Digital Radio Guide

World Broadcasting Unions

FOREWORD

The purpose of the Digital Radio Guide is to help engineers and managers in the radio broadcast community understand options for digital radio systems available in 2019. The guide covers systems used for transmission in different media, but not for programme production. The in-depth technical descriptions of the systems are available from the proponent organisations and their websites listed in the appendices. The choice of the appropriate system is the responsibility of the broadcaster or national regulator who should take into account the various technical, commercial and legal factors relevant to the application.

We are grateful to the many organisations and consortia whose systems and services are featured in the guide for providing the updates for this latest edition. In particular, our thanks go to the following organisations:

- European Broadcasting Union (EBU)
- North American Broadcasters Association (NABA)
- Digital Radio Mondiale (DRM)
- HD Radio
- WorldDAB Forum

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Introduction

Digital technology has steadily transformed the way in which programmes are made in the last twenty years. Broadcasters have invested in digital systems for contribution and production and for some, 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.

This guide 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 for radio broadcasters in adopting digital technology in radio broadcasting.

There is a significant difference in the analogue to digital transition for television and radio. The transition from analogue to digital television has usually been driven by a national plan for the transition, which has necessarily included the switching off of analogue television according to a prescribed timetable, though there are still nations continuing with analogue television. Analogue switch off for television has released radio spectrum that has provided considerable income for governments, as well as improving quality and choice for viewers. The financial gains for governments in switching off analogue radio would be considerably smaller. Only a few nations have developed national regulatory plans for the analogue to digital transition for radio.

Furthermore, there are countless millions of analogue radios in the public's hands, in the home and in vehicles, and switching off analogue radio could be unpopular and unfair on less economically advantaged users.

However, the eventual transition from analogue to digital for all communications systems including radio is inevitable and will happen in time. The decision for managers today is to find the best balance in timescale for the public interest for their environment.

The timescale for the analogue to digital transition for radio is not the only complex decision that needs to be made today. Unlike the situation for analogue radio, common worldwide standards for digital radio have not been possible in our more complex world. A number of different systems have emerged, each with their own environments and proponents. Broadcasters and regulators need to evaluate the alternative systems and decide which is the optimum system for their environment.

Digital radio can also be provided as part of a digital television multiplex. This option is not covered in this report.

This Digital Radio Guide focuses primarily on the various standalone digital radio systems in operation today and their associated standards. The guide considers not only terrestrially-based digital systems but also overviews the services now available via satellite radio.

This guide is a compilation of inputs provided by WBU members for the benefit of the world broadcasting community. Note that references to relevant worldwide websites and a glossary of acronyms are provided in Appendices C and D at the end of this guide.

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. FM reception on car radios and portables can be 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 improved coverage and availability.

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 development of digital radio 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 digital radio system should be capable of being transmitted via terrestrial, satellite and cable systems.

The digital radio systems in operation are listed in Table 2.1.

The 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. But in the development of digital systems, it is now clear that similar standardisation will not 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.

Table 2.1: Digital Radio Systems

	AVAILABILITY	
SYSTEM	**Terrestrial in service date**	**Satellite in service date**
DAB - Digital Audio Broadcasting ETSI EN 300 401 ITU-R Rec. BS.1114 Digital System A	1995 (UK, Norway, Denmark and Sweden)	---
DRM - Digital Radio Mondiale ETSI ES 201 980 ITU-R Rec. BS. 1514 (below 30 MHz) ITU-R Rec. BS. 1114 Digital System G (above 30 MHz))	2003 (international HF)	---
HD Radio (iBiquity Digital taken over by DTS, which was then bought by Xperi) (FCC Docket 99-325, NRSC-5 Standard) in the HF and MF Bands ITU-R Rec. BS. 1514 (MF band) ITU-R Rec. BS. 1114 Digital System C (FM band)	2007 (USA)	---
SiriusXM Satellite Radio	---	2001 (North America)
ISDB-TSB (Integrated Services Digital Broadcasting - Terrestrial Sound Broadcasting) (ITU-R Rec. BS. 1114 Digital System F)	---	---

Notes:

--- Not applicable

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. AM 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 1950s 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 scarcer. 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 CD 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 an AM/FM radio.
- The data capability of digital radio can be used directly or combined with activities such as Internet radio.

Terrestrial Transmission Systems

This chapter provides a technical overview of the various digital radio systems available for terrestrial application: DAB, DRM, ISDB-TSB, and HD Radio. These systems operate in various frequency bands and offer different attributes and features.

4.1 DAB/DAB+/DMB

The DAB/DAB+/DMB family of standards is the most globally widespread digital radio broadcasting platform, offering radio broadcasters significant cost advantages and offering regulators considerable spectrum efficiencies over analogue and other digital systems.

It was developed under the Eureka 147 project in Europe for reception by mobile, portable and fixed receivers with a simple non directional antenna, and can be used in terrestrial, broadcast networks.

It was originally planned for implementation in two spectrum bands: VHF Band III and L Band, although the use of L Band has now been deprecated.

The DAB family of standards includes DAB, DAB+ and T-DMB and is collectively referred to here as DAB, although DAB+ is the variant which is currently being deployed globally for the delivery of digital radio. Further technical details can be found in Appendix A: The DAB/DAB+ System Description.

4.1.1 System Development

The Eureka 147 project was established in 1985 by 17 countries and the European Union to encourage a bottom up approach to technological development and to strengthen the competitive position of European companies in the world market. The Eureka 147 Consortium was founded in 1987 with 16 partners from Germany, France, the Netherlands and the UK. The Eureka 147 standard was defined in 1993 with ITU Recommendations released in 1994 and an initial ETSI standard released in 1995. Eureka closed the Eureka 147 project on 1 January 2000.

The first Eureka 147 prototype equipment was demonstrated in 1988 on the occasion of the Second Session of WARC-ORB conference held in Geneva. The first consumer type receivers developed for pilot projects were released in 1995. The first services commenced transmitting in the UK, Denmark and Sweden in 1995. It was officially launched at the Berlin IFA (a major consumer electronics show) in 1997.

WorldDAB[1] was formed in 1995 to encourage international cooperation and coordination for the introduction of DAB to the consumer market. The technical work previously carried out by Eureka 147 now takes place within the Technical Committee of

[1] Further information on WorldDAB at http://www.worlddab.org/

WorldDAB. DAB/DAB+ is defined by international ITU recommendations, ETSI, Cenelec and IEC standards and national standards (e.g., Australian, British receiver standards).

WorldDAB is the global industry forum responsible for defining and promoting DAB, the digital radio broadcasting standard for many broadcasters around the world.

With unique cross industry representation, WorldDAB's 90-plus members cover 27 countries and include experts from broadcasters, regulators, and network providers, through to manufacturers of receivers, chips, professional equipment and automobiles.

Sharing case studies and best practice, WorldDAB's not-for-profit remit allows it to give unbiased advice, supporting and hosting industry events, briefings and tailored workshops providing insights, analysis and market intelligence.

WorldDAB defines and promotes DAB by offering support on all aspects of the switch from analogue to digital radio. This includes regulation, licensing, technology trials, network build out, marketing and production of digital radio content.

Many ancillary aspects, such as multimedia delivery, distribution interfaces and user interactivity are also formally defined in ETSI standards.

4.1.2 DAB/DAB+ adoption

- Following the successful launch of DAB+ in Malta, Australia and Switzerland in 2009, the standard is now the technology recommended by the European Broadcasting Union (EBU R138[2]) with national transmission networks having been rolled out in key markets.
- South Korean broadcasters have been broadcasting in DAB and T-DMB for many years and their government will formally adopt a digital radio standard for Korea in the near future.

The DAB+ family is the most widely adopted digital radio standard. DAB+/DAB/DMB is on air in nearly 40 countries and is popular because it:

I. is an open standard with no annual licence fees to be paid by broadcasters;
II. allows AM and FM broadcasters to move to a common digital platform;
III. is proving to be far greener and more cost effective to build and operate than any other analogue or digital radio standard;
IV. allows broadcasters more capacity and listeners more choice and functionality;
V. has the largest and most diverse range of low cost receivers;
VI. is being integrated as standard by the majority of motor vehicles manufacturers worldwide.

[2] https://tech.ebu.ch/docs/r/r138.pdf

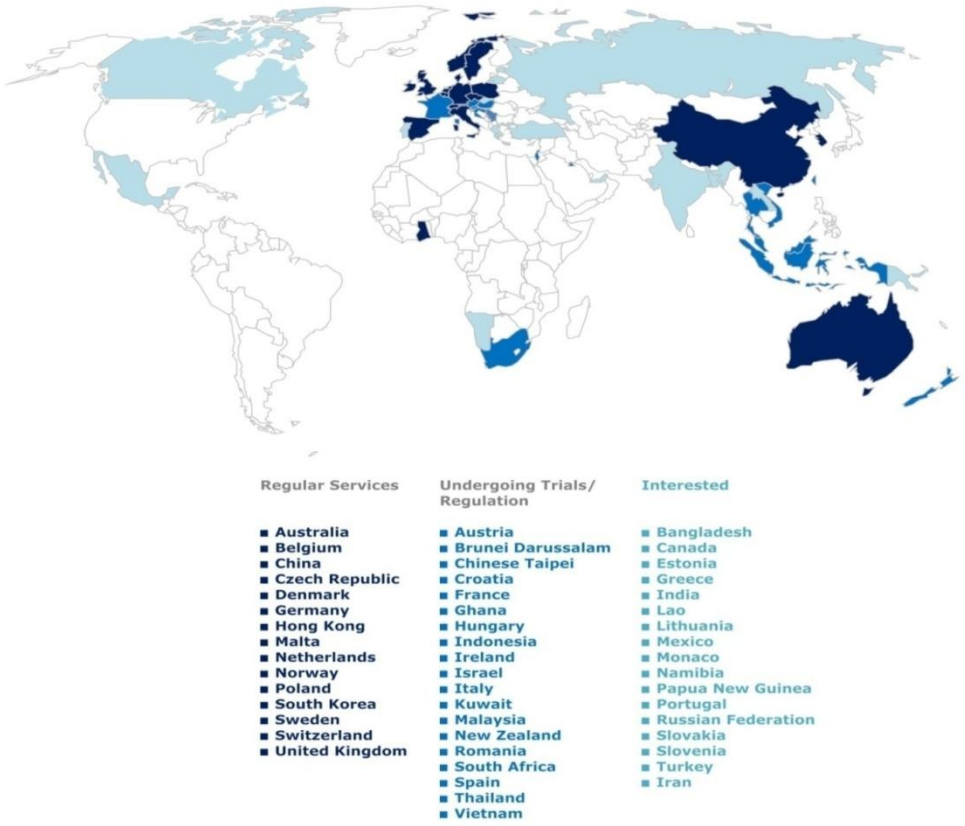

Figure 4.1.1: WorldDAB Country update shows the detailed status of DAB/DAB+ adoption in 32 countries across Europe, Asia Pacific and Africa.

Table 4.1.1: DAB main system features

DAB main system features	
Single Frequency Network (SFN) capability	All transmitters working on a single frequency.
Flexible audio bit rate	Allows reconfiguration of the multiplex.
Data services	Separately defined streams or packets.
Programme Associated Data (PAD)	Embedded in the audio bit stream and adjustable.
Service Information	Used in the operation and control of receivers, and for delivery of simple service information.
Operating frequency range	30 to 300 MHz

4.1.3 Principal Advantages and Challenges

Advantages:

DAB/DAB+ has many advantages including:

- It is an open standard with no annual licence fees to be paid by broadcasters.
- It can be implemented for a range of applications such as wide area or local delivery of audio and data services for mobile, portable and fixed reception.
- It can be delivered terrestrially.
- It is designed to be used across a wide spectrum range, from 30 to 300 MHz.
- It uses a wideband COFDM modulation system which provides a robust transmission which is multipath resilient and can provide high availability coverage.
- It can be implemented using on-channel repeaters in Single Frequency Networks (SFNs) or low power gap fillers and extenders. SFNs may also provide "network gain" giving improved service availability over single channel services.
- It can accommodate a varying number of audio services of differing quality with associated data. The audio quality can range from simple mono speech to high quality stereo.
- Data can also be delivered independently of the audio services, and standardised applications exist to enhance the audio service with visuals, programme guides, and others.
- It uses mature technologies such as MPEG 1 Layer II (DAB) and HE AAC v2 (DAB+) audio coding systems and COFDM modulation, which are also used in the DVB-T video broadcasting standard. This has led to low cost single chip solutions for receivers.
- It has been standardised by international ITU recommendations, European ETSI, CENELEC, IEC standards and national standards (e.g., Australian, British receiver standards).

- A large number of receivers are available for portable, PC, mobile, in-car and in-house reception. Receiver prices continue to fall with low cost units now available at less than 20USD.
- DAB+ transmission has been shown to be an environmentally friendly technology when compared to FM[3] (Business Case):
  - Energy consumption typically 1/40th of an equivalent FM service
  - Overall operating costs typically 1/10th of equivalent FM services
  - Capital costs of equipment typically 1/10th of equivalent FM services
- The standards include a number of features which can be used to implement Emergency Warning Systems and functionality including:
  - Automatic power on from standby through Emergency Warning signalling
  - Automatic switching of services to a specific Emergency Broadcast both within an ensemble or on a different ensemble
  - Various multimedia support including text, images and applications
- Well placed to be part of a Hybrid radio future, with terrestrial broadcast carrying audio and small data services alongside IP connectivity offering additional higher bandwidth services, personalisation and backchannel interactivity.

Challenges:

- The MPEG 1 Layer II audio coding systems are now dated (compared with new systems) but they offer excellent robustness against channel errors due to unequal error protection (UEP). All countries which adopted DAB, with the exception of the UK, have now converted to DAB+ audio coding to take advantage of the higher efficiency delivery – up to 2.5 times as many services can be delivered using DAB+ compared to DAB.
- While a wide range of low cost DAB receivers are already available, they are still generally seen as being too costly for general public acceptance in developing countries, particularly when compared to the very low cost AM and FM radios that many listeners currently use. As integration increases and single (RF + Baseband) chips become the norm, prices continue to fall and are expected to reach acceptable prices in those countries in the near future.
- The standard capacity of DAB+ using rate ½ FEC is 1.152Mbps. Given a bit rate per service of 64kbps, a single DAB+ ensemble can carry 18 services. In a conversion model, this may sometimes pose challenges for some radio broadcasting markets, which are typically served by a mixture of narrowcasting, community, commercial and national services using AM and FM frequencies with different or overlapping licence and coverage areas giving local, medium or wide area coverage. Conversely, the requirement for multiplexing will over time reduce the number of transmission sites and result in more consistent and cost effective coverage of digital radio services. Some jurisdictions are considering this useful for overcoming FM congestion and the introduction of planned digital service coverage areas.

[3]See "Economical Advantages of DAB+" under Cost reductions with DAB+ at www.worlddab.org

- In some countries, VHF Band III may be in use for other purposes. When converting to digital radio, sufficient spectrum for the conversion of analogue radio broadcasting services to digital, and any new services, must be found.

4.1.4 DAB Family of Standards Global Overview

More than 40 countries have legislated for the integration of DAB/DAB+/DMB Digital Radio in Europe and Worldwide. Outside Europe, the key areas of development are currently found in Australia, South East Asia, Korea, China, the Middle East and South Africa.

In the UK, Norway, Denmark and Switzerland, the standard is well established with household penetration[1] of at least 50% in each of those markets. Norway was the first country in the world to set a date (2017) for complete analogue switch off (ASO).

In 2011, Germany launched DAB+ services. The Netherlands launched national services in September 2013; and, in June 2014, France launched DAB+ services in Paris, Nice and Marseille, with a further plan for additional multiplexes. Italy has trial services covering 75% of the population with regular services launched in Trentino in December 2012.

The European Broadcast Union (EBU) has called for the adoption of digital broadcast radio across Europe[4], alongside Hybrid radio services (for example, using RadioDNS). At the same time, government administrations are looking to build cross-border links to develop a European consensus about radio's digital future.

Automotive

- All major car manufacturers are fitting DAB in their vehicles
- In the UK 91%, Switzerland 85% and Norway 98% of new cars come with DAB/DAB+ as standard
- WorldDAB has established an automotive task force, collaborating with car manufacturers on installation of digital radio as standard across Europe and beyond
- Territories with national DAB coverage account for 60% of all new car sales in Europe, and car makers are planning accordingly

European collaboration

- **EU governments** are working together to accelerate rollout of DAB in Europe, building cross-border links to develop a European consensus about radio's digital future

[4]*Recommendation R138* https://tech.ebu.ch/docs/r/r138.pdf

- A **European Digital Radio Alliance** was established in 2016 to make digital radio the standard and the preferred choice of listeners across Europe. EDRA's strategy is to promote a hybrid DAB/FM solution that will support all broadcasters and consumers in Europe and allow individual countries to go digital at their own speed. 12 founding members represent over 300 public service and commercial radio stations.
- The **European Broadcast Union (EBU)** has called for the adoption of digital broadcast radio across Europe and for the inclusion of digital capability in all new radio receivers.
- WorldDAB is engaging with the **European Commission** about the potential inclusion of digital terrestrial radio in the Digital Single Market Strategy, to ensure the allocation of Band III spectrum to digital radio, and to propose EU regulation that all new radio receivers (consumer and automotive) be capable of receiving FM and digital services.

Digital switchover

- Several European markets are considering their long term plans for broadcast radio, including potential digital switchover scenarios.
- Norway was the first country to confirm a DSO date (2017); and Switzerland is planning for DSO in 2020-24.
- WorldDAB has a working group focused on DSO, to coordinate activities and share best practice, attended by Belgium, Czech Republic, Denmark, Germany, The Netherlands, Norway, Poland, Sweden, Switzerland and the United Kingdom.

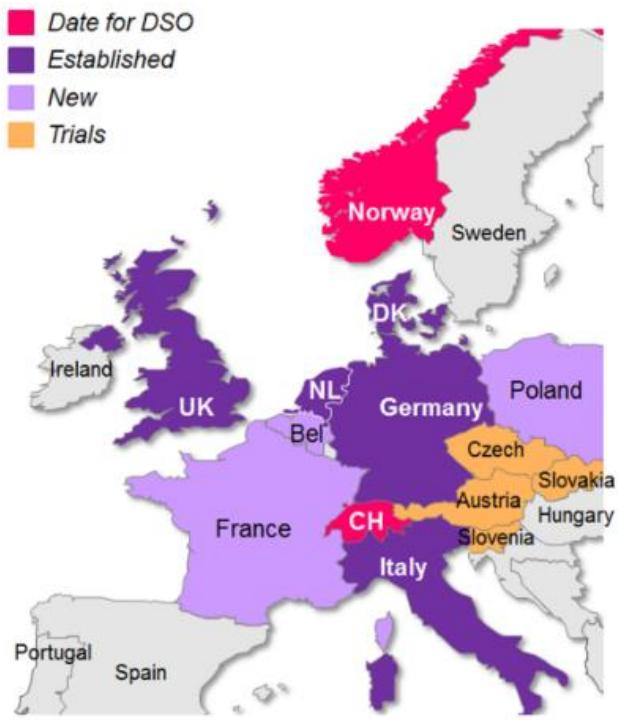

Figure 4.2.3: Digital radio in Europe

Asia Pacific and Rest of World

- Australia successfully launched DAB+ in 2009, followed by Hong Kong in 2011.
- Indonesia launched permanent services in Jakarta in April 2016.
- Thailand, Malaysia and Vietnam are now investigating digital radio options. WorldDAB has organised workshops in each of these countries.
- South Africa has an ongoing DAB+ trial covering 21% of the population.
- Turkey, Tunisia, United Arab Emirates and Kuwait are trialing DAB+.

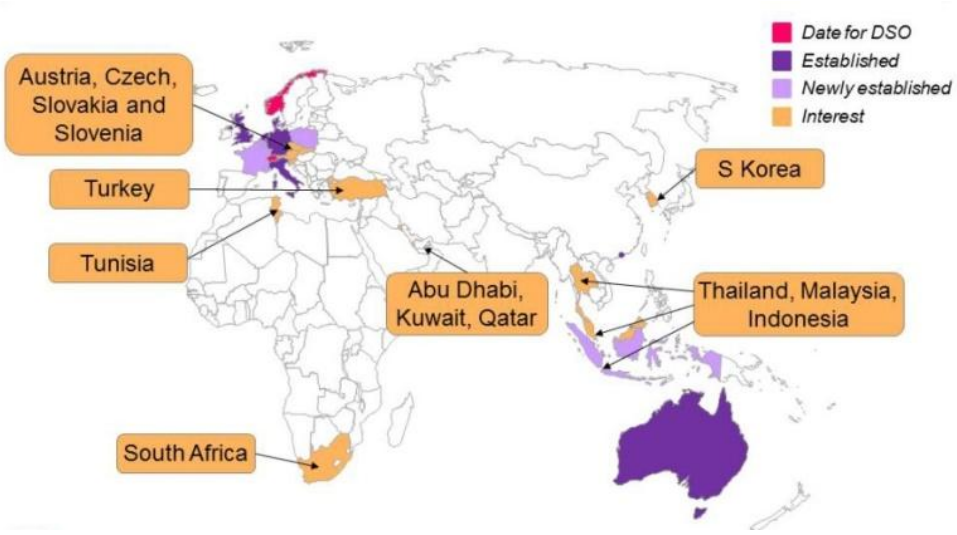

Figure 4.2.4: Digital radio in APAC

Receivers

- DAB receivers are now available from €12 with prices continuing to drop
- Receivers with colour screens now retail for less than €65
- There is ongoing work to create consistent receiver specifications in different countries, building on work already undertaken in the UK and Germany

Europe: regular services

- **Belgium**: The Flemish Government has confirmed its commitment to DAB+ (with the stated aim of digital switchover) and in Wallonia, the government agreed to partly finance investment for DAB+.
- **Denmark:** Issued a clear roadmap for digital radio, with a transition to DAB+ by 1st October 2017, a new national multiplex on air in 2018 and a decision on DSO when 50% of listening is digital.
- **France**: The CSA published a timetable at the end of 2015 for rollout of digital radio across the whole country. All major metropolitan areas of France will be covered by the end of 2020. This is in addition to the current offering of over 100 DAB+ stations currently on air in Paris, Marseille and Nice.
- **Germany**: Secured financing for public broadcasters 2017-20 (3x previous funding) and is preparing a second national multiplex. The nationwide DAB+ network has been extended by around 50 transmitters. Germany is now developing a DSO strategy.

- **Ireland**: National Public Broadcaster RTÉ operates a full-service multiplex across a five transmitter network covering 52% of the population in the main cities.
- **Italy:** 85% of the population is covered by a DAB+ signal.
- **The Netherlands**: The country has seen the fastest growth for DAB+ (launched 2013).
- **Norway:** Had digital switchover in 2017, starting with first FM switch off on 11 January 2017 and completed on 9 December 2017.
- **Poland**: Polskie Radio has extended coverage of its DAB+ services to 56%.
- **Slovenia:** The regulator issued licences for a national DAB+ network and the network has been operational since September 2016, covering over 70% of the population.
- **Spain:** DAB services are on air in Madrid and Barcelona including their metropolitan areas, covering 20% of the Spanish population.
- **Switzerland:** Announced plans for DSO between 2020 and 2024 and 53% of listening is now via digital.
- **UK**: DAB listening and ownership has continued to grow and the 50% criterion for DSO was reached during 2018. The UK government is considering next moves.

Asia Pacific: regular services

- **Australia:** Continues to lead the way in Asia Pacific – with DAB+ household penetration rising to 23.6%. The latest quarterly GfK Report shows the number of people listening to radio via a DAB+ device has grown to 3.35 million in the five capital cities. Work is underway for regional DAB+ coverage.

Asia Pacific, Africa, Middle East North Africa: trials and/or regulation

- **China**: DAB is on air in Beijing.
- **Chinese Taipei:** A DAB single frequency network (SFN) trial is operated by SuperFM (the commercial broadcaster) and covers major cities including Taipei and New Taipei.
- **Indonesia**: Public broadcaster Radio Republik Indonesia (RRI) has launched DAB+ digital radio services in Jakarta.
- **Kuwait**: Preparations are underway for the second phase of a DAB+ trial. A decision regarding commercial roll out is expected once all trials have been completed.
- **Malaysia:** a DAB+ trial multiplex is on air shared by both public and commercial broadcasters.

- **New Zealand**: Digital radio services have been introduced on a trial basis in two cities.
- **South Africa**: a large scale DAB+ trial covers 21.5% of the population with 18 services.
- **Thailand**: The National Broadcasting and Telecommunications Commission (NBTC) is preparing plans for DAB+ introduction.
- **The UAE**: A major media group is on-air with 12 DAB+ services. The Telecoms Regulation Authority (TRA) is working the commercial launch of DAB+ including receiver specifications to cover all radio receivers including AM/FM/DAB+.
- **Turkey**: a DAB trial in Istanbul and Ankara broadcasts five simulcast stations.

4.1.5 Infrastructure Requirements

DAB/DAB+/DMB is a wideband technology requiring services to be multiplexed before transmission. The use of VHF in Band III means services will be typically transmitted from high sites such as the tops of hills, buildings or towers.

Stations that were originally broadcasting more than one AM / FM programme from the same site can fully encapsulate the multiplexed stream of the DAB+ system in the STL (studio-to-transmitter link), significantly reducing the costs associated with discrete feeder links.

DAB/DAB+ transmission requires a multiplexer to create the ensemble of services alongside the required signalling channel (FIC). The services may consist of audio or data services.

Each audio service should be encoded in the relevant format (e.g. MPEG II Layer 2 for DAB, HE AAC v2 for DAB+), and data services (e.g. for Slideshow, Electronic Programme Guides, etc.).

In recent years, "low-cost" multiplexers have been created, using Software Defined Radio (SDR) technology along with free and open-source software systems. This has led to the use of DAB+ in a range of local and community ensembles. The significantly lower cost of such systems compared to traditional broadcast equipment has opened up the opportunities of digital radio to a wider group of broadcasters, and increased innovation especially around Hybrid radio services.

Traditionally DAB+ multiplexer or ‘head-end’ infrastructure consists of:

- one ensemble multiplexer which includes and provides core transmission functionality such as signalling, timing and ETI stream construction
- one ensemble controller to allocate capacity to the studio multiplexers
- one or more studio multiplexers
- one or more associated studio multiplex controllers which define and control the services and content delivered, including audio type and bit rate, Program

Associated Data input such as scrolling Text (Dynamic Label Segment / DLS) and Images (Slideshow / SLS), as well as data services for functionality such as Service and Programme Information (SPI)

- one or more audio encoders per studio or ensemble multiplexers

The studio multiplexers are generally operated independently of each other by different radio networks. Each studio or service multiplexer will generally also have an associated data multiplexer or data server to provide the Program Associated Data (PAD) and data services, although the data multiplexer function can be shared and located at the ensemble multiplexer site.

Current implementations of head-end systems are placing more emphasis on software implementation and, as such, functions such as service/studio multiplexers are increasingly becoming software implementations either in a combined encoder/studio multiplexer/controller unit or in the ensemble multiplexer unit.

All functions in the head-end can be made redundant to minimise on-air impact or loss of service due to either equipment failure or maintenance activities. Commercial broadcasters typically require service availability of around 99.97% which is equivalent to 3.5 hours of service unavailability per year.

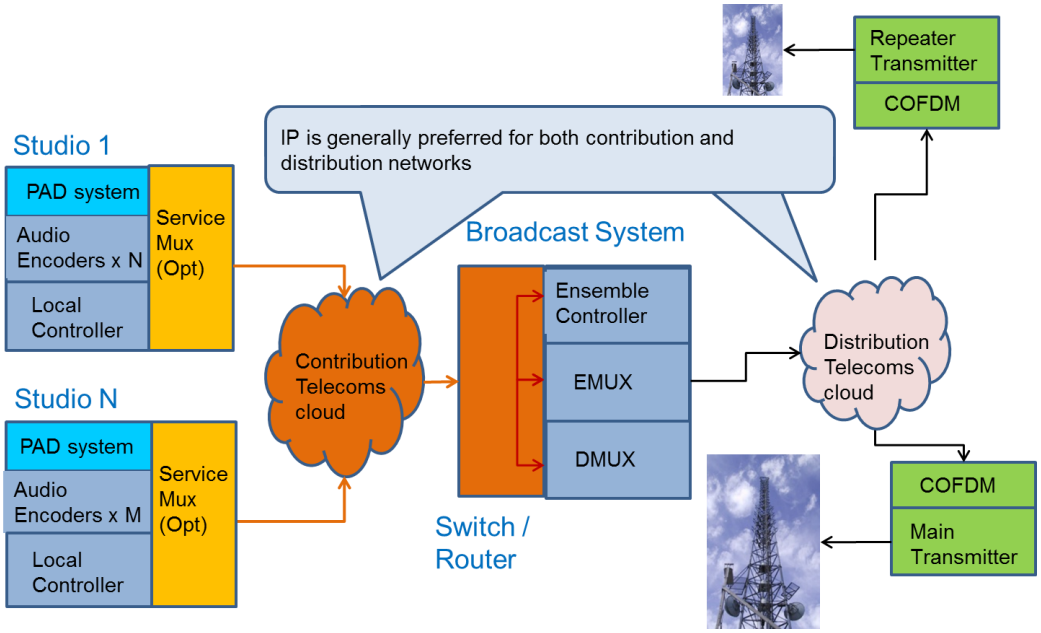

Figure 4.2.5: DAB System Structure

The structure of the DAB family of standards offers a wide range of architectures to allow optimisation and cost minimisation for all types of network combinations and requirements, from ensembles operated by a single network with multiple channels, e.g. the BBC in the UK, to ensembles which have three or more independent commercial networks which each have several services e.g. commercial multiplexes in Australia, or to a combination of public, private and even wide area community services on a shared multiplex.

4.1.6 Synergies with Other Systems

(1) Hybrid Services

DAB is an efficient broadcasting (e.g., one-to-many) system capable of providing reliable digital services to all users located in a coverage zone in real time. It is especially suitable for the reception by mobile and portable receivers.

On the other hand, fixed and mobile broadband is more suitable to deliver on-demand media services to individual clients or relatively small groups of clients. In particular, mobile telecom systems are technically able to provide services to multiple users in the same time, providing that total bandwidth usage does not exceed capacity, causing data congestion.

Also, the use of telecom services in the "one-to-many" scenario is potentially much more expensive for the listener than the use of free to air DAB+ broadcast audio, depending on the cost of their mobile data subscription.

It is advantageous for broadcasters to provide a combination of both one-to-many broadcast service for the primary distribution of content (audio and simple multimedia)

and one-to-one service for richer or personalised multimedia and interactivity in a hybrid model.

For example, a traffic/travel information service may consist of two parts: one part carried over the broadcast signal (free to air), and additional elements delivered over mobile data, either directly from the broadcaster or via a third-party service provider.

4.1.7 Receivers

In today's global market, over 75 million DAB, DAB+ and DMB devices have been sold to consumers, and this market continues to grow as the technology becomes more established. Consumers are benefitting from an increased choice of services and functionality over existing analogue devices.

Digital radio receivers are available for domestic use and on-the-move, while an increasing number of receivers are being developed to satisfy the demand for in car listening. The manufacturing of digital radios has significantly developed over time both visually and functionally. Digital radios can incorporate features including visual slideshow, programme guides, colour and touch screens, and the ability to pause, rewind and record live shows, giving the listener a more interactive and enriched listening experience.

Advertisers can also take advantage of these enhanced features by using the colour screens to display special offers, product photos, advertiser's logos, store locations, opening hours – co-timed with the audio and all delivered efficiently and effectively via broadcast digital radio.

Types of receivers available on the market

- Clock radios
- Docker radios
- Portable radios
- In-car (line fit and aftermarket)

The development of digital receivers will continue to develop and grow influenced by the following factors:

- Increased data and content from broadcasters
- The availability of interactive services
- Technological innovation
- Consumer demographics, behaviour and demand

As technology advances and cost reduction through increased silicon integration increases, consumers will be able to enjoy an increased selection of receivers, on sale at a wide range of price points with better processing and capabilities.

Digital Radio in-car

DAB, DAB+ and DMB, were originally designed to work within a mobile environment, making it an ideal carrier of free-to-air broadcast entertainment and information. A large percentage of radio listening remains in-car and the broadcasting industries around the world are working hard to include the automotive sector in their plans.

The benefits of implementing DAB/DAB+ in an automotive receiver

- DAB/DAB+ allows for delivery of driver information data into the car including TPEG. TPEG offers real time traffic and travel information. DAB+ is an efficient way of broadcasting TPEG information into the car alongside traditional audio Traffic and Travel information.
- Cost efficient delivery channel for information services at no additional ongoing cost to the driver.
- More channels and content offering a wider variety of radio services.
- More choice of stations.
- Easy to tune through search for station names and not frequencies.
- Clear sound quality and clarity.
- Additional features includes in-car screen graphics and information that can display album cover art, song titles, artists names, news, sports results and more.
- Tunnel re-broadcast systems and emergency announcements.
- Service following when driving between networked services.

There are many options for adapting existing analogue radios, such as small adapter units, which can be fitted to the dashboard and connected directly to the existing radio, or by a straight replacement of the entire head-end.

4.1.8 WorldDAB Receiver Profiles

WorldDAB defines a number of receiver profiles that may be used by regulators and others to develop strategies and policies for digital radio broadcasting within national boundaries or with reference to trans-national and harmonised markets. It seeks to define levels of functionality and support within each of the profiles that can be used equally between device manufacturers and broadcasters.

More information about the DAB family of standards is included as Appendix A.

4.2 DRM – Digital Radio Mondiale

DRM is a digital radio standard for the existing radio broadcast bands (as deployed for analogue AM and FM radio). It supports both local/regional coverage scenarios, as well as large-area and international transmissions. DRM focuses on digitizing and enhancing radio services and transmissions of individual broadcasters.

Figure 4.2.1: DRM Logo

The DRM system encompasses a high level of flexibility in its design. These are noted in this subsection in the signal flow sequence going from the delivery from a programme studio or network control centre to a transmission site and on to reception and decoding in a receiver.

4.2.1 Key Features of the System Design for the Markets to be Served by the DRM System

The DRM system is a flexible digital sound broadcasting system for use in all the terrestrial radio broadcasting bands below 300 MHz (i.e. AM bands and VHF bands).

In the consumer radio receiver, the DRM system provides the capability to receive digital radio (including sound, program related data such as advanced text, and other data such as EPG, still pictures and traffic information) in all the broadcasting bands below 300 MHz. It can function in an independent manner, but will more likely be part of a more comprehensive receiver – much like the majority of today's receivers that include AM and FM analogue reception capability.

DRM enables a broadcaster to provide between one to four services on a single transmission signal: Typical single-channel MW transmissions may typically carry one to two audio services accompanied by text-based data applications. FM transmissions provide the capacity for up to three audio services along with various accompanying and stand-alone data applications. This enables broadcasters to enhance their overall listenership by providing additional services tailored to wider audiences.

DRM's EWF – Emergency Warning Feature – allows to instantly alert DRM listeners in case of pending natural or man-made catastrophes. EWF combines the particular benefits of terrestrial transmission (such as battery-powered receivers and coverage of the affected area from long-distance transmitter locations without depending on local infrastructure) with the improvements enabled through DRM digital radio. DRM receivers can be directed to automatically re-tune and/or switch to the emergency broadcast (possibly with automatic switch-on from deep standby mode). The content of the emergency transmission combines classic audio announcements with the advanced text application Journaline – the latter allowing immediate access to detailed multi-lingual information and instructions, thus including hearing impaired users and those not speaking the local language.

The DRM standard has two main configurations, depending on the frequency of transmission. "DRM30" is the term applied when the frequency is below 30 MHz (the

traditional AM bands). “DRM+” is the term applied when the frequency is in the VHF bands, that is between 30 MHz and 300 MHz. DRM30 can be used in either 9 or 10 kHz channels, and also provides high capacity modes using double channel bandwidths. DRM+ is used in 100 kHz channels. Therefore DRM can operate in the existing channel assignments defined in the past for analogue transmissions.

Differences on how much of the total available bit stream of these channels is used for audio, for error protection and correction, and for data transfer depend on the intended use and individual configuration (for example, ground wave, short distance sky wave or long distance sky wave, with a data application service or without one). In other words, there are modal trade-offs available so that the system can match the needs of broadcasters worldwide.

As noted in more detail in subsequent parts of this subsection, the DRM system has the following structure. It employs xHE-AAC (Extended HE-AAC) audio coding, which is the most advanced audio coder currently available. This audio coder provides equally high quality for music and speech signals, including stereo reproduction, even at very low bit rates. Orthogonal Frequency Division Multiplexing (OFDM) and Quadrature Amplitude Modulation (QAM) are used for the channel coding and modulation, along with time interleaving and forward error correction (FEC). Pilot reference symbols are injected to permit a receiver to “equalise” the channel by comparing a known stored bit sequence with the corresponding received sequence of these special bits, and adjusting accordingly if there are differences in the received compared to the stored sequence.

The DRM consortium believes that a consumer radio receiver needs to be capable of decoding any or all of several terrestrial transmission standards; that includes, in particular, the complementary open digital radio standards DRM (narrow-band digital (for <300 MHz RF) and – where applicable – the DAB multiplex standard (for >30 MHz RF), as well as analogue for the LF, MF, HF and VHF (including the FM) bands. The DRM standard is an important component within the receiver, as DRM transmissions today are estimated to reach half the world population thanks to international coverage, while local digital radio services may be based on DRM or DAB, or a combination thereof. In addition, it is unlikely that a consumer radio designed to receive terrestrial digital transmissions would exclude the analogue capability anytime in the foreseeable future.

4.2.2 Brief Description of the DRM System

(1) Overall design

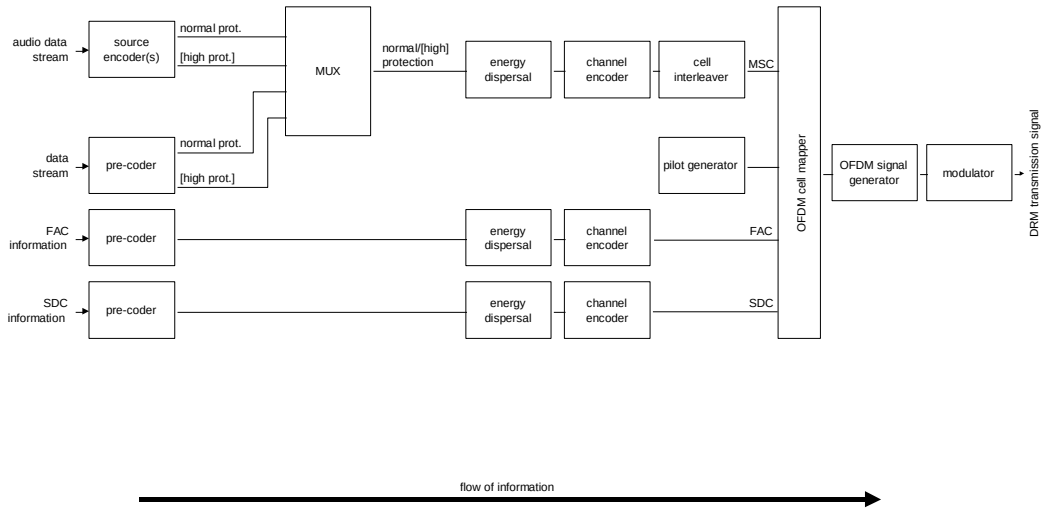

Figure 4.2.2: Transmission Block Diagram

Figure 4.2.2 depicts the general flow of different classes of information (audio, data, etc.) after their origination in a studio or control centre (that would be depicted to the left of the figure) to a DRM transmitter exciter/modulator (on the right). Although a receiver diagram is not included in the figure, it would represent the inverse of this diagram.

There are two classes of basic information:

- the encoded audio and data that are combined in the main service multiplexer;
- information that bypasses the multiplexer that are known as fast access channel (FAC) and service description channel (SDC), whose purposes relate to identification and control for a transmitter and for appropriate decoding selection within a receiver.

The audio source encoder and the data pre-coders ensure the adaptation of the input streams onto an appropriate digital format. Their output may comprise two parts requiring two levels of protection within the subsequent channel encoder.

The multiplex combines the protection levels of all data and audio services in a proper format within the frame structure of the bit stream.

The energy dispersal provides an ordering of the bits that reduces the possibility of unwanted regularity in the transmitted signal.

The channel encoder adds redundant bits as a means for error protection and correction and defines the mapping of the digitally encoded information into QAM cells, which are the basic carriers of the information supplied to the transmitter for modulation.

Cell interleaving rearranges the time sequence of the bits as a means of "scrambling" the signal so that the final reconstruction of the signal at a receiver will be less affected by fast fading than would be the case if "continuous" speech or music were transmitted.

The pilot generator injects information that permits a receiver to derive channel-equalization information, thereby allowing for coherent (includes phase information) demodulation of the signal.

The OFDM cell mapper collects the different classes of cells and places them on a time-frequency grid.

OFDM depends on each of many subcarriers carrying its own sinusoidal amplitude/phase signal for a short period of time. The ensemble of the information on these subcarriers contains what is needed for transmission. In the case of DRM, for a 10 kHz channel, there are hundreds of subcarriers.

The modulator converts the digital representation of the OFDM signal into the analogue signal that will be transmitted via a transmitter/antenna over the air – essentially phase/amplitude representations as noted above modulating the RF.

With a non-linear high-powered transmitter, the signal is first split into its amplitude and phase components for injection in the anode and grid circuits, respectively, and then recombined (by the action of the transmitter itself set at the correct differential delay time), and then recombined prior to final emission. This splitting is not necessary for linear amplification.

(2) Distribution Interface

Referring to the extreme left of Figure 4.2.2, apart from audio and data applications that are multiplexed, additional information is sent that is required to instruct the transmitter to select the correct mode, error protection level, etc. and to send information in the transmission to the receivers to permit them to switch to the selection of several variables to allow for proper decoding. (The boxes and arrows for this are not shown directly in Figure 4.2.2.) In the aggregate, this collection of information and the means to get it to the transmitting station is called the "Distribution Interface" (DI).

These signals can emanate from a studio, or from a more elaborate network control centre, and be transmitted via land lines or via satellite circuits to the appropriate transmitter station(s). These details will not be noted here, but can be found in the related ETSI documents (see below).

There are two Distribution Interfaces currently standardized, all based on the shared standard DCP – Distribution & Communication Protocol (ETSI TS 102 820; with the associated document ETSI TS 102 358):

- MDI – Multiplex Distribution Interface: covers the transport of the digital DRM multiplex signal and additional modulation configuration from the DRM Multiplexer (located at the studio or the transmitter site) to the DRM Modulator

(part of a DRM-ready transmitter); see ETSI TS 102 821 (DRM MDI – Multiplex Distribution Interface).

- RSCI – Receiver Status and Control Interface: covers the transport of receiver status information in addition to the DRM multiplex from a DRM receiver (baseband decoder) to service layer decoders or outside processing/recording/archiving modules as well as commands to control the receiver's behaviour (such as re-tuning to a specified frequency); see ETSI TS 102 349.

(3) Audio Source Coding

Figure 4.2.3 depicts the two audio codecs supported in the DRM standard: MPEG xHE-AAC (Extended High Efficiency AAC) and MPEG AAC with SBR and PS. They can operate in a range of bit rates and configurations, including mono, stereo and even stereo-decoder compatible 5.1 Surround Sound modes.

xHE-AAC is the latest MPEG audio codec development, a superset of the widely used HE-AAC v2 codec: xHE-AAC unifies music and speech-coding and supports low-bitrate configurations as common for many DRM transmission modes, Internet streaming and mobile music download services. The xHE-AAC encoder automatically chooses the optimum audio configuration for the specified target bit rate, thereby eliminating the need for the broadcaster to get involved with the detailed audio configuration parameters.

Due to the adoption of xHE-AAC, it is a realistic scenario for broadcasters to plan for two stereo services within a single MW transmission (a standard channel of 9 or 10 kHz bandwidth), three high-quality stereo transmissions in a single FM band broadcast, or FM-like audio quality for a SW transmission with even the most robust signal configuration.

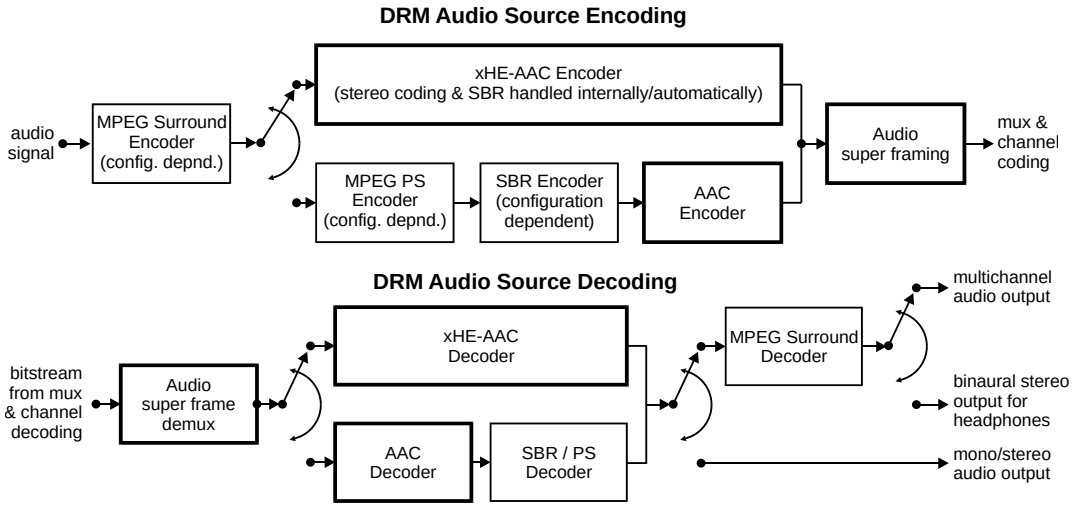

Figure 4.2.3: DRM Audio Source Encoding and Decoding

SBR (Spectral Band Replication) is a special means of enhancing the perception of a spectrally truncated low band audio signal by utilizing, on a dynamic basis, the spectral content of the low band information to simulate the missing higher band behaviour. SBR is automatically used for xHE-AAC services, while in the case of AAC it can be enabled for certain audio configurations.

(4) Data Applications

The DRM standard includes a full range of elementary multimedia components, which allow to enhance the radio experience for listeners and to open new revenue potential for broadcasters. The core applications are specified in the DRM Receiver Profiles (as available for download from www.drm.org):

- **DRM Text Messages**

  Typically programme-related information such as title and artist names; short scrolling text information (max. 128 characters) are auto-updated on the radio receiver's screen.

  Journaline
  Advanced full-text service with simple menu structure for interactive and on-demand information look-up on the receiver; typical content offerings include news, weather, sport results, programme background information (e.g. songs of the last hour with artist background), stock price updates, distance learning offerings, etc.

  Journaline provides multilingual text services free over-the-air without the need for Internet to stay up-to-date even when on the move. On connected radio sets, broadcasters can in addition trigger Hot-Button listener backchannel engagement such as phone call-ins to a talk show, sending of SMS messages to participate in games and polls, being linked to web sites for ticket purchases, etc. Special test-to-speech support options also enable the use of Journaline for in-car receivers. Additionally, geo-referencing of Journaline information links with navigation systems enables locally relevant content filtering.

- **EPG – Electronic Programme Guide**

  Informs about upcoming programmes; some receivers may allow listeners to search for specific content or program future recordings with the push of a button.

- **Slideshow**
  Images and simple animations are auto-updated on the radio receiver's screen; enables 'view into the studio', music album covers, or photos accompanying the news; particularly suitable for higher-capacity local DRM services (DRM+).

- **TPEG and TMC**

Traffic updates for route planning optimization of in-car navigation systems; targeting local and regional DRM services.

The flexible configuration of the DRM multiplex allows for a fine-granular assignment of transmission capacity to each data application.

(5) Multiplexing, including special channels and energy dispersal

This section refers to the left side of Figure 4.2.2 through "energy dispersal", not including the DI and audio/data encoding portions.

As noted in Figure 4.2.2, the DRM system total multiplex consists of three channels: the MSC, the FAC and the SDC. The MSC contains the services – audio and data. The FAC provides information on the signal bandwidth and other such parameters, and is also used to allow service selection information for fast scanning. The SDC gives information to a receiver on how to decode the MSC, how to find alternative sources of the same data, and gives attributes to the services within the multiplex.

The MSC channel may contain up to four MSC streams, any one of which can carry one audio or up to four data components (in packet mode or enhanced packet mode). The gross bit rate of the MSC is dependent on the channel bandwidth and transmission mode being used. Typical bit rates available to the transport of audio and data components are in the range of 10—35 kbps for DRM30 standard channels, and 37—186 kbps for DRM+ transmissions. In all cases, it is divided into 400 millisecond frames in the case of DRM30 and 100 millisecond frames in the case of DRM+.

From a listener's perspective, besides pure audio services (with optional Text Messages), DRM supports pure data services (consisting of one data component) and audio services with PAD (Programme Associated Data, extending the audio service by one-four data applications automatically presented to the listener when tuning to the audio+PAD service).

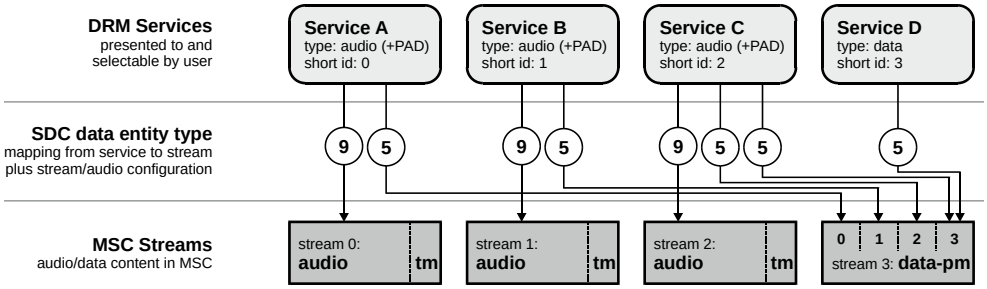

Figure 4.2.4: Relationship between DRM Services and MSC Streams

The FAC's structure is also built within a 400 or 100 millisecond frame, and is designed without interleaving, for example, to ensure rapid delivery of the information it contains. The design without interleaving is also to ensure fastest decoding of basic data by the Rx

before it can do the audio decoding. The channel parameters are included in every FAC frame segment. The service parameters are carried in successive frames, one service per frame.

The SDC's frame periodicity is 1200 milliseconds for DRM30 and 400 milliseconds for DRM+. The fields of information are: multiplex description, service label, conditional access, frequency information, frequency schedule information, application information, announcement support and switching, coverage region identification, time and date information, audio information, FAC copy information, and linkage data. As well as conveying these data, the fact that the SDC is inserted periodically into the waveform is exploited to enable seamless switching between alternative frequencies.

(6) Channel coding and modulation

The coding/modulation scheme used is a variety of coded orthogonal frequency division multiplexing (COFDM), which combines the OFDM with the Multi-Level Coding (MLC) based upon convolutional coding. The convolutional coding provides a level of error protection. These two main components are supplemented by time interleaving ("scrambling" of the bit stream) and the provision of pilot (predetermined value) cells for instantaneous channel estimation. All of this mitigates the effects of short-term signal fading, whether selective or flat.

Taken together, this combination provides excellent transmission and signal protection possibilities in the narrow nine or ten kHz channels in the LF, MF and HF broadcasting frequency bands. It can also be used for "multi-channel" DRM use; that is 18 or 20 kHz channels, using two contiguous ITU-R channels. This level of bandwidth will permit very good stereo broadcasting or multiple services in the same RF channel. For DRM+ with a higher set of available data rates, high robustness and/or multiple services up to surround sound services are possible.

For OFDM, the transmitted signal is composed of a succession of symbols, each including a "guard interval," which is a cyclic time prefix that provides a "dead time" to counter intersymbol interference due to multipath delay spread. Orthogonality refers to the fact that, in the case of the design of the DRM system, each symbol contains between 100 and 200 subcarriers spaced evenly across the channel in such a way that their signals do not interfere with each other (are orthogonal). The precise number of subcarriers, and other parameter considerations, are a function of the actual letter modes used: ground wave, sky wave, and highly robust transmissions.

QAM is used for the modulation that is impressed upon the subcarriers to convey the information. Two primary QAM constellations are used: 64-QAM and 16-QAM for DRM30 and 16-QAM and 4_QAM for DRM+. In each case, the higher constellation provides the highest audio quality, but is less robust. In addition, a 4-QAM (QPSK) signal, which is very robust, is used for some of the signalling.

The interleaver time span (applied to the MSC) for HF transmissions is generally two seconds, to cope with time and frequency selective fading by protecting the audio and data from rapid fades during the natural sequence of speech and music. When less

difficult propagation conditions are expected (for the LF and MF bands and better behaved HF transmissions), a shorter interleaver of 0.4 seconds can be used. For the VHF bands, the time interleaver is set at 0.6 seconds, since this provides good immunity from Doppler effects in fast moving vehicles.

The multi-level convolutional coding scheme uses code rates in the range between 0.4 and 0.8, with the lower rates being associated with more difficult propagation conditions. A 0.5 code rate means that only half the transmitted bits within the overall coded block are used for the actual services in the multiplex, whereas a 0.8 rate means 80% are.

4.2.3 Transmitter Considerations

Beyond the modulator box in Figure 4.2.2 is the transmitter exciter. The DRM system exciter can be used to impress signals on either linear or non-linear transmitters. For DRM30, AM transmitters can often be converted for DRM use by the addition of a DRM Modulator. This allows both AM and DRM operation, although not simultaneously unless additional channels are available. For DRM+, it is likely that a new solid state transmitter will provide a more efficient operation, although conversion of some FM transmitters is feasible; transmitters capable of FM and DRM simulcast transmission are available to support the transition period from analogue-only to digital-only.

It is expected that high-powered non-linear transmitters will be the more usual way of transmitting, much as is done now with analogue modulation. However, there are broadcasting service situations where very low powered linear transmissions could be the best way to serve the public.

With respect to non-linear amplification (Class C operation), the incoming DRM signal needs to be split into its amplitude and phase components prior to final amplification. Using QAM modulation, there is a small discrete set of possible amplitudes and phases. The amplitude component is passed via the anode circuitry; the phase component is passed through the grid circuitry. These are then combined with the appropriate time synchronization to form the output of the transmitter.

Measurements of the output spectra show the following: the energy of the digital signal is more or less evenly spread across the channel, the shoulders are steep at the channel edges, and drop rapidly to 40 dB or so below the spectral density level within the assigned channel, and the power spectral density levels continue to decrease rapidly outside the assigned channel in permits conformance to the ITU-R mask.

(1) Over the air

The digital phase/amplitude information on the RF signal is corrupted to different degrees as the RF signal propagates. Some of the HF channels provide challenging situations of fairly rapid flat fading, multipath interference that produces frequency-selective fading within a channel and large path delay spreads of a few milliseconds or more, and ionospherically induced high levels of Doppler spreads on the order of one or more hertz.

The error protection and error correction incorporated in the DRM system design mitigates these effects to a great degree. This permits the receiver to accurately decode the transmitted signal information.

Extensive field tests have verified these performance statements.

(2) Selecting, demodulating and decoding of a DRM system signal at a receiver

A receiver must be able to detect which particular DRM system mode is being transmitted to handle it properly. This is done by way of the use of many of the field entries within the FAC and SDC.

Once the appropriate mode is identified (and is repeatedly verified), the demodulation process is the inverse of that shown in Figure 4.2.3. Similarly, the receiver is also informed which services are present, and, for example, how source decoding of an audio service should be performed.

4.2.4 Further Information

The "**DRM Introduction and Implementation Guide**" is available as a free download from the DRM website **www.drm.org**. This document provides a more detailed description of the DRM standard, its features and applications, as well as considerations for a successful roll-out.

For expert readers, the following ETSI specifications describe the technical parameters and definitions of the DRM signal and related standards:

- ETSI ES 201 980 v 4.1.1 (2014-01): the "signal in the air" specification
- ETSI TS 101 968: the data applications specification
- ETSI TS 102 820, TS 102 821 and TS 102 358: the distribution interface specifications

The ITU has published detailed planning parameters to support the proper and successful network planning for DRM transmissions, individually or alongside other digital and analogue transmissions, along with supporting considerations:

- ITU-R Rec. BS.1514: 'System for digital sound broadcasting in the broadcasting bands below 30 MHz' (DRM30)
- ITU-R Rec. BS.1615: 'Planning parameters for digital sound broadcasting at frequencies below 30 MHz' (DRM30)
- ITU-R Rec. BS.1114: 'Systems for terrestrial digital sound broadcasting to vehicular, portable and fixed receivers in the frequency range 30-3 000 MHz' (DRM+)
- ITU-R Rec. BS.1660: 'Technical basis for planning of terrestrial digital sound broadcasting in the VHF band' (DRM+)

- ITU-R Rec. BS.1894: ’Digital radio broadcast service, captioned radio’

4.3 Japan's Digital Radio Broadcasting (ISDB-TSB)

4.3.1 Overview

The Integrated Services Digital Broadcasting – Terrestrial for Sound Broadcasting (ISDB-TSB) system was developed for terrestrial Digital Sound Broadcasting (DSB) and was included in the ITU-R Recommendation BS.1114-3 in 2004. The system specification was developed by the Association of Radio Industries and Businesses (ARIB) in October 1998. Laboratory experiments and field trials using Tokyo Tower were carried out to verify the system performance in 1999 and the final specification was approved as a Japanese Standard in November 1999.

Two stations were launched in Tokyo and Osaka in the frequency band 188 MHz to 192 MHz in October 2003.

4.3.2 The Methods

A terrestrial TV broadcasting frequency band that fits for mobile communications, Orthogonal Frequency Division Multiplexing (OFDM) that withstands interference caused by multiple paths (delayed waves), a modulation method that fits for communications with cell phones and mobile receivers, powerful error correction function, etc., have been adopted to allow good communications with cell phones and mobile receivers.

Concerning information compression technology and multiplexing technology, MPEG-2 has been adopted after diverse compatible communications with digital broadcasting (such as terrestrial digital TV broadcasting, BS digital broadcasting, CS digital broadcasting) were considered. MPEG-2 offers a common base for signal processing, which leads to reduction in the production cost of receivers by using LSI-chip and consolidation of receivers, as well as easy exchange of data with other media.

Since this broadcasting system has the common segment structure with terrestrial digital TV broadcasting, the receivers can be consolidated.

(1) Audio encoding system

MPEG-2 AAC (Advanced Audio Coding) and SBR (Spectral Band Replication) have been adopted. However, SBR is optional.

This system satisfies the ITU-R standard, which enables high-quality multiple channelling at a low bit rate of 144 kbps. It has been adopted by BS digital broadcasting and terrestrial digital TV broadcasting. The adoption to the DSB resulted from the consideration of cross-media communications.

(2) Restricted reception system

MULTI2 system has been adopted.

A scramble system has been adopted for charged broadcasting (Pay service). It is the MULTI2 system that has already been adopted for terrestrial digital TV broadcasting, BS digital broadcasting, and CS digital broadcasting. The adoption to the DSB resulted from the consideration of cross-media communications. Introduction of charged broadcasting depends on the result after the feasibility is examined.

(3) Multiplexing System

MPEG-2 system has been adopted, therefore various digital contents such as sound, text, still picture, moving picture and data can be transmitted simultaneously.

In addition, cross-media communications were considered because the MPEG-2 system has been adopted in terrestrial digital TV broadcasting, BS digital broadcasting and CS digital broadcasting.

(4) Transmission channel encoding system

Modulation method

OFDM method that withstands interference with multiple paths has been adopted. One of DQPSK (Differential Quadrature Phase Shift Keying), QPSK, 16 QAM (Quadrature Amplitude Modulation), and 64 QAM can be used. Since different forms of broadcasting are expected, parameters are available for setting carrier modulations and coding rate of inner code.

Error correction system

Reed Solomon (204, 188) for external signalling and convolution coding (convolution rates: 1/2, 2/3, 3/4, 5/6, 7/8) for internal signalling have been adopted.

The adoption resulted from the consideration of high coding efficiency and high burst error correction capability for external signalling, various options of coding rates for internal signalling and cross-media communications.

According to the broadcaster's purpose, they can select the carrier modulation method, error correction coding rate, etc., of the system. The Transmission and Multiplexing Configuration Control (TMCC) carrier transmits the information to the receiver pertaining to the kind of modulation method and coding rate used in the system.

(5) Transmission bandwidths

A transmission bandwidth that uses one OFDM segment of 6/14 MHz (approx. 429 kHz) bandwidth has been primarily adopted. In addition, a transmission bandwidth that uses three OFDM segments is also available.

Figure 4.3.1 shows ISDB-TSB and full-band ISDB-T transmission concept and its reception.

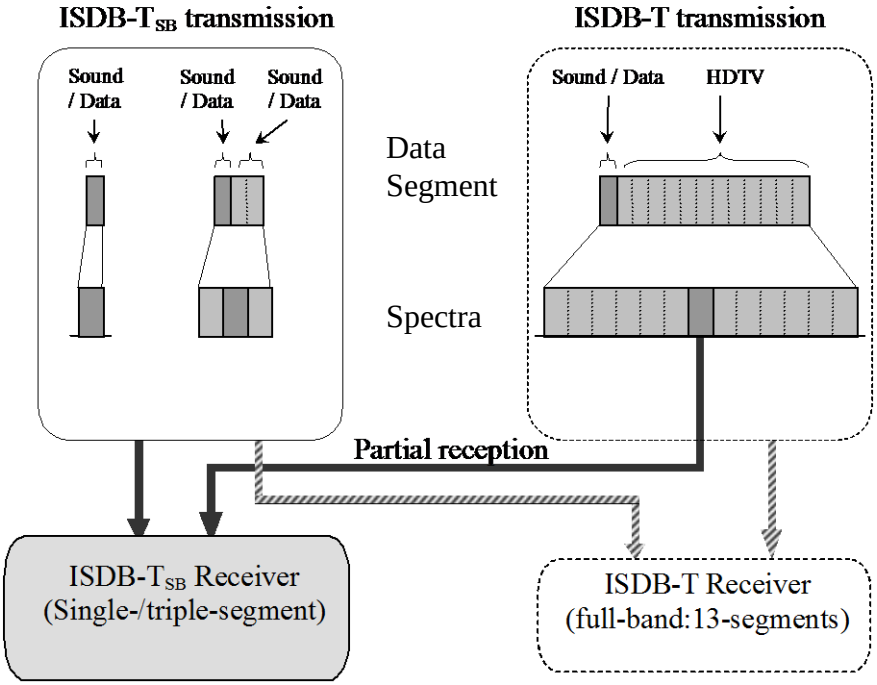

Figure 4.3.1: ISDB-TSB and full-band ISDB-T transmission concept and its reception

(6) Hierarchical transmission and partial reception

In the triple-segment transmission, both one layer transmission and hierarchical transmission can be achieved. There are two layers of A and B in the hierarchical transmission. The transmission parameters of carrier modulation scheme, coding rates of the inner code and a length of the time interleaving can be changed in the different layers.

The centre segment of hierarchical transmission is able to be received by single-segment receiver. Owing to the common structure of OFDM segment, single-segment receiver can partially receive a centre segment of full-band ISDB-T signal whenever an independent program is transmitted in the centre segment.

Figure 4.3.2 shows an example of hierarchical transmission and partial reception. In Japan, hierarchical transmission mode has to be used in the case of triple-segment transmission.

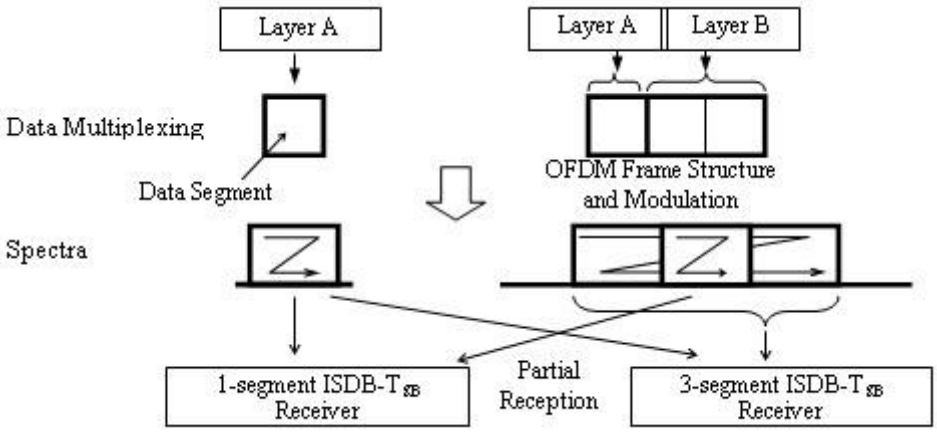

Figure 4.3.2: Example diagram of hierarchical transmission and partial reception

(7) Connected transmission

Efficient transmission

Connected transmission is defined as a transmission of multiple segments (e.g., multiple programmes) from the same transmitter with no guard band.

In addition, the channels of independent broadcasters can be transmitted together without guard bands from the same transmitter as long as the frequency and bit synchronisation are kept the same between the channels.

But broadcasters can have their own RF channel in which they can select transmission parameters independently.

The following two advantages are available from connected transmission:

- Facility and maintenance costs are low because only a single broadcasting facility is required.
- Effective use of the frequency is enabled because no guard band between segments is required.

The connected transmission technique is in operation for the first time in the world.

An example of connected transmission for three TS's (TS1, TS2, and TS3) is shown in Figure 4.3.3. Each TS signal is independently channel-coded. After OFDM-frame adaptation, all segments symbol data are adapted for OFDM-signal generation by single IFFT.

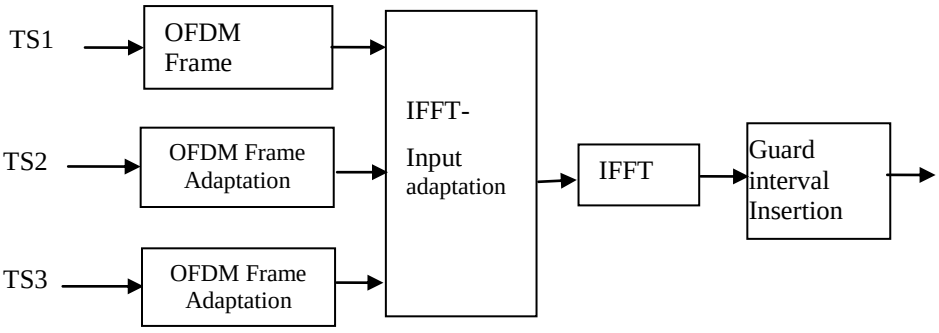

Figure 4.3.3: Example of connected transmission (three TS's)

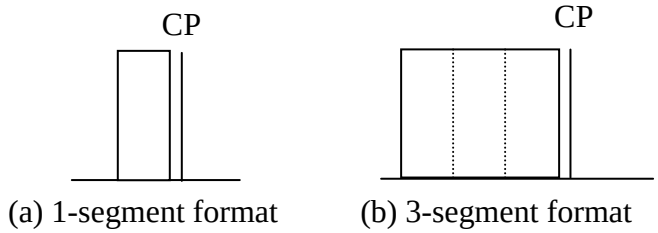

Figure 4.3.4: CP carrier in an ordinary transmission

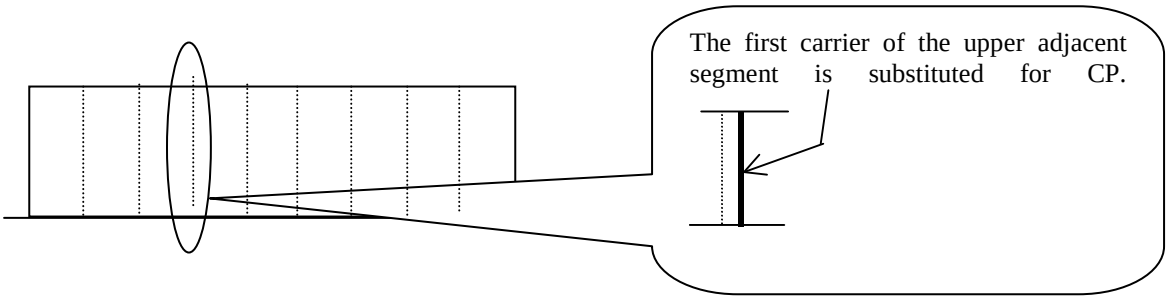

Figure 4.3.5: CP carrier in connected transmission

Parameter restrictions in connected transmission

The same mode should be applied for all segments. Mode means an identification of transmission mode based on the carrier spacing of OFDM carriers.

The same guard interval length must be used for segments. Because all OFDM symbols in connected transmission should be synchronised with each other, modes having different symbol lengths cannot be mixed.

(8) Transmission capacities

The transmission capacities of the single-segment and the triple-segment are shown in Table 4.3.1 and 4.3.2 respectively.

Table 4.3.1: Information bit rates for the single-segment transmission (Segment BW=6/14MHz)

Carrier Modulation	Convolutional Code	Information Rates (kbps)			
		Guard Interval Ratio 1/4	Guard Interval Ratio 1/8	Guard Interval Ratio 1/16	Guard Interval Ratio 1/32
DQPSK QPSK	1/2	280.85	312.06	330.42	340.43
	2/3	374.47	416.08	440.56	453.91
	3/4	421.28	468.09	495.63	510.65
	5/6	468.09	520.10	550.70	567.39
	7/8	491.50	546.11	578.23	595.76
16QAM	1/2	561.71	624.13	660.84	680.87
	2/3	748.95	832.17	881.12	907.82
	3/4	842.57	936.19	991.26	1021.30
	5/6	936.19	1040.21	1101.40	1134.78
	7/8	983.00	1092.22	1156.47	1191.52
64QAM	1/2	842.57	936.19	991.26	1021.30
	2/3	1123.43	1248.26	1321.68	1361.74
	3/4	1263.86	1404.29	1486.90	1531.95
	5/6	1404.29	1560.32	1652.11	1702.17
	7/8	1474.50	1638.34	1734.71	1787.28

Table 4.3.2: Information bit rates for the triple-segment transmission*[5]

Carrier Modulation	Convolutional Code	Information Rates (kbps)			
		Guard Interval Ratio ¼	Guard Interval Ratio 1/8	Guard Interval Ratio 1/16	Guard Interval Ratio 1/32
DQPSK QPSK	½	0.842	0.936	0.991	1.021
	2/3	1.123	1.248	1.321	1.361
	¾	1.263	1.404	1.486	1.531
	5/6	1.404	1.560	1.652	1.702
	7/8	1.474	1.638	1.734	1.787
16QAM	½	1.685	1.872	1.982	2.042
	2/3	2.246	2.496	2.643	2.723
	¾	2.527	2.808	2.973	3.063
	5/6	2.808	3.120	3.304	3.404
	7/8	2.949	3.276	3.469	3.574
64QAM	½	2.527	2.808	2.973	3.063
	2/3	3.370	3.744	3.965	4.085
	¾	3.791	4.212	4.460	4.595
	5/6	4.212	4.680	4.956	5.106
	7/8	4.423	4.915	5.204	5.361

4.3.3 Characteristics

(1) More channels

Terrestrial TV broadcasting was discontinued in July 2011. However, in the case of radio, existing AM, FM, and SW analogue services are expected to continue, thus digital radio is being positioned as an opportunity to provide more channels.

(2) Consortium

At present, digital radio broadcasting is operated by a consortium where corporations interested in digital radio broadcasting have participated. The official name of the consortium is a corporate judicial body called the Association for Promotion of Digital Broadcasting or the DRP (Digital Radio Promotion) for short. The establishment of the consortium was permitted by the Ministry of Internal Affairs and Communications. The DRP has two offices, in Tokyo and Osaka. The operation fund is provided by the member companies. Members include NHK, radio stations, TV

5 In the case of the triple-segment transmission, information rate can be calculated by the combination of segment information rates.

stations, data broadcasting companies, trading companies, automakers and other companies interested in digital radio in the private sector. Over 70 organizations and companies have joined the consortium throughout Japan.

The objectives of the DRP are as follows:

- Implementation of experimental broadcasting for practical application
- Development of broadcasting services
- Research and study on trends in demand
- Promotion and spread of reception

(3) Experimental broadcasting for practical application

The DRP is the only corporate judicial body licensed. Its experimental stations are located in Tokyo and Osaka. The broadcasting facilities are owned and operated by the DRP.

4.3.4 Receivers

(1) Receiver test centre

A receiver test centre has been installed in the DRP office to check the operation of receivers and to support development efforts.

The major activities are as follows:

- To define and revise a specification for standard test streams, and print and distribute its copies
- To make connection experiment items and connection manuals, and distribute its copies
- To define a specification for transmission signals on experimental radio waves
- To operate experimental radio waves and to publicize operation schedules

(2) Trial receivers

At present, no receivers are sold in the commercial market.

Thus, different types of trial receivers were developed for the use of experimental hearing.

Trial receivers include PC-card receivers that have an antenna on the top of a PCMCIA card, portable receivers (1-segment only) for the DRP, and PDA

(Personal Digital Assistant) receivers where a digital radio adapter is mounted.

(3) Receivers expected

In addition to the above mentioned trial receiver types, the following types of receivers can be expected:

- cell phone type receivers
- ordinary and smaller palmtop type receivers
- car stereo type receivers for mobiles, and so on

4.3.5 Overview of Services

Among the current services being broadcast, the following types of contents are unique to digital radio broadcasting.

(1) Multiple voice broadcasting

Listeners can choose a news item, foreign language course, cooking program, etc., in addition to multiple-language concurrent broadcasting of weather forecast and stories.

(2) 5.1 surround broadcasting

Surround broadcast is being provided which includes still images and textual information linked to its programs, for example, photos during performances in a live concert.

(3) Broadcasting of simplified moving images

Actions of a DJ in a studio booth, music promotion images, etc. are being broadcast linked to the programs.

(4) Download service experiment

With the interactive function of cell phones and PDAs, experiments are being provided, including sales of tickets and CDs, and tallying up of questionnaires. Such experiments also include download service of music titles that were broadcast.

4.3.6 Outlook for the Future

At present, digital radio broadcast experiments for practical application are underway through providing different contents of services and operation forms.

The following subjects must be handled successfully for the spread and development of digital radio broadcasting:

- To transfer the experimental broadcasting into actual broadcasting and to expand service areas
- Early release of receivers in the commercial market
- Early start of services in major cities in Japan
- Nationwide deployment of digital radio broadcasting after 2011, when analogue TV broadcasting comes to ends and frequency re-allotments are completed.

4.4 HD Radio System

The HD Radio system was developed by United States based iBiquity Digital, now Xperi. HD Radio was designed to offer digital radio services for regions where limited spectrum prevents the allocation of new frequencies for digital broadcasting. The HD Radio system allows broadcasters to simultaneously transmit both an analogue and digital signal without the need for additional spectrum for the digital signal. The HD Radio system takes advantage of under-utilised portions of the spectrum on either side of the analogue carrier (as defined by the service frequency allocation "mask") and implements frequency re-use by including digital carriers in quadrature to the existing analogue carrier. In either case, the analogue signals are in close proximity to the digital signals and great care must be taken to prevent any interference between them.

The HD Radio system is designed to work in hybrid mode (compatible analogue and digital) as well as to migrate to an all-digital system once analogue radios have been largely replaced in the future. Please refer to figures Figure 4.4.2 to Figure 4.4.6. According to iBiquity Digital, holder of the HD Radio trademark, the "HD" in "HD Radio" does not stand for "High Definition" or "Hybrid Digital".

The HD Radio system offers a number of advantages for broadcasters, consumers and regulators. The HD Radio system replicates the existing coverage patterns of each radio station thereby retaining the existing economic value of the station. Broadcasters can convert to digital broadcasts with a relatively modest investment and retain the vast majority of their existing physical plant. In addition, the introduction of the digital signal in the existing channel allows the broadcaster to retain the station's existing dial position. Because the system supports simulcast of the analogue and digital signals, consumers are able to upgrade to digital over an extended period, taking into account normal equipment replacement cycles. Regulators benefit from this approach because there is no need for extra spectrum allocations or licensing of new stations immediately.

The HD Radio system offers the following features:

- CD quality audio in the FM-band and FM quality audio in the AM band[6]

[6] See the Report of the National Radio Systems Committees, DAB Subcommittee Evaluation of the iBiquity Digital Corporation System Part 1 – FM IBOC, November 29, 2001 ("FM NRSC Report") and Part 2, AM IBOC, dated April 6, 2002 ("AM NRSC Report").

- Digital coverage nearly equivalent to existing analogue coverage. In areas where the digital signal is lost, the system automatically blends to the analogue back-up signal to ensure coverage is never less than existing coverage.
- Advanced coding technologies and time diversity between the analogue and digital signals ensure a robust signal.
- The FM system has demonstrated significant robustness in the presence of severe multi-path, and the AM system has demonstrated significant robustness in the presence of impulse noise.
- The FM system offers options for introducing new data services ranging from 1 to 300 kbps depending on the mode of operation.

According to iBiquity Digital, the HD Radio system has been authorized for commercial launch in the United States, Mexico, Panama, and the Philippines and tested in several other countries such as Romania, Brazil, Argentina, Chile, China, Thailand, Vietnam, Indonesia, Australia, New Zealand, Switzerland, France, and Ukraine. The system is currently in operation on more than 2200 stations throughout the United States and is operational on approximately 75 stations in other countries.

4.4.1 HD Radio Standards Activity

Both the AM and FM HD Radio systems have received international endorsements as well as endorsements in the United States. The AM HD Radio system is included in an ITU-R recommendation adopted in October, 2002 where it is classified as the "IBOC DSB System" (IBOC stands for In-Band, On-Channel, and is pronounced EYE-bahk). The FM HD Radio system is included in an ITU-R recommendation adopted May, 2003 where it is classified as "Digital System C". In the United States, the Federal Communications Commission (FCC) endorsed both the AM and FM HD Radio systems on October 10, 2002.[7] Moreover, the National Radio Systems Committee (NRSC), an industry standards-setting body sponsored by the National Association of Broadcasters (NAB) and the Consumer Electronics Association (CEA), endorsed the FM HD Radio system in a report dated November 29, 2001[8] and the AM HD Radio system in a report dated April 6, 2002.[9] The NRSC endorsement was an outgrowth of an extensive testing program of both the AM and FM HD Radio systems.

The NRSC supervised independent testing of the HD Radio system in both the laboratory and in the field under a comprehensive set of conditions. The tests were designed to assess both the performance of the digital system as well as the compatibility of the

[7] *Digital Audio Broadcasting Systems And Their Impact on the Terrestrial Radio Broadcast Service*, MM Docket No. 99-325, *First Report and Order* (October 10, 2002).

[8] DAB Subcommittee Evaluation of the iBiquity Digital Corporation IBOC System Part 1 – FM IBOC dated November 29, 2001 ("NRSC FM Report").

[9] DAB Subcommittee Evaluation of the iBiquity Digital Corporation IBOC System Part 2 – AM IBOC dated April 6, 2002 ("NRSC AM Report").

digital system with existing analogue operations in the AM and FM bands. In the laboratory, the digital system was subjected to a range of conditions associated with typical broadcasts in the AM and FM band. For example, the FM system was tested in the presence of multiple forms of multipath fading as well as numerous examples of co-channel and adjacent channel interference. In the case of AM, the digital system was tested in the presence of impulse noise in addition to the typical co-channel and adjacent channel interference associated with the AM band.

Field tests were conducted using commercial AM and FM stations selected for their characteristics in terms of interference from adjacent-channel stations as well as to represent a variety of antenna and implementation configurations. For both the laboratory and field tests, objective measurements were recorded and considered in the evaluation process. In addition, thousands of audio samples were produced and used to conduct an extensive subjective evaluation process. General population listeners were asked to rate a variety of sound samples from the laboratory and field tests to assess the real-world response to the introduction of the HD Radio system. The test results demonstrated that the HD Radio system consistently outperformed existing analogue AM and FM radio. Moreover, the tests established that the introduction of the HD Radio system will not cause harmful interference to existing analogue broadcasts in the vast majority of cases. In those cases where new interference is expected to occur, it is expected that new interference will be most common in peripheral areas outside the core coverage areas of a station. The NRSC concluded that this minimal risk of additional interference is more than outweighed by the improved audio quality and performance that the HD Radio system repeatedly demonstrated throughout the test program.[10]

4.4.2 HD Radio AM and FM Receivers

The conversion of stations to HD Radio broadcasts has been accompanied by the introduction of HD Radio receivers for every major receiver segment. As of December 31, 2013, more than 17.5 million HD Radio receivers were in the commercial market. HD Radio technology is available as original equipment and aftermarket automobile receivers as well as in home AVR, table-top and portable receivers. Virtually all automobile manufacturers serving the North American market offer HD Radio receivers in their vehicles as standard equipment. Aftermarket HD Radio receivers can be purchased online and at thousands of traditional retailers.

HD Radio receivers are in use, and additional receivers are being sold routinely in the U.S., Canada and Mexico. Alpine, Clarion, JVC, Kenwood, Pioneer, and Sony sell aftermarket automobile receivers with HD Radio technology in Canada. Denon, Onkyo and Yamaha offer HD Radio home AVR products. The following automotive brands offer HD Radio receivers in their cars sold in North America: Acura, Audi, Bentley, BMW, Buick, Cadillac, Chevrolet, Dodge, Ford, GMC, Hyundai, Infiniti, Jaguar, Jeep,

[10] *See* NRSC FM Report at 9; NRSC AM Report at 8.

Land Rover, Lexus, Lincoln, Mazda, Mercedes-Benz, Mini, Mitsubishi, Porsche, Ram, Rolls-Royce, Scion, Subaru, Tesla, Toyota, Volkswagen, and Volvo.

These receiver sales reflect the trend by manufacturers to standardise products for global or regional rather than national markets. Consumers will have the benefit of lower prices and a larger selection of HD Radio receivers by leveraging the commercial success of HD Radio technology in other North American markets.

HD Radio receivers are inherently simpler and lower cost than new band receivers since much of the circuitry required for the digital signals is common to that used to process the existing analogue signal. As a result, HD Radio receivers typically cost no more than 20% more than existing analogue receivers.

HD Radio receivers are affordable with many models priced from $39.99 to $129.99. Figure 4.4.1 shows the range of radio products available including portable radios, personal navigations devices, home receivers, and car receivers.

Figure 4.4.1 - Typical HD Radio receivers

The technology is now implemented in fourth generation HD Radio semiconductors featuring lower power consumption and lower costs.

4.4.3 HD Radio System Technical Design Overview

The HD Radio system is designed to permit a smooth evolution from current analogue Amplitude Modulation (AM) and Frequency Modulation (FM) radio to a fully digital In-

Band On-Channel (IBOC) system. This system can deliver digital audio and data services to mobile, portable, and fixed receivers from terrestrial transmitters in the existing Medium Frequency (MF) and Very High Frequency (VHF) radio bands. The system is designed to allow broadcasters to continue to transmit analogue AM and FM simultaneously with new, higher-quality and more robust digital signals, allowing broadcasters and their listeners to convert from analogue to digital radio while maintaining each station's current frequency allocation.

The HD Radio system allows a broadcast station to offer multiple services. A service can be thought of as a logical grouping of application data identified by the HD Radio system. Services are grouped into one of two categories:

1. Core Services:
    a. Main Programme Service (both Audio and Data (Programme Info))
    b. Supplemental Programme Service (Multicast Audio and Data (Programme Info))
    c. Station Information Service (SIS)
2. Advanced Application Services (AAS)

The flow of service content through the HD Radio broadcast system is as follows:

1. Service content enters the HD Radio broadcast system via Service Interfaces;
2. Content is assembled for transport using a specific protocol;
3. It is routed over logical channels via the Channel Multiplex;
4. And finally it is waveform modulated via the Waveform / Transmission System for over-the-air transmission.

The system employs audio encoding to reduce the sampled audio signal bit rate and baseband signal processing and forward error correction to increase the robustness of the signal in the transmission channel. This allows a high quality audio signal plus ancillary data to be transmitted in adjacent frequency partitions and at low levels that do not interfere with the existing analogue signals.

4.4.4 Core Services

(1) Main Programme Service (MPS)

The Main Programme Service (MPS) is a direct extension of traditional analogue radio. MPS allows the transmission of existing analogue radio-programming in both analogue and digital formats. This allows for a smooth transition from analogue to digital radio. Radio receivers that are not HD Radio enabled can continue to receive the traditional analogue radio signal, while HD Radio receivers can receive both digital and analogue signals via the same frequency band. In addition to digital audio, MPS includes digital data related to the audio

programming. This is also referred to as Programme Information (Programme Info).

(2) Supplemental Programme Service (SPS)

The Supplemental Programme Service (SPS) provides capacity for additional audio programmes in a multicast transmission. This service enables radio stations to send up to eight unique audio programmes. Radio receivers that are not HD Radio enabled can continue to receive the traditional analogue radio signal, while HD Radio receivers can receive the new SPS content. In addition to digital audio, SPS includes digital data related to the audio programming. This is also referred to as Programme Information (Programme Info).

(3) Station Information Service (SIS)

The Station Information Service (SIS) provides the necessary radio station control and identification information, such as station call sign identification, time and location reference information. SIS can be considered a built-in service that is readily available on all HD Radio stations. SIS is a required HD Radio service and is provided dedicated bandwidth.

(4) Advanced Application Services (AAS)

Advanced Application Services (AAS) is a complete framework in which new applications may be built. In addition to allowing multiple data applications to share the Waveform / Transmission medium, AAS provides a common transport mechanism as well as a unified Application Programming Interface (API). On the transmission side, broadcasters utilise the common AAS interface to insert service(s) into their signal; receiver manufacturers utilize the AAS 'toolkit' to efficiently access these new services for the end-user. AAS includes separate audio programming such as reading services and other secondary aural and data services.

(5) Waveforms and Spectra

The HD Radio system provides a flexible means of transitioning to a digital broadcast system by providing three new waveform types: Hybrid, Extended Hybrid, and All Digital. The Hybrid and Extended Hybrid types retain the analogue FM signal, while the All Digital type does not.

All three waveforms operate well below the allocated *spectral emissions mask* as currently defined by the United States Federal Communications Commission.
The *digital signal* is modulated using *orthogonal frequency division multiplexing* (OFDM). OFDM is a parallel modulation scheme in which the data stream modulates a large number of orthogonal subcarriers, which are transmitted simultaneously. OFDM is inherently flexible, readily allowing the mapping of logical channels to different groups of subcarriers.

FM Hybrid Waveform

The digital signal is transmitted in sidebands on either side of the analogue FM signal in the *Hybrid waveform*. The power level of each sideband is approximately 23 dB below the total power in the analogue FM signal for a combined digital power level -20dBc. Additionally, the digital power may operate at elevated levels up to -10dBc for increased digital coverage. The *analogue signal* may be monophonic or stereo, and may include subsidiary communications authorisation (SCA) channels. This service option provides up to 96kbps of capacity. See Figure 4.4.2 for more details.

Broadcasters also have the option to transmit the digital carriers at asymmetric power levels. With asymmetric sidebands, the broadcaster is able to increase the power level of the digital sideband farthest away from any first adjacent station, thereby minimizing any interference. As has been demonstrated in tests and real-world experience in the United States, this allows stations to minimize the risk of adjacent-channel interference while maximizing digital coverage.

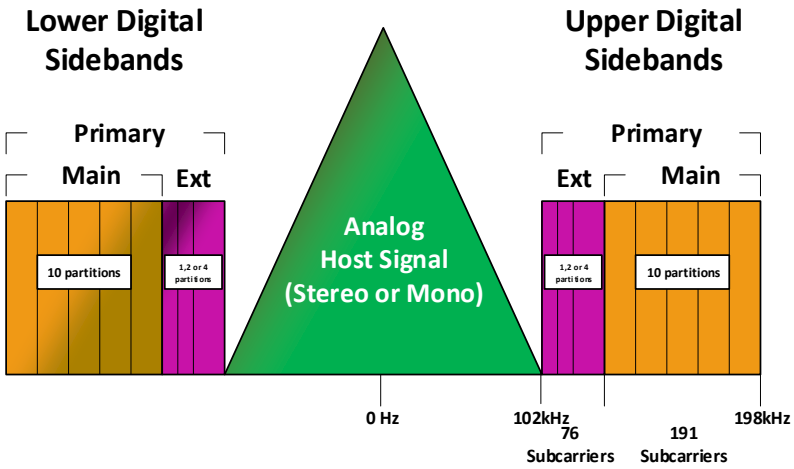

Figure 4.4.2 - Hybrid spectrum allotment of FM HD Radio system; Extended Hybrid operation involves use of up to four Extended Partitions in addition to the 10 Main Partitions

FM Extended Hybrid Waveform

In the *Extended Hybrid waveform*, the bandwidth of the Hybrid sidebands can be extended toward the analogue FM signal to increase digital capacity. This additional spectrum, allocated to the inner edge of each primary sideband, is termed the primary extended sideband. This service option provides up to 144kbps of capacity. See Figure 4.4.2 for more details.

FM Single Sideband Waveform

The *Hybrid waveform* may also be transmitted in a single-sideband configuration. This transmission option may be selected for broadcast markets where radio

stations are spaced by 100kHz or closer. This service option provides up to 144kbps of capacity. See Figure 4.4.3 for more details.

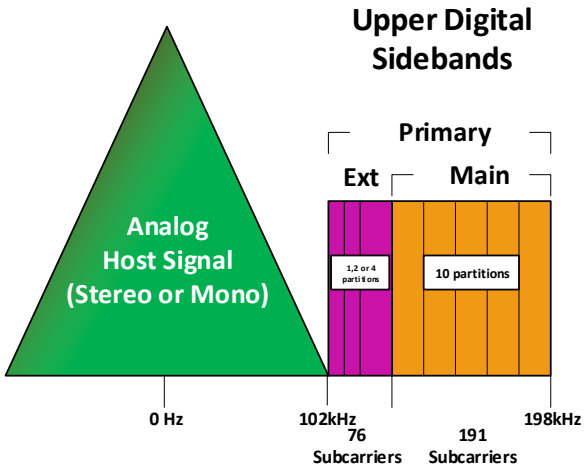

Figure 4.4.3 - Single Sideband spectrum allotment for FM hybrid HD Radio system

FM All Digital Waveform

The greatest system enhancements are realised with the *All-Digital waveform*, in which the analogue signal is removed and the bandwidth of the primary digital sidebands is fully extended as in the Extended Hybrid waveform. In addition, this waveform allows lower-power digital *secondary sidebands* to be transmitted in the spectrum vacated by the analogue FM signal. Approximately 300 kbps of capacity is available in All Digital mode. See Figure 4.4.4 for more details.

The *All Digital waveform* may also be transmitted in a single-sideband configuration. This transmission option may be selected for broadcast markets where radio stations are spaced 100 kHz or closer. This service option provides up to 144kbps of capacity.

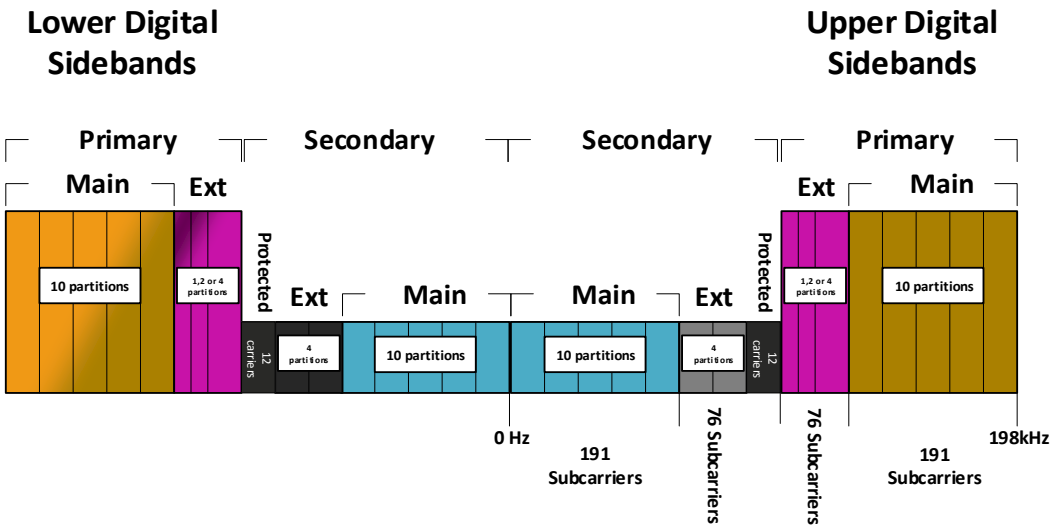

Figure 4.4.4 - All Digital spectrum allotment of FM HD Radio system

AM Hybrid

Unlike the FM HD Radio system, the AM system contains no extended hybrid capacity. The basic hybrid broadcast mode enables transmission of up to 36kbps audio service. The transmission utilises 3 bands of digital carriers at different power levels, which minimize station-to-station interference.

The allocation scheme is represented in Figure 4.4.5 for more details.

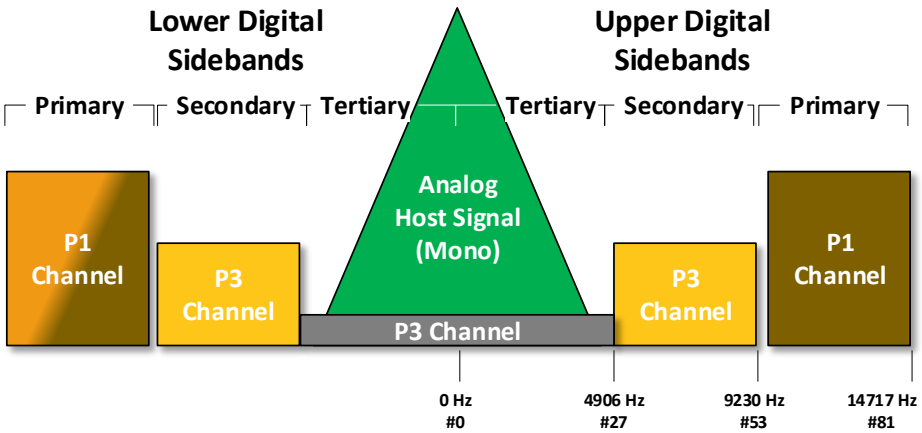

Figure 4.4.5 - Hybrid AM HD Radio system spectrum allotment

AM Core-Only Waveform

The core-only AM transmit mode removes the digital carriers under the analogue host. This operational service eliminates any potential interference to the analogue transmission, but reduces the digital throughput to 20kbps. Stereo broadcast can be achieved by utilising the parametric stereo functions in the HDC codec. The allocation scheme is represented in Figure 4.4.6

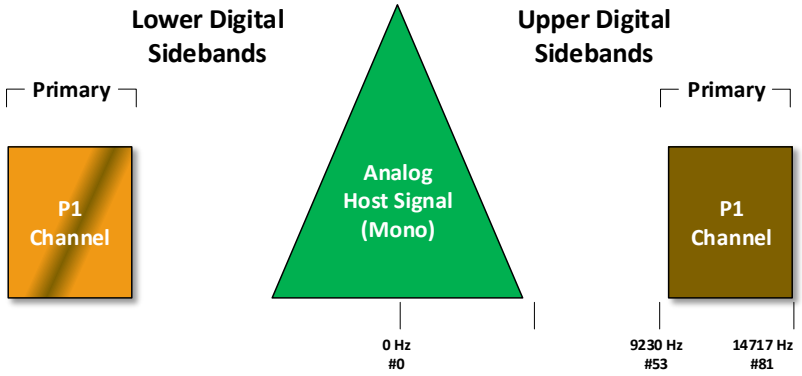

Figure 4.4.6 - AM HD Radio Core-Only spectrum allotment

AM All Digital Waveform

The HD Radio system allows for transition to a full digital broadcast. The broadcast modes can be a full digital capacity service (40kbps) with all primary, secondary and tertiary sidebands, or a reduced capacity service (20kbps) with only primary sidebands. The allocation scheme for full capacity service is provided in Figure 4.4.7

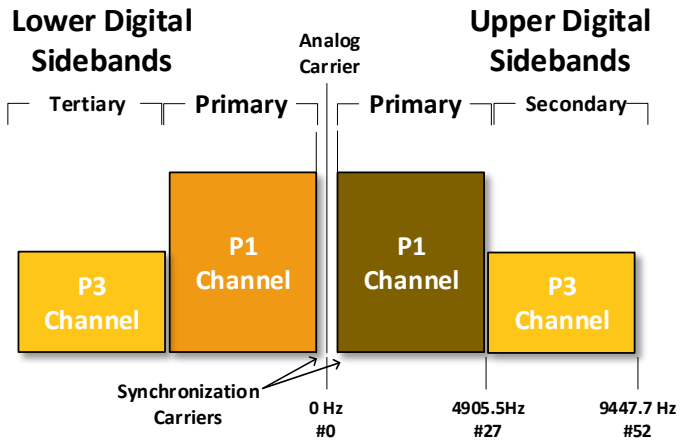

Figure 4.4.7 – All Digital AM HD Radio system spectrum allotment

4.4.5 HD Radio Subsystems

A basic block diagram representation of the system is shown in Figure 4.4.8. It represents the HD Radio digital radio system as three major subsystems.

- Audio source coding and compression
- Transport and Service Multiplex
- IBOC OFDM

The HD Radio system model resembles the layered model in ISO 7498.

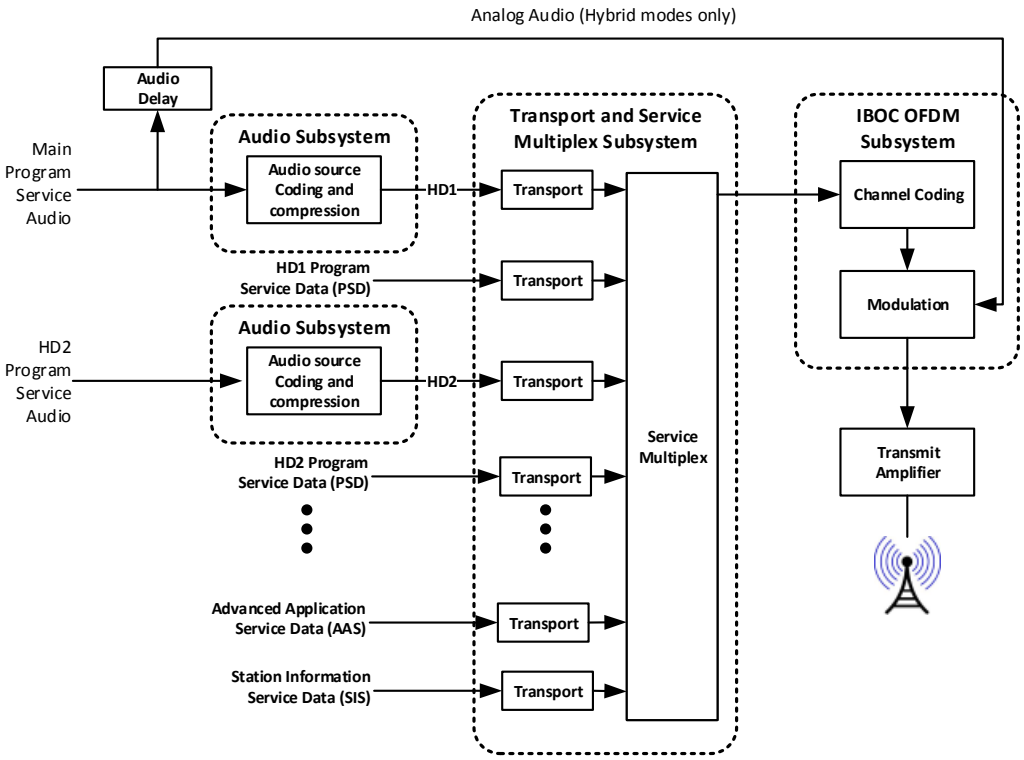

Figure 4.4.8 - Functional Block Diagram of HD Radio Transmission System

(1) Audio Source Coding and Compression

The Audio subsystem performs the source coding and compression of the sampled digitised Main Programme Service (MPS) Audio programme material and all Supplemental Programme Service (SPS) audio content. "Source coding and compression" refers to the bit rate reduction methods, also known as data compression, appropriate for application to the audio digital data stream. In hybrid modes the MPS Audio is also analogue modulated directly onto the carrier for reception by conventional analogue receivers. Several categories of data may also be transmitted on the digital signal including station identification, messages related to the audio programme material, and general data services.

(2) Transport and Service Multiplex

"Transport and service multiplex" refers to the means of dividing the digital data stream in "packets" of information, the means of uniquely identifying each packet or packet type (data or audio), and the appropriate methods of multiplexing audio data stream packets and data stream packets into a single information stream. The transport protocols have been developed specifically to support data and audio transmission in the AM and FM radio bands. The HD Radio system transport is modeled loosely on the ISO 7498 standard.

4.4.6 RF/Transmission System

"RF/Transmission" refers to channel coding and modulation. The channel coder takes the multiplexed bit stream and applies coding and interleaving that can be used by the receiver to reconstruct the data from the received signal, which because of transmission impairments, may not accurately represent the transmitted signal. The processed bit stream is then modulated onto the OFDM subcarriers that are transformed to time domain pulses, concatenated, and up-converted to the FM band.

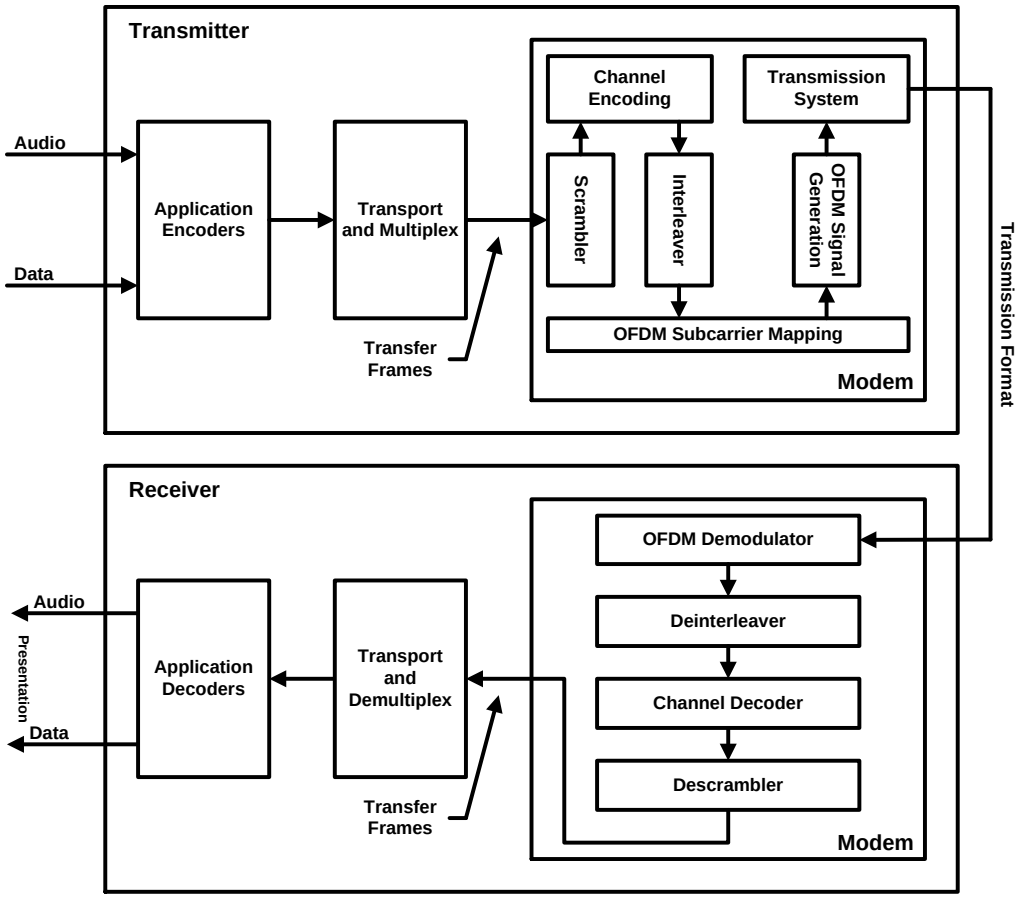

Figure 4.4.9 - Block diagram of HD Radio transmission & reception multiplexing

4.4.7 Receiver Systems

A functional block diagram of an HD Radio FM receiver is presented in Figure 4.4.10 The signal is received by the antenna, passed through an RF front end, and mixed to an intermediate frequency ("IF"), as in existing analogue receivers. Unlike typical analogue receivers, however, the signal is then digitised at IF, and digitally down-converted to produce in-phase and quadrature baseband components. The hybrid signal is then separated into an analogue component and a digital component. The analogue FM stereo signal is digitally demodulated and de-multiplexed by the FM receiver to produce a sampled, stereo audio signal.

The baseband digital signal is first sent to the modem, where it is processed by the First Adjacent Cancellation system to suppress interference from potential first-adjacent analogue FM signals. The signal is then OFDM demodulated, and passed to the FEC decoding and de-interleaving function. The resulting bit stream is processed by the codec function to decompress the source-encoded digital audio signal. This digital stereo audio signal is then passed to the blend function.

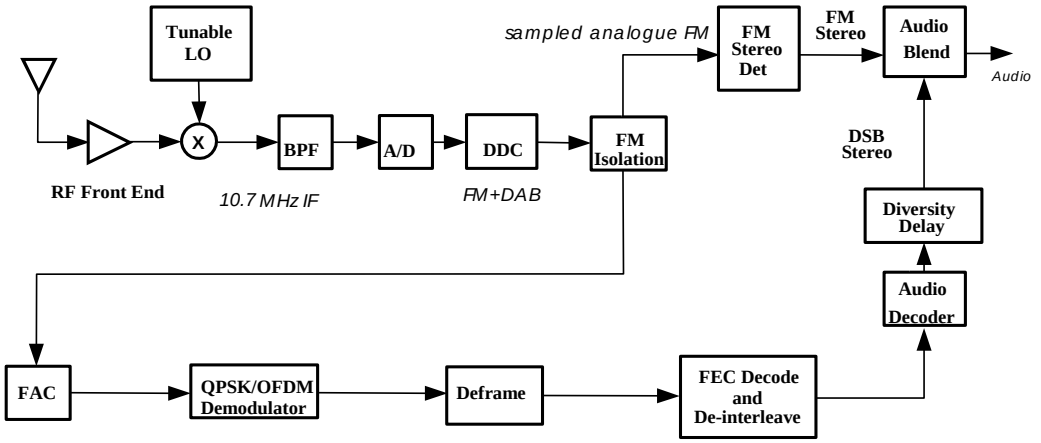

Figure 4.4.10 - FM hybrid IBOC receiver functional block diagram

4.4.8 Common System Features

HD Radio broadcasting provides many benefits that can help radio remain competitive with other distribution platforms. Digital broadcasts provide listeners with enhanced audio quality. Digital FM broadcasts offer CD-quality sound, and digital AM provides stereo FM-quality sound. The digital system eliminates the hiss, clicks and pops frequently associated with analogue broadcasts. Advanced coding techniques virtually eliminate multipath interference for digital FM broadcasts, which can be particularly important in dense urban areas. The system also supports new audio and data services that cannot be offered using an analogue broadcasting platform.

(1) Sound Quality
Sound quality of digital radio systems has improved dramatically in recent years with progressively lower bitrates being shown in various applications as achieving near CD quality. Rates well below 96 kbps are routinely utilised in digital radio systems in operation in North America and meeting with wide customer acceptance.

(2) Audio Frequency Response
It is difficult to evaluate the exact frequency response of a codec, because it will change dynamically depending on the available bit rate and the difficulty of encoding the instantaneous audio material. A quick example can be demonstrated using a single-carrier frequency sweep on any codecs. Typically total frequency response of 20 kHz is measured in such tests, even at 16 kbps. On the other hand, encoding a rich stereo programme on the same codec at 16 kbps, may result in a pure monophonic signal of less than 5 kHz. Consequently, the codec model has to be tailored to the desired frequency response and overall quality of the programme content being broadcast.

(3) Multipath Tolerance
OFDM based systems are capable of handling multipath within a guard interval. HD Radio system has also been shown to tolerate significant effects of multipath in challenging propagation conditions.

(4) Information Services
All HD Radio broadcasters have the ability to offer "Programme Information" such as the artist name, song title and station information. The system is able to transmit this information for all digital channels, including multicast channels. The Programme Information feature offers a richer experience than the analogue radio broadcast data service ("RBDS") due to greater capacity and more flexibility in how the system displays information. Programme Information helps broadcasters meet listener expectations for this information, which is routinely available from satellite radio and Internet streaming.

The system's multicasting feature allows digital FM broadcasters to introduce up to eight new digital-only programmes that are unrelated to a station's analogue broadcast. Although multicasting is an optional feature, it is a popular option among HD Radio broadcasters. Radio stations typically transmit two or three additional audio programmes. These multicast channels are broadcast along with the digital simulcast of the station's existing analogue programming. The digital simulcast channel is referred to as the HD1 channel. Multicast channels are referred to as HD2/HD3/HD4 channels. Multicasting allows broadcasters to offer new choices to consumers without the need for a new station or any significant capital expense. Broadcasters use multicasting to offer a wide range of new formats and innovative programming. Multicasting has been used to introduce ethnic language and cultural programming that would not be economically viable as a main channel broadcast. Other broadcasters have used multicasting to create

extensions of their existing programming, to offer new public affairs programming, to introduce new music formats and to experiment with new programming targeting local audiences.

"Artist Experience" allow broadcasters to transmit static visual images that are displayed on the screen of the receiver. These images can include the album art associated with the song being broadcast, related images of the band or artist, station logos and commercial images.

iTunes Tagging allows broadcasters to include a special code along with their music programming. Listeners can press a "Tag" button on their receiver to download the code. When the listener synchronizes an iPhone or iPod with the radio, a screen automatically offers the option to purchase the songs "Tagged" on the radio. "Bookmarking" allows listeners to generate a list of songs but does not include the automatic ability to purchase.

The HD Radio system also allows broadcasters to offer new data services unrelated to the audio broadcast. Some stations broadcast news, sports, weather, and other information that can be accessed by touching a button on the screen of the radio. The HD Radio system can be used to broadcast traffic updates and new map information for car navigation systems faster than Radio Broadcast Data System (RBDS) or satellite based systems and without incurring any charges for use of cellular networks. The point-to-multipoint architecture of FM radio makes it particularly suited to these types of data services.

The HD Radio system provides capability to transmit public service messages and notifications through the Emergency Alert service. This public service broadcast may be integrated into existing warning and messaging systems. The digital information conveyed in the alert service may be used to trigger or "wake-up" receivers, provide audible messages in different languages, and display important text information to the consumer.

4.4.9 Infrastructure Requirements

Figure 4.4.11 highlights the basic infrastructure for broadcasting HD Radio technology. Radio stations require three main digital processing components to implement HD Radio functionality:

(1) Exciter Engine – digital modulation component to generate the OFDM waveform
(2) Exporter – manages the audio processing for HD1 and multicast programmes
(3) Importer – manages data feeds and capacity configurations for advanced data features such as traffic services and programme images

Studio automation equipment is recommended to provide full content synchronisation of programme text (Programme Info) and album images. It is desirable to have content managed in a database or other programme catalogue.

Studio-Transmitter-Link (STL) equipment is also necessary to relay formatted digital packets from the studio to the transmitter site.

Radio stations should also have reliable IP networks. Much of the content is digital audio or data from internal or external sources. Reliability of data feeds and latency of content distribution must be managed by experienced IP engineers to ensure highest quality of service.

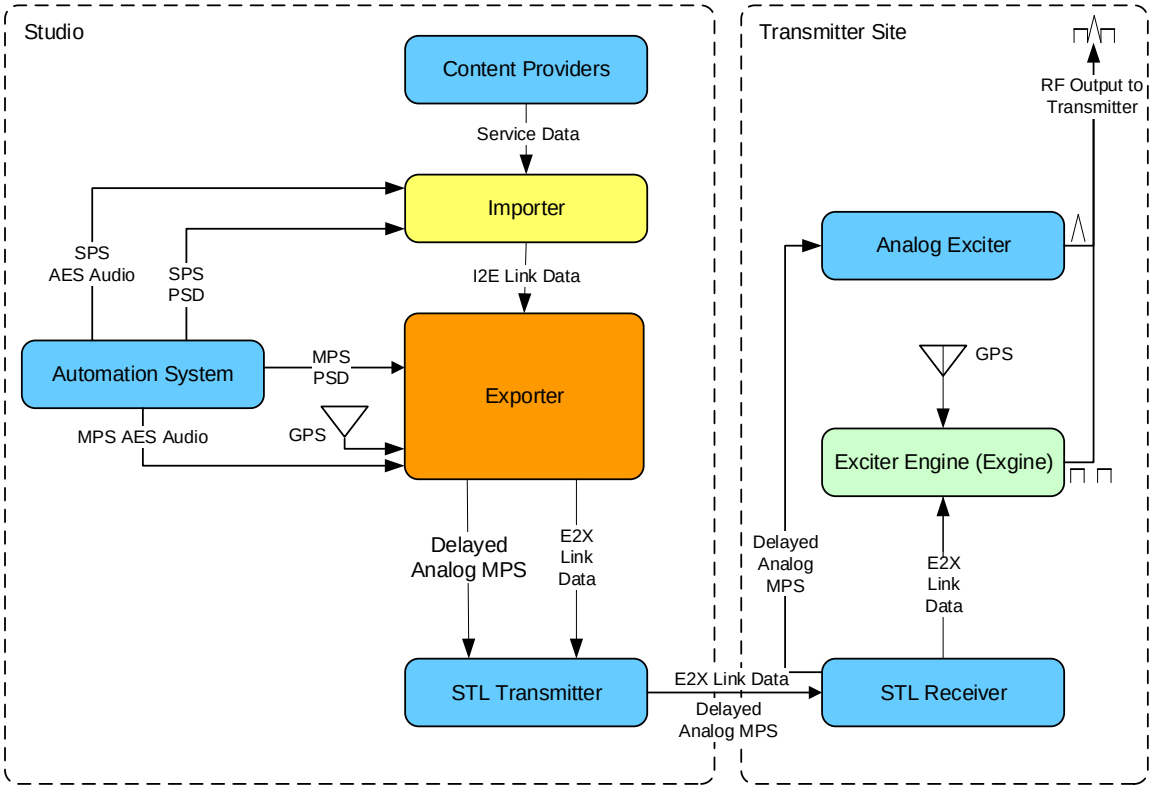

Figure 4.4.11 - HD Radio Infrastructure

Combining the digital and analogue signals can be achieved with a variety of methods. For AM hybrid broadcast, the analogue and digital signals are combined in the HD Radio exciter before feeding the transmitter.

For FM hybrid broadcast, the analogue and digital signals are combined through separate RF paths, separate antenna paths, or a common path. A summary of the different methodologies for combining FM hybrid signals is provided in Figure 4.4.11. Each method of operation has different cost and power considerations.

(1) Low-level combined

Also known as Common Amplification, low-level combining involves combining the analogue and digital signals prior to RF amplification stage. This solution involves only one transmit amplifier, but requires appropriate headroom.

(2) High-level combined

This solution allows radio stations to maintain existing amplifier for analogue and use lower-powered amplifier for the digital. Typically, a 10dB combiner is used. However, the analogue transmitter must operate at higher power level to account for loss. This may result in increased operating costs at the radio station.

(3) Separate dual-antennas

Alternatively, radio stations may operate separate antennas for the analogue and digital transmission. This configuration results in signal combining in free space. Care must be taken to manage the antenna spacing and orientation in order to maximize digital coverage and reduce pattern nulls with respect to the analogue coverage. Generally, separate antennas result in lowest operational cost to the radio station.

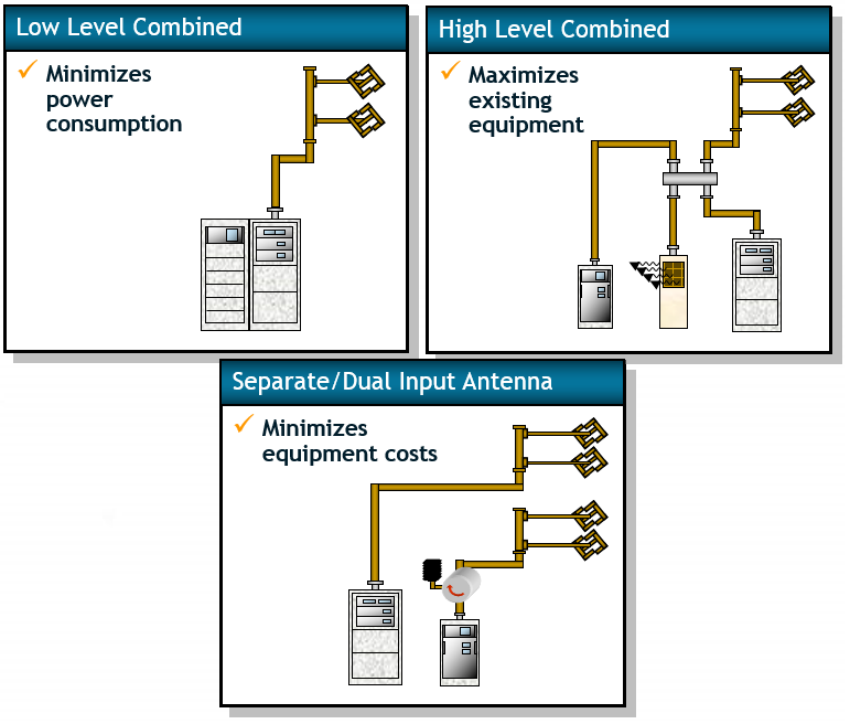

Figure 4.4.12 - HD Radio system FM hybrid combining methods

4.4.10 Deployment Status

Status of Rollout of HD Radio Technology in the U.S.

The US Federal Communications Commission (FCC) authorized US broadcasters to commence HD Radio broadcasts in 2002. Since that time, more than 2,200 AM and FM stations have adopted HD Radio technology throughout the United States. There are HD Radio stations operating in every state, the District of Columbia and Puerto Rico. Over 500 stations in the United States support Artist Experience on over 900 digital channels. US broadcasters have introduced more than 1,475 multicast channels resulting in more than 2,675 digital streams in use today. The multicasting feature has resulted in a surge of creativity among FM broadcasters seeking to reach listeners with new formats. Some broadcasters have used multicasting to create extensions to existing formats. Others have created hyper niche formats or unique market specific formats that might not be commercially feasible on the full FM signal. Many non-commercial stations have used multicasting to offer new public affairs programming.

Some statistics:

2,232 Stations have been converted
274 Measured Markets
198 Top 200 Measured Markets
50 States Served (+ DC & PR)
Population Served: 282 Million (90% US 6+)

1,469 Multicasts
1,168 HD2 Channels
269 HD3 Channels
32 HD4 Channels
Population Served: 257 M

HD Radio Rollout in Mexico

Mexico authorized the introduction of HD Radio technology for the AM and FM bands in 2011. Since stations began converting to digital operation in 2012, 38 AM and FM stations have been equipped with HD Radio broadcast equipment, including 13 stations in Mexico City. These stations reach some 32 million people nationwide – more than 25% of the Mexican population. As has been the case in the United States, Mexican broadcasters are experimenting with the new services the HD Radio system can support. There are over 25 new multicasting channels in operation delivering subscription-free digital music and infotainment channels to the Mexican public.

Automakers continue to expand the number of vehicles with built-in HD Radio receivers to Mexico, including Buick, Chevrolet, Dodge, Ford, GMC, Infiniti, Jeep, Lincoln, Mazda, Mitsubishi, Mercedes-Benz, Ram and Toyota. HD Radio aftermarket and home products are also available from multiple brands including Alpine, Kenwood, Insignia, Pioneer and Sony. Major Mexican retailers such as Best Buy, Coppel, Elektra, FAMSA, Liverpool, Sears and Woolworth carry diverse models.

Some statistics:

38 Stations Converted
24 Cities
9 Top 20 Cities
Population Served: 32.1 Million (27% of population in Mexico)

Global deployments of HD radio [Source: According to iBiquity Digital, now Xperi.]

- **Philippines** – The Philippines National Telecommunications Commission finalised its rules for FM digital radio operations on November 11, 2007. RMN Broadcast led the first HD Radio station conversion in Philippines and 15 HD Radio stations converted to HD Radio broadcasting including ABSCBN, FEBC, Eagle, IFM and WT Wild FM currently being expanded coverage with HD Radio infrastructure and more Broadcasters are converting like RJ, Big Radio and Yes FM to support the nationwide HD Radio coverage.

- **Thailand** – In March 2006, an HD Radio system was installed for a public radio network currently operating three HD Radio stations in Bangkok to provide public targeting mass transit commuters with HD Radio based Traffic and Data information systems.

- **Vietnam** - Voice of Vietnam (VOV) commenced AM and FM HD Radio trial transmissions in Hanoi in June, 2008 including multicasting, in anticipation of making HD Radio technology a standard. In February, 2009, a joint trial with VOV and the Asia Pacific Broadcast Union (ABU) took place in Hanoi. Trial operations continue in Hanoi and Ho Chi Minh City (Saigon). The HD Radio based Data and Traffic was evaluated by VoV.

- **Bangladesh** – On January 1, 2012, Dhaka FM 90.4 became the first station in the country to commence HD Radio broadcasts.

- **China** – iBiquity, now Xperi, conducted a test of HD Radio technology with a test station in China during February 2008 in Beijing. In 2011, iBiquity and Digital Wave (a Chinese technology company) formed a joint venture called HuaSheng Technologies LLC to pursue adoption of a customised HuaSheng system as the digital radio standard in China.

- **Canada** – The Canadian Broadcasting Corporation (CBC) began HD Radio testing in September 2006, focusing on transmissions from Toronto and Peterborough, Ontario. The Canadian Radio-Television and Telecommunications Commission (CRTC) has since revised its policy on digital radio to allow HD Radio operations pursuant to Public Notice CRTC 2006-160. Xperi is seeing continued growth in Canada with the successful launch of Canadian Multicultural Radio (CMR) 101.3 FM in Toronto and widespread availability of HD Radio receivers.

- **Brazil** – Since the first HD Radio station went on air in September, 2005, about 30 stations in Brazil have installed the technology covering an area of 30 million people. Brazil's Ministry of Communications is currently evaluating formal authorisation of digital radio operations in the country.

- **Dominican Republic** – Raíces FM initiated the first FM HD Radio operations in the country in late 2008. Two more stations have since begun regular digital broadcasts. INDOTEL, the national spectrum regulator, has announced that any station can use HD Radio technology on a provisional basis, and plans to announce an official national standard in the near future.

- **Trinidad and Tobago** – Star 94.7 FM and Guardian Media are broadcasting HD Radio signals commercially in Port-of-Spain.

- **Panama** – HD Radio on-air testing/demonstrations started in late 2008 and Panama's President signed a bill into law on 12 May 2009 making the HD Radio system the official (and only) digital radio standard in that country. Antena8 100.1 in Panama City was the first commercial digital station in the country, and two more stations have since joined them on the air.

- **Argentina** – AM HD Radio technology was tested in 2004 with initial trials in Buenos Aires. Further testing of the technology was conducted in early 2007.

- **Colombia** – Caracol Radio conducted tests of FM HD Radio technology in 2008-09 in Bogota.

- **Bosnia** – Trial and tests of HD Radio technology began in Sarajevo in March 2007.

- **Czech Republic** – Initial testing of the HD Radio system commenced in Prague in February 2007.

- **Germany** – Radio Regenbogen began HD Radio operations on 102.8 MHz in Heidelberg on December 3, 2007 pursuant to government testing authority and operated through 2008. Extensive reports were submitted to the German regulatory agency for further consideration.

- **Poland** – An HD Radio trial began in Warsaw in 2006 in order to demonstrate the technology to local radio stations.

- **Switzerland** – VHF testing sponsored by Radio Sunshine and Ruoss AG began in Lucerne in April 2006 and operated through 2011.

- **Ukraine** – The first FM HD Radio broadcasts in Kiev went on the air in October 2006 on two FM stations operated by the First Ukrainian Radio Group.

- **Romania** – An on-air HD Radio Technology demonstration with multicast was held in Baia Mare, Romania on 23-24 October 2008 featuring broadcasters and regulators, on an FM station owned by 2M Prima Telecom. In June 2010, Radio Guerrilla 94.8 in Bucharest launched HD Radio Technology. In January 2012, Rock FM 100.6 in Bucharest began broadcasting four digital programs. Bucharest FM 100.6 and Craiova FM 98.0: HD1 Rock FM, HD2 Kiss FM, HD3 One FM, HD4 Magic FM.

4.4.11 Latest updates from NABA

HD Radio

4.4.11.1 The Consumer Benefit

As with other consumer electronics (CE) digital upgrades, the HD Radio system provides consumers substantial advantages over legacy analogue technology. CE digital transitions have historically given consumers better quality, more choice, more services, and interactivity -benefits that are all realized by the HD Radio system.

HD Radio technology improves audio quality: consumers receive sound quality equal to or better than (depending upon bit rate) analogue FM. The potential for CD-like sound quality for over the air services is possible. HD Radio signals are much less prone to interference than existing analogue signals as well, leading to cleaner audio.

HD Radio technology increases choice: through the multicasting capability, digital FM broadcasters are able to offer multiple audio channels over a single FM frequency. The new audio channels, known as HD2, HD3, etc., offer consumers new, diverse, targeted content. Multicasting has led to an explosion of programming creativity, with formats such as dance, garage band, gospel, bluegrass, jazz, comedy and indie rock. A greater selection of audio choices has expanded listener appetites for new music. These new audio sources are often referred to as “infinite shelf space” and radio needs these additional channels to meet a more diverse consumer taste in music.

The opportunity for additional public service programming exists including emergency alerting and programming, minority language programming, and community services and information. The opportunity to better serve the listener is all enhanced by digital radio.

The HD Radio system provides new services and interactivity: by using Program Service Data (PSD), stations can display text information such as artist, song title, station call letters or other real-time information like stock quotes and sports scores on the radio’s screen. Market research suggests that program associated information is an important feature for customer satisfaction. Industry-leading companies are implementing systems to deliver real-time and on-demand traffic data to consumers using HD Radio technology. Working with CE manufacturers, music tagging for HD Radio technology is supported, enabling consumers to purchase music they hear on the radio through on-line music

stores. Station logo and cover art image support are available through the HD Radio feature "Artist Experience." Through Artist Experience, the listener is presented with an image-rich enhancement to their listening experience. Commercial announcements may also be enhanced with client logos and product images.

Emergency Alerts may be enhanced by HD Radio technology's ability to provide images and text content in addition to the traditional audio information contained in the alerts. Digital receivers, even while in a standby mode, are able to receive HD Radio Emergency Alert messages and turn on during the announcement. This feature significantly increases the effectiveness of emergency alerts.

Other advanced services in the early stages of implementation include electronic programme guide and store-and-replay functionality. For consumers, digital radio standardization would make possible a uniform product offering, enhancing the user experience with familiar graphical user interface (GUI) displays tailored to the services offered by a common digital radio platform.

Finally, since all local radio station dial positions can remain the same, the HD Radio system requires little or no change in well-established consumer behaviour. Consumers purchasing HD Radio receivers will simply tune to their favourite programs and stations and enjoy the digital upgrades in quality, choice and services automatically as stations transition from analogue to digital.

4.4.11.2 The Broadcaster Benefit

The HD Radio system facilitates a smooth upgrade to digital broadcasting by using existing infrastructure and minimizing implementation costs, providing a means for broadcasters to compete against new digital media and grow the broadcast industry. Broadcasters' existing studios, towers and antenna equipment are maintained under the HD Radio system. Each station will require a new digital exciter to provide basic HD Radio services and a digital service multiplexer, known as the Importer, to enable multicasting and other advanced services. The overall upgrade costs for a station range from USD $23,000 to $195,000, depending on its existing infrastructure, with an average around USD $100,000. Stations will be able to preserve their current consumer base and retain all brand equity associated with their dial positions, typically developed at great expense over long periods of time. HD Radio technology has the potential to provide broadcasters new revenue through multicasting, advanced data services and other new applications.

New business models enabled by HD Radio technology include expanding current offerings, such as additional programming streams through multicasting, as well as the transmission of news services, and wireless data and other advanced digital applications, which are becoming widespread in North America. A radio station's revenue potential is increased by allowing broadcasters to better target listening audiences and offer niche services. And, the HD Radio system provides radio broadcasters with the most economical means of transmitting wireless data services to mobile platforms such as GPS and portable entertainment devices and smart phones. Hundreds of millions of units of

these products are sold each year. Having access to mobile platforms is key to growing the broadcasting industry marketplace. Using the HD Radio system, radio broadcasters have the potential to compete in this market with sufficient bandwidth and a low cost, high quality digital data pipe.

Widespread adoption of analogue FM as an application feature on mobile phones and digital media players is paving the way for future adoption of HD Radio technology on these devices. Several media players have already incorporated analogue FM tuners, and a significant percentage of smart phones sold in the US, Mexico and European markets include analogue FM tuners.

4.4.11.3 The Benefit to Manufacturers and Retailers

Manufacturers and retailers have a strong interest in upgrading radio technology from analogue to digital. A uniform digital radio standard across North America would incentivize manufacturers that have benefited tremendously from previous digital product upgrades, and the broad base of manufactures building various HD Radio products will capture that same opportunity in radio's digital transition.

The basic existing analogue radio technology, which has been stable for many years, offers limited opportunity to add new features, and thus limits sales growth. The HD Radio system provides manufacturers with an opportunity to upgrade a very large product category. The large installed base of analogue radio equipment is being replaced over time, and new audio products, even whole new product categories, are being developed with increased functionality and potentially higher profit margins. For high growth wireless devices like mobile phones, media players, personal navigation systems, telematics systems and converged versions of these consumer electronics products, HD Radio technology offers the potential to increase device functionality by adding digital radio to these devices with the potential benefit of delivering wireless data and audio services. For automotive OEM and tier 1 suppliers, a uniform North American product offering means reduced receiver head unit model inventory, and the ability to conduct more thorough testing of a reduced subset of receivers, resulting in better performance and lower costs.

4.4.11.4 Benefit to Regulatory Agencies

Allocation of new spectrum for digital radio is not required as the HD Radio IBOC (In-Band, On-Channel) signal is carried within the same frequencies that broadcasters currently utilize. As a result of these and other factors, in a first Report and Order in October 2002, the FCC selected the HD Radio IBOC system as the sole technology AM and FM radio broadcasters will use to upgrade to digital in the United States. In March, 2007, in a Second Report and Order, the FCC adopted service rules and other requirements for terrestrial digital radio. Subsequent regulatory actions by the FCC since then have implemented incremental improvements and modifications to operational parameters such as allowing increased transmit power in the digital sidebands of HD Radio signals.

In Mexico, HD Radio technology was adopted officially by the CoFeTel (now known as El Instituto Federal de Telecomunicaciones or IFT) on June 16, 2011. Since the formal adoption, more than 70 radio stations have upgraded to HD Radio technology and offer over 115 Digital Programs. HD Radio technology has a presence in four of the top ten Mexican markets with 33% population coverage. The technology may be found in 15 OEM automotive brands in Mexico across 50 models.

In Canada, the CRTC released a targeted policy review of the commercial radio sector (Broadcasting Regulatory Policy CRTC 2014-554) on October 28th, 2014. Included in this review was a flexible approach for introducing HD Radio technology in Canada, designed to allow for innovation and experimentation. Licensees are required to apply to Innovation, Science and Economic Development Canada (ISED) for experimental authorization and inform the CRTC in writing of any experimentation with HD Radio (or other digital radio technologies) that they undertake, including the type of service they intend to provide.

Presently, twelve radio stations are on-air with HD Radio in Canada across seven markets: Toronto, Hamilton, Vancouver, Markham, Montreal, Ottawa and Calgary. While limited, this represents a significant increase within a twelve month period.

Adoption of HD Radio in Canada has a number of issues that need to be addressed in this experimental period. ISED deals with spectrum and technical issues in Canada, and has yet to provide broadcasters with a consistent technical framework or provisional technical rules to understand the full impacts of more widespread deployment. Operating parameters are authorized on a case by case basis and only the stations directly involved have knowledge. A database is currently not available to permit stations to gain knowledge from prior experience.

An opportunity to develop consistent technical rules and share the experience gained may encourage innovation and experimentation on a broader scale.

ISED has acknowledged the need for an engineering study, which could then be shared with the CRTC and the Radio Advisory Board of Canada (RABC), to gain an understanding of the adjacent channel impacts of HD Radio technology on existing radio stations. Understanding the impact of HD Radio technology on the existing broadcast infrastructure in Canada and a simple and supportive licensing regime would give Canadian broadcasters the confidence that a transition is both possible and desirable.

Implementation of HD Radio requires radio stations to pay licensing fees to the patent holder to use the technology. While main station (HD1) license fees have been waived during experimentation for broadcasters who implement the technology ahead of formal adoption, a uniform licensing policy is available following formal adoption. The certainty and stability of future licence fees are a factor in employing the technology. The affordability and flexibility of fees will contribute to further deployment.

4.4.11.5 Market information

The radio receiver remains one of the most ubiquitous devices in our lives. It is estimated that there are over 575 million radio receivers in use today in the United States. Over 92% of all people over the age of 12 listen to the radio every week. As of June 2016, there were more than 15,330 licensed radio stations. The average American listens to AM or FM radio more than 22 hours per week.

Canada has a little more than 1,250 radio stations. In 2016, Numeris reports that nearly 90% of Canadian consumers, 12 years or older, tune in weekly spending almost 18 hours of their media time with radio.

In Mexico there are more than 1,300 radio stations. PwC Mexico reports that more than 7 out of 10 Mexicans listen to radio and on average spend 18% of their day doing so.

Radio provides critical public service as a central part of the Emergency Alert System (EAS) in the U.S., and with similar alerting systems in Canada and Mexico. Radio is a primary means of dissemination of news and information, and as a source for public service announcements. In other words, radio informs, enlightens and entertains all key elements for a civil society.

The basic motivations for transitioning from analogue to digital technology are enhanced performance, added capabilities, reliability, flexibility and cost efficient manufacturing. Despite the obvious benefits of digital radio, terrestrial radio has remained one of the last bastions for analogue service, due in part to the large installed base of analogue receivers requiring replacement as well as the low cost of including analogue radio in other products (for example, the inclusion of analogue FM radio in smart phones). While recent broadcast standards activities indicate increasing interest in the digitalization of VHF band II (87.5 to 108 MHz), many countries lack the additional spectrum required to accommodate a parallel transition of radio from analogue to digital service on a new frequency assignment. This is certainly the case in North America.

IBOC technology allows broadcasters to add digital signals to their existing analogue broadcasts without new spectrum (“hybrid” broadcasts), while providing the capability for an eventual move to all-digital transmission. In short, the technology acts as a bridge from analogue to digital services.

To be clear, the hybrid mode includes both the existing analogue and the new digital services. Broadcasters are using this mode during rollout of the technology to permit the continued operation of analogue-only radios while new HD Radio receivers deliver the new enhanced services as well as existing analogue reception. In the future, when the market penetration of HD radio receivers is sufficiently high, broadcasters may switch to the all-digital mode resulting in additional benefits including greater digital coverage (than available in hybrid mode) and the potential for greater throughput.

HD Radio technology supports low-cost receivers; a significant factor for digital audio broadcasting deployment and acceptance. IBOC transmission methodology utilizes

adjacent digital signals that permit existing tuner components and antenna circuitry commonly used in the manufacture of analogue signal receivers to be employed.

5. Moving Forward with Digital Radio

The following short chapter is based on the WorldDAB+ workshop titled "Moving Forward with DAB+" held in Kuala Lumpur on 29th February 2016. The author presents his views on digital radio, smart radio and hybrid radio, augmented by the presentations and discussions he had with digital radio experts such as Mr. Simon Fell, Former Director of Technology & Innovation, EBU; Dr. Graham Dixon, Head of Radio, EBU; Mr. Lindsay Cornell, Technical Committee Chair, WorldDAB and Principal Systems Architect, BBC (UK); and experts from WorldDAB. Also referred to are related documents including R138 [1] & the web document, "Digital Radio Toolkit: Key Factors in the Deployment of Digital Radio", a report published on 19 December 2014 by EBU [2].

5.1 Digital Radio in APAC and beyond

In every region of the world the digital radio take up is not on par with other media such as television and other Information & Communication Technologies (ICTs). Analogue radio broadcasting is the dominant form of radio broadcasting, especially for Free-to-Air (FTA) operations. There are a number of terrestrial digital radio transmission technologies available; DAB/DAB+, DRM/DRM30/DRM+ and ISDB-Tsb.

Digital radio broadcasting started around the middle of 1990s. However, over two decades digital distribution of radio content has been slow to emerge in the radio broadcasting industry. With a slow take up of digital television, especially in the Asia-Pacific region, other digital delivery services and technologies, such as the Internet, mobile devices/services and television, have gained market acceptance while radio broadcasting analogue has remained the most cost-effective and primary distribution mechanism for terrestrial broadcasting.

5.2 Technology Position in APAC

In Asia-Pacific, ABU holds the position of technology neutrality. What does technology neutrality mean to the ABU family? It is the principle that the ABU leaves the choice to its members to select the digital radio standard they want. However, in the European region, the EBU, through its R138 gives the preference to DAB/DAB+. As per the 3rd page of the R138 document, it recommends that immediate deployment of digital radio be done using DAB transmission as defined in ETSI EN 300 401 with DAB+ services as defined in ETSI TS 102 563 for digital radio broadcasting in VHF Band III. It also recommends the use of DRM as defined in ETSI ES 201 980 for digital radio broadcasting in the frequency bands currently used for analogue radio broadcasting, when DAB coverage is not possible [R138, p3].

The project *Digital Radio Toolkit* built on the EBU's Recommendation on Digital Radio Distribution in Europe (EBU R 138), which primarily suggested the deployment of DAB+ services and, only if DAB coverage is not possible, the use

of DRM as a broadcasting alternative. As a further step, the *Digital Radio Toolkit* report offers guidelines on how to launch digital terrestrial radio, based on the experiences of the three countries leading this process in Europe: Norway, Switzerland and the United Kingdom. The report proposes good practices for introducing digital radio, though one needs to assess the local context in their respective country.

As presented by ABU in various recent fora, national contexts are significant in the radio market. General social and economic conditions such as each country's wealth, radio listening pattern or its citizens' ICT awareness, affect the uptake of digital radio. Other specific issues play an important role, such as the level and nature of competition, the relative strength of public service media organisations, the co-existence and share of national, regional or local networks and stations, the size of the advertising market, or policies and regulations.

5.3 Key success factors for radio digitisation

There are eight key elements for the digitisation of radio, as per the EBU Digital Radio Toolkit report; viz. institutional structure, policy and regulation, content and offer, technology, switchover process, public communications, consumer electronics and the car industry.

Terrestrial radio is the only radio which is distributed universally and free at the point of consumption. At the same time, it is also the only platform that guarantees the delivery of public service content and its associated democratic values. In its current analogue form (mainly and dominantly FM), there seems to be no more room for development in most European countries and in a number of countries in the Asia-Pacific region and the rest of the world. It is required that World Broadcasting Unions do what is possible within their power to guarantee the future of broadcasting (for both radio and television).

The report summarises five requirements for digital radio to succeed. They are coverage, cost, content, collaboration and communication. At the end of the digitalisation process, digital radio coverage must be at least the same as that of analogue radio, including coverage along major roads. Listeners will not accept losing coverage which existed with analogue services. The content needs to be strong, with clear added value when comparing the digital and analogue portfolio of services. This means not only more services, but also more diversity, targeting unattended audiences. The launch of digital radio has associated costs, mainly distribution costs and production costs for new content. Carefully planning and building economies of scale will help broadcasters deal with these additional costs. Returns are not immediate. If the process is managed successfully, these costs are outweighed by long-term benefits. Led by broadcasters, all the stakeholders must work together in the technological and communications sectors. Their involvement may vary according to the stage of the process, but all of them are necessary. This relationship must be built on trust and confidence. Public communication is essential to make citizens aware of the new platform and its

associated services. It is also a central tool in involving the related industries. The message must be consistent to avoid confusion in the market.

The above five requirements lead to a commitment from all stakeholders. This commitment clearly shows the goals and ambitions of the industry and sends the strongest possible signal, helping to generate momentum among listeners. For them, digital radio represents an expanded offer of services, not just limited to traditional programming but as a driver of other audio innovations in broadcasting and on IP platforms. In the television industry, we have observed this in Europe as well as in the APAC region. In the Freeview model, broadcasters form a consortium to build a common digital terrestrial and satellite delivery platform. Freeview especially promised an over the air (OTA) as a free-to-air (FTA) service. The competition will be on content rather than the technology of the delivery platform.

It is time for the industry and broadcasters, especially public and private broadcasters, to compete on content, but cooperate in technology. It is essential to find the right regulatory incentives to foster the involvement of broadcasters. A balance is needed between an attractive content proposition and its associated costs. Hybrid radio brings together the efficiency and sophistication of broadcasting. In the switchover process, stakeholders must reduce uncertainty about the future by setting guidelines. Raising awareness among the public and persuading them to switch to digital radio are key communication goals. Working with manufacturers, importers and retailers fosters their involvement and the take-up of digital radio. In-road safety and road information provided by digital radio is added value for the car industry.

5.4 The key successes factors that are described in the report are:

1. Involve all stakeholders
2. Set up an industry body
3. Send a unified message to the authorities
4. Provide regulatory incentives
5. Rethink your licensing system
6. Implement correct regulation
7. Add value to your offer
8. Find unattended audiences
9. Rely on familiar and well positioned brands
10. Exploit economies of scale
11. Design a product strategy, not a platform strategy
12. Drive people to digital listenership
13. Ensure good coverage
14. Reduce transmission costs
15. Extend collaboration to all technical platforms

16. Make the case for local radio
17. Be flexible with the quality
18. Use digital technologies in a digital way
19. Plan the process
20. Fix a clear calendar
21. Set realistic criteria for the switch-off
22. Communicate a single, clear and accurate message
23. Plan promotion
24. Target the related industries
25. Make affordable devices available on the market
26. Offer future-proof devices
27. Ensure a good buying experience
28. Target the car industry early
29. Attend to the aftermarket
30. Ensure a seamless in-car radio experience

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6. Issues related to Terrestrial Systems

6.1 Spectrum Availability

Government policies on frequency management and spectrum pricing affect all radio broadcasting development. 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 VHF and L-Bands).

In many countries, administrations have allocated spectrum for digital broadcasting, both radio and TV.

The DRM system is designed to work within the existing band and channel structure for all the broadcasting bands below 30 MHz. As such, its use of the spectrum conforms to the Geneva Treaty of 1975 for ITU-R Regions 1 and 3, the long wave and medium wave channels have a 9 kHz bandwidth, or multiples thereof, depending on the channel assignment; the Rio Treaty of 1981 for Region 2 medium wave specifies a 10 kHz bandwidth; and the shortwave channel bandwidth is 10 kHz for all the HF broadcasting bands. Thus, no new spectrum is required. Furthermore, based upon ITU-R decisions during 2003, DRM signals can be used operationally in these bands, with the existing channel bandwidths, interspersed with the analogue broadcasts. That is, there are no specially allocated segments of bands for digital transmissions. Ongoing testing has verified the feasibility of this approach.

In the US, the government has approved HD Radio as a way to alleviate the need for new spectrum to implement terrestrial digital radio.

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 much to be gained from digital broadcasting in the short-wave bands because current analogue systems require a number of simultaneous broadcasts to ensure reliable reception under changing ionospheric conditions.

Case Study: Allocations in Region 1

In the UK, where spectrum is being allocated for seven Eureka 147 DAB multiplexes, the granting of license has been in VHF Band III, which is very suitable for terrestrial DAB (T-DAB) transmissions. Across Europe, both VHF and L-Band frequencies will be used for T-DAB services. At a planning meeting

set up by the CEPT (European Conference of Postal and Telecommunications Administrations) 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 VHF 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 VHF 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 VHF 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.

At the International Telecommunications Union (ITU) in Geneva, the Regional Radiocommunications Conference 2006 (RRC-06) took place from 15 May to 16 June 2006. The new agreement, GE06, includes the frequency plans for T-DAB and DVB-T in Band III and for DVB-T in Bands IV/V for Region 1 (parts of Region 1 to the west of meridian 170°E and to the north of parallel 40°S) and in the Islamic Republic of Iran (see Figure 6.1.1).

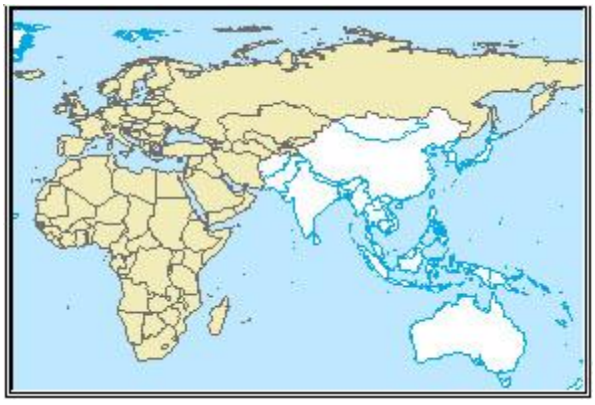

Figure 6.1.1: RRC-06 planning area

The table below shows the results of the RRC-06. The results are evaluated with regard to the proportion of the assigned requirements relative to the submitted ones.

Table 6.1.1: Assignments

	Band III		Bands IV/V
	T-DAB	DVB-T	DVB-T
Total	8817	7411	56 533
Assigned	8379	6703	55 409
% Assigned	95.0%	90.4%	98.0%

The planned allotments and assignments for T-DAB in part of the planning area centred around Europe are shown in Figure 6.1.2.

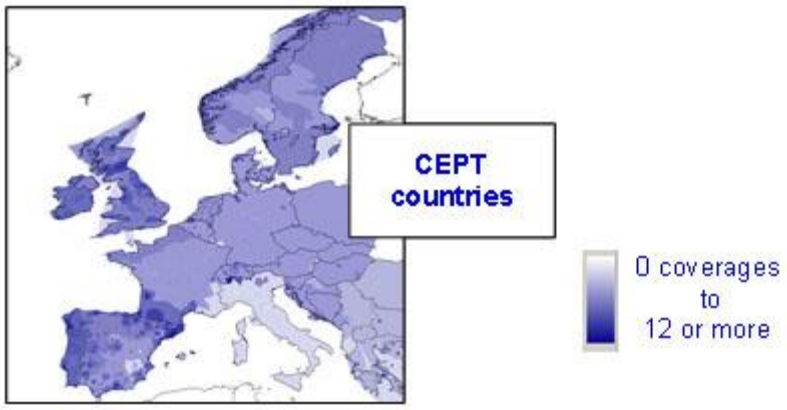

Figure 6.1.2: T-DAB coverages in Band III

The number of coverages can be estimated by analysing the coverage maps taking into consideration, when relevant, the overlapping areas between allotments or assignment areas. The table below shows the estimated number of coverages (distinguishing between nationwide coverage and partial coverage) for the CEPT counties.

Table 6.1.2: Coverage

	Estimated number of coverages T-DAB in Band III (in CEPT)	
	Nationwide	Partial
Average	2.4	1.7
Median*	3.0	1.0
Max	5.0	9.0

**Median: 50 % of the countries have this number or more*

The above table shows that the majority of the European countries, within CEPT, obtained three nationwide coverages for T-DAB and one additional partial coverage.

An estimation of the channel usage in Band III for T-DAB is shown in Figure 6.1.3.

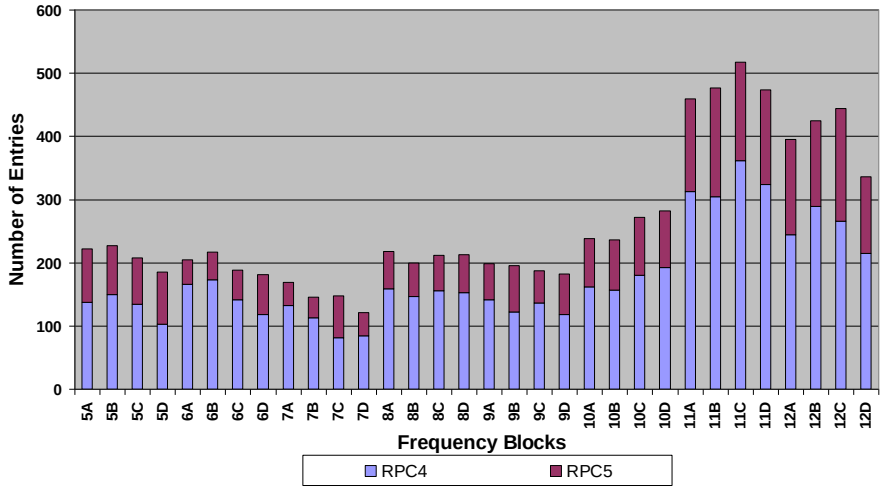

Figure 6.1.3: Estimation of the channel usage in Band III for T-DAB (RPC4: suitable for mobile reception; RPC5: suitable for portable indoor reception)

Figure 6.1.3 shows that T-DAB mobile reception (RPC4) represents the major proportion of the T-DAB requirements and that channels 11 and 12 are the most used for T-DAB.

The GE06 Agreement offers a great deal of flexibility for using a digital entry in the plan for another application provided that the peak power density in any 4 kHz is respected. Such flexibility can allow, for example, for using a DVB-T entry by 4 x T-DAB entries or by 4 x T-DMB entries and also can allow for accommodating future developments of digital technology.

The end of the transition period for Band III was fixed to 2015 (for some non-European countries it is 2020, see details in Figure 6.1.4). During that period, analogue television has to be protected. Around 25% of the T-DAB entries in the new plan have to be coordinated with analogue television in neighbouring countries before implementation. As a consequence, certain constraints (time constraints, power reduction, particular antenna patterns, etc.) might be imposed to those T-DAB requirements during the transition period. In addition, around 7% will have to coordinate with other digital requirements and around 2.5% with other primary services (e.g., PMR - Private Mobile Radio).

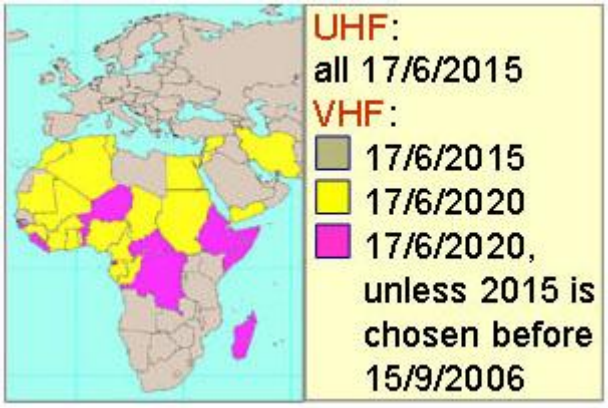

Figure 6.1.4: End of the transition period

In summary, the full potential of the new digital plans will not be available until the analogue switch off.

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 Canada's Communications Research Centre (CRC). It was found that indoor reception at L-Band is comparable to that achieved at VHF frequencies. The reason is that the shorter wavelength at L-Band offsets the increased attenuation through walls at the lower VHF frequencies.

6.2 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 UK, France, Italy, etc.

(1) HD Radio (IBOC)

IBOC transmission schemes are particularly well suited for ensuring a smooth transition to digital services. Since they are designed for compatibility with the existing analogue 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

analogue 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 analogue 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" analogue 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 analogue and the audio program, while degraded, will not go away all together, and is likely to remain with the listener throughout the impairment.

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.

(2) DRM (Digital Radio Mondiale)

Two types of simulcast are present in the DRM design. The first is confined to a 9 or 10 kHz channel. Half the channel is used for an analogue signal capable of envelope detection (in order that a conventional AM radio receiver can demodulate the signal). The other half is a DRM digital signal that requires digital demodulation. The second technique requires 18 or 20 kHz of 2 adjacent channels where one channel contains standard AM and the other contains either a 4.5/5 or 9/10 kHz DRM signal.

For Regions 2 and 3 the simulcast solution is potentially much simpler as the Long and Medium Wave bands have been allocated 18/20 KHz channels. In Region 3 the 18 kHz allocation is also protection against night time sky wave interference.

6.2.1 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, DRM 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 US has also emphasised robust performance in a multipath fading channel. Using sophisticated signal processing techniques such as Complementary Punctured Coding, 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.

Tests and operational broadcasting have shown that DRM coverage is equivalent to the corresponding analogue service it is replacing. Coverage, in this sense, refers to the intended broadcast area, wherein the digital signal retains its high audio quality.

7. Internet Radio

Internet opened new possibilities for radio. Internet Radio has become a mature medium with its distinctive characteristics. There are many tens of thousands of Internet Radio stations worldwide, ranging from big portals down to small local and individual streaming stations.

The main assets of Internet Radio are its low entry costs, global reach, interactivity and personalisation. Internet Radio has proved to be most successful if associated with conventional radio broadcasting over terrestrial or satellite networks. Nevertheless, many standalone Internet Radio stations have become commercially successful.

Internet Radio redefines radio content. Not only does it introduce new music and speech formats, but also can embellish them with text, graphics and video. It allows users to listen to a wide selection of audio items when and where it is convenient. These on-demand radio services may dramatically affect the pattern of listening and listening habits. Internet Radio has highlighted many legal and regulatory issues that need to be addressed. These issues relate to copyright, licensing, content regulation, merchandising, advertising and security. However, these topics exceed the scope of this paper.

The EBU, on behalf of the WBU, made an application to the Internet regulatory body, ICANN, for the management of the high level domain name '.radio'. This was done in order to ensure that radio broadcasters can make equitable use of this Top Level Domain (TLD) name at a cost to only cover administration, and not further profits. The application was granted by the Internet Corporation for Assigned Names and Numbers (ICANN) in June 2016 and the new TLD .radio was open for registration in August 2017.

7.1 dot.radio Initiative

The dot.radio initiative aims to offer a domain name for radio services via Internet and/or for radio broadcasters for their web presence. New TLD names are now arriving on the scene and will change how people relate to the internet. In particular, a small number of them address specific communities. In 2012, the EBU requested the support of key radio organisations across the world, and submitted an application to ICANN for a Community TLD for the string RADIO.

This new TLD is specific to the radio sector in all its many facets, and one of the further goals is to prevent speculators and cybersquatting in this new internet space. This extension is a safe and high-value internet space for websites, mail systems and other internet applications.

After five years spent making the application and aligning with ICANN procedures, the TLD .radio welcomes the following categories of applicants: broadcast radio stations, web radios, radio amateurs, radio professionals (journalists, radio hosts, DJs) and radio-

related companies selling radio goods and services. It is time to consider leaving .com, .org and other country based TLDs to move into the fresh, clearly defined .radio internet extension, which is managed for and by the Radio Community.

2500 .radio domains have already been registered. As part of the radio industry, you can now register your own domains:

My-station.radio	www.my-station.radio / someone@my-station.radio
My-programme.radio	www.my-programme.radio / someone@my-programme.radio
My-company.radio	www.my-company.radio / someone@my-company.radio
My-product.radio	www.my-product.radio / someone@my-product.radio
My-name.radio	www.my-name.radio / someone@my-name.radio

A World .radio Advisory Board has been set up to provide guidance and feedback from the Radio Community and ensure that its governance is aligned with the needs of the whole sector.

To request a .radio domain, applicants should contact a registrar (company selling internet domains), provided it has signed an agreement with the EBU to sell .radio domains, or the EBU, which will act as a reseller (www.register.radio).

The price for registering a .radio domain name is different for companies and individuals. It depends on the registrar offering the product, since registrars themselves define their price and their marketing policy. It also depends on whether some additional services are included in the yearly fee (like hosting, mailing, certificates, etc.).

For companies, typical prices are between 220€ and 250€ per domain and per year. For individuals, the price is around 25-30€. To benefit from the lower price, the domain designation for individuals needs to derive from their lastname (e.g. alain-artero.radio; a-artero.radio; aartero.radio; or arteroa.radio). In the case of radio amateurs, it should be made of up of their call sign (e.g. JY5IG.radio).

Beside the use of their domain(s), .radio registrants can benefit from extra services for free. The first service put in place is a dedicated URL shortener "on.radio". It allows redirecting URLs like:

Today.on.radio/no1podcast

or

On.radio/rock-program

or

Live.on.radio/news20h

or

Tonight.on.radio/top40

to any web page on a .radio website.

7.2 Various Services

Last FM

www.last.fm

This London-based station offers a number of features, including show business gossip and a forum for launching new artists. By typing in three favourite singers, users can obtain a list of stations featuring these performers. As users add tracks they build a profile, which can be compared with others who have similar tastes. If users skip a song or give it a bad rating, they will never hear it again.

Radio-Locator

www.radio-locator.com

Radio-Locator provides a broad list for finding a US radio station, Internet streaming radio and world radio. It claims that it is the only website which provides a comprehensive list of radio stations worldwide. It has links to over 15,100 stations and over 10,500 online streams. There are drop down menus to search for stations and users do not need to register to listen to music. The only things missing are links to Internet-only stations.

Shoutcast

http://www.shoutcast.com

Shoutcast is Nullsoft's Winamp-based distributed streaming audio system. It is an audio homesteading solution that allows anyone on the Internet to broadcast audio from their PC to listeners across the Internet, or any other IP-based network (Office LANs, college campuses, etc.). Shoutcast's underlying technology for audio delivery is MPEG Layer 3, also known as MP3 technology. The Shoutcast system can deliver audio in a live situation, or audio on-demand for archived broadcasts.

8. Hybrid Radio

Terrestrial broadcast technologies, such as those mentioned in this book, provide the means to deliver audio and data content in a robust and cost-effective way.

A 2017 report from the European Broadcasting Union detailed a cost-benefit analysis[11] on the different ways of distributing live, linear radio to audiences. This concluded that

[11] https://tech.ebu.ch/publications/tr_2017_radio

digital terrestrial radio using DAB/DAB+ was, for most practical situations, the most cost-effective method for delivering an ensemble of live radio services. This was compared against building out FM networks and internet (IP) streaming, where each additional listener results in an additional cost to the broadcaster.

However, current distribution methods of terrestrial broadcast are not well-suited to high-bandwidth delivery of data associated with the radio service, such as may be needed on modern multimedia devices (e.g. high-resolution images, on-demand audio content). The nature of broadcast also means it is not an appropriate means to deliver any fine level of personalization (e.g. contextual advertising, content recommendations), and are completely unable to provide a 'backchannel' (e.g. enabling audiences to send information back to the radio service).

IP platforms are bi-directional and support higher bandwidth for both fixed and mobile applications, and are able to address each listener individually enabling personalization.

Hybrid Radio describes the combination of both broadcast and IP platforms in an improved and unified user experience.

Table 8.1 Comparison of Radio Delivery

	Broadcast	IP	Hybrid
Robust audio delivery	X		X
Free-to-air for audiences	X		X
High-bandwidth multimedia delivery[12]		X	X
Personalized content		X	X
Back-channel from audiences		X	X

A device capable of supporting Hybrid Radio must therefore have the means to make use of both broadcast and IP, and also the means to locate IP services from a broadcast service.

The methods to do this are described in the standard published by ETSI, "RadioDNS Hybrid Radio; Hybrid lookup for radio services" (ETSI TS 103 270). This details how certain parameters present in the broadcast services can be used to then locate associated IP services, in a robust and verifiable way.

Usable broadcast parameters exist for most of the audio platforms described in this document, including DAB/DAB+ (Using the Fast Information Channel), FM (Using RDS), DRM and HD Radio. These parameters provide a globally unique way of identifying a radio service, and thus a way of uniquely locating IP services provided by the broadcaster or their chosen service provider. Since the parameters are part of the broadcast stream, they share the same level of trust as the audio itself – controlled and protected by the relevant regulatory authorities in their countries.

[12] Most digital broadcast platforms provide the means for low-bandwidth delivery of multimedia, which can be a complement to those delivered over IP

The standard describes how broadcast parameters may be used to form a DNS domain name. This domain name can then be used by an IP-connected device to perform a Domain Name Lookup, a common function when accessing the internet. The result of this DNS lookup is to direct the device to an internet domain which is then able to provide additional services over IP.

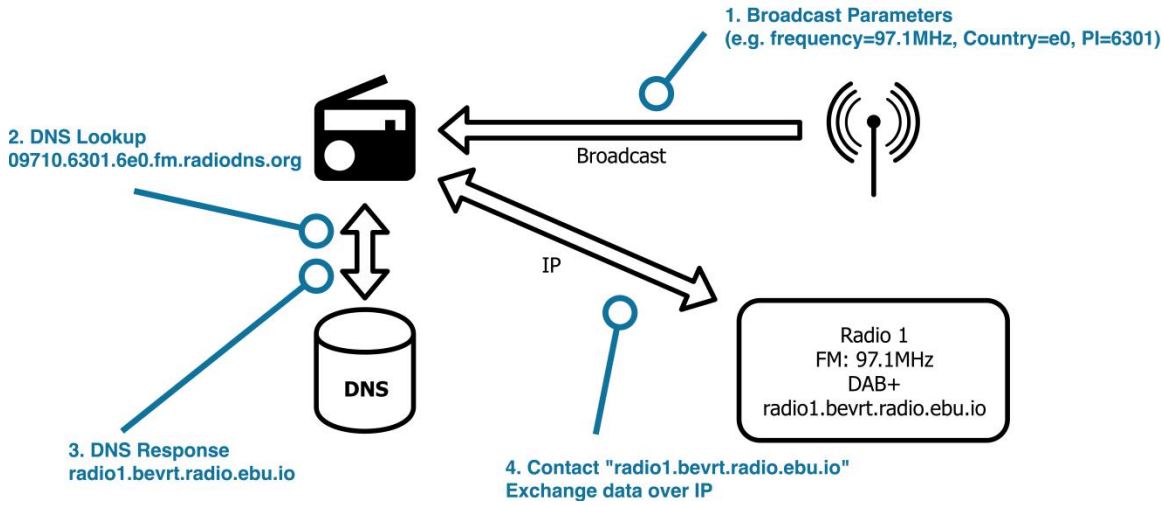

Figure 8.1 Hybrid Look up Diagram

For example, an FM radio service is uniquely identified by its RDS parameters and frequency. The domain is constructed from these parameters and frequency in a specific format, appropriate to the platform.

To identify the radio service “Radio 1” from VRT in Belgium, on 91.7 MHz with a broadcasted country code of E0 and PI code 6301, the following domain name is constructed:

```
09170.6301.6e0.fm.radiodns.org
```

Querying this domain returns the following DNS (CNAME) record:

```
radio1.bevrt.radio.ebu.io
```

This means that additional services can be located from the domain name ‘radio1.bevrt.radio.ebu.io’. In this case, the EBU is acting as the service provider on behalf of VRT, but this could as easily be registered to the VRT themselves, or a different third-party.

The end result is that information contained in the radio broadcast can be used to direct a device to a location on the internet. From this point on, the device can use this for additional IP services, related to the broadcast.

These services may be defined in additional standards. For example: Visuals, Meta data and Interactions, which are described in next three sub-sections.

8.1 Visuals

While some broadcast platforms define methods for slides that can be sent alongside the audio, this is inevitably constrained by available bandwidth. As modern devices evolve with larger, higher-resolution displays, this shortcoming becomes more apparent.

Broadcast ensures a basic visual service for all devices, but using IP service takes advantage of higher bandwidth. The methods to do this are described in ETSI TS 101 499, "Hybrid Digital Radio (DAB, DRM, RadioDNS); SlideShow; User Application Specification", the common standard covering the delivery of visuals over both broadcast and IP platforms.

For example, a 16kB 320x240 image broadcast over DAB at 8kbps may be acquired (approximately) in around 16s. Given the increased bandwidth, a higher-resolution image could be downloaded over IP in a fraction of the time. It could also make use of some additional identifying information, such as a rough geographical location to provide a more localized weather report image.

8.2 Metadata

Additional information about a radio service can enhance the user experience and link the listener to related content. For example, while broadcast contains some identifying information (including service names, genres, languages, descriptions, etc.) this information is limited in its scope. Having the ability to provide richer data, potentially personalized to the device or individual user, means that the scope of this additional information can be larger and more valuable to a listener.

For example:

- Longer names, descriptions in different languages;
- Station logo links in a range of different formats;
- Links to alternative platforms on which the service can be consumed, enabling the device to seamlessly follow a radio service between broadcast and IP platforms, as reception quality dictates;
- List of Programme Information, and on-demand or podcast content;

The methods to do this are described in ETSI TS 102 818, "Hybrid Digital Radio (DAB, DRM, RadioDNS); XML Specification for Service and Programme Information (SPI)". This gives a structured data format in which service and programme information can be expressed, for delivery over IP. By using XML (Extensible Markup Language), this means the structured format can be easily extended and enhanced for additional uses - for example, by enabling phonetic descriptions of station names for voice-controlled platforms.

8.3 Interactions

In addition to enhancing interactivity with a radio service by providing additional information and content either through visuals (where a listener could click on an image to be taken to a web page using an embedded browser on their device), or metadata (where a listener may be able to interact with web or social network links, again using an embedded browser on their device), a device may make use of more direct interactions back from the listener.

This is referred to as a "back-channel" and may cover anything from live interaction such as like/dislike or a message back to the radio studio, or a non-live interaction such as bookmarking interest at a particular time for later use (useful, for instance, while driving).

9. Summary and Conclusions

Conventional radio broadcasting on AM and FM has been around for about a century. New digital broadcasting technologies such as DAB, HD radio, and DRM have been developed and are used in many parts of the world. Traditional on-air radio has much strength and is still a vibrant medium. It is likely that it will remain a principal delivery mechanism of radio content for some decades.

The developed countries have developed a plurality of digital radio systems, for industrial reasons and because of different national circumstances. Countries who have not been involved in the development of these systems face the difficult task of deciding which system or systems to use.

Members of the WBU hold different views about which systems are best, so the WBU cannot give advice on which system to use. What we have tried to do in this report is explain the options, though it must be recognised that the parts of the reports describing the different systems have been written by system proponents.

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- Des DeCean: Challenges facing broadcasters with the introduction of digital radio, Australian Broadcasting Summit, February 2003

11. APPENDIX-A: The DAB (Eureka 147) System - System Description

Overview

[Editor's Note: this appendix contains information provided for the first edition of this report and no longer fully represents the status of the DAB system. A major update is in preparation.]

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

Like almost all digital radio systems, Eureka 147 uses standard audio compression techniques and COFDM. As Eureka 147 was the first standardised digital radio system, the audio compression techniques used in all Eureka 147 implementations are now somewhat dated.

A Eureka 147 transmission has an emission bandwidth of 1.536 MHz, which is capable of providing a range of useful data rates depending on the level of protection. The multiplex contains audio programs, program associated data and, optionally, other data

services. Each audio program or data service is independently error protected with a variable coding overhead, the amount of which depends on the requirements of the broadcasters (transmitter coverage and reception quality). A specific part of the multiplex contains information on how the multiplex is configured, so that a receiver can decode the signal correctly, and possibly, information about the services themselves, the links between different services, and conditional access information for subscription services.

Eureka 147 is a mature system with 29 standards and related documents published by the European Telecommunication Standards Institute (ETSI). The ITU has included details of the Eureka 147 system in its Digital Sound Broadcasting (DSB) Handbook and Recommendations BS.1114 and BO.1130.

Modes of Operation

Eureka 147 provides four transmission mode options that allow for a wide range of transmission frequencies, between 30 and 3000 MHz, and network configurations. For the nominal frequency ranges, the transmission modes have been designed to provide good mobile reception by overcoming multipath echoes, which occur when the signal bounces off buildings and other objects and receivers must deal with multiple and slightly out of phase versions of the same signal.

Mode I is most suitable for a terrestrial SFN in the VHF range, because it allows the greatest distances between transmitters. Mode II is most suitable for hybrid satellite/terrestrial transmission up to 1.5 GHz and local radio applications that require one terrestrial transmitter. Mode II can also be used for a medium to large scale SFNs in the L Band by inserting, if necessary, artificial delays at the transmitters and/or by using directive transmitting antennas. Mode III is most appropriate for cable, satellite and complementary terrestrial transmission, since it can be operated at all frequencies up to 3 GHz for mobile reception and has the greatest phase noise tolerance. Mode IV is most suitable for medium to large scale SFNs in the L Band while still accommodating mobile reception at reasonable highway speeds (up to approximately 120 km/h). However, it is less resistant to degradation at higher vehicle speeds than this.

Table A.1: Eureka 147 Transmission Parameters

System Parameter	Transmission Mode			
	I	II	III	IV
No. of radiated carriers	1536	384	192	768
Nominal Maximum transmitter separation for SFN	96 km	24 km	12 km	48 km
Nominal frequency range for mobile reception	≤ 375 MHz	≤ 1.5 GHz	≤ 3 GHz	≤ 1.5 GHz
Speed/Coverage trade off	No	No	No	Yes
Frame Duration	96 ms	24 ms	24 ms	48 ms
Total Symbol Duration	1246 μs	312 μs	156 μs	623 μs

System Parameter	Transmission Mode			
	I	II	III	IV
Useful Symbol Duration	1000 μs	250 μs	125 μs	500 μs
Guard Interval Duration	246 μs	62 μs	31 μs	123 μs
Null Symbol Duration	1297 μs	324 μs	168 μs	648 μs

Data Capacity

Audio and data services are carried in the main service channel (MSC) of the Eureka 147 multiplex. This channel supports a gross data rate of 2.304 MBps. However, the net data rate (e.g., the actual capacity available for use) depends on the protection level applied to services. For audio-only services, the net capacity of the ensemble varies between 783 (highest protection) and 1728 kbps (lowest protection). The corresponding range for data only services is 576 and 1728 kbps. At a median protection level, the available net capacity for both audio and data services is 1.152 MBps.

Within the MSC, each audio or data service is carried in a subchannel. Up to 63 subchannels can be supported, each of which is treated individually as far as error protection is concerned.

Data Services

Each audio program contains PAD with a variable capacity (minimum 667 bps, up to 65 kbps), which is used to convey information together with the sound program. Typical examples of PAD applications are dynamic range control information, a dynamic label to display program titles or lyrics, speech/music indication and text with graphic features.

Additionally, general data may be transmitted as a separate service. This may be either in the form of a continuous stream segmented into 24 ms logical frames with a data rate of n x 8 kbps (n x 32 kbps for some code rates), or in packet mode, where individual packet data services may have much lower capacities and are bundled in a packet sub multiplex. A third way to carry independent data services is as a part of the Fast Information Channel (FIC) that carries multiplex control and service information. Typical examples of independent data services that could use the FIC are a Traffic Message Channel, correction data for Differential GPS and paging.

Some elements of Service Information (SI) data can also be made available to the listener for program selection and for the operation and control of receivers, such as the name of a program service, the program type, title and language, transmitter identification and controls for switching to traffic reports, news flashes or announcements.

Features and Applications

Digital radio is gradually migrating from audio services with some PAD, e.g. broadcasters in the UK with legacy DAB generally only include DLS scrolling text, into a far more interactive and rich experience through additional features such as SLS images, click-through URLs, categorised text and images with long term storage and hybrid data

delivery for Service and Programme Information. This section describes some technical developments of the DAB system, as undertaken by the WorldDAB Forum.

While the technical possibilities of the DAB family of standards are wide ranging the challenge is to use the features in a meaningful way which benefits the listener. Further, the implementation of some features can be done in a number of ways. To help broadcasters and receiver manufacturers, WorldDAB is continually updating recommendations and guidelines, e.g. see Digital Audio Broadcasting (DAB); Rules of implementation; Service information features, TS 103 176.

Dynamic Label Segment and DL Plus

The Dynamic Label Segment (DLS) carries text information with a length up to 128 characters in the PAD channel. DLS is delivered on a per service basis at an update rate determined by the broadcaster. It is a very simple and effective way of supplementing the audio content with additional information such as:

- station promotions
- track now playing / title and artist
- news headlines
- weather information
- advertising information

It requires a minimum of a simple alphanumeric text display on the receiver for presentation. Simple displays as short as 16 characters can be used for small handheld devices with text scrolling, through to multiline character displays and graphics displays as are provided on some portable and table top devices, vehicles and smartphones.

DL Plus is an extension of DLS which allows the listener to select the kind of information they are interested in. For that purpose, DL messages are complemented by tags which identify specific content of the DL message by its content type.

Users can select the content types of information to be presented; they do not need to read, or even be aware of, the complete stream of DL messages.

DL Plus is a backwards compatible extension of the DL feature, as the transmitted tags are not visible in the DL message so that listeners with receivers without a DL Plus decoder still view the DL messages as before. For the broadcaster, the additional data rate (for tag transmission) is significantly less than the data rate necessary for the text.

A receiver can use the content classification and tagging in two different ways, by improving the presentation of the text messages and/or by providing the information to other applications and devices.

DL messages may contain any kind of text, some will be quite general e.g. news headlines, while others relate directly to the audio e.g. artist and title information. In this latter case, special consideration is given to allow correct grouping of all the different item-related information and an unambiguous reference to the audio of the respective

programme item. This timing information may also be used to ensure that the text and audio make sense for time-shifted programmes.

By identifying text by content type, DL Plus can automatically provide information to other devices like smartphones, tablets and PCs. This means listeners can interact with the radio station more easily because the transfer of telephone and SMS numbers, URLs and event information may be done with a single click. DL Plus is designed to stimulate the integration of radio with other devices in order to strengthen the competitiveness of radio with respect to other media and to gain new and greater audiences.

Number of audio services in a multiplex

Eureka 147 uses MPEG 1 Layer II and MPEG 2 Layer II audio compression standards, and permits full data rate coding at the sampling frequency of 48 kHz and half data rate coding at the sampling frequency of 24 kHz. Half data rate coding is not fast enough to capture all of the information in a speech signal, so this sampling rate is only used where there is some distortion.

Eureka 147 is capable of processing mono, stereo and dual channel (e.g., bilingual) programs. A range of encoded data rate options are available (8, 16, 24, 32, 40, 48, 56, 64, 80, 96, 112, 128, 144, 160 or 192 kbps per monophonic channel). In stereophonic or dual channel mode, the encoder produces twice the data rate of a mono channel. The range of possible options can be utilised flexibly by broadcasters depending on the quality required and the number of sound programs to be broadcast.

A stereophonic signal may be conveyed in the stereo mode, or particularly at lower data rates in the joint stereo mode. This mode, typically used at 144 - 224 kbps, uses the redundancy and interleaving of the two channels of a stereophonic program to maximise the overall perceived audio quality.

The degree of error protection (and hence ruggedness) can also be varied to meet the needs of the broadcasters. In the case of audio services, five protection levels (1 to 5) have been specified in order to cater for a variety of applications. Level 5 affords the lowest protection and is designed for cable systems. It allows a high number of program services, but does not have the strong error protection necessary for operation in multipath environments. Protection Level 3 is better suited to mobile operation. To allow more flexibility in accommodating subchannels, Protection Levels 4 and 2 have also been introduced with somewhat weaker and stronger performance than Protection Level 3 (respectively). Protection Level 1 is suited to applications with a very high sensitivity to transmission errors while Protection Level 4 is intended for less demanding applications (for example services addressed to fixed receivers).

Table A.2 outlines the typical number of services that can be delivered for a selection of audio data rates for different levels of error protection.

Table A.2: Example of possible number of programs

Audio data rate (kbps)	Protection level (increasing protection)				
	5	4	3	2	1
24*	N/A	64	48	36	24
32	54	41	36	29	24
64	27	20	18	14	12
128	13	10	9	7	6
192	9	7	6	5	4
224	7	6	5	4	3
256	6	5	4	3	3

** At most audio data rates, Eureka 147 uses Unequal Error Protection, an error protection procedure which allows the bit error characteristics to be matched with the bit error sensitivity of the different parts of the audio frame. At the lowest data rate, 24 kbps, Eureka 147 uses Equal Error Protection, an error protection procedure which ensures a constant protection of the bit stream.*

Audio Quality

ITU R Recommendation BS.1115 specifies use of MPEG 1 Layer II at 256 kbps (stereo mode), for broadcast applications requiring CD quality. This recommendation is based on subjective listening tests undertaken in 1992. At the time, MPEG 1 Layer II at 192 kbps (joint stereo mode) was also tested but was found to only marginally meet the audio quality requirement. Additional tests in 1993 failed to reveal sufficient improvement in the codec to warrant inclusion of this lower data rate in the ITU recommendation.

Further listening tests were performed in 1995, as part of the US Electronic Industries Association's (EIA) evaluation of digital radio systems. A range of audio coding systems were tested including MPEG 1 Layer II at 224 and 192 kbps (joint stereo modes). The findings of this work indicate the MPEG 1 Layer II codec at 224 kbps is capable of meeting the basic audio quality criteria specified by the ITU R. The lower rate of 192 kbps again failed to meet the required quality.

Spectrum Issues

Eureka 147 Channel Plans

In 1995, the introduction of terrestrial Eureka 147 was discussed by the European Conference for Posts and Telecommunications (CEPT) in Wiesbaden. In cooperation with representatives of regional and international organisations such as the EBU, the European Commission and the ITU, it was agreed that a total of 73 channels would be used for future and current digital audio broadcasting services. Each channel was 1.536 MHz wide with appropriate guard bands between each channel and at the edge of each band.

The European CEPT channel plan encompassed four frequency bands, namely VHF Bands I, II and III and L Band. Allotments were made to allow the implementation of two Eureka 147 ensembles in any given country or area in Europe. The majority of these allotments were in VHF Band III and the lower part of the L Band (1452 MHz 1467 MHz). Allotments in the 230 240 MHz sub band of VHF Band III are subject to coordination with national defence users and the L Band was divided into terrestrial and satellite segments. Further consideration of L Band allotments was made at a second CEPT conference at Maastricht in 2002.

A second channel plan has been developed for Canada that covers only the L Band. This plan also provides for 23 channels, but with different guard bands to the CEPT Plan.

Comparing the characteristics of the two plans, the Canadian channel plan provides an interchannel guard band some 18% greater than the CEPT channel plan. Maximizing the spacing between adjacent channels is desirable, as this contributes to improved adjacent channel isolation which results in less stringent implementation constraints. In contrast, the CEPT channel plan trades off a larger interchannel guard band for increased guards at the band edges to facilitate sharing with other services operating near the band edges.

To facilitate receiver tuning and minimize scan times, manufacturers will assume, or at least prioritise, the use of certain centre frequencies as defined by the CEPT and/or Canadian channel plans. The use of ”non-standard” frequencies could result in the need for manual tuning or, alternatively, require the receiver to undertake a complete scan of the band(s) based on the 16 kHz grid spacing. The latter is likely to take considerably longer and could be seen as a distinct disadvantage. Although manufacturers have been encouraged to incorporate the Canadian channel plan in their designs, it remains unclear what level of support will be afforded to the plan and whether there are cost implications for manufacturers in supporting both channel plans.

For Australia, there is a further complication if VHF Band III is used for digital radio. In this scenario, adoption of the Canadian channel plan would result in a “mixed” frequency table arrangement (e.g., use of the CEPT channel plan at VHF Band III and the Canadian channel plan at L Band). In view of these uncertainties, adoption of the Canadian channel plan would appear justified only if significant benefits, in terms of improved adjacent channel isolation, were shown to be associated with the wider channel spacing of this plan. In the absence of any published data, the Communications Laboratory undertook measurements of the adjacent channel isolation afforded by the two channel plans, using a limited range of transmitting and receiving equipment available at that time. The results of these tests indicate no significant difference in adjacent channel performance.[13]

Planning Parameters

The planning parameters that could be used for the implementation of Eureka 147 services draw on a number of ITU and European sources:

[13] Communications Laboratory Technical Note 99/01, ‘The impact of European and Canadian L-Band channel spacings on adjacent channel operation”, 20 April 1999.

The ITU DSB Handbook

EBU "Technical bases for T DAB services network planning and compatibility with existing broadcasting services," Document BPN 003 Rev. 1, May 1998;

Chester 97, "The Chester 1997 multilateral coordination agreement relating to the technical criteria, coordinating principles and procedures for the introduction of terrestrial digital video broadcasting (DVB T)," 25 July 1997;

ITU R Recommendation BT.1368, "Planning criteria for digital terrestrial television services in the VHF/UHF bands," 14 April 1998.

Propagation Properties

General aspects of Propagation Properties are covered in the Spectrum Usage section of this report. The two bands in which Eureka 147 are likely to be implemented are VHF Band III and L Band.

VHF Band III

VHF Band III is well suited to the provision of terrestrial digital radio services over large coverage areas. The frequencies are still sufficiently low for good reception in moving vehicles of Eureka 147 Mode 1 transmissions. VHF Band III has less man made noise than VHF Bands I and II and does not suffer from a number of the anomalous propagation characteristics which are a problem in VHF Band I.

Recent system developments

Digital radio is likely to turn from a simple audio-only service, merely simulcasting existing analogue programmes, into a far more interactive and rich experience across several platforms including DAB, using scrolling text and on demand digital services. This section describes some technical developments of the Eureka 147 DAB system, as performed by the WorldDAB Forum.

As this section shows, the technical possibilities of DAB are practically unlimited. The challenge is to harness the technical developments and to restrict them reasonably to those for which an international consensus of broadcasters, manufactures and other players could be reached.

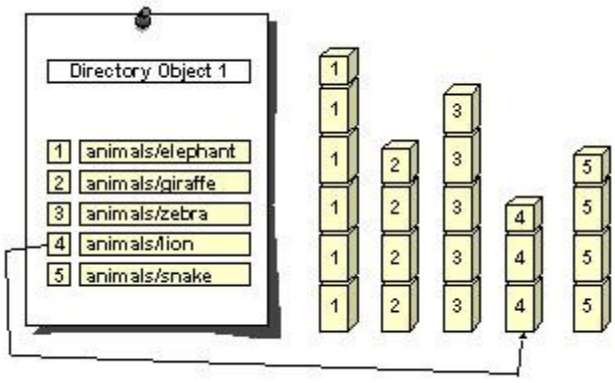
Multimedia Object Transport (MOT)

The MOT protocol allows the standardised transport of audio-visual information, such as still pictures and web pages. It can be used in the PAD and packet mode. MOT is particularly suitable for two applications: Broadcast Website (BWS) and Slide Show (SLS).

The basic principle of the MOT data carousels[14] is that each file to be broadcast is divided into segments of equal length and then the segments for all files are repeated cyclically in the broadcast stream. Each segment is tagged with an identifier to say which file it belongs to and a segment number to identify which segment of the file it is. Segmenting the file in this way means that the system will still work in an error-prone channel because, even for large files, the minimum amount of data that must be received without error is just a segment rather than the whole file. If a segment is received in error, the receiver can just wait for the next time that segment is broadcast, and the file identifier and segment number allow the receiver to correctly reconstruct each file.

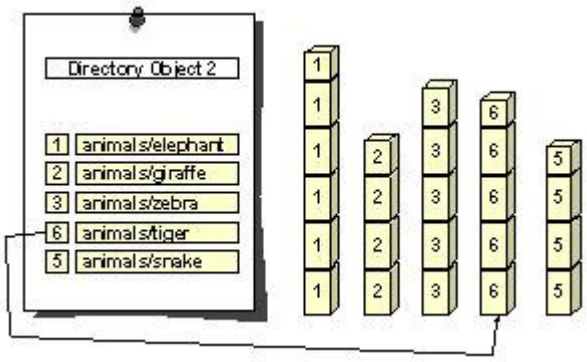
This on its own, however, is not sufficient; with a "sea" of segments, the receiver can reconstruct the files but cannot know how to access them or how to manage them. What is needed is a "table of contents" for the carousel that contains a list of all the files contained within the carousel. With suitable version control applied to this "table of contents," it is possible to detect any change to the carousel simply by examining the version of the table of contents. If a file is changed, the version number for the file will change. This will, in turn, change the "table of contents," which will result in a change in its own version number. A simple comparison of the "table of contents" before and after the change allows the receiver to determine exactly what has changed, and to perform any cache management as appropriate.

In MOT, the "table of contents" function is handled by the MOT Directory Object and its operation is illustrated below:



If we replace the file animals/lion with a new file called animals/tiger, the carousel would then appear as shown below:

[14] EN 301 234 V1.2.1 Digital Audio Broadcasting (DAB); Multimedia Object Transfer (MOT) protocol.



The receiver can tell that the carousel has changed because the Directory Object has a new version, and by comparing the old and new Directory Objects, it can immediately determine that the file animals/lion has been replaced by animals/tiger.

The MOT Directory Object serves two functions:

- To provide reliable management of the files so that any changes to the carousel are understood by the receiver.
- To provide a name and other information for each file so that it may be accessed by an application.

Slide Show and Categorised SLS

The Slideshow user application[15] involves sequences of images (JPEG, PNG or APNG). The order and presentation time of this service is generated by the broadcaster. The transmission time depends primarily on the file sizes of the pictures and the chosen PAD data rate. For example, album art coded as a JPEG image using the standard QVGA size (320 x 240 pixels) requires a transmission time of 22s when the PAD or packet mode data rate is 16 kbps.

The images transported are usually associated with the audio and hence the presentation timing and synchronisation with the audio components is often critical. For example, if the audio component is an advertisement, it is important to ensure that the image is displayed while that audio is being played and not overlap with the next advertisement which will be for a completely different product.

SLS images have a number of parameters which instruct the receiver how to display and store the SLS images (or objects) as shown in Table A-9.

[15] TS 101 499 V3.1.1, Hybrid Digital Radio (DAB, DRM, RadioDNS); SlideShow; User Application Specification

Table A-9: MOT parameters and use

Parameter	**Use**
ContentName	A unique identifier, this can be the file name
TriggerTime	Used to synchronise the display of the image with the audio. Images shall not be displayed unless a valid TriggerTime is supplied.
ExpireTime	The object shall be stored until the ExpiryTime is reached, then it is deleted from the receiver's memory.
CategoryID / SlideID	This parameter specifies the category and sequence order inside the category of the slide
CategoryTitle	A textual description of the category
ClickThroughURL	Optional URL parameter which is used to link to a webpage
AlternativeLocationURL	An optional parameter that allows devices with IP connectivity to acquire an alternative image, e.g. a higher resolution image
Alert	Used to indicate an emergency warning

When the receiver has the necessary memory, e.g. a smartphone, the Categorised SlideShow parameters provide instructions on how to store and organise the images provided. SLS objects which do not have an associated Category ID / SlideID are not stored beyond their display time. All objects are only stored up to their ExpireTime.

The ability to associate a ClickThroughURL, to either normal or categorised objects/images, provides the user whose receiver is connected to the internet to access additional information associated with the image. For example the image may be the album art for a song- the ClickThroughURL could then be that of a webstore for the purchase of the song or album. Similarly the image may be of an advertised product and the ClickThroughURL that of a store selling that product.

As the standard SLS image size is QVGA and many receiver devices have higher resolution screens, e.g. cars and smartphones, the user may allow the receiver to retrieve a higher resolution image via an IP connection using the AlternativeLocationURL. The image may also be a different to the broadcast delivered image.

The Alert parameter allows receivers to indicate that an emergency situation is occurring.

Broadcast Website (BWS)

BWS is the delivery of html pages for display in a browser on the receiving device. For example, a set of html pages could be delivered to a smartphone and when selected, displayed using the smartphone's browser. The html pages can also include further links (URLs) which can be used to retrieve additional webpages when the receiving device is connected to the internet.

Service and Programme Information (SPI)

The DAB family of standards supports the delivery of Service and Programme Information (SPI) over both the DAB broadcast channel and TCP/IP ancillary channel (if available). The SPI data includes Service Information (services) and Programme Information (schedules, programmes, and programme events). Additionally, programmes and programme events can be linked together into groups (e.g. for grouping programmes together into serials or series), which may have additional Group Information.

The SPI is captured using an XML schema data model[16] and can be delivered by either DAB broadcast or TCP/IP. The service provider may provide all the XML documents over the broadcast platform only; or they may provide all the documents in parallel via the broadcast platform and TCP/IP to additionally support connected devices; or they may provide the Service Information (SI) document over the broadcast platform and the remaining documents via TCP/IP; or some other combination.

The Service Information (SI) document holds a definition of services provided by the service provider, including any relevant metadata and bearer details, such as:

- Names (in different lengths and languages)
- Descriptions (in different lengths and languages)
- Logos (in different sizes (both recommended and custom), and formats e.g. JPEG and PNG)
- Genres
- Keywords
- Bearers the service can be received over (both broadcast and IP)
- Geolocations

In addition, services can be grouped together.

Programme Information (PI) is composed into a schedule. A "linear schedule" describes programmes for a linear service (radio station) over a defined time interval, typically around a 24-hour period from midnight to midnight. Individual programmes may also include programme events, signifying events within the programme. A linear schedule may also indicate that the programme or programme event is available on-demand. An "on-demand schedule" describes programmes that are available on-demand, either via IP or delivered by a broadcast Filecast Channel, during defined acquisition periods. The programme contains information specific to an individual programme, including its descriptive elements, timings, and any bearer information that differs from the parent service the PI document belongs to.

[16] TS 102 818 V3.1.1, Hybrid Digital Radio (DAB, DRM, RadioDNS); XML Specification for Service and Programme Information (SPI)

The programme element can contain the following elements:

- nameGroup (shortName, mediumName, longName)
- location (includes timing and bearer information)
- onDemand (includes presentationTime, acquisitionTime and bearer information)
- mediaDescription
- genre
- keywords
- memberOf
- link
- programmeEvent (includes nameGroup, onDemand and location information)

Group information allows programmes and programme events to be put into groups. These may be series, serials or just general themes. A hierarchical approach also allows groups to be member of other groups.

There are a wide range of possibilities available to service providers in the way that they partition information into SPI XML documents. When broadcast over DAB, some constraints are placed on the content of the individual documents and each XML document is encoded into a binary format, and delivered using the MOT protocol in directory mode, as described in ETSI TS 102 371[17]. Binary encoding provides a high level of compression of the XML documents by allowing only specific data sizes and values.

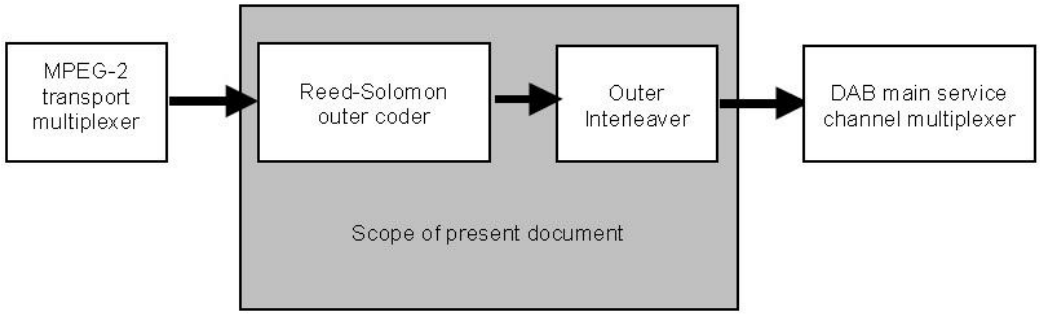
Mobile TV

When video services are provided within the DAB family of standards they are usually referred to as T-DMB. Video services include the accompanying audio content and other metadata or auxiliary media information all of which is encapsulated within an MPEG-2 Transport Stream (MPEG-2 -TS)[18]

The MPEG-2 TS has Reed-Solomon FEC coding attached and is interleaved using a convolutional interleaver as shown in Figure A-3. The resulting stream is then inserted in a DAB streaming mode data sub-channel[19].

[17] TS 102 371 v3.1.1, Digital Audio Broadcasting (DAB); Digital Radio Mondiale (DRM); Transportation and Binary Encoding Specification for Service and Programme Information (SPI)
[18] TS 102 428 v1.2.1. (2009-04)
[19] TS 102 427 1.1.1 (2005-07)

Figure A-3: T-DMB MPEG-2 TS encapsulation



Video services are typically transported using DAB sub-channel bit rates between 256 and 512kbps, although there is no limit of the bit rate used up to the maximum that can be transported given the choice of convolutional FEC protection level.

Service Following

Service following is the term applied to maintaining the same audio or data content that the user has selected in varying reception conditions when travelling by car or train. Many broadcast network topologies are possible, for example the selected service may be carried on more than one ensemble, may carry common programming with other DAB services, and for audio services, may also be carried on FM-RDS, IP or another bearer.

The best service following experience for the listener is achieved when the broadcaster minimizes the timing differences between different bearers, taking into consideration the different coding and decoding delays of the different systems. Reliable service following also requires that all the identifiers used are properly allocated in such a way as to make them unique within their respective scope.

DAB provides signaling carried in FIG 0/6 that enables service providers to inform receivers about the broadcast networks and service configurations that allow service following to take place (much of which is static, since it refers to transmitter network configurations that change only infrequently), and also provides dynamic information to control that information which is used at any given time to take account of changes during the day. Three types of information may be involved with service following - service linking information, Other Ensembles Services information and Frequency information. Service following generally provides information to allow precisely the same service to be followed, and when linking information is needed, this is called hard linking. Service providers are also able to indicate suitable alternative content - related services - and this is called soft linking. Receivers shall investigate all possible hard links before checking for soft links, and since the content is not identical for a soft link, it is preferred that the user request to follow the link.

To assist broadcasters and ensure that receiver manufacturers worldwide implement service following correctly, WorldDAB has produced information to support on this process[20].

Announcement Switching

The Announcement feature of DAB allows the receiver to change audio sources when an announcement is signalled by a broadcaster. Announcements are signalled through FIGs 0/18, 0/19, 0/25 and 0/26.

A typical example of an announcement is a traffic voice message where, when the feature is enabled by the listener, the receiver will automatically change services, and in some cases multiplexes, to output the voice message on current traffic situations or emergencies for a brief period of time before resuming the previous interrupted service. A further example is the use of the Announcement feature for general emergency situations, in which case the receiver can be directed by a broadcaster, or multiplex controller, to instruct all receivers to output a particular service which carries emergency information.

Announcements are commonly supported by automotive receivers due to the usefulness of traffic announcements and information and its availability on existing FM-RDS systems through TMC (also see the section on TPEG below).

Conditional Access

The DAB system includes a comprehensive conditional access system[21]. The CA system can be used to deliver content for pay for use schemes whether on a subscription or per use basis, e.g. to view a football game on a Mobile TV or T-DMB service, or to listen to a concert live. The DAB CA system provides the features necessary to add encryption and control using a third party system.

IP datacasting in DAB

The DAB system is capable of carrying IP packets (datagrams) using IP/UDP protocol[22]. As these packets travel unidirectionally from a service provider to many users simultaneously, this is a form of IP Multicasting, e.g., pushing the same contents to several users concurrently. The IP datagrams are tunnelled through a DAB packet mode service component. This is done by encapsulating the IP datagram in an MSC data group on packet mode transport level. It is not necessary to establish a connection between the transmitter and the user prior to the transmission of data.

[20] TS 103 176, Rules of implementation: Service information features
[21] EN 300 401, Radio Broadcasting Systems; Digital Audio Broadcasting (DAB) to mobile, portable and fixed receivers
[22] ES 201 735, Digital Audio Broadcasting (DAB); Internet Protocol (IP) Datagram Tunnelling

IP datacasting is a useful option for DAB systems required to work with IP-enabled devices such as smartphones and tablets. The IP layer is used as a common communications layer between the two systems. IP datacasting over DAB can provide data content such as video, audio, web pages and files and can also enable the personalisation of broadcast services.

Dynamic Label

This application carries text information and control characters with a length up to 128 characters in the PAD channel. It requires a simple alphanumeric text display of 2 lines, 32 characters each. If the length of the text to be displayed is longer than 64 characters, the text can be incremental or scrolling.

Broadcast Website

BWS is a local interactive service; the user selects information already received by a browser. This "radio web" service allows the access to a limited number of websites, as chosen by the broadcaster ("walled garden"). BWS can be rendered either by a PC or a car navigation platform using a ¼ VGA display (320 x 240 pixels). HTML version 3.2 and a storage capacity of 256 kB are required.

Slide Show

This application involves sequences of still pictures (JPEG or PNG). The order and presentation time of this service are generated by the broadcaster. The transmission time depends primarily on the file sizes of the pictures and the chosen PAD data rate. For example, a CD cover coded as JPEG 320 x 240 requires a transmission time of 22s (PAD or packet mode data rate of 16 kbps is assumed). No local interaction is required.

A visual component, associated with audio, would potentially greatly help radio advertisers to increase advertising revenue. For example, instead of talking about the new model Volvo had just released, it would be good if we could see some pictures while we hear about its great features.

Electronic Programme Guide (EPG)

The DAB Electronic Programme Guide (EPG) allows programmers to signpost on a screen on the radio their key music positions, programmes and benchmark features, and set up opportunities to record or auto-retune the radio to their station.

Schedules can be sent to the receiver several days in advance of broadcasts, allowing opportunity to highlight and lock listeners into new on-air activities early on. They can also be updated frequently to reflect last-minute changes to on-air output.

Experience of Television EPGs show that they can build station loyalty and time spent watching, and provide a significant enhancement to recall of on-air promotional trails.

It is expected that the EPG will become a standard feature on many DAB Digital Radios, as it has become a worldwide technical standard that can be freely adopted by receiver

manufacturers. The EPG was the result of a two-year task force made up of broadcasters and receiver manufacturers working together within WorldDAB, the forum that promotes development of Digital Radio to the Eureka 147 standard.

As in TV, EPG will be useful to help users find, preview, select, listen and record radio programmes, particularly if there are many, possibly several hundred, radio programmes in a given area.[23] The EPG will be used to provide programme listings information for both audio and data services and as a mechanism for the user to select services, programmes and related content. A key requirement is that the EPG must work on a range of receivers with differing display capabilities, resources and back-channel capabilities. To achieve this, a flexible multi-layer structure has been defined. The EPG data is broken down into service information (ensembles and services) and programme information (schedules, programmes, groups and events). Additionally, programmes and events can be linked together into groups (e.g. for grouping programmes together into serials or series).

EPG will be useful to promote new programmes and to attract new listeners. It is also enabled for future technologies such as Personal Media Recording (DAB equivalent of PVR). Manual or automatic time-shifting of the programme will be possible for the user to choose what and when they want to listen.

An EPG standard "XML Specification for DAB Electronic Programme Guide" has been developed by WorldDAB. [24] Work is still continuing into the transportation and compression of the EPG data. EPG is currently being broadcast experimentally on 8 multiplexes in the UK.

DAB Virtual Machine (DAB Java)

Analogous to DVB Multimedia Home Platform (MHP), but suitably scaled down to fit into narrow-band DAB channel, DAB Java provides a flexible and extendible platform (middleware) for all new DAB data services. DAB Java is standardised by ETSI.[25] The platform enables the rapid implementation and deployment of new business ideas by enabling the applications (and applets) to access DAB resources. Future data services for DAB will be realized most efficient based on DAB Java in terms of time to market and platform independence. This approach enables DAB to be integrated in large scaled Java – based software environments, e.g. cars using widely accepted standards.

The concept of a virtual machine has been chosen to allow for execution of any DAB applications independent of the hardware specific configuration. The DAB Java Framework is divided into three basic modules or packages: a) a DAB-specific extension of the Java API, b) a runtime support for the DAB applications execution environment, and c) a DAB I/O package for signalling the DAB Java extension over the DAB signal.

[23] Currently there are 320 DAB radio programmes on air in the UK, including 50 in London.
[24] TS 102 818 v1.1.1 Digital Audio Broadcasting (DAB); XML Specification for DAB Electronic Programme Guide (EPG), ETSI
[25] TS 101 993 V1.1.1 (2002-03) Digital Audio Broadcasting (DAB);A Virtual Machine for DAB: DAB Java Specification, ETSI

End-to-end reference implementations have been successfully developed to demonstrate the benefits and new possibilities of DAB Java. These implementations include an EPG application, a BWS application, a stock market ticker and some local-interactive games. The BBC has developed an interactive DAB Java – based application "Composer Biographies." Bosch has demonstrated an integration of DAB Java in an OSGI-based telematics system (GPS device).

Figure A.3 shows the architecture of DAB Java.

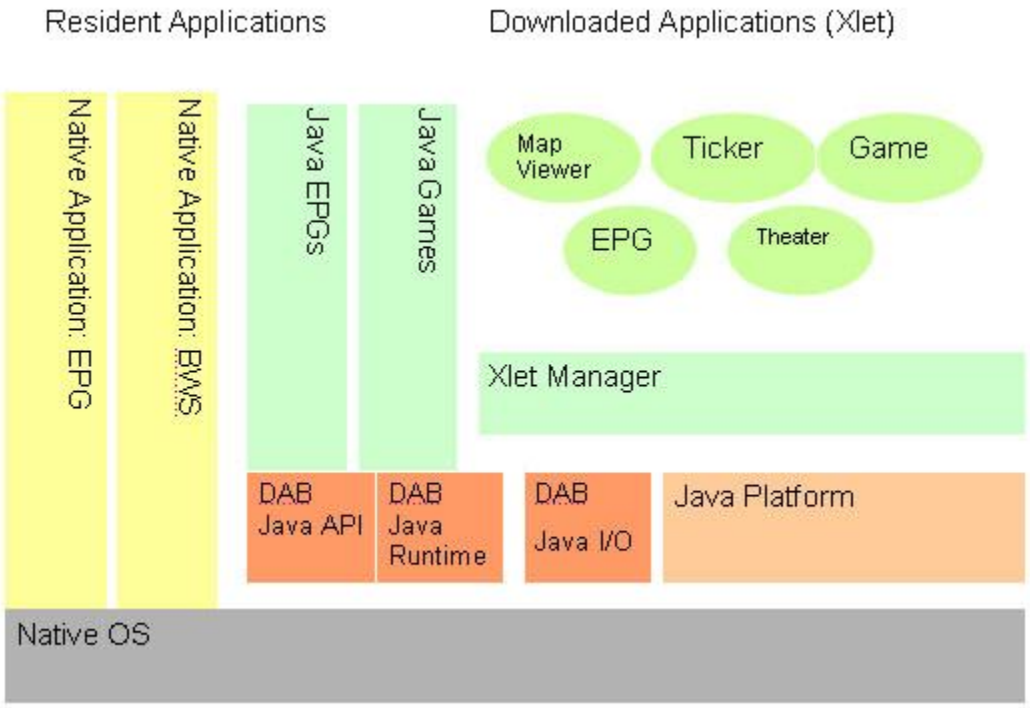


Figure A.3

The development and implementation of DAB Java requires close cooperation of content, service, network providers and terminal manufacturers.

DAB Receiver Interfaces

In order to introduce new applications in the mature market with millions of DAB receivers deployed, it is essential to allow the legacy receivers to connect to the new application decoders via an agreed interface. To this end, The WorldDAB Forum has developed a specification for the Receiver Data Interface (RDI).[26] Nevertheless, as RDI has some technical limitations (e.g. flexibility, fixed bandwidth), it has been decided to develop a new interface. The WorldDAB Forum and the DRM Forum have agreed to cooperate in defining a generic physical USB interface for all digital radio receivers.

[26] EN 50255 Digital Audio Broadcasting system; Specification of the Receiver Data Interface (RDI), CENELEC

Furthermore, a generic low level driver interface based on Digital Command Set for Receivers (DRCS) specification will be developed, taking into account of copy protection and digital rights management issues.

Conditional Access

The DAB system already includes a comprehensive conditional system (see Chapter 9 of EN 300 401). Further work is now underway to develop a simple, yet reliable system to be used in commercial receivers using a common scrambling algorithm and a common receiver interface, however allowing the use of different commercial CA systems such as Simulcrypt and Multicrypt.

SBR Layer II

Spectrum Band Replication (SBR) is a process, proposed by Coding Technologies and now standardised within MPEG-4 Audio, designed to potentially improve spectrum efficiency of the DAB system by reducing the audio bit rate for the same quality, while retaining backwards compatibility. Some initial studies indicate that about 30% improvement could be achieved.

The EBU Project group B/AIM (Audio In Multimedia) is carrying studies on error sensitivity and compatibility with non-SBR receivers. Some preliminary results show that the inclusion of SBR in the DAB system does not significantly degrade the C/N performance of the DAB system, neither in terms of Threshold of Audibility (TOA) nor Point of Failure (POF).

Studies are continued on balancing the benefits and drawbacks of SBR. The matters to be addressed involve the increase of complexity (and thus cost) of the receiver and the related IPR issues. No decision has been made by the WorldDAB Forum to date about the viability of including SBR in the standard and recommending its incorporation into commercial receivers.

File caching in the receiver

The WorldDAB Forum has now established a specification for using an optional caching facility in the receiver. The user will benefit from a so-called "rewind radio," which will allow listening of the latest programme at any time. The caching device will also allow the user to use the DAB receiver as a PVR (Personal Versatile Recorder) device for time-shifted playout of audio events (with or without associated data). It should be pointed out the use of caching may change the way people access and enjoy radio listening. It potentially widens the programming possibilities offered by the broadcaster, but also introduces new technical and operational problems (copyright, EPG, etc).

In September 2003, RadioScape, which specialises in digital radio software, launched a new module called RS200L. One of the features of this module is the inclusion of Rewind Radio that enables about ten minutes of audio to be stored on chip RAM. This can be used to listen to a news clip again or time shift by pausing and resuming the radio. The module has been designed using the DRE200 chip from Texas Instruments, which is probably one of the world's bestselling receiver chips for the Eureka 147 standard. This

chip has now been superseded by a new version, DRE310, that can decode more than one channel simultaneously and includes time-shifted radio, announcement support, service linking (FM/DAB ensemble switching), TII (Transmitter Identification Information) and MP3/Windows Media Audio CD support.

TopNews

TopNews is a commercial name for Bosch/Blaupunkt's system which allows broadcasters (and multiplex providers) to download via a suitable DAB data channel (e.g. MOT, MSC packet mode) the news and other audio files or other objects coded in MP3 to the receiver. The user is appropriately informed of the existence of these audio objects and could access them at their convenience. The broadcaster is responsible for contents and needs to update the audio file contents regularly. There is no need for return link to the service provider. This "audio anytime" system is particularly attractive for in-car applications.

IP datacasting in DAB

The DAB system is capable of carrying IP packets (datagrams) using IP/UDP protocol.[27] As these packets travel unidirectionally from a service provider to many users simultaneously, this is a form of IP Multicasting, e.g., pushing the same contents to several users concurrently. The IP datagrams are tunnelled through a DAB packet mode service component (SC). This is done by encapsulating the IP datagram in an MSC data group on packet mode transport level. It is not necessary to establish a connection between the transmitter and the user prior to the transmission of data.

For connection oriented point-to-point transport, TCP has to be used (rather than UDP). TCP requires an interaction channel for the return flow of acknowledgements.

Further work is necessary to be carried out similar to that performed by the DVB-IPI project in order to specify the discovery and selection of the data services by the user.

The Digital Video Broadcasting (DVB) Project has developed a data broadcasting standard describing an IPv4 and IPv6 datagrams encapsulation in MPEG-2 transport stream. This system is commonly called Multi-Protocol Encapsulation (MPE) or Data Piping[28] and includes dynamic address resolution, multicast group membership and other supporting procedures and protocols. The overhead due to encapsulation is reasonably low, e.g., below 3%.

IP datacasting is an interesting option for the DAB systems required to work with IP-enabled devices such as mobile phones. The IP layer could be used as a common communications layer between the two systems. IP datacasting over DAB will bring the data content such as moving pictures, audio, web pages, computer programmes and software upgrades reliably to each user (or a group of users) and will thus expand significantly market opportunities of DAB. IP datacasting will pave the way towards the personalisation of broadcast services.

[27] ES 201 735 V1.1.1 Digital Audio Broadcasting (DAB); Internet Protocol (IP) Datagram Tunnelling
[28] EN 301 192 V1.3.1 (2003-05) Digital Video Broadcasting (DVB); DVB specification for data broadcasting

TPEG transport in DAB

It is well known to all broadcasters that radio is an ideal (and the cheapest) medium to inform travellers about the road conditions and traffic jams – provided that such information is timely and relevant, in the correct location. Currently, analogue FM radio uses a well-established RDS-TMC (Traffic Message System) system. However, the TMC is essentially limited to inter-urban road events and every decoder must have a location database to interpret any message received.

TPEG was developed by the EBU to overcome these limitations. TPEG delivers very rich location referencing information with every message, so that receivers do not need a location database. Thus, navigation systems which are now becoming a standard commodity in the car can "machine read" the location content and localise an event directly onto the map display. A text-only device (such as a PDA) is able to present locally found names, such as a railway station name and a platform number, directly to an end user as a text message. Such a message can be rendered in the language of choice of the end user. TPEG can filter the information to avoid receiver overload, so that end users can select messages on any number of criteria, such as the type of location, mode of public transport, direction of travel, event, etc.

TPEG can be transported within the DAB system in the Transparent Data Channel (TDC) in a stream-like format; bytes come out in the same order they go in.[29] The TDC Specification allows TPEG data to be carried in three modes: packet mode, stream mode and X-PAD. Nevertheless, this approach, which is specified in the present version of the DAB standard, involves several problems in terms of reception reliability and interpretation. It has therefore been proposed to transport TPEG as one of the multimedia applications in the MOT data channel. This would imply the following main advantages: MOT is already implemented in most receivers and enables efficient object compression, power saving and delta updates and has much lower overhead than TDC.

TPEG[30] replaces and enhances RDS TMC using the DAB family of standards as the ideal platform for traffic and travel information. Traffic and Travel Information (TTI) data services require less than 1.4% of the total data capacity (typically 16kbps) to provide feature rich, language independent services for drivers. Next generation TPEG offers real added value to drivers and is of interest to the car industry, services offered include:

- Traffic event / news
- Traffic weather
- Driver assistance
- Local hazard warning
- Traffic flow / prediction
- Parking information

[29] Guidelines for TPEG in DAB, B/TPEG Plenary Group 00/113 available from www.ebu.ch/bmc_btpeg.htm
30 see www.tisa.org/technologies/tpeg

- Fuel prices
- Local interest

TPEG can be transported within the DAB system in a Transparent Data Channel (TDC). The TDC Specification allows TPEG data to be carried in three modes: packet mode, stream mode and X-PAD.

Hybrid DAB Radio

Hybrid DAB radio augments DAB broadcast services with alternative and additional features provided through the internet. The addition of IP connectivity allows a wider range of ancillary services and features which can add value to the listeners experience as well as the content delivered by the broadcaster.

As shown in Figure A-4, audio services and their PAD are typically delivered using DAB. Additional metadata such as Service and Programme Information can be delivered using either DAB or IP while additional features such as interactivity and alternative SLS images are delivered via IP only.

Figure A-4: Hybrid radio feature delivery example

The IP connectivity can be provided to the DAB receiver in a number of ways such as:

- While in the home, connect the radio receiver to in-home broadband via WiFi
- When in the car, connect the car's infotainment system to the mobile broadband network through Bluetooth from the listeners mobile phone
- When on the move, use local WiFi hotspots or mobile broadband

There are many use cases for hybrid radio that demonstrate the value of the additional features including:

- Brand recognition – Service and Programme Information such as logos, strap lines and broadcast schedules can be delivered via DAB broadcast or IP to enhance recognition of the broadcasters service
- Brand building and listener loyalty - Slide images and DLS text can have associated URLs which when selected by the listener will present the associated website on the receiver's browser. This can be used to deliver added value from the broadcaster via IP in the form of games, give-aways and general interaction.
- Increased advertising value – Advertising slide images and text has increased value when the listener can gain immediate access to special offers as demonstrated in internet only radio. When the URL is activated, the target content can be delivered via the broadcaster's website allowing the broadcaster to measure the interest in the product.
- Maximises image quality - For high resolution screen devices such as smartphones and vehicles, targeted hi-resolution images can be delivered instead of the standard QVGA images providing better clarity and more details

At the time of writing, the availability of hybrid devices is just beginning. Examples include the LG Stylus 2 DAB smartphone launched in 2016 and the Frontier-Silicon[31] UNDOK App which allows the control of home receivers through a smartphone connected to WiFi in the home.

Hybrid radio provides the most cost effective delivery of rich media radio for both the listener and the broadcasters. The listener receives the data intensive audio and basic PAD via free-to-air broadcast DAB radio and only incurs mobile data costs and capacity use when the user decides to engage. The broadcaster can deliver the vast majority of their standard content by the most cost effective and high availability means in DAB while still providing all the features that are supplied in internet only radio, reducing overall operating costs and maximising availability.

Coverage Planning Guidelines and Parameters

The planning parameters used for the implementation of DAB transmission networks draw on a number of ITU, EBU and other sources including:

- ITU-R BS.1660-6 Technical basis for planning of terrestrial digital sound broadcasting in the VHF band, 08/2012
- EBU TR 021, Technical bases for T-DAB services network planning and compatibility with existing broadcasting services, October 2013
- EBU, TR 024. SFN frequency planning and network implementation with regard to T-DAB and DVB-T, October 2013
- EBU TR 025,Report on frequency and network planning parameters related to DAB+, October 2013

[31] http://www.frontier-silicon.com/

- ITU-R Final Acts of the Regional Radiocommunication Conference for planning of the digital terrestrial broadcasting service in parts of Regions 1 and 3, in the frequency bands 174-230 MHz and 470-862 MHz (GE-06)
- UK OFCOM DAB Planning study documents and annexes, 2012
- ACMA, Broadcasting Services (Technical Planning) Guidelines 2007 (as amended in 2009)
- CRA report, "Planning Field Strength and derivation for T-DAB reception for mobile and indoor", BTC Australia for CRA, January 2008

The studies and, in particular, the reference documents from the ITU and the EBU have been updated over several years with further revisions expected.

Advanced demodulation technique for COFDM

The Communications Research Centre Canada (CRC) developed an advanced COFDM demodulation technique[32] which reduces the effect of the Doppler effect and therefore increases the maximum speed, allowing vehicle speeds up to 140 km/s while achieving a target bit error rate (BER) of 10-4. Canadian DAB broadcasters use L-Band (1452 to 1492 MHz) and would like to use Transmission Mode IV instead of Mode II, because the former allows for a larger separation distance between on-channel re-transmitters than in the case of Mode II. However, Mode IV in L-Band limits the speed to less than 100 km/h, so this new technique could help. Further studies are required to investigate whether this technique could be useful for VHF bands and whether the chip manufacturers could accommodate it readily into their chip design.

Technical Standards

International Standards

ETSI Standards[33]

Eureka 147 standards are formalised by ETSI and are available for download. The current list of ETSI standards relating to Eureka 147 are in Table A.4. The main ETSI standard for Eureka 147 is EN 300 401.

Table A.4: ETSI Standards relating to Eureka 147

Number	Title
EN 300 401 V1.3.3 (May 2001)	Digital Audio Broadcasting (DAB); DAB to mobile, portable and fixed receivers (THIRD EDITION)

[32] Thibault, Zhang, Boudreau, Taylor, Chouinard: Advanced Demodulation Technique for COFDM in Fast Fading Channels, IBC 2003 Proceedings, p. 416 to 422

[33] EBU BPN 062

Number	Title
EN 300 797 V1.1.1	Digital Audio Broadcasting (DAB); Distribution interfaces; Service Transport Interface (STI)
EN 300 798 V1.1.1	Digital Audio Broadcasting (DAB); Distribution interfaces; Digital baseband In-phase and Quadrature (DIQ) Interface
EN 301 234 V1.2.1	Digital Audio Broadcasting (DAB); Multimedia Object Transfer (MOT) protocol
EN 301 700 V1.1.1	Digital Audio Broadcasting (DAB); Service Referencing from FM-RDS; Definition and use of RDS-ODA
EN 302 077 V1.1.1	Electromagnetic compatibility and Radio spectrum Matters (ERM); Harmonised EN for Terrestrial Digital Audio Broadcast (TDAB) equipment used in the sound broadcasting service.
ES 201 735	Digital Audio Broadcasting (DAB); Internet Protocol Datagram Tunnelling
ES 201 736 V1.1.1	Digital Audio Broadcasting (DAB); Network Independent Protocols for Interactive Services
ES 201 737 V1.1.1	Digital Audio Broadcasting (DAB); DAB Interaction Channel through GSM / PSTN / ISDN / DECT
ETS 300 799	Digital Audio Broadcasting (DAB); Distribution interfaces; Ensemble Transport Interface (ETI)
TR 101 495 V1.1.1	Digital Audio Broadcasting (DAB); Guide to DAB Standards; Guidelines and Bibliography
TR 101 496-1 V.1.1.1	Digital Audio Broadcasting (DAB); Guidelines and Rules for Implementation and Operation
TR 101 496-2 V.1.1.2	Digital Audio Broadcasting (DAB); Guidelines and Rules for Implementation and Operation
TR 101 496-3 V.1.1.2	Digital Audio Broadcasting (DAB); Guidelines and Rules for Implementation and Operation
TR 101 497 V1.1.1	Digital Audio Broadcasting (DAB); Rules of Operation for the Multimedia Object Transfer Protocol
TS 101 498-1 V1.1.1	Digital Audio Broadcasting (DAB); Broadcast Website Application, Part 1:User Application Specification
TS 101 498-2 V1.1.1	Digital Audio Broadcasting (DAB); Broadcast Website Application, Part 2: Basic Profile Specification
TS 101 499 V1.1.1	Digital Audio Broadcasting (DAB); MOT Slide Show; User Application Specification
TS 101 735 V1.1.1	Digital Audio Broadcasting (DAB); Internet Protocol Datagram Tunnelling
TS 101 736 V1.1.1	Digital Audio Broadcasting (DAB); Network Independent Protocols for Interactive Services
TS 101 737 V1.1.1	Digital Audio Broadcasting (DAB); DAB Interaction Channel through GSM / PSTN / ISDN / DECT

Number	Title
TS 101 756 V1.1.1	Digital Audio Broadcasting (DAB); Registered Tables
TS 101 757 V1.1.1	Digital Audio Broadcasting (DAB); Conformance Testing for DAB Audio
TS 101 758 V2.1.1	Digital Audio Broadcasting (DAB); DAB Signal Strengths and Receiver Parameters
TS 101 759 V1.1.1	Digital Audio Broadcasting (DAB); DAB Data Broadcasting Transparent Data Channel
TS 101 860 V1.1.1	Digital Audio Broadcasting (DAB); Distribution Interfaces; Service Transport Interface (STI); STI Levels
TS 101 993 V1.1.1	Digital Audio Broadcasting (DAB); A Virtual Machine for DAB: DAB Java Specification
TS 102 818 V1.1.1	Digital Audio Broadcasting (DAB); XML Specification for DAB Electronic Program Guide (EPG)

Receiver Standards

European receiver standards have been developed by CENELEC, IEC and national standards bodies (e.g., UK). A list of relevant receiver standards is in Table A.5.

Table A.5: Receiver Standards for Eureka 147

Reference	Title
CENELEC EN 50255	Digital Audio Broadcasting system - Specification of the Receiver Data Interface (RDI)
CENELEC EN 50248	Characteristics of DAB receivers
CENELEC EN 50320	The DAB Command Set for receivers
IEC 62105	Digital Audio Broadcasting System - Specification of the Receiver Data Interface (RDI)
IEC 62104	Characteristics of DAB Receivers

ITU Publications and Recommendations

The International Telecommunications Union (ITU) has a number of publications and Recommendations relating to Eureka 147 and digital radio in particular. The “DSB Handbook - Terrestrial and satellite DSB to vehicular, portable and fixed receivers in the VHF/UHF bands” is an aggregation of ITU input documents and data. Relevant recommendations are in Table A.6.

Table A.6: ITU Recommendations relevant to Eureka 147

Reference	Title
BS.1115	Low data rate audio coding
BS.774-2	Service requirements for DSB to vehicular, portable and fixed receivers using terrestrial transmitters in the VHF/UHF bands
BS.1114-3	Systems for terrestrial DSB to vehicular, portable and fixed receivers in the frequency range 30-3 000 MHz
BO.789-2	Service for DSB to vehicular portable and fixed receivers for broadcasting-satellite service (sound) in the frequency range 1 400-2 700 MHz
BO.1130-4	Systems for digital satellite broadcasting to vehicular, portable and fixed receivers in the bands allocated to BSS (sound) in the frequency range 1 400-2 700 MHz

12. Appendix-B: HD Radio System Description

[Editor's Note: this appendix contains information provided for the first edition of this report and no longer fully represents the status of the HD Radio system. A major update is in preparation.]

Introduction

This Appendix is a high-level description of the HD Radio system. It is intended for broadcasters considering transmission of digital radio signals, equipment manufacturers designing digital radio receivers, and anyone else interested in how HD Radio technology works. Minimal technical knowledge is required.

The system supports new audio and data services that coexist with existing frequency modulation (FM) analogue service on VHF Band II assignments from 87.5 MHz to 108 MHz and existing amplitude modulation (AM) analogue services in the medium wave (MW) portion of the medium frequency band (MF) from 535 kHz to 1705 kHz. Operation in these frequency ranges is subject to certain regulatory conditions. Therefore, the North American digital radio system standard adoption and deployment is proposed in accordance with these regulatory conditions, while ensuring operation of the existing analogue broadcasting services.

Interference protection requirements for FM sound broadcasting in Band II are defined by the International Telecommunication Union – Radiocommunication Sector (ITU-R). HD Radio technology was designed to satisfy the frequency spacing and spectral mask for FM sound broadcasting for Band II in ITU-R Region 2.

This Appendix focuses on the simultaneous "hybrid" transmission of existing analogue FM with digital HD Radio signals. Some sections may also apply to the hybrid of existing analogue AM with digital HD Radio signals. While all-digital transmission is a functional mode in deployed HD Radio receivers, transmission in this mode has only been used experimentally and is not covered in this Appendix.

Detailed information on HD Radio technology is available from the National Radio Systems Committee (NRSC, a technical standards-setting body co-sponsored by the Consumer Technology Association and the National Association of Broadcasters; see in particular the NRSC-5 Standard) at http://www.nrscstandards.org, and DTS, Inc. (developers and implementers of HD Radio technology) at http://www.dts.com.

Overview

HD Radio technology is a method to transmit digital radio signals. It allows digital radio signals to exist in the same band as analogue AM and FM radio signals, and on the same channel as these existing signals. This is generically known as "in-band, on-channel" or "IBOC" (pronounced EYE-bahk) digital radio. As noted in the Position Paper, in the hybrid mode of operation, existing analogue radio signals are preserved; low-level HD Radio digital signals are added immediately adjacent to (or in the case of AM HD Radio, underneath of) an analogue signal. HD Radio technology provides a comprehensive and flexible transition to an "all-digital" world, whenever it may occur, since it also supports an all-digital mode of operation in which an all-digital radio signal would occupy that

same spectrum. No new spectrum allocations are required for the digital radio signal, either now or in the future.

The HD Radio signal can contain the same content as an existing analogue radio signal, including audio and related metadata such as song title and artist. It can contain additional audio channels and metadata. Moreover, other digital content can also be transmitted, such as images or data that are unrelated to any of the audio programs — all on the same HD Radio signal.

All existing analogue radio receivers are compatible with hybrid transmissions of analogue FM and HD Radio signals. HD Radio receivers for audio will blend from an analogue to a digital radio signal, if it is available. If a digital radio signal is not available, the receiver will stay tuned to the analogue FM signal.

HD Radio technology was evaluated extensively in the United States by the National Radio Systems Committee (NRSC), resulting in a recommendation to the FCC for the adoption of the HD Radio IBOC technology. Subsequent to the NRSC evaluation of IBOC, the NRSC developed the NRSC-5 IBOC Digital Radio Broadcasting Standard. The latest version of this standard may be found at the following URL: http://www.nrscstandards.org.

Supported Services and Bandwidth Management
Audio is one of many types of services supported by the HD Radio system. A few services are mandatory; the remaining services are optional.

Main Program Service
The Main Program Service (MPS) is the primary digital audio channel from the broadcaster. If the radio station is transmitting a hybrid of the analog radio signal and the digital HD Radio signal, then the MPS is a digital simulcast of the analog signal. In this way, the analogue audio acts as a "backup" to the digital audio, and HD Radio receivers will "blend" from the analogue to the digital audio and vice versa depending upon reception conditions.

As a digital audio signal, the MPS can offer better audio quality than the analogue signal. Static, noise, and other impairments found in analogue signals do not exist in the MPS. The audio quality is consistent throughout the digital signal coverage area.

The MPS is commonly known as "HD-1", and is a mandatory part of the HD Radio signal.

Supplemental Program Service
The Supplemental Program Service (SPS) provides for additional digital audio channels on the same HD Radio signal as the MPS.

These channels may contain different programming than the MPS, such as foreign-language programs, other music formats, or simulcasts from a different radio station. SPS audio quality can be similar to that of the MPS. Unlike the MPS, the SPS audio channels do not have an analogue backup, and when the digital signal is lost by the receiver, the SPS audio channels will mute.

Multiple SPSs are supported. Each SPS is commonly known as “HD-2,” “HD-3,” etc., and SPS is an optional part of the HD Radio signal.

Programme Service Data

The MPS and each SPS can contain textual Program Service Data (PSD) that is synchronized to the current audio program. Examples include the artist and title of a song, the phone number for a talk show, the score of game, or the name and slogan of a commercial advertiser.

HD Radio PSD is equivalent to the Program Service (PS) and RadioText (RT) features of the RDS digital data subcarrier used with analogue FM.

Use of PSD is optional, but is recommended to match the HD Radio listening experience with analogue FM containing RDS.

Advanced Application Services

Advanced Application Services (AAS) are data channels on the same HD Radio signal as MPS and SPS (if SPS services are present). Examples include images of logos for the radio station or advertiser, or album artwork linked to specific songs. These services can greatly enhance the radio listening experience, matching that provided by internet-based audio streaming services, but with no additional data usage fees for the listener.

AAS data does not necessarily have to relate to any audio program, or even the radio station itself. Examples include emergency alerts for severe weather, earthquakes, or terrorism; real-time road traffic data for navigation devices; or remote switching of electrical devices to optimize the load on the electric power grid. Broadcasters can potentially generate additional recurring revenue by transmitting these services for a third party.

Station Information Service

The Station Information Service (SIS) contains basic, non-audio information about the radio station, such as the call sign, frequency, slogan, or electronic program guide (EPG), among other things. This is similar to the basic information found in the RDS digital data subcarrier used with analogue FM.

The SIS also contains control information about the HD Radio signal, such as technical details for other services available on the signal. Receivers use the SIS data as part of the HD Radio signal acquisition process.

The SIS is a mandatory part of the HD Radio signal.

Bandwidth Management

HD Radio signals have a limited amount of bandwidth, constrained primarily by the AM and FM radio channel allocation rules.

For maximum audio fidelity, the entire HD Radio signal bandwidth could be used for the MPS and the SIS (which uses very little bandwidth). If one SPS is required, then half of the bandwidth could be allocated for the MPS, and the other half could be allocated to the

SPS. But if the SPS is primarily for monaural talk radio, then substantially less than half of the bandwidth can be used for the supplemental service, and the bandwidth of the MPS can be increased to more than half.

These examples highlight some of the many possible combinations; the broadcaster is free to re-allocate the given bandwidth as needed.

Implementing HD Radio Transmissions

System Configurations

The HD Radio system, utilizing an IBOC approach, allows for a smooth evolution from analogue sound broadcasting to comprehensive digital sound and data broadcasting. In support of this evolution, the system introduces two conceptual configurations of operation. HD Radio receivers are designed to support both configurations so consumers only need to upgrade from existing analogue equipment to HD Radio equipment once:

- **Hybrid configuration**: both analogue and digital signals are transmitted in a single radio channel. This may be considered a transitional configuration. Broadcasters and consumers alike see little benefit in the immediate termination of analogue broadcasting as would be required if a digital radio system was implemented that required broadcasters and consumers to immediately "switch" to a new system, not compatible with existing analogue service. The benefit of the hybrid configuration is that analogue sound broadcasting service is maintained, while simultaneously offering new digital sound and data services, receivable on HD Radio receivers. This configuration supports simulcasting of audio programs on analogue and digital signals and supports smooth audio "blending" between the two (for the MPS);
- **All-digital configuration**: a digital signal only is transmitted in the radio channel. This may be considered a future implementation. In this configuration the broadcast stations cease transmitting analogue sound service and broadcast only the digital sound and data services; consumers who have upgraded to HD Radio receivers during the transmission of hybrid services will continue to receive the all-digital signals as well.

Basic Infrastructure

The HD Radio signal is a different signal than the existing analogue radio signal, and requires different types of equipment to transmit. However, this equipment is typically used in conjunction with existing analogue equipment. In some cases, existing equipment can be used to transmit both analogue and HD Radio signals. In other cases, existing equipment may need to be updated or augmented to accommodate HD Radio transmission.

For analogue FM, existing systems transmit a signal approximated by the red line shown in Figure B-1 labelled "FM." The entire transmission system is tuned specifically for the center frequency of the radio station (represented as 0 kHz frequency offset in Figure B-1), for the bandwidth of the red line (approximately 100 kHz away from the center on both sides), and for the authorized power of the radio station.

To transmit the HD Radio digital signal with an existing analogue FM signal, additional equipment is needed to transmit the signals represented by the gray bars, *PL* and *PU*, shown in Figure B-1 and which represent the HD Radio "digital sidebands." Note that the HD Radio signals are placed below (left) and above (right) the analogue FM signal; the FM signal itself remains essentially unchanged. The total occupied bandwidth of the analogue plus HD Radio digital signal is approximately ±200 kHz.

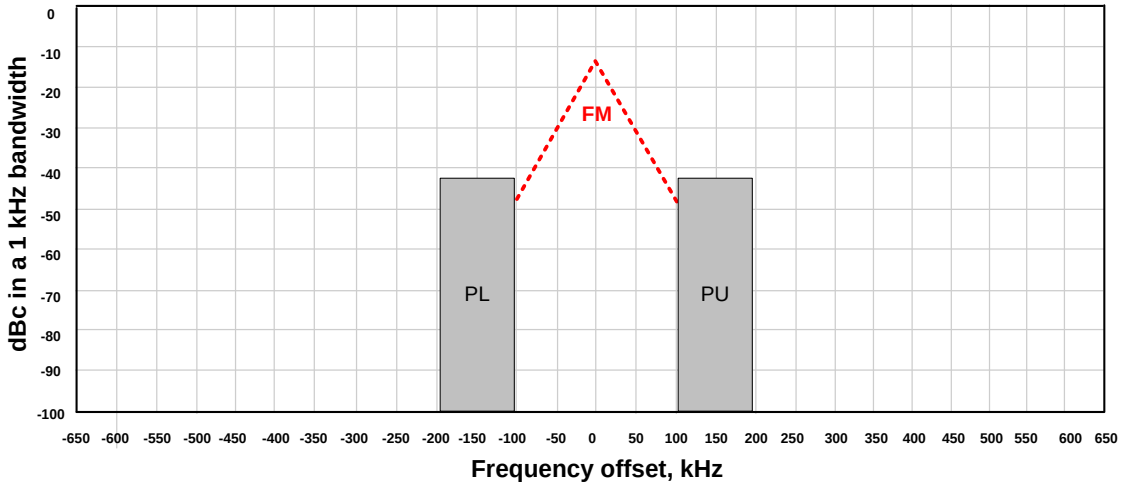


Figure B-1: Hybrid analogue FM and HD Radio signals

In some cases, an existing analogue system can already transmit the wider bandwidth and handle the additional power required for the HD Radio signal digital sidebands. If so, less equipment and fewer modifications are required to implement HD Radio transmissions.

In other cases, if the existing system cannot transmit the wider bandwidth and/or handle the additional power, then existing equipment may need to be upgraded, or additional equipment may be needed. Some broadcasters even choose a separate transmitter site exclusively for the HD Radio digital signal, and leave the existing analogue transmitter system on-the-air as-is (choosing to combine the analogue and digital signals in the antenna system).

Power, Signal Strength, and Coverage

In the original design of the HD Radio system, two key factors were considered in determining the power used to transmit the digital portion of the HD Radio signal:

- The coverage of the digital HD Radio signal should be similar to the coverage of the analogue FM signal;
- Because of the greater efficiency of the digital transmission system, a lower signal strength (than used for analogue FM) should be sufficient to successfully receive an HD Radio signal.

Transmitted radio frequency (RF) power is usually expressed in units of watts, such as 100 kilowatts (100 kW). Although the power of HD Radio signals can also be expressed in watts, it is generally more useful to use decibels below the analogue carrier (dBc). For

example, the total power of the HD Radio signals shown in Figure B-1 is approximately 20 decibels below the analogue carrier (−23 dBc per digital sideband).

The scale of a decibel is logarithmic rather than linear. So if the power of the analogue signal is 100,000 W, the power of the digital signal at:

−20 dBc, the power is 1.0% of 100,000 W, or 1,000 W;

−14 dBc, the power is 4.0% of 100,000 W, or 4,000 W;

−10 dBc, the power is 10.0% of 100,000 W, or 10,000 W.

In the United States, FM stations are authorized by the Federal Communications Commission (FCC) to operate at −14 dBc (4.0% of the analogue signal power) down to a minimum of −20 dBc (1.0% of analogue). The maximum allowed power is −10 dBc below the analogue FM signal (10% of analogue) but requires the broadcaster to submit to the FCC an engineering submission demonstrating adequate protection of nearby radio signals. At this highest power level, the outdoor and indoor digital reception coverage typically outperforms analogue reception coverage under similar conditions.

High-Level Combining (Separate Amplification)

Three principal methods are used for producing the HD Radio hybrid FM signal. The method that was most popular at the introduction of HD Radio technology is known as “high-level combining” or “separate amplification” and is shown in Figure B-2. With this method, the existing station transmitter has its output combined with the output of a separate digital transmitter compatible with HD Radio technology. The resulting hybrid signal is then fed to the existing station antenna.

HD Radio FM high-level combining uses two transmitters to produce the transmitted signal. This approach requires the addition of an HD Radio digital transmitter and the associated combiner, filter and digital exciter. Since both an analogue and digital transmitter will be operated at the site, power demands may require the upgrade of electrical service to the facility. Heat load will also increase and may require additional cooling to remain within acceptable limits.

The high-level combining method is inefficient due to power differences between the analogue and digital portions of the signal. In order to achieve the requisite isolation and linearity, RF combiners used for hybrid HD Radio signal generation sacrifice approximately 10% (~0.5 dB) of the analogue power and 90% (~10 dB) of the digital power to a reject load. However, because the digital power requirements in HD Radio technology are low (−20 dBc to −10 dBc), this loss is tolerable.

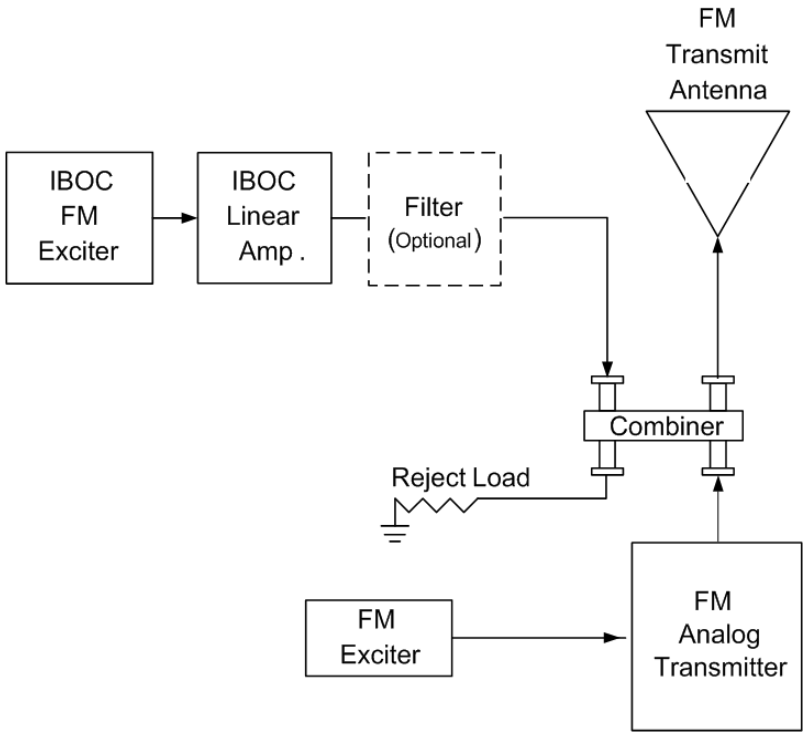


Figure B-2: FM HD Radio high-level, separate amplification

Another issue is that of peak-to-average ratio (PAR). Because the digital signal varies in amplitude as well as frequency, the PAR of an FM hybrid HD Radio signal is about 5.5 dB. For example, in the case of an FM station with an analogue total power output (TPO) of 10 kW, the digital carrier power of the HD Radio signal would be 1000 watts at −10 dBc or 100 watts at −20 dBc. Assuming combiner loss as discussed above, the analogue transmitter would need to be increased to 11.1 kW to overcome combiner insertion loss. The digital transmitter would have to provide for an average output power of 1 kW to overcome the 10 dB combiner loss for −20 dBc injection. The IBOC transmitter would also need to be sized to accommodate 5.5 dB of additional overhead for PAR. This sizing for peak power would amount to approximately three and a half times the average power requirement.

Low-level Combining (Common Amplification)

A second method for producing a hybrid IBOC signal is “low-level combining” or “common amplification” as depicted in Figure B-3. In this implementation, the output of an analogue FM exciter is combined with the output of an HD Radio exciter. The combined signal is fed to a broadband linear amplifier to raise the power to the desired TPO. This method is both power and space efficient and reduces the number of independent elements in the broadcast chain.

Separate and Dual-Input Antenna

The third implementation is known as the separate antenna method. This methodology takes one of two forms; physically separate antennas for the analogue and digital signals, as depicted in Figure B-4, or a dual-input antenna shown in Figure B-5.

In the separate antenna implementation, signals are routed from independent digital and analogue amplifiers to dedicated radiating elements for each signal. Two methods of separate antenna implementation are in use today. The basic form is an independent antenna for the digital signal, often previously installed as an analogue backup antenna. A physically separate antenna is often problematic as it can be difficult to achieve parity between analogue and digital coverage.

The second method, known as an interleaved antenna, places a digital antenna "bay" at the mid-point of the analogue radiating element array. In this design, the phase of the digital antenna elements is typically inverted (i.e., installed upside down) to provide additional isolation between the analogue and digital signals.

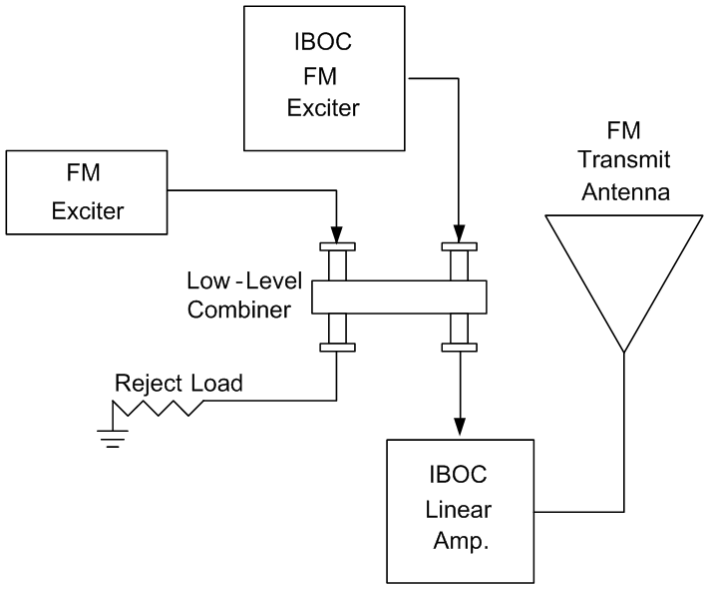


Figure B-3: FM HD Radio low-level, common amplification

Regardless of which separate antenna method is employed, the FCC authorizes use of this method in the United States as follows:

- The digital transmission must use a licensed auxiliary antenna;
- The auxiliary antenna must be within three seconds of latitude and longitude of the main antenna (used for the analogue transmission);
- The height above average terrain (HAAT) of the auxiliary antenna must be between 70 and 100 percent of the HAAT of the main antenna.

When using the separate antenna method, it is important for the digital antenna to have a minimum of 40 dB of isolation from the analogue antenna in order to keep

intermodulation products within acceptable limits. Attention to the proper placement of the antenna elements along with the use of an RF isolator on one or both transmitters may be required to minimize mutual coupling.

Replicating radiating element placement with regard to the leg and crossbar portions of the tower, for both the analogue and digital transmitting elements, will help to ensure that the patterns of the digital and analogue antennas are congruent. Since physically separate radiators are employed in this design, analogue signal radiation may be superior to the digital signal radiation due to the height difference between the centers of radiation (analogue will be higher). Despite this drawback, the advantage of using separate antennas is the elimination of the combiner loss. Dual-input antennas have the advantage that the center of radiation is identical for both the analogue and digital aperture resulting in near-identical analogue and digital RF coverage.

Since system designs vary in dimension as well as configuration, the physical space and implementation constraints should be reviewed with equipment manufacturers to determine the appropriate solutions.

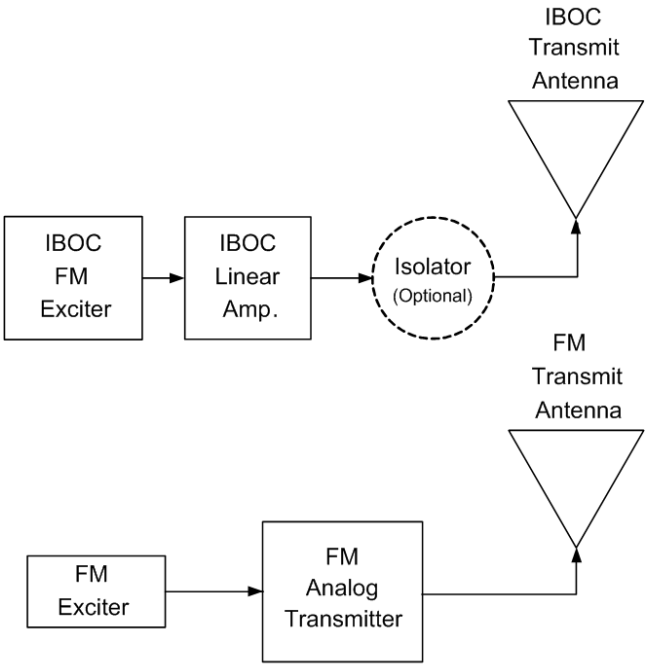


Figure B-4: FM HD Radio Separate Antenna Implementation

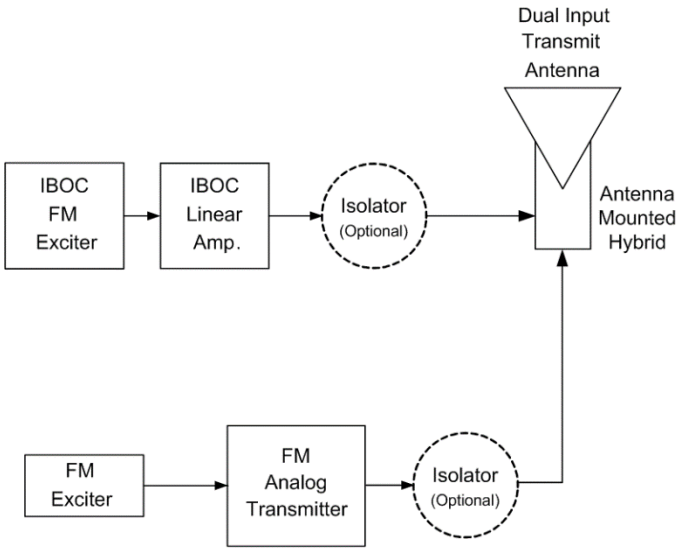


Figure B-5: FM HD Radio Dual-Input Antenna Implementation

Simulcast and Analogue/Digital Audio Blending

An effective method for dealing with RF channel fading in a mobile reception environment (for example, radio reception in a moving automobile) is to provide a second channel conveying the same information. Transmitting the same information on a second channel shifted in time can enhance the total system performance when the two channels are recombined at the receiver. This technique is called "time diversity."

HD Radio technology takes advantage of time diversity in the MPS by introducing a time delay between the analogue and digital transmitted versions of the simulcast MPS audio channel of four to eight seconds, and then by realigning these digital and analogue signals in the receiver. Synchronizing the MPS digital audio service and the analogue FM audio service is essential to allow HD Radio receivers to smoothly transition between the analogue and the digital versions of the signal. This analogue to digital audio transition is called "blending."

HD Radio Service Modes

The HD Radio broadcasting system functionality affords many degrees of freedom in the choices that can be made to optimize system end-to-end performance.

These include:

- Audio robustness versus audio quality and latency;
- Data throughput versus data robustness;
- Audio quality versus data throughput trade-offs (upper Layers);
- Scrambling;
- Channel coding;
- Interleaver design;
- Allocation of the various digital subcarriers (which comprise the digital sidebands).

By choosing and combining these factors in appropriate ways, a wide variety of information data rates, audio/data combinations and bit error rate performance for anticipated channel conditions can be achieved.

For the HD Radio system, several such combinations have been defined, enumerated and designated for the hybrid FM system and the all-digital FM system. These designated combinations are the defined service modes of the HD Radio system.

Audio Service Definitions

In hybrid HD Radio systems, the analogue portion of the over-the-air signal is identical to the signal of existing analogue-only broadcasting systems. As previously noted, broadcasting using the HD Radio system is compatible with much of the existing analogue-only broadcasting equipment and the transmitted signal is compatible with existing analogue-only receivers. The FM analogue program audio is the means by which the broadcast system maintains compatibility with analogue-only receivers. It is used synergistically with the MPS digital audio in hybrid mode as backup audio, to provide improved robustness at the receiver under circumstances of signal fading and blockage.

As detailed above, multicast or SPS channels are additional audio channels that may be added in addition to the MPS. The amount of bandwidth allocated to the MPS and SPS channels is determined by HD Radio service mode selected and by the total number of audio streams transmitted. Digital audio is the primary or main audio delivery mode in both hybrid and all-digital modes. In all-digital mode, the main audio signal is augmented with another lower-latency and lower-bandwidth digital channel which acts as backup audio in lieu of the analogue channel (used in hybrid mode, which no longer exists in all-digital mode). While the MPS channel is backed up by the analogue signal, the SPS channels are stand-alone and receivers tuned to an SPS channel will mute when the digital signal becomes unreceivable.

Audio Classes

In the hybrid modes of operation, the maximum digital audio quality achievable for an MPS channel is described by audio service class 1 in Figure B-4. The actual audio quality of a given digital audio channel is defined by the bitrate used for that audio channel which determines the audio frequency response, stereo separation and dynamic range (parameters shown for class 1 in Figure B-5 are realized for an MPS bit rate of 96 kbps which is the maximum available for a normal hybrid transmission). Class 2 audio service is, at a minimum, accomplished by the simulcast analogue channel. Typically, the simulcast analogue audio channel is stereophonic. In all-digital modes, a digital backup channel (separate from the main channel audio) is supported which can provide class 2 audio service.

Table B-1: Audio Service Classes

Class	Service	Audio Type	Maximum Audio Frequency Response	Maximum Stereo Separation (dB)	Maximum Dynamic Range	Quality Level
1	FM main	stereo	20 – 20,000 Hz	70 dB	96 dB	Virtual CD
2	FM backup	monophonic	20 – 15,000 Hz	N/A	65 dB	FM mono

Digital Data Service Definitions

The HD Radio system supports extensive datacasting services. Six data transport services have been defined for hybrid FM HD Radio as follows:

- CODEC digital audio transport;
- Text transport;
- Control channel transport;
- Packet/message transport;
- File transport;
- Generic streaming data transport.

To support these transport services, the HD Radio system has defined the following classes of data:

Table B-2: Classes of Data Service

Class	Service	System	Minimum Rate (bit/s)	Maximum Rate
1	Dedicated fixed rate	Hybrid, All-digital	860; FM	N/A
2	Adjustable rate	Hybrid, All-digital	0	Equal to at least the maximum rate of audio CODEC
3	Opportunistic variable rate	Hybrid, All-digital	0	Equal to maximum rate of audio CODEC

Dedicated fixed-rate services employ a fixed data rate that cannot be changed by the broadcaster. Adjustable rate services operate at a constant rate that, unlike fixed-rate services, is selectable and changeable by the broadcaster by trading off audio quality or robustness for data throughput. To increase the data rate, the broadcaster reduces the audio bit-rate (and therefore audio quality or robustness) and reallocates it to data. To increase audio quality, the data is reduced. The adjustable rate services operate by dynamically allocating digital subcarriers among error correction, audio and data services.

Opportunistic variable-rate services offer data rates that are dynamically related to the complexity of the encoded digital audio. Simpler audio passages (e.g., simple tones,

narrow bandwidth audio, and silence) require lesser bit rates, permitting the unused throughput to be used for data. The audio encoder dynamically measures audio complexity and adjusts data throughput accordingly, without compromising the quality of the encoded digital audio.

Datacasting

Datacasting is defined as delivering data content from a content provider to a receiver end user via the HD Radio system. This data can include, but are not limited to, the following:

- Streaming perceptual audio CODEC (HDC) applications;
- Still and streaming video applications;
- Message/packet based applications;
- File-based applications;
- Audio storage and retrieval applications;
- Billing and management;
- Text/XML (extended mark-up language) applications;
- Specialized applications with specialized receivers;
- Datacasting services with various defined levels of quality of service for each.

HD Radio system datacasting users are of three types:

- Content providers who create and package content for broadcast over the HD Radio system;
- Operations, administrative and maintenance (OAM) users who manage the broadcast system for content delivery, billing and other administrative tasks support;
- Receiver end-users who make use of the content broadcast by the HD Radio system.

For purposes of datacasting definition and specification, the HD Radio system consists of two parts:

- Broadcast network system that receives content from content providers and delivers it to individual broadcast station systems;
- Broadcast station systems that receive content from the broadcast network system, or from local content providers for broadcast.

13. APPENDIX-C Relevant Websites

Advanced Television Systems Committee (ATSC)	www.atsc.org
Asia-Pacific Broadcasting Union (ABU)	www.abu.org.my
Audio Engineering Society (AES)	www.aes.org
BBC (DAB)	www.bbc.co.uk/digitalradio
BBC (Research and Development)	www.bbc.co.uk/rd
BBC World Service (Radio)	www.bbc.co.uk/worldservice
Public Media Alliance	https://publicmediaalliance.org/
Crown Castle International	www.crowncastle.com
Crown Castle UK	www.crowncastle.co.uk
Dalet	www.dalet.com
Digital Radio Mondiale (DRM)	www.drm.org
Digital Video Broadcasting (DVB)	www.dvb.org
European Broadcasting Union (EBU)	www.ebu.ch
DTS (HD Radio)	www.dts.com
International Telecommunications Union	www.itu.int
National Association of Broadcasters (US)	www.nab.org
National Association of Shortwave Broadcasters US (NASB)	www.shortwave.org
National Radio Systems Committee US (NRSC)	www.nrscstandards.org
North American Broadcasters Association	www.nabanet.com
Office of Communications UK (Ofcom)	www.ofcom.org.uk
Radio Academy (UK)	www.radioacademy.org
Real Audio	www.real.com
Roke Manor Research (UK)	www.roke.co.uk
Sadie	www.sadie.com
Sirius Satellite Radio	www.siriusradio.com
World Broadcasting Unions (WBU)	www.worldbroadcastingunions.org
WorldDAB	www.worlddab.org
XM Satellite Radio	www.xm.com

14. APPENDIX-D Glossary of Acronyms

AAC	Advanced Audio Coding
AAS	Advanced Application Services
ADR	Astra Digital Radio
AM	Amplitude Modulation
API	Advanced Programming Interface
ATM	Asynchronous Transfer Mode
BBC	British Broadcasting Corporation
BER	Bit Error Rate
Bit	Binary digit
Bitrate	Rate of flow of bits per second
BSS(S)	Broadcast satellite services (Sound)
BWS	Broadcast Website
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
CELP	Code Excited Linear Prediction
CEMA	Consumer Electronics Manufacturers Association
CEPT	European Conference of Postal and Telecommunications Administrations
codec	Coder / Decoder
COFDM	Coded Orthogonal Frequency Division Multiplex
CP	Continual Pilot
CRC	Communications Research Centre Canada
CRTC	Canadian Radio-television and Telecommunications Commission
DAB	Digital Audio Broadcasting
DARS	Digital Audio Radio Service

DAT	Digital Audio Tape
DAW	Digital Audio Workstation
DMB	Digital Multimedia Broadcasting
DQPSK	Differential Quadrature Phase Shift Keying
DRB	Digital Radio Broadcasting
DRDB	Digital Radio Development Bureau
DRM	Digital Radio Mondiale
DRP	Digital Radio Promotion
DSB	Double Side Band
DSL	Digital Subscriber Line
DSR	Digital Satellite Radio
DTH	Direct to Home
DTS	Digital Theatre System
DTT	Digital Terrestrial Television
DVB	Digital Video Broadcasting
DVB-H	Digital Video Broadcasting – Handheld
DVB-T	Digital Video Broadcasting – Terrestrial
DXB	Digital Extended Broadcasting, a German-funded project
EBU	European Broadcasting Union
EIA	Electronic Industries Alliance (formerly Electronic Industries Association)
EMK	Electronic Media Kiosk
EPG	Electronic Program Guide
ETI	Ensemble Transport Interface
ETS	European Telecommunications Standard
ETSI	European Telecommunications Standards Institute
Eureka	European R and D programme
FAC	Fast Access Channel
FCC	Federal Communications Commission (US)
FIC	Fast Information Channel
FM	Frequency Modulation

FDMA	Frequency division multiple access
FHG	Fraunhofer Institute (Germany)
FIC	Fast Information channel
GPS	Global Positioning System
GSO	Geostationary (Satellite) Orbit
GSM	Global System for Mobile Communications
HEO	Highly Elliptical Orbit
HVXC	Harmonic Vector Excitation Coding
IEEE	Institute of Electrical and Electronics Engineers
IFPI	International Federation of the Phonographic Industry
iMP	Integrated Media Player
IP	Internet Protocol
ISDB-TSB	Integrated Services Digital Broadcasting – Terrestrial for Sound Broadcasting
ITU	International Telecommunications Union
ITU-R	ITU Radiocommunications Sector
IBAC	In-Band Adjacent Channel
IBOC	In-Band / On-Channel
JPEG	Joint Photographic Experts Group
kbps	1000 bits per second
LCD	Liquid Crystal Display
LF	Low Frequency
LW	Long wave
LEO	Low earth orbit (satellite)
MATS	Mobile Aeronautical Telemetry Services
MCI	Modular Control Interface
MD	Mini Disc
MDI	Multiplex Distribution Interface
MF	Medium Frequency
MHP	Multimedia Home Platform
MLC	Multi-Level Coding

MP3	MPEG Audio Layer 3 (see MPEG)
MPEG	Moving Pictures Expert Group
MPS	Main Program Service
MOT	Multi-media Object Transfer
MSC	Main Service Channel
MW	Medium wave
NAB	National Association of Broadcasters (US)
NABA	North American Broadcasters Association
NHK	Nippon Hoso Kyokai (Japan Broadcasting Corporation)
NICAM 728	Near-Instantaneously Companded Audio Multiplex (728 is bit rate in kbps)
NRSC	National Radio Systems Committee (an industry sponsored technical standard setting body, co-sponsored by CEMA and NAB in the US)
OEM	Original Equipment Manufacturer
OFDM	Orthogonal Frequency Division Multiplexing
P2P	Peer-to-Peer Networking
PAD	Programme Associated Data
PC card	A plug in card for a Personal Computer, which allows it to receive DAB
PDA	Personal Digital Assistant
PNG	Portable Network Graphics
POF	Point of Failure
PTY	Programme Type Codes
PVR	Personal Versatile Recorder
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RAM	Random Access Memory
RDS	Radio Data System
RDI	Receiver data Interface
RF	Radio Frequency
RSCI	Receiver Status and Control Interface
SBR	Spectral Band Replication
SCA	Subsidiary Communications Authorization

SDC	Service Description Channel
SDI	Service Distribution Interface
SFN	Single Frequency Network
S-DAB	Satellite DAB
SDARS	Satellite Digital Audio Radio Service
S-DMB	Satellite Digital Multimedia Broadcasting
SIS	Service Information Service
SLS	Slideshow
SMIL	Synchronized Multimedia Integration Language
SR	Sveriges Radio (Swedish Radio)
SSB	Single Side-Band
STL	Studio-to-Transmitter Link
SW	Short-wave
Simulcasting	Simultaneous transmission of a programme
T-DAB	Terrestrial DAB
TCM	Trellis coded Modulation
TDC	Transparent Data Channel
TDM	Time Division Multiplex
TDMA	Time Division Multiple Access
T-DMB	Terrestrial Digital Multimedia Broadcasting
TMC	Traffic Message System
TMCC	Transmission and Multiplexing Configuration Control
TOA	Threshold of Audibility
TPEG	Transport Protocol Experts Group
TTSL	Total Time Spent Listening
UEP	Unequal Error Protection
USB	Universal Serial Bus
VHF	Very high Frequency
VPN	Virtual Private Networks
VRT	Belgian Public Service Broadcaster

W(A)RC	World (Administrative) Radio Conference
WiFi	Wireless technology brand (coined by WiFi Alliance)
WiMAX	Worldwide Interoperability for Microwave Access
WMA	Windows Media Audio
WorldDAB	Organisation for promoting digital radio (DAB) based on the Eureka 147 system.

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