Digital broadcasting of studio–quality HDTV by satellite in the 21–GHz frequency range and by coaxial cable networks

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Backed up by extensive research and demonstrations, the frequency band 21.4 – 22 GHz was finally allocated to the broadcasting satellite service by WARC–92. The band is intended to be used for near studio–quality digital HDTV with associated multi–channel surround sound.

Digital transmission can cope with the propagation conditions in this band, which are more difficult than those encountered in the 11 or 12 GHz downlink bands, and allows more flexibility for frequency planning than analogue schemes.

In cable networks, digital multi–level modulation permits the use of relatively narrow–band transmission channels.

The article gives an overview of the current state of development.

1. The frequency issue

Since 1984, the European Broadcasting Union (EBU) has pursued the allocation of a frequency band to the broadcasting satellite service (BSS) in the 20–GHz frequency range. This was prompted by the need to seek expansion possibilities for BSS in order to provide transmission capacity for wide–band HDTV services, and by the fact that there existed a corresponding allocation in the Radio Regulations (22.5 – 23 GHz) for ITU Regions 2 and 3 (the Americas, Asia and Australasia) which could be taken up under certain conditions. It should be recalled that in the 11.7 – 12.5 GHz BSS band, WARC–77 had assigned only five 27–MHz wide satellite channels per country.

At WARC–92 (Torremolinos/Malaga, Spain, February/March 1992), the band 21.4 – 22 GHz was allocated to the BSS in Regions 1 and 3, whereas in the Americas (Region 2), the band 17.3 – 17.8 GHz was allocated to BSS (HDTV). The existing allocation between 22.5 and 23 GHz was deleted. The new 21–GHz band is intended for HDTV. The band will become fully available on 1 April 2007, but an interim procedure (Resolution 525 of WARC–92) was adopted; this Resolution defines provisions that can be applied for coordinating both experimental and operational systems before this date [1].

* Adapted from a paper delivered by the author at NAB HDTV World, Las Vegas, April 1993.

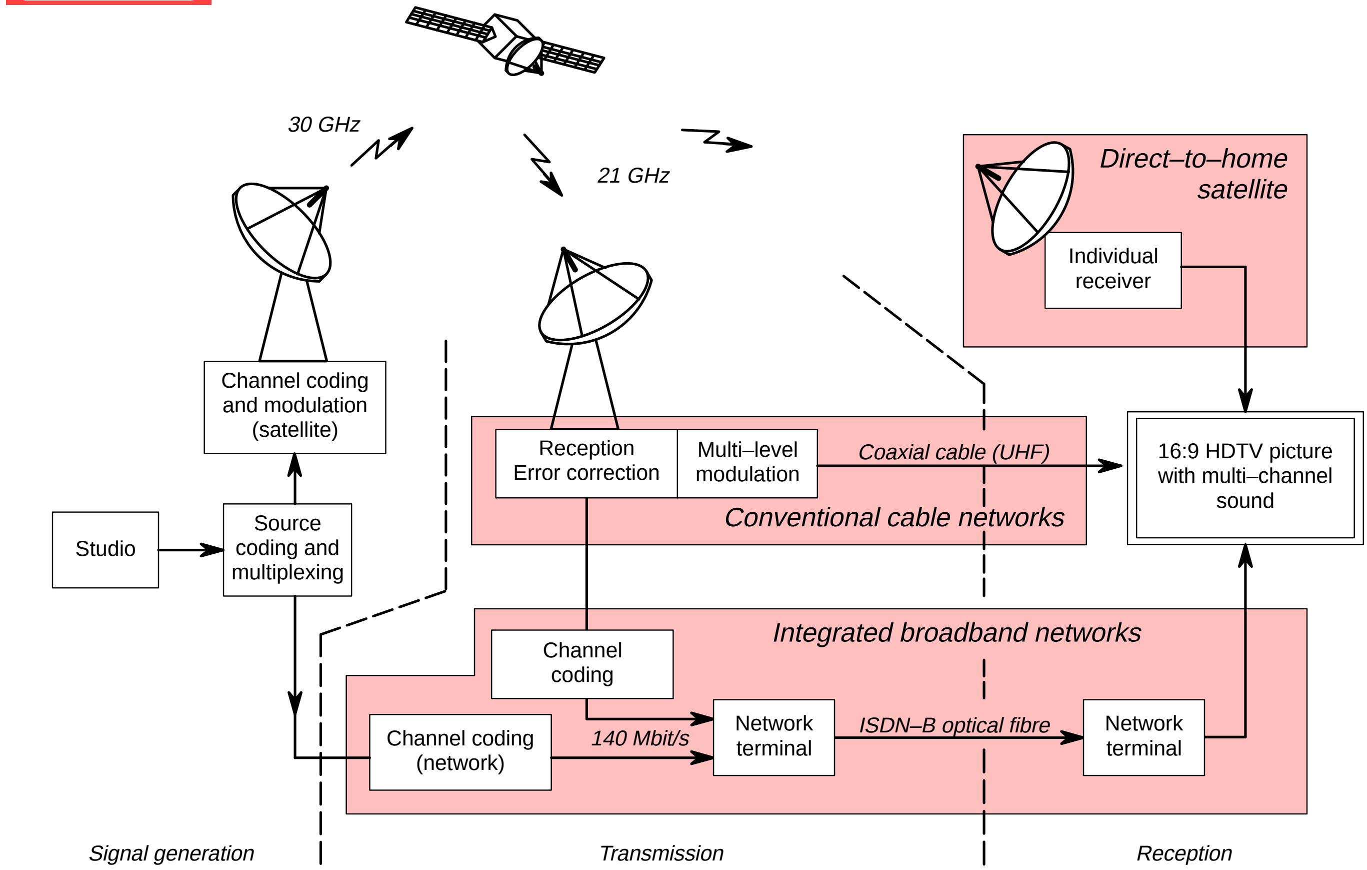


Figure 1
Possible overall system concept for the transmission and reception of digitally–coded studio–quality HDTV.

2. System demonstrations

Much research work was undertaken in order to demonstrate the technical feasibility of satellite broadcasting of studio–quality HDTV in the 20–GHz frequency range [2, 3]. Picture coding and transmission techniques were studied in particular. Input documents from all parts of the world, especially from Europe, Japan, Canada and the United States, led to the establishment of a sound technical basis, documented by the CCIR in a comprehensive report [4]. During WARC–92, the EBU was able to organize a major technical demonstration of studio–quality HDTV satellite transmission. The European Space Agency (ESA) had kindly made available the Olympus satellite for the event. However, for operational reasons, the experimental 20/30 GHz payload of the satellite could not be switched into the necessary wide–band mode so the demonstration was carried out using a satellite simulator only. There were programme sequences in both production standards 1125/60/2:1 and 1250/50/2:1 (1920 and 1440 pixels/line). It is fair to say that the delegates who saw the pictures and listened to the seven–channel surround sound were overwhelmed by the artistic impact and the technical beauty of this new medium [5].

Satellite transmission of this 140 Mbit/s signal was finally demonstrated at a press conference given by the IRT in Munich on 1 and 2 October 1992. DBP–Telekom provided the link to and from the experimental 20/30 GHz transponder on one of the DFS–Kopernikus satellites, using a 2.5–m earth station.

On 4 February 1993, the RAI demonstrated in Turin a 30/20 GHz satellite transmission of studio–quality HDTV vis the Olympus satellite, with a data–rate of 70 Mbit/s only. Telespazio provided its 2.5–m transportable up–link station.

All the demonstrations mention above used, for the picture coding algorithm, a hybrid discrete cosine transform (DCT) with motion compensation and variable–length coding (VLC). The video codecs were built by the Institut für Rundfunktechnik (IRT, Germany), HIVITS[1] and Alcatel–Telettra (Italy). Although not used in these demonstrations, one European research project[2] has devel-

1. HIVITS is a research project funded partially by the European Community in the framework of the RACE programme. The project was terminated in December 1992.

2. Bosch, SEL, Technical University of Hanover.

oped a four sub–band codec for a 140–Mbit/s bit–rate. This approach is described in [6].

3. Overall system configuration

3.1. The media environment

Satellite transmission of digital studio–quality HDTV is probably not the next step in the technical development of television broadcasting. It is more likely to be the next but one step. Digital television of standard (or of even lower than standard) definition will come first. By 1995, at best a picture quality corresponding to CCIR Recommendation 601 (4:2:2) can be expected, probably in the 16:9 aspect ratio. The introduction of studio–quality HDTV will depend heavily on the availability of affordable and sufficiently light–weight high–quality HDTV displays, projection systems, etc., for domestic use. However a service which is to be started in the year 2000 must fit into the structure of the media environment as it will be at that time. As illustrated in *Fig. 1*, three main means of delivery should be possible:

– individual reception with 60 to 90 cm antennas;

– cable reception in conventional coaxial networks;

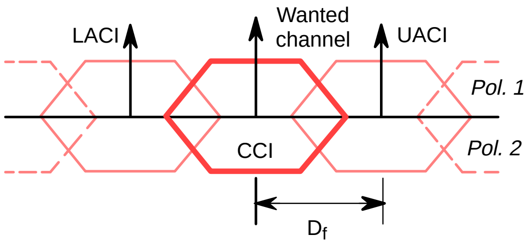
– optical fibre circuits, i.e. delivery by the broadband ISDN.

The last of these is of special importance for library and other subscription services in interactive video and multi–media applications.

At 21 GHz, a channel scheme of slightly overlapping channels of equal strength has been the basis of all investigations. The signals on the opposite “hand” of polarization are positioned in a co–channel configuration, taking account of the relatively wide bandwidth (see *Fig. 2*).

3.2. The need for a common receiver concept

HDTV viewing sites will be characterized – even at home – by a relatively large picture and the sense of realism will be further enhanced by the multi–lingual and/or multi–channel surround sound [7]. A configuration of five loudspeakers (three in the front and two at each side of the viewing position) has recently been approved as a standard proposal by CCIR Task group 10/1 and it is now recommended by the CCIR [8]. If a central sub–woofer is used, these loudspeakers may be quite small – tiny even. The five sound channels can be accom-



LACI: lower adjacent–channel interferer
UACI: upper adjacent–channel interferer
CCI: co–channel interferer
D_f channel spacing (typically 50 MHz for 70Mbit/s useful data–rate using TCM–8PSK)

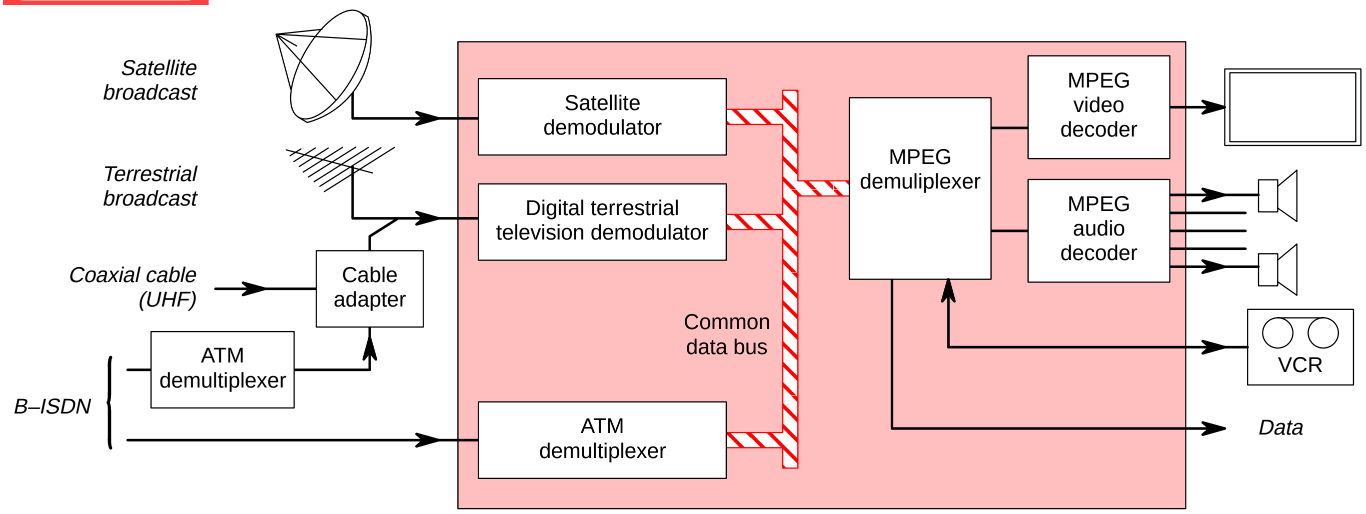
Figure 2
Channeling scheme under investigation for digital HDTV satellite transmission.

modated within a 384 kbit/s bit–stream while preserving full Compact Disc quality by making use of a bit–rate reduction technique compatible with ISO 11172–3 Layer II (MUSICAM) [9].

The displays (louspeakers, video screen, etc.) are connected to the approprtiate outputs of ther processing units (i.e. the decoders) which form the heart of the home terminal. Naturally, there is the requirement that these processing units should accept input signals from all television and HDTV sources or delivery systems such as satellite and terrestrial transmitters, coaxial and optical cables (B–ISDN), video cassette recorders, laser disc players, etc. In addition, it should allow for the interconnection of computers and other multi–media applications. *Fig. 3* shows an example of a structure of a modular digital television and HDTV receiver for various kinds of delivery [9]. It should be noted that the nucleus of this processing unit is represented by the data bus fed by the various demodulators and carrying the packet–data multiplex, which in turn contains the complete information of vision, sound and ancillary data. There are dedicated decoders for each service component. A prerequisite without which this common receiver concept will not function, is the definition of a compatible multiplex and a compatible baseband coding technique (i.e. bit–rate reduction scheme), such as MPEG2.

4. Satellite transmission aspects

The results of the current developments will open up the 20–GHz frequency range for satellite broadcasting. The new band, 21.4 – 22 GHz, allows for potentially wider channels than those assigned for the 12–GHz DBS service. The transmission will undoubtedly be fully digital in order to secure the required picture and sound quality, and in order to cope successfully and in a spectrum–efficient way with the adverse propagation conditions encountered in the 21–GHz range.



Note: The receiver/decoder may contain only those input stages which are required by the user. These may be integral parts of the receiver, or plug–in units, purchased according to the requirements, or self–contained boxes. The essential point is that *all* input stages should serve the *same* data bus. For this purpose, a unique, standardized multiplex structure is needed, but not necessarily a unique bit–rate.

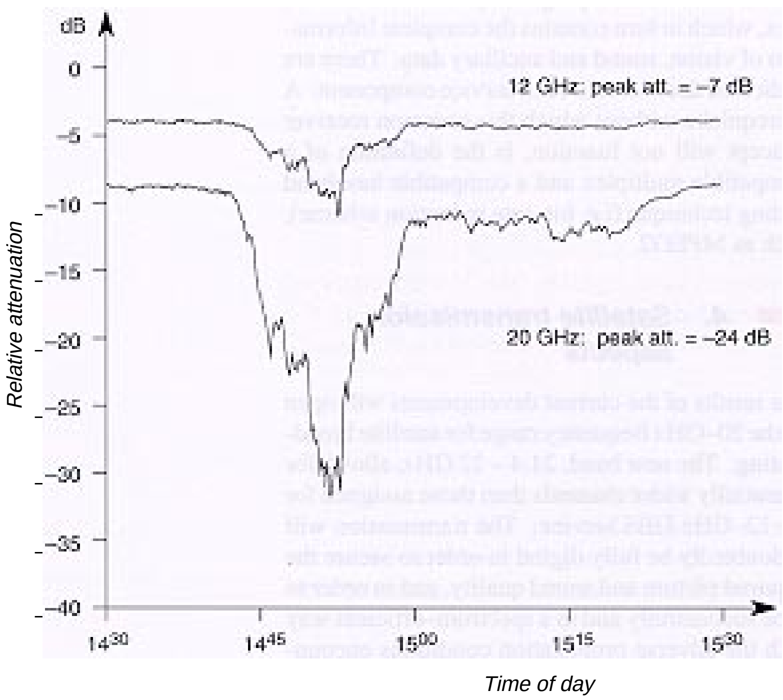
Figure 3
Example structure of a modular digital television and HDTV receiver for various forms of delivery.

Two atmospheric effects have to be taken into account:

- relatively deep rain fades (typically three times the corresponding decibel value at 12 GHz);
- limited atmospheric cross–polar discrimination (XPD).

Fig. 4 shows a comparative recording of a 12–GHz and a 20–GHz beacon signal transmitted from the DFS–Kopernikus satellite during the passage of a heavy thunderstorm.

Figure 4
Rain attenuation at 12 and 20 GHz during a heavy thunderstorm.



It can be shown that for reasonable satellite output powers (100 W into a 1° beamwidth), service continuity can be achieved for 99.6% of the worst month for moderately rainy countries in central Europe [2, 11]. For this percentage of time, the atmospheric purity with respect to polarization planes is reduced to some 19 or 20 dB, regardless of the potentially much better XPD performance of the satellite transmit antenna and ground receiving antennas. Under such conditions, only “simple” digital modulation techniques such as QPSK or trellis–coded 8PSK (TCM–8PSK) can operate on both planes of polarization from the same orbit position, as indicated in *Fig. 2*.

Studies are currently in progress within the HD–SAT research project[3] with a view to increasing the service availability by a combined action on the system parameters. The adoption of linear polarization (rather than the circular polarization favoured hitherto), coupled with a careful choice of the X and Y polarization planes, may lead to significantly better atmospheric XPD values at time percentages beyond 99% of the worst month and may, in turn, significantly improve the atmospheric co–channel interference ratios at high attenua-

3. HD–SAT is partially funded by RACE (ref. 2075). The aim is to study all aspects of the satellite and cable broadcasting of digital studio–quality HDTV, including multi–channel sound and with provision for new powerful data services. It will also define the interworking of such a system with integrated broadband communications (IBC) networks. Some satellite hardware aspects will be studied also. The project partners are: Alcatel Telettra, Alenia Spazio, Cable Management Ireland, CCETT, IRT, RAI–Radiotelevisione Italiana, Star Telematics Ltd., Télédiffusion de France, Thomson CSF, University of Salford. The project is supported by the European Broadcasting Union.

tion values[4]. Consequently, modulation systems could be developed which would provide increased service continuity (up to 99.9% of the time).

Layered modulation is now being considered in conjunction with unequal error protection and hierarchical picture coding. Possible approaches are, for example, asymmetric phase constellations of complex I/Q–modulation (studies under way at the IRT in Germany) or an RF multiplex in the time domain of two or three different (i.e. more or less robust) digital modulation schemes in combination with time–compressed data. The latter approach is being studied by the Centre Commun d'Etudes de Télédiffusion et Télécommunications (CCETT) in France [12].

The need for such a technique is triggered by the fact that any digital modulation service, when combined with a forward–error correction (FEC) strategy, tends to degrade rapidly once the carrier–to–noise ratio (C/N) falls below a certain threshold. The basic idea is to allow this drop–out of service to happen in steps, rather than abruptly at a single C/N value, as shown in *Fig. 5*. In order to allow detection at lower C/N values within a given bandwidth, the available energy must be spread over a lesser number of useful (i.e. information) bits. In other words, E_b/N_o must be increased. It is also essential that the limits for clock recovery and system synchronization are pushed to lower C/N values. Both requirements can only be achieved by layered modulation, supplemented with unequal error protection for "fine tuning". In practice, a high–definition (high bit–rate) data stream is associated with a spectrum–efficient modulation scheme which works well under clear–sky conditions and with a few decibels of rain attenuation. A second, and possibly a third, bit–stream corresponding to lower data rates, and hence lower levels of picture quality such as standard or limited–definition television (SDTV, LDTV) are associated with a more robust but less spectrum–efficient digital modulation. The trade–off involves accepting a drop of signal quality at a C/N level somewhat above that which would occur for a stand–alone HDTV modulation system (curve 1 in *Fig. 5*), in order to gain in service continuity, albeit with a lower–definition picture. In order to avoid frequent switching between HDTV

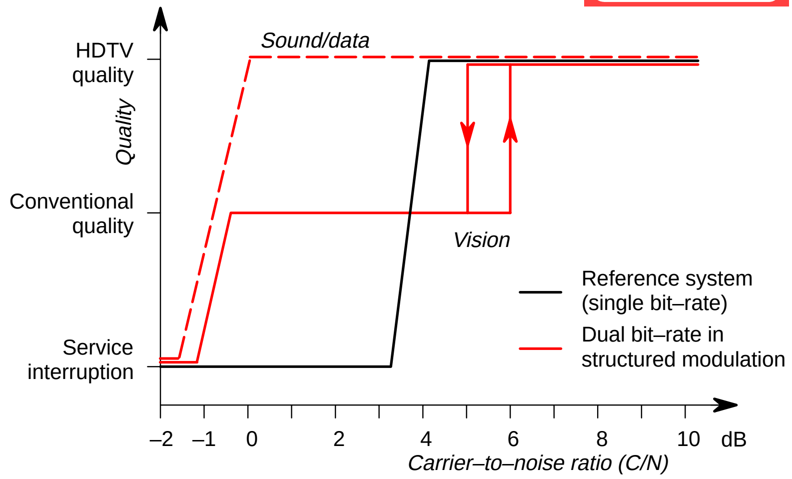


Figure 5
Comparison of failure characteristics of single and dual–layer modulation system (example [13]).

and SDTV close to the first critical C/N threshold, some sort of hysterisis should be incorporated.

Much work is still needed to work out optimal layered modulation schemes and to demonstrate their benefits. It is expected that such a technique will also help to reduce further the necessary satellite transmit power.

In Europe, layered modulation does not seem to be essential at 12 GHz. A power margin of 4.5 dB would guarantee, in most countries, a service continuity of 99.9% during the worst month. There is nevertheless substantial hope that the adoption of layered modulation may eventually allow the introduction of 12 GHz DBS services in tropical regions where extremely severe rain fades have, up to now, prevented countries from taking up their satellite frequency assisgnments.

5. Cable distribution aspects

Substantial investments have been made for the installation of cable networks for the distribution of broadcast signals. These networks are based on coaxial cables in a "tree and branch" structure. It is therefore of paramount importance that the distribution of studio–quality HDTV is not confined to integrated broadband networks such as the B–IDSN, but can also be achieved via the coaxial cable systems already in service.

In contrast to a satellite channel which is power limited, the most precious resource on cable is bandwidth. Digital wideband signals should therefore be transcoded so they will fit into narrower channels. By exploiting the good signal–to–noise ratios and the excellent intermodulation properties of modern cable networks, multi–level coding of the digital signal is possible if the receiver/decoder can cope with linear distortions such as those re-

4. The experience with direct–to–home services in the 11–GHz fixed satellite service band has shown that the necessary adjustment of the polarization when installing a satellite receiving dish does not create significant problems for the user.

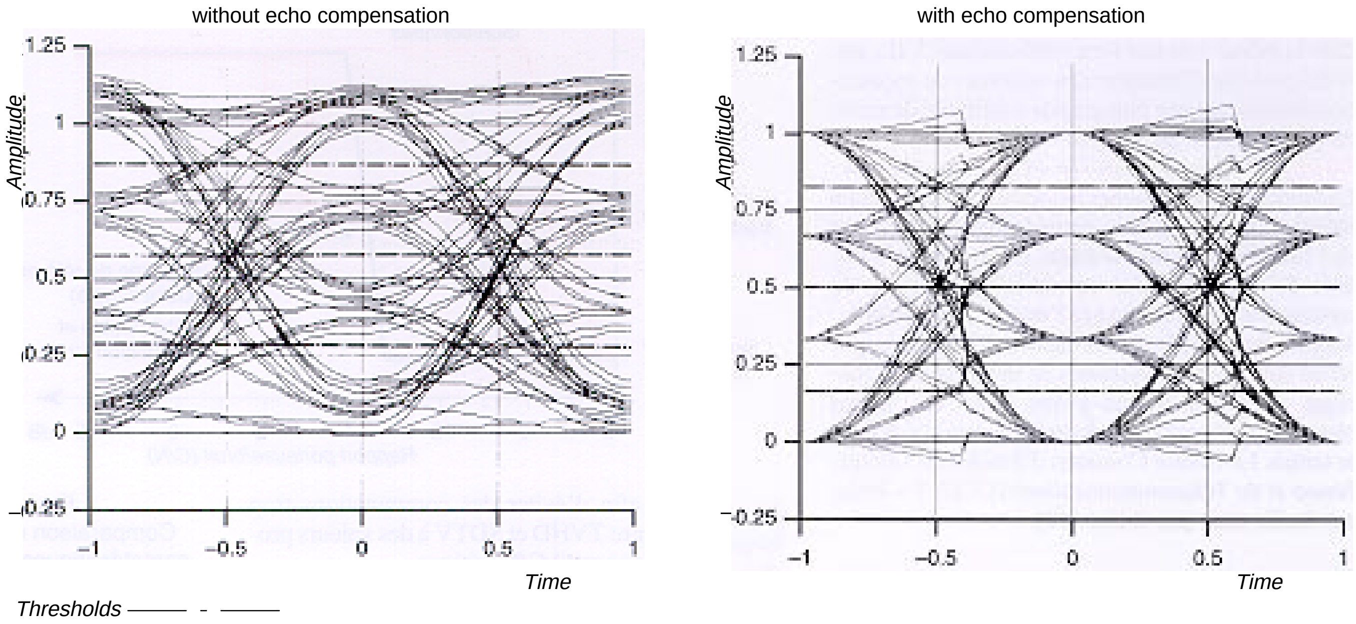


Figure 6
Eye–diagrams of a 16–QAM signal.
(The computer simulation shows the signal at one of the orthogonal outputs of the I/Q demodulator.)

sulting from signal echoes. Due to the many discontinuities in a cable system, echoes (and short–term echoes in particular) are unavoidable, although cables that are suitable for D2–MAC or PAL (including teletext) exhibit good return–loss performance. Echo cancellation is also useful in reducing the performance demanded of cable networks; in this respect it is useful to recall that a single echo of about 7% amplitude (with reference to the full amplitude range of the demodulated signal) is sufficient to close the "eye" of an eight–level digital signal.

Within the HD–SAT project, two cable modulation techniques are currently under investigation, both of which are based on eight levels: 64QAM and 8–level VSB. Both schemes permit the transmission of a bit–rate of about 60 Mbit/s within a channel 12 MHz wide[5]. A first demonstration including echo compensation is foreseen in December 1993 at the CCETT. *Fig. 6* shows the results of an IRT simulation for the echo compensation of a distorted four–level signal (16–QAM) using a quantized feedback technique. A concise description of digital cable modulation and echo–cancellation techniques is given in [14].

5. One developpment goal of HD–SAT is to provide virtual studio–quality HDTV with a bit–rate of about 40 Mbit/s. The time–multiplexed baseband signal (comprising video, multi–channel sound, data services, signal identification, conditional access data and baseband error protection – the so–called "outer code" – would thus amount to some 45 Mbit/s. Assuming a convolutional "inner code" for additional channel forward error–correction (rate 3/4), each cable channel would be required to convey a data capacity of about 60 Mbit/s.

Mr. Christoph Dosch *graduated in telecommunications engineering at the Technical University of Munich and has been with the Institut für Rundfunktechnik since 1976. He is currently Deputy Head of the Broadcasting Service and Transmitter Engineering Department.*

In the past, much of his work has been concerned with the various aspects of satellite sound and television broadcasting (PAL, MAC/packets, FM, DSR). He contributed to the development of the 16–channel Digital Satellite Radio (DSR) system for 12–GHz broadcast satellite.

Recently he has been working on satellite sound broadcasting to moving vehicles in the 1–GHz range and the satellite broadcasting of all–digital HDTV in the 20–GHz range, a field in which he is currently leading a major research project.

Mr. Dosch is an active participant in the CCIR and in EBU Working Parties R and V. He is Chairman of EBU Sub–group R3 (Satellite broadcasting). Within both the EBU and the CCIR he has been involved in the standardization of new broadcasting systems and in the preparation and representation of broadcasters' interests in the ITU World Administrative Radio Conferences dealing with satellite broadcasting (WARC–BS 77, WARC–ORB(85)/(88) and WARC–92).

6. Conclusions and future prospects

Encouraged by the new frequency allocation of the band 21.4 – 22 GHz for the BSS in ITU Regions 1 and 3, which was achieved at WARC–92 and which is intended for wideband HDTV, the research work is continuing in Europe, especially within the RACE HD–SAT project. The goal is the development of coding and transmission schemes for satellite and for cable networks in order to provide studio–quality HDTV, as available in today's studios, in the viewers' homes, accompanied by multi–lingual/multi–channel surround sound and powerful new data services. The studies are also concerned with interconnections to IBC networks and the development of the necessary space technology. There is every confidence that a total bit–rate of 45 Mbit/s (baseband signal) would suffice to meet the requirements. Due care is being taken to ensure a coordinated development with respect to other delivery media. It is probable that, some time in the future, there will be a need also to make digital HDTV signals available in (or through) broadband fibre–optic networks and by terrestrial broadcast emissions. The broadcasting of studio–quality HDTV by satellite must therefore fit into the newly–emerging landscape of digital HDTV and digital television broadcasting. As much commonality as possible should be sought for the signal parameters pertinent to the various means of delivery. As a minimum, a common and reconfigurable time–division multiplex needs to be developed for all of these applications.

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