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Abstract :

The Scanning Formats extension of the HAMLET project finds its source in the Recommendation on Scanning Formats formulated by the RACE Image Communication Project Line (January 1994). The purpose of this deliverable is to re-analyze the considerations presented in this recommendation, to raise new elements – technological improvements, new considered services, simulation results – and to try to evaluate the fallbacks of the studies on progressive and interlaced coding efficiency.

Keywords :

Scanning Formats, Progressive, Interlace, Image capture, Scanning Artefacts, Signal Processing, Deinterlacing, Reinterlacing, Filtering, Multi-resolution, Scalability, Slow-motion, Chroma-keying, Aspect Ratio, Frame Rate, Still Picture, Multimedia, Coding Efficiency, Display.

Summary

Progressive scanning is the most direct approach to represent two-dimensional images. However, in the early years of television, an interlaced format was chosen in order to efficiently save bandwidth. Even if this latter format introduces some well known artefacts such as *interline twitter*, *line crawling* and *field aliasing*, these effects were not so annoying at the time of early television, mainly due to the limited spatial definition and the limited brightness range of the cameras and the displays at that time. Today, with the progress in technology, these artefacts become more obvious. However it is still true without any reasonable doubt that for analog television interlaced scanning offers an improved picture quality compared to progressive scanning at the same transmission bandwidth. This does not necessarily hold for digital television because the picture quality depends on the coding efficiency at a given bit rate. In such a context, the advent of the future digital and/or high-definition television may be seen as a good opportunity to bring a change in scanning formats. Even if the use of a progressive format could require at first sight twice the bandwidth of the interlaced one, the increase in vertical and temporal correlations within and between frames provides a significant improvement in the coding efficiency. Also, even if an interlaced scheme is chosen for the future digital television, a progressive format may still be of interest as an intermediate format in order to improve the coding of interlaced sequences. Advantages and drawbacks of interlaced and progressive scannings are reported in this deliverable.

Contents

Advantages and Drawbacks of Interlaced and Progressive Scanning Formats

1 Introduction

Interlaced and progressive scanning formats often have been the center of intense discussions about their respective advantages and drawbacks, especially in the context of making a choice for the future digital television. Chosing one or the other format basically reverts to the problematic choice between an ingenious bandwidth reduction (yet offering satisfying quality for the end-user) and an improved visual quality at the display. Signal processing theory tells us that halving the information rate, which is the case when the interlaced format is chosen instead of the progressive one, must reduce the quality of the displayed picture and so the saving in bandwidth is accompanied by a variety of effects like *line crawling* and *interline twitter* [1]. However interlaced format has been chosen in the early years of television considering it was one of the most interesting solution to achieve data compression with regard to the available technology. It also offered a clever trade-off between image data compression and display quality. Today, the improved quality of the sources and displays make the viewer much less tolerant of the defects of the interlaced format, especially for large displays (e.g. peripheral vision), at close viewing distance and high brightness levels. The change from analog to digital television may be seen as a good opportunity to change formats. Hopefully, since most digital communication services are new, the backward compatibility constraints in the choice of a scanning format are still limited. This choice however needs to be made with much care, to avoid backward and lateral compatibility problems that would become difficult to solve in the future [2]. In addition, in order to leave space for future upgrades throughout all the video coding chain it could be envisaged as a wise step not to degrade image quality at the very beginning of the process, i.e. inside the camera, choosing a lossy scanning format. But even if an interlaced scheme is still chosen for future developments, a progressive format may be still of interest as an intermediate format for improving the coding efficiency and simplify image processing.

This deliverable will discuss advantages and drawbacks of interlaced and progressive formats considering multiple viewpoints. The following section (section 2) will be devoted to the historical reasons which led to the choice of interlaced format for the early television. We then will discuss the influence of the scanning format on the visual perception of the displayed image (section 3). Next sections are structured following the logical order of blocks inside a typical video broadcasting chain (figure 1), from the signal generation to the final displaying, and involves camera technology (section 4), signal processing aspects (section 5), coding performances (section 6) and display technology (section 7). Finally, last section (section 8) will describe some scenarios for the introduction of a progressive scanning format in television.

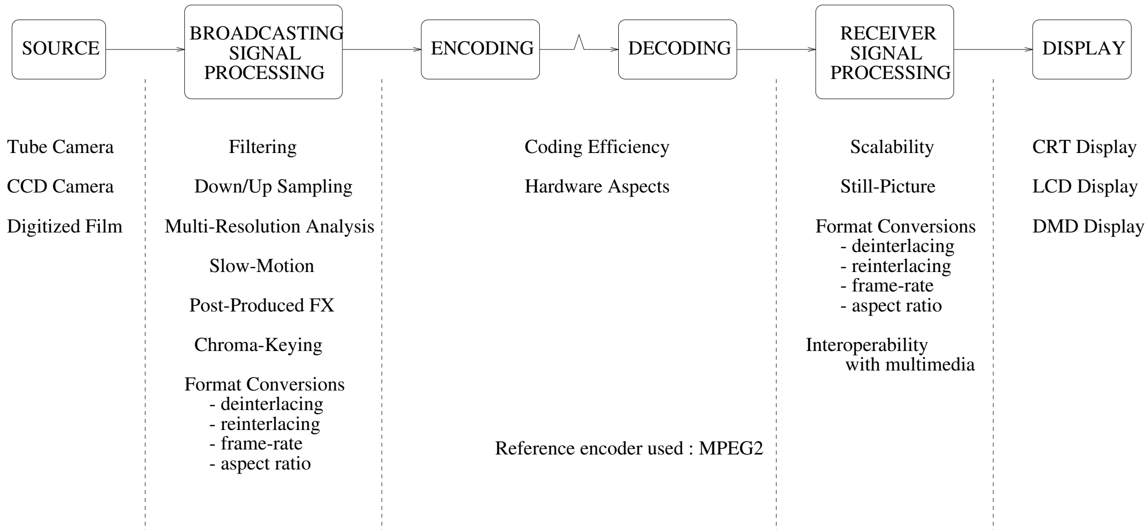


Figure 1: Video broadcast main blocks and aspects directly related

2 Historical Considerations

2.1 The Choice of an Interlaced Format

The choice of the actual television system arose from numerous compromises between the visual quality of the displayed image, the bandwidth required for the transmission, the technical feasibility of the fundamental components (analysis tube, cathodic ray tube, etc.), the cost price of the receiving set and other economic considerations.

At the time of early television, a 50Hz field frequency was chosen considering principally the following points [3] :

1. *Correct movement restoration.* Image frequency (or frame frequency) must be larger than 15 images/second in order to avoid a jerky effect in fast motions.
2. *Display tube.* Cathodic ray tubes have exponential decreasing brightness response. The light emitted from a portion of the screen is pulsed, leading to some flickering effect. In usual working conditions of screen size and brightness, field flickering disappears for frequencies above 50Hz. By means of interlacing, the *mean lightening* emitted from a portion of the screen is pulsed at field frequency. Consequently, *field frequency* must be at least equal to 50Hz.
3. *Device conception.* An economic realization of the receiver involves some restrictions to the field frequency in order to avoid visible defects due to the influence of

the 50Hz-alternative mains onto the display process. Hum effect may influence polarization voltages and lead to some interference with the luminance signal. Also, magnetic radiation issued from the feeding transformer may influence the cathodic beam and alter the geometry of the displayed picture. These defects are much less perceptible when they appear static on the screen. It implies that they have to be synchronized with the display frequency.

These considerations led to the choice of a 50Hz field frequency (60Hz for countries for which a 60Hz mains was adopted).

About the format itself, interlaced was mainly chosen for limiting the bandwidth required to transmit a television channel : interlacing can be seen as a subsampling process capable to reduce the bandwidth by a factor of two (figure 2) without limiting the vertical resolution in static pictures. Interlaced format also allows to make hardware implementation easier (e.g. deflection control at the Cathodic Ray Tube - CRT) and consequently lower the price of consumer's television set.

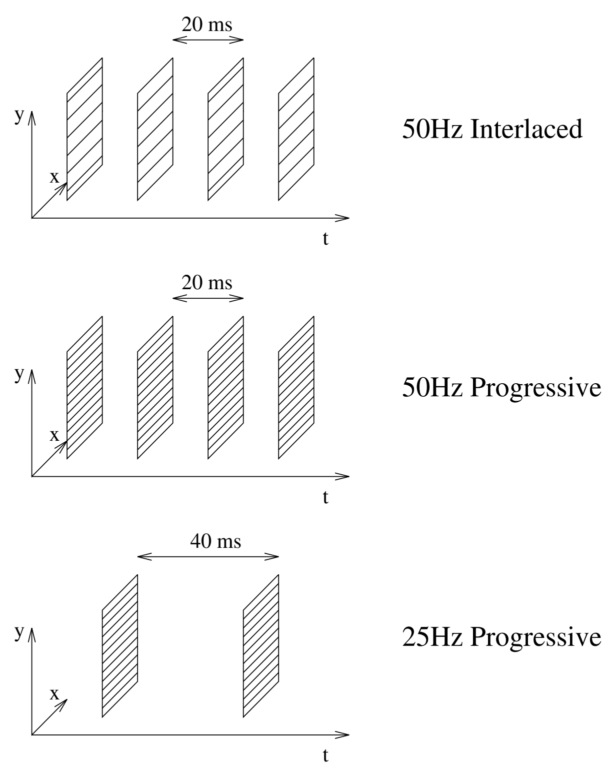


Figure 2: The different scanning formats

Unfortunately, interlacing produces some specific defects like *interline flicker*, *line crawling* and *pairing*. These defects will be further described in section 3.

2.2 About a 25Hz-progressive Format

In order to avoid the above mentioned defects, let us notice that a 25Hz-progressive format might have been chosen at the time of the early television instead of the interlaced format. Twenty-five frames a second are high enough for a very large class of picture material, including all films. However, each frame has to be repeated in order to convert the display refresh into a 50Hz refresh rate and so avoid large area flickering. This technique works fine and is commonly used to screen films (24Hz-progressive) on cinema, broadcasting films on television or even as an intermediate format within particular television cameras [4]. 25Hz-Progressive format requires the same bandwidth as interlaced but does not suffer from the interlaced defects. However, this format was not chosen at the start of early television. First, because frame memories needed to perform the frame repetition were nearly non-existent at that time (and certainly too expensive to be integrated in every receiver). But also because the deflection processing at the display must be twice as fast as for interlaced, resulting again in increasing the cost price of the receiver. At last, let us notice that repeating twice the same image may lead to some annoying jerk effect in moving parts of the scene at critical velocities. In order to avoid this, the integration time of the camera must be equal to the elapsed time between two successive images : 40ms for 25Hz-progressive instead of 20ms in the case of 50Hz-interlaced/progressive. Consequently, 25Hz-Progressive sequences suffer from increased blur in quick moving parts of the scene.

3 Visual Considerations

3.1 Scanning Artefacts

The "analog" scene captured by a television camera may be seen as a function depending on three variables : the time, the horizontal and the vertical directions. In order to convert this function into a one dimensional electric signal, it is required to sample (at least) two of these parameters. Therefore, the time variable and the vertical dimension have been sampled (figure 2). The resulting video signal provides signal at fixed moments and fixed lines. This "scene"-scanning process generates some defects which might be visible under some conditions :

1. *Line structure visibility.* Caused by the vertical sampling and increased by close viewing.
2. *Jerk in motion.* Appears when the temporal sampling frequency is too low (below 15 images/second).
3. *Large area flicker.* It depends more on the CRT refresh (pulsed excitation and exponential decreasing brightness response) rather than the choice of the temporal sampling frequency itself. However, they are related. This large area flickering effect is increased for high brightness values and for peripheral vision (increased flicker-sensitivity of the eye).

3.2 Additional Artefacts of Interlaced Format

The above mentioned defects of the scanning process stands for progressive format as well as for interlaced. In addition, interlaced format suffers from further defects. These are [1, 3, 6]:

1. *Interline flicker.* When lines are enough spaced to be distinguished by the eye (large displays or close viewing distance), alternating fields causes the twittering of the line structure. Also, if an object has a sharp horizontal edge, it will be present in one field but not in the next. The refresh rate of the edge will be reduced to the frame rate, 25Hz (or 30Hz) and will become visible as twitter.
2. *Line crawling.* Whilst the vertical resolution of a test card is maintained with interlaced, apart from the twitter noted, the ability of an interlaced standard to deal with motion is halved. Line crawling is caused by the halving of the vertical resolution for slowly moving parts of the picture in the vertical direction. It also causes diagonal moving edges to be crenelated.
3. *Pairing.* Interlacing is correct when the lines resulting of the merged fields are strictly equally spaced. For different reasons, it could not be the case at the display. It may thus bring some lines nearer causing larger black intervals to appear. This *pairing* effect increases the line structure visibility and damage the image quality.

These effects may also be explained in the light of the sampling theory [5, 6]. In a frequency domain, sampling reverts to repeat the spectrum of the "analog" scene at harmonics of the field repetition and the line repetition rates (figure 3). In order to avoid aliasing (i.e. overlapping of the different repeated spectra) a pre-sampling filtering must be performed at the camera.

Temporal pre-filtering is only due to the remanence effect in the camera tube. The choice of this parameter is not obvious because various applications have to be considered: from very slowly moving pictures to scenes with very quick motion. Those filtering effects are poor.

The vertical spatial pre-filtering is obtained by defocusing the camera optics or the electron beam (i.e. modifying the analysis spot size). The spot acts as an integrator of the luminance over a finite region. Once again, the performances of such system are poor. For digital television, were horizontal direction has also to be sampled, templates for horizontal pre-filtering filters were optimized by the CCIR and EBU.

The scanning defects visible at the display are caused by the presence of the repeated spectra (dotted lines in figure 3). In order to reduce it, some post-filtering must be performed. Most of this post-filtering count upon the properties of the human vision. The human eye may be compared to a spatio-temporal low-pass filter. Although there is no separability between space and time, the behavior of the eye may be assimilated to a 50Hz-cutoff frequency low-pass temporal filter and a spatial low-pass filter with a cutoff frequency of approximately 25 cycles by degree of visual angle (e.g. 250 cycles/screen

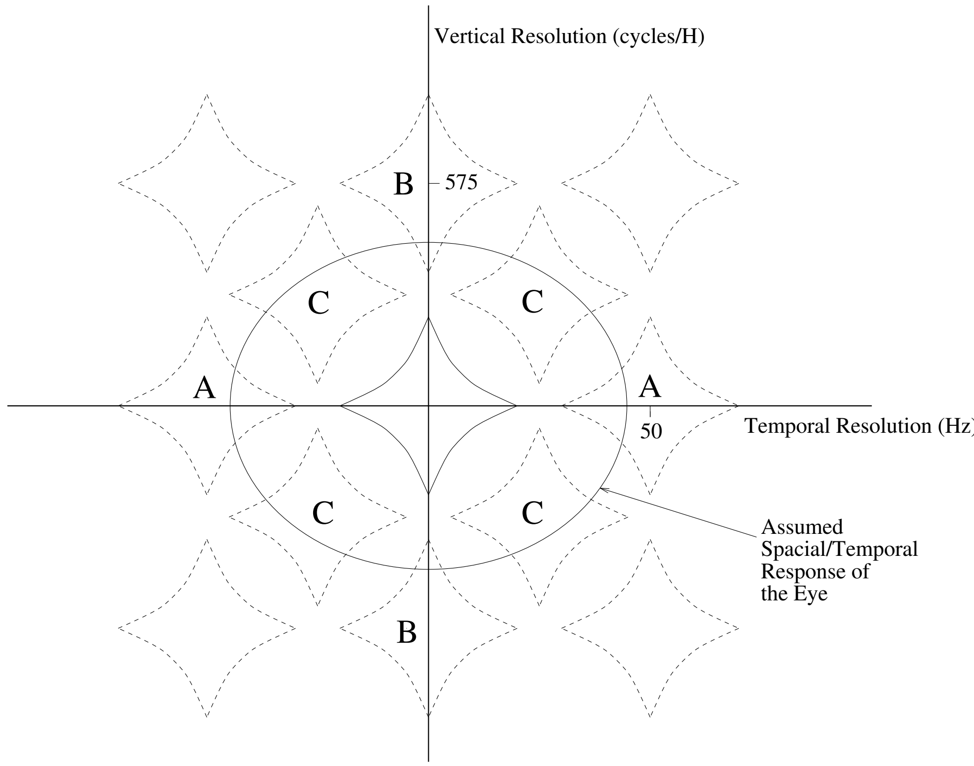


Figure 3: Repetition of the spectra for interlaced scan (25Hz/575 lines)

height for a viewing distance of 6H or 350 cycles/H at 4H). This is also shown in figure 3.

The spectra repeated at the multiple of the field frequency are responsible for the large area flicker (particularly the spectra labeled A). Some post-filtering is obtained from the tube remanence and the temporal low-pass filtering effect of the eye.

The repeated spectra along the vertical frequency axis are responsible of the line structure visibility (particularly the spectra labeled B). As no vertical low-pass filtering is used for the display, the only way to eliminate that effect is to take advantage of low-pass property of the human eye and the finite size of the picture tube spot. In order to have the wanted eye low-pass effect, the observer has to stay far enough from the screen. The line structure is generally dimensioned for a viewing distance of six times the height of the screen.

As shown in figure 3, the interlaced scanned format has also spectra located at quincunx points (labeled C). Those spectra are responsible for the interline flicker and the crenelated diagonal moving edges.

3.3 Kell factor

These same spectra are also responsible for the introduction of a so named *Kell factor*. A vertical sampling frequency of 575 lines per screen height theoretically allows to display vertical spatial frequencies up to 287.5 cycles per screen height. However, extending the vertical bandwidth up to this limit leads to an additional flicker due to the aliased spectra as illustrated in figure 4.

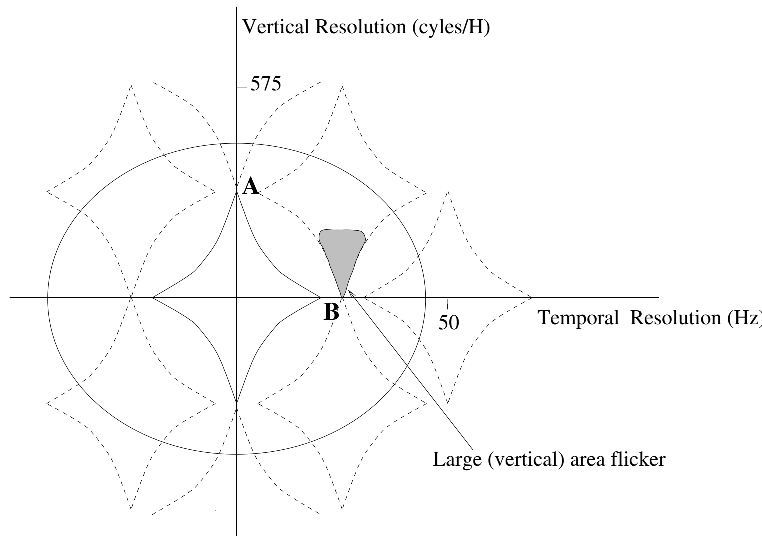


Figure 4: 25Hz flickering (Interlaced 50Hz/575 lines)

The effect of this repeated spectra, in particular the effect of the flicker area represented in figure 4, can easily be explained. At first, let us notice the relationship that exists between the points labeled A anb B in this same figure. Point labeled A represents a static (i.e. temporal frequency equals zero) television sequence which contains the highest possible vertical definition. On the opposite side, the point labeled B only has a poor vertical definition but owns the maximum allowed temporal resolution. The television sequences associated to these "spectral points" are illustrated in figure 5. This figure shows that, when these two sequences are displayed in the interlaced format, they give rise to the same displayed sequence and the viewer is not able anymore to determine which was the original scanned sequence. It is the definition itself of the aliasing phenomenon. In this case, it produces an additional flicker.

This flicker has a low vertical frequency, which means it affects large (vertical) areas, and has a temporal frequency close to 25Hz which reveals to be annoying. In order to minimize this effect, some additional pre-filtering has to be performed, reducing the vertical resolution below its theoretical limit. This reduction factor is called the *Kell factor* (figure 6) and has a typical value of 0.7 (but may vary up to 0.9 or 1 if no filtering is processed). This filtering is achieved at the camera.

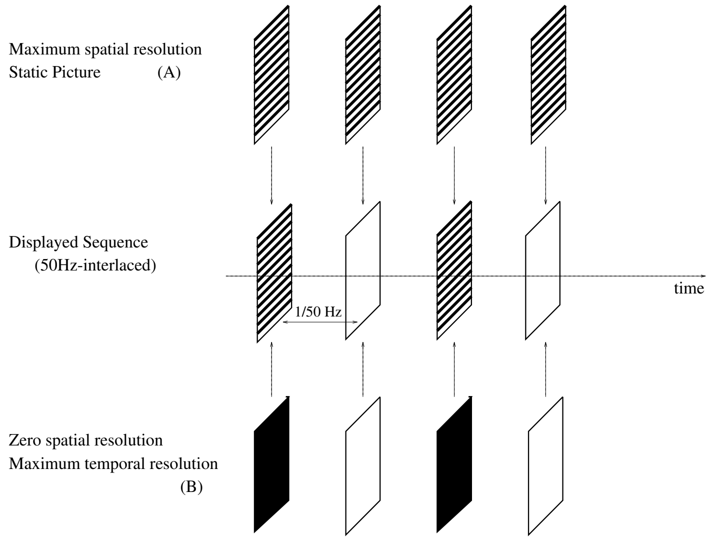


Figure 5: Aliasing phenomenon (50Hz-interlaced)

3.4 Progressive format

Compared to interlace, progressive scanning offers the benefits of a improved vertical resolution, especially on moving parts of the picture for which intra field aliasing is avoided. As illustrated in figure 7, progressive scanned sources do not suffer from interline flicker or crenelated moving edges (label C on figure 3). Also, they do not require additional vertical filtering like mentioned for the Kell factor.

3.5 Subjective Comparison between Progressive and Interlaced formats

Tests have shown that, all other things being equal (screen size and total number of lines per screen height), a 2:1 interlaced picture has to be viewed from almost twice as far away as a progressive scan picture [1]. It was also shown that for the same viewing distance, progressive scan needs about 35% fewer lines compared to interlaced in order to offer the same vertical resolution [7].

4 Source Image Capture Aspects

The influence of source image capture devices reflects throughout all the video broadcasting chain and also on the choice of the scanning format. The substantial SNR loss incurred in progressive scanning compared to interlaced in pickup tube camera technology has practically determined the concentration of all the researches on the interlaced format. However, the introduction of the HDTV together with the fast growing of the CCD technology seem to modify this scenario. In fact, while researches on conventional interlaced cameras mainly focus on upgrades regarding lower weight, dimensions, cost,

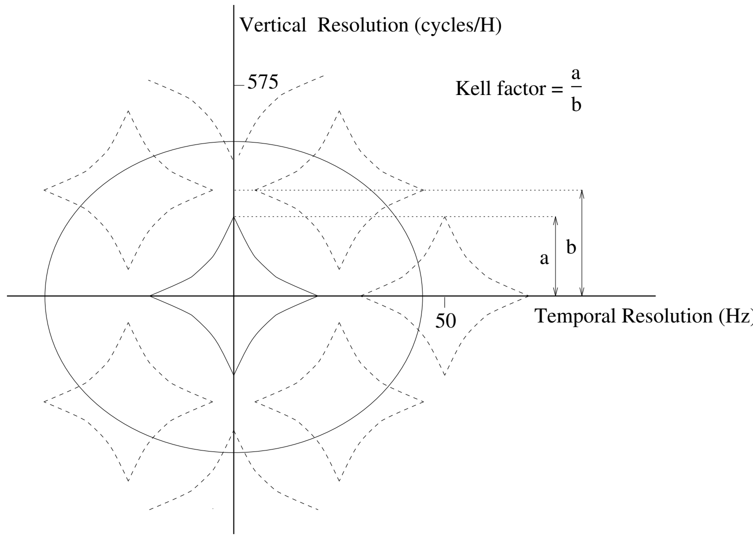


Figure 6: Kell factor (Interlaced 50Hz/575 lines)

target voltage, and easier control (for important parameters such as the temporal aperture), requirements of HDTV lead to improve the performances of the CCD technology. These progresses can thus be used to reduce the performance gap in sensitivity and SNR between interlaced and progressive scan. In the following some of the latest contributions in this domain are briefly synthesized.

SNR evaluation for a video-camera passes through a study of noise sources, physically related to the characteristics of image capture and of the generation of the output current/voltage signal. There are basically two kinds of noise sources in a TV camera [8] : the first one is *quantum noise* (or *shot noise*), related to the photoelectric converter present in a tube pickup and in the photo diodes of CCD; its power spectrum is flat both for tube and for CCD cameras. The second one is *device noise* (or *triangular noise*), which for tube is mainly due to the first stage amplifier noise, and it increases in proportion to the cube of the signal bandwidth. The latter is 9 dB lower with interlaced than with progressive scanning [10]. It explains the poor quality of sequences taken through a classical progressive tube camera, as well as the low contrast and brightness observed in these pictures.

More difficult is an efficient computing of SNR for a CCD camera, because of the presence of various device noise sources (*reset noise*, *amplifier noise*, *shot noise* of the dark current), with specific frequency behavior and without a clear dominance of a single component. In addition it is noticeable that CCD chips usually performs interlaced scanning by summing the signal charge of two vertically adjacent pels, alternating the combinations of the two pels by the field, so the signal voltage (and sensitivity) in the progressive operation is half the interlaced one. By summing up the increase/decrease of noise power contributions and taking into account the last consideration, the SNR determined by device noise of a progressive CCD camera decreases by (6+α) compared to that of an interlaced one, where -3 $< \alpha <$ +3 expresses the variable dominance of one noise over the others and depends on the manufacturing technology. Moreover,

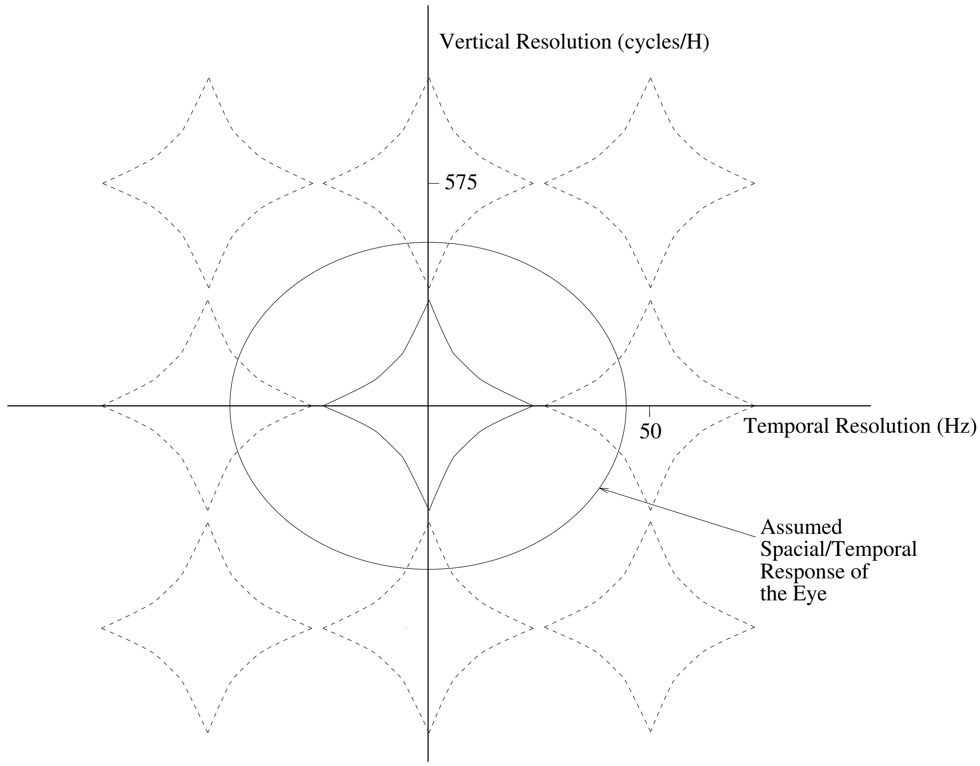


Figure 7: Repetition of the spectra for progressive scan (50Hz/575 lines)

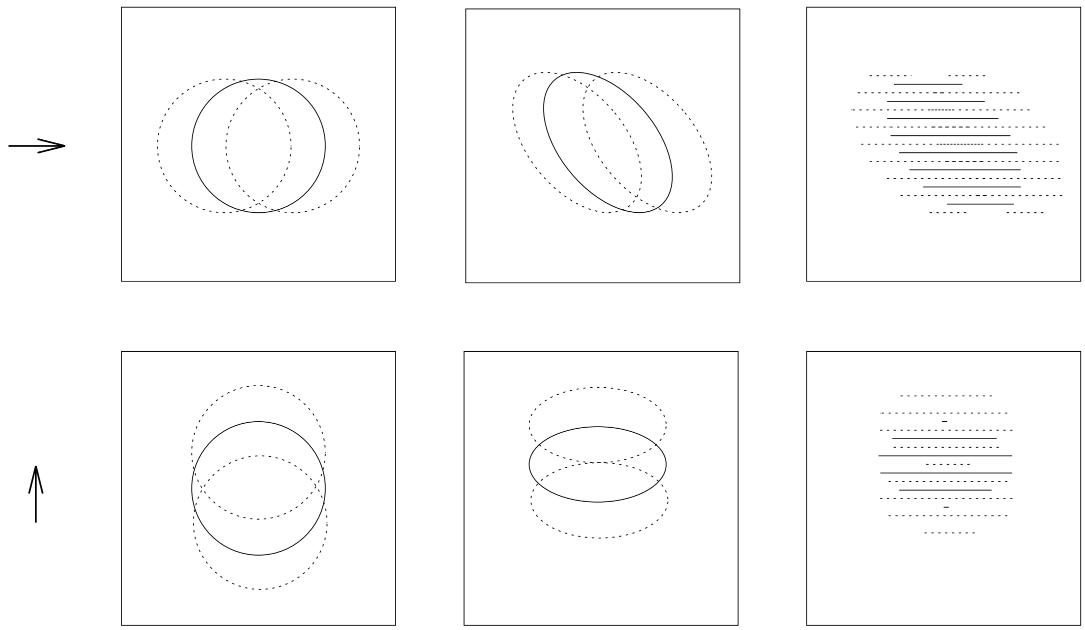
if effective SNR in camera operation is to be considered (after gamma and aperture correction), it leads to table 1, performed on HDTV 1125 lines cameras [8].

Image Device	Tube		CCD	
Scanning system	Interlace	Progressive	Interlace	Progressive
Signal bandwidth (MHz)	30	60	30	60
Nominal SNR (dB)	47	38	around 50	41-47
Effective SNR in camera operation (dB)	34-38	25-29	37-40	29-37

Table 1: Effective SNR estimate of 1125 lines HDTV camera

It can be observed how the technological gap between interlaced and progressive is considerably reduced passing from tube to CCD. Moreover, although in a first period mostly interlaced cameras have been developed, an interesting recent realization [9] shows that the specific design of a CCD video camera for progressive scanning allows to increase significantly its performances, with a cost comparable to that of interlaced. In particular this realization is a 525 lines 1:1 16:9 camera that employs a new image-capture system called *Multiple-Frame-Interline-Transfer* (M-FIT). The M-FIT CCD is a different design for the storage-cell and for the signal transfer mechanism between the photo diode and the storage-area, which leads to a dynamic range twice as large as that of a conventional device, owing to the use of the M-FIT CCD for progressive scanning with similar performances as conventional CCD for interlaced one.

Depending on the camera technology which is used, i.e. tube or CCD, the motion rendition of moving objects may also differ [11]. Figure 8 shows the motion rendition of a disk moving at constant velocity (horizontal and vertical motions) across the field of view, as shot by the different camera types.



(a) Progressive frame-transfer CCD

(b) Progressive line-transfer CCD or progressive tube-type camera

(c) Interlaced tube-type camera

Figure 8: Motion rendition of a moving disk

As illustrated, using a progressive frame-transfer CCD camera allows to shot frames like a photograph. This improves the picture display, especially when there is a need for displaying slow motion or still picture. Tube scanning (interlaced as well as progressive) or line-transfer CCDs suffer from distorsions due to the movement of the object during the capture of the image.

Apart from video-cameras an important source of motion picture material for future television is constituted by films. Film is a medium that will never suffer of any backward compatibility problem because its recording quality is the highest possible, it can be considered as an extremely high-band RGB. The importance of the archives maintained by the cinematographer companies is considerable (Hollywood studios and production community dispose of the largest library of motion pictures in the world), so it is not negligible to study how to optimally convert this source material into digital data. If we do not consider the debate on optimal resolution and RGB-to-YUV conversion, it is generally agreed that a 25Hz (24Hz) progressive scanning is the base condition. Compatibility with existing interlaced TV sets is therefore guaranteed by use of frame-repetition (as in the MPEG2 case). This repetition does not produce evident motion jerking effects, due to a series of technical tricks used when filming with a cine-camera, that otherwise could occur if a 25Hz video-sequence is converted to 50Hz by simple frame or field repetition without considering temporal aspects (like the exposure time for example).

Thus, from the source point of view, progressive scanning is the best candidate when film materials are used, and the latest technological progress allow video progressive CCD cameras to be used with the same quality as interlaced ones.

5 Signal Processing Aspects

The second item inside the Recommendation on scanning formats [12] states that a progressive scanning makes most signal processing operations much easier than interlaced scanning, e.g. vertical filtering, interpolation and decimation, slow motion, still picture display, multi-resolution analysis, hierarchical coding and pre-display processing. The most common comment to this affirmation is that this operations are apparently easier, but since all the systems must work with a doubled clock frequency and with higher memory usage, the real complexity is greater and not lower for progressive.

In this section the most important signal processing operations commonly applied to the video signal are examined, focusing the attention on scanning format requirements and evaluating their complexity impact in a proper scenario where it is above all distinguished between services to be realised at the broadcasting side (slow motion, chroma-keying), at the receiver side (still picture, interoperability) or at both sides with different complexity and quality (format aspect and frame rate conversions). The first couple of signal processing operations which merits to be considered regards logically the mutual scan conversion in order to evaluate their complexity.

5.1 Deinterlacing / Reinterlacing

Compatibility between interlaced and progressive can be achieved only if the conversion algorithms can guarantee a sufficient picture quality at a moderate cost. It is generally known that deinterlacing is more complex than reinterlacing because new information not present in the input data must be created.

The results of Race TRANSIT works (recently come to conclusion), can be used to state these debates [13]. They prove that a satisfactory progressive to interlaced conversion is achievable through a vertical low-pass filter, characterized by a frequency response accurately designed and well-reproducing the one of a real interlaced camera (Kell factor), followed by a vertical subsampling with different phase for the two fields. This study on the filter shape has produced various good filters well tested in literature, such as the 11-tap known as HHI filter.

On the contrary, in order to reach a comparable quality in the interlaced to progressive conversion it is clear that a sophisticated technique, based on a combination of motion analysis and spatial interpolation, is needed. Moreover, the motion estimation algorithm is usually specifically designed to this aim, since classical block-matching implemented for coding purposes does not fit the specific constraints. Subjective assessments have been performed based on test-sequences and the evaluation of the scores shows a significant gap between the motion compensated deinterlacing algorithms and the other solutions (low-cost linear interpolations). The utilization of such complex techniques at the receiver side, i.e. after the decoding of the interlaced bit streams, does not seem realistic today and it would be surely of interest to pursue studies on effective low-cost solutions, possibly making use of standard MPEG2 motion information.

The HAMLET Extension on Scanning Formats intends to investigate the possible advantages of using a progressive format as an intermediate format for the coding of interlaced images. Unlike TRANSIT development, HAMLET deinterlacer is meant to be placed upstream the coder. In order to get the best coding efficiency, a particular attention must be paid to the quality of the reconstruction of the progressive sequence from the interlaced input. The deinterlaced sequence has to represent the "analog" scene hidden behind the interlaced input as well as possible. In other words, the fields added to the interlaced sequence for converting into progressive must be spatially and temporally coherent with the already existing fields. In particular, the calculation of the motion vectors must be finely tuned and a method allowing a perfect reconstruction has to be found. The analysis inside HAMLET will be based on the *general sampling theory* which was proposed recently to handle interlaced images and proved to be successful [14, 15].

5.2 Filtering

Vertical filtering is intrinsically more effective for signal sampled on a progressive grid, both in terms of complexity and final results.

If the interlaced filtering is performed *intraframe*, although two frames have to be processed for progressive at the time of only one for interlaced, adjacent vertical pels are available with a delay of 20 ms, and all the process could be executed in real-time at the same speed as progressive. Moreover, filtering two fields merged produces ghost-effects and motion judder in presence of motion.

If the interlaced filtering is *intrafield* the process could be sped-up, but two more sophisticated filters have to be designed (phase linear/not linear, phase shifting) and results are degraded in presence of critical patterns (near horizontal moving lines) producing annoying artefacts. Note that this second solution is currently employed with effectiveness inside the 4:2:2 $\rightarrow$ 4:2:0 MPEG2 pre-processing but in this case the filtering is applied on the much less critical chrominance components. The same conversion for a progressive MPEG2 encoder, usually requires a trivial 3-tap filter (so faster to be implemented than the two classic 7-tap FIR of interlaced) and offers better performances of almost 1 dB.

5.3 Multi-resolution analysis - HDTV/TV scalability

Multi-resolution processing of video signals could be historically divided in two great domains: frequency scalable and spatial scalable techniques. In the former the downward conversion HDTV-TV is performed in the frequency domain (subband, DCT) through a proper selection of a sub-pattern of spectral coefficients, while the latter provides conversion by FIR filtering (vertical or vertical/temporal). Within MPEG2 scalable profiles, the spatial scalability is the only scalability feature accepted by the standard where picture spatial resolution is involved. Frequency scalability, although deeply considered during the preparatory working years of the expert group, has been discarded at the end, mainly because interlaced performs poorly in terms of separation of the vertical frequencies. The encoded MPEG2 signal can produce a decoded lower layer with high quality (apart from drift problems) from the simplest data partitioning operation (e.g. the selection of the lowest transmitted coefficients), only effective with progressive scanning. Moreover, an intermediate progressive step is often considered in interlaced-to-interlaced conversion, as actually recommended inside the specifications of a spatial scalable MPEG2 decoder when processing the lower layer to build the spatial prediction for the higher layer [16]. Other studies [17] pointed out the clear theoretical advantages of progressive sampling lattice in scalable applications and suggest that the transmission of the only progressive signal could guarantee a good compatibility with both HDTV and TV receiving systems.

5.4 Slow Motion

Slow motion can be regarded as a conversion to a higher frame rate (see the subsection 5.7). The increased frame rate is displayed at the same original frame rate, thus slowing down the action. Conventionally, slow motion replay has been achieved by simple field repetition, process that gives rise to undesirable jerky motion effects. To overcome these problems high-quality slow motion algorithms recently projected [18, 19] are all based on high-quality deinterlacer, specifically projected or adapted to this purpose. Typically the whole process is a cascade of such deinterlacer followed by a temporal interpolation, where the number of intermediate interpolated pictures depends on the desired target frame-rate. This application is considered as a broadcast service because in a short scenario it will take the place of dedicated cameras currently used especially for sport applications. In the future, it may become available as an add-on TV domestic feature.

5.5 Chroma-keying

Digital chroma-keying is intended to replace the historical analog process based on the use of the blue component to separate elements from a scene. Basically good performances in isolating objects from an image to overlap it on another are achievable only through good region and contour detection, surely easier in progressive scanned picture than in blurred (since field-merged) interlaced picture. Within the researches currently under development always progressive reference material is considered.

5.6 Aspect Ratio Conversion

Aspect ratio conversion can be used both at the transmitter and receiver sides. Typically, it concerns the conversion between 4/3 and 16/9 formats. Probably digital television will start in 16/9, so the problem of compatibility with 4/3 material is real. The re-sampling is essentially a filtering problem (pure horizontal, pure vertical or mixed), where above considerations on vertical filter and scanning format are valid.

5.7 Frame Rate Conversion

This conversion can be used at both transmitter and receiver sides. It primarily concerns conversions between :

1. 50Hz/59.94Hz/60Hz : compatibility between European/Japanese and American standards.
2. 50Hz/100Hz : a means to improve video domestic quality still using an interlaced TV screen, so saving compatibility; due to this advantage it has already found a place in the market. Some upgrades to the pure intra algorithms, making use of motion estimation are already available. This new solution [20] is provided by the cascade of a deinterlacer, a temporal interpolator and a reinterlacer, in order to obtain an interlaced 100Hz sequence where only every fourth picture is an original. The complexity of the algorithm presently fits better with studio or broadcasting application.
3. 50Hz/72Hz : workstations and PC monitors often work at the frequency of 72Hz because these displays are viewed from a much closer distance than TV set and so a higher fame rate is considered necessary to eliminate any visible flicker. In the framework of windows containing video, this conversion problem copes with interoperability between digital television and multimedia.

5.8 Still Picture

If the picture to be displayed in still-mode is progressive, this process is automatic and reduces to an editing problem. If the incoming signal is interlaced an interpolation is logically needed. The quality of the deinterlacing algorithm is in this case more critical because artefacts are actually clearer than what can appear in motion. Even more if the purpose is to grab the image and record it as already possible nowadays with some multimedia software.

5.9 Interoperability with Multimedia

The mere fact that video and audio data is in a digital form is itself a form of interoperability. This is already a significant improved step compared to analog. Compliance with international standardization rules is the second condition of bit stream interoperability. Another more complex issue is whether the transport that is suitable for consumer application is also suitable for computer workstation applications. The Planning Sub-committee Working Party-4 of the FCC Advisory Committee for Advanced Television Services [21] has identified several key-requirements for interoperability in the US ATV system. About display issues, the choice of a progressive scanning was considered as relevant (PS/WP4 Rec.3).

The objective usually called "HDTV on computer workstations" or "multimedia TV terminals" is achievable through video processor modules able to resize the input signal, convert it into a window, locate it and overlapped it with computer graphics or other video windows. In the resize process a deinterlacer step is always present to maintain good quality.

6 Coding Aspects and Future Work inside the HAMLET Scanning Extension (WP2)

When working with digital video, digital image compression has to be performed in order to transmit the data with a reasonable bit rate. Since compression is performed, the picture quality is no longer directly linked to the resolution of the picture (in number of pels) but depends on how compression is achieved (however, the picture resolution gives an upper limit to obtainable picture quality). Considering a compression like MPEG2, picture quality may vary according to the output bit rate, the quality of the motion estimation and the scanning format used within the coder.

Coding moving interlaced pictures as merged fields exhibits "combing" due to the temporal offset between scanning the first and the second field. This effect generates a range of high frequency DCT coefficients when frame blocks are coded and increases the number of bits that are required to transmit the block. To get round the combing problem, MPEG-2 can use field DCT modes which transform the two fields separately, based on an inter field motion compensation. However, the increased spatial distance between field lines make field DCT mode less efficient than frame DCT modes when combing is absent. Further, the increased temporal spacing between fields of same parity degrades the quality of the coders motion-compensated prediction and augments the number of bits required to send the predictor error signal [22, 23]. Also, the existence of field aliasing make the research of the true motion vectors between fields more difficult [24]. The absence of combing in progressive pictures increases the correlation between pixels within a block, which concentrates the blocks energy into fewer DCT coefficients when transformed, and consequently lowers the transmission bit rate. The disadvantage of progressive formats compared to interlaced is the increased pel rate. The question is whether the improvements in bit rate reduction efficiency due to progressive coding can overcome the increased pel rate.

From the point of view of a theoretical analysis of the source coding efficiency of interlaced and progressive format, the first step is the design of a reliable model of both the video signal and the coding process. This aim is achievable only under some assumptions and constraints. Such models can be found in the literature as in [25] where they are built up and studied, and in [26] for a compared analysis. Briefly, the former is a study intending to get more insight in the nature (and the intrinsic limits) of interlaced signal, developed mainly in the Fourier domain and based on the following assumptions: spatially band limited scene characterized by global motion and directly sampled on a quincunx vertical/temporal grid; the latter work, assuming an ideal Nyquist progressive sampling (the interlaced sequence derives by subsampling), adopts a specific model for the source sequence, a stationary Gauss-Process with isotropic PSD. The first common stage is the Intra analysis. In [25] the intrafield processing gives evidence to the two alias terms in each field's spectrum, with opposite sign, which disappear in intraframe case when no-motion between the two fields occurs. In [26] the intrafield interlaced coding is compared with intraframe progressive coding by means of Rate/Distortion curves obtained through the model, and showing better performances for interlaced. Moving to interframe motion compensated processing (hybrid coding), both the models allow to enhance the intrinsic constraints of interlaced representation for both the motion estimation and the motion compensated interpolation. In [25] the inherent advantages of the interfield same parity motion compensation, rather than opposite parity are also proved.

The MPEG-2 coding reference model accepts both interlaced and progressive pictures, but only the 25Hz/625 lines 1:1 format conforms to MP@ML, while decoding the 50Hz/625 lines 1:1 format presently requires the much more expensive H1440L designed for the HDTV. This is a real gap for progressive in the framework of an evaluation made upon a realistic scenario, and to this aim in [12] is suggested to define an intermediate MPEG level compatible with the 50Hz/625 lines progressive format. However, as done for all this paper, for the future work, we will consider a progressive format with a conventional double number of pel, i.e. a double amount of information. And about coding, the aim of the simulations is to test the capacity to use efficiently the increased spatial and temporal correlation present inside statistic data available after a progressive sampling. It is to be considered however that, since the MPEG2 was mainly developed for interlaced and used with interlaced material as reference, it contains some mechanisms like the frame/field choice for the prediction and for the DCT transform which allow to subdue its intrinsic constraints. The MPEG2 Draft Recommendation leaves some degrees of freedom in the project of the encoder, so a wide range of them has been developed and tested during the last two years, starting from the TM4 reference model. Inside HAMLET/WP2 and in collaboration with the parallel research on the hardware carried on inside the WP5, a software codec has been developed by HAMLET partners and it is presently under modifications and optimizations to best cope with progressive. In fact many algorithmic simplifications are possible for an MPEG2 encoded designed on purpose for progressive signal: no need to choose between frame/field in picture type, in macroblock prediction and in block DCT transform, but also in the hierarchical motion estimator.

An important matter that will be explored at the final stage of simulation within WP2 concerns the visibility of coding artefacts produced by interlaced and progressive codecs. In other words, whether the effects of the rougher quantization is more annoying on progressive pictures than the amplification of flicker artefacts on interlaced ones or not.

Tests already have shown [22] that the coding of interlaced or progressive sequences is nearly equivalent when comparing the SNRs of the decoded sequences. Although a progressive format contains twice as many pixels as interlaced, it seems that the amount of information is not twice as large but may be seen twice as redundant. A good coding method eliminates this redundancy. It also has been found that coding progressive sequences may improve the subjective quality of the decoded sequence, even if the latter is displayed in a interlaced format [27]. Even if a interlaced scheme is chosen for the future digital television, an intermediate progressive format (inside the codec) may thus be useful in order to provide a better quality of the displayed sequence (interlaced or progressive) but also simplify further signal processing [15, 22, 28, 29].

About the doubled clock-frequency (sampling rate passes from 27 MHz of CCIR601 resolution to the 54 MHz of the corresponding progressive) basically two different approaches could be envisaged for a possible progressive encoder and decoder chips, taking into account present solutions adopted for HDTV interlaced encoder and decoder on advanced project inside HAMLET. The HAMLET H1440 encoder demonstrator [30] overcomes problems related to the high data-rate (4 times CCIR601, so 108 MHz) through a sophisticated parallel architecture based on 4 coding processors working each on a vertical stripe of the picture at standard TV data-rate; this solution makes possible the use of already experimented ASIC chips designed for SDTV encoding. The adoption of the same strategy could be envisaged for a possible progressive encoder (picture divided into 2 stripes instead of 4), and the additional complexity compared to an interlaced TV encoder is quite little. The H1440 decoder [31] on the contrary, since at the decoder side less computational power and memory size are needed, has been projected with an ad-hoc VLSI structure that processes the whole picture data, an 110 MHz input data stream. Although a parallel architecture is internally used when possible (IDCT, dequantization, low layer and high layer) there are chipsets running at 54 and even 67,5 MHz, so at the limit of VLSI technology. Taking into account these experimented data, a progressive TV decoder could be seen as a downscaling of the complexity problems here already solved.

7 Display Aspects

Television is the most difficult application of any display technology, requiring the ability to provide grey scales, full colour, rapid response speed (below 20 ms), high contrast (over 50:1) and brightness (at least 200 cd/m^2) with good uniformity (at least 5%), all at a relatively low cost. Up to now only CRT technology seemed to match these needed characteristics, but as in camera technology there is a fast growing of researches and developments in this area. New promising systems, which have already conquered lead positions in parallel applications (like LCD in portable computer displays and rear video projectors), now challenge CRT even as TV display. The most promising system configurations currently in advanced study are *Active Matrix LCTV*, *Digital Micromirror Device* and *Plasma Display Panel*, which present interesting behaviors for interlaced and progressive scanning formats.

Active matrix LCD is by now a mature technology [32]. The latest tests and comparisons show a picture quality near to CRT, with a considerable reduction in weight and dimensions. They work by incorporating in every picture element an active electronic device, usually a thin film transistor (TFT). However, even if the TFT is the most critical component of the system, picture quality depends also on the properties of the liquid crystal, on the colour filters and upon the way the display is driven. In fact, although the basic performances of these displays can often match that of a good CRT, when experimenting them with present TV transmission systems (PAL, SECAM, NTSC) some problems arise because these systems were specifically designed around CRT. Apart from the gamma pre-correction which is applied at source and specifically designed on the brightness-voltage curve of CRT, thus producing distortion on LCD, the more important problem is the use of interlaced scan. Pixels belonging to lines of one parity are addressed in every other field, i.e. each 40 ms for PAL. Due to the temporal response of an LCD element, more similar to a flat response rather than to the typical decreasing characteristic of the beam-target interaction of CRT, these pels can often be visible when the other field is presented after 20 ms. This phenomenon has no consequence for stationary regions but gives unpleasant smearing effects on the edges of moving objects. That is why usually an internal proscan conversion is performed (also in rear-projectors, see [33]), in order to drive the lines of each frame sequentially. The fact that the charging-time for the pel capacitance driven by the TFT must be reduced (tc$< 32\mu s$) is no problematic with current technology.

Very promising but relatively new, so still in a prototype stage, is the technology named Digital Micromirror Device (DMD), a spatial light modulator. The DMD is a new kind of semiconductor technology [34] that combines electronic, mechanical and optical technology, in order to create an all digital display by the use of micro-mirrors reflecting light, each of them being associated with a picture element. Its peculiar characteristics are the minimal dimension of each image element, which allows high integrability in large scale (structures of 2048x1152 pels have been realised for HDTV purpose), and a good fastness in response to digital driving signals (usually bit-plane data PWM modulated). DMD projectors are two or three times more efficient than LCD technology when compared for brightness (increased optical efficiency of the mirrors compared to liquid-crystal valves). Unlike a conventional CRT which works in interlaced (the glow of the phosphor in the CRT persists long enough for the interlaced technique to work), the DMD has no persistence and must display the entire picture every 1/50 of a second. This makes the DMD well suited for future progressive displays. Inside the architecture already projected to support a DMD for the video available today, a proscan converter is always present.

Progressive scanning for Plasma Display Panel (PDP) is strongly desirable, because AC PDPs have inherent memory which requires, in interlaced operation, to switch-off the lines of the opposite field. It leads to line structure and 50Hz flicker. Moreover, PDP is an alternative to the LCD because of its very wide viewing angle, very large display size (1.5 meter diagonal with 2048x2048) and 24 bit color scale, and because AC plasma displays have a very long lifetime (40 years) [35].

As in the case of the examples found in literature for LCD, the algorithms employed for this interlace-to-progressive conversion are usually very simple (field repetitions, spatial interpolations). Global performances should surely benefit of an high-quality deinterlacing block placed upward in the video chain, and even more with progressive input pictures.

8 Scenarios for the Adoption of a Progressive Television Scheme

This section analyses three scenarios that might be used for the implementation of the future digital television and discuss their impact on the decision of adopting a progressive television format or not. These scenarios show that this decision basically depends on the choice of the broadcasting format. Two of these scenarios also show the possibility for both interlaced and progressive technologies to coexist, ensuring backward compatibility with old (interlaced) material during a transient period.

8.1 Scenario 1 : Interlaced Broadcasting Format

For this first scenario, we assume the adoption of an interlaced broadcasting format for all television programmes (see figure 9). It represents the worst situation for gradually switching to a progressive format. Indeed, in such a context, both studios and end-consumers have no advantage to move towards a progressive scheme :

- Since television studios have to deliver their programmes to broadcasters in an interlaced format, it makes no sense to adopt a progressive format for whole studio chain: the improved quality of the progressive format will inevitably be spoiled at the reinterlacer. However, a progressive format may be used for improving the quality of some local applications (signal processing, digital chroma-keying, etc.). This progressive format will be generated through the use of a deinterlacer, probably located inside the application box itself. Nevertheless, adopting a interlaced broadcasting format will force progressive to come down to a marginal format.

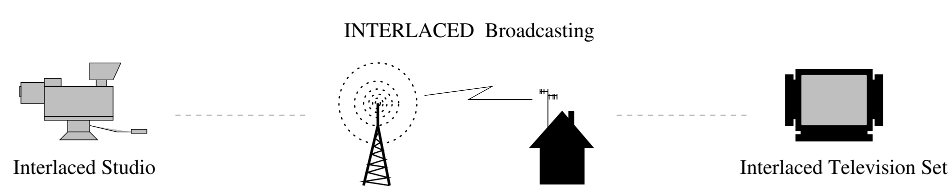


Figure 9: First scenario : Adopting an Interlaced broadcasting format

- It also makes no sense for the consumer to purchase a progressive display. Even if the use of a progressive television set may improve the visual quality of the displayed images, economical considerations will force the marked to offer receivers based on low-cost deinterlacers only. The slight quality improvement that will result will not balance the increased price and complexity of the progressive sets. Also, requiring about the same complexity, 100Hz-interlaced displays offer a much better improvement compared to the 50Hz-progressive displays, when both have to deal with a 50Hz-interlaced input.

8.2 Scenario 2 : Progressive Broadcasting Format

As second scenario, we will now assume the adoption of a progressive format for the broadcasting (figure 10). This choice give rise to new considerations :

- Current scenario allows *full progressive transmission*, from the very beginning of the process (image capture) to its far end (end-consumer receiving set). Compared to the first scenario, this scheme is able to improve visual quality (improved vertical definition and absence of the interlaced artefacts) at every stage of the process.
- *Compatibility with interlaced studio.* As intermediate step towards a full progressive scheme, "old" interlaced studio may keep their material and broadcast programmes by preliminary using a deinterlacer. Besides removing the interlaced artefacts (but not restoring the vertical definition loss inherent to the interlaced format as mentioned previously for the Kell factor) the deinterlacer is also supposed to improve the digital coding of interlaced sources. This last point will be studied in the next WP2/Scanning Formats deliverables.

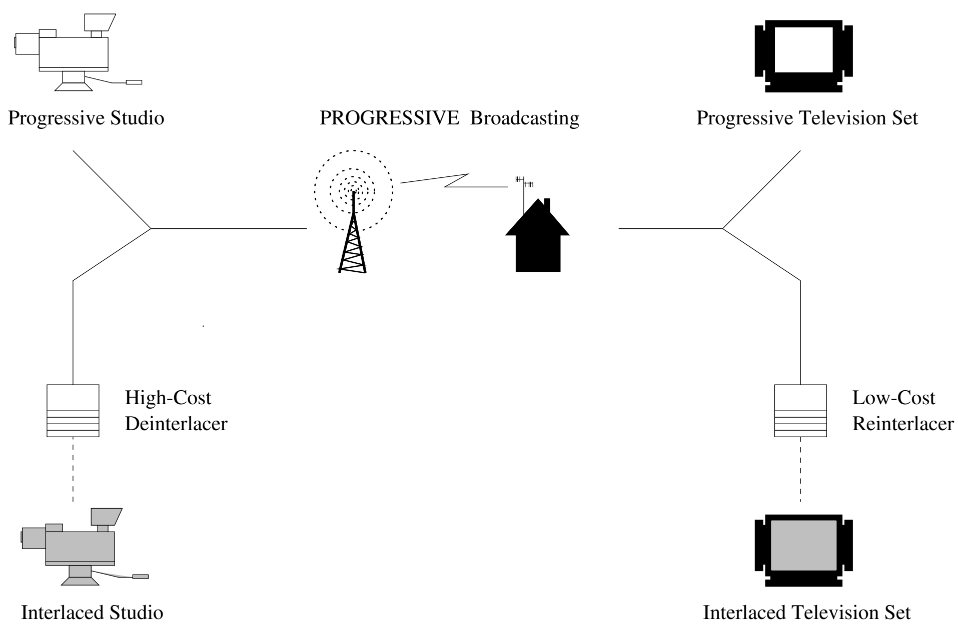


Figure 10: Second scenario : Adopting an progressive broadcasting format

- *Compatibility with interlaced receiving sets.* In order to receive progressive programmes, owners of interlaced displays will have to purchase a progressive to interlace converter. This format conversion is very easy to achieve and may be implemented as a low-cost settle box. Since progressive digital broadcast is expected to improve the coding efficiency, owners of interlaced displays will enjoy a better image quality compared to the first scenario, even if all interlaced defects will be generated at their display. Moreover, since the adoption of a progressive format goes hand in hand with the advent of the digital television, owners of an old analogue interlaced display will inevitably have to purchase a digital decoder. It's is foreseeable that this decoder will also offer the required deinterlacer at its output. So, besides the digital decoder, no additional format converter will be needed.

- Since the adoption of a progressive format give rise to higher image quality at every stage of the television chain, *the crossing between the interlaced and the progressive worlds will come naturally.*
- In the first scenario, we noticed that even if the consumers decide to adopt progressive displays, they would not be satisfied with since economic considerations will force the end-user market to offer low-cost (implying low-quality) deinterlacers only. In the current scenario, the potential deinterlacer is located at the studio side and gives the opportunity to work with complex *high-quality format conversions.*

8.3 Scenario 3 : Free Broadcasting Format

As last scenario, we will now study the broadcasting of both interlaced and progressive formats, depending on the signal found at the studio output (see figure 11). This scheme results from the combination between the two previous scenarios. All considerations emitted for the second scenario remain valid. Since digital television is able to encode both interlaced and progressive formats using the same syntax (see the MPEG2 syntax), it makes possible the two formats to coexist and be broadcasted together.

- Interlaced studios are not required to use a deinterlacer at their output anymore. Interlaced programmes may then be received by the old television sets without format conversion, or by progressive displays through the use of a deinterlacer. Furthermore, the owners of a progressive display may take advantage of the increased horizontal scanning velocity of their television set, and switch to a 100Hz flicker-free interlaced mode, since the poor quality of the low-cost deinterlacing.
- In order to display progressive programmes, interlaced television sets will have to be coupled together with a reinterlacing settle box. Another (costly) solution would be the broadcasting of both interlaced and progressive versions of the same programme at the same time. However, it does not make sense since the adoption of a progressive format will probably coincide with the arrival of digital television. Consumers will have to change their "analogue" television sets or at least purchase a digital decoder. As we already mentioned, nothing prevents this decoder to include the required progressive to interlaced converter. No format duplex is thus needed for the broadcasting anymore.

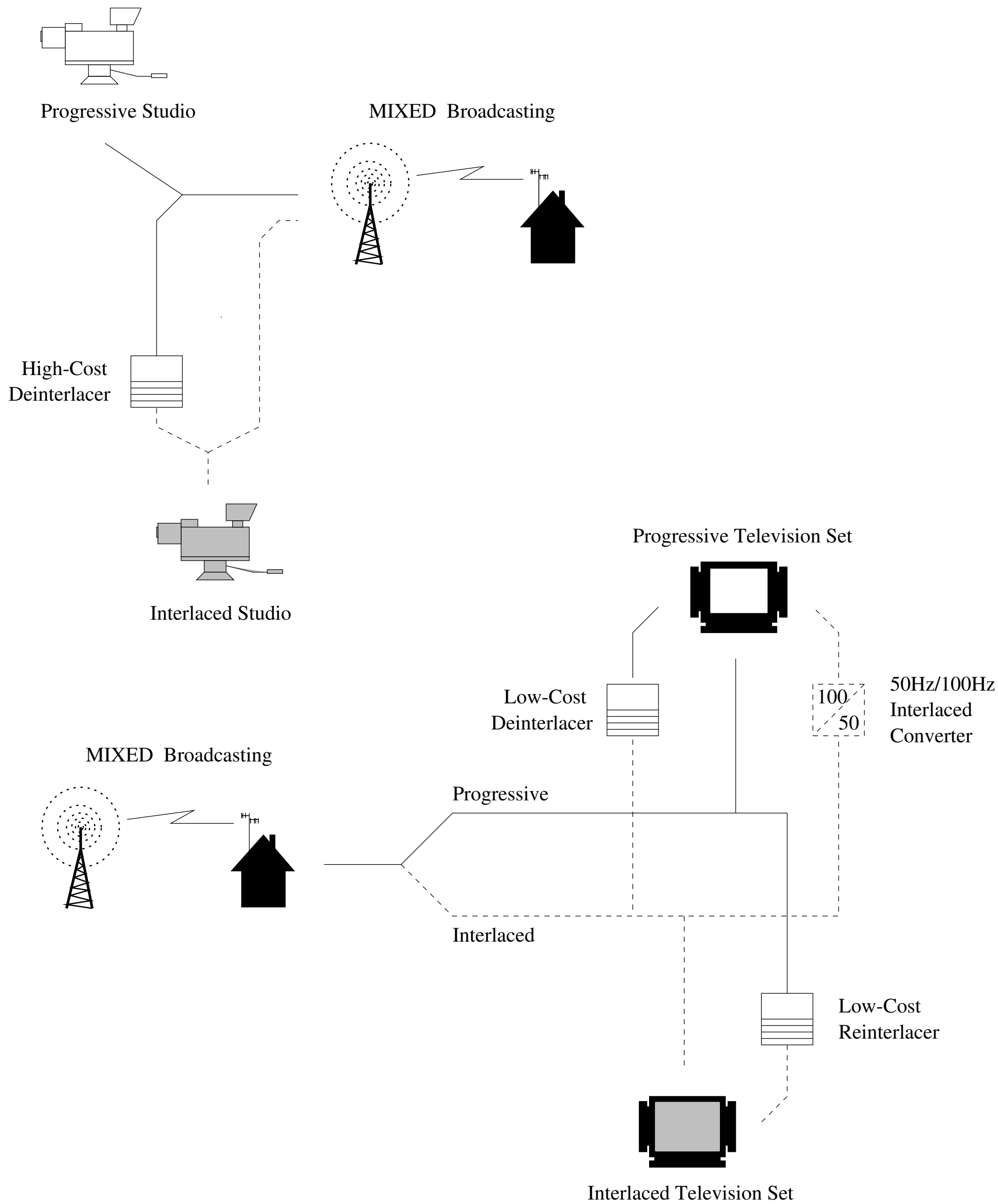


Figure 11: Third scenario : Adopting an free broadcasting format

8.4 About the Adoption of a 50Hz-progressive Format

The *Digital Video Broadcast* group (DVB) defined a set of standards that will be used to implement digital television transmission in Europe. The DVB standards describe digital television transmission over cable, satellite and terrestrial. All three standards are based on a MPEG2 main profile/main level coding (MP@ML). The differences are on the modulation techniques.

In the existing MPEG2 hierarchy, a 50Hz-progressive scanning format implies the use of the expensive MPEG2 high-1440 level which was designed to work with pixel rate up to four times higher than the main level. The 50Hz-progressive transmission lies in between these two levels and would ideally need the definition of an intermediate level at main profile. Such proposition was forwarded to the DVB and the MPEG Implementation Guidelines group in January 1995.

The 25Hz-progressive format can be reached with the main level. However, such format - probably ideal for 24 (25) Hz movies - may not be appropriate to cope with 50Hz-interlaced or progressive sources as shot by 50Hz-frame rate cameras (see section 2.2). It may require the use of an high-cost temporal interpolator at the receiver side or further information coming from an assistance channel.

9 Conclusions

As discussed in this deliverable, both interlaced and progressive formats have their respective advantages and drawbacks. Choosing one of them as the definitive solution of the scanning problem would be utopian, at least when considering today's state of the technology. Nevertheless, it must be stated that one day, technological progress will definitively tip the balance and make it worthwhile to move to a progressive scanning.

Other things being equal, it would objectively represent a poor technical return on investment to move from the interlaced to the progressive scanning : the improved picture quality and the enhanced picture processing do not balance all efforts and costs needed to change the overall television topology in case of adopting a progressive format.

However, the advent of the future digital television will inevitably bring deep changes in this topology : consumers will have to change their television sets (or at least, purchase a digital decoder), broadcasters and studios to adapt themselves to this new technology. In such a context, drastic changes will occur in our current television system. These changes may be seen as a unique opportunity to adopt a progressive scheme, implying only minor costs compared to the overall budget involved in such operation. With the advent of digital television, the question about the uselessness of interlaced scanning will raise since digital coding offers many other ways to save bandwidth. From this analysis it seems that, mostly to achieve an important package of services which will come together with future television, a format conversion toward progressive is desirable. Also, the adoption of a progressive format while changing the television system would be a provident attitude for facing the new requirements which can arise in the future (e.g. multimedia and compatibility with the computer world).

For all these reasons, several progressive formats have already been choosen for the introduction of the new digital HD television in the U.S. [36]. In Japan, the launching a new standard called EDTV-II (*Enhanced Digital TeleVision*) will also make use of a progressive format (480x720, 59.94 Hz) [37]. In a European context, the adoption of a progressive scanning format will have to cope with the decision of the DVB group, which expressed itself in favour of the MP@ML MPEG2 coding scheme. Just as it is, MP@ML does not allow the coding of 50Hz-progressive sequences. However, this limitation only comes from the definition of the MP@ML itself which was decided to restrict the *pixel* rate below the one needed by a 50Hz-progressive format. On a practical/technical point of view, this problem is meaningless since the 50Hz-progressive format may be coded using the same *bit* rate as interlaced at same or improved visual quality. In other words, it would have been more judicious defining the MP@ML to include the 50Hz-progressive format. On the contrary, the 50Hz-progressive format has been classified with other high-cost formats that require a more complex high-1440 level-compliant decoder (MP@H-14). As proposed by the RACE Image Communication Project Line, this syntax problem may be solved by defining an intermediate MPEG2 level compatible with the 50Hz-progressive format.

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