Satellite DSB systems

— and their potential impact on the planning of terrestrial DAB services in Europe

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This article deals with both the system and frequency management aspects of digital sound broadcasting by satellite in L-band, and gives a short description of the newer satellite digital audio systems and their possible impact on T-DAB planning and implementation.

Introduction

With over 2 billion radio receivers in use worldwide, sound radio is undoubtedly still one of the most popular mass media. It has been part of our lives since the 1920s and, over time, has become the most trusted, user-friendly and cheapest mass media. Its popularity is no less today, despite the advent of many other information media – including television, mobile telecommunications and the Internet. In order to transform sound radio into a viable medium for the 21st century, it will have to migrate from analogue technology into the digital domain. It will have to adopt not only traditional means of delivery (i.e. terrestrial transmitters) but also new transport and distribution mechanisms such as satellite, cable, telecommunication networks (both wired and wireless) and the Internet.

Analogue radio has been characterized by a set of common transmission standards for AM/FM terrestrial broadcasting *worldwide*. In the digital domain, however, diverse economic and regional interests have lead to a multitude of transmission standards for Digital Sound Broadcasting (DSB) [1].

The first *digital* terrestrial broadcast technology to be successfully developed and marketed in Europe is the Digital Audio Broadcasting (DAB) system [2]. Actively supported by the EBU, widely promoted by the World-DAB Forum and with a wide range of receiver terminals that are becoming more affordable, the DAB system has been adopted for terrestrial broadcasting in Europe as the replacement for analogue FM technology.

More recently, the Digital Radio Mondiale (DRM) system has been developed and standardized to replace AM technologies, primarily using frequency bands below 30 MHz. Other terrestrial system propositions have been developed in different parts of the world (e.g. ISDB-T in Japan, IBOC in the US).

1. DSB stands for Digital Sound Broadcasting, meaning any digital sound broadcasting system – regardless of the system approach – that is deployed in the WARC-92 bands (1 - 3 GHz).
2. DAB, in this article, implies the Eureka-147 Digital Audio Broadcasting system, according to ETSI Standard ETS 300 401.

Motivation for DSB systems and services

Radio broadcasting *by satellite* is not a new idea. The main motivation for broadcasting by satellite has always been the relatively wide coverage area (for example, it is possible to cover the whole of Europe with one beam), coupled with the fact that the transmitted signal is available to practically all receivers immediately after the launch of the satellite. By comparison, it may take many years to construct a terrestrial network which will achieve a high degree of coverage (say 95% or more of the population) – particularly if the territory is large and mountainous.

So what are the main issues concerning satellite broadcasting? They can be summarized as follows:

* **Costs** It requires relatively substantial upfront investment for the ground and satellite segments, as well as for the receiver terminals. There is also a very high commercial risk associated with such a venture.
* **Coverage** The vast majority of sound broadcasting services in Europe are intended to cover national, regional or local areas. The relatively large coverage of a satellite beam is unlikely to be necessary for these smaller coverage areas.
* **Spectrum availability** There is a distinct lack of suitable spectrum.
* **Portable/mobile reception** This is perhaps the most critical issue, which still represents a significant challenge for system design engineers: how to provide for highly-reliable satellite reception to portable (i.e. indoor) receivers as well as to receivers in moving vehicles – especially in highly build-up urban zones where no line-of-sight between the satellite and the receiver exists – while still using relatively simple (e.g. whip-like) receiving antennas rather than high-gain parabolic antennas.

Currently, there are several hundred radio channels available on the commercial satellite systems operating in either the 10 – 11 GHz FSS frequency band or the 12 GHz BSS band. Examples include Astra Digital Radio (ADR), Eutelsat, Hotbird, Sirius, Telecom, Hispasat, Kopernikus, Intelsat and others. In order to receive a signal from the satellite, a line-of-sight between the satellite and the receiver is required. The receiver usually uses a fixed high-gain parabolic receiving aerial directed towards the satellite. Mobile and portable (indoor) reception is not possible. These systems are not given any further consideration here.

This article will now concentrate on satellite DSB systems that are designed for deployment in the frequency bands between 1 and 3 GHz, where it is potentially feasible to provide reception for mobile and portable receiving terminals. Both the system and frequency management aspects of satellite DSB are considered, and a short description is given of the newer satellite digital audio systems, and their possible impact on T-DAB planning and implementation.

Abbreviations

AAC	(MPEG-2/4) Advanced Audio Coding
AM	Amplitude Modulation
BSS	Broadcast Satellite Service
CDMA	Code Division Multiple Access
CEPT	European Conference of Postal and Telecommunications Administrations
COFDM	Coded Orthogonal Frequency Division Multiplex
DAB	Digital Audio Broadcasting (Eureka-147)
DBEG	Digital Broadcasting Experts Group
DRM	Digital Radio Mondiale
DSB	Digital Sound Broadcasting
ETSI	European Telecommunication Standards Institute
FM	Frequency Modulation
FSS	Fixed Satellite Service
GEO	Geostatony Orbit satellite
HEO	Highly-inclined Elliptical Orbit
IBOC	In-Band On-Channel
ISDB-T	Integrated Services Digital Broadcasting – Terrestrial
ITU	International Telecommunication Union
LSI	Large Scale Integration
MPEG	Moving Picture Experts Group
OFDM	Orthogonal Frequency Division Multiplex
S-DAB	Satellite - Digital Audio Broadcasting
S-DSB	Satellite - Digital Sound Broadcasting
T-DAB	Terrestrial - Digital Audio Broadcasting
TDM	Time Division Multiplex(ing)
VHF	Very High Frequency
WARC	(ITU) World Administrative Radio Conference

DSB system considerations

The first studies into the feasibility and viability of satellites, as a means for delivering broadcasts to portable and mobile receivers, go back to the 1970s. At this time, analogue FM technology was being considered. Faced with the issue of mobile reception that suffered from corruption due to multipath reflections, the first digital system – Eureka-147 DAB – was proposed and designed in the 1980s, specifically to solve this problem. Its concept was successfully demonstrated to the delegates of the Second Session of the WARC-ORB Conference in Geneva, in 1988.

As a result of these demonstrations, the ITU conference WARC-92 (further details are given in the next main section, *Spectrum allocations*) allocated spectrum in the frequency bands between 1000 and 3000 MHz for future satellite and complementary terrestrial DSB services. This frequency range was chosen on the basis of theoretical studies carried out by the EBU, taking into account the optimal trade-off between the required satellite transmitting power and the transmitting antenna size. Also, this band was considered to be potentially suitable for mobile and portable reception, assuming that a sufficiently high propagation margin could be incorporated in the link budget.

Extensive studies carried out by the WorldDAB Forum showed that a stand-alone satellite system, using a present-day satellite technology, would not be able to provide for mobile and portable reception. Therefore, it was suggested that a so-called *hybrid* system should be used. This consists of a coherent use of a satellite system and a complementary terrestrial transmitter network. The latter re-transmits the satellite signals in areas where the satellite signals are not strong enough, such as in cities or outside the satellite coverage areas.

The hybrid satellite/terrestrial system was aimed at achieving satisfactory coverage (at 99% of the locations for 99% of the time) for mobile, portable and fixed receivers in all types of reception environments – including dense urban, suburban and rural zones where a line-of-site path to the satellite may not be possible. The initial satellite-only service would be complemented progressively by terrestrial gap-fillers and the coverage extended over a period of time until the target service area had been reached. To this end, it was considered highly desirable that the satellite and terrestrial systems should be complementary and interoperable.

Furthermore, the WorldDAB studies showed that the multi-carrier modulation scheme (COFDM) used by the EU-147 system requires a 6 to 7 dB back-off margin in the transmitter power, compared to a single-carrier system. It was therefore concluded that COFDM is better suited (than a single-carrier approach) for terrestrial usage – where the primary limitations are interference and multipath – but is less suitable for a stand-alone satellite system.

Moreover, it may be concluded that a hybrid satellite/terrestrial approach is likely to offer distinct advantages over either stand-alone satellite or stand-alone terrestrial systems – in terms of service quality availability and receiver costs for the listener. The new generation of satellite systems being deployed in the USA confirms this.

As the Eureka-147 DAB system is based on a programme multiplex which carries a combination of many separate services that can be at a variety of bit-rates, the capability of this system to support the uplinking of programme data streams from several locations has been questioned. It was believed that one of the major advantages of the single-carrier approach was that it would support uplinking from different locations, and not just from a single central “hub” earth station. However, it was demonstrated in a study carried out by the BBC [1] that a single DAB multiplex can be constructed at the satellite receiving antenna by using a TDM approach. This approach offers an additional advantage when compared with the single-carrier approach; namely, the use of a transparent transponder, meaning that a dedicated on-board multiplexer and on-board processing can be avoided. The key requirements are the synchronization and accurate frequency matching of all the feeds coming from the different earth stations.

It may therefore be concluded that the DAB system, using a multi-carrier OFDM approach, is suitable not only for terrestrial DSB but also for satellite DSB, provided that complementary terrestrial repeaters are to be used for urban and other difficult satellite reception areas. The use of OFDM on the satellite down link may facilitate receiver front-end processing that is common with the terrestrial receivers, thus reducing the cost of the receivers.

Spectrum allocations

The World Administrative Radio Conference that was held in Malaga-Torremolinos (Spain) in 1992 (known as WARC-92) allocated three frequency bands in the range from 1000 – 3000 MHz for satellite digital sound broadcasting.

* **1452 – 1492 MHz**

  Also known as L-band [3], this is a worldwide [4] allocation (except for the USA). In Europe, this 40 MHz wide band is the only band in the range 1000 – 3000 MHz that is presently available for the use of Broadcast Satellite Service (sound), or BSS (sound) for short. The lower part of this band (i.e. 1452 – 1467 MHz) is currently allocated for terrestrial DAB (T-DAB) purposes, according to the Wiesbaden-95 CEPT T-DAB Special Arrangement. This part of L-band corresponds approximately to nine T-DAB blocks, each being about 1.75 MHz wide (a guard band is included).

  Recently, the CEPT has decided to allocate and plan another 12 MHz (i.e. seven T-DAB blocks) for T-DAB services in the remaining frequency range 1467 – 1492 MHz. A CEPT Conference [5] will take place in June 2002 and is strongly supported by the EBU. EBU Members consider that this planning conference will help to accelerate the rollout of T-DAB services in the European market. It is the current perception that one of the main barriers to the deployment of T-DAB is that there is insufficient frequency spectrum available to accommodate all existing public national radio services, let alone all the commercial, local, community and other radio stations. It is also recognized that L-band is less than ideal for large-area coverage (e.g. national and sub-national services) by terrestrial means – but no other spectrum is available in a more suitable frequency range (e.g. in the VHF band).

* **2310 – 2360 MHz**

  Commonly called the 2.3 GHz band or S-band, it is 50 MHz wide and is only allocated for BSS (sound) [6] use in the USA and India.

* **2520 – 2655 MHz**

  Also located within S-band, this BSS band is allocated worldwide for community reception. In particular, this band is considered in Japan. In the sub-band, 2535 – 2655 MHz, a previous restriction to community reception has now been removed for Belarus, the Russian Federation, the Ukraine and certain parts of Asia.

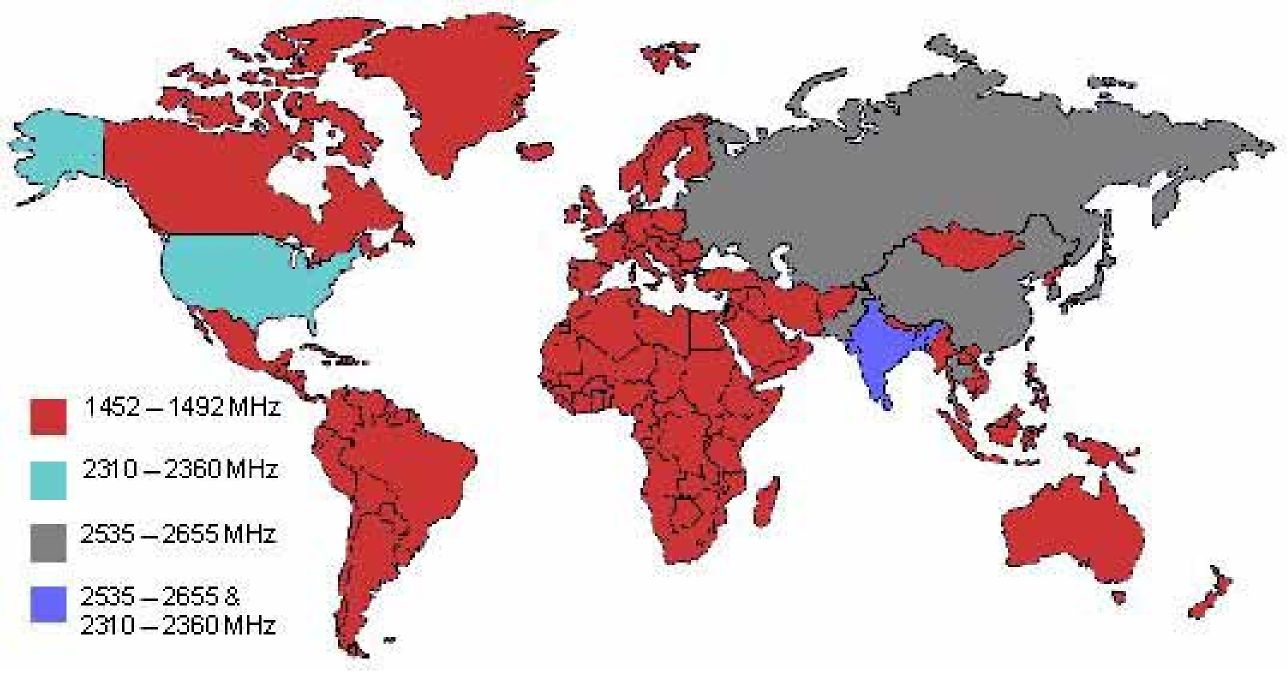
Current satellite DSB systems

Background and overview

In May 2001, a CEPT Frequency Management meeting reported that "*Advanced Broadcast Satellite Service (sound) services are already being offered in parts of Europe by WorldSpace via the AfriStar GEO satellite system. Some European Administrations – e.g. UK (for EAST), France (for F-SAT-DAB) and Poland – have filed at the ITU for GEO-based BSS (sound) networks. Germany (for MEDIASTAR) and Luxembourg (for GLOBAL RADIO) have filed at the ITU for HEO-based BSS (sound) systems within the band 1452 – 1492 MHz.*"

The above information indicated that there is some interest in satellite DSB in Europe. A project called MediaStar was very seriously considered in the late nineties by DaimlerChrysler AeroSpace AG. Neverthe-

3. Strictly speaking, L-band denotes the frequency range 1000 – 2000 MHz. Similarly, S-band represents the range 2000 – 3000 MHz.
4. In some countries on a secondary basis until 1 April 2007.
5. This will be a special arrangement between CEPT administrations.
6. And complementary terrestrial sound broadcasting.



Worldwide allocations for satellite DSB.

less, the project could not be pursued as it lacked financial backing. Consequently, so far, no dedicated DSB satellite has been deployed to serve the European territory.

In respect of the above-mentioned issues, a set of conclusions made by the WorldDAB Forum back in 1999 are still valid and can be summarized in the following four points [2]:

1) No service provider in Europe has been able to develop a profitable business case out of satellite DAB because of the lack of commitment of potential users and the slow roll-out of terrestrial DAB services.
2) The WARC-92 frequency spectrum reserved for satellite/terrestrial DAB was partly planned in Europe for terrestrial DAB (i.e. the Wiesbaden-95 Plan) and an extension to this terrestrial segment is to be planned for T-DAB. There is probably insufficient spectrum left available for commercially viable, pan-European, multi-channel satellite broadcasting services.
3) Stand-alone satellite-only DAB systems are not of great interest to broadcasters because they cannot overcome the shading effects. To this end, complementary satellite/terrestrial systems are necessary. This subject requires further study.
4) DAB satellite systems in the WARC-92 L-band are not allowed in certain parts of the world because of the incompatibility with other services (e.g. aeronautical mobile telemetry services). Europe could use the L-band only if the spill-over problem into the US and Russia is successfully resolved. Until the end of 1999, no such solution had been found by the ITU.

While Europe has focused on rolling out terrestrial DAB services, WorldSpace successfully launched a first satellite for Africa and some time later for Asia. More recently, a satellite DSB service has been deployed in the US by Sirius and XM Radio.

A system called **Global Radio** may deliver satellite DSB services for Europe in the years ahead. However, there currently remain significant technical, economic and regulatory obstacles. One issue that could hamper efforts to spread mobile digital radio service in Europe is the fragmented European regulatory and licensing landscape. Hopefully, within the changing political climate of an expanding European community – that favours European-wide projects and commercial ventures to support the cultural and linguistic diversity of its nations – a more suitable market may be created for the implementation of satellite DSB services.

The main parameters of the four satellite DSB systems, either currently in use or being considered, are summarized in *Table 1*. Further details are given in the following sub-sections.

Table 1:
Overview of the four satellite DSB systems either currently in use or being considered.

System	WorldSpace	Sirius	XM	Global Radio
Standard	System D/F Rec. BO.1130-3	Proprietary	Proprietary	System A Rec. BO.1130-3 [a]
Operational since	Late '90s	End of 2001 or early 2002	2001	Around 2004
Orbit	GEO	HEO	GEO	HEO
No. of satellites	1 per coverage/3 beams	3 per coverage	2 per coverage	3 per coverage
Coverage	AfriStar: Africa AsiaStar: part of Asia AmeriStar: Latin America	USA	USA	Europe
Frequency	1.5 GHz	2.3 GHz	2.3 GHz	1.5 GHz
Reception	Line-of-site (LOS)	Mobile	Mobile	Mobile
Business model	Transponder lease	Subscription Advertising	Subscription Advertising	Unknown

a. Modified to be used with AAC+ coding.

WorldSpace

The WorldSpace system [3] is a Geostationary (GEO) satellite system designed for the delivery of digital sound broadcasting services in the 1452 – 1492 MHz frequency band. At present, WorldSpace is broadcasting in the upper 1467 – 1492 MHz frequency range. The system is not compatible with the Eureka-147 DAB system, although it is often misleadingly labelled as a "DAB" system. The major differences are the bandwidth of the multiplex (Eureka: 1.5 MHz, WorldSpace: 2.3 MHz) and the fact that WorldSpace uses a single carrier while the Eureka system uses a multi-carrier OFDM approach.

The WorldSpace satellite network will ultimately consist of three GEO satellites: AfriStar (orbiting over Europe since October 1998), AsiaStar (launched in March 2000) and AmeriStar (scheduled for launch in 2001 but probably delayed to 2002). WorldSpace and Alcatel recently announced a joint initiative to build, launch and operate a dedicated satellite DSB (S-DSB) system for Europe. A coverage map for this satellite system, however, is not yet available because the system architecture is still being finalised. Such a system would be potentially interesting for EBU members [7].

The WorldSpace system is now known as Digital System D_S in ITU documents and is described in Annex 4 to Recommendation ITU-R BO.1130-3 [8] [4]. Generally, the system allows reception only if there is a direct line-of-sight (LOS) between the satellite and the receiver. Experience shows that the system will not perform well if there is an obstruction (such as foliage, a window, etc.) between the satellite and the receiver.

7. An informative Press Release can be found at: **http://www.worldspace.com/pressroom/press_release24.htm**.
8. Another WorldSpace system, Digital System D_H, could be a possible candidate for any proposed European system. It is an enhancement of Digital System D_S in terms of mobile reception and terrestrial transmission.

Nevertheless, WorldSpace has developed a system to re-broadcast the satellite signal terrestrially on another frequency, in order to mitigate line-of-site losses (see the above ITU-R Recommendation, Digital System F). As opposed to Digital System D, this system is said to be capable of being used with the existing WorldSpace GEO satellites, AfriStar, AsiaStar and AmeriStar, to enable uninterrupted reception in areas where tall buildings, trees or overpasses block the line-of-site to the satellites. At present, and to the best of the authors' knowledge, no experimental evidence of the effect of the terrestrial transmitter assistance has been reported.

To ameliorate mobile reception difficulties, WorldSpace has also recently proposed, at ITU-R SG 6E meetings, new satellite transmission modes based on a time division multiplex, and/or time interleaving.

Altogether, taking account of the various possible combinations of the satellite mode and the associated terrestrial mode, there are about nine possible combinations that may enable mobile reception.

Another unusual method proposed to overcome the obstruction limitations to line-of-sight reception systems involves "time diversity", exploiting two broadcast channels from a given satellite. Although experimental evidence has not yet been provided, developers of this method (Fraunhofer IIS-A and WorldSpace) completed a successful test and demonstration of this technique in August 2000. However, the benefits of such a two-channel approach would need to be traded off against its spectrum inefficiency. The spectrum efficiency may suffer even more, if a terrestrial gap-filler component required another frequency channel.

Sirius

The Sirius system [5] was originally designed for GEO satellite delivery (but has more recently changed to an intended HEO delivery) of digital broadcasting services in North America using the 2.3 GHz frequency band, where it is currently in operation. Sirius should not be confused with the European "Sirius 2" and "Sirius 3" satellites which also have several analogue and digital sound transmissions.

Three satellites will provide coast-to-coast mobile reception in North America. The full service is expected to start at the end of 2001 or at the beginning of 2002. No information has been found about the standard being used but it is likely that the WorldSpace system approach will be used. Sirius is intended for mobile reception; the marketing of Sirius is aimed almost entirely at the motorist.

XM

The XM system [6] is another new American satellite radio venture. It is a proprietary system consisting of two GEO satellites, separated in an orbital arc by 30° (space diversity at the transmitter), which provide coast-to-coast reception in North America. The two satellites operate on two different frequencies in S-Band (frequency diversity) and provide the same set of radio programmes almost synchronously; there is a time offset of several seconds between the satellites (time diversity) in order to overcome short breaks when a vehicle drives under bridges and underpasses.

No public information is thought to be available on the technical details of the system design. The XM system is capable of providing mobile reception in rural unobstructed areas but, in built-up areas, terrestrial repeaters will have to be constructed. Terrestrial gap-fillers have not yet been implemented and it is not known what will be their operational and spectral characteristics. The terrestrial component may use OFDM modulation and a frequency channel that is different from the one used by the satellite. It is not certain how the satellite receivers now on the market will cope with the future terrestrial re-broadcasts.

Global Radio

The most recent proposal for a European satellite DSB system is that of Global Radio [7]. It is understood that this system may be implemented and deployed in 2004. The present design of the system is based on the Eureka-147 technology – in order to benefit from the compatibility of existing terrestrial DAB receivers already deployed in the European market – but it may be adapted further to match the propagation characteristics of the satellite channel [9]. The system would broadcast from three highly-inclined elliptical orbit (HEO) satellites in order to serve high-latitude countries such as Norway and Sweden more efficiently. Each satellite would operate eight hours a day. Also, if HEO satellites are used instead of GEO, terrestrial repeaters – to ensure coverage in large cities with high buildings – might be less important due to the generally high incidence angle of the overhead signal coming from an HEO satellite.

Other systems

In Japan, Mobile Broadcasting Corp.(MBC) recently authorized Space System/Loral to begin work on a spacecraft to deliver mobile audio, video and data services. MBC, a consortium led by Toshiba, Toyota, Fujitsu, Nippon TV and Panasonic, aims to start service in early 2004. More than fifty channels of programming are to be broadcast, using CDMA and MPEG-4 for the audio transmissions. Field demonstrations in the Shinbashi and Ginza areas of Tokyo have shown high performance quality. First-generation LSI receiver chips have also been validated. Second-generation receivers using high-density LSI chips will be available by mid-2002.

A second project led by Hitachi also plans to enter the Japanese mobile market.

Commercial and programming aspects of satellite DSB

AfriStar (WorldSpace)

The first WorldSpace satellite, AfriStar, was launched successfully in October 1998 (service started in October 1999). The footprint of AfriStar lies mainly in Africa. Nevertheless it has a spill-over coverage into southern and central Europe. For example, reception in Berlin was demonstrated during one of the WorldDAB Module 4 meetings about two years ago.

Programming

AfriStar is delivering 46 programmes of news, music, education etc. in English, French and several national languages. Among the known broadcasters are: the BBC, CNN, WRN, Bloomberg, Capital Radio, Radio Monte Carlo, La 7 FM, RFI and others. The details are available at:
http://www.worldspace.com/programming/progamming_guide.htm.

Audience

No audience research data is available as yet. Currently, all WorldSpace audio services are free-to-air. There is no customer subscription. Later, they will be experimenting in some markets, such as India, with a subscription audio service. At some point in the future, they plan to offer premium audio services that will be tailored to the tastes of certain audience segments and these will be subscription-based.

9. The MPEG-1 Layer II audio coding system currently used by EU-147 may be replaced by the MPEG-4 AAC+ algorithm in the future Global Radio system.

Business plan

WorldSpace collects revenue primarily from capacity service agreements and also from advertising sales. In future, multimedia and audio subscription services may be offered. Eventually, they will also collect a small percentage as royalties on the sales of the receivers. Concerning their expectations to make a profit, they hope to be in the black within 3 - 5 years, following the successful launch of all three satellites, i.e. in 2004 to 2006.

WorldSpace has recently started to offer not only sound radio channels but also its multimedia services. It has between 150,000 and 200,000 receivers in use so far – about half in Africa and Europe and the remainder in Asia and the Middle East. It hopes to reach the 500,000-receiver level – the critical mass required for advertising campaigns – by mid-2002 and to break even within two years. Most revenues are currently derived from transponder leases.

AsiaStar (WorldSpace)

The second WorldSpace satellite, AsiaStar, was launched in March 2000 (service started in September 2000) for the Asian market. Marketing has started in Singapore, Indonesia and India, with Malaysia, Thailand, and The Philippines to follow. So far the response has been favourable, particularly in India where BPL, one of the largest distributors of electronics products, is contracted to distribute their receivers throughout the Indian market. In Indonesia, WorldSpace is linking up with PT Agis, a large well-known distributor in that region. Specifically for the Asian market, low-cost receivers – retailing in the range of $50 to $100 – were expected to be entering the market in the first quarter of 2001. These are produced by JS Info in S. Korea and SVI of Thailand.

Sirius

Sirius uses three satellites, operating in the 2.3 GHz band, to broadcast up to 100 digital radio channels across North America. Mobile reception is the goal. There is no advertising and the service costs the listener $12.95 a month. A network of 94 ground repeaters is being built in North America to augment the satellite signal in tunnels and dense urban areas with tall buildings. Apparently, a Sirius-type network could also use the 1.5 GHz band to provide satellite DSB services for Europe. However, this would mean further demand being placed upon this frequency band in Europe.

XM

XM uses two satellites, operating in the 2.3 GHz band, to broadcast more than 100 digital radio channels – covering music, news, comedy and sports – across North America. A regular commercial service has already begun. Mobile reception is the goal. Presumably, because of its dependency on GEO delivery, XM will have to rely on even more terrestrial repeaters than Sirius (HEO delivery). There is some advertising and the service subscription costs $9.95 a month.

Global Radio

Global Radio plans to offer pan-European services with 60 to 70 entertainment, information and mobile telematics channels, tailored to different country’s cultures and languages. During the year 2000, Global Radio signed a strategic financial partnership with NTL, the UK network provider, and Wit SoundView Group, a US investment banking group.

Availability of DSB receivers

The availability of reliable and affordable receivers in sufficient quantities, as well as some possibility of a choice of different makes and models, is critical for the success of the DSB market.

T-DAB receivers

The T-DAB receiver market in Europe is still largely caught in the classic "chicken and egg" situation. Despite substantial early investment in DAB by broadcasters, manufacturers and network operators, consumer awareness is still extremely low, receiver prices are high compared to analogue receivers and the growth of new radio and data services is very patchy. None of the players has yet found the means to break through the current bottlenecks. The pay models that have facilitated the introduction of digital television are not available, because sound broadcasting is fundamentally a free-to-air service.

T-DAB services are operational or being developed in over 40 countries including the majority of Europe. Over 210 million listeners across Europe and 284 million people around the world can now receive more than 400 different DAB services.

T-DAB receivers have now been on the market since summer 1998. More than 50,000 T-DAB receivers have been sold so far in Europe, with the UK and Germany being the biggest markets. There now exist DAB car radios, hi-fi units, PC cards and software, as well as portable receivers and other exciting new developments and prototypes such as the DAB palm-top receiver.

T-DAB receivers can be implemented with digital signal processing (DSP) integrated circuits and can be integrated with mobile phones and personal digital assistants. The EtherAction Terminal version 1.0 represents

A stand-alone DAB receiver from Roberts.

A Hi-Fi DAB tuner from Arcam.

An in-car DAB unit from Clarion.

A DAB PDA from EtherAction, based on a Compaq iPaq.

the first commercially-available implementation of an integrated all-in-one device containing a DAB receiver, GSM/GPRS mobile phone and a hand-held computer (iPaq from Compaq).

The multimedia services range from conventional DAB radio broadcasts with associated data, to advanced personalised interactive multimedia services. Examples of possible services are news, games, financial information, TV, video, music, traffic information etc.

At the recent COMDEX show in Las Vegas, South Korean company PersTel showed a prototype of a tiny portable T-DAB radio (DR-201) based on the Texas Instruments TMS-320C5000 digital signal processor chip. The device offers MP3 recording as well as voice recording and FM tuning.

Portable T-DAB receivers from PersTel.

For further information on T-DAB receiver availability, visit the website of the WorldDAB Forum:
http://www.worlddab.org/

Another useful (independent) website for keeping up with T-DAB developments is:
http://www.wohnort.demon.co.uk/DAB/

Satellite DSB receivers

In the following sub-sections, a short survey of the available satellite DSB receivers is given.

WorldSpace

WorldSpace receivers are currently being produced by five manufacturers: Hitachi, JoyEar, JVC, Matsushita (Panasonic) and Sanyo. A dealer in the UK reported that the take-up of commercial receivers is satisfactory. The cost is £99. Throughout Europe, approximately 8,000 receivers, mainly from Hitachi, have been sold. (It should be noted that receivers currently offered by these companies are being advertised on the WorldSpace website for $160 - 210.) WorldSpace anticipated "having approximately 125,000 receivers in the African, Middle East and Asian markets by the close of the year 2000". It is not known whether this expectation was realized. More recently, WorldSpace issued a press release saying that about 150,000 receivers had been sold in Nigeria for a retail price of about $60.

A WorldSpace receiver from JoyEar.

Sirius

It is claimed that Sirius receivers are being produced by Alpine, Clarion, Delphi Delco, Jensen, Kenwood, Panasonic, Pioneer, Sony and Visteon. The prices for car radios (Kenwood) lie in the range $330 - 600. Ford and DaimlerChrysler are expected to provide cars equipped with Sirius for all their lines. BMW is expected to offer Sirius in all its models sold in North America. Adapters will also be available to allow existing car radios to receive Sirius broadcasts.

XM

Special XM in-car and home receivers have been designed. They are manufactured by Alpine, Audiovox, Clarion, Delphi Delco, Motorola, Panasonic, Pioneer, Sanyo, Sony, Visteon and others. XM radios will be line-fitted in the 2002 Cadillac Seville and DeVille models. Other vehicle brands will also be provided with

XM receivers from next year. A three-band (AM, FM and satellite) receiver is expected to retail at around $250 or more.

An XM car radio from Pioneer.

Global Radio

Global Radio would probably make use of the existing T-DAB receiver base (with suitable extensions for satellite reception [10]). By the time of a possible implementation of this service, it is presumed that terrestrial receivers that could be reused for satellite DSB reception will already be widely spread across the market.

Impact of satellite DAB on T-DAB planning

The CEPT has a planning meeting, scheduled to take place in June 2002, to allot to member administrations an additional seven T-DAB blocks (out of 14) in the 1467 – 1492 MHz frequency range for terrestrial sound broadcasting purposes – probably on a one-allotment-per-coverage-area basis. This would effectively extend the Wiesbaden-95 Plan to include a "third priority" allotment for each administration. The seven remaining blocks would presumably be left for satellite broadcasting usage.

Time setback

Originally the CEPT intended to hold an official T-DAB Planning meeting sometime in 1999. However, due to an interest in the band by satellite broadcasting groups (e.g., Global Radio and Alcatel, etc.), the CEPT T-DAB preparatory work was delayed while propositions in favour of maintaining the 1467 – 1492 MHz band for exclusive satellite broadcasting usage were considered. It was only towards the end of 2000 that the CEPT decided to go ahead with a T-DAB planning meeting to be held in 2002.

Planning approach

At present, satellite proponents are still pressing the CEPT to employ a type of T-DAB planning which is based on what they call the "islet concept". Such an approach would effectively mean that, within any given country, only specific small-area coverages (at most, the size of large cities, perhaps) and involving only selected sites (in cities, for example) would be treated. They hope thereby to reduce drastically the amount of spectrum that will be needed to satisfy T-DAB requirements [11]. It should be noted that if *complete-area* coverage were to be based on the "islet concept", more spectrum may be required, because the efficiencies of large-scale SFNs would be lost.

The "islet" approach stands in contrast to the "national, complete-area coverage" planning that was carried out in Wiesbaden. A CEPT decision on which type of planning is to be used in 2002 will be taken towards the end of 2001. Based on the results of a survey of the requirements of CEPT administrations, it is now clear that a significant number of CEPT member countries are requesting complete geographical coverage of their territories [12].

10. Including AAC+ adaptor?
11. They would also prefer that the CEPT considers the "old" Wiesbaden T-DAB blocks as well, for allotment at the forthcoming Planning meeting in order to reduce the demand on the 1.467 – 1.492 GHz spectrum.
12. Informal discussions with some administrations have indicated that, at present anyway, "islet" planning is not what they are interested in.

Planning constraints

The CEPT project group responsible for preparing the T-DAB planning work (CEPT FM PT32) will have available – at most – seven T-DAB frequency "blocks". It is not yet clear which seven of the 14 blocks in the designated frequency range will be marked for T-DAB. The answer to this question will also be decided on the basis of administrations' needs.

Once the precise positions (frequencies) of the T-DAB blocks have been decided, the CEPT planning will have to take into account existing "other services". It is not yet clear whether there are any *existing* satellite broadcasting services which will be able to claim protection at the Planning meeting. If so, this would further complicate the planning process. In general, such satellite systems work at low power levels. This makes them extremely sensitive to the higher power terrestrial transmissions [13]. Interference from satellite to T-DAB is not generally considered to pose a problem.

If certain administrations intend to structure their T-DAB requirements so as to provide a terrestrial gap-filler core for support of future satellite broadcasting usage, this would probably not increase the planning difficulties at the CEPT Planning meeting, because of the (probable) "equitable" allotment distribution basis of the planning. It is not clear how this would affect T-DAB planning after the Planning meeting. To a certain extent, this would depend on whether the (gap-filling) terrestrial frequencies used were co-frequency (with the satellite) or not. Should the satellite downlink use a single-carrier system and the terrestrial repeaters a multi-carrier system such as OFDM, then different frequencies should be used.

Furthermore, the CEPT has decided that T-DAB planning is only to be based on parameters corresponding to the Eureka-147 standard. This was explicitly done in order to avoid still further planning complications that would arise with respect to the (differing) WorldSpace system [14,15], and also because of CEPT's commitment to using the Eureka-147 DAB standard.

T-DAB as a "complement" to satellite broadcasting

We will now examine what might be the impact on the planning of T-DAB, if it were to be considered as a gap-filling addendum to a full satellite service.

Assuming that all, or a part, of the available 1.5 GHz band were to be used for satellite transmissions, with supporting T-DAB gap-fillers, the planning of T-DAB would consist of at least two separate components:

1) T-DAB gap-fillers in conjunction with satellite DAB [16], and

2) independent T-DAB "other usage".

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13. It should be kept in mind that the satellite footprint (i.e., the coverage area) can be quite large (e.g., 14,000,000 square km for a WorldSpace beam) and that, within the coverage area, the field strength reached will be near to (but above) the minimum usable field strength everywhere. In general, terrestrial services will be working substantially above the minimum field strength value, especially the nearer one approaches the terrestrial transmitter site. Only at the edge of the terrestrial coverage area would it be expected that the field strength would drop to values near the minimum. It is for this reason that the satellite coverage will generally be "overwhelmed" by a terrestrial component.

14. It should be noted that Global Radio claims it will be using a Eureka-147 type system, although the audio source coding system will be MPEG-4 AAC+.

15. It should be noted that it is the CEPT position that, in Europe, only the Eureka-147 system should be promoted for use for terrestrial digital radio broadcasting.

16. In this context "S-DAB" is used for satellite DSB using the Eureka-147 standard.

Gap-filler planning for satellite DSB

Eureka-147 (T-DAB)

Gap-fillers would probably be planned on the basis of need: the “holes” in the satellite coverage would be “filled” as required, repeating the satellite co-frequency [17] terrestrially. Planning would be done more or less throughout the large satellite footprint (which, presumably, would enclose large sections of Europe), depending on whether the goal was full-area coverage or population coverage.

Frequency planning in this case is “easy”: the main considerations would be the number and the placement of the gap-fillers; i.e., in general, no lengthy thoughts/coordination would be needed with respect to frequency selection. Things may be far more complicated if AAC+ coding were to be used for the satellite component, unless the same audio coding is used for both the satellite and the terrestrial repeaters.

WorldSpace

The gap-fillers would probably be planned on the basis of need: the “holes” in the satellite coverage would be “filled” as required, transposing the satellite frequency [18]. Planning would be done more or less throughout the large satellite footprint (which, presumably, would enclose large sections of Europe), depending on whether the goal was full-area coverage or population coverage.

Frequency planning in this case is less “easy”: the main considerations would be the number and the placement of the gap-fillers, in addition to (lengthy) thoughts/coordination that would be needed with respect to (alternate) frequency selection.

If the goal is to ensure mobile reception, significantly more gap-fillers would probably be needed for a WorldSpace type of system (assuming terrestrial repeaters would even provide a solution) than for a Eureka-147 system which can benefit from SFN network gain.

Independent terrestrial (T-DAB) service planning

T-DAB planning (as being carried out at present by the CEPT) would be made *more* difficult because of the probable need to protect satellite DSB services. Not only would the satellite co-frequency be forbidden for T-DAB transmissions within the satellite footprint, but so also would the upper and lower adjacent T-DAB blocks [19], further restricting possible terrestrial assignments.

The European Community DBEG discussions

The European Commission has invited the Digital Broadcasting Experts Group (DBEG), which is comprised of representatives from the EC Member States, to include digital radio in its deliberations of such matters as the “digital switchover”.

A first discussion on radio took place in Summer 2001. In those discussions, Global Radio and WorldSpace re-iterated their view that the MPEG-2 Layer 2 audio compression system, which is used today for DAB, is outdated – though this argument has not been accepted by the CEPT.

17. Other-frequency repeaters could be used, but co-frequency usage would be the simplest approach.
18. Other-frequency repeaters (probably) must be used.
19. Near the terrestrial transmitters, “holes” would be “punched” in nearby areas of the generally lower field strength coverage of satellite transmissions. This problem could be compounded for a WorldSpace satellite transmission, which might be even more sensitive to adjacent-block interference than is Eureka-147 (the adjacent-block protection ratio about -30 dB to -40 dB). Furthermore, the WorldSpace frequency “block” is 2.3 MHz wide compared to 1.7 MHz for DAB.

At the same meeting, WorldSpace and Global Radio asked the DBEG group to study the possibilities for a common digital radio set which would be able to receive all European digital radio broadcasts. They offered to reconcile the satellite segment of their two systems into a single system, and use the T-DAB system for terrestrial gap fillers. It is also not yet clear what the DBEG group will make of this offer, and what if any action they will take. A common digital radio and/or a common integrated circuit set is an important commercial decision to be taken by consumer equipment manufacturers.

Summary of "impact on T-DAB"

In summary, it can be said that the satellite interests have had the following "impact" on T-DAB planning in the past, or may have in the future:

* In the recent past, T-DAB planning for new allotments has been delayed by 2 - 3 years.
* At present, broadcasters (as well as the CEPT) are devoting extra planning effort to study the "islet concept".
* If the "islet concept" is taken on board at the next CEPT T-DAB Planning meeting, and if less than seven T-DAB blocks in total are foreseen for the resulting Plan, the future development of T-DAB and/or the expansion of T-DAB SFNs in L-band will become more difficult.

In the longer term, if satellite DSB systems are introduced, the following scenarios may arise:

* An accelerated demand for T-DAB planning may occur, assuming that there is synergy and complementarity between satellite DSB and T-DAB in terms of the system design and services offered.
* T-DAB planning may become more difficult if the available frequencies must be shared with satellite DSB whose interests are to be protected.
* Additional "complementary" T-DAB planning activities could become necessary, to the extent that satellite services would need terrestrial ground support (Eureka-147 or other).
* If many incompatible digital satellite systems are introduced, this may be counterproductive for digital radio in general.
* In addition to the T-DAB and satellite planning "interactions" at 1.5 GHz, there will also be an interaction between the purely terrestrial use of the 1.5 GHz band and that of the VHF band. That is to say, the more T-DAB transmissions that can be realized in Band III, for example, the less the pressure on T-DAB in the 1.5 GHz band, and vice versa.

Conclusions

The conclusions from this article can be summarized in the following points:

* As the process of migrating from analogue to digital broadcasting technologies is taking place, European countries and EBU Member Organizations have initially decided to give priority to the deployment of *terrestrial* DSB using the Eureka-147 DAB system, on a country-by-country basis. Currently, supranational radio services are provided by using BSS satellites at 11 and 12 GHz for stationary reception only.
* The rollout of T-DAB in Europe is relatively slow. One of the reasons is insufficient spectrum. To improve the situation, it has been decided to use a further seven DAB frequency blocks in L-band (in addition to the nine blocks already planned at the Wiesbaden-95 Conference).
* It should be pointed out that L-band is the optimum band for *satellite* DSB to mobile and portable receivers. On the other hand, experience shows that L-band is not ideal for *terrestrial* DSB, in particular if large-area coverage is required.
* By expanding the use of L-band for terrestrial DSB, less space has been left than originally envisaged for the deployment of the satellite DSB services in Europe. There is a danger that the remaining seven

DAB blocks (equivalent to about 12 MHz) may not be enough to launch commercially-viable satellite DSB services (each requiring several tens of channels to achieve economies of scale).

- The 1452 – 1492 MHz band may become a place for competition between terrestrial DAB and future satellite DSB services: however, both delivery mechanisms should be regarded as complementary, although targeting different customers and markets.
- It would be advantageous if the future satellite DSB system would have maximum commonality with the existing terrestrial DAB system; this would help both in terms of coherent frequency-planning possibilities and receiver compatibility, i.e. so that the terrestrial DSB users could use their receiver for future satellite DSB transmissions (perhaps with simple add-ons).
- If the systems used for terrestrial and satellite DSB are too different, difficulties will arise in the planning of both services in the same band. In addition, a new generation of "dual-standard receivers" would have to be introduced onto the market in order to ensure compatibility.
- The frequency availability in L-band will become a major barrier if the satellite DSB services require a complementary terrestrial component, using a different frequency channel to provide for mobile recep-

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tion. Thus, a hybrid satellite/terrestrial DSB system effectively needs double the frequency spectrum (or even triple, in the case of XM-like radio systems), compared to a stand-alone satellite (or stand-alone terrestrial) system.

* Further study is required to determine the ideal strategy for any introduction of satellite DSB in such a way as to provide synergies with the current implementation of T-DAB and offer viable prospects to satellite DSB at the same time.

* Broadcasters should consider the future of satellite DSB in Europe, in the context of other developing media that are potentially capable of providing large-area coverages. The first candidate system to provide supranational coverage is the newly-developed terrestrial Digital Radio Mondiale (DRM) system. The second candidate is the Internet. At the time of writing this article, there are already some 5000 radio stations available on the Internet, each of these providing access worldwide. On-demand (pay) radio services may be available also on mobile telephones, especially when the 2G and 3G services come into place.

* All the systems mentioned in this article have their strengths and weaknesses. There will be a multitude of different delivery and transport mechanisms available in the future. Broadcasters are increasingly agnostic about the different delivery media and will provide content to all of them, suitably adjusted and tailored to match the media and the receiver/terminal properties.

* Satellite DSB has yet to find its proper position in the European media landscape of the future.

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