RADIO DIRECTION FINDING

by Fritz Nusser

1. Introduction

In fact the idea of Radio Direction Finding (RDF) already was born, when *Heinrich Hertz* discovered the directional property of radio waves. Antennas with directional qualities will enhance fieldstrength of the wanted signal and supress - in the best case - unwanted signals from different directions. In a first approximation we suspect the origin of the signal in the direction with the highest fieldstrength. Two or more reasonably spaced RDF stations allow triangulation of the transmitter.
Military users soon recognized the value of additional tactical and strategical informations and WW I and WW II brought us triumphant advances of RDF in all aspects. RDF is part of passive EWF (Electronic WarFare), the targeted station tries to radiate information in a narrow beam to its addressee, thus avoiding detection by RDF. Today equipment for all modes and wavelengths is sold, although RDF has lost importance as a navigational aid since the introduction of GPS.
Non-professional users as well can profit from RDF, if they opt for a suitable system. This short overview shows aspects of professional RDF and hopefully might give some advice to the inclined hobbyist.

2. A (very) short history of RDF

Early RDF systems were rotating dipoles and loops or the *Star RDF.*
The first ones yield ambiguous results with two maxima vertical to the plane (dipole) or in the plane (loop). A second signal from an isotropic auxiliary antenna had to be added to the signal to suppress the signal from the "wrong" side (see Fig.1).
The Star RDF consisted of 48 longwires of 60 m length in a star-shaped array. A loop goniometer scanned the individual antennas for maximum signal. Already 1920 many merchant ships used RDF loops and 1922 German aircrafts had loops and auxiliary antennas stretched in their wings for navigation as well as for RDF.

*Bellini and Tosi*invented the **Bellini-Tosi Gonimeter**, but it took many years until production. A coil is rotated inside an electrical field fed from the N-S and E-W antenna signal components such finding the angle of maximum signal. The antenna can be a **Crossed-Loop Antenna** or an **Adcock Antenna**.
*Adcock*proposed an array of 4 or more vertical monopoles or dipoles erected in a circle; two opposite antennas deliver a signal from their direction. Obviously more antenna pairs yield stronger signals and higher accuracy. **Krug Antennas** (Wullenwebers) are a huge array of vertical elements, arranged in a multitude of concentric circles.

Watson-Watt fed the N-S and E-W signal components of the Bellini-Tosi Goniometer to the deflection plates of a CRT - real-time RDF became true. Later on the goniometer coil was motor-driven and both channels (and the auxiliary) used individual RF amplifiers for high sensitivity. This was the 3-channel RDF, widely used since around 1950. The early *TELEGON* Series from *TELEFUNKEN* were typical examples of that technique and if you ever were doomed to adjust those monsters for synchronous phase and gain in all three amplifiers, you'll remember for ever.

For HF the **Adcock/Watson-Watt** lay-out remained the standard system until today, although goniometer motors were replaced by solid-state devices and the long Adcock monopoles nowadays alternatively can be active verticals of 1m height (R & S) or Crossed-Loops with a vertical monopole in the centre of the ring.
The synthesized receiver opened new horizons, because now results remotely commanded could be transmitted from all stations to the NCS: **Automated RDF** became reality. Digital results furthermore allowed the application of statistical methods for sampling and evaluation of results with a dramatic increase of accuracy and precision. Even site-inherent - and equipment errors could be corrected for now.

Doppler RDFsystems use circularly arranged vertical dipoles, which are scanned. After each scanning cycle - a few ms - the difference in frequency between the individual antennas (Doppler effect) allows the calculation of the direction of the radiation source.

The **Correlation Interferometer RDF** measures the angle of the incident wavefront by comparing the phase at different antenna elements of the array, which mostly is arranged in an L-shape.
DSP based RDF with sensor array processing allow quasi simultanous handling of several waves arriving from different directions. They are the base for **Multichannel RDF** equipment where a multitude of parameters can be on display: DF values vs. frequency and time, signal strength vs. frequency, signal strength vs. time, etc. Thus even frequency hopping systems can be tackled.

So far we assumed **fixed-site applications**, but a few systems prove to be good for **mobile use** as well: Crossed-Loop Antennas (mostly shipboard), Adcock antennas for VHF/UHF (tactical DF, law enforcement) or Doppler arrays. The use of mobile systems is clearly limited by the dimensions of the antenna for a given frequency range, the constant rocking of the antenna (ships) and the ever changing reflections in varying surroundings.

Equipment for mobile near field RDF needs be mentioned here as well. It mostly is made up of loops or **Ferrite Rod Antennas** and is used for groundwaves only. Ferrite antennas work fine for the purpose, although their sensitivity is low compared with loops, because of their very **low Effective Height**.
Another, military near-field, RDF I was trained on many years ago. It might be similar to the famous **Kapsch „Guertelpeiler„** from WW II. As far as I remember, the receiver somehow was buckled on the poor soldiers body, from there wires, the antenna, ran into each sleeve, the wrist-watch contained some controls and a howling tone in the earphones indicated: nearly there! What was meant to be an unobtrusive method to pinpoint clandestine stations raised a laugh when that guy turned up, spreading his arms like a scarecrow and consulting his wrist-watch....

3. Performance and limitations of RDF systems

For casual RDF rotating antennas (Ferrite rods for groundwaves, directional beam antennas or loops for HF/VHF) will do the job. They are adjusted for minimum audio signal, which is easier to find than maxima. Results are ambiguous, but in many cases that's ok.

For professional systems **amplitude-comparison** Watson-Watt RDF is widely applied. The most used type of antennas are Adcocks and Crossed-Loops. An Adcock Antenna array consists of 4 to 12 vertical monopoles, rarely dipoles, arranged in one or two circles of 12 to 50 m diameter. The monopoles may be replaced by very smart active antennas of only 1 m height or by Crossed-Loops. A single Crossed-Loop is made of two loops, one mounted perpendicular inside the other. The diameter normally is around 1 m.

In **phase-comparison** systems three or more elements of an antenna array are such arranged, that the relative phases of their signals are unique for every incident wavefront. Bearings are computed by analyzing the relative phases. Correlation Interferometers antennas mostly are arranged in a L-shape of typically 50 ...150 m length, **Doppler Antennas** normally consist of a ring of dipoles. They mainly are used for VHF/UHF.

How do the different systems compare?
Auxiliarx RDF with rotating antennas is not meant to compete with "grown-up" systems, but they can, in many cases, be of help to confirm a signals origin or suppress a source of noise - and that's not bad at all. However the use of directional beams is limited by their dimensions and direction sensing is not possible. Untuned loops and especially Ferrite rods suffer from a **low Effective Height** resulting in poor sensitivity.There is no display of the bearing.

Dedicated Watson-Watt RDF with Crossed-Loops or Adcock Antennas present online bearings on a CRT or TFT. Digital data furthermore allow statistical evaluation and correction for systematic errors. Both antennas react sensitive on **multipath reception** and on **reflections** of the wavefront on nearby structures of "suitable" length. Crossed-Loops always should be mounted "on top". They don't like other antennas, buildings, chimneys or your clothesline. Adcocks are allergic to buildings and power lines. Crossed-loops are reasonable sensitive, but they are much affected by polarization errors in steep skywaves during the local night **(Night Effect)**. Adcocks are much more tolerant of **polarization errors** and their sensitivity is much better than for crossed-loops. When an Adcock Antenna uses crossed-loops instead of monopoles "SSL" is possible: the systems can measure azimuth **and elevation** of the incident wavefront and calculate the distance to the source (only works for one hop).

Correlation Interferometers consist of 6...9 monopoles or Crossed-Loops arranged in L-shape or in a circle of about 50 m diameter. Incident waves up to about 80°(!) can be evaluated, the system is not sensitive for polarization errors. Interferometers are, contrary to loops and Adcocks, not sensitive for reflected waves, because they are, like Dopplers, **wide-aperture systems**. Wide-aperture in this context refers to antenna spacings near one wavelength or beyond. This means, that the software can handle site errors and correct them.

Professional fixed-site RDF for HF today will use either one of several possible Adcock Antenna arrays and a Watson-Watt bearing processor or a Correlation Interferometer with all the nice electronics associated. Results are not judged visually, sophisticated algorithms at the NCS employ statistical methods for filtering and correction of the bearing results.

4. RDF for non-professional users

There is, after all, little doubt about what we would prefere for our station. But: only few people are lucky owners of a plot of land, free of power lines and road traffic, ready to install a full sized Adcock Antenna. Costs are quite high and installation comprises concrete foundations with grounding meshes, cable connections buried in earth and a rather demanding site calibration. However, RDF for non-professionals is within reach, **if we make some compromises.**

If you decide, you would like to go beyond the possibilities of casual RDF, you might consider an untuned Crossed-Loop antenna with Watson-Watt bearing processor and CRT display. The antenna is small, installation is easy and the results are acceptable. Such equipment is produced mainly for navigational purposes onboard trawlers, if they don't want to rely on GPS only. After many e-mails and discussions I finally opted for Japanese company **TAYO MUSEN's TD-C358**, which since a few weeks is operational in my Shack. The equipment is distributed by several representatives; in my case Danish company Hans Buch A/S proved to be a good and reliable partner. Prices are locally fixed, the complete set sells at around EUR 10'000.-- (add VAT, transport and customs).

The RDF TD-C358 is specified for frequencies between 200 kHz and 16 MHz. It comes along with a Crossed-Loop Antenna of 0.8 m dia., 30 m of 7-core coax connecting cable (not to be shortened), an external loudspeaker, all manuals (including circuit diagrams and fault finding tables) and even some spare parts.

Installation is straightforward. The delivered antenna flange should be welded on top of a mast with the cable running inside. Adjust the antenna with a compass. The connecting cable must be fixed carefully, with 30 kg it is quite heavy. Use a sleeve, if exposed to the sun. Additionally any 50 Ohm antenna can be connected for receive-only mode. This RDF does not need an auxiliary antenna for sensing, the vertical signal component is taken from mid-tappings of the E-W and N-S coils within the antenna foot.

Antenna and receiver/bearing processor are for professional use on ships. Everything is very rugged and well made. No doubt, the TD-C358 is of good quality, but it is an old design. Its receiver, a double superheterodyne, may well be inferior to your receiver. It is optimized for RDF with a fixed bandwith of 2 kHz; listen-through audio quality is poor. Modes are the usual ones, frequency is set manually, via keyboard or out of 400 memory channels. Manual AGC can optimize bearings of very strong signals, normal setting is "Auto". "Clarify" control operates as a BFO. After installation, the setup can be corrected via the keyboard for phase/amplitude errors in IF filters, cables, etc. The manual gives a list of test-points to measure before sealing the antenna foot.

Because I will change QTH next year, I didn't invest too much time in **site evaluation.** The antenna now is mounted only about 80 cm above the roof of a 4-storey building in town and although the view is splendid, there are conducting structures (air ducts, elevator cabinet, my other antennas, etc) within a few meters, which reflect selectively incoming wavefronts. The connecting cable runs horizontally a long way from the antenna, a bad solution too, which at least asks for Ferrite rings every few meters. I can't expect too much from this installation, but it is reality and the results will improve next year. Every installation must include **site-calibration.** A professional near-field calibration in town is not possible and we depend on "real" stations of known origin good, reproducible signals. This procedure, for all frequencies and for all directions can be very time-consuming.

Operation of the TD-C358is easy. In the absence of a signal you should see a trace-tangle in the centre of the CRT, stress in one direction indicates an interfering signal and this means, that any usable signal must be stronger. If the troublemaker is broadband and of local origin, you're in trouble. You may well **hear** the signal in between, but you can't **see** it in between. A suitable signal however will extend the beam to a propeller-shaped Lissajou figure in two directions.
Strong signals will give long vectors on the display. By pressing "Sense" the figure is bent towards one side, thus indicating the direction to the transmitter. Bearings are read from the 360° scale. That is the ideal situation for RDF, often found with groundwaves or DX stations with low incident angles. Unfortunately practice is different, nearly always the bearing is unstable, it slowly swings around a mean value. Polarizing errors let the figure violently shake around 360° and RDF for some stations even is impossible. It needs a certain experience to find out the "correct" bearing: The vector length should be at or near maximum, the direction should be repeated and the sensed signal should be symmetric. "Correct" indicates, the system is working ok, but it cannot compensate for site-inherent errors. These can be very large or sensing becomes

even impossible. Sounds horrible, but even big Adcock Antennas, under some conditions, will deliver results, which are completely wrong. What can be done then? The answer is: repeat measurements many times and, if possible, at different days - and that's exactly what commercial systems automatically are doing. With manual RDF short duration signals virtually are hopeless.

The **quality of bearings** therefore is very different. Bearings of groundwaves normally will be within a few degrees off the true value. The same is valid for DX stations above 10 to 16 MHz, arriving under flat angles. Most other bearings will be true between +/- 5° up to +/- 25°, the last value often indicates, that measurement could not be repeated. A site calibration is an absolute must for reasonable results. Finally there is "mission impossible", no way to get any decent results: Signal too weak, steep incident angle, local reflections, etc. FSK transmissions sometimes create such problems, when the two, or more, frequencies cause totally different reflections and several vectors point in all directions.

Can we, under these circumstances, justify the whole effort to operate RDF? Yes, we can, because: RDF is just one of many ways to gather information on HF signals. This means that we normally have more facts, like language, callsign, propagation properties, transmission mode or skeds, which have to match our bearings. As an example, a network is heard on several frequencies and we wonder, if one or several transmitters are used. RDF will give an answer, even if the direction cannot be defined exactly. Or we can prove, a station is mobile, because its movements are large enough, e.g. ships. Beware of Broadcasters, your strange bearing may be perfectly ok, but international services constantly change their transmitters Always, however, we can only find out the direction of a station and not the location; I cannot, from my QTH, discriminate between transmissions from Afghanistan, Pakistan or India and between China and the Korea purely by RDF.

To sum it up, the TD-C358 mostly will give good results, if enough bearings can be taken and if the installation has been properly calibrated; some experience is needed. When the bearings, for one or another reason, are inaccurate, they still will deliver valuable additional informations. "Impossible" bearings and those, which quite simply are wrong, are system-inherent and have to be accepted, never try to "adjust" a bearing until it fits your theory.
I would wish, this may help you to decide, whether you might want to try RDF for yourself one day.

5. References

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