Worldwide Survey of Direct-to-Listener Digital Audio Delivery Systems Development Since WARC-92

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ABSTRACT

Each country was allocated frequency band(s) for direct-to-listener digital audio broadcasting at WARC-92. These allocations were near 1500, 2300, and 2600 MHz. In addition, some countries are encouraging the development of digital audio broadcasting services for terrestrial delivery only in the VHF bands (at frequencies from roughly 50 to 300 MHz) and in the medium-wave broadcasting band (AM band) (from roughly 0.5 to 1.7 MHz).

The development activity increase has been explosive. This article summarizes current development, as of February 1993, as it is known to the author. The information given includes the following characteristics, as appropriate, for each planned system: coverage areas, audio quality, number of audio channels, delivery via satellite/terrestrial/or both, carrier frequency bands, modulation methods, source coding, and channel coding[1]. Most proponents claim that they will be operational in 3 or 4 years.

I. WHAT IS DBS-RADIO AND DIGITAL AUDIO BROADCASTING (DAB)?

DBS-Radio, that is direct-to-listener reception from a satellite, is a concept that incorporates the idea of reception into mobile, outdoor portable, and indoor portable (table top) receivers, as well as receivers with fixed directional outdoor antennas. What distinguishes it from DBS-TV is that the receiver/antenna system is supposed to work without an unobstructed direct line-of-sight to the satellite from the receiver's antenna. Most planned systems using this concept are being designed for all environments—rural, suburban, and urban reception. Some systems concentrate on mobile reception; most consider indoor reception to "table top" radios to be of equal or greater importance.

This collection of requirements forced a search for frequency allocations somewhere between 500 and 3000 MHz for satellite delivery. A simple tradeoff analysis shows that lower frequencies require spacecraft downlink antennas that are too large and higher frequencies require power levels per broadcast channel that are too high. Thus, after much preliminary work during the 1980's, DBS-Radio got to be an agenda item for WARC-92, with the proviso that if there were to be any frequency allocations, they would be above 500 MHz and below 3000 MHz.

Digital Audio Broadcasting (DAB) refers to any modern digital source coding, modulation and signal processing technique that will permit high quality audio to be broadcast and received with the audio quality preserved for the listener after RF propagation and decoding. The term encompasses any delivery method, terrestrial, satellite, and "hybrid"[2], and any reasonable frequency band allocated to broadcasting, from the AM band up to S-band.

The radio broadcasting industry in the USA is interested in digital audio for local terrestrial broadcasting to enhance audio quality and coverage under the existing licensing arrangements and overall structure of the use of roughly 11,000 radio stations. These broadcasters are nearly unanimous in their aversion to the introduction of satellite delivery of DAB, with its wide area coverage possibilities.

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1 Any errors in up-to-date system descriptions are solely the responsibility of the author.

2 "Hybrid" refers to a satellite system design where in urban situations it may be necessary to "boost" the received satellite signal at one or more low power terrestrial transceiver sites for reception by the consumer receivers; also called "gap fillers".

II. THERE IS SUBSTANTIAL DBS-RADIO AND DAB ACTIVITY NOW ON A WORLDWIDE BASIS

During the 1980's, there was not much interest in the introduction of DAB services, either via terrestrial or satellite delivery. Two groups, one in the USA and one in Europe, largely within the confines of CCIR activities, studied the possibility of developing feasible broadcasting services. The activity was mostly centered on satellite delivery. Through these pioneering studies and a few WARCs, by 1988 it appeared that at least the developing nations had some interest in encouraging the introduction of BSS(Sound)[aka DBS-Radio]. The literature on the topic at that time concentrated on the value of providing "compact disk" quality audio into cars and other moving vehicles.

A European consortium, spearheaded by the CCETT laboratory in France and the IRT laboratory in Germany, with support from consumer manufacturers, the European Broadcasting Union and many European governments, moved from paper studies to the development of hardware. By the autumn of 1988, in time for WARC-88 in Geneva, this consortium, named Eureka 147, was able to demonstrate "CD" quality audio into a van driving around Geneva. The transmitter was located on a nearby mountain top. Demonstrations, experiments, and pilot broadcasting operations have continued with this system by French, German, British, and Canadian organizations.

During the period from 1988 until WARC-92 convened in February 1992, a few organizations noted the need, on a worldwide basis, for audio quality channels with less than "CD" reception quality as the goal. The Voice of America, with support from NASA, was among this small group. Partly as a result of this view, and with speeches made around the world at symposia, regional meetings preparing for WARC-92, etc., developing nations also became interested in DBS-Radio. It is not difficult to see how a large developing nation could use satellite delivery to its advantage. Therefore, when WARC-92 convened, just about every nation in attendance was in favor of allocating some spectrum for BSS(Sound) somewhere between 500 and 3000 MHz.

The development of an acceptable revision of the Table of Allocations to accommodate this new service was extremely difficult. The Conference nearly was torn apart on this issue. As is well-known, this part of the spectrum is heavily used, and is also coveted by other new services. The final compromise was to allocate three frequency bands. Each nation accepted one or more of these bands, sometimes with conditions limiting the use until 2007.

There are some spectrum management nuances related to the introduction of the service on a co-primary basis and the need to coordinate with neighboring nations, but the essence of the result is the following:

- 40 MHz in L-band (1452-1492 MHz)
- 50 MHz in S-band (2310-2360 MHz)
- 120MHz in S-band (2535-2655 MHz).

Roughly 1/2 the world's population lives in nations that chose the L-band allocation and the other half preferred one of the S-band allocations. The USA added a footnote that flat out prohibits the use of the L-band allocation; former Soviet Union Republics added a very restrictive footnote on the use of L-band, but not as strong as the USA one; most European nations, while choosing L-band, restrict its use to secondary status until 2007. For broadcasting, this is tantamount to prohibiting its use. Other than the USA and the USSR, the other nations that have a footnote allocation for one or both of the S-band allocations did not add any restrictive use of L-band. Thus, the Table of Allocations appears as an L-band allocation worldwide, with very important footnotes dealing with S-band preference, and with restrictions on the use of L-band. [A map depicting these allocations appears in J. Hollansworth's paper in this proceedings.]

A Planning Conference is supposed to be convened in 1998 or earlier. In the meantime, the upper 25 MHz of each of the 3 bands noted above can be used for operational broadcasting systems. Existing co-primary services are to be protected via standard ITU coordination procedures.

Spurred on by the activity leading to WARC-92, which was primarily about satellite delivery, and hence the use of frequencies above 500 MHz, interest developed about 2 years ago to use modern digital techniques for purely terrestrial radio broadcasting in the existing radio broadcasting bands (FM & AM).

The European Eureka 147 system is being tested for such a service, primarily for initial use at VHF just above 200 MHz. The European plan would be eventually to vacate the existing FM broadcasting in the 88.5-108 MHz band, but in the interim to use the higher VHF frequencies. This may take a long time. The Eureka 147 system requires a full 1.5 MHz spectral block within which 6 "CD" quality programs are broadcast via hundreds of subcarriers. Each program has its subcarriers spread across the entire 1.5 MHz. The subcarriers of the 6

programs are interleaved in frequency. With this concept it is not feasible to retain the current structure of local broadcasting, e.g. individual transmitter towers and different coverage patterns.

The situation in the USA is quite different. Four organizations are now engaged in source coding/ transmitter/receiver development with the goal of moving digital services directly into the FM band, without disturbing the existing FM broadcasts. All of these are to be tested during the next 12 months through a testing program being designed and administered by the Electronic Industries Association (EIA).

The EIA will also be testing the satellite delivery receiver development sponsored by the Voice of America and being developed at the Jet Propulsion Laboratory. The field testing will be done at S-band using a TDRS satellite. Finally, the EIA will be testing the Eureka 147 system at L-band.

In summary, the interest in DAB has burgeoned since WARC-92. This is manifest in part by the amount of development work underway.

III. SUMMARY OF KNOWN ACTIVITIES AS OF FEBRUARY 1993

Largely through the use of two tables, the developmental activities known to the author are summarized in this section. One table deals with delivery systems; the other with receiver systems.

Delivery Systems

Table I, entitled DBS-Radio Systems, summarizes the different systems either under development or where some interest has been expressed or that were under development and were abandoned recently. With one dormant exception, all had a satellite component.

With respect to the satellite downlink, EIRP's range from approximately 45 dBW to over 50 dBW. Beam sizes vary from tens of thousands of square miles to millions of square miles at the 1/2 power points. Digital Satellite Broadcasting Corp. plans to use the extremely narrow beams to cover the highly populated areas of the USA; Afrispace plans to cover the 12 million square miles of Africa plus most of the middle-east with only 3 beams.

Note in Table I that the first 6 entries are all for coverage of the USA by satellite. Therefore, these will be using the planned USA band (2310-2360 MHz).

Neither Japanese nor Australian activities appear in the table. Both nations have expressed considerable interest in BSS(Sound). Australia was a leading proponent at WARC-92. The author expects in the not too distant future these two nations will introduce more details. Japan plans to introduce satellite DAB in the upper S-band, but there doesn't seem to be any urgency. Australia could well follow Canada's approach, and use L-band for both satellite and terrestrial delivery some time in the future.

Digital Receivers

Table II, entitled Digital Receivers, summarizes digital receiver development, including 3 that have been abandoned recently.

These range from systems still under early stages of development, such as the JPL one, to one that has been under test and evaluation for the past 5 years—Eureka 147. The Eureka consortium includes 3 major European consumer electronic manufacturers—Thomson, Philips, and Grundig. They are working on consumer packaging, and plan to be in production in 1995.

As noted earlier, the Eureka 147 system requires a 1.5 MHz frequency block to operate. This need is based on a fundamental decision regarding propagation effects for mobile receivers that was made many years ago. The designers believe that this level of frequency diversity is needed to combat frequency fading and related multipath effects. There is some evidence from recent Canadian measurements that this is the case. More precisely, it can be said that a channel coding and modulation mechanism such as that used by Eureka 147 has its mobile performance degraded if the block bandwidth is less than 1.5 MHz.

All the USA developers, including the JPL, are designing with the thought that this spread of what is effectively a 200 kHz or less program channel is not needed. It is anticipated that techniques such as adaptive equalization will permit the use of typical broadcast channels. In the JPL case, these could be as small as 50 kHz to accommodate the digital equivalent of monophonic FM. "CD" quality would require 4 times this channel bandwidth.

Entry #4 in the Table, Project Acorn, is unique in the sense that the FM and digital signals are simulcast

from the same transmitter antenna. The digital signal's power is roughly 30 dB less than the FM signal. It "rides" the instantaneous FM signal, shifted somewhat in frequency, with a multiplicity of subcarriers similar to that of Eureka 147, but not spread over such a large band. This is an example of what is called an "in-band/on-channel" system. Fixed installation tests with direct line-of-sight have been conducted. These show that the digital signal can be extracted from the much higher power FM signal at the receiver, and that the digital signal does not appear to distort FM reception. Mobile tests are expected soon.

The other USA "in-band" systems would use spectrum in the FM band that are unused in a local area.

Lastly, Project Acorn has been working on a digital variant of its technique to be used in the AM band. Some successful tests have been run, again with fixed installations and direct line-of-sight.

IV. CONCLUSIONS

1. Explosiveness

Tables I and II, which may be a little out-of-date and possibly incomplete, serve to show the large amount of recent activity on DAB, using both satellite and terrestrial delivery mechanisms. This is either a slow revolution or a fast evolution!

2. Remaining Barriers

Before 1992, any use of satellites for digital radio was blocked—no frequency allocations. Since this barrier was effectively removed, the current chief barrier is financing. This is clearly true for the satellite delivery systems. All serious proponents are faced with a high capital investment requirement.

Although financing as a barrier is less important for the development of purely terrestrial systems, it should be borne in mind that the radio broadcasting industry is not wealthy at the individual station level. There is substantial inertia to change.

Regulatory procedures are time-consuming. Nevertheless, the author feels that sooner or later there will be one or more licenses in the USA for satellite delivery. And there will be satellite delivery available in other parts of the world, obviously not globally all at once.

3. Standardization

The Electronic Industries Association's testing program is an important spur to getting things done in the USA. In about one year we should know what works well, etc. among the systems that will be tested, primarily for local broadcasting use.

The Europeans and Canadians are asking for standardization to be made as soon as possible. They propose the Eureka 147 system to be the standard. Based on recent CCIR meetings on digital audio, in particular positions of the delegates from the USA and Japan, it is unlikely that any serious efforts on standardization will begin until the EIA test results are known.

TABLE I – DBS-RADIO SYSTEMS

SYSTEM AND ORGANIZATION	DELIVERY			PLANNED USE FREQ. BAND				COVERAGE		COMMENTS
	SAT.	TERR.	BOTH	AM	FM	L	S	U.S.	ELSEWHERE	
1. Satellite CD Radio	x						x	x		2 sats, same 30 channels to all of U.S. on diff. freqs. U.S.; CD only; subscription service, primarily for mobile reception; FCC Public Notice under way.
2. American Mobile Sat. Corp.	x						x	x		2 sats, includes spot beams for Alaska, Hawaii, Puerto Rico; FCC filing in Dec.'92; both CD and "FM" qual. dig.
3. Digital Sat. Bdcstg. Corp.	x						x	x		2 sats; broad coverage of U.S. plus 31 very small beams for major U.S. markets; 20m. sat. antenna; subscrip. and open bdcstg; Dec.92 FCC filing.
4. Primosphere (Q Prime)	x						x	x		2 sats; 23 near CD & 6 talk channels; open bdcstg; FCC filing in Dec.'92.
5. Loral Aerospace Holdings	x						x	x		1 sat for lower 48 states; CD qual.; Dec'92 FCC filing.
6. Echosphere (Sky___?)	x						x	x		[no info.]
7. Inmarsat										[Nothing specific; only know it is interested.]
8. Odyssey (TRW)										[Nothing specific; only know it is interested.]
9. Afrispace;Worldspace	x					x			x	Has FCC license to experiment on a non-interference basis into Africa; has a Trinidad/Tobago applic. for Caribbean system; currently, low power, lightsat method for line of sight coverage with very large beams, e.g. 1/3 of Africa per beam
10. Radiosat International	x					x	x	x	x	Global system with 3 or 4 sats; very narrow beams; primary customers are international broadcasters; no filings with anyone.
11. Radiosat (G. Noreen)	x					x		x		Defunct; was going to use 1 to 2 MHz of mobile sat. spectrum to broadcast into vehicles in the U.S.
12. Strother Communic.		x				x		x		Dormant; wanted to test DAB terrestrially; got FCC experimental licenses for a few cities.
13. Eureka 147 (EBU)			x		x	x		x	x	Originally, both sat and terr for Europe, then Canada, then the world; deemphasis of sat in Europe, but Australia, Canada interested in sat as well as terr; well along with successful experiments.
14. Canadian Bdcstg Corp			x			x			x	Complete revision of radio broadcasting over to L-band; use of Eureka 147; very successful terr. experiments; system requires "blocks" of 6 CD channels using same transmitter, hence not acceptable to local U.S. broadcasters; nevertheless to be tested by the EIA in upcoming U.S. tests; satellite interest 8 to 10 years from now; terrestrial operations as soon as possible.
15. Brazil & Mexico			x			x			x	Mexico following Canada's lead; Brazil more interested in going straight to satellite delivery for all of South America.
16. Indostar (Indonesia)	x					x			x	Combined satellite, with S-band for community TV; has sent Advance Notice to the IFRB; a small number of "mono FM" channels to broadcast into the Indonesian islands.

TABLE II – DIGITAL RECEIVERS

SYSTEM AND ORGANIZATION	AUDIO QUALITY LEVELS				FREQ. BAND				SOURCE CODING	COMMENTS
	CD	"FM STEREO"	"FM MONO"	"AM"	AM	FM	L	S		
1. Eureka 147 (EBU)	x	x	x	x		x	x		Musicam	At prototype production model stage; orig. just "CD quality", but now can handle various audio quality levels; versatile for terr. coverage shaping through the use of "active echoes" (coverage extenders and gap fillers); cannot be used for indiv. 200 kHz channels, a major drawback for U.S. local broadcasters; EBU pushing hard to make this a worldwide standard now.
2. Sat CD Radio/Stanford Telecom	x						x	x	(Open)	Archival, no more work going on; was to be a Eureka 147 competitor, using frequency hopping for frequency diversity rather than subcarriers spaced over 2 MHz or so.
3. JPL (VOA/NASA)	x	x	x	x		x	x	x	(Open) AT&T	Breadboard devt. under VOA sponsorship; for sat. deliv., although could be used in FM band since channels are no more than 200 kHz wide; uses a modular concept, with fixed and port. having the simplest design, and mobile complexities added for car use; to be tested at S-band during the EIA testing period this year.
4. Proj. Acorn (USA Digital) Gannett, Westinghouse, CBS	x				x	x			Musicam	The "In-band/on-channel" system favored by the NAB; tests so far successful on line of sight over the air simul. brdcsting of FM and dig.; use low powered dig. signal superimposed on the analog signal.
5. Lincom	x					x			?	Defunct; was to be an "in-band/adjacent channel" system.
6. American Digital Radio	x					x			?	Defunct; was to be an "in-band/adjacent channel" system.
7. German/French & U.S.cable feeds	x									Just to note that cable feed systems in the U.S. and Europe exist using C-band and Ku-band feeds.
8. General Instrument	x					x			Dolby?	Entering EIA testing with a claim to modify its cable delivery system for broadcasting locally; no details yet.
9. AT&T	x					x			PAC (AT&T)	Entering the EIA testing with its high quality 128 kbps stereo source coder and a channel coding system, which is not well defined, for use with 200 kHz broadcast channels.
10. AT&T and Amati	x					x			PAC (AT&T)	Entering the EIA testing with the same source coder as in #9, but with a different channel coder, even less well defined.