The Status, Development and Future Role of Radiobeacon Differential GNSS

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Marine radiobeacons have been used to broadcast differential corrections for global navigation satellite systems (DGNSS) for nearly a decade. The method has become the accepted international standard for maritime applications. The background to the development of the system is described and the current status of radiobeacon DGNSS services around the world reported. The applications are discussed, including the function of radiobeacon DGNSS as the position sensor within integrated systems, together with the performance requirements imposed by associated systems such as ECDIS and Automatic Identification Systems. The advantages and disadvantages of the radiobeacon system in regulatory, administrative and technical terms are discussed and the potential for development of the system is considered. The future role of radiobeacon DGNSS in the overall mix of systems is assessed taking into account the introduction of geo-stationary overlays, and possibly Loran-C, for provision of DGNSS corrections.

1. INTRODUCTION. Marine radiobeacons have been used to broadcast differential corrections for almost 10 years. This method has become recognised as the international standard for maritime applications. In October 1997, there were 161 maritime radiobeacons in 24 countries known to be broadcasting differential corrections for global navigation satellite systems (DGNSS). All the Scandinavian countries and most of the European countries with Atlantic coastlines were providing such services, as were the USA, Canada, Australia, China, Japan and some of the Gulf States. In most cases, these services were only partly deployed or were being expanded. Services were planned or proposed in Korea, South Africa, Russia and South America. There are technical advantages in using radiobeacons for this purpose, but there are also performance limitations. Developments are underway to overcome some of these limitations, and the availability and accuracy of these systems has increased considerably since they were first deployed. The recognition of radiobeacon DGNSS as a standard system for maritime use means that it is required to function as the primary position sensor for Integrated Navigation Systems, ECDIS and Automatic Identification Systems. The expected deployment of geostationary overlay systems with the capability of broadcasting DGNSS corrections and the proposals for using Loran-C signals as a carrier for the same purpose make it appropriate to consider how radiobeacon DGNSS will fit into the overall mix of systems, and how it should be developed to fulfil its role most effectively.

2. BACKGROUND. Marine radiobeacons were the first generally-deployed radio aid to navigation, becoming widespread in Europe in the 1930s. Their role then was for direction-finding; the antenna on the ship was rotated to find a null in the signal, which gave a line of position to the transmitter. Two such lines of

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position would provide a fix, three bearings would provide a fix and an indication of its quality (a 'cocked hat'). The accuracy of the bearings was generally of the order of a few degrees, depending on the strength of the signal, the quality of the onboard equipment and any land effects on the propagation path. This was a rather crude positioning technique by modern standards, but a revolutionary development in its time. For example, vessels crossing the Atlantic could home in on a radiobeacon, rather than relying only on a visual landfall. The system is hardly used at all by commercial vessels today, since they are equipped with satellite and hyperbolic radionavigation receivers, but a significant if declining number of small craft use the system, and it still has a role as a simple backup. The present system utilises the LF/MF band 283·5–315 kHz in Europe (285–325 kHz in other parts of the world). Most countries have beacons covering their major shipping lanes, and many have complete coastal coverage. The idea of using marine radiobeacons for broadcasting differential corrections to global navigation satellite systems arose in the mid 1980s. It had a number of attractions: the transmitters were under the control of the maritime administrations, and they had an effective range comparable with the expected validity of the corrections. There were already plans in some parts of the world to re-organise the service to meet changing needs. In Europe, a Regional Administrative Radio Conference had been organised in Geneva in 1985 to change the channel spacing and modulation method of radiobeacons to adapt the service to automatic direction finders (ADF). These never became widely used, since they were overtaken by the availability of low-cost hyperbolic radionavigation receivers (Loran-C and Decca Navigator). However, the changes also allowed the use of the signals to carry supplementary data for navigation purposes, and the change to continuous (rather than time-shared) transmissions made differential transmissions a possibility. At the same time, work was proceeding in the USA, within the Radio Technical Commission for Maritime Services (RTCM), to develop a standard format for differential broadcasts.[1] The RTCM standard was not restricted to radiobeacons, but that was its main application initially. Developments in Europe and North America were coordinated through the International Association of Lighthouse Authorities (IALA) of which the US and Canadian Coast Guards are members. This resulted in a submission to the International Telecommunication Union (ITU) of a draft recommendation for the technical characteristics of the system.[2] This recommendation incorporated the RTCM format and has been approved and adopted worldwide.

3. STATUS OF RADIOBEACON DGNSS SERVICES. IALA acts as a coordinating body for a number of radionavigation systems, including radiobeacon DGNSS. In addition to drafting inputs to the International Maritime Organisation (IMO) and ITU on the operational and technical requirements of systems, IALA maintains a master list of services operated by its members throughout the world.[3] This list is updated periodically and the latest information (October 1997) shows 24 countries providing DGNSS services from 161 transmitting stations, with a further 49 planned. The services in many cases are operating on a test basis, although some have been declared operational. The status of the

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system in the UK and Ireland has been anomalous in that it has been operated as an encrypted, commercial service. This is due to change in 1998 when a free, unencrypted service will be implemented, complying with all the relevant international standards.[4] Another part of the IALA co-ordination role is the allocation of Reference Station and Transmitter identification numbers. Numbers are allocated in blocks to countries or regions. When an administration wishes to allocate a number they notify IALA of their preferred choice from the appropriate block, and it is checked to ensure that there is no duplication. This role was adopted with the approval of IALA's membership which includes all the operators of radiobeacon DGNSS services and of the ITU, which has overall authority on spectrum matters and the technical characteristics of radio transmissions.

4. REGULATORY DEVELOPMENT. The main reasons for the widespread adoption of radiobeacon DGNSS have been regulatory and administrative rather than technical. Radiobeacons do not allow a very high data rate compared with UHF or VHF transmissions and do not provide very widespread coverage compared with satellite services or low frequency transmitters. However, the advantage of available spectrum under the control of recognised authorities is substantial. It was possible to provide the service by adding another carrier to existing radiobeacons, or in some parts of the world by modulating an existing second carrier. This entailed a relatively minor modification to existing equipment and no change to the Radio Regulations. Once these advantages had been recognised, efforts were concentrated on ensuring that the service would provide the performance required. However, substantial changes to the frequency plans were required. In North America, these could be managed relatively easily, since only two administrations were involved at the time. Only co-ordination along the US/Canadian border was needed. In Europe, the situation was more complicated. In 1985, there were 32 countries in the European Maritime Area, and the new plan worked out at the 1985 Geneva Conference included 379 stations.[5] There were also substantial numbers of aeronautical, non-directional beacons in the band in some countries. When European administrations started to consider deploying differential services at the end of the 1980s, it became clear that major re-planning of the band would be necessary. There were discussions about whether to allocate a part of the band for differential services or slot them into the existing plan. The latter course was taken more for regulatory than technical reasons, and in 1991 IALA (with the approval of the ITU) called a conference of interested administrations to re-plan the band, retaining as many of the existing allocations as possible.[6] The allocations of those countries which did not participate in the conference, and the allocations to aeronautical beacons, were also left unchanged. The plan which arose from that meeting was recognised as a compromise solution, although it has served quite well.

5. APPLICATIONS. The applications of radiobeacon DGNSS fall into two main categories: navigation and positioning. The services are used for navigation in restricted waters, such as the Swedish archipelagos and through the Great Barrier Reef, as well as for port approaches and entrances. Positioning applications include buoy-laying and hydrographic surveying. The system may

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also be used, often in combination with other systems, for dynamic positioning, rig moves, pipe-laying, cable-laying and dredging. In the navigation applications, the output from the DGNSS receiver may form the position sensor input to an Integrated Navigation System (INS), an Electronic Chart System (ECS) or an Automatic Identification System (AIS). In these applications the inherent integrity checking of a differential system is particularly important. Accuracy and stability are also important in all three cases. The INS would normally incorporate automatic track following, which requires a stable input. The ECS may be integrated with a radar display and a varying input would degrade the clarity of the display. The AIS may be required to distinguish between targets passing close to each other, or between vessels anchored close together, so that a high degree of precision is essential. The potential use of ECS and AIS in combination to predict a vessel's heading, rate of drift, rate of turn and other parameters, and to convey this information to other users, demands very high integrity of the positioning system. The same technology being developed for AIS purposes could also be applied to aids to navigation, providing the identity, status and exact position of a mark, together with additional pilotage data, such as windspeed and tidal flow. In this case, the accuracy and integrity of the positioning device would be particularly important, in order not to give misleading information to the user.

6. FUTURE DEVELOPMENT. Countries operating radiobeacon DGNSS services are likely to offer them for recognition by IMO as part of the Worldwide Radionavigation System.[7] The services will be used to meet the requirements for navigation in waters where freedom to manoeuvre is restricted; for example, harbour approaches and entrances, and traffic separation schemes. This recognition will set stringent targets for the authorities operating these systems. In 1997, IALA began drafting a recommendation to its members on the standards to be adopted for the operation and monitoring of these services to ensure that the targets are met. The increasing importance of the DGNSS service, and the declining use of the direction-finding service, have prompted moves within ITU and IALA towards a further, more substantial, replanning of the band. This is expected to lead to a smaller number of higher powered stations, dedicated to DGNSS transmissions only. These changes should not affect the user of the service, since the location from which the corrections come is not significant, as long as they are within their range of validity. The optimisation of frequency allocations can be a complicated task, especially when many existing allocations have to be respected. On the previous occasions, it was achieved by a mixture of computer processing and human judgement. Options were proposed and then tested using a computer program. A more sophisticated program is being developed by the University of Wales, Bangor and is expected to be available in 1998. This will allow a much more thorough consideration of the options, and the achievement of an optimal solution both in terms of spectrum use and quality of service. The plan will have to allow for the future development and expansion of the service, by the many countries planning to deploy radiobeacon DGNSS.

7. DEVELOPMENTS IN TRANSMISSIONS. It has been indicated that the trend will be towards higher-powered transmitters. This will not necessarily be to increase the range, but rather to ensure very high availability in areas of crucial

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importance, such as port entrances. There are some fundamental limitations on the performance of transmitting systems operating at these frequencies. Antenna efficiencies are relatively low because, with a wavelength of 1 km, the antenna will be considerably shorter than the ideal. There are various ways in which this situation can be improved: by top-loading the antenna, by improving the groundplane and by reducing the losses, but this is still a fundamental limitation. When two carriers must be transmitted, for direction-finding as well as differential corrections, relatively broad tuning of the antenna system is necessary, with a consequent reduction in effectiveness. The move towards dedicated, single-carrier transmissions will improve this situation greatly. Another effect of moving to a single carrier will be the possibility of using more efficient, non-linear amplifiers, so that power losses in the transmitter will be reduced. These advantages are already being realised in some parts of the world, such as Australia, where 1 kW transmitters and 10 percent efficient antennas provide very high availability, even in high-noise, tropical areas. In lower noise regions, such transmitters would provide effective ranges of several hundred nautical miles. The majority of transmissions at present have a data rate of 100 bits per second (bps), but an increasing number are using 200 bps. This is the maximum rate which can be accommodated within the present European channel spacing, but higher rates might be considered where this limitation does not apply. There is a trade-off between accuracy and range: accuracy increases with data rate, but range is reduced, as the energy is spread over a greater bandwidth.

8. DEVELOPMENTS IN RECEIVERS. There are three significant areas of development in receiver technology for radiobeacon DGNSS: digital signal processing (DSP), noise cancellation and frequency diversity. The first is a general advance in performance of receiving equipment with the increasing use of DSP and the trend towards the 'software radio'. Developments in correlation techniques have reduced the usable signal to noise ratios greatly in recent years for systems such as Loran-C. Whilst there are basic differences in the systems, improvements on a lesser scale have also occurred in the short history of radiobeacon DGNSS receivers and are likely to continue. The other two developments both come from the same source, Prof. Per Enge, one of the pioneers of radiobeacon DGNSS in the USA. The technique of noise cancellation uses a second channel to sample the atmospheric noise, reverse its phase and add it back to the wanted signal, cancelling the unwanted noise. This has been demonstrated successfully and is particularly effective for the burst noise which is characteristic of the 300 kHz band.[8] The second development which underwent trials in Scandinavia in 1997, with promising results, is aimed at decreasing susceptibility to skywave interference, by providing frequency diversity.[9] The data are transmitted on two channels simultaneously, when one fades due to own skywave interference, the other is likely to be unaffected or may show constructive interference. Initial results indicate that, with a separation of some 2·5 kHz, fading on the two channels is not correlated, so that it is very unlikely that both signals will be attenuated at the same time. This introduces an extra dimension to the frequency planning problem, but is nevertheless worth considering. Finally, the method of station selection used by a receiver is important. Some receivers simply select the

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strongest signal available, and this can lead to problems. For example, a strong skywave signal from a distant station can be received for a short period before fading out, leaving the receiver searching again. If this happens repeatedly, it can seriously affect the usability of the system. There should be provision for manual selection, since the user will normally know the frequency and location of the nearest station. The best automatic technique is the use of the radiobeacon almanac information (Message Type 7). This allows the receiver to build up a log of usable signals in the area and to anticipate, given some intelligent processing, the best signal to use, based on knowledge of the movement of the user. The method of implementation of such techniques is up to the receiver manufacturer, rather than any standardisation organization, but such intelligent use of the information available could help to ensure continuous availability of a good quality signal.

9. FUTURE ROLE. The place of radiobeacon DGNSS in the overall mix of systems will depend on how well it satisfies the needs of the mariner. If other systems using geostationary satellites or Loran-C transmissions are seen to meet the requirements more effectively, then maritime administrations will have to consider these. Indications at present are that these systems will not offer any advantage in terms of accuracy. The requirement set out in IMO Resolution A.815(19) for restricted waters is 10 m (95 percent). This can easily be met by the radiobeacon system, the main limitation being the quality of the user equipment. Availability of the service is likely to be comparable with the alternatives, although the effect of atmospheric noise at LF/MF frequencies is a serious consideration. This problem can be overcome to a large extent by proper planning of the service; that is, deployment of sufficient transmitters with appropriate powers. The nature of the maritime requirement is generally local in the sense that high accuracy and availability are needed in harbour approaches and entrances and areas monitored by Vessel Traffic Services. There are exceptions to this general rule; for example the Swedish archipelago and the Australian Great Barrier Reef, where high accuracies are needed away from port areas. However, these requirements are being met by deployment of transmitters on suitably placed islands. There is no perceived requirement, at present, for wide area coverage of the open ocean. Unless this situation changes, it seems likely that radiobeacon DGNSS will continue to fulfil the maritime requirement well into the next century, without the need for investment in other systems. However, the Eurofix concept has the attraction of providing a second independent fixing system (Loran-C) as well as an alternative DGNSS source.[10]

10. CONCLUSIONS.

1. DGNSS using marine radiobeacons is now a mature service; however, its increasing importance and its widening deployment will necessitate more sophisticated planning in the future.

2. Radiobeacon DGNSS is operational, on trial or planned in at least 28 countries.

3. IALA acts as a coordinating organisation for the system worldwide.

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4. The recognition of the service as part of the IMO Worldwide Radionavigation System will require the adoption of stringent operating and monitoring standards.

5. Developments in transmitter technology are providing much greater availability than when the system was first implemented.

6. Developments in receiver technology could improve performance still further.

7. The role of the system in meeting maritime requirements is likely to remain well into the next century.

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KEY WORDS

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