

A Propagation Experiment for Modelling High Elevation Angle Land Mobile Satellite Channels

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ABSTRACT

This paper summarises the results of a feasibility study for conducting high elevation angle propagation experiments in the European region for land mobile satellite communication. The study addresses various aspects of a proposed experiment. These include the selection of a suitable source for transmission, possibility of gathering narrow and wide band propagation data in various frequency bands, types of useful data, data acquisition technique, possible experimental configuration and other experimental details.

1. Introduction

Propagation characteristics of land mobile satellite links play an important role in the design and viability of such a system for civilian use. The main problems arise due to the shadowing and multipath effects caused by the nature of environment in the vicinity of a mobile. The propagation effects worsen as the elevation angle is reduced. As a result geostationary satellites do not provide an optimum solution for land mobile communications in many parts of Europe. An alternative is to use a suitable non-geostationary orbit so that satellites appear at high elevation angles ($> \approx 50$ deg) throughout Europe (1). It is expected that the advantages gained in terms of reduction in degradation due to propagation should be large enough to warrant the added complexity in the sys-

tem architecture. However, at present the advantages possible by the use of this architecture are difficult to quantify precisely since propagation data for elevation angles above ≈ 50 deg are very scarce (2).

In addition there is currently an interest in wide-band characterization of such a channel for applications such as satellite sound broadcasting (3). Most measurements to date have attempted a narrow-band characterization of the land mobile satellite (LMS) channel. Hence there is a need to obtain data for such applications.

The present frequency allocation for LMS services is a bandwidth of around 4 MHz in L-band. It is expected that this bandwidth will not be adequate to provide the projected demand for future LMS applications. Hence an allotment in another frequency band may be essential. The present LMS channel propagation data are limited to UHF and L bands. Therefore there is a need to expand the data-base to other possible frequency bands.

This paper is an outcome of a study performed by the University of Surrey for the European Space Agency (ESA). A part of the work was performed by Racal - Decca Advanced Development Ltd., U.K. under a sub-contract.

The main objective of the study was to assess the feasibility of conducting propagation experiments for land mobile satellite communication service at eleva-

tion angles greater than 50 deg. The study was expected to result in a recommendation for one or more experiments which can statistically quantify the elevation angle dependence of narrow-band and wide-band propagation characteristics in L (1.5 GHz), S (3 GHz), C (4/6 GHz), K_u (11 - 15 GHz) and K_a (20 - 35 GHz) bands. In this paper the main features of the investigation have been summarised. The details are available elsewhere (4). As a follow-on of the study an experiment is currently being developed at the university. The present status of this experiment is also briefly stated.

2. Source for transmission

A basic requirement in the design of the experiment was to identify a suitable source for transmission in the desired frequency bands at an elevation angle > 50 deg. Due to the inherent advantage of using a satellite beacon as a source, investigations were performed to select a suitable satellite. Investigations were also conducted to identify an alternative platform.

2.1. Satellite sources

The evaluation for the suitability of a satellite source was based on the following considerations.

- i) Frequency of transmissions in the desired bands.
- ii) Transmission bandwidth.
- iii) High elevation visibility - within mainland Europe/outside mainland Europe.
- iv) Passive or active (transponded) mode.

In addition to the GPS and GLONASS satellite constellations, several other satellites (all geostationary) were considered for wide-band measurements. It was noted that all these other satellites required active mode of transmission and provided visibility only outside mainland Europe.

The decision reached during the first phase progress meeting was to preclude locations outside Europe due to difficult logistics and doubts regarding the applicability of the data-base to European environments. As a result, GPS and

GLONASS satellites were the only possible satellite sources for wide-band measurements. Further considerations such as the required measurement bandwidth and the available technical data-base of individual systems led to the choice of GPS satellites as the only possible wide-band satellite source. This implied that a multi-band experiment using a satellite source was at present not possible. Moreover, considering the bandwidth requirements for applications such as satellite sound broadcasting, only the P-code transmissions, which could provide bandwidths of about 4 MHz, were considered suitable. At the time (early 1989) the availability of GPS constellation over Guildford, at elevation angles > 50 deg, was estimated to be over 6.5 hours/day. Figure 1 shows the NAVSTAR-6 visibility (> 50 deg) over Guildford as a function of elevation angle.

Similarly for narrow-band measurements about a dozen possible satellites were considered. Most of these satellites could not provide visibility of sufficient duration or were only visible outside mainland Europe. OSCAR-13 was identified as the only possible satellite source (S band) capable of providing the required visibility. However, the severely limited dynamic range available from its beacon was considered inadequate. Therefore, for narrow-band measurements the only possibility was to use a suitable alternative platform.

2.2. Alternative platforms

Alternative platforms can be used to transmit in any desired band and bandwidth. In addition, the required receiver complexity is reduced. Some types of platforms offer the possibility of a complete control over the elevation angle - a very important parameter in this experiment. Another interesting feature was the possibility of transmitting multi-band, narrow and wide band signals, simultaneously.

The following types of platforms were considered.

- (i) Tower
- (ii) Balloons of different types including

airship
(iii) Helicopter

After careful consideration airship and helicopter were retained as possible alternatives. Although a Helicopter can provide a complete control of the elevation angle, doubts were raised about its suitability in an urban environment with regards to the air-space regulations and difficulty in maintaining a constant elevation angle in situations where the mobile may only be visible for limited periods and its speed may vary (eg. due to traffic lights). It was also noted that the hardware to be used on a helicopter would have to be suitably designed so as to minimize vibration effects. Thus further investigations were considered necessary.

2.3. Experimental configuration

A multi-band experiment with the capability of both narrow and wide band transmissions is capable of providing a variety of useful data under identical environmental and experimental conditions. Therefore this configuration was retained for a detailed study. It may be noted that at present this type of experiment can only be conducted by the use of a platform simulating satellite transmissions. It was assumed that a L-band experiment using GPS transmissions can also be conducted to increase the database and to quantify the confidence limits of the simulated measurements.

3. Main elements of experiment

The main elements of the proposed experiment are : a platform transmitting multi-band,narrow and wide-band signals which simulate the space segment and an instrumented mobile equipped with suitable receivers and data acquisition hardware,traveling at a given speed along a specified route - the ground segment. The data-acquisition was proposed to have the capability of analysing samples of data in real time but major data analysis was proposed to be performed off-line. Figure 2 shows the main sub-systems of the experiment. An elevation angle control mechanism and co-ordination ele-

ments have been included on the airborne platform together with the transmitter,antenna and data acquisition sub-systems.

3.1. Platform

As noted earlier, helicopters and airships or a combination of these two were considered as possible platforms. The main issues investigated were,

- (i) Air-space restrictions
- (ii) Cost
- (iii) Vehicle tracking technique
- (iv) Recordable data on the platform
- (v) Overall feasibility/special requirements

Enquiries indicated that helicopters and airships have specific flying corridors in Guildford/London areas but these corridors could provide all types of environments. It was noted that helicopters are generally not permitted to fly below about 500 m whereas airship flights are not permitted above the same height. Both platforms can hover,permitting static measurements when necessary.

The use of a helicopter was favoured for the final phase of the study because of factors such as proven success of helicopters in previous experiments,cost consideration and its expected greater simulation accuracy .

It was however considered necessary that the antenna mount and other hardware be designed to ensure compatibility with an airship ,if this option was exercised later.

It was then necessary to identify a suitable technique for tracking the instrumented mobile for maintaining a constant geometric relationship between the mobile and the platform. Several possibilities were considered. These include the use of navigation information from GPS satellites , the use of a tracking antenna,the use of navigation information on the helicopter and the use of a visual tracking technique employed in an earlier experiment. The implementation of the visual tracking technique appeared simple, although it was noted that the available accuracy would be dependent on the skill of the pilot and may consequently vary.

The possibility of using this technique was discussed with a pilot and technical staff of a helicopter firm. The main conclusions of the meeting was that the technique seemed feasible and the tracking accuracy could be improved with careful planning. In addition the logistic problems were seen to be tractable. It was noted that any equipment to be mounted on the helicopter would have to be certified by the Civil Aviation Authority.

3.2. Frequency considerations

L (1.5 GHz), S (3 GHz), C (4/6 GHz), K_u (11 - 15 GHz) and K_a (20 - 35 GHz) bands were identified for the study. The process of obtaining the necessary frequency clearance can be very time consuming. Amateur bands exist close to these bands and were considered to offer minimum regulatory constraints for the experiment and were therefore used for defining the baseline transmitter/receiver hardware.

3.3. Transmitter and receiver design

The investigations into the design of transmitter and receiver equipment to provide narrow and wide band signals in these frequency bands has verified the feasibility of constructing the system considered [Racal study,(4)].

Since the rate at which the changes in multipath signals can be tracked during the broad-band experiment is very limited, the vehicle speeds suggested for these tests are typically below 12 % of those used for the narrow-band experiments. It might seem therefore that there was to be no advantage in developing hardware which could carry both narrow-band and broad-band reception simultaneously. However, since the cost of the additional hardware involved is likely to be a small proportion of the total cost of equipment procured, this remains a feasible approach.

The work required to fit an adjustable antenna array to the helicopter was considered to be a major cost factor and is expected to require the experience of specialised aircraft fitters. For this reason it was considered essential to carry out

the work with an aircraft operating company with a particular interest or experience in developing similar externally mounted equipment.

3.4. Data types

The main types of data identified are real and quadrature components of the received signal for the narrow band transmissions and the complex impulse response for wide band transmissions. Other useful types of data identified are the elapsed time, mobile velocity and the elevation angle of platform. Some auxiliary data are useful during the analysis and interpretation of results. Suggested alternatives were voice records, key-board codes identifying broad terrain features, video records, receiver calibration and photographs. The use of video records was expected to be used in the development of a passive channel sounding technique. Such an approach using a camera and an photo-transistor has been attempted with some success before (6). Useful auxiliary data to be recorded on the helicopter include elapsed time, video/audio records, elevation angle variations (if possible), height of helicopter and other useful data if available.

3.5. Data acquisition and analysis

The use of a personal computer using a suitable interface with the receiver was the favoured data acquisition technique. The use of a tape recorder is proposed for recording the data set on the helicopter. One of the main problems in this experiment with regard to the data acquisition technique is the vast amounts of data generated.

The throughput for the wide-band measurements, without using any data reduction technique, is about 720 Mbytes/hour. This requires 21.6 Gbytes storage for a 30-hour experiment. However, it is possible to reduce the data storage requirement by using techniques such as real-time data reduction algorithms or reduction in quantization bits.

The throughput for the narrow-band measurements is much lower. Using data reduction through averaging in the K_u

and K_u bands - which contribute maximum data samples - it is possible to reduce the throughput even further. For example the throughput at 90 Km/hr reduces from 105.1 Mbyte/hr to 14.2 Mbyte/hr. The K_u and K_a band data however do not contain the doppler information.

3.5.1. Storage medium

The high throughputs expected implies that the storage device must have a large capacity. Optical disk, fixed hard disk and removable hard disk were considered.

A major constraint in the selection of the storage medium arises due to the mobile environment. Manufacturers usually do not guarantee a reliable operation in such an environment. The optical disk solution provides a likely solution in this experiment if the reliability consideration is waived. It is expected that the reliability can be improved by using ruggedized personal computer (PC) which together with the optical disk drive may be mounted on a vibration resistant mount.

Suitable software packages have been identified for both real-time data analysis and off-line data analysis. Formats for data presentation in line with previous ESA experiment (PRODAT campaign) were also identified.

3.6. Environment characterization

To optimize the measurements a representative sample of data must be obtained with a minimum of effort and cost. A careful selection of route can help to achieve this goal. Two possibilities were considered.

(i) Typical/worst case database

For each environment, a typical/worst case representative routes (\approx a few kilometers) are chosen and data collected on the same route as a function of elevation/bearing angles. This should permit an accurate characterization of the channel as a function of elevation angle in a well controlled manner.

One difficulty in this approach is the lack of an acceptable definition/criterion for the selection of an environment. A

typical locality in one country may not be representative of the whole Europe. It is felt that if 3-4 regions are carefully selected the resulting data base should provide statistics with acceptable confidence

(ii) Large area data-base

For each environment data are collected over a large area as a function of elevation angle. This approach has been used in many land mobile propagation experiments and is well suited when there is unlimited visibility, eg. from a satellite transmission.

The proposed solution is to use the first approach for the helicopter measurement and the second with GPS transmissions. The satellite measurements can provide unlimited data and provide confidence in the helicopter measurement.

Environment may be categorized in several ways. For example, PRODAT results have been given for three categories, viz. open areas (eg. motorways), partial obstruction (eg. suburbs of cities) and almost complete obstruction (eg. city). For this experiment six categories were proposed. This should permit a better indication of the grade of service expected in various environments but it is noted that management of this database is more complex.

The proposed characterization and some possible locations in the UK are as follows :

- (1) Dense urban - (city centre of a large city) : Central London
- (2) Urban - (suburbs of a large city/city centre of a small city) : Outskirts of London, Guildford city centre
- (3) Rural open - Motorways : M-3, M-25
- (4) Rural/Suburban - (roads with some woods/residential areas/villages) : A-type roads around Guildford
- (5) Rural dense forest : Some B-type roads around Guildford
- (6) Mountainous regions : Not specified

Locations across mainland Europe can similarly be identified.

3.7. Experimental configuration

Two possible configurations for measurements are possible.

- (1) Narrow-band and wide-band measurements performed on separate runs.
- (2) Both the measurements performed on the same run

The second option minimizes the time duration of the experiment. Hence an investigation was performed to check the feasibility of this configuration.

It was noted that this would require simultaneously recording of 20 channels with a consequent increase in the overall throughput and added complexity in the data acquisition hardware. Further investigations showed that doppler information for wide-band measurements can be extracted only at very low vehicle speeds and in L - band (upto 10 km/h) and S-band (up to 5 km/h) only. This limitation arises due to the data reduction method used in the receiver (the sliding correlator approach). Moreover in practice relative speed variations of the same order of magnitude are possible between the mobile and the helicopter resulting in an additional doppler component . It may be expected that it will then be difficult to resolve components due to vehicle motion .

From the above discussion it is evident that only static wide-band measurements are possible for higher frequency bands ,i.e., C,K_u and K_a bands. Even for L and S bands static measurements should be preferred due to the uncertainty of resolving the doppler components. Racial study (4) has shown that should it be decided to perform simultaneous measurements,the increase in the transmitter/receiver hardware complexity is not significant.

It is concluded that at high vehicle speeds only narrow-band measurements are possible. For static and possibly very low vehicle speeds both measurements can be done simultaneously. However, since static narrow-band measurements are of limited interest it is proposed that the two sets be performed separately to minimize the complexity.

3.8. Duration of campaign

For land mobile satellite service the events of interest depend on the immediate vicinity of the mobile. Hence it is expected that ,provided the routes are chosen with care ,a good confidence may be obtained with limited measurements. It was noted that existing databases vary from 1 Million samples to 750 Mbytes corresponding to a distance of from 50 km to over 750 kms.

For this experiment a 30 hour campaign was tentatively proposed for each region. The main purpose was to estimate the costs involved with this data-base requirements. A total of 3-4 regions were considered representative . A 20 hour period is allocated exclusively to the narrow-band measurement. This corresponds to 1000 km of data at an average speed of 50 km/h. However it can be noted that measurements over each route are repeated several times as a function of elevation angle.

A period of 10 hours was allocated for the wide-band measurement. This corresponds to 50 kms of data at an average speed of 5 km/h. The database is expected to provide an adequate base-line information to designers of future satellite sound broadcasting systems. The size of this database compares well with those of other experimenters. Moreover further data may be expected from the proposed propagation experiment using GPS transmissions.

4. Conclusions and present status

From the extensive search performed during the study,L-band P-code transmissions of the GPS satellites have been identified as the only satellite source for the broad-band measurements in the European region.

Considering the interest in multi-band - broad and narrow band channels it is concluded that a helicopter is the best platform for the experiment . The visual tracking technique appeared to be feasible but other alternatives are possible.

The investigations into the design of transmitter and receiver equipment to provide signals for the measurements

have verified the feasibility of constructing the system considered. It is concluded that the cost of the additional hardware required to perform simultaneous narrow-band and wide-band measurements is likely to be a small proportion of the total cost of equipment procured and hence remains a feasible approach. The work required to fit an adjustable antenna array to the helicopter is expected to constitute a major cost component and will require the experience of specialized aircraft fitters. For this reason it will be essential to carry out the work with an aircraft operating company with a particular interest or experience in developing similar externally mounted equipment.

A data acquisition system using a personal computer and the optical disk technology has been favoured to store the vast amounts of data which are expected to be generated in the mobile. A tape recorder is considered adequate for recording data on the helicopter. Suitable formats for presentation of the analysed result have been proposed.

A six-category environment characterization has been proposed. It is further suggested that the experiment be conducted in 3 - 4 carefully selected regions across Europe with 10 hours of broad-band and 20 hours of narrow-band measurements in each region. More data for the broad-band channel are expected to be available through measurements of transmissions from satellites in the GPS constellation.

The university is continuing further development of a scaled down version of the experiment. The experiment uses an alternative platform for transmitting CW beacons in S and lower K_u band and a mobile with a dual-band receiver and a data acquisition system using a personal computer. First results of the experiment are expected to be available in the following months.

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REFERENCES

1. IEE colloquium on Highly Elliptical Orbit Satellite Systems, 1989. Digest no. 1989/86 (London, 24 May).
2. Richharia, M. 1989. Review of propagation aspects of highly elliptical orbits, IEE colloquium on Highly Elliptical Orbit Satellite Systems, Digest no. 1989/86 (London, 24 May).
3. Advanced digital techniques for UHF satellite sound broadcasting, 1988, ed. R.J. Levey, Published by European Broadcasting Union Technical Centre.
4. University of Surrey, 1989, A study on the feasibility of high elevation angle propagation experiments applicable to land mobile satellite services - Phase 1 and 2 reports, Contract no 8084/88/NL/PB.
5. Vogel W.J. and Hong S. (1988), Measurement and modelling of land mobile satellite propagation at UHF and L-band, IEEE Trans. on Antenna and Propagation, vol. 36, No. 5, P. 707-719.

NAVSTAR-6 (GUILDFORD)
 MAXIMUM ELEVATION 76.5 (deg)

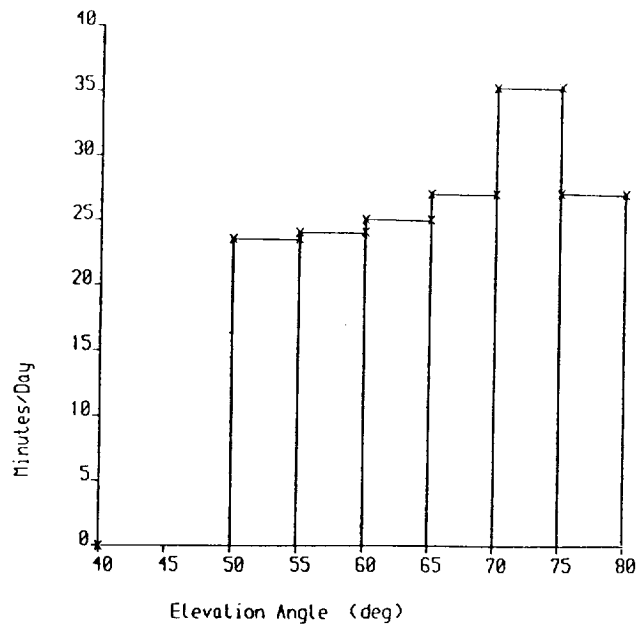


Figure 1: NAVSTAR-6 visibility/day over Guildford as a function of elevation angle

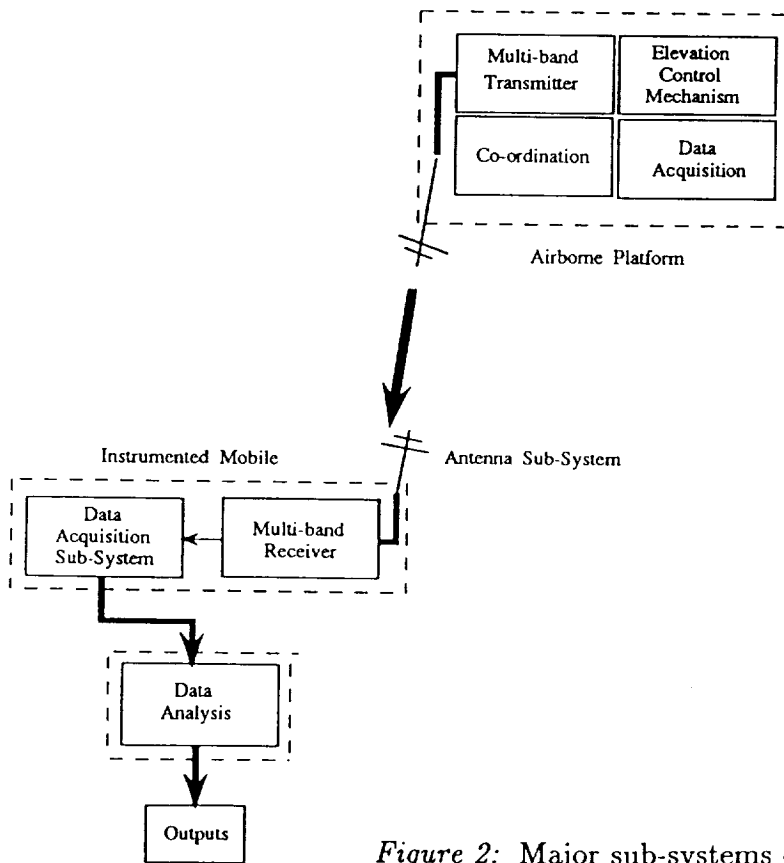


Figure 2: Major sub-systems of the experiment