CHAPTER 21.4
TELEVISION BROADCAST RECEIVERS

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GENERAL CONSIDERATIONS

Television receivers are designed to receive signals in two VHF bands and one UHF band, and optionally a complement of the cable-TV channels, according to the United States and Canadian standards. The lower VHF band (channels 2 to 6) extends from 54 to 88 MHz in 6-MHz channels, with the exception of a gap between 72 and 76 MHz. The higher VHF band (channels 7 to 13) extends from 174 to 216 MHz in 6-MHz channels. The UHF channels are spaced 254 MHz above the highest VHF channels, comprising 56 6-MHz channels extending from 470 to 806 MHz. Cable channels extend continuously from 54 to approximately 1000 MHz, also with 6-MHz spacing. Figure 21.4.1[1] shows the CATV channelization plan adopted jointly by the NCTA and EIA in 1983 and revised in 1994. The television tuner is thus required to cover a frequency range of more than 15:1. TV tuners of past generations use separate units to cover the UHF and VHF bands. Current design practice includes the circuitry to receive all bands in a single unit.

The signal coverage of TV transmitters is generally limited to line-of-sight propagation, with coverage extending from 30 to 100 mi depending on antenna height and radiated power. The coverage area is divided into two classes of service, depending on the signal level. The service area labeled class A is intended to provide essentially noise-free service and specifies the signal levels shown.

Channels	Peak signal level, μV/m	Peak open-circuit antenna voltage, μV
	Class A service	
2–6	2500	3500
7–13	3500	1800
14–69	5000	800
	Class B service	
2–6	225	300
7–13	630	300
14–69	1600	250

For the limiting area of fringe service the signal levels are defined as shown for class B service. The typical level of the sound signal is from 3 to 20 dB below the picture level, due to radiated sound power and antenna gain. The block diagram of a monochrome TV receiver for analog signal reception is shown in Fig. 21.4.2.

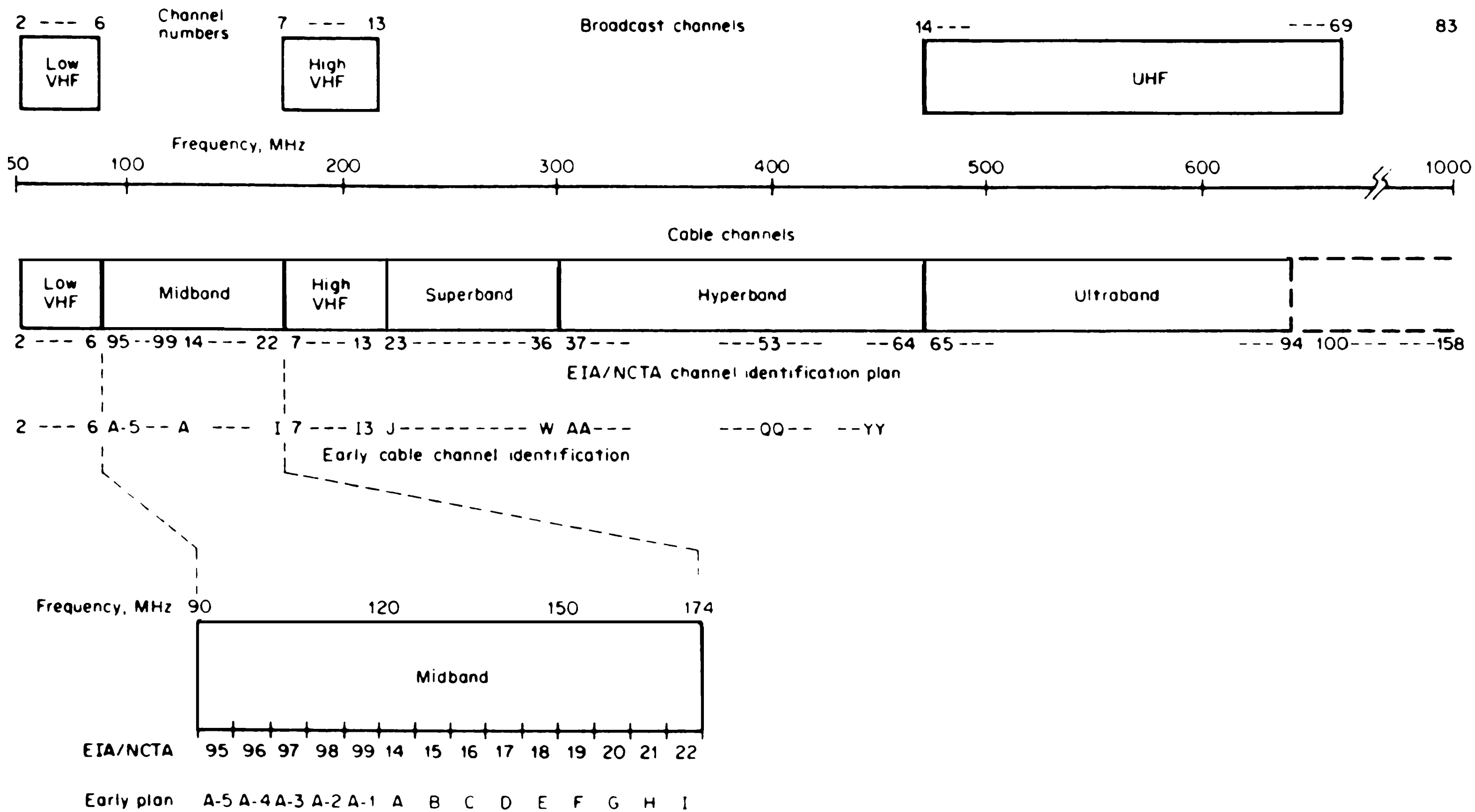


FIGURE 21.4.1 Frequency spectrum and channel designation for broadcast and cable television. (*From EIA IS-6. Revised Aug./1992*)

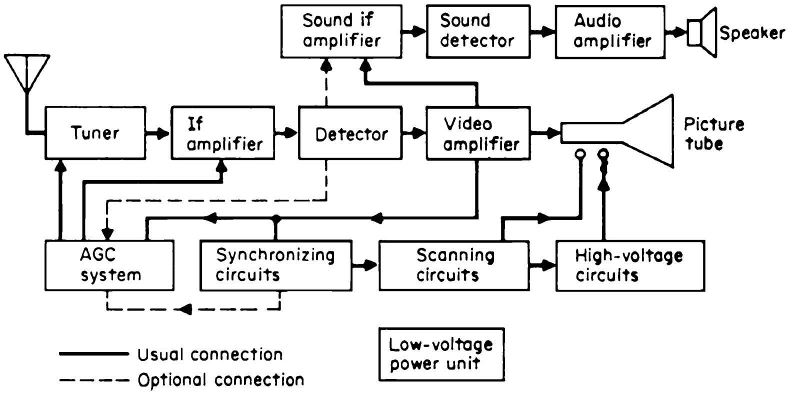


FIGURE 21.4.2 Fundamental block diagram, monochrome receiver. (*From Benson & Whitaker, Ref. 2*)

RECEIVERS FOR DIGITAL TELEVISION TRANSMISSIONS

From Analog to Digital—the Contrast

When comparing a block diagram of the typical receiver for digital transmission to that of a current analog receiver, the first impression is the difference in complexity. A digital receiver (Fig. 21.4.3) contains more functional blocks, several of which differ greatly and have a high degree of complexity while still containing others that are similar to those of an analog set. The digital set contains more silicon ICs, as both memory and signal processor devices, many of which are custom designs at this date, a factor that may increase the set cost by \$200 to \$300 compared to a baseline NTSC set having a similar display size.

One basic advantage of the digital format is the increase in information that can be transmitted in a standard channel (6 MHz for the United States). This leads to packing three to four programs into a channel, or in the case of the U.S. Advanced Television System Committee (ATSC) Standard, a single HDTV signal or a group of up to four standard definition (SD) TV programs. Complexity here involves comparing the nearly 150,000 picture elements in an NTSC picture display to the 2 million picture elements of an HDTV display, an increase of 13 to 1. This equates to an RGB studio signal having 3×1080 active lines $\times$ 1920 samples per line $\times$ 8 bits per sample $\times$ 30 pictures per second, which equals approximately 1.5 Gb/s.[3] By using video compression, especially MPEG-2, this can be reduced to a more reasonable value of 20 Mb/s for transmission as a TV signal.

Many private concerns (broadcast and cable) within the United States as well as other countries are not interested in using digital transmission as a carrier for HDTV pictures. Instead their involvement with digital transmission is for satellite direct-to-home broadcast and for program coverage throughout the country, including a more robust signal throughout all areas for mobile and personal portable use. These diverse requirements have led to differing, optimized, digital RF modulation schemes. For example, the ATSC system uses a vestigial sideband system (VSB), quadrature phase-shift keying (QPSK) has been selected for satellite-to-home, quadrature-amplitude modulation (QAM) is the method chosen for digital cable (D-CATV), and for terrestrial area coverage in several countries outside the United States the orthogonal frequency division multiplex (OFDM) multicarrier modulation scheme has been selected. Each of these leads to differences in the receiver configuration as will be described later.

With current analog TV signal transmission, as the distance from the transmitter to the receiver increases, the picture becomes progressively noisier (snowy), until it is judged as “unwatchable,” although the sound might still be acceptable. With the digital signals and the high degree of data compression, however, the picture remains crystal clear and noisefree until a certain distance from the transmitter (deteriorating signal-to-noise ratio by 1 to 2 dB) at which point the picture suddenly breaks up and is completely lost (brick wall effect,

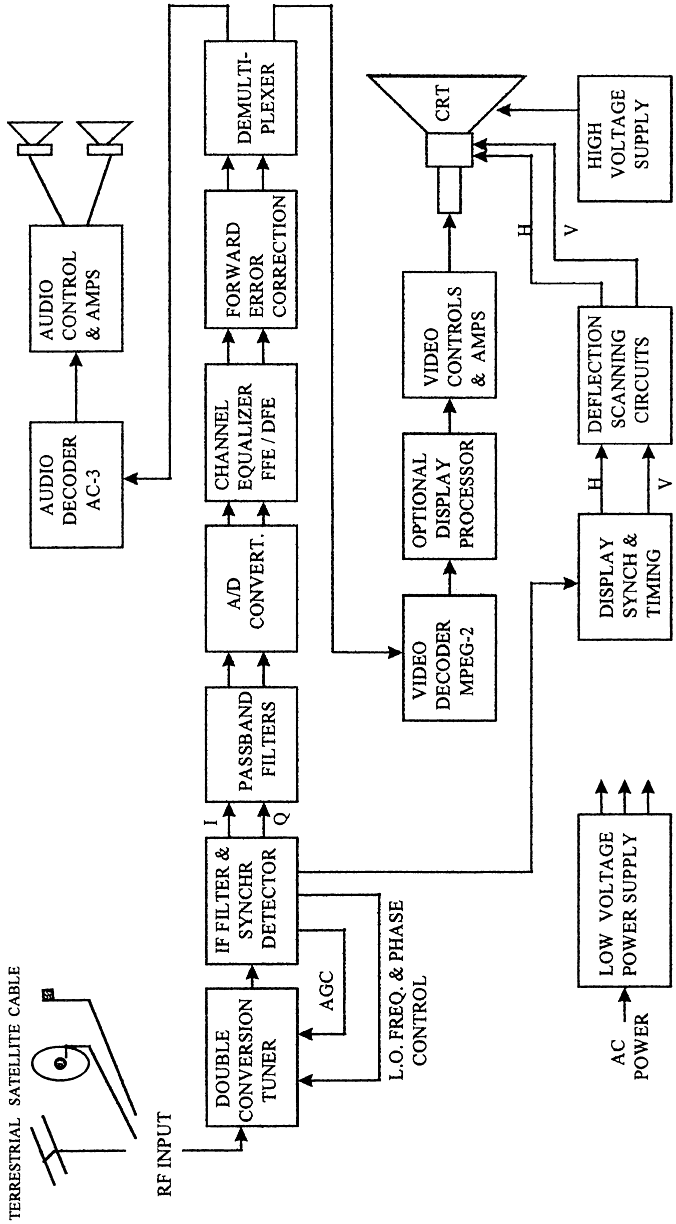


FIGURE 21.4.3 Block diagram of typical receiver for digital TV transmissions.

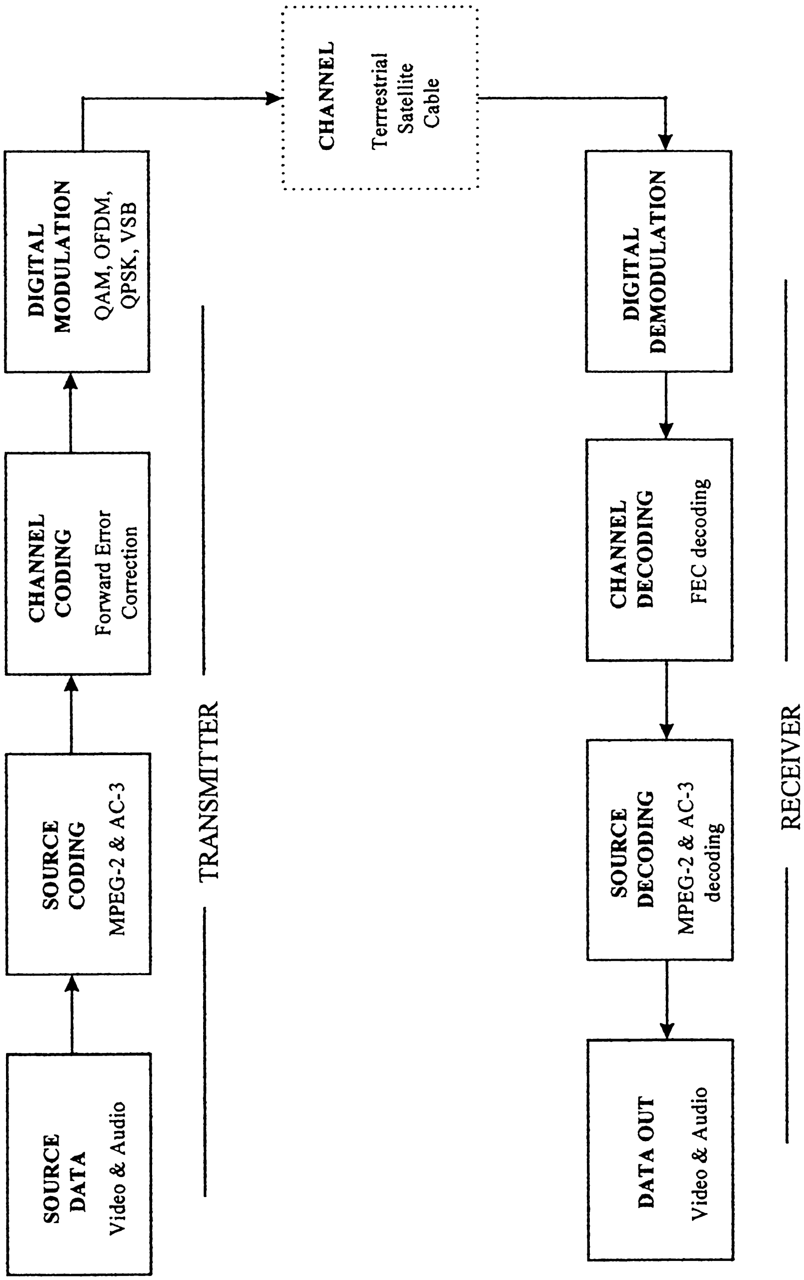


FIGURE 21.4.4 Basic elements of a digital TV system.

sometimes referred to as the waterfall effect) as compared to the gradual deterioration of an analog TV signal. A similar phenomenon can be observed in a satellite-to-home system. A storm cloud or leaves on trees can reduce the signal level just below the threshold at which point the received picture is lost completely, again a change of only 1 to 2 dB. In an effort to overcome the deficiencies of the transmission channel such as ghosts, noise, fades, and co-channel interference, the digital signal is encoded with forward error correction (FEC), often called channel coding, at the transmitter end. This necessitates complementary decoding at the receiving end, as shown in Fig. 21.4.4. The various types of encoding used with current digital TV systems are Reed-Solomon, Viterbi, trellis, interleaving, and convolutional, or a combination of these (concatenated coding system), depending on the robustness of the channel (cable, satellite or terrestrial).[4] For a cable system, this additional signal processing ensures high-quality service throughout the entire system with no signal deterioration at the extremities.

The final difference to be discussed is the mapping of the demodulated video signal onto the display means (CRT, LCD, and so forth). Typically, this will be one-to-one, that is, the display system will be designed to match the specification (scan lines and pixels or samples per line) of the decoded video. This is true except for the ATSC system where five distinctively different video formats have been allowed for transmission. In the receiver, these must be converted to the natural parameters of the display device (display field rate, interlaced or progressive display, lines per field, and samples per line). Details will be covered in a later section.

Set-top boxes and high-definition (HD) or digital-ready TV sets will be the mechanism that brings digital technology to the consumer for the next several years as the transition from analog to digital takes place. Currently within the United States three of the modulation techniques to be discussed later have become "standards" in a particular application, i.e., VSB for terrestrial, QAM for cable, and QPSK for direct-to-home satellite. Although the ability to design a TV set that can accommodate all three exists, the cost to the consumer would be prohibitive. To include a range of sets in the retail product line to handle each individual application might be cost effective, but would be prohibitive to the retailer as well as very confusing to the customer. In order to achieve flexibility needed by customers who have changed their TV delivery service frequently over the years, a set-top box that is unique to the service has become the answer. Not only does this solve the input signal demodulation problem in an economic way, the output of each box connects to a standard, existing NTSC receiver, thereby allowing the customer to use his old set with the new service. Typically, for cable and satellite, these boxes are rented from the local cable provider or the retail outlet that sells and installs the satellite system hardware. Recent set-top boxes from at least two manufacturers have included the dual function of being a terrestrial HDTV decoder as well as a satellite decoder for the DirecTV system. This eases the "Which box should I buy?" decision for the consumer. Signals available from these boxes include composite video (CVBS), S-video (Y/C) for standard TV receivers, and high-resolution component video (Y, P_b, P_r) and RGB to drive HDTV-ready monitor receivers.

Although new fully integrated digital HDTV sets are available on the market, their price is still considerably above the standard market level for a TV set. The most popular designs currently available are the "HD Ready TVs," which have upgraded display capability consisting of wider bandwidth video, up to 30 MHz, progressive scan, a higher-resolution CRT or projection display mechanism, and input connectors and wide-band circuitry which accepts progressive ($2f_H$) video signals or interlaced signals ($1f_H$) and convert them to progressive. A block diagram of an HD-ready receiver design is shown in Fig. 21.4.5.

QAM DIGITAL MODULATION

QAM digital modulation has been found to be advantageous for cable systems because of its simplicity, robustness, and its ability to deliver high-quality video signals in a 6-MHz channel over a hybrid fiber/coaxial network to subscriber homes where the signals are received via set-top boxes. The QAM signal can be considered to be a double-sideband suppressed carrier amplitude-modulated scheme. The input data bit stream is split into two independent data streams with one modulating the in-phase carrier while the other modulates the quadrature carrier component. Higher-order systems (M), e.g., $M = 16, 64, \ldots$, contain additional sets of carriers that are evenly phase spaced from the others.[5] Figure 21.4.6 shows a block diagram of a QAM receiver that can decode either the usual 64-QAM (20 Mbit/s) or the higher information density 256-QAM signal (40 Mbit/s).[6]

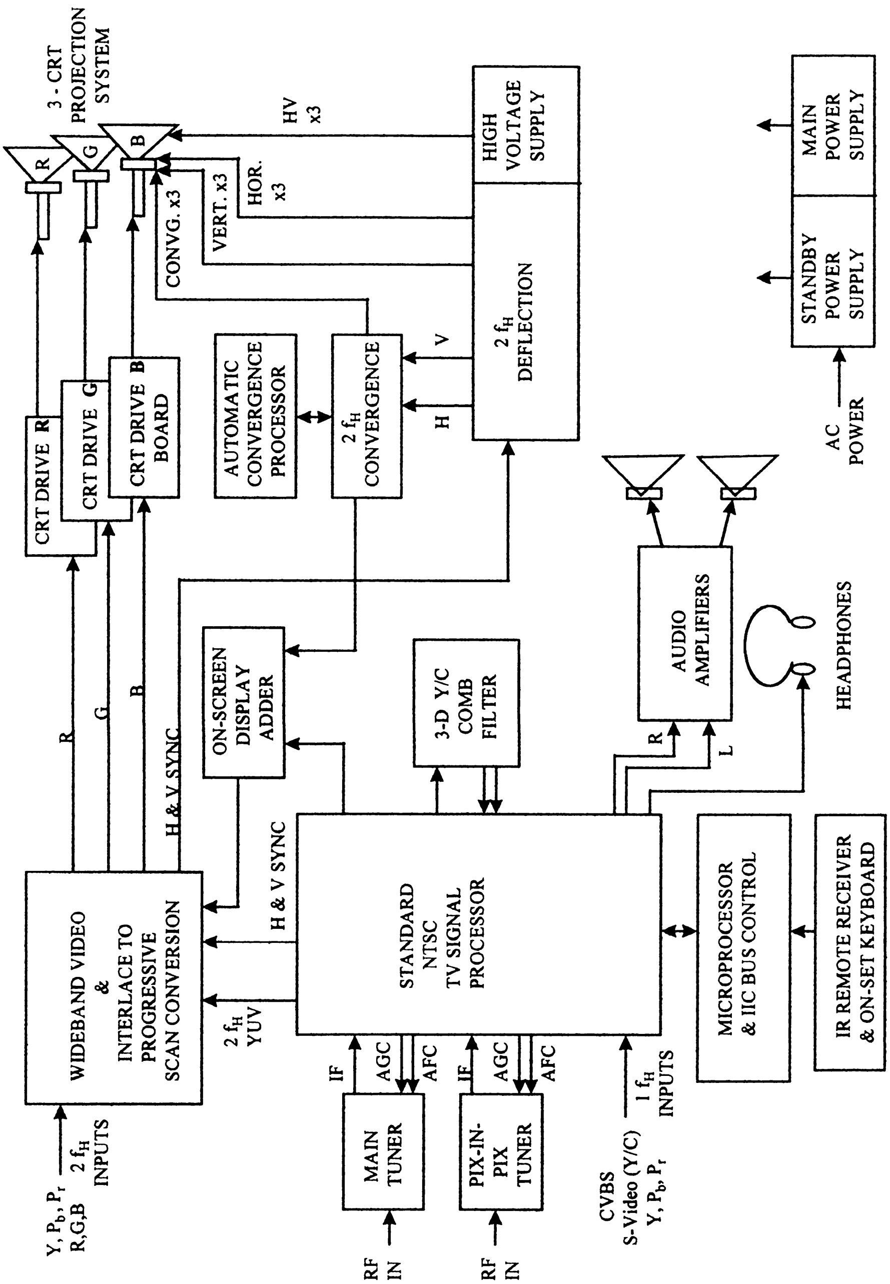


FIGURE 21.4.5 HD-ready TV receiver block diagram.

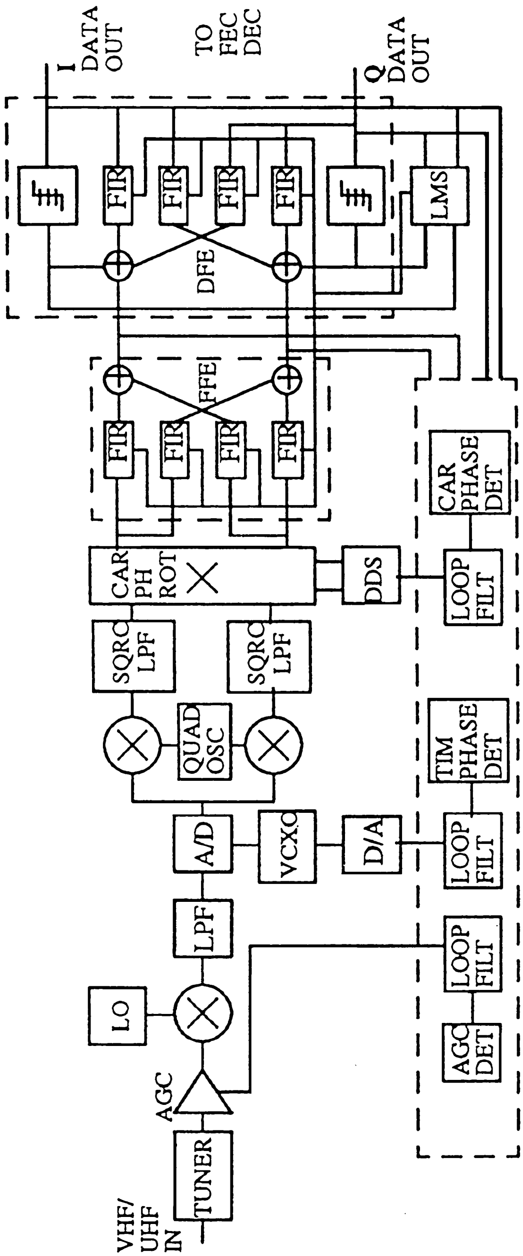
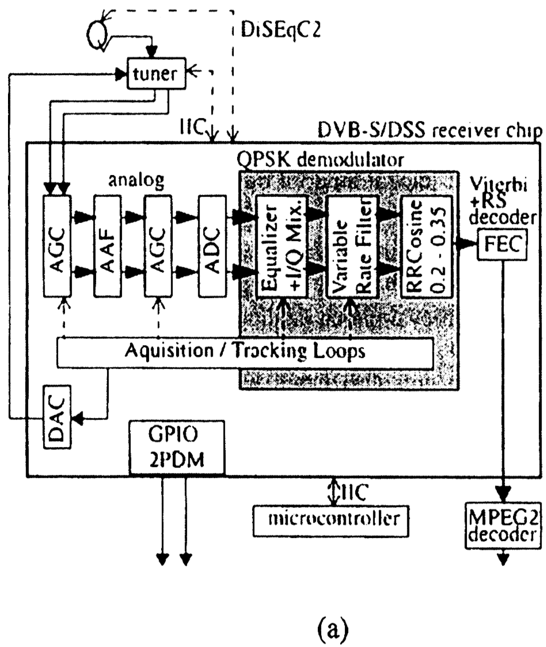


FIGURE 21.4.6 Block diagram of a QAM receiver. *(From Ref. 6)*



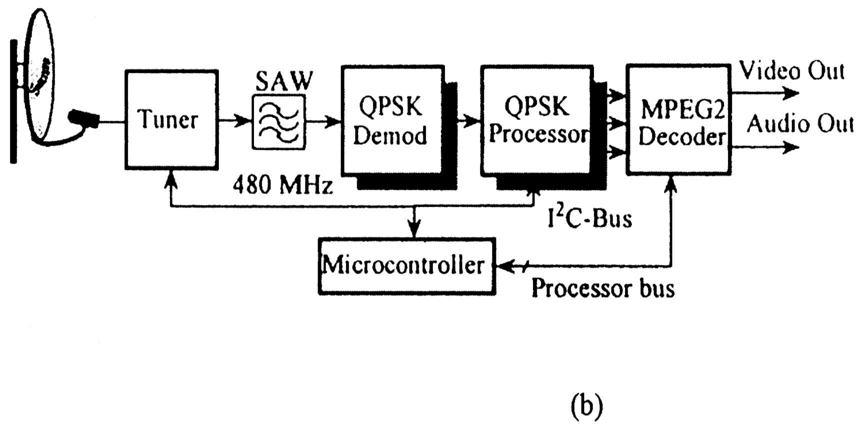


FIGURE 21.4.7 Receivers for QPSK transmission: (a) demodulation after A/D conversion; (b) demodulation prior to A/D conversion. (*From Refs. 9 and 10*)

The tuner is of conventional TV tuner design with somewhat tighter specs for local oscillator phase noise and hum modulation. An AGC amplifier maintains a constant signal level to the second mixer that transposes the IF signal to baseband where it is low-pass filtered to remove all frequencies that would cause aliasing in the analog-to-digital A/D converter. The signal is then demodulated into in-phase I and quadrature Q components and again low-pass filtered. Because free-running oscillators were used in earlier stages, a carrier phase rotation corrector stage is needed to realign the amplitudes of the I and Q components. This stage is part of a feedback loop that uses equalized I and Q as inputs. An adaptive equalizer consisting of a feed-forward section and a decision-feedback section removes amplitude and phase distortion caused by reflections and imperfections in the previous filters and the transmitter upconverter. These equalizer stages are made up of sections of programmable-tap FIR filter sections. Following equalization and symbol quantization, the forward error correction takes place. The data are then fed to MPEG-2 and AC-3 source decoders (not shown) for final processing. Two somewhat modified implementations of QAM demodulators for cable TV application are given in recent literature.[7,8] In the first, the QAM waveform is sampled at a low IF instead of baseband. This has led to simplified hardware implementation, whereby QAM decoding, including equalization, is achieved on one IC chip. The second design, also intended for use in a set-top cable box, describes two ICs; one performing as downconverter, containing the IF amplifier, local oscillator, quadrature demodulator, and AGC. The second IC contains antialias filters, A/D converters, digital I/Q demodulators, frequency and time domain equalizers, symbol-to-byte mapping, and Reed-Solomon forward error correction.

QPSK QUADRATURE-PHASE-SHIFT KEYING

QPSK quadrature-phase-shift keying is the accepted digital modulation for satellite-to-home application. This technique is used in direct broadcast satellite (DBS) systems in the United States (DirecTV and others), the European direct video broadcast (DVB) Eureka system, and the Japanese 8-PSK system. *M*-PSK is similar to *M*-QAM in that multiple phases of the carrier ($M = 4$ for QPSK, 8 for 8-PSK) are modulated by split bit streams. The modulation, however, is only phase, thereby leading to a constant amplitude RF signal. At the receiver, the process is similar to that for QAM, except that the decision leading to reconstruction of the transmitted bit stream is made only on phase information.[5] A receiver block diagram and circuitry, therefore, is very similar to that shown earlier for the QAM case. Circuits that convert the signal to a baseband digital signal before demodulating the QPSK signal as well as the alternate process of demodulating QPSK as an analog signal at IF, then doing the remaining signal processing, have been built.[9,10] In the former, extensive analog circuitry is used after the tuner to accomplish antialias band filtering, AGC and A/D conversion. A block diagram is shown in Fig. 21.4.7*a*. The block diagram of the second approach, Fig. 21.4.7*b*, is similar to that shown for a QAM receiver in Ref. 7, except that the QPSK demodulator consisting of a quadrature demodulator with $4\,f_{if}$ local oscillator is located in the first IC with outputs to the A/D converters being baseband analog I and Q signals. In both cases, the QPSK demodulation is followed by channel decoding, which includes filtering, deinterleaving and FEC, usually Reed-Solomon type. Synchronizing either to the carrier or to the recovered I and Q signals, Fig. 21.4.8, is also an important feedback loop that is contained in most receiver designs of this type.[11]

ORTHOGONAL FREQUENCY DIVISION MULTIPLEX

Orthogonal frequency division multiplex (*OFDM*) can be thought of as a multiple carrier version of QAM in which the individual carriers are equally spaced in frequency across the channel bandwidth. The input data stream is split into parallel blocks of symbols, each of which modulates a separate carrier. The carriers are then summed and transmitted. Owing the orthogonality of the carriers, the sampled output is effectively the inverse discrete Fourier transform of the input sequence. This parallel transmission or multiple carrier modulation (MCM) technique avoids several problems such as fading and impulse noise, which affect single carrier modulation (SCM) systems. At the receiver end, the signal is down-converted and sampled at the appropriate frequency, locked to the transmitted signal, then passed to the discrete Fourier transform demodulator where the

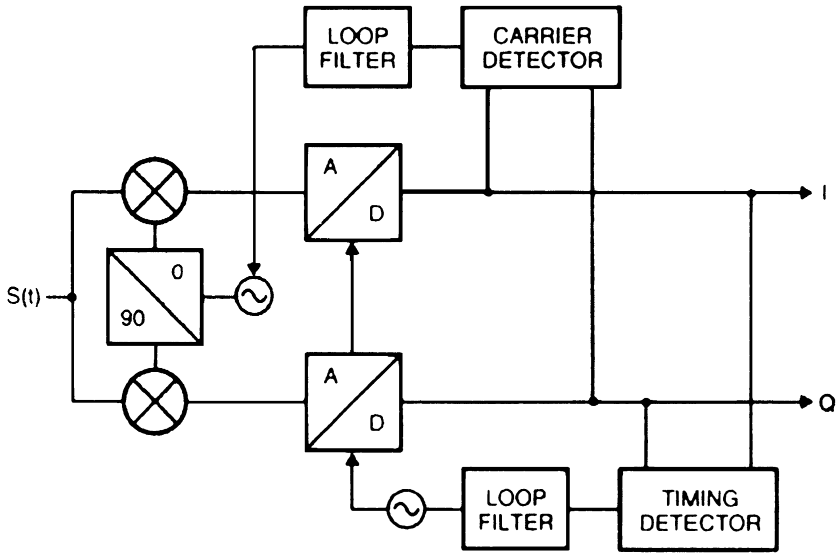


FIGURE 21.4.8 Demodulator concept having both carrier and clock recovery. (*From Ref. 11*)

symbols are recovered.[5] Figure 21.4.9 shows a block diagram of the classical OFDM system for television, including transmitter and receiver. At the transmitter the processes that occur prior to the IFFT are done in the frequency domain, while those after the IFFT are in the time domain. At the receiver, the process is complementary with those processes ahead of the FFT being in the time domain and those after the FFT being in the frequency domain.[12]

OFDM modulation has been selected for digital terrestrial TV broadcast (dTTb) in Europe not only for fixed location reception but also for mobile and portable applications. In the United States, some factions have vigorously pushed for OFDM as opposed to the Grand Alliance vestigial-sideband system, which will be covered later in this section.

An OFDM receiver that follows the block diagram shown previously is shown in Fig. 21.4.10. This design features a single IC chip that contains both analog and digital circuits for implementing much of the OFDM demodulation. The analog part contains an antialiasing filter, AGC stage, and A/D converter, which outputs 8 bit resolution to the digital part of the IC. The digital part of the chip contains a signal detection unit that aids in start-up, channel change and provides AGC; an I/Q mixer for down-converting the signal to baseband; and an I/Q resampler where carrier and sampling clock frequency adjustments are made. The FFT unit can perform either 2k or 8k demodulation. The parallel symbols are then converted to serial bit stream and sent through the Viterbi plus Reed-Solomon error decoding. The output of the chip then consists of a bit stream that is sent to the MPEG-2 decoder for source decoding.

VESTIGIAL SIDE-BAND MODULATION

Eight-level vestigial side-band modulation (8-VSB) was proposed by the Grand Alliance in 1993. A testing phase was completed and the FCC accepted the system in 1995 as the standard for terrestrial digital television including both high and standard definition for the United States. The tests showed that the proposed system was robust to not only in-channel noise, ghosts, or reflections, but also the coexistent NTSC stations which would be broadcasting on the same and adjacent channels during the years of transition from analog to digital. In extensive field tests made in the Charlotte, N.C. area in 1994, the VSB system using 12 dB lower radiated signal than

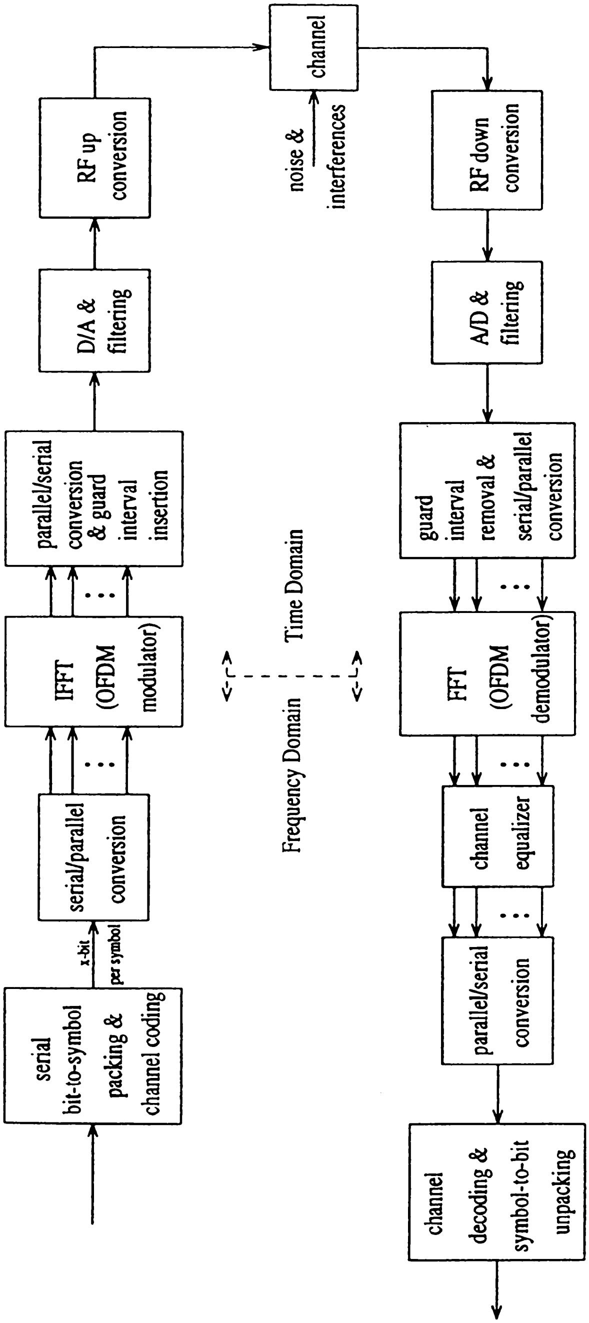


FIGURE 21.4.9 OFDM system diagram. *(From Ref. 12)*

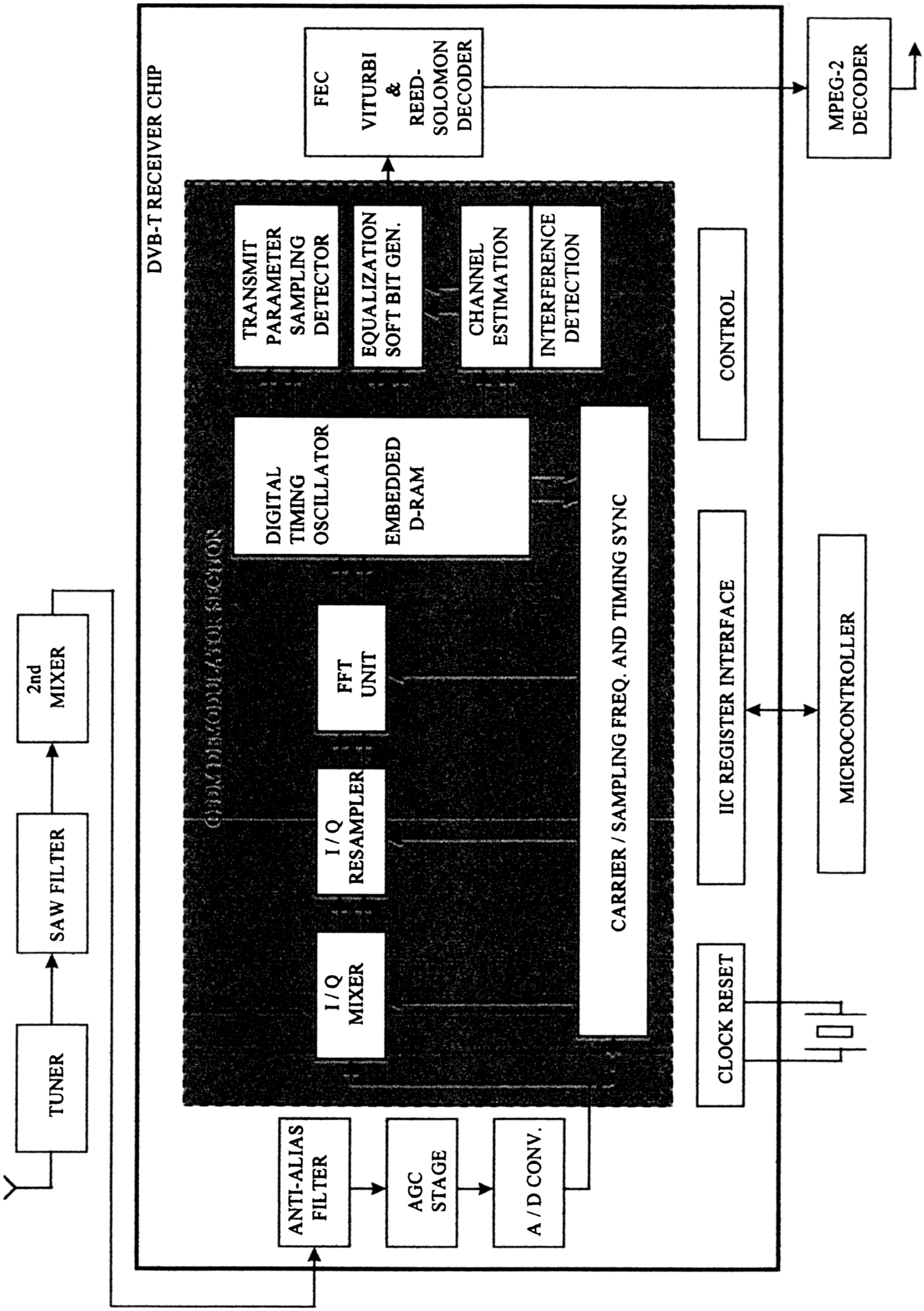


FIGURE 21.4.10 DVB-T OFDM receiver block diagram. *(Redrawn from Ref. 13)*

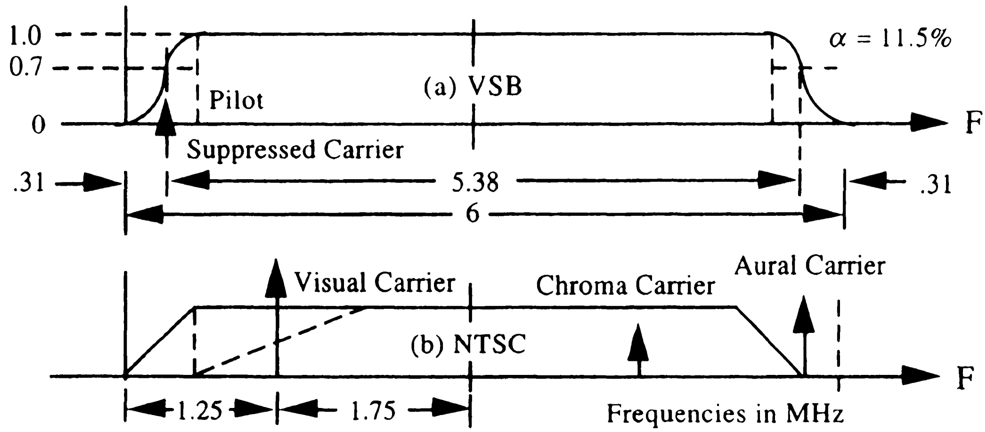


FIGURE 21.4.11 VSB and NTSC RF spectra. (*From Ref. 14*)

the NTSC broadcast outperformed NTSC by a significant margin.[14] The actual calculated and measured margin at which picture or sound deterioration takes place in the presence of white noise favors 8-VSB over NTSC by 19 dB. The spectrum of VSB and NTSC are similar in that both completely fill the 6-MHz channel and that both use a carrier that is located near the lower channel edge. In VSB, however, the spectrum of the modulation within the channel is nearly flat and uniform, as compared to NTSC's chroma subcarrier and sidebands and the FM modulated sound carrier at the upper end of the channel. A comparison is shown in Fig. 21.4.11. Much testing has also been done on cable systems of a 16-VSB modulation system that has a throughout of nearly 40 Mbit/s, double that of the 8-VSB system.[15] The discussions between the Advanced Television Systems Committee and the cable industry to set one standard for HDTV transmission appear to be nearing the consensus stage.

To date, most TV manufacturers have developed and marketed digital TV sets having capability to decode the full HDTV 8-VSB standard. The blueprint for the system and prototype hardware has been reported in numerous technical publications.[14–17] A simple block diagram of the receiver is shown in Fig. 21.4.12.

A similarity can be seen between these major blocks and those shown for the digital TV receivers described earlier, especially the OFDM receiver. Trellis decoding by Viterbi means and Reed-Solomon FEC is a dominant part of each of the receivers. Each has some means to equalize the channel to correct for ghosts and bursts. The VSB system, however, uses only the I component for data recovery and therefore needs only a single A/D converter and channel equalizer instead of the two matched units used in other systems. While the other systems synchronize by using the demodulated data symbols and therefore need quadrature correction circuitry, the VSB system has three transmitted mechanisms for synchronizing the receiver to transmitter. The first is the pilot carrier located 0.31 MHz in from the lower band edge. A frequency/phase-locked loop (FPLL) in the receiver, Fig. 21.4.13, establishes synchronization to this carrier. A noncoherent AGC feedback adjusts the gain of the IF amplifier and tuner to bring the signal into range of the A/D converter. Repetitive data segment syncs consisting of four symbols per segment provide the second synchronizing means. These sync pulses are detected from among the synchronously detected random data by a narrow bandwidth filter. A feedback loop, Fig. 21.4.14*a*, then creates a properly phased 10.76 MHz symbol clock along with a coherent AGC control voltage that locks the proper demodulated signal level to the A/D converter. A third mechanism is to compare the received data field segment with a set of ideal segments (field 1 and field 2) contained in a frame sync recovery circuit within the receiver. This circuit is shown in Fig. 21.4.14*b*.

Following this, a circuit determines if there is a co-channel NTSC signal. If so, the NTSC interference rejection comb filter, a one-tap linear feed-forward filter that has nulls nearly corresponding to the frequencies of the NTSC video carrier, chroma subcarrier, and aural carrier, is switched in Fig. 21.4.15. This filter degrades white noise performance by 3 dB and will not be included in receivers after all NTSC transmitters are silent.

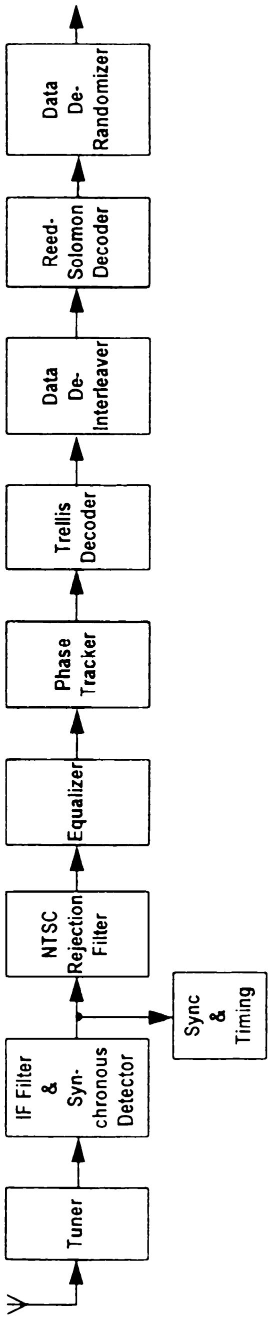


FIGURE 21.4.12 VSB Receiver. *(From Ref. 15)*

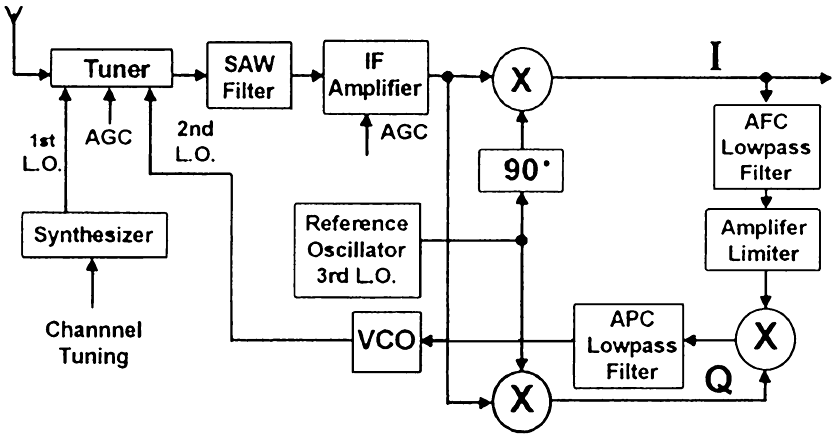


FIGURE 21.4.13 Tuner—IF frequency/phase lock loop. (*From Ref. 15*)

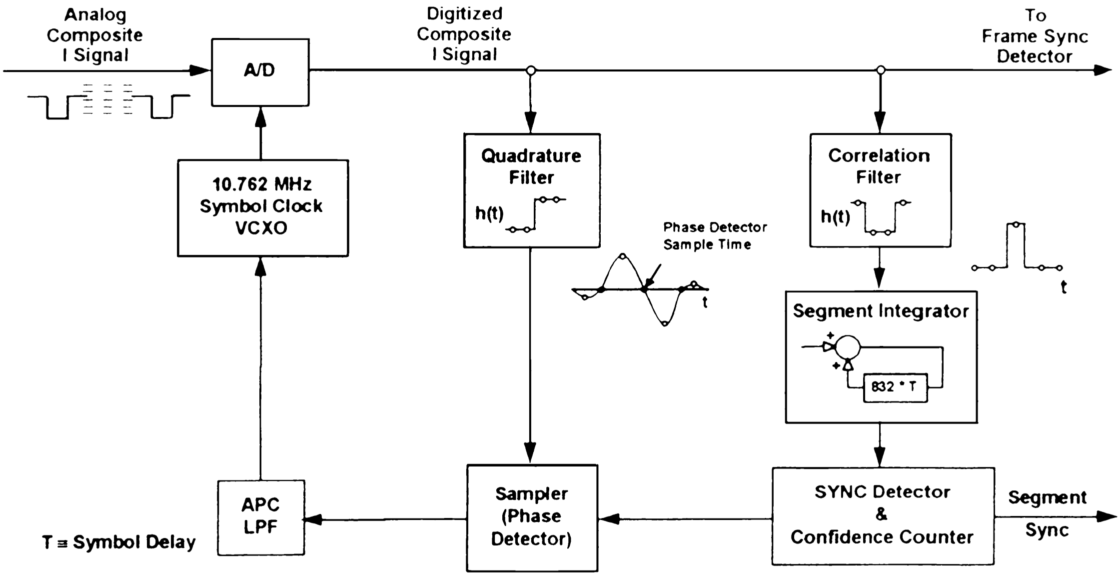
Following the NTSC interference rejection filter is a channel equalizer that compensates for linear channel distortions such as tilt and ghosts. The prototype system used a 64 tap feed-forward transversal filter followed by a 192 tap decision feedback filter. A least-mean-square algorithm was used to compare the transmitted training signal, pseudo-noise sequences which are a part of the data filed sync, to a stored image of the training signal with the error being feed-back to set the tap coefficients. Once equalization is achieved at this level, the circuit can lock on to either data symbols throughout the frame or the data itself for further fine-tuning of the ghost canceling. Airplane flutter is usually too rapid for a full tap evaluation and is therefore handled by the latter technique. A block diagram of the equalizer is shown in Fig. 21.4.16.

The next block in the receiver chain is a phase tracking loop, Fig. 21.4.17, which tracks out phase noise that had not been removed by the Tuner-IF PLL operating on the pilot carrier. This circuit consists of a digital filter that constructs a Q signal from the existing I signal. These signals are then used to control a complex multiplier or phase derotator. It has been reported that the 8-VSB receiver system consisting of the front-end FPLL and the phase-tracking circuit can compensate for phase errors up to –77 dBc/Hz at a 20 kHz offset from the carrier.

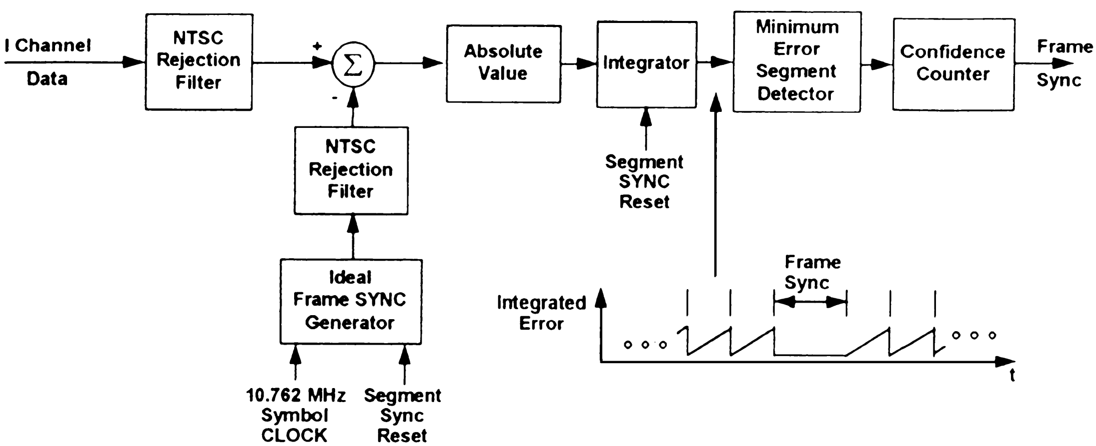
The next block provides deinterleaving of the 12 symbol intersegment code interleaving which was applied in the transmitter. At the same time, trellis decoding takes place in a structure shown in Fig. 21.4.18. Here, one trellis decoder is provided for each branch although in more recent designs, a single trellis decoder is used in a time-multiplexed fashion to reduce IC complexity.[18,19] Following trellis decoding, Reed-Solomon decoding takes place. At this point, channel decoding is complete and the data are ready to be split into the appropriate audio and video packets and sent to the source-decoding circuitry.

The receiver-to-transmitter lock-up and signal-decoding process takes place in the following sequence:[16]

1. Tuner first local oscillator synthesizer acquisition
2. Noncoherent AGC reduces unlocked signal to within A/D range
3. Carrier acquisition (FPLL)
4. Data segment sync and clock acquisition
5. Coherent AGC of signal (IF and RF gains properly set)
6. Data field sync acquisition
7. NTSC rejection filter insertion decision made
8. Equalizer completes tap adjustment algorithm
9. Trellis and RS data decoding begins



a. Segment sync and symbol clock recovery.



b. Data frame sync detection.

FIGURE 21.4.14 (a) Segment sync and symbol clock recovery; (b) data frame sync recovery. (*From Ref. 14*)

SOURCE DECODING

Source decoding consists of decoding the AC-3 audio and the MPEG-2 video which had been encoded at the transmitter using the main profile at high level (MP@HL) specification.[3,16,20] A block diagram of an MPEG-2 decoder is shown in Fig. 21.4.19. Here video frames are created from the compressed packet data and stored

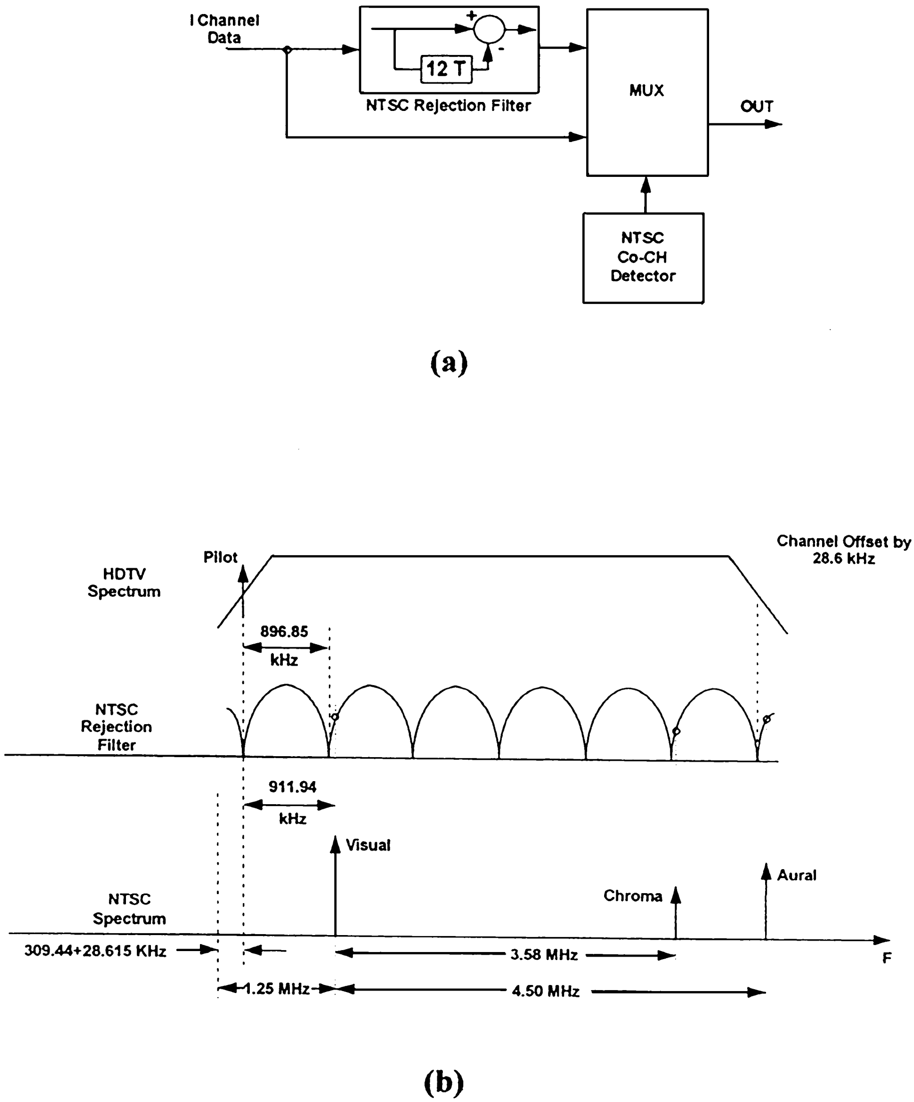


FIGURE 21.4.15 (a) NTSC interference rejection filter; (b) comb filter spectrum. (*From Ref. 14*)

in frame memory. The decoded video is then read out and passed on to the display circuitry of the receiver in whatever format is required by that display.

The final piece of the TV receiver system is the display. The drive requirements of the display do not necessarily match the format of the decoded video signal. In fact, the ATSC Standard permits the transmission of any one of numerous video formats (Table 21.4.1).[16]

The requirement for this section of the receiver, therefore, is to scan convert or format convert the decoded video from the MPEG-2 decoder into the form needed by the display. Typically, this is accomplished by loading the video into RAM-type memory (frame buffer) and clocking the video out at a rate and in a format needed for the display (pixels per line, lines per frame/field, progressive or interlaced fields).[21] In the case where there is not a 1:1 match between the total number of video pixels in a frame and the display pixels, e.g., displaying an HDTV

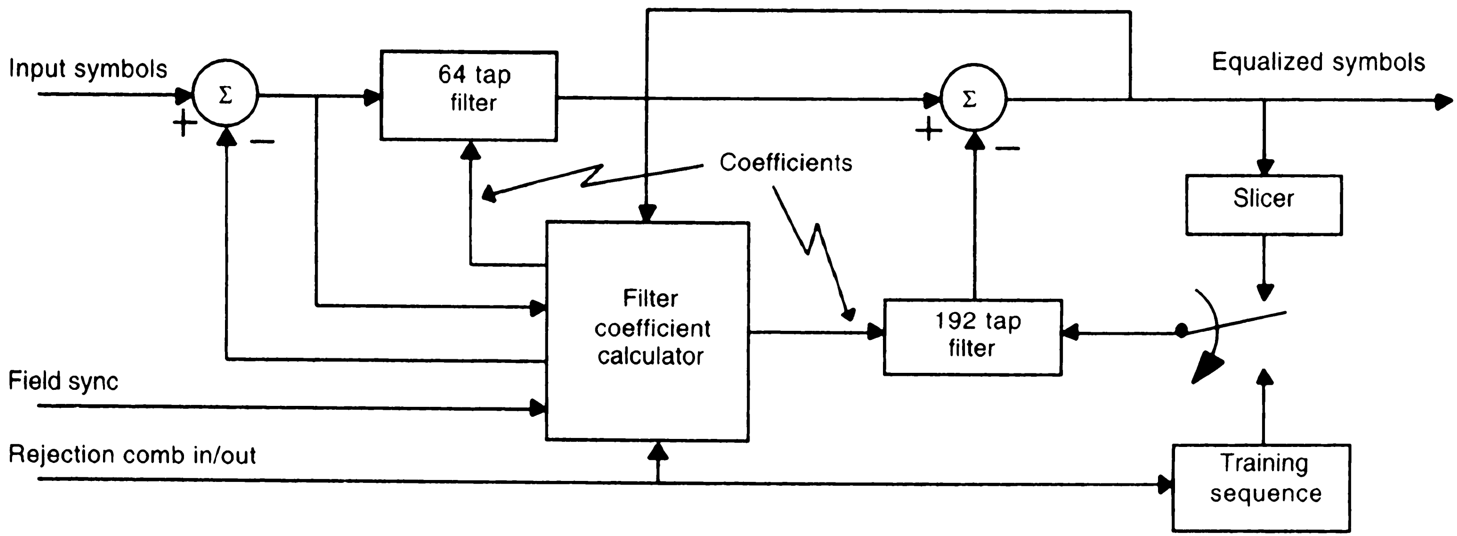


FIGURE 21.4.16 VSB receiver equalizer. (*From Ref. 3*)

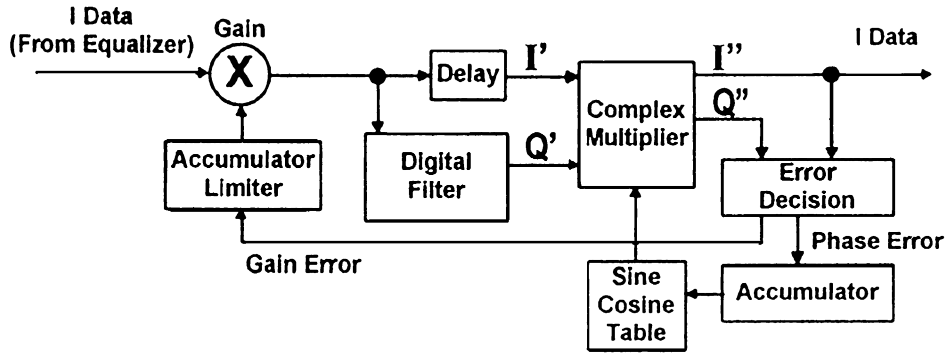


FIGURE 21.4.17 Phase-tracking loop block diagram. (*From Ref. 15*)

signal on a standard NTSC-type SDTV display, an intermediate step of data interpolation, frame storage, and smoothing is needed (Fig. 21.4.20). Often, noise reduction and motion compensation is included in this step. In some newer designs a considerable saving in memory requirements can be achieved when the downconversion of the video information is accomplished within the MPEG-2 decoding process[22,23] (Fig. 21.4.21).

The video signals in the display section are usually in the Y/C format, then converted to Y, P_b, P_r format and finally to analog R, G, B format, especially if driving a direct-view CRT or CRT projection display. The parameters of the final video signals for several of the more popular ATSC display formats of Table 21.4.1 is shown in Table 21.4.2.

Figure 21.4.22 gives a comparison of bandwidth requirements for various values of horizontal picture resolution. It is interesting to note that although the video channel bandwidth requirements are identical for the

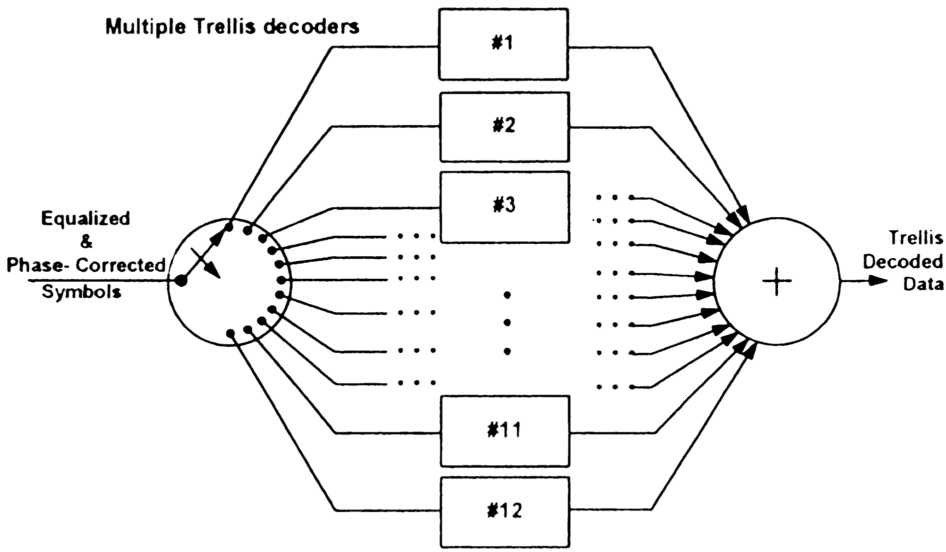


FIGURE 21.4.18 Intersymbol code de-interleaver and trellis decoders. (*From Ref. 15*)

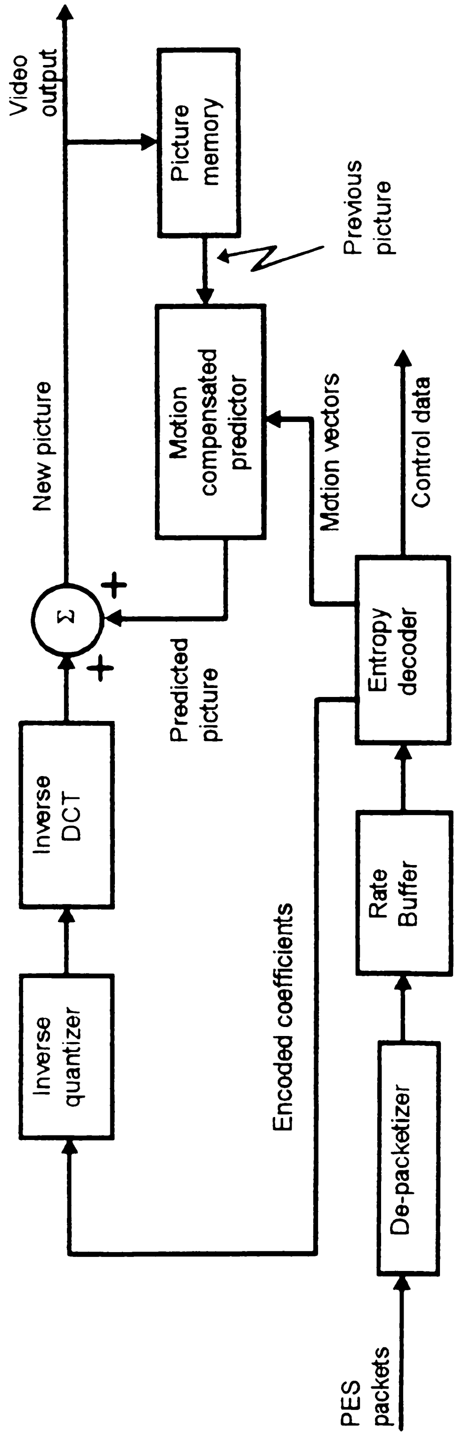


FIGURE 21.4.19 MPEG-2 video decoder block diagram. *(From Ref. 3)*

TABLE 21.4.1 ATSC Digital Television Standard Video Formats (From Ref. 16)

Vertical lines	Pixels	Aspect ratio	Picture rate
1080	1920	16:9	60I, 30P, 24P
720	1280	16:9	60P, 30P, 24P
480	704	16:9 and 4:3	60P, 60I, 30P, 24P
480	640	4:3	60P, 60I, 30P, 24P

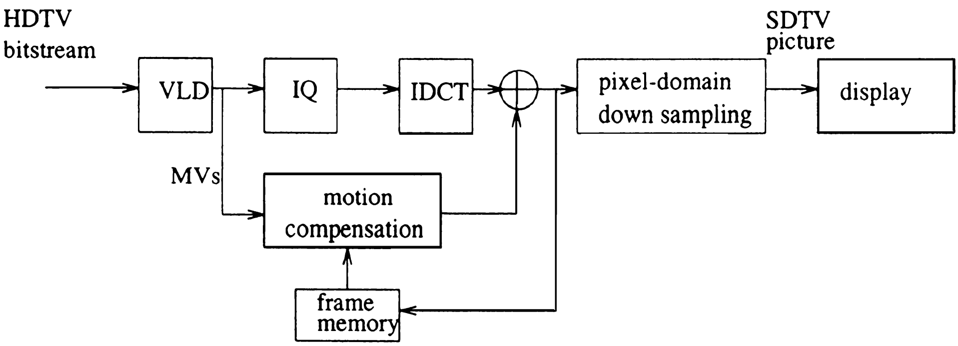


FIGURE 21.4.20 The traditional down-conversion method in the pixel domain. (*From Ref. 22*)

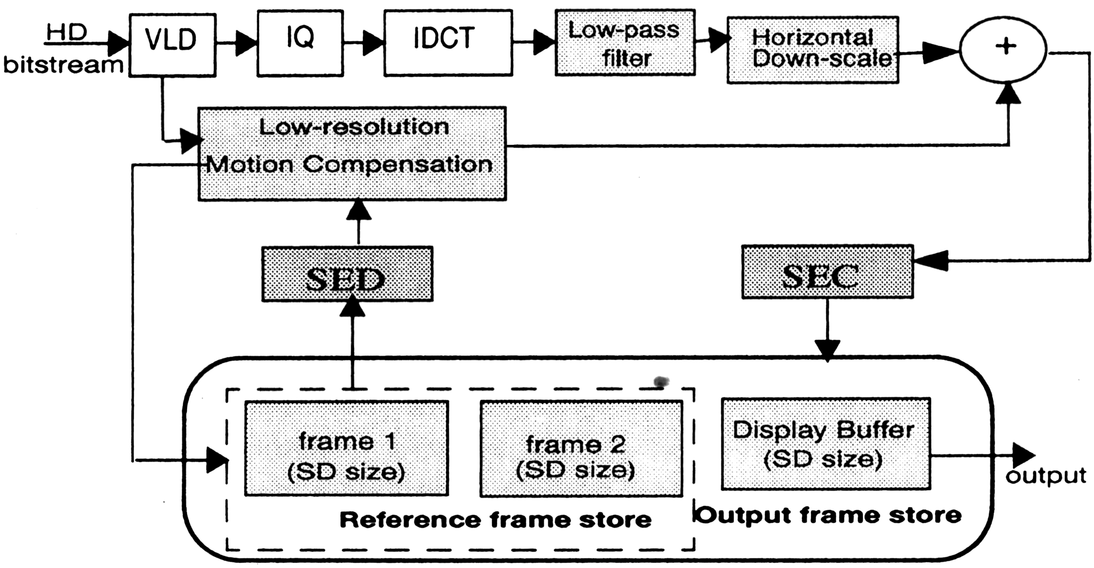


FIGURE 21.4.21 HD to SD low cost decoder. (*From Ref. 23*)

TABLE 21.4.2 Picture Parameters, Video Bandwidth Requirements and Scan Frequencies for Several Display Systems

System	Type	Active picture elements		Total elements	Rate per second	Video bandwidth* (MHz)	Horizontal frequency (kHz)
HDTV	1080i	H pixels	1920	2200			
		V lines	1080	1125	30 frames (60 fields)	37.125	33.57
HDTV	720p	H pixels	1280	1650			
		V lines	720	750	60 frames	37.125	45
NTSC (16:9) (SDTV)	525i	H pixels	704	858			
		V lines	480	525	30 frames (60 fields)	13.5	15.75
VGA (16:9)†	480p	H pixels	704	858			
		V lines	480	525	60 frames	27	31.5

*Similar to ITU-R BT.601-4 which uses only 704 of 720 pixels and only 480 of 483 lines.
†Video bandwidth values are for the Nyquist criterion.

1080i and 720p systems, the picture resolution of the two systems differs by a factor of 1.5. Discussion of how much resolution is really necessary to sell HDTV to the public has been going on for the past 10 years, and may continue. Figure 21.4.23 shows the results of a study made on several integrated HD and HD-Ready TV sets now available in the marketplace. These sets were driven at the video inputs with a 1080i signal and each

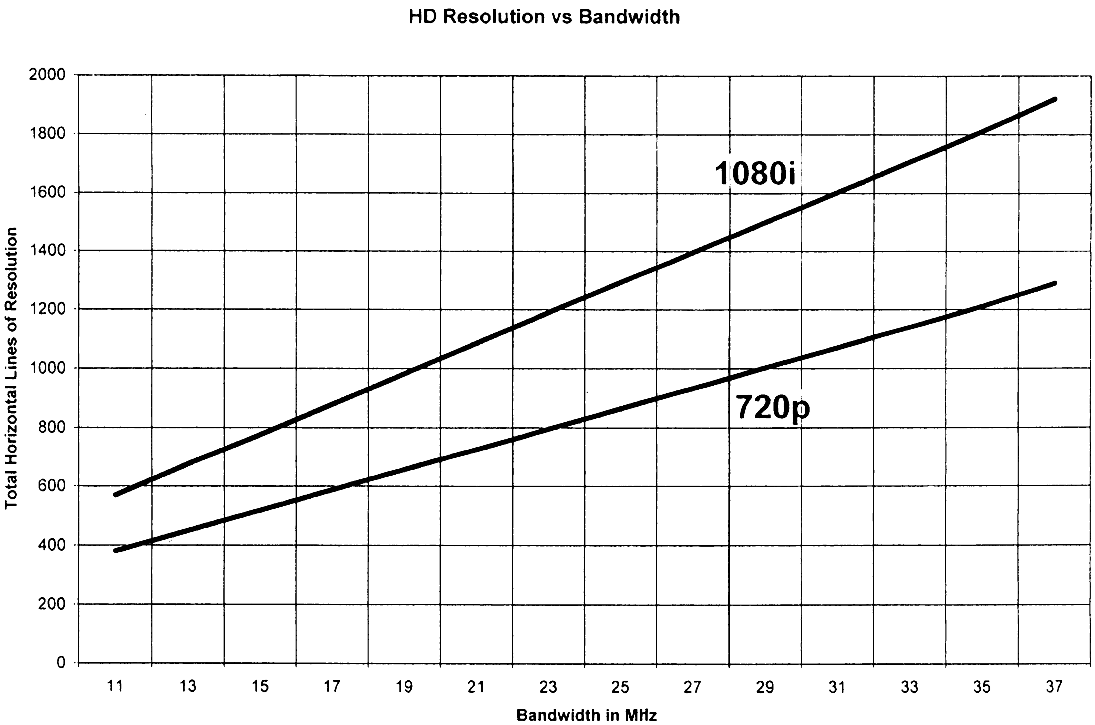


FIGURE 21.4.22 High-definition picture resolution vs. video bandwidth.

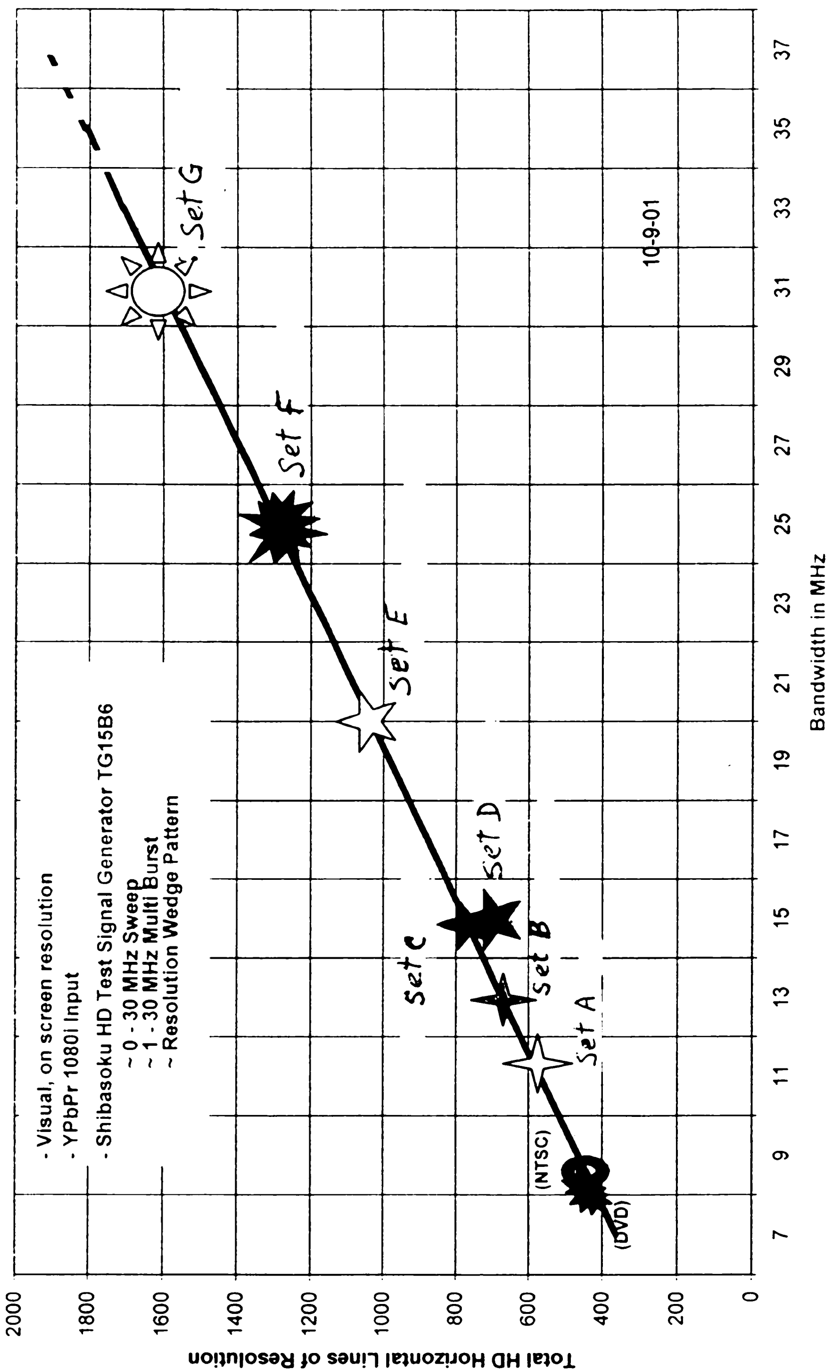


FIGURE 21.4.23 Picture resolution performance of several HD and HD-Ready TV sets.

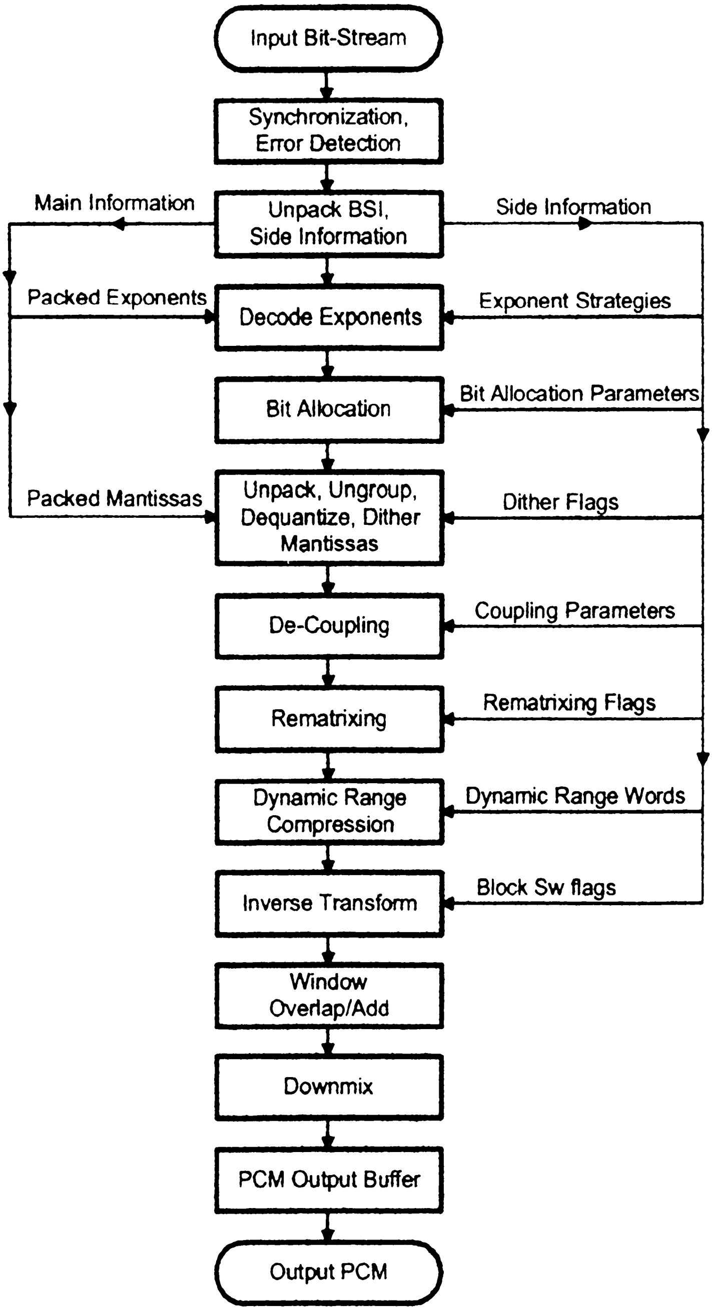


FIGURE 21.4.24 Flow diagram of the AC-3 decoding process. (*From Ref. 25*)

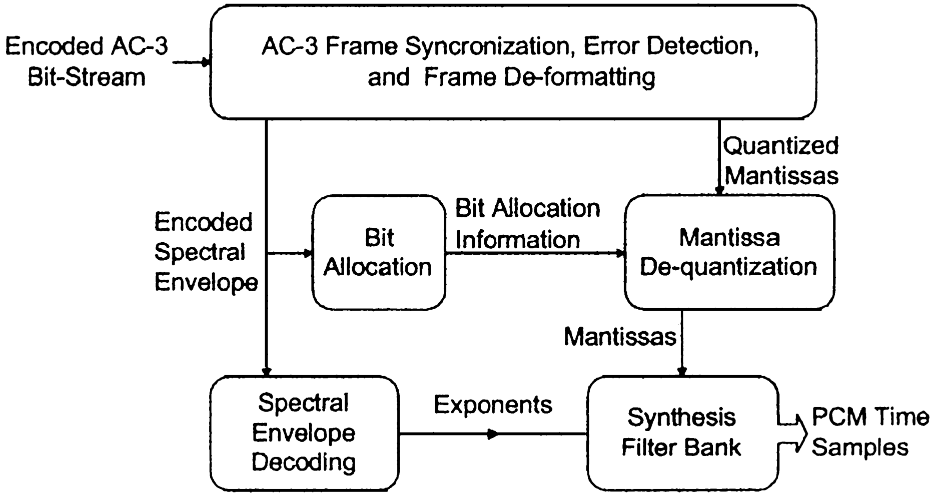


FIGURE 21.4.25 AC-3 audio decoder. (*From Ref. 25*)

either displayed full resolution or down-converted to the native scan/video capability of the receiver. The major diagonal line on the chart represents the 1080i locus with full HD resolution at one end and NTSC at the other. In the case of several receivers, severe aliasing of the multiburst pattern caused the observed picture to be judged to have a lower frequency value than the design intent. Second generation designs will most likely correct these deficiencies.

The audio that had been encoded at the transmitter using the AC-3 specifications is decoded into one to six audio channels, all at line level (left, center, right; left surround, right surround, and low-frequency enhancement sub woofer[25]). Since the low-frequency enhancement channel has an upper bandwidth limit of 120 Hz, it is usually not counted as a complete channel, but only as 0.1 channel, leading to the designation of AC-3 as having 5.1 channels. It is not necessary for a receiver to decode all the available channels. A monophonic receiver will need to provide only one output audio signal. In this case, the receiver's decoder will down-mix the six channels into one. A popular decoder design will provide a down-mix of six into two audio outputs for use in lower cost stereo TV sets.

The AC-3 bit stream is composed of frames each containing sync, encoding/decoding information, and six blocks of audio data. These frames are decoded using the process shown in Figs. 21.4.24 and 21.4.25. Each frame can be decoded as a series of nested loops in which each channel can be handled independently. This process can be accomplished in an audio DSP IC. One such implementation for the full 5.1 channel output uses 6.6K RAM, 5.4K ROM, and 27.3 MIPS. A lower-cost 2 channel implementation requires the same amount of ROM and nearly the same MIPS, but only 3.1K RAM.[24] PCM to analog (D/A) converters, amplifiers, level and balance controls, and speakers complete the audio system.

DISPLAYS

Liquid-Crystal Displays (LCDs)

Use of both monochrome and color LCDs has become popular, especially in small personal portable television receivers. The operation of these devices is not limited by the high-voltage requirements of conventional CRTs. Instead, the picture raster is constructed of a rectangular MOS switching matrix of from 240 to 600 horizontal elements and from 200 to 400 vertical elements.[26] The gates of all the thin-film transistors (TFTs) in a given

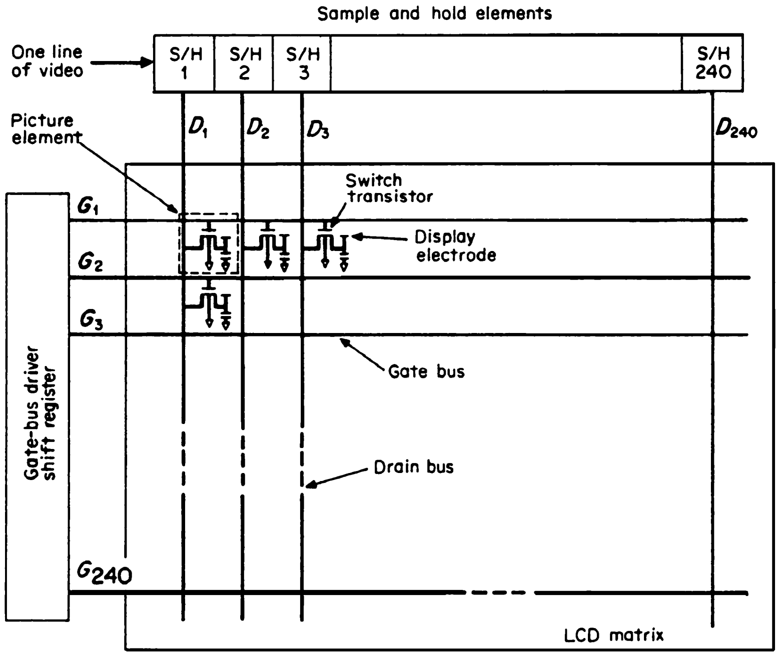


FIGURE 21.4.26 LCD television picture display. (*From Benson & Whitaker, Ref. 2*)

horizontal row are connected to a common bus (Fig. 21.4.26). Likewise the drains of all transistors in a vertical column are connected to a common bus. Vertical scan (row addressing) is produced by sequentially driving the gate buses from the shift register. Horizontal scan, which contains the video information (column addressing), is somewhat more difficult because of the stray capacitance and cross-under resistance associated with drain bus. A given line of video is broken into the same number of pieces as there are pixels in the horizontal row, and stored in the sample-and-hold (S/H) stages, which all drive their respective drain bus lines simultaneously, thus creating a line sequential display. The information on a drain is, therefore, changed only once for each horizontal period (63.5 μs).

A color LCD contains a repeating sequence of red, green, and blue filters covering adjacent pixels of a horizontal row.[27] The sequence is offset by one pixel in adjacent rows. The video and chroma signals are decoded and matrixed in the conventional manner. The *R-G-B* signals are then clocked into the line S/H stages in the appropriate sequence.

LARGE-SCREEN PROJECTION SYSTEMS

The display for picture sizes of up to 36 in. diagonal usually consists of a direct-view CRT. For pictures above 36 in., a relatively new technology has emerged and a number of projection technologies have become popular for domestic use.

Plasma display panel (PDP) systems are a relatively new type of direct view display. Typical sizes have been 40 in. with 4:3 length-to-height ratio, 42 and 60 in. diagonal with a 16:9 length-to-height ratio. The major advantage to a PDP is that it has a depth of only a few inches. This product has been touted as the “picture on the wall.” The structure consists of two pieces of glass separated by an insulating structure in the form of small pockets, cells, or stripes. Each cell is filled with an ionizing gas such as neon and xenon. On the facing sides of the glass plates are metal electrodes, vertical (column) on one and horizontal (row) on the other (Fig. 21.4.27).

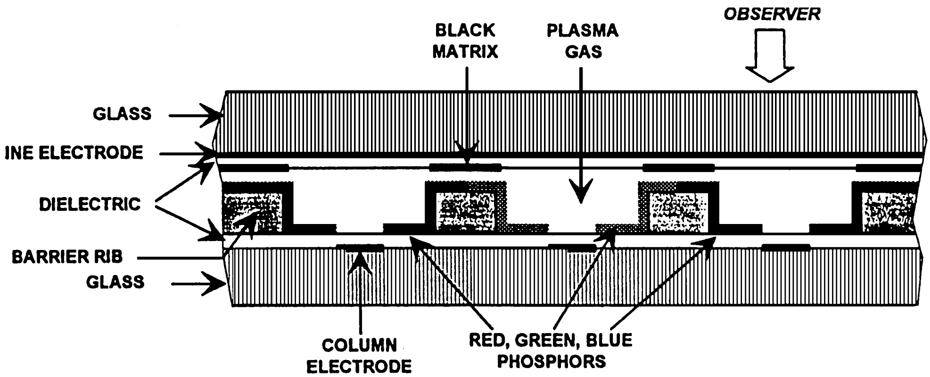


FIGURE 24.4.27 Cross-section of one pixel of an AC plasma display panel. (From Ref. 28)

When a voltage of several hundred volts is applied to a given row and column electrodes, the gas in the appropriate cell ionizes giving off ultraviolet light, thus exciting the color phosphor deposited on the glass plate. Since a cell is either on or off, pulse modulation is used to obtain a shade of gray or a desaturated color. This is accomplished in the driving circuitry by slicing each video field into 8 to 10 subfields and then driving all cells at the subfield rate. The 60-in. unit possesses a resolution of 1280 × 720 (HDTV quality) and has a 500-to -1 contrast ratio in a dark room. The 42-in. units have 852 × 480 or 1024 × 1024 pixel counts. Light output over 500 cd/m^2 has been measured. Although this technology has been shown to produce bright, outstanding pictures, the consumer price is still somewhat higher than any of the other display systems at this time.

CRT projection systems consisting of three cathode-ray tubes, with a typical raster diagonal of 3 to 5 in., produce three rasters in red, green, and blue, being driven by the respective *R*, *G*, and *B* drive signals. These images are projected through three wide-aperture lenses to either a highly reflective screen having a diagonal dimension of 50 in. to 8 or 10 ft (front projection) or to the back of a diffused translucent screen having diagonal dimension of 40 to 70 in. (rear projection) (Fig. 21.4.28). By careful adjustment of the deflection and orientation of the CRTs and lenses, the rasters are brought into precise registry and geometric congruence.[29,30] Various surfaces (typically two or four) of the rear projection screen are impressed with patterns of fine-pitch grooves that form lens elements to "focus" or control the direction of the light as it leaves the screen. Medium screen gains (three to six) are preferred and can be designed for more uniform image brightness over a wider viewing angle. Currently, brightness levels of 600 cd/m^2 can be achieved with rear projection systems having a picture size of 35 to 50 in. measured diagonally. Since the projection system has no shadow mask in its electrooptical path, the system can achieve better resolution than a conventional large-screen direct-view color CRT. At this time, CRT projection is the preferred display system for large screen HDTV.

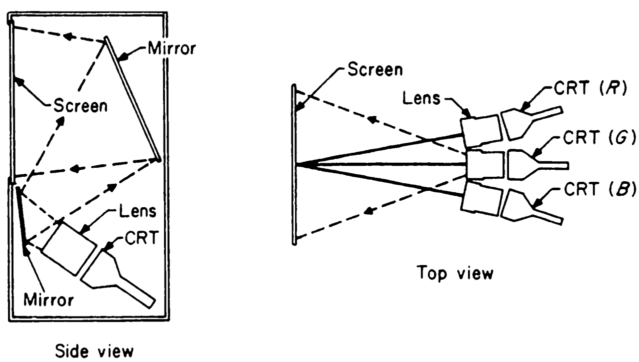


FIGURE 21.4.28 Mechanical arrangement of large-screen rear-projection receiver.

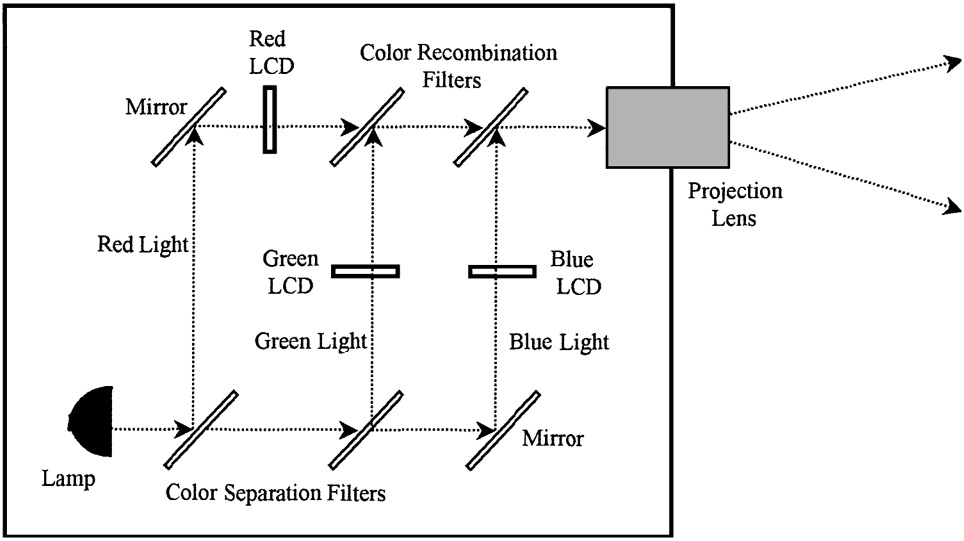


FIGURE 21.4.29 Typical LCD projection system.

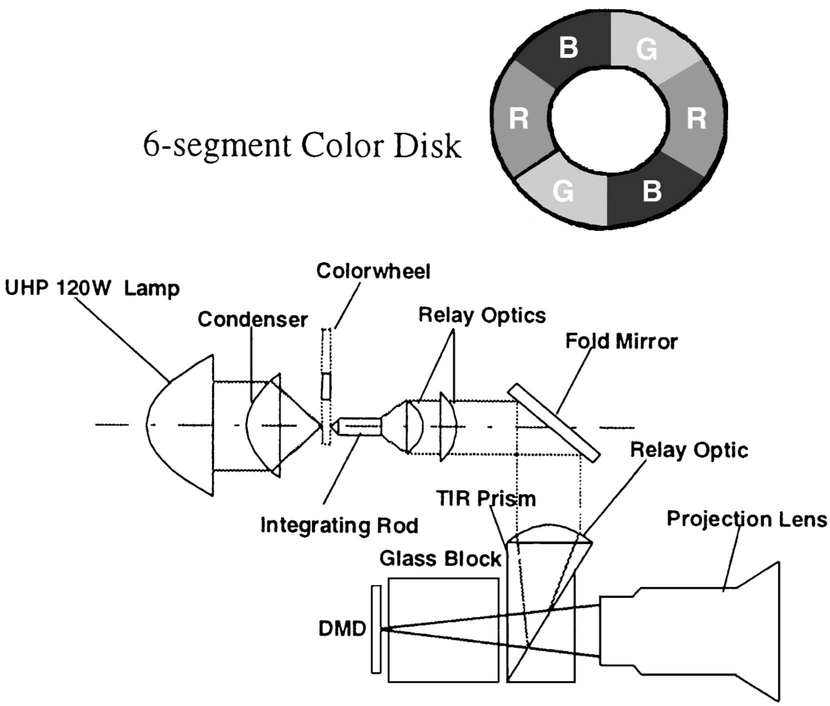


FIGURE 21.4.30 Optical system using a digital micromirror device. (From Ref. 33)

LCD projection systems use three LCD panels each measuring 1 to 2 in. diagonal. A single high-intensity light bulb illuminates a series of color-selective dichroic mirrors that split the light into three paths. Each light path passes through its respective LCD panel (red, green, and blue). The three light paths are then combined into one by another series of dichroic mirrors and passed through a lens that projects the image onto either a front or a rear screen (Fig. 21.4.29). Light output of the unit can be improved by adding a collimating element consisting of several microlenses just in front of the illuminating lamp.[31] As in the case of CRT projection, the precise alignment of LCD panels and mirrors is essential to register the three color images. Another novel design that has not yet been universally adopted uses only two LC panels, one black and white (B/W) and one three-color unit. This simplifies the mechanical design, uses fewer components, and has simpler convergence alignment. The B/W panel supplies the brightness to make up for the low transparency of the color panel. Video signals to the two panels are matrixed in a unique manner to yield correct color performance.[32]

LCD projectors currently exist in home theater size (front projection), rear projection self-contained large-screen TV sets, and small portable units having weight of 5 to 10 lb and light output of 500 lm to greater than 1000 lm for use in classroom.

Digital micromirror device (*DMD™*) *display* systems also called digital light processing (DLP™) use a semiconductor IC that contains an array of small mirror elements mounted on its surface, one for each pixel. When an electrical charge is applied to the substrate under a mirror, it will tilt by +10° (ON) and −10° (OFF). In the +10° configuration, the light from a high-intensity light is reflected through a lens and projected onto the viewing surface. In order to obtain shades of gray, the electrical charge to the mirrors is pulse modulated. Two configurations of this basic architecture have been developed. In the first, three DMD ICs, one for each color, are used. The light splitting, combining, and convergence of the three images is similar to that described for the LCD projector. The second configuration, now becoming more popular, uses a small six-segmented color wheel in the light path (Fig. 21.4.30).[33] The video signal sent to the DMD is that of a field sequential format in which the DMD is activated to the red picture image when the light is passing through the red portion of the color filter wheel; likewise for blue and green. Currently DMDs having picture definition of 1280 × 720 pixels are being used in HDTV applications.[34,35] Because of the light weight of the mechanism, DLP projectors are also becoming popular as portable units for classroom and traveling use. (DMD and DLP are trademarks of Texas Instruments.)

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