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STUDY GROUPS 1 AND 2

SOURCE: TELECOMMUNICATION DEVELOPMENT BUREAU (BDT)

TITLE: DIGITAL RADIO GUIDE

Please find hereafter the Digital Radio Guide for your consideration.

World Broadcasting Unions
Technical Committee (WBU-TC)

Digital Radio Guide

FOREWORD

The basic purpose of this Guide is to help engineers and managers to understand various aspects of analogue to digital conversion in radio broadcasting. Although the main focus is on ‘broadcasting’ systems, the Guide includes a fair amount of description of the ways in which digital technology can be applied in other related areas, such as programme production. It is my sincere hope that the publication will be a useful tool for radio broadcasters to evaluate the various options available to them.

I would like to thank **Mr. G. J. Harold** of Brendon Associates, United Kingdom, who basically prepared the Guide, for having accomplished a difficult task, as well as the member Broadcasting Unions for incorporating additional material in several sections.

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Digital Sound Broadcasting : the Future for Radio

1 Introduction

Digital technology has steadily transformed the way in which programmes are made and distributed in recent years. Already many broadcasters have invested in digital systems for contribution and production and now the switch from analogue to digital is moving along the broadcasting chain into transmission. At the same time, digital developments are drawing together the broadcasting, telecommunications and computer industries in a process of convergence. For all broadcasters, this is leading to a new and challenging business environment in which they are searching for a clear ‘multimedia’ role.

Although similar changes are happening in both radio and television, this Guide deals with radio. It is designed to help managers, including those in developing countries, identify the technical and business forces that are driving the analogue to digital conversion process. There are many benefits that radio broadcasters stand to gain by adopting digital technology and the current interest in digital television should help and encourage the switch from analogue to digital in radio broadcasting. The issue is likely to be brought into sharper focus if and when individual countries or regional groups set timetables for phasing out existing analogue services.

This Guide to Digital Radio begins by reviewing how digital technology is being applied in programme production and network transmission and the benefits that such changes are able to deliver. It then shifts the focus to transmission systems and receivers, where digital technology offers immediate quality improvements and much more, including the opportunity to develop added value services.

Over a period of many years, broadcasters have invested to improve the quality and availability of FM and AM radio services to the large and growing number of listeners using car radios and portables. However, both AM and FM have shortcomings. The arrival of the CD further highlighted the constraints with AM and FM, where the transmission and reception limitations are most obvious in the AM bands.

For very large area coverage, the concept of delivering radio services by DTH (Direct-to-Home) satellite broadcasting is attractive, but can be costly to implement if a simulcasting strategy is adopted to keep faith with listeners now receiving terrestrial transmissions. And how well can satellite broadcasts be received with mobile and portable radios?

How can broadcasters, faced with making important investment decisions about new broadcasting systems determine the best way forward and prepare realisable plans for a digital future? When to invest, in which system and what are the benefits? These are critical questions and this Guide is designed to help broadcasters navigate successfully into the digital age.

2 What is Digital Radio?

Since the early days of broadcasting, analogue systems have been used to carry programmes from the studios to the listeners. Now, due to the growing number of broadcasters and programme services, the frequency bands allocated to AM and FM radio in many regions of the world are full. The resulting congestion in the radio spectrum has led to a decline in reception quality and is a real constraint to further growth. Furthermore, in densely populated areas, FM reception on car radios and portables can be very poor. This is due to the effect of severe multipath propagation caused by signal reflections and shadowing due to high buildings.

Digital transmission technology can offer much improved coverage and availability. It is expected to replace analogue transmissions in many areas, but as digital systems are incompatible with current AM and FM broadcasting systems, new receivers will be needed.

In basic form, digital radio is an application of the technology in which sound is processed and transmitted as a stream of binary digits. The principle of using digital technology for audio transmission is not new, but early systems used for terrestrial television sound (such as NICAM 728) need considerable bandwidth and use the r.f. spectrum inefficiently, by comparison with today’s digital systems.

The development of digital radio has been helped by the rapid progress that has been made in digital coding techniques used in r.f. and audio systems. This has led to improved spectrum efficiency, more channel capacity, or a combination of these benefits. Digital compression techniques used in audio systems have improved sound quality at low bit rates to the extent that radio broadcasts can be made on location and then transmitted to the broadcaster’s production studios over telephone circuits in high quality.

Ideally, to reach the widest range of listeners, a genuinely universal digital radio system should be capable of being transmitted via terrestrial, satellite and cable systems.

The first public digital radio service intended for direct-to-home reception from a satellite was launched in Germany in the early 1990’s – Digital Satellite Radio (DSR). Offering 16 high quality audio channels, it can be received throughout the coverage footprint of the geo-stationary satellite by a fixed receiver with an antenna having line-of-sight to the satellite. The DSR system delivers a high quality audio signal to the listener, but uses the radio spectrum inefficiently by today’s standards for digital systems. It requires a 27MHz satellite channel for its 16 stereo programmes. Also, DSR is unsuited to the portable and mobile (car radio) markets.

Although still in use, the system has not proved to be a commercial success. For radio broadcasters entering the field of digital services there are useful lessons to be learned from the DSR development.

More recently, Astra Digital Radio (ADR) has been developed for the distribution of sound signals to domestic fixed receivers and for feeding local transmitters and cable head ends.

ADR was expected to meet the need in Europe for digital pay radio services. Using a standardised digital compression technique, MPEG-1, Layer II, to compress the source audio, ADR can make available more than 100 programmes of ‘near CD’ quality. With a nominal bandwidth of 130 kHz, the spectrum efficiency compared to DSR is greatly improved, but ADR is also unsuitable for mobile or portable reception; in part because of the broadcast band used.

Today, there are new digital radio systems being developed, working as pilot projects, or in the process of being launched. The list is set out in Table 1.

Table 1. Digital Radio Systems

SYSTEM	AVAILABILITY: Terrestrial in service date	AVAILABILITY: Satellite in service date
Eureka 147 (ITU-R Digital System A)	1995 (for the U.K., Norway, Denmark and Sweden)	(2)
WorldSpace (ITU-R Digital System D)	(4)	1998
JPL/VOA (ITU-R Digital System B)	(2)	(2)
BST-OFDM ISDB (Japan)	(2)	(2)
SDARS (U.S.)	(1)	2004 (3)
In-Band/On-Channel (IBOC) - FM and AM (U.S.)	(2)	(1)
Digital AM (SW and MW replacement)	(2)	(2)

Notes:

(1) Not applicable

(2) Systems under development. No date set for a service.

(3) Latest date for compliance with frequency licence.

(4) Investigations underway into low power terrestrial repeaters and adaptive equalisers in the receivers to combat multipath.

As Table 1 shows, seven distinct digital radio systems have been or are in the process of being developed for the digital radio market. If sub-groups are included, the number of possible systems increases to more than a dozen.

The table illustrates the wide spread in stage-of-development for the different systems by the range of projected ‘start of service’ dates.

A great strength of the present analogue transmission systems is the world-wide standardisation on just two systems (FM and AM). This enables listeners to use one radio to receive programmes at any location. At this point in the development of digital systems, it appears unlikely that a similar standardisation will be achieved. Differing market requirements are driving digital systems to be more specialised and tailored to meet regional, national, or application-oriented needs. Furthermore, the complexity of digital systems compared to existing analogue techniques fosters this differentiation.

3 Why Digital Radio?

The existing AM and FM analogue systems suffer from inherent short-comings and neither can offer uniform reception quality throughout the coverage area. A.M. radio reception is constrained by bandwidth limitations, which restrict the audio quality and by interference from other co-channel and adjacent channel transmissions. This is particularly troublesome during the hours of darkness. The start of FM services in the 1950's improved the audio bandwidth and overcame the night-time interference, but the broadcasts were designed to be received using fixed receivers with external antennas. When listened to in vehicles or on portables, reception suffered from the effects of reflected signals (multipath) and other forms of interference, particularly in suburban and city areas.

Another aspect of AM and FM analogue transmissions is the inefficient use of the spectrum (relative to what is possible using digital technology). As pressure on the radio spectrum rises, this finite resource becomes more scarce. Digital radio is seen by some administrations as a potential source of income and spectrum, as a way to encourage the resource to be used more efficiently.

There are many ways in which digital radio systems can improve upon analogue systems:

- Digital signals are more robust than analogue and can be transmitted successfully at lower transmitter powers.
- Digital systems using coded multicarrier modulation offer much improved reception on mobile car radios and portables.
- Advanced digital compression techniques enable low bit-rates to be used successfully, whilst still producing sound of near C.D. quality. This makes digital systems more spectrum efficient.
- The digital bit-stream can be used for transmitting both audio and data.
- A digital radio is much easier to use/tune than is an AM/FM radio.
- There is increasing competition for the public's time from the non-broadcast media such as the C.D. By comparison, many AM (in particular) and FM services offer poor audio quality.
- The data capability of digital radio can be used directly or, with some modification, for other related broadcasting activities such as Internet radio.

4 Digital Technology in Production – the Experience To-date

During the past decade, digital equipment has improved efficiency in radio production. In the first phase of conversion, new equipment was used as a 'stand-alone' replacement for obsolete or worn-out analogue equipment. For example:

- Digital Audio Tape (DAT) Machines
- Digital Audio Editors
- Compact Discs (in place of vinyl recording discs)
- Digital Coders and Decoders (CODECS) (for contribution circuits)
- Computers for News Departments

More recently, digital technology has been harnessed to integrate and change production and post-production processes. The compression and editing of digital sound signals is increasingly carried out at PC workstations and the trend is towards fully flexible computer based systems. These are capable of handling the broadcasting process all the way from the microphone to the transmitted programme.

These changes raise strategic managerial issues for broadcasters. Hardware and software standards need to be established for networks and data exchange and for a given application, it must be decided whether proprietary or non-proprietary equipment is appropriate.

System requirements for digital production fall into a number of distinct categories:

- News Systems (for news gathering and processing)
- Digital Audio (for production and processing)
- Archiving (for the storage of audio and text)
- Automation (for scheduling and control)

To take full advantage of the new technology, staff must be multi-skilled so that the benefits from the investment can be realised. The savings in time and cost resulting from the analogue to digital conversion need to be tracked so that the financial return from the conversion can be quantified.

Today, work-stations are widely used at all stages of production and much is being done to improve the multi-tasking capability and the man-machine interface to make it easier for operators to use the wide range of digital effects and applications now available.

Success in the next stage of digital development in programme production will be influenced by the choice of standard and the degree of compatibility achieved. For example, successive stages of digital processing in the broadcasting chain must not generate significant artefacts that degrade the audio signal.

The current trend to open up specialised hardware to a programming language such as JAVA is an important development.

4.1 News gathering

At the start of the production chain, where the programme material is gathered by a reporter on location, the continuing trend to reduce size, whilst expanding the capability of portable lap-top PC's, is proving to be of great benefit. Hardware developments leading to weight reduction with increased performance have been matched by developments in software, communications and compression techniques. Many base stations now have automatic systems that support remotely controlled recording via standard and DTMF telephones.

Digital equipment provides the improved quality that is now expected and journalists have access to a wide variety of equipment and recording media. DAT has the advantage of long storage times with uncompressed recordings, but presents problems with editing. Mini Disc (MD) recorders offer an alternative solution and some can be used with a lap-top computer for basic editing. For more elaborate editing, portable sound work-stations are available.

4.2 News production

Systems for the management and production of news programmes using computers have developed and changed dramatically since they first appeared in the 1970's. This in part reflected the mainframe to PC revolution arising from the exponential growth in processing power and the television requirement for machine control and computer based network management of news production and transmission.

But the era of newsroom computers controlling studio production devices is now drawing to an end and the latest newsroom systems are increasingly modular in concept. The individual building blocks need to be capable of integration with others and to be replaceable. The overall system must be capable of processing information from press agencies or correspondents' despatches to the transmission of programmes. Of key importance is access to archive material, with easy to use search routines for text, audio and data, efficient messaging and script movement and management information systems.

Implicit in these requirements is a need for:

- Non-linear editing and
- Digital storage, retrieval and playback.

The way in which news material is managed on computer disks and accessed from them is a key issue for new systems. For broadcasters needing large systems there is the requirement to support many hundreds of users.

Currently, the market in news systems is occupied by four major suppliers:

- Avid News (from Avid Technology)
- Electronic News Production System – ENPS (the Associated Press / BBC system)
- Newsmaker Systems - (a system which moves closer to the Web browser environment)
- Tektronix (using the Newstar text editing system)

All these systems are targeted primarily at the television market, but in an increasingly bi-media and multi-media world, the same basic technologies are used for television and radio. Training is an important consideration and systems that can be used after a short period of training have a valuable advantage.

4.3 Digital Audio – production and processing

The arrival of digital audio workstations (DAWS), which began to appear in the early 1980's was expected to result in major savings in post production time and costs. To date, this expectation has not been fulfilled to the degree expected because many operational digital audio workstation platforms from different manufacturers are often incompatible in terms of interchanging file formats (except for basic unformatted data files).

This problem leads to additional expense and time being expended in order to transfer audio files between formats, as they are moved through the post production processes. Fortunately, it appears that the DAW's industry is concerned about this problem. If not dealt with, it will in the end damage credibility and reduce manufacturers' profits. Several initiatives have been taken to try to resolve this problem. It is important that a solution is found that will stand the test of time.

Leaving aside the problem of compatibility, many broadcasters have derived very positive benefits through changing from analogue to digital in production areas. Single and multi-track editors can be used successfully by staff after only a few hours or days training and audio can be distributed instantly throughout an entire station.

And in addition to the basic features, many DAWs provide software for web publishers and database management; making full use of current client / server technology.

4.4 Storage and archiving

There is a wide variety of digital recording formats currently available. The digital evolution began with digital audio tape (DAT), but now there are DAWs (two track and multi-track), samplers (used only for recording short sound events because the storage is on computer memory), digital cart machines and hard disc recorders. All of these different formats can be used by radio stations.

Although these devices use the same conversion processes (from analogue to digital and vice versa), the storage arrangements are different; being mainly magnetic tape, magnetic hard disc or magneto optical disk.

When compared to tape, hard discs offer near instant random access, allowing the operator to locate quickly any point in a recording. Some hard disc recorders offer play list editing, which is both fast and non-destructive. Others re-write data on the disc, so making the original material irretrievable.

The most appropriate format for a given radio station will depend on the scale and type of broadcast operation. Tape based systems using DAT or MDM (modular digital multi-track) with a DAW for editing can provide a low cost digital system. The recording medium (tape) is inexpensive and if used in conjunction with a two track DAW and an existing computer, the set-up costs for the overall digital system can be kept to a minimum.

There is no shortage of equipment suppliers in this field and the falling cost of computer equipment is making it increasingly attractive for broadcasters to work in a digital environment. The increase in storage capacity available on hard disk is providing fast and easy access to audio material electronically rather than physically. This change virtually eliminates the cost and time of dealing with CD's, records and tapes.

With the wide range of compression formats now in use, it is important that any new system can handle MPEG, Dolby and ADSPCM at different compression ratios and sampling rates.

4.5 Automation

Computer systems available today can provide integrated planning and automation at a fully digital radio station. The equipment available ranges from simple stand-alone or client server PC based systems through to large scale multi-user systems.

For an analogue station that has digital sub-carrier data (such as RDS), management of the analogue audio has to be supplemented by the need to manage the data. At a station designed to process radio services using all-digital audio systems, there is a need to manage the data channels in addition to the digital audio and text.

At a digital radio station, the automation process is at the hub of four functional areas:

- The station database where the audio is stored in digital form.
- The studio where the automation functions include studio and news prompters and schedule monitors.
- The scheduling and editing areas for music, news etc.
- The communications and administrative activities.

5 Network Transmission

In recent years, developments in satellite technology have provided a range of options for network operators. There is a wide choice of equipment, although as yet no emergence of an industry standard. The analogue to digital conversion process has been a major factor in releasing network capacity and digital transmission offers greater flexibility, for example by halving the bit rate to produce two voice quality channels from one mono channel.

A recent development has arisen from the need to download audio files into computers and file servers. Several manufacturers have responded to this demand by designing receivers that meet the need with expanded digital down-load capability and storage capacity and in some cases the facility to integrate content in world-wide web (www) style.

In the coming years, it may be that satellite technology for network transmission and SNG will adopt standards based on DVB or ATSC DTV. If this route is followed (or a similar system is chosen), wide-band audio will be included with data and video in one standard for multi-media distribution.

For radio broadcasters intending to start digital transmissions, whether via terrestrial transmitters, satellites, cable or some combination, the existence of a standard (such as an ITU-R recommended broadcast format standard) is a useful platform from which to start the planning.

A multi-channel digital services broadcaster is involved in processing the audio streams and the functions needed to manage the streams. The broadcaster, or broadcast service provider, has to manage and control an array of network management functions. These may include:

- Management of the programme data stream.
- A service or programme guide.

- Conditional access codes (if applicable)
- Transmission path redundancy and fail-safe systems
- Channel capacity and re-configuration management
- Control of remote equipment

The requirements are to varying degrees interactive and may need an overseeing system.

In planning the final transmission link, it is essential to have a reliable prediction programme to establish the coverage from single or networked transmitters; so that the antenna heights and transmitter powers can be assessed. To simplify the engineering and to minimise the cost of introducing a new terrestrial service, maximum use needs to be made of any infrastructure, - including sites, masts, towers and buildings, provided for existing FM and AM analogue services. In-band/on-channel (IBOC) digital broadcast systems are expected to be well-suited to achieving this goal, since much of the existing infrastructure would be shared between the new and existing service.

5.1 The elements of a DAB network

An outline digital radio network is shown in Fig. 1, using the Eureka 147 DAB standard as an example. It illustrates many of the factors that have to be taken into account when building any digital network.

This figure reflects the flexible nature of a E-147 signal and the good data capacity achieved by virtue of its relatively wide bandwidth (approximately 1.5 MHz). A narrower band service such as that envisioned with an AM or FM IBOC system, while having a structure similar to that shown in the figure, would likely be simpler in that it would support a smaller number of programs and data services.

A conventional fm network is essentially a parallel arrangement of individual and mostly independent services. for a dab network, the organisation responsible for putting together the multiplex of integrated programme and data services has a new role at the core of the network.

The programme services are brought together as a combined multiplex in two stages.
the first stage is carried out by each of the broadcasters sharing the network and involves assembling:

- Coded audio
- Programme associated data (PAD)
- Service information
- Control and status information (for processing the service data)
- Independent data services

At the second stage, a full multiplex is assembled by the multiplex operator. This involves:

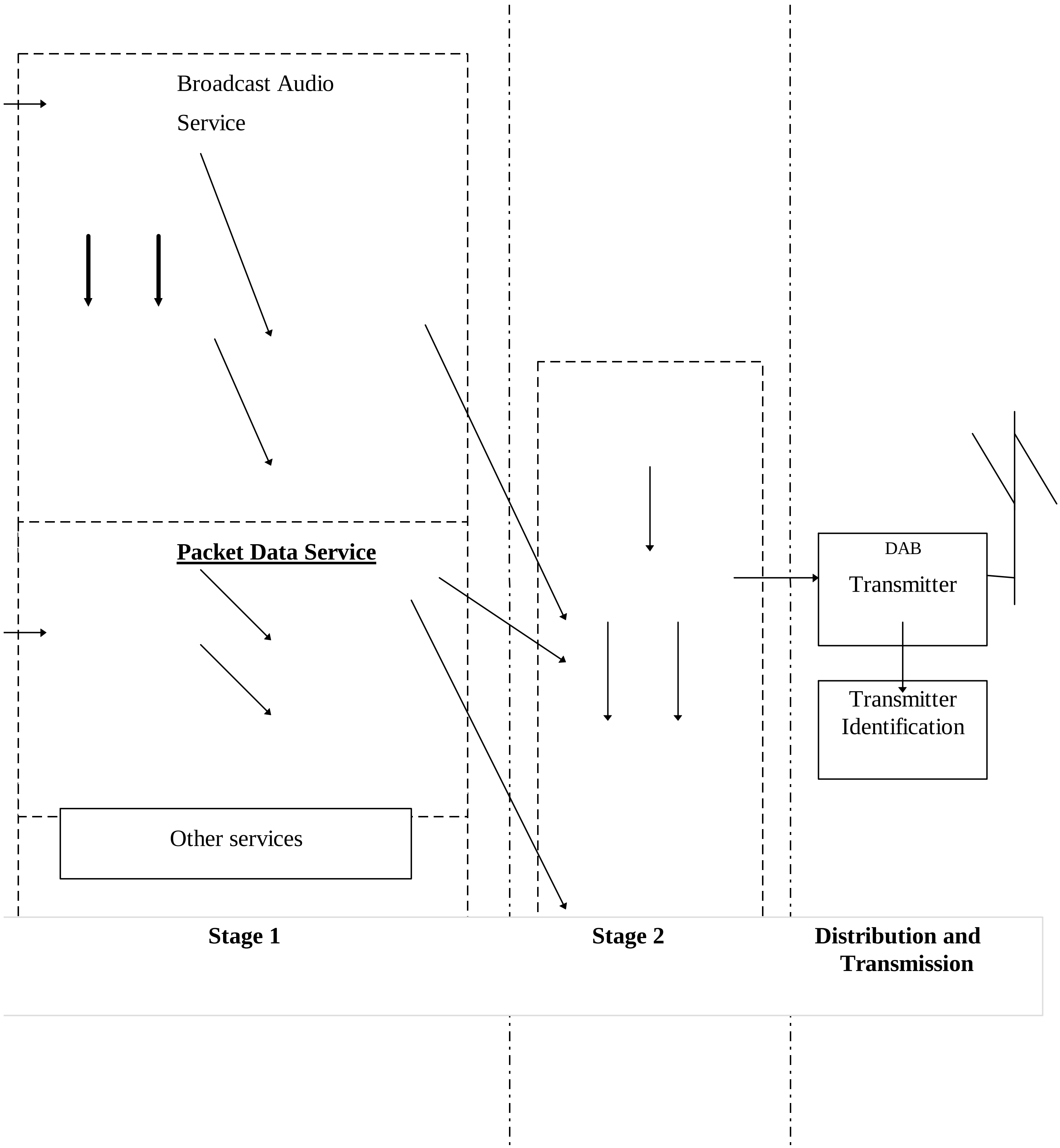
- Building service multiplex data in the DAB ensemble, except for information added at the transmitter
- Adding control and status information (for transmitter control or sending back to the service provider)

One of the main features of a DAB multiplex is its inherent flexibility, and the capability of being frequently reconfigured. To use this flexibility, coordination between the different programmers and data providers is needed.

For distributing a multiplex signal to the transmitters, one method is to use a vision link, but the cost becomes high when many sites are involved. For the Eureka 147 system, an Ensemble Transport Interface (ETI) can be used. The interface signal is compatible with standard telecommunications circuits. The cost of additional equipment is recovered from revenue savings in distribution circuits. other digital radio systems can make similar arrangements. For am and fm iboc systems, which utilise significantly less bandwidth than the Eureka 147 signal, simpler studio to transmitter links should suffice, and in some cases, existing links are in fact expected to be usable.

At transmitting sites, the time needed to introduce digital transmissions is mainly determined by practical considerations such as: site suitability, mast strengthening (for new antennas), equipment housing and power supplies.

Figure 1. Outline DAB Network Example - (based on Eureka 147)



6 Terrestrial Transmission

6.1 Operational Systems

In Section 2 of this Guide, mention is made of three operational digital sound transmission systems, of which two are satellite based (DSR and ADR) and the third is the NICAM 728 stereo sound system used to provide high quality audio for terrestrial television services (PAL and SECAM).

The development of the Eureka 147 digital broadcasting system was started in 1987 and it is currently the most mature system. The result of the development programme is a multi-service system that can be operated at any transmission frequency up to 3 GHz. It can deliver a robust signal to fixed, mobile and portable receivers; all with simple non-directional antennas. Many broadcasters throughout the world are now operating Eureka 147 terrestrial networks on extended pilot tests and trials or as regular broadcasts. However, the system is suitable for delivering services by satellite only, hybrid systems (satellite with terrestrial co-channel fillers), mixed systems (satellite with terrestrial re-broadcasting), or via cable networks.

As well as supporting a wide range of audio coding rates and hence audio qualities, a Eureka 147 flexible digital multiplex can support a range of source and channel coding options. These include programme associated data and independent data services.

Government operated national broadcast networks are particularly well-suited to Eureka 147, which is also in use for local radio, as well. However, regions where broadcasting is primarily local, or community based and privately owned and operated, or regions with limited spectrum available for new services, may find it more difficult to adopt the Eureka approach.

A list of countries using Eureka 147 Terrestrial DAB (T-DAB) is given in Table 2.

The specification of the Eureka 147 system is an agreed European standard and an ITU recommended international standard, where it is known as ITU-R Digital System A.

Eureka 147 uses MPEG-1, Layer 2 and MPEG-2, Layer 2 digital audio compression. controlled coding redundancy applied to the signal gives good error protection and high power efficiency. By spreading the transmitted information in both frequency and time, the effects of channel distortion and fades at the receiver are avoided, even under severe multi-path conditions.

The main features of Eureka 147 are summarised in Table 3.

Table 2. Countries with Eureka 147 Installations (April 1998)

COUNTRY	TERRESTRIAL EUREKA 147 DAB INSTALLATIONS			
	Operational or Pilot Network	Trials and Experiments	Number of Transmitters	Frequency Band
Australia	Test facility in Canberra	-	4	L-Band
Belgium	National Ensemble	-	11	Band 3
Canada	15 Private Broadcasters plus 4 CBC networks	-	several experimental plus 4 service transmitters	L-Band
China	-	Tests	3	85 MHz
Denmark	National Ensemble	-	3	Band 3
Finland	National Ensemble	-	3	Band 3
France	Pilots in Paris	-	6	L-Band
Germany	Many Pilots	-	200+	Band 3 and L-Band
Hungary	1 Multiplex	-	1 (High power)	Channel 13A
India	-	Tests (Delhi)	1	-
Israel	1 Pilot (70% coverage)	-	2	Band 3
Italy	-	2 Experimental services	4	Band 3
Malaysia		Pilot to start in 1998	3	Band 3
Mexico	-	Trials	-	L-Band
Netherlands	1 National Multiplex	-	3	Band 3
Norway	1 National Multiplex plus 1 Private Broadcaster	-	3	Band 3
Poland	National multiplex (4 services)	-	1	-
Portugal		Tests in Lisbon to start in May 1998		Band 3
Singapore	-	Trials	-	L-Band and Band 3
Slovenia		Tests / trials		
South Africa	Pilots	-	-	Band 3 and L-Band
S. Korea	-	Tests	-	-
Spain	-	Tests (during 1998)	-	-
Sweden	National Multiplex	-	50	Band 3
Switzerland	Pilot with 4 Regional Ensembles	-	3 12	Band 3 L-Band
U.K.	National Ensemble	2 London Experimental Multiplexes	29	Band 3

Table 3. Eureka 147 Main System Features

EUREKA 147 MAIN SYSTEM FEATURES	
Single Frequency network (SFN) capability	All transmitters working on a single frequency.
Flexible audio bit-rate	Allows re-configuration of the multiplex.
Data services	Separately defined streams or packets.
Programme Associated Data (PAD)	Embedded in the audio bit-stream and adjustable.
Facilitates Conditional Access	DAB ensemble transports conditional access information (CAI) and provides signal scrambling mechanism.
Service Information	Used in the operation and control of receivers.
Operating frequency range	30MHz to 3GHz.

In terrestrial form, development of the Eureka 147 system is essentially completed. As such, it provides for:

- The possibility of increasing the number of channels in areas where the FM bands are fully used;
- Because of its large data capacity, it paves the way for multimedia/radio services;
- The ability to create synergies with other technologies such as GSM and GPS;
- Overall, the Eureka 147 DAB system can be substantially more efficient than FM;
- Competition between broadcasters based on programme content rather than creating technical barriers which limit competition.

Work continues on alternative terrestrial systems (*e.g.*, AM and FM IBOC, BST-OFDM) and there are several reasons for this:

Eureka 147 is a “new-band” system requiring new spectrum allocations in addition to the universally allocated AM and FM analog sound broadcasting bands. Many countries have eithere implemented Eureka 147 in the allocations set aside for digital radio at WARC-92, or otherwise made spectrum available, but regions also exist where there is not sufficient spectrum available for the introduction of a new-band service;

A commercial radio station, whose intrinsic value is determined to a large part by not only its coverage area but the relationship of its coverage area to that of other stations’ in the same market, could be irreparably harmed economically by the transition from analog service to a multiplexed service, which is likely to have the effect of altering these coverage area relationships;

A Eureka 147 transmission is a multiplex of services and broadcasters have to co-operate and share the multiplex. In a competitive radio market, this sharing of facilities and coverage area may not be desirable;

The Single Frequency Network (SFN) feature is of most value to national broadcasters (public service or commercial) and to broadcasters needing regional or national coverage. Hence in different countries it can be a less or more necessary feature. (Note: IBOC systems based on OFDM will also support the SFN configuration.)

More advanced audio compression algorithms have been developed (*e.g.*, AAC) since the MPEG-1/2 standards were established, which can now provide broadcast quality audio at significantly lower bit rates (on the order of 50% or more), resulting in a more efficient use of spectrum.

More information about the Eureka 147 system is included as Appendix A.

6.2 Systems under development

There are numerous serious efforts currently underway (June 1998) to develop *in-band* terrestrial digital broadcasting systems, that is, systems which can operate within the existing frequency allocations for terrestrial sound broadcasting. Three separate efforts are underway in the United States to develop in-band/on-channel (IBOC) systems for the AM and FM bands, and are discussed below in Section 6.2(a); also, there are three additional efforts being undertaken to develop digital methods for AM broadcasters operating in the short-wave and medium-wave bands, discussed in Section 6.2(b).

6.2 (a) AM/FM In-band/On-channel (IBOC) Systems

IBOC is the approach preferred by broadcasters for introduction of terrestrial DAB services in the United States given the lack of spectrum availability for implementation of a new-band system such as Eureka 147. ([1], [2]) IBOC systems are designed to be used in the existing broadcast bands and to be compatible with the analog signals currently in use.

However, many countries outside the United States are cautions about IBOC systems for the following reasons:

- IBOC systems are expected to cause some degradation to existing analogue services and/or reduce their coverage, although to what extent is still unclear;
- IBOC systems have not yet been examined or demonstrated to independent bodies such as the ITU.

IBOC systems typically take advantage of the un-used portion of the spectrum for the AM or FM service which is in the immediate vicinity of the analog carrier (as defined by the service frequency allocation "mask"), or implement frequency re-use by including an additional carrier (or carriers) in quadrature to the existing analog carrier. In either case, the analog signals are in close proximity to the digital signals and great care must be exercised to prevent unwanted interference between them.

A series of laboratory and field tests were conducted by the Electronic Industries Association (EIA) and the National Radio Systems Committee (NRSC, co-sponsored by the EIA and the NAB) during the 1994-96 time period on a number of “1st-generation” IBOC systems (listed in Table 4). ([2] –

[7]) Of those systems participating, four were of the IBOC type (three FM, one AM). Characteristics of these IBOC systems, and in addition, characteristics of some of the "next-generation" systems currently under development, are given in Tables 5 and 6.

All four of these 1st-generation IBOC systems were shown (by the EIA/NRSC tests) to be unsuitable for deployment as viable DAB systems, for various reasons. In spite of this overall result, all four systems did demonstrate excellent audio quality in an unimpaired environment, [8] (also refer to [9] for analysis of audio quality in an impaired environment) and an evaluation done by one of the proponents (after testing was complete), USA Digital Radio, Inc. (USADR), on their IBOC systems as well as the corresponding test data, concluded that the IBOC concept was valid, again, in spite of the EIA/NRSC test results. [10]

Table 4. Systems Participating in EIA/NRSC DAB Tests

		TESTS PERFORMED IN:	
SYSTEM	**TYPE/BAND**	**LAB**	**FIELD**
Eureka 147	New-band terrestrial /L-band	✓	✓
VOA/JPL	Satellite/S-band	✓	✓
AT&T/Lucent	IBAC/FM-band	✓	✓
AT&T/Lucent/Amati	**IBOC/FM-band**	✓	
USADR FM-1	**IBOC/FM-band**	✓	
USADR FM-2	**IBOC/FM-band**	✓	
USADR AM	**IBOC/AM band**	✓	

Table 5. Comparison of FM IBOC System Parameters

	1ST-GENERATION SYSTEMS				NEXT-GENERATION SYSTEMS(1)	
PARAMETER	AT&T/AMATI (DSB)	AT&T/AMATI (LSB)	USADR-FM1	USADR-FM2	USA DIGITAL RADIO	DIGITAL RADIO EXPRESS
Diversity	None	None	None	None	Time and Frequency	Time and Frequency
Simulcast with analog?	No	No	No	No	Yes	Optional
Audio coding rate	160 kbps	128 kbps	128-256 kbps (variable)	128-256 kbps (variable)	96 kbps	128 kbps
Audio coding technique	PAC	PAC	Musicam	Musicam	PAC	MPEG2-AAC
Channel bit rate	264 kbps	216 kbps	392 kbps	384 kbps	240 kbps	256 kbps(2)
Channel coding	Reed-Solomon	Reed-Solomon	Concatenated code (variable rate)	Concatenated code (variable rate)	CPC(3)	Concatenated (Trellis outer, block inner)
Modulation technique	DMT(4)	DMT	Multicarrier/CDM	Multicarrier/CDM (w/freq. slide)	OFDM	OFDM
RF bandwidth(5)	150 kHz	75 kHz	200 kHz	400 kHz	134 kHz	140 kHz
Data capacity	<15 kbps	<15 kbps	<64 kbps	<64 kbps	>64 kbps	>64 kbps(2)

Notes:

(1) Information on Lucent Digital Radio's FM IBOC system not available for inclusion in this guide (6/98);

(2) Estimated; exact figures not yet disclosed (6/98);

(3) CPC is an acronym for Complimentary Punctured Code;

(4) DMT is an acronym for Discrete Multitone, a form of orthogonal frequency division multiplexing developed by the Amati Corporation;

(5) Figures for RF bandwidth represent bandwidth of digital signal components only and do not include bandwidth of accompanying analog signal.

Table 6. AM IBOC Comparison of System Parameters (USA Digital Radio)

PARAMETER	1ST-GENERATION SYSTEMS	NEXT-GENERATION SYSTEMS
RF bandwidth	40 kHz	30 kHz
Audio coding rate	96 kbps	48 / 32 / 16 kbps
Channel coding	Rate 3/4 FEC	Under development
Channel bit rate	128 kbps	Approx. 96 kbps

Note: Information regarding Digital Radio Express' and Lucent Digital Radio's AM IBOC systems was not available for inclusion in this guide.

1997 proved to be a key year in the development of the next generation of IBOC systems. Beginning with the 1997 NAB convention, held in Las Vegas, Nevada, USADR and its affiliated organisations—Xetron, of Cincinnati, OH, working on the AM IBOC development; Westinghouse Wireless Solutions, of Linthicum, MD, focusing on program management and FM IBOC design; and Lucent Technologies, Murray Hill, NJ (who had earlier been in "competition" with USADR), involved in audio coding design and IBOC "all-digital" systems—released a number of technical papers ([10] - [14]) which described new techniques for IBOC signal processing and "breakthroughs" which they felt would greatly improve upon the performance of their first-generation systems.

These papers were accompanied by exhibits at both the 1997 NAB convention (in April 1997) and The NAB Radio Show (in October 1997), as well as "focus group" meetings and a number of engineering "open house" demonstrations for the broadcasting industry, at the development facilities in Cincinnati, OH (Xetron), and Linthicum, MD (Westinghouse Wireless Solutions), demonstrating the strides being made in AM and FM IBOC system development and the level of effort being expended thereon.

Also in 1997, a new IBOC system proponent emerged—Digital Radio Express (DRE), San Jose, CA [15]—with a prototype FM IBOC system apparently ready for test in early 1998, in hardware prototype form, and plans to roll out an AM IBOC system in 1998 also in hardware form and ready for test. DRE has as a prime investor a major semiconductor manufacturer, TriTech Semiconductor, and expects to have its FM IBOC receiver design (shown in prototype form in Figure 2) reduced to a single IC which will be easily incorporated into existing receiver designs, according to DRE.

Figure 2. DRE FM IBOC Prototype Hardware – receiver (left) and exciter (right)

And, in May of 1998, a third proponent, Lucent Digital Radio, a wholly-owned subsidiary of Lucent Technologies, announced their intentions to develop and market AM and FM IBOC technology. Lucent had, until February of 1998, been working with USADR on their IBOC system developments, but have now elected to pursue this development effort independent of USADR.

Some of the specific aspects of these next-generation IBOC systems, in particular those expected to make them viable technologies, include the following:

> Audio Coding - Many of the compatibility problems encountered in the first-generation IBOC systems were a direct consequence of the spectral occupancy of those systems (i.e. the amount of bandwidth required), which is proportional to the amount of data which needs to be transmitted. Advances made in audio coding technology, since the development of the 1st-generation IBOC systems, have allowed the design of the next-generation systems to obtain the sought-after audio quality in significantly less bandwidth than that used for the systems tested by EIA/NRSC. ([16], [17]) This can be seen by comparing the RF bandwidth values provided in Tables 5 and 6 (for 1st- and next-generation systems).

Signal compatibility - Because lower bit rates are now being used for the digital audio datastreams, it has been possible to make the IBOC digital sidebands narrower than before, which should help to alleviate the compatibility problems encountered with the earlier system designs. In particular, the sidebands are constrained to frequencies higher than ±(114+15) kHz above the channel centre frequency - this is expected to improve compatibility of the IBOC signal to the analog host, which in the earlier systems was being compromised by IBOC digital energy around 114 kHz being translated into the received analog main channel stereo audio signal (114 kHz is the third harmonic of 38 kHz, which is the analog stereo audio L-R subcarrier centre frequency).

On the high end of the IBOC spectrum, the digital sidebands are constrained to frequencies below approximately ±200 kHz, which should eliminate the 2nd-adjacent channel digital-to-digital compatibility problems of the 1st generation systems. Spectral occupancy of USADR's next-generation AM system has also been reduced from its original value by 25% (from 40 kHz to 30 kHz).

Time diversity - One of the most straightforward methods of improving a radio signal's susceptibility to a number of interference problems, in particular multipath, is by increasing its bandwidth. This is the approach which has been taken in the implementation of the Eureka 147 DAB system - during the Eureka development, it was established that an RF bandwidth of 1.5 MHz, in conjunction with sophisticated digital signal processing techniques, would effectively combat multipath and other interference problems.

This broadband approach to interference mitigation is unsuitable for use in an AM or FM IBOC DAB system, since such a broadband signal would be completely incompatible with the existing 20 kHz-wide AM and 200 kHz-wide FM analog signals. However, the next-generation IBOC systems all make use of a technique that appears to be equally effective, one that *is* compatible with in-band digital radio. The cornerstone of this approach is a process known as *time diversity*, and it takes advantage of the fact that multipath fading and signal obstruction events are relatively short in duration, on the order of 1 to 5 seconds. Analyses and simulations done by USADR ([10], [12]) indicate that by applying time diversity in conjunction with interleaving and error-correcting codes, corruption of the audio signal by these types of interference can be virtually eliminated.

Data services - each of these systems will have an embedded digital data-carrying capacity, over and above that needed for digital audio. USADR expects their next-generation FM IBOC system to support the data services shown in Table 7. Their AM system is expected to have two data channels, as well—an auxiliary data channel at 2.4 kbps, and an opportunistic ancillary data channel whose capacity will vary but will on average be approximately 2 kbps.

Table 7. USADR FM IBOC Data Broadcasting Options

TYPE	DATA RATE	DESCRIPTION	APPLICATIONS
Program Associated Data (PAD)	8 kbps	Data associated with radio station's main channel audio signal	• Receiver display • Station ID, song title & artist} • Receiver configuration (e.g., multiplex operation)
Ancillary Data	2-32 kbps	"Opportunistic" data channel contained within audio codec; actual rate is a function of audio program	• Traffic • Weather • Financial reports/updates • Other low-rate, non-real-time applications such as paging, email
Auxiliary Data	64 kbps	Independent data channel with guaranteed throughput; real-time, robust in mobile environment	• Traffic • Weather • Financial reports/updates • Other low-rate, non-real-time applications such as paging, email • "High-rate" datacasting, multimedia

Less is known at present about the data broadcasting options for the DRE systems, but for their FM system they have indicated that an FM data subcarrier (residing in the baseband spectrum of the analog FM signal) has been incorporated and that this subcarrier will support a 64 kbps data rate, which could be used to provide a data service separate from the digital audio, or alternatively could be used as additional redundancy for the digital audio signal itself.

FM/AM IBOC commonality - both USADR and DRE have expressed a commitment to insuring that their FM and AM IBOC systems can be easily and cost-effectively combined into a unified IBOC receiver design. For example, the USADR AM and FM systems are designed so that their digital clocks are related, which should allow for fewer parts and reduced interference in the final implementation.

Testing is being done on these new IBOC proposals throughout the latter part of 1998. The NRSC is working closely with the proponents to insure that these tests will make it possible for broadcasters and receiver manufacturers to evaluate these next generation systems and in particular assess the improvement realised over existing AM and FM services.

6.2 (b) Short-wave and Medium-wave “Digital AM” Systems

Set against the increasing use of FM transmissions for ‘local’ broadcasting world-wide and the plethora of other media developments (CD’s, DAT etc.), the audio quality of AM analogue signals is a limitation for broadcasters.

All AM audio broadcasts are assigned to the three traditional bands, long wave (LW), medium wave (MW) and short-wave (SW). During daylight hours, LW and MW transmissions are limited to groundwave propagation, which produces a stable transmission path, but a restricted coverage area. At night, reflections from the ionosphere create the interference and fading characteristics that seriously degrade the received signal quality.

Although it might be expected that satellite direct-to-home (DTH) transmissions would in time replace short-wave and medium wave services, the evidence to date is that there are fundamental limitations in providing DTH services to mobile and portable receivers. (see Section 7 - Satellites.)

Despite the poor audio quality and reception problems with short-wave and medium wave transmissions, there are benefits:

The transmissions are in general under the control of the broadcasters

Frequencies in the internationally broadcasting bands can normally be found by working through agreed procedures.

Jamming can be difficult and costly

In the past, although the concept of digital short-wave was discussed, the audio quality then possible at very low bit-rates was poor. Recent improvements in compression algorithms and digital technology at very low bit rates have changed this picture.

Currently, a number of possible systems are being evaluated and two groups are actively involved in promoting the introduction of digital AM as a unified standard. They are:

Narrow-band Digital Broadcasting (NADIB) – a European Eureka group (EU 1559) and

Digital Radio Mondiale (DRM) – a world-wide consortium of broadcasters and manufacturers. ([18], [19])

The main system requirements for a digital broadcasting system operating below 30MHz have been defined by the DRM group as:

A system based on a single non-proprietary world-wide standard that offers significant audio quality improvement over analogue short-wave and capable of multimedia operation.

Having the capability of dynamic bit-rate adjustment.

Having transmission protocols for each type of programme material that can be processed automatically by a range of low cost receivers.

Offering low conversion costs for AM transmitters (from analogue to digital)

Ideally, a system replacing analogue transmissions should allow the progressive introduction of digital AM during the transition period.

To meet the requirement, three systems are currently being considered. They are:

Skywave 2000 – (Thomcast)

T^2M Telefunken – Multicast

JPL/VOA – (ITU-R System B development)

<u>Skywave 2000</u>

This system was devised by Thomcast and is under active development. It is a multi-carrier digital AM system in which protection against multi-path is provided by a guard interval and the system is designed for use in all the AM bands. It produces a compatible digital and analogue signal that can be used by receivers available now and by future digital receivers. In addition to the sound quality improvement, which is the primary objective for this application, the digital signal will also enable some new services to be provided.

The system has been demonstrated in tests and trials carried out during the past two years. Using a test rig, Thomcast engineers have been able to simulate the operating conditions of AM broadcasting for different transmission channel characteristics and transmission modes. The rig can be configured for simulcast or full digital operation.

During the transition phase from analogue to digital, it is proposed to satisfy the compatibility requirement by simultaneously transmitting a half bit rate version of the digital audio signal and a compatible SSB transmission of the analogue signal with residual carrier.

By September 1997, the development had reached the stage of over-air experiments to assess the audio quality improvement, digital transmission coverage and compatibility with existing services. Transmitters capable of being modified for analogue SSB operation are expected to be suitable for being adapted for Skywave 2000.

Telefunken Multicast (T^2M)

Telefunken Sendertechnik in a joint venture with Deutsch Telekom (DT) the Daimler Benz research Institute has been involved in the development of a single carrier digital modulation system for the AM bands using amplitude phase shift keying (APSK).

Trials of this system have been carried out on medium wave and short wave transmitters. A bit rate of 20 kbits/s was used for the audio and 1 kbit/s for ancillary data, the bandwidth being contained within the 9 kHz or 10 kHz channel spacing used in the long wave and medium wave bands.

A further stage of development helped to progress the testing of this digital transmission system and resulted in the Telekom / Telefunken Multicast (T^2M) transmission system. This current system enables AM analogue and digital signals to be broadcast from a single transmitter. The AM modulation is reduced to 80% and routed to the transmitter AF input in the normal way. The digital signal is added using a 9 or 10 kHz sub-carrier, which is then fed into the A.F. input of the transmitter. With this method, the reduction in AM signal modulation makes 20% available for the digital sub-carrier.

The system also has a feature that provides ‘graceful degradation’ in the receiver to avoid the sudden point of failure with falling carrier-to-noise ratio, which is a fundamental problem with digital broadcast systems.

In April 1997, Telefunken demonstrated the T^2M Multicast modulation on-air for the first time using a 500kW short-wave transmitter at a site near Berlin.

To reduce the effect of channel fading, adaptive equalisation techniques have to be used in the receiver, controlled by means of a periodic test signal. The audio coding used in the system tests is MPEG 2 Layer 3 and a nominal audio bandwidth of 6 kHz is possible. At such low bit-rates, the dominant impairments tend to be coding artefacts rather than lack of frequency response.

In one standard AM channel, this system can provide either:

AM analogue plus one or two digital programme channels with the same programme content, or

several digital programmes with different programme content, or

high quality with both digital channels combined.

JPL / VOA (ITU-R System B)

This single carrier transmission system was designed originally for satellite and complementary terrestrial broadcasting in the L and S Bands. After successful testing of the system for the satellite application, the design has been adapted to meet the requirements for robust digital radio delivery in the short-wave bands. For the short-wave application, the baseline parameters were set as:

A 10 kHz r.f. bandwidth compatible with the existing use of the HF broadcasting sub-bands.

Digital signal only using the full 10 kHz bandwidth.

Audio quality level target set at the best obtainable within 10 kHz, allowing for the level of pre-correction needed to compensate for ionospheric propagation effects and interference from other co-channel and adjacent channel broadcast services.

The design of this digital system as adapted for short-wave has the following features:

Coherent MPSK design

Forward error correction (FEC)

Time interleaving

Adaptive equalisation – to mitigate against multi-path.

The system can be used on existing transmitters with little modification and tests of the system over h.f. propagation paths in late 1996 confirmed that:

The system can support an information data rate of 32 kbits/s in a 10 kHz channel.

For the same coverage, transmitter power levels will be lower than for conventional AM analogue.

Error correction coding can achieve reliable quality audio.

Adaptive equalisation is needed to compensate for severe multipath with h.f. propagation.

Further development testing is planned for this system.

The similarities and differences between these terrestrial digital AM systems are summarised in Table 8.

6.3 Spectrum Availability

Government policies on frequency management and spectrum pricing affect all radio broadcasting development. [20] In some countries the radio spectrum is looked upon as a means of raising revenue.

Administrations in different countries operate different policies, but there are common threads. Whether frequencies are allocated through auctions or by other means, spectrum is undeniably a scarce resource and especially so in the bands that are most useful for digital audio broadcasting (including the existing shortwave bands, existing AM and FM bands, as well as the upper v.h.f. and L Bands).

In many countries, however, broadcasters have been able to convince their administrations to allocate spectrum for digital broadcasting, both radio and TV. Suitable frequencies for DAB have been identified on v.h.f., on L-band, and on S-band.

In the U.S., the government is looking towards the development of IBOC as a way to alleviate the need for new spectrum to implement terrestrial digital radio. In testimony given to the U.S. Congress by the Chief of the Mass Media Bureau of the Federal Communications Commission (FCC) in May 1998, it was stated that

'….the electronics and broadcasting industries are now testing a technology that would permit terrestrial digital audio broadcasting in the existing AM and FM bands. Called "In-band-on-channel" or IBOC, this technology would permit the superimposition of a digital radio signal on the same channel as the existing analog signal. Both could be used at the same time. Thus, *without the need for additional spectrum* [emphasis added], the developers believe they can provide a new digital radio service. They also believe that both the AM and FM digital signals will far surpass in quality their analog counterparts'.

The Bureau has been working closely with IBOC developers and has granted several experimental licenses to permit equipment and system testing. Later this year, we expect to receive a petition for rulemaking proposing a[n IBOC] digital audio broadcasting system.

In the UK, where spectrum is being allocated for seven Eureka 147 DAB multiplexes, the granting of license has been in v.h.f. Band III, which is very suitable for terrestrial DAB (T-DAB) transmissions. Across Europe, both v.h.f. and L-band frequencies will be used for T-DAB services. At a planning meeting held set up by the CEPT (European Conference of Postal and Telecommunications Administrations and held in Wiesbaden) in 1995, frequency blocks in three bands were considered:

VHF Band I (47 – 68 MHz)

VHF Band III (174-240 MHz)

L-Band (1452 – 1467.5 MHz)

The Wiesbaden plan made allotments for digital audio broadcasting in v.h.f. channels 11 and 12 and in the L-Band, and considered the implications of protecting non-DAB services within the planning area. These include airborne military services and television services in the v.h.f. bands as well as fixed and aeronautical telemetry in the L-Band.

Overall, there were sufficient allotments made in the Wiesbaden plan for the initial needs of DAB, but looking ahead, additional frequency allocations will be needed in Europe. Most organisations planning to launch today and expand T-DAB services favour v.h.f. frequencies.

The position on T-DAB frequencies in other parts of the world is similarly complicated and underlines the point that frequency allocation is an outstanding issue that will remain high on the DAB agenda for some time to come.

In terms of propagation performance at L-Band using T-DAB, concern about the efficiency of the 1.5 GHz Band has been largely removed as a result of extensive technical evaluation and field measurements, mainly by CRC in Canada. It was found that indoor reception at L-Band is comparable to that achieved at v.h.f. frequencies. The reason is that the shorter wavelength at L-Band offsets the increased attenuation through walls at the lower v.h.f. frequencies.

The constraints and uncertainties that cloud the issue of frequency allocations for new digital terrestrial services in the VHF and L-Bands are not such a problem for AM digital developments. There is some prospect that the congestion now in the AM Bands could be reduced with digital broadcasting. Potentially, there is most to be gained from digital broadcasting in the short-wave bands, because of a reduction in the number of simultaneous broadcasts. These are necessary with current analogue transmissions to ensure reliable reception under changing ionospheric conditions.

Table 8. Digital AM – the Proposed Systems Compared

	Skywave 2000	T^2M	VOA / JPL
Single carrier	No	Yes	Yes
Multi-carrier	Yes - 96 (for minimum configuration)	-	-
Simulcast capability	Yes	Yes	No
Possible operating modes	a) - Standard AM DSB. b) – SSB (upper or lower) c) – Analogue compatible AM + digital d) – Full digital (using reduced or no carrier depending on the transmitters used)	a) - Analogue + 2 digital channels b) - Analogue +lower digital channel c) - Analogue + upper digital channel d) - Digital channel (replacing analogue)	Digital only
Symbols guard interval	6 ms / 3 ms	Not applicable	Not applicable
Audio coding standard	Modified MPEG 2	MPEG 2 Layer 3	
Compatibility with existing AM receivers(1)	Yes	Yes	No
Service data capacity	200-1,200 bps	Currently 1,000 bps, but likely to be increased.	(Tests have shown that a total information transfer rate of 32 kbps can be used)
Audio bandwidth **Simulcast**	4.5 / 6 kHz		Not applicable
Full-digital	9 / 12 kHz	6 kHz mono and 2x4 kHz stereo	6 kHz
Channel coding	Trellis coded modulation (TCM)		BPSK modulated carrier
Modulation scheme	Parallel modulation – digital QAM mode in OFDM	Serial modulation	Serial modulation
Transmitter modifications required	Modulator modifications needed	Digital modulator.	Minor modifications may be needed.

(1) For reception of analog signal portion of system; digital receiver needed for digital component.

6.4 The Implications of Simulcasting

Whilst the benefits of digital broadcasting and the opportunities offered by this technology are clear to broadcasters, there is concern about the time and cost implications of the transition from analogue to digital. Until the coverage from digital broadcasts matches that from existing FM and AM services, it is unrealistic to cut existing transmissions and disfranchise listeners. It could be some years before the new digital services provide comparable coverage and a receiver base is established. Only then can the analogue services be closed down.

The transition from analogue to digital is helped in many countries by cooperation between public and private broadcasters, that jointly develop the necessary infra-structure and create attractive new programmes, and suitable regulatory arrangements. Examples of such cooperation exist in Canada, Sweden, the U.K., France, Italy, etc.

IBOC transmission schemes are particularly well suited for insuring a smooth transition to digital services. Since they are designed for compatibility with the existing analog signals, there is little or no disenfranchisement of listeners at the onset of service. New receiver costs are minimised since much of the existing circuitry can be shared by the analog and digital portions of the receiver. And over time, as IBOC receiver penetration reaches a “critical mass,” individual broadcasters can be expected to have significant flexibility in determining when and how to phase out the analog portion of the IBOC signal all together.

In addition, the simulcasting of audio material in some IBOC systems, while done primarily to facilitate time diversity, can also mitigate the undesired digital receiver behaviour experienced in cases of severe signal obstructions or extreme cases of interference. In these cases, systems without time diversity (such as Eureka 147) exhibit what is called a "cliff effect" failure, in that the audio signal is perfect one second, and completely gone ("muted") the next. In a simulcast IBOC system, the existence of the "backup" analog signal for purposes of time diversity has the added effect of eliminating the cliff effect failure mode, since in those cases the receiver will blend to analog and the audio program, while degraded, will not go away all together, and is likely to remain with the listener throughout the impairment.

In the case of digital AM, the cost to the broadcasters of simulcasting on an entirely new network of terrestrial transmitters could be prohibitive. This makes the proposed systems from Telefunken (T^2M) and Thomcast (Skywave 2000) potentially very attractive. The compatible formats proposed with these developments should ensure that during the inevitably long transition period from analogue to digital, existing and new receivers would be capable of receiving the same programmes. These systems offer an evolutionary path with valuable benefits for both broadcasters and listeners. Most importantly, the additional cost for transmitter modifications and operating charges should be modest.

These developments are at a relatively early stage and their viability has to be assessed, but the work carried out to date is encouraging. The audio quality achievable with simulcasting remains to be established.

6.5 Coverage

The move from analogue to digital transmission raises important questions under the heading ‘coverage’.

One of the main differences between analogue and digital broadcasts is the mode of failure when the received signal starts to fail. It happens at the edge of the service area and at locations within the coverage footprint where the signal strength is affected by shadowing or interference. When the signal strength reduces, analogue reception is often described as degrading “gracefully.” By contrast, a digital signal will at some point fail suddenly and completely. Whilst usually robust in areas of generally poor analogue reception, the digital signal gives little indication as it approaches a point of failure.

Within a defined coverage area, the service availability from analogue and digital services will be affected by the type of receiver (fixed, mobile or portable), by the type of environment (urban, rural), and by the topography. It is also a function of the transmission frequency and the system performance.

COFDM signals (such as those used in the Eureka 147 and AM and FM IBOC schemes) have characteristics which facilitate the planning of single frequency networks (SFN’s) to a greater or lesser extent and make it easier to extend coverage. Provided that a broadcast on the same frequency from a different transmitter, or a reflected transmission from the main transmitter, arrive at the receive antenna within the system’s guard interval, the reflected signal will combine in a constructive way to reinforce reception.

One of the objectives for the Eureka 147 system was to transmit a digital signal (a number of digitised analogue radio programmes plus data) to a mobile receiver over a difficult transmission channel. Extensive testing has confirmed that this requirement has been achieved successfully. The same characteristics of Eureka 147 ensure much more rugged reception on portable receivers.

Recent development of IBOC systems in the U.S. has also emphasised robust performance in a multipath fading channel. Using sophisticated signal processing techniques such as Complementary Punctured Coding, [13] along with time and frequency diversity, the next-generation IBOC systems are expected to exhibit fading channel performance commensurate with that achieved in the Eureka 147 system, but this remains to be demonstrated.

6.6 Costs

When assessing the financial implications of converting from analogue to digital transmission it is important to remember that cost and price are different and the relationship between them is not simple. The price of transmission services is influenced strongly by market forces, the action of the buyers, whilst the cost is directly related to the cost of component products needed to set up and run new facilities and networks.

For a broadcaster planning to start digital broadcasting with direct responsibility for the transmission element, the cost begins with the equipment:

Transmitters

Antennas

Antenna support structures

Buildings / Equipment cabins

Installation

Programme feeds

Power

There will be large variations in the component costs depending on the number of transmitters needed to provide the required coverage and the availability, or not, of suitable sites and buildings.

For terrestrial DAB, Eureka 147 is the only digital system for which a substantial number of pilot and trial installations have been completed to date and for which the costs are known. A list of organisations that can supply transmission equipment or services can be found in Appendix C.

The pilot Eureka 147 DAB transmitters that have been set up in many countries continue to provide information about the performance of single and multiple (SFN) transmitter networks. This has helped to build confidence in digital transmission and a good understanding of the costs involved.

IBOC digital system implementation costs are expected to be smaller than those experienced with Eureka 147, due to the in-band nature of the system, which obviates the need for an entirely new transmission system, from transmitter to antenna, required by a new-band service. The principal costs associated with an FM in-band system are expected to be in the RF combiner needed to combine the modulated digital and analog signals; for AM in many cases the IBOC signal can be supported by the existing transmitter with little modification.

The costs associated with AM digital are difficult to quantify at this early stage. The expectation is that the transmission work will be limited to replacement or modification of the h.f. or m.f. transmitter modulator. Much will depend on the results of tests yet to be carried out.

6.7 Timescales

For broadcasters thinking about the conversion of their terrestrial transmission systems from analogue to digital, the question is not “should the investment be made?” but, “when should the investment be made?” The combined benefits form a substantial package of improvements; better audio quality, better quality reception, spectrum efficiency, and the opportunity to start innovative programme and data services (made possible by the flexible programme and data mix).

When to invest? The answer to this question depends on the type of broadcaster, the location and the coverage required. Another key factor is the availability and price of receivers for the consumer market. Only the larger broadcasters have the resources to start digital transmissions when there are only a few expensive receivers available. In the case of Eureka 147, a number of major broadcasters have taken the lead as is evident from Table 2 and many more have begun with more modest tests and trials. The next two years may be critical for the roll-out of Eureka 147 in the world-wide market for T-DAB.

Once the decision to move into digital transmission has been taken, simulcasting in one form or another is essential to hold listeners during the transition period. The cost of this for some broadcasters could be the major factor when setting a timetable for starting digital transmission.

In the Eureka 147 case, every broadcaster moving to digital transmission needs access to a slot or slots on a multiplex. Multiplex availability will be limited in the years when simulcasting will restrict broadcasters’ ability to free other v.h.f. frequencies used for the analogue services. Fixed (hi-fi) and mobile (car) receivers are expected to be available on the domestic consumer market by mid ’98 and portable receivers within about four years. Based on the range of production prototype receivers shown at IFA in August ’97, these dates could be met. However, whether this will be the case will depend on the consumer electronics industry.

In the U.S., IBOC services are not likely to begin for at least two years or more, to allow for completion of system development and testing, and to allow for governmental decisions on the exact form that digital broadcasting will take.

The development of digital transmission systems for AM short-wave and medium wave broadcasting is also uncertain. It is too early to be sure which of the four proposed systems is most likely to be adopted as a world-wide standard. There is also the competition from satellite based L-Band digital radio services now proposed as alternatives to short-wave and medium wave services. First in the field is the WorldSpace Afristar satellite, which is scheduled for launch in late 1998.

More details of this development are given in Section 7.1 (b).

6.8 Control of the Distribution and Transmission System

Historically, many broadcasters owned and directly controlled their transmission facilities. In many cases, the same conditions applied to the distribution links from studio centres to transmitters.

In recent years, the world-wide trend to de-regulate and privatise publicly owned enterprises has led to the sale of the assets of public service broadcasters that are not considered part of the core business. Do these changes have implications for digital radio development?

The issues are:

Investment

Control

Performance monitoring

Operating costs

The extent to which these issues are of concern will depend upon the contractual arrangements made between the broadcasters and their transmission services contractor.

An interesting example of where a broadcaster has benefited financially from the sale of the transmission assets is the BBC in the UK. When its transmitter network was privatised at the end of 1996, the income from the sale was made available to the BBC to fund radio and television digital developments. However, this source of funding to launch digital broadcasting is not generally available to public service broadcasters.

<u>Investment</u>

For some public service broadcasters, the problem with investment is that funds for capital development are geared to government budget cycles and not to a specific business plan. Also the public service broadcaster is more likely to be constrained and restricted from diversification and development outside what is seen as a strictly public service remit.

The same constraints do not generally apply to privatised transmission companies. They are encouraged rather than restrained when attempting to develop their businesses in ways that lead to growth and generate economies of scale, as both will benefit the public service broadcaster.

If the proceeds from the sale of part or all of a public service broadcaster's transmission assets are made available for investment by the broadcaster in the core business, there are two obvious benefits. The funds retained can be used to accelerate the analogue to digital change in production areas and the transmission expenditure is moved from the capital to the revenue account.

Private sector broadcasters have the option of raising private sector capital from banks or shareholders to meet start-up costs for digital broadcasting. However, there may well be regulatory hurdles to overcome to implement digital broadcasting.

Control and performance monitoring

In the case of a Eureka 147-DAB system, assembly and control of the multiplex carrying the broadcasters' services can be in the hands of a broadcaster itself, a transmission services provider, or a third party. This extra step in the transmission chain has to be taken into account when setting up the transmission contract to avoid later disputes over accountability.

Operating costs

A direct comparison of the cost of operating an FM network and an 'equivalent' terrestrial Eureka 147-DAB network for a hypothetical case is difficult to make. On balance, it is likely that the cost difference will be small and as such not a primary issue in the decision to move from analogue to digital.

Nevertheless, factors that will influence the operating cost include :

the number of transmitters needed to provide the coverage and to meet the service availability criteria.

Transmitter power input and power charges

Distribution network charges

In general, the cost of the distribution network, transmission power, and multiplex operations are shared among content providers, and the charges per DAB programme tend to be lower than on FM. Thus, the gradual migration from FM to DAB has significant economic appeal in the long term, if the costs of the transition itself are neglected and the comparative coverage area of each broadcaster is maintained.

7 Satellite Transmission

7.1 Systems Under Development

7.1 (a) The Broad Picture

For many years, satellites in geo-stationary orbits (GSO's) have been used successfully by broadcasters for distributing programmes and services from the originating studios to terrestrial transmitting stations. It is cost-effective and reliably delivers high quality signals to each transmitting station. This method of distribution is of particular benefit to international broadcasters that in the past relied on SSB and DSB short-wave signals for feeds to remote relay stations.

Today, radio broadcast services can be included in the bandwidth used for an FM satellite television signal, or as part of a bundle of digital channels as used in Astra Digital Radio [21]. In all cases, satellite tuners are needed to receive these broadcasts, which are usually transmitted in the Ku Band.

Direct radio broadcasts from geo-stationary satellites to fixed receivers with externally mounted line-of-sight antennas is routine and presents no problems. It is a much more demanding requirement to reach receivers that are mobile or portable, but the majority of radio listeners have radio receivers of this type. Any radio transmission system, terrestrial or satellite, which fails to deliver a satisfactory service to such receivers will probably not find widespread acceptance.

The main difficulty in providing a satellite broadcast to an audience on the move is occasional blockage by buildings etc. This can reduce the signal by 10 to 20 dB, which it is impractical to compensate for with an increased link margin.

A number of other organisations have put forward proposals for direct satellite sound services and two have international broadcasting as one of their main objectives. They are: -

WorldSpace – using geo-stationary satellites.

MediaStar – using satellites in high elliptical orbits.

The common ground between these two proposals is that they both apply data delivery technology for transmitting primarily radio broadcasts. Also, both propose using the L-Band spectrum allocation agreed at WARC ’92 for satellite sound services in most countries world-wide as part of a compromise package.

Apart from an intention to start services in the upper part of the 1452 to 1492 MHz band, the two proposals are very different and the current status of each development is outlined in this section.

In the WARC ’92 agreement, the U.S. secured frequencies in the S-Band (2310-2360 MHz) for digital sound broadcasting. In April 1997, the U.S. Federal Communications Commission (FCC) awarded 12.5 MHz of S-band spectrum (from 2320 to 2345 MHz) each to two organisations:

Satellite CD Radio Inc. (SCDR)

American Mobile Radio Corporation (AMRC)

7.1 (b) WorldSpace – ITU-R System D

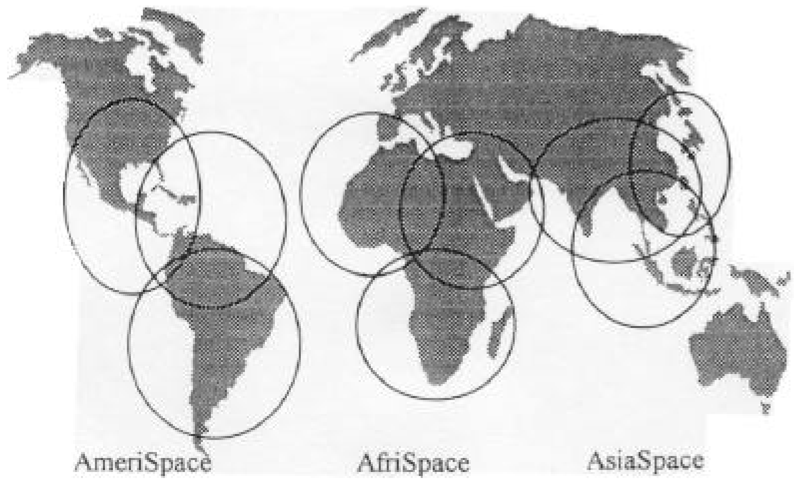
WorldSpace [22] is a commercial organisation based in Washington D.C. with world-wide interests. It is planning to launch in stages three geo-stationary satellites, named AfriStar, AsiaStar and AmeriStar. They will have L-Band payloads with on-board processing and each satellite will cover its designated target area with three “spot” beams. The aim is to provide digital radio services to audiences in the footprints of these satellites using partly proprietary technologies. As the names imply, the continental zones to be served by these satellites are Africa, Asia and Central and South America.

The primary aim of the original WorldSpace concept was to provide a simple radio service, but as the project has developed, there is now more emphasis on multimedia features involving data and image transmission.

The WorldSpace proposal is innovative and has a number of points in its favour. These include the size of the coverage areas in relation to the cost of the satellites, advanced low bit-rate audio coding and straight forward satellite up-linking arrangements. However, it is not best suited to cope with the difficult requirements of mobile reception and in some of the areas served, the satellites are seen at low elevation angles.

The approximate target regions for the transmissions from each satellite in the WorldSpace system are shown in Fig. 3.

Figure 3. WorldSpace Coverage Map (Transmission Footprints)

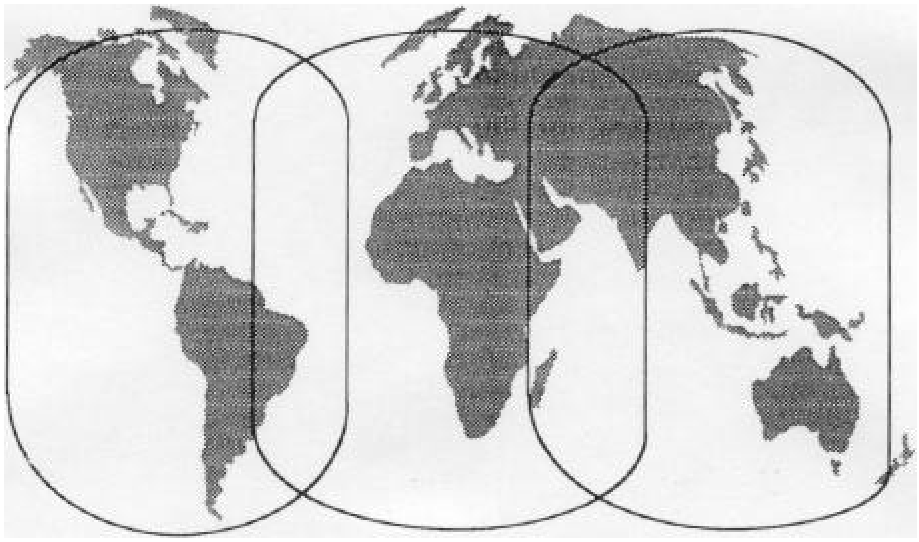


Depending on the audio quality required for each service, each beam on one of the satellites will be capable of carrying up to 96 x 16 kbit/s services. Audio coding developed by the Fraunhofer Institute (FHG) for the project is based on the MPEG Layer 3 algorithm with customisation to suit the WorldSpace project. The coding rate for each service is available in simple multiples of a basic 16 kbits/s channel, up to a maximum of 128 kbits/s. Subjectively, the system is said to offer audio quality standards :

Better than AM	16 kbits/s
Mono FM	32 kbits/s
Better than 'near stereo' CD	64 kbits/s
Stereo CD	128 kbits/s

Broadcasters using the service will be able to up-link their programmes from either centralised hubs or via individual feeder links located in any of the up-link footprints of the 3 satellites. Whilst this ease of access for broadcasters is a plus feature, the low power single channel up-link with its large footprint is vulnerable to jamming.

Figure 4. WorldSpace Up-link Coverage



AMERISPACE AFRISPACE ASIASPACE

Broadcasters using the WorldSpace system will have the choice of using a low power up-link local to the studio, or routing their service(s) to a remote, high power up-link site. This arrangement is possible by the use of Frequency Division Multiplex Access (FDMA) for the up-link.

When received at the satellite, the signals from the up-link stations will be 'assembled' by the on-board processors to form a broadcast multiplex. The arrangement will allow each of the three spot beams to downlink its own multiplex. In short, the on board processing simplifies the up-linking procedures.

The down-link for each beam uses Time Division Multiplex Access (TDMA) and the base-band processing on-board the satellite carries out the FDM to TDM conversion.

The WorldSpace organisation was founded in 1990, but its profile has risen significantly in the last two years, as a result of securing substantial funding for the project. This financial support has made it possible for WorldSpace to build and launch the satellites under contracts placed with Alcatel and other major companies. The start-up funding has given credibility to the project and has enabled WorldSpace to establish a substantial team of technical and professional people in Washington D.C. and elsewhere to manage the project.

For its transmission system, WorldSpace will be using a system it has developed itself (early in 1998, WorldSpace made some details of the system available to the ITU-R and the system is now designated ITU-R System D). The WorldSpace decision to use time division multiplexing (TDM) provides a greater link margin (the extent to which the clear sky carrier to noise ratio exceeds the threshold for reception level) than would be available with a COFDM system such as Eureka 147. A greater link margin can be used to serve a larger coverage area, but cannot overcome the problem of blockage, which is a fundamental problem for all satellite systems.

The WorldSpace transmission system maximises the output power of its satellites and enables the receiver design to be simpler, but it is not well suited to mobile reception.

Receivers for the WorldSpace system are referred to in more detail in a later section of this Guide (see Section 10). Agreements reached in June 1996 with SGS-Thomson and ITT Intermetall to produce a very large number of silicon chipsets marked an important milestone in the development of receivers for this project. By implication, the r.f. specification for the system had at that stage been completed.

An announcement about the manufacturers of the WorldSpace Starman receivers was made in June 1997. The named manufacturers were :

Hitachi

JVC

Panasonic

Sanyo

With financial backing already secured, few would doubt that the WorldSpace satellites will be launched (the first, AfriStar, is scheduled for 1998) and the earth station control and monitoring infrastructure will be completed. Whether it will become a commercial success is another matter and much will depend on the take-up by the broadcasters and the price and performance of the receivers. In particular, the performance of car receivers in an urban environment is likely to be an important factor. In Spring 1998, WorldSpace projected initial receiver costs to be 200 – 250 US dollars, with lower prices subsequently.

There are also security issues to consider. The subject is dealt with in Section 10 and is important for any broadcaster using the system. Selective blocking of an up-link contribution to the multiplex and deliberate jamming by a third party are potential concerns.

7.1 (c) MediaStar

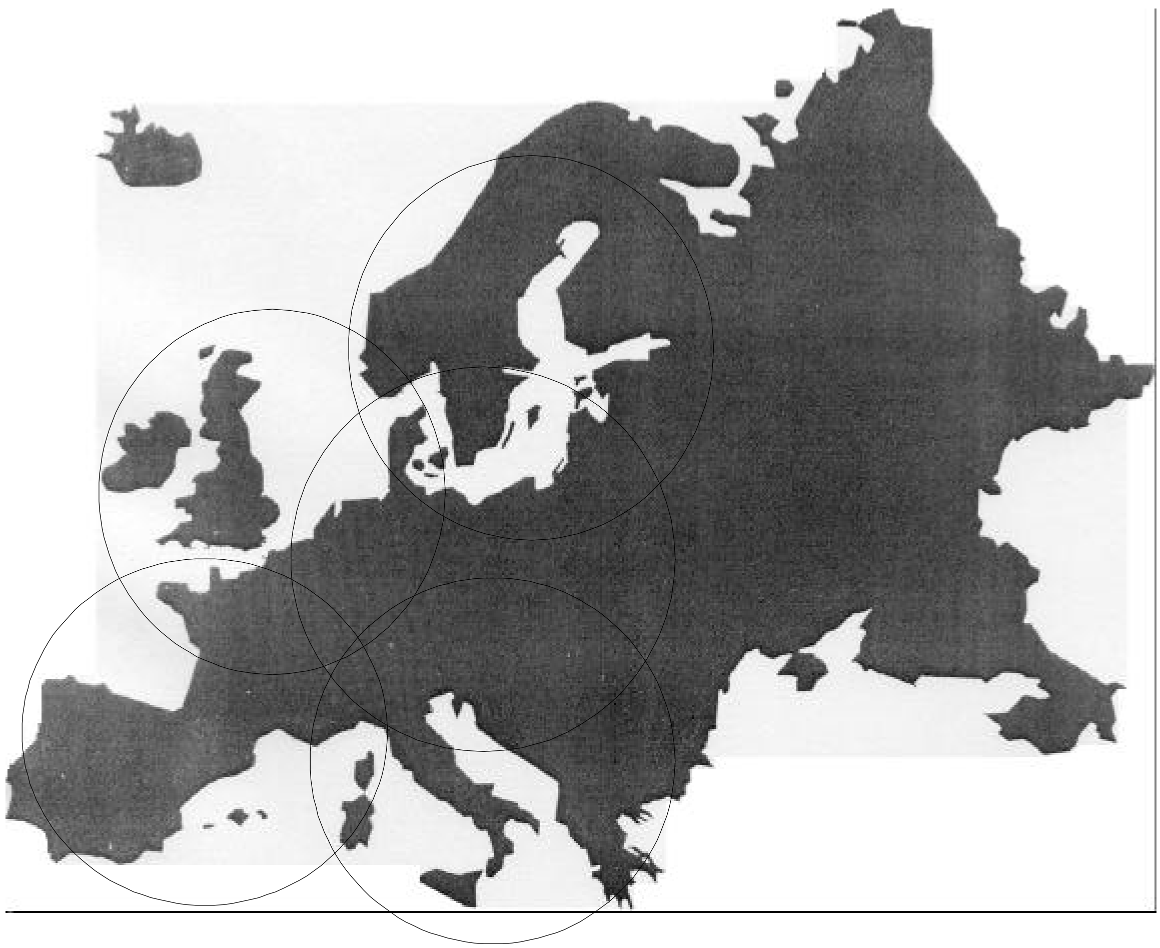
One proposal that has been based on using the Eureka 147 system in compatible S-DAB form, MediaStar, [23] was designed to transmit radio and other services from satellites located in highly inclined elliptical orbits (HEO's). This means that for countries in high latitudes, angles of incidence of greater than 45 degrees could be achieved. This compares with less than 25 degrees for a geo-stationary satellite. The northern hemisphere is seen as a primary coverage target and Mediastar was conceived to complement and extend the coverage achieved with terrestrial Eureka 147 transmitters.

The full MediaStar system envisaged ultimately a constellation of six satellites of which, at any one time, three would be in the sector of their orbits (the active arc) when transmission can take place. Each satellite would be capable of providing five spot beams or four spot beams and one wide beam (for pan-European coverage).

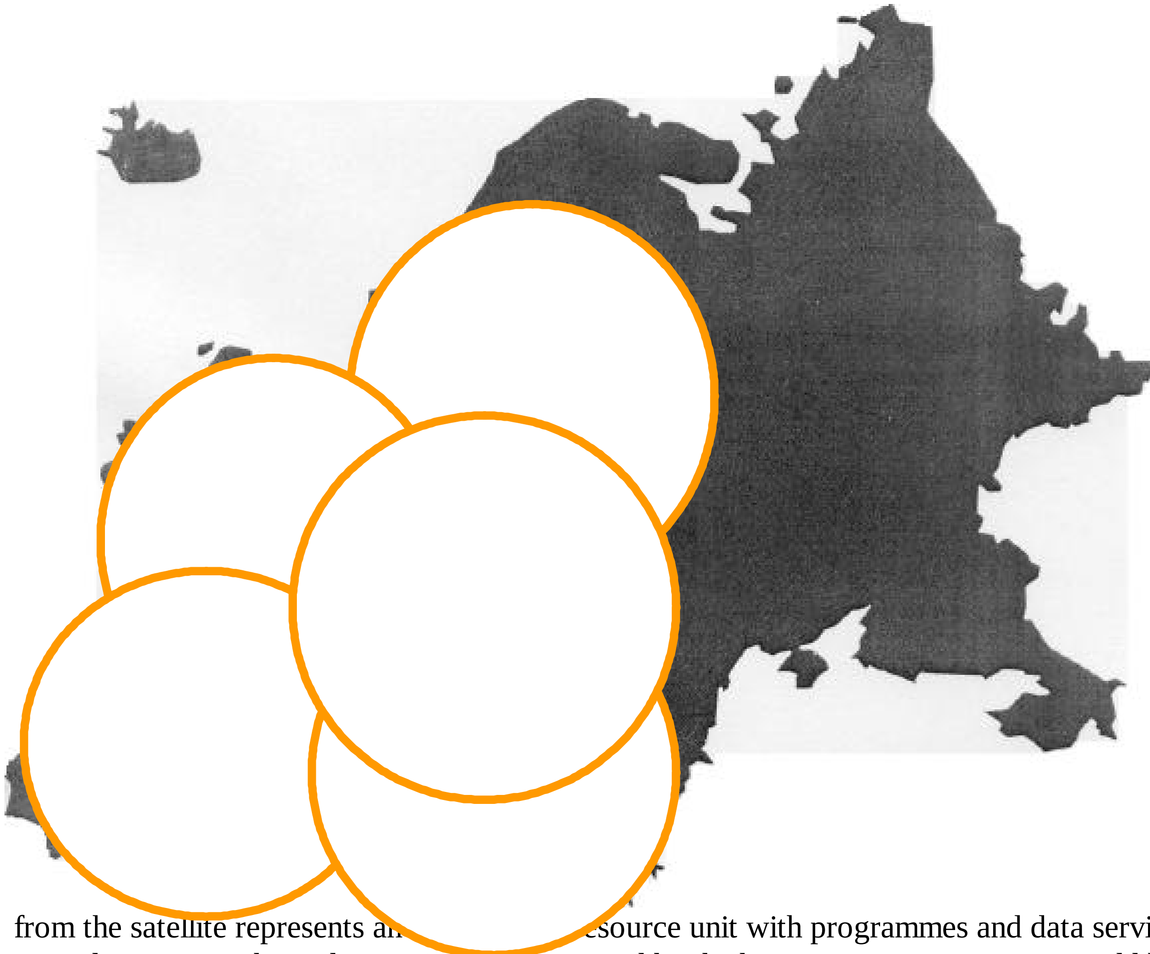
With this arrangement, the potential service capacity at any one point in the coverage area is for two DAB multiplexes carrying twenty 'CD quality' (196 Kb/s) services plus fourteen multiplexes broadcast from terrestrial transmitters.

A European coverage example is shown in Fig.5.

Figure 5. Mediastar : European Coverage (5 Beam Example)



A feature of the Mediastar concept is the ‘Electronic Multi-media Kiosk’ (EMK). Each spot beam



from the satellite represents a[illegible]esource unit with programmes and data services of special interest to the audiences in the area served by the beam. Incoming services would be received by the EMK via lines or data networks and the kiosk would serve as the up-link station where the DAB multiplex can be dynamically assembled for transmission to the satellite.

To ensure continuous services to the target regions, each satellite is required to carry the transmission for four hours and provide seamless hand-over from one satellite to the next. Electronic beam steering using a phased array antenna is necessary to ensure that after each hand-over the coverage remains unchanged.

The MediaStar concept could provide additional broadcast and data services that are likely to appeal to an audience distributed over a large service area. Also, it could offer special programming for different user groups. However, to date it has not been possible to develop a business plan for the project that can deliver a rate of return to support the development.

Nevertheless, the Eureka 147 system (on which MediaStar is based) allows a flexible approach to complementary T-DAB and S-DAB services and two development scenarios are possible:

Create a stand-alone S-DAB satellite system with terrestrial gap-fillers as necessary to ensure urban coverage, or

Start with terrestrial DAB services and then develop limited single frequency networks (SFN’s) in densely populated areas; with satellite delivery added later to provide regional or countrywide coverage.

The Eureka 147 DAB standard takes account of the varying propagation requirements in terrestrial and satellite channels by modifying the coding and framing parameters for optimum performance in the different frequency bands (Modes I, II and III). However, special receivers are not needed for satellite reception, since user terminals for the different propagation channels are already under development for the car radio market. Only the antenna characteristics will be different for terrestrial and satellite reception and for mobile reception a combined antenna would be the best solution.

This unique receiver option is an advantage with Eureka 147, as it is not expected that S-DAB will remove the need for T-DAB transmissions. Satellite power and channel limitations in L-Band and the blocking problems with satellite signals are seen as problems which will take a long time, if ever, to resolve.

Satellite implementation of the Eureka 147 system using HEO or GEO satellites is still some way in the future. Successful over-air tests and demonstrations of Eureka 147 at L-Band have taken place using GEO satellites and helicopter simulations. These have confirmed that the system works well over a satellite channel.

Recent work [24] has shown that by using synchronised earth stations broadcasters will not need to access a single ground station from which to assemble and transmit the DAB multiplex. The proposed solution is to use distributed but synchronised ground stations to deliver on-air multiplexing. This is particularly important for international broadcasters for whom sharing a multiplex involves first combining individual contributions from locations that are widely dispersed geographically. This new approach has been tested via satellite and found to be very robust.

7.1 (d) Jet Propulsion Laboratory /Voice of America (VOA / JPL) – ITU-R System B

The JPL /VOA ITU-R System B was conceived originally as a flexible, power and spectrum efficient system for broadcasting digital audio and ancillary data to fixed, portable and mobile receivers via satellite or terrestrial transmitters. It is a single channel per carrier system capable of operating over a wide range of data rates. A service provider using the system can match and optimise the transmitter power and bandwidth needed for a given service quality. Programmes can be multiplexed on separate carriers by frequency division (FDM), or on one carrier by time division (TDM).

The objective for the first phase of the VOA / JPL development was to provide industry with a proven digital transmitter and receiver design for use in the L and S Bands via satellite. This then could be used to develop a receiver for the consumer electronics market.

As part of the development, a series of performance and propagation tests were carried out and included:

Satellite field trials (using the TDRS 3 satellite)

Laboratory tests with simulated on-channel and adjacent channel interference.

System B has technical similarities to the WorldSpace system, but so far lacks the commercial backing that has given momentum to the WorldSpace project. The System B signal is convolutionally encoded and then time interleaved. It uses QPSK modulation and achieves bandwidth efficiency by pulse shaping.

Improved receiver performance in difficult reception environments is achieved by:

Optimising the channel decoding rate to counteract fading.

Closely spaced antenna diversity (2 antennas on the same receiver)

Receiver equaliser: to select the strongest signal when reflected signals are present. (This can be effective, but adds complexity and cost to the receiver)

Subsequently, ITU-R System B has been proposed in modified form for terrestrial ‘narrow-band’ digital broadcasting as mentioned in Section 6 (b).

7.1 (e) Satellite CD Radio Inc. and American Mobile Radio Corporation (AMRC)

There are two organisations preparing to operate multi-channel digital radio services across the continental U.S. via satellite, where satellite digital audio radio services (SDARS) are seen as a means of providing subscription services to a niche market. Satellite CD Radio and AMRC, succeeded in obtaining the two licences that were issued in April 1997.

Later, the Federal Communications Commission, the regulator in the U.S. Administration, set out the “service rules” to which the satellite DARS operators will have to conform. These include the following:

<u>Frequencies</u>: based on the understanding that 12.5 MHz in S-Band is needed for a viable S-DAB service, the Commission has divided the available 25 MHz of spectrum into two equal blocks, enabling each operator to provide 19 to 44 high quality audio channels.

<u>Construction Timetable and Licence Terms</u>: the Commission will require licensees to launch satellites within four years and be fully operational within six years. The licence terms will cover eight years of subsequent operation.

<u>Terrestrial Repeaters</u>: - this is still a grey area and the Commission is likely to seek further comment before ruling. One issue that has already been agreed to by both the Commission and the service providers, however, is that local origination of programming material from terrestrial repeater sites will not be permitted – the repeaters will only be allowed to re-distribute signals which emanate from the satellites themselves. It seems likely that any terrestrial repeaters will be restricted to operate within the frequency bands allocated to each service.

After the Federal Communications Commission announced details of the ‘service rules’, the licensed groups released some technical details of their proposed systems.

The systems have two important features in common. The first is that both propose using spatial diversity by placing geo-stationary satellites at the east and west sides of continental U.S. The satellites will simultaneously transmit the same information with the aim of minimising the effect of signal blockage and multi-path fading on receivers. The second common feature is that both intend to use terrestrial repeaters to reduce reception blockage in urban areas where continuous direct line-of-sight is not possible.

Satellite CD Radio intends to use spread spectrum Code Division Multiplex Access (CDMA) modulation and a less complicated concept for terrestrial repeaters than its competitor. SCDR proposal to receive and then re-transmit the satellite signal within the 12.5 MHz S-DARS allocation. Nearly thirty ‘CD quality’ channels will be available.

Satellite CD Radio expects to be operating by the end of 1999, and has four satellites under construction at the present time (6/98) – three designated for in-orbit use, and one ground spare.

AMRC proposes to use TDM/QPSK modulation and each of the two satellites for this system will be configured to transmit two carriers having 2.5 MHz bandwidth. Each carrier ‘pair’ will contain the programme material for 24 channels of ‘CD quality’. The remaining 2.5 MHz will be used for the terrestrial repeater channels, which therefore will be able to rebroadcast only half the channels carried on the satellites.

The AMRC approach has many technical similarities to the WorldSpace system including the ability to support satellite on-board processing. The Satellite CD Radio proposal supports only a ‘bent pipe’ satellite transponder arrangement.

7.2 Frequency allocations (Broadcast Satellite Services – Sound)

Frequency allocations for BSS (Sound) were agreed at the 1992 World Administrative Radio Conference (WARC). These were the first allocations made specifically for the reception of radio broadcasts direct from satellites. The allocations made at the conference are summarised in Table 9.

Table 9. Frequency Allocations for Digital Satellite Broadcasting (DSB)

L-Band	**S-Band**	
1452 – 1492 MHz (40 MHz)	2310 – 2360 MHz (50 MHz)	2535 – 2655 MHz (120 MHz)
Allocated world-wide except for: U.S. Mexico (see note next column) Not available until 2007 at least in: Belarus Russia Ukraine In 31 countries, the use of this band is on a secondary basis until 2007.	Allocated to: U.S. India Mexico (Note: at WARC ’97 Mexico changed its allocation from L-band to S-band at 2310-2360 MHz)	Allocated to: China Japan India Russia Plus 8 others, mainly in Asia.

The allocations were made subject to Resolution 528 (WARC ’92), which called for the convening of an ITU conference (preferably no later than 1998) to plan the bands allocated to BSS (Sound). Until such a conference takes place, broadcasting satellite systems may only be introduced within the upper 25 MHz of each band subject to a co-ordination process being followed. During this period, terrestrial services may also be introduced, subject to co-ordination with administrations whose services may be affected.

In the event of the Planning Conference required by Resolution 528 taking place, the 40 MHz allocated at L-Band is expected to be well short of the potential demand from administrations.

BSS (Sound) is specifically excluded from the Radio Regulations used to co-ordinate and notify fixed satellite services (C-Band and Ku Band). If, despite Resolution 528 of WRC ’92, no plan exists, the co-ordination procedure of Resolution 33 of the Radio Regulations must be applied. This is necessary to protect existing installations in space and co-primary terrestrial services (that is services with equal rights). Although for the three allocated BSS (Sound) Bands allocated at WARC ’92, no power flux density (PFD) limits were placed on emissions from BSS (Sound) satellites, existing terrestrial services do have protection under Resolution 33. This states that agreement must be obtained from administrations whose terrestrial services would be affected.

Resolution 528 also calls on the ITU (and specifically Study Group ITU-R) to review the criteria for BSS sharing. Potentially, BSS (S) services could interfere with existing co-primary services such as mobile aeronautical telemetry services (MATS) and unfortunately WARC ’92 failed to specify that existing services would eventually have to move to other bands.

Based on the very low protection requirements claimed for MATS, ITU-R meetings have concluded that BSS (S) fixed and mobile services cannot share the same frequency band. To date, this problem is unresolved.

If satellite radio broadcasting is to become a reality, administrations must make spectrum available where BSS (S) services have priority.

7.3 Coverage

It is not difficult to determine the coverage area of a satellite service when providing a signal to a fixed receiver with a receive antenna positioned for line-of-sight reception. Provided that the link margin is positive for the required Bit Error Rate (BER), satisfactory reception will be obtained under these conditions. With a higher link budget and hence greater margin, the satellite beam can be wider and a greater coverage area will be served.

In the systems described in Section 7.1, the WorldSpace satellites have relatively high power amplifiers and use a single carrier QPSK modulation system. Each satellite can provide coverage across a large geographic area. Alternatively, the greater link margin available with this arrangement could be used to provide a stronger signal over a smaller area, enabling listeners to receive the broadcasts and data services using simpler low gain (less directional) antennas.

For example, coverage from the proposed MediaStar configuration could provide a service to about one third of the area covered by each WorldSpace satellite for a comparable link margin.

The difference in margin between the WorldSpace and MediaStar systems mainly reflects the use by WorldSpace of single channel QPSK modulation against the COFDM modulation used in Mediastar.

For a global coverage, these proposals seem to be complementary. When fully operational, WorldSpace will have three satellites in geo-stationary orbits to cover South and Central America, Africa and the Far East, whilst MediaStar proposes a six satellite constellation to cover northern latitudes. However, in practice the systems are incompatible and there could be areas of potential overlap and inevitably, accidental ‘spill-over’.

In this section, the comments so far have considered coverage only in relation to fixed receivers. Other considerations arise if coverage is defined in terms of areas in which a satisfactory service is also available to mobile and portable receivers. All satellite systems will suffer from dropouts when line-of-sight reception is lost and this is most likely to happen in densely populated urban and city environments. A high elevation angle will reduce the problem, but not eliminate it. And it cannot be assumed that, even in equatorial zones, the geo-stationary satellites have a high elevation angle. If a geo-stationary satellite is not in the optimum orbital slot for a given receiver location, quite low elevation angles can be experienced.

The solution to the problem of blockage is terrestrial gap-fillers, not link margin improvement, and local re-broadcasting using these gap-fillers will be needed to maintain coverage with any satellite system.

For WorldSpace, these will need to operate at different frequencies from those used for the direct satellite signal. Because the MediaStar system is designed using COFDM modulation, co-channel repeaters could be used, which can receive the satellite signal and then re-transmit it on the same frequency.

In the example of the U.S. systems, Satellite CD Radio and AMRC, the spatial diversity achieved with two geo-stationary satellites will reduce, but not eliminate, the problem of blockage. For these systems, technical details of proposed solutions to the gap filling problem in urban areas are not yet available.

7.4 Costs

For broadcasters investing in the delivery of digital radio services via satellite, there are important strategic and financial implications. There are potential long-term benefits from this form of transmission, but there are risks.

The costs associated with setting up a new digital satellite service are:

The cost of up-linking (capital or revenue).

Space segment costs for the required capacity (leasing or purchase).

Investment to set up new services.

The cost of simulcasting (medium and long term).

Finally, to offset this expenditure, there is the potential for generating revenue streams.

With the exception of WorldSpace, the organisations proposing to offer broadcasters L-Band or S-Band satellite capacity for digital radio have not reached the implementation stage, but are still undertaking development or are working on business cases for investment capital.

As services become available, broadcasters in the front line for channels will benefit from incentive discounts in some form, but stand the highest risk if listeners are not attracted in sufficient numbers to buy into the new satellite services, purchase receivers and pay subscriptions.

In this section, the costs to the broadcasters are indicative only and are based on figures that have been mentioned in open forums.

7.4 (a) Up-linking

The capital cost of an up-linking facility at a broadcaster’s originating studio is expected to be about $150,000 US.

7.4 (b) Space Segment

The space segment cost is a charge to the broadcaster that mainly reflects the initial investment by the satellite service provider.

To build and launch a single geo-stationary satellite, the cost is around 400 million US dollars and the satellite can be expected to have a service life of about 12 years. With high-risk projects of this type, the rate of return on the investment is likely to be in excess of 30 %. On this basis, the annual leasing cost of a single 16 kbits/s 24 hour channel could be expected to be in the region of 500,000 US dollars, if the capacity of the satellite is (say) about three hundred 16 kbit/s channels.

To suit different broadcasters and to reflect time-of-day variable rates, the satellite service provider is likely to offer a range of tariffs with options for different time slots and bit rates. Peak time short term leasing can be expected to be at very much higher rates.

7.4 (c) Investment in New Services

Broadcasters are aware that first and foremost listeners respond to programme content. Digital technology can enhance and help to develop services, but will not on its own build and retain substantial audiences. Broadcasters must use the technology for new and innovative services.

7.4 (d) The Cost of Simulcasting

For an existing terrestrial broadcaster planning to start satellite transmissions, there is no alternative to simulcasting for a significant period. This overlap gives time for the new receiver base to build and for existing listeners to migrate to the new medium.

The cost of simulcasting has two components, the space segment and up-link charges. The major expense is the space segment charge and the annual leasing cost for (say) a 24 hour per day 64 kbps regional channel could be around 2 million US dollars.

There are ways of reducing these costs, although some loss in the availability or quality of services will result. For the terrestrial transmitters carrying existing services, the options are reduced power working and (for short-wave broadcasters to reducing the number of frequencies used to try to guarantee effective propagation. Both measures represent modest savings in marginal costs and will only partially contribute to the satellite ground and space segment charges.

Satellite costs are to a first approximation proportional to the capacity reserved and another way of reducing the simulcasting cost is to begin satellite operations at a very low bit-rate, say 16 kbps. The downside of this arrangement is risk that listeners will experience a service quality that is less than they had been led to expect.

7.4 (e) Possible Revenue Streams

In many countries, public service broadcasters are faced with a shrinking income from public funds and are having to find ways of boosting their income from licence fees or government grants. There is no standard funding formula and countries operate very different regulatory regimes. As a result, the scope for generating supplementary income streams will be greatly influenced by the local regulatory environment.

Experience with media launches has shown that improved technical quality helps to establish a new service, but it is no guarantee of success. Even the improvement in quality that would result from a change from AM short-wave to digital satellite delivery is unlikely to break this pattern and may not be enough to ensure a successful take-up.

To encourage listeners to invest in new receivers, one driver needs to be new services - new radio programmes and data services independent of the programme services. In this way, listeners can see a clear differentiation between existing and new services. Broadcasters moving into terrestrial digital audio transmission have been developing complementary data services. Examples are general news, sports news and business reports, accessed by web browsing software. Satellite digital broadcasting will likely adopt a similar strategy.

In summary, there is potential for generating a useful income stream on the back of satellite digital radio service, but it should not be undertaken without first thoroughly researching:

The regulatory position on data services.

The market for data services.

7.5 The Systems Compared

Table 10. Satellite Digital Radio Systems – Comparison Table

Part 1 - General

Features	**WorldSpace**	**Mediastar**	**Satellite CD Radio**	**AMRC**
Satellite orbit	3 x GEO	3 x HEO	2 x GEO	2 x GEO
Satellite position		63^0 Inclination	80^0 W & 110^0W	85^0 W & 115^0 W
Coverage	Africa, Asia and the Americas	Europe	N. America (U.S.)	N. America (U.S.)
Project funding **- Secured ?** **- Source ?**	 Yes Unknown	 No -	 Yes Private & public	 Yes Private
Satellite launch date ?	Oct. '98 (AfriStar)	No	Late 1999	2000
Status of tests and trials ?	Helicopter simulation	Helicopter simulation plus satellite	-	-
Receivers available ? **- prototype** **- consumer**	 Yes Expected Dec.'98	 Yes No date	 ? 	 ?
Terrestrial repeaters necessary ?	Yes	Yes	Yes	Yes
Up-link vulnerable to jamming ?	Yes	To a limited degree	To a limited degree	To a limited degree
Service available to receivers that are : **- static** **- portable** **- mobile**	 Yes Yes (outside) Unlikely	 Yes Yes (outside) Yes	 Yes Yes Yes	 Yes Yes Yes
Cost per 24 hr. / 16kbps /channel / annum	Probably negotiable, but likely to be about $500k US	Unknown	Unknown	Unknown

Table 10. (cont.)

Part 2 - Technical

Features	WorldSpace	Mediastar	Satellite CD Radio	AMRC
Satellite on-board processing	Yes	No	No	No
Transmission system standard	ITU-R System D Proprietary [1]	ITU-R System A (Eureka 147)	Proprietary	ITU-R System D (modified) Proprietary
Audio coding **System** **Bit rate**	Modified MPEG 2 Layer 3 (“MPEG 2.5”)	MPEG Layer 2	MPEG 2.5 128 kbps	? 128 kbps
Compatibility with T-DAB	No	Yes	Yes	No
Channels available	288 per satellite (at 16 kbps)	100 for the system (at 64 kbps)	30 (at 128 kbps)	24 (at 128 kbps)
Modulation system	TDM / QPSK	COFDM	CDMA (spread spectrum)	TDM / QPSK
Diversity scheme	Frequency/spatial	Time/frequency	Time / spatial	Frequency/ spatial
Up-link frequency	X Band	?	7060/7062.5 MHz	7025/7075 MHz
Down-link frequency	L-Band	L-Band	S-Band 2320-2332.5 MHz	S-Band 2332.5-2345 MHz

[1] Information submitted to ITU-R in early 1998.

7.6 Timescales

Broadcasters thinking about becoming ‘early adopters’ of satellite delivered digital radio services have limited options. The only system discussed above that does not have orders for satellites as of June 1998 is the MediaStar system.

The projected service dates for the satellite DAB systems in this Guide and intended for reaching home, car and portable receivers are listed in Table 11. Satellite systems such as Astra Digital Radio are not included as they can only be received by fixed installations or via cable.

Table 11. Satellite Systems – Projected Service Dates

WorldSpace	
AfriStar	1998
AsiaStar	1999
AmeriStar	1999
MediaStar	(not set)
Europe	
American Mobile Radio Corporation (AMRC)	
U.S.	Before 2001
Satellite CD Radio	
U.S.	End 1999

8 Other Transmission Systems (Video and Audio)

Other system proposals have been made that include audio broadcasting, but are essentially broad-based technology. The two examples frequently mentioned are the European Digital Video Broadcasting system (DVB) and the Japanese Band Segmented OFDM / Integrated Services Digital Broadcasting (ISDB).

These systems have been conceived primarily for video and data applications, but for completeness are described briefly in this guide.

8.1 Digital Video Broadcasting System (DVB)

As the name implies, DVB is essentially a system whose main objective is the transmission of digital television. Formats have been developed for satellite, terrestrial and cable delivery, which are interoperable to the maximum extent.

Bringing together transmitter and receiver manufacturers and broadcasters into one DVB project, the objective was to produce compatible DVB specifications for satellite, cable and terrestrial transmission. Of these three requirements, the problems of terrestrial delivery (severe multi-path and a wide range of signal strengths) are the most difficult to resolve.

The solution to the DVB-T problem was seen to be the adoption of OFDM modulation, but without time interleaving as is used in many T-DAB systems. The DVB-T specification was issued in 1996 and subsequently submitted for approval as an ETSI standard. DVB-T can to some extent serve mobile receivers provided a large overhead for forward error correction is used.

Although not designed for the radio market, some believe that DVB-T could be a competitor for Eureka 147 if the introduction of DAB receivers is much delayed. Those who suggest that digital radio services could use DVB-T commercially make the case on the grounds that the DVB-T market is potentially much larger than the DAB market and this is the key to lower receiver prices. Also, although DVB-T was not designed for mobile reception, tests by Deutsche Telekom and others have shown that DVB-T, under certain conditions, could provide mobile reception.

Those who disagree with this idea have pointed out that the power consumption of a DVB-T receiver may be higher than that of a DAB receiver and also the synchronisation circuit in DVB-T is more complex and potentially expensive.

In its development cycle, DVB-T is about two years behind Eureka 147 T-DAB. It will remain a possible competitor to Eureka 147 until DAB services are established and a large receiver base is built up, although the consumer electronics industry and EBU do not see these as substitute technologies.

8.2 Integrated Services digital broadcasting (ISDB)

In Japan, NHK has proposed an integrated broadcasting system, which can be used for terrestrial, satellite and cable applications. The development is known as Integrated Services Digital Broadcasting (ISDB). The system has been designed to carry video, sound and a wide range of data in one broadcasting channel and ISDB will use standards common to computer and telecommunications networks.

For the terrestrial application (T-ISDB), it is proposed to adopt a transmission scheme that uses band segmentation with orthogonal frequency division multiplexing (BST-OFDM).

For T-ISDB to be successful, it has to deliver high quality sound, video and multi-media services and for the radio market will need to be capable of :

- Coping with fading and multi-path interference to meet the needs of users with portable and mobile receivers.
- Maintaining compatibility with existing analogue services.
- Operating in single frequency networks (SFN’s).

In the T-ISDB system, a segmented OFDM approach (BST-OFDM) is used, resulting in a channel made up of frequency blocks (BST segments) which have a common structure which provides for flexibility and expandability. The transmission bandwidth is 432 kHz or multiples of this.

For reception on fixed receivers, theoretical studies have been carried out to show the performance of single frequency networks (SFN’s) where the T-ISDB transmitters are assumed to be located at existing transmitter sites. This study has determined the relationship between coverage and guard interval in the design of a SFN.

In the case of mobile reception, NHK has carried out laboratory tests and field trials using two transmitters to form a single frequency network. The results established the pattern of Bit Error Rate (BER) performance along a route between the two transmitters. It showed how the coverage was extended by the use of a SFN and further trials are planned with a SFN using three transmitters.

The ISDB system has been approved as an experimental Digital Terrestrial Broadcasting System (DTTB) in Japan where the Ministry of Post and Telecommunications (MPT) is expected to carry out full trials in 1998.

9 Regulatory Policy and Standards

As the use of the radio spectrum for an increasingly wide range of broadcasting and other services continues to grow, effective control of its usage is essential. Without such regulation, harmful interference to legitimate users would become widespread. And because radio propagation does not stop at national or geographical boundaries, the regulatory rules need to be applied at an international level.

Digital technology is at the foundation for the process of convergence between broadcasting, communications and information technology industries. All these industrial sectors are actively involved with developments that cross the traditional boundaries and link what have in the past been separate markets. Two examples that relate to broadcasting are data services distributed via digital broadcasting platforms and Internet radio. These developments have far reaching implications and the changes are global and not constrained by national or regional borders.

The work of the ITU is changing in the new environment created by the converging technologies, but it retains an important role. In radio communications, the task is to develop and approve recommendations for radio system specifications, spectrum management and satellite orbit utilisation - and all of these are inter-related.

9.1 Radio System Standards

As the world-wide communications industry has become more lightly regulated, how important are radio system standards? Although their value may not be as obvious as the radio regulations, some very tangible benefits are obtained if broadcasting system standards are adopted. Some examples are:

Interconnectivity and information transfer is possible by using defined interfaces and protocols in system components.

Service providers and broadcasters gain from the economies of scale through reduced purchase, installation, training and maintenance costs.

Greater operational flexibility can be achieved, because equipment and interfaces can operate across different broadcasting systems.

The downside of working to common system standards is the time, expertise and effort needed to obtain agreement at an international level to the system concept definition, functionality and performance. Also, standards sometimes have the effect of “locking in” what can, in a relatively short time, become an obsolete technology.

The main beneficiaries of system standards are the end users. In the case of radio, this means the broadcasters and listeners. They both benefit from being able to purchase equipment that is cheaper because of economies of scale, although some developing countries with no indigenous consumer electronics industry have to rely on imports to meet demand.

A weakness identified in some procedures for setting system standards is that full system interoperability may not be achieved because system components are standardised individually. An example of a revised working method that avoided this problem was the ISO / IEC MPEG ‘standard’. By defining a set of recommended tools for a variety of systems for different applications, but insisting on one tool for one application, MPEG was able to produce a successful result.

System standards fall into five distinct categories: -

International Standards - normally world-wide standards as designated by the ITU.

Regional standards - (approved by bodies such as the joint EBU/ETSI/CENELEC Technical Committee in Europe).

National Standards – (such as the North American ANSI Standards Institute)

De-facto Standards – where industry standards are adopted internationally.

Proprietary Standards – where the system or component specifications may not be disclosed since they are protected by international patents.

9.2 Radio spectrum management and satellite orbit utilisation

The benefits of having standards relating to spectrum management are most evident in the fields of frequency co-ordination and international frequency management. The ITU recommendations on radio system standards have a direct impact on spectrum management through parameters such as inter-service sharing, spurious emissions and generally on the efficient utilisation of the spectrum.

If mutually incompatible standards emerge, this could seriously limit the scope for market access, lead to the proliferation of different standards and restrict competition where proprietary standards become dominant.

The ITU continues to be the international intergovernmental forum where world-wide broadcasting standards are agreed and set. It was at the WARC in 1992 that the search for common world-wide frequency bands for satellites and terrestrial sound broadcasting resulted in the L-Band and S-Band allocations referred to in Section 7.

9.3 Recent progress on the Eureka 147 Standard

During 1997, two new agreements involving international standards for Eureka 147 were established.

First, broadcasters, transmission operators, consumer electronics manufacturers and regulatory bodies agreed on common frequency rasters in the v.h.f. and L-Bands. The agreement allows the use of both CEPT and Canadian frequency rasters globally, allowing for a greater economy of scale, and making DAB receivers easier to tune.

The second agreement came when the Eureka 147 Project agreed the Multimedia Object Transfer (MOT) specification for DAB. MOT will allow DAB to carry, for example, Internet pages reliably to portable and home receivers. This specification will be further developed as MOT Part 2 to enable DAB data channels to cope with the future demands. MOT Part 2 will employ the carousel principle to allow data streams designed for digital video to be carried also via DAB.

9.4 Recent progress on In-band DAB Standards

Standards-setting efforts for in-band digital radio systems—the AM and FM IBOC systems under development in the U.S., as well as the SW, MW, and LW digital AM systems discussed above—are in various stages of progress. As mentioned above (in Section 6.2b), two groups are actively involved in promoting the introduction of digital AM as a unified standard. They are:

- Narrow-band Digital Broadcasting (NADIB) – a European Eureka group (EU 1559); and

- Digital Radio Mondiale (DRM) – a world-wide consortium of broadcasters and manufacturers.[2]

In March of 1998, DRM was officially launched at its inaugural meeting held in Guangzhou, China, with the participation and sponsorship of the following organisations:

- Academy of Broadcasting Sciences, China
- Asia Pacific Broadcasting Union (ABU), Asia
- BBC World Service, U.K.
- Continental Electronics Corporation, U.S.
- Deutsche Telekom AG, Germany
- Deutsche Welle, Germany
- European Broadcasting Union (EBU), Geneva
- Fraunhofer-Gesellschaft , Germany
- Harris Corporation, U.S.
- International Broadcasting Bureau, U.S.
- Merlin Communications International, U.K.
- Nozema, The Netherlands
- Radio France Internationale, France
- Radio Nederland Wereldomroep, The Netherlands
- Retevision, Spain
- Sangean Electronics Inc, U.S.
- Sony International (Europe)
- Technology for Communications International, U.S.
- Telediffusion de France, France
- Tecsun General, China
- Telefunken Sendertechnik GmbH, Germany
- Thomcast SA, France

Developers of IBOC systems in the U.S. fully expect that IBOC digital audio systems will ultimately be recognised as ITU recommended approaches, and have been participating in the activities of ITU Working Parties 10A (Sound broadcasting at frequencies below 30 MHz) and 10B (Terrestrial sound broadcasting at frequencies above 30 MHz), where such recommendations will be formed. USADR, in particular, has recently been very active in these groups, and at the March 1998 international meetings made a number of technically detailed submissions which are laying the foundation for ITU recommendations in the areas of AM and FM IBOC digital radio.

Within the U.S., the Federal Communications Commission has indicated that they expect to receive petitions for rulemaking from IBOC proponents during 1998, which will begin the process of modifying the existing rules for AM and FM radio services to accommodate IBOC digital audio systems.

10 Receivers

Although they are the crucial link at the end of the chain from broadcasters to listeners, receivers seldom appear to be given the attention that they warrant. This is surprising because receiver production is by any standards a large volume industry. The fact that the market is large and competitive should encourage manufacturers and ensure that the designs are right. In the case of digital radios, with added features and services, the ergonomics of the man machine interface are very important.

The key questions about receivers are:

Are they available?

Are they user-friendly?

How much do they cost?

How well do they work? (Do they receive ‘all bands’?)

How much power do they consume? (a prime concern for portable receivers where battery consumption is a major consideration)

It is often said that the problem of introducing completely new systems, such as digital radio, is the perennial ‘chicken and egg’ – with broadcasters reluctant to invest and introduce new services in the absence of receivers in the market and vice versa. Whilst this clearly is true, it oversimplifies the problem by separating the broadcasters from the receiver manufacturers and it ignores the listeners!

Affordable receivers and new services are crucial to the success of digital radio and this section focuses on these aspects. It summarises the state of receiver development for both the terrestrial and satellite systems that have been described.

10.1 Terrestrial Digital Radio

10.1 (a) Eureka 147 T-DAB

The 1997 Internationale Funkaustellung in Berlin was a landmark event for DAB. It was the showcase for some fifteen manufacturers to display the first consumer-type digital radios that are expected to appear on the retailers’ shelves during 1998.

The receivers were demonstrated using live broadcasts and data services provided over-air from Germany and other European countries. (Extensive T-DAB pilot broadcasts and trials have been operating in various European countries for the past two years).

At this phase of the development of DAB, the manufacturers of receivers are concentrating on the mobile (car) market for a number of reasons:

Eureka 147 was designed specifically to achieve solid interference free mobile reception.

The power consumption of the first generation consumer market receivers is not a problem for mobile (in car) applications.

There is a large market for ‘original fit’ radios.

Car radios are ideal products for incorporating traffic messaging, DAM / FM linking and other special features in ‘top of the range’ radios.

The first generation of radios for the consumer market also includes hi-fi units that incorporate DAB tuners in addition to the normal am/fm tuners. And the PC has not been overlooked, with two manufacturers showing plug-in DAB receiver boards.

The scaling down of the size of DAB receivers from the early prototypes has been dramatic and is continuing with radios now available to fit into the standard car- mounting frame.

Although portable DAB receivers are not yet available, they are expected to appear on the market within about two years. The power consumption of the fully integrated DAB chips available now is approximately 2 watts, which is considered to be too high for portable receiver. But within the projected time-scale for the design manufacture of portable DAB receivers, the power requirement will be reduced by LSI (Large Scale Integration) technology.

An important contribution to the development of future DAB receivers is the WorldDAB Human Interface Project (HuMIDAB), which is looking into the ergonomic and user / radio interface problems. It is addressing the problems that arise for users because of the great number of options and services that are available with DAB.

It is crucial that DAB is not made too complex for users. In an interesting move, the BBC has sponsored the development of a DAB receiver with only two buttons; ‘on/off’ and ‘next station’.

10.1 (b) AM and FM IBOC Radio Systems

IBOC receivers are inherently simpler and lower cost than new-band receivers such as those used with the Eureka 147 system since much of the circuitry required for the digital signals is common to that used to process the existing analogue signals. The DRE receiver board shown above (in Figure 2) was demonstrated at the 1998 NAB Convention in Las Vegas, NV, and is being reduced to a single IC by DRE's semiconductor manufacturing partner, TriTech Semiconductor. When this development is complete, the DRE FM IBOC receiver is expected to be only slightly more expensive than an existing FM receiver.

USADR is also paying close attention to the receiver design aspect of their digital radio system. Their prototype receivers, currently under construction, will realise a very high degree of integration between the AM and FM sections, due to the judicious selection of such system parameters as IF frequencies and digital sampling rates. Also, the USADR receivers will implement the baseband processing functions for traditional analogue AM and FM signals (also available in an IBOC system) digitally, resulting in near-optimum performance.

10.2 Satellite Digital Radio Receivers

10.2 (a) WorldSpace

For a satellite broadcasting service to be successful, it is crucial for receivers to be in the market place when the service is launched. WorldSpace has tried to meet this requirement by first ensuring that a large number of chip-sets will be available to the receiver manufacturers.

Two suppliers, SGS-Thomson and ITT Intermetall, have each been contracted to manufacture at least one million chip-sets that will provide receiver manufacturers with two sources of supply. Four receiver manufacturers (Hitachi, JVC, Panasonic and Sanyo) are expected to be making sets, and the initial price of an audio receiver is likely to be about $200 - 250 US. (- as announced at Africa Telecom in May 1998).

The Fraunhofer Institute (FHG) has been responsible for the audio coding and receiver development for WorldSpace and has used helicopter-based tests to simulate satellite transmissions. FHG developed a prototype test receiver for the trials. The four manufacturers will develop prototype commercial receivers and production units.

The stated intention of WorldSpace is to have receivers in the retail market at the time of the October launch of the first satellite (AfriStar). The range of receivers and retail prices will become clear at that stage.

10.2 (b) Eureka 147 S-DAB

The development of T-DAB receivers is well advanced, but the manufacturers will be reluctant to commit resources to build S-DAB capable versions until Mediastar or another Eureka 147 based proposal emerges as a fully funded satellite project.

The adoption of the Eureka 147 system for a satellite application may happen after the terrestrial T-DAB transmissions are well established. One of the main benefits this series development brings is that a large number of receivers purchased for T-DAB and using the same modulation system would be in use by the time that S-DAB is implemented. It makes the case for adopting the same modulation scheme for the satellite and terrestrial applications of Eureka 147. This is despite the problem that COFDM modulation is not optimum for satellite broadcasting and results in a 6 to 7dB lower link margin.

A straight forward up-grade path can be achieved by designing a T-SDAB receiver that can be used to receive both T-DAB and S-DAB signals, simply by adding components external to the basic receiver – such as the antenna sub-assembly. Discussions in the WorldDAB technical groups led to a proposal that L-Band S-DAB reception should be achieved via one connector. This would allow r.f. to pass from the antenna to the receiver and carry d.c. plus i.f. a.g.c. signalling back to the S-DAB r.f. front end. However, a more limited interface arrangement was accepted, in which only the r.f. and d.c. phantom power to feed the antenna L.N.A. are available at the interface.

11 Risks

Any broadcaster preparing to switch from analogue to digital transmission has to make a careful assessment of the risks involved in the move. This applies to both terrestrial and satellite transmission, although the risks are not necessarily the same.

11.1 Terrestrial Transmission

Most of the risk factors with terrestrial digital radio stem from doubts about the viability of the proposed systems (performance, availability etc.) and uncertainties about the prevailing business and regulatory environment.

In the case of Eureka 147, there is clear evidence from extensive tests, trials and pilots to reassure potential users that the T-DAB technology works well as a radio transmission system. T-DAB also has to be successful in business terms; enabling broadcasters and transmission service providers to derive a useful return on the capital investment. Its capability to deliver data services must be exploited when outstanding regulatory and business issues are resolved.

The regulatory environment in different countries is not the same, but the UK example is useful to illustrate some of the problems. Many radio broadcasters believe that simply replicating existing FM and AM services on DAB will not on its own justify the investment. They hope to make early use of the data handling capability, which includes such features as world-wide web pages, financial data and car navigation systems. This is referred to as independent data (ID) to distinguish it from programme associated data (PAD). The latter is a stream of data contained within the standard DAB audio channel that can be extracted in the receiver and displayed as text. And there are differing views about whether PAD capacity could sensibly be sold and used for non-DAB applications.

Currently, these boundary lines have not been set firmly in position, as broadcasters and regulators feel their way into new territory.

Another area of uncertainty that may now have been resolved relates to channel capacity and data services; the issue of how data will be carried over DAB. The debate centres on whether the standard to be adopted should be based on the MOT (Multimedia Object Transfer) stream standard or a Data Carousel.

For the U.S. development, clearly an IBOC digital system is inherently less risky than a new-band system, due to the more straightforward and lower-cost implementation, and the superior way in which the new and old services are integrated together. The main risk factor at this point is in whether the next generation systems described above can outperform the 1st generation systems sufficiently so as to be a viable service.

For the short-wave and medium wave developments, the risks are less well defined, because these systems are in an early stage of development, although in this case it should be remembered that the proposals are aimed at a different radio audience and face a different form of competition.

Table 12. Terrestrial Digital Radio: Risk Factors

System	**Eureka -147**	**FM / AM** **IBOC**	**SW /MW:** **Skywave 2000** **T2M (TF)** **System B (JPL/VOA)**
Adopted or proposed as a standard?	Yes – recommended by the ITU as System A	To be proposed as a world-wide standard; could also become a de facto standard	To be proposed as a world-wide standard
Receivers available? - Fixed - Mobile - Portable	Yes – hi-fi and car radios in consumer market prototype form from 15 mfgs. *	Prototype form (DRE, USADR)	Only as experimental versions for system development
Development stage reached?	Extensive pilot projects and service trials.	Prototype testing planned for 1998	Systems have been tested
Subjective audio performance:	Near CD quality	Near CD quality (FM) FM or better (AM)	MF groundwave equivalent
Data capacity	Substantial data capacity within the dynamic multiplex	Substantial (FM) Limited (AM)	Limited
Availability of frequencies / channels ? (L-Band and v.h.f.)	Allocations exist but proving insufficient for needs	Uses existing FM and AM allocations	Uses existing h.f. channels
Transmitter hardware ?	Available from several manufacturers.	Prototype testing underway	Existing equipment will need some modification.
Simulcasting	Not in the same band	Depends upon system	Intended

*‘Software’ receiver available late 1998.

11.2 Satellite Transmission

Coverage using terrestrial transmission can be expanded progressively, but satellite delivery cannot be started incrementally. It requires substantial initial investment by the broadcaster or service provider to launch a satellite equipped with the necessary transponder capacity and power.

On existing satellites, L-Band transponder capacity is very limited and became a major constraint when tests were carried out on operational satellites as part of the Eureka 147 and WorldSpace development programmes. Even when L-Band transponder capacity was made available, there were severe power and time constraints.

The risks now for broadcasters thinking about using satellite transmission for direct to home digital radio are significantly higher than for those moving into terrestrial digital transmission.

Table 13 summarises the risk issues:

Table 13. Risk Issues for Direct Broadcast Satellite Digital Radio

	System			
Issues	**WorldSpace (Africa, Asia, Latin America)**	**MediaStar (Europe)**	**Satellite CD Radio (U.S.)**	**AMRC (U.S.)**
System status as a world standard?	Considered by ITU-R as System D. Currently under consideration by administrations.	ITU System A – recommended as a world standard for satellite and terrestrial DAB	Proprietary	Similar to ITU-R System D
Receivers available?	1999	T-DAB prototype receivers available for L-Band – with modified front end.	1999	2000
Stage of development?	First satellite launch in October '98	Tested but no firm plans for implementation	Being implemented	Being implemented
Technical / System	TDM/QPSK	COFDM	CDMA (Spread spectrum)	TDM/QPSK (AMRC is more complicated than SCDR)
Availability of frequencies / channels?	L-Band – subject to co-ordination.	L-band – subject to co-ordination.	Licensed for 12.5 MHz band	Licensed for 12.5 MHz band
Satellite capacity?	96 x 16 kbps channels / beam. 3 beams per satellite.	Satellite not yet designed	30 x 128 kbps channels	24 x 128 kbps channels
Terrestrial repeaters ?	Yes	Yes	Yes	Yes
Up-linking requirements	Multiple uplinks possible	Multiple uplinking possible with on-air multiplexing	Uplink from broadcast/control centre	Uplink from broadcast/control centre

12 Digital Radio and the Internet

Based on a recent survey in the one European state, it has been projected that the number of homes with access to the Internet and on-line services will total 7.5 million by 2002. This is three times the number expected to be equipped to receive digital television by the same date and is just one indication of the success and market penetration of the Internet.

In the light of such evidence, it is not surprising that public service broadcasters as well as commercial stations are looking to develop into the 'third medium' (television, radio and now the Internet). The scale of the interest in this new medium is illustrated by the presence now of over 600 European radio stations of which nearly 50% offer audio content on their web sites. Some broadcasters are very active and have established web sites that are attracting the interest of a large and increasing number of Internet users. One public service broadcaster, the BBC, has already produced one of Europe's largest web sites with a content that is 70% linked to existing television and radio programming with the remaining 30% uniquely web material. The second most popular Web site in Europe is operated by the German broadcaster, ZDF.

The BBC's venture into this branch of multi-media was only started in 1997, but is already achieving around 4.3 million page views per month for its 'News Online' service. For international audiences, BBC World Service in English is now available in audio on-line via Audionet, a US based Internet broadcaster. Improvements in audio compression have made these services possible and in much better quality than can be delivered via short-wave.

World-wide, the potential audience for Internet broadcasters is currently around 50 million. The audio capabilities of the Internet are being exploited by organisations such as the U.S. based Progressive Networks, which uses data compression to deliver audio in mono of acceptable quality via a 28.8 baud rate modem. It is the combination of improved data compression and faster modems that has made real time audio on the Internet such a viable development.

An attraction for end users is that access to such services is free. The software needed to decode the audio stream is made available to be down loaded at no cost. This policy encourages growth in the user community and helps companies such as Real Audio to sell server software that is needed by the broadcasters at a price of around $3,000 US. The Real Audio encoder compresses digital audio files in common formats such as Windows WAV and Macintosh AIFF and then converts them to a real audio format. That format can then be played with the Real Audio Player software. The most recent audio encoder uses techniques from Dolby compression systems.

Amongst other Internet broadcast services, the World-wide Broadcasting Network offers interactive news training and communications programming using audio and limited quality video.

As well as providing established broadcasters that use the Internet with an extension to their conventionally transmitted services, a few commercial broadcasters are attempting to operate Internet only services. By aiming at niche markets these 'broadcasters' hope to achieve satisfactory returns on their investments exclusively through the Internet 'channel'. It is not clear whether any have yet moved into profit.

The position on copyright for Internet broadcasters is under discussion in many countries and to date there is no general consensus. In the U.S., Broadcast Music Inc. (BMI) and the American Society of Composers and licence holders are set up to issue licences for 'desktop' broadcasting.

The picture world-wide is that existing regulatory frameworks cannot deal with the consequences of radio programme distribution via the Internet. In many countries, the legal status of material on the Internet is unclear and in the absence of a legal framework, some radio regulatory organisations have acted unilaterally. Undoubtedly, the radio regulations will need to be changed for the new era of multi-media and this issue has already become a problem in the case of DAB in which the non-audio data transmissions may be regulated differently from digital radio.

13 Finance

The interest in terrestrial digital broadcasting as an investment opportunity is mainly amongst the industry professionals. The investments made to date have been by the broadcasters, transmission service providers and receiver manufacturers in the consumer electronics market.

Market research has confirmed that the listeners are showing a high degree of interest in the prospect of improved of existing services and the arrival of new services. This research supports the view that digital radio will be a satisfactory medium to long-term investment, with the return on capital invested being realised over a timeframe of five to ten years.

In Europe, the investment in Eureka 147 T-DAB has been led by the national broadcasters. These public service broadcasters have committed a substantial amount of research effort into developing innovative audio and data services that use the new technology.

Eureka 147 is particularly well suited to a public broadcaster's remit, because of the obligation to provide full national coverage. The feature that helps to meet this requirement is the Single Frequency Network (SFN). Commercial broadcasters are expected to form consortia to bid for frequencies and the operation of the commercial multiplexes.

Investment in development of IBOC digital radio in the U.S. has been led by commercial interests, most notably broadcasters, semiconductor manufacturers and companies with strong telecommunications background and interests.

The investment potential of digital television has been thoroughly researched, but the opportunities of digital radio have not been so widely acknowledged. The financial returns from investing in digital radio will come in part from value-added services and also the increasing number of listeners with multimedia computers for whom Internet access could be much faster.

Investment decisions have to be taken against a range of information inputs. Market research has confirmed that annual sales figure for radios is some three times that for television. The research has shown that, in one example (the U.K.) some 85 % of the population listen to radio for 20 hours per week. This points to a healthy environment in which to launch improved and new services.

Whichever system is adopted for digital transmission, all broadcasters, public service or commercial, face the same problem, funding the investment. Possible sources of finance are:

13.1 Private Equity Capital (Development capital or venture capital)

The providers in this area are normally seeking a return on investment in 3 to 5 years. The funding is generally structured as a combination of ordinary shares, that aim to give investors capital growth, plus an income based element such as preference shares. For this type of investment, the internal rates of return needed would be around 30%, making this an expensive form of capital.

13.2 Increased Public Funding

In the present economic and political climate, there are few public service radio broadcasters that can have serious expectations of substantially increased funding. More usually, budgets are being squeezed and many broadcasters are seeing parts of their operation being privatised.

In one case (the UK), the proceeds from the sale to the private sector of the BBC's transmission services are, by agreement with the government, being used to fund the move into digital technology. However, this option may not be available elsewhere.

13.3 Meeting the cost of "New Media" activities

As interest has grown in using the Internet, public service broadcasters may be faced with some criticism. They risk being accused of using their public service income to support and subsidise the new media activities. Such activities could be regarded as counter to rules designed to ensure fair competition.

14 Possible Pilot Projects

Tests and trials are not pilot projects, but are carried out by specialist research and development staff to prove new systems. Pilot projects are designed to give staff who will later become responsible for the operation and maintenance of full scale digital transmission systems, the opportunity to train and gain experience on small scale pilot installations.

Pilot projects can only be started for systems that have already passed through their main development and testing phase and when hardware is available to at least pre-production standards. And for small broadcasters, where funds for the initial purchase can be a serious problem, it is important to identify and minimise the costs.

14.1 Terrestrial Digital Radio Pilot

Eureka 147 is presently the only terrestrial digital radio system for which a full range of equipment can be purchased. Other developments, such as the AM and FM IBOC systems, are presently at the test and trial stage, and pilot projects are not expected for another 6-12 months (from June 1998).

The important questions to be considered for planning a pilot study are:

Where to site the transmitter? (to provide the planned the service coverage)

How to organise the studio to transmitter feed?

How to find space in the allocated radio spectrum for a DAB multiplex in an appropriate allocation at FM or in the L-Band?

Where to obtain test receivers that are essential for reception monitoring?

How to arrange for the staff involved with the project to be given appropriate training?

<u>Where to site the transmitter</u> ?

Whether the requirement is for a pilot study or a full service, broadcasters need to establish the station design parameters (including the location of transmitting antennas, effective radiated powers and radiation patterns) together with plots for the coverage areas and interference analysis.

Major broadcasters have the research resources in the form of computer programmes and survey and measurement equipment. With terrain data available, such facilities can be used for studies world-wide and broadcasters without such an in-house resource can obtain the service on a consultancy basis.

15 Training

Training objectives and practices in broadcasting have changed very significantly in recent years and the needs of the digital era have influenced many training developments.

Training for programme operations and maintenance is no longer aimed purely at reinforcing the technical skills of engineering staff. The multi-skilling approach that is now essential for today's business and technical environment has changed the well segregated task and skill structures that traditionally existed in the industry.

The change is reflected in training establishments. They are now centres for developing broadcasting skills. Today, the ability to use the technology is tied in closely to other broadcasting skills. When converting from analogue to digital equipment, the system changes are characterised by:

Greater inherent complexity, but improved reliability.

Hybrid audio, where an analogue production area has been part converted to digital.

A wide variety of storage media (DAT, Mini Disk, MOD, CD Rom, Hard Disk, Digital Cart Machine)

Digital contribution circuits and transmission networks.

Networked (LAN and server based) audio or multi-function systems.

With greatly improved equipment reliability, the focus of the maintenance activities has moved from hardware fault diagnostics and repair to system set-up and housekeeping. For the digital broadcasting age, computer engineers need to be given audio training and audio engineers need knowledge of computers and networking.

To cover the full range of operation and maintenance skills needed to support a digital production facility, the training subjects must include:

The support and maintenance of transmission equipment and systems such as dynamic multiplexes.

Host system management including:

Installation of new software releases

Archiving

Back-up equipment and routines

Equipment repair through board replacement

The use of diagnostics to trace faults to module or board level.

With the increasing availability of local up-linking for satellite programme distribution, there is a need for training staff in the skills needed to operate and maintain up-link and receiver equipment. This type of equipment is used extensively for satellite newsgathering (SNG) and outside broadcasts (OBs).

On a broader front, there is a need for multi-media training covering all aspects from the basic technology to the use of the Internet and World Wide Web for both research and broadcasting.

Fault diagnosis in digital audio formats is quite different from analogue systems and staff need to learn how to resolve problems using appropriate equipment and techniques. Today, test sets are available to help find and correct problems on digital audio equipment. One example is digital audio test sets for the AES/EBU digital format. Such sets are important tools for testing and troubleshooting.

The importance of training is widely recognised by broadcasters and manufacturers often include it as part of the initial purchase package. Many manufacturers also provide workshop sessions and other events where the equipment and trainers travel to major broadcasting events.

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Appendix A

The Eureka 147 System

Overview

The Eureka DAB System has been designed to ensure rugged and reliable reception by listeners using fixed, portable or mobile receivers with non-directional antennas. The system is spectrum and power efficient (equivalent or better than FM radio) and can be operated at any frequency up to 3 GHz for mobile reception and at higher frequencies for fixed reception. It is suitable for use on terrestrial, satellite, hybrid (satellite with complementary terrestrial) and cable networks. It currently uses the following audio compression techniques, MPEG 1 Audio Layer 2 and MPEG 2 Audio Layer 2 and supports a range of audio coding rates. It has a flexible digital multiplex, which can support a range of source and channel coding options. This includes programme associated data (PAD) services and independent data services (IDS).

Eureka 147 is currently the only digital audio system that has met all the requirements of the ITU for a new digital sound broadcasting system. It is designated 'Digital System A' and has the status of a world-wide standard (ITU-R Recommendations BS 1114 and BO 1130 for terrestrial and satellite sound broadcasting respectively). It is an open standard, fully specified within the European Telecommunications Standards Institute (ETSI), in ETS 300 401.

The system provides strong error protection in the transmitted signal. The information transmitted is spread in both the frequency and time domains and the effects of channel distortions and fades are eliminated from the recovered signal in the receiver. This is achieved even when the receiver is in a location with severe multipath propagation, whether stationary or mobile.

Efficient utilisation of the spectrum is achieved by interleaving multiple programme signals and by the system's ability to operate additional transmitters as gap fillers in a single frequency network (SFN). A gap-filling transmitter in this arrangement receives and re-transmits the Eureka 147 signal on the same frequency.

Major System Features

The Eureka 147 signal carries a multiplex of several digital services simultaneously. The system bandwidth is 1.536 MHz with a total transport bit-rate capacity of 2.4 Mbps in the complete multiplex or 'ensemble' and a useful bit-rate of about 1.5 Mbps. Depending on the broadcaster's requirements in terms of coverage and reception quality, the amount of error protection is adjustable independently, with a coding overhead ranging from 33% to 300% (25% to 200% for audio).

The ensemble contains audio programmes, programme related data and other data services. Normally the receiver will decode several of these services in parallel. Part of the multiplex carries information about how the multiplex is configured to enable the receiver to decode the signal correctly.

The main features of the system are summarised in Table A1 below.

Table A1.

Eureka 147 – Principle Features

Feature	**Function**
Flexible audio bit-rate	8 kbps to 384 kbps
Data services	As a separately defined stream or packet structure.
Programme Associated Data (PAD)	Embedded in the audio bit stream. Adjustable from 667 bps minimum at the expense of bit-rate available for the coded audio service.
Conditional Access (CA)	Applies to each individual service, or packet (in the case of packet –mode data). Does not include subscriber management.
Service Information	Utility for establishing links to services in other DAB ensembles, for the operation and control of receivers and to give the listener information on programme Selection.

Outline of the Eureka 147 System

Generating the Signal

Figure 1 in the main text of this Digital Radio Guide is a block diagram showing in outline the concept of a DAB signal generator and a Eureka 147 network.

Each service signal is coded at source level, then error protected and time interleaved in the service multiplexer. The services are then brought together and multiplexed in the Main Service Channel (MSC) to a pre-determined, but adjustable multiplex configuration. The multiplexer output is combined with the multiplex control and service information, which is transported in the Fast Information Channel (FIC) to form the transmission frames in the transmission multiplex.

The output from the transmission multiplexer is then processed using Orthogonal Frequency Division Multiplexing (OFDM) as a last stage before the signal is ready to be transposed to the assigned frequency band and transmitted.

Receiving the Signal

Figure A1 below shows the receiver concept.

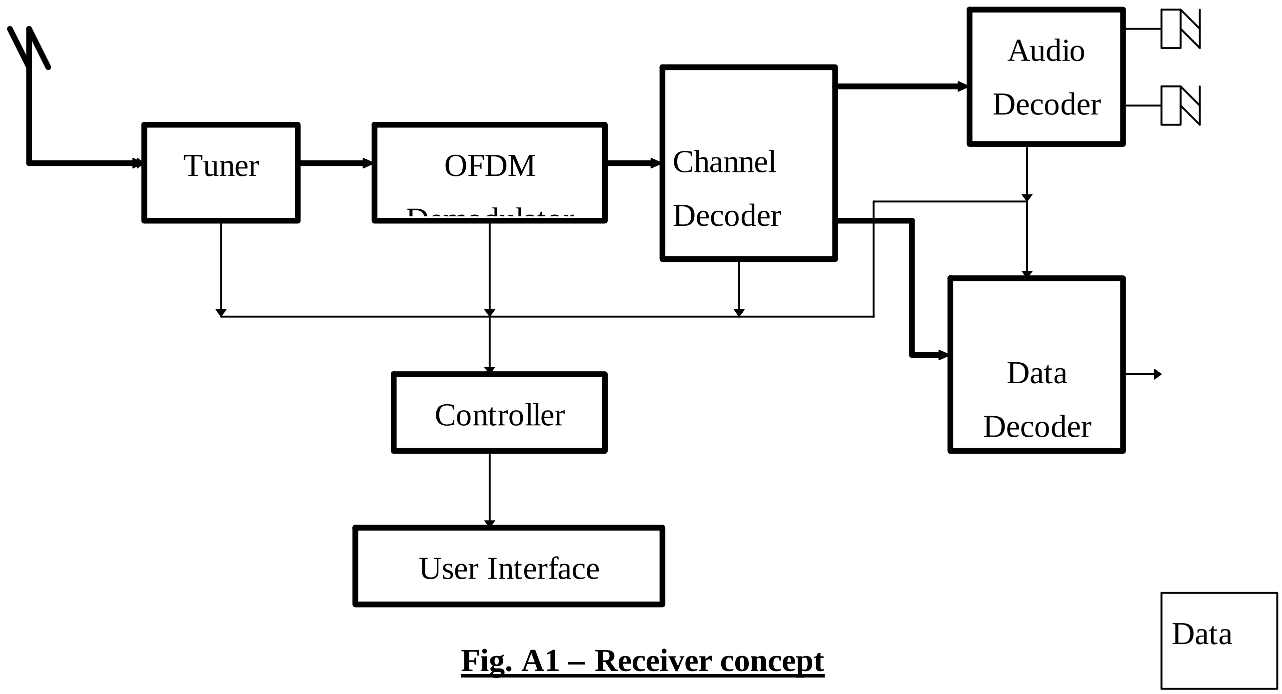


Fig. A1 – Receiver concept

In the analogue tuner the DAB ensemble is selected and the digitised output is fed to the OFDM demodulator and channel decoder, where transmission errors are eliminated. The information in the Fast Information Channel is passed to the user interface for service selection. The main service channel data is processed in the audio decoder or in a data decoder as appropriate.

Designing a Terrestrial Eureka 147 Network

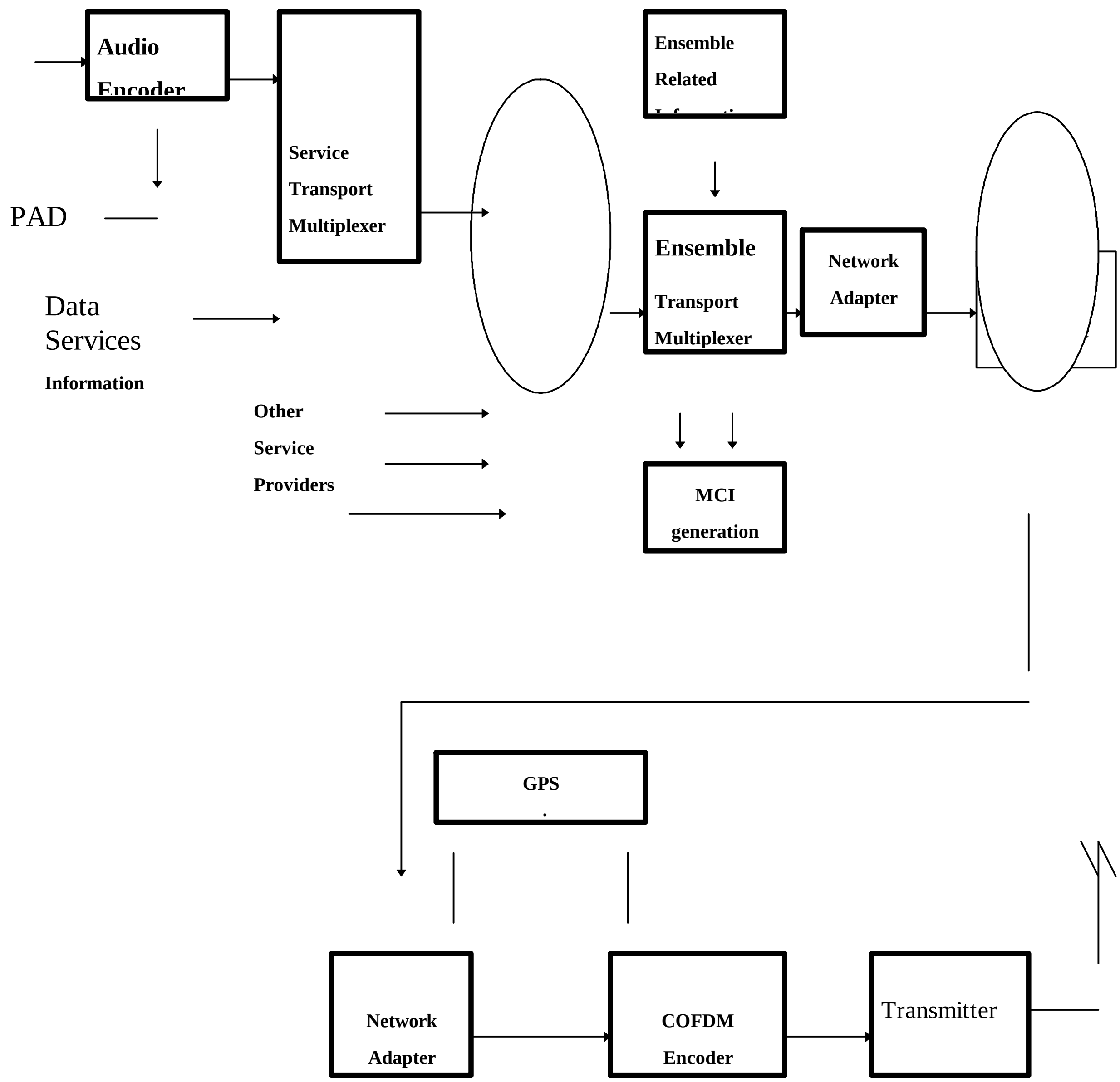
This section outlines one example of a distribution format developed for sending the DAB ensemble to transmitting stations. The arrangement is shown in block diagram form in Figure A2.

First, the audio signal and associated data from the production studio is encoded by the Service Provider. This data is then passed via a Service Transport Network to the Ensemble Provider and is then fed to the Ensemble Transport Multiplexer. The controller associated with this multiplexer can make scheduled reconfigurations (of the multiplex) to suit the requirements of the programme content in each part of the ensemble.

The Ensemble Provider manages the capacity of the complete ensemble based upon information obtained from the different Service Providers. The information is assembled as a set of data representing the complete ensemble.

Fig. A2

Terrestrial Eureka 147 Network



The output of the multiplexer is passed to the network adapter where timing information and error correction is added. At the same time, the framing structure is changed to a more rugged format which can then be used on a telecommunications network. As the signal is now 'network adapted', the precise method of distribution and the timings of the distribution network are unimportant.

At each transmitter site, the DAB signal is re-synchronised so that all the transmitters in the network are precisely ‘in phase’. This is essential to obtain the benefits of a single frequency network. In the example shown, synchronisation is achieved by associating the timing information on the incoming network adapted signal to a reference derived from a GPS receiver. The process is carried out by the network adapter.

From the network adapter, the DAB signal passes to the COFDM encoder which generates the QPSK modulated carriers to form the DAB signal to be transmitted.

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Appendix B

DAB Services and Networks : Coverage in February 1998

(Source : WorldDab Forum)

Country	Number of services	Population Coverage (%)	Population Coverage - millions
Australia	Tests	Non-applicable	
Belgium (Flandria)	6 plus data	70%	4.2
Canada	30	31%	8.9
China	7	n.a.	
Denmark	8 plus data	25%	1.3
Finland	5	20%	1.0
France	18 plus data	17%	10.0
Germany	120 plus data	37%	30.1
Hong Kong	Tests start August 1998		
Hungary	3	29%	3.0
India	Tests	n.a.	
Israel	?	70%	3.8
Italy	6	10%	5.7
Japan	Tests	n.a.	
Malaysia	Tests in 1998	n.a.	
Mexico	Tests	n.a.	
Netherlands	8 plus data	45%	6.7
Norway	5	35%	1.5
Poland	4	8%	3.1
Portugal	6 (from May 1998)		
Singapore	Tests in 1998	n.a.	
Slovenia	Tests	40%	0.5
South Africa	2	n.a.	
South Korea	n.a.	n.a.	
Spain	Tests	n.a.	
Sweden	11 plus data	65%	5.6
Switzerland	25 plus data	28%	2.0
United Kingdom	23 plus data	60%	34.0
United States	Tests	n.a.	
Totals	**287**		**121.4**

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Appendix C

List of DAB Transmission Equipment Manufacturers, System Suppliers and Service Providers.

Organisation	Country	Equipment / Service
Alan Dick	U.K.	Antennas, support structures, filters etc. for Band III.
Castle Tower	UK	DAB transmission services.
Deutsche Telecom	Germany	DAB transmission services.
Eddystone Radio	U.K.	Transmitters, multiplexers, network adapters, COFDM coders, Band III amplifiers.
Itelco	Italy	DAB transmitters.
I.T.I.S	France	Source encoders, multiplexers, COFDM encoders, SFN adapters etc.
Kathrein Werke KG	Germany	Antennas and associated equipment.
N.T.L.	U.K.	DAB transmission services.
Richard Hirschmann	Austria	Transmitter systems.
Rohde and Schwarz	Germany	Turnkey transmission systems and test equipment.
Sira Sistemi Radio	Italy	DAB L-Band antennas and components.

Appendix D

World Wide Web Addresses

Advanced Television Systems Committee (ATSC)	atsc.org
Asia-Pacific Broadcasting Union (ABU)	abu.org.my/abu
Audio Engineering Society (AES)	aes.org
BBC (DAB)	BBC.CO.UK/DAB
BBC (Research and Development)	bbc.co.uk/rd
BBC Training (Centre for Broadcasting Skills)	bbc.co.uk/woodnorton
BBC World Service	bbc.co.uk/worldservice
Castle transmission International	ctxi.com
Commonwealth Broadcasting Association (CBA)	oneworld.org/cba
Dalet	dalet.com
Digital Forum	dab.org
Digital Radio Mondiale (DRM)	drm.org
Digital Video Broadcasting (DVB)	dvb.org
European Broadcasting Union (EBU)	ebu.ch
Financial Times (Media and Telecoms.)	ftmedia.com
International Telecommunications Union	itu.ch
Lucent Technologies (Lucent Digital Radio)	lucent.com
National Association of Broadcasters (U.S.)	nab.org
National Transcommunications Ltd. (NTL)	ntl.co.uk
North American National Broadcasters Association (NANBA)	tvo.org/nanba
Radio Academy	radacad.demon.co.uk
Real Audio	real-audio.com
Roke Manor research	roke.co.uk
Sadie	sadie.com
Sony	sony.com
Thomcast	thomcast.thomson-csf.com
USA Digital Radio	usadr.com
World Broadcasting Unions (WBU)	tvo.org/nanba/wbu
World Radio Network	wrn.org
WorldDAB	worlddab.org
WorldSpace Corporation	worldspace.com
WorldSpace Foundation	worldspace.org
World-wide broadcasting network	wbnet.com

Appendix E

Glossary of Terms

ADR Astra Digital Radio

AM Amplitude Modulation

ATM Asynchronous Transfer mode.

BBC British Broadcasting Corporation

BER Bit Error Rate

Bit Binary digit

Bit Rate

Rate of flow of bits per second

BSS(S) Broadcast satellite services (Sound)

CA Conditional Access

CBC Canadian Broadcasting Corporation

CCETT

Centre Commun d'Etudes de Telediffusion et Telecommunication
(Research Laboratories of France Telecom and Telediffusion de France)

CD Compact Disc

CDMA Code Division Multiple Access

CEG Consumer Equipment Group

CEMA Consumer Electronics Manufacturers Association

CEPT European Conference of Postal and Telecommunications Administrations

CODEC Coder / Decoder

COFDM Coded Orthogonal frequency Division Multiplex

DAB Digital Audio Broadcasting

DARS Digital Audio Radio Service

DAT Digital Audio Tape

DAW Digital Audio Workstation

DQPSK

Differential Quadrature Phase Shift Keying

DRB Digital Radio Broadcasting

DSB Double Side Band

DSR Digital satellite Radio

DTH Direct to Home

DTT Digital Terrestrial Television

DVB Digital Video Broadcasting

EIA Electronic Industries Alliance (formerly Electronic Industries Association)

EMK Electronic Media Kiosk

ETI Ensemble Transport Interface

ETS European Telecommunications Standard

ETSI European Telecommunications Standards Institute

Eureka European R and D programme

FCC Federal communications Commission (U.S.)

FM Frequency Modulation

FDMA Frequency division multiple access

FHG Fraunhofer Institute (Germany)

FIC Fast Information channel

GSO Geo-stationary (satellite) orbit

GPS Global Positioning System

HEO Highly Elliptical Orbit

ITU International Telecommunications Union

ITU-R ITU Radiocommunications Sector

IBAC In-Band Adjacent Channel

IBOC In-Band / On-Channel

kbps 1000 bits per second

LW Long wave

LEO Low earth orbit (satellite)

MATS Mobile Aeronautical Telemetry Services

MD Mini Disc

MPEG Moving Pictures Expert Group

MOT Multi-media Object Transfer

MW Medium wave

NAB National Association of Broadcasters (U.S.)

NHK Nippon Hoso Kyokai (Japan Broadcasting Corporation)

NICAM 728

Near-Instantaneously Companded Audio Multiplex
(728 is the bit rate in kbps)

NRSC National Radio Systems Committee (an industry sponsored technical standard setting body, co-sponsored by CEMA and NAB in the U.S.)

PAD Programme Associated Data

PC card

A plug in card for a Personal Computer, which allows it to receive DAB.

PTY Programme Type Codes

QPSK Quadrature Phase Shift Keying

RDS Radio Data System

RDI Receiver data Interface

RF Radio Frequency

SFN Single Frequency Network

S-DAB Satellite DAB

SDARS

Satellite Digital Audio Radio Service

SI Service Information

SSB Single Side-Band

SW Short-wave

Simulcasting

Simultaneous transmission of a programme

T-DAB Terrestrial DAB

TCM Trellis coded Modulation

TDM Time Division Multiplex

TDMA Time Division Multiple Access

VHF Very high Frequency

W(A)RC

World (Administrative) Radio Conference

WorldDAB

Organisation for promoting digital radio (DAB) based on the Eureka 147 system.