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HIGH FREQUENCY POSITION LOCATION: AN ASSESSMENT OF LIMITATIONS AND POTENTIAL IMPROVEMENTS

MAY 1981

By

MELVIN G. HEAPS

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US Army Electronics Research and Development Command
ATMOSPHERIC SCIENCES LABORATORY
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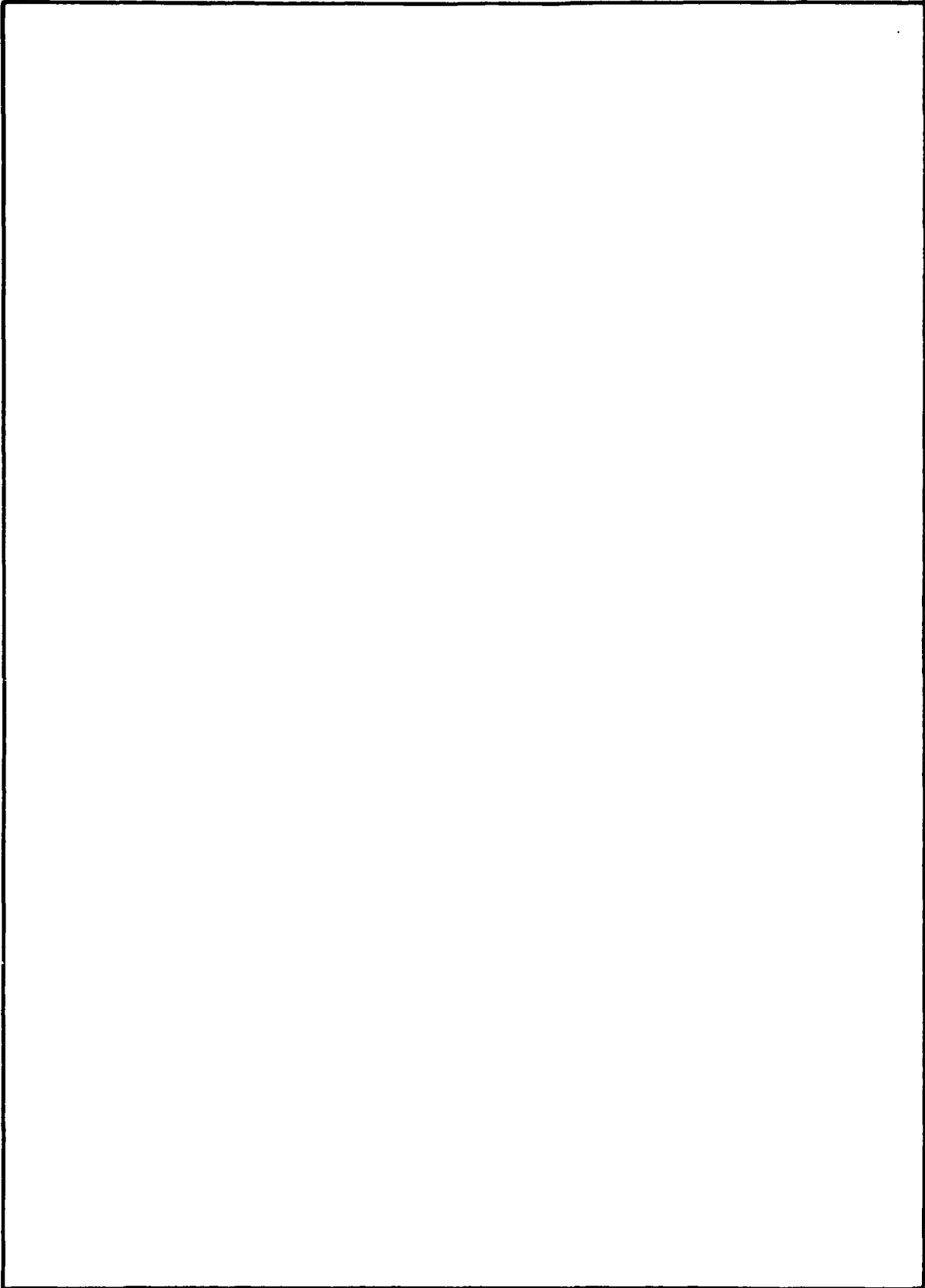
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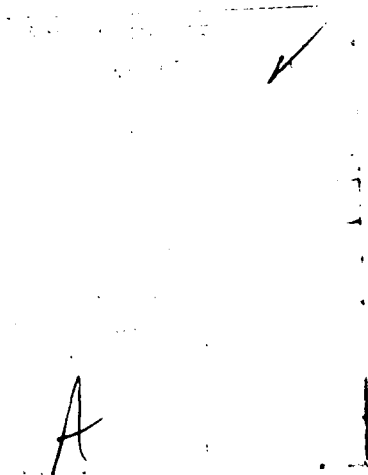
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The general problems of using high frequency direction finding techniques as an accurate means of surveillance and position location are assessed. The primary emphasis is on determining the range errors associated with a single site locator by using the intercepted sky wave. Current errors in position locations are on the order of 20 km due to ionospheric variability, antenna size limitations, and data acquisition and processing problems. Improvements in position location accuracies to the order of 1 km will require complementary use of the direct wave and/or the ground wave.		

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SUMMARY

This report addresses the question of using high frequency (HF) radio wave direction finding (DF) techniques as an accurate means of surveillance and position location on the modern battlefield. The desired accuracy in position would be on the order of 0.1 km for tactical applications.

The initial concept explored is that of a single site locator (SSL), 100 to 200 km to the rear of the battle area, which would sense HF emitting targets at approximately the same distances on the other side of the battle area. Currently, state-of-the-art techniques have errors on the order of 20 km in position location. The main sources of error can be grouped into the following areas:

- ionospheric variability and irregularity;
- antenna and system size limitations; and
- data acquisition, processing, and interpretation.

The prognosis on improvement of SSL range accuracies is that errors in position location can be reduced to 5 to 10 km by incorporating the real-time ionosphere variability into ray retracing calculations and through improved sophistication in software for data acquisition and interpretation. The basic limitation is the use of a radio wave path which employs the ionosphere as a reflecting medium. The possibility of employing several SSL systems to form a larger net may yield uncertainties of only 5 km or slightly less. However, the basic limitations due to the ionosphere remain, and accuracies smaller than a few kilometers cannot be attained in the foreseeable future.

The ultimate goal of achieving HF position location accuracies on the order of 0.1 km may possibly be attained if the approach to the solution is altered. This alternative would involve a two-tier method. The first tier would be the use of the type of SSL discussed above for surveillance and location of the desired targets to within accuracies of 5 to 10 km, and the second tier would be the use of mobile units relying on either the ground wave or direct wave to triangulate on the desired target. This alternative approach implies several changes in philosophy. First, by using a mode of HF propagation other than the sky wave, the effective range of detection has been reduced to less than 100 km and often to less than 30 km. Second, the use of the ground wave implies that two or three mobile units shall be deployed in or very near the battle area. This alternate approach, while offering potential increases in position location accuracy, obviously involves noncomplementary trade-offs in effective range of the mobile units, number of sites involved, and coordination of efforts.

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1. INTRODUCTION

For more than 40 years the standard link for communication between two widely separated points has been the use of the high frequency (HF) band of the radio wave spectrum. The widespread use of HF communications is due to several factors: the technology is well-known and relatively simple, the equipment is easy to manufacture and deploy, and the cost is much less than technologically more sophisticated systems involving microwaves or satellites.

Within the defense community there has been renewed interest in HF communications which stems from rekindled awareness of HF as an important backup or even primary link in our defense communications system. In addition, the knowledge that Soviet forces depend heavily on HF communication leads to the question of how best to exploit this dependence on HF to our tactical advantage. This report concentrates mainly on this latter question, sketches the state-of-the-art accuracies in HF direction finding and position location (commonly referred to as HF-DF), and outlines two programs for improving these accuracies in HF position location.

2. BASIC CONSIDERATIONS AND PHYSICAL LIMITATIONS

HF position location by use of a single site locator (SSL) involves not only receiving or intercepting a signal from a transmitter, but also receiving the signal in such a way that two angles of arrival and a distance parameter can be determined. The azimuthal angle, like the angle of a compass, gives the direction from which the signal comes. Figure 1 illustrates the elevation angle and a parameter, usually the height of the reflecting layer of the

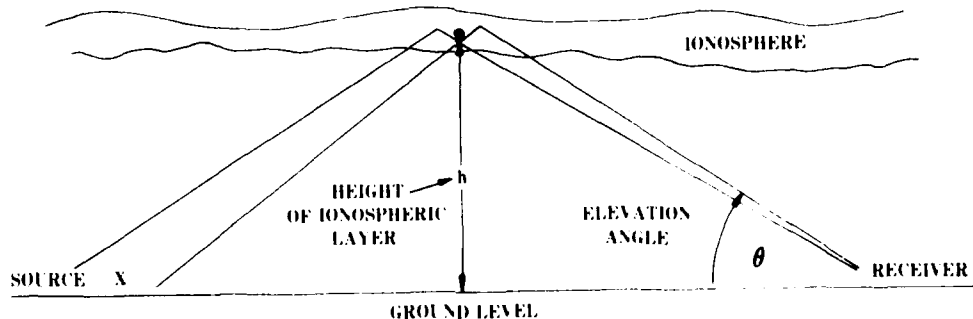


Figure 1. The elevation angle, θ , and the ionospheric height, h , used to determine the range of the emitting source.

ionosphere, from which the distance (range) to the transmitter is determined. However, any emitting HF source yields two types of waves, one which propagates along the earth-air interface (the ground wave) and the other which propagates through the atmosphere (the direct wave) eventually to be reflected off the ionosphere (the sky wave). The proportion between the two waves for any given transmitter depends on antenna design and orientation. Generally speaking, when one is close to the source, about 50 km or less, the

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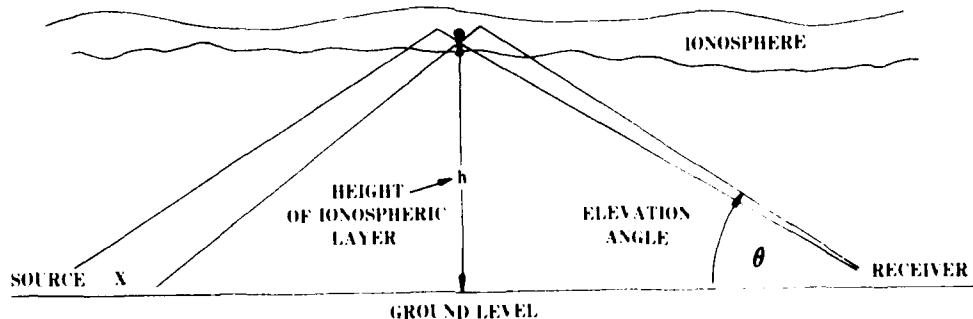


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ground wave is the strongest signal received--although the distance could be as small as 20 km or as large as 100 km depending on the topography, soil type, and soil conductivity. In this region the reflected sky wave is of near vertical incidence and yields little useful information on direction or range. Thus for "close-quarters" HF-DF, a system which utilizes the ground wave would be the most applicable. In the region roughly 50 to 100 km from the source (again these limits are only approximate), both the ground wave and the sky wave can be received (with the subsequent interference problem), but with the constraint that the ground wave is fading out while the sky wave still has a large angle of vertical incidence, so that little useful DF information can be obtained from a ground-based HF-DF system. In this region a useful HF-DF system would be on an airborne platform, above the ground wave and suitably shielded from the sky wave, which would utilize the directly incident HF wave. At ranges of greater than 100 km, and most optimally at ranges of a few hundreds of kilometers, the "conventional" ground-based HF-DF system using the sky wave should be employed. Figure 2 shows a schematic of these options.

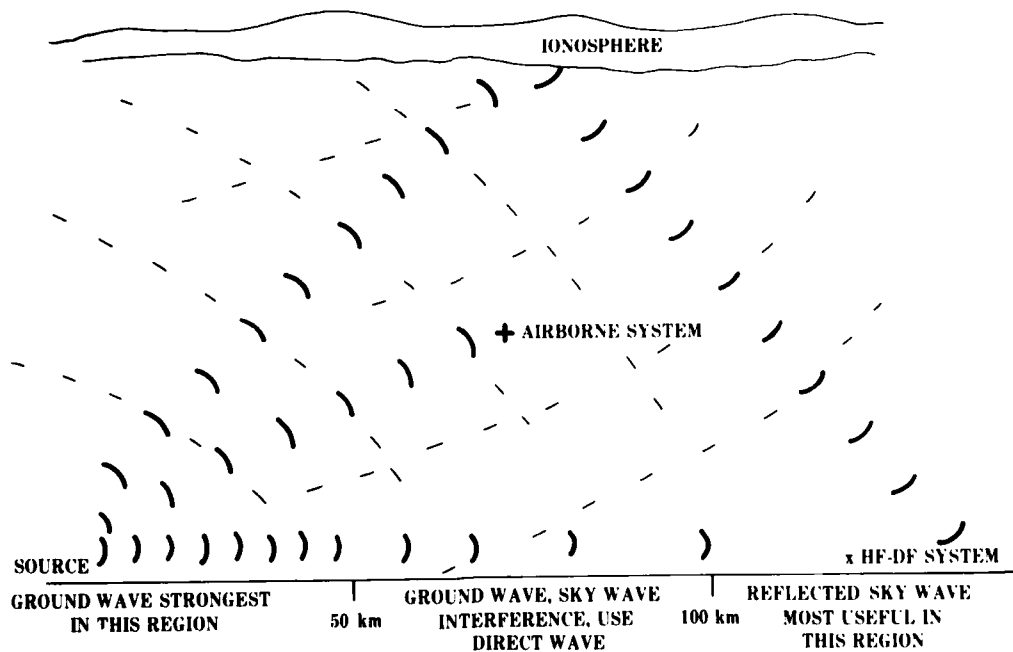


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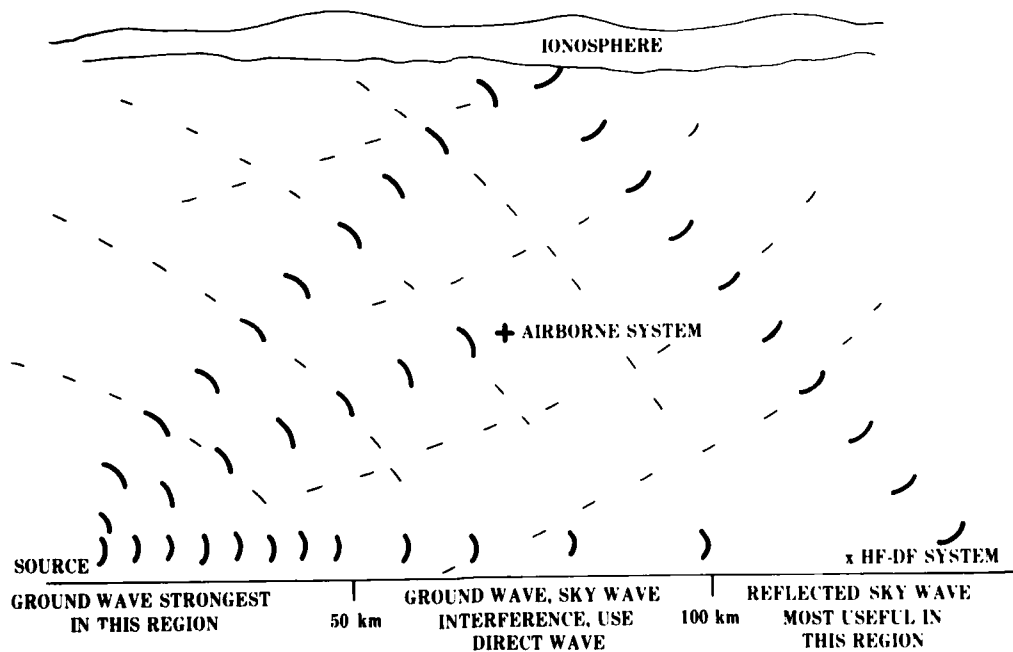


Figure 2. Schematic of options.

Several limitations and uncertainties now arise. These limitations and uncertainties may be grouped into three categories. The first category deals with the ionospheric variability and irregularity which must be considered. The second category concerns the physical size and alignment of the antenna system one desires to field. The last category includes the problems of data acquisition, processing, and interpretation.

The first category of limitations concerns the ionospheric variability and irregularity which interfere with an accurate determination of the true direction of arrival of the incident HF signal. Ideally the ionosphere should be a perfectly smooth reflecting medium at a fixed height above the surface of the earth for all points. In practice there are many effects which must be accounted for. The height of the ionospheric reflective layer, which is itself a function of frequency of the radio wave, varies in time. This type of variation may occur at any time, but is especially noticeable at sunrise and sunset. The ionosphere may also be tilted a few degrees; that is, planes of constant electron density are not precisely parallel to the earth. Again such tilts are prevalent in the day/night transition zone. Traveling ionospheric disturbances (TID) also cause variations in height and tilt which are not directly relatable to solar influence. Actually there is an entire spectrum of waves or irregularities in the ionosphere--from TID with wavelengths on the order of 1000 km and periods of tens of minutes down to waves of a few kilometers or less in size and variations of a few seconds. These factors tend to make the reflective layer look rather corrugated and specular. Many ionospheric variations have been successfully incorporated into the determination of radio propagation paths, but of necessity such techniques can include only the large-scale, regular ionospheric variations. A basic constraint for attaining small HF position location errors is the inclusion of the real-time ionospheric behavior into the ray retracing programs; this behavior is now being included in some systems. Vertical ionospheric soundings can yield the real-time ionospheric heights overhead, and oblique soundings from transmitters not collocated with the receiver (which is presumably at the HF position location site) can yield additional information on tilts and some TID. The basic limitation is that this information is most likely not for the section of the ionosphere from which the desired HF intercept is being reflected. Thus, the conditions observed overhead or obliquely must be extrapolated to the desired point of reflection. This procedure is an improvement, but it still leaves room for error.

The commonly used HF band runs from 2 to 30 MHz, which corresponds to wavelengths ranging from 150 m down to 10 m. Much of the HF communication traffic is carried on the lower frequency, that is, longer wavelength, end of the band. To accurately determine the angle of arrival, the "antenna" should be at least as large as the wavelength of the signal being received--in practice several small dipoles or similarly designed antennas are linked together to form a larger array of the requisite size. Thus, one is faced with a basic constraint: the antenna system must be at least 100 to 200 m in size. Larger arrays will buy increased accuracy but create increased deployment problems. Smaller sized systems will simply not produce sufficient angular resolution.

The third major category of limitations lies in the area of data acquisition, processing, and interpretation. Several problems arise due to limitations

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The third major category of limitations lies in the area of data acquisition, processing, and interpretation. Several problems arise due to limitations

mentioned in the above categories. Resolution of the angles of arrival due to the limitations in antenna size implies that the reported value will tend to wander. Fading (even loss) of the signal can occur due to increased ionospheric absorption and several types of signal interference mechanisms. Multipath propagation of signals can cause problems in selection of the correct ionospheric parameters for the matching path and can also introduce interference fading. Co-channel interference involves the reception of unwanted, spurious signals and creates subsequent problems in signal discrimination. Also interference between the ordinary and extraordinary waves of the same signal can occur. Many of these problems have been mitigated in recent years through increasing use of computerized data handling and sophisticated software routines for signal processing and interpretation. To maintain and to improve these advances, a basic requirement would be the inclusion of a sophisticated minicomputer in any HF position location system.

Thus far the limitations of a system using the sky wave have been the main topic. However, the ground wave can also be used in position location efforts, but again there are constraints and associated limitations. Use of the ground wave means that only the azimuthal angle of arrival can be determined and therefore more than one point of detection must be used to specify the location of the emitter. In addition, the ground wave can be used effectively only at ranges of less than 100 km (often very much less). While the many problems of ionospheric variability are avoided through use of the ground wave, an analogous set of problems also exists for this mode of propagation. Topography, soil type, and soil conductivity will change the true path of the ground wave from that of a segment of a great circle (that is, the shortest distance between two points on a smooth, uniformly conducting, spherical earth). Ground wave propagation has not been studied as extensively as direct wave or sky wave propagation, and many of these uncertainties still need to be quantified.

Another basic limitation for all types of HF-DF systems is that the location of the system itself must be known to a greater accuracy than the allowable error in range. For HF-DF systems which use the sky wave, with the associated large errors in attainable accuracy in position location, this limitation is not a major problem. However, when the desired accuracy in range is a fraction of a kilometer, the ability to determine one's own position even more precisely may become a severe limitation.

3. EXAMPLES OF SOME HF-DF RANGE ERRORS

The previous section points out that errors in HF-DF have several sources. Currently, we feel that HF-DF arrays have limits in resolution of the angle of arrival on the order of 1° ; but for large arrays which are carefully surveyed, the error can be reduced to 0.1° . (This error is instrumentation error; actual propagation through the medium is another factor.) Practical constraints on the sizes of easily fielded systems generally yield angle acquisition errors on the order of 2° . Ionospheric tilt can introduce errors in the vertical angle of incidence on the order of 2° to 3° . The ionosphere is not a smoothly reflecting medium and produces a "corrugated" wavefront which in turn makes an exact determination of the angle of arrival difficult. The signal may travel different paths in the ionosphere and suffer varying degrees of

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absorption along these paths. In short, the ionosphere is the single largest source of error and may produce total errors in angle of arrival on the order of 10° for ranges larger than 300 km and up to 30° for ranges less than 300 km.

Figure 3 schematically illustrates some of the ionospheric irregularities mentioned previously which create errors in determining the true angle of arrival and in turn cause some of the problems in signal interruption also mentioned above. Some of the range determination errors inherent in HF-DF

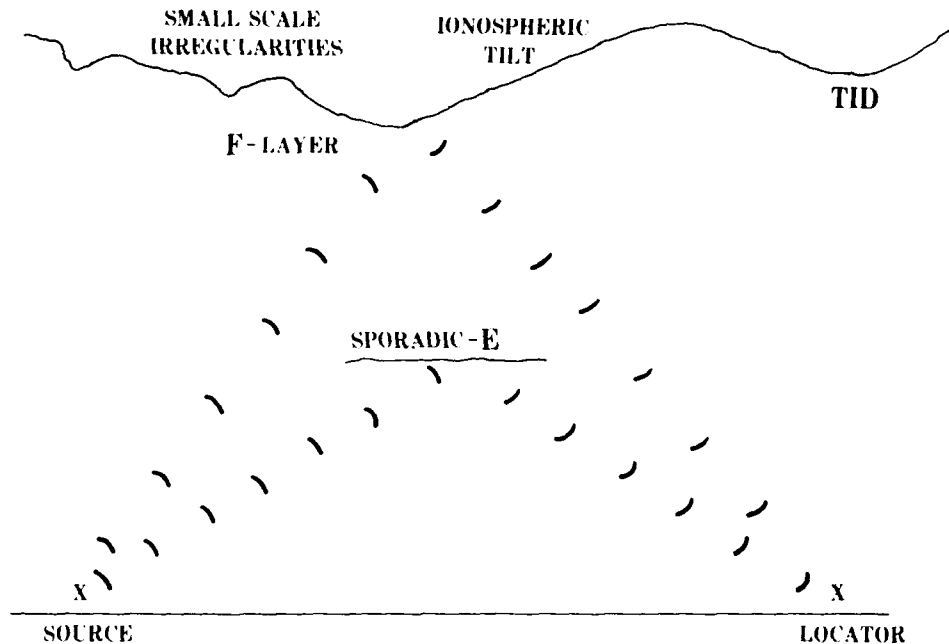


Figure 3. Origins of the uncertainty in the angle of arrival due to the ionosphere.

work can be quantified for a given situation. Table 1 shows potential position location errors for a source located 200 km from the HF-DF system. The general points to be gleaned from this table are that errors in the determination of the elevation angle are more severe than those affecting the azimuthal angle and that the errors associated with the system are generally smaller than those associated with the ionospheric variability. These factors again underscore the basic limitations due to ionospheric constraints.

The rule of thumb for currently attainable position location accuracies seems to be on the order of 20 km. Total time required to acquire, direction find, and locate a signal can be as short as 5 s, but in most circumstances would be longer.

4. OUTLINE OF HF-DF IMPROVEMENTS

Several areas where improvements in HF-DF position location accuracies can be obtained will now be outlined. Attention will be directed initially to the concept of the SSL which uses the sky wave as its means of detection.

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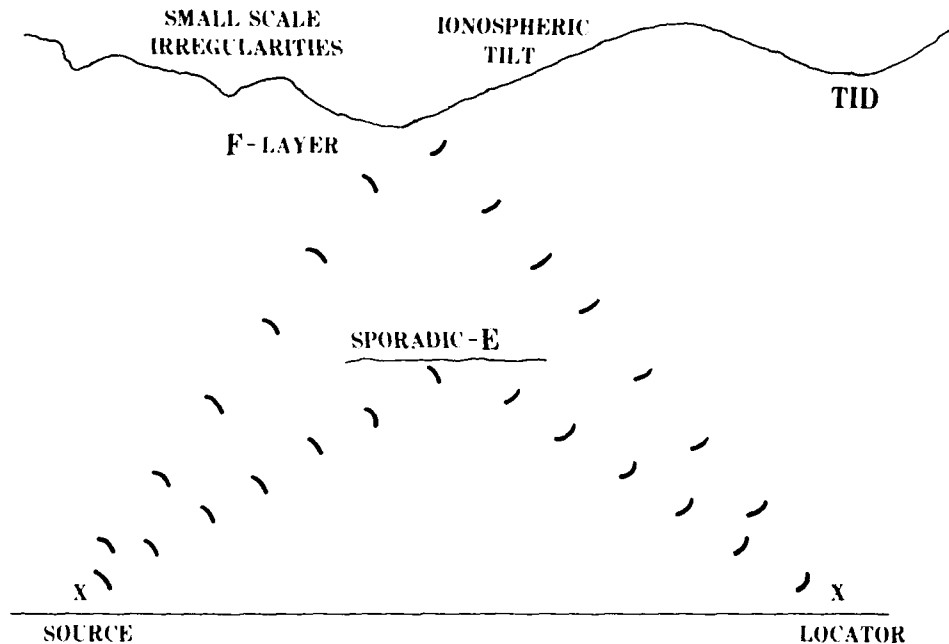


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TABLE 1. POTENTIAL ERRORS IN POSITION LOCATION

Distance: 200 km from emitter to locator

Reflecting Layers: E-layer at 120 km height and F-layer at 250 km height,
one-hop mode

Type of Error	Typical Error	Errors in Range (km)	
		E-layer	F-layer
Resolution limit of system	1°	7.0*	9.8
		3.5	3.5
Variation of ionospheric height	10 km	16.3	7.7
Ionospheric tilt	2°	14.4	20.4
		4.2	8.7

*Most types of errors create an ellipse of uncertainty about the true emitter location; when two values are listed, the upper value is the error in range and the second value is the cross-range (azimuthal) error.

The largest potential errors in position location are due to ionospheric variability. An ionosonde can be used to yield information on the height of the reflective ionospheric layer and to follow the time variations in this height. Current systems use a vertical ionosonde (that is, transmitter and receiver are collocated at the HF-DF site) which cannot yield detailed information on ionospheric tilts. Oblique soundings are recommended for use where two or more sounder transmitters are located some distance away from the receiver at the HF-DF site. The use of multiple oblique soundings will enable one to determine ionospheric tilts and provide some degree of resolution for other ionospheric irregularities. Currently the ionosphere can produce errors in the angle of arrival of the HF signal of several degrees which yield errors in the range of 20 km or larger. We believe that a more accurate determination of the ionosphere, when coupled to a ray retracing program, can yield accuracies on the order of 5 to 10 km. However, a basic limitation is that the state of the ionosphere cannot be measured at all points, and most particularly at the desired point of reflection. Thus extrapolation must be from a known point to a desired point; and it is this extrapolation which, in part, prevents attainment of accuracies of better than 5 to 10 km.

Table 1 has illustrated that a 1° error in the angle of arrival due to limits in resolution of the system produces errors in range on the order of 10 km. However, we now feel that such system resolution errors can be reduced to approximately 0.1°, which would mean effective errors in range on the order of 1 km.

Other areas of improvement are those of computer hardware and software and data processing and interpretation. The largest gains in the area of HF-DF accuracies in the last 5 to 10 years have been through better handling of the tremendous amounts of data which HF-DF can provide. With increased demands of

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ray retracing techniques, more sophisticated hardware and software must be employed.

For systems which utilize modes of radio wave propagation other than the sky wave, a few general suggestions may be made. The magnitude of the potential uncertainties in ground wave and direct wave detection needs to be quantified and means explored of simultaneously using the weak ground wave and nearly vertical incident sky wave in the range of 50 to 100 km from the emitter. Direct wave DF is very system dependent (that is, platform dependent) and the range of these errors needs to be established.

5. PROPOSED PROGRAMS FOR HF-DF IMPROVEMENT

The considerations and limitations outlined in the previous sections would suggest two approaches to be followed in reducing the current errors in HF-DF location accuracies. The first approach, hereafter referred to as program A, is based on the concept of an SSL which is positioned some few hundred kilometers from the desired source and which uses the HF sky wave as a means of surveillance and location. The emphasis here is to extend the state of the art by using known technologies such that the limiting factor in HF position location becomes the basic ionospheric uncertainty. Such an approach has a good probability of meeting the established goals. The second approach, program B, would use a two-tier method of solution. The first tier incorporates program A to reduce the area of uncertainty in location to a circle of approximately 10 km diameter. The second tier would consist of mobile HF-DF units which would use either the ground wave or direct wave at much closer range to achieve the desired accuracies in position location. The second tier of program B implies a change in concept. Use of the sky wave, with its inherent uncertainty, is abandoned in favor of the ground wave or direct wave. The consequence is that the HF-DF unit must be about 50 km from the emitter and more than one mobile unit must be used. Attaining position location accuracies of less than 1 km thus implies noncomplementary trade-offs in range and complexity. Table 2 presents a brief outline of the programs.

6. CONCLUSIONS

The state-of-the-art HF-DF accuracies for surveillance and position location are 15 to 20 km at best for an SSL system. The sources of error in position location can be grouped into three categories:

- ionospheric variability and irregularity, < 20 km;
- antenna and system size limitations, 10 km; and
- data acquisition, processing, and interpretation.

The approximate errors in range have been indicated where appropriate. We believe that the above errors can be reduced to the following limits:

- ionospheric (propagation medium) induced errors, 5 to 10 km, and
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TABLE 2. HF-DF ACCURACY IMPROVEMENTS

PROGRAM A		PROGRAM B	
Objective	Reduce the errors in HF position location accuracy from the current 15 to 20 km to 5 to 10 km.	Objective	Improve the accuracies in HF surveillance and position location to fractions of a kilometer.
Method of attack	Identify and quantify the ionospheric variability and irregularity which cause HF-DF uncertainties. Incorporate real-time ionospheric soundings and quantification from preceding step into ray retracing programs. Develop software to handle the demands of the above incorporation. Incorporate into operational HF-DF system.	Method of attack	Design system to rely on the ground wave or direct wave. Use more than one mobile system to triangulate on emitter. Identify and quantify the uncertainties in ground wave HF direction finding. Establish procedure to fix locations of and coordinate efforts between multiple units.
Technical barriers	Adequate quantification of ionospheric structure. Development of ray retracing program to incorporate real-time ionospheric variability. Matching software to capabilities of operational system.	Limitation	Effective range of detection is less than 100 km, more often on the order of 50 km or less.
Probability of success	Good	Technical barriers	Adequate quantification of terrain effects on ground wave HF-DF. Means of accurately fixing the position of mobile units to fractions of a kilometer. Data exchange and processing between mobile units. Synthesis of tactically operable system.
		Probability of success	Fair to good.

Such improvements depend on the continued incorporation of state-of-the-art computer hardware and software into the SSL to handle increased data processing requirements.

SSL surveillance and position location can be improved to accuracies of 5 to 10 km. Further improvement in HF DF accuracies may be obtained by additional

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SSL surveillance and position location can be improved to accuracies of 5 to 10 km. Further improvement in HF-DF accuracies may be attained by additional utilization of the HF ground wave or direct wave. Improvements in position location accuracies to fractions of a kilometer using these modes of HF propagation will involve noncomplementary trade-offs in other areas:

- Range of detection is reduced: 50 km or less for the ground-wave, on the order of 100 km for the direct-wave;

- Number of systems is increased: two or three mobile units would be deployed near the battle area; and

- Coordination and communication demands are increased.

Position location accuracies on the order of a fraction of a kilometer may possibly be achieved by using a ground wave or direct wave method of detection, but with the loss of certain advantages provided by a sky wave SSL. An integrated approach to the HF position location problem is recommended. This approach would employ all methods.

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