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WN-001

Web Note

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

This Web Note discusses basic aspects of general DF technology and application in 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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About RDF Products Application Notes...

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: How long has radio direction finding technology been around?

Answer: Almost as long as radio itself. There is ample documentation of the use of DF by both sides during World War I. DF technology made tremendous strides immediately following World War I, being essentially commensurate with the rapid technological progress of vacuum-tube based radio technology in general during that time. Although these early DF systems were very primitive by today's standards, they nonetheless solidly established many fundamental aspects of DF technology still in use today.

Q: In addition to "DF" I have also seen references in the literature to "ADF" and "RDF". What do these refer to?

A: Literally speaking, "DF" refers to "direction finding", "ADF" to "automatic direction finding", and "RDF" to "radio direction finding". These terms are frequently used interchangeably.

Q: Is there any particular significance to "ADF"?

A: "Automatic" (radio) direction finding is early terminology that was used to differentiate DF systems requiring manual intervention to function versus those that didn't. To explain, it is possible to build very simple and low-cost DF systems that require manual rotation of the antenna and other operator intervention to obtain bearings. These mostly fall into the category of null-steering and right-left indicator systems. Although there may be some instances where such simple systems can be useful, non-automatic DF systems are very labor-intensive to use and so limited in capability that they are seldom used for modern DF applications.

Q: What is a "right-left indicator"?

A: A right-left indicator is a simple non-automatic DF system that essentially is a bi-quadrant indicator that requires repeated physical rotation of the DF antenna. These systems were mostly used on vehicles in mobile DF applications. When the DF antenna is correctly mounted on the vehicle, the bearing display indicator can tell the operator only that the target transmitter is either to the right or left. With a certain level of operator skill, patience, persistence, and luck, the operator can eventually home-in on the transmitter. Although right-left indicators were once widely used in law-enforcement applications (due to their low cost), they have been supplanted by true automatic DF systems.

Q: What is the underlying principle of DF?

A: In the most general sense, all non-rotating radio direction finding systems employ a DF antenna having an array of spatially-displaced aerials (three or more are required for non-ambiguous operation) that are illuminated by the received signal wavefront. The resulting voltages produced by these aerials exhibit characteristics (phase, amplitude, or both) that are then measured. Since these characteristics are unique for every received azimuth for a properly designed DF antenna, the wavefront angle-of-arrival (bearing) can be ascertained by appropriately processing and analyzing the aerial output voltages.

Q: Can you break that down into more specific DF technology categories?

A: Modern non-rotating DF systems tend to fall into one of two broad categories. In *phase-comparison* DF systems, three or more aerials are configured in such a fashion that the relative *phases* of their output voltages are unique for every wavefront angle-of-arrival. Bearings can then be computed by appropriately analyzing the relative phases of these output voltages. Phase-comparison DF systems include Dopplers and interferometers. In *amplitude-comparison* DF systems, two or more directive antenna arrays are configured in such a fashion that the relative *amplitudes* of their outputs are unique for every wavefront angle-of-arrival. Bearings can then be computed by appropriately analyzing the relative amplitudes of these output voltages. Amplitude-comparison DF systems include Watson-Watts and Wullenwebers.

Q: You have made reference to "non-rotating" DF systems. What does this mean?

A: In some older DF systems one or more aerials were rapidly spun around on a turntable. In modern non-rotating DF systems, the DF antenna aerials are stationary with any necessary "rotation" achieved non-mechanically by electronic switching.

Q: What DF technique is employed by DF systems manufactured by RDF Products?

A: As of this writing, all RDF Products DF systems employ an amplitude-comparison DF technique known as the Adcock/Watson-Watt DF technique.

Q: How does the Adcock/Watson-Watt DF technique work?

A: See RDF Products Web Note WN-002 ("Basics of the Watson-Watt DF Technique").

Q: What are the essential components of a DF system?

A: The essential components of a DF system are the DF antenna, DF receiver, DF bearing processor, and DF bearing display. These components are discussed in detail in RDF Products Web Note WN-002.

Q: What DF system component is primarily responsible for DF system bearing accuracy?

A: In a properly designed DF system, the DF antenna is nearly always the dominant factor with regard to DF system bearing accuracy. RDF Products DF antennas have typical

RMS bearing accuracies of 1.5 to 3.0 degrees, depending upon the model. RDF Products DF receivers/bearing processors, on the other hand, have typical RMS bearing accuracies of well under 0.5 degrees. Overall bearing accuracy is thus largely established by the DF antenna. This is even more the case when site errors are factored in as well.

Q: Is DF sensitivity also primarily established by the DF antenna?

A: Absolutely. Although DF receiver IF bandwidth and DF bearing processor bearing integration time also influence DF sensitivity, the DF antenna is by far the dominant component. In fact, the DF antenna is the most important component with regard to nearly all aspects of DF performance, and is the DF system component most difficult to design.

Q: I noticed that in other RDF Products literature, you refer to RDF Products DF systems as "narrow-aperture". What does this mean?

A: The "aperture" of a DF system refers to the maximum fraction of a wavelength sampled by the DF antenna (DF antenna aperture is often referred to as its "spacing"). For a narrow-aperture DF system, the spacing is less than a half-wavelength. Medium-aperture DF systems employ spacings from a half- up to a full-wavelength. Wide-aperture DF systems employ spacings of a full-wavelength or more.

Q: Are wide-aperture DF systems better than narrow-aperture ones?

A: Wide-aperture DF systems have the advantage of offering very significant "site-error suppression" capability. What this means in plainer language is that they are less vulnerable to bearing errors caused by multi-path reception (i.e., wavefront reflections from buildings and other structures within line-of-site of the DF antenna). Narrow-aperture DF system do not have this capability. On the other hand, narrow-aperture DF systems employ much more economical and compact DF antennas covering wider frequency ranges.

Q: I noticed that a competitor who manufactures pseudo-Doppler DF systems claims that their systems are immune to bearing errors caused by multi-path reception. Is this really so?

A: Although pseudo-Doppler DF systems can be designed to provide significant site-error suppression, the effect is not noticeable unless the DF antenna has an aperture of at least a half-wavelength and has eight or more aerials. Any claim that a pseudo-Doppler DF system employing a 4-aerial narrow-aperture DF antenna can provide noticeable site-error suppression should be viewed with extreme skepticism.

Q: What are the relative merits of Adcock/Watson-Watt and pseudo-Doppler DF systems?

A: This is a rather involved topic that is addressed in detail in Web Note WN-004 ("A Comparison of the Watson-Watt and Pseudo-Doppler DF Techniques"). In brief summary, however, the Adcock/Watson-Watt DF technique offers better sensitivity, flexibility, and listen-through capability, and in general is superior for DF applications requiring a compact, narrow-aperture DF antenna. Narrow-aperture pseudo-Doppler DF systems offer the advantage of relatively simple DF antennas, resulting in easier-to-implement high frequency performance (a definite advantage above 1000 MHz). Medium- and wide-aperture pseudo-Doppler DF systems offer site-error suppression as mentioned earlier, but at the expensive of greater size and cost.

Q: What is the bearing accuracy of RDF Products DF systems?

A: Typical bearing accuracy of RDF Products DF systems varies from 1.5 to 3.0 degrees RMS, depending upon the frequency range. Be aware, however, that these numbers are based on measurement data recorded in tests conducted on a near-ideal site. Bearing accuracy for DF systems deployed in more typical installations is always worse, especially in mobile DF applications where the DF system is installed on a land-vehicle or aircraft.

Q: What do you mean by "RMS" bearing accuracy?

A: "RMS" is an abbreviation for "root mean square", which is a weighted error averaging technique that places a greater weight on larger bearing errors than smaller ones. RMS averaging has long been the averaging technique employed in the DF industry as the standard figure-of-merit for bearing accuracy. See RDF Products Application Note AN-003 ("Measuring Bearing Accuracy of Mobile Adcock DF Antennas") for a detailed discussion of bearing error averaging and other topics associated with the measurement and evaluation of bearing errors.

Q: Do I need good bearing accuracy in mobile DF applications?

A: In most cases, no. Mobile DF applications almost always involve tracking and homing on a target transmitter. Even if bearing errors are large, the mobile DF station will eventually arrive at the location of the target transmitter. To clarify this point, imagine two different scenarios, one where the mobile DF station has no bearing error and the other where the mobile DF station has a 30 degree bias error. In the first scenario, the mobile DF station will (in principle, at least) drive a straight line toward the target transmitter. In the second scenario, the mobile DF station will still arrive at the target transmitter, but will drive an arc rather than a straight line. The bottom line is that mobile DF applications tend to be very forgiving of bearing errors, but very demanding with regard to system dynamics and bearing display format.

Q: What about bearing accuracy requirements in fixed-site DF applications?

A: Bearing accuracy requirements for fixed-site DF stations are much more demanding. In most instances, the broader mission of fixed-site DF stations is triangulation of the target transmitter in coordination with other DF stations (i.e., *radio-location*). In triangulation, even small bearing errors can result in a relatively large area of uncertainty with regard to the location of the target transmitter. Good fixed-site performance therefore requires good site selection where multi-path induced bearing errors are minimized.

Q: I noticed that in other RDF Products literature, you refer to RDF Products DF systems as "single-channel". What does this mean?

A: "Single-channel" means that the DF system employs only one radio receiver. This is in contrast to "multi-channel" DF systems that require two or more radio receivers to function. Most multi-channel DF systems employ two or three receivers.

Q: Are multi-channel DF systems better than single-channel ones?

A: In general, multi-channel DF systems are capable of superior performance. On the other hand, the requirement for several closely-matched specialized receivers is a severe cost driver that makes multi-channel DF systems cost-effective only for very high-end applications. In addition, the requirement for additional receivers greatly reduces DF system compactness.

Q: I understand that a single-channel DF system trades off some performance for major cost savings, but can you tell me the specific performance attributes that are compromised?

A: All single-channel DF systems require the use of some form of a tone modulation technique in the DF antenna to encode the signals from each aerial or directive array so that their outputs can be combined without loss of information and sent to the single receiver. All of the ills of single-channel DF systems are associated with this tone modulation process. The four primary ones are limitations on the ability of the DF system to respond to short-duration signals, degraded performance when attempting to DF on signals with certain modulation formats, poor audio listen-through capability for certain signal modulation formats, and somewhat reduced DF sensitivity.

Q: How well do RDF Products DF systems handle these issues?

A: Actually, pretty well. With regard to ability to respond to short-duration signals, RDF Products DF systems can respond to signals with durations as short as 35 milliseconds, thus facilitating good performance when tracking pulsed radio beacons and other short-duration signals. Similarly, DF performance is quite good for AM and FM signals (the most common voice modulation formats). Likewise, audio listen-through capability is also good for AM and FM signals (although less so for SSB signals). Although there is a significant degradation in DF sensitivity in comparison to multi-channel DF systems, DF sensitivity is still quite good. In general, the Adcock/Watson-Watt DF technique as implemented by RDF Products handles these compromises well.

Q: How do pseudo-Doppler DF systems compare with regard these same issues?

A: In general, not so well. Although pseudo-Doppler DF systems can be designed to respond to short-duration signals as well as Watson-Watt DF systems (the technique employed by RDF Products DF systems), they tend to exhibit bearing jitter (fluctuations) when obtaining lines of bearing on FM signals. To compensate for this, pseudo-Doppler DF systems employ long bearing averaging times to smooth out this jitter. Unfortunately, this degrades ability to respond to short-duration signals. Audio listen-through capability tends to be very poor, particularly for FM signals (in most cases, it is necessary to temporarily disable DF capability in order to have acceptable audio listen-through capability). Finally, pseudo-Doppler DF systems exhibit much more DF sensitivity degradation than do Watson-Watts.

Q: I have seen advertisements for DF systems in various law enforcement magazines. Are these any good?

A: These systems are very narrowly focused on tracking pulsed radio beacons in mobile DF applications. The ones that work reasonably well are designed to respond to a "signature beacon" (a "cooperative" beacon transmitter with a special modulation format that helps the DF receiver identify it as the desired signal). For emitters lacking this signature, however, (i.e., "non-cooperative" transmitters) performance varies from marginal to unusable. These systems also cover only very narrow frequency bands, can only accommodate a very small number of frequency channels, and have poor bearing accuracy. In addition, pricing is no better than that of more capable RDF Products DF systems. In general, these are sub-professional-quality DF systems that do well for their single intended task (finding cooperative transmitters), but lack the features and precision required for a wider range of DF applications.

Q: I'm not sure I understand how this "signature beacon" is able to improve system performance. Can you elaborate on this?

A: These law enforcement DF systems are all pseudo-Doppler types with azimuth ring displays. The classical problem with this approach is that the ring display indicates bearings not only when the beacon signal is present, *but also displays erroneous noise-induced bearings between beacon pulses*. As a result, it is very difficult for the operator to differentiate the desired signal bearings from the undesired noise bearings. Some systems rely on manual squelch controls to quiet the bearing display between beacon pulses, but this is very inconvenient at best, and is ineffective for weak signals. To improve performance, a "signature beacon" is used that amplitude modulates each beacon pulse with a 32 Hz "validation" tone. The DF receiver is then designed to keep the bearing display squelched (blanked) until this 32 Hz tone is detected. When the validation tone is detected, the receiver enables the bearing display to allow the desired bearing to be presented. When the beacon pulse ends, the validation tone is likewise no longer present and the bearing display is once again squelched. The operator therefore sees only valid signal bearings with relatively few noise bearings in between beacon pulses. This principle is very similar to the "tone squelch" technique employed in many two-way radios to improve the ability of the receiver squelch circuitry to differentiate between desired signals and noise.

Q: That sounds very clever, but what happens when these systems are used to track signal sources other than signature beacons?

A: That's the big problem. To track such "non-cooperative" signal sources that are not modulated by the validation tone, the receiver validation tone detector must be disabled and the manual bearing squelch relied upon to help differentiate between valid bearings and ones induced by noise. Performance is usually poor as a result. These systems are really designed to work well only with the cooperative signature beacons. RDF Products DF systems, in contrast, perform well with almost any signal format.

Q: I noticed that your literature places a great deal of emphasis on the importance of the DF bearing display. Why is this such a major issue?

A: The highly dynamic nature of mobile DF applications is such that considerable judgement is often required to differentiate a valid bearing from erroneous ones induced by noise and reflections. Inexpensive bearing displays such as mechanical pointers and LED rings are extremely difficult to interpret under such conditions. Numeric bearing displays are almost useless. In contrast, the RDF Products Models DFP/DFR-1000B and DFR-1000B employ real-time *polar* bearing displays that not only indicate the azimuth, but also indicate the *quality* of the bearing in a highly unified, intuitive format. To explain, bearings induced by noise and reflections tend to be associated with *shorter* display vector lengths while valid bearings tend to be associated with *longer* display vector lengths. The real-time polar bearing display is thus an enormously powerful tool for helping the operator deal with the demanding requirements of mobile DF.

Q: So is this polar bearing display the reason why RDF Products DF systems do not require cooperative signature beacons?

A: That's right. The display bearing vector length is long when the beacon pulse is present, and then greatly shortens between beacon pulses. With this highly intuitive bearing display format, the operator can easily discriminate between valid signals and background noise, so no signature beacon is required. As a result, RDF Products DF systems are effective with almost any signal format, in contrast to most other DF systems that function well only for certain specific signal formats.

Q: How is this accomplished with the DFP-1010B - it has no bearing display?

A: The DFP-1010B outputs bearings to the host computer in a format that contains both the necessary azimuth and magnitude information so that true polar bearings can be emulated on the host computer display using appropriate software. Since the DFP-1010B outputs these bearings at a rate of 50 bearings/second, the computer-emulated polar bearing display has the same real-time appearance as the real-time polar bearing display on the DFP-1000B. At 50 bearings/second, this computer-emulated display is faster than both standard motion pictures (shot at 24 frames/second), PAL-format TV (shot at 25 frames/second) and NTSC-format TV (shot at 30 frames/second).

Q: Do any of your competitors use real-time polar bearing displays?

A: To our knowledge, none of our competitors use real-time polar bearing displays. Of those few who did at one time, most are now out of business and those that remain have abandoned this display format in their current products.

Q: Why is that?

A: In many cases, they simply do not have sufficient experience in mobile DF to understand the enormous benefits of this display format. In others, they rely on non-polar azimuth ring displays on account of their lower cost (despite the severe performance trade-off). In still other cases, their DF systems are not truly intended for operation in demanding mobile DF applications where the dynamic performance benefits of the real-time polar bearing display are necessary.

Q: I just want to make sure I fully understand something. I've noticed that even though some other vendors have advertised their DF systems as being "mobile", it is necessary to stop the vehicle in order to obtain good bearings. Are you saying that RDF Products DF systems can actually obtain good bearings even when the vehicle is in motion?

A: Absolutely. RDF Products DF systems originally were expressly designed to handle the demanding requirements imposed by mobile tracking of pulsed radio vehicle beacons in law enforcement applications where good bearings had to be obtained even if *both* the mobile DF station and radio beacon were *simultaneously* in motion. This was the driving requirement not only for the real-time polar bearing display as previously discussed, but also for the enormous effort that was invested in all aspects of the equipment design to ensure that it met the dynamic performance requirements essential for mobile DF in dense-signal urban multi-path environments. Even though the scope of newer RDF Products DF equipment has been expanded to accommodate fixed-site DF applications as well, the dynamic performance requirements necessary for top-notch mobile DF operation have not been compromised at all (and actually has been improved to be able to respond to even shorter-duration signals).

Q: I have seen advertisements in the ham radio and other magazines for very low-cost DF systems. These seem almost too good to be true. Is there some "catch"?

A: Yes. These systems are an excellent case-in-point for the old adage that "you get what you pay for". They are designed for casual DF applications such as amateur radio transmitter "fox-hunts" where truly good DF performance is not required. Furthermore, these units often require users to fabricate their own DF antennas and perform intrusive modifications to external (user-supplied) host receivers. These are sub-professional-quality DF systems that are ill-suited to the demanding requirements of serious DF applications. Although these low-cost systems have been around in various forms for over 25 years, they have never gained much traction as a result of their inability to work well for all but the lowest-end applications.

Q: What is the principle of operation of these systems?

A: The simplest of these systems are right-left indicators that require physical rotation of the DF antenna as discussed previously. The better of these systems are narrow-aperture (4-aerial) pseudo-Doppler systems. In the best of these systems, the manufacturer supplies four car-top whip antennas with phase-matched coaxial cables, magnetic mounts, an "X" frame to correctly space these whips on the car-top, an antenna commutator (electronic switching unit), and a controller/bearing display unit. In other instances, the manufacturer requires the user to supply the whip antennas, phase-matched cables, and construct any necessary mounting frame.

Q: What about the receiver?

A: The receiver is supplied by the user. It accepts the output from the antenna commutator and connects to the controller/bearing display unit via its FM audio output.

Q: So what are the problems?

A: There are several. First, small amounts of receiver mistuning can cause large bearing shifts. (In fact, with some receivers, the bearing can even shift when the volume control setting is changed.) Second, if the receiver has selectable IF bandwidths, large bearing shifts occur whenever the IF bandwidth is changed. Third, simultaneous DF operation and audio listen-through capability is not possible in most of these systems because of the commutation tone (it is necessary to disable DF capability to obtain audio listen-through). Fourth, these systems suffer from the trade-off inherent in all pseudo-Doppler systems in that best sensitivity cannot be obtained simultaneously with best bearing accuracy (for best sensitivity, the antennas should be cut at or near resonance, which degrades bearing accuracy - for best bearing accuracy, the antennas must be cut short, which degrades sensitivity). Fifth, these systems cannot operate well over wide frequency ranges without changing or repositioning antennas. Sixth, operation is possible only with receivers having FM demodulation capability. Finally, the non-polar azimuth-ring bearing display format makes it difficult to discriminate between valid bearings versus noise and reflections, particularly when signals are weak or of short duration.

Q: I notice that some of the manufacturers of these systems claim that their units

have sophisticated microprocessor algorithms that improve the received bearings. Is there any merit to this?

A: The primary purpose of such algorithms is to attempt to offset the difficulties operators encounter interpreting the confusing indications of the non-polar azimuth ring bearing displays in dynamic signal environments. As mentioned earlier, the real-time polar bearing displays employed in RDF Products DF equipment provides (by means of the vector length) an inherent and highly intuitive bearing quality indicator that provides an easy means by which the operator can distinguish between legitimate bearings and undesired noise and reflections. The inferior quality non-polar azimuth ring displays employed by these low-cost pseudo-Doppler systems, however, can provide no such discrimination - an illegitimate bearing produced by noise is given the same weight and prominence as a legitimate one produced by a valid signal. To mitigate this very serious flaw, some manufacturers employ microprocessor algorithms to attempt to "filter" the bearings before sending them to the display.

Q: How do these filter algorithms work?

A: Most of these algorithms employ some combination of averaging and selective sampling. Averaging allows a reduction in bearing display jitter, (which is nearly always a severe problem with azimuth ring displays). Selective sampling is an effort to further refine this by attempting to throw out bearings that seem to be erroneous (or at least inconsistent with the average).

Q: Are these algorithms effective?

A: To varying degrees, depending upon the signal format and reception conditions. For moderate to strong signals of substantial duration, these algorithms are capable of providing substantial improvement. For weak signals, ones that fade in and out, and signals of short duration, however, these algorithms can be easily "fooled", and are best disabled (to prevent them from becoming part of the problem rather than part of the solution). The most important thing to keep in mind, however, is that the real purpose of these algorithms is to compensate for the fact that the manufacturers have chosen an inexpensive but inferior and difficult-to-interpret non-polar azimuth ring bearing display format. In contrast, RDF Products DF equipment employs more expensive (but vastly more capable) real-time polar bearing displays that, in conjunction with a human operator, are far more effective and much harder to fool than any microprocessor algorithm.

Q: Does RDF Products DF equipment employ any such algorithms or filters?

A: Yes. All RDF Products DF receivers and bearing processors incorporate selectable bearing averaging as well as selectable track-and-hold, both of which are very useful enhancements.

Q: How do RDF Products DF equipment specifications compare against those of these low-cost systems?

A: A simple comparison tells the whole story. As you can verify from our product data sheets posted on our website, RDF Products DF equipment specifications are lengthy and detailed. This is in sharp contrast to the "specifications" provided by the manufacturers of these low-cost systems, which are perfunctory and incomplete (in most cases, such basic specifications as DF bearing accuracy and sensitivity are not even published).

Q: Does the availability of GPS technology overshadow DF technology?

A: In cases where the transmitter is "cooperative", GPS can offer a very elegant radio location solution that is superior to DF. As a case in point, a vehicle tracking system can consist of a GPS receiver on the target vehicle that establishes its location with extreme accuracy and then sends this information via radio link to the monitoring station. With this information in hand, the monitoring station can precisely track the location of the vehicle, using a real-time moving map display.

Q: But how would GPS technology deal with non-cooperative transmitters?

A: For non-cooperative transmitters (which is to say any transmitter with which a GPS receiver cannot be co-located), GPS technology would not work. GPS is therefore not a viable solution for interference location, frequency management, signal intelligence, and most other activities for which DF would be employed. In short, GPS is not a viable alternative to DF in most applications.

Even for cooperative transmitters, GPS technology has certain disadvantages and limitations. In the case of the vehicle tracking system, it would be necessary that the GPS antenna always be able to "see" the satellite, which would frequently not be possible when the vehicle is inside buildings or in densely wooded areas. Cost is another issue. In the case of the GPS vehicle tracking system, the vehicle would have to be fitted with a GPS receiver, GPS antenna, a radio transmitter/receiver to allow the GPS data to be polled, and an antenna for this radio transceiver. In contrast, the DF vehicle tracking system requires only a pulsed beacon transmitter and an antenna. As a result, the system installation cost per vehicle is far less for the DF tracking system. This would be an important concern for an application where a large fleet of vehicles would be outfitted (i.e., in a stolen vehicle recovery system).

Another potential disadvantage of the GPS approach is that it can be easily disabled. Although this would not be an issue for non-hostile applications, it would be an issue in a vehicle recovery system where a thief might be able to identify and disable the hard-to-hide and hard-to-conceal GPS antenna. <>