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Web Note

QUESTIONS & ANSWERS: A USER'S GUIDE TO RADIO DIRECTION FINDING SYSTEM SENSITIVITY

This Web Note discusses the basic issues associated with the definition and measurement of DF system sensitivity 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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In keeping with RDF Products' business philosophy that the best customer is well informed, RDF Products publishes Application Notes from time to time in an effort to illuminate various aspects of DF technology, provide important insights how to interpret manufacturers' product specifications, and how to avoid "specsmanship" traps. In general, these Application Notes are written for the benefit of the more technical user.

RDF Products also publishes Web Notes, which are short papers covering topics of general interest to DF users. These Web Notes are written in an easy-to-read format for users more focused on the practical (rather than theoretical) aspects of radio direction finding technology. Where more technical discussion is required, it is presented in plain language with an absolute minimum of supporting mathematics. Web Notes and Application Notes are distributed on the RDF Products Publications CD and can also be conveniently downloaded from the RDF Products website at www.rdfproducts.com.

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Question: Why is it so difficult to get straight answers from DF equipment manufacturers in response to questions regarding DF system sensitivity?

Answer: In part, this is a result of the reality that there are certain complexities and subtleties associated with this subject that are difficult to succinctly explain in plain language.

Q: Is this the only reason?

A: Unfortunately not. All too often, DF manufacturers cloak information regarding DF system sensitivity principles and measurement procedures under an aura of mystery and arcane technical jargon, the implication being that such measurements can be properly conducted only with the resources and technical expertise of the vendor. Tests conducted by users producing results that appear to be inconsistent with vendor equipment performance specifications are often challenged on the basis of procedural errors, non-ideal sites, non-calibrated test equipment, and various other factors. We strongly suspect that the real policy driving such challenges is to obfuscate the issue to prevent users from objectively and independently verifying published performance specifications. This policy also makes it more difficult for users to make legitimate "apples-to-apples" DF sensitivity comparisons between equipment manufactured by different vendors.

Q: I notice that many vendors do not publish DF sensitivity specifications. Why is this?

A: In many cases, they probably just lack the technical skill or resources required to conduct the measurements. In others, they prefer to dodge this issue because their equipment is not very sensitive.

Q: Realistically speaking, can I, as a user, reasonably expect to be able to independently conduct such DF sensitivity measurements?

A: Actually, it is quite possible for technically-oriented users to do this, and RDF Products Application Note AN-004 ("Measuring Sensitivity Of Mobile Adcock DF Antennas", available on the RDF Products Publication CD) was expressly written for this purpose. Although most users will probably not wish to attempt this, they should at least be armed with sufficient technical knowledge to be able to understand (and challenge, if necessary) the DF manufacturers' specifications.

Q: Having reviewed other RDF Products Web Notes, I understand that the three fundamental components of a DF system are the DF antenna, DF receiver, and DF bearing processor. Which of these components is primarily responsible for DF sensitivity?

A: In almost any well-designed DF system, the DF antenna is primarily responsible for DF sensitivity (as well as DF performance in general). This is primarily a result of the fact that good DF antennas are difficult to design and involve many trade-offs (especially ones that must function over wide frequency ranges).

Q: I found a DF vendor on the Internet that claimed a DF sensitivity of "1.0 microvolt" for a VHF DF system. Is this a good number?

A: This specification is totally meaningless since it does not specify any qualifying factors. Unless there is a typographical error, this vendor undoubtedly lacks the necessary technical expertise to legitimately specify DF sensitivity, much less measure it.

Q: What do you mean by "qualifying factors"?

A: A proper DF sensitivity measurement at the very minimum requires some specified *threshold criterion*. In voice communication, for example, the sensitivity of an AM receiver, might be specified as "1.0 microvolt *for a 10 dB signal-to-noise ratio (SNR)",* where the sensitivity threshold criterion is the 10 dB SNR. In the case of a data receiver, as another example, sensitivity might be specified as "0.5 microvolts *for a bit error rate (BER) of one bit out of every 10,000",* where the sensitivity threshold criterion is the BER. In both cases, these threshold criteria (SNR and BER) are *qualifying factors*. Sensitivity specifications lacking threshold criteria are completely meaningless.

Q: Are there other qualifying factors that would have to be considered in the above example?

A: Yes. It would be necessary to specify the receiver bandwidth prior to the demodulator (usually the IF bandwidth), and also the post-demodulation bandwidth as well since both of these parameters significantly influence the measurement outcome. Also, the receiver input impedance should be specified in the above example unless it is understood to be 50 ohms (as is commonly the case).

Q: So what would a proper DF system sensitivity specification look like?

A: A proper DF system specification would specify the necessary electric field strength in microvolts per meter at the DF antenna to produce a bearing with some specified amount of bearing "jitter" (uncertainty), with receiver IF (pre-demodulation) bandwidth and bearing processor (post-demodulation) bandwidth specified as qualifying factors.

Q: That's quite a mouthful. Can you break that down one item at a time, starting with the meaning of "microvolts per meter"?

A: Yes. When an receiving antenna is illuminated by an electromagnetic field (i.e., a radio wave), a signal voltage appears at the antenna output terminals as a result. The magnitude of this output voltage depends upon the characteristics of the antenna. If this antenna is a *current element* (a hypothetical wire or rod antenna where current is uniformly distributed across the element's length), and is 1.0 meter long, *its open-circuit* *(unloaded) output voltage will be equal in magnitude to that of the electric field strength of the illuminating signal.* To illustrate by example, *a wavefront with an electric field strength of 1.0 microvolt per meter will cause an open-circuit voltage of 1.0 microvolt to appear at the output terminals of this 1.0 meter long current element antenna.* Since all DF systems employ an antenna, any meaningful sensitivity specification must be given in terms of electric field strength as the input, the dimensions of which are microvolts per meter.

Q: I have seen published literature where DF manufacturers specify the DF sensitivity of their receivers alone. In one instance, a manufacturer claimed a receiver DF sensitivity of -120 dBm. Are you saying that this is not meaningful?

A: Although such a specification may be useful as a DF receiver sensitivity acceptance test benchmark when tested with a DF antenna simulator, it's not meaningful if the manufacturer does not also publish a separate specification for the sensitivity of the entire DF system (including the DF antenna) in terms of electric field strength at the DF antenna. As discussed earlier, the DF antenna is the key component of any DF system, and any quantification of DF sensitivity that omits reference to the DF antenna is meaningless at best and misleading at worst.

Q: I also noticed that a very prominent manufacturer of pseudo-Doppler DF systems specifies DF sensitivity based on dBm signal amplitude referenced to the four inputs to the antenna summer. Is this also a misleading specification?

A: Again, this specification completely ignores the efficiency/inefficiency of the DF antenna elements. You probably also noticed in this manufacturer's sensitivity specification that there is no mention of "microvolts per meter field strength". At the very best, this specification is incomplete and therefore meaningless. When a manufacturer provides such "specifications", the astute buyer can conclude that 1) the manufacturer lacks the necessary technical sophistication to present a proper sensitivity specification, or 2) the manufacturer has the necessary sophistication, but is reluctant to expend the resources to conduct the necessary tests, or 3) the manufacturer has the necessary test data, but realizes that it is not impressive and is therefore reluctant to publish it. In either case, the astute buyer should see this as a "red flag" that the manufacturer does not build professional-quality DF systems.

Q: I don't understand why receiver sensitivity is sometime specified in "microvolts" and at other times in "dBm". What is dBm?

A: The term "dBm" is engineering shorthand for "decibels referenced to one milliwatt" and is a convenient method for specifying power. A power of 1.0 milliwatt is equal to 0 dBm, 0.1 milliwatt equals -10 dBm, 0.01 milliwatt equals -20 dBm, etc. Power levels expressed in dBm can easily be converted into microvolts if the receiver input impedance is known. As an example, a receiver with a 50 ohm input impedance having a sensitivity of -107 dBm can also be specified as having a sensitivity of 1.0 microvolt (using a simple conversion formula). Using dBm as a means of specifying receiver sensitivity is a little more succinct than using microvolts since the receiver input impedance does not need to be specified.

Q: That sounds reasonable. To move on then, what do you mean by "bearing jitter"?

DFP-1000B DF Bearing Processor/Display

A: Bearing jitter is best thought of as a *signal-to-noise ratio figure-of-merit specific to DF applications*. The concept of signal-to-noise ratio in DF applications (generally referred to as *bearing-to-noise ratio,* or BNR) can best be visualized by considering the real-time polar bearing display employed by the RDF Products DFP-1000B DF processor (see photo). When a signal is received, the polar bearing display responds by generating a vector (line) emanating outward from the center of the display face to indicate the received azimuth. If the signal is strong, the trace appears completely steady. As the signal magnitude decreases, however, so does the BNR, until at some point random fluctuations in the indicated azimuth begin to appear. This phenomenon is referred to as *bearing jitter*, and is a manifestation of the fact that sufficient noise is present along with the desired signal to cause an element of uncertainty as to the indicated azimuth. As the signal continues to weaken, the BNR will correspondingly diminish and ultimately reach some point where a usable bearing reading can no longer be obtained.

Q: How do you quantify bearing jitter?

A: Bearing jitter can be quantified in terms of bearing-to-noise ratio as discussed above or, more commonly, in terms of *RMS bearing jitter*. These two figures-of-merit are essentially interchangeable since one can be easily converted to the other. In RDF Products DF systems, the DF sensitivity threshold criterion is defined as "6 degrees RMS bearing jitter", which corresponds to a bearing-to-noise ratio of about 20 dB.

Q: Do all DF manufactures use this same 6 degrees RMS bearing jitter/20 dB BNR as their DF sensitivity threshold criterion?

A: No. Many manufacturers of sub-professional-quality DF systems simply specify a "usable bearing" as their threshold criterion. Since this is highly subjective and open to interpretation, it should never be accepted by a user and should be a tip-off that the vendor in question either lacks the skill or resources to quantify DF sensitivity, or is looking for a way to "improve" the specification. Many other manufacturers employ threshold criterion worse than 6 degrees RMS bearing jitter/20 dB BNR. Although there are sometimes legitimate reasons to adopt different sensitivity threshold criterion standards, it is important that the standards be objective and related to actual operational requirements. As an example, a common sensitivity threshold criterion in the two-way FM radio industry is “12 dB SINAD”. This criterion is legitimate as it realistically represents the minimum SNR required for intelligible voice communication. If arbitrary standards are employed, the informed buyer should be wary that the vendor may simply trying to inflate the specification at the expense of usefulness. As a case in point, one DF vendor uses a 3 dB BNR as the DF sensitivity threshold criterion. A BNR of 3 dB is far to low to be of any practical use, and its use is clearly an effort by the manufacturer to puff-up the specification.

Q: How did RDF Products arrive at 6 degrees RMS bearing jitter/20 dB BNR as its DF sensitivity threshold criterion?

A: This criterion was established based on careful tests of the ability of a mobile DF station to track and home-in on a weak signal. 6 degrees RMS bearing jitter was determined to be a very conservative sensitivity threshold criterion for such applications (i.e., mobile DF operators experienced only minimal difficulty tracking transmitters at this threshold criterion).

Q: You mentioned receiver IF bandwidth as one of the “qualifying factors” for a DF sensitivity specification. How does IF bandwidth influence DF sensitivity?

A: Wider IF bandwidths allow more noise to reach the receiver demodulator and thus reduce bearing-to-noise ratio. Of course, the IF bandwidth must be sufficiently wide to accommodate the bandwidth of the received signal. In typical VHF/UHF applications (e.g., narrow-band FM voice communications), an IF bandwidth of 15 kHz is employed. RDF Products thus specifies 15 kHz as the IF bandwidth for DF sensitivity specifications. RDF Products DF receivers and bearing processors all offer selectable IF bandwidths of 6/15/30/200 kHz.

Q: You also mentioned “post-demodulation” bandwidth as one of the qualifying factors. What does this mean?

A: After the signal is demodulated and converted to a format suitable for driving the bearing display, additional filtering is applied that further reduces bandwidth. This process is often referred to as “bearing integration” or “smoothing”, but is really just a form of post-demodulation bandwidth reduction that helps filter out noise. The bandwidth of this bearing integration filter is thus referred to as the “post-demodulation” bandwidth. Although a narrow post-demodulation bandwidth (corresponding to a higher level of bearing integration) improves bearing-to-noise ratio, it does so at the expense of the ability of the DF receiver to respond to short-duration signals (i.e., the bearing display appears more sluggish). Since bearing integration has a very significant effect on any DF sensitivity specification, it is important that the vendor specify this parameter as one of the qualifying factors.

Q: So let me guess - some vendors specify unreasonably long bearing integration times in order to puff-up their DF sensitivity specifications?

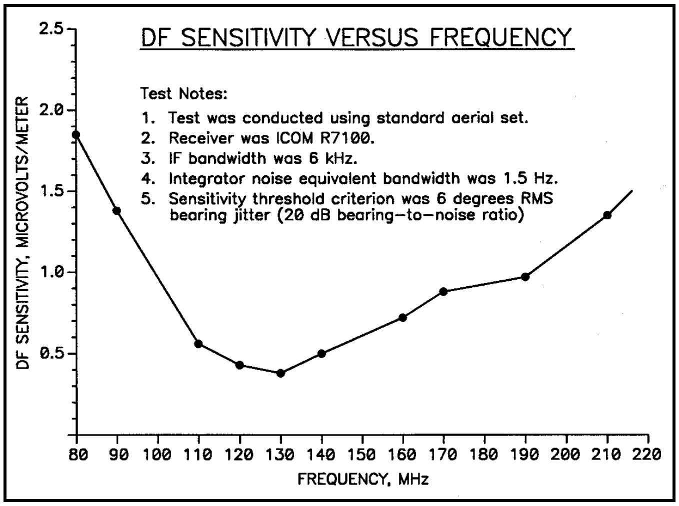
A: Unfortunately, yes. Once again, as with any specification, the qualifying factors should correspond as closely as possible those that can be expected under actual operational conditions. Many DF manufacturers do not even specify bearing integration time as a qualifying factor in their DF sensitivity specifications. Others specify bearing integration times that are impractically long for most DF applications (e.g., 1.0 second). Although a bearing integration time of 1.0 second might be suitable for long-duration signals in static DF environments, it would be useless for pulsed beacons and other short-duration signals. It would similarly be useless for mobile DF applications where the dynamics of a moving transmitter or DF receiver would cause rapid bearing changes that a DF receiver with such a slow response time would not be able to follow.

Q: So what bearing integration time would be appropriate as a qualifying factor for a DF sensitivity specification?

A: Unfortunately, there is no simple answer to this since the matter is application dependent. RDF Products DF equipment DF sensitivity is specified for "medium" bearing integration, which corresponds to a bearing integration time of approximately 150 milliseconds, which in turn corresponds to a post-demodulation filter (integrator) bandwidth of approximately 1.5 Hz. This actually results in a bearing display that is faster than necessary for most applications, but is a comfortable bearing integration time for nearly all mobile DF applications. In any case, it is an honest qualifying factor that does not attempt to "puff-up" the DF specification and is more than fast enough for most DF applications.

Q: One DF manufacturer that I spoke with claimed that their DF antennas exhibited approximately the same DF sensitivity over their full operating frequency range. Can this be true?

A: If their DF antennas cover a wide frequency range, this is very unlikely. As can be seem from the DF sensitivity plot for the RDF Products DMA-1309R0 80-220 MHz mobile Adcock DF antenna (see illustration below), DF sensitivity tends to be best somewhere near the middle of the band (where the aerials are resonant and therefore most efficient), falling off somewhat sharply below resonance and somewhat more gradually above resonance. The general shape of this plot is very typical of DF antennas. Note that the DMA-1309R0 was optimized for best sensitivity in the 108-137 MHz civil aviation band.



DF Sensitivity Versus Frequency For RDF Products
DMA-1309R0 Mobile Adcock DF Antenna

Q: In general, do DF antennas tend to be more sensitive at lower or higher frequencies?

A: The answer to your question depends upon the underlying assumptions. In general, however, monopole and dipole antennas (the basic elements of RDF Products DF antennas) tend to become less sensitive at higher frequencies *all other factors being equal.* In other words, a quarter-wave monopole antenna resonant at 100 MHz is more sensitive (at 100 MHz) than a quarter-wave monople antenna resonant at 200 MHz is at 200 MHz, *despite the fact that both antennas have identical gain at their respective resonant frequencies.*

Q: What causes this?

A: The underlying phenomenon is known as “space loss”. This is actually something of a misnomer, since there is really no “loss” of transmitted signal. Space loss is actually a manifestation of the fact that receiving antennas are shorter (other things being equal) at higher frequencies and thus intercept less of an illuminating wavefront. To go back to our 100 MHz versus 200 MHz quarter-wave resonant monopole example for a moment, the 100 MHz antenna would be twice as tall as the 200 MHz one, and the terminal output voltage of the 100 MHz antenna would be twice that of the 200 MHz one (for the same illuminating electric field strength).

Q: So does this mean that lower-frequency DF systems are more sensitive than higher frequency ones?

A: Other factors being equal, yes. The problem is, other factors are often not equal. As a good case in point, a mobile DF antenna designed for the 30-88 MHz low-VHF band may be physically constrained to using shorter aerials, which would compromise sensitivity. In contrast, a DF antenna designed for operation in the 118-174 MHz high-VHF band (where the aerials are already short enough that their heights need not be constrained) would not be burdened by this compromise and might thus have better overall sensitivity.

Q: While looking at that graph plotting DF sensitivity of the DMA-1309R0 mobile Adcock DF antenna, I noticed that DF sensitivity was better than 0.5 microvolts per meter in the civil aviation band. This seems much better than specifications I have seen for pseudo-Doppler DF systems employed in this same frequency range. Does your DF technique have an inherent sensitivity advantage?

A: Yes. RDF Products DF equipment employs the single-channel Watson-Watt DF technique in conjunction with Adcock DF antennas. For reasons discussed in Web Note WN-004 ("A Comparison of the Watson-Watt and Pseudo-Doppler DF Techniques"), the Watson-Watt/Adcock DF technique yields a very significant sensitivity advantage that is typically on the order of 10 dB.

Q: Then why is it that most DF manufacturers build pseudo-Doppler rather than Adcock/Watson-Watt DF systems?

A: The simple and direct answer to your question is that pseudo-Doppler DF antennas are far simpler and less expensive to design and manufacture than Adcocks, and can be done by people with more limited understanding of the principles underlying radio direction finding technology.

Q: So are you saying that the pseudo-Doppler DF technique is inferior to the Adcock/Watson-Watt?

A: That would be too sweeping a generalization. As discussed in WN-004, the pseudo-Doppler DF technique does have certain advantages over the Adcock/Watson-Watt. In most of the applications for which low-cost narrow-aperture pseudo-Doppler DF systems are advertised and used, however, these advantages are not realized. In that context then, it is fair to say that Watson-Watt/Adcock DF systems are far better matched to customer requirements for such applications. This is especially true for mobile DF applications.

Q: One last question. What does RDF Products use for its DF antenna test site?

A: We originally used a 20' x 60' elevated test range located in a clear flat area in the middle of the Arizona desert. The test platform has been carefully leveled, and is fully covered with 1/4" wire mesh. The operating console is located beneath the platform to avoid interference to the measurements. Both mobile and fixed-site antennas can be tested. After our relocation to Vancouver, Washington, we constructed a 36' x 64' ground-mounted test site that provides equally good results.

20' x 60' Elevated DF Antenna Test Range

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