the common HF4 set, included a rotating plastic plate with a line, the "cursor", used to help measure the angle. This could be difficult if the tips of the ellipse did not reach the edge of the display, or went off it. By aligning the cursor with the peaks at either end, this became simple. Hash marks on either side of the cursor allowed measurement of the width of the display, and use that to determine the amount of blurring.

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External links

- HF/DF - Royal Navy High Frequency Radio Direction Finding, WW2 (http://www.naval-history.net/xGM-Tech-HFDF.htm)
- Huff-Duff simulator demo (http://www.youtube.com/embed/eYGvAm8MMvQ)

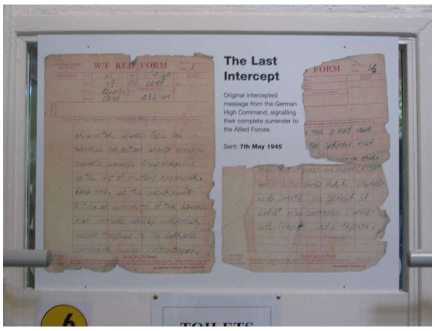
Signals intelligence

"Sigint" redirects here. For other uses, see Sigint (disambiguation).

RAF Menwith Hill, a large site in the United Kingdom, part of ECHELON and the UKUSA Agreement. (2005)

Signals intelligence (often contracted to **SIGINT**) is intelligence-gathering by interception of signals, whether between people ("communications intelligence"—COMINT) or from electronic signals not directly used in communication ("electronic intelligence"—ELINT), or a combination of the two. As sensitive information is often encrypted, signals intelligence often involves the use of cryptanalysis. Also, traffic analysis—the study of who is signaling whom and in what quantity—can often produce valuable information, even when the messages themselves cannot be decrypted.

As a means of collecting intelligence, signals intelligence is a subset of intelligence collection management, which, in turn, is a subset of intelligence cycle management.



The last German message intercepted by the British during World War II, signaling Germany's unconditional surrender

History

For more details on this topic, see Signals intelligence in modern history.

Intercepting written but encrypted communications, and extracting information, probably did not lag long after the development of writing. A simple encryption system, for example, is the Caesar cipher. Electronic interception appeared as early as 1900, during the Boer Wars. The Boers had captured some British radios, and, since the British were the only people transmitting at the time, no special interpretation of the signals was necessary.

Unit 8200 (the SIGINT unit of the Israeli Intelligence Corps) base on Mount Avital, Golan Heights

Signals intelligence work can be dangerous even in peacetime. Numerous peacetime international incidents involving the loss of life, including the USS Liberty incident, USS Pueblo (AGER-2) incident, and the shooting down of Flight 60528, occurred during signals intelligence missions.

A52 *Oste*, an Oste class ELINT (Electronic signals intelligence) and reconnaissance ship, of the German Navy

In the United States, there has been legal controversy over what signal intelligence can be used for and how much freedom the National Security Agency has to use signal intelligence. Therefore, the government has recently changed how it uses and collects certain types of data, specifically phone records. President Barack Obama has asked lawyers and his national security team to look at the tactics that are being used by the NSA. President Obama made a speech on January 17, 2014 where he defended the national security measures, including the NSA, and their intentions for keeping the country safe through surveillance. He said that it is difficult to determine where the line should be drawn between what is too much surveillance and how much is needed for national security because technology is ever changing and evolving, therefore, the laws cannot keep up with the rapid advancements.

Satellite ground station of the Dutch Nationale SIGINT Organisatie (NSO) (2012)

However, President Obama did make some changes to the national security laws and how much data can be legally collected and surveyed. The first thing that was added, was more presidential directive and oversight so that privacy and basic rights are not violated. The president would look over requests on behalf of American citizens to make sure that their personal privacy is not violated by the data that is being requested. Secondly, surveillance tactics and procedures are becoming more public, including over 40 rulings of the FISC that have been declassified. Thirdly, further protections are being placed on activities that are justified under Section 702, such as the ability to retain, search and use data collected in investigations, which allows the NSA to monitor and intercept interaction of targets overseas. Finally, national security letters, which are secret requests for information that the FBI uses in their investigations, are becoming less secretive. The secrecy of the information requested will not be definite and will terminate after a set time if future secrecy is not required. Concerning the bulk surveillance of Americans phone records, President Obama also ordered a transition from bulk surveillance under Section 215 to a new policy that will eliminate un-necessary bulk collection of metadata.

The details of this transition are still being worked out. One of the proposals being investigated is an outside third party source holding the bulk metadata, where the NSA would then need to ask permission to access the data if it is relevant to national security. President Obama emphasized that the government is not spying on ordinary citizens, but rather working to keep America safe.

More technical definitions of SIGINT and its branches

In the United States and other nations involved with NATO, signals intelligence is defined as:

- A category of intelligence comprising either individually or in combination all communications intelligence (COMINT), electronic intelligence (ELINT), and foreign instrumentation signals intelligence, however transmitted.
- Intelligence derived from communications, electronic, and foreign instrumentation signals.

The JCS definition may overemphasize "foreign instrumentation signals". That part should be considered in combination with measurement and signature intelligence (MASINT), which is closely linked to foreign instrumentation such as telemetry or radio navigation. An ELINT sensor may find a radar, and then cue (i.e., guide) a COMINT sensor for listening in on the talk between the radar and its remote users. A nonspecific SIGINT sensor can cue a Frequency Domain MASINT sensor that can help identify the purpose of the signal. If MASINT cannot identify the signal, then the intelligence organization may task an IMINT aircraft or satellite to take a picture of the source, so photo interpreters can try to understand its functions.

Being a broad field, SIGINT has many sub-disciplines. The two main ones are communications intelligence (COMINT) and electronic intelligence (ELINT). There are, however, some techniques that can apply to either branch, as well as to assist FISINT or MASINT.

Disciplines shared across the branches

Targeting

A collection system has to know to look for a particular signal. "System", in this context, has several nuances. Targeting is an output of the process of developing *collection requirements*:

> "1. An intelligence need considered in the allocation of intelligence resources. Within the Department of Defense, these collection requirements fulfill the essential elements of information and other intelligence needs of a commander, or an agency.
>
> "2. An established intelligence need, validated against the appropriate allocation of intelligence resources (as a requirement) to fulfill the essential elements of information and other intelligence needs of an intelligence consumer."

Need for multiple, coordinated receivers

First, atmospheric conditions, sunspots, the target's transmission schedule and antenna characteristics, and other factors create uncertainty that a given signal intercept sensor will be able to "hear" the signal of interest, even with a geographically fixed target and an opponent making no attempt to evade interception. Basic countermeasures against interception include frequent changing of radio frequency, polarization, and other transmission characteristics. An intercept aircraft could not get off the ground if it had to carry antennas and receivers for every possible frequency and signal type to deal with such countermeasures.

Second, locating the transmitter's position is usually part of SIGINT. Triangulation and more sophisticated radio location techniques, such as time of arrival methods, require multiple receiving points at different locations. These receivers send location-relevant information to a central point, or perhaps to a distributed system in which all participate, such that the information can be correlated and a location computed.

Intercept management

Modern SIGINT systems, therefore, have substantial communications among intercept platforms. Even if some platforms are clandestine, there is a broadcast of information telling them where and how to look for signals. A United States targeting system under development in the late 1990s, PSTS, constantly sends out information that helps the interceptors properly aim their antennas and tune their receivers. Larger intercept aircraft, such as the EP-3 or RC-135, have the on-board capability to do some target analysis and planning, but others, such as the RC-12 GUARDRAIL, are completely under ground direction. GUARDRAIL aircraft are fairly small, and usually work in units of three to cover a tactical SIGINT requirement, where the larger aircraft tend to be assigned strategic/national missions.

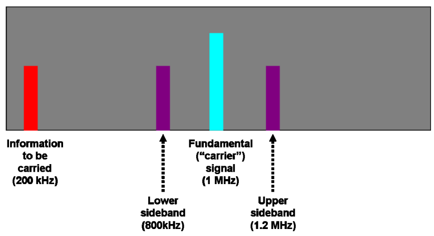
Before the detailed process of targeting begins, someone has to decide there is a value in collecting information about something. While it would be possible to direct signals intelligence collection at a major sports event, the systems would capture a great deal of noise, news signals, and perhaps announcements in the stadium. If, however, an anti-terrorist organization believed that a small group would be trying to coordinate their efforts, using short-range unlicensed radios, at the event, SIGINT targeting of radios of that type would be reasonable. Targeting would not know where in the stadium the radios might be, or the exact frequency they are using; those are the functions of subsequent steps such as signal detection and direction finding.

Once the decision to target is made, the various interception points need to cooperate, since resources are limited. Knowing what interception equipment to use becomes easier when a target country buys its radars and radios from known manufacturers, or is given them as military aid. National intelligence services keep libraries of devices manufactured by their own country and others, and then use a variety of techniques to learn what equipment is acquired by a given country.

Knowledge of physics and electronic engineering further narrows the problem of what types of equipment might be in use. An intelligence aircraft flying well outside the borders of another country will listen for long-range search radars, not short-range fire control radars that would be used by a mobile air defense. Soldiers scouting the front lines of another army know that the other side will be using radios that must be portable and not have huge antennas.

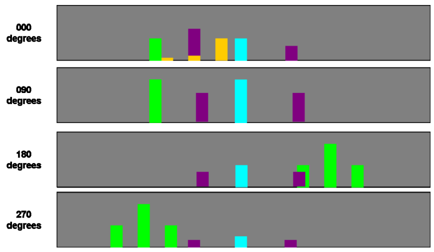
Signal detection

Even if a signal is human communications (e.g., a radio), the intelligence collection specialists have to know it exists. If the targeting function described above learns that a country has a radar that operates in a certain frequency range, the first step is to use a sensitive receiver, with one or more antennas that listen in every direction, to find an area where such a radar is operating. Once the radar is known to be in the area, the next step is to find its location.



Simplified spectrum analyzer display of superheterodyned, amplitude modulated signals.

If operators know the probable frequencies of transmissions of interest, they may use a set of receivers, preset to the frequencies of interest. These are the frequency (horizontal axis) versus power (vertical axis) produced at the transmitter, before any filtering of signals that do not add to the information being transmitted. Received energy on a particular frequency may start a recorder, and alert a human to listen to the signals if they are intelligible (i.e., COMINT). If the frequency is not known, the operators may look for power on primary or sideband frequencies using a spectrum analyzer. Information from the spectrum analyzer is then used to tune receivers to signals of interest. For example, in this simplified spectrum, the actual information is at 800 kHz and 1.2 MHz.



Hypothetical displays from four spectrum analyzers connected to directional antennas. The transmitter is at bearing 090 degrees.

Real-world transmitters and receivers usually are directional. In the figure to the left, assume that each display is connected to a spectrum analyzer connected to a directional antenna aimed in the indicated direction.

Countermeasures to interception

Spread-spectrum communications is an electronic counter-countermeasures (ECCM) technique to defeat looking for particular frequencies. Spectrum analysis can be used in a different ECCM way to identify frequencies not being jammed or not in use.

Direction-finding

Main article: Direction finding

The earliest, and still common, means of direction finding is to use directional antennas as goniometers, so that a line can be drawn from the receiver through the position of the signal of interest. (See HF/DF.) Knowing the compass bearing, from a single point, to the transmitter does not locate it. Where the bearings from multiple points, using goniometry, are plotted on a map, the transmitter will be located at the point where the bearings intersect. This is the simplest case; a target may try to confuse listeners by having multiple transmitters, giving the same signal from different locations, switching on and off in a pattern known to their user but apparently random to the listener.

Individual directional antennas have to be manually or automatically turned to find the signal direction, which may be too slow when the signal is of short duration. One alternative is the Wullenweber array technique. In this method, several concentric rings of antenna elements simultaneously receive the signal, so that the best bearing will ideally be clearly on a single antenna or a small set. Wullenweber arrays for high-frequency signals are enormous, referred to as "elephant cages" by their users.

An alternative to tunable directional antennas, or large omnidirectional arrays such as the Wullenweber, is to measure the time of arrival of the signal at multiple points, using GPS or a similar method to have precise time synchronization. Receivers can be on ground stations, ships, aircraft, or satellites, giving great flexibility.

Modern anti-radiation missiles can home in on and attack transmitters; military antennas are rarely a safe distance from the user of the transmitter.

Traffic analysis

Main article: Traffic analysis

When locations are known, usage patterns may emerge, from which inferences may be drawn. Traffic analysis is the discipline of drawing patterns from information flow among a set of senders and receivers, whether those senders and receivers are designated by location determined through direction finding, by addressee and sender identifications in the message, or even MASINT techniques for "fingerprinting" transmitters or operators. Message content, other than the sender and receiver, is not necessary to do traffic analysis, although more information can be helpful.

For example, if a certain type of radio is known to be used only by tank units, even if the position is not precisely determined by direction finding, it may be assumed that a tank unit is in the general area of the signal. Of course, the owner of the transmitter can assume someone is listening, so might set up tank radios in an area where he wants the other side to believe he has actual tanks. As part of Operation Quicksilver, part of the deception plan for the invasion of Europe at the Battle of Normandy, radio transmissions simulated the headquarters and subordinate units of the fictitious First United States Army Group (FUSAG), commanded by George S. Patton, to make the German defense think that the main invasion was to come at another location. In like manner, fake radio transmissions from Japanese aircraft carriers, before the Battle of Pearl Harbor, were made from Japanese local waters, while the attacking ships moved under strict radio silence.

Traffic analysis need not focus on human communications. For example, if the sequence of a radar signal, followed by an exchange of targeting data and a confirmation, followed by observation of artillery fire, this may identify an automated counterbattery system. A radio signal that triggers navigational beacons could be a landing aid system for an airstrip or helicopter pad that is intended to be low-profile.

Patterns do emerge. Knowing a radio signal, with certain characteristics, originating from a fixed headquarters may be strongly suggestive that a particular unit will soon move out of its regular base. The contents of the message need not be known to infer the movement.

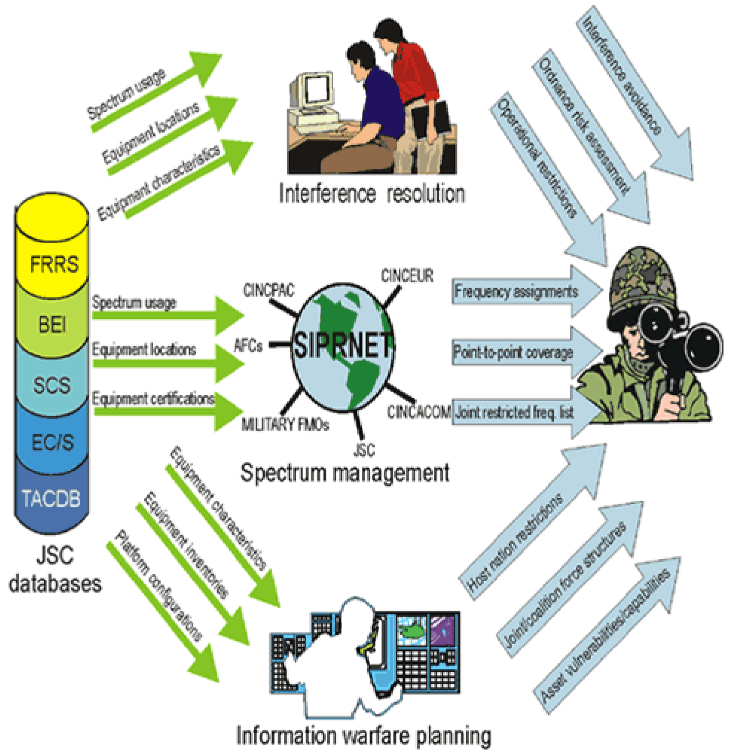
There is an art as well as science of traffic analysis. Expert analysts develop a sense for what is real and what is deceptive. Harry Kidder, for example, was one of the star cryptanalysts of World War II, a star hidden behind the secret curtain of SIGINT.

Electronic Order of Battle

Generating an **Electronic order of battle** (EOB) requires identifying SIGINT emitters in an area of interest, determining their geographic location or range of mobility, characterizing their signals, and, where possible, determining their role in the broader organizational order of battle. EOB covers both COMINT and ELINT. The Defense Intelligence Agency maintains an EOB by location. The Joint Spectrum Center (JSC) of the Defense Information Systems Agency supplements this location database with five more technical databases:

1. FRRS: Frequency Resource Record System
2. BEI: Background Environment Information
3. SCS: Spectrum Certification System
4. EC/S: Equipment Characteristics/Space
5. TACDB: platform lists, sorted by nomenclature, which contain links to the C-E equipment complement of each platform, with links to the parametric data for each piece of equipment, military unit lists and their subordinate units with equipment used by each unit.

For example, several voice transmitters might be identified as the command net (i.e., top commander and direct reports) in a tank battalion or tank-heavy task force. Another set of transmitters might identify the logistic net for that same unit. An inventory of ELINT sources might identify the medium- and long-range counter-artillery radars in a given area.



EOB and related data flow

Signals intelligence units will identify changes in the EOB, which might indicate enemy unit movement, changes in command relationships, and increases or decreases in capability.

Using the COMINT gathering method enables the intelligence officer to produce an electronic order of battle by traffic analysis and content analysis among several enemy units. For example, if the following messages were intercepted:

1. U1 from U2, requesting permission to proceed to checkpoint X.
2. U2 from U1, approved. please report at arrival.
3. (20 minutes later) U1 from U2, all vehicles have arrived to checkpoint X.

This sequence shows that there are two units in the battlefield, unit 1 is mobile, while unit 2 is in a higher hierarchical level, perhaps a command post. One can also understand that unit 1 moved from one point to another which are distant from each 20 minutes with a vehicle. If these are regular reports over a period of time, they might reveal a patrol pattern. Direction-finding and radiofrequency MASINT could help confirm that the traffic is not deception.

The EOB buildup process is divided as following:

- Signal separation
- Measurements optimization
- Data Fusion
- Networks build-up

Separation of the intercepted spectrum and the signals intercepted from each sensors must take place in an extremely small period of time, in order to separate the deferent signals to different transmitters in the battlefield. The complexity of the separation process depends on the complexity of the transmission methods (e.g., hopping or time division multiple access (TDMA)).

By gathering and clustering data from each sensor, the measurements of the direction of signals can be optimized and get much more accurate than the basic measurements of a standard direction finding sensor. By calculating larger samples of the sensor's output data in near real-time, together with historical information of signals, better results are achieved.

Data fusion correlates data samples from different frequencies from the same sensor, "same" being confirmed by direction finding or radiofrequency MASINT. If an emitter is mobile, direction finding, other than discovering a repetitive pattern of movement, is of limited value in determining if a sensor is unique. MASINT then becomes more informative, as individual transmitters and antennas may have unique side lobes, unintentional radiation, pulse timing, etc.

Network build-up, or analysis of emitters (communication transmitters) in a target region over a sufficient period of time, enables creation of the communications flows of a battlefield.

COMINT

"COMINT" redirects here. It is not to be confused with COMINTERN.

For the fifth episode of the first season of the television series *The Americans*, see COMINT (The Americans).

COMINT (Communications Intelligence) is a sub-category of signals intelligence that engages in dealing with messages or voice information derived from the interception of foreign communications. It should be noted that COMINT is commonly referred to as SIGINT, which can cause confusion when talking about the broader intelligence disciplines. The US Joint Chiefs of Staff defines it as "Technical information and intelligence derived from foreign communications by other than the intended recipients".

COMINT, which is defined to be communications among people, will reveal some or all of the following:

1. Who is transmitting
2. Where they are located, and, if the transmitter is moving, the report may give a plot of the signal against location
3. If known, the organizational function of the transmitter
4. The time and duration of transmission, and the schedule if it is a periodic transmission
5. The frequencies and other technical characteristics of their transmission
6. If the transmission is encrypted or not, and if it can be decrypted. If it is possible to intercept either an originally transmitted cleartext or obtain it through cryptanalysis, the language of the communication and a translation (when needed).
7. The addresses, if the signal is not a general broadcast and if addresses are retrievable from the message. These stations may also be COMINT (e.g., a confirmation of the message or a response message), ELINT (e.g., a navigation beacon being activated) or both. Rather than, or in addition to, an address or other identifier, there may be information on the location and signal characteristics of the responder.

Voice interception

A basic COMINT technique is to listen for voice communications, usually over radio but possibly "leaking" from telephones or from wiretaps. If the voice communications are encrypted, the encryption first must be solved through a process of introelectric diagram in order to listen to the conversation, although traffic analysis (q.v.) may give information simply because one station is sending to another in a radial pattern. It is important to check for various cross sections of conversation. It is equally important to make sure that you have the correct x pattern in relation to the a2 pattern.Wikipedia:Please clarify These can be found by using the signals intelligence set given to all Naval communications officers and enlisted personnel with direct access to signals intelligence communications.Wikipedia:Please clarifyWikipedia:Citation needed

Obviously, the interceptor must understand the language being spoken. In the Second World War, the United States used volunteer communicators known as code talkers, who used languages such as Navajo, Comanche and Choctaw, which would be understood by few people, even in the U.S., who did not grow up speaking the language. Even within these uncommon languages, the code talkers used specialized codes, so a "butterfly" might be a specific Japanese aircraft. British forces made more limited use of Welsh speakers for the additional protection.

While modern electronic encryption does away with the need for armies to use obscure languages, it is certainly possible that guerrilla groups might use rare dialects that few outside their ethnic group would understand.

Text interception

Not all communication is in voice. Morse code interception was once very important, but Morse code telegraphy is now obsolete in the western world, although possibly used by special operations forces. Such forces, however, now have portable cryptographic equipment. Morse code is still used by military forces of former Soviet Union countries.

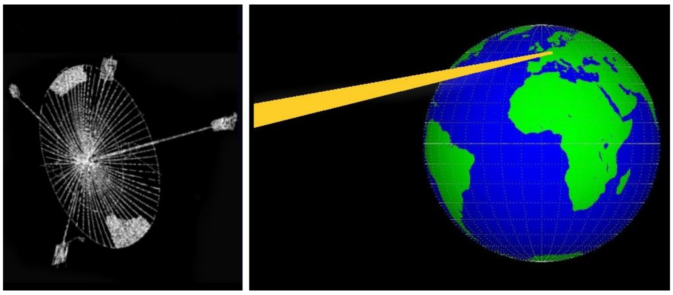
Specialists scan radio frequencies for character sequences (e.g., electronic mail) and facsimile.

Signaling channel interception

A given digital communications link can carry thousands or millions of voice communications, especially in developed countries. Without addressing the legality of such actions, the problem of identifying which channel contains which conversation becomes much simpler when the first thing intercepted is the *signaling channel* that carries information to set up telephone calls. In civilian and many military use, this channel will carry messages in Signaling System 7 protocols.

Retrospective analysis of telephone calls can be made from call detail records (CDR) used for billing the calls.

Monitoring friendly communications



DNI depiction of a NRO SIGINT satellite obtaining data on Western Europe

More a part of communications security than true intelligence collection, SIGINT units still may have the responsibility of monitoring one's own communications or other electronic emissions, to avoid providing intelligence to the enemy. For example, a security monitor may hear an individual transmitting inappropriate information over an unencrypted radio network, or simply one that is not authorized for the type of information being given. If immediately calling attention to the violation would not create an even greater security risk, the monitor will call out one of the BEADWINDOW codes used by Australia, Canada, New Zealand, the United Kingdom, the United States, and other nations working under their procedures. Standard BEADWINDOW codes (e.g., "BEADWINDOW 2") include:

1. **Position:** (e.g., disclosing, in an insecure or inappropriate way, "Friendly or enemy position, movement or intended movement, position, course, speed, altitude or destination or any air, sea or ground element, unit or force."
2. **Capabilities:** "Friendly or enemy capabilities or limitations. Force compositions or significant casualties to special equipment, weapons systems, sensors, units or personnel. Percentages of fuel or ammunition remaining."
3. **Operations:** "Friendly or enemy operation – intentions progress, or results. Operational or logistic intentions; mission participants flying programmes; mission situation reports; results of friendly or enemy operations; assault objectives."
4. **Electronic warfare (EW):** "Friendly or enemy electronic warfare (EW) or emanations control (EMCON) intentions, progress, or results. Intention to employ electronic countermeasures (ECM); results of friendly or enemy ECM; ECM objectives; results of friendly or enemy electronic counter-countermeasures (ECCM); results of electronic support measures/tactical SIGINT (ESM); present or intended EMCON policy; equipment affected by EMCON policy."
5. **Friendly or enemy key personnel:** "Movement or identity of friendly or enemy officers, visitors, commanders; movement of key maintenance personnel indicating equipment limitations."
6. **Communications security (COMSEC):** "Friendly or enemy COMSEC breaches. Linkage of codes or codewords with plain language; compromise of changing frequencies or linkage with line number/circuit

designators; linkage of changing call signs with previous call signs or units; compromise of encrypted/classified call signs; incorrect authentication procedure."

7. **Wrong circuit:** "Inappropriate transmission. Information requested, transmitted or about to be transmitted which should not be passed on the subject circuit because it either requires greater security protection or it is not appropriate to the purpose for which the circuit is provided."
8. Other codes as appropriate for the situation may be defined by the commander.

In WWII, for example, the Japanese Navy made possible the interception and death of the Combined Fleet commander, Admiral Isoroku Yamamoto, by BEADWINDOW 5 and 7 violations. They identified a key person's movement over a low-security cryptosystem.

Electronic signals intelligence

Electronic signals intelligence (ELINT) refers to intelligence-gathering by use of electronic sensors. Its primary focus lies on non-communications signals intelligence. The Joint Chiefs of Staff define it as "Technical and geolocation intelligence derived from foreign noncommunications electromagnetic radiations emanating from other than nuclear detonations or radioactive sources."

Signal identification is performed by analyzing the collected parameters of a specific signal, and either matching it to known criteria, or recording it as a possible new emitter. ELINT data are usually highly classified, and are protected as such.

The data gathered are typically pertinent to the electronics of an opponent's defense network, especially the electronic parts such as radars, surface-to-air missile systems, aircraft, etc. ELINT can be used to detect ships and aircraft by their radar and other electromagnetic radiation; commanders have to make choices between not using radar (EMCON), intermittently using it, or using it and expecting to avoid defenses. ELINT can be collected from ground stations near the opponent's territory, ships off their coast, aircraft near or in their airspace, or by satellite.

Complementary relationship to COMINT

Combining other sources of information and ELINT allows traffic analysis to be performed on electronic emissions which contain human encoded messages. The method of analysis differs from SIGINT in that any human encoded message which is in the electronic transmission is not analyzed during ELINT. What is of interest is the type of electronic transmission and its location. For example, during the Battle of the Atlantic in World War II, Ultra COMINT was not always available because Bletchley Park was not always able to read the U-boat Enigma traffic. But "Huff-Duff" (High Frequency Direction Finder) was still able to find where the U-boats were by analysis of radio transmissions and the positions through triangulation from the direction located by two or more Huff-Duff systems. The Admiralty was able to use this information to plot courses which took convoys away from high concentrations of U-boats.

Yet other ELINT disciplines include intercepting and analyzing enemy weapons control signals, or the Identification, friend or foe responses from transponders in aircraft used to distinguish enemy craft from friendly ones.

Role in air warfare

A very common area of ELINT is intercepting radars and learning their locations and operating procedures. Attacking forces may be able to avoid the coverage of certain radars, or, knowing their characteristics, electronic warfare units may jam radars or send them deceptive signals. Confusing a radar electronically is called a "soft kill", but military units will also send specialized missiles at radars, or bomb them, to get a "hard kill". Some modern air to air missiles also have radar homing guidance systems, particularly for use against large airborne radars.

Knowing where each surface-to-air missile and anti-aircraft artillery system is and its type means that air raids can be plotted to avoid the most heavily defended areas and to fly on a flight profile which will give the aircraft the best chance of evading ground fire and fighter patrols. It also allows for the jamming or spoofing of the enemy's defense network (see electronic warfare). Good electronic intelligence can be very important to stealth operations; stealth aircraft are not totally undetectable and need to know which areas to avoid. Similarly, conventional aircraft need to know where fixed or semi-mobile air defense systems are so that they can shut them down or fly around them.

ELINT and ESM

Electronic Support Measures (ESM) are really ELINT techniques, but the term is used in the specific context of tactical warfare. ESM give the information needed for **Electronic Attack (EA)** such as jamming. EA is also called **Electronic Counter-Measures**. ESM provides information needed for **Electronic Counter-Counter Measures (ECCM)**, such as understanding a spoofing or jamming mode so one can change one's radar characteristics to avoid them.

ELINT for meaconing

Meaconing is the combined intelligence and electronic warfare of learning the characteristics of enemy navigation aids, such as radio beacons, and retransmitting them with incorrect information.

Foreign instrumentation signals intelligence

Main article: FISINT

FISINT (Foreign instrumentation signals intelligence) is a sub-category of SIGINT, monitoring primarily non-human communication. Foreign instrumentation signals include (but not limited to) telemetry (TELINT), tracking systems, and video data links. TELINT is an important part of national means of technical verification for arms control.

Counter-ELINT

Still at the research level are techniques that can only be described as counter-ELINT, which would be part of a SEAD campaign. It may be informative to compare and contrast counter-ELINT with ECCM.

SIGINT versus MASINT

Main article: Measurement and signature intelligence

Signals intelligence and measurement and signature intelligence (MASINT) are closely, and sometimes confusingly, related. The signals intelligence disciplines of communications and electronic intelligence focus on the information in those signals themselves, as with COMINT detecting the speech in a voice communication or ELINT measuring the frequency, pulse repetition rate, and other characteristics of a radar.

A model of a German SAR-Lupe reconnaissance satellite inside a Russian Cosmos-3M rocket.

MASINT also works with collected signals, but is more of an analysis discipline. There are, however, unique MASINT sensors, typically working in different regions or domains of the electromagnetic spectrum, such as infrared or magnetic fields. While NSA and other agencies have MASINT groups, the Central MASINT Office is in the Defense Intelligence Agency (DIA).

Where COMINT and ELINT focus on the intentionally transmitted part of the signal, MASINT focuses on unintentionally transmitted information. For example, a given radar antenna will have sidelobes emanating from other than the direction in which the main antenna is aimed. The RADINT (radar intelligence) discipline involves learning to recognize a radar both by its primary signal, captured by ELINT, and its sidelobes, perhaps captured by the main ELINT sensor, or, more likely, a sensor aimed at the sides of the radio antenna.

MASINT associated with COMINT might involve the detection of common background sounds expected with human voice communications. For example, if a given radio signal comes from a radio used in a tank, if the interceptor does not hear engine noise or higher voice frequency than the voice modulation usually uses, even though the voice conversation is meaningful, MASINT might suggest it is a deception, not coming from a real tank.

See HF/DF for a discussion of SIGINT-captured information with a MASINT flavor, such as determining the frequency to which a *receiver* is tuned, from detecting the frequency of the beat frequency oscillator of the superheterodyne receiver.

Defensive signals intelligence

There are a number of ways that a person or organization can defend against signals intelligence. There is a delicate balance between the level of protection and the actual threat, as expressed in the clichés about "tinfoil hats".

One must begin by defining the threat. It is considerably more difficult to defend against detection that one is signaling, as opposed to defending against an opponent discovering the content of the transmitted message. Appropriate encryption can protect against content interception, but protecting against signal detection, especially with a capable opponent, requires measures to make the signal hard to detect – which can also make it difficult for the intended recipient to receive the signal. Any defensive program needs to consider the nature of the threat and the capabilities of the opponent.

Strong and well-managed encryption

Encryption is central to the defense. The encryption process is vulnerable if the cryptographic keys are not strong and protected, and, on computers, if the cleartext is not deleted when not needed.

Appropriate transmission security

When using radio transmitters, use directional antennas that have as little "spillover" into sidelobes as possible. If it is most important to hide the location of a transmitter, the minimum is to cable the antennas as far as possible away from the transmitter proper. In many circumstances, aiming the antenna upward to a satellite will help hide its location.

The amount of total transmission power needs to be minimized, and the power preferably should be split into multiple and changing frequencies using spread spectrum techniques. If possible, avoid transmitting when hostile SIGINT satellites or monitoring aircraft are overhead.

If in an urban area, avoid using regular commercial power to transmit. There are ways in which the signal can "leak" into power and ground lines. The adversary may cut electrical power for a few seconds, which will tell him there is a line-operated transmitter if the transmission stops, and that there is a battery-powered transmitter if it continues. If these power cuts are targeted at a large number of small locations in quick succession (e.g. individual city blocks) during transmissions then the approximate location of line-powered transmitters can be detected, particularly when used in conjunction with other RDF methods.

Use highly variable transmission schedules and vary frequencies if technically possible. Try to avoid transmitting from exactly the same location twice, because any previous RDF attempts will have noted the approximate transmitter co-ordinates, which can be quickly refined if the same location is used repeatedly.

Also see low probability of intercept radar.

Appropriate receiving security

If Operation RAFTER-style intercept is a threat, protect against this form of unintentional radiation MASINT by using optoisolators or other shielded techniques (e.g., waveguides) to bring in the radio frequency received signal, and shield the local oscillator and intermediate frequency stages in the superheterodyne receiver. This technique should be far less effective against the new generation of software-defined radio.

Unintentional radiation on power or ground circuits is a threat here as well; use appropriate TEMPEST or other techniques.

Protection against compromising emanations

There are risks that electronic, acoustic, or other information could "leak" from a computer system or other electronic communications devices.

The risk

Understanding details of the risks requires a substantial knowledge of electronics, but a simple example might serve. Many people have put a radio receiver near a computer, to listen to music as they work, and discovered that the radio suffered clicks, squeals, and other interference. These interfering signals are radiating from various parts of the computer, especially its display but often also from the power and grounding system. TEMPEST is the name for one family of protective measures against an opponent intercepting these emanations and extracting sensitive information from them.

While not strictly within the scope of protecting against "leakage", a place where sensitive information is processed or discussed needs protection against hidden microphones, wiretaps, and other "bugging". Sometimes, an electronic sweep to verify TEMPEST compliance reveals the presence of hidden transmitters. Again, there is probably more suspicion than reality in most cases. A member of a crime organization, in the middle of a nasty divorce, or a foreign intelligence agent might have reason to worry, but, even with the serious questions about warrantless surveillance in the US and other countries, there is little reason for someone to go to the risk and expense of illegal surveillance on an ordinary citizen. TEMPEST is usually associated with direct electromagnetic radiation from the device, either free-space or through power and ground lines. TEMPEST generically talks about acoustic isolation, but that is fairly easily solved through physical security and noise damping, as well as searches for microphones.

There are several threats that have not been officially defined in the unclassified literature. Nevertheless, there are some informed guesses:

- **NONSTOP** is a threat that involves some type of coupling of compromising RF energy from a classified system, which "leaks" into an independent RF-transmitting or -recording device such as cell phones, PDAs, pager, alarm systems. Commercial AM/FM radios are not considered a risk.
- **HIJACK** is a similar threat of coupling, but to some type of digital computer or related equipment.
- **TEAPOT** is a very different vulnerability, which appears to apply to incidental audio modulation of the backscatter from an RF, typically microwave, directed into the secure area. A passive resonant cavity bug of this type was discovered in a Great Seal of the United States presented by the USSR, but containing a resonant cavity with a wall that moved with sound in the room, thus imposing frequency modulation onto the backscattered signal.

Mitigation and countermeasures

The word TEMPEST itself, and its meaning, are unclassified. Some of the techniques for measuring the compliance of a piece of equipment, or whether it is actually emitting compromising emanations, are classified. A good deal of the information has come into public view either through Freedom of Information Act queries, books talking about interception techniques, inferences drawn from partially released documents, and straightforward thinking by electronic engineers. Some documents released fully or partially under FOIA:

1. Red/Black Installation Guidance
2. Specification for Shielded Enclosures
3. Specification for Shielded Enclosures (partially redacted)

A number of individuals have made a hobby of ferreting out TEMPEST and related information, and firms in the broader-than-TEMPEST business of technical surveillance counter-measures (TSCM) also reveal concepts.

Protection against side channel attacks and covert channels

A side channel attack is an unintentional vulnerability of an encryption device, not related to the encryption algorithm. Potential vulnerabilities include different processing and thus transmission speeds for blocks of plaintext with certain statistical characteristics, changes in power consumption, or compromising emanations.

Covert channels are deliberate means to elude communications security. They send out an unauthorized signal by stealing bandwidth from a legitimate, often encrypted channel. One low-bandwidth method would be to send information by varying the inter-block transmission times. A steganographic covert channel might use the low-order bit of pixels in a graphic image, perhaps not even consecutive pixels, in a manner that would not be obvious to a person looking at the graphic.

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External links

- Part I of IV Articles On Evolution of Army Signal Corps COMINT and SIGINT into NSA (http://www.armysignalocs.com/index_jan_14.html)
- NSA's overview of SIGINT (http://www.nsa.gov/sigint/)
- USAF Pamphlet on sources of intelligence (http://www.fas.org/irp/doddir/usaf/afpam14-210/part16.htm)
- German WWII SIGINT/COMINT (http://fykse.dnsalias.com/radio/dok/german_sigint.pdf)
- Intelligence Programs and Systems (http://www.fas.org/irp/program/index.html)
- *The U.S. Intelligence Community* by Jeffrey T. Richelson (http://books.google.ca/books?id=BaeJNdRySPoC)
- *Secrets of Signals Intelligence During the Cold War and Beyond* by Matthew Aid et. al. (http://books.google.ca/books?id=KaR5O4PKNAoC)
- Maritime SIGINT Architecture Technical Standards Handbook (http://www.tscmplus.com/sigintarchmsh.pdf)

Avalanche transceiver

Avalanche transceivers or **avalanche beacon** are a class of active radio beacon transceivers operating at 457 kHz and specialized for the purpose of finding people or equipment buried under snow. When the owner sets out on a skiing descent, the transceiver is activated, causing the device to emit a low-power pulsed beacon signal during the trip. Following an avalanche, and if the holder of the transceiver is safe and has not themselves been caught by the avalanche, they may switch the transceiver from transmit into receive mode, allowing use as a radio direction finding device to search for signals coming from other skiers' transmitter beacons who may be trapped. A 457 kHz beacon is an active device that requires batteries. A ski suit may also contain a passive RECCO transponder sewn into the clothing.

Digital avalanche transceiver with LED display

Early avalanche beacons transmitted at 2.275 kHz (2275 Hz). In 1986, the international frequency standard of 457 kHz was adopted, and this remains the standard today. Many companies manufacture beacons that comply with this standard.

An avalanche beacon is not considered a preventive measure against possible avalanche burial, but rather it is a way to reduce the amount of time buried.

History

In 1968, Dr. John Lawton invented the first effective avalanche transceiver at Cornell Aeronautical Laboratory in Buffalo, New York, with the first units being sold in 1971 under the “Skadi” brand name. This unit, functioning at 2.275 kHz, converted the radio frequency to a simple tone audible to the human ear. By following the tone to where it was loudest, the beacon operator could use it to locate the buried beacon by using a grid searching technique.

In 1986, IKAR adopted the frequency of 457 kHz. In 1996 ASTM adopted the 457 kHz standard.

The following are the currently accepted international standards for Avalanche Transceivers operating on the 457 kHz frequency.

- 457 kHz, frequency tolerance ±80 Hz
- 200 hours transmitting at +10C (assumed inside protective clothing)
- 1 hours receiving at −10C (assumed handheld)
- operation from −20C to +45C
- carrier keying (pulse period) 1000±300 ms

Now that the frequency 457 kHz had become an international standard, and the problems of range had been discussed and analyzed, everyone was most interested in ease of use. With a new generation of entirely automatic apparatuses existing on the market containing a microprocessor that analyzed the beacon's signals or pulses to determine both the direction and distance of the victim, a new digital age was born. In 1997, the first digital beacon was introduced at the Winter Outdoor Retailer show by Backcountry Access under the brand name "Tracker". The Tracker DTS soon became the most widely used beacon in North America, and is still sold and used by many backcountry enthusiasts. Today, consumers have a wide range of choices for digital beacons from companies like Ortovox, Arva, Pieps, Mammut, and Backcountry Access. Although beacon technology is constantly evolving and improving, practicing and being familiar with your beacon remains the most important aspect for performing timely rescues and preventing avalanche fatalities.

Types of beacons

There are two types of avalanche beacons: digital and analog. They both adhere to the international standard as described above, and only differ in the method(s) used to indicate to the user where the buried beacon is located. Most beacons currently being sold are digital, because of their enhanced ease of use and higher recovery rates.

Digital avalanche transceiver with LCD display

Analog

The original avalanche beacon was an analog beacon which transmitted the pulsed signal as an audible tone to the user. The tone gets louder when the user is closer to the transmitting beacon. These beacons have also been augmented with LEDs that provide a visual indication of signal strength, and earpieces to increase the ability of the listener to hear the tone.

Digital

Digital transceivers take the strength of the signal and the emitted dipole flux pattern and compute distance and direction to the buried transceiver.[1] In order to calculate the emitted dipole flux pattern, a digital transceiver must have at least two antennas, although most modern transceivers have three. The digital beacons will then indicate the direction to the victim's beacon as an arrow on the display, and provide audio cues such as varying pitch or frequency. Most low- to mid-range beacons have a segmented arrow capable of pointing in five to eight forward directions only, displaying a 'U-Turn' indicator if the user is traveling away from the victim. Higher end beacons such as the Mammut® Pulse Barryvox and Arva® Link are equipped with a digital compass and free-flowing arrow, facilitating more exact direction finding, even rotating to maintain direction between pulses of the transmitting beacon (a feature that is impossible without a digital compass or sophisticated accelerometer). In addition, many higher end beacons can point to victims 360°, including behind the user if the user is moving in the wrong direction. Many digital beacons are also capable of being used in analog mode for more advanced rescuers, or to enhance reception range.

W-Link

Several high-end digital beacons are also equipped with a secondary "supplementary" frequency referred to as W-Link. This frequency broadcasts additional details to other transceivers capable of receiving the W-Link signal. Advertised brand-independent features of W-Link include:

- The ability to resolve multiple, complex burial situations by better differentiating individual transceivers
- More reliable estimation of the number of burials
- More reliable and quicker marking/unmarking of victims (i.e. forcing the transceiver to ignore an already found victim)
- More reliable selection of victim search, as the closest victim may not be the easiest to recover
- Ability to transmit and receive additional data including wearer's vital signs or identification

Vitals Detection

Beacons transmitting on the W-Link frequency send a specific device code to assist in isolating and pinpointing multiple signals, and facilitate all of the above features. Certain beacons like the Mammut® Pulse Barryvox also detect micro-movements in the user, including the minuscule movement generated by a heart beat. These beacons will transmit this information across the W-Link frequency, so that any user with another W-Link capable transceiver can determine whether or not a buried victim is alive, and formulate rescue triage based on that situation. The idea behind this is that if everyone in a group is wearing a vitals-capable W-Link transceiver and some group members are buried in an avalanche, the remaining group members will be able to determine which of the buried victims are still alive, and focus rescue efforts on those members.

To compensate for group members without vitals-capable beacons (including lower-end beacons without W-Link and W-Link capable beacons without vitals detection), the rescuer's W-Link beacon will often display two indicators on the display for each victim. One indicator shows that a victim's beacon is transmitting on the W-Link frequency while another shows that the victim is moving. This helps mitigate the potential risk of mis-categorizing an alive victim as dead because their beacon is not transmitting vitals data, and thus the rescuer does not see the "alive" indicator on their transceiver.

Controversies of W-Link

As a universal rule, W-Link capable transceivers do not display personally identifiable characteristics of the buried victims, although they are capable of doing this. This is to eliminate conflicts of interest in rescue situations where a rescuer may choose to save one person before (or instead of) another, even if another person is closer or easier to rescue. By not identifying any buried victims, the rescuer is not left with a decision of which person to save, and are spared the moral implications and consequences of his or her choices. Critics of the W-Link system, especially of the vitals-detecting transceivers, argue that even without offering personally identifiable information, the W-Link transceivers still present moral implications, and complicate rescue efforts because these transceivers will distinguish between W-Link capable and incapable victims with an indicator on the display, further segregating victims with a vitals-data capable beacons. Critics argue that this leads to an unfair distribution of rescue resources and personnel to persons with higher-end or newer transceivers, and deprives everyone of an equal chance for rescue. For this reason transceiver manufacturer Arva Equipment has elected to omit received vitals data from being displayed on their Link transceiver, although the beacon does transmit them. A scenario that W-Link critics will use to exemplify their point is as follows:

> A four-person group goes on a backcountry tour into avalanche terrain. A husband and his wife are both equipped with the same W-Link, vitals-sensing transceiver. They just met the other two group members the day before. One of them has a basic digital beacon, and the other has a modern, digital W-Link beacon that does not transmit vitals data. Along their tour, three of the group members are caught in an avalanche, leaving only the husband to rescue them. He quickly activates his transceiver and it gets a lock on all three victims. The display shows two beacons 10 and 12 meters directly in front of him, one with W-Link signal and one with regular signal only. It also shows one beacon 33 meters behind him transmitting W-Link and vitals data saying the victim is alive.

In this scenario, it is clear to distinguish between all three victims even though the transceiver does not display their names; his wife is 33 meters behind him, while the other two people he just met are much closer, and close together, as well. The moral implications are that the man will either choose to save his wife, likely at the expense of the other two group members' lives, or he will rescue one or both of the other group members, allowing his wife to die. In a rescue situation without the additional information, a competent rescuer would triage and initially rescue the two closer victims. If the husband chooses this path, he will have to live with the knowledge that he could have saved his wife but choose not to, for the rest of his life.

Frequencies and Technical Information

The W-Link frequency in use varies based on geographical location. Currently the frequencies are **869.8 MHz in Region A** and **916-926 MHz in Region B.** Region A consists of the majority of the European Union, Sweden, Norway, Greenland, Iceland, and other countries in that vicinity. Region B consists of Canada and the United States. W-Link frequencies are not permitted for use in Russia, China, India, Australia, New Zealand, Japan, and other various countries in Asia and Eastern Europe. Users may disable W-Link capabilities on their individual beacon when traveling to these countries, although switching between Regions B and A may require servicing by an authorized retailer.

Search Techniques

Main article: Avalanche rescue

Due to the highly directional nature of the 457 kHz signal at the ranges common for avalanche burial (and the range specified in the standards), there have been many techniques developed to search for buried beacons. Good beacon search abilities are considered a required skill for recreational backcountry skiers, mountaineers as well as avalanche professionals such as ski guides, ski patrollers, search and rescue volunteers and professionals. Recreationalists and professionals alike take part in drills, practice and scenarios as a regular part of avalanche skills training.

The burial of a single beacon may involve search using one of several methods:

- Grid search
- Induction search
- Circle method

These search methods are adapted and extrapolated to scenarios where there is more than one burial.

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[1] ISSW 2000

Triangulation

This article is about measurement by the use of triangles. For other uses, see Triangulation (disambiguation).

In trigonometry and geometry, **triangulation** is the process of determining the location of a point by measuring angles to it from known points at either end of a fixed baseline, rather than measuring distances to the point directly (trilateration). The point can then be fixed as the third point of a triangle with one known side and two known angles.

Triangulation of Kodiak Island in 1929.

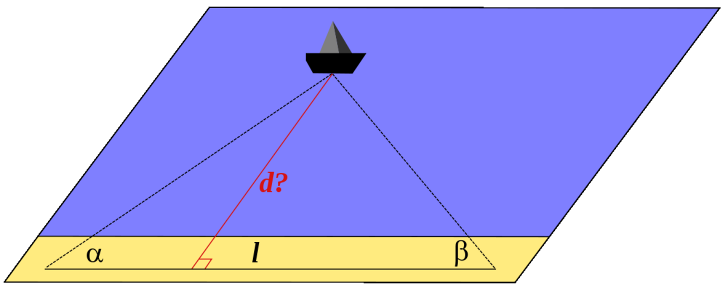
Triangulation can also refer to the accurate surveying of systems of very large triangles, called **triangulation networks**. This followed from the work of Willebrord Snell in 1615–17, who showed how a point could be located from the angles subtended from *three* known points, but measured at the new unknown point rather than the previously fixed points, a problem called resectioning. Surveying error is minimized if a mesh of triangles at the largest appropriate scale is established first. Points inside the triangles can all then be accurately located with reference to it. Such triangulation methods were used for accurate large-scale land surveying until the rise of global navigation satellite systems in the 1980s.

Applications

Optical 3d measuring systems use this principle as well in order to determine the spatial dimensions and the geometry of an item. Basically, the configuration consists of two sensors observing the item. One of the sensors is typically a digital camera device, and the other one can also be a camera or a light projector. The projection centers of the sensors and the considered point on the object's surface define a (spatial) triangle. Within this triangle, the distance between the sensors is the base b and must be known. By determining the angles between the projection rays of the sensors and the basis, the intersection point, and thus the 3d coordinate, is calculated from the triangular relations.

Distance to a point by measuring two fixed angles

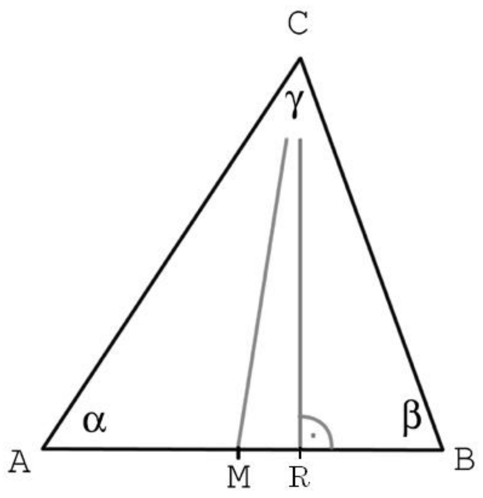
The coordinates and distance to a point can be found by calculating the length of one side of a triangle, given measurements of angles and sides of the triangle formed by that point and two other known reference points.



Triangulation may be used to calculate the coordinates and distance from the shore to the ship. The observer at *A* measures the angle α between the shore and the ship, and the observer at *B* does likewise for β . With the length *l* or the coordinates of *A* and *B* known, then the law of sines can be applied to find the coordinates of the ship at *C* and the distance *d*.

The following formulae apply in flat or Euclidean geometry. They become inaccurate if distances become appreciable compared to the curvature of the Earth, but can be replaced with more complicated results derived using spherical trigonometry.

Calculation



$$\ell = \frac{d}{\tan\alpha} + \frac{d}{\tan\beta}$$

Therefore

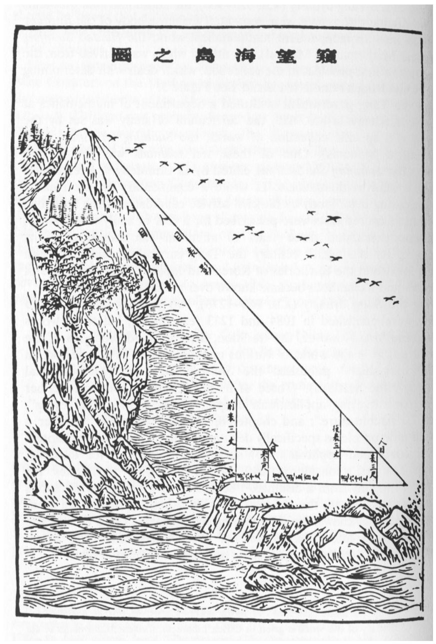
$$1/d = 1/l * (\tfrac{1}{\tan\alpha} + \tfrac{1}{\tan\beta})$$

Using the trigonometric identities tan α = sin α / cos α and sin(α + β) = sin α cos β + cos α sin β, this is equivalent to:

$$1/d = \frac{\sin(\alpha+\beta)}{\ell\ \sin\alpha\sin\beta}$$

From this, it is easy to determine the distance of the unknown point from either observation point, its north/south and east/west offsets from the observation point, and finally its full coordinates.

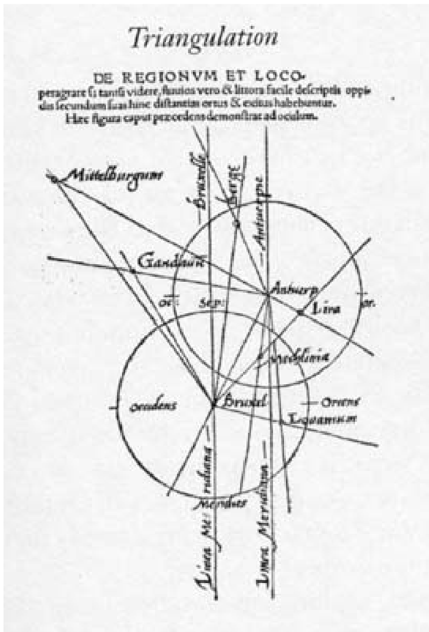
History



Liu Hui (c. 263), How to measure the height of a sea island. Illustration from an edition of 1726

Triangulation today is used for many purposes, including surveying, navigation, metrology, astrometry, binocular vision, model rocketry and gun direction of weapons.

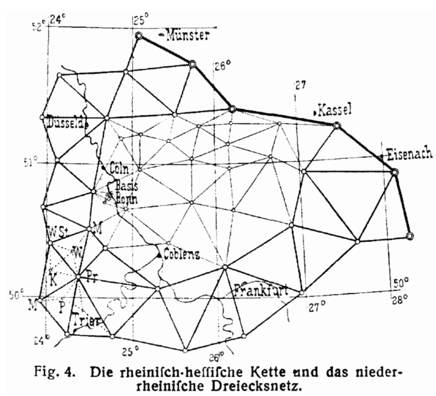
The use of triangles to estimate distances goes back to antiquity. In the 6th century BC the Greek philosopher Thales is recorded as using similar triangles to estimate the height of the pyramids by measuring the length of their shadows and that of his own at the same moment, and comparing the ratios to his height (intercept theorem);[1] and to have estimated the distances to ships at sea as seen from a clifftop, by measuring the horizontal distance traversed by the line-of-sight for a known fall, and scaling up to the height of the whole cliff.[2] Such techniques would have been familiar to the ancient Egyptians. Problem 57 of the Rhind papyrus, a thousand years earlier, defines the *seqt* or *seked* as the ratio of the run to the rise of a slope, *i.e.* the reciprocal of gradients as measured today. The slopes and angles were measured using a sighting rod that the Greeks called a *dioptra*, the forerunner of the Arabic alidade. A detailed contemporary collection of constructions for the determination of lengths from a distance using this instrument is known, the *Dioptra* of Hero of Alexandria (c. 10–70 AD), which survived in Arabic translation; but the knowledge became lost in Europe. In China, Pei Xiu (224–271) identified "measuring right angles and acute angles" as the fifth of his six principles for accurate map-making, necessary to accurately establish distances;[3] while Liu Hui (c. 263) gives a version of the calculation above, for measuring perpendicular distances to inaccessible places.[4][5]



Gemma Frisius's 1533 proposal to use triangulation for mapmaking

In the field, triangulation methods were apparently not used by the Roman specialist land surveyors, the *agromensores*; but were introduced into medieval Spain through Arabic treatises on the astrolabe, such as that by Ibn al-Saffar (d. 1035).[6] Abu Rayhan Biruni (d. 1048) also introduced triangulation techniques to measure the size of the Earth and the distances between various places. Simplified Roman techniques then seem to have co-existed with more sophisticated techniques used by professional surveyors. But it was rare for such methods to be translated into Latin (a manual on Geometry, the eleventh century *Geomatria incerti auctoris* is a rare exception), and such techniques appear to have percolated only slowly into the rest of Europe. Increased awareness and use of such techniques in Spain may be attested by the medieval Jacob's staff, used specifically for measuring angles, which dates from about 1300; and the appearance of accurately surveyed coastlines in the Portolan charts, the earliest of which that survives is dated 1296.

Gemma Frisius and triangulation for mapmaking



Nineteenth-century triangulation network for the triangulation of Rhineland-Hesse

On land, the cartographer Gemma Frisius proposed using triangulation to accurately position far-away places for map-making in his 1533 pamphlet *Libellus de Locorum describendorum ratione* (*Booklet concerning a way of describing places*), which he bound in as an appendix in a new edition of Peter Apian's best-selling 1524 *Cosmographica*. This became very influential, and the technique spread across Germany, Austria and the Netherlands. The astronomer Tycho Brahe applied the method in Scandinavia, completing a detailed triangulation in 1579 of the island of Hven, where his observatory was based, with reference to key landmarks on both sides of the Øresund, producing an estate plan of the island in 1584.[7] In England Frisius's method was included in the growing number of books on surveying which appeared from the middle of the century onwards, including William Cuningham's *Cosmographical Glasse* (1559), Valentine Leigh's *Treatise of Measuring All Kinds of Lands* (1562), William Bourne's *Rules of Navigation* (1571), Thomas Digges's *Geometrical Practise named Pantometria* (1571), and John Norden's *Surveyor's Dialogue* (1607). It has been suggested that Christopher Saxton may have used rough-and-ready triangulation to place features in his county maps of the 1570s; but others suppose that, having obtained rough bearings to features from key vantage points, he may have estimated the distances to them simply by guesswork.[8]

Willebrord Snell and modern triangulation networks

The modern systematic use of triangulation networks stems from the work of the Dutch mathematician Willebrord Snell, who in 1615 surveyed the distance from Alkmaar to Bergen op Zoom, approximately 70 miles (110 kilometres), using a chain of quadrangles containing 33 triangles in all. The two towns were separated by one degree on the meridian, so from his measurement he was able to calculate a value for the circumference of the earth – a feat celebrated in the title of his book *Eratosthenes Batavus* (*The Dutch Eratosthenes*), published in 1617. Snell calculated how the planar formulae could be corrected to allow for the curvature of the earth. He also showed how to resection, or calculate, the position of a point inside a triangle using the angles cast between the vertices at the unknown point. These could be measured much more accurately than bearings of the vertices, which depended on a compass. This established the key idea of surveying a large-scale primary network of control points first, and then locating secondary subsidiary points later, within that primary network.

Snell's methods were taken up by Jean Picard who in 1669–70 surveyed one degree of latitude along the Paris Meridian using a chain of thirteen triangles stretching north from Paris to the clocktower of Sourdon, near Amiens. Thanks to improvements in instruments and accuracy, Picard's is rated as the first reasonably accurate measurement of the radius of the earth. Over the next century this work was extended most notably by the Cassini family: between 1683 and 1718 Jean-Dominique Cassini and his son Jacques Cassini surveyed the whole of the Paris meridian from Dunkirk to Perpignan; and between 1733 and 1740 Jacques and his son César Cassini undertook the first triangulation of the whole country, including a re-surveying of the meridian arc, leading to the publication in 1745 of the first map of France constructed on rigorous principles.

Triangulation methods were by now well established for local mapmaking, but it was only towards the end of the 18th century that other countries began to establish detailed triangulation network surveys to map whole countries. The Principal Triangulation of Great Britain was begun by the Ordnance Survey in 1783, though not completed until 1853; and the Great Trigonometric Survey of India, which ultimately named and mapped Mount Everest and the other Himalayan peaks, was begun in 1801. For the Napoleonic French state, the French triangulation was extended by Jean Joseph Tranchot into the German Rhineland from 1801, subsequently completed after 1815 by the Prussian general Karl von Müffling. Meanwhile, the famous mathematician Carl Friedrich Gauss was entrusted from 1821 to 1825 with the triangulation of the kingdom of Hanover, for which he developed the method of least squares to find the best fit solution for problems of large systems of simultaneous equations given more real-world measurements than unknowns.

Today, large-scale triangulation networks for positioning have largely been superseded by the Global navigation satellite systems established since the 1980s. But many of the control points for the earlier surveys still survive as valued historical features in the landscape, such as the concrete triangulation pillars set up for retriangulation of Great Britain (1936–1962), or the triangulation points set up for the Struve Geodetic Arc (1816–1855), now scheduled as a UNESCO World Heritage Site.

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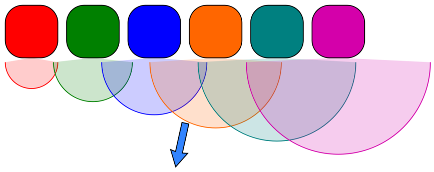
Phased array

This article is about general theory and electromagnetic phased array. For the ultrasonic and medical imaging application, see phased array ultrasonics. For the optical application, see phased-array optics.

In antenna theory, a **phased array** is an array of antennas in which the relative phases of the respective signals feeding the antennas are varied in such a way that the effective radiation pattern of the array is reinforced in a desired direction and suppressed in undesired directions.[1]



Principle of operation of phased array (PA). The PA probe consists of many small elements, each of which can be pulsed separately. In the figure the element on the right is pulsed first, and emits an energy wave that spreads out like a ripple on a pond (largest semicircle). The second to right element is pulsed next, and emits a ripple that is slightly smaller than the first because it was started later. The process continues down the line until all the elements have been pulsed. The multiple waves add up to one single wave front travelling at a set angle. In other words, the beam angle can be set just by programming the pulse timings.

An antenna array is a group of multiple active antennas coupled to a common source or load to produce a directive radiation pattern. Usually, the spatial relationship of the individual antennas also contributes to the directivity of the antenna array. Use of the term "active antennas" is intended to describe elements whose energy output is modified due to the presence of a source of energy in the element (other than the mere signal energy which passes through the circuit) or an element in which the energy output from a source of energy is controlled by the signal input. One common application of this is with a standard multiband television antenna, which has multiple elements coupled together.

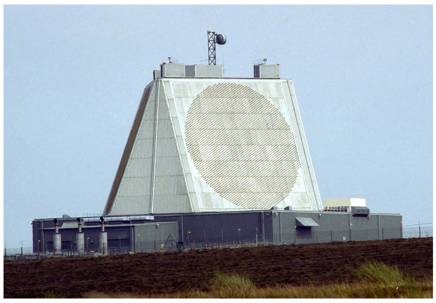
History

Phased array transmission was originally developed in 1905 by Nobel laureate Karl Ferdinand Braun who demonstrated enhanced transmission of radio waves in one direction.[2][3] During World War II, Nobel laureate Luis Alvarez used phased array transmission in a rapidly steerable radar system for "ground-controlled approach", a system to aid in the landing of aircraft. At the same time, the GEMA in Germany built the PESA Mammut 1.[4] It was later adapted for radio astronomy leading to Nobel Prizes for Physics for Antony Hewish and Martin Ryle after several large phased arrays were developed at the University of Cambridge. The design is also used in radar, and is generalized in interferometric radio antennas. In 2007, DARPA researchers announced a 16 element phased array integrated with all necessary circuits to send at 30–50 GHz on a single silicon chip for military purposes.[5]

PAVE PAWS passive electronically scanned array radar in Alaska

Usage

The relative amplitudes of—and constructive and destructive interference effects among—the signals radiated by the individual antennas determine the effective radiation pattern of the array. A phased array may be used to point a fixed radiation pattern, or to scan



RAF Fylingdales active electronically scanned array rapidly in azimuth or elevation. Simultaneous electrical scanning in both azimuth and elevation was first demonstrated in a phased array antenna at Hughes Aircraft Company, Culver City, California in 1957.[6]

The phased array is used for instance in optical communication as a wavelength-selective splitter.

For information about active as well as passive phased array radars, see also active electronically scanned array.

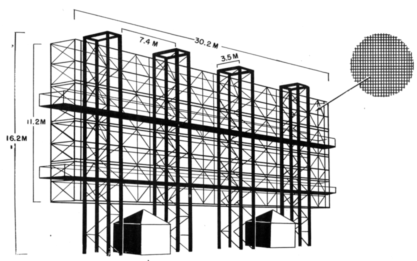
Cobra Dane passive electronically scanned array

Broadcasting

In broadcast engineering, it is required that phased arrays be used by many AM broadcast radio stations to enhance signal strength and therefore coverage in the city of license, while minimizing interference to other areas. Due to the differences between daytime and nighttime ionospheric propagation at mediumwave frequencies, it is common for AM broadcast stations to change between day (groundwave) and night (skywave) radiation patterns by switching the phase and power levels supplied to the individual antenna elements (mast radiators) daily at sunrise and sunset. More modest phased array longwire antenna systems may be employed by private radio enthusiasts to receive longwave, mediumwave (AM) and shortwave radio broadcasts from great distances.

BMEWS & PAVE PAWS Radars

On VHF, phased arrays are used extensively for FM broadcasting. These greatly increase the antenna gain, magnifying the emitted RF energy toward the horizon, which in turn greatly increases a station's broadcast range. In these situations, the distance to each element from the transmitter is identical, or is one (or other integer) wavelength apart. Phasing the array such that the lower elements are slightly delayed (by making the distance to them longer) causes a downward beam tilt, which is very useful if the antenna is quite high on a radio tower.



Mammut phased array radar World War II

Other phasing adjustments can increase the downward radiation in the far field without tilting the main lobe, creating null fill to compensate for extremely high mountaintop locations, or decrease it in the near field, to prevent excessive exposure to those workers or even nearby homeowners on the ground. The latter effect is also achieved by half-wave spacing – inserting additional elements halfway between existing elements with full-wave spacing. This phasing achieves roughly the same horizontal gain as the full-wave spacing; that is, a five-element full-wave-spaced array equals a nine- or ten-element half-wave-spaced array.

Naval usage

Phased array radar systems are also used by warships of many navies. Because of the rapidity with which the beam can be steered, phased array radars allow a warship to use one radar system for surface detection and tracking (finding ships), air detection and tracking (finding aircraft and missiles) and missile uplink capabilities. Before using these systems, each surface-to-air missile in flight required a dedicated fire-control radar, which meant that ships could only engage a small number of simultaneous targets. Phased array systems can be used to control missiles during the mid-course phase of the missile's flight. During the terminal portion of the flight, continuous-wave fire control directors provide the final guidance to the target. Because the radar beam is electronically steered, phased array systems can direct radar beams fast enough to maintain a fire control quality track on many targets simultaneously while also controlling several in-flight missiles. The AN/SPY-1 phased array radar, part of the Aegis combat system deployed on modern U.S. cruisers and destroyers, "is able to perform search, track and missile guidance functions simultaneously with a capability of over 100 targets." Likewise, the Thales Herakles phased array multi-function radar on board the Formidable class frigates of the Republic of Singapore Navy has a track capacity of 200 targets and is able to achieve automatic target detection, confirmation and track initiation in a single scan, while simultaneously providing mid-course guidance updates to the MBDA Aster missiles launched from the ship. The German Navy and the Royal Dutch Navy have developed the Active Phased Array Radar System (APAR).

See also: Active Electronically Scanned Array, Aegis combat system and AN/SPY-1

Active Phased Array Radar mounted on top of Sachsen class frigate F220 *Hamburg's* superstructure of the German Navy.

Phased arrays are used in naval sonar, in active (transmit and receive) and passive (receive only) and hull-mounted and towed array sonar.

Space probe communication

The MESSENGER spacecraft is a mission to the planet Mercury (arrival 18 March 2011). This spacecraft is the first deep-space mission to use a phased-array antenna for communications. The radiating elements are linearly-polarized, slotted waveguides. The antenna, which uses the X band, uses 26 radiative elements but can gracefully downgrade.[7]

Weather research usage

AN/SPY-1A radar installation at NSSL, Norman, Oklahoma. The round dome primarily provides weather protection.

The National Severe Storms Laboratory has been using a SPY-1A phased array antenna, provided by the US Navy, for weather research at its Norman, Oklahoma facility since April 23, 2003. It is hoped that research will lead to a better understanding of thunderstorms and tornadoes, eventually leading to increased warning times and enhanced prediction of tornadoes. Current project participants include the National Severe Storms Laboratory and National Weather Service Radar Operations Center, Lockheed Martin, United States Navy, University of Oklahoma School of Meteorology, School of Electrical and Computer Engineering, and Atmospheric Radar Research Center, Oklahoma State Regents for Higher Education, the Federal Aviation Administration, and Basic Commerce and Industries [8]. The project includes research and development, future technology transfer and potential deployment of the system throughout the United States. It is expected to take 10 to 15 years to complete and initial construction was approximately $25 million.[9]

Optics

Within the visible or infrared spectrum of electromagnetic waves it is possible to construct optical phased arrays. They are used in wavelength multiplexers and filters for telecommunication purposes,[10] laser beam steering, and holography. Synthetic array heterodyne detection is an efficient method for multiplexing an entire phased array onto a single element photodetector.

Radio-frequency identification (RFID)

Recently, phased array antennas have been included in RFID systems to significantly boost the reading capability of passive UHF tags passing from 9m (30ft) to 180m (600 ft).[11]

Human-machine interfaces (HMI)

A phased array of acoustic transducers, denominated airborne ultrasound tactile display (AUTD), was developed at the University of Tokyo's Shinoda Lab to induce tactile feedback.[12] This system was demonstrated to enable a user to interactively manipulate virtual holographic objects.[13]

Mathematical perspective and formulas

A phased array is an example of *N*-slit diffraction. It may also be viewed as the coherent addition of *N* line sources. Since each individual antenna acts as a slit, emitting radio waves, their diffraction pattern can be calculated by adding the phase shift φ to the fringing term.

We will begin from the *N*-slit diffraction pattern derived on the diffraction formalism page.

$$\psi = \psi_0 \left(\frac{\sin\left(\frac{\pi a}{\lambda}\sin\theta\right)}{\frac{\pi a}{\lambda}\sin\theta} \right) \left(\frac{\sin\left(\frac{N}{2}kd\sin\theta\right)}{\sin\left(\frac{kd}{2}\sin\theta\right)} \right)$$

Now, adding a φ term to the $kd\sin\theta$ fringe effect in the second term yields:

$$\psi = \psi_0 \left(\frac{\sin\left(\frac{\pi a}{\lambda}\sin\theta\right)}{\frac{\pi a}{\lambda}\sin\theta} \right) \left(\frac{\sin\left(\frac{N}{2}\left(\frac{2\pi d}{\lambda}\sin\theta + \phi\right)\right)}{\sin\left(\frac{\pi d}{\lambda}\sin\theta + \phi\right)} \right)$$

Taking the square of the wave function gives us the intensity of the wave.

$$I = I_0 \left(\frac{\sin\left(\frac{\pi a}{\lambda}\sin\theta\right)}{\frac{\pi a}{\lambda}\sin\theta} \right)^2 \left(\frac{\sin\left(\frac{N}{2}\left(\frac{2\pi d}{\lambda}\sin\theta + \phi\right)\right)}{\sin\left(\frac{\pi d}{\lambda}\sin\theta + \phi\right)} \right)^2$$

$$I = I_0 \left(\frac{\sin\left(\frac{\pi a}{\lambda}\sin\theta\right)}{\frac{\pi a}{\lambda}\sin\theta} \right)^2 \left(\frac{\sin\left(\frac{\pi}{\lambda}Nd\sin\theta + \frac{N}{2}\phi\right)}{\sin\left(\frac{\pi d}{\lambda}\sin\theta + \phi\right)} \right)^2$$

Now space the emitters a distance $d = \frac{\lambda}{4}$ apart. This distance is chosen for simplicity of calculation but can be adjusted as any scalar fraction of the wavelength.

$$I = I_0 \left(\frac{\sin\left(\frac{\pi a}{\lambda}\sin\theta\right)}{\frac{\pi a}{\lambda}\sin\theta} \right)^2 \left(\frac{\sin\left(\frac{\pi}{4}N\sin\theta + \frac{N}{2}\phi\right)}{\sin\left(\frac{\pi}{4}\sin\theta + \phi\right)} \right)^2$$

As sine achieves its maximum at $\frac{\pi}{2}$, we set the numerator of the second term = 1.

$$\frac{\pi}{4}N\sin\theta + \frac{N}{2}\phi = \frac{\pi}{2}$$

$$\sin\theta = \left(\frac{\pi}{2} - \frac{N}{2}\phi\right)\frac{4}{N\pi}$$

$$\sin\theta = \frac{2}{N} - \frac{2\phi}{\pi}$$

Thus as *N* gets large, the term will be dominated by the $\frac{2\phi}{\pi}$ term. As sine can oscillate between −1 and 1, we can see that setting $\phi = -\frac{\pi}{2}$ will send the maximum energy on an angle given by

$$\theta = \sin^{-1}(1) = \frac{\pi}{2} = 90°$$

Additionally, we can see that if we wish to adjust the angle at which the maximum energy is emitted, we need only to adjust the phase shift φ between successive antennas. Indeed the phase shift corresponds to the negative angle of maximum signal.

A similar calculation will show that the denominator is minimized by the same factor.

Different types of phased arrays

Main article: Beamforming

There are two main types of beamformers. These are time domain beamformers and frequency domain beamformers.

A graduated attenuation window is sometimes applied across the face of the array to improve side-lobe suppression performance, in addition to the phase shift.

Time domain beamformer works by introducing time delays. The basic operation is called "delay and sum". It delays the incoming signal from each array element by a certain amount of time, and then adds them together. The most common kind of time domain beam former is serpentine waveguide. Active phase array uses individual delay lines that are switched on and off. Yttrium iron garnet phase shifters vary the phase delay using the strength of a magnetic field.

There are two different types of frequency domain beamformers.

The first type separates the different frequency components that are present in the received signal into multiple frequency bins (using either an Discrete Fourier transform (DFT) or a filterbank). When different delay and sum beamformers are applied to each frequency bin, the result is that the main lobe simultaneously points in multiple different directions at each of the different frequencies. This can be an advantage for communication links, and is used with the SPS-48 radar.

The other type of frequency domain beamformer makes use of Spatial Frequency. Discrete samples are taken from each of the individual array elements. The samples are processed using a Discrete Fourier Transform (DFT). The DFT introduces multiple different discrete phase shifts during processing. The outputs of the DFT are individual channels that correspond with evenly spaced beams formed simultaneously. A 1-dimensional DFT produces a fan of different beams. A 2-dimensional DFT produces beams with a pineapple configuration.

These techniques are used to create two kinds of phase array.

- Dynamic - an array of variable phase shifters are used to move the beam
- Fixed - the beam position is stationary with respect to the array face and the whole antenna is moved

There are two further sub-categories that modify the kind of dynamic array or fixed array.

- Active - amplifiers or processors in each phase shifter element
- Passive - large central amplifier with attenuating phase shifters

Dynamic Phased Array

Each array element incorporates an adjustable phase shifter that are collectively used to move the beam with respect to the array face.

Dynamic phase array require no physical movement to aim the beam. The beam is moved electronically. This can produce antenna motion fast enough to use a small pencil-beam to simultaneously track multiple targets while searching for new targets using just one radar set (track while search).

As an example, an antenna with a 2 degree beam with a pulse rate of 1 kHz will require approximately 16 seconds to cover an entire a hemisphere consisting of 16,000 pointing positions. This configuration provides 6 opportunities to detect a Mach 3 vehicle over a range of 100 km (62 mi), which is suitable for military applications.

The position of mechanically steered antennas can be predicted, which can be used to create electronic countermeasures that interfere with radar operation. The flexibility resulting from phase array operation allows beams to be aimed at random locations, which eliminates this vulnerability. This is also desirable for military applications.

Fixed Phase Array

Fixed phase array antennas are typically used to create an antenna with a more desirable form factor than the conventional parabolic reflector or cassegrain reflector. Fixed phased array radar incorporate fixed phase shifters. This kind of phase array is physically moved during the track and scan process. There are two configurations.

- Multiple frequencies with a delay-line
- Multiple adjacent beams

The SPS-48 radar uses multiple transmit frequencies with a serpentine delay line along the left side of the array to produce vertical fan of stacked beams. Each frequency experiences a different phase shift as it propagates down the serpentine delay line, which forms different beams. A filter bank is used to split apart the individual receive beams. The antenna is mechanically rotated.

Semi-active radar homing uses monopulse radar that relies on a fixed phase array to produce multiple adjacent beams that measure angle errors. This form factor is suitable for gimbal mounting in missile seekers.

Active Phase Array

Active phased arrays elements incorporate transmit amplification with phase shift in each antenna element (or group of elements). Each element also includes receive pre-amplification. The phase shifter setting is the same for transmit and receive.

Active phase array do not require phase reset after the end of the transmit pulse, which is compatible with Doppler radar and Pulse-Doppler radar.

Passive Phase Array

Passive phased arrays typically use large amplifiers that produce all of the microwave transmit signal for the antenna. Phase shifters typically consist of waveguide elements that contain phase shifters controlled by magnetic field, voltage gradient, or equivalent technology.

The phase shift process used with passive phase array typically puts the receive beam and transmit beam into diagonally opposite quadrants. The sign of the phase shift must be inverted after the transmit pulse is finished and before the receive period begins to place the receive beam into the same location as the transmit beam. That requires a phase impulse that degrades sub-clutter visibility performance on Doppler radar and Pulse-Doppler radar. As an example, Yttrium iron garnet phase shifters must be changed after transmit pulse quench and before receiver processing starts to align transmit and receive beams. That impulse introduces FM noise that degrades clutter performance.

Passive phase array is used with AEGIS.

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External links

- Radar Research and Development - Phased Array Radar (http://www.nssl.noaa.gov/par/)—National Severe Storms Laboratory
- Shipboard Phased Array Radars (http://www.harpoonhq.com/waypoint/articles/Article_044.pdf)
- NASA Report: MMICs For Multiple Scanning Beam Antennas for Space Applications (http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19870018450_1987018450.pdf)
- Principle of Phased Array (http://www.radartutorial.eu/06.antennas/an14.en.html) @ www.radartutorial.eu
- 'Phased Array' microphone system of Tony Faulkner (http://www.sengpielaudio.com/TonyFaulknerPhasedArray06.htm)
- Software tool to predict the radiation pattern of an antenna array (http://antennaarraycalculator.blogspot.com.es/p/calculator.html)

Amateur radio direction finding

Amateur radio direction finding

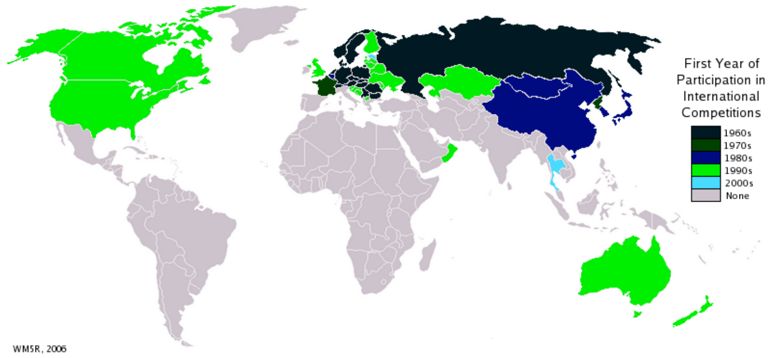
A German competitor on a 2-metre band ARDF course.

Highest governing body	International Amateur Radio Union
First played	1950s, in northern and eastern Europe
Characteristics	
Contact	Non-contact
Team members	Individual
Mixed gender	Separate categories
Type	Outdoor
Presence	

Amateur radio direction finding (**ARDF**, also known as **radio orienteering** and radiosport) is an amateur racing sport that combines radio direction finding with the map and compass skills of orienteering. It is a timed race in which individual competitors use a topographic map, a magnetic compass and radio direction finding apparatus to navigate through diverse wooded terrain while searching for radio transmitters. The rules of the sport and international competitions are organized by the International Amateur Radio Union. The sport has been most popular in Eastern Europe, Russia, and China, where it was often used in the physical education programs in schools.

ARDF events use radio frequencies on either the two-meter or eighty-meter amateur radio bands. These two bands were chosen because of their universal availability to amateur radio licensees in all countries. The radio equipment carried by competitors on a course must be capable of receiving the signal being transmitted by the five transmitters and useful for radio direction finding, including a radio receiver, attenuator, and directional antenna. Most equipment designs integrate all three components into one handheld device.

History



Nations that have participated in major international competitions since the first European Championship in 1961

The sport originated in Northern Europe and Eastern Europe in the late 1950s. Amateur radio was widely promoted in the schools of Northern and Eastern Europe as a modern scientific and technical activity. Most medium to large cities hosted one or more amateur radio clubs at which members could congregate and learn about the technology and operation of radio equipment. One of the activities that schools and radio clubs promoted was radio direction finding, an activity that had important civil defense applications during the Cold War. As few individuals in Europe had personal automobiles at the time, most of this radio direction finding activity took place on foot, in parks, natural areas, or school campuses. The sport of orienteering, popular in its native Scandinavia, had begun to spread to more and more countries throughout Europe, including the nations of the Eastern Bloc. As orienteering became more popular and orienteering maps became more widely available, it was only natural to combine the two activities and hold radio direction finding events on orienteering maps.

Interest in this kind of on-foot radio direction finding activity using detailed topographic maps for navigation spread throughout Scandinavia, Eastern and Central Europe, the Soviet Union, and the People's Republic of China. Formal rules for the sport were first proposed in England and Denmark in the 1950s.[1] The first European Championship in the sport was held in 1961 in Stockholm, Sweden. Four additional international championships were held in Europe in the 1960s, and three more were held in the 1970s. The first World Championship was held in 1980 in Cetniewo, Poland, where competitors from eleven European and Asian countries participated. World Championships have been generally held in even-numbered years since 1984, although there was no World Championship in 1996, and there was a World Championship in 1997. Asian nations began sending national teams to international events in 1980, and teams from nations in Oceania and North America began competing in the 1990s. Athletes from twenty-six nations attended the 2000 World Championship in Nanjing, China, the first to be held outside of Europe.Wikipedia:Link rot[2]


A member of the Republic of Korea national team sprints to the finish line of an eighty meter ARDF course.

As the sport grew in the 1960s and 1970s, each nation devised its own set of rules and regulations. The need for more clearly defined and consistent rules for international competitions led to the formation of an ARDF working group by the International Amateur Radio Union (IARU) in the late 1970s. The first ARDF event to use the new standardized rules was the 1980 World Championship. These rules have been revised and updated over the years, increasing the number of gender and age categories into which competitors are classified, as well as formalizing the start and finish line procedures.[3] While some variations exist, these standardized rules have since been used worldwide for ARDF competitions, and the IARU has become the principal international organization promoting the sport. The IARU divides the world into three *regions* for administrative purposes. These regions correspond with the three regions used by the International Telecommunications Union for its regulatory purposes, but the IARU has also used these regions for sports administration. The first IARU Region I (Europe, Africa, the Middle East, and ex-USSR) Championship was held in 1993 in Chtelnica, Slovakia,Wikipedia:Link rot the first IARU Region III (Asia and Oceania) Championship was held in 1993 in Beijing, China,Wikipedia:Link rot[4] and the first IARU Region II (North and South America) Championship was held in 1999 in Portland, Oregon, USA. In addition to participation in international events, most nations with active ARDF organizations hold annual national championships using the IARU rules.

ARDF is a sport that spans much of the globe. In 2012 over 570 athletes from thirty-three countries, representing four continents, entered the 16th World Championships held in Kopaonik, Serbia [5] Organized ARDF competitions can be found in almost every European country and in all the nations of northern and eastern Asia. ARDF activity is also found in Thailand, Australia, New Zealand, Canada, and the United States. Although they represent a broad range of amateur radio interests in their nations today, several member societies of the International Amateur Radio Union were originally formed for the promotion and organization of the sport and continue to use the term *radiosport* in their society name. These include the Federation of Radiosport of the Republic of Armenia (FRRA),[6] the Belarusian Federation of Radioamateurs and Radiosportsmen (BFRR),[7] the Chinese Radio Sports Association (CRSA),[8] and the Mongolian Radio Sport Federation (MRSF).[9] To promote the sport, the IARU has delegated individuals as ARDF Coordinators for each IARU region to help educate and organize national radio societies and other ARDF groups, especially in nations without prior activity in the sport.

Description of competition and rules

The rules used throughout the world, with minor variations, are maintained by the IARU Region I ARDF Working Group.[10] Although these rules were developed specifically for international competitions, they have become the de facto standard used as the basis for all international competitions worldwide.

An ARDF competition normally takes place in diverse wooded terrain, such as in a public park or natural area but competitions have also been held in suitable suburban areas. Each competitor receives a detailed topographic map of the competition area. The map will indicate the location of the start with a triangle and the location of the finish with two concentric circles. Somewhere within the competition area designated on the map, the meet organizer will have placed five low power radio transmitters. The locations of the transmitters are kept a secret from the competitors and are not marked on the map. Each transmitter emits a signal in Morse code by which it is easily identifiable to the competitors. The transmitters automatically transmit one after another in a repeating cycle. Depending on entry classification, a competitor will attempt to locate as many as three, four, or all five of the transmitters in the woods, and then travel to the finish line in the shortest possible time. Competitors start at staggered intervals, are individually timed, and are expected to perform all radio direction finding and navigation skills on their own.

Standings are determined first by the number of transmitters found, then by shortest time on course. Competitors who take longer than the specified time limit to finish may be disqualified.

ARDF events use radio frequencies on either the 2-meter or 80-meter amateur radio bands. These two bands were chosen because of their universal availability to amateur radio licensees in all countries. Each band requires different radio equipment for transmission and reception, and requires the use of different radio direction finding skills. Radio direction finding equipment for eighty meters, an HF band, is relatively easy to design and inexpensive to build. Bearings taken on eighty meters can be very accurate. Competitors on an eighty meter course must use bearings to determine the locations of the transmitters and choose the fastest route through the terrain to visit them. Two meters, a VHF band, requires equipment that is relatively more complicated to design and more expensive to build. Radio signals on two meters are more affected by features of the terrain. Competitors on a two meter course must learn to differentiate between accurate, direct bearings to the source of the radio signal and false bearings resulting from reflections of the signal off hillsides, ravines, buildings, or fences. Large national or international events will have one day of competition using a 2-meter frequency and one day of competition using an 80-meter frequency.

In addition to the rules of the sport, ARDF competitions must also comply with radio regulations. Because the transmitters operate on frequencies assigned to the Amateur Radio Service, a radio amateur with a license that is valid for the country in which the competition is taking place must be present and responsible for their operation. Individual competitors, however, are generally not required to have amateur radio licences, as the use of simple handheld radio receivers does not typically require a license. Regulatory prohibitions on the use of amateur radio frequencies for commercial use generally preclude the awarding of monetary prizes to competitors. Typical awards for ARDF events are medals, trophies, plaques, or certificates.

Entry categories

Although all competitors at an ARDF event use the same competition area and listen to the same set of five transmitters, they do not all compete in the same category. Current IARU rules divide entrants into different categories based on their age and gender. Only the M21 category must locate all five transmitters, while the other categories may skip only a specified transmitter or transmitters.

An ARDF competitor in the W19 category on an eighty meter course.

- M19—Men ages 19 and younger, 4 or 5 transmitters
- M21—Men of any age, 5 transmitters
- M40—Men ages 40 and older, 4 or 5 transmitters
- M50—Men ages 50 and older, 4 or 5 transmitters
- M60—Men ages 60 and older, 3 or 4 transmitters
- M70—Men ages 70 and older, 3 or 4 transmitters
- W19—Women ages 19 and younger, 4 or 5 transmitters
- W21—Women of any age, 4 or 5 transmitters
- W35—Women ages 35 and older, 4 or 5 transmitters
- W50—Women ages 50 and older, 3 or 4 transmitters
- W60—Women ages 60 and older, 3 or 4 transmitters

Youth competitions

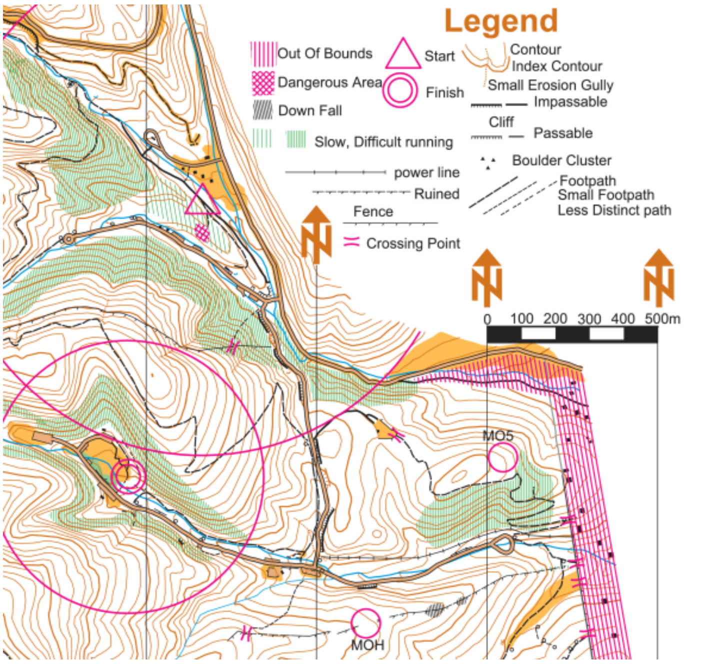
The International Amateur Radio Union rules for ARDF competitions include provisions for youth competitions. These competitions are restricted to competitors aged fifteen years or younger. The course lengths are shorter (up to six kilometers), the transmitters may be located closer to the start (500 meters), and a course setter may require that fewer transmitters be located.

Local variations

The IARU rules go into great detail about certain procedures that are unique to international championships events. Not every ARDF competition follows all of these rules. Common variations to the generally accepted rules exist at local events. Most smaller events do not have large juries or on-course referees. Some events will use simpler start procedures, such as using only one starting corridor instead of two. ARDF events on the two meter band in North America sometimes use frequency modulation instead of amplitude modulation for the transmission of the Morse code identifications.[11]

Map and course details

Ideally, the topographic maps used in ARDF competitions are created using the International Specification for Orienteering Maps 2000 (ISOM) [12] set by the International Orienteering Federation and used for orienteering competitions. In fact, many ARDF competitions use existing orienteering maps, in collaboration with the orienteering clubs that created those maps.



A portion of an orienteering map marked for an ARDF competition. Here, labeled circles indicate the locations of two of the five transmitters, but these do not appear on the maps given to competitors.

Course design is an important element of a successful competition. The international rules adopted by the IARU include both requirements and recommendations for basic course design. Important requirements are that no transmitter may be within 750 meters of the start, no transmitter may be within 400 meters of the finish or any other transmitter on course, and that there is no more than 200 meters elevation change between the start, finish, and all transmitters. The IARU rules for international competitions recommend that courses be designed for six to ten kilometers of total travel distance through the terrain. A well-designed course will present the competitors with an athletic challenge in addition to the challenges of land navigation and radio direction finding. Depending on the course design and competition, winning times at World Championship events are often less than 90 minutes for two meter courses, and can be under 60 minutes for eighty meter courses.[13]

Equipment and clothing

ARDF equipment is a specialty market, and much of what is available for purchase comes from small commercial vendors or small-batch production by individuals. Building equipment, such as handheld antennas, from published designs or kits is also a popular activity.[14] Clothing and other equipment is sold through specialty orienteering equipment suppliers or general outdoor sports retailers.

Transmitter equipment

ARDF transmitters have a low power output and operate in either the two meter or eighty meter amateur radio band. The transmissions are in Morse code. Each transmitter sends a unique identification that can be easily interpreted even by those unfamiliar with the Morse code by counting the number of dits that follow a series of dashes. The transmitters on course all transmit on the same frequency and each transmit in sequence for one minute at a time in a repeating cycle. Within a few meters of each transmitter, an orienteering control flag and punch device will be present. For many events and all major events the punch device is an electronic system, such as SPORTident, used in orienteering competitions. This records the time competitors visit each control on a small device that they carry. An alternative is to use pin punches which the competitor uses to make a distinct pattern on a control card they carry. Competitors need to locate the control flag at the transmitter site and use the punch device to record their visit. Good course design will attempt to preclude, as much as possible, runners interfering with the transmitter equipment as they approach the control. At large international or national events, jurors might be present at transmitter controls to ensure fair play.

A transmitter, orienteering control flag, paper punch and electronic punch device at an ARDF control.

The IARU rules include detailed technical specifications for transmitter equipment.[] Transmitters for two meters are typically 0.25 to 1 watts power output, and use keyed amplitude modulation. The transmitter antennas used on two meters must be horizontally polarized and omnidirectional. Transmitters for eighty meters are typically one to five watts power output keyed CW modulation. The transmitter antennas used on eighty meters must be vertically polarized and omnidirectional. It is common for the transmitter, a battery, and any controlling hardware to be placed inside a weatherproof container such as an old ammunition case or large plastic food storage container for protection from the elements and wildlife.

Receiver equipment

A homemade eighty meter receiver

The radio equipment carried on course must be capable of receiving the signal being transmitted by the five transmitters and useful for radio direction finding. This includes a radio receiver that can tune in the specific frequency of transmission being used for the event, an attenuator or variable gain control, and a directional antenna. Directional antennas are more sensitive to radio signals arriving from some directions than others. Most equipment designs integrate all three components into one handheld device. On the two meter band, the most common directional antennas used by competitors are two or three element Yagi antennas made from flexible steel tape. This kind of antenna has a cardioid receiving pattern, which means that it has one peak direction where the received signal will be the strongest, and a null direction, 180° from the peak, in which the received signal will be the weakest. Flexible steel tape enables the antenna elements to flex and not break when encountering vegetation in the forest. On the eighty meter band, two common receiver design approaches are to use either a small loop antenna or an even smaller loop antenna wound around a ferrite rod. These antennas have a bidirectional receiving pattern, with two peak directions 180° apart from one another and two null directions 180° apart from one another. The peak directions are 90° offset from the null directions. A small vertical antenna element can be combined with the loop or ferrite rod antenna to change the receiving pattern to a cardioid shape, but the resulting null in the cardioid is not as sensitive as the nulls in the bidirectional receiving pattern. A switch is often used to allow the competitor to select the bidirectional or cardioid patterns at any moment. ARDF receiver equipment is designed to be lightweight and easy to operate while the competitor is in motion as well as rugged enough to withstand use in areas of thick vegetation.

Clothing

The IARU rules specify that the choice of clothing is an individual decision of the competitor, unless the meet director specifies otherwise. Although comfortable outdoor clothing is all that is required for participation, specialty clothing developed for the sport of orienteering is also worn by ARDF competitors. Nylon pants, shirts, or suits, gaiters or padded socks for lower leg protection, and specialty shoes for cross-country running through wooded terrain are popular choices. Some competitors may choose to carry food or water on course, and wear a small waist pack or hydration pack for this purpose. At large international or national events, competitors may be required by the meet director to wear identifying numbers pinned to their clothing, and many wear team uniforms in their national colors.

Other equipment

In addition to the radio equipment and topographic map, an ARDF competitor uses a magnetic compass for navigation. The most popular compass types are those that are also popular for use in orienteering. Some events may require or suggest that competitors carry a whistle for emergency use. In at least one World Championship event, competitors were provided with cards written in the native language of the host country, intended to aid in communications with local citizens in the event that a competitor needed emergency aid or directions. In general, the use of cellular phone, or two-way radio equipment on course is prohibited. All competitors are encouraged to wear a watch to keep track of their time on course and not finish over the time limit set for the competition.

Variations

Sprint events have shorter courses with an expected winning time of 15 minutes and use either a 1:5000 or 1:4000 map. They use lower powered transmitters on the eighty metre band which transmit in sequence for only 12 secs with the cycle repeating every minute. The IARU Region 1 Rules [15] require 2 sets of 5 transmitters where each set operates on a different frequency. The Morse code transmitted by the second set of transmitters is slightly faster (PARIS 70) than the first set (PARIS 50) to differentiate the two sets. There is also a "spectator" control and a "beacon" control which both operate on different frequencies to the other ten, so four frequencies are used in total. It is possible to combine the spectator control with the beacon control. Competitors start at 2 min intervals and have to visit between 3 and 5 controls out of the first set (according to their age class) before visiting the compulsory spectator control. They then visit the requisite controls from the second set before punching the compulsory beacon control, prior to finishing.

Fox Oring is a variation of the sport that requires more orienteering skills. In a Fox Oring course, the radio transmitters put out very little power, and can be received over only very short distances, often no more than 100 meters. The location of each transmitter will be indicated on the map with a circle. The transmitter does not need to be exactly at the circle's center or even located inside the circle, but one should be able to receive its transmissions everywhere within the area indicated by the circle. A competitor must use orienteering skills to navigate to the area of the circle on the map and only then use radio direction finding skills to locate the very low power transmitter.[16]

Another variation of the sport, Radio Orienteering in a Compact Area, requires less athletic skill and more technical radio direction finding skills. In a ROCA course, the transmitters put out very little power, typically 10 to 200 mW, and can be received over only very short distances. The transmitters are physically small, and marked with a control card that is no larger than a typical postcard with a unique number identification. Because of the low power and short distances involved, most ROCA competitors walk the entire course, and focus their attention on the radio direction finding tasks rather than navigation.[17]

Another form of recreational radio direction finding activity in North America that includes the use of automobiles for transportation is most often referred to as *foxhunting* or *transmitter hunting*, but is sometimes confused with the organized international sport of amateur radio direction finding.

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External links

ARDF organizations

- International Amateur Radio Union (IARU) (http://www.iaru.org/)
- ARDF in IARU Region I (http://www.ardf-r1.org/)
- ARDF in IARU Region II (http://www.ardf-r2.org/)
- ARDF in IARU Region III (http://www.iaru-r3.org/ardf/r3ardf.htm)

ARDF Events

- 2012 ARDF World Championships (http://ardf.darc.de/contest/12091215/12091215.htm)
- 2010 ARDF World Championships (http://www.darc.de/referate/ardf/contest/10091517/10091517.htm)
- 2008 ARDF World Championships (http://www.darc.de/referate/ardf/contest/08090406/08090406.htm)
- 2006 ARDF World Championships (http://www.darc.de/ardf/contest/06091416/06091416.htm)
- 2004 ARDF World Championships (http://www.darc.de/ardf/contest/04090911/04090911.htm)

ARDF Information

- ARDF web sites of IARU member societies (http://www.ardf-r1.org/links.htm)
- ARDF web sites organized by country (http://www.pejla.se/ardf_links_swe.htm)
- Radio orienteering simulator RASOR (http://www.pejla.se/ardf_games.htm)
- web site of german ardf group (http://www.peilsport.de)

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