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DAB – Where is it going?*

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1 The formation of the Eureka 147 Project

With digital technology gaining rapidly increasing acceptance in all handling of electrical signals and digital processing power getting less and less expensive due to the quick progress of integrated circuit technology, first considerations of the feasibility of digital sound broadcasting began in the late seventies. Significant challenges were at once seen when the required data rates for unimpaired transmission of high-quality sound programmes – particularly to mobile receivers – were identified. Envisaged as a possible future step-by-step replacement for FM broadcasting services, early experiments with digital signals in the FM band revealed little tolerance of the existing receivers to sharing this band with digital broadcasts, especially at the transmitting power levels formerly thought necessary.

Then the Compact Disc appeared; with its superb audio quality it soon became a very great success in the consumer market. FM radio no longer was comparable in quality. Even worse: the quality of the FM service was degraded by the increasing number of stations being allocated into the limited Band II of the radio spectrum. This situation again stimulated the search for new broadcasting technologies. Feasibility studies were carried out at a few places in Europe, leading to a better understanding of the basic requirements for a suitable approach to digital sound broadcasting. Market reasons called for an audio quality which is indistinguishable from that of a CD. Satellite sound broadcasting systems were being developed, operating with nearly unreduced audio data rates in the TV satellite frequency bands (DSR and DMAC Packet sound channels), serving only stationary receivers connected to dish antennas. However, FM's consistency of service quality is most severely affected when received in a car, hence a new system should provide unimpaired mobile reception under all circumstances. This implies that the new transmission system had to be immune to multipath propagation interference. Also, terrestrial delivery with all options of local, regional and national coverage areas is essential to provide the same service flexibility as FM. The need for spectral efficiency commanded schemes with very drastic reductions of the data rates for sound programmes. Fortunately, new methods in data reduction for digital audio signal were being developed at this time, giving hope for achieving low bit rates without sacrificing audio quality.

By the end of 1985, after a long period of individual contacts held by The *German Aerospace Research Establishment DLR* with industry, broadcasters, research institutes and administrations from four countries, a consortium willing to start a joint project to develop a Digital Audio Broadcasting System was formed and was ready to sign a cooperation agreement about one year later. The governments of France, Germany and the Netherlands expressed their intentions to support their own national participants of this project with grants and assist it in administrational affairs. The Eureka initiative was suggested as the proper framework for this multinational research effort. The Research Ministers' Conference 1986 in Stockholm notified Digital Audio Broadcasting (DAB) as Eureka Project 147.

2 How the project is organized

At the start of the project 16 signatories from industry, broadcasters, research institutions and universities of France, Germany and the Netherlands signed the cooperation agreement for a four-year project. A short time later the BBC joined the consortium. The list of the pro-

Tab. I. Original members of EUREKA 147 in phase I

AEG AG	D
Bosch-Blaupunkt	D
British-Broadcasting Corporation	UK
Centre Commun d'Etudes de Télédiffusion et Télécommunications	F
Deutsche Thomson-Brandt	D
Forschungsinstitut der DBP	D
Fraunhofer-Gesellschaft, AIS	D
Grundig AG	D
Institut für Rundfunktechnik GmbH	D
Intermetall, Halbleiterwerk der Deutschen ITT Industries	D
Nederlandse Philips Bedrijven	NL
Telefunken Sendertechnik GmbH	D
Universität Hannover	D

* Presentation held at the 1st International Symposium on DAB – 1992

ject partners is given in *table I*. The project was intended to begin officially in January 1987, but due to difficulties in funding resources the offical start was delayed until January of 1988. Nevertheless, some important investigations relating to digital sound broadcasting were already under way before the official start of Eureka 147. The European Broadcasting Union had initiated research work at the *CCETT* in Rennes, France, for a digital satellite sound broadcasting system aimed at mobile reception. As a valuable asset, the promising approach pursued in this project could be tied into EU 147 from the beginning, since the CCETT became a co-founding member of the Eureka consortium.

The resources committed to the project by the partners were quite remarkable. In total the manpower allocated to this challenging research and development task was 360 man-years, amounting to a capital expenditure of about 80 million DM. Equally impressive was the support given by the governments to ease the risks involved in such a project. The German Minister for Research and Technology alone granted about 34 million DM in support of Eureka 147. Work was assigned to four Working Groups, headed by a Steering Committee responsible for technical decision making, and a Programme Board dealing with contractual, legal, promotional, membership and external affairs. The German Aerospace Research Establishment was chosen to provide the project management. The individual Working Groups 1 to 4 had the following terms of reference: 1. Channel coding and transmission system, 2. Source coding, 3. Integration and receiver design aspects, 4. Recording. Working Group 4 later was abandoned due to diverging interests of the partners. Several special task forces were formed according to temporary requirements.

3 *Results achieved in phase I of Eureka 147*

As the headline indicates, Eureka 147 – after a very successful first period of four years – is continued in a second phase, aiming towards the soon introduction of DAB in Europe.

31 Technical achievements

The goals set at the beginning of the project called for data reduction of digitally coded sound signals, requiring less than 200 kbit/s per stereo programme for an audio quality indistinguishable from that of a compact disc. Unimpaired mobile radio reception should be provided practically everywhere in the coverage area. Spectral efficiency should allow to transmit at least 16 high-quality stereo programmes in the bandwidth of a terrestrial television channel, with additional provisions for ancillary data transmission. This combined set of demanding features was of course expected to be met in receiving equipment having the size of today's car radios and comparable prices for the consumers.

In both fields of channel coding/transmission and source coding, four different approaches were suggested by the partners of the project and investigated in great detail. By thorough comparisons and after assessing the advantages and drawbacks of each solution with respect to its implementation in IC technology, one most promising approach was selected in each field. In sound coding an algorithm was found and hardware developed allowing bit rates of 384...128 kbit/s per stereo programme, with CD quality maintained at 256 kbit/s and excellent quality achieved at 192 kbit/s for stereo sound. This compared well with the goals set when launching the development. For channel coding and transmission the Coded Orthogonal Frequency Division Multiplex (COFDM) approach was selected as the most suited solution to overcome the adverse effects of multipath propagation disturbances. COFDM employs a wideband multicarrier transmission scheme with convolutional error protection coding and time and frequency diversity methods, together with guard intervals to master the intersymbol interference of dispersive radio channels. Transmitting power required for such a digital system is dramatically reduced compared to conventional FM broadcasting. Also, the immunity against multipath propagation distortions opens new ways for frequency planning: the concept of *single-frequency networks,* where all stations broadcasting the identical ensemble of programmes may transmit on exactly the same frequency channel. This feature allows impressive savings of frequency spectrum, when large areas have to be served with the same set of programmes. DAB as specified today accomodates six high-quality stereo programmes in a system bandwidth of 1.5 MHz. This figure is much better than the target set at the start of the project, not even considering the additional benefits of the single-frequency network option.

The solutions found for sound coding, channel coding and modulation require a colossal amount of signal processing power. The progress of integrated circuit technology kept step with the demanding requirements of this project. While chips for integrated sound encoders/decoders are appearing this year from several sources, clear indications from circuit manufacturers show that also a one-chip solution is feasible for the channel decoder. Within the Joint European Submicron Silicon Inititative (JESSI), a flagship project, JESSI-DAB (AE-14), is active to bring chip sizes down to the small silicon areas needed for inexpensive consumer products. Another challenge addressed is the reduction of power dissipation for battery-operated portable receivers.

Even though the task of *recording* digital audio signals was deleted from further activities within Eureka 147, one can say that the results of this project have found their first application in the *Digital Compact Cassette (DCC)* recently presented by the consumer industry. The sound coding system used originates from work done in Eureka 147.

In summary, it is correct to say that the Eureka 147 project has achieved its objectives in phase I. This is clearly documented in a complete preliminary system specification available to the project partners since the beginning of this year.

32 Demonstrations and tests of EU 147/DAB

Soon after the official start of the project, first experimental hardware became available and was demonstrated to experts in the fileds of broadcasting and radio regulations. On two occasions, WARC '88 and ITU-COM '89, a 7 MHz wide experimental UHF DAB system – carrying but one data-reduced stereo sound channel – was shown in Geneva. The resonance of the experts was enthusiastic, as unimpaired mobile reception was demonstrated in a convincing way. The year 1990 saw a small-scale presentation of DAB at NAB's Convention in Atlanta, Georgia, and a series of tests and demonstrations carried out by a Canadian task group consisting of public and private broadcasters and the Department of Communications. In Toronto, Montreal, Ottawa and Vancouver DAB operated flawlessly. An extensive report attested DAB excellent suitability as a candidate for a new broadcasting system. Four major events in 1991 brought DAB to the attention of a wider public. The National Association of Broadcasters invited Eureka 147 to bring a mobile demonstration of DAB to the NAB Convention '91 in Las Vegas and to the Radio '91 Show in San Francisco. Aroused by the presentation in Atlanta, the successful tests in Canada and negotiations between Eureka 147 and the NAB, the impact was enormous, though not generally favourable to any digital sound broadcasting system. Proponents of so-called 'In-Band Systems' fiercely attacked EU 147/DAB as being unsuited for the US broadcasting scenario and coming at a time when the broadcasters – for economic reasons – would not want any technical or market change. The other events where DAB found a high degree of attention and approval were the Radio Festival in Birmingham, UK, and at the International Radio Show in Berlin. A specific test performed in Canada must be included in this list because it had decisive influence on the outcome of the WARC '92. Successful L-band (1.5 GHz) experiments were conducted in Toronto, proving that L-band is a feasible option for terrestrial broadcasting of DAB. In 1992 the DAB Symposium in Montreux is the main public activity of Eureka 147.

Eureka 147/DAB demonstration at the DAB Symposium 1992 in Montreux

33 Finding frequency spectrum for DAB

The continuous efforts in demonstrations of Eureka 147 DAB mainly served two closely related purposes: gaining acceptance for the system and finding support in the administrations for allocations of frequencies to a future DAB service. Some of the reluctance to begin with the DAB development certainly can be accounted to the bleak outlook in frequency matters. But the mood changed immensely when more and more successful tests and demonstrations convinced all experts that DAB can soon become a reality when spectrum is allocated. So, thorough surveys of usage of the frequency bands ranging from 50 MHz to 1 GHz were made – especially in Germany. They revealed no chances of obtaining new spectrum for DAB *outside* of the broadcasting bands. Nevertheless, a positive answer was given by identifying channels *within* the broadcasting bands where DAB could be started, at least in a number of European countries. These channels are not free at the moment, but arrangements to remove present users from these frequencies seem possible. The channels most likely to become available for DAB in Central Europe are TV channel 12, Band I in the VHF range and some upper UHF channels. Some East European countries and Scandinavia may have a chance to make use of a part of the FM band. Germany in particular has set its course to launch a DAB service on TV channel 12 and – where necessary — on TV channels 3 or 4 by mid-1995. To this end planning is under way to remove all low-power television retransmitters assigned to this channel until the end of 1994. In France, where difficulties exist in using TV channel 12, Band I is considered as a starting position for DAB, also using the so-called 'taboo' channels of television in the UHF band. The United Kingdom is attempting to regain from the mobile services some section of the VHF Band III for broadcasting DAB. In all, there is hope that DAB will find starting frequency bands in all of Europe, which may, however, differ considerably from country to country. The receiver manufacturers are not happy with this situation, because it forces them to build receivers with very wide front-end tuning ranges. Their preferred choice would be a receiver tuning from 50 to 250 MHz only. When DAB will have matured to the predominantly used broadcasting service, an organized migration of DAB from its initially used frequencies into the FM Band II may be appropriate, replacing FM services and ending an inevitably long period of simulcasting FM and DAB programmes.

New prospects are opened by the recent decision of WARC '92 to allocate a band 40 MHz wide at 1.5 GHz to satellite and terrestrial digital sound broadcasting.

Banned from immediate use by footnotes protecting existing services, this band will become available worldwide in the year 2007. Some countries, e.g. Canada, Mexico and Australia, are determined to apply this band to DAB much sooner. Our Canadian friends have shown: EU 147/DAB is applicable and performing well in this band. Could this indicate a future trend towards migration into the L-band, becoming a world standard DAB system there?

34 International standardization

One important objective of the multinational research effort in Eureka 147 is the development of a European or even better a world standard for digital sound broadcasting. Consequently, the project partners have engaged themselves heavily in international standardization procedures where appropriate. An outstanding result was achieved in the standardization of coding algorithms for digital storage media. The Moving Pictures Expert Group (MPEG) of the ISO/IEC selected two source coding methods developed in Eureka 147 as the proposed standard for high-quality data-reduced sound coding. They are now subject to international approval as a standard. One method, the so-called ISO MPEG Layer II, is the source coding algorithm chosen for DAB.

Eureka 147, in close cooperation with the EBU, also introduced its DAB system approach to the CCIR. Study Groups 10 and 10/11S of the CCIR in 1991 adopted two recommendations for requirements relating to terrestrial and satellite sound broadcasting systems, outlined jointly by EBU and EU 147. In an annexe to these recommendations, EU 147/DAB (named Digital System A) is the only system mentioned, and it fulfils these requirements.

Recently a Joint Task Committee of EBU, the European Telecommunications Standards Institute (ETSI) and EU 147 was formed to work out a European Telecommunication Standard for digital sound broadcasting based on the specification now existing for DAB. The drafting of this standard is expected to be finished early 1993. Then the full specification of DAB will be made public and circulated to the national standardization bodies for adoption.

CENELEC is also willing to prepare a standard for DAB receivers. A task group will be formed soon. No specific date can be given as yet for the issue of a proposal for this standard.

4 Phase III of Eureka 147

41 New partners, commitment and funding

The Eureka 147 project, by virtue of its achievements, has become very attractive to industry, broadcasters and telecom enterprises. Accordingly, a number of organizations have applied to be admitted to the consortium. Even though the group is looking for a broad basis of supporters, it is aware that expanding the group too much will make it less efficient in its work. Also, a just rule has to be applied in accepting new industry partners who have not shared the high risks of the early stages of the development, but now may benefit from joining a successful and riskless venture. Furthermore, phase I has shown that there was no field with noticeable lack in expertise. All this leads to only few additions on the list of partners for phase II of EU 147. *Table II* shows the members of the consortium as of May 1992. It should be noted that a number of original partners have changed their names and affiliation in the meantime, so they are not new to the project. The total manpower committed to phase II of the project is around 170 man-years at an estimated cost of about 45 million DM. Grants from governments can again be expected. In Germany 15 million DM will be granted by the Minister for Research and Technology.

Tab. II. Present membership of EUREKA 147 in phase II

Becker Autoradio GmbH	D
Bosch-Blaupunkt	D
British Broadcasting Corporation	UK
Centre Commun d'Etudes de Télédiffusion et Télécommunications	F
Daimler Benz AG, Forschungsinstitut	D
Deutsche Thomson-Brandt, TCE	D
Forschungsinstitut der DBP Telekom	D
Fraunhofer Gesellschaft, IIS	D
Grundig AG	D
Institut für Rundfunktechnik GmbH	D
Intermetall, Halbleiterwerk der Deutschen ITT Industries	D
Philips Consumer Electronics	NL
Popov Institute, St. Petersburg	CIS
RAI, Radiotelevisione Italiana	I
Rohde & Schwarz GmbH	D
Swedish Telecom Radio	S
Télédiffusion de France	F
Telefunken Sendertechnik GmbH	D
Thomson LER	F
Thomson LGT	F

42 Objectives of phase II

The second phase of Eureka 147 was started in January 1992 and is scheduled to run until the end of 1994. Building on the sound basis of the specification found in phase I, it will address the many questions that need to be answered before DAB can go on the air as a regular service. Most important, the preliminary specification must be readied to a final specification in which all details have been verified by experiments and measurements. This will mean very substantial efforts in large-scale field testing, especially for all aspects of single frequency networks (SFN). Several subgroups have been formed to test SFNs from Band I to Band V. Reliable information on protection ratios between DAB and other services and criteria for service quality must be found by measurements to establish new rules for service planning. Practical solutions for feeding such networks are needed, considering that each station transmits a multiplex of programmes coming perhaps from

very diverse programme providers. The new feature of DAB offering a common ancillary data channel in conjunction with the ensemble of programmes requires protocols and structures for a versatile handling of e.g. value-added data services.

The organization of the project is similar to phase I. Only the objectives of the three Working Groups have changed. Working Group 1 handles all matters associated with the up-dating and completion of the specification and will act in the committees formed with ETSI and CENELEC. Working Group 2 is responsible for field testing and verification of the specification and will set up subgroups when necessary. Working Group 3 deals with the ancillary data capability of DAB.

43 Equipment availability

Extensive field testing needs sufficient DAB equipment in all test areas. So far, only a limited number of exciters and receivers of the second experimental prototype series is available to the members of the consortium. These sets will all be in action in the field testing campaigns. As the number of receivers is somewhat larger than the number of exciters, satellite distribution of a fully coded DAB signal, bundling up to six programmes, is under preparation. This 'base-band' DAB signal, transmitted via an FM-modulated transponder, can be received by commercially available equipment and then be transposed for true DAB emission to the desired frequency band.

More equipment is scheduled to appear early in 1993. Task Groups to build the third generation of experimental equipment were set up by the industry members of the consortium. The group lead by *Thomson Consumer Electronics* will produce the receivers. Transmission equipment will be produced by a group lead by *Telefunken Sendertechnik.* Both groups are interested to learn about the quantities of receivers and transmitters that may be purchased by parties plannig their own experiments with DAB. It is anticipated that several hundred receivers and several tens of exciters may be ordered. Prices of the equipment will of course depend strongly on the quantity of sets being sold. An estimate of the prices is due soon.

For the introduction of a pilot DAB service in 1995, consumer type receivers are necessary in adequate quantities and affordable prices. Here the results of the JESSI-DAB project play an important role. A complete chip-set for DAB signal processing will be needed already for the first generation of consumer products, because only this will allow to manufacture DAB car radios of standard size at acceptable costs.

5 Implementation aspects for DAB

51 Situation in Europe

Very soon in the first phase of the project, Eureka 147 and the European Broadcasting Union established close contacts and good relations, although on a very informal basis only. The emerging friendly cooperation has been to the advantage of both organizations. Many of the previous demonstrations have been carried out as cooperative efforts as is the Symposium of Montreux. Thus, the members of EBU have been kept informed about DAB, and the EBU has been able to introduce the requirements of the broadcasters into the development work. The Technical Centre of EBU – on a confidential basis – is well aware of all technical details of the DAB system. So, in this context, the interest and the acceptance has grown steadily among the European broadcasters. Today it can be assumed with confidence that no relevant opposition exists against the well-proven solutions found in EU 147/DAB. But to promote a rapid introduction of DAB requires more! Here, forceful promotion groups, as the *Club DAB* in France and *DAB Platforms* in Germany and the Netherlands, come in. Only owing to the insistant efforts of the DAB Platform, the frequency allocation question in Germany was brought to a quick and practical solution. This in turn leads to the expectation that a DAB service may be started in 1995. We wish the other groups a comparable success in promoting DAB in their territories. More such promotional groups are welcome and may help to make DAB a soon reality everywhere in Europe.

52 Overseas perspectives for DAB

The country most actively investigating the possibilities of implementing DAB is Canada. Nowhere else has DAB seen more rigourous and extensive testing and demonstrations outside of Eureka's laboratories. A wealth of information has been collected and reported by the Canadian experts. Most valuable were the experiments conducted with DAB at 1.5 GHz (L-band). Many incorrect and malevolent arguments made by opponents about the performance of DAB in this band were clearly refuted in on-the-air tests. The positive results obtained explicitly helped to convince the delegates of WARC '92 when discussing the need of a broadcast allocation at 1.5 GHz. The consortium acknowledges Canadas determination to implement DAB and has entered an agreement with broadcasting representatives of this country. Mexico closely follows the Canadian intentions and is also a partner in this agreement. Australia is another highly motivated country looking at the chances DAB offers. For Australia, a satellite DAB service, augmented by terrestrial transmissions, would be very desirable. A welcome opportunity to test DAB at L-band from satellite may open up, when an Australian telecom satellite for mobile services, in its preoperational phase, might be used for DAB tests.

The situation in the United States is very undecided yet. After a strong attempt by NAB officials to come to a quick acceptance by an endorsement of EU 147/DAB, a part of NAB's membership opposed the decision made by the Board of Directors and urged to support only American-designed systems. The approaches mostly favoured claim to allow each FM station to operate additionally a digital transmitter on-channel or in the adjacent channel, without mutual interference or interference to other stations. For these so-called 'in-band' systems the same coverage area is promised as for the FM station. No such system has been tested on the air yet. Laboratory tests of the NAB, however, seem to indicate

that the performance of such systems will be far inferior than claimed and that the Band II spectrum in metropolitan areas will not accommodate all additional digital stations. Thus, 'in-band' systems do not give every broadcaster an equal chance to simulcast his programmes digitally, let alone the chances for today's AM broadcasters. The allocation of L-band in Region 2, to which the US opposes, but which may be used by Canada and Mexico, will exert additional pressure on the situation in the USA. So it may be anticiated that, in the long run, the outlook for EU 147/DAB should not be too bad after all. The Eureka group will reconsider the situation, when the US position gets more distinct.

6 Conclusion

Digital Audio Broadcasting, as developed by the Eureka 147 consortium, is well-proven and has the features that broadcasters and listeners are looking for. Industry is determined to make it an important business. DAB is moving with increasing pace to the first application in a regular service. Terrestrial delivery will surely be in use long before a satellite DAB service will appear. The chances of becoming the future standard for broadcasting are good. The DAB Symposium 1992 in Montreux may be an important milestone on the road towards universal acceptance of this remarkable achievement in research and engineering.

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Zusammenfassung

DAB – Wie geht es weiter?

Nach ziemlich langwierigen Vorabklärungen, Machbarkeitsstudien, Verzögerungen und neuen Anläufen wurde das Eureka-Projekt 147 für den digitalen Tonrundfunk (Digital Audio Broadcasting, DAB) 1988 gestartet; in den ersten vier Jahren der Projektphase I erfuhr es einen bemerkenswert raschen Fortschritt. Heute besteht ein weitherum gut aufgenommener Normenvorschlag für den künftigen digitalen Tonrundfunk, und entsprechende Geräte wurden bereits vielerorts getestet. In einer zweiten, der dreijährigen Projektphase sollen alle Systemaspekte in ausgiebigen Feldversuchen gesichert, die interessanten neuen Eigenschaften untersucht und die Betriebskriterien und organisatorischen Vereinbarungen aufgestellt werden, die die Einführung des Dienstes gegen Mitte dieses Jahrzehnts erlauben.

Résumé

DAB – Que se passe-t-il?

Après des examens préliminaires passablement laborieux, des études de faisabilité, des retards et de nouveaux départs, le projet Eureka 147 concernant la radiophonie numérique (Digital Audio Broadcasting, DAB) a démarré en 1988 et fait des progrès remarquablement rapides durant les quatre premières années de la phase I. A ce jour, il existe une proposition de norme pour la future radiodiffusion numérique, bien accueilli dans de larges cercles d'intéressés, et les premiers appareils correspondants ont déjà été testés en de nombreux endroits. Dans une deuxième phase du projet, tous les aspects du système doivent être vérifiés, de nouvelles propriétés intéressantes seront examinées, les critères d'exploitation et les conventions administratives seront mises sur pied, ce qui devrait permettre l'introduction de la prestation vers le milieu de la décennie.

Riassunto

DAB – il punto della situazione

Dopo un lungo periodo di accertamenti, diversi studi di fattibilità, ritardi e nuovi tentativi, nel 1988 è stato avviato il progetto Eureka 147 relativo alla radiodiffusione audiodigitale (Digital Audio Broadcasting, DAB). Nella prima fase del progetto, durata quattro anni, si sono registrati notevoli progressi. Attualmente esiste una proposta di norma per la radiodiffusione audiodigitale futura che è stata accolta dalla maggior parte dei Paesi e sono già stati sottoposti a prove in diversi posti gli apparecchi adatti. In una seconda fase di tre anni saranno consolidati tutti gli aspetti del sistema mediante estese prove in campo, saranno esaminate interessanti caratteristiche nuove e allestiti criteri d'esercizio e accordi a livello organizzativo che permetteranno di introdurre il servizio verso la metà di questo decennio.

Summary

DAB – Where is it going?

After a relatively long period of preliminary investigations and feasibility studies, hesitations and stimulation, Digital Audio Broadcasting was started as Eureka Project 147 in 1988; in its four years of phase I it has seen remarkably quick progress. Now a widely accepted proposal for the future digital sound broadcasting standard is available, and hardware has been tested in many locations. A second phase of the project, scheduled to run for three years, will be used to verify all system aspects in extensive filed tests, exploit the exciting new features of this versatile broadcasting system and establish the implementation criteria as well as organizational arrangements for the introduction of DAB services in the middle of this decade.