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TERRAIN AND IONOSPHERIC EFFECTS ON ELT TRANSMISSIONS TO A SARSAT SPACECRAFT

by

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ABSTRACT

In order to carry out an RF link analysis for a Search and Rescue Satellite System (SARSAT) it is necessary to determine the effects of local terrain and surface cover, and of the ionosphere, on emergency locator transmitter (ELT) transmissions. This report summarizes the results of a study carried out by the Communications Research Centre (CRC) in order to assess the probable magnitude of such effects. It is concluded that signal attenuation and fading of an ELT signal, due to local topography and surface cover, probably do not exceed about 6 dB at spacecraft elevations above about 20°, except possibly in Pacific Coast forest areas. Considerable fading of the 121.5 MHz frequency may be caused by the night-time high-latitude ionosphere. A major area of uncertainty is the actual radiation pattern of an ELT under 'crash' conditions. An appropriate measurement program of such patterns is suggested.

1. INTRODUCTION

The objective of the Search and Rescue Satellite System (SARSAT) is to provide a capability for quickly locating emergency locator transmitter (ELT) signals throughout the entire Canadian Search and Rescue zone[1].

The SARSAT system configuration is illustrated in Figure 1. The ELT radio signals are transmitted to the orbiting satellites which relay them to one or more ground stations. The ground stations detect the presence of the ELT signals, make doppler shift measurements on the signals, and process the signals to determine the position of the ELT.

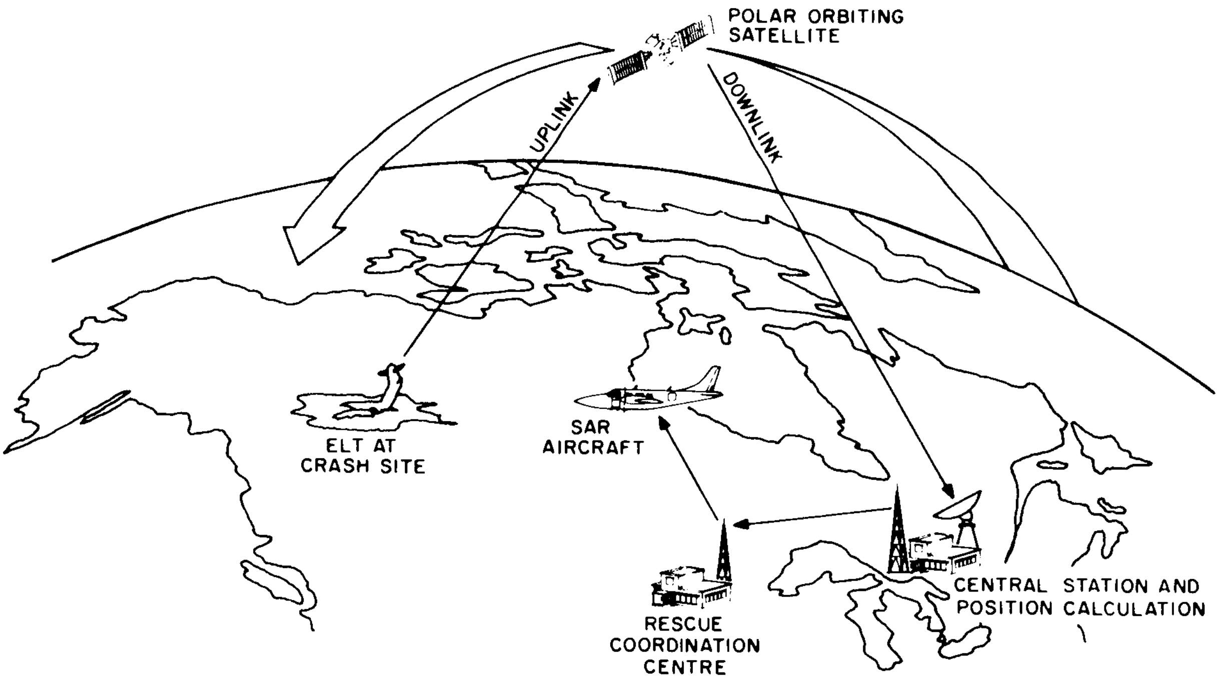

Figure 1. Satellite-aided search and rescue system. The uplink frequency is at 121.5, 243, or 406 MHz. The downlink frequency is above 1 GHz.

In order to carry out an RF link analysis as part of the design phase of a SARSAT system, it is necessary to know the effects of local terrain and of the ionosphere on the signals radiated by an ELT. Such a study, (excluding of course the ionosphere), for the case of an airborne detection system, has been carried out by Petrie[2].

This report contains comments on the results presented in reference 2 and extends the work to the SARSAT situation. Areas in which experimental data is lacking are noted, and suggestions for further measurement program are presented.

2. DEFINITION OF PROBLEM

The problem addressed by this report is to determine the probable received power at a SARSAT spacecraft, from an ELT, under a variety of ELT siting conditions.

The problem breaks down into four largely independent sub-problems:

(a) What range of effective radiated powers (ERP's) and radiation pattern characteristics may be expected of ELT's operating under a variety of actual crash conditions?

(b) What attenuation may be expected from trees or snow cover surrounding the ELT? What is the elevation dependence of this attenuation?

(c) What restrictions does the actual surface topography of the earth place on the spatial coverage of an ELT?

(d) What, if any, are the effects of the ionosphere on the ELT signal?

The latter point is not strictly in the domain of this report, but it does represent one set of parameters required in order to carry out meaningful ELT-SARSAT path-loss estimates.

3. DETERMINATION OF LIKELY ELT RADIATION PATTERNS AND ERP'S

Since reference 1 quotes reference 2 in regard to radiation patterns and ERP's, any comments made in the following in regard to Petrie's report (reference 2) also hold for reference 1.

Theoretical radiation patterns of a $\lambda/4$ vertical monopole antenna were computed in reference 2 for a variety of antenna heights and ground parameters. It is not clear how the proximity to the antenna of the ELT transmitter unit itself has been taken into account, or what current distributions and integration limits were used in examples where the ELT was elevated above ground. Only two of the many predicted patterns were adequately compared (measured data points shown) with experimentally determined patterns (121.5 and 243 MHz; 'good' ground; height of antenna base 0 metres). At high elevation angles the predicted and measured radiation patterns differ by up to 10 dB. Indeed, a calculation of ELT power output, based on measured field-strengths which were considered to be in good agreement with theoretically predicted values, leads to a value of 3 mW. This is 9-15 dB lower than the expected nominal ELT output power under any temperature conditions (reference 1, p. 72). This discrepancy was not commented upon by Petrie.

Under many actual crash conditions, the ELT is hardly likely to be oriented in the ideal way as assumed in the calculations of reference 2. Even if the ELT were hand-held in a vertical position, clear of any objects such as aircraft structure or vegetation, the effects of the proximity to the antenna of the person holding the ELT must be taken into account.

In other words, in any but highly idealized situations, the actual ERP/radiation pattern of an ELT depends upon a number of parameters, most of which are exceedingly hard to adequately model theoretically. For this reason, it is felt that the only sure way to gather statistics relating to actual ELT radiation patterns/ERP's is by experiment. Such experiments do not yet appear to have been carried out.

3.1 POSSIBLE EXPERIMENT

Records should be obtained, if available, which show the siting of ELT's found in actual crash situations. A subset of these records should be chosen as being fairly representative and, in each case, the physical environment of the ELT should be simulated as closely as is reasonable (primarily height of ELT above ground; orientation of ELT antenna with respect to the surface of the ground; and proximity of metallic surfaces to the ELT). In addition, tests should be made in which the ELT is hand-held, both vertically and horizontally with respect to the earth's surface.

Radiation patterns are probably best measured (certainly most cheaply) by towing a receiving antenna behind a light aircraft as has been previously done at CRC. The aircraft would make a number of passes directly over the ELT site from different directions. Elevation angle determination from aircraft ground-speed, and time from closest approach, should be sufficiently accurate for this purpose.

A measurement program as outlined above should be carried out on relatively level ground clear of trees. In this way, effects due to the detailed nature of the ELT site can (hopefully) be separated from other effects due to trees and large-scale topography. These latter effects can probably be accounted for sufficiently accurately, except as noted in the next sections, on the basis of data already existing in the literature. Any attempt to include these effects in the measurement program would result in the need for a considerably expanded program.

4. GROUND SURFACE COVER EFFECTS

4.1 GRASS AND SIMILAR COVER

No appreciable effect is expected at any SARSAT frequency if the ELT is situated above this type of ground cover. If the ELT is located on the ground surface, beneath such cover, little effect is expected at 121.5 MHz. More appreciable effects might be noted at 243 and 406 MHz, particularly if the vegetation is wet. No data appears to be available that would enable bounds to be set on possible effects.

Since, as will be seen in Section 4.2, most trees have little effect on signal level at elevation angles greater than about 20°, it is extremely unlikely that noticeable effects would occur due to grass or similar vegetation other than at very low elevation angles.

4.2 TREES

Data from reference 2 shows that 'moderately to heavily' wooded sites (30-40, 5m-8m pine trees/1000 sq. metres) can cause significant attenuation at both 121.5 and 243 MHz at elevation angles below about 20°, eg.,

elevation angle (deg.)	5°	10°	20°
attenuation (dB) at 121.5 MHz	5-15	2-5	1-2
attenuation (dB) at 243 MHz	7-20	5-10	2-4

Results from available literature (eg., 3, 4, and 5) show a relatively consistent frequency dependence of such attenuation. Using the frequency dependence shown in reference 5, corresponding values of attenuation at 406 MHz were estimated to be:

elevation angle (deg.)	5°	10°	20°
attenuation (dB) at 406 MHz	9-25	8-14	3-6

These values apply only to 'moderately to heavily' wooded Eastern Ontario areas. Such values are, however, reasonable estimates for treed areas over much of Eastern Canada.

Measurements made by the CRC VHF/UHF Propagation Group at Inuvik, N.W.T., would indicate that attenuations at each frequency in treed areas representative of Northern and Arctic Canada would probably be a factor of about 0.5, or less, (in dB) of the values tabulated above, e.g., 3 dB rather than 6 dB.

An area where attenuation due to trees is likely to be rather higher than tabulated above is the Pacific Coast of B.C.. Here, tree heights may attain 30-60 metres, underbush is dense, and trees and vegetation are usually wet. Data given in reference 5 indicates that losses (in dB) might be higher in rainforest by a factor of about 4 than in coniferous forest, such as found in Eastern Canada. This estimate may be too large since Pacific Coast rainforest, although dense by Canadian standards, is not as dense as Asian rainforest to which the numbers in references 5 and 6 refer. For this reason the losses resulting from Pacific Coast forest will be taken, rather arbitrarily, to be a factor of two higher (in dB) than encountered in typical Eastern Canada situations.

There would seem to be little point in trying to measure more precisely attenuations representative of Eastern and Northern Canada situations, since it is doubtful that SARSAT data recorded at elevation angles of less than 10° or so can be relied upon in many operational situations. At small elevation angles, large variations in attenuation may be expected for only small changes in the position of the receiving antenna (6, 7, 8). Extrapolating this (ground-based) result to the SARSAT case would lead to the expectation of heavy fading of the received ELT signal at low elevation angles, if the ELT is located in a treed area. (See also comments on ionospheric effects causing low-angle fading).

If data obtained at elevation angles of less than 20° are to be used routinely, there may be some value in better determining the range of attenuation values of Pacific Coast rainforest, particularly at 243 and 406 MHz.

4.3 SNOW

Snow cover may be considered to have little effect on ELT performance if the ELT is situated above the snow cover.

Petrie (reference 2) presents curves which show the (calculated) effect of a snow cover upon the radiation pattern of an ELT resting upon the earth's surface. As in the case of tree cover, the effect of relatively large amounts of snow cover appears to be negligible at elevation angles greater than about 20°. The losses at 121.5 and 243 MHz are as follows:

Snow Cover Thickness (metres)	0.3	1	2
elevation angle 20°	<1 dB	2 dB	3 dB
elevation angle 10°	1 dB	5 dB	10 dB
elevation angle 5°	1 dB	10 dB	20 dB

On the basis of Petrie's calculations, there appears to be little frequency dependence of attenuation. No other experimental work has been found to confirm this point, but the result is to be expected since the loss tangent of ice is relatively flat throughout this frequency range. In the absence of appropriate experimental data it is assumed the above tabulated losses to also hold for a frequency of 406 MHz.

4.4 SUMMARY OF SURFACE COVER EFFECTS

(a) Attenuation due to trees or to snow cover is not likely to be significant at elevation angles above about 20° except, possibly, in dense Pacific Coast rainforest.

(b) If coverage below 10°-20° elevation is required, additional measurements of Pacific Coast rainforest and deep snow attenuation (1-2 metres) are required in order to verify the expected high attenuations in these situations.

(c) Tree cover might cause severe signal amplitude fading at low elevation angles.

5. SURFACE TOPOGRAPHY

The influence of terrain on ELT signal levels, as discussed by Petrie (reference 2), is for the case of airborne receivers, and is thus not directly relevant to the present discussion.

5.1 'REFLECTION' EFFECTS

The calculation of ELT radiation patterns, by Petrie (reference 2), for example, usually assume that the earth's surface is an infinitely large, smooth plane. The presence of nulls in the radiation patterns results from interference between the direct wave from transmitter to receiver and that reflected from the earth's surface. The assumption of a spherical, rather than plane, earth changes the details somewhat. Practically speaking, however, unless the ELT is located upon almost perfectly smooth ground or on ice-covered water, the random nature of the earth's surface irregularities (hills, etc.) preclude an exact calculation of the location of the radiation pattern nulls. The most reasonable statement that can be made is that nulls will usually occur *somewhere* in the radiation pattern of an ELT.

If the earth's surface is relatively smooth on the scale of a radio wavelength sharp nulls, exceeding perhaps 30 dB, may be found. As the surface roughness increases, or becomes tree-covered, the null depth tends to diminish. In the limit of a very rough surface no reflected waves exist and a relatively smooth radiation pattern will exist. Since it is surface roughness on the scale of a radio wavelength that is important here, it is clear that little can be said *in general* as to expected null depth.

5.2 'DIFFRACTION' EFFECTS

Consider a transmitter-receiver link in which some obstacle (hill) extends just up to the line-of-sight. Under this condition, the minimum loss, due to diffraction by the obstacle crest, will be 6 dB if the obstacle has a very sharp crest. If the obstacle has a very smooth crest, the diffraction loss under this condition can exceed 20 dB.

The influence of an obstacle *below* the line-of-sight does not become negligible until the obstacle lies below the 1st (at least) Fresnel zone with radius given by

$$r_1 \approx \sqrt{550\ d/f} \text{ metres (for an earth-space link)}$$

where f is in MHz and d is the distance from the ELT, in Km, to the obstacle in question.

It is easy to show that, at the SARSAT frequencies, isolated obstacles do not cause significant diffraction losses if they are more than 2° away from the optical line-of-sight (measured from the ELT). Similarly, it is easy to show that when the spacecraft is more than a degree or two below the optical horizon as represented by a hill or mountain, the diffraction losses become extremely large.

In mountainous areas it should however be noted that signals may occasionally propagate from an ELT to a spacecraft by reflection from mountain-sides a number of kilometres from the actual ELT location. Such reflections *may* give rise to spurious doppler data points which would contribute to location error.

The visibility of an ELT by a spacecraft is thus limited, for all practical purposes, by the optical horizon formed by surrounding hills or mountains. Diffraction losses by the surface of the earth itself, as in low-angle paths over very smooth terrain, are not significant when the elevation of the propagation path is above a degree or so.

5.3 SUMMARY OF TERRAIN EFFECTS

(a) Reflections from the earth's surface usually result in interference nulls being present in the radiation pattern of an ELT.

(b) The depth and location of these nulls is usually not predictable in a useful way unless the terrain is assumed to be quite smooth.

(c) Spatial coverage of an ELT beacon is limited by terrain to, for all practical applications, the optical horizon.

6. IONOSPHERIC EFFECTS

6.1 FADING

Actual attenuation of an ELT signal by the ionosphere may be considered negligible at all SARSAT frequencies. On the other hand, the presence of irregularities in the ionosphere can cause fading, or scintillation, of an ELT signal as the spacecraft receiver moves along its orbit. The severity of such fading depends upon a host of parameters, making detailed predictions extremely difficult. Statistically, however, the following* 'fading margins' (for 99% reliability) may be taken as guidelines for spacecraft elevation angles above 20°-30°.

f (MHz)	Latitude $\lesssim$ 60°		Latitude $\gtrsim$ 60°	
	day	night	day	night
121.5	2 dB	6 dB	4 dB	12 dB
243	1 dB	2 dB	3 dB	9 dB
406	----	1 dB	2 dB	7 dB

At low elevation angles, and at geomagnetically disturbed times, fading margins can exceed those presented above.

6.2 'FARADAY' POLARIZATION PLANE ROTATION

The ionosphere causes the plane of polarization of a linearly polarized wave to rotate as it passes from the ground to a spacecraft (reference 9). As the spacecraft moves, the total electron content between it and the ground continually changes, resulting in a continual rotation of the plane of polarization of the signal received at the spacecraft. If the spacecraft antenna is sensitive to changes of the plane of polarization of the received signal, this signal will show continual quasi-periodic fading during any

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* based on experimental and theoretical studies carried out at CRC

satellite pass. The total number of rotations of the plane of polarization between the beginning or end of a pass, and the pass mid-point (max. slant range to min. slant range) are approximately (for a zenith pass)

f (MHz)	Number of Rotations	
	day	night
121.5	77	18
243	16	4
406	6	2

The above number would be approximately halved if only that part of the satellite pass between elevation angle 20° and the zenith is used. If the spacecraft does not pass through the zenith as seen from the ground, these numbers will be further reduced; perhaps by 25-50% for 'typical' cases.

7. SUMMARY

(a) An experimental determination of ELT radiation patterns, in simulated 'crash' conditions, should be carried out.

(b) Trees and snow cover are not likely to cause significant attenuation at elevation angles greater than about 20°, whereas significant attenuation and signal fading may result at elevation angles below 20°.

(c) Nulls, due to ground reflections, are likely to be present in the radiation patterns of ELT's; but their location and depth are not usefully predictable.

(d) Spatial coverage of an ELT beacon, in the absence of other effects, is limited by terrain, for practical purposes, to the region above the optical horizon.

(e) The ionosphere may cause significant fading of a received ELT signal at 121.5 MHz, particularly at night when margins in excess of 10 dB may be required for 99% reliability.

(f) The ionosphere causes the plane of polarization of an ELT signal to rotate numerous times during a given pass, resulting in quasi-periodic fading of the received signal.

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8. ABSTRACT: In order to carry out an RF link analysis for a Search and Rescue Satellite System (SARSAT) it is necessary to determine the effects of local terrain and surface cover, and of the ionosphere, on emergency locator transmitter (ELT) transmissions. This report summarizes the results of a study carried out by the Communications Research Centre (CRC) in order to assess the probable magnitude of such effects. It is concluded that signal attenuation and fading of an ELT signal, due to local topography and surface cover, probably do not exceed about 6 dB at spacecraft elevations above about 20°, except possibly in Pacific Coast forest areas. Considerable fading of the 121.5 MHz frequency may be caused by the night-time high-latitude ionosphere. A major area of uncertainty is the actual radiation pattern of an ELT under 'crash' conditions. An appropriate measurement program of such patterns is suggested.

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EXECUTIVE SUMMARY

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AUTHOR(S): F.H. Palmer

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This work was carried out at the request of the SARSAT Group, Space Systems Directorate, Communications Research Centre. The results are used in support of a proof-of-concept study of a search and rescue satellite (SARSAT) being carried out by the above group. As requested, the report describes the effects of local topography and ground surface cover on signals propagating from an Emergency Locator Transmitter (ELT) to SARSAT. The ultimate customer will be the governmental body authorized to set up an operational SARSAT system.

The findings of this report are significant to the SARSAT project since they indicate the limitations that will be placed on SARSAT performance by the proximity of snow, vegetation, and other surface cover to the ELT transmitter. The lack of knowledge regarding the effective radiated power of an ELT under actual 'crash' conditions is pointed out and an appropriate measurement program is suggested.

The author participated in the SARSAT proof-of-concept project as an intradepartmental consultant. This report, together with a companion report entitled "The Apparent Noise Temperature of the Earth as seen by a SARSAT Spacecraft Receiving Antenna", concludes the author's contribution.

SOMMAIRE À L'INTENTION DE LA DIRECTION

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TITRE: Effets du sol et de l'ionosphère sur les émissions de radiobalise de secours en direction de l'engin spatial SARSAT

AUTEUR(S): F.H. Palmer

DATE: Mai 1979

Cette analyse a été effectuée à la demande du Groupe SARSAT de la Direction des systèmes spatiaux du CRC. Les résultats obtenus sont utilisés à l'appui d'une étude de la viabilité d'un satellite de recherche et de sauvetage (SARSAT) effectuée par ce groupe. Comme il a été demandé, le rapport décrit les effets de la topographie locale et des accidents de terrain sur les émissions de radiobalise de secours en direction de l'engin spatial SARSAT. En définitive, le client sera l'organisme gouvernemental autorisé à établir le système SARSAT opérationnel.

Les conclusions de ce rapport auront des retombées importantes sur le projet SARSAT puisqu'elles vont indiquer les limites de performance imposées au système SARSAT en raison de la neige, de la végétation et des autres accidents de terrain dans le voisinage de la radiobalise de secours. Le rapport fait ressortir l'absence de données sur la puissance apparente rayonnée d'une radiobalise de secours dans des conditions réelles d'écrasement et propose un programme de mesure pertinent.

L'auteur a participé à cette étude sur la viabilité du projet SARSAT à titre d'expert-conseil au sein du MDC. Ce rapport, ainsi que le document complémentaire intitulé "Température de bruit apparente de la Terre détectée par l'antenne réceptrice d'un engin spatial SARSAT" résument la contribution de l'auteur.

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