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WN-007

Web Note

QUESTIONS & ANSWERS: A USER'S GUIDE TO USING LOOP VERSUS ADCOCK RADIO DIRECTION FINDING ANTENNAS

This Web Note discusses the advantages and disadvantages of loop and Adcock DF antennas in Watson-Watt radio direction finding systems in an informal, easy-to-read Question & Answer format. It is especially intended for users who are new to the field, and specifically addresses frequently asked questions.

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Question: I'm new to radio direction finding, so could you please explain to me the exact function of Adcocks and loops in Watson-Watt radio direction finding systems?

Answer: As explained more fully in Web Note WN-001 ("Basics Of The Watson-Watt DF Technique", available from the RDF Products website and Publications CD), a DF antenna array compatible with a Watson-Watt DF receiver/bearing processor is required to produce two orthogonally-oriented bi-directional "figure-of-eight" gain patterns in the horizontal plane. The two most common antenna configurations employed to obtain this desired gain pattern are the Adcock aerial pair and the loop. This bi-directional pattern is illustrated in Figure 1. For good bearing accuracy, the lobes should be circular and of the same size, and the nulls very deep.

Q: What is an Adcock aerial pair?

A: To construct an Adcock aerial pair, two omnidirectional antennas (usually monopoles or vertical dipoles) are spaced apart by some fraction of a wavelength in the same horizontal plane. The outputs from these two antennas are then combined using a special network that vectorially subtracts these two outputs. The resulting azimuthal gain pattern is the desired bi-directional pattern illustrated in Figure 1, with the peaks occurring along the axis of the two antennas and the nulls occurring broadside. Two such Adcock aerial pairs (co-located, but orthogonally oriented) are required to construct a standard four-aerial Adcock DF antenna suitable for a Watson-Watt DF system as illustrated in Figure 2.

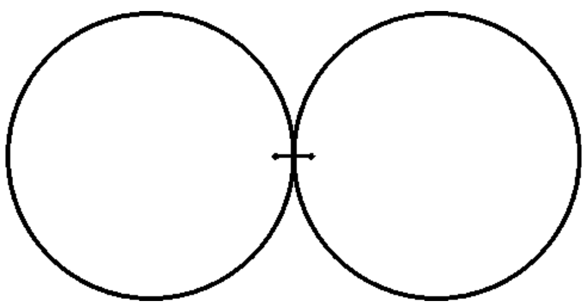


Figure 1 - Bi-directional Azimuthal Gain Pattern

Figure 2 - Mobile Adcock DF Antenna

Q: Help me understand this bi-directional gain pattern in Figure 1. What am I seeing here?

A: Figure 1 is a "bird's eye" view of the gain pattern, looking down on the Adcock aerial pair, where the two dots at the end of the short line indicate the location (tips) of the two vertical aerials.

Q: OK, that helps, but what exactly do you mean by "azimuthal gain pattern"?

A: The azimuthal gain pattern can be thought of as a sensitivity plot. Imagine for a moment that an assistant is holding a transmitter at some distance from the Adcock aerial pair while you are monitoring the resulting voltage produced from the Adcock aerial pair output terminals. You then direct your assistant to walk the transmitter in a path that consistently maintains this same output voltage. This path would then appear as the figure-of-eight horizontal (azimuthal) gain pattern of Figure 1.

Q: How far apart should the two omnidirectional antennas comprising the Adcock aerial pair be spaced?

A: There are two fundamental constraints. On the one hand, we want the spacing to be as wide as possible for best sensitivity. If the spacing is too narrow, sensitivity is reduced and accurate balancing becomes more difficult to obtain (imbalances result in bearing errors). On the other hand, if the spacing is too wide, the lobes become distorted (i.e., they lose their circularity), which also results in bearing errors. A fairly comfortable spacing range is 1/10 to 1/3 of a wavelength at the operating frequency, although this range can be extended if necessary for a wide coverage DF antenna if some bearing accuracy and sensitivity trade-offs can be accepted.

Q: What is a loop?

A: Fundamentally, a loop is constructed by winding one or more vertically-oriented turns of wire (typically in a circular or rectangular configuration), with the feedpoint placed in series (usually at the base). Operation is actually very similar to that of the Adcock aerial pair as discussed above, with the same bi-directional azimuthal gain pattern as illustrated in Figure 1. The peaks occur along the loop axis, while the nulls occur broadside. Figure 3 is a pictorial illustration of a loop antenna. Two such loops (co-located, but orthogonally oriented) are required to construct a loop DF antenna suitable for a Watson-Watt DF system.

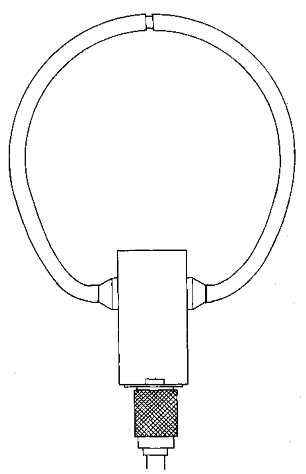


Figure 3 - Loop Antenna

Q: How large should the loop be?

A: This is a matter of some controversy. On the one hand, the literature states that the total linear length of the loop element (whether it is a single- or multi-turn loop) should be no greater than 1/10 of a wavelength at the highest operating frequency. When this constraint is met, current through-out the loop remains in-phase and the loop can be conveniently analyzed as a radiating inductor. On the other hand, loops constrained to this size are very small and thus exhibit poor sensitivity. Common practice in radio direction finding applications for a single-turn loop is to limit the diameter to no greater than 1/10 wavelength at the highest operating frequency (although this is really too large as will be subsequently explained).

Q: Why does the loop have to be so small?

A: In an ideal situation where the received signal is purely vertically-polarized, the loop can actually be much larger (and thus more sensitive). In real-world situations, however (i.e., as soon as the DF antenna is moved off of the vendor's carefully controlled test range), received signals invariably contain horizontally-polarized components. The loop's response to these horizontally-polarized components is such that the bi-directional azimuthal gain patter of Figure 1 becomes distorted (the nulls become filled-in) causing serious bearing errors. All loop antennas are vulnerable to this problem, but the magnitude of this vulnerability greatly increases for larger loops.

Q: I'm going to have more questions regarding the loop's susceptibility to bearing errors caused by horizontally-polarized signals in a moment, but first I would like to know if the loop's small size is always a disadvantage.

A: It is from the standpoint that its small size diminishes sensitivity (when it comes to antennas, bigger is usually better). This can be greatly mitigated if the loop antenna is tuned to resonance, but a tuned loop can operate only over a narrow bandwidth (typically less than 5% of the resonant frequency). On the other hand, the fact that a loop is still functional even though it is very small can be an important advantage at lower frequencies (particularly in mobile DF systems) where an Adcock would be so large as to be impractical. This compactness can be further enhanced using ferrite loops.

Q: What is a ferrite loop?

A: A ferrite loop is an ultra-compact multi-turn loop antenna wound on a ferrite rod. A familiar example of a ferrite loop is the loopstick antenna found inside most AM broadcast receivers. The presence of the ferrite provides a sensitivity enhancement.

Q: Are ferrite loops more sensitive than the type of loop antenna illustrated in Figure 3?

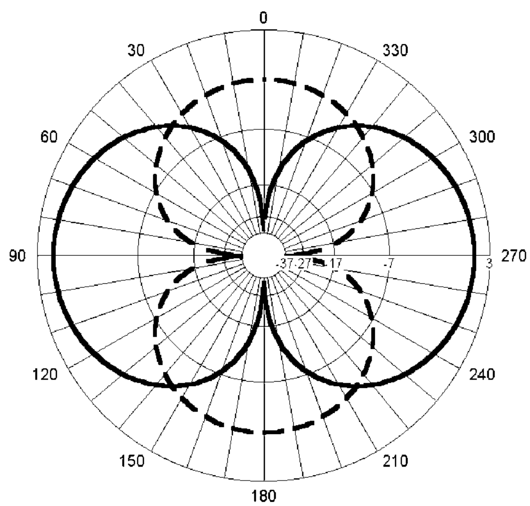
A: No. Although the "air" loop of Figure 3 does not employ a ferrite to enhance sensitivity, it is still much more sensitive than a comparable ferrite loop as a result of its much larger size.

Q: How does the sensitivity of a loop compare with that of an Adcock?

A: In most instances, it is much worse. This issue is discussed in some depth in Application Note AN-002 ("A Comparison of Loop and Adcock DF Antennas for Single-Frequency Fixed-Site DF Applications", available from the RDF Products website and Publications CD).

Q: I would like to return to the issue of loop antenna susceptibility to bearing errors caused by horizontally-polarized signals so that I can have a better understanding of this issue. Can you walk me through it one step at a time?

A: Sure. As you will recall from an earlier part of our discussion, the "magic ingredient" necessary for good Adcock or loop DF antenna bearing accuracy is the ability of the bi-directional arrays to exhibit undistorted figure-of-eight azimuthal gain patterns with deep nulls as illustrated in Figure 1. Anything that compromises the quality of this gain pattern directly results in bearing errors. As it happens, a loop antenna exhibits different azimuthal gain patterns for vertically- and horizontally-polarized signals. If we were to plot both gain patterns simultaneously, the result would be as illustrated in Figure 4 where the solid and dashed lines respectively represent the vertically- and horizontally-polarized gain patterns. Notice how these patterns are orthogonally-oriented to each other.



<u>Figure 4</u> **- Loop Azimuthal Response To Vertically-Polarized (solid line) And Horizontally-Polarized (dashed line) Signals**

Q: I see that. But why is this a problem?

A: The problem is that in real-world conditions, most received signals will have both vertically- and horizontally-polarized components. If the loop is capable of responding to both components as illustrated in Figure 4, *the horizontally-polarized (dotted line) response will cause the nulls to fill-in and thereby seriously distort the overall gain pattern. The resulting composite gain pattern of a loop antenna receiving a signal having both vertically- and horizontally-polarized components might look something like that illustrated in Figure 5.* A gain pattern with such severe distortion would result in very serious bearing errors.

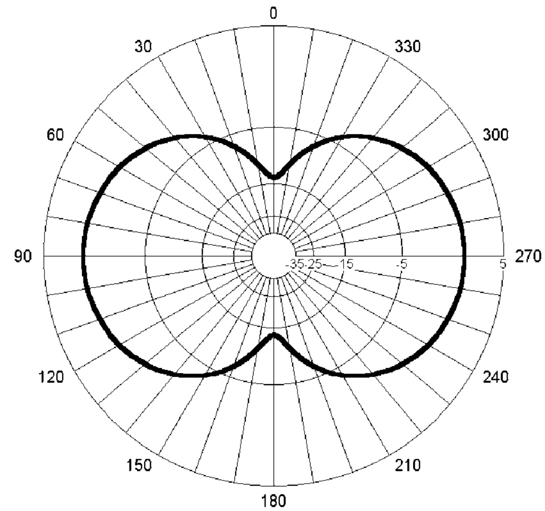


Figure 5 - Loop Composite Azimuthal Response To Signal With Mixed Vertical- And Horizontal-Polarized Components (illustrates degraded nulls that result in bearing errors)

Q: Just how important are these nulls? Can you put some numbers on this?

A: Other factors being ideal, a 40 dB null would result in a peak bearing error of 0.6 degrees, 30 dB 1.8 degrees, 20 dB 5.7 degrees, and 10 dB 17.5 degrees. Clearly, good nulls are important.

Q: I noticed that the horizontally-polarized lobes of the gain pattern of Figure 4 are smaller than the vertically-polarized lobes. Why is that?

A: The size of the horizontally-polarized lobes relative to that of the vertically-polarized lobes changes with the elevation angle of the received signal. At high elevation angles (i.e., for sky-wave signals that have been reflected off the ionosphere, for example), these lobes would be large (thus indicating a serious susceptibility of the loop to pattern distortion). These lobes gradually reduce in size for lower elevation angles, disappearing almost altogether for signals received at zero degrees elevation (i.e., on the horizon).

Q: So does that mean that for signals received at zero degrees elevation, horizontally-polarized signal components cause no adverse effect?

A: Theoretically, yes, and this is the basis for the claim made by vendors selling loop DF antennas that since "typical" signals are received mostly at or near zero degrees elevation, the horizontal polarization problem is not serious.

Q: Is it truly the case that typical signals are actually received at zero degrees elevation?

A: This claim is very doubtful at best and does not at all correspond with real-world experience. If the DF system must function in an urban environment, for example, signal reflections off high objects will certainly result in high elevation angle reception. Similarly, if the loop antenna must be mounted on an aircraft, it will often have to receive signals at significant negative elevation angles (loops are notorious for their poor performance on aircraft). Another problem that occurs is wavefront "tilt". If the ground is not perfectly conductive (as is usually the case), the received wavefront tends to tilt forward, thus effectively creating an "elevation angle" even though the signal is nominally at zero degrees elevation. There are other important reasons this "zero elevation angle exemption" does not hold water as well.

Q: What are these other reasons?

A: First of all, the range of elevation angles around zero degrees where loops can offer significant rejection of horizontally-polarized signals is very narrow. To clarify this, Figure 6 is an elevation angle plot of the response of a small diameter loop antenna to horizontally-polarized signals. Notice that even though the rejection of horizontally-polarized signals is very sharp at zero degrees elevation (i.e., on the horizon), the response increases very abruptly for small positive or negative elevation angles. Even for positive or negative elevation angles as small as 10 degrees, most of the rejection capability is already lost.

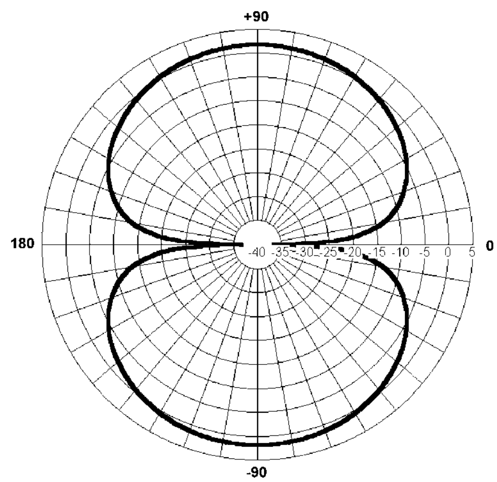


Figure 6 - Small Loop Elevation Response To Horizontally-Polarized Signal

Q: Help me understand this elevation pattern of Figure 6. What am I seeing here?

A: Figure 6 is a profile or sideways view of the gain pattern (as opposed to the "birds eye" view of Figure 1). Imagine for a moment that the loop is mounted on a tower. If a transmitter producing a horizontally-polarized signal is placed directly in front of or behind the loop (facing it broadside) at the same height, very little signal would be received (corresponding to the nulls at 0 and 180 degrees elevation in Figure 6). As the transmitter is moved in a circular pattern above or below the loop (i.e., maintaining a constant distance), the received signal would begin to increase. Maximum signal strength would be obtained with the transmitter directly over or under the loop.

Q: That makes sense. So are you saying that in a practical scenario, the ability of the loop antenna to reject horizontally-polarized signals at zero degrees elevation is of marginal practical benefit?

A: Yes. And the problem gets even worse. The ability of the loop to reject horizontally-polarized signals at zero degrees elevation is contingent upon the loop being *very* small. Some vendors attempt to use loops up into the high VHF range. In order to obtain sensitivity, these loops are rather sizeable and thereby violate the requirement that loops be very small compared to a wavelength at the highest operating frequency. As a consequence, they lose most of their ability to reject horizontally-polarized signal components at zero degrees elevation. To illustrate this, Figure 7 is an elevation plot of the response of a 6" diameter square loop to horizontally-polarized signals at 150 MHz (corresponding to a loop diameter of just under 1/10 wavelength). Note that unlike for the small diameter loop response illustrated in Figure 6, this larger loop is ineffective in rejecting horizontally-polarized signals at *any* elevation angle (including zero degrees), even though the size of this loop is still fairly modest.

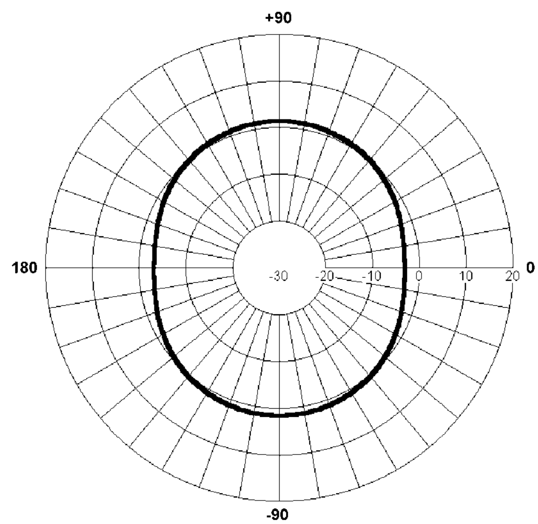


Figure 7 - 1/10 Wavelength Diameter Loop Elevation Response To Horizontally-Polarized Signal

Q: Based upon what you have said, it would seem that there is very little to recommend loops. Why would anyone use them?

A: The answer to this question requires a short digression to the history of radio direction finding. In the very early days of radio direction finding during the first part of the 20th century, loops were used almost exclusively due to the absence of better alternatives. Although loops generally worked reasonably well during the day, bearings obtained during hours of darkness exhibited large and violent fluctuations, resulting in major bearing errors and uncertainty. This "night effect" as it was then called was eventually correctly attributed to the fact that night-time reception was predominated by sky-wave propagation, resulting in horizontally-polarized signal components which caused severe distortion of the loop gain patterns (and thus major bearing errors). F. Adcock of Great Britain solved this problem during World War I by designing a phased-array type bi-directional antenna employing two spaced vertical aerials with difference-phased outputs (i.e., the Adcock aerial pair discussed above). Although similar to the loop antenna in that the same bi-directional figure-of-eight azimuthal gain pattern was achieved, this vertically-polarized "Adcock" aaerial pair was nearly impervious to bearing errors induced by horizontally-polarized signal components. Adcock patented his design in 1919 (British Patent No. 130490), and the Adcock antenna array was widely hailed as a major step forward in DF technology.

Back to the point of your question then, loops are very "traditional" and are sometimes employed on that basis alone. With the state of DF technology as we know it today, however, the only legitimate application of the loop antenna for radio direction finding is where compactness requirements preclude the use of the larger Adcock. Typical modern-day applications for loop DF antennas are compact mobile and ship-board DF antennas operating below the VHF range.

Q: Why are Adcocks so much better at providing good bearings for signals having horizontally-polarized components?

A: The vertically-oriented monopoles or vertical dipoles typically employed by Adcocks inherently reject horizontally-polarized signal components, responding instead only to the vertically-polarized signal components. The desired bi-directional azimuthal gain patterns are thus preserved. Although non-ideal ground planes for monopole Adcocks and the horizontal support boom for dipole Adcocks can diminish this rejection somewhat as discussed in AN-002, Adcocks still work far better than loops.

Q: I have seen mobile DF antennas advertised on the Internet that employ loops from the low HF range all the way up into the VHF range as high as 200 MHz. In light of what you have just said, why would any vendor use such an approach?

A: We would imagine that up through the HF range, the designer felt compelled to use loops (probably of the ferrite variety) to meet the size constraints required of a compact mobile DF antenna (even though resulting sensitivity would be very poor). To continue to use loops into the VHF range where the size constraints would permit the use of an Adcock is a bad design approach, since loop performance in the VHF range is very poor compared to that of an Adcock.

Q: Were the antenna gain plots of Figures 4-7 obtained by actual measurement or computer modeling?

A: They were obtained by computer modeling using NEC (Numerical Electromagnetics Code). NEC is a very sophisticated antenna modeling algorithm that is widely relied upon in the electromagnetics industry for accurate modeling of antennas. It has been in a constant state of evolution for the past 30 years and is considered to be the best available computer program for the modeling of wire antennas. <>