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TECHNICAL MEMORANDUM

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A CLOSE APPROACH HF D.F. SYSTEM FOR TACTICAL USE ESPECIALLY IN HEAVILY TIMBERED AREAS

R.F. Treharne, B.Sc., B.E.

SUMMARY

The distance factor is of great importance in setting the accuracy and target density of close approach HF d.f. systems. Several methods of operational deployment are discussed. The attenuation of the forest wave, interference produced by the skywave and the sensitivity of simple aerials are discussed. A spaced loop system would have advantages at night in reducing skywave effects. Various aspects of the performance of such systems are discussed. It is concluded that the most practical system which could be put into the field quickly could be vehicle mounted. In heavily timbered areas, it would have an accuracy of 250 m on daytime tasks at ranges of the order of 5 km. Range at night would be limited to less than 3 km, although there is some prospect of improving this by using time of arrival selection techniques.

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POSTAL ADDRESS: Chief Superintendent, Electronic Research Laboratory
Box 2151, G.P.O., Adelaide, South Australia, 5001

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1. INTRODUCTION

The accuracy of locating high frequency (HF) radio transmitters depends on many factors(ref.1,2) including the type of locating system employed, but a dominant factor is the distance to the target(ref.3). High accuracy requirements lead to the need for mobile direction finders operating at very short distances, (a few kilometres) from the target, which need to be steered by less accurate systems such as airborne or skywave direction finders or single station locators.

The purpose of this paper is to discuss the problems associated with the design of close approach HF d.f. systems.

This paper contains the gist of one which was published in July 1971, extended to the case of single sideband voice transmissions.

2. DISTANCE FACTOR IN HF TARGET LOCATION SYSTEMS

The accuracies obtained with various HF location systems may be deduced from the characteristics of basic observations such as standard deviation (SD) of bearing or SD of eastings and northings of position measurement, coupled with the geometrical considerations involved(ref.1,2). For short distance tactical systems geometrical considerations are just as important as basic radio observations. As a first order approximation the error parallelogram of a d.f. system using horizontal triangulation has an area which is proportional to the square of the distance of the d.f. stations from the target. This distance factor is the main reason why airborne d.f. when operated at 15 km (or less) is superior to Adcock or quasi - Doppler type d.f. which must be operated at a distance of at least 300 km from the target transmitter. This is because of technical reasons associated with the use of vertical receptors and by virtue of the geometrical implications of trying to measure bearing angles of steep skywaves. It is evident that ground based d.f. may be used to produce a further improvement in accuracy beyond that obtained by ARDF, because the distance to the target can be reduced even further. For example, if the distance is reduced significantly below 15 km, say to 1.5 km, the distance factor would reduce the area of error by 100 times given similar angles of cut, bearing measurement accuracies, number of cuts and baseline geometry. In Table 1 the accuracy of location expected from a typical system at various distances is shown.

It is apparent that a most important feature of a close approach d.f. system is the closeness of the approach - any suggestion that such a system should be capable of operation at 20 or 30 km distance would defeat this important feature of the system.

3. TARGET DENSITY

An operational by-product of reducing the distance of operation of a target location system is the reduction in the size of the target area which may be covered by a single system. If the potential targets are uniformly distributed the number of targets available is in proportion to the radial distance squared. Therefore, any close approach system tends to be strictly dedicated to obtaining accurate results on a small number of targets, one at a time.

4. TECHNIQUES OF OPERATIONAL DEPLOYMENT

The operational deployment of this type of system is open to development. One method would be to operate from a vehicle which would navigate the road or vehicle track system in much the same way as the aircraft navigates a baseline, so giving the equivalent of a multi station d.f. network. Since the vehicle speeds are about one-fifth of the speeds of the aircraft this technique would seem appropriate for location distances a similar fraction of aircraft distances, that is 3 km or a little more. The vehicle distance meter would be used to locate the site of each bearing instead of using an elapsed time method as in the case of the aircraft. Whether the constraints imposed by the road system in relation to the desired targets would permit this would vary from case to case.

A second method of deployment would be on foot. Speed and mobility would be greatly reduced and the multi station baseline system, so useful with airborne d.f., would have to be replaced. Navigation would become a major problem. Two methods suggest themselves, namely, homing, in which the operator moves on foot towards the target, and sidetracking, in which the operator moves to the flank of his first bearing. The latter method has the advantage that measurement of sense is not needed.

In any of the above operations, methods of navigation, control, steerage, mobility and so on need to be integrated to achieve the objectives. The last named would have to take into account the subsequent action intended, e.g., intelligence collection followed by withdrawal, immediate offensive action, and so on.

5. PROPAGATION FACTORS

The propagation aspects have an important control on the performance of a close approach d.f. system. Signals may arrive at the receiving point via a number of different modes of propagation. Close to the transmitting aerial a direct line of sight exists. The distance in nautical miles of such a line of sight path over uniform earth surface is given approximately by the sum of the square roots of the heights of the transmitting and receiving aerials in feet, plus about 20% to allow for atmospheric refractive effects. An aircraft flying at 2000 ft has a radio horizon of about 17 n.m. Such direct waves have low basic transmission loss so that strong signals are received via this mode. For ground d.f. this mode is not very useful. (Aerial heights of 3 m would be expected to cover a few miles if the ground were smooth and unobstructed, but in practice ground irregularities and obstructions such as trees preclude the usefulness of this mode.) A vertically polarized surface wave ("ground wave") is usually the dominant mode of propagation in open country. Calculation(ref.4,5) of the basic transmission loss of such surface waves is well understood provided the earth conductivity and dielectric properties are known and the earth along the path is uniform. Further losses occur if the path involves transmission through heavily timbered areas.

5.1 Skywave interference

As the distance from the transmitter is increased a point is reached where skywave signals may arrive with strength comparable with the surface wave, even though the skywaves have travelled some 600 km up to the ionosphere and back. At this point direction finding becomes difficult due to the interference between the two waves ("night effect"). The distance at which this occurs depends on the directional patterns of the transmitting and receiving aerials and varies over wide limits depending on the amount of wave absorption which the ionosphere is introducing at the time. If the operating frequency is above the critical frequency for vertically incident waves on the ionosphere no skywaves are reflected and the limit on the usefulness of the surface wave is set mainly by noise levels; however this situation is not likely in practice if the target transmitter is being used for short distance skywave communication - it would be used on a lower frequency.

During the daytime, ionospheric absorption may limit the strength of the skywaves(ref.8) by 25 dB or more; the worst time for d.f. is at night at frequencies below critical when strong skywaves would be received. For example, at 5.0 MHz the skywave and the surface wave from an isotrophic transmitting aerial (e.g., a sloping wire would be roughly isotrophic) would be about equal at 17 km for average ground constants (by contrast, the distance would be some 200 km over sea water). Through thickly timbered areas in which both transmitter and receiver are totally immersed in the trees, (that is, in jungle conditions) vertically polarized waves suffer considerable additional attenuation. For jungle having a biomass (total green weight of the trees forming the jungle) of the order of 360 tonnes/hectare and with median tree heights of the order of 10 m, the additional attentuation of the vertically polarized wave at 5 MHz is about 20 dB(ref.6). Therefore, it would be desirable to provide directivity in the d.f. aerial so that skywaves could be attenuated by this 20 dB plus a margin to reduce skywave signals to negligible proportions, perhaps by another 15 dB, or 35 dB in all. Such protection against skywaves is unlikely to be achieved in practice by portable receiving aerials which are limited to polar diagrams of a simple cosine pattern as these patterns would give this protection for waves arriving not more than one degree from the vertical; it is known that ionospheric tilts near the magnetic equator in the absence of spread(ref.7) can be 9 degrees at night giving a maximum protection of 16 dB. During the daytime the divergence may be 3 degrees for which some 35 dB protection may be provided by cosine type patterns.

In Table 1 are shown the calculated margins between 5 MHz skywave signals and the forest wave signals for various distances, for night time and for day time, using either a simple loop or a special aerial system designed to have a null response overhead. The performance of the simple loop system is such that it should not be troubled by skywaves at a distance of up to 10 km or more during the day but at night the maximum range would be less than 3 km, unless means are used to gate out the skywave.

5.2 System sensitivity

In addition to consideration of the interference produced by the skywaves, it is necessary that the forest wave have sufficient strength to overcome the noise level in the system. The sensitivity of a typical d.f. receiver has been found to be 30 μV/m for 10 dB signal to noise ratio when using 30% amplitude modulation. If a heterodyne beat note or single sideband system is used instead of the amplitude modulation an increase in sensitivity of about 10 dB should result, that is, 10 μV/m.

In the case of heterodyne beat note detection the improved sensitivity arises from the effective reduction in post detection bandwidth (to about 50 Hz) which is due to the ability of the human ear and brain to pickout the required beat note. With single side band speech the improved sensitivity arises from the concentration of intelligence in the smaller bandwidth and the removal of the need for a carrier wave. No allowance is made in this d.f. case for any increased sensitivity arising from the ability of the human ear to reject those suppressed carrier sidebands which are not related to the desired carrier, an effect which is important in understanding speech communications, but not in d.f. The field strength expected in forest at 5 MHz from a 10 w transmitter and short vertical aerial is about 20 μV/m giving a signal to noise ratio of 15 dB at 5 km. For a one watt transmitter the signal to noise ratio would be only 5 dB at 5 km; to maintain a 15 dB signal to noise ratio with one watt it would be necessary to reduce the distance to about 3 km. The State forests in the South East of South Australia have been used for preliminary experiments. These forests provide radiowave propagation charcteristics similar to those of tropical areas of equivalent biomass since it is the vertical sap and its height which seems to control the attenuation. Rain has little additional effect on the attenuation even when it wets the trees.

For more powerful transmitters, e.g. 100 w, and for lightly timbered areas, system sensitivity is not likely to be a limiting factor, and the ratio of surface wave to skywave will determine if d.f. is possible.

5.3 Polarization

The remarks in this report apply to vertical polarization of the surface wave. When no vertically polarized wave is radiated ground d.f. is not possible with vertical loop antennas.

6. CONCLUDING REMARKS

The most important feature of a close approach target locating system is the closeness of the approach since this has an overriding influence on accuracy and on the number of targets. Distance of the order of 5 km or less are recommended.

Three methods of operational deployment have been described; one involves using a road vehicle much in the same way as an aircraft is used in airborne systems; the others involve movement on foot. Considerable development of the techniques of deployment is needed; this involves the whole system not just the d.f. instrument.

The propagation factors require special attention. The attenuation of the surface wave in forest is high; this seems to be the basic reason why experience suggests that ground d.f. in the forest is difficult when compared with open country such as in the Western Desert of North Africa. This reduced ground wave makes the problem of skywave interference more acute. During the daytime a simple vertical loop aerial should provide sufficient skywave margin a little beyond 10 km but would be useless beyond 3 km at night. A special aerial having a cosine vertical pattern (e.g. coplanar, horizontally spaced vertical loops) would give additional protection from skywaves and should permit operation at distances beyond 17 km during the day and a little beyond 5 km at night.

The simple loop system should have sufficient sensitivity with transmitters of more than 10 w power at distance of more than 5 km; one watt transmitters would have to be approached within 3 or 4 km in forest to be heard for d.f. purposes. The sensitivity of a spaced ferrite system is not known since no such system has been made. However, it is possible that it may be only a few decibels less than that obtained from a simple ferrite aerial.

The most practical form of system which could be put into the field quickly would appear to be vehicle mounted. It would need to include communications, control and road navigational facilities. A simple loop aerial system would have a range of better than 10 km during the daytime on transmitters with more power than 10 w. On lower powered transmitters, it would be necessary to be closer than 5 km. During the night the simple system would not be satisfactory further than 3 km. In more open country greater operating distances should be possible.

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TABLE 1. PREDICTED PERFORMANCE OF CLOSE APPROACH D.F. SYSTEM
(HEAVILY TIMBERED CONDITIONS)+

Distance KM	Accuracy* Metres radius	Receiving aerial ∅	Overhead skywave margin dB	
			Day **	Night ‡
3	150	A	-38	-13
5	250	A	-28	(-3)
10	500	A	-18	(7)
17	850	A	(-5)	(20)
3	150	B	-63	-29
5	250	B	-53	-19
10	500	B	-43	(-9)
17	850	B	-29	(4)

* Accuracy expected from a well placed 2-string fix with bearing error of 3 degrees, confidence level 66%.

\+ Forest biomass equivalent to that of Pak Chong(ref.6) i.e., 890 trees per hectare, median height 10 m, 360 tonnes per hectare.

** Ionospheric tilts, 3 degrees by day, 9 degrees by night, maximum.

∅ Receiving aerials; Type A, vertical loop
Type B, spaced vertical loops with overhead null.

( ) Skywaves may be expected to corrupt d.f. measurements.

‡ Daytime performance may be obtained at night by use of a timing technique to confine observations to surface wave.

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