



Technical Report On Digital Radio Technology (DRT)



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Abstract

Digital Radio Technology (DRT) in India represents a significant shift in broadcasting, aligning with the government's initiatives to modernize communication systems and enhance public service broadcasting. DRT, which transmits audio and data digitally over the airwaves, is being pursued as a means to improve audio quality, expand coverage, and introduce new services. Unlike traditional analog systems, digital radio delivers clearer sound, efficient spectrum utilization, and the ability to support additional features such as text, images, and metadata like emergency alerts and weather updates.

The Indian government, through regulatory body Telecom Regulatory Authority of India (TRAI), broadcast statutory autonomous body Prasar Bharati, and the Ministry of Information and Broadcasting, promotes DRT to provide better access to information, especially in rural areas and remote areas ensuring a robust and inclusive communication infrastructure. These technologies may support the government's "Digital India" initiative, contributing to the overall digital ecosystem. DRT is expected to enhance public broadcasting, foster content diversity, and offer more interactive, data-rich services, ensuring radio remains a vital communication tool for all citizens.

Digital radio technologies can significantly enhance India's broadcasting landscape by efficiently utilizing existing AM and FM frequency bands, providing superior audio quality, and ensuring reliable services.

1. Evolution of Radio Communication

The evolution of radio communication is a fascinating journey of innovation that transformed the way humans share information over long distances. Here's an overview of key developments:

i. Early Theories and Experiments (19th Century):

James Clerk Maxwell (1864): Maxwell developed a theory predicting the existence of electromagnetic waves, which could travel through space. His equations laid the foundation for understanding radio waves.

Heinrich Hertz (1887): Hertz confirmed Maxwell's theory by demonstrating the transmission and reception of electromagnetic waves. He produced the first man-made radio waves in his experiments.

ii. Guglielmo Marconi and the Birth of Radio (Late 19th- Early 20th Century):

Marconi (1895): Often considered the father of radio, Guglielmo Marconi successfully transmitted wireless signals over long distances. By 1901, he achieved the first transatlantic radio transmission.

Spark-Gap Transmitters: Early radio communication used spark-gap transmitters to send Morse code signals over long distances. These were inefficient and noisy, but they marked the first practical use of radio for communication.

iii. Voice Transmission and the Rise of AM Radio (Early 20th Century):

Reginald Fessenden (1906): Fessenden achieved the first voice transmission using amplitude modulation (AM). This was a major step in evolving radio from Morse code to voice communication.

Lee De Forest (1906): He invented the Audion tube, which amplified weak radio signals and allowed for clearer transmissions, boosting the development of voice radio.

iv. World War I and Radio's Role (1914-1918):

During World War I, radio communication became vital for military operations. Governments invested heavily in radio technology, which led to rapid advancements.

Frequency Modulation (FM) Beginnings: Edwin Armstrong developed frequency modulation (FM) in the 1930s, which significantly reduced static and improved sound quality compared to AM.

v. Commercial Radio and Golden Age (1920s-1950s):

First Commercial Stations: KDKA in Pittsburgh became the first commercial radio station in 1920. By the 1930s, radio was a major form of mass communication, bringing news, entertainment, and music into homes.

Shortwave Radio: Shortwave radio emerged, allowing signals to bounce off the ionosphere and reach global audiences. This technology became critical for international broadcasting and military communications.

Golden Age of Radio: Radio dramas, variety shows, and news programs dominated the airwaves from the 1920s to the 1950s before television became widespread.

vi. World War II and Post-War Radio Innovations (1939-1945):

Radio played a crucial role in World War II for communication, propaganda, and intelligence. Innovations like radar, which used radio waves for detecting objects, were developed during this time.

Post-War Era: After WWII, FM radio gained popularity due to its superior sound quality, especially for music broadcasting.

vii. Satellite and Digital Radio (1960s-2000):

Satellite Communication (1960s): The launch of communication satellites like Telstar enabled radio signals to be transmitted globally, marking the beginning of satellite radio.

Digital Radio (1990s): Digital Audio Broadcasting (DAB) emerged, providing clearer sound and more channels. Internet radio and satellite radio services, like SiriusXM, expanded the reach of radio.

viii. Modern Radio Communication (21st Century):

Software-Defined Radio (SDR): SDRs allow radios to be controlled via software, making them more flexible and capable of adapting to different frequencies and Streaming platforms and podcasts have revolutionized how audio content is consumed, giving radio a new digital life. [1]

2. Analog versus digital Radio

Characteristic	Analog Radio	Digital Radio
Signal Type	Analog radios use continuous signals that vary in amplitude or frequency to represent information.	Digital radios convert voice and data into binary format (0s and 1s), which is then transmitted.
Audio Quality	The audio quality can degrade due to interference and noise, especially at the edges of the coverage area.	Superior audio quality with automatic error correction, reducing noise and interference.
Bandwidth	Analog radios typically use more bandwidth for a single channel.	More efficient use of bandwidth, allowing for multiple conversations on the same channel.
Battery Life	Generally, analog radios consume more power during transmission, leading to shorter battery life.	More efficient power usage, often resulting in up to 40% longer battery life.
Capacity	Limited to one conversation per channel, which can restrict communication in busy environments.	Can double the capacity of existing channels, supporting more users and private conversations.
Interference	More prone to static and interference from other electronic devices. [2]	Less susceptible to interference and static, providing clearer communication. [3]

3. DAB/DAB+ (Digital Audio Broadcasting)

3.1 Introduction:

Digital Audio Broadcasting (DAB) is a digital radio standard for broadcasting audio, mainly used in Europe and some other regions. It's designed to provide higher-quality sound, more efficient spectrum usage, and a greater range of content compared to traditional analog FM or AM radio.

Digital Audio Broadcasting (DAB) is a digital radio technology introduced as a modern alternative to traditional analog FM and AM radio broadcasting. First conceptualized in the 1980s, DAB was designed to address several limitations of analog broadcasting, such as limited channel capacity, lower sound quality, and susceptibility to interference. Since its launch in Europe in the 1990s, DAB has become a widely adopted standard across various regions, providing a better listening experience with enhanced features and broader content variety.

Digital System A, also known as the Eureka 147 Digital Audio Broadcasting (DAB) system, was developed for both satellite and terrestrial broadcasting applications in order to allow a common lowcost receiver to be used. During 1980s, DAB was introduced as a research project in Europe and was gradually adopted by the different standardization bodies such as ITU and ETSI. The first country to broadcast a range of radio station through DAB was United Kingdom (UK). DAB uses a wide-bandwidth broadcast technology. It operates in VHF Band III (174-240 MHz) and L band (1452-1492 MHz). DAB has country specific modes of transmission, operating in varied bands according to requirements.

In 2006, DAB+ standard was introduced as an upgraded version of DAB. Based on DAB, this new standard utilizes MPEG-4 compression instead of MPEG-2, making it more efficient and enabling the broadcast of more services without compromising audio quality. The HE-AAC v2 audio codec (also known as eAAC+) was adopted for DAB+. AAC+ employs a modified discrete cosine transform (MDCT) algorithm. It also incorporates the MPEG Surround audio format and enhanced error correction coding using Reed-Solomon coding. DAB+ has been standardized as European Telecommunications Standards Institute (ETSI) TS 102 563. Since DAB is not forward compatible with DAB+, older DAB receivers cannot receive DAB+ broadcasts. However, DAB receivers capable of supporting the DAB+ standard after a firmware upgrade were available as early as July 2007. The forward compatibility of DAB receivers was not in line with the DAB+ receivers i.e. DAB receivers were unable to receive DAB+ programmes. [4]

3.2 DAB Architecture:

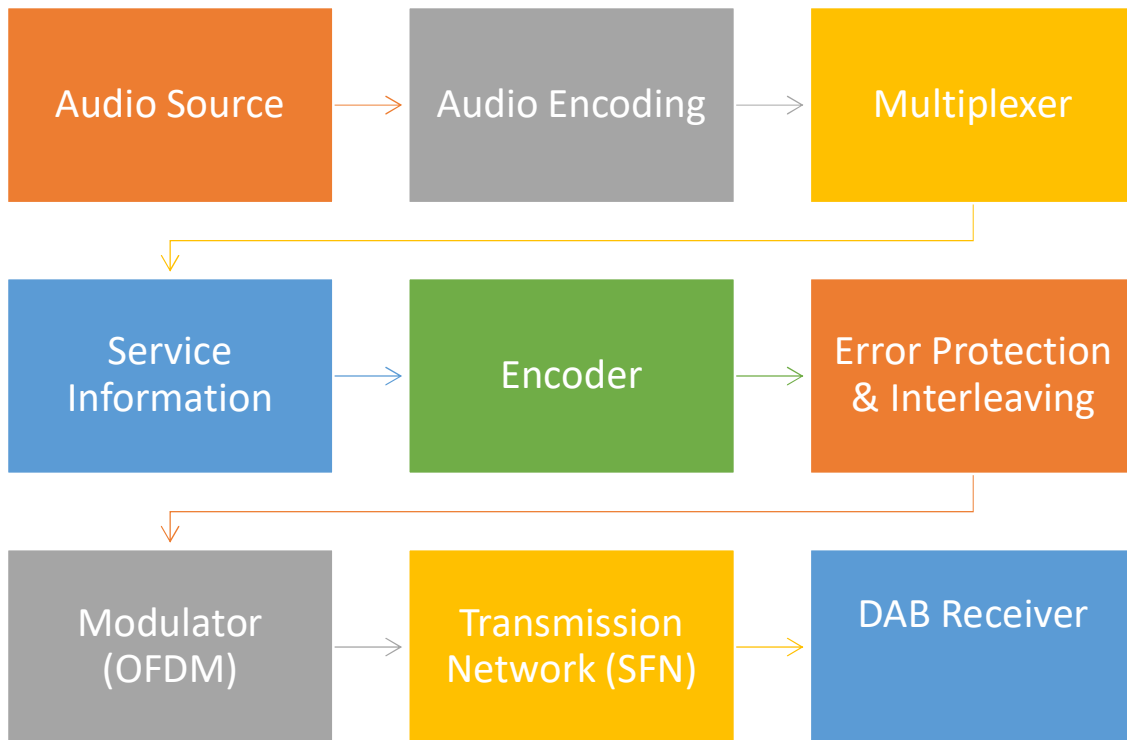


Figure 1 DAB Architecture

1. Audio Capture: Audio content is captured from various sources, processed, and sent to the encoder.

2. Encoding and Compression: The audio is compressed into digital format using MPEG algorithms to maintain quality with reduced data size.

3. Multiplexing: Multiple audio channels are combined into a single data stream, enabling the broadcaster to transmit several programs on a single frequency.

4. Service Information Encoding: Program metadata is added, allowing listeners to view program names, schedules, and other details on their receivers.

5. Error Correction and Interleaving: Error correction techniques and time interleaving are applied to protect against transmission errors.

6. OFDM Modulation: The digital data stream is modulated using OFDM, dividing it into multiple sub-carriers to improve signal robustness.

7. Transmission: The DAB signal is broadcast over a network of transmitters and repeaters to cover large geographic areas, using SFNs to maximize coverage and spectrum efficiency.

8. Reception and Decoding: The DAB receiver decodes the digital signal, reconstructs the audio, and displays metadata on the user interface.[5]

3.3 Technical Specification:

1. Frequency Bands

- VHF Band III: 174 - 240 MHz (widely used globally for DAB)
- L-Band: 1.452 - 1.492 GHz (used in some regions like Canada, though less common due to limited coverage and penetration challenges)

2. Modulation Scheme

- Orthogonal Frequency Division Multiplexing (OFDM): DAB employs OFDM with 1,536 sub-carriers spaced at 1 kHz intervals, which improves resistance to multipath interference.
- Differential Quadrature Phase Shift Keying (DQPSK): Each sub-carrier is modulated using DQPSK, which enhances signal resilience in mobile reception.

3. Transmission Modes

- DAB uses four transmission modes to cater to different environments and network structures:
 - **Mode I:** Suitable for terrestrial transmissions in Band III (most widely used)
 - **Mode II:** Suited for mobile and terrestrial L-band transmissions
 - **Mode III:** Allows for satellite-based transmission
 - **Mode IV:** Another mode for satellite-based transmission, primarily for Band III and higher speeds

4. Audio Compression

- MPEG Audio Layer II (MP2): DAB uses MP2 for audio compression, which provides efficient compression while maintaining good audio quality.
- Bitrate: Audio bitrates typically range between 64 kbps (mono) to 192 kbps (stereo) depending on the broadcaster's quality and channel requirements.

5. Data Rates and Bandwidth

- Total Bandwidth: Each DAB channel occupies approximately 1.536 MHz of bandwidth.
- Bitrate per Multiplex: A DAB multiplex (or ensemble) can carry up to approximately 1.2 Mbps of data. This is divided among multiple services (audio channels and data).
- Audio Bitrate Range: 32 kbps to 256 kbps per audio channel, depending on the level of audio quality required and channel allocation.

6. Error Protection

- Forward Error Correction (FEC): DAB uses convolutional coding and FEC to detect and correct errors during transmission, ensuring robustness.

- Time Interleaving: This technique disperses data bits over time, reducing the impact of signal fading or burst errors, especially in mobile reception.

7. Service Information (SI) and Program-Associated Data (PAD)

- Dynamic Label Segment (DLS): Displays text information such as station names, song titles, and artist information.
- Multiplex Configuration Information (MCI): Provides detailed info about the multiplex, including service identifiers and parameters.
- MOT (Multimedia Object Transfer): Allows transmission of images and multimedia content, like album covers and weather graphics.

8. Compatibility with DAB+

- DAB+ Standard: Uses advanced audio coding (AAC+) for better compression, allowing for more efficient use of the bandwidth and improved audio quality at lower bitrates.
- Backward Compatibility: DAB receivers manufactured since around 2007 support both DAB and DAB+ transmissions, but DAB-only receivers do not support DAB+.

9. Transmission Power and Coverage Range

- Power: Typically varies depending on the terrain and population density but is generally between 1-10 kW.
- Coverage: SFNs improve DAB coverage, especially in rural areas and mountainous regions.

10. Receivers

- DAB receivers are built to decode audio, metadata, and multimedia objects. Many modern receivers also support DAB+ to accommodate regions transitioning to or using DAB+.[5]

11. Standards and Protocols

- **ETSI Standards:**
 - ETSI EN 300 401: Defines DAB transmission protocol.
 - ETSI TS 102 563: Specifies DAB+ for audio coding using AAC.
 - ETSI EN 300 797 and ETSI EN 300 798: Define SFN and repeater configurations for DAB networks.

[6]

12. Application of DAB

1. Public Broadcasting and Radio

- **Multi-Channel Radio:** DAB enables the broadcast of multiple audio channels within the same frequency band, allowing public broadcasters to offer a broader range of content.
- **High-Quality Audio:** Public stations can deliver higher sound quality and diverse programming, providing a better listening experience than AM/FM.

2. Emergency Broadcasting and Public Safety

- **Emergency Alerts:** DAB can instantly broadcast emergency messages across all channels within a network, ensuring that critical information reaches the public quickly.
- **Additional Data for Alerts:** In addition to audio, DAB can broadcast visual data like evacuation maps, safety instructions, or contact information for emergency services.

3. Traffic and Navigation Information

- **Real-Time Traffic Updates:** DAB provides traffic information directly to vehicles, helping drivers stay informed about real-time traffic conditions, road closures, and detours.
- **Location-Based Services:** Some DAB systems support GPS integration, providing location-specific traffic information or alternative routes based on current road conditions.

4. Multimedia and Visual Content Broadcasting

- **Image and Slideshow Broadcasting:** DAB supports the broadcasting of multimedia content such as slideshows, station logos, album art, and maps. This enriches the listening experience and provides valuable information, especially for in-car DAB receivers.
- **Weather Maps and Forecasts:** DAB stations can broadcast weather updates, including images or icons indicating temperature, precipitation, and other weather conditions.[7]

3.4 Advantages of DAB:

- 1.Improved Audio Quality
2. Efficient Spectrum Use
3. Resistance to Interference and Noise
4. Additional Data and Multimedia Services
5. Increased Channel Availability
6. Better Mobile Reception
7. Energy Efficiency
8. Support for Emergency Alerts
9. Future-Ready Technology
10. Enhanced Listening Experience
11. Broadcast Coverage in Remote and Rural Areas
12. Reduced Interference between Stations
13. Smooth Channel Switching
14. Supports Hybrid Broadcast Solutions [7]

3.5. Limitations of DAB:

1. Higher Cost for Listeners and Broadcasters
2. Coverage Limitations
3. Lower Audio Quality at Low Bitrates
4. Limited Support for Emergency Services
5. Obsolescence of Older Radios
6. Signal and Reception Issues in Buildings
7. Latency Issues
8. Limited Interactivity and Innovation Compared to IP-Based Options
9. Spectrum and Licensing Costs
10. Environmental Concerns
11. Technical Complexity for Small Broadcasters
12. Standard Compatibility Issues [7]

3.6. Deployment Status:

1. Europe

- **Leading Region in DAB Adoption:** Europe has been the leader in DAB adoption, with many countries switching from analog FM to digital radio, led primarily by countries in Western and Northern Europe.
- **Norway:** The first country to fully transition from FM to DAB, shutting down its national FM radio stations in 2017. This has set a precedent for other countries considering a similar shift.
- **United Kingdom:** One of the earliest adopters of DAB, with over 50% of radio listening done via digital platforms, including DAB. Over 97% of the UK population has DAB coverage, with a wide range of national and local stations available.
- **Switzerland:** Switched off FM radio broadcasts, going fully digital with DAB+.
- **Germany:** Provides extensive DAB+ coverage, with DAB+ being a major digital radio standard. In 2020, Germany mandated that all new car radios must be DAB+ compatible.
- **France:** DAB+ launched in 2014 and has been expanding since, covering major cities like Paris, Marseille, and Lyon. It is expected that 17 multiplexes, will have started broadcasting during the summer of 2023. At the end of these start-ups, the coverage of the metropolitan population by DAB+ will exceed 50%

Data Summary:

- Over 80% of new cars in Europe come with DAB+ receivers.

- The European Electronic Communications Code (EECC) requires all new car radios in the EU to support digital terrestrial radio (DAB/DAB+) from 2021 onwards.

2. Asia

- **South Korea:** One of the early adopters of digital radio broadcasting in Asia. DMB (Digital Multimedia Broadcasting), a technology compatible with DAB, has been popular for multimedia services, especially in cars.
- **China:** Tested DAB in various cities, though the adoption has been slow. China has focused more on its proprietary digital standards.
- **Japan:** Japan uses ISDB-T for digital multimedia broadcasting rather than DAB, focusing on a system that combines digital radio and TV.

Data Summary:

- Asia's approach to DAB has been fragmented, with some countries experimenting with DAB while others adopt alternative standards or streaming platforms.

3. North America

- **United States:** The US has not adopted DAB. Instead, it uses HD Radio (a different digital radio standard) for terrestrial radio. HD Radio is widely available in the US and has seen moderate adoption.
- **Canada:** Experimented with DAB in the late 1990s but decided to discontinue it. The country has adopted HD Radio, though streaming services are more popular.

Data Summary:

- North America has largely focused on HD Radio and internet radio. DAB is not currently part of the regulatory framework in either the US or Canada.

4. Africa

- **South Africa:** Leading the adoption of DAB in Africa, with DAB+ trials taking place in Johannesburg and Pretoria since 2014. The South African Broadcasting Corporation (SABC) has been involved in promoting DAB+, but adoption has been slow.
- **Other African Nations:** DAB has seen limited adoption in other parts of Africa, where FM radio remains dominant due to infrastructure costs and limited digital radio receivers.

Data Summary:

- DAB+ is still in early stages in Africa, with only a few countries conducting trials or considering adoption.

5. Global DAB Adoption Summary

Region	Major Adopters	Coverage	Standard
Europe	UK, Norway, Germany, Switzerland, France	> 90% in leading countries	DAB/DAB+
Asia	South Korea, China (limited), Singapore (ceased)	Limited to trials or metropolitan	DAB, DMB
Oceania	Australia	> 50% population coverage	DAB+
Africa	South Africa (trials)	Limited	DAB+
Middle East	UAE, Qatar (trials)	Limited	DAB+

[8]

4. Digital Radio Mondiale (DRM/DRM+):

4.1 Introduction:

Digital Radio Mondiale (DRM) is an advanced digital radio standard designed to replace AM and FM broadcasts with high-quality digital signals. It offers several benefits over analog radio, such as improved audio quality, increased coverage, and lower energy consumption. DRM supports features like stereo sound, data broadcasting, text messaging, and emergency alert capabilities. It operates on various frequency bands (AM, FM, shortwave) and is especially suited for reaching rural and remote areas, making it a valuable tool for enhancing communication access globally.

DRM has excellent sound quality plus the ease-of-use that comes from digital transmissions. The improvement brought by DRM in the AM bands is immediately noticeable, and DRM in the VHF/FM bands removes the fading that mars FM reception. DRM can be used for a range of audio content, and has the capacity to integrate text and data. This additional content can be displayed on DRM receivers to enhance the listening experience.

DRM in AM bands uses the existing AM broadcast frequency bands and is designed to fit in with the existing AM broadcast band plan, based on signals of 9 kHz or 10 kHz bandwidth. It also has modes requiring only 4.5 kHz or 5 kHz bandwidth, and modes that can take advantage of wider bandwidths – 18 kHz or 20 kHz – allowing DRM to operate alongside AM transmissions in every market of the world. DRM in the VHF/FM bands occupies 100 kHz channels.

The DRM system uses COFDM (Coded Orthogonal Frequency Division Multiplex). This means that all the data, produced from the digitally encoded audio and associated data signals, is shared out for transmission across a large number of closely spaced carriers. All of these carriers are contained within the allotted transmission channel. Time interleaving is applied in order to mitigate against fading. Various parameters of the OFDM and coding can be varied to allow DRM to operate successfully in many different propagation environments – the selection of the parameters allows transmissions to be planned that find the best combination of transmit power, robustness and data capacity.

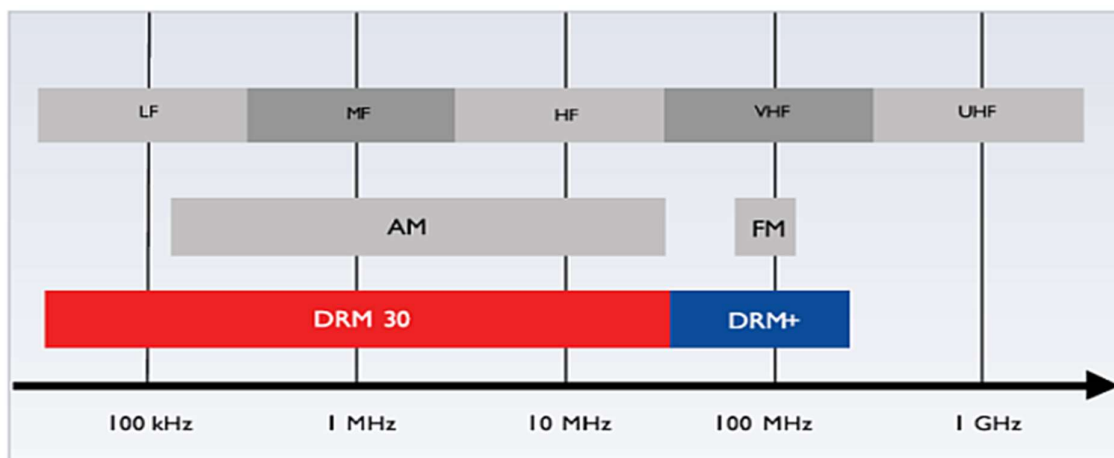


Figure 2 DRM frequency distribution [9]

DRM Transmissions below 30 MHz:

The DRM standard used in the AM bands (also referred to as DRM30) can deliver FM-comparable sound quality and is specifically designed to utilise the broadcast bands below 30MHz (Long Wave, Medium Wave and Short Wave) which allow for very-long-distance signal propagation.

DRM in AM bands is designed to fit in with the existing AM broadcast band plan, based on signals of 9 kHz or 10 kHz bandwidth. It also has modes requiring only 4.5 kHz or 5 kHz bandwidth, and modes that can take advantage of wider bandwidths – 18 kHz or 20 kHz – allowing DRM to operate alongside AM transmissions in every market of the world.

DRM Transmissions above 30 MHz:

The DRM standard used above 30MHz (also referred to as **DRM+**) can operate in Band I, Band II and Band III.

The extension of DRM to the VHF bands ensures that the standard in these bands has the same multiplex and signalling scheme, the same OFDM design (with new parameters) and the same audio codecs.

DRM in the VHF bands is implemented in the standard as robustness mode. Its spectrum usage parameters are determined from the internationally agreed norms in the FM band (88 to 108 MHz).

4.2. DRM Architecture:

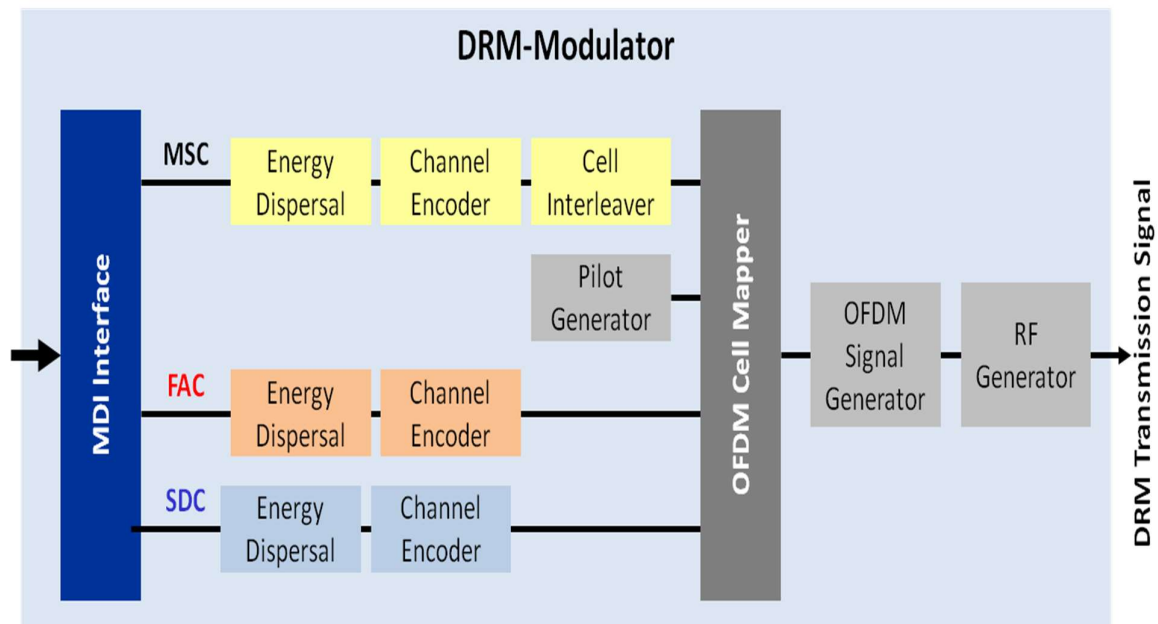


Figure 3 DRM Architecture

[10]

4.3. Technical Specifications:

Digital Radio Mondiale (DRM) is a digital radio standard designed to replace traditional AM and FM radio services, offering better audio quality and more efficient use of the radio spectrum. Its frequency spectrum and transmission parameters are tailored for different bands, such as shortwave (SW), medium wave (MW), longwave (LW), and VHF bands (including FM).

(a) Frequency Bands in Use:

- **DRM30:** Covers frequency bands below 30 MHz, typically used in AM bands like SW, MW, and LW. It's useful for long-distance transmissions.
- **DRM+ (or DRM+ in FM):** Operates between 30 MHz and 300 MHz, primarily used in the VHF band, overlapping with FM broadcast frequencies (88–108 MHz).

(b) Bandwidth:

- **DRM30:** Operates with bandwidths of 4.5, 5, 9, 10, 18, or 20 kHz, making it compatible with existing AM bandwidth allocations.
- **DRM+:** Typically uses 96 kHz, making it suitable for higher-quality audio transmission in the FM spectrum.

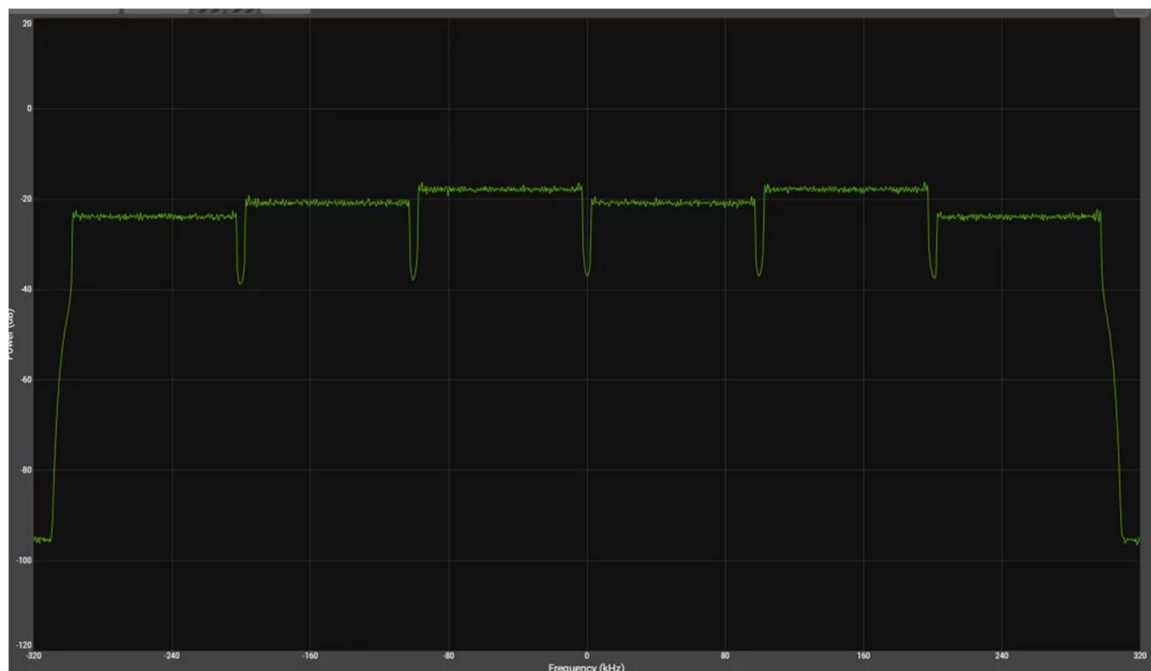


Figure 4 DRM frequency analysis [11]

Standard Recommendations:

ETSI Standards

The DRM System Specification has been approved and published by the European Telecommunications Standards Institute (ETSI). The standard has evolved from the original, which covered only the AM bands, to the current version which includes operating modes for all the frequency bands below 300 MHz .

ITU Regulation

The DRM Consortium has worked closely with the ITU and administrations to ensure that DRM can be deployed globally.

1. ITU-R BS.1514 – System for digital sound broadcasting in the broadcasting bands below 30 MHz
2. ITU- R BS.1615 – “Planning parameters” for digital sound broadcasting at frequencies below 30 MHz
3. ITU- R BS.1114 – Systems for terrestrial digital sound broadcasting to vehicular, portable and fixed receivers in the frequency range 30-3000 MHz
4. ITU-R BS.1660 – Technical basis for planning of terrestrial digital sound broadcasting in the VHF band.

4.4 DRM Advantages:

DRM is greener, clearer, wider, bigger, better quality & audio content and cost efficient

Listeners

- a. Excellent quality sound in stereo, up to CD quality.
- b. Data such as text, pictures and Journal.
- c. Easy tuning on station name.

Manufacturers

- a. Replace receivers with new digital receivers.
- b. Increase the market potential.
- c. Increase possibilities for new areas of interest and content.

Broadcasters

- a. Multilingual programmes are possible plus extra information.
- b. Reduced power consumption of up to 40-50%.
- c. Increased opportunity for revenue generation streams.

Regulators

- a. Uses less spectrum and releases spectrum for other use.
- b. An international standard.
- c. Low power cost-green broadcasting.
- d. Emergency warning alert.

4.5 Limitation of DRM:

Slow Global Uptake: While some regions, like India and parts of Europe, have adopted DRM, its global implementation has been slow. Most countries still use traditional AM/FM, limiting the reach of DRM broadcasts.

Receiver Availability: There are fewer DRM-compatible receivers available compared to traditional radio receivers. This limits consumer adoption, especially in less technologically developed regions.

Limited Channels on AM/MW: On traditional AM bands, there may be limited bandwidth for DRM transmission, especially in densely populated areas.

4.6 Deployment Status:

India:

The rollout of DRM in the AM bands for regular domestic broadcasts by the Indian public broadcaster All India Radio (AIR) is ongoing. Currently 37 high power DRM medium wave and 4 DRM shortwave transmitters are installed. Four transmitters (one each in four metro cities) are now carrying pure DRM transmissions round the clock. The remaining 33 transmitters are working in simulcast mode with one hour daily in pure DRM.

All India Radio (AIR), the public service broadcaster, used to be the sole radio broadcaster on the subcontinent. It has a vast network of 742 transmitters – 7 of SW, 122 of MW and 613 of FM. AIR's coverage in MW + FM is 90% by area and 98% by population, whereas only around 59% by area in the FM band.

At present, 388 Private FM stations are operational, and the Indian government has announced plans to expand their operation. In addition to the public service broadcaster AIR and private FM radio stations, Community Radio Stations (CRS) are also present in India. At the request of the public broadcaster All India Radio, the DRM Consortium conducted a **DRM for FM demonstration** in Delhi and Jaipur some years back. Full features of DRM in pure DRM (single DRM block with up to 4 services – 3 audio and 1 multimedia each), also simulcast (analogue FM and up to 4 DRM blocks), multi-DRM (up to 6 DRM blocks, with 18 programmes) and DRM in white spaces (up to 5 DRM blocks in the white space of 600 kHz between 2 analogue FM stations) were successfully demonstrated without any interference. A government decision for digitising the FM band in India is still expected. Over 6 million new cars fitted with DRM receivers are on the roads in India, currently. Major car brands using DRM for their infotainment systems are: Maruti Suzuki, Hyundai, Toyota, MG Motor, Mahindra, Mercedes Benz and Tata. The first phase of the DRM trial was in Delhi and demonstrated the key features of DRM. The second phase was carried out in Jaipur with the aim to prove the compatibility of DRM with the FM band “channelisation” in India.

Countries broadcasting using DRM:

India, Pakistan, Indonesia, China, South Africa, Germany.

Countries considering the adoption of DRM:

Australia, Malaysia, Nepal.

[12]

5. HD Radio:

5.1 Introduction:

HD Radio is a digital broadcast standard developed by iBiquity (now part of Xperi) that enhances AM and FM radio broadcasts with digital signals, offering improved audio quality and additional features compared to traditional analog radio. The "HD" in HD Radio stands for "Hybrid Digital," as it allows stations to broadcast both analog and digital signals on the same frequency, so listeners with analog radios can still receive broadcasts, though without the added benefits.

HD radio is a trademark for an in band on channel (IBOC) Digital radio broadcast technology. HD radio generally simulcasts an existing analog radio station in digital format with less noise and with additional text information. HD Radio is used primarily by AM and FM radio station in the United States, U.S. Virgin Islands, Canada, Mexico and the Philippines, with a few implementations outside North America.

In-Band On-Channel (IBOC) HD Radio transmits the digital signals in unused portions of the same channel as the analog AM and FM signals (in-band on-channel). As a result, radios are more easily designed to pick up both signals, which is why the HD in HD Radio stands for "hybrid digital," not "high definition." HD Radios tune into the station's analog signal first and then look for a digital signal. The European DRM system shares channels similar to HD Radio, but the European DAB system uses different frequencies for its digital transmission.

The term "on channel" is a misnomer because the system actually broadcasts on the ordinarily unused channels *adjacent to* an existing radio station's allocation. This leaves the original analog signal intact, allowing enabled receivers to switch between digital and analog as required. In most FM implementations, from 96 to 128 kbit/s of capacity is available. High-fidelity audio requires only 48 kbit/s so there is ample capacity for additional channels, which HD Radio refers to as "multicasting".

HD Radio is licensed so that the simulcast of the main channel is royalty-free. The company makes its money on fees on additional multicast channels. Stations can choose the quality of these additional channels; music stations generally add one or two high-fidelity channels, while others use lower bit rates for voice-only news and sports. Previously these services required their own transmitters, often on low-fidelity AM. With HD, a single FM allocation can carry all of these channels, and even its lower-quality settings usually sound better than AM.



Figure 5: Introduction of HD Radio[13]

5.2 HD radio Architecture:

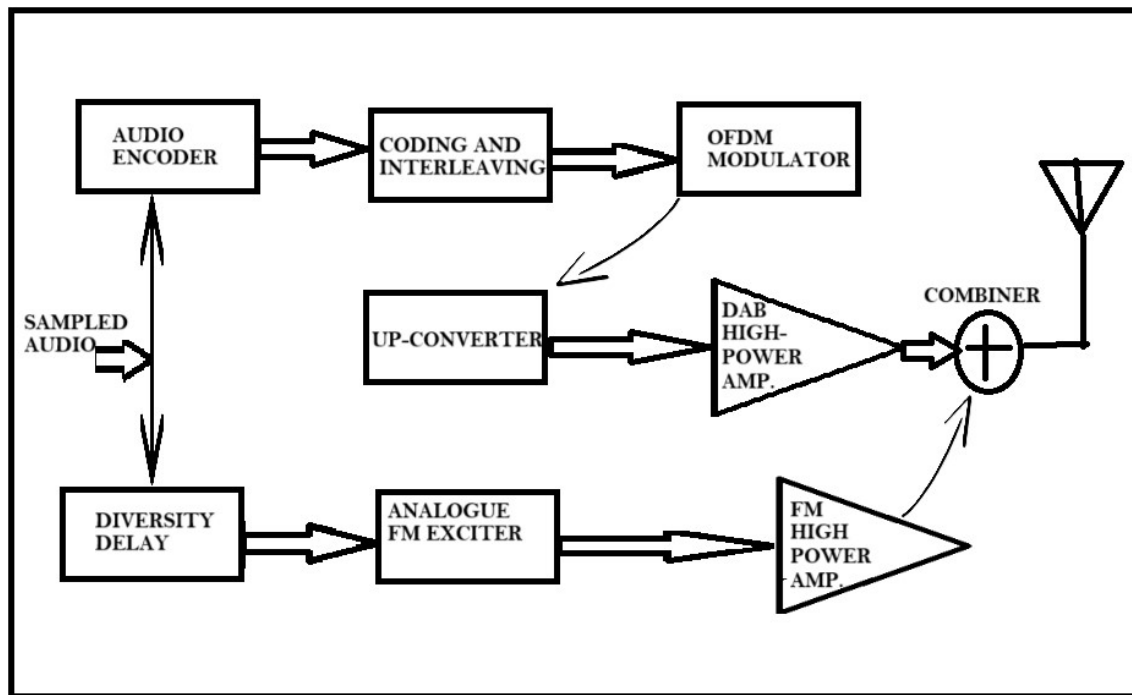


Figure 6 HD Radio Architecture[14]

Frequency spectrum allocation in an Analog FM:

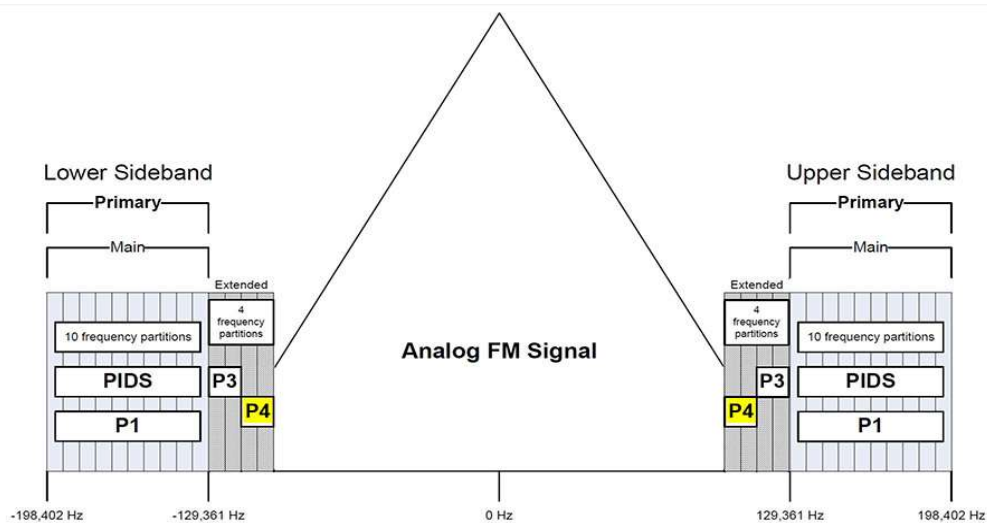


Figure 7: frequency spectrum allocation[15]

This diagram shows the frequency spectrum allocation in an analog FM (Frequency Modulation) broadcasting signal, illustrating how digital signals can be embedded within an FM signal. Here's a breakdown of the components:

1. **Analog FM Signal (Centre Triangle):**

- The large central triangle represents the main analog FM signal, centered at 0 Hz. It is flanked by sidebands where additional digital signals are placed.

2. **Upper and Lower Sidebands:**

- To the left (lower sideband) and right (upper sideband) of the analog FM signal, frequency slots are reserved for digital components.
- Both sidebands contain identical structures, extending from approximately ± 129.361 kHz to ± 198.402 kHz.

3. **Primary and Extended Bands:**

- Each sideband has a **Primary** and an **Extended** section. The primary section consists of frequency partitions dedicated to main digital components, while the extended section offers additional capacity.

4. **P1, PIDS, P3, and P4 Components:**

- The diagram shows different digital partitions within the sidebands, each labeled as **P1**, **PIDS**, **P3**, and **P4**.
- **P1**: Likely refers to the primary digital data block.
- **PIDS**: Could stand for "Program Information Data Service," providing metadata or additional data services.
- **P3** and **P4**: These partitions may represent auxiliary or extended digital data blocks, with **P4** in a distinct color (yellow) to denote a specific role or different data format.

5. Frequency Partitions:

- The primary section in each sideband has 10 frequency partitions for the main digital data, while the extended section has 4 partitions, allowing for a structured division of digital content within the sidebands.

5.3 Technical specifications:

Modulation Techniques: Explanation of Orthogonal Frequency Division Multiplexing (OFDM) and its role in transmitting digital signals.

Spectrum Utilization: How HD Radio can broadcast both digital and analog signals on the same frequency band.

Audio Quality: The improvements in sound quality due to digital compression algorithms and error correction techniques.

Bandwidth Efficiency: Discusses the spectral efficiency of digital signals, allowing multiple streams (main channel, subchannels) to coexist.

Multiple Channels: HD Radio enables "multicasting," where a single frequency can transmit multiple sub-channels (e.g., HD1, HD2, HD3). This allows broadcasters to provide additional programming without needing additional spectrum allocation.

Separate Programs: Each sub-channel can offer entirely different content, such as news, music, or language-specific programming. [15]

5.4 Advantages of HD Radio:

This section elaborates on the key benefits:

Sound Quality: Digital signals reduce noise, providing near-CD-quality sound for FM and improved audio for AM.

Multicasting: Ability to transmit multiple channels on a single frequency (e.g., HD1, HD2, HD3).

Data Services: HD Radio allows for additional data streams, such as text information (song titles, artists), traffic updates, and weather alerts.

Compatibility: Dual-mode transmission allows for backward compatibility with analog receivers while enabling digital features on compatible devices.[16]

5.5 Limitation of HD Radio:

Low Global Adoption: HD Radio is mainly used in the United States, Mexico, and Canada. It has not seen widespread international adoption, making it less useful in regions outside North America.

Receiver Availability: Although some car manufacturers and higher-end audio systems come equipped with HD Radio receivers, most standard radios do not support HD Radio.[20]

5.6 Deployment Status:

India:

HD Radio technology has not been widely adopted in India. The country has instead focused on Digital Radio Mondiale (DRM) for its digital radio broadcasting needs, particularly in the AM (Mediumwave) and FM bands.

No Official HD Radio Implementation: Unlike the U.S., where HD Radio is widely adopted, there is no substantial movement towards adopting HD Radio technology in India. All India Radio (AIR), the national broadcaster, has focused on expanding its DRM network rather than experimenting with HD Radio, which is more suited to markets where FM broadcasting dominates.

HD Radio does not have a notable presence in India, and the country's digital radio landscape is dominated by DRM technology with no HD Radio subscriber base as of now.

United States:

The United States remains the largest and most developed market for HD Radio technology. The Federal Communications Commission (FCC) approved HD Radio as the digital radio standard in 2002. Since then, the adoption of HD Radio has grown, particularly in metropolitan areas and in the automotive industry.

Adoption: Over 2,500 stations across the U.S. broadcast in HD, with many offering additional subchannels (HD2, HD3).

Canada:

Canada has not widely adopted HD Radio. In the early 2000s, the Canadian government and broadcasters focused more on satellite radio and internet streaming as their main digital radio solutions.

Asia:

HD Radio adoption in Asia is limited, with many countries exploring other digital radio standards or relying on internet streaming.

Japan: Japan's focus has primarily been on Integrated Services Digital Broadcasting (ISDB), its own standard for digital television and radio, which includes radio services delivered via satellite.

South Korea: South Korea has invested more in DMB (Digital Multimedia Broadcasting) technology, focusing on mobile digital services.

China: China has largely bypassed HD Radio in favour of other digital radio technologies and internet-based radio services. [17]

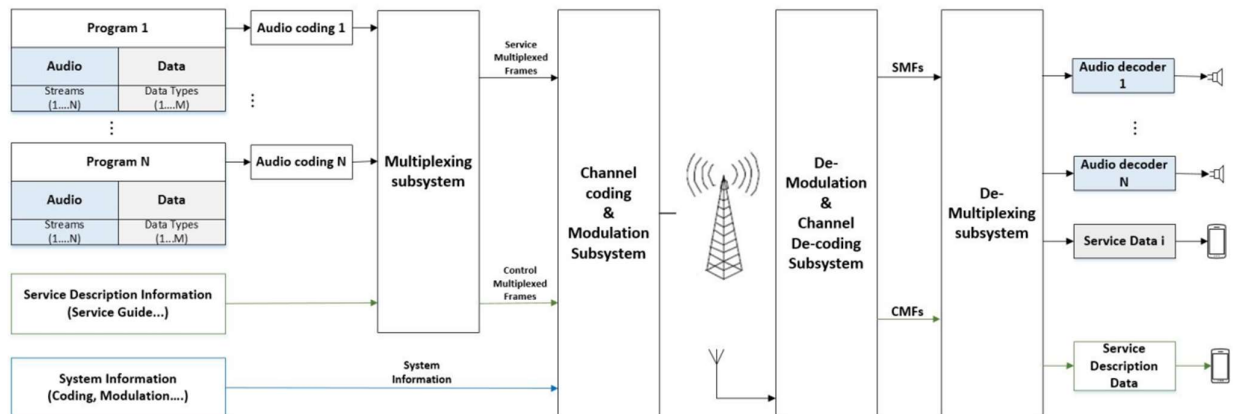
6. Convergent Digital Radio (CDR)

6.1 Introduction:

CDR is a digital broadcasting system developed to operate within the FM frequency band (87–108 MHz) while ensuring compatibility with existing analog FM radio in China. The research and development of CDR began in 2007, led by the Academy of Broadcasting Sciences under the General Administration of Radio and Television. Since 2011, the Hiroshima Institute has taken the lead in completing key technology research, development, and testing for digital audio broadcasting in FM bands. In 2013, the proposed industry standard was submitted and officially promulgated in August by the General Administration of Broadcasting. The first CDR digital broadcast frequency, "Audiovisual 102," was launched in Shenzhen in October 2013, marking the beginning of CDR broadcasts in various locations. Most CDR broadcasts currently operate alongside local Voice of China FM frequencies. In January 2018, the China State Administration of Press and Publication announced that CDR had been officially recognized as an international standard by the International Telecommunication Union (ITU).

[18]

6.2 CDR Architecture:



[19]

Figure 2: CDR system structure

CDR system consists of both transmitting and receiving systems. On the transmitting side, the CDR transmitter takes two types of input. The first input is the radio program, which includes multiple audio streams and data services, collectively defined as Main Service Data (MSD) in the CDR standard. The second input is Service Description Information (SDI), which carries program guide details, MSD configuration, and network information.

The multiplexing subsystem generates Service Multiplexed Frames (SMF) containing MSD bits and Control Multiplexed Frames (CMF) containing SDI bits. System Information (SI) is used to determine the modulation scheme,

coding, and channel capacity. After channel coding and modulation, the SI, MSD, and SDI bits are transmitted on their respective subcarriers.

On the receiving side, the CDR receiver processes each received physical layer frame. The SI is first decoded in the de-modulation and de-coding subsystem, configuring the modulation and coding settings for SDI and MSD subcarriers. The SDI bits in the CMFs are then processed and sent to the de-multiplexing subsystem. After processing SDI bits, the MSD bits in the SMFs are processed, and the selected audio stream is extracted by the de-multiplexer. The stream then passes through the DRA+ decoder, allowing playback to the user.

6.3 Technical Specifications:

CDR operates in the FM broadcast frequency band (87–108 MHz) and can also support AM broadcasts. It provides digital audio broadcasting and data broadcasting services through two modes: "all-digital mode" and "analog-to-digital synchronous mode." In all-digital mode, digital broadcast signals operate alongside existing analog FM signals within the same FM channel. In analog-to-digital synchronous mode, digital broadcast signals use a separate frequency band specifically designated for digital services.

The system utilizes the DRA+ digital audio coding standard, a technology developed in China that is also widely used in the DTMB digital TV standard. DRA+ ensures high compression efficiency and low decoding complexity while maintaining high-quality audio, comparable to typical surround sound.

CDR technology supports a flexible spectrum mode based on 100 kHz RF sub-bands, allowing signal bandwidth expansion up to 800 kHz to accommodate high-data-rate services for multiplexed digital audio and data transmission. Additionally, it supports multi-frequency collaborative operation, which enhances transmission performance in fading channel environments.

[20]

6.4 Advantages of CDR:

High Compression Efficiency with Good Audio Quality- The DRA+ digital audio coding standard ensures high compression efficiency, low decoding complexity, and sound quality close to surround sound.

Supports Emergency Broadcasting Systems- CDR is integrated into China's emergency broadcasting system, enabling the transmission of urgent messages at national, provincial, municipal, and county levels.

Flexible Spectrum Modes for Analog-to-Digital Transition- The system provides flexible spectrum modes, facilitating a smooth transition from analog to digital broadcasting.

6.5 Limitations of CDR:

Limited Adoption & Low Penetration Rate- CDR has a low adoption rate among developers and the public, making it difficult to implement on a larger scale.

Competition with Internet-Based Digital Broadcasting- With the rise of internet-connected vehicle infotainment systems, networked digital broadcasting is preferred over CDR, reducing its demand.

Declining Implementation in Vehicles- Most car manufacturers, both domestic and international, are omitting CDR support in favor of networked digital broadcasting, reducing CDR's relevance in modern vehicles.

6.6 Deployment Status:

China

China has undertaken significant initiatives to deploy CDR technology in national broadcasting projects. One of the major implementations is the "Digital Wireless Coverage Project for Central Radio and Television Programs," launched in 2014. This project aims to establish 2,562 over-the-air (OTA) transmission stations across the country to enable full digital television coverage. The project plans to install 5,846 digital television transmitters across 3,117 television stations to broadcast 12 national TV programs, along with more than 300 CDR transmitters to broadcast three digital national radio programs. The deployment of OTA digital radio coverage is based on utilizing the existing analog FM frequency resources at local transmitting stations without altering the original FM frequency allocation plan. The CDR system allows simultaneous transmission of both analog FM and digital broadcasting services, ensuring a smooth transition to digital broadcasting. The CDR system architecture comprises front-end systems, transmission links, and coverage networks with essential components such as source encoders, audio encoders, and multiplexers. At local transmitting stations, both analog FM signals and CDR digital signals are received via satellite, processed, and then broadcasted via CDR transmitters. A key advantage of this CDR deployment is cost reduction, as only satellite receivers and CDR transmitters are required at FM transmit stations, while audio encoders and multiplexers remain centralized at the satellite uplink department. Additionally, CDR technology plays a crucial role in China's national emergency broadcasting system, which operates at four levels: national, provincial, municipal, and county. Emergency alerts and messages are transmitted using satellite links (DVB-S standard), ASI/IP interfaces, optical cables, and Ethernet networks. Special emergency broadcasting adapters are deployed to ensure automatic wake-up and mandatory reception of emergency messages.

[20]

7. RAVIS (Real-time AudioVisual Information System)

7.1 Introduction:

RAVIS (Real-time AudioVisual Information System) is designed for operation in terrestrial VHF broadcasting bands, enabling local broadcasting with a wide coverage radius that ensures reception even in remote areas. The system's receiver is capable of receiving both new digital programs and analogue FM broadcasting stations with automatic detection of the program type.

RAVIS is developed to deliver high-quality multi-programme sound, video with multiple sound accompaniment channels, and other related or unrelated data. It is designed for reliable reception under various conditions, including urban environments, wooded and mountainous regions, and water areas. The system ensures uninterrupted service even in motion, without direct line of sight to the transmitter antennas, and in scenarios involving multipath signal propagation.

The channel coding and OFDM modulation scheme in RAVIS adapts data transmission to channel characteristics, allowing different QAM modulation levels and channel coding rates to optimize the balance between bitrate and reliability.

The low bit-rate and reliable data channels offer higher interference protection, extended coverage, and enhanced reception stability compared to the main service channel, making RAVIS a robust broadcasting system for diverse operational conditions.

[21]

7.2 RAVIS System Functional Blocks:

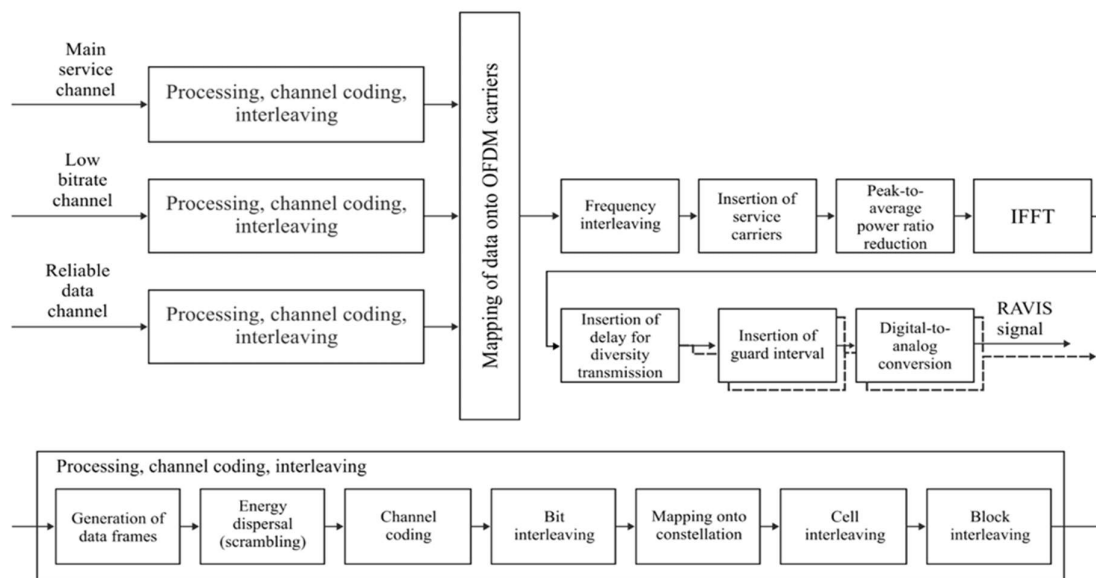


Figure 9: The transmitter functional block diagram [22]

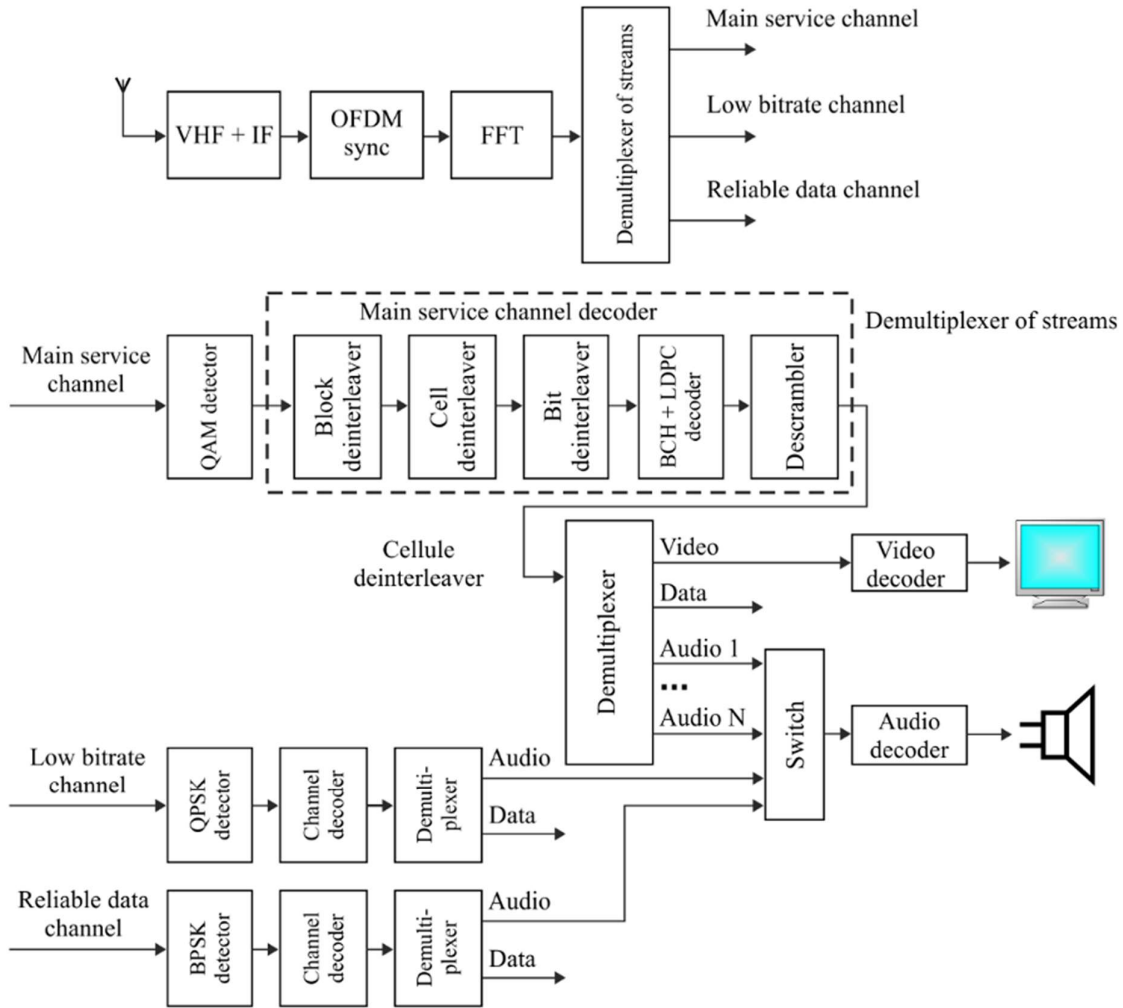


Figure 10: The receiver functional block diagram [22]

RAVIS supports multiple levels of QAM modulation and varying channel coding rates within the main service channel to optimize the balance between bitrate and interference protection.

The main service channel is responsible for transmitting video and audio data, with a maximum bitrate of 900 kbit/s. In addition to this, RAVIS includes two specialized channels for enhanced reliability:

- The low bit-rate channel, designed for high-reliability transmissions such as emergency voice alerts, operates at approximately 12 kbit/s.
- The reliable data channel, used for auxiliary data with high reliability, functions at around 5 kbit/s.

These two channels offer greater interference protection, extended coverage, and improved reception stability compared to the main service channel.

The modulation and coding schemes vary across channels:

- The main service channel supports QPSK, 16-QAM, and 64-QAM modulation with FEC coding rates of 1/2, 2/3, or 3/4.
- The low bit-rate channel uses QPSK modulation with an FEC coding rate of 1/2.
- The reliable data channel operates with BPSK modulation and an FEC coding rate of 1/2.

To enhance transmission efficiency, pilot carriers and service carriers are embedded in the multiplexed OFDM stream. These carriers assist in synchronization, channel distortion correction, and transmission of additional information, including modulation parameters, channel coding details, and logical data channel availability for reception.

While peak-to-average power ratio reduction is not mandatory in RAVIS, its implementation is recommended to improve system performance.

[22]

7.3 Technical Specifications

RAVIS (Realtime AudioVisual Information System), is designed to improve spectrum efficiency in VHF Bands I and II, currently used for analog FM audio broadcasting.

RAVIS supports data rates from 150 to 900 kbps within a 200 or 250 kHz radio frequency channel. This capacity allows for transmission of over 10 stereophonic audio programs or a video program with multiple audio channels, maintaining audio quality comparable to analog FM.

RAVIS ensures stable mobile reception (up to 250 km/h) in urban, topographically challenging, mountainous, forested, and water areas—environments characterized by multipath propagation and limited direct antenna visibility.

MPEG-4 AVC (ISO/IEC 14496-10) and MPEG-4 HE-AAC (ISO/IEC 14496-3) standards are used for video and audio encoding. Advanced channel encoding and COFDM modulation contribute to high spectrum efficiency.

Flexible channel encoding and modulation parameters (forward error correction rate, constellation pattern, guard interval) enable stable broadcasting in diverse environments (urban, rural) and single-frequency network (SFN) implementation.

Within the available bitrate, various service configurations are possible, including audio, video, still images, text messages, and other data.

The system's channel bandwidth allows deployment within European FM broadcasting frequency allocations, concurrently with analog FM or other narrowband digital terrestrial broadcasting systems.

[23]

7.4 Advantages of RAVIS

High-Quality Multimedia Support – Supports various video resolutions at up to 25 fps with bit rates up to 850 kbit/s per service stream. Also supports mono, stereo, and 5.1 audio formats with bit rates up to 192 kbit/s.

Efficient Transmission Methods – Uses COFDM modulation and a combination of BCH and LDPC coding, providing robust transmission and error correction.

Flexible Service Configuration – Supports multiple data formats, including JPEG, PNG, BMP, ASCII text, real-time A/V broadcasting, and Electronic Program Guide (EPG).

Seamless Service Access – Supports conditional access (CA) and fast content discovery through EPG.

Scalability and Spectrum Efficiency – Offers spectrum efficiency from 0.77 to 3.64 bit/s/Hz, providing adaptable data rates based on channel bandwidth.

7.5 Limitations of RAVIS:

Limited Bandwidth Options – Supports only three specific bandwidths (100 kHz, 200 kHz, 250 kHz), restricting adaptability to wider frequency ranges.

Complex Transmission Parameters – Use of COFDM, BCH, and LDPC coding may require sophisticated receiver designs, increasing hardware complexity.

Limited Net Data Rates – Net data rates range from 80 kbit/s to 900 kbit/s.

Limited Standardization Outside Specific Regions – The system is based on GOST R 54309-2011, which may limit its global adoption compared to widely used multimedia broadcasting standards.

7.6 Deployment Status:

Russian Federation:

Across Russia, over 2000 analog TV stations operate in the 76–100 MHz band, primarily broadcasting national programs. The 87.5–108 MHz band is heavily utilized for analog FM radio broadcasting, with over 2500 stations. Frequency resources are nearly exhausted in some regions. Electromagnetic compatibility with existing TV stations on channels 4 and 5 restricts frequency availability. A 1999 decision by the State Commission for Radio Frequencies of the Russian Federation prohibits new television broadcasting licenses in the 87.5–100 MHz band (shared by sound and television broadcasting) to preserve this band for VHF FM radio. Plans for Band II digitization are pending. The potential use of the Russian-developed Digital Mobile Narrowband Multimedia Broadcasting System RAVIS (Realtime Audiovisual Information System) in Band II (87.5–108 MHz) and Band I (66–74 MHz) is under consideration.

[23]

8. Comparison Table of Digital Radio Technology:

Feature	DAB	DRM	HD Radio	CDR	RAVIS
Primary Use	Public broadcasting	Broadcast radio (AM/FM, shortwave)	Broadcast radio (FM/AM, U.S.)	Digital audio & data broadcasting in FM bands	Local broadcasting
Modulation	OFDM (Orthogonal Frequency Division Multiplexing)	COFDM	IBOC (In-Band On-Channel)	System Information (SI)-based modulation	COFDM
Audio Codec	DAB+	xHE-AAC	Proprietary	DRA+	MPEG-4 HE-AAC
Spectrum Efficiency	DAB - 0.78 bits per Hz DAB+ -1.09 bits/Hz	DRM- 3.4 - 4.0 bits/Hz DRM+ - 1.94 bits/Hz	0.70 to 0.93 bits/Hz	-	0.77 to 3.64 bits/Hz
Coverage	~60 km	~300 km Shortwave ~1000 km	FM HD Radio: ~20 -100 km AM HD Radio: ~200-400 km	-	Stable mobile reception up to 250 km/h
Adoption	UK, Germany, France	India, Indonesia	U.S.	China	Russia
Cost	Very Low	Low	Medium	Medium	High
Additional Features	Multimedia, text data, emergency alerts.	Emergency alerts, data services	Extra data channels, song tagging	Emergency alert integ., multi-frequency collab, hybrid analog-digital mode	Supports video), audio, real-time A/V broadcasting, text messages, and EPG
Typical Applications	Public Broadcasting and Radio	Public broadcasting, rural coverage	Commercial radio in the U.S.	Digital audio broadcasting, emergency alerts, hybrid FM-digital radio	Local broadcasting for high-quality multimedia transmission

[24]

9. Professional Digital Radio Communication Systems

While digital radio technologies described above are designed for public broadcasting, other systems like DMR, TETRA, and APCO P25 serve distinct communication needs.

Unlike technologies described above, these systems focus on secure and both way communication within specialized user groups rather than mass media transmission.

9.1 Digital Mobile Radio (DMR):

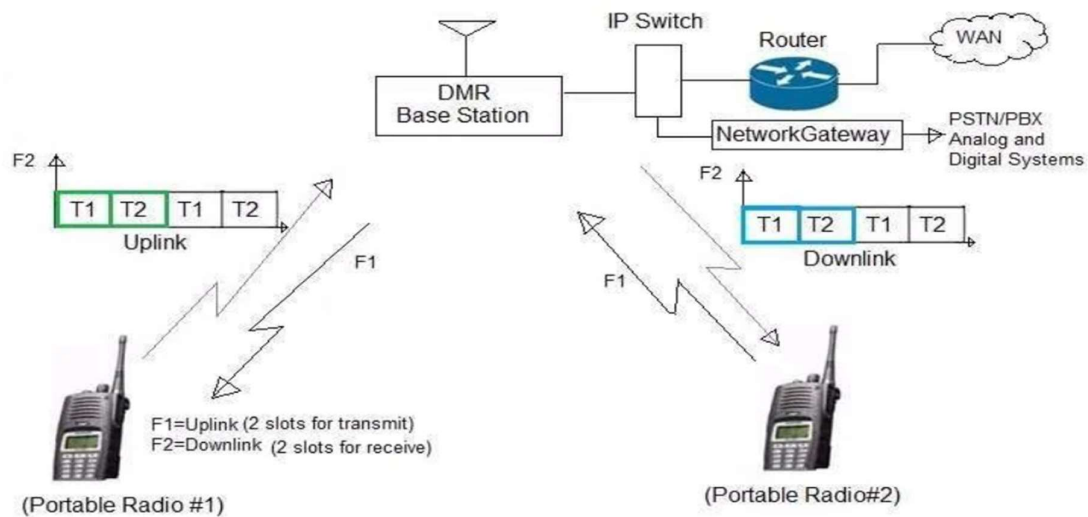
9.1.1 Introduction:

Digital Mobile Radio (DMR) is a digital radio standard developed by the European Telecommunications Standards Institute (ETSI). It is widely adopted across the globe and designed to meet the communication needs of professional users in industries such as public safety, transportation, utilities, manufacturing, and more. DMR employs a digital signal to transmit voice and data, offering enhanced clarity, improved coverage, and increased capacity compared to analog systems. [25]

9.1.2 DMR Architecture:

The figure depicts **DMR network architecture**. As shown DMR consists of two main elements Base station and portable subscriber radio units. The area to be covered using DMR technology is divided into number of cell sites. Each cell site consists of one or more than one Base Stations (BSs). Each Base Station can be interfaced with LAN using IP switches or with WAN using routers. Often network gateways are used in order to have connectivity with PSTN/PBX to provide connections with analog and digital telephone systems.

DMR Network Architecture



[26]

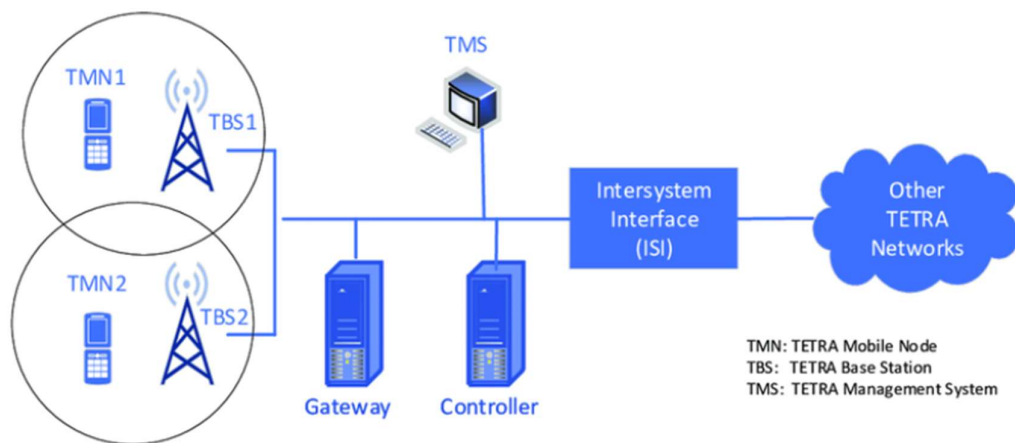
Figure 11 DRM Network Architecture

9.2 Terrestrial Trunked Radio (TETRA):

9.2.1 Introduction:

TETRA Radio Frame is a digital communication system utilized by emergency services, security forces, and other agencies. It permits features like texts and location monitoring and offers quality voice communication and encryption for privacy. When communication is most needed, TETRA's particular radio frequencies are utilized for reliable operation in difficult situations like crises or distant locations.[27]

9.2.2 TETRA Architecture:



[28]

Figure 12 TETRA Architecture

- **System Components:**

- Mobile Stations (MS): The handheld or vehicle-mounted radios.
- Switching and Management Infrastructure (SwMI): The central switching system.
- Base Stations (BS): The transceivers that communicate with mobile stations.
- Subscriber Identity Modules (SIM): Similar to mobile phone SIMs, used for authentication.

- **TETRA Network:**

- Trunking principles, efficient channel use.
- Describe how TETRA uses TDMA (Time Division Multiple Access) to enable simultaneous communications.
- Explain coverage areas, scalability, and redundancy.

9.3 APCO 25

9.3.1 Introduction:

Project 25 (P25 or **APCO-25**) is a set of standards for digital land mobile radio (LMR) developed collaboratively by public safety agencies and manufacturers to ensure interoperable communication. It addresses the critical need for effective communication during emergencies, recognizing that incompatible radio systems can severely hinder response efforts. P25 aims to enable seamless communication between first responders and other public safety professionals, improving coordination and response times. The Telecommunications Industry Association (TIA) publishes the P25 standards as the TIA-102 series. While designed primarily for North American public safety, P25 technology is used in other applications worldwide. P25 supports analog and digital modes, offering flexibility and interoperability with older systems. It uses IMBE and AMBE+2 voice codecs and offers various encryption options, including DES, Triple-DES, AES, and others. P25 can operate in talk-around, conventional, or trunked modes.

9.3.2 APCO 25 Architecture:

Phase I uses the full rate (7.2 kbps) IMBE vocoder, whereas the Phase II employs the half-rate (3.6 kbps) AMBE+2 vocoder to digitize the analog audio.

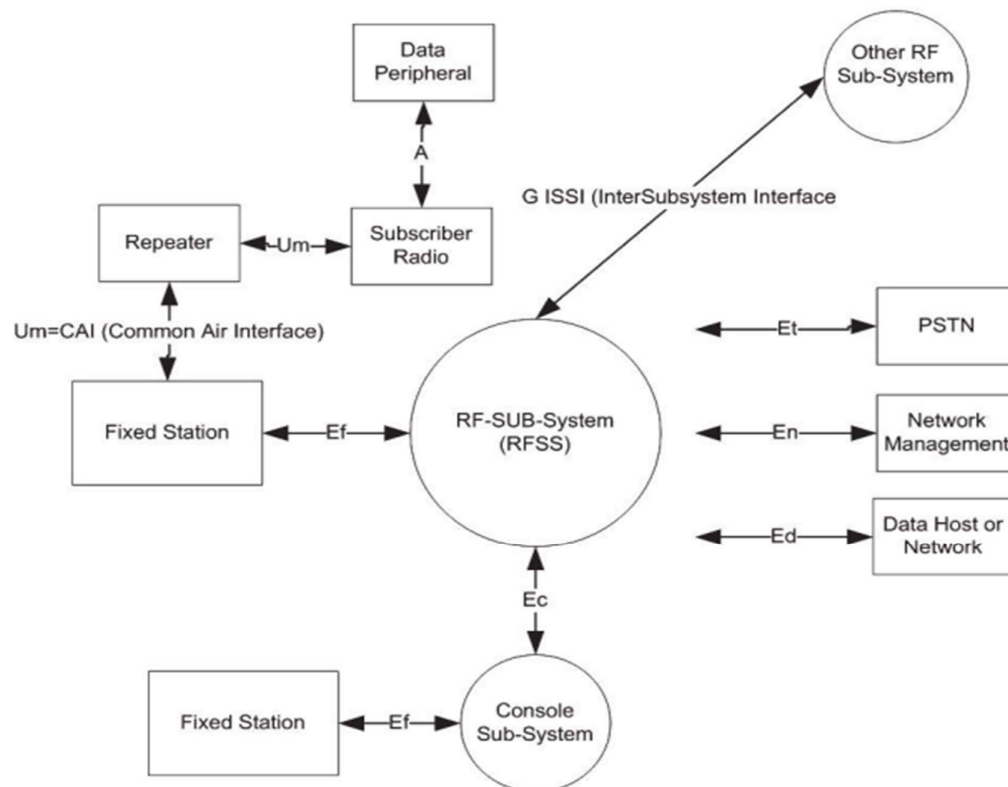


Figure 13 APCO Architecture

9.4 COMPARISON TABLE

Feature	DMR	TETRA	APCO25
Primary Use	Commercial, Industrial	Public Safety, Professional Mobile Radio	Public Safety, Interoperability
Modulation	4FSK	$\pi/4$ -DQPSK	Phase I: C4FM or CQPSK; Phase II: HCPM and H-DQPSK
Audio Codec	AMBE+2	ACELP	Phase I: IMBE ; Phase II: AMBE+2
Spectrum Efficiency	0.12 bit/s/Hz	0.16 bits/Hz	Phase I : 0.08 bits/Hz Phase II: 0.12 bits/Hz
Coverage	Medium	High	Very High
Adoption	Global (business, industry)	Europe, Asia, Africa	Primarily North America, Worldwide
Cost	Generally lower than TETRA or APCO P25	Higher than DMR, lower than APCO P25	Generally higher than DMR or TETRA
Additional Features	Encryption, GPS, voice & data	Encryption, direct mode, group calls	Supports both voice and data transmissions, conventional and trunked radio modes, routine and emergency calls, clear and encrypted voice (OTAR)

10. Potential Challenges and Ecosystem Requirements for digital radio technologies:

10.1 Potential Challenges:

1. Infrastructure and Deployment Costs

- **High Initial Investment:** Upgrading existing analog broadcasting infrastructure to digital can be expensive. Broadcasters need to invest in new transmitters, antennas, and other infrastructure to support digital signals.
- **Transition Period:** There may be a long and costly dual transmission period where both analog and digital signals are broadcast to cater to all users, especially in regions where analog receivers are still dominant.

2. Receiver Availability and Cost

- **Cost of Digital Receivers:** In some regions, the cost of DRM or DAB-capable receivers can be high, especially compared to standard analog radios. Without affordable receivers, consumer adoption may be slow.
- **Limited Receiver Choices:** Initially, the variety of digital radio receivers (portable, car radios, smartphones) may be limited, reducing consumer incentive to switch.

3. Regulatory and Spectrum Management

- **Spectrum Allocation:** Regulatory bodies need to manage spectrum efficiently, potentially reallocating spectrum currently used by analog services. This can be a complex process that varies by country.
- **Interference and Compatibility:** There may be challenges in terms of managing interference between analog and digital transmissions, especially in overlapping frequency bands, during the transition phase.

4. Consumer Awareness and Demand

- **Lack of Awareness:** Many consumers may not fully understand the benefits of digital radio over traditional AM/FM, making it harder to generate demand for digital receivers.
- **User Resistance to Change:** Some users may be resistant to adopt digital technology if they are satisfied with existing analog services, especially in rural or low-tech areas where traditional radio is well-established.

5. Coverage and Signal Quality

- **Signal Penetration:** In some regions, especially rural areas or places with challenging geography, the signal strength of digital radio may not be as robust as analog transmissions, leading to coverage gaps.

- **Network Density:** To ensure consistent coverage, especially in DRM+ and DAB, a dense network of transmitters may be required, which can be costly to install and maintain.

6. Data Rates and Content Delivery

- **Limited Bitrate for Multiple Services:** In digital radio, there is a need to balance bandwidth between audio quality and additional services (like text, images, and multimedia). This can result in a compromise on audio quality if more services are packed into the available spectrum.
- **Compression Artifacts:** Digital radio often uses compression techniques (like AAC+ for DRM) to save bandwidth, which can sometimes degrade the sound quality compared to uncompressed analog signals.

7. Interoperability and Standards Fragmentation

- **Multiple Standards:** Different digital radio standards (DRM, DAB, HD Radio, etc.) are being used in different parts of the world. This can create compatibility issues for manufacturers and broadcasters, who need to decide which technology to support.
- **Device Integration:** Ensuring that digital radio receivers are integrated into devices such as smartphones, cars, and home entertainment systems can be a challenge due to varying technology standards.

10.2 Ecosystem Requirements

To overcome these challenges and ensure the success of digital radio technology, several **ecosystem requirements** must be met:

1. Affordable and Widely Available Receivers

- **Subsidized Receivers:** Governments or broadcasters may need to subsidize the cost of digital receivers to encourage early adoption, especially in underserved or lower-income regions.
- **Mass Production:** Manufacturers should focus on producing affordable, energy-efficient, and user-friendly digital radio receivers to reach a broad market, from high-end users to rural areas with basic needs.

2. Strong Regulatory and Government Support

- **Clear Transition Plans:** Governments should develop and enforce clear policies and timelines for the analog-to-digital transition, ensuring broadcasters, manufacturers, and consumers are all on the same page.
- **Spectrum Management:** Regulatory bodies should allocate and manage spectrum in a way that supports both analog and digital services during the transition phase without causing interference.

3. Comprehensive Coverage and Network Expansion

- **Nationwide Coverage:** For digital radio to be successful, especially in large, geographically diverse countries, broadcasters must invest in building a comprehensive network that ensures signal availability even in remote regions.
- **Single-Frequency Networks (SFN):** Technologies like DRM and DAB can benefit from single-frequency networks (SFN), where the same frequency is used over a wide area.

4. Consumer Awareness and Education Campaigns

- **Public Awareness Campaigns:** Governments, broadcasters, and manufacturers should collaborate on awareness campaigns that educate the public about the benefits of digital radio, from better sound quality to additional features (like emergency alerts and multimedia).
- **Incentives for Early Adopters:** Providing incentives like discounts on digital radios or offering exclusive digital content can encourage early adopters to switch from analog to digital.

5. Innovative Content and Services

- **Additional Features:** Digital radio's ability to offer more than just audio is one of its key advantages. Broadcasters should invest in delivering innovative services such as text updates, real-time traffic information.
- **Localization of Content:** Offering region-specific content, language options, and culturally relevant programming can enhance user engagement and drive the adoption of digital radio, particularly in multicultural and multilingual regions.

6. Interoperability and Multi-Standard Support

- **Hybrid Radios:** Devices that support both analog and digital radio formats can help bridge the gap between the two technologies, ensuring a smoother transition for consumers.
- **Standardization:** Industry-wide standardization efforts can help ensure that digital radio technology is interoperable across different regions and devices, reducing confusion for manufacturers and consumers.

7. Long-Term Sustainability

- **Energy Efficiency:** Both the transmission infrastructure and digital receivers must be energy-efficient to keep operational costs low, especially in regions with limited power supply.
- **Sustainable Business Models:** Broadcasters need to develop sustainable business models to monetize digital radio, such as through targeted advertising, subscription services, or premium content offerings.

[30]

11. Conclusion:

Digital radio technology represents a significant advancement over traditional analog systems, providing enhanced audio quality, improved spectrum efficiency, and additional functionalities. It enables clearer and more reliable communication by minimizing interference and noise. Digital systems also offer data services, such as text messaging, GPS tracking, and telemetry, making them more versatile in various industries, including public safety, transportation, utilities, and commercial sectors.

Global standards such as, **Digital Radio Mondiale(DRM), Digital Audio Broadcasting(DAB), HD Radio, CDR, RAVIS** and have been widely adopted due to their ability to serve commercial communication needs. These technologies offer better range, scalability, and security features compared to analog systems.

Despite these advantages, digital radio technology faces challenges such as high infrastructure costs, limited interoperability between proprietary systems. As industries evolve and demand more integrated services, digital radio will likely coexist with broadband technologies, serving niche areas that require reliability, security, and efficient spectrum usage.

Further, digital radio technology is a transformative development, providing robust communication solutions globally. It continues to evolve to meet the demands of modern communication networks, but its future will likely involve hybrid models integrating both traditional digital radio and newer broadband systems.

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Abbreviations:

Abbreviation	Expansion
AAC	Advanced Audio Coding
AIE	Air Interface Encryption
AIR	All India Radio
AM	Amplitude Modulation
BS	Base Station
CD	Compact disc
COFDM	Coded Orthogonal Frequency Division Multiplex
CRS	Community Radio Stations
DAB	Digital Audio Broadcasting
DLS	Dynamic Label Segment
DMB	Digital Multimedia Broadcasting
DMR	Digital Mobile Radio
DQPSK	Differential Quadrature Phase Shift Keying
DRM	Digital Radio Mondiale
DRT	Digital Radio Technology
E2EE	End-to-End Encryption
EECC	European Electronic Communications Code
ETSI	European Telecommunications Standard Institute
FEC	Forward Error Correction
FM	Frequency Modulation
GPS	Global Positioning System
IBOC	In Band On Channel
ISDB	Integrated Services Digital Broadcasting
ISI	Inter symbol Interference
ITU	International Telecommunication Union
LSB	Lower Side Band
MCI	Multiplex Configuration Information
MOT	Multimedia Object Transfer
MPEG	Moving Picture Experts Group
MS	Mobile Station
NRSC	National Radio Systems Committee

OFDM	Orthogonal Frequency Division Multiplex
PMR	Professional Mobile Radio
SABC	South African Broadcasting Corporation
SDS	Short Data Services
SFNs	Single Frequency Networks
SIM	Subscriber Identity Modules
SWMI	Switching and Management Infrastructure
TDMA	Time Division Multiple Access
TEI	Text Encoding Initiative
TETRA	Terrestrial Trunked Radio
USB	Upper Side Band
VHF	Very High Frequency