HD Radio™ How it compares to other Digital Radio Technologies

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Introduction

From the UK to Ukraine and Malaysia to Mexico, the digital radio format debates are heating up. The interest is at its highest level ever, with the transformation from analog to digital radio being reviewed around the world. This change is a logical next step, as radio is one of the oldest communication technologies in existence, yet it is among the last information and entertainment medium to operate on an analog transmission platform.

There are many technologies to consider: DRM, DAB-Eureka 147, HD Radio™, DVB-H, DVB-t, TDAB, DVB-S, Worldspace, XM, Sirius, ADSL (internet), Media Flo™ and ISDB-t to name few! But which technology will carry a country successfully into the future? The choice between the different digital radio technologies can be confusing and complex and due to the very nature and importance of radio any mistake could be catastrophic. The technology choice must satisfy all parties involved: listeners, broadcasters, regulatory and government agencies and manufacturers.

The listener typically wants more choices, interactivity and higher quality; this would be confirmed by the fast implementation of DVD and MP3 players, digital cable and terrestrial TV; all successful because of these attributes. The broadcaster wants a low investment with a high return; this may be measured by a financial result or in the case of a non-commercial public station by it being able to provide a better service to the community. Manufacturers wish to see a fast return on any R&D investment with the lowest risk and it could be assumed that governments and regulatory agencies wish to have a seamless and effective process of implementation, use the least amount of their valuable bandwidth while providing the maximum benefit to the country.

So how does a country make the right selection? This paper will examine the options available in relation to the key players mentioned. The technologies of DRM, DAB and HD Radio™ were specifically developed to allow broadcasters to transition from analog to digital and each system has been implemented with varying amounts of success. The contents of this paper will include a discussion on HD Radio and how it differs from each of these technologies, in particular relating to their fundamental elements; the audio codec, frequency of operation, modulation and error correction methods, implementation and operation costs, market opportunity, costs and availability of radio receivers.

HD Radio

iBiquity Digital Corporation is the inventor of the HD Radio brand of IBOC (In-Band On Channel) technology. iBiquity is a company formed by the merger of USA Digital Radio and Lucent Digital Radio, with the goal of creating an IBOC digital radio system. HD Radio operates on both AM-MW and FM VHF Band II either in a digital-only mode, or in a "hybrid" digital plus analog mode. Most broadcasts for the foreseeable future will use the hybrid mode. The result is that AM stations will have FM quality sound and FM stations can achieve CD-like quality audio or carry multiple audio programs (known as multicasting). IBOC as the name implies, allows a digital signal to be added to the existing analog service within a radio stations allocated channel AM and FM assignment. These simulcast modes know as “hybrid” and apply to both AM & FM. The HD Radio hybrid mode places low-level digital carriers in the upper and lower sidebands of the analog spectrum. The implementation on AM is similar in that the upper and lower sidebands contain low level digital signals. Since, the analog AM signal is amplitude modulated (as opposed to frequency modulation), the AM HD Radio hybrid signal can carry digital information in a quadrature phase component. Thus it can be placed directly beneath, or in quadrature to the analog modulation.

Like DRM and DAB, HD Radio employs COFDM modulation. The audio compression algorithm (CODEC) initially developed for HD Radio was a perceptual audio coding (PAC), a Bell/Lucent algorithm but was changed to the HDC™ codec in 2003. The change to the new audio codec was made to improve low-bitrate efficiency. The new code developed by iBiquity and Coding Technologies shares much of its attributes with other state-of-the-art codecs, but differs in its ability to deliver near CD quality at rates as low as 96 kbps and FM quality audio at rates as low as 20 kbps. HDC has also the unique ability to segregate audio into core and enhanced layers for transmission on discreet carrier segments. Research shows that stereo audio can be transmitted with startlingly superior quality at rates as low as 48 kb/s.

As per the Eureka 147 technology HD Radio employs C-FEC, Interleaving, and frequency and time diversity. In addition HD Radio provides subcarrier and pulse-shaping, first adjacent channel cancellation, channel state indication and complimentary combining. All these techniques significantly improve reception under major interference conditions.

The FM design provides a flexible means of transitioning to a digital broadcast system by providing three waveform types: hybrid, extended hybrid, and all digital. The hybrid and extended hybrid types retain the analog FM signal, while the all digital type does not. In hybrid mode, the AM version can carry 36kb/s of data for the main audio channel, while FM stations can carry information at up to148 kb/s.

Supplementary channels can be added to increase the number of traditional programs or special programs like weather, traffic, or reading service for the visually impaired, datacasting is also possible and Program Associated Data (PAD) which is metadata about the program and station, are included in the standard. The hybrid mode has an advantage that an HD Radio receiver will first lock onto an analog signal first, then FM stereo and then to digital. If the digital signal is lost, it will blend slowly back to analog, the same way a car radio will blend from stereo to mono given a weak signal. The perception is one of current analog tuning characteristics and not of the acquisition delays or “cliff effects” due to signal loss with other digital transmissions.

While iBiquity is responsible for the development of these standards, it has been the Federal Communications Commission (FCC) which is responsible for its regulation in the U.S. In the U.S., the National Radio Systems Committee (NRSC) has served as the standards body for IBOC and has established the NRSC-5 IBOC standard, with the latest version being NRSC-5-A. The International Telecommunications Union’s recommendation of iBiquity’s AM and FM HD Radio systems for worldwide implementation of digital broadcasting is documented in ITU-R Recommendation BS.1514 (April 2001) and ITU-R Recommendation BS.1114.

A characteristic of HD Radio is that a radio station can choose an implementation method ideally suited to its current installation. A combiner is often used, either before the amplifier stage (know as common amplification) or after the amplification stage (know as separate amplification). In addition, stations can employ a completely separate transmitter and can use a separate antenna system on the same tower. Each method has its advantages and is suited to different situations depending on the current installation.

In the USA by the end of 2006 over 1200 radio stations are expected to be operating, in both AM and FM. This relates more than 20,000 transmission hours per day. A large number of stations are also making use of the multicasting capability making HD Radio the most transmitted digital technology available. Tests have taken place in Asia, Europe and South America. Many countries including the Philippines and Brazil are seriously considering adopting HD Radio as a standard in the near future. Brazil for instance has over 20 HD Radio sites in operation.

Any comparison between technologies must evaluate each as it relates to the people using the technology; the listener, broadcaster, regulator and manufacturers. It is important to understand how technology markets work and what is needed to succeed. The evaluation from all points of view particularly those directly involved in the technology are critical for success. Each player must see a distinct advantage and be able to gain benefits from the technology.

The audio CODEC (Coding – Decoding) system is the most critical element in the resulting audio quality of any digital radio system. A codec works by exploiting the properties of the human auditory system; in particular, the spectral and temporal masking effects of the inner ear. Essentially, the system codes only audio signal components that the ear will hear, and discards any audio information that, according to the psychoacoustical model, the ear will not perceive. Thus valuable bit-rate capacity is allocated only to coding and conveying information that is important to maintaining a high subjective audio quality.

Current codec systems available include MP2, MP3, AAC+ and HDC. The MP2 and MP3 codecs were among the first innovative methods of compressing audio bit rates to levels that could be useful. Over time, improvements led to a far more efficient method; AAC, which significantly outperforms both MP2 and MP3 coding systems.

Then in 1999, a new technology was developed by Coding Technologies called Spectral Band Replication (SBR), and when this technology was combined with existing audio codecs performance again improved significantly. The combination of SBR with AAC is called High Efficiency AAC or AAC+ and is one of the most efficient audio codecs in existence. Coding technologies have since improved further the coding algorithms which produced HDC, the codec used in HD Radio.

Audio CODEC	Bit Rate required to provide	Digital Radio System
MP2	**192**	**DAB Eureka 147**
MP3	**128**	**DMB**
AAC	**96**	**DVB-H**
AAC+	**64**	**DRM**
HDC	**48**	**HD Radio**

Table 1 shows the relationship between audio codec's minimum bit rate for good audio quality and the digital system that currently employs that particular method of coding.

The audio codec chosen for use for the DAB system was MPEG Audio Layer 2 (MP2). This is the predecessor of the now famous MP3 audio codec. The MP2 system uses a much higher bit rate than

MP3 in order to achieve a given level of audio quality. For example an MP2 CODEC must use at least 96 kb/s to provide the same level of audio quality as 64 kb/s for MP3 or 48kb/s for AAC+ or HDC. The MP2 audio codec was chosen namely for its ever-present use on digital cable, satellite and terrestrial TV. This is exemplified by the fact that a digital TV system uses as much as 256kb/s to provide a similar quality to that of a good FM radio signal.

A comparison of performance for each technology is best understood by looking at the bit rate required to provide a certain level of audio quality. Table 1 lists the audio codecs and their bit rates required to provide "Good Audio Quality", which could be perceptually compared to good reception FM Stereo.

The later the development of the digital radio system the more efficient and the more radio programs can be fit into a given bandwidth. Logically the more spectrally efficient the system is the more flexibility it can provide and or cost efficient it can be.

Audio Quality Level	Relationship To FM Quality	MP2 BIT Rate Kb/s	Number of Programs per DAB multiplex
CD-Quality	**Better than FM**	**256**	**4**
Very Good Quality	**FM with good Reception Quality**	**224**	**5**
Good Quality	**FM with average Reception quality**	**192**	**6**

Table 2 shows the relationship between audio quality levels, bit rate and number of stations per Eureka 147 DAB multiplex

Frequency of Operation

DRM technology is capable of operating in the bands of SW, MW and LW as well as the latest intention to implement in the FM band although not expected to be available in commercial form until later in the decade.

DAB typically uses two frequency bands: Band III (174 – 239 MHz) as used in the United Kingdom and L-band (1452 – 1490 MHz) as used in Canada and parts of Europe. Although VHF Band III is a very good selection for its transmission characteristics, it is in most parts of the world extensively used for television, and because of its almost unequaled coverage capabilities it is in most countries unlikely to be given up. Also L-band in the USA and other countries is already used for military and marine communications. Some countries have not yet employed any transmission in the L-Band, but a very real problem with this particular band of frequencies is that the coverage per kilowatt of power is poor and becomes an expensive method of transmission particularly if the objective is to obtain nation wide coverage. For reasonable signal reception there must be strong signal strength consequently a great number of transmitters would be needed, organized in a cellular infrastructure, in addition relatively high transmission powers will be required. The result is that an enormous investment would be necessary for any country with a large landmass and widespread population.

HD Radio operates in the same band as existing analog AM-medium wave and FM-VHF Band II. This has advantages to all involved, from the broadcaster; the "dial position" does not change, there will also be less infrastructure change necessary and lower capital costs to implement. From the listeners point of view; the existing analog radio still works, and when the Listener wishes to purchase a new radio it will be because of the quality, signal robustness and new services available. It could be assumed that most governments would prefer not to require new licenses just to provide similar content and service. It is a good assumption that any government would prefer to employ additional spectrum for other applications allowing for additional services. From the transmitter and receiver manufacturers point of view there is less risk and lower R&D necessary; as the equipment is an upgrade to existing products. iBiquity has already designed both the exciter and receiver modules so it is a simple matter of integration into existing equipment.

Modulation and error correction schemes

The ideal digital transmission scheme is to provide high data capacity in minimal bandwidth while requiring as little transmission power to provide robust reception. Robust reception is obtained on mobile digital communication systems by using error correction technology to fix bit errors that occur in transmission. Since the late 1980's when DAB was designed, the strength of the error correction technology used on mobile digital systems has increased significantly. The improvements are mostly due to the increase in speed of silicon chips which allow more complex error correction schemes to be used. This increase in the strength of error correction technology allows higher data rates to be transmitted in the same amount of bandwidth, which increases spectral efficiency. DRM and HD Radio use similar data rates and consequently have similar spectral efficiencies.

Implementation and Operational costs

Due to DAB's inherent need for a new frequency spectrum an entire new transmission infrastructure is required. Due in part to the large amount of radio stations per city and the type of spectrum available in most countries it is impractical to think of DAB technology as an analog replacement system. L-Band transmitters and components are in general more expensive than the equivalent standard analog and digital radio equipment; this is due to the fact that the frequency of operation dictates higher silicon costs for the amplification part of the equipment and that the amount of existing analog. On the other hand DRM and HD Radio extensively employ analog transmitter types with a new exciter system. The quantity of this type of transmitter being sold on a regular basis makes HD Radio and DRM equipment tend to be lower. This can be observed in the transmission equipment sector with over 300 radio AM and FM transmitter manufacturers but less than half a dozen DAB.

Due to its use of existing infrastructure and low technical constraints HD Radio will work with most existing AM and FM equipment. For AM it is necessary, as with DRM, to purchase a new digital exciter. FM HD Radio implementation can be accomplished by using either the existing transmitter or antenna system and a new exciter or installing a complete new, but lower power, parallel system. The power ratio required is approx 20 dB (100:1) so the amount of power required for the digital part of the signal is very low with a typical cost of less than $80,000 USD for the complete system. If the existing antenna is used and high level combiner employed then the implementation cost is lower; around $35,000 USD but the annual operating cost due to the increased power consumption would be higher.

The level of transmitter power required not only has a large effect on the cost of the capital equipment but also on its operating costs. Transmitter powers are highly dependent on both the frequency and bandwidth of the transmitted signal – the lower the frequency and the narrower the bandwidth the lower the required transmitter power will be and hence the lower the cost. Taking these two factors into account, the transmitter powers required for a HD Radio and DRM to provide similar coverage as a DAB multiplex would be significantly lower. This would indicate immediately that cost to operate either a DRM or HD Radio transmitter as compared to a DAB system would be less expensive.

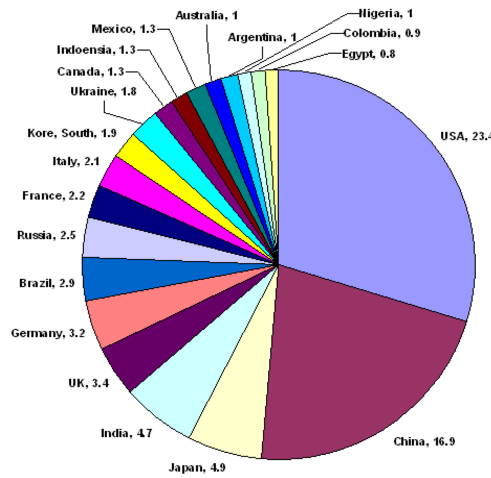
The operating costs for both DRM and HD Radio in most cases increase by only a small amount. For both systems it is estimated that the annual operating cost would typically increase by no more than 15%. One important note is that if an HD Radio or DRM broadcaster was to operate in an all digital mode the required transmission power would be between 10 and 20 dB's less and has such operational costs would be reduced, possibly by as much as 80%.

Receivers

HD Radio receivers have been available in the USA for several years and it is expected that there will be 40 models available by the end of 2006.

Receiver manufacturers view the potential size and accessibility to be most important. For a radio receiver manufacturer to sell radios there must be a well installed base of broadcasters and an incentive for the listener buy a new radio. This may be more channels, services or exciting and new content. It has been clearly demonstrated in both the UK and Canada with DAB that listeners will not buy a new radio based strictly on improvements in sound quality or reception.

All technologies mentioned require the purchase of a new radio to receive a digital signal. It can be assumed that the potential market for receivers will be proportional to the existing analog base. The installed world base of radio receivers is approximately 2.5 Billion radios; a graph of the top 20 receiver countries is shown below.



Conclusion

Each technology has gained a foothold in certain areas: DAB in Europe, DRM in Asia and HD Radio in the Americas, and hence each could be considered a success in their own right.

All technologies to some extent work in different frequency bands and therefore all could be implemented at the same time. While this is feasible, however, aggregating services in this manner will drive initial receiver costs higher and risk the initial adoption rates of all the technologies, particularly in the short term.

Each technology has its advantages and to some extent each technology would meet certain countries' requirements. Apart from the spectral inefficiency of DAB to most extent from a technical point of view the standards are very similar.

It therefore must be concluded that the differences between the technologies lies in the conditions of implementation.

A feature of note is that HD Radio allows hybrid multicast in FM, doubling or tripling the amount of radio programs in a market without interruption to the existing analog service.

The key to HD Radio is that it requires no large government intervention as it does not require additional spectrum allocations, this is because each digital signal is simultaneously transmitted within the same spectral mask of an existing AM or FM allocation. HD Radio is designed, through power level and spectral occupancy, to be transparent to the analog radio listener. HD Radio allows economy of spectrum while enabling broadcasters to supply digital quality audio to their present base of listeners, without significant investment in time or money.

Summary

As a whole, HD Radio offers a lower cost, more transparent implementation and definite advantages for additional revenue or opportunities to serve the public for the broadcaster. No new frequencies are required, easing regulatory issues, and existing large radio markets reduce the risk for both receiver and transmitter manufacturers. The listener would be motivated to purchase a new receiver due to the additional content, greater quality and advanced services. Overall no technology is perfect or meets everyone needs, and the final solution will be that of a compromise that can hopefully manifest itself to a successful and practical digital implementation.

Acknowledgements

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