20. TELEVISION BROADCASTING

20.1. Structure of TV Pictures

As it was discussed in Chapter 4, a picture is a peculiar set of data. Unlike sound, a picture -before being transmitted- it has to be converted into a time function. For this reason, it is divided into small elements, called pixels. Taking into account the typical viewing distance, the aspect ratio of the picture and the resolution of the eye, a picture is composed of about half a million of pixels, arranged in about 600 lines, each containing about 800 pixels. The luminance and the colour information of each pixel is then sequentially, pixel by pixel converted by an optoelectric transducer (a camera) into an electrical signal, i.e. into a time function.

The above procedure becomes even more complicated if moving pictures have to be transmitted. As it is known from cinematography, to get the illusion of continuous motion, consecutive pictures have to be projected with a frequency of at least 20...25 Hz. For flicker-free moving pictures, however, the repetition frequency has to be increased over the so-called fusion frequency of the eye which is about 40...50 Hz.

In cinematography, flickering is avoided by projecting each frame of the movie picture twice or even three times before the next frame is taken. Unfortunately, this simple procedure could not be implemented in TV since it would have required either to store the actual picture (the information of all pixels) in a great memory and then scan the surface of the cathode ray tube twice or to transmit each picture twice during the same period of time which would have resulted in an unacceptable increase of the bandwidth.

Let us remind that in 1936, when TV was introduced, the level of electronics was very low. Therefore we have to highly appreciate that ingenious solution which removed flickering without increasing the number of pictures in one second above 25. This procedure is known as *line interlacing* and its principle is shown in Fig. 20.1. For the sake of simplicity, the principle is explained on a picture consisting of only 13 lines. Since the horizontal and the vertical deflection of the electron beam works simultaneously, the lines scanned by the electron beam are slightly tilted. Because of the small number of lines, this tilt is exaggerated in the Figure, it is negligible in reality.

As it can be seen in the Figure, the lines 1, 2, 3, etc. are scanned in a way that free space is left between them. The last line (7) reaches the bottom of the picture at the half of its way and then 'jumps' (retraces) vertically to the top where the line is finished. After horizontal retracing to the left side, the starting position of the next line (8) falls just between the lines 1 and 2. This happens also with all the following lines, i.e. the lines are interlaced, wherefore, the two halves *-fields-* of the picture merge into each other. At the end of the last line (13.), the beam retraces both horizontally and vertically, i.e. jumps to the top left corner and the first field of the next picture starts to be scanned.

The result is the same as for the trick used in cinematography: the flickering frequency will be the double of the number of TV pictures *-frames-* transmitted in one second. In other words, instead of a given number of frames, twice as much fields are transmitted. The time necessary for transmission of one frame remains the same as if the picture were transmitted in one piece, i.e. only the frequency of vertical deflection -which determines the flickering- is doubled (from 25 to 50 Hz).

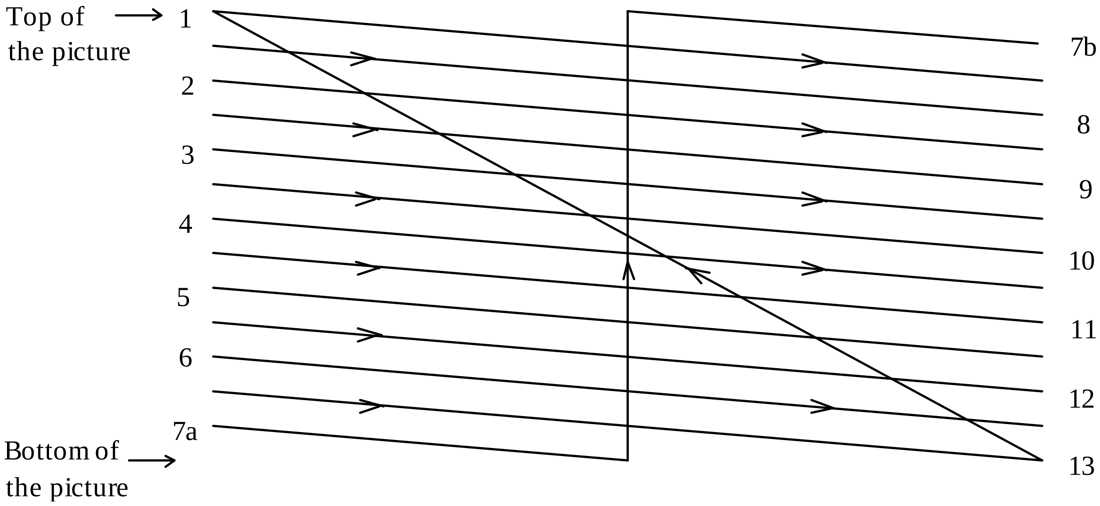

Figure 20.1 Line Interlacing (Odd Line Number)

Let us remark that interlacing can be relatively simply realized only for odd line numbers. In the case of even line number, the vertical deflection should be alternated in accordance with the odd an the even frames.

20.2. Monochrome Video Signal

In the case of black-and-white pictures information about the luminance and about the position of the pixels has to be transmitted. The *luminance signal*, denoted usually as Y, is a time dependent voltage proportional to the brightness of the pixel actually being scanned. Since the pixels are put in order by scanning, obviously it is not necessary to `address' each pixel, it is sufficient instead to `mark' the beginnings of the lines and of the fields. This is done by the *line* and by the *field synchronization* pulses which are added to the luminance signal. Thus all pixels are put into their proper places in the receiver provided the speed of the horizontal and the vertical deflection is the same as it was in the transmitter.

To be able to distinguish the luminance signal from the synchronization pulses, the amplitude range of the *composite video signal* has been divided into two parts: the greater part (70 %) is reserved for the video information while the rest is used for the synchronization. In the receiver, the signals can be well separated by a simple amplitude discriminator.

20.3. Colour TV Pictures

It was shown in Chapter 4. that a colour pixel can be unambiguously described by three independent data, e.g. by the luminance and by the x and y co-ordinates of the CIE colour diagram. Primary colours, such as the red, the green and the blue or -more precisely- the (R,G,B) signals corresponding to them can, however, also be used. Colorimetric calculations have shown that introducing the term of the so-called *white reference C*, the relation between the the luminance and the above colour components is

$$Y = 0.3 \cdot R + 0.59 \cdot G + 0.11 \cdot B \qquad (20.1)$$

or in a slightly rewritten form:

$$0.3(R\text{-}Y) + 0.59(G\text{-}Y) + 0.11(B\text{-}Y) = 0 \qquad (20.2)$$

The latter form of the equation can be well illustrated by an area diagram shown for an arbitrary *R*-*G*-B trio in Fig. 20.2. In accordance with eq. (20.2), the shadowed area above the horizontal line of *Y* equals to the shadowed area below this line, furthermore the heights of these rectangles correspond to the differences (*R*-*Y*), (*G*-*Y*) and (*B*-*Y*). These components, called the *colour-difference signals* are signed values, those above the *Y* line are positive and those below the line are negative. It is important to realize that the colour-differences are not independent of each other: if two are given the third can be computed. It might happen that one of the colour-differences is zero. If two are zero, however, the third must be zero, too, since the weighted sum of the three colour-differences must be zero, as stated by eq. (20.2). In this case, $R = G = B = Y$, i.e. the pixel is 'C'-white. In any other case, at least two colour-differences have to be different from zero which shows that the colour information is carried by the colour-differences while *Y* is independent of them.

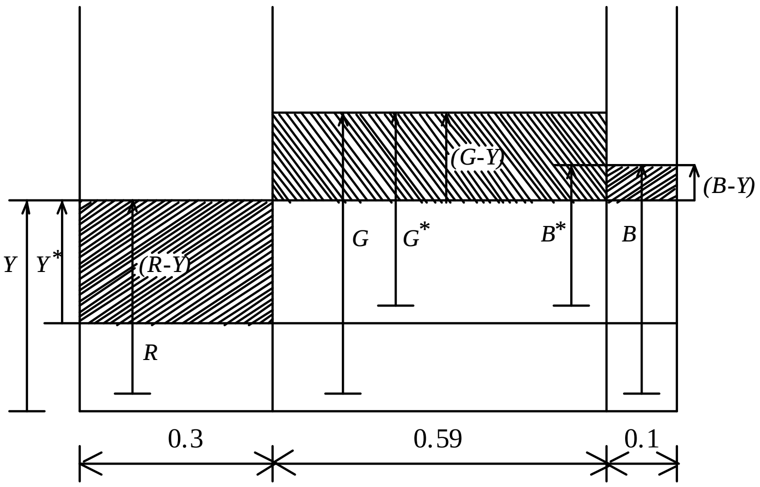

Figure 20.2 Area Diagram Used in Colour Television

Instead of primary colours, colour-differences (*R*-*Y*) and (*B*-*Y*) -called the ***chrominance signals***- and the luminance signal (*Y*) are transmitted by the colour-TV systems. This choice has many advantages. The most important of them is that such color composite signal is ***compatible*** with the existing monochrome systems since a black-and-white receiver can use the *Y* signal directly to reconstruct the picture (without colors) while a color receiver reconstructs the primary colors from the chrominance and the luminance signals and produces the picture in colour by means of additive mixing of colours.

Another great advantage is that the chrominance signals can be transmitted within a narrow bandwidth. This is due to the fact that the eye-resolution of colour pictures is worse than that of black-and-white pictures.

20.4. Proper Reproduction of Colours

Until this point, it has not been examined whether the colours are reproduced by the primary colours really exactly, i.e. whether they match the actual colours. Fortunately, this problem has already been solved by colour photography and printing long before television was introduced.

Human vision, aspect, taste and habit have produced a strange situation as far as the reproduction of colour pictures is concerned: colours are not judged by all means as lifelike even when they are identical with the actual ones. Instead of, they are judged to be good when the topic shown in the picture is `painted' in colours which would be actual if it were illuminated by *white light.*

Since the spectral distribution of daylight is permanently changing with the periods of the day, with the weather, etc., and since different artificial light sources have also different spectral distributions, always certain colour differences arise between the actual colours of subjects and persons surrounding us and their `standard colours' stored in our memory. The human eye has got used to this to such an extent that we have the same colour impression about our daily-seen environment in the artificial light like in the daylight, although the colours of the faces, of the furniture etc. are obviously different in the two lights.

Several more examples could be given to illustrate that we like to see the known subjects and persons in colours they would have when illuminated by white light. Thus the proper reproduction of colours does not necessarily mean lifelike reproduction, these two are equal only if reference white light is used.

20.5. Analog Color-TV Systems

The first colour-TV broadcasting system has been introduced in the USA. The project was started by the National Television System Committee by the end of the '40-s and regular colour-TV transmission began in 1953. The system, named NTSC which came from the abbreviation of the above committee, is still used in the USA, in Japan and in most American and some Far-East countries.

The NTSC -being the first system adapting the transmission of `colour' programs to the existing monochrome-TV broadcasting standards and -what is more**-** to the millions of monochrome TV receivers which, of course, were autocrat at that time- played a pioneer role. Without compatibility the introduction of colour TV would certainly have been delayed by many years.

Several inventive ideas and system considerations of the NTSC are still used by systems developed since that time. Even more, in certain aspects, such as the primary colours, it is still regarded as a standard. It can be stated without exaggeration that the two European systems, the PAL **(**Phase Alternating Line**)** and the SECAM **(**SÉquentiel Couleur Á Memoire**)** have been developed from the NTSC system and also the MAC (Multiplex Analogue Components) which is a new system used in satellite colour-TV broadcasting is based mostly on experiences of the NTSC system.

In spite of very serious efforts, an agreement about a uniform European system has failed. Following the NTSC, SECAM was patented in 1957 and PAL in 1961. The most important goal of both the SECAM and the PAL was to eliminate the major drawback of the NTSC system: its sensitivity to phase errors. Although choosing different ways, both were successful and what is interesting: both rely on a very particular electronic component the mass-production of which became possible just by the end of the '60-s: the electromechanical delay-line having the delay of one TV line (64 μs).

20.5.1. The NTSC System

The basic idea of the NTSC system originates from the following observation: If a sinewave of a small amplitude is added to the monochrome TV signal, it causes only an almost unnoticeable interference provided its frequency is the odd multiple of the half of the line frequency. Essentially, this was the key to how additional colour information could be added to the monochrome composite video signal without disturbing it while the bandwidth of the composite signal remained the same as it had been before.

To make use of the above idea, one more question had to be answered: how to use this low-level sinewave as a carrier of *two* simultaneous chrominance signals? As the answer to this question, QAM has been chosen by the NTSC. In fact, QAM is the sum of two AM-DSB/SC signals, carriers of which have the same frequency but the phase of one of them is shifted 90^o with respect to the other. In the TV receiver the QAM signal is demodulated by two multipliers (reference signals of which are also 90^o out-of-phase). Both demodulators demodulate only the AM component, whose carrier is in phase with the reference reconstructing thus the chrominance signals.

To sum up: the colour information is transmitted by the NTSC system so that the chrominance signals are carried by a QAM carrier whose frequency is an odd multiple of the half of the line frequency (3.58 MHz). With this choice of frequency, the interference of the modulated colour signal with the luminance signal is hardly noticeable on the screen, fulfilling thus the compatibility issue: programs broadcasted in NTSC system can be received and enjoyed (of course, as monochrome) also on monochrome receivers.

As it was mentioned before, the weakest point of the NTSC system is its sensitivity to phase errors. Although QAM is principally an amplitude modulation, this unpleasant feature originates just from the QAM. Since the modulation and demodulation are based on exact phases (90^o) between the carriers, the deviations from this value cause a noticeable distortion (crosstalk) of colours. This was the main reason why the European version of the NTSC was not introduced at the beginning of the '60-s, instead of, great effort was made to develop such procedures which would be less sensitive or not sensitive at all to phase errors.

20.5.2. The SECAM System

Essentially, the SECAM utilizes the correlation which can be found between the colour information of two pixels positioned over each other. In other words, it does not cause a great error if one of the two chrominance signals is `borrowed' from the pixel of the previous line located just over the actual pixel. Using this idea, it is sufficient to transmit only one of the chrominance signals in one line, provided the receiver is capable to store the other chrominance signal received one line earlier and to use it as if it had been arrived in the actual line.

So the base of the SECAM procedure is the line-alternating transmission of only one of the chrominance signals and the substitution of the missing one by the chrominance signal transmitted in the previous line and stored in the receiver. Generally, human eye cannot notice any error in pictures reproduced in this way because the difference between two consecutive lines is small, anyway.

There is one aspect more `legalizing' this procedure: the resolution of the human eye for colour pictures is about 5 times worse than that of the monochrome pictures. Since the TV transmission has been originally specified so that it should meet the resolution of monochrome pictures, the actual line number is much higher than that is required for colour pictures. This means that using the same colour information for two neigbouring lines the (vertical) resolution is still better than necessary.

In accordance with the SECAM standard, only the (R-Y) colour difference signal is transmitted in one line, then the (B-Y) signal in the next line, etc., and this is alternately repeated line after line. The principle of the system is also given in its full name: 'Séquentiel Couleur Ŕ Memoire', i.e. 'Sequentially Memorized Colours'.

It follows from the above discussion that -compared with the NTSC- the great advantage of the SECAM is that only *one chrominance* is transmitted at a time. Consequently, since there is no need of the quadrature modulation, the system has become free of all problems related to the phase errors resulting in distorted colours. Knowing that, the authors of the SECAM obviously did not insist on QAM: FM has been chosen instead since being much more insensitive to noises and to interference and requiring no precise reference for the demodulation.

'Unfortunately', an FM signal instantaneously changes its frequency so that its interference with the *Y* signal cannot be hidden by the solution used by NTSC. The apparent deadlock was opened by a brilliant key: Interference can be made invisible if the raster of stationary points produced by the interference randomly changes in time. This idea has been realized as follows: The frequency of the subcarrier has been chosen as a multiple of the line frequency which, for itself, would cause a very strong interference visible on the screen as a raster of stationary points. To `disturb' this raster, i.e. to make it move very quickly, the initial phase of the subcarrier related to the phase of the line synchronization signal is inverted at the beginning of every third line and in every second field. So the interference becomes quasi-random which is even more true when the frequency of the subcarrier is changing by the modulation.

20.5.3. The PAL System

Principally, the PAL is a modification of the NTSC with the main effort to eliminate the system sensitivity to the phase errors. Since the principle of the modification is a phase alternating in the rhythm of the line frequency, the system is called the 'Phase Alternating Line'. Like the NTSC, PAL also uses QAM but modifies it so that the phase of the red chrominance signal is inverted in every second line. So in one line, the phase of the chrominance signals is the same as for the NTSC while the phase of the red chrominance signal is shifted by 180^{o} in the next line, etc.

Phase alternating, in itself, does not eliminate phase errors, it modifies, however, the spectrum of the QAM signal in a way which can be favourably exploited. Namely, due to phase alternating, the 'nodal points' of the spectrum representing the energy of the red chrominance signal become separated from those of the blue chrominance signal. So the modulated chrominance signals can be separated by a special filter ('comb-filter') *before* being demodulated. This is very important because the demodulation and thus phase errors are the same as in the case of NTSC (a multiplier has to be used to demodulate the signal with suppressed carrier). In this case only the amplitudes of the demodulated chrominance signals are slightly reduced (proportionally to the cosine of the phase error), the colour-crosstalk, however, is eliminated, since both demodulators (multipliers) are fed by only one chrominance signal. The colours are not distorted because the amplitude of the chrominance signals are affected to the *same* extent causing only a little decrease in the hue.

20.5.4. The MAC System

Before the discussion of satellite TV-broadcasting systems, let us explain why the terrestrial colour-TV systems are not ideal to be applied there. The common features of the terrestrial colour-TV systems which are of interest for answering this question are as follows:

- the colour information is transmitted by means of a relatively *high frequency subcarrier* (~3.54.5 MHz),
- *AM-VSB modulation* is used for the transmission of the composite video signal (consisting of the luminance, of the subcarrier modulated by two chrominances and of the synchronization pulses).

Because of the limited power available on satellites, FM is used exclusively as being a modulation which produces a good quality transmission with minimum power consumption. The noise power spectral density of the FM demodulator output, however, differs a lot from that of the AM-VSB. If we suppose that additive white noise is present in the transmission channel, the noise power spectral density of an AM demodulator is constant in frequency (thus the same amount of noise is superposed to the luminance and to the chrominance signals). At the output of an FM demodulator, the noise power spectral density increases with the square of the frequency adding thus much more noise to the chrominance signal located at the high frequency end of the composite video-signal spectrum.

To solve the noise problem and to improve the relatively old colour-TV systems, a family of new procedures, called the Multiplex Analogue Components (MAC) was developed at the beginning of the '80-s, when the already existing satellite communications started to be used for broadcasting, too.

Unlike the conventional terrestrial systems which -according to their principle- can be considered as FDM systems, MAC is an incompatible, TDM-based system. The video signal is still analog but the chrominance and the luminance signals are compressed in time and sequentially \`inserted' into the transmitted signal. Line and field frequencies are the same as that of the PAL but the colour-difference signals are transmitted sequentially similarly to the method used by the SECAM (one chrominance signal in one line). The compression ratio which is given by the time of the original to that of the compressed signal is 1.5 for the luminance and 3 for the chrominance signal. Obviously, the signals are not compressed by leaving out any of their details, instead, they are \`accelerated', i.e. less time (but greater bandwidth) is required for their transmission. This is made so that one of the chrominance signals compressed to one third and the luminance signal compressed to two thirds are inserted into the time-slot of one original line.

20.6. Digital TV Systems

From the beginning of the '90-s, digital procedures started to be used also in the TV technique. Sampling, quantization, coding, as well as the storage and filtering of digital signals offer possibilities previously unthinkable in this area.

The first step was done at the beginning of the '80-s when a digital studio-standard was accepted. The aim of the standard was to minimize the conversion problems caused by the differences in line frequencies of the different systems. For that purpose, 13.5 MHz was recommended as the sampling frequency of the luminance signal, being a common multiple of the line frequencies used by the NTSC, PAL and SECAM. Using such sampling frequency, an orthogonal structure of samples is produced for all systems which makes signal transcoding, e.g. the NTSC into PAL, considerably easier.

In the next step the TV receiver had to be digitized. In the course of that the composite video signal has been completely processed digitally. The choice of the sampling frequency was the greatest problem because of two different aspects: According to one of them, the sampling frequency should be \`tied' to the subcarrier frequency since in this case the composite video signal is very easy to decode. According to the other, the sampling frequency should be `tied' to the line frequency since in this case it is easier to solve the storage and the post-processing of the video signal, although the decoding of the composite video signal becomes more complex. Examples can be found in different colour video processing methods for the application of both aspects.

Parallel to the spreading of the digital TV, the development of high definition television (HDTV) has been started throughout the world. All projects aim to transmit the HDTV picture with the slowest possible data rate, i.e. with the minimum bandwidth. HDTV has been defined so that it has both the vertical and the horizontal resolution double of that of the conventional TV. The aspect ratio of the picture has been also changed to 16:9 which corresponds to the aspect ratio of the wide-screen movie.

Unfortunately, like for the terrestrial TV broadcasting, there is no chance for a uniform HDTV system. The reasons are rather economical and political than technical. Among the different HDTV versions, the Japanese system is in the most advanced stage. Experimental HDTV transmission started there in 1985 and regular broadcasting has been on since 1990.

The principle of the Japanese HDTV lies on the multiple sub-Nyquist sampling and encoding (MUSE) which reduces the information content of the high resolution picture. The principle of this method is that the human eye cannot follow fast changes in pictures. Therefore, those parts of the pictures which are moving fast are transmitted with reduced resolution while the standing parts are transmitted with the finest resolution since the time is sufficient to do so if the content is not changing.

The standing and the moving parts of the pictures are distinguished by the so-called motion detector. Beside that, so-called motion-vector compensation is used for the transmission of slowly varying parts of the picture. Instead of transmitting the information content of the slowly moving part, it is more reasonable (requires a smaller data rate) to transmit the direction and the speed of the motion. This can be described by a vector, called the motion-vector. The above strategies are used in all HDTV systems.

MUSE, however, has two significant drawbacks: it is not compatible with any other system and the transmission is analog (digital signal processing was in an early stadium at the beginning and middle of the '80-s).

Recently, digital signal processors (DSP) have been developed with such a high operational speed that many special operations can be performed in real time. That is why the USA and Western Europe incline more and more towards pure digital HDTV transmission.

Bandwidth of the transmitted signal can be incredibly reduced by decreasing the high redundancy of the moving pictures without being noticed at all by the viewer. Also the previously mentioned properties of the eye (finite resolution and the impotence of following fast motions) can be well exploited. A series of pure digital procedures such as motion detection, discrete cosine transform, DPCM coding, motion compensation, time compression, etc., are used in the new HDTV procedures to achieve optimum quality of the picture within the possible smallest bandwidth.

In spite of the experimental HDTV transmission from the Summer Olympic Games in Barcelona, actually no uniform point of view exists in Europe. The system used there was the so-called HD-MAC which transmits the picture in analog form, similarly to the MUSE. At the same time there is another European recommendation for purely digital transmission.

Among the four recommended systems, Digicypher has the greatest chance to be used in the USA. Unlike to the European and Japanese plans, this will be used in terrestrial TV broadcasting. The final decision is to be made in 1993.

Control Questions

1. What is the principle of interlacing?
2. What are the characteristics of the area diagram?
3. What is the principle of the proper reproduction of colours?
4. What are the main parameters of the NTSC, PAL and SECAM systems?
5. What is the HDTV?

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Abbreviations

AM	Amplitude Modulation
AM-VSB	Vestigal Side Band Amplitude Modulation
CIE	Commission International de l'Éclairage
DPCM	Differential Pulse Code Modulation
DSP	Digital Signal Processor
FDM	Frequency Division Multiplex
HDTV	High Definition Television
MAC	Multiplex Analogue Components
MUSE	MUltiply sub-Nyquist Sampling and Encoding
NTSC	National Television System Committee
PAL	Phase Alternating Line
QAM	Quadrature Amplitude Modulation
SECAM	SÉquentiel Couleur Á Memoire
TDM	Time Division Multiplex