



Provided by the author(s) and University of Galway in accordance with publisher policies. Please cite the published version when available.

Title	Champions in our midst: the father of digital video broadcasting
Author(s)	Corcoran, Peter
Publication Date	2015
Publication Information	Corcoran, Peter and Dukes, Stephen and Reimers, Ulrich H (2015) Champions in our midst: the father of digital video broadcasting'. Consumer Electronics Magazine, IEEE, 4 (2):71-78.
Publisher	IEEE
Link to publisher's version	http://dx.doi.org/10.1109/MCE.2015.2394991
Item record	http://hdl.handle.net/10379/5355
DOI	http://dx.doi.org/10.1109/MCE.2015.2394991

Downloaded 2024-04-17T03:40:10Z

Some rights reserved. For more information, please see the item record link above.



Champions in Our Midst

The father of digital video broadcasting.

By Peter Corcoran and Stephen Dukes

ONE OF THE BENEFITS OF JOINING THE IEEE Consumer Electronics (CE) Society is that you get access to senior engineers and researchers from our industry. They are often at our conferences, workshops, and local Chapter meetings and frequently play an active role in the organization of Society activities. Many of our members are also well-known professionally within their own fields and have championed some of the many foundation technologies on which our industry relies. There are quite a few of these “champions” in our Society, and this series of articles is intended to introduce you to them so that, should you bump into them at one of our conferences or workshops, you’ll know who they are and why they are involved in the CE Society.

In this issue, we feature a gentleman who is considered a pioneer of digital TV technology and who is frequently referred to as the “father of digital video broadcasting,” Prof. Ulrich H. Reimers of the Technische Universitaet of Braunschweig, Germany. The Digital Video Broadcasting (DVB) Project is an industry-led consortium of nearly 300 broadcasters, manufacturers, network operators, software developers, regulatory bodies, and others in more than 40 countries committed to designing global standards for the delivery of digital TV and data services.

Reimers studied communication engineering at the Technische Universitaet Braunschweig and pursued a research career at the university’s Institut fuer Nachrichtentechnik (IfN—Institute for Communications Technology). In 1982, he started working on HDTV in the studio equipment industry. Between 1989 and 1993, he was the technical director of Norddeutscher Rundfunk in Hamburg, one of the major public broadcasters in Germany. In 1993, he was appointed professor at the Technische Universitaet Braunschweig and managing director of the IfN. He is one of the founders of DVB and was the chair of the technical module (TM) within the DVB Project from 1993 to 2012 and a board member of Deutsche TV-Plattform (the German institution



Ulrich H. Reimers.

coordinating the interests of all organizations involved in the TV industry) from 1992 to 2012.

He is the author of more than 120 publications and various textbooks on DVB. Prof. Reimers has received numerous international and national awards, among them the International Broadcasting Convention (IBC) John Tucker Award in 1998 and Hall of Fame membership of the International Electrotechnical Commission. He is also an editor and contributing author of the leading reference text

Digital Video Broadcasting [1]. If you want a technical book to explain digital broadcasting, this is certainly the one to buy.

But enough from me; time to let our champion introduce us to DVB technology and provide a reflection on its history and development over the last 20 years, coupled with a look at what is yet to come. And who better to write this than our latest Champion of CE, Ulrich H. Reimers.



Digital Video Broadcast

By Ulrich H. Reimers

Digital Video Broadcast (DVB) is the name of a family of standards developed by a consortium of companies, research centers, and institutions from around the world. The original name of the consortium was the DVB Project. It was conceived in 1991 and officially founded in 1993. DVB standards are available in up to three generations. An example would be the family of standards for transmission over satellite: DVB-S (which was finalized in 1993), DVB-S2 (approved in June 2003), and DVB-S2X (an extension of DVB-S2, aiming mainly at professional applications, which was approved in February 2014). DVB-C and DVB-C2 are available for distribution over cable networks, and DVB-T and DVB-T2 are available for terrestrial transmission. Approximately 1 billion DVB receivers are in operation worldwide. Figure 1 shows the status of the introduction of just the terrestrial digital TV systems in the various parts of the world and demonstrates the wide adoption of DVB-T and DVB-T2.

A plethora of standards and implementation guidelines exist to create a complete DVB ecosystem, including DVB's solutions for the Internet delivery of media content (DVB-IP), the standards for service information and data broadcasting, the various documents in the field of security, and the implementation guidelines for audio and video coding, to mention a few. So as not to expand this article unduly, only solutions for the delivery of content over the traditional broadcast media (cable, satellite, and terrestrial networks) will be referred to in this article.

One may think that DVB's successes are driven by a mastermind: a brilliant scientist, engineer, or market maven who knew it all in advance. However, that is not how it happened. DVB is about people, their devotion to a common

goal, and their willingness to cooperate in friendship (at least most of the time).

By the way, not everything DVB developed became a great success. For instance, the development of transmission systems addressing handhelds, smartphones, and tablets, such as DVB-H or DVB-SH, ended up as a complete market failure.

LOOKING BACK TO WHEN IT ALL STARTED

To understand why DVB was conceived, we need to look back to the second half of the 1980s. In Japan, the multiple subsampling encoding system, and in Europe, the HD-MAC system developed within the Eureka 95 project, were technically ready for the transmission of HDTV via satellite and through cable networks. Both systems used digital signal processing, but, for the actual transmission, analog signals were specified. In Europe, no solution for terrestrial broadcasting of analog HDTV signals was considered by the industry, which made terrestrial broadcasters very nervous. As a result, the PALplus consortium got together to design a solution for terrestrial networks, which would not provide real HDTV pictures but an enhanced phase alternating line (PAL) quality—and the aspect ratio 16:9 [2]. Standard PAL receivers would be able to receive PALplus signals in a 4:3 aspect ratio undistorted. PALplus, therefore, was planned to become the terrestrial

Narrowband interference can be mitigated by excluding the affected OFDM carriers.

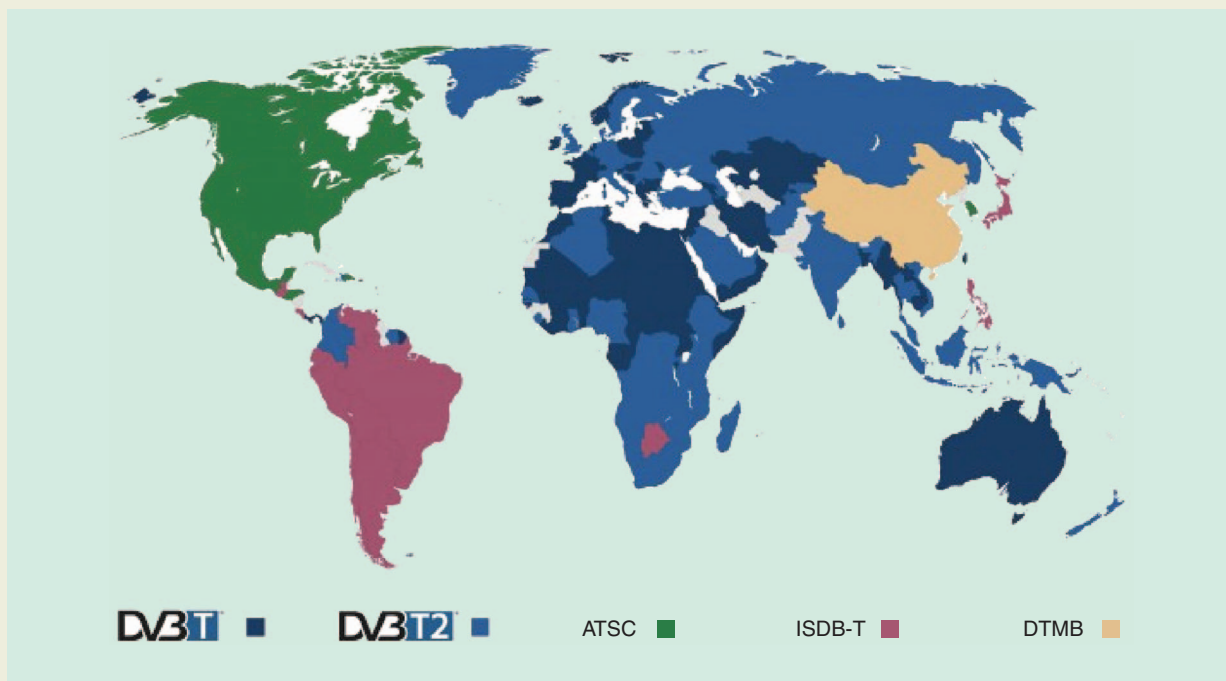


FIGURE 1. The status of the introduction of digital terrestrial TV in various parts of the world. (Image courtesy of www.dvb.org.)

companion of HD-MAC in an attempt trying to keep terrestrial broadcast from obsolescence.

Over time, certain members of the steering board of the PALplus consortium started to feel that, for various reasons, there would be no HD-MAC mass market. One reason they saw was the problem with the then-expensive, heavy, and clumsy tube displays that would be required for watching HDTV in the living room. Flat-panel displays were still a dream, and the only alternative would have been the use of video projectors with HDTV resolution, which were unaffordable at the time. Questioning the success of HD-MAC openly was unthinkable since the European Union had spent a lot of money supporting Eureka 95 and companies like Philips and Thomson saw HD-MAC as the future of TV. In consequence, a secret weekend meeting was held in May 1991 at the Schoenburg Castle overlooking the Rhine River. The members of the PALplus Steering Board (including myself, who represented the German public broadcast system Arbeitsgemeinschaft der oeffentlich-rechtlichen Rundfunkanstalten der Bundesrepublik Deutschland) attended the meeting. The single goal of that meeting was to find an answer to the question: if HD-MAC doesn't fly, what can we do for the European TV industry? After a long discussion, the small group concluded that we would try to initiate a project that would make TV distribution digital. It was a brave conclusion since none of the participants had any experience with digital TV beyond the use of digital signal processing of baseband video in production studios. What helped in the discussions was an interesting development going on elsewhere.

In the United States, in 1987, a national initiative of the U.S. Federal Communications Commission aimed at developing a standard for the terrestrial transmission of HDTV. At the initial stage, the call for proposals produced a veritable gold rush climate, which led to 21 possible systems being submitted, some of which only tried to attain the compatible improvement of NTSC. By 1990, the list of remaining system concepts that could be taken seriously had been reduced to nine. On 1 July 1990, General Instruments was the first company to recommend a fully digital system. This fact was known to the team at Schoenburg Castle, and it made us believe that "digital is doable!"

Resulting from the first discussion in 1991, the European Launching Group was born in the spring of 1992. This was a group with participants from all sections of the trade who first met unofficially and did not evolve into the International DVB Project until September 1993 [3]. Some of the fundamental rules of DVB were radically different from those defined in the typical national and technology-oriented consortia of the past: We decided that developments in the complex field of electronic media can only be successful when all of the important organizations working in this field participate in such a development and when the commercial interests are allowed to carry the same weight as technical considerations in the definition of the technological objectives. As a result, four constituencies were defined to get all interested players from around the world involved, including broadcasters, network operators, manufacturers,

A plethora of standards and implementation guidelines exists to create a complete DVB ecosystem.

and regulators. The commercial working group, Commercial Module, was installed and is responsible for the definition of commercial requirements (CRs) for the new systems from the viewpoint of the users. Their requirements form the basis of work within the TM. After completion of the development, the Commercial Module to this day verifies the specifications for the new systems and passes them on to the steering board for final decision.

As an industry consortium, DVB can generate specifications but is unable to turn them into standards. By means of a cooperation contract with the standards institutes the European Telecommunications Standards Institute (ETSI) and the European Committee for Electrotechnical Standardization, an integration of specifications from the DVB Project into the regular standardization procedures of both institutes is ensured.

WHY DIGITAL TV?


Before the development of the first-generation DVB transmission standards started, many organizations doubted its commercial success. Why should a system for entertainment TV be commercially successful in a saturated market competing with a multitude of existing TV standards, some of which, such as PAL, were in use for many years and, therefore, address a great number of compatible receivers?

To address these doubts, the DVB Project compiled a catalog of possible goals, which, in those early days, could still be described as classical or typical of traditional broadcasting.

- 1) Digital TV might enable the transmission of very high-quality HDTV images, possibly even via future terrestrial broadcasting networks.
- 2) DVB systems might enable the broadcasting of programs of contemporary technical quality (standard-definition TV) using narrowband channels for transmission, or it might enable an increase of the number of programs offered within the existing transmission channels.
- 3) DVB systems might be the method of broadcasting to low-cost pocket TV receivers, equipped with built-in receiving antennas or short rod antennas, which would guarantee stable reception for a number of TV programs.
- 4) TV receivers in vehicles (e.g., trains, buses, or cars) might be served by DVB systems with broadcasts of a superb quality, i.e., DVB systems might enable stable reception in moving vehicles even over difficult radio channels and at high speeds.
- 5) Moreover, as a data transmission technique, DVB might retain the typical characteristics of digital technology, such as the stability of the reception within a very clearly defined coverage area, the possibility of simple distribution over telecommunication lines as one service

among many, and the possible integration into the world of personal computers.

As work progressed, the objectives changed considerably. For a certain period of time, HDTV lost its role as a primary objective, and, only when systems such as DVB-S2, DVB-C2, and DVB-T2 were developed, HDTV again became the key service target. The servicing of portable receivers remained an objective during the development of DVB-T, the standard for terrestrial transmission, but, for several countries, it turned out to be not as important as originally envisaged. From



DVB systems might enable the broadcasting of programs of contemporary technical quality using narrowband channels for transmission.

the extensive list of optional parameters for the terrestrial standard, it is possible to choose operational modes suitable for portable reception. Finally, mobile reception was not included in the original user requirements of the DVB system. To the surprise of many, DVB-T is capable of providing stable mobile reception up to very high speeds, and DVB-T2 is even better in this respect.

Over the course of time, the data container became a key DVB concept, the role of which cannot be overestimated [3]. This concept illustrates the idea that underlies the design of all DVB transmission standards. A data container is defined by the fact that a maximum amount of data per unit of time can be transmitted in it quasi error free. It does not matter what kinds of data are transmitted as long as they are packetized and supplemented with additional data, such as synchronization information, in accordance with the rules of the various DVB standards. The content of the data container or parts of the content can be securely scrambled. The data container, therefore, represented a radical deviation from the traditional broadcast paradigm “one channel, one TV program.” The catalog of possible goals was, thus, extended by new elements.

- 1) DVB enables a multiplication of the number of TV programs that can be broadcast on one transmission channel or in one data container.
- 2) DVB supports the broadcasting of other kinds of media such as radio programs and data for entertainment and business purposes.
- 3) DVB enables a flexible choice of image and audio quality, including the choice of HDTV, as long as the resulting data rate does not exceed the capacity of the data container.
- 4) For use in connection with pay services, there are very secure coding methods, which ensure that unauthorized access to such services is extremely difficult, if not impossible.

DVB STARTS TO DELIVER

The first important result of the DVB Project emerged in the second half of 1992 under my leadership, as I had been asked to take over the responsibility for all technical work from day one. This result was the report to the European Launching Group on the “Prospects for Digital Terrestrial Television” [4], which was presented in November 1992. This report showed how, and with what aims, a DVB system for Europe could be developed. The report was relatively heavily weighted in favor of terrestrial transmission and toward HDTV as the probable quality objective. In this respect, it was a product of its time and took into account the fact that, at the end of 1992, the official European development policy was still centered on the satellite transmission of HD-MAC.

The first complete system specification was the recommendation for satellite transmission (DVB-S) adopted by the TM of the DVB Project in November 1993. In December, the steering board approved this recommendation, and, in November 1994, by a unanimous decision of all of the member states of ETSI, this became the European Norm EN 300 421. When working on the DVB-S specification, the members of the TM had to master a steep learning curve. Only a very limited number of participants had experience with the transmission of signals over satellite links, and there were intensive discussions about the kind of forward error correction (FEC) that should be used. The CE manufacturers had an important role to play since they had to investigate the commercial viability of the algorithms that were suggested. DVB-S uses a concatenation of a Reed–Solomon and a convolutional code. How long we debated about the constraint length of that convolutional code.

A group of cable network (CATV in those days) operators saw the advent of DVB-S as a challenge to their position in the broadcast content delivery market and wanted to quickly finalize a comparable system for distribution over cable. In January 1994, the specification for DVB distribution via cable (DVB-C—EN 300 429) followed.

The development of what became DVB-T (EN 300 744) turned out to be significantly more difficult than the design of DVB-S and DVB-C. The Commercial Module even split up into two groups: one that just looked at the CRs for terrestrial broadcasting and a main group responsible for all other DVB work items. In consequence, DVB-T was only approved in December 1995. The first country planning to introduce terrestrial digital TV based on the DVB standard DVB-T was the United Kingdom. Several organizations in the United Kingdom were eager to start DVB-T as early as possible since the pay TV operator BSkyB was planning to introduce digital TV via satellite using DVB-S. With a view to the fact that, in the United Kingdom, terrestrial free-to-air broadcasting played and continues to play an important role, these organizations did not want to see terrestrial DVB lagging behind. And really, BSkyB commenced digital satellite broadcasting based on DVB-S on 1 October 1998. Digital terrestrial was launched on 15 November 1998. At the start, six multiplexes were operated by four so-called multiplex operators.

The plans in the United Kingdom led to difficult discussions in the TM. It was clear from the start that orthogonal frequency-division multiplexing (OFDM) would be chosen as

the fundamental modulation scheme based on the experience gained with digital audio broadcasting (DAB) over a number of years. Whereas most countries were looking for the use of DVB-T in large single-frequency networks (SFNs) and were, therefore, advocating OFDM with 8 K (8,192) individual carriers and long guard intervals, the U.K. representatives were afraid that such a choice might delay the introduction of DVB-T in consumer receivers because of the complexity of an 8 K OFDM processor. Their plan was to retain the traditional structure of multifrequency networks and to even continue using the existing rooftop aerials. ("If an installer is asked to climb onto the roof and reposition the existing worn antenna, it will probably break—and then he might install a satellite dish rather than a new terrestrial antenna, and we will lose a terrestrial household to BSkyB." Finally, a compromise was achieved in one of the famous "TM coffee breaks," and both 2 K (2,148) OFDM as well as 8 K OFDM became options in the DVB-T specification.

Using 8 K OFDM was thought to be critical in case the receiver starts moving since the intercarrier distance of the individual OFDM carriers in an 8-MHz channel is only 1,116 Hz, and the Doppler shift occurring when the receiver moves was considered critical. It was quite a breakthrough when the research of myself and my team at the Technische Universitaet Braunschweig proved that this expectation was wrong. Figure 2 shows the C/N required as a function of the Doppler frequency for three different implementations of a DVB-T receiver [5]. When DVB-T is transmitted at UHF 474 MHz (channel 21 in Europe), then the Doppler frequency 100 Hz corresponds to a speed of 227 km/h with which the receiver approaches the transmitter. The DVB-T mode used is 8 K OFDM, 16 QAM, the relative length of the guard interval is 1/8, and the code rate of the inner code is 2/3. Receiver 1 uses a single antenna and is optimized for stationary reception. Receivers 2 and 3 use antenna diversity with maximum ratio combining and correspond to different receiver generations.

DVB-S, DVB-C, and DVB-T show a significant amount of similarity in the algorithms used and, therefore, may be called the DVB first-generation family of specifications for broadcast transmission. The term *data broadcasting* is understood differently in different parts of the world. In DVB, data broadcasting means the delivery of data other than audio and video packets to the user terminal. It is a facet of applying the concept of the data container explained earlier. The first specification that DVB developed to be able to deliver all sorts of data via a broadcast channel introduced the features data piping, data streaming, data carousel, object carousel, and multiprotocol encapsulation. In reality, the latter is used for sending IP packets, although other protocols are supported. The application of DVB-C as the DOCSIS downstream in countries outside the United States relies on the use of multiprotocol encapsulation or its successor DVB-GSE

DVB enables a multiplication of the number of TV programs that can be broadcast on one transmission channel or in one data container.

(Generic Stream Encapsulation). DVB developed DVB-GSE when the importance of transporting IP packets had grown so much that implementers required the highest possible efficiency on the transport layer. GSE thus eliminates the embedding of IP packets first into the multiprotocol encapsulation structure, which then is embedded in the MPEG-transport stream. DVB-GSE is conceptually on the same level as the transport stream.

THE DVB-x2 SOLUTIONS

Over a number of years, DVB was busy working on specifications that were supposed to complete the original ecosystem [6]. Interactive TV was an issue, and many specifications of interaction channels over cable, satellite, and even terrestrial channels were developed. The multimedia home platform was designed—a software environment for consumer devices including the Blu-ray Disc. DVB was convinced that a transmission system was required that would allow broadcast content delivery to the just emerging smartphones. DVB-H (H: handheld), therefore, was created with Nokia in the driver seat, accompanied by a higher-layer system called IP datacast [7]. Somehow, the DVB members thought that the classical transmission channels would continue using DVB-S, DVB-C, or DVB-T until, in 2001, some U.S. satellite operators approached the DVB Project and said, "We would like to introduce HDTV over satellite and are looking for the highest possible data rate. Could DVB please propose a solution?" This was the beginning of the development of a new family of specifications, starting with DVB-S2 and leading to DVB-C2 and DVB-T2.

Both engineers and scientists working on DVB systems had gained significant additional knowledge since the first generation had been finalized. This knowledge resulted from practical experience using the existing systems and from scientific research.

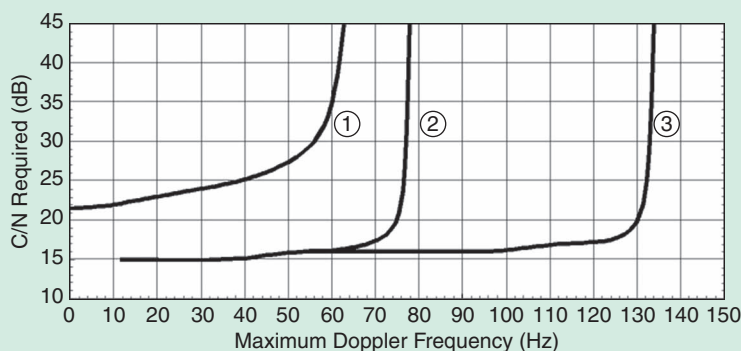


FIGURE 2. The mobile reception of DVB-T by three different receivers.

GI FFT	1/128	1/32	1/16	19/256	1/8	19/128	1/4
32 K	28 μ s 8.4 km	112 μ s 33.6 km	224 μ s 67.2 km	266 μ s 79.8 km	448 μ s 134.4 km	532 μ s 159.6 km	
16 K	14 μ s 4.2 km	56 μ s 16.8 km	112 μ s 33.6 km	133 μ s 39.9 km	224 μ s 67.2 km	266 μ s 79.8 km	448 μ s 134.3 km
8 K	7 μ s 2.1 km	28 μ s 8.4 km	56 μ s 16.8 km	66, 5 μ s 19.95 km	112 μ s 33.6 km	133 μ s 39.9 km	224 μ s 67.2 km
4 K		14 μ s 4.2 km	28 μ s 8.4 km		56 μ s 16.8 km		112 μ s 33.6 km
2 K		7 μ s 2.1 km	14 μ s 4.2 km		28 μ s 8.4 km		56 μ s 16.8 km
1 K			7 μ s 2.1 km		14 μ s 4.2 km		28 μ s 8.4 km

FIGURE 3. The OFDM modes and guard intervals supported by DVB-T2.

The complexity of algorithms implementable in consumer devices had increased significantly. Algorithms for FEC that in the past either did not exist or whose use in the consumer world was thought to be unaffordable started to be acceptable. Features that were ruled out for cost reasons by CE manufacturers in the first generation, such as time interleaving, i.e., requiring storage in the decoder, were now allowed to be discussed. As a result, the second-generation systems led to a significant step forward in performance and complexity. One of the most debated new elements was the choice of FEC. Turbocodes and low-density parity check (LDPC) codes were the competitors, and, only after a series of extensive tests, DVB decided on LDPC codes, which has since become a key element in the second-generation family of standards. DVB-S2 proved to be so excellent

that the International Telecommunication Union (ITU), in August 2006, created a "Draft New Recommendation on a Digital Satellite Broadcasting System with Flexible Configuration (TV Sound and Data)." The summary text of the document says: "with a performance approaching the Shannon limit"—an accolade for DVB engineers—and specifically for Alberto Morello (Radiotelevisione Italiana, Italy), the chair of the TM ad hoc group that designed the system.

Before starting the development of DVB-T2, in January 2006, a study mission chaired by Nicolas Wells (BBC, United Kingdom) was launched that was tasked with investigating a wide range of algorithms (technologies) that might be used in this new system. Based on the results of the study mission, the Commercial Module generated a CR document, which the steering board approved in April 2007. Again it was the United Kingdom that felt under pressure to introduce DVB-T2 as early as possible, and, therefore, the CR recommended the finishing of DVB-T2 in a time frame that would allow the start of the first services in early 2009. With a view to the constraints that already existed when DVB-T was developed, the CR demanded that the existing DVB-T antenna and cable installations remain usable. This requirement ruled out the idea of implementing multiple-input, multiple-output (MIMO) since, for MIMO, new aerials would have been needed. In hindsight, the exclusion of MIMO turned out to be a good idea since the performance of DVB-T2 is so excellent that the efforts on the transmitter and receiver side required for the introduction of MIMO would not have been worthwhile. "Don't touch rooftop aerials that for many years were used for analog TV even if you plan to implement a second-generation digital system." We finalized the specification in June 2008, and, in December 2009, the first DVB-T2 services were launched in the United Kingdom. DVB-T2 uses the same FEC that was chosen for DVB-S2 and OFDM. The highest OFDM mode is 32 K (32,768). Figure 3 presents a list of OFDM modes supported by DVB-T2. The olive-colored combinations are already known from DVB-T.

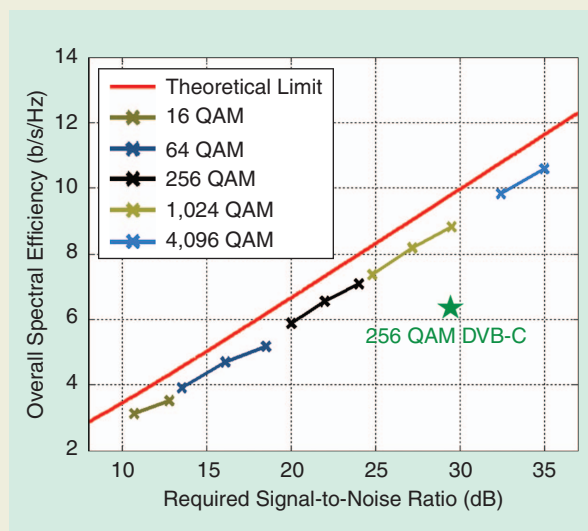


FIGURE 4. A comparison of the robustness and spectral efficiency of DVB-C and DVB-T2.

The gray combinations are not supported. The horizontal rows represent the available OFDM modes. The columns show the various values of the relative length of the guard interval. The figures shown indicate the absolute length of the guard interval in microseconds and the consequences on the size of the SFNs possible with the relevant combination of OFDM mode and guard interval. For instance, the combination 8 K OFDM and guard interval $\frac{1}{4}$ supports terrestrial networks in which contributions from various transmitters arriving at the receiver are allowed to have traveled along a path difference of up to 67.2 km.

DVB-T2 includes a list of features that make the system applicable to various scenarios beyond traditional broadcasting. One of these features is the future extension frame (FEF). This is a time window in the DVB-T2 signal in which various other signals can be embedded. The system Tower Overlay over LTE-A+ (TOOL+), developed by my team and me at the Technische Universitaet Braunschweig, embeds signals in the FEF that are based on the system long-term evolution (LTE) [8]. The system was demonstrated at IBC 2014 and will be field tested in Paris, France, in early 2015.

In November 2006, the TM launched a study mission, chaired by Christoph Schaaf (Kabel Deutschland, Germany), tasked with looking into the next-generation cable system. The study mission reviewed modulation scheme-related technologies, channel coding technologies, and preprocessing technologies. Based on the results of the study mission, the Commercial Module developed CRs, which were approved by the DVB Steering Board in February 2008. Many of the requirements are comparable to those presented for

The servicing of portable receivers remained an objective during the development of DVB-T.

DVB-T2, for example, DVB-C2 shall/should provide at least 30% more data rate in a given channel than possible with DVB-C. It has to be part of a family of DVB-x2 standards. Other requirements are very specific to cable networks since they are able to offer interactive services. Examples include the following.

- ▼ DVB-C2 shall be available for consideration as an alternative downstream coding and modulation scheme for the DOCSIS systems currently using DVB-C.
- ▼ DVB-C2 shall include techniques for improving the efficiency of carriage of IP data.
- ▼ DVB-C2 shall allow cost-effective integration of DVB-C2 into Edge QAM solutions for modulation equipment.
- ▼ DVB-C2 shall provide a low-latency mode meeting the requirements of interactive services.

The DVB-C2 specification was finalized in March 2009. To the surprise of many, DVB-C2 is based on OFDM with guard interval [4 K (4,192) OFDM in 8-MHz channels], like DVB-T and DVB-T2, and, therefore, differs significantly from DVB-C, which uses a single-carrier modulation (QAM). In 7.61-MHz bandwidth, DVB-C2 accommodates 3,408 OFDM carriers—the carrier distance is approximately 2.2 kHz. DVB-C2 uses

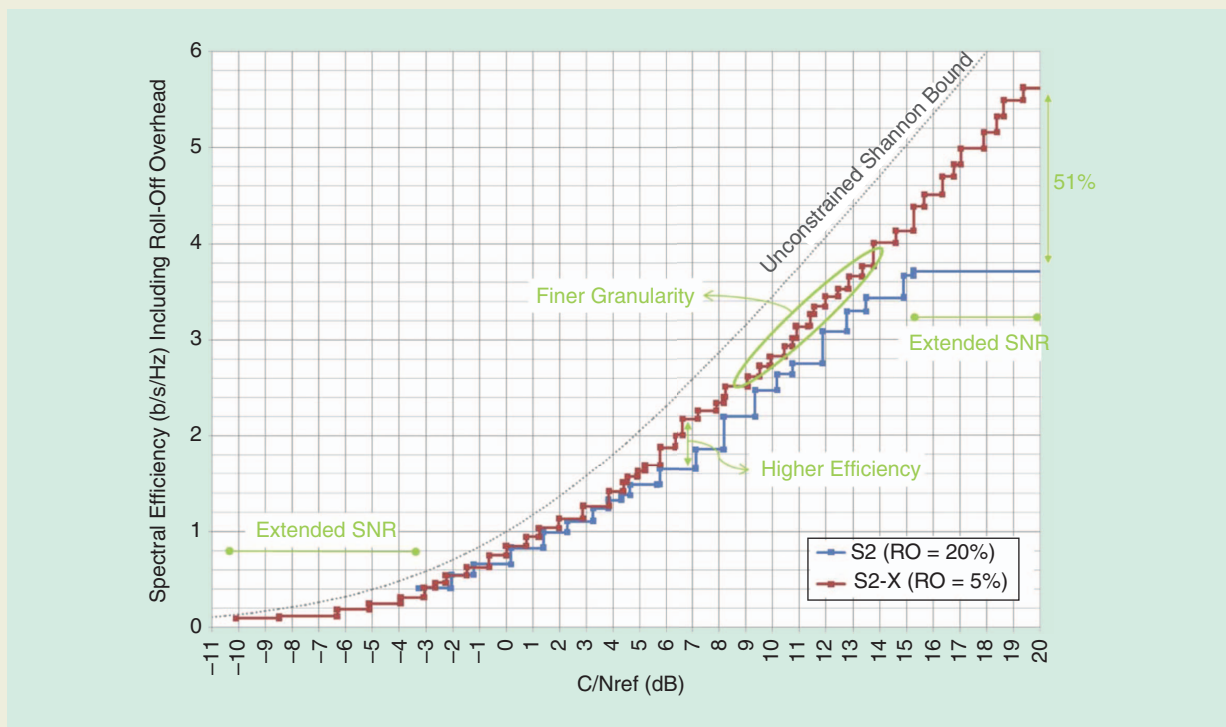


FIGURE 5. A comparison of the performance of DVB-S2 and DVB-S2X. (Image courtesy of www.dvb.org.)

LDPC FEC, like DVB-S2 and DVB-T2 and, therefore, is part of the DVB-x2 family of standards. 4,000 QAM is the highest modulation constellation supported. Channel bonding on the physical layer is possible. Narrowband interference can be mitigated 6.5 bits/s/Hz by excluding the affected OFDM carriers. In comparison to DVB-T2, signaling has been simplified. Figure 4 shows a comparison of the highest modulation supported by DVB-C and the various modes possible in DVB-C2. In this specific example, in the case of DVB-C2, four 8-MHz channels are channel bonded to form a 32-MHz channel. The guard interval chosen has a relative length of 1/128. The theoretical limit shown is the famous Shannon limit. At the highest spectral efficiency reached by DVB-C of about 6.5 b/s/Hz DVB-C2 is about 7 dB more robust than DVB-C.

Digital TV might enable the transmission of very high-quality HDTV images, possibly even via future terrestrial broadcasting networks.

DVB-S2X is the latest specification that DVB developed in the field of satellite broadcast systems. It is applicable to direct-to-home and professional applications. It retains many of the features of DVB-S2 but extends its performance by, for instance, shortening the roll-off to 5 or 10% by allowing more combinations of FEC and modulation and by adding new constellations. Figure 5 compares the performance of DVB-S2 and of DVB-S2X. DVB-S2 was designed for carrier-to-noise ratios from -3 dB to +15 dB. DVB-S2X extends this range significantly (-10 dB to +20 dB). Under optimal channel conditions, DVB-S2X is able to deliver 5.6 bits/s per Hz. DVB continues working actively toward a variety of innovative solutions. Obviously, UHDTV is a hot topic these days. The inclusion of "second screens" in the DVB ecosystem requires appropriate specifications. The long-term future of terrestrial broadcast systems is being discussed.

ACKNOWLEDGMENTS

The success of DVB is the success of literally hundreds of companies and organizations and of hundreds of people working in the commercial, legal, technical, and PR departments of these companies. A meeting of the DVB TM, which since 2012 has been successfully chaired by my successor Nicolas Wells (BBC), is typically attended by 90 engineers. The meetings of the 11 ad-hoc groups of the TM (see <https://www.dvb.org/groups/TM>) bring together some 200 people. Therefore, it is certainly fair to say that DVB is an example of a truly international organization in which an elite group of people work very hard to foster the progress of our industry.

I wish to thank all of my colleagues in DVB, the contributors to the work on the various modules, the members of the DVB Project office, and the former and current DVB

management teams for the excellent work over the years. It is hardly believable that we could achieve so much in so many different areas in such a wonderful spirit of cooperation—in an organization in which all decisions require consensus.

ABOUT THE AUTHOR

Ulrich H. Reimers (reimers@ifn.ing.tu-bs.de) studied communication engineering at the Technische Universität Braunschweig, Germany. Following research at the university's Institut fuer Nachrichtentechnik (IfN—Institute for Communications Technology) he joined Broadcast Television Systems in Darmstadt, Germany. Between 1989 and 1993, he was the technical director of Norddeutscher Rundfunk in Hamburg, one of the major public broadcasters in Germany. Since 1993, he has been a professor at the Technische Universität Braunschweig and the managing director of IfN. He was the chair of the TM within the DVB Project from 1993 to 2012 and a board member of Deutsche TV-Plattform (the German institution coordinating the interests of all organizations involved in TV) from 1992 to 2012. Since 2012, he has been the vice president of strategic development and technology transfer at the Technische Universität Braunschweig. He is the author of more than 120 publications and various text books on DVB. He has received a significant number of international and national awards and is an honorary fellow of DVB. Recently, he and the research teams at IfN invented innovative solutions for the coexistence of broadcast and wireless broadband such as "Dynamic Broadcast," "Tower Overlay over LTE-A+ (TOoL+)," and "Redundancy on Demand."

REFERENCES

- [1] U. Reimers, *Digital Video Broadcasting*, 2nd ed. Berlin: Springer-Verlag, Sept. 2004.
- [2] R. J. G. Ellis, *The PALplus Story*. Macclesfield, United Kingdom: The Architects' Publishing Partnership Ltd., 1997.
- [3] U. Reimers, Ed., *DVB—The Family of International Standards for Digital Video Broadcasting*, 2nd ed. Berlin: Springer-Verlag, 2005.
- [4] The Working Group on Digital Television Broadcasting (WGDTB), "Report to the European Launching Group on the prospects for digital terrestrial television," DVB Document WGDTB 1063, Nov. 1992.
- [5] U. Ladebusch and C. Liss, "Terrestrial DVB (DVB-T): A broadcast technology for stationary portable and mobile use," *Proc. IEEE*, vol. 94, no. 1, pp. 183–193, Jan. 2006.
- [6] U. Reimers, "DVB—The family of international standards for digital video broadcasting," *Proc. IEEE*, vol. 94, no. 1, pp. 171–182, Jan. 2006.
- [7] G. Faria, J. A. Henriksson, E. Stare, and P. Talmola, "DVB-H: Digital broadcast services to handheld devices," *Proc. IEEE*, vol. 94, no. 1, pp. 194–209, Jan. 2006.
- [8] D. Rother, S. Ilsen, and F. Juretzek, "A software defined radio based implementation of the 'Tower Overlay over LTE-A+' system," in *Proc. 2014 IEEE Int. Symp. Broadband Multimedia Systems and Broadcasting (BMSB 2014)*, Beijing, China, p. 6.

