Chapter 19
Satellite Networks

19.1 TV Broadcast Coverage:

The service provider base station (TV program source) transmits over an up link to a geostationary (geosynchronous) satellite in the equatorial plane at *36000km*. The satellite rotates about the earths polar axis in a circular orbit every 24 hours and hence, appears stationary and therefore is called geostationary earth orbit (GEO) (Fig. 19.1).

Position relative to a point on the earth is defined by the elevation and azimuth to the satellite. In early analog satellite TV, each TV program (*6MHz* bandwidth) is frequency modulated onto a separate carrier resulting in a basic channel bandwidth of $36MHz$. Typically, 24 channels are used with a guard band of $4MHz$ between adjacent channels.

In order to protect the signal received from the base station on the uplink interfering with the signal transmitted by the satellite on the downlink from a separate frequency band is used for transmission in the uplink and downlink directions, i.e. each channel is allocated a separate carrier signal in both the uplink and downlink directions with the same fixed spacing between channels.

The parabolic dish focuses the signal at the focal point with all waves in phase. At the focal point, a low noise block converter (LNB/LNC) is located. It consists of a low noise amplifier and a frequency down converter. This amplifier is needed since the signal is weak due to the large distances traveled.

The down conversion is needed since the range of frequencies used exceeds the bandwidth of the coaxial cable. This reduced frequency is called satellite intermediate frequency$(SAT-IF)(950MHz)$. The signal output by the LNB is passed on to an electronic module within the satellite known as the transponder subsystem (Fig. 19.2).

Since microwave power amplifiers are linear only over a limited frequency band each channel signal is amplified separately. Thus, the individual modulated channel signals are first separated out using filters. Each is then frequency shifted to its allocated downlink frequency band and then combined to form the downlink signal that is broadcast over a defined area called foot print or field of coverage.

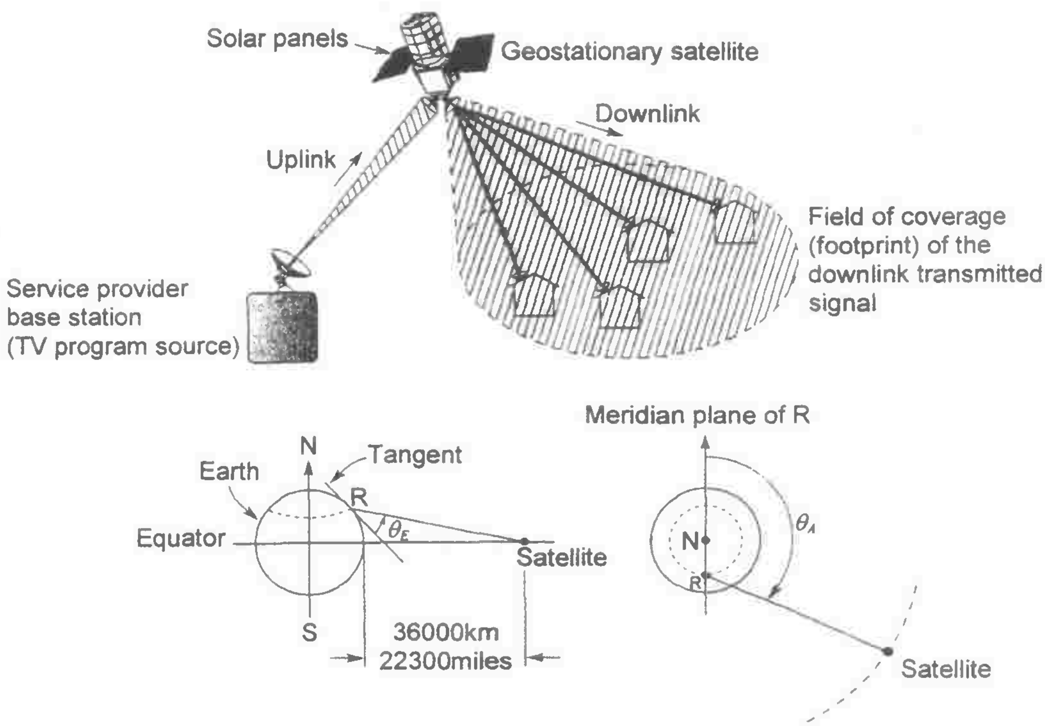


Fig. (19.1) Geostationary satellite
a) network *b) position on the earth*

At the receiving dish, the signal is first down shifted in the LNB, and then passed on to the set top box (STB) over a coaxial call. The electronic circuitry in the STB (Receiver – decoder) demodulates the received signal by first filtering out each channel signal. The corresponding carrier signal for each channel is then used to recover the signal of the related TV program that has been selected by the subscriber.

Satellites use frequencies in the microwave frequency band since they propagate through free space in straight lines and can be focused into a beam of a definite width. In the uplink a narrow beam width is used to ensure that maximum amount of energy in the signal transmitted by the base station is received by the satellite's receiving antenna.

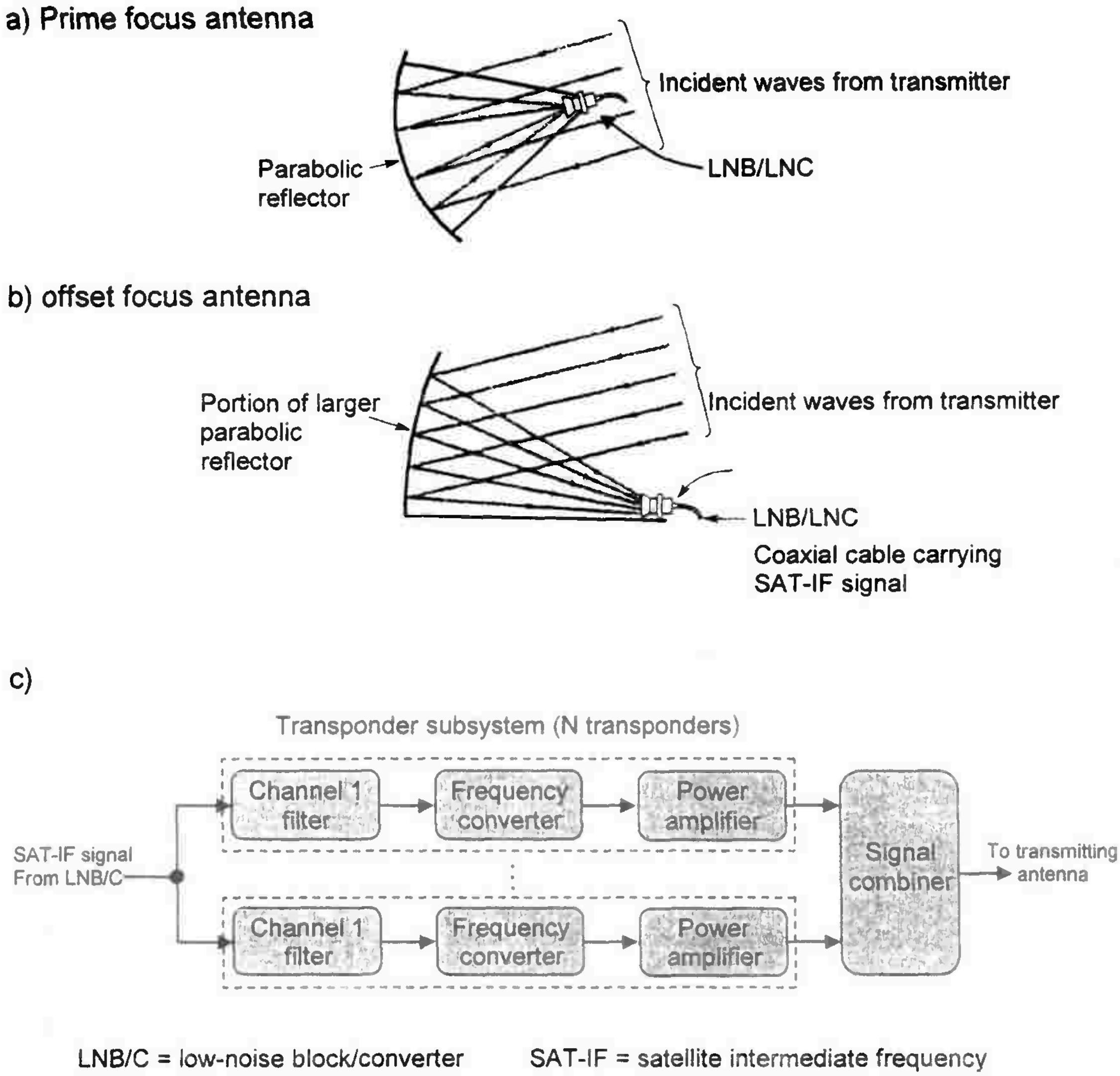


Fig. (19.2) Satellite components

a) LNB of satellite at focus.
b) LNB offset to avoid masking by LNB.
c) On board transponder subsystem.

Conversely, a wide beam width is needed in the downlink to ensure that the signal is received by all antennas within the satellite's foot print. The size of the dish required to receive the signal broadcast by the satellite is determined by the output power of the satellite's transmitter which depends on the number of transponders and the area of coverage.

In early satellites the dish was $1-4m$. With later systems, multiple satellites are used to cover a similar area, and hence dishes as small as $45cm$ are used, for orbital position spacing of 10° to avoid interference. For most early analog TV broadcast the frequency bands used were within C band. Thus, the uplink ranges from 5.925 to $60425GHz$ and the downlink $3.7-4.2GHz$. Typical channel bandwidth of $40MHz$ including guard bands are used. Both horizontal and vertical polarizations are used. Thus, a total of $500MHz$ bandwidth could support about 24 active analog channels.

Most transponder systems contain a number of spare transponders to replace any that malfunctions. A command and telemetry subsystem is used to send commands to the satellite to switch spare units into service normally after $10-12$ years of service.

19.2 Satellite TV Bands:

Radio waves above 50 MHz used to carry TV signals do not propagate far beyond the horizon. At higher frequencies they propagate similar to light. This is unlike radio waves of greater wavelength (500 kHz-30 MHz) which are reflected by the ionosphere: Geostationary satellites are used. Two main parameters have to be taken into account for the choice of frequency bands used for satellite communication

1. Noise level: All sources of noise (atmospheric, galactic or artificial) decrease almost linearly with frequency and become negligible above 5 GHz (except for background noise due to the Big Bang).
2. Attenuation due to the atmosphere and atmospheric disturbances (rain, clouds and fog). Atmospheric attenuation by clear weather is low below 15 GHz, and then increases with frequency with remarkable peaks at 22 GHz (due to absorption by water vapor) and 60 GHz (due to absorption by oxygen). Attenuation due to rain is very limited below 3 GHz and increases progressively up to 80 GHz, where it reaches a stable maximum. Thus, the most appropriate frequencies seem to be between 3 and 5 GHz (Fig. 19.3). The first band used (C band) is from 3.7 to 4.2 GHz, while Ku band is 10-15 GHz where fixed satellite service uses bands from 10.95-11.7 GHz (uplink) and 12.5-12.75 GHz (downlink).

Two different levels of polarization are used for satellite transmissions. Linear polarization means that the direction of the electric field vector is fixed. Thus, we can transmit two waves of identical frequency and of orthogonal polarizations, modulated by different signals without interference. This allows practically to double the transmission capacity in a given frequency band. In circular polarization the two field vectors (electric and magnetic) rotate along the propagation axis at the rate of one turn for every wavelength while keeping them orthogonally. We may have circular left and circular right, then we have a device that can separate these two directions of rotation. Thus, again we may double the transmission capacity

19.3 Direct Broadcast Satellite(DBS):

Direct to home (DTH) satellite TV transmission started in 1970. Terrestrial stations transmit via an uplink to the control station of the satellite. This satellite contains a certain number of transponders (one per channel for analog TV). The transponder retransmits TV signals to earth. This uplink is modulated in the same way and occupies the same bandwidth as the downlink. Each transponder is transparent to the signal. Its main task is to make a simple frequency change followed by power amplification of that part of the frequency spectrum that corresponds to the channel to be retransmitted to the service area (Fig. 19.2).

Frequency used by the uplink of satellites operating in the Ku bands are generally within the bands from 14 to 14.8 GHz and from 17.3 to 18.1 GHz. The terrestrial station must have power in excess of 1 kW (3 dBW) and large antenna gain (>60 dB) since it must be highly directional to avoid interference with neighboring satellites. This implies large dimensions (>10 m) this corresponds to EIRP of 90 dBW, while EIRP of DBS is 30-40 dB Wless.

The DBS range from 11.1 to 12.5 GHz wide is split into 40 channels of 27 MHz wide. This has been possible by using orthogonal polarizations with guard space between adjacent channels of the same polarization (Fig. 19.3). In this way, it has been possible to place 40 channels within 800 MHz band which otherwise would have occupied approximately 1200 MHz ($40\text{x}27=1080 \pm 10\%$ for guard space).

The start of digital TV transmission in 1996 on ASTRA and Eutelsat gave new life to the DBS band. It is certain that analog transmission will be replaced by digital transmission over the complete Ku band on all satellites.

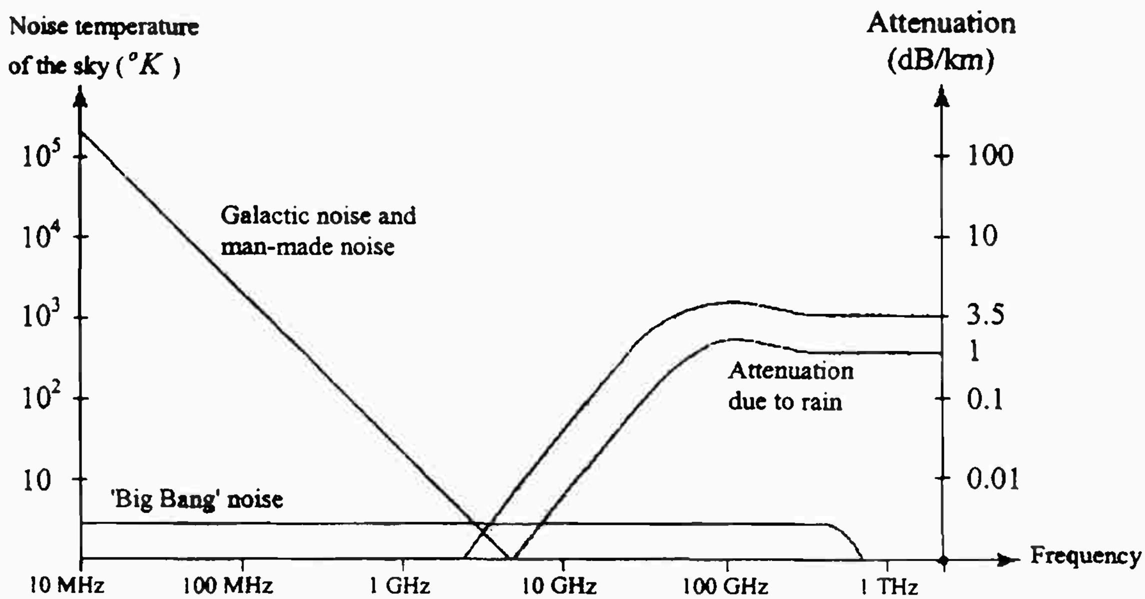


Fig. (19.3) Noise temperature and main attenuation as a function of frequency

19.4 The Satellite Receiver:

Signals arriving from satellites 36000 *km* away from the earth are extremely weak. A parabolic antenna is used which concentrates the beam onto a focus. A low noise block converter (LNB or LNC) is the active part of the antenna. It consists of a selective amplifier and a frequency converter, which lower the incoming frequency range of the order of 12 *GHz* (a frequency too high for transmission by a coaxial cable) to a frequency called satellite intermediate frequency (SAT-IF), which is in the range of 1-2 *GHz* which will be applied to the receiver 's input. The energy reflected by the parabolic mirror should be transferred as completely as possible to the LNC by a device called the source.

This device is situated at the focus of the mirror and consists of concentric rings or corrugated conic horn. The role of the source is to adapt the input impedance of the LNB to that of the reflected wave in order to recover the maximum energy at the converter input. The energy of the incoming wave is transmitted to the receiving probe of the LNB, which is made of $\lambda/4$ antenna (0.8 *cm* for Ku band). If the source is connected to the LNB in the way described above assuming the LNB has only one probe, then only one linear polarization will be received; horizontal or vertical, depending on the orientation of the probe (Fig. 19.5).

With most satellites now using two polarizations (horizontal and vertical), it has been necessary to insert a device between the source and LNB allowing it to choose the desired polarization through the use of an electrical command coming from the receiver. Such a device is called polarizer. It must reject the undesired polarization. This property is called cross polarization attenuation. A mechanical polarizer rotates the receiving probe by means of a small motor controlled by pulses with a variable duty cycle. The polarization correction (skew) has to be memorized for each channel being received in order to be automatically controlled at the channel change. The antenna itself is motorized to be able to turn to different satellites, over an arc, In the new integrated LNB, the source, polarizer and LNB are integrated in one block. In this case, there is no real polarizer as such but two orthogonal probes (one horizontal and one vertical) that are switched according to the desired polarization. This switching is controlled by changing the value of the power supply delivered to the LNB by the coaxial cable (13-14V) for vertical polarization, (17-18 V) for horizontal polarization. This avoids the need for a separate cable for the polarizer.

The LNB converter is a key element of the receiving station, since the value of its local oscillator and the input filtering define the frequency range being received, while its noise temperature will determine the performance of the station. It uses high technology gallium arsenide (GaAs) semiconductors.

The LNB is made up of a receiving probe, a low noise amplifier (LNA), band pass filter and frequency downconverter which lowers the incoming frequency by means of a local oscillator into a much lower frequency suitable for the coaxial cable (which may be tens of meters long) and delivers also a power supply of 18 V with current $200 mA$. An analog satellite receiver is shown (Fig. 19.6). The tuner block provides channel selection, amplification and frequency downconversion of a channel in the satellite carrier (950-2150 MHz) to a standardized IF (480 MHz). This signal is filtered with a bandwidth of 27 or 36 MHz, amplified, limited and FM demodulated.

For an accurate generation of the local oscillator frequency, a frequency synthesizer is used which is controlled by the microcontroller of the receiver. Video processing is limited to the rejection of audio subcarriers, deemphasis and amplification to deliver a standard composite video signal. Audio processing performs also frequency conversion by means of a frequency synthesizer programmable between 16.2 and 19.2 MHz. The receiver is under the control of a microcontroller which commands all this programmable circuitry (tuner, audio, LNB supply, polarizer and positioner, and stores all this information in nonvolatile memory EEPROM.

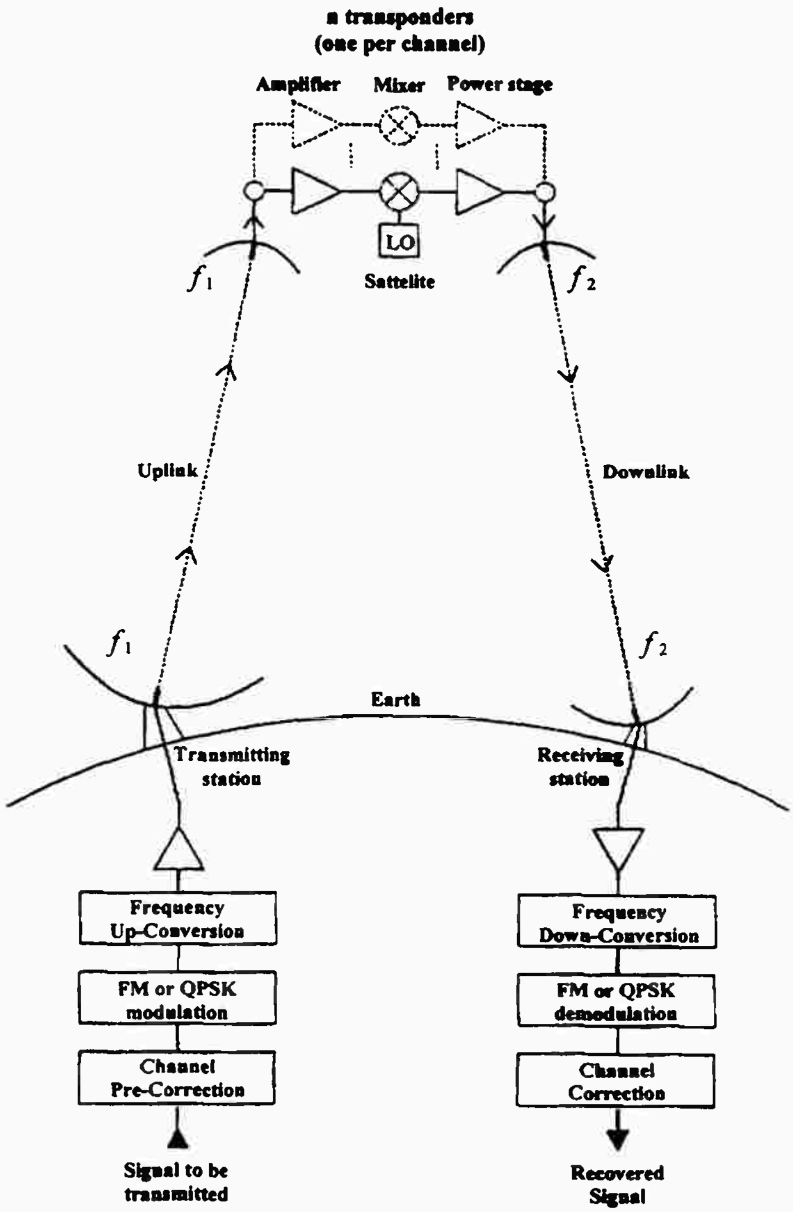


Fig. (19.4) Satellite TV transmission system

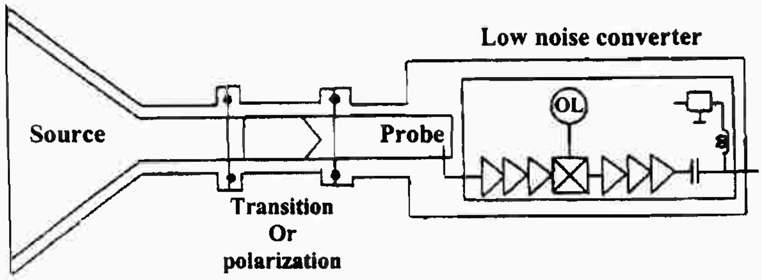


Fig. (19.5) Source and LNB

19.5 Digital TV:

The bit stream containing the multiplexed set of digital TV programs is passed through a microwave modem to convert it into an analog signal within the allocated frequency band. The modulation scheme used is QPSK, i.e., 2 bits / symbol. For most digital TV transmissions, the frequency band used is in the Ku band $(10.7-14.5GHz)$.

In the downlink direction, the band used is $10.7-11.7GHz$ for new analog TV programs and $12.2-12.7GHz$ for digital broadcast satellites (DBS) and $11.7-12.7GHz$ for digital video broadcasting satellite (DVBS) in Europe.

The allocated bandwidth is used to provide 32 channels of $24MHz$ at a symbol rate of $20M$ baud. Hence, with QPSK, a typical channel bit rate is $40Mbps$. For DVBS, the allocated bandwidth is used to provide 40 channels $33MHz$ each, supporting a symbol rate of $27.5M$ baud and $55Mbps$ bit rate. The video and audio compression standard is based on MPEG2.

The $4:2:0$ digitization format is used. The output stream produced by a single program encoder is called program stream (PS) and the output stream containing multiple program is called the transport stream (TS). The arrangement is shown (Fig. 19.7).

If the digitized TV program is to be stored rather than broadcast, then the program stream is used directly. If it is to be multiplexed with other programs, then the output streams from the set of program encoders are fed to the transport stream multiplexer, and then fed to either a satellite or terrestrial transmitter. The format of this stream is shown (Fig. 19.7b). It is divided into a string of 188 byte packets, each comprising a 4 byte header and a 184 byte contents field called payload. The header contains a number of fields which include a symbolization byte to enable the receiver to interpret the packet header and its contents, a packet

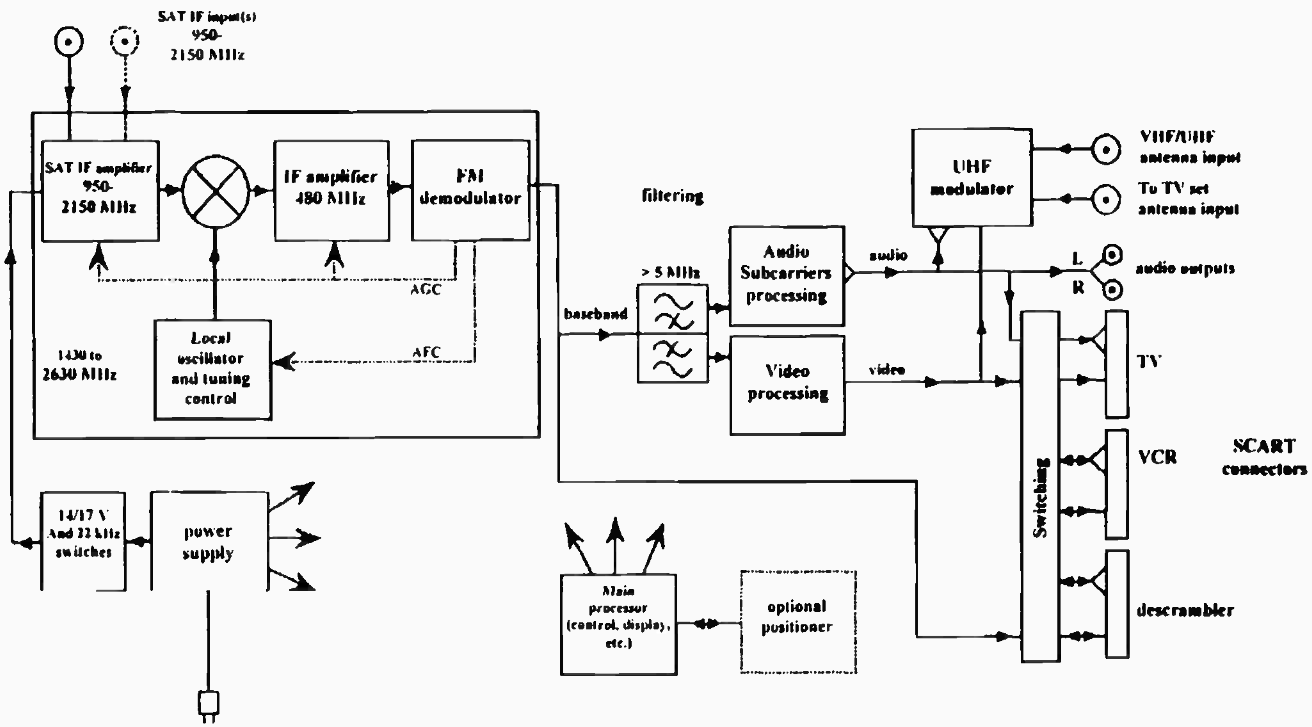


Fig. 19.6 Block diagram of analog satellite receiver

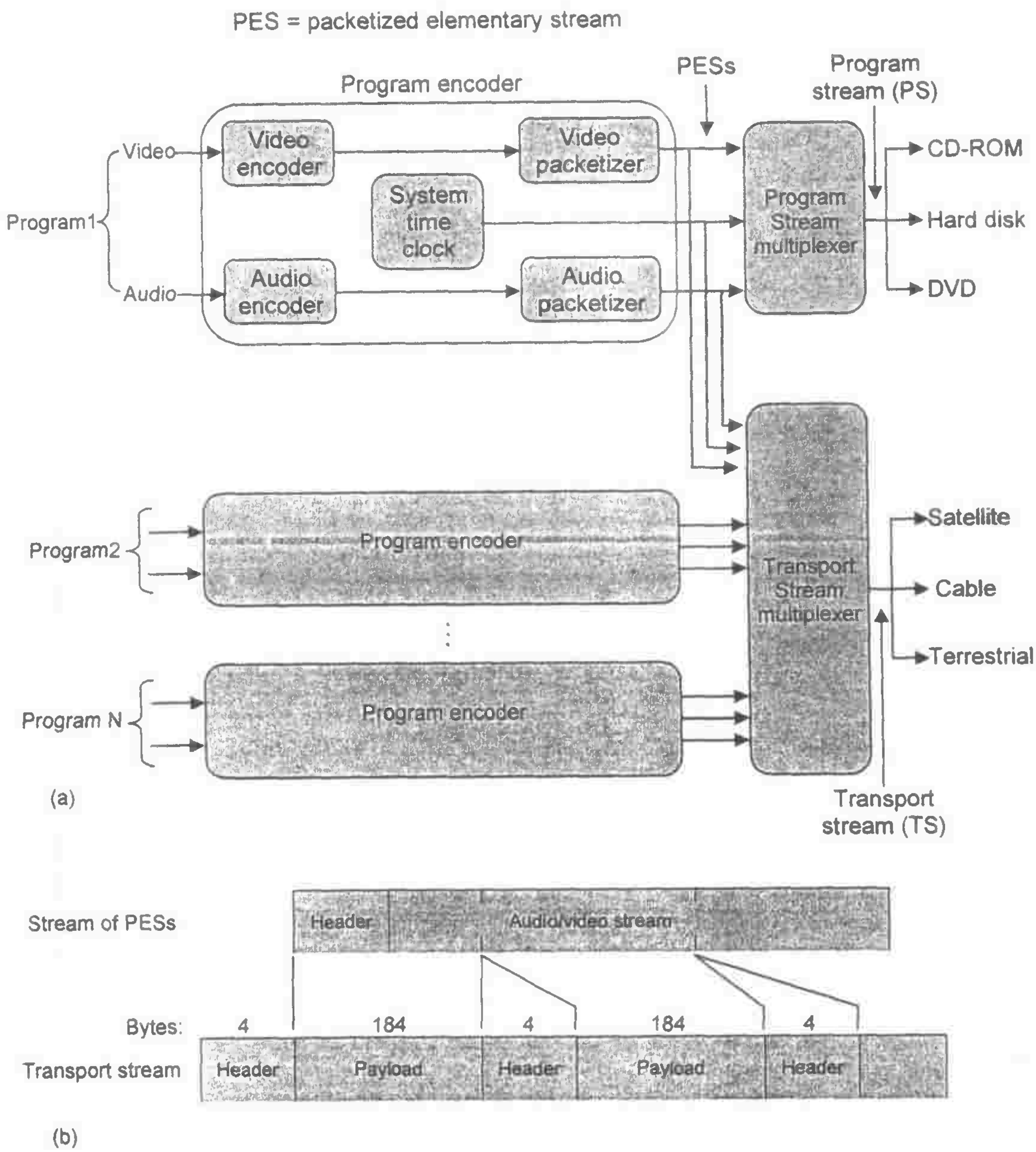


Fig. (19.7) TV program multiplexing

a) PS and TS generation *b) TS format* identifier to enable the receiver to relate the TS packet payload to the correct program encoder source (PES) during its reassembly, an adaptation flag (bit) and a payload flag (bit).

Typically, the length of the PES output by the video and audio packetizer is 2048 bytes, and hence, these must be fragmented (segmented) into multiple 184 byte segments for transmission. Fig. (19.8) shows the individual blocks associated with each channel interface. The bit streams of multiple TV programs are multiplexed together into a single bit stream of 188 byte packets. each comprising a 4 byte header and a 184 byte payload. A forward error control scheme $(204,188)$ is applied to each packet. This involves the addition of check bytes, byte interleaving and convolutional encoding. Interleaving involves rearranging the order of transmission of the bytes in each 204 byte block, so that an error burst longer than 8 bytes will affect no more than 8 sequential bytes in the original 204 byte block (Fig. 19.8b).

Prior to transmission, each 204 byte block output by the coder is fragmented into twelve 17 byte subblocks. The first byte from each of the 12 subblocks is then transmitted and so on. The reverse operation is performed at the receiver to reorder the bytes. In this way should an error burst occur within a block during its transmission this will affect only every seventeenth byte in the original 204 byte block, and hence be detected and corrected by the decoder. A typical convolution encoder is shown (Fig. 19.8c) which is used to minimize the effect of random single bit errors.

Since 2 bits are output for every bit input into the encoder, it is $1/2$ convolutional encoder. Hence, for every 204 byte block output by the interleaved 408 bytes are transmitted. It is also possible to operate such encoders at a higher rate by deleting selected bits from the bit stream produced by the encoder. This technique is called puncturing, which achieved code rates of $2/3, 3/4, 5/6, 7/8$. This has the effect of reducing the error connection proportion of the code, and hence, the rate used is a compromise between the level of error correction required and the amount of tolerable transmission overheads.

The satellite network is used to provide a high bit rate channel to the set top box of each subscriber. It can also support interaction with remote information source. This is a remote server computer attached to the internet.

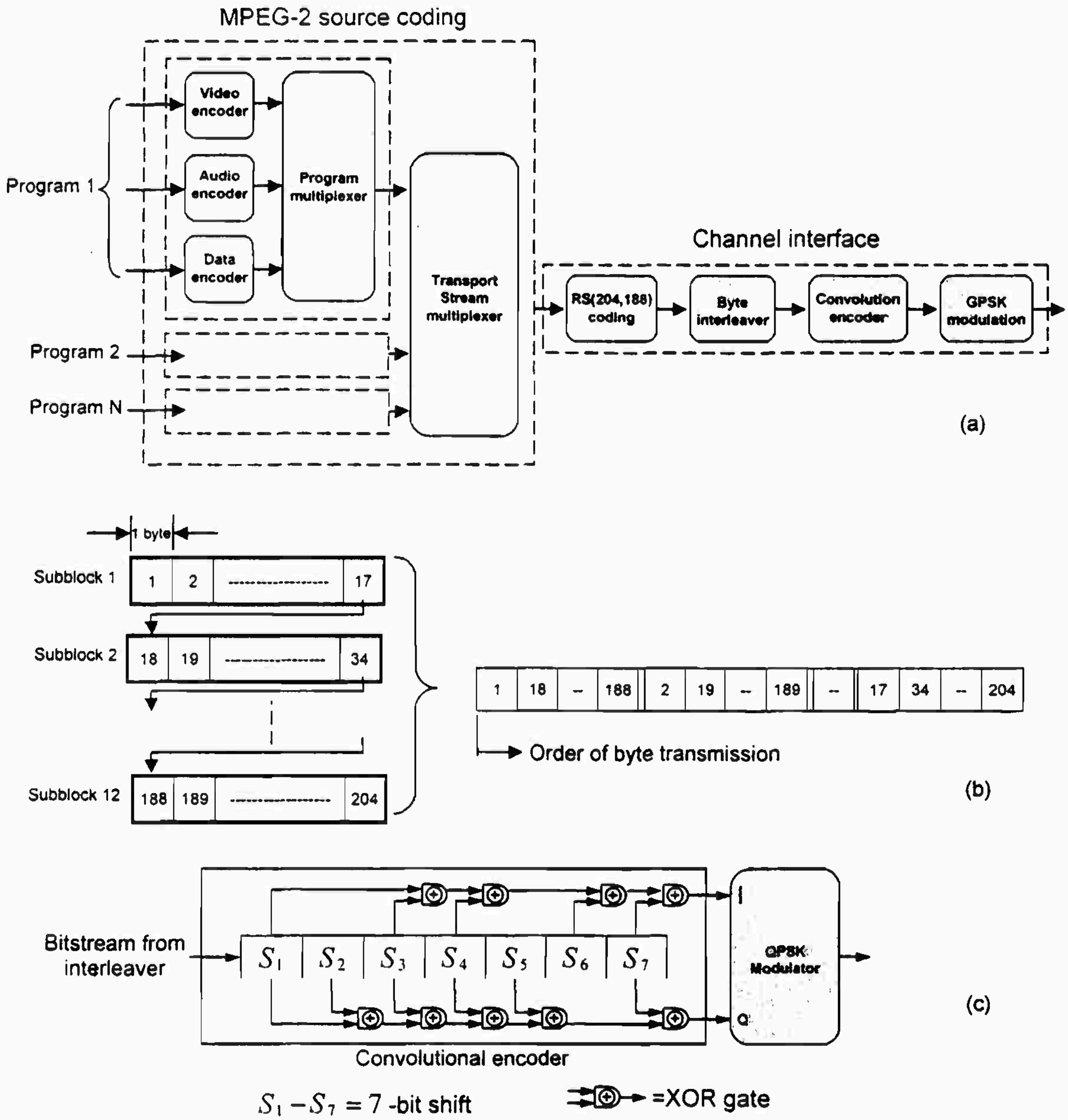


Fig. (19.8) Satellite TV interface

a) Schematic *b) Interleaver* *c) Convolutional encoder*

The most popular way of providing an interaction channel is through PSTN (with modems) or an ISDN. Data that is broadcast is stored in the STB and can be accessed interactively by the subscriber and displayed on the TV screen. Such channels are controlled by conditional access, i.e., scrambling. Another example is pay for view service.

The local interactions in these cases involve a subscriber inserting a smart card into a slot in the STB. Another example is voting in talent contests and purchase requests. All low bit rate interaction is done through PSTN (fixed or mobile phones) or ISDN.

The MPEG2 source coding and channel interface for digital TV broadcasts over terrestrial networks are similar to those used with satellite networks.

The main difference is the type of modulation used. In order to obtain a wide field of coverage, terrestrial broadcasts are omnidirectional. Thus, the receiving antenna may receive multiple copies of the same signal from a variety of paths. Most power is in the direct path (line of sight) but reflections from buildings and atmospheric refractions cause multipath dispersion or delay spread leading to ISI. The higher the transmitted bit rate, and hence, the shorter each bit cell period, the larger the level of ISI. It is for this reason that coded orthogonal division multiplexing (COFDM) is used. The main components of a COFDM modulator are shown (Fig. 19.9). Using COFDM, instead of just a single carrier, multiple orthogonal (equally spaced) carriers are used, each of which is independently modulated by one or more bits from the encoded bit stream to be transmitted.

In the simple example shown (Fig. 19.9), five carriers are used, each of which is modulated by a single bit from the transmitted bit stream using on – off keying (OOK). The first carrier is a DC level while the remaining carriers are $f_s, 2f_s, 3f_s, 4f_s$.

The period T_s is the symbol period and is equal to the time to transmit 5 bits of the encoded bit stream (on off keying). If N carriers were used, each modulated by QPSK, then T_s would be the time to transmit $2\times N$ bits from the encoded bit stream. During each symbol period the five modulated signals are added together to form the signal (symbol) that is transmitted in the time domain (Fig. 19.9c) and in the frequency domain (Fig. 19.9d). At the receiver, before starting to process each received symbol, the receiver waits a short interval - called the guard interval - to ensure that all delayed versions of the direct path signal that make up the symbol have arrived.

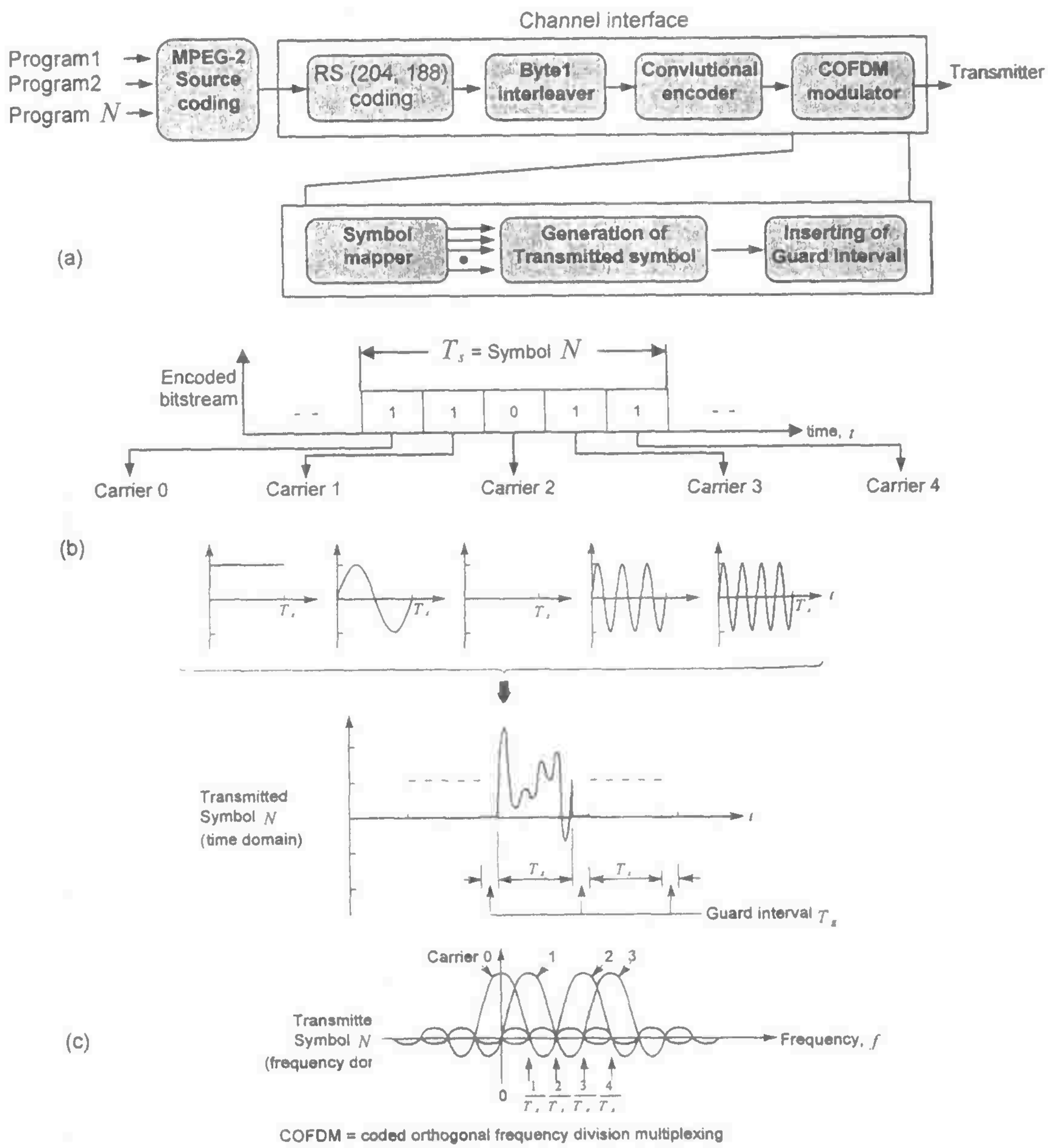


Fig. (19.9) COFDM system

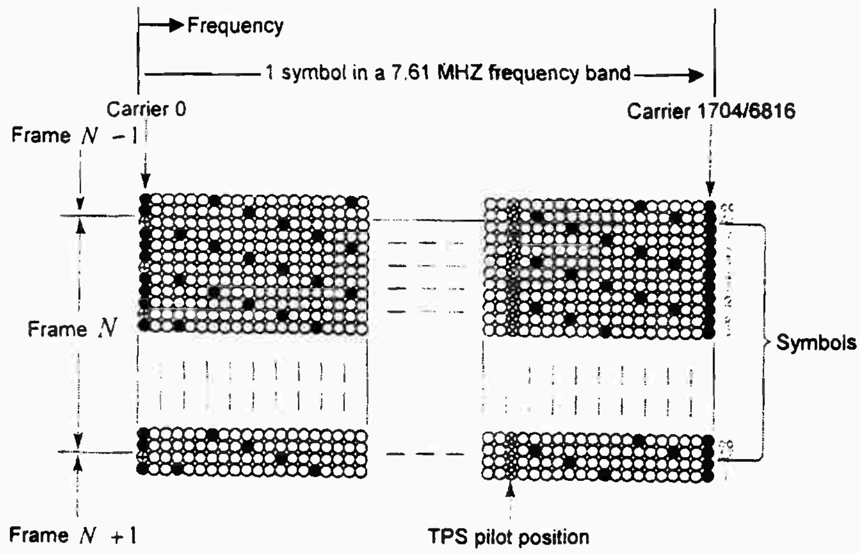
a) interface components

b) symbol generation (time domain)

c) frequency domain symbols

There is no interference in this case, but rather there is reinforcement of the power of the symbol signal. The signal is processed to determine which carrier signal is present in the symbol. Thus, the receiver can determine the original bit stream. The orthogonal carriers used are $1/T_s$ apart. In practice, the generation of each symbol is carried out digitally using an IDFT. The digitized (discrete) output by the IDFT is converted to an analog symbol using D/A prior to transmission. Similarly, the received symbol is first converted into a digital (discrete) form using A/D before a symbol is processed using DFT to determine the carriers that are present. Adding a guard interval to avoid ISI making it too long, limits the bit rate. Usually, since it is necessary for the receiver to detect reliably the start of each new symbol that is received, symbol synchronization must be maintained. The stream of symbols is divided into 68 symbol blocks. Each block of symbols is called a frame (Fig. 19.10).

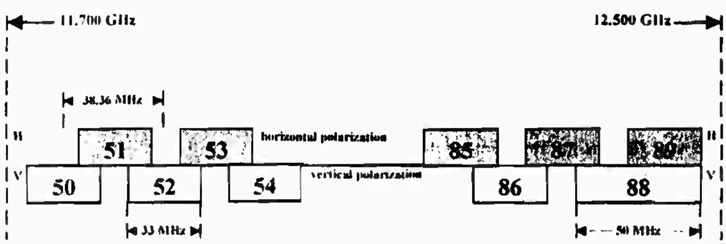
Along each row are the individual frequency carriers in each symbol (assumed 1705 carriers). Each carrier may be modulated by on – off keying (OOK), or separately modulated using either QPSK, 16 QAM or 64 QAM. Since each carrier can transmit 2,4 or 6 bits per signal transition, each carrier can transmit a capacity (kbps) of $2/4/6\,\frac{1}{T_s}$, since each carrier has a bandwidth of f_s assuming one bit occupies bandwidth $\frac{1}{T_s}$. The bit stream relating to specific carrier positions in each of the 68 symbols of a frame carries one of two defined bit sequences called pilots, the continual pilot and the scattered pilot. The receiver achieves and maintains symbol synchronization by searching for these two pilot sequences in the known carrier position. Once in synchronization, the bit stream of the eighteenth carrier from the end of each symbol is used to form a subframe that contains operational parameters to enable the receiver to interpret correctly the received symbol stream. The contents of each subframe include the length of the guard interval, type of modulation of the other carriers that are used and the rate of the convolutional coder. The bit rate that is available with each $6/8\,MHz$ broadcast channel is determined by the modulation method that is used for each carrier. A typical bit rate is $24Mbps$, allowing for the loss of transmission capacity caused by the guard interval and after removing the pilots for 16 QAM modulation (prob19.7).



⊕ = continual pilot ⊗ = transmission parameter signaling (TPS) pilot

● = scattered pilot O = user data

Fig. (19.10) Frame format



(b)

Fig (19.11) Linear Polarization in digital satellite TV

The $(204,188)$ coder and a 3/4 convolutional coder reduce this figure to about $16Mbps\,(24\times(184/272))$. To increase the number of channels, both linear polarizations, horizontal and vertical are used (Fig. 19.11).

19.6 Digital TV Receiver:

The satellite receiver or STB is often called integrated receiver decoder (IRD). The upper part of Fig (19.12) illustrates the steps on the transmission side which has to deliver a multiplex of MPEG-2 programs on one RF channel.

Video and audio signals of the programs to be broadcast are each applied to an MPEG -2 encoder, which delivers the video and audio packetized elementary streams (PESs) to the multiplexer. These PESs are used by the multiplexer, to from 188 byte transport packets and probably scrambled. Error correction increases the packet length to 204 bytes. In addition convolutional coding multiplies the bit rate by a factor of $1.14\left(r = 7/8\right) to\ 2\left(r = 1/2\right)$.

Formatting of the data (symbol mapping) followed by filtering and D/A conversion produces the I and Q analog signals. These signals modulate in QPSK an IF carrier of the order of $70MHz$. This IF is upconverted into the appropriate frequency for its transmission to the satellite transponder. This frequency change brings the frequency to the required value (of the order of $14GHz$) for the uplink to the satellite transponder, where it will be frequency converted again for diffusion (downlink) to the end user is the Ku band $(10.7-12.75GHz)$.

On the receiver side, the lower part of Fig. (19.12) shows the steps in the reverse order of transmission. In the antenna part, amplification and a first downconversion take place in the low noise converter (LNC) – a low noise block (LNB), which changes the frequency to the $950-2150MHz$ range (SAT IF) and is then led by a coaxial cable to the input of the IRD.

In the IRD, a second downconversion used for RF channel selection delivers IF $480MHz$. The demodulation of this IF delivers the I and Q analog signals. After A/D conversion, filtering and reformatting of I and Q (symbol demapping) the forward error correction recovers the transport packets of 188 bytes.

The demultiplexer selects the PES corresponding to the programs chosen by the user, which may be descrambled by the user smart card. The MPEG–2 decoder reconstructs the video and audio of the desired programs.

The block diagram of Fig (19.13) represents the main functional blocks of a satellite IRD.

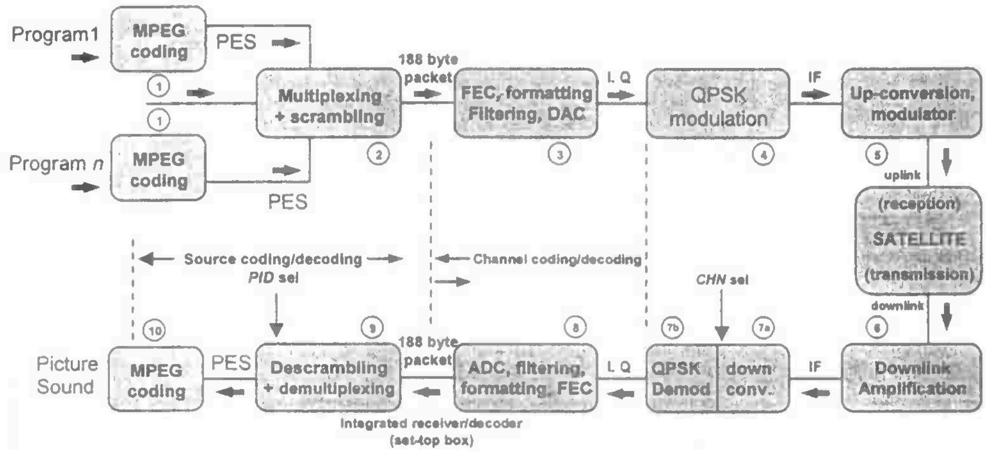


Fig. (19.12) Complete DVB transmission / reception

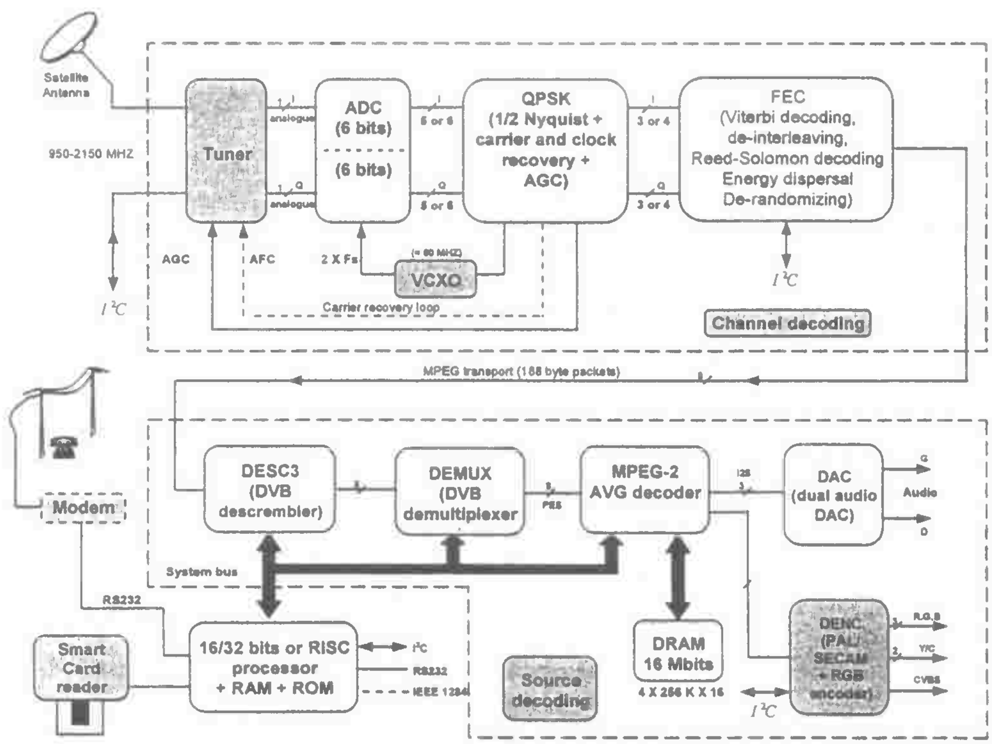


Fig. (19.13) IRD block diagram

The signals received from the satellite ($10.7-12.75GHz$) are amplified and downconverted into the $950-2150MHz$ range by the LNB located at the antenna focus and applied to the IRD's input. The tuner selects the required RF channel in the $950-2150MHz$ range and converts it into a $480MHz$ IF and realizes the required selectivity by means of a surface acoustic wave filter (SAW).

The signal is amplified and coherently demodulated to obtain the analog I and Q signals. Recovery of the carrier phase required for demodulation is carried out in a carrier recovery loop. The ADC receives the analog I and Q signals which it then converts at twice the symbol rate (27.5M symbols / s in Europe).

The QPSK block in addition to its functions in carrier and clock recovery loops carries out the half Nyquist filtering, which is complementary to the one applied on the transmitter side to the I and Q signals.

Digitized I and Q signals are delivered to the next block FEC (forward error correction). Viterbi decoding of the convolutional code – deinterleaving – Reed Solomon decoding are performed is this order.

The DESCR (descrambler) receives the transport packets and communicates with the main processor. It realizes the selection and descrambling of the packets of the required program. The DEMUX (de multiplexer) selects by means of programmable filters the PES packets corresponding to the program chosen by the user.

The audio and video PES outputs of the DEMUX are applied to the input of the MPEG block. Video signals reconstructed by the MPEG–2 decoder (digital YUV) are then applied to a digital video encoder for conversion into analog RGB+sync.

Decompressed digital audio signals are fed to DAC, which delivers the analog left and right signals. The whole system is controlled by a powerful 32 bit microprocessor which controls all the circuitry, interprets user commands from the remote control. The software (many hundred bits bytes) is located in a flash EPROM in order to permit eventual updates off air or via the communication ports.

The IRD can communicate with PC or modem by means of one or more communication ports (serial RS232 to parallel 1EEE 1284) as well as telephone line via an integrated modem to allow for interactivity access to pay per view services or access to the internet.

Problems

1. Explain and analyze the operation of the convolutional decoder of Fig. (19.8c).

2. A digital satellite channel interface uses the MPEG–2 transport stream multiplex, (204,188) block, code rate 3/4 convolutional encoder and QPSK modulation. Determine the number of overhead bits associated with the interface, and hence, the useful bit rate for 20M baud.

3. Repeat the above problem for 30M baud. What do you conclude?

4. Compare the transmission at $500MHz \text{ and } 12GHz$ as far as the bit rate, ISI and multipath effects in COFDM digital terrestrial broadcasting.

5. Calculate the bit rate for 16 QAM modulation after removing the pilots and allowing for the loss of transmission capacity caused by the guard interval for each $6/8\,MHz$ digital broadcast channel.

6. In the above problem find the bit rate taking into account the overheads in (204,188) coder and a rate 3/4 convolutional coder.

7. For digital video program of 4Mbps find how many programs are needed in the above problem.

8. Verify the structure of frame format in Fig. (19.10).

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