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Abstract. :

The purpose of this deliverable is to compare the coding efficiency of both interlaced and progressive scanning formats by means of MPEG-2 simulations. Statistical results about frequency homogeneity and motion compensation performances are first presented to evaluate how much a format can be compressed compared to the other one. A second part is dedicated to the coding efficiency itself by means of MPEG-2 encoding considering the same channel bit-rate whatever the transmission format.

Keywords

Scanning Formats, Progressive, Interlaced, Deinterlacing, Interlacing, Coding Efficiency, MPEG-2 Encoding, DCT Distribution, Motion Compensation, Bit-rate Control.

Summary

Interlaced versus progressive scanning is an important issue when dealing with digital television. Not only because the change from analog to digital communication may be seen as an opportunity to change formats, but also because of the well-known artifacts of interlaced scanning (interline twitter, line crawling, and field aliasing) compared to the natural way of representing two-dimensional images as the progressive format does. However, digital broadcasting has to face the problem of transmitting twice the bit-rate of the progressive format. It is the purpose of this deliverable to study this problem, and especially to check if the increased vertical and temporal correlations of the progressive pictures provide a significant improvement in the coding efficiency. In that case, progressive scanning may also be used as an intermediate transmission format to improve the coding performances of interlaced sequences.

Moreover, the main criteria in digital TV encoding is the picture quality, then, assuming that progressive display is more pleasant than interlaced, subjective picture assessment should be taken into account to evaluate how much a progressive picture can be compressed compared to an interlaced one. To answer all these questions is the objective of the scanning formats extension of the RACE R2110 HAMLET project (High Definition Advanced Multilevel Encoding Techniques). Within the framework of the workpackage 2, two digital transmission chains have been simulated, an interlaced one and a progressive one by means of MPEG-2 MP@ML encoding, optimized for each format. Progressive and interlaced source sequences are used, deinterlaced and interlaced when necessary, to perform successful comparisons between both format in each possible configuration.

Contents

Coding Efficiency of Interlaced and Progressive Scanning Formats

1 - Introduction

It is not the purpose of this paper to cover the historical considerations that led to the adoption of an interlaced scanning television, or to discuss the well-known interlaced artifacts described in [1], but rather to investigate new techniques to improve the efficiency of MPEG-2 based-encoders, and especially, within the HAMLET/WP2 project, to study the influence of the scanning mode on the coding efficiency and the possible use of the progressive as an intermediate coding format [2]. Three deliverables are planned to sum up all the studies performed on that subject, the first one is a list of theoretical and technical considerations on the advantages and drawbacks of interlaced and progressive scanning formats [1], the second specifies a generic format converter [3], and the last is the present one.
This paper originates from the following comments : progressive format seems much more attractive than interlace for signal operations, progressive format has the advantage of compatibility with computer graphics, multimedia applications and film production, and finally progressive scanning allows a better display. Unfortunately, progressive requires twice the number of pels of interlaced signals, and is more hardware consuming. Despite these drawbacks progressive is very attractive, and various results are already available [4,5,6,7], but they differ on their conclusions. Thus, further investigation is required, which is the object of this deliverable.

Both progressive and interlaced source pictures have been used for the simulations, because of the influence of the original format. Progressive to interlace and interlace to progressive conversions insure the compatibility between each format. Simulation results should allow the following questions to be answered : which kind of scanning format must be used for input images ? What is the most adapted display mode ? And finally what is the best transmission format ?

After a presentation of the progressive MPEG-2 encoders used for testing, and especially the simplifications done, a chapter is dedicated to the statistical properties of both formats in order to evaluate how much they can be compressed regarding their spatial homogeneity and motion interpolation capabilities (thanks to their temporal correlation). This chapter is followed by the main part, which contains the encoding simulation results together with subjective picture evaluation carried on by expert viewers.

Based on these results different conclusions are drawn to show that progressive display improves the overall picture quality, without loss of coding performances compared to the existing interlaced format. And finally, it leads to the statement that progressive transmission may be also an intermediate step towards progressive broadcasting.

2 - Progressive Encoder

A progressive MPEG-2 software encoder has some parameters to be set to be MPEG-2 compliant. Some are specific to the progressive format and optimized for it [8]. The MP@ML profile is used, even if 625/50/1 can not be transmitted using it. This is firstly because the objective of this deliverable is to compare both formats with the same picture size, and secondly because a new level might be further included in the MPEG-2 final standard specification to comply with progressive scanning.
Within HAMLET/WP2 two software encoders have been developed and will be called Thomson scheme and UCL scheme [5] in the following (the default scheme is the Thomson's one). They differ mainly by the motion estimator and bit-rate control.

The parameters specific to the progressive format are the following :

- *progressive_frame* set to 1, coded video contains only progressive frame pictures. In this case, restrictions apply as follow : *picture_structure* = "frame" and *frame_pred_frame_dct* = 1, allowing only frame DCT and frame predictions to be used ;

- *frame_pred_frame_dct* set to 1, affects the syntax of the bitstream. For each macroblock, this flag suppresses useless flags like *frame_motion_type* (2 bits) and *dct_type* (1 bit) from the bitstream;

Accordingly, progressive coding allows to reduce the side-information by 3 bits/macroblock. It also lowers the number of vector to be transmitted since no field motion vectors exist in such case.

Besides the MPEG-2 syntax, the new sampling grid structure of the progressive format allows some possible simplifications :

- The motion estimation is based on a pyramidal structure which leads to a very simplified and efficient data processing. Only 1 vector has to be computed (frame vector) when 5 are required for the interlaced format (4 field vectors and one frame vector) for only one temporal direction. Furthermore it leads to a simplified mode decision process.

- Chrominance filters for up and down sampling are less complex than in the interlaced case, for instance the following implementation has been simulated :

  ☐ Down sampling with one 5-tap FIR filter instead of two 7-tap FIR filters (one for each field);
  ☐ Up sampling with two 2-tap filters (one for each line parity) instead of two 2-tap and two 3-tap filters (one for each field and each line parity);

Other MPEG-2 parameters are the VLC intra tables (*intra_vlc_format = 1*), the non-intra quantization matrix (flat), the macroblock mode selection, the thresholding of the DCT coefficients, the quantizer type (*q_scale_type* = 0), the zig-zag matrix (*alternate_scan*= 0). The values are the same for both formats for sake of simplification and because no significant difference has been observed with other choices. All these points are not in the scope of this paper and will not be further discussed.

3 - Interlacing and Deinterlacing

For the simulations, four different processes are used for interlaced to progressive and progressive to interlaced conversions. Whatever the format, these converters are key points in a broadcasting chain [9], therefore a special attention has been paid to this problem, and this is the subject of this chapter.

First of all, a distinction has to be done between process at the encoder side and at the decoder side. Whereas the first one requires a high picture quality, the second one can not use expensive tools. Having in mind these considerations, the encoder interlaced to progressive conversion is a high quality motion compensated deinterlacer from UCL [3,10], whereas the decoder one is a low cost macroblock-based motion compensated deinterlacer making use of the MPEG2 transmitted motion vectors.
The first application requires a finely tuned calculation of the motion vectors in order to recover, in the reconstructed progressive sequence, the initial temporal and vertical correlation existing inside the original "analog" signal. Once these vectors have been found, a deinterlacing method that handles field aliasing properly has to be used. This is achieved by means of the general sampling theory which was proposed recently to handle interlaced images and proved to be successful. Linear spatio-temporal interpolation has also been studied in [11], but complementary results are required before concluding.
The second deinterlacer is a low cost solution thanks to the absence of motion estimation. The different macroblocks make use of the MPEG-2 transmitted vectors when available, otherwise vertical interpolation is performed (for instance for intra macroblocks, intra frames). Motion compensated interpolation is fulfilled only for the luminance component, whereas the chrominance is vertically interpolated with a linear filter. Moreover, all these processes are macroblock based, which means that they do not require information from the surrounding macroblocks. It will be shown later on that this last requirement is too hard since a line structure appears in the borders of the macroblocks, thus better results can be expected with the neighboring blocks.

Concerning the progressive to interlaced conversion, it is performed by means of a simple 11-tap filter known as "HHI filter" (figure 1) followed by a vertical subsampling by a factor of two. This filter introduces a vertical definition loss according to the Kell factor. This factor is meant to reduce the line flicker that appears on bright and sharp horizontal edges when displaying in an interlaced format. The moderate complexity and sufficient efficiency of this filter make it suitable for both encoder and decoder applications.

-4	8	25	-123	230	728	230	-123	25	8	-4

Fig. 1 - "HHI filter" coefficients

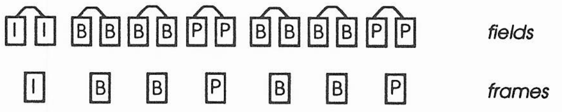
4 - Statistical Properties of Both Interlaced and Progressive Formats

Three different statistical measurements have been performed to compare the potential ability of each format to be compressed. The first one is based on the frequency homogeneity (with the DCT coefficients distribution), the second one on the motion estimation behavior provided by the motion compensated DFD (Displaced Frame Difference) between the reference and interpolated frames, and the last one on the coding gain of progressive over interlaced scanning (without bit-rate control, i.e. with the same quantizer step size).

4.1 MPEG-2 Encoder Parameters

The aim of that section is to give (or anyway try to) a ratio value between bit-rates needed for a progressive transmission versus an interlaced transmission considering the same picture quality. Moreover, it will be interesting to have these values for each picture type (I, B or P).
To do so is quite difficult between different scanning formats, how can it be guaranteed to have the same picture quality ? How can it be guaranteed to compare exactly the same information ? However, the following parameters have been selected, even if other solutions might be used, having in mind that the progressive format performs probably worse than interlaced (in terms of compression rate when the quality is fixed), and that these values have preferably to be done is the worst conditions to obtain a low anchor :

-The encoder complies with the MP@ML profile of the MPEG-2 standard except for its use of the progressive 625/50/1 format (not currently supported by it);
-The picture quality can be considered at least as good when the same quantization step is used for each pictures and each format (worst case for progressive). In this section quality is related to the quantization step (the lower is the quantization step, the higher is the quality). It makes the comparisons between both formats more convenient and allows to work at "fixed quality". However, this definition does not take into account the properties of the human vision. The subjective picture quality of both formats will be discussed later on;
-The GOP structure is selected starting from the following point : assuming the classical GOP structure for interlaced I, B or P frame pictures (figure 2-a).


a) Interlaced. Frame pictures. M=3, N=12

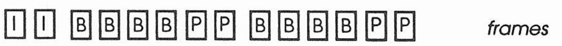

b) Corresponding progressive GOP structure

Fig. 2 - GOP structures used

After deinterlacing the same frames lead to two progressive pictures, corresponding to figure 2-b, the picture content between the interlaced and deinterlaced frames is thus exactly the same as well as the picture type.

Extrapolating this structure to the progressive source sequences leads to the non MPEG-2 GOP structure of figure 2-b. Of course, this structure is non-optimal for progressive scanning (again worst case), but it makes the comparisons between interlace and progressive easier in this first study. Another structure will be considered later on this deliverable.

With that trick it will be possible to compute directly for each picture the ratio between the bit-rate required for progressive coding versus interlaced coding when interlaced and progressive pictures are transmitted with the same picture quality.

It should also be pointed out that the reference I or P pictures for motion estimation and compensation are always the nearest ones as explained in Figure 3.

Finally the motion vector range is taken equal to [-63, +64] in the vertical direction, whereas [-127, +128] is selected for the horizontal one, whatever the sequence and the temporal distance between the reference and decoded pictures. These vectors are computed with a 5 levels hierarchical block-matching algorithm, and a search window set to (4×2) pels at each level.

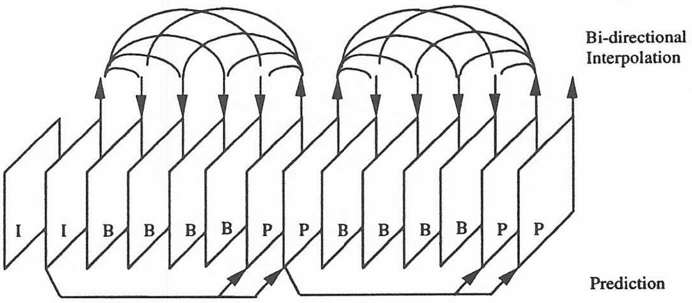


Fig. 3 - Reference pictures for progressive coding

4.2 Source Sequences

Four 720x576 50Hz sequences have been selected for the simulations. Two are interlaced and have been deinterlaced with a high quality motion compensated deinterlacer [3], and two are progressive sequences. The following gives their characteristics :

- **Interlaced :**

  # *Mobile and Calendar* : 50 interlaced pictures originated from a tube camera, its progressive version is obtained by motion compensated deinterlacing [3];

  # *Flower and Garden :* 50 interlaced pictures originated from a tube camera, its progressive version is obtained by motion compensated deinterlacing [3];

- **Progressive :**

  # *Renata RAI* : 100 progressive pictures originated from an HDTV tube camera, its interlaced version is obtained through vertical filtering (with the HHI 11-tap filter, taking into account the Kell Factor) and subsampling. In the following it will be called *Renata* for the progressive version and *Renata F* for the interlaced version (because of the Kell filter). Once it will be called *Renata F/F*, it means that both the interlaced output and the progressive input sequences are filtered.

Kiel Harbour : 100 progressive synthetic pictures, obtained by digitizing and processing a photo with synthetic motion, its interlaced version is obtained through vertical filtering (as for *Renata*) and subsampling. In the following it will be called *Kiel;* and *Kiel F* for the interlaced version.
Pendel : 50 progressive pictures, originated from a progressive tube camera;
Pops : 60 progressive pictures, originated from a progressive CCD camera;
Foot : 50 progressive pictures, originated from a progressive tube camera;
Kiel 2 : 40 progressive pictures, from the same sequence as previous Kiel but not at the same moment;

The first four sequences have been processed with the Thomson scheme whereas the last four are processed with the UCL scheme.

4.3 DCT Coefficients Distribution

An MPEG-2 encoder can process interlaced pictures in different ways. For instance a macroblock can be frame DCT coded or field DCT coded (the mode selection differs from the coding schemes), whereas only frame DCT is allowed for progressive pictures. In figure 4 and 5 the DCT distributions for these different modes are plotted, they represent the distribution of the squared DCT coefficients for the luminance component, averaged over all the DCT blocks (8x8) in each mode, for the whole sequence. In addition to the DCT mode, the distinction is done between intra (Figure 4) and inter (Figure 5) macroblocks.

One of the assessments at the beginning of this project was that the double bit-rate of the progressive scanning could be compensated by a better spatial and temporal correlation. This chapter tries to give some insight for this, and the conclusion depends on the scanning format and the amount of motion within the sequences :

1)- For sequences with motion (*Flower* and *Renata*), field DCT is known to perform better because of the absence of vertical frequencies (visible in the frame DCT mode). In that case progressive is expected to be better than interlaced when both formats have the same vertical resolution, and not worse with a double resolution since progressive is supposed to be more homogeneous. This is clearly what figure 4 shows;
2)- For sequences without motion (*Mobile*) frame DCT takes more advantage of the spatial homogeneity, and therefore is similar to progressive encoding. Thus no differences between both formats are expected and visible in figure 4.

The general behavior for both formats seems to be the following one. When the source sequences are interlaced, fixed pictures are similar for both scanning modes, and moving ones are better when deinterlaced. Extrapolating these results to the progressive case (twice the vertical resolution) leads to similar performances for progressive and interlaced coding for moving images, and better interlaced coding for non moving ones (to be confirmed).
Concerning the temporal correlation, it will be studied thoroughly in the next paragraph, because it is mainly linked to the motion estimator performances, to the deinterlacing efficiency and to the picture quality (noise).

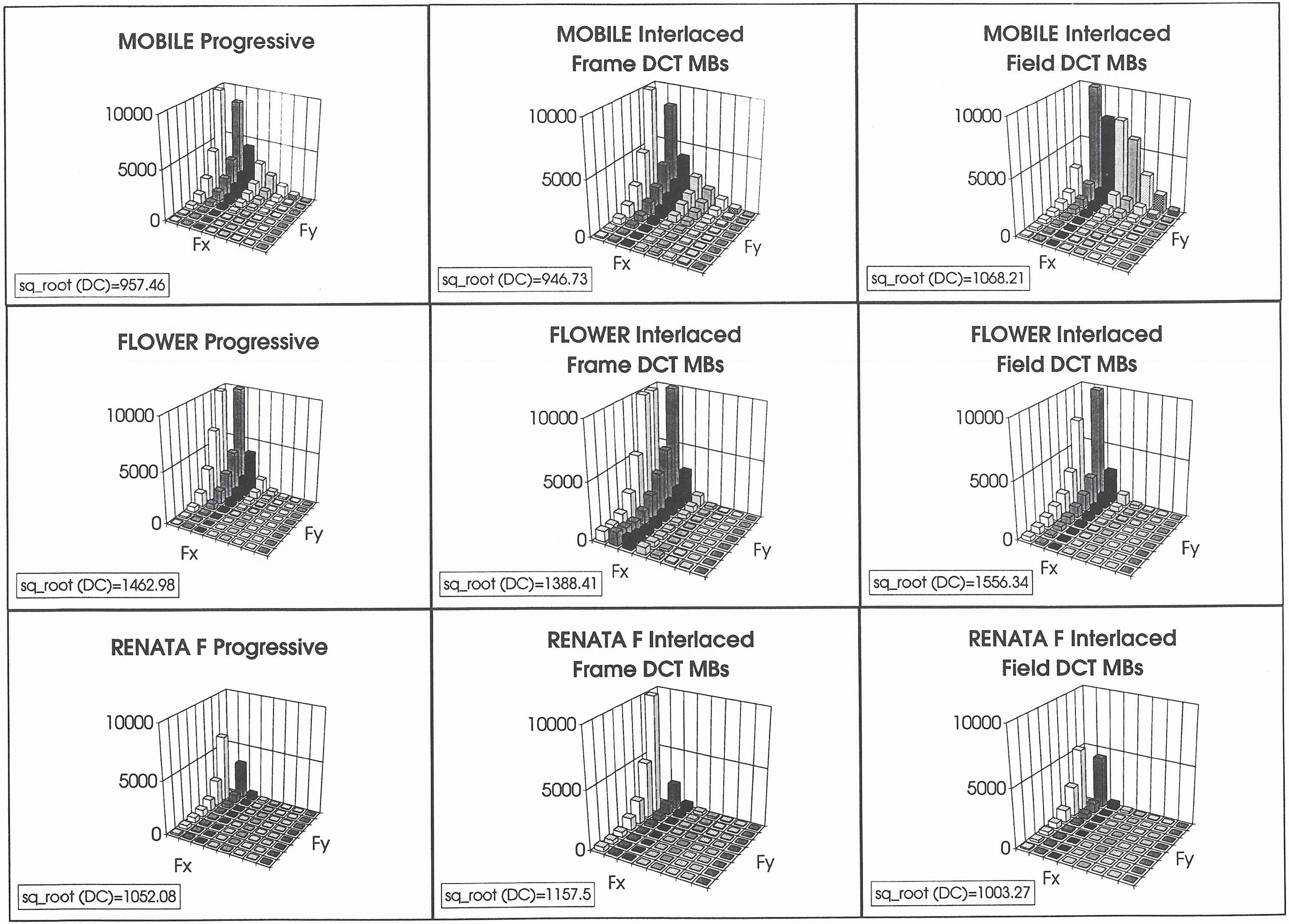


Fig. 4 - DCT coefficients distributions of intra coded macroblocks

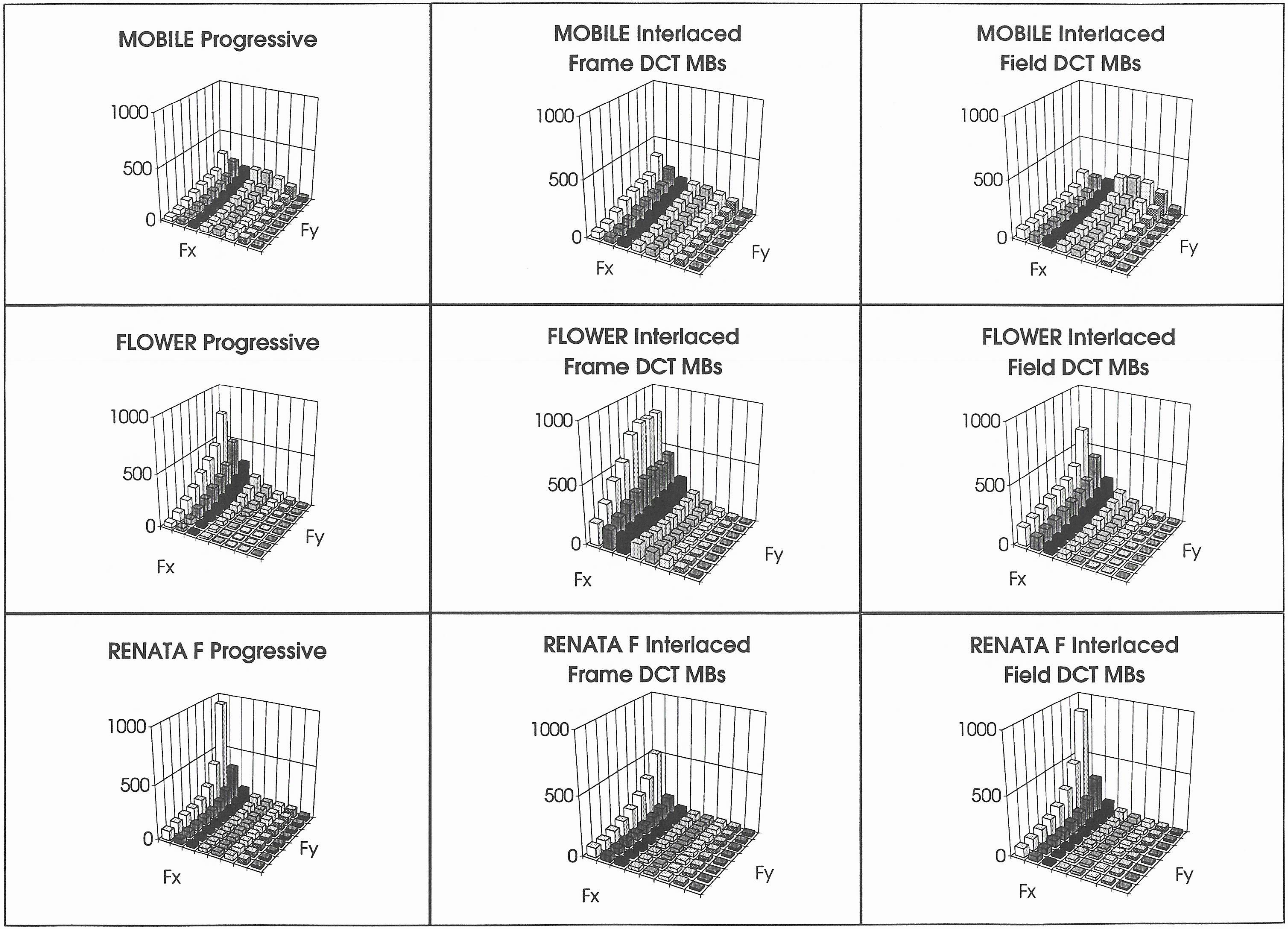


Fig. 5 - DCT coefficients distributions of inter coded macroblocks

4.4 Motion Compensation Performances

Another assessment concerning progressive scanning is that it improves the motion estimation performances. The MPEG-2 standard allows different kinds of motion prediction, either field or frame prediction, and forward (P frames) or bidirectional (B frames) in a macroblock basis. To measure the performances of a specific motion estimator, the prediction error can be used, it is also called Displaced Frame Difference (DFD). In Figure 6 the mean DFD values for the four first sequences are plotted for both interlaced and progressive processing, and for the P and B frames. Only the best prediction mode selected is used.
The unavoidable drawback of this trial is that the prediction error is computed between the current coded picture and the previous decoded one. The DFD depends therefore on the decoded pictures quality, and thus on the bit-rate. By using the same quantization step, this drawback is removed.

The conclusions from these figures are picture dependent as well as motion dependent as for the previous DCT distributions :

- ***Interlaced original pictures*** :

  - 1)- Without motion (*Mobile*) the picture is mainly frame coded, progressive and interlaced formats are thus similar. No differences are therefore expected except from the deinterlacing artifacts. The B frames are slightly better predicted in the interlaced case, and the P frames slightly better in the progressive one. It is probably due to the prediction structure (figure 3) which leads to a lower temporal distance for one of the two P frame;
  - 2)- With motion (*Flower*) the interlaced picture is mainly field coded, motion estimation is therefore difficult due to the high vertical frequencies. It leads to a more efficient progressive estimation helped by a deinterlacing without artifacts;

- ***Progressive original pictures*** : Interlacing performs better mainly because of the vertical resolution (Cf. the *progressive F* curve in the *Renata F* graph when the progressive sources are low-pass filtered). The greater resolution of the progressive pictures enhances the DFD measures mainly at the borders of moving objects. Another reason is the camera noise in the original progressive sequence (mainly in *Renata*) which explains that *Kiel* performs better than *Renata*.

The general behavior for both formats seems to be the following one, and confirms previous results from section 4.3 :
When the source pictures are interlaced, fixed pictures are similar for both scanning modes, and moving ones are better when deinterlaced. Extrapolating these results to the progressive case (twice the vertical resolution) and the help of the *Renata* sequence leads to similar or worse progressive coding for moving images (first half pictures of *Renata)*, and better interlaced coding for non moving ones (last half pictures of *Renata*).

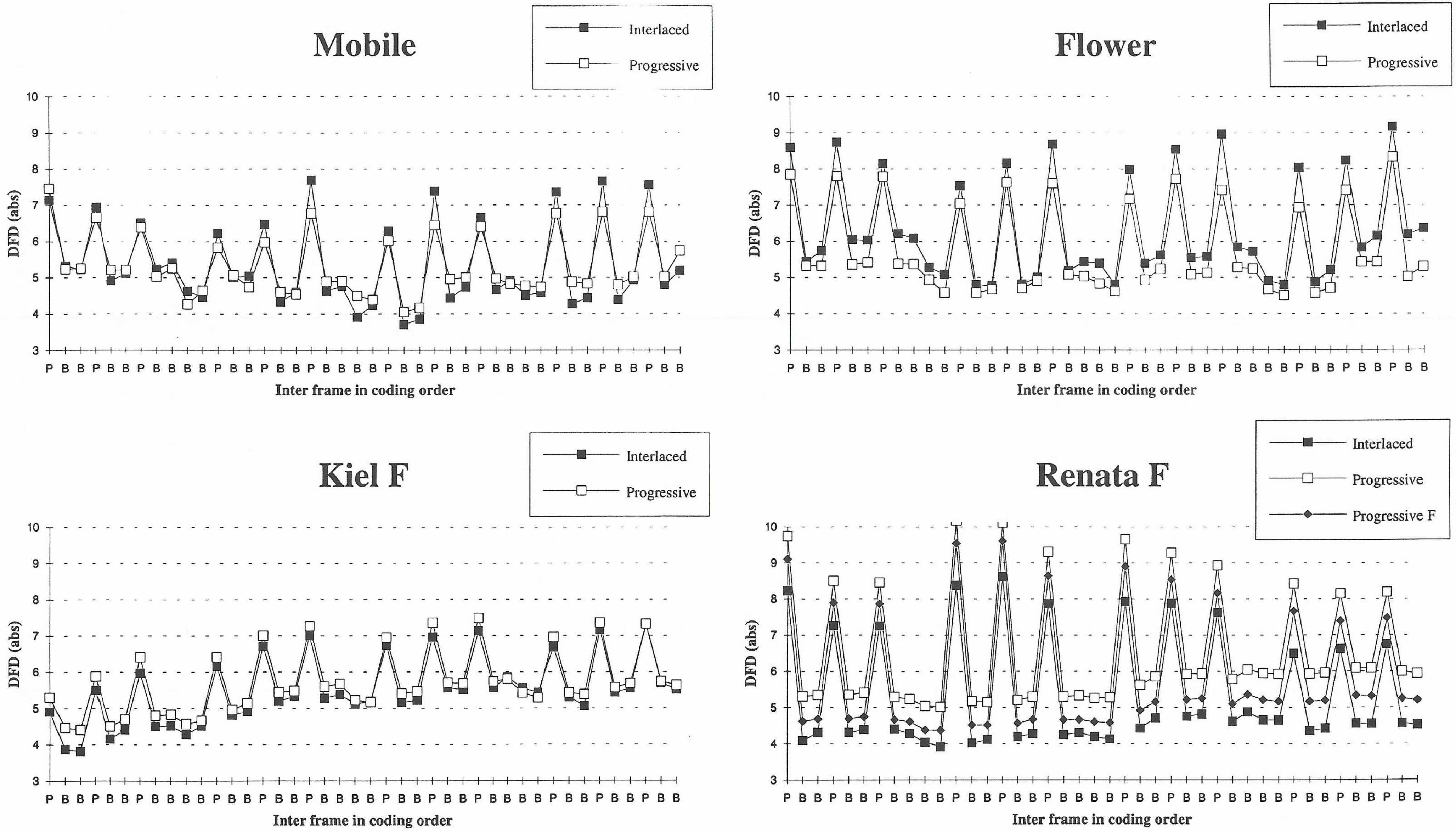


Fig. 6 - Motion compensated DFD

4.5 Coding Gain

From the previous analysis, it is not possible to draw a clear conclusion. The object of this chapter is to measure the overall differences between both formats by means of bit-rate measurements. Considering that the double number of pels has to be transmitted with the progressive format, that both scanning modes have at least similar spatial correlation and motion prediction capabilities, what is the bit-rate required for both format when the same quantization step is used ?

4.5.1 Interlaced versus Progressive

The most important statistical measure is the bit-rate required for interlaced and progressive pictures quantized with the same step size. It means what is the bit-rate required to have the same coding degradation in both cases ? Therefore, the coding gain is introduced and defined as the ratio of the bit-rate required for progressive pictures over the bit-rate for interlaced pictures at the output of the respective encoders. The considerations which led to the adoption of this trial are detailed in chapter 4.1.

For the simulations, the quantizer scale code is set to values leading to a bit-rate near 4 Mbit/s in the same interlaced case (Cf. table 1), but also to a similar picture quality for each sequence (*Mobile* is difficult and requires 6 Mbit/s to be similar to the others). These values have been obtained by a first encoding of the different sequences with the bit-rate control on.

	Mobile	**Flower**	**Kiel**	**Renata**
I Frame	5	9	7	6
P Frame	8	12	10	9
B Frame	14	20	15	13
Bit-rate (Mbit/s)	6	4	4	4

Table 1 - Quantizer scale codes used

Then, the coding gain has been computed for the four first sequences, and plotted in Figure 7. In addition, the averaged values are drawn in table 2. Previous considerations on chapters 4.3 and 4.4 are useful to explain the differences :

- ***Interlaced original pictures*** :

    1)- Without motion (*Mobile*), the pictures are frame coded, the spatial correlations and the motion performances are similar for both formats. The double number of pels of the progressive leads to a coding gain near 2.0 for I frames. The double number of vectors for progressive compared to interlaced frame coded pictures leads to a coding gain near 2.0 for B frames (for B frames the bit-rate required for the motion vectors is 50% to 60% of the total bit-rate). The coding gain for the P frames is lower than for the B frames, because the motion estimator performs better than in interlace, and the bit-rate required for the motion vectors is less important;

2)- With motion (*Flower*), the pictures are field coded. The number of motion vectors is the same in both case (2 fields vectors are transmitted per macroblock). It can thus be expected to have a coding gain near 1.0 for the B frames. Progressive performs slightly better for the motion prediction, the coding gain is expected to be lower than 2.0 for the P frames (the motion vector bit-rate is low compared to the DCT coefficients for P frames). Finally, the resolution and spatial correlations are the same for both formats, the coding gain for I frames should be near 2.0;

- *Progressive original pictures* :

  For *Renata* and *Kiel* the same conclusions are valid. I frames requires twice the bit-rate in the progressive case (this is confirmed by the *Renata* F curve, when filtered the coding gain is lower than 2.0). P frames depends on the prediction performances (slightly better for *Kiel*), and for B frames the high quality of the prediction, and the fact that the main bit-rate is due to the motion vectors (with the same number of vectors for both formats) lead to coding gain values near 1.0. This is not the case for the end of the sequence *Renata*, because the motion range is lower at the end, thus interlaced pictures are frame coded, and the number of vectors divided by two. The coding gain is thus nearly multiplied by 2, and previous conclusions on non moving pictures are still valid for I and P frames.

	Mobile	**Flower**	**Kiel**	**Renata**
Coding Gain	1.71	1.16	1.32	1.69

Table 2 - Mean coding gain values

4.5.2 Influence of the Increased Vertical Resolution

At first sight, the main conclusion which can be drawn from the previous chapter is that progressive pictures require more bits than interlaced ones. One assumption is that this is because of the increased vertical resolution, in other words the coding gain is computed between pictures with different vertical resolutions. To check that, the coding gain is computed on one sequence (*Renata*) between the interlaced version and the original progressive source after Kell filtering to reach the same definition as the interlaced one. The result plotted in table 3, shows that the coding gain is better when the source is filtered (1.44 instead of 1.69) and this 0.25 improvement seems valid for all the sequences.

	Progressive	**Progressive Filtered**
Coding Gain	1.69	1.44

Table 3 - *Renata*, mean coding gain values with and without filtering

Thus, progressive scanning of pictures requires twice the raw bit-rate of interlaced before compression, and between 1.1 and 1.7 after MPEG-2 encoding with a higher vertical resolution, otherwise an additional gain of 0.25 is expected.

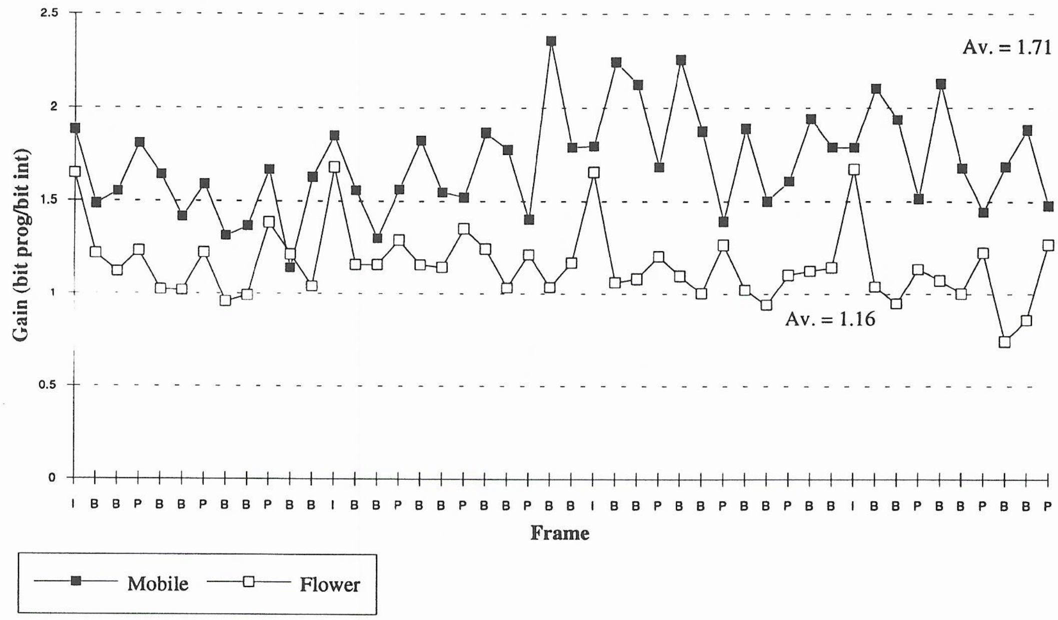
In addition, the previous distinctions can be done to give the following classifications on the bit-rate required to transmit progressive signals encoded with the same quantization step as their corresponding interlaced signals :

-Sequences with similar vertical resolution (deinterlaced or *Renata F*) :
With motion : coding gain for I frames : 1.7;
P frames : 1.3 to 1.6;
B frames : 1.0 to 1.2;
Progressive allows to transmit twice the number of lines with nearly the same bit-rate as the interlace;
Without motion : coding gain for I frames : 1.8 to 2.0;
P frames : 1.4 to 2.0;
B frames : 1.5 to 2.2;
Progressive allows to transmit twice the number of lines with less than twice the bit-rate of the interlace;

-Sequences with different vertical resolution (progressive pictures) :
With motion : coding gain for I frames : 1.8 to 2.0;
P frames : 1.6 to 1.8;
B frames : 1.0 to 1.5;
Progressive allows to transmit twice the number of lines with less than twice the bit-rate of the interlace;
Without motion : coding gain for I frames : 2.3;
P frames : 1.5 to 2.4;
B frames : 1.5 to 2.0;
Progressive requires twice the bit-rate of the interlace to transmit twice the number of lines;

If it is agreed that this is the worst case for progressive scanning because a non optimal GOP structure has been simulated, and that the same quantizer step size leads probably to a better picture quality when progressive display is used, then, at the same bit-rate, similar picture quality can be expected with progressive scanning in main cases. This will be verified in the next chapter by processing each sequence with the bit-rate control on, that is by considering the same transmission channel.

Coding gain (constant Q)



Coding gain (constant Q)

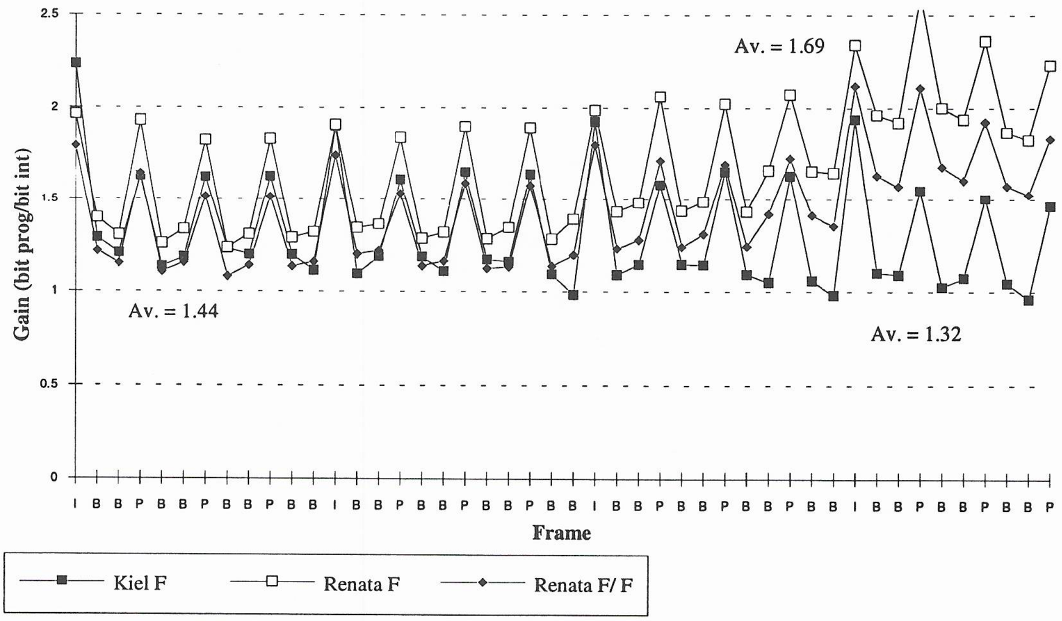


Fig. 7 - Coding Gain

5 - Coding Efficiency of Both Interlaced and Progressive Formats

For the simulations the scenario depicted in figure 8 has been used : two different broadcasting chains have been developed, an interlaced and a progressive one. For each one progressive or interlaced source materials are used with the corresponding scanning format conversion when necessary.

The first results concern the Peak Signal to Noise Ratio (PSNR) defined as follows :

$$\mathrm{PSNR_{dB}} = 10 \times \mathrm{Log_{10}}\left(\frac{255^2}{\frac{1}{N_i \times N_j} \sum_{i=1}^{N_i} \sum_{j=1}^{N_j} \left| S(i,j) - D(i,j) \right|^2} \right)$$

Where *S(i,j)* is the source pixel at location (i,j), and *D(i,j)* the corresponding one in the decoded picture of size $N_i \times N_j$.

These measures, computed between identical formats, do not assess the subjective picture quality, but they are an indicator of the differences between two different sequences of the same format. If different scanning formats are compared the influence on the PSNR is important, thus careful attention has to be paid, and subjective analysis is recommended.

Two bit-rates have been selected (6 Mbit/s for *MOBILE* and 4 Mbit/s for the other sequences) in order that the picture quality over the whole set of sequences is constant (PSNR between 30 and 35 dB).

In addition a subjective expertise is provided, because progressive display is supposed to be more pleasant than interlaced.

PSNR values and subjective picture evaluation are useful to compare both transmission formats, but complementary results are provided to check which format is better and for what bit-rates. In the same way, simulations with different picture quality at the same bit-rate will show the effect of the picture complexity on the scanning format efficiency. Finally, the influence of the deinterlacing process is also analyzed because interlaced sources are used for both transmission chain.

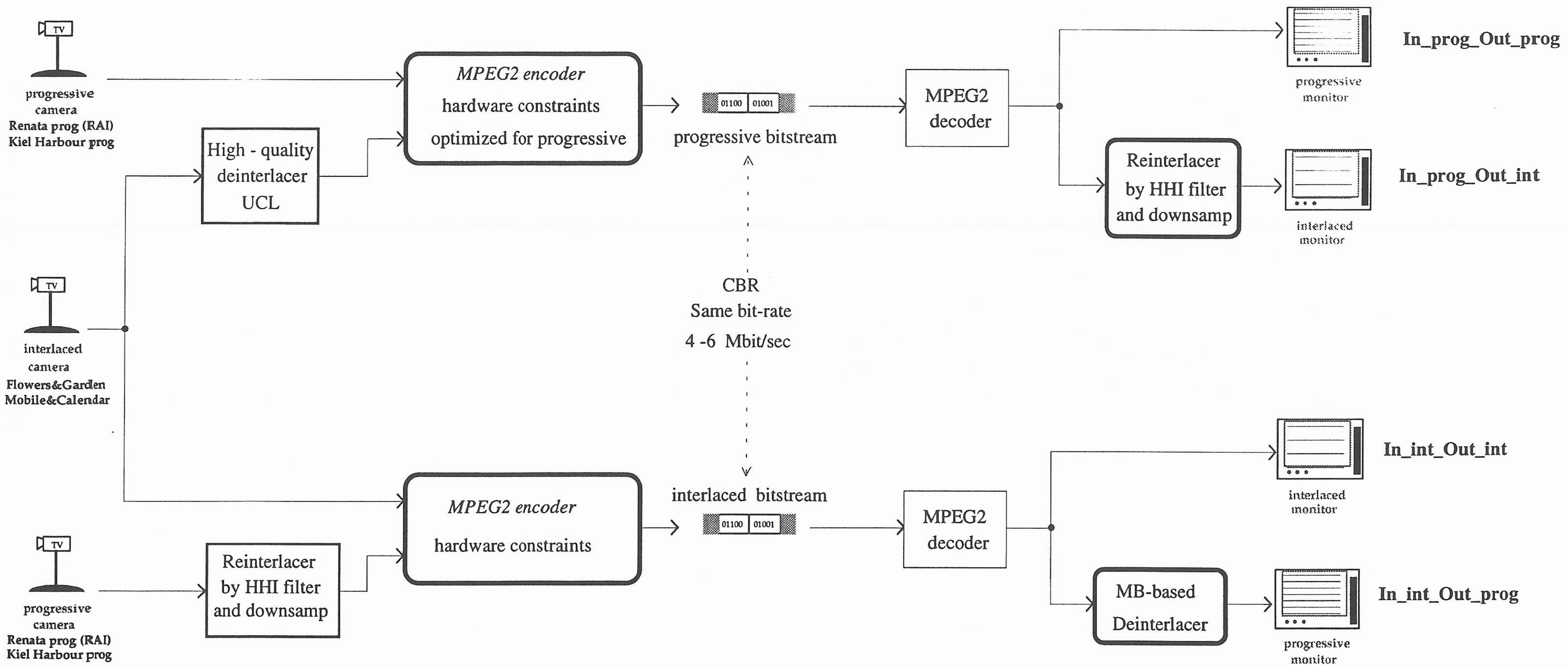
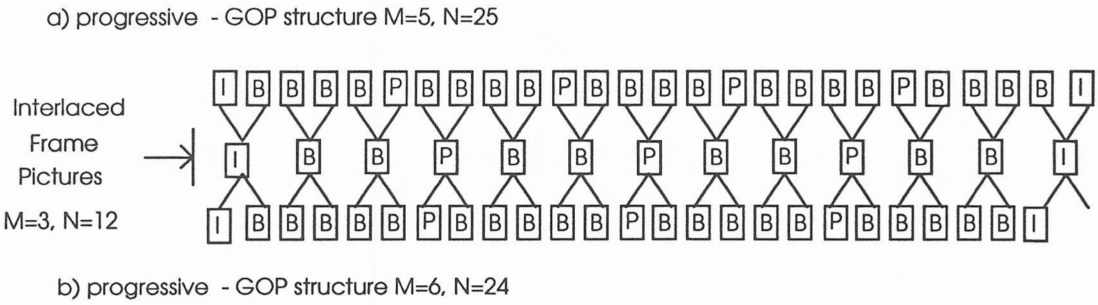


Fig. 8 - Interlaced and Progressive transmission formats

5.1 MPEG-2 Encoding Parameters

The same parameters as in the previous chapters are used, except the GOP structure. For interlaced signals the classical one is used (M=3, N=12). However, for progressive pictures, two possibilities have been discussed :
The first one considers a GOP structure twice that of the interlaced case, which means M=6, N=24 (figure 9-b) to have the same temporal spacing between P frames for both formats. The second one is computed to have a lower temporal distance between P frames to improve the temporal prediction, it leads to M=5, N=25 (figure 9-a).

The choice was done after software simulations, and the last one appears to be slightly more efficient than the first one.
Consequently, for the following simulations, M=5, N=25 was used.


a) progressive - GOP structure M=5, N=25

b) progressive - GOP structure M=6, N=24

Fig. 9 - GOP structure used

5.2 Coding Efficiency Comparisons

5.2.1 PSNR Measures

Four different outputs have been processed for each input sequence yielding four different PSNR values (two progressive and two interlaced PSNR). In figures 10 to 13 these PSNR values are plotted for the luminance component and each source sequence. In each graph the curves represent one of the four following broadcasting options :

- *Int_Int* : Interlaced encoding and display = *In_int_Out_int* figure 8;
- *Prog_Int* : Progressive encoding and interlaced display = *In_prog_Out_int* figure 8;
- *Int_Prog* : Interlaced encoding and progressive display = *In_int_Out_prog* figure 8;
- *Prog_Prog* : Progressive encoding and display = *In_prog_Out_prog* figure 8.

The mean values are summed up in tables 4 and 5, for interlaced and progressive display respectively.
When two sequences with the same display format are used, a better PSNR value generally means a better picture quality. If the display format is not the same, it should

be taken into account that progressive display leads to a more pleasant picture quality. Consequently a lower PSNR value in progressive does not necessarily mean a lower picture quality.

From these statements the following conclusions can be drawn for each display format :

- **Interlaced display :**

	Mobile		Flower		Kiel		Renata	
Coding Format	Prog	Int	Prog	Int	Prog	Int	Prog	Int
PSNR (dB) Y	29.32	32.30	30.38	30.64	32.11	31.61	33.49	33.14
PSNR (dB) U	33.90	34.45	33.47	33.39	39.08	39.23	36.07	35.69
PSNR (dB) V	31.85	32.11	31.87	31.38	37.82	38.00	37.86	37.67

	Foot[1]		Kiel 2[1]		Pendel[1]		Pops[1]	
Coding Format	Prog	Int	Prog	Int	Prog	Int	Prog	Int
PSNR (dB) Y	32.23	30.84	29.17	27.81	41.25	41.87	36.35	36.99
PSNR (dB) U	...	...	....	....	....	....	....	....
PSNR (dB) V	...	....	....	....	....	....	....	....

Table 4 - PSNR (dB) for interlaced signals

Progressive coding leads to better performances (PSNR and picture quality) for 4 sequences over 8 (*Kiel, Renata, Foot, Kiel 2*). For two of the other sequences (*Flower* and *Pendel*) the visual quality is in favor of the progressive format, confirming that the PSNR difference is too low to be significant (less than 0.3 dB). *Pops* is visually similar (difference equal to 0.6 dB), and the last one (*Mobile*) performs better when interlaced coded (1 dB more).
Thus from the PSNR point of view, the two formats are similar (average PSNR : 0.17 dB in favor of the progressive format), except when the deinterlacing failed.

- **Progressive display :**

	Mobile		Flower		Kiel		Renata	
Coding Format	Prog	Int	Prog	Int	Prog	Int	Prog	Int
PSNR (dB) Y	31.30	27.51	31.41	26.59	30.36	26.10	31.12	27.18
PSNR (dB) U	34.26	33.28	34.10	33.68	40.47	39.21	35.55	34.24
PSNR (dB) V	32.29	31.44	32.30	30.83	39.15	37.85	37.47	36.32

Table 5 - PSNR (dB) for progressive signals

The only conclusion from the previous table is that the macroblock based deinterlacer does not perform very well. It means that very simple solutions can not be used, and that careful design should be done to reach an acceptable quality.

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[1] UCL scheme [5]

- **Interlaced chain / Progressive chain :**

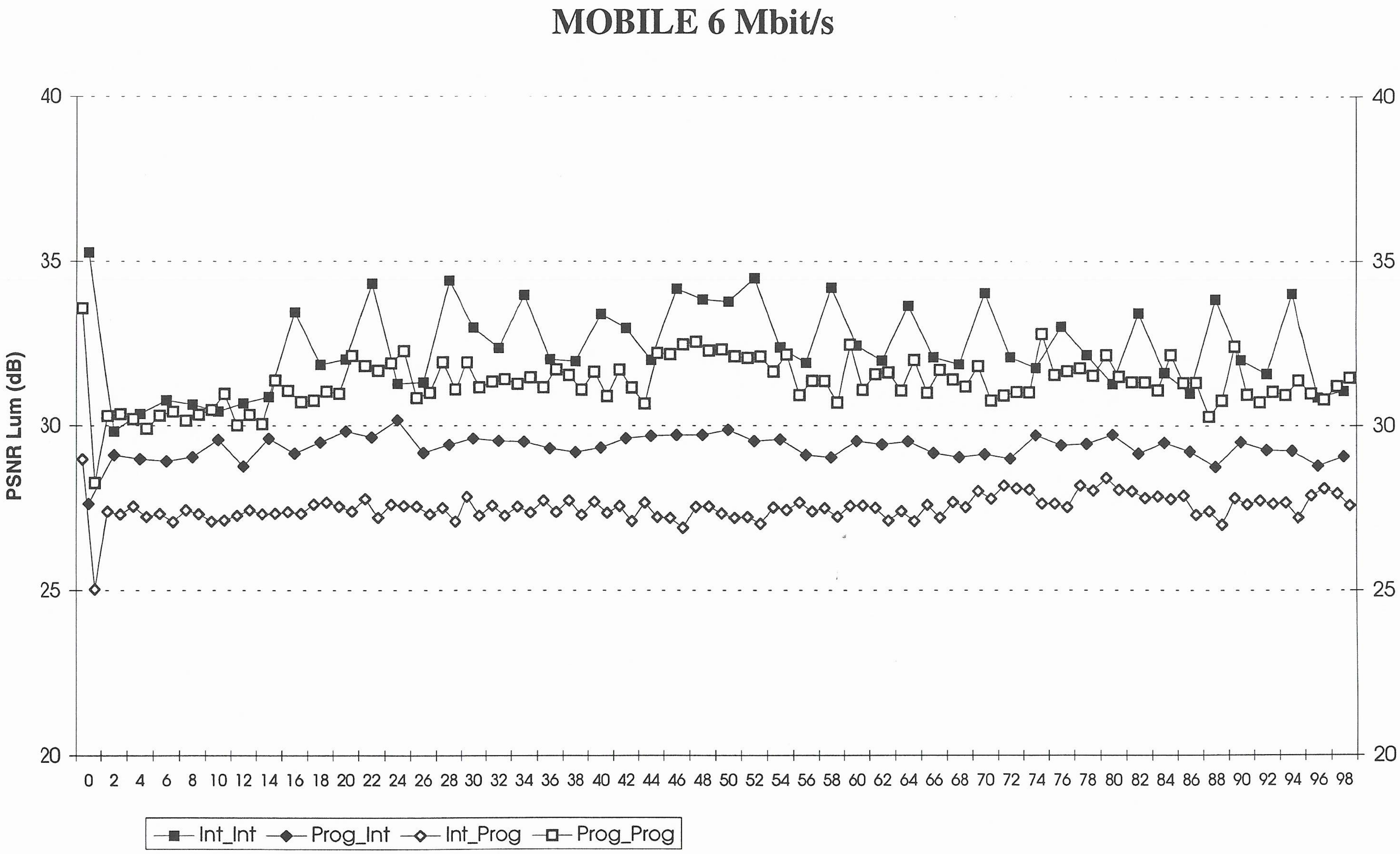
In this scenario an all progressive chain is compared to an all interlaced one, i.e. interlaced encoding and display compared to progressive encoding and display.

	Mobile		Flower		Kiel		Renata	
Coding Format	Prog	Int	Prog	Int	Prog	Int	Prog	Int
PSNR (dB) Y	31.30	32.30	31.41	30.64	30.36	31.61	31.12	33.14
PSNR (dB) U	34.26	34.45	34.10	33.39	40.47	39.23	35.55	35.69
PSNR (dB) V	32.29	32.11	32.30	31.38	39.15	38.00	37.47	37.67

Table 6 - PSNR (dB) for progressive / interlaced broadcasting

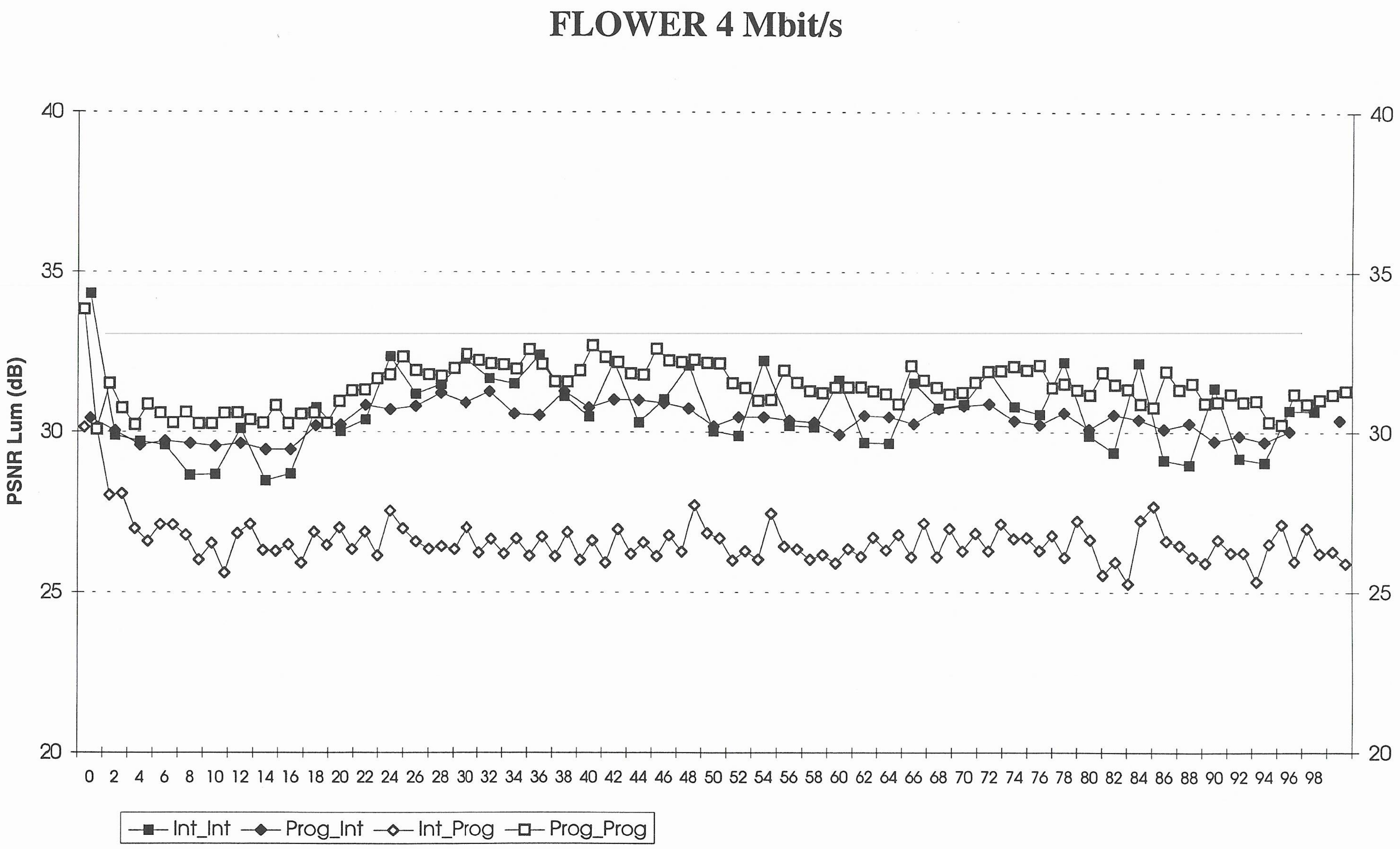
From these figures interlace seems better than progressive except for *Flower*. But the comparison is done between different formats, and progressive display is generally more pleasant than interlaced. A subjective evaluation is thus required.

It is noticeable that *Renata* shows the largest difference with 2 dB more for interlaced which can be considered significant compared to the other differences (around 1 dB).



MOBILE 6 Mbit/s

Fig. 10 - PSNR (dB) of MOBILE at 6Mbit/s, for both interlaced and progressive formats



FLOWER 4 Mbit/s

Fig. 11 - PSNR (dB) of FLOWER at 6Mbit/s, for both interlaced and progressive formats

KIEL 4 Mbit/s

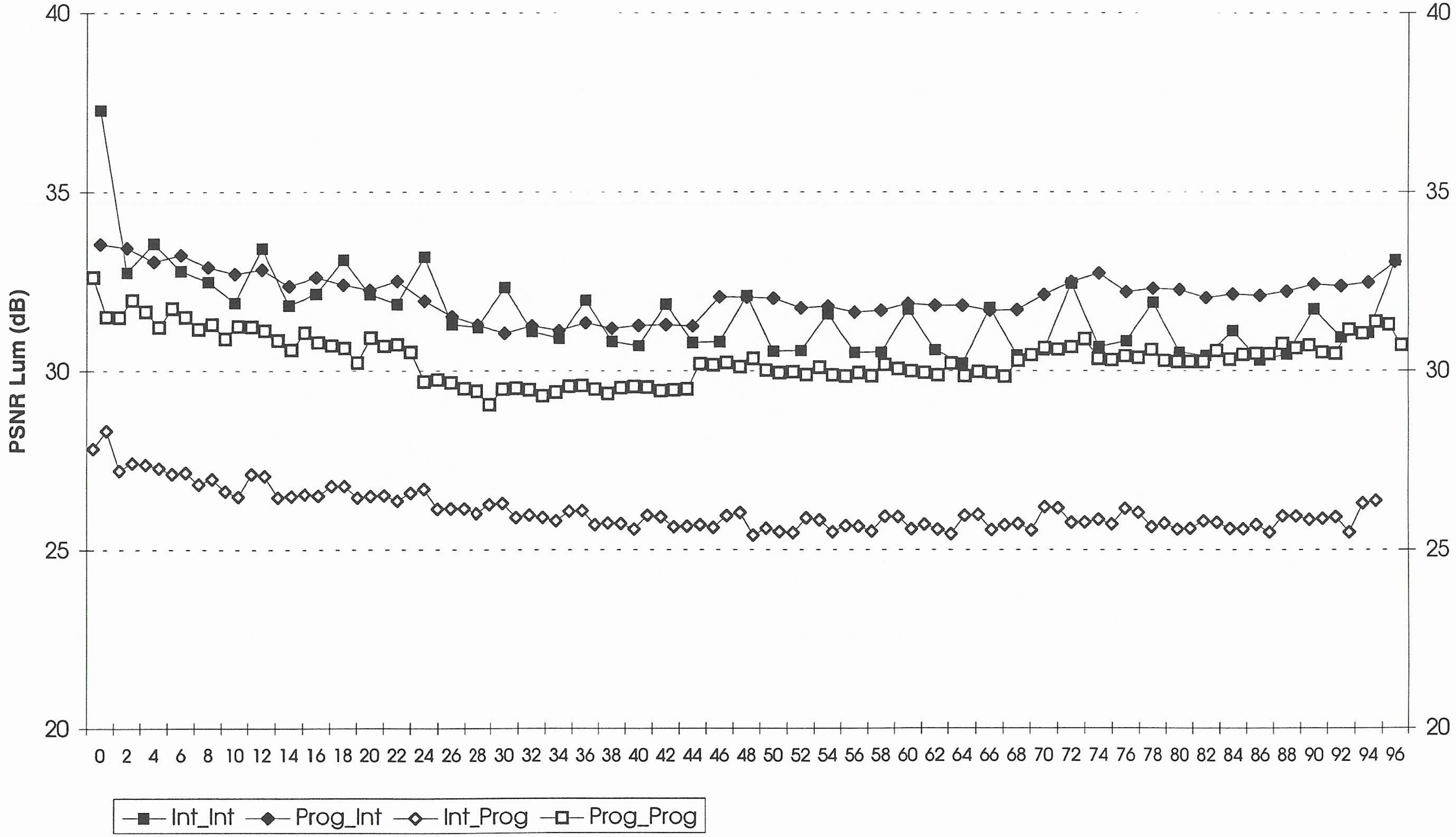


Fig. 12 - PSNR (dB) of KIEL at 4Mbit/s, for both interlaced and progressive formats

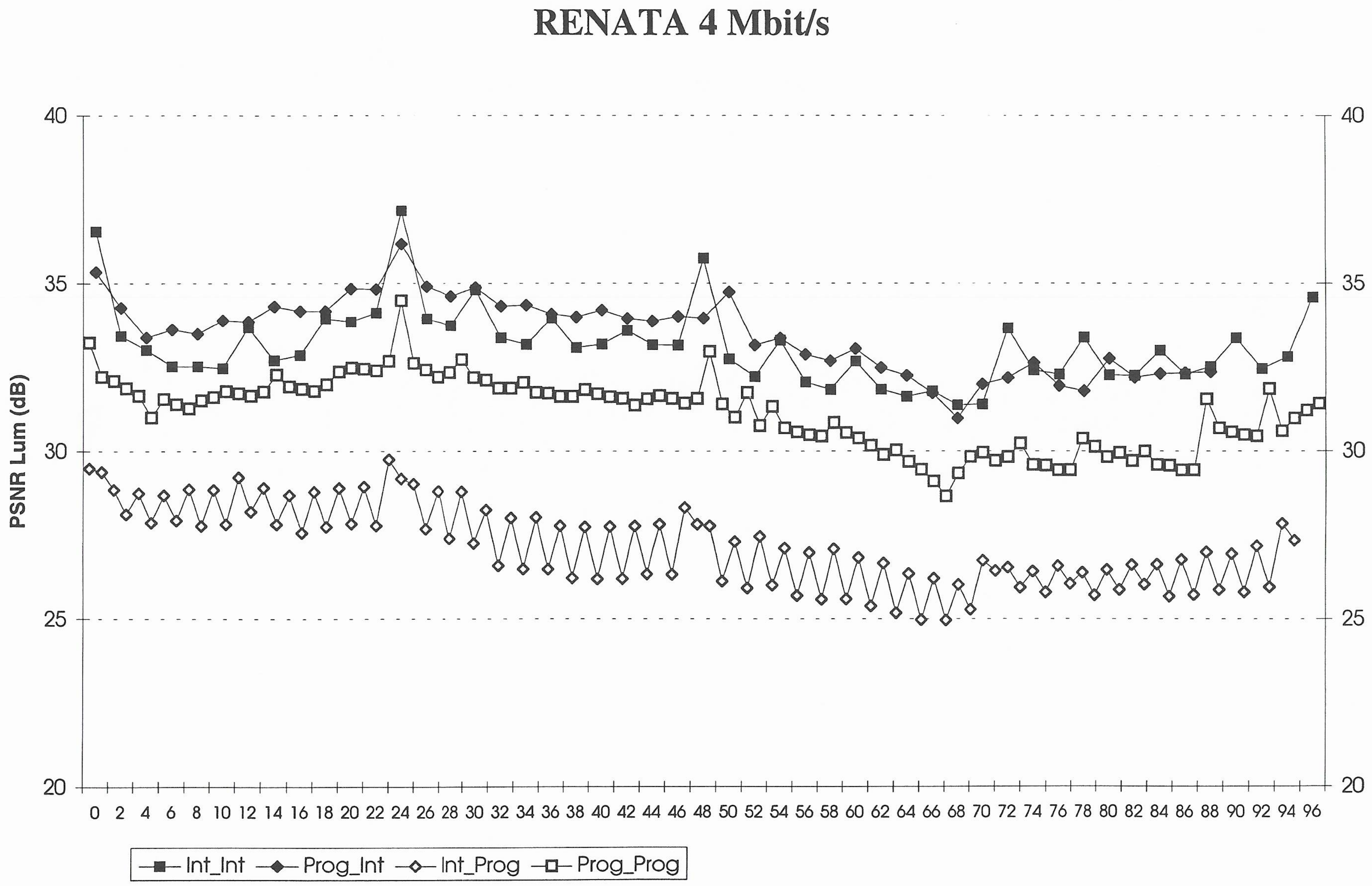


Fig. 13 - PSNR (dB) of RENATA at 4Mbit/s, for both interlaced and progressive formats

5.2.2 Subjective tests

The subjective picture quality evaluations were done on 2 different monitors : an interlaced one (SONY BVM 2010 P) and a progressive one (BARCO CC1D 120 T), both of them using a Trinitron tube. Moreover, comparisons between the same formats were done with the same monitor, whereas comparisons between different formats were done on the two different screens. Because of this unavoidable drawback, the conclusions must be drawn carefully.

Considering that the PSNR values are quite conform, or at least coherent, with the picture quality, the following contents the analysis performed on the four first sequences with both measures. The comparisons concern three scenarii : First the whole progressive chain facing the whole interlaced one (*Prog_Prog / Int_Int*), then the progressive transmission versus the interlaced one with interlaced display (*Prog_Int / Int_Int*), and finally the interlaced transmission versus the progressive one with progressive display (*Int_Prog / Prog_Prog*).

- ***MOBILE*** :	*Prog_Prog/Int_Int* :	The coding artifacts are slightly more visible in the progressive pictures, but the absence of effects due to the interlaced scanning (in particular in the calendar and sheep) leads to a progressive picture slightly more pleasant than the interlaced one (the PSNR is 1dB lower for progressive, cf. Table 6).
	Prog_Int/Int_Int :	Even if the coding artifacts are similar, the loss of resolution in the progressive case (probably due to the kell filter) leads to a better interlaced chain (3dB loss for progressive, cf. Table 4).
	Int_Prog/Prog_Prog :	It will be the same conclusion for the whole set of sequences within this scenario, the poor quality of the macroblock-based deinterlacer can not be compared to the progressive neither interlaced broadcasting chain.
- ***FLOWER*** :	*Prog_Prog/Int_Int* :	The interlaced format leads to visible artifacts such as blocking effects in the sky, line flicker in the tree or in the house edges. Borders of moving objets are also damaged. Thus progressive broadcasting is better than interlaced (the PSNR is 0.8dB better for progressive, cf. Table 6).
	Prog_Int/Int_Int :	In addition to the previous considerations, a loss of resolution in the progressive case appears (once again probably due to the kell filter) but the overall quality is still a little better for progressive (the PSNR is 0.3dB lower for progressive, cf. Table 4).

	Int_Prog/Prog_Prog :	The poor quality of the deinterlacer is obvious with a line structure created on the flowers and the foreground tree.
- ***KIEL*** :	*Prog_Prog/Int_Int* :	Progressive processing of Kiel removes the flicker due to the interlaced scanning (in the water, shrouds, and wharf) to give a more pleasant picture, but the coding artifacts are masked by the flicker in the interlaced case, then the overall picture quality is comparable with a small advantage to the progressive format (PSNR 1.3dB lower).
	Prog_Int/Int_Int :	The Kell-filtering of the progressive pictures reduces the blocking effect, thus progressive coding leads to a better picture quality (PSNR 0.5dB better).
	Int_Prog/Prog_Prog :	See previous sequences.
- ***RENATA*** :	*Prog_Prog/Int_Int* :	Similar conclusions as for Kiel : no flicker in moving parts and better resolution in fixed areas for progressive, coding artifacts less visible for interlaced. But in this case the advantage is in favor of the interlaced format (PSNR 2dB lower in progressive).
	Prog_Int/Int_Int :	Once again, the Kell filtering decreases the visibility of the artifacts, but not enough to be better than interlaced in slow moving areas. The two formats are similar (PSNR 0.4dB lower for progressive).
	Int_Prog/Prog_Prog :	See previous sequences.

Then from the previous analysis, five remarks can be made :

1)- As expected progressive display is more pleasant than interlaced, mainly because of the absence of flicker;

2)- This flicker masks the coding artifacts which can become visible in progressive;

3)- Progressive coding and interlaced display can improve the picture quality compared to progressive display thanks to the Kell filter which acts as a post-filtering;

4)- The same Kell filter decreases the resolution of an interlaced source sequence (probably because the bandwidth of the Kell filter used for progressive to interlaced conversion is lower than that of real interlaced cameras);

5)- The Macroblock-based deinterlacer is not acceptable, a line structure in the borders of the macroblock is too annoying. It can be improved by using the surrounding macroblocks, but it will not be as good as interlaced scanning without careful design of the deinterlacer.

And the following conclusions can be pointed out :

1)- If an all progressive chain is compared to an all interlaced one, progressive is generally preferred to interlace, mainly due to the display;
2)- If interlaced display is used, progressive transmission can improve the picture quality if progressive sources are used, and the loss of resolution with interlaced sources can supersede the reduction of blocking effects. Finally similar performances between each coding format are achieved.

5.2.3 Bit-Rate Control Parameters

Besides the coding efficiency, the bit-rate control parameters have been processed for the whole progressive and interlaced chains. The results are plotted in figures 14 to 17 for the respective source sequences. For each one, the right side of the page is dedicated to the progressive chain and the left side to the interlaced one. On the upper graph the PSNR is drawn together with the bit-rate, for each frame and in the display order. On the lower graph, it is the buffer occupancy together with the quantizer step size, for each frame and in the coding order.
For these two graphs one curve is linked to the picture quality (PSNR or quantization step) the other one to the bit-rate (bit-rate or buffer fullness).

The main conclusion from these figures is that progressive transmission leads to a more stable bit-rate control, and thus to a more homogeneous picture quality.

To draw conclusions between an all progressive and an all interlaced broadcasting chain is difficult because subjective evaluation between different formats is not an easy task. In addition, one of the point this deliverable has to study is the use of progressive as an intermediate transmission format. For that purpose, complementary results are needed such as the influence of the bit-rate, i.e. is a format better at a given bit-rate and worse at another one? Similarly, what is the effect of a deinterlacer in the coding efficiency? Are the conclusions dependent on the picture complexity? All these questions are the subject of the next chapter.

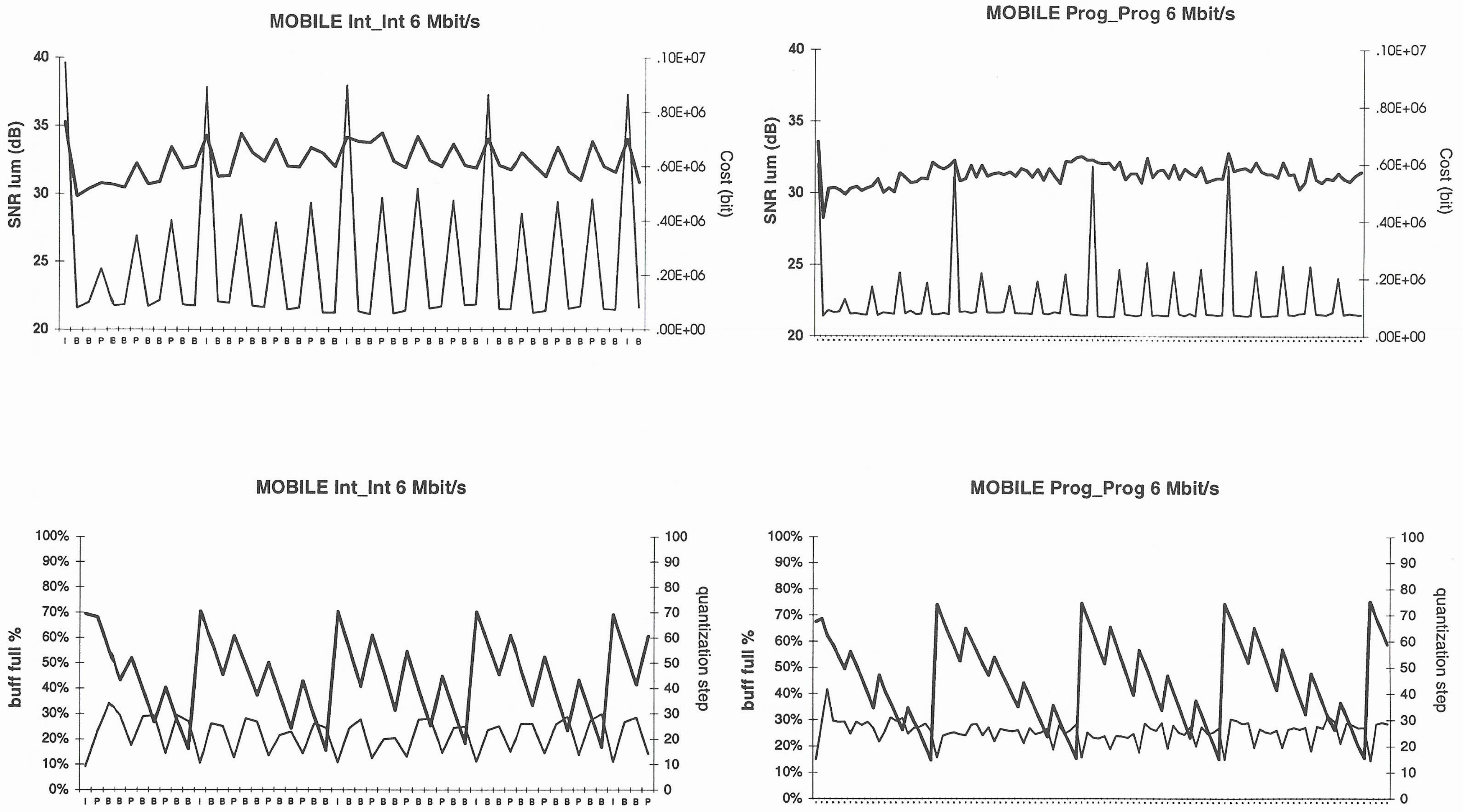


Fig. 14 - Bit-rate control parameters of MOBILE at 6Mbit/s for both progressive and interlaced encoding

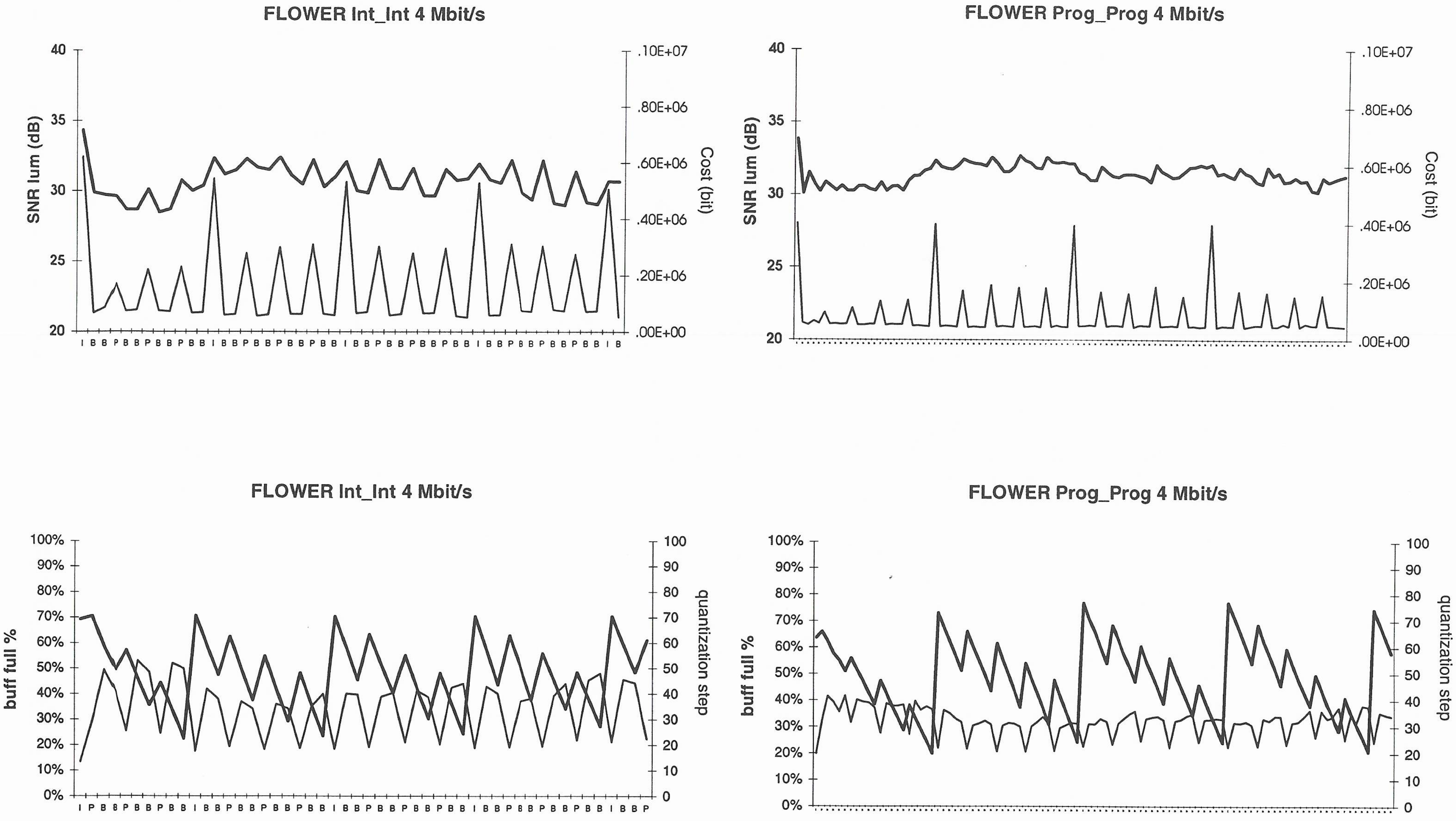


Fig. 15 - Bit-rate control parameters of FLOWER at 4Mbit/s for both progressive and interlaced encoding

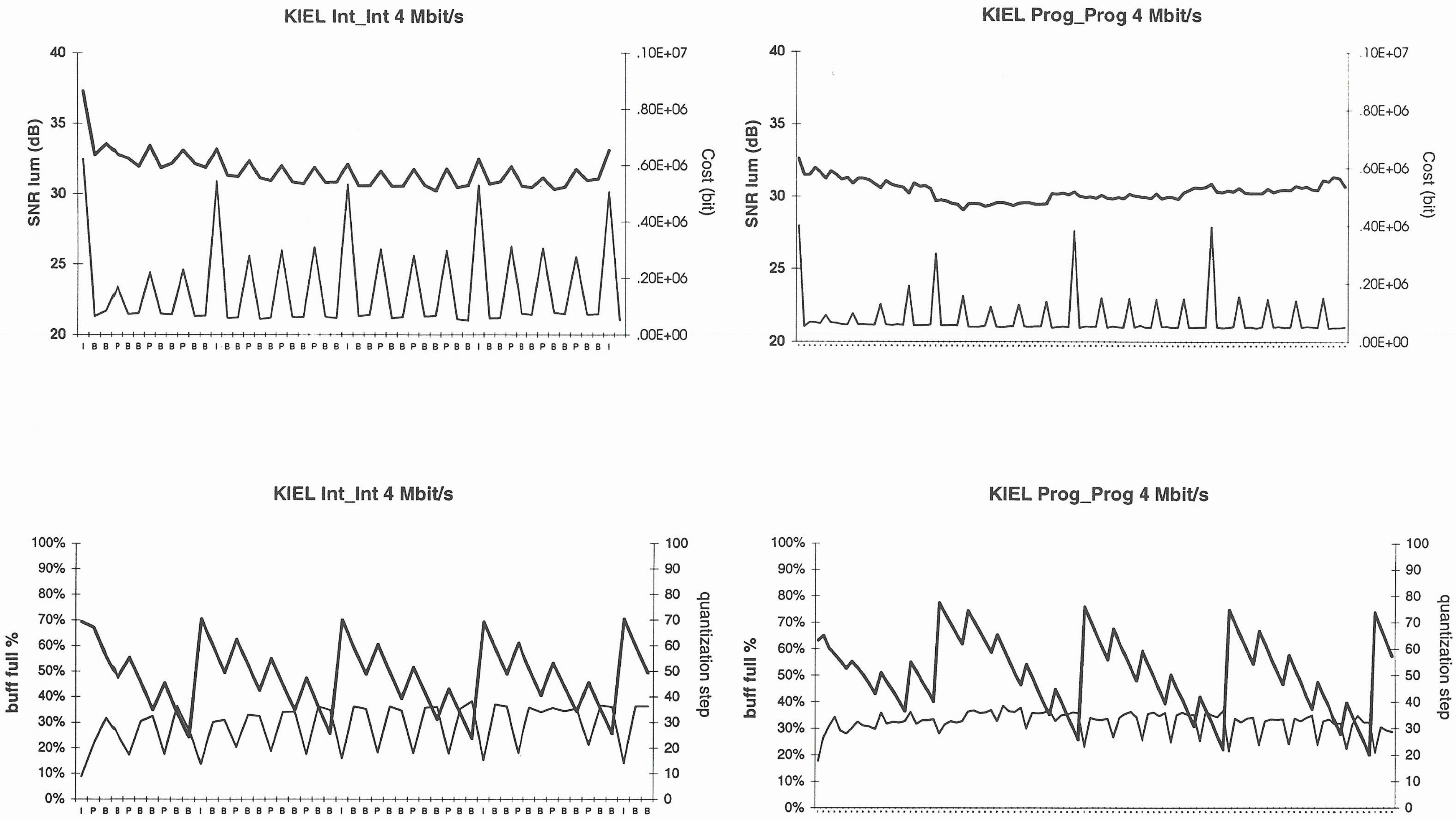


Fig. 16 - Bit-rate control parameters of KIEL at 4Mbit/s for both progressive and interlaced encoding

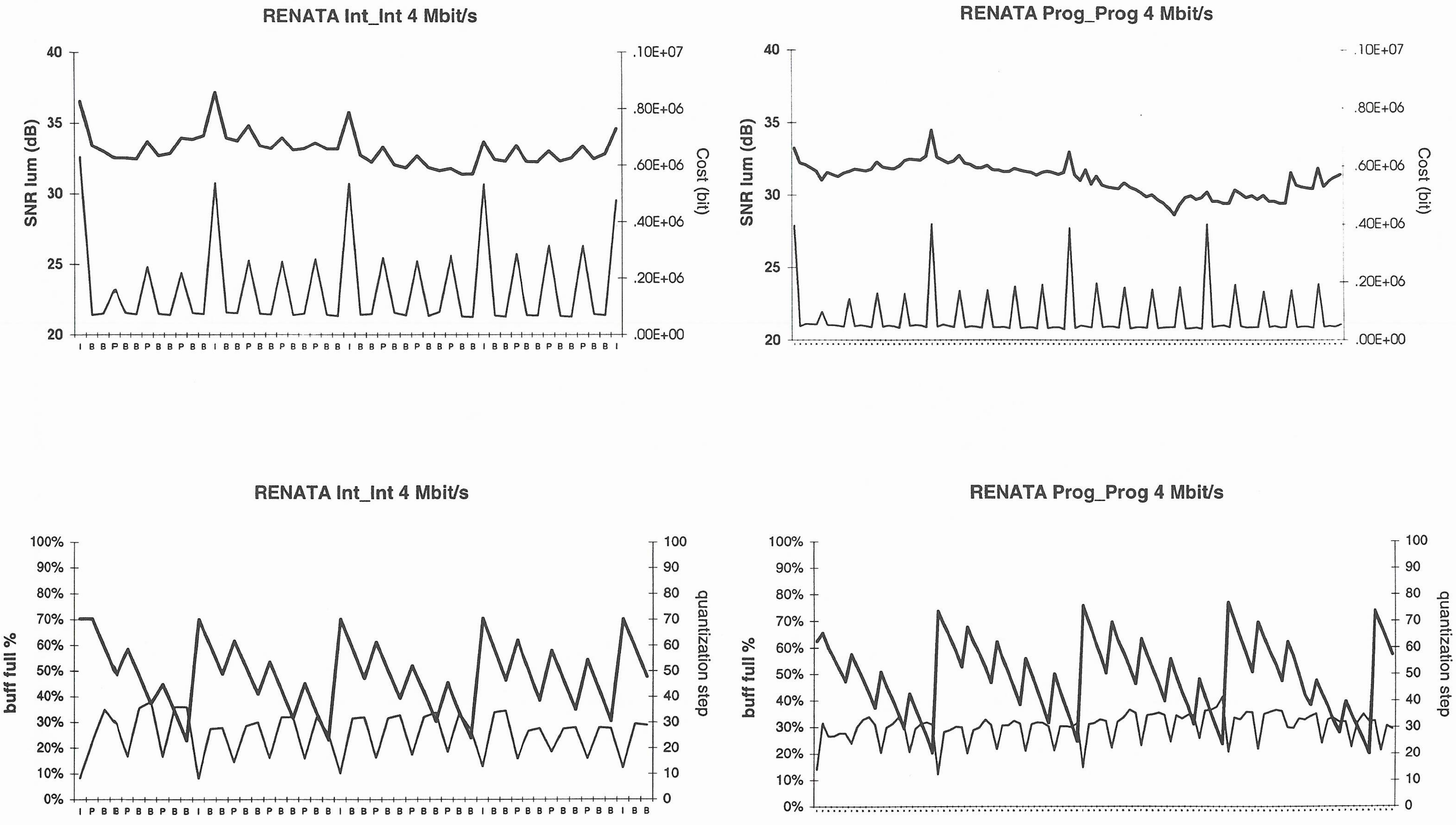


Fig. 17 - Bit-rate control parameters of RENATA at 4Mbit/s for both progressive and interlaced encoding

5.3 Influence of the Bit-Rate

Is the results of the comparisons between progressive and interlaced scanning dependent on the bit-rate? To answer this question, simulations on the sequence *Pops* have been performed at 2, 4 and 6 Mbit/s. Results in table 7, clearly show that if interlace is better at high bit-rates this is still true at low ones if not even more (the difference between both formats is 0.60 dB at 6 Mbit/s and increases up to 1.7 dB at 2 Mbit/s).
The number of pels as well as the vertical and horizontal resolution are very critical at low bit-rates, and, even with interlace, prefiltering is often required to smooth the picture content. If at high bit-rates the increased vertical resolution can be compensated, it is not true at low ones. It can also be supposed that for some sequences progressive can be better at high bit-rates and worse at low ones (to be confirmed).

Bit-rates	**2 Mbit/s**		**4 Mbit/s**		**6 Mbit/s**	
Coding Format	Prog	Int	Prog	Int	Prog	Int
PSNR (dB) Y	32.17	33.87	36.35	36.99	37.98	38.58
PSNR (dB) U	...	...	...	...	...	...
PSNR (dB) V	...	...	...	...	...	...

Table 7 - PSNR (dB) at different bit-rates

5.4 Influence of the Picture Complexity

From chapter 4, it seems that the conclusions differ depending on the picture content. Table 8 and figure 18 sum up the previous results by decreasing order of complexity value (in dB). The PSNR can be considered related to the difficulty to encode a picture, thus it is selected as complexity measure (a high complexity gives a low value).
From table 8 and figure 18, progressive performs clearly better for complex images and a little worse for pictures with a low complexity. The reason is that for a low complexity the picture is homogeneous, thus the progressive format bring no additional information compared to interlace. Since twice the number of lines should be transmitted it results in slightly lowering the PSNR of the decoded pictures. However, since the gap is nearly equal to 0.5 dB, and since both progressive and interlaced PSNR are high, no noticeable difference between both formats can be seen.

	Kiel 2 (28dB)		**Foot** (31dB)		**Kiel** (32dB)		**Renata** (33dB)		**Pops** (36dB)		**Pendel** (41dB)	
Coding Format	Prog	Int	Prog	Int	Prog	Int	Prog	Int	Prog	Int	Prog	Int
PSNR (dB) Y	29.17	27.81	32.23	30.84	32.11	31.61	33.49	33.14	36.35	36.99	41.25	41.87
PSNR (dB) U	...	...	...	...	39.08	39.23	36.07	35.69	...	...	...	...
PSNR (dB) V	...	...	...	...	37.82	38.00	37.86	37.67	...	...	...	...

Table 8 - PSNR (dB) for different picture complexity

These values are drawn in figure 18, and an interpolated curve tries to generalize the behavior of the gap between interlaced and progressive versus the complexity of the source sequence. The complexity is given by the mean PSNR of the decoded pictures in interlaced and progressive format. From this curve it seems that the threshold when interlaced becomes better in term of PSNR than interlaced is around 34, 35 dB (to be confirmed with more simulations).

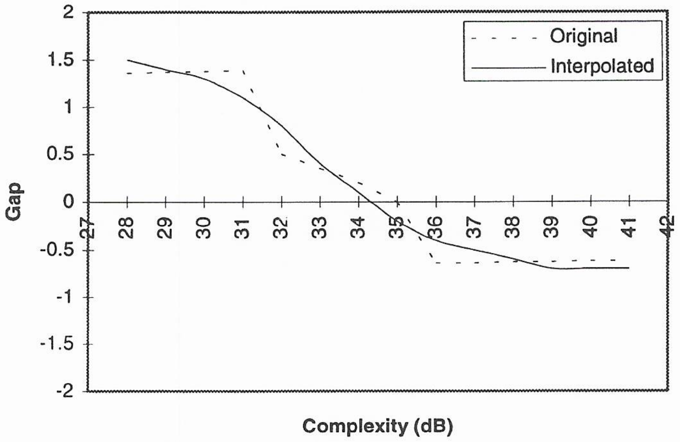


Fig. 18 - Difference between interlaced and progressive coding versus complexity

Moreover, the two extremities of the curve seem to have a behavior similar to an asymptote, it means that the maximal gap values are limited to around [+1.5, -0.5].
It should also be pointed out that the previous results are related to progressive source sequences, and in the case of deinterlaced pictures the conclusions are probably different due to the effect of the deinterlacing process.

5.5 Influence of the Deinterlacing

Moving towards progressive transmission will require conversions from progressive to interlaced and interlaced to progressive scanning to manage present studio environment. Thus the effects of the deinterlacing have to be studied to be sure that it handles field aliasing properly.
Table 9 depicts the results of simulations performed on the Kiel 2 progressive source sequence. The original pictures are progressive encoded and interlaced displayed to give the PSNR value called *progressive* in table 9, this sequence is then interlaced coded and displayed, and its PSNR computed in column *interlaced* (this PSNR refers to the original sequence that has been interlaced). Finally, the previous sequence is *deinterlaced* to go back to progressive coding.
As expected, the deinterlaced sequence is better than the interlaced one, because the original progressive source pictures perform already better than the interlaced version, and because the deinterlacing is artifacts free on that sequence.

Coding Format	Progressive	Interlaced	Deinterlaced
PSNR (dB) Y	29.17	27.81	28.36
PSNR (dB) U	...	...	...
PSNR (dB) V	...	...	...

Table 9 - PSNR (dB) between interlaced, deinterlaced and progressive signals

These results are very dependent on the quality of the deinterlacer, thus conclusions may take into account possible low quality deinterlacing. However, it can be assume that future deinterlacing will become better and better.

6 - Conclusion

In this deliverable, the coding efficiency of both progressive and interlaced scanning formats are compared by means of PSNR values and subjective picture quality analysis. The main goal was to evaluate the impact of using a progressive transmission format compared to the existing interlaced one.

It was demonstrated in the first part that there is a raw factor of 1.1 to 1.7 between the bit-rate required for the transmission of progressive and interlaced pictures with the same quantizer step size and non-optimal GOP structure. It means that a progressive format allows to transmit twice the number of lines with less than twice the bit-rate. The second part leads to the conclusion that the absence of interlaced artifacts (mainly line flicker) and the use of an optimal GOP structure allows the use of a greater compression factor in the case of progressive processing and display. At the same bit-rate an all progressive broadcasting chain, from the source capture to the final display, is thus preferable to an all interlaced one, except for an increased hardware complexity since twice the number of pixels is scanned.

Moreover, with interlaced display, the progressive transmission can be considered at least as good as the interlaced one and better if progressive sources are encoded (the degree of improvement is linked to the complexity of the source material, the higher the complexity the bigger the improvement is). Unfortunately, the conclusions are not so clear when dealing with interlaced sources : the loss of resolution supersedes sometimes the reduction of blocking effects and the conversion from progressive to interlaced scanning after decoding can either improve (post-filtering of the coding artifacts) or decrease (loss of resolution) the picture quality depending on the source sequences available. Consequently, it has been shown that progressive does not lead to a loss of performances, that on the contrary it brings a more stable picture quality, even if the MPEG-2 standard has been optimized for interlaced signals.

Thus, from a picture quality point of view, progressive scanning is a very attractive format for the transmission, and even more for the visualization of pictures. In addition, progressive can be used as an intermediate step towards progressive broadcasting of TV signals without loss of performances compared to the existing interlaced format.

Finally, with such a broadcasting format compatibility with the multimedia applications (Computer, broadcasting, transmission, virtual, film, ...) will be simplified and more efficient.

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