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APPENDIX REIMERS01

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090 ##$aTK6678 $b.D5213 2005
130 0#$aDigitale Fernsehetechnik. $1English.
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246 3#$aDigital video broadcasting
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1 Digital Television – a First Summary

1.1 Definitions and Range of Application

The expression "digital" is one of the elements of language which has frequently been used and very often misused in the past few years. "Digital" alone means that there are elements which can be counted on the fingers. In the everyday language of information technology the expression "digital" is often used as a synonym for "sampled, quantized and presented in binary characters". In the field of electronic media technology "digital" is a mark of quality which was first used when the compact disc (CD) was introduced on the market and offered to the general public.

The expression "digital studio" describes the introduction of digital signal forms into radio and television production. The audio and video signals are sampled by means of predetermined sampling frequencies and quantized by predetermined numbers of quantization steps. As a rule, further source coding is not used during processing and distribution, however it may take place in individual pieces of equipment.

The signals which are received by "digital" television receivers in most cases are still analogue input signals (NTSC, PAL, SECAM), which are then internally digitised and processed as digital signals. The presentation of the image, however, remains analogue.

From what has been said, it is evident that the terminology must be carefully defined in order to limit confusion to a minimum. "Digital Television", sometimes termed "Digital TeleVision (DTV)", or "Digital Video Broadcasting (DVB)", usually means the transmission of digitised audio, video and auxiliary information as data signals. However, since these data signals must in most cases be modulated onto continuous-time carrier waves in order for them to fit in the transmitting channel, the actual transmission in digital television uses analogue signals.

In the context of this book the expression "digital television" should in fact be understood as the system for the transmission of audio, video and auxiliary data described above. However, it is not possible to concentrate only on the channel coding and modulation, furthermore necessary system components must be included, in particular the technology for the source coding of audio and video signals and multiplexing. The latter is required for the co-ordination of various elementary streams to form one signal. The expression "multiplexing" is not really quite apt because this simplifies the

owing, for example, to noise in the channel – a phase is decoded which passes beyond one of the two decision thresholds (= axis in figure 9.9), there will only be one erroneous bit.

Before transmission, the IF signal is upconverted to radio frequency.

In this way two bits per symbol are transmitted; hence in ideal circumstances the utilisation of the bandwidth, referred to the gross bit rate, is $B = 2$ bit/(s · Hz). However, owing to the non-ideal filters (finite width of the filter slopes) the bandwidth utilisation is actually smaller. Depending on the configuration of the system, the ratio between bandwidth and symbol rate (BW/R_s) would be in the range of about

$$\frac{BW}{R_s} = 1.27 \frac{\text{Hz}}{\text{symbols/s}} \quad (9.1)$$

Hence the bandwidth utilisation would be about

$$B = \frac{\text{bits per symbol}}{BW / R_s} = \frac{2 \text{ bits/symbol}}{1.27 \text{ Hz} / \frac{\text{symbols}}{\text{s}}} = 1.57 \frac{\text{bit}}{\text{s Hz}} \quad (9.2)$$

The bandwidth utilisation can also be referred to the net bit rate, i.e. to the number of information bits only, without the error protection. In this case the calculated value, as indicated above, must be multiplied with the code rates of the outer and inner codes.

9.4 Decoding Technique

On reception of the signals transmitted from the satellite, the processing steps that were carried out at the encoder have to be reversed. In particular, the errors which occurred in the channel must be corrected. Moreover, it is necessary to recover the synchronising information, which is required for the channel decoding.

The decoder consists of the following components (figure 9.10):

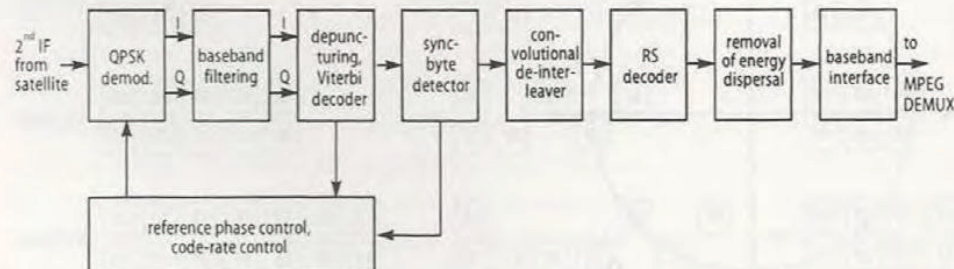


Fig. 9.10. Block diagram of signal processing at the receiving end

mitting end. The synchronisation of the clock frequency generated at the receiver is effected by means of a band-pass filter and a subsequent PLL, where the centre frequency of the oscillator corresponds with the clock frequency, which in turn corresponds with the symbol rate. After an amplitude limitation the clock signal is ready for the digital signal processing.

There are further techniques described in the literature [LEE, PROAKIS, KAMMEYER, MÄUSL] which generate the error signal for the oscillator within the analogue as well as within the digital range.

10.4.5 Demodulation of the QAM Signal

The demodulator has the task of converting the QAM signal to the baseband and simultaneously splitting it into its in-phase and quadrature components. After the temporal multiplication with two carrier signals which are orthogonal to each other in phase, the resulting sum-frequency signals of the two components must be suppressed by one low-pass filter each. If the multiplication and the filtering are achieved by means of analogue signal processing, then both components will subsequently be available for A/D conversion in the baseband.

By using conventional analogue technology a reasonably priced demodulator can be manufactured. The disadvantage of this solution is to be found in the two parallel paths through which the in-phase and quadrature components have to pass before sampling as well as in the parallel sampling itself.

The parallel signal paths can be transferred to the digital level if the modulated signal is fed into a single A/D converter in its entirety. In this case the demodulation is carried out by the multiplication with two digital carrier signals. The required sampling rate for the sampling of the QAM signal at the IF level, in accordance with the sampling theorem, will have to be at least twice that of the highest frequency to be found in the signal. For transmission in an 8-MHz channel the resulting minimal sampling frequency would be:

$$f_{\min} = 2 \left(f_{IF} + \frac{B}{2} \right) = 2 \left(36.15 \text{ MHz} + \frac{8 \text{ MHz}}{2} \right) = 80.3 \text{ MHz}. \quad (10.14)$$

The high clock rate has various disadvantages when used in consumer receivers (e.g. high cost, high power consumption), so that a totally digital solution must be ruled out at this moment.

A demodulation alternative arises if the QAM signal from the IF range at 36.15 MHz is converted to a second IF range. The centre frequency of the signal should be chosen so as to correspond to the transmitted symbol rate. This technique offers the advantage that the converted QAM signal as a whole can be oversampled by a clock signal of a frequency which is exactly four times the value of the transmitted symbol rate. In the case of a symbol

The "continual pilots" are present in each symbol at the same carrier position (in the case of 2K, for instance, at the 45 positions 0, 48, 54, 87 ... 1323, 1377, 1491, 1683, 1704; in the case of 8K, for instance, at the 177 positions 0, 48, 54, 87 ... 6435, 6489, 6603, 6795, 6816). The distribution along the frequency axis is chosen, so that within one channel no periodicities can occur. Therefore the continual pilots can be used for the coarse adjustment of the frequency of the local oscillator in the receiver. In order to make the synchronising information as robust as possible against transmission errors, the continual pilots have an amplitude which, in comparison to the carriers containing useful information, is increased by the factor $4/3$. That is why they are also called boosted pilots.

The "scattered pilots" are scattered over the transmission frame according to a definite plan. This plan can be easily identified in figure 11.5. The aim of the scattering is, firstly, to make a large number of pilots within each symbol for the fine adjustment of the receiver available. Secondly, the scattered pilots can contribute to the temporal synchronisation. Thirdly, the receiver will be able to perform a nearly continuous analysis of the frequency- and the temporal plane, which can be used for the evaluation of the current channel condition ("channel estimation"). The scattered pilots are also transmitted with increased amplitude.

The "transmission-parameter signalling pilots" (TPS pilots) permit a transmission of additional information with which the temporal synchronisation, i.e. the recognition of the beginning of the transmission frame, can be ensured. Moreover, they provide the information about the transmission parameters used. The details of this will be discussed in the following. The TPS pilots, just as the continual pilots, can be found in precisely fixed carrier positions (in the case of 2K, for instance at the 17 positions 34, 50, 209, 346, 413 ... 1262, 1286, 1469, 1594, 1687; in the case of 8K, at the 68 positions 34, 50, 209, 346, 413 ... 6374, 6398, 6581, 6706, 6799). TPS pilots are transmitted with an amplitude, which represents the average amplitude of all carriers transmitting useful information.

The numbers of the various types of pilots named per symbol cannot just be added to determine the channel capacities lost for the transmission of useful information, as the possibility that a continual pilot may be at a position intended for a scattered pilot cannot be ignored (see figure 11.5). On closer examination it may be seen that each of the continual pilots is co-located in every fourth symbol with a scattered pilot. This results, on average, in 1512 carriers with useful information per symbol in the 2K case, and in 6048 carriers with useful information in the 8K case, which means that approximately 13% of all carriers have to be utilised for synchronisation, etc.

Attention has already been drawn to the fact that the continual pilots and the scattered pilots are individually modulated so that from an analysis of

this modulation the receiver can, among other things, derive information for the tuning. The modulation is carried out in accordance with the structure of a maximum-length sequence, which is known to the transmitter and to the receiver.

Maximum-length sequences (*m*-sequences) are often referred to as pseudo-random sequences. They have some prominent features. One of these is the ideal, pulse-shaped, periodically recurring auto-correlation function, which is of particular importance in this connection [LÜKE 2].

A maximum-length sequence can be generated by a shift register, in which the positions indicated by the descriptive polynomial are linked by means of EX-OR circuits (see also section 9.3). The polynomial used here has the form

$$g(X) = X^{11} + X^2 + X^0.$$

X^{11} represents the input of the first cell; X^0 represents the output of the shift register. All sequences commence with the initialisation condition $X^5 = 1$, in such a way that the first bit at the output of the shift register coincides with the first carrier of a symbol. Further shifting within the register takes place such that there is a shift step to each carrier, independently of whether it is a pilot or not. When the temporally coincidental carrier happens to be a continual pilot or a scattered pilot, a modulation symbol is allocated to the pilot by the bit at the output of the shift register. When this bit is 0, then the pilot is modulated with the positive real part $+4/3$, when the bit is 1, then the pilot is modulated with the negative real part $-4/3$. The imaginary part of the modulation symbol is always zero. If the adjacent carriers in figure 11.5 which form part of a symbol are examined from left to right, i.e. along the frequency axis, a subsampled maximum sequence will be detected at the 176 or 701 positions per symbol at which continual or scattered pilots are to be found. This maximum sequence can now be used for fine-tuning in the receiver.

In every transmission frame the data denoted as TPS are transmitted within each symbol. Basically, they constitute a special data channel, which can carry important information for the duration of every transmission frame. The receiver requires this information for the demodulation of the subsequent transmission frame. The purpose of the TPS data is therefore similar to that of the so-called fast-information channel of the DAB system [ETS 401]. Within each transmission frame there are 68 successive symbols. Each of these symbols contains one bit from a 68-bit TPS word. For the 2K variant 17 carriers per symbol are made available for TPS, and for the 8K variant 68 carriers. In each symbol these TPS carriers all transmit exactly the same individual bits in parallel.

The information prepared by the TPS refers to the modulation procedure (QPSK, 16-QAM, 64-QAM), the constellation model for the case of hierarchical modulation with the possible values $\alpha = 1$ or $\alpha = 2$ or $\alpha = 4$ (see section 11.5), the coderate of the inner error protection ($1/2$, $2/3$, $3/4$, $5/6$, $7/8$), the duration of the guard interval ($\Delta = 1/32$, $\Delta = 1/16$, $\Delta = 1/8$, $\Delta = 1/4$), the OFDM variations (2K and 8K) and the position of the transmission framework within the framework (1,2,3,4). In addition, a cell identifier is also transmitted to identify the network cell from which the received signal is being transmitted [LADEBUSCH].

In view of the importance of an error-free reception of the TPS data, these are transmitted in parallel many times over and are also separately error protected. A shortened BCH code (67, 53) is used. The individual bits are modulated for the TPS carriers with differential 2-PSK (see section 7.2).

A maximum of 68 bits can be used for TPS. 31 bits are required for the word recognition and error protection. 31 bits are used at the moment. The remaining 6 bits are reserved for further use.

11.4 Decoding Technique

The DVB-T standard EN 300 744 only describes the transmitted signal and thus does not specify the receiver side. So various possibilities for the realisation of the units in the decoder are conceivable. The implementation strongly depends on the reception environment. Basically, the processing steps which were carried out at the encoder have to be reversed. In figure 11.6 the fundamental construction of the corresponding receiver is shown

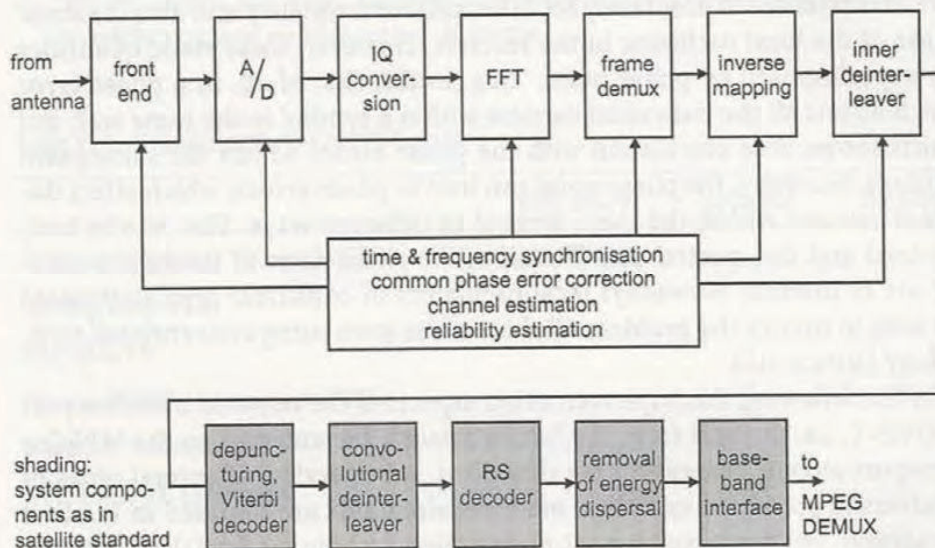


Fig. 11.6. Block diagram of signal processing at the receiving end

[MØLLER]. During the introduction of the first regular DVB-T digital TV service in the UK in November 1998, the first integrated digital receiver chip set was based on 3 chips and only supported the 2K mode. In the meantime single-chip solutions combining A/D conversion, COFDM processing and channel decoding are available and fully standard compliant.

A DVB-T receiver needs to cope with several impairments that occur during terrestrial transmissions (see section 11.1). In addition, the receiver front end will add noise and phase noise to the signal [KLINKEN]. Receiver implementations may differ in the way they handle time and frequency synchronisation and channel estimation. The pilots, which are spread in time and frequency within the OFDM signal, have a known amplitude and phase. Therefore, the measuring of the channel frequency response for attenuation and phase can be carried out on the basis of the continual pilots and on the scattered pilots. Knowing the amplitude and phase of all the individual pilot signals, the receiver is able to equalise each subcarrier. This ideally reverses the effects of the transmission channel. Various so-called channel estimation techniques have an important effect on the overall performance of the receiver [STRUBENH].

The stability of the oscillators required in the receiver is of great importance for the overall performance. On the one hand, the single carriers, which are approx. 1.1 kHz or 4.4 kHz apart, can only be separated free of crosstalk if it can be guaranteed that the sampling is carried out exactly at the zero crossings of all $\sin(x)/x$ functions not belonging to the desired carrier (see section 7.6). On the other hand, it must remain possible for the phase information, which is integrated into the QPSK- or QAM-modulated individual carriers, to be recovered. With the aid of the pilots described before, it is possible to accurately set the oscillator frequency and also the static phase of the local oscillator in the receiver. However, these static quantities are superimposed by phase noise. This results, first of all, in a phase error which affects all the individual carriers within a symbol in the same way, but which shows little correlation with the phase errors within the subsequent symbols. Secondly, the phase noise can lead to phase errors, which affect different carriers within the same symbol in different ways. This is why both the level and the spectral distribution of the phase noise in the local oscillator are of interest. Nowadays local oscillators of consumer type equipment are able to master the problem of phase noise even using conventional technology [MUSCHALL].

In the following the implementation aspects of the network interface part of DVB-T, i.e. the part from the "air interface", the antenna, to the MPEG-2 transport stream generation are described. An overview of several types of receivers is presented and their main requirements are outlined in the first paragraph. For the development of reception techniques for DVB-T signals

extensive experiences of the analogue TV reception can be used. The required components and their specific requirements for DVB-T signals are explained in the next section, followed by some new technologies which evolved with the development of digital television.

11.4.1 Receiver Classes

With the focus on implementation aspects it is most important to first determine in which reception environment, namely stationary, portable, or mobile, the receiver device will be operated. While the option "stationary" is mostly associated with reception by a rooftop outdoor antenna and a device which is not very often moved from one place to another, "portable" means that the device can easily be carried or taken from one point to another. It will contain a built-in omnidirectional antenna and will mostly be operated in a nomadic mode; i.e. it will not be operated while moving fast. "Mobile" means reception while moving at high speeds in automobiles, buses, trains, and so on.

In table 11.2 various DVB-T receivers and their main operational environment are outlined. For each of these devices a different reception concept is required. Some characteristic key points related to these devices are:

- A high-end IDTV set will need a high-end reception system which gives optimum reception under difficult (but stationary, sometimes indoor) receiving conditions. It may contain one antenna within the housing of the whole IDTV but can also use an external indoor antenna as well as an outdoor rooftop antenna.
- Set-top boxes are quite similar, maybe with less performance. They will possibly contain an integrated antenna.

Table 11.2. General classification of DVB-T receivers

	stationary	portable	mobile
Integrated Digital TV set (IDTV)	X		
Set-top Box (STB)	X		
Portable TV		X	
Personal Digital Assistant (PDA)		X	X
Home-PC extension	X		
Notebook-PC extension		X	X
Car receiver			X

- The emphasis of handhelds and PDAs is on a lowest possible power consumption combined with smallest packaging. Nevertheless they will be used under quasi-mobile receiving conditions. Also these receivers often have to be "world receivers", allowing reception in all possible environments (frequency range, channel arrangement, bandwidth) and they should be able to handle all possible DVB-T parameter combinations. These devices have to work with simple rod antennas or antennas integrated into the housing. Sensitivity and dynamic range of their tuners will become a classification and quality mark.
- PC-Extensions (like PCI-cards) or USB-adapters will suffer from the highest price pressure. Often manufacturers of these devices have a limited know-how of RF and IF design techniques and technologies, so they have to buy ready developed modules (so-called NIM, see below). One design aspect will be the interference of the PC environment emitting into the DVB-T receiver device.
- Car receivers have to cope with the most difficult receiving conditions, described by the mobile channel. They will use advanced technologies, for instance antenna diversity. Technically they undoubtedly will be the most sophisticated of all types of receivers. The advantage of a car receiver is that it can be adapted to the (most of the time) window-integrated antenna and pre-amplifier system to get the best performance out of DVB-T. This receiver also has to be a "world receiver" (see above), sometimes a receiver which also features other reception standards, like analogue TV, ATSC or ISDB-T. Due to the requirement to integrate the receiver into the infrastructure of an automobile, most of these devices will be OEM devices. Aftermarket devices will probably only play a small role.

Going deeper into technical aspects of the different devices a further classification is possible. Important factors may be dynamic range, input sensitivity, channel adaptation speed, power requirements and EMC immunity (see table 11.3).

11.4.2 Straight Forward Technology – the Classical Approach

For a first rough overview of a DVB-T reception system one can start with a very "classical" approach of a receiver design. It contains a tuner for down-conversion of the incoming RF signal to the first IF, some IF processing like filtering of the downconverted spectrum, maybe a further down-conversion to a second IF, and finally the DVB-T decoder for demodulating and decoding the baseband signal to MPEG-2 data. Figure 11.7 summarises this approach. It is generally valid for most receivers.

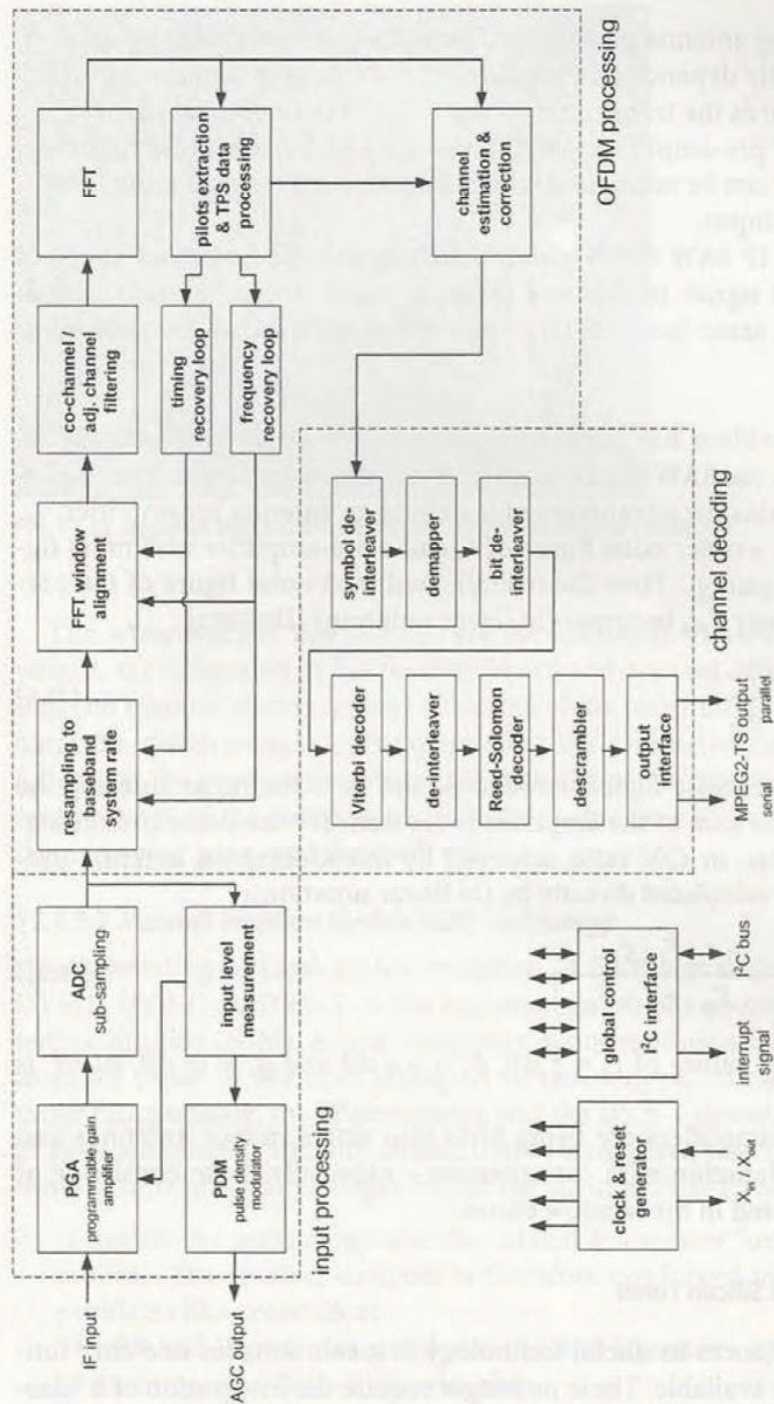


Fig. 11.12. Block diagram of a typical DVB-T decoder chip

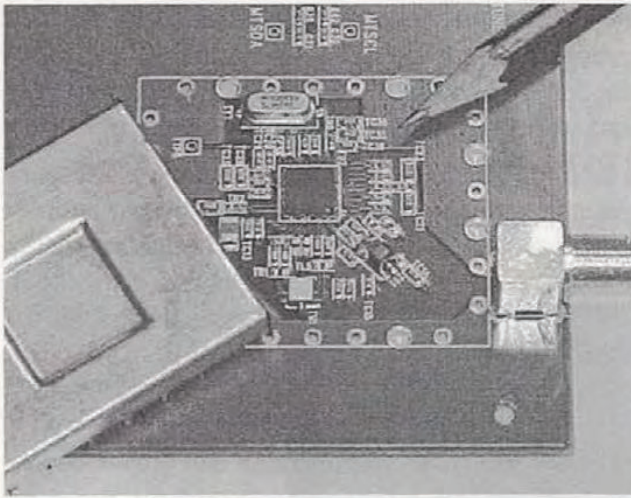


Fig. 11.13 Microtune single-chip tuner integrated onto the receiver's main PCB³

The advantages of this concept are the following: Tuners are small, lightweight, are integrated in the receiver board and are cost-effective in production (no manual placement and soldering of the tuner module). On the other hand the disadvantages in comparison to the more classical tuners are the following: the power dissipation is higher, the performance is slightly lower and the cost of the components is higher – but this list is from a snapshot from the year 2002, and time will tell.

11.4.3.3 Network Interface Module (NIM) Technology

One interesting technology for reception of DVB signals in general – be it DVB-S, DVB-C, or DVB-T- is the implementation of a so-called Network Interface Module (NIM). A NIM integrates in one module all signal processing from RF input to MPEG-2 transport stream output, containing the whole tuner functionality, the IF processing and the DVB-T decoder chip. The size of such a module is roughly double that of a standard tuner module. A NIM shows a number of advantages for the design of a DVB-T receiver:

- It has all the technology and the related know-how "on board", in one module. The receiver designer is therefore not forced to bother with RF problems like crosstalk etc.
- The RF and IF processing and also the PCB layout are optimally adapted to the integrated DVB-T decoder chip.
- NIMs from various manufactures can be interchanged. The control software needs to be adapted, which usually is rather simply done by re-

³ With kind permission of Microtune (TEMIC-Tuners)

designing the appropriate I²C bus routines, and a rather small PCB layout adaptation is typically required.

- Since NIMs are available for the different DVB transmission systems, namely satellite, cable, and terrestrial, they allow for the design of exactly the same receiver for all DVB systems.

Figure 11.14 shows a typical Network Interface Module (NIM).

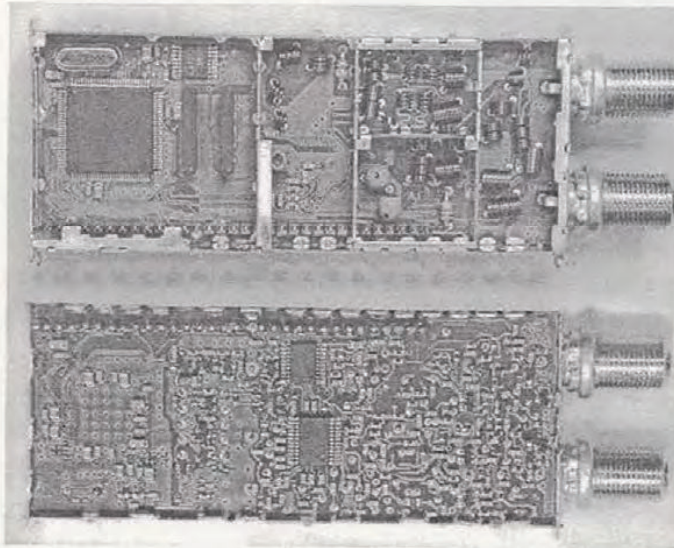


Fig. 11.14 Network Interface Module (NIM) from Philips⁴ (top and bottom view)

Integrating a NIM into a receiver design is a good choice for PC-extension cards and for set-top boxes. If the performance is good enough they may be used for IDTVs. But for other receiver classes, NIMs have two main disadvantages:

- The size of a NIM is still quite large, so it may not be the perfect choice for small receivers like in PDAs or USB card extensions.
- It is not possible to control the RF- and IF-processing parameters, especially of the AGC from outside the NIM. These parameters, therefore, cannot be adapted or optimised for difficult reception conditions like the mobile channel. The NIM is therefore less suited for automotive receivers and PDAs
- The designer has to take the module "as it is". Exchanging parts, e.g. the DVB-T decoder or the SAW filter, for a part from a different supplier is not possible.

⁴ With kind permission of Philips Components, Business Unit Tuners.