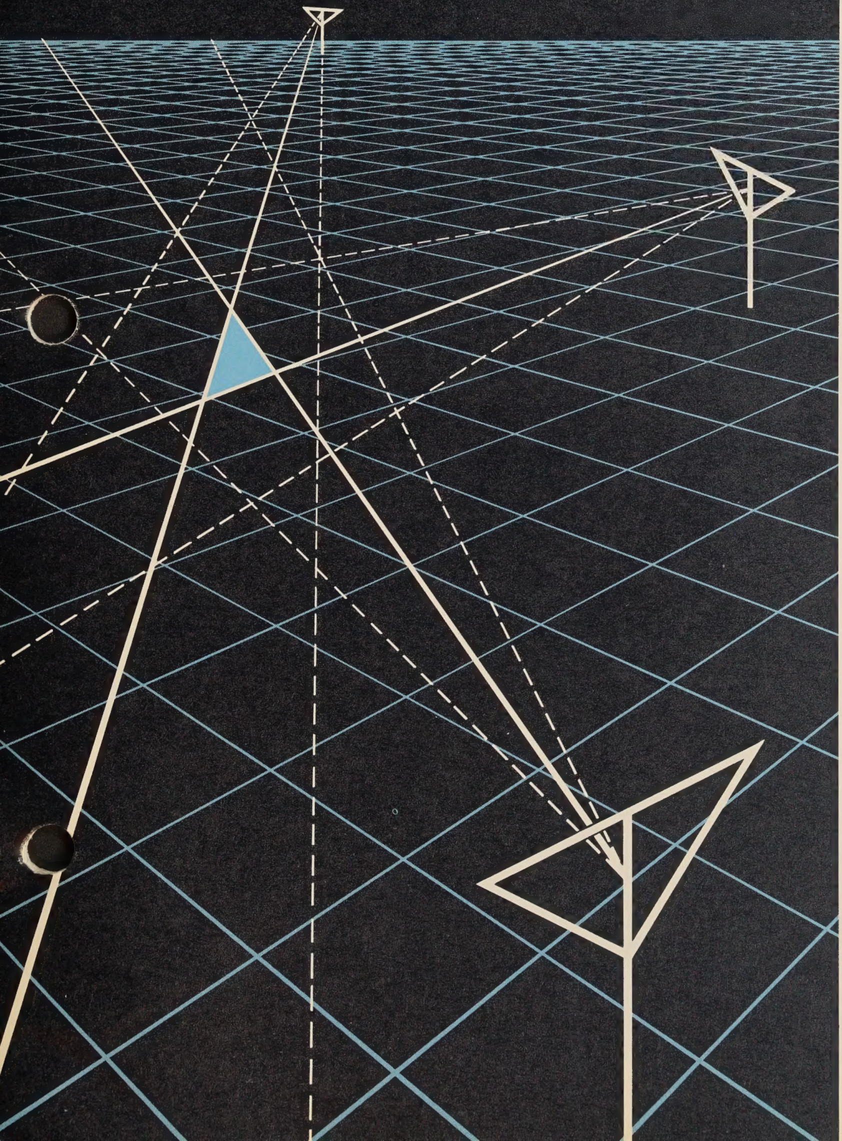
VOL. 9 NO. 1 JANUARY/FEBRUARY 1982

Improving System and Environmental DF Accuracy



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Tech-notes

The main objective of direction finding is locating the direction to the transmitter. If two or more direction finders are used, the objective is usually to locate the transmitter site. In both cases, accuracy is extremely important. This is especially true in military situations where the location of the transmitter may reveal the location of enemy forces.

The main sources of inaccuracies in direction finding are anomalies in signal propagation, imprecise coordinate location of the DF platform, and receiving and DF processing errors. This article will discuss some of the causes of environmental errors, DF unit system error, and the correction table. The error range to use in triangulation will also be discussed, along with ways to improve the accuracy.

DF Accuracy

The five major causes of DF errors are: reflections, re-radiations, diffraction, refraction, and fading signals.

Reflections and re-radiations present similar symptoms. Reflection occurs when the signal bounces off a conducting surface, taking on a new direction. Re-radiation happens when the signal causes a conducting surface to oscillate at the same frequency, appearing to be a second transmitter of the same signal. In either case, the DF antenna receives the signal from two different directions at the same time. The DF unit will try to display the two bearings to the best of its ability. In many DF units the two signals get averaged, causing an apparent line of bearing (LOB) somewhere between the two actual directions. This could be confusing to the operator, especially if the wind is blowing, causing the reflecting (or re-radiating) surface to move enough to change the direction of the reflection. Such movement can cause wide variations in the apparent LOB. See Figure 1A and B for examples of how reflection and re-radiation occurs.

By definition, diffraction is the breaking up of a wave, as when a wave "bends" around the side of a mountain. An example of diffraction is depicted in Figure 2A. Figure 2B demonstrates refraction of a wave traveling from one medium to another. The lower frequencies are more susceptible to refraction. In *real-world* situations, refraction could appear over a lake, where the air is much more humid, or over a large valley, where the air is much drier.

The last of the five deterrents to accurate direction finding is signal fading. Signals can fade in the shadow area of

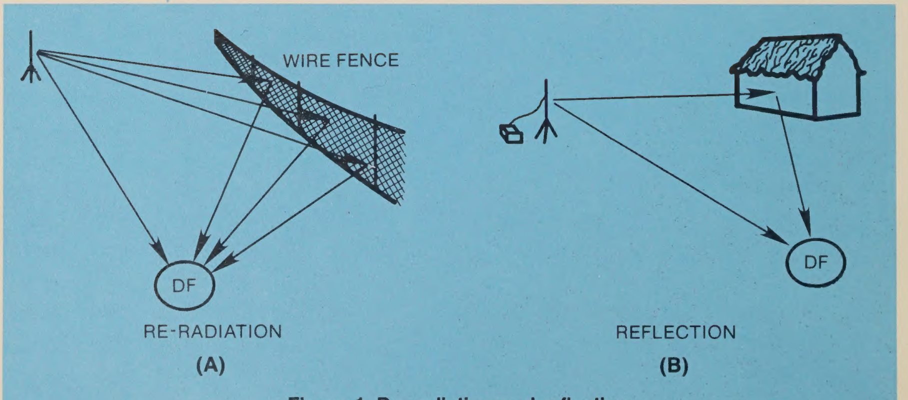
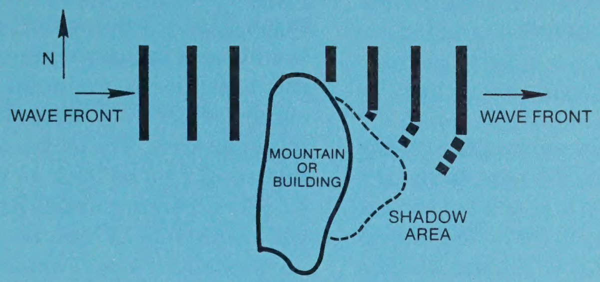
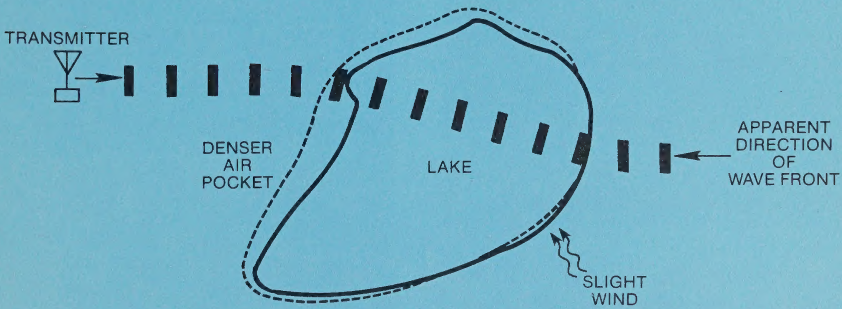


Figure 1. Re-radiation and reflection.



(A) Signal being blocked by an object, causing diffraction.



(B) Signal refraction because of change of humidity over the lake.

Figure 2. Diffraction and refraction.

a mountain or building (see Figure 2A) if the transmitter is too far away to supply enough signal strength, or if there is a reflection or re-radiation at about 180° lagging from the main signal, causing cancelling. Any time the signal fades in and out, the DF station is more susceptible to environmental noise.

The phenomena that cause DF inaccuracies are often undetectable by the operator, but use of correction tables can help to maintain accuracy. In a fixed-site location, the use of correction tables is fairly simple. A correction table can be constructed by transmitting and receiving transmissions from known locations.

A more severe calibration problem occurs with mobile DF units. Because the errors caused by the environment are different for each location, to get absolute accuracy, a correction table would have to be generated at each new location. In most applications this will not be feasible. Part of the problem can be solved by using five or six DF units over a wide baseline for triangulating and deleting any bearings that seem unreasonable. If the mobile DF is a van unit, a correction table can be generated for the van. This will improve accuracy, but will still be less accurate than a fixed-site system.

The Baseline

The "baseline" is an imaginary line connecting all the DF sites in the DF system. The length of the baseline is the distance between the two outermost DF sites, measured on the straight line connecting those sites. Figure 3 shows an example of a DF baseline.

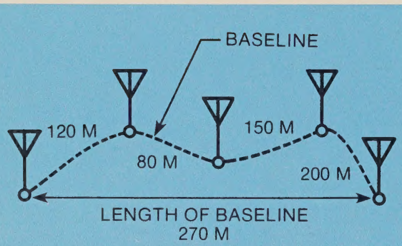


Figure 3. Sample baseline.

The optimum baseline is a circle with the target transmitter on the inside, where the length of the baseline is the diameter of the circle. The second-best case is where the target transmitter is at the intersection of two LOB's that form a right angle. This situation is represented in Figure 4.

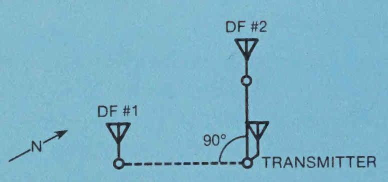


Figure 4. Second-best baseline.

To obtain the most accurate LOB, all direction finding should be performed over level ground, where there are no hills, valleys, trees, or buildings to interfere with the signal. Only rarely can the optimum conditions be met, but the problems can be minimized if care is taken. Figure 5 shows the basic rule of thumb used in determining the size of the baseline to maintain the high degree of accuracy needed for transmitter location. The length of the baseline should be as long as the *field* is deep for accurate direction finding. This will insure that at least two of the DF units establish a wide-angle cut on the transmitter.

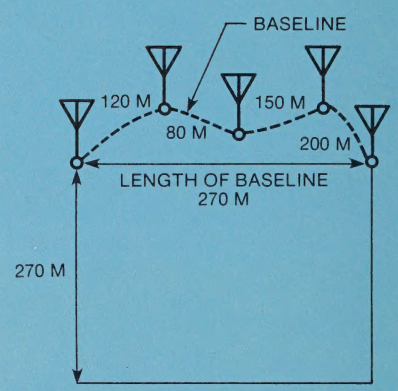


Figure 5. Baseline consideration.

Correction Tables

Direction finding is a beneficial supplement of communications surveillance systems, but it does not give exact locations. As described earlier in this article, there are many variables that can cause inaccurate DF bearings. The information gained from a DF unit is meant only to supplement other information for locating a transmitter, but with the use of the correction table, the accuracy increases.

Correction tables can come in many different forms. The style of the correction table depends on the accuracy required, the frequency range covered, and the capabilities of the people operating the DF unit. It is not the intent of this article to describe how to generate a correction table; that information will appear in a later article.

Figure 6 and Tables 1 and 2 show different examples of correction methods. Figure 6 is an example of a correction plot, which gives the user a good "feel" for the expected errors for any possible LOB. Table 1 is a correction table that could be used if high accuracy is needed. The data for this table was taken in 10-degree increments and the results passed through a curve-fitting algorithm to create a 1-degree increment table. The major drawback of this type of table is the time required to get a correction value from it, especially if the DF unit operator is doing any kind of frequency scanning. The most common type of correction table is shown in Table 2. The problem with this type of table is the inaccuracy introduced because of the fewer number of data points taken, and the linear interpolation usually used to find corrections between the 10-degree increments and the chosen frequencies.

The correction table may be lengthy due to the inclusion of all the frequency steps needed to cover a wide frequency band. If the number of frequencies can be optimized, the correction table will be made shorter. To optimize for a particular application, such as when the frequency band of interest is relatively narrow, say about 50 MHz, a correction table with small frequency steps can cover the band of frequencies. This method also helps to increase accuracy because the errors caused by

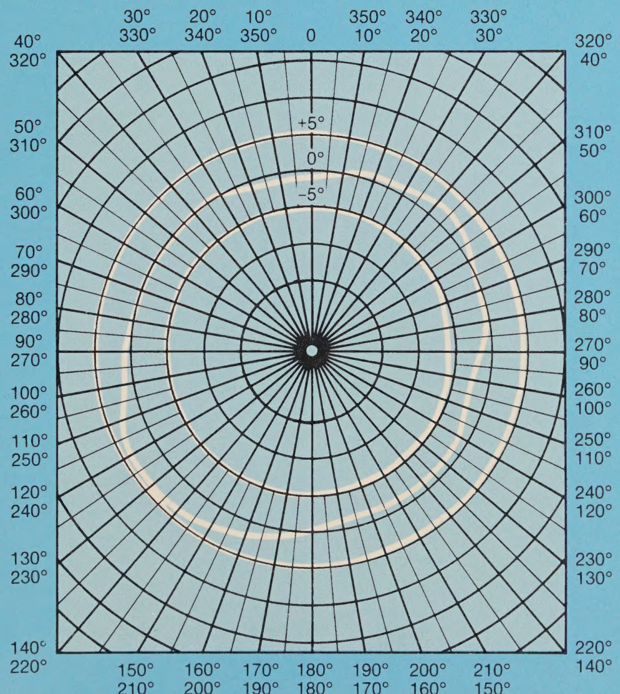


Figure 6. Correction plot.

WJ-9871 — Frequency: 260.000 — Log Number: C539

LOB	Correction	LOB	Correction	LOB	Correction	LOB	Correction	LOB	Correction	LOB	Correction
0	-1.0	60	1.0	120	-1.0	180	0.0	240	4.0	300	0.0
1	-1.0	61	0.9	121	-1.0	181	0.1	241	4.0	301	-0.0
2	-0.9	62	0.8	122	-0.9	182	0.2	242	3.9	302	-0.0
3	-0.8	63	0.6	123	-0.9	183	0.3	243	3.9	303	-0.0
4	-0.8	64	0.5	124	-0.9	184	0.4	244	3.8	304	-0.0
5	-0.6	65	0.4	125	-0.9	185	0.5	245	3.7	305	-0.0
6	-0.5	66	0.3	126	-0.9	186	0.6	246	3.6	306	0.0
7	-0.4	67	0.2	127	-0.9	187	0.7	247	3.5	307	0.0
8	-0.3	68	0.1	128	-1.0	188	0.8	248	3.3	308	0.0
9	-0.1	69	0.0	129	-1.0	189	0.9	249	3.2	309	0.0
10	0.0	70	0.0	130	-1.0	190	1.0	250	3.0	310	0.0
11	0.1	71	-0.0	131	-1.0	191	1.1	251	2.8	311	-0.0
12	0.3	72	-0.0	132	-1.0	192	1.2	252	2.6	312	-0.0
13	0.4	73	-0.0	133	-1.0	193	1.3	253	2.4	313	-0.0
14	0.5	74	-0.0	134	-1.0	194	1.4	254	2.1	314	-0.0
15	0.6	75	-0.0	135	-1.0	195	1.5	255	1.9	315	-0.0
16	0.7	76	0.0	136	-1.0	196	1.6	256	1.7	316	-0.0
17	0.8	77	0.0	137	-1.0	197	1.7	257	1.5	317	-0.0
18	0.9	78	0.0	138	-1.0	198	1.8	258	1.3	318	-0.0
19	1.0	79	0.0	139	-1.0	199	1.9	259	1.1	319	-0.0
20	1.0	80	0.0	140	-1.0	200	2.0	260	1.0	320	0.0
21	1.0	81	-0.0	141	-1.0	201	2.1	261	0.9	321	0.0
22	1.0	82	-0.1	142	-1.0	202	2.2	262	0.9	322	0.0
23	1.0	83	-0.2	143	-1.0	203	2.3	263	0.9	323	0.1
24	1.0	84	-0.3	144	-1.0	204	2.4	264	0.9	324	0.1
25	1.0	85	-0.4	145	-1.0	205	2.5	265	0.9	325	0.1
26	1.0	86	-0.5	146	-1.0	206	2.6	266	1.0	326	0.1
27	1.0	87	-0.6	147	-1.0	207	2.7	267	1.0	327	0.1
28	1.0	88	-0.8	148	-1.0	208	2.8	268	1.0	328	0.1
29	1.0	89	-0.9	149	-1.0	209	2.9	269	1.0	329	0.0
30	1.0	90	-1.0	150	-1.0	210	3.0	270	1.0	330	0.0
31	1.1	91	-1.1	151	-1.0	211	3.1	271	0.9	331	-0.1
32	1.1	92	-1.2	152	-1.0	212	3.2	272	0.9	332	-0.2
33	1.2	93	-1.4	153	-1.0	213	3.3	273	0.8	333	-0.3
34	1.4	94	-1.5	154	-1.0	214	3.5	274	0.7	334	-0.4
35	1.5	95	-1.6	155	-1.0	215	3.6	275	0.5	335	-0.5
36	1.6	96	-1.7	156	-1.0	216	3.7	276	0.4	336	-0.6
37	1.7	97	-1.8	157	-1.0	217	3.8	277	0.3	337	-0.7
38	1.8	98	-1.9	158	-1.0	218	3.9	278	0.2	338	-0.8
39	1.9	99	-1.9	159	-1.0	219	3.9	279	0.1	339	-0.9
40	2.0	100	-2.0	160	-1.0	220	4.0	280	0.0	340	-1.0
41	2.1	101	-2.1	161	-1.0	221	4.0	281	-0.1	341	-1.0
42	2.1	102	-2.1	162	-1.0	222	4.1	282	-0.1	342	-1.1
43	2.1	103	-2.1	163	-1.0	223	4.1	283	-0.1	343	-1.1
44	2.2	104	-2.2	164	-1.1	224	4.1	284	-0.1	344	-1.1
45	2.2	105	-2.2	165	-1.1	225	4.1	285	-0.1	345	-1.1
46	2.2	106	-2.2	166	-1.1	226	4.1	286	-0.1	346	-1.1
47	2.1	107	-2.1	167	-1.1	227	4.0	287	-0.1	347	-1.1
48	2.1	108	-2.1	168	-1.1	228	4.0	288	-0.0	348	-1.0
49	2.1	109	-2.1	169	-1.0	229	4.0	289	-0.0	349	-1.0
50	2.0	110	-2.0	170	-1.0	230	4.0	290	0.0	350	-1.0
51	1.9	111	-1.9	171	-0.9	231	4.0	291	0.0	351	-1.0
52	1.9	112	-1.8	172	-0.9	232	4.0	292	0.0	352	-1.0
53	1.8	113	-1.7	173	-0.8	233	4.0	293	0.0	353	-1.0
54	1.7	114	-1.6	174	-0.7	234	4.0	294	0.0	354	-1.0
55	1.6	115	-1.5	175	-0.6	235	4.0	295	0.0	355	-1.0
56	1.5	116	-1.4	176	-0.5	236	4.0	296	0.0	356	-1.0
57	1.4	117	-1.3	177	-0.3	237	4.0	297	0.0	357	-1.0
58	1.2	118	-1.2	178	-0.2	238	4.0	298	0.0	358	-1.0
59	1.1	119	-1.1	179	-0.1	239	4.0	299	0.0	359	-1.0

Table 1. 1° increment correction table.

Low-Bay of the WJ-9880 Antenna, Serial Number: XXXX

Freq. Avg.	0	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
40.000	4	3	3	3	3	3	2	1	0	-1	-1	-2	-2	-3	-3	-4	-4	-5	-5
45.000	4	3	3	4	4	2	2	1	0	-1	-1	-1	-2	-2	-3	-3	-3	-4	-4
50.500	3	3	3	3	3	2	1	0	-1	-1	-2	-2	-2	-2	-3	-3	-4	-4	-4
60.500	3	3	3	3	3	3	1	0	-1	-2	-2	-1	-1	-1	-1	-2	-3	-4	-4
65.500	1	1	2	3	3	3	2	0	-1	-2	-2	-2	-1	0	0	-1	-2	-3	-3
70.500	1	-2	-3	-1	0	4	6	5	4	0	-3	-5	-6	-3	0	4	2	0	-4
80.500	1	0	0	0	1	2	2	1	0	-1	-1	-1	0	0	0	0	-1	-2	-2

Freq. Avg.	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	RMS
40.000	-5	-5	-4	-3	-3	-3	-2	-2	-1	0	2	3	4	4	5	4	4	3.283
45.000	-4	-4	-3	-3	-3	-2	-2	-1	0	1	1	2	3	3	3	4	4	2.818
50.500	-4	-3	-2	-2	-2	-2	-2	-2	-1	0	2	3	3	3	3	2	3	2.584
60.500	-3	-2	-1	-1	0	0	-1	-1	-1	0	2	3	3	4	4	3	2	2.368
65.500	-3	-3	-1	-1	0	0	-1	-1	-2	-1	0	2	4	4	3	2	1	2.077
70.500	-6	-5	-4	-1	3	4	5	3	0	-3	-5	-3	2	6	8	8	5	4.102
80.500	-3	-2	-1	0	1	1	1	0	0	-1	0	1	2	3	3	2	2	1.416

Table 2. Sample correction table.

small frequency steps become smaller. If there are only very few specific frequencies that are of any interest, those frequencies can be the only ones that appear in the table. But, if the full frequency coverage is needed and high accuracy is also required, then either one person must constantly flip through a lot of correction table pages, or some mechanical assistance will be required.

The mechanical assistance can take many forms. It can be a plastic chart with a window, azimuth scale and frequency scale, an electronic memory bank that outputs a corrected LOB by decoding the frequency and azimuth, or it could be a full-fledged microprocessor system that will not only resolve any error, but can indicate a higher accuracy potential by directing the DF unit to use a different antenna bay or indicate the RMS value for a given frequency to show the amount of accuracy that can be expected. Whichever method is chosen, the tradeoffs are accuracy, cost, time, and power consumption.

An important aspect to keep in mind when choosing the correction method is the style of DF operations being performed. If it is a fixed site or man-transported unit, where the antenna can be set with zero degrees pointing north all the time, the correction methods described will work well. When the antenna is hard-mounted to a van, the operator of the DF unit cannot always be assured of getting the antenna pointed north every time. So, if determining map locations are critical, a north variance offset will have to be included (in addition to the difference between north and magnetic north). The correction for north variance cannot be added until the correction for the environment has been completed. Figure 7 is a flow chart showing a proper order of events for correcting DF errors.

Triangulation

If multiple DF sites are netted together to do triangulation, the responsibility of doing error correction rests with each site. The error correction is performed

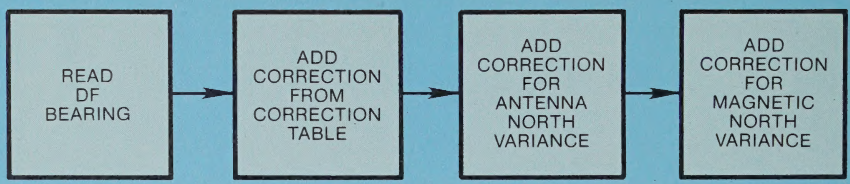


Figure 7. LOB correction flow chart.

exactly as described earlier, but uncertainty also occurs in transmitter location because of statistical error. Figure 8 shows the results of using two DF sites in a net, assuming each site has a ±3-degree error range.

The error range, in triangulation, can be one of two numbers, depending on the required accuracy. As an average, the error range could be the manufacturers' RMS specification. A more accurate measure of the error range is the standard deviation of the corrections at the desired frequency. This value is listed on the correction table of Table 2 under RMS values. (The standard deviation can be considered the RMS value about the average offset. Whenever Watkins-Johnson specifies an RMS value for its UHF/VHF DF units, it can be treated as the standard deviation.) This error range does not guarantee that the true LOB is within the ±RMS range, but that the RMS range is where the transmitter is most likely to be. Also, remember the error range is plus or minus the RMS value.

Notice the shaded rhombus in Figure 8. The two DF sites have made a fix on the transmitter, but because of the uncertainty in the exact LOB, the transmitter could be anywhere in the *shaded area.* Figure 9 shows the effect of adding a third DF site for a triangulation, or a "fix" on the transmitter. There are now three intersections where the transmitter could be. There is a high probability that the transmitter is somewhere in the triangle formed by the three intersections. But, there is a

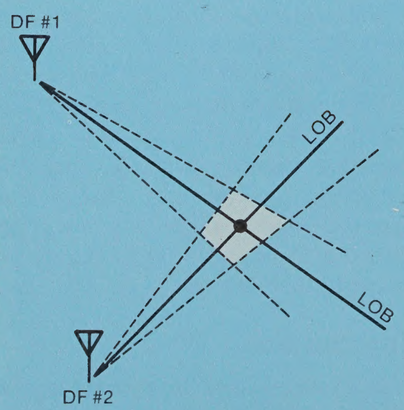


Figure 8. Two DF sites with ±3° error.

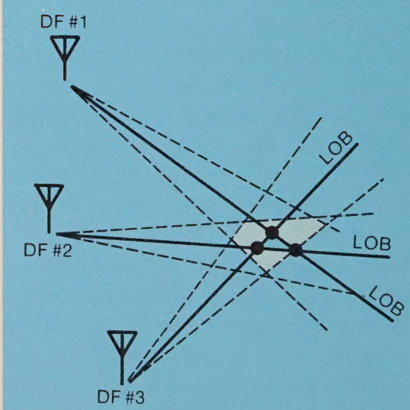


Figure 9. Three DF sites with ±3° error.

significant probability that the transmitter is outside the triangle, but within the pentangle-shaped shaded area. By adding the third DF site, the probable area for the transmitter has been reduced.

By adding more and more DF sites the total area for the probable transmitter location decreases and that probable region can be broken up into varying degrees of probabilities where more and more lines intersect.

One of the most common mistakes in netting is taking for granted that all the DF reports are correct. Figure 10 shows what happens when a DF unit is affected by environmental conditions. If all four DF bearings were believed, the probable area for the transmitter becomes very large. If DF site number 4 were ignored, the same condition as described in Figure 9 exists with a much more acceptable probable area. If the bearing from DF site number 1 is considered the affected LOB, then another acceptable probable area for a transmitter is formed. The decision as to which LOB to consider as being the affected unit should be based on the terrain and other information known about the location of the transmitter.

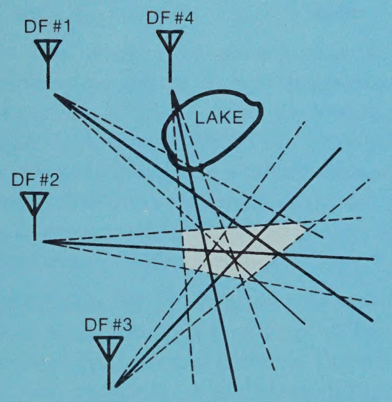


Figure 10. Four DF sites, one with an incorrect bearing.

When doing triangulation, it is wise to be suspicious of information received by a DF unit if there is sufficient evidence to the contrary.

Summary

This article has tried to give the reader a general feel for what causes errors in direction finding, and how to work around some of the problems. The problems presented are common to all direction finders. There are some problems that may be peculiar to a particular model of direction finder that are not covered here and can be determined only by extensive tests of that unit.

The use of correction tables will greatly improve the system accuracy of any DF unit. In fixed-site applications, a correction table can also be used to correct for near-field re-radiations, which can help accuracy.

When using multiple DF units in a netted DF system, the easiest method to increase accuracy is to use more DF units, and to take any other information into account (such as terrain and last known position).

Glossary of Terms

1. **Correction Table**
   A convenient and systematic display of correction values.

2. **Curve Fitting**
   The process of manipulating the linear interpolated data to form a smooth curve.

3. **Data Values**
   The value taken during DF tests to be used as correction values; the true LOB minus the DF reading.

4. **DF**
   Direction finding. The process of finding the angle of arrival of an RF field or wave front.

5. **DF Unit**
   The direction finder. The device used to do direction finding. Usually consists of a superheterodyne receiver with a direction finder assembly attached.

6. **Interpolation**
   The process of calculating approximate values between two known values.

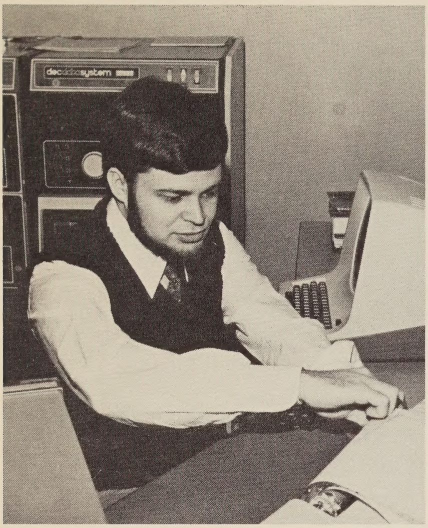
7. **LOB**
   Line of Bearing. The bearing displayed or calculated from the display of a direction finder.

8. **Netted DF Systems**
   The combination of two or more DF units to locate a transmitter.

9. **RMS**
   Root Mean Square. A value indicating the average amount of deviation in the data values.

10. **SD**
    Standard Deviation. A statistical measure of the deviation of data values around the average of the data.

Author:



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He has worked on several direction finders, including a new ruggedized manpack WJ-8975, and rack-mount WJ-8971A processors. He is presently involved in designing a microprocessor controlled direction finder, which is the next generation of direction finders for Watkins-Johnson Company.

Previously, Mr. Harrington was a co-op student at Georgia Institute of Technology. His work experience there includes: microprocessor development and work with several radars at the Experimental Station, Assistant Test Engineer with the propulsion test stands at NASA in Huntsville, Alabama, and Assistant Engineer at the Integrated Circuit Development Lab, also with NASA in Huntsville, Alabama.

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Printed in U.S.A.