CCITT SGXV **Doc. #475**
Working Party XV/4
Specialists Group on Coding for Visual Telephony

Source : NL, F, FRG, UK, I, S, N, E, Gr.
Title : Pre- In- and Post Codec Filtering

Enclosed you will find a document trying to give an answer to the ongoing discussion of using various filters before, inside and after the codec. The work to finalize this paper is still under progress, but some conclusions could help to make some decisions on loopfilter related matters.

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1 Summary

In this contribution an overview is given concerning filters to be used or be ommitted in the Reference Model. Three clusters are identified, before the codec denoted as pre codec processing, in the source encoder and decoder denoted with in codec processing and after the decoder denoted with post codec processing.
For each of these positions different filters need to be constructed, using space variant or space invariant filters. For the choice which filter should be taken various constraints have to be taken into account, among which the computational load and hardware complexity.

In this contribution results are given of various comparisons, with different filters on different positions.
The results concerning the pre codec processing are not available at this time, the study is still under progress.
Post codec processing and In codec processing are considered, for the post codec processing it was important that similar results where achieved as in the case of a noise reduction filter in front of the frame memory.
As for the in-codec processing; the performance of the noise reduction filter h_n versus h_p and the performance of the [1 2 1] filter versus the adaptive directional filter was verified.
Measurements on the transform were carried out to give some insight on the adaptation rules for the filters.

2 Conclusions

In this contribution image quality enhancement by filtering was studied. Experiments were carried out in order to able to make a decision on the filters to be used in the codec.
Comparisons are made for in-codec filters among which the noise reduction filter h_n in front of the frame memory versus the prediction filter h_p after the frame memory. Simulations are carried out for two types of prediction filters; an adaptive and a fixed filter.

In-codec processing

In the appendix A the results are given for MISS and CLAIRE, when the 121-filter is replaced by the adaptive filter. With CLAIRE, a slight improvement of 0.2 dB is reached. For MISS, on the contrary, using the adaptive filter instead of the 121-filter leads not to better results, compared to RM7. From visual inspection, it appears that the differences between the results of the adaptive and the 121-filter are negligible.

One of the reasons of the disappointing results may be the extra amount of overhead bits. It appeared that, compared with RM7, for CLAIRE about 140 extra overhead bits per frame are needed, for MISS even 380 bits per frame.

Taking into consideration the fact that for the adaptive filter a more complex hardware construction is needed, **we conclude that this adaptive filter should not be included for standardization.** Studies for adaptation rules are necessary to improve the performance of the encoder and decoder.

Post-codec processing

A comparison is calculated for RM7 results versus RM7 + h_{post}. In appendix C the results showed that subjective the image was smoothed. The post codec processed results were preferable. These results looked somewhat blurred but this was probably caused by the used look-up tables. The values were obtained from measures inside the loop.

At present no convincing evidence was obtained to propose a noise reduction filter h_n in front of the frame memory.

3 Introduction

Theory for filtering images has been already developed, ongoing research is focussing now on moving images.

Especially for Low Bitrate Coding according to CCITT SG XV the question arises in which way the performance of the Hybrid DPCM/transform codec could be improved by pre-codec, in-codec and post codec filtering.
At very low bitrates at $q \times 64kbit/s$ where $q = 1$ the adopted algorithm produces visible artifacts. Some of these artifacts can be described with false contours, mosquitos[1], quantization errors[2] and blocking.

Sometimes these impairments might be reduced by the sophisticated decisions rules. The distortions will be concealed or suppressed under the visibility threshold. Due to the synchronous network, the transmission buffer and the control mechanism abruptly overrides the adaptive rules of the source encoder and the video multiplex encoder. The flexibility i.e. adaptivity is force to non-image related rules such as channel capacity. By this change of the control and the feedback of the control parameters to the source encoder the picture quality would be affected.

Theory developed for various filter types are based on assumptions coming from 1-D signal processing and based on rigid mathematical models.
The developed Hybrid/DPCM transform codec is highly adaptive and therefore to improve the performance of the coding configuration, adaptive techniques should be adopted.

In general two type of filters could be recognized; filters for concealment purposes and filters for reconstruction purposes. In the case of the first type of filters the artifacts caused by the coding procedure is removed by smearing or frequency cut off, e.g. convolution filters, Median filters. The second type of filters are like Kalman filters, which actually produce a reconstruction of the image signal. Bearing in mind the computational load and the hardware complexity the first type of filters are considered.
The position of the filters need to be discussed first on the high level, pre-codec, in-codec and/or post codec.
A priori a post codec could be the small devil in the black box due to the manufacturers freedom of implementation and its possibility of picture enhancement.
Enclosed a discussion and evaluation is given of the position and the type of filters, taking into account the computational load and the hardware implementation and last but not least the status of the flexible hardware.

In the next sections first the position and the necessity of various filters are discussed. After which the chosen filter algorithm is described. The hardware aspects for the realization are than revealed.
The obtained simulation results, adopting the described methods are evaluated.

[1] high frequency noise which appears at contours
[2] depends on quantization stepsize

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4 Position of the filter

First an overview is given at which position the filters should be considered. In figure 1 and in figure 2 the positions for the pre and post processing filters are depicted, whereas the filters inside the source encoder are depicted in figure 3.

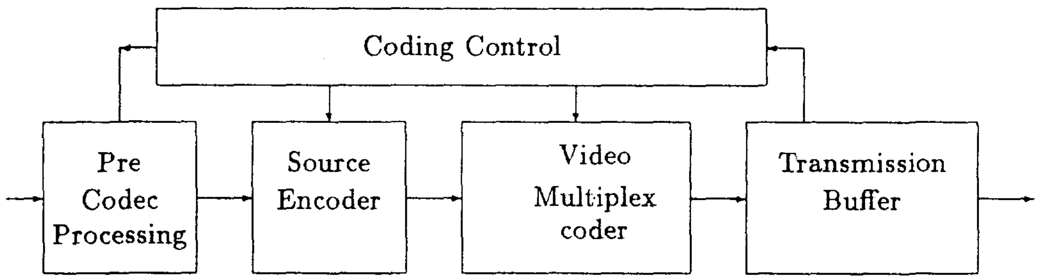

Figure 1: Structure of the transmitting side

In figure 1 a pre processing filter is positioned in front of the source encoder. The construction of this filter and the post codec processing filter are both not a matter for standardization. These filters can influence the overall performance of the codec a great deal.
The pre processing at the moment consists of a conversion from a local used TV system towards the Common Intermediate Format (CIF).
Some constraints for the CIF-converter are; camera noise, resolution, jerkiness, and processing delay which are for the coming service important aspects [9].
In figure 2 a post codec processing unit is positioned after the source decoder. The wording post processing is somewhat ambiguous. Post processing could be interpreted as the conversion CIF to local TV standard, but it could also mean the processing of the reconstructed image. In this section post codec processing means the processing of the reconstructed image directly from the decoder and post processing[3] — which is more general — the conversion towards the local TV standard.

[3] includes post codec processing

22K

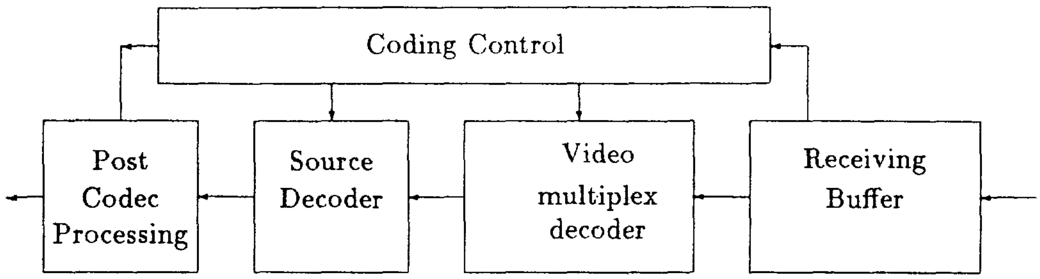

Figure 2: Structure of the receiver side

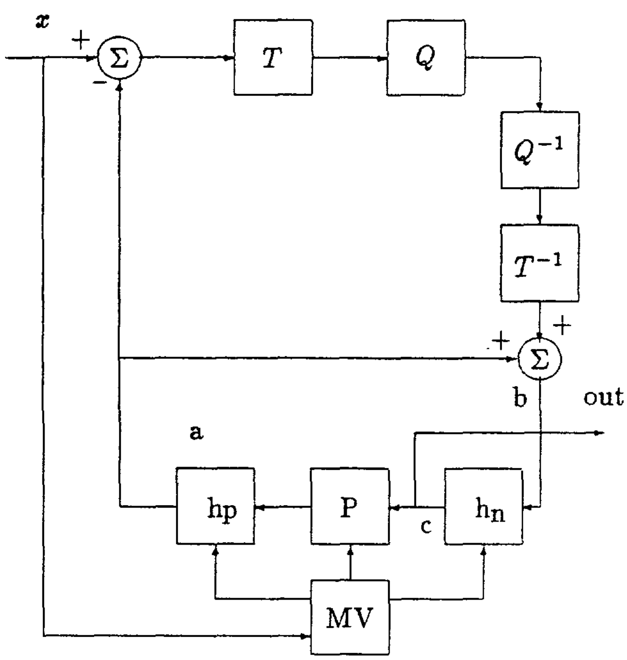

Figure 3: Structure of the source encoder

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In [11] the outline of the used configuration is given and the basics of the Hybrid DPCM/Transform codec are explained. In de configuration as depicted in figure 3 two filters are situated in the encoder on filter in front of the frame memory denoted with h_n and one filter after the frame memory denoted with h_p. Where the indices n and p stand for noise and prediction. Which filter should be used to achieve the best picture quality.

5 In-Codec processing filters

5.1 Filtering of the Transform-Coefficients

In nearly all coding strategies, insignificant coefficients are deleted. As depicted in figure 4, this process can be modeled by filtering using a filter $\mathcal{H}$ which operates in the coefficient domain [14] [12] [13]. The filter operator $\mathcal{H}[.]$ multiplies every coefficient of the input block by a real number [10]. As can be shown, an equivalent operator $h[.]$ exists which can be applied in the spatial domain to a block of pels and which provides, after transformation the same result;

$$\mathcal{H}[BD] = \mathcal{T}\{h[bd(s,t)]\} \quad (1)$$

Where bd(s,t) is the block difference in the pixel domain, $\mathcal{T}$ the operator which performs the transform and $\mathcal{H}$[BD] the transformed filtered block: In appendix E some results are given of measuring the average values of the transform coefficients. For the sequences generated by the US we observe that high frequency components disturb the efficiency of the adaptation rules [15].

In figure 4 the reconstructed block $\tilde{x}$ is computed: obviously, $\tilde{x}$ is composed of $h[x]$ which is the input signal, degraded by filtering the transform coefficients, and n which is the quantization noise, and $\hat{x}$ - h[$\hat{x}$] representing an additional distortion of the block. Using the filter h in the reconstruction loop, as shown in figure 5 this distortion can be compensated, and the reconstructed block becomes:

$$\tilde{x} = h[x] + n \quad (2)$$

Note that the ideal case is $x = \tilde{x}$, which can be obtained without filtering and quantizing ($h = 1, n = 0$). Obviously, using the structure in

figure 5, the degradations within each block is a tradeoff between filtering effects (some sort of un sharpness) and quantizing distortion.
With simulation results it was proven that pure quantization of the blocks result in unacceptable artifacts. Moderate filtering of the blocks yields a "smoother" picture.

5.2 Space invariant filter

To reduce the noise circulating in the loop a filter after the frame memory is adopted. The transfer function of the filter H_p with the filter coefficients [1 2 1] is:

$$\begin{aligned} H_p(\omega_x, \omega_y) &= \sum_{n_x}\sum_{n_y} h_{[121]}(n_x. n_y) \exp(-j\omega_x n_x - j\omega_y n_y) \\ &= \frac{1}{4}(1+\cos(\omega_x))(1+\cos(\omega_y)) \quad (3) \end{aligned}$$

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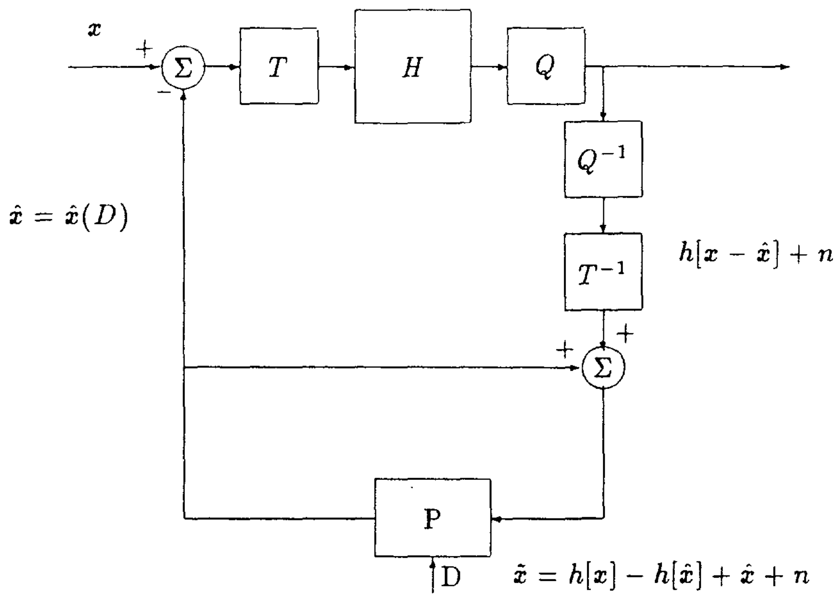

Figure 4: Filtering without feedback filtering

where $h_{[121]}(n_x, n_y)$ denotes the impuls response of the h_p filter. The 1-D transfer function is depicted in figure 6

The filter is controlled with the displacement vector $\vec{D}$ if the displacement vector is non-zero than the block dbd(q,t) is to be filtered. The 2-D representation of the filter is given with:

$$\begin{bmatrix} \frac{1}{16} & \frac{1}{8} & \frac{1}{16} \\ \frac{1}{8} & \frac{1}{4} & \frac{1}{8} \\ \frac{1}{16} & \frac{1}{8} & \frac{1}{16} \end{bmatrix} = \begin{bmatrix} \frac{1}{4} & \frac{1}{2} & \frac{1}{4} \end{bmatrix} \otimes \begin{bmatrix} \frac{1}{4} \\ \frac{1}{2} \\ \frac{1}{4} \end{bmatrix}$$

The 2-D filter consists of a Kronecker product of two 1-D filters. It is known that the filter as shown in figure 6 is too strong and the results at higher bitrates become therefor too blurred. An adaptive filter which first determines an dominant direction after which a set of coefficients are chosen did not give the expected gain. In appendix A the results are given, an average gave 0.2 dB improvement. But this method will increase the hardware complexity. An explanation for this results is the extra side information necessary to signal the decoder which filter is used.

5.3 Space variant filter

In previous section two space invariant filters were discussed, the coefficients of space variant filters depend on the local statistics of the signal to be filtered. Heuristically one could explain that this type of filter is more suited for the non-stationary image signals than the space variant ones. BUT the filters need to be implemented therefor care has to be taken construction number crunching monster. In [3] [4] and [5] an explanation of the algorithm for noise reduction filter h_n was given.

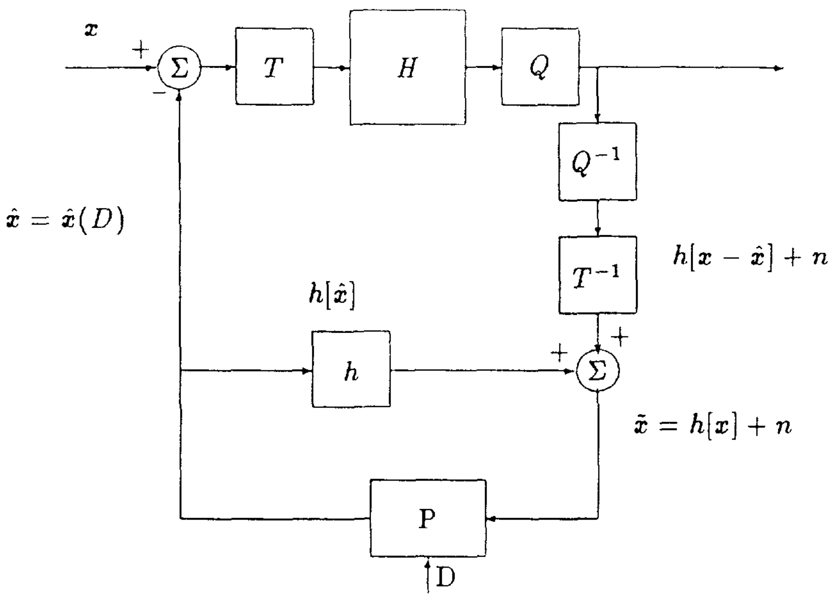

Figure 5: Filtering in reconstructed loop

5.3.1 The algorithm of the noise reduction filter

The two dimensional filter is constructed by a concatenation of two one dimensional filters. The filters have an edge preserving property.

Let $s(i,j)$ be the image[4] of size $dx \times dy$:

$$y(i,j) = s(i,j) + n(i,j) \tag{4}$$

[4] with additive noise $n(i,j)$ where the average is 0 and un-correlated with the source signal

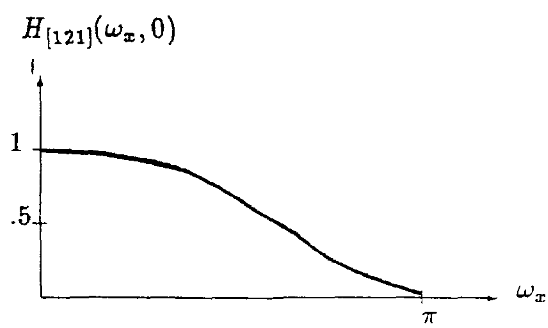

Figure 6: 1-D Transfer function of [1 2 1] filter

The prediction denoted $\hat{s}(i,j)$ of $s(i,j)$ can be expressed with MSE as distortion measure by:

$$\hat{s}(i,j) = \mu_s(i,j) + \frac{\sigma_s^2(i,j)}{\sigma_s^2(i,j) + \sigma_n^2(i,j)} \cdot \{y(i,j) - \mu_y(i,j)\} \tag{5}$$

Denote $\mu_s(i,j)$ the estimate of the average of the noise free signal, $\mu_y(i,j)$ the estimate of the noisy signal, $\sigma_s^2(i,j)$ variance of the signal and $\sigma_n^2(i,j)$ the variance of the noise.
The estimate for the expectation $\mu_y(i,j)$ and the variance $\sigma_y^2(i,j)$ of y in an certain position (i,j) can be derived with the local variance and local average in a so called observation area. This observation area is defined around the position (i,j) for which the statistics need to be calculated.

Let the window for the observation area be a of size $2n+1$. Now the 1-dimensional filter [5] can be expressed with [6] [7]:

$$\hat{s}_1(i,j) = \hat{\mu}_s(i,j) + \frac{\hat{\sigma}_s^2(i,j)}{\hat{\sigma}_s^2(i,j) + \sigma_n^2(i,j)} \cdot \{y(i,j) - \hat{\mu}_y(i,j)\} \tag{6}$$

with:

$$\hat{\mu}_s(i,j) = \hat{\mu}_y(i,j) = \frac{1}{2n+1} \sum_{k=i-n}^{i+n} y(k,j) \tag{7}$$

Suppose that signal and noise are un correlated the expression can be formulated with:

$$\hat{\sigma}_s^2(i,j) = \left\{ \begin{array}{ll} \hat{\sigma}_y^2(i,j) - \sigma_n^2(i,j) & \text{if } \hat{\sigma}_y^2(i,j) > \sigma_n^2(i,j) \\ 0 & \text{else} \end{array} \right\} \tag{8}$$

$$\hat{\sigma}_y^2(i,j) = \frac{1}{2n} \sum_{k=i-n}^{i+n} \{y(k,j) - \hat{\mu}_y(i,j)\}^2 \tag{9}$$

The resulting noise filter consists of a concatenation of N one dimensional sub-filters.

$$\hat{s}(i,j) = [T_2[T_1[y(i,j)]]] \tag{10}$$

5.3.2 Hardware considerations

Each filter can have a different spatial orientation. Two spatial orientations will be considered. The sub-filter orientations are depicted in figure 7.

In this figure the spatial orientation is called a window. A window consists of five pixels on a line. The noise filter operates over the block boundaries of an 8×8 pixel input block.

Denote the image $I(i,j)$ where i,j indices giving the size of the image. Suppose the input signal is disturbed with additive noise $n(i,j)$ with zero mean and un correlated

[5] suppose for horizontal direction first

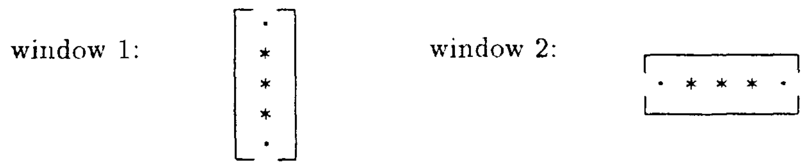

Figure 7: Used 1-Dimensional windows

with the input signal, the input signal can be expressed with:

$$y(i,j) = I(i,j) + n(i,j) \tag{11}$$

The filter length $L = 5$ and a 1-D approach can be used, eq. 11 can be writen as:

$$y(i) = I(i) + n(i) \tag{12}$$

An estimation $\hat{I}_3$ needs to be calculated for the actual signal I_3. Taking into account the number of orientations, the filtering is carried out in two steps; first horizontal after which the vertical filter is applied. The estimate $\hat{I}_{3,1}$ after applying the filter once can be expressed with:

$$\hat{I}_{3,1} = \overline{y} + \frac{\hat{\sigma}_I^2}{\hat{\sigma}_I^2 + \hat{\sigma}_n^2}.\{y_3 - \overline{y}\} \tag{13}$$

where $\overline{y}$ denotes the mean value in the window:

$$\overline{y} = \frac{1}{5}\sum_{i=1}^{5} y_i \tag{14}$$

and the window variance estimate becomes:

$$\hat{\sigma}_I^2 = \begin{cases} \sigma_y^2 - \hat{\sigma}_n^2 & \text{if } \sigma_y^2 > \hat{\sigma}_n^2 \\ 0 & \text{else} \end{cases} \tag{15}$$

where the variance for the observations:

$$\sigma_y^2 = \frac{1}{4}\sum_{i=1}^{5}\{y_i - \overline{y}\}^2 \tag{16}$$

and $\hat{\sigma}_n^2$ the estimated noise variance.
The values of the filter coefficients using $SNR = \frac{\hat{\sigma}_I^2}{\hat{\sigma}_n^2}$ can

calculated with:

$$\hat{s}_{3,1} = \bar{y} + \frac{SNR}{1 + SNR}[y_3 - \bar{y}] \tag{17}$$

Using the equation 17 the filter coefficients c_1 — c_5 could be derived

$$c_{1,2,4,5} = \frac{1}{5}[1 - \frac{SNR}{1 + SNR}] \tag{18}$$

$$c_3 = \frac{1}{5}[1 + 4\frac{SNR}{1 + SNR}] \tag{19}$$

unless:

$$\hat{s}_3 = c_1 y_1 + c_2 y_2 + c_3 y_3 + c_4 y_4 + c_5 y_5 \tag{20}$$

The estimation of the noise variance is obtained using an lookup table. The estimate of the noise variance depends on the quantizer stepsize g and the motion vector of the prediction of the block and is assumed to be constant in the block $\hat{b}(q,t)$.
The used values are given in table 1.

The output of the first filtering is input for the proceeding filtering, a new estimation of the noise variance is calculated and a scaling with a factor 0.75.

Rewriting 20 gives:

$$\hat{s}_3 = \alpha s_3 + (1 - \alpha)\bar{s} \tag{21}$$

where

$$\alpha = \frac{\hat{\sigma}_s^2}{\hat{\sigma}_s^2 + \hat{\sigma}_n^2} \tag{22}$$

Actually α is an expression how strong the filter has a lowpass character; $0 < \alpha \leq 1$. In figure 8 the transfer function of the noise reduction filter is given, also the h_p of the [1 2 1] is given.

The hardware complexity of the space variant filter is equivalent to the DCT.

6 Post codec processing filter

The post-codec processing filter is situated as depicted in figure 2 and figure 9.

The character of this filter is similar to the noise reduction filter, it should preserve the edges, and should suppress the noise caused by the coding procedure. The objective this filter should be reconstruction instead of concealment. In the experiments carried out the filter has a similar structure as described in section 5.

	in codec		post codec			
			no motion		*motion*	
g	$\sigma_n^2 lum$	$\sigma_n^2 chr$	$\sigma_n^2 lum$	$\sigma_n^2 chr$	$\sigma_n^2 lum$	$\sigma_n^2 chr$
4	0	0	6	4	11	7
6	3	1	7	4	12	8
8	7	2	8	5	13	8
10	10	3	9	6	14	9
12	13	4	10	6	15	9
14	17	5	11	7	16	10
16	20	6	12	8	17	11
18	23	7	13	8	18	11
20	27	8	14	9	19	12
22	30	9	15	9	20	13
24	33	10	16	10	21	13
26	37	11	17	11	22	14
28	40	12	18	11	23	14
30	43	13	19	12	24	15
32	47	14	20	13	25	16
34	50	15	21	13	26	16
36	53	16	22	14	27	17
38	57	17	23	14	28	18
40	60	18	24	15	29	18
42	63	19	25	16	30	19
44	67	20	26	16	31	19
46	70	21	27	17	32	20
48	73	22	28	18	33	21
50	77	23	29	18	34	22
52	80	24	30	19	35	23
54	83	25	31	19	36	23
56	87	26	32	20	37	23
58	90	27	33	21	38	24
60	93	28	34	22	39	24
62	97	29	35	23	40	25
64	100	30	36	23	41	26

Table 1: Lookup table for luminance and chrominance filter coefficients

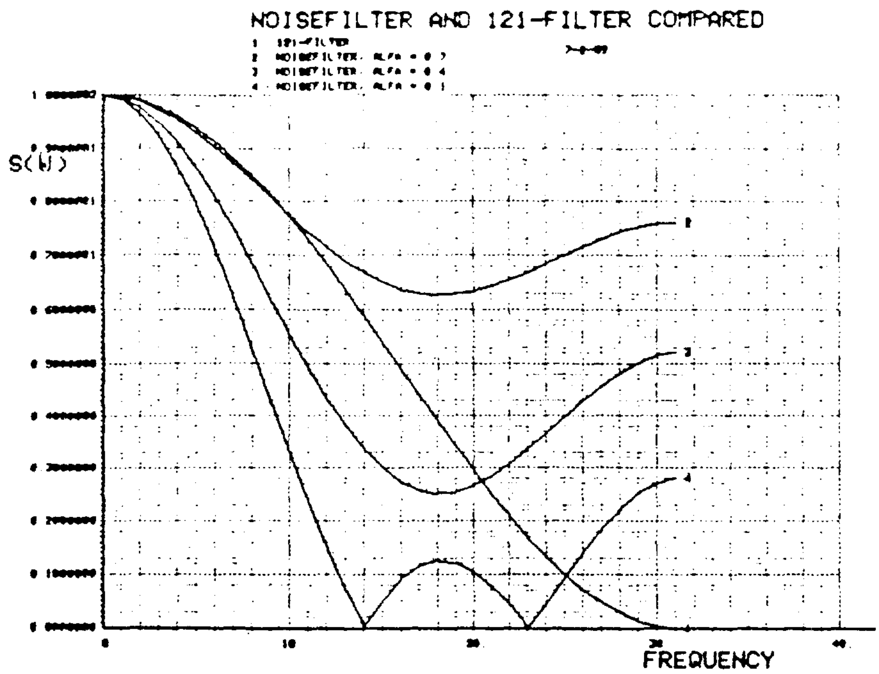

Figure 8: Example filter characteristics for various α

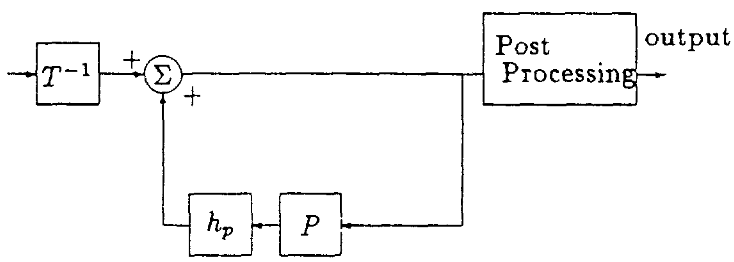

Figure 9: Position post codec processing in the decoder

7 Experiments

Comparisons of following methods were carried out:

Sequence	Comparison
Miss America Claire	RM7 versus RM7 - [1 2 1]+ adaptive noise reduction
Claire Miss America Swing Salesman	RM7 + post codecprocessing
Claire Miss America Swing	RM7 versus RM7 - [1 2 1] + noise filter
Claire Miss America Swing	RM7 versus RM7 + post processing

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A Results of an adaptive filter h_p versus the fixed [1 2 1] filter

Statistics Reference Model 7

PTT Research Neher Laboratories
Visual Communications Research
Date : 3 - 2 - 1989

Sequence : CLAIRE
Number of tracks for statistics : 78

Temporal resolution : 10 Hz

				NONE		ADAPTIVE FILTER	
	Item			15th pict.	mean seq	15th pict.	mean seq
1.	RMS for luminance			3.236	3.254	3.140	3.143
2.	SNR for luminance			37.932	37.894	38.194	38.198
	SNR for chrominance(U)			39.444	39.265	39.906	39.870
	SNR for chrominance(V)			42.687	42.687	42.973	43.071
3.	Mean value of step size			18.000	19.709	17.500	18.994
4.	Mean value of the number of non-zero coefficients			2.456	2.914	2.631	2.824
5.	Mean value of the number of zero-coefficients			5.703	5.741	4.808	5.093
6.	Block type of Macro	Fixed		240	272	250	268
		Coded MC		41	52	40	50
		Fixed MC		5	8	9	10
		Coded		110	64	97	68
		Intra		0	0	0	0
7.	Block type of Y	Fixed		1252	1249	1247	1242
		Coded MC		112	133	101	127
		Fixed MC		72	106	95	115
		Coded		148	96	141	100
		Intra		0	0	0	0
8.	Block type of UV	Fixed		679	661	679	660
		Coded MC		15	24	14	21
		Fixed MC		77	96	84	99
		Coded		21	11	15	11
		Intra		0	0	0	0
9.	Number of bits	Macro attributes		1075	834	1237	1095
		End of block		872	759	828	751
		Motion vectors		240	360	238	362
		Coefficients	Y	3614	3747	3456	3512
			U	138	158	115	141
			V	90	67	67	61
			Total	3842	3972	3638	3714
		Total		6029	5925	5941	5922

Bits for first frame	58218	58218
Number of forced to fixed mb's	0	0
Bits stuffed due to buffer underflow	0	0

Statistics Reference Model 7

PTT Research Neher Laboratories
Visual Communications Research
Date : 3 - 2 - 1989

Sequence : MISS AMERICA
Number of tracks for statistics : 49
Temporal resolution : 10 Hz

Item			NONE 15th pict.	NONE mean seq	ADAPTIVE FILTER 15th pict.	ADAPTIVE FILTER mean seq
1. RMS for luminance			3.054	3.163	3.034	3.178
2. SNR for luminance			38.433	38.135	38.490	38.091
SNR for chrominance(U)			39.029	38.730	39.011	38.695
SNR for chrominance(V)			39.979	39.380	40.137	39.410
3. Mean value of step size			16.667	18.823	16.667	19.388
4. Mean value of the number of non-zero coefficients			2.039	2.001	2.159	1.950
5. Mean value of the number of zero-coefficients			2.487	2.889	2.849	2.705
6. Block type of Macro	Fixed		219	203	227	208
	Coded MC		47	73	45	70
	Fixed MC		7	24	6	28
	Coded		123	96	118	90
	Intra		0	0	0	0
7. Block type of Y	Fixed		1251	1114	1282	1116
	Coded MC		86	128	90	120
	Fixed MC		130	260	114	272
	Coded		117	81	98	75
	Intra		0	0	0	0
8. Block type of UV	Fixed		609	533	626	539
	Coded MC		26	44	19	41
	Fixed MC		82	150	83	155
	Coded		75	65	64	57
	Intra		0	0	0	0
9. Number of bits	Macro attributes		1302	1304	1723	1686
	End of block		1004	1022	940	947
	Motion vectors		295	596	273	611
	Coefficients	Y	2581	2411	2483	2178
		U	315	275	260	229
		V	147	297	153	258
		Total	3043	2983	2896	2665
	Total		5644	5905	5832	5909

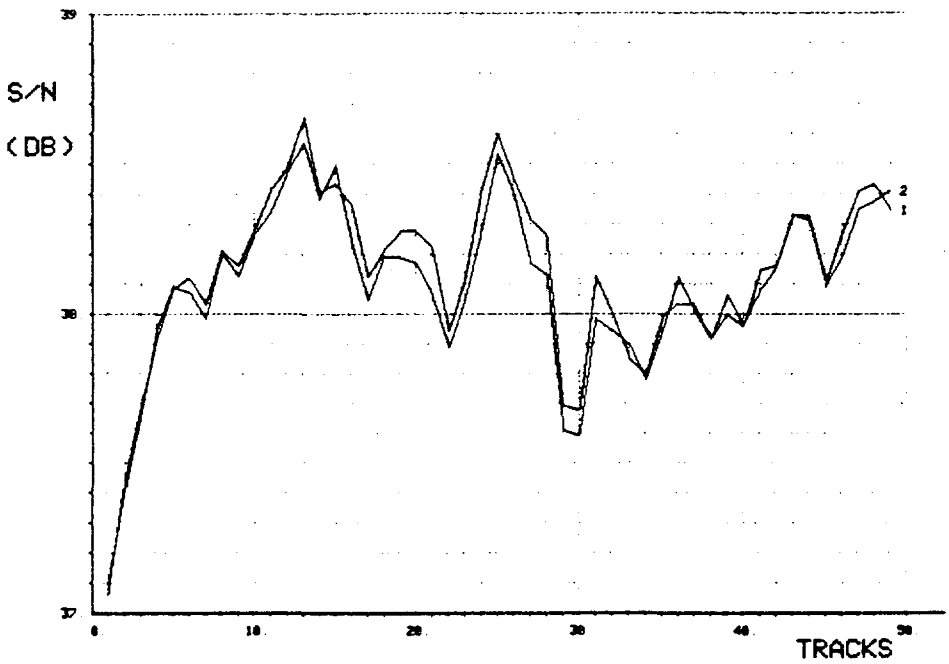
Bits for first frame	50479	50479
Number of forced to fixed mb's	0	0
Bits stuffed due to buffer underflow	0	0

236

MISS AMERICA

1 · RMD
2 RMD - 121 + ADAPTIVE FILTER

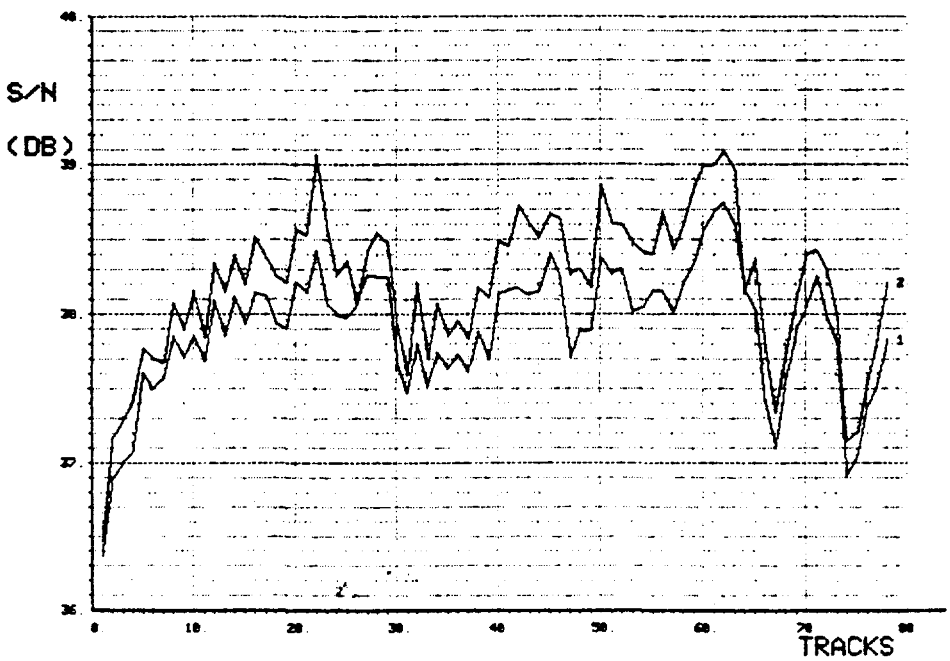
3-2-89



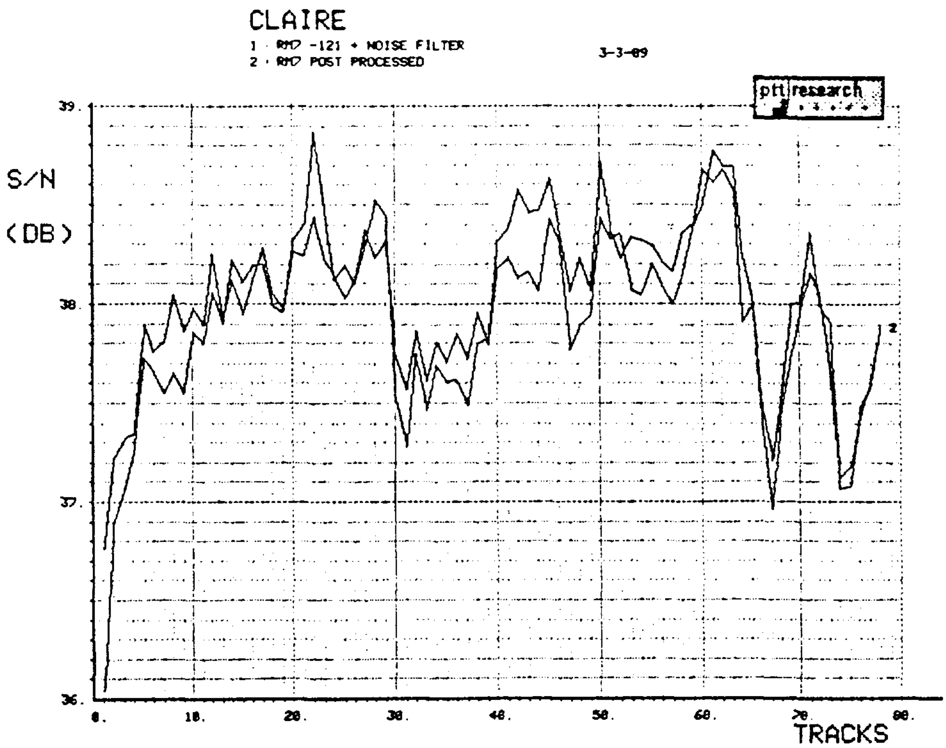
CLAIRE

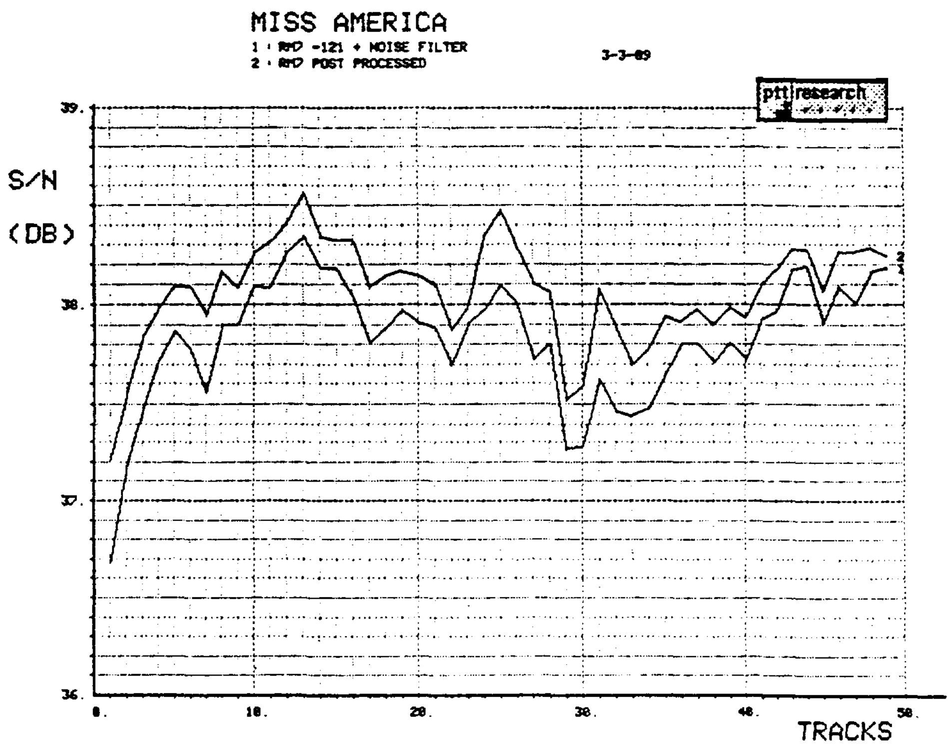
1 · RMD
2 · RMD - 121 + ADAPTIVE FILTER

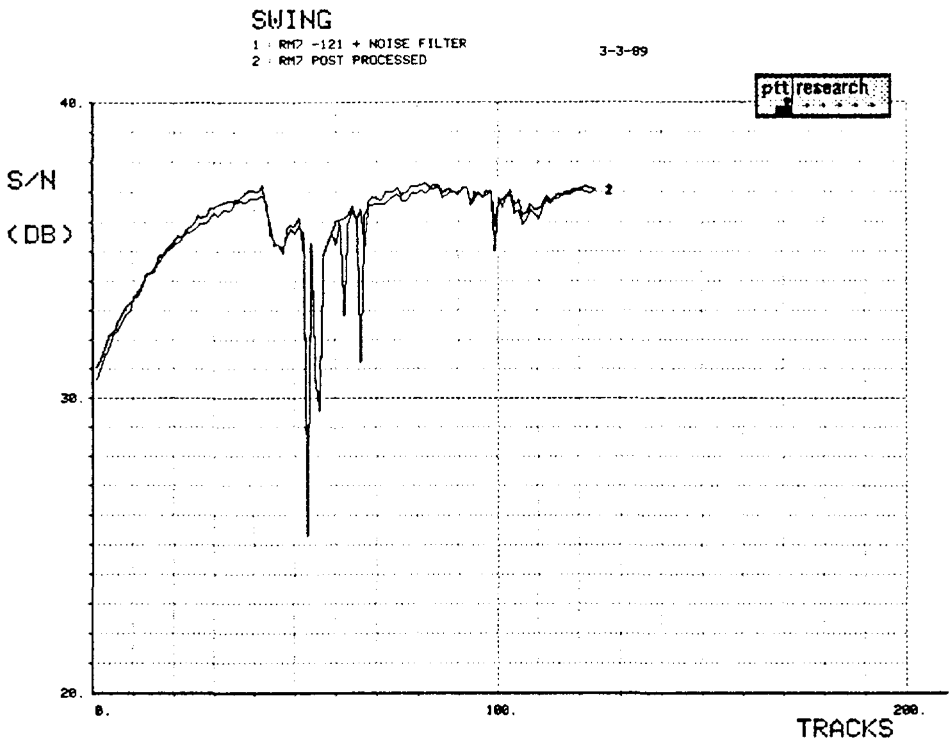
3-2-89



B Results of the noise reduction filter h_n versus RM7+ h_{post}






SWING
1 : RM7 -121 + NOISE FILTER
2 : RM7 POST PROCESSED
3-3-89
ptt research
S/N
(DB)
40.
30.
20.
0.
100.
200.
TRACKS
2

C Results of RM7 versus RM7 and post processing

Statistics Reference Model 7

PTT Research Neher Laboratories
Visual Communications Research
Date : 3 - 3 - 1989

Sequence : Claire
Number of tracks for statistics : 78
Temporal resolution : 10 Hz

	rm7		post processed	
Item	15th pict.	mean seq	15th pict.	mean seq
1. RMS for luminance	3.236	3.254	3.174	3.224
2. SNR for luminance	37.932	37.894	38.099	37.971
SNR for chrominance(U)	39.444	39.265	39.515	39.249
SNR for chrominance(V)	42.687	42.687	42.806	42.659

Sequence : Miss America
Number of tracks for statistics : 49
Temporal resolution : 10 Hz

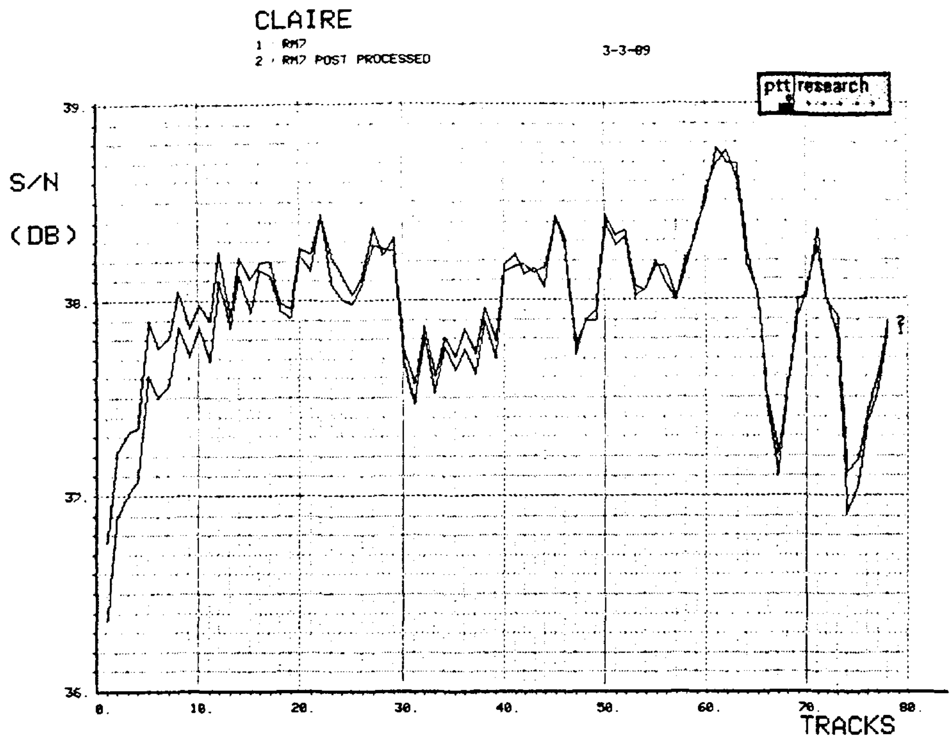
	rm7		post processed	
Item	15th pict.	mean seq	15th pict.	mean seq
1. RMS for luminance	3.054	3.163	3.097	3.190
2. SNR for luminance	38.433	38.135	38.311	38.059
SNR for chrominance(U)	39.029	38.730	38.988	38.753
SNR for chrominance(V)	39.979	39.380	40.160	39.544

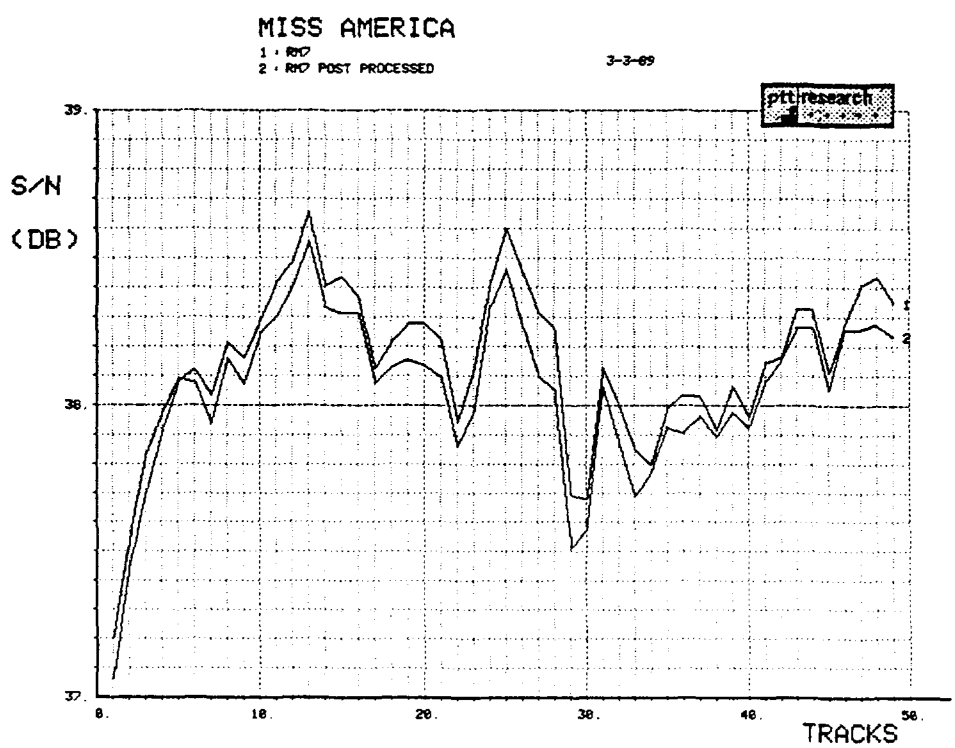
Sequence : Swing
Number of tracks for statistics : 124
Temporal resolution : 10 Hz

	rm7		post processed	
Item	15th pict.	mean seq	15th pict.	mean seq
1. RMS for luminance	5.124	4.526	4.842	4.307
2. SNR for luminance	33.938	35.248	34.431	35.685
SNR for chrominance(U)	35.673	38.064	35.956	38.140
SNR for chrominance(V)	36.467	38.807	36.676	38.719

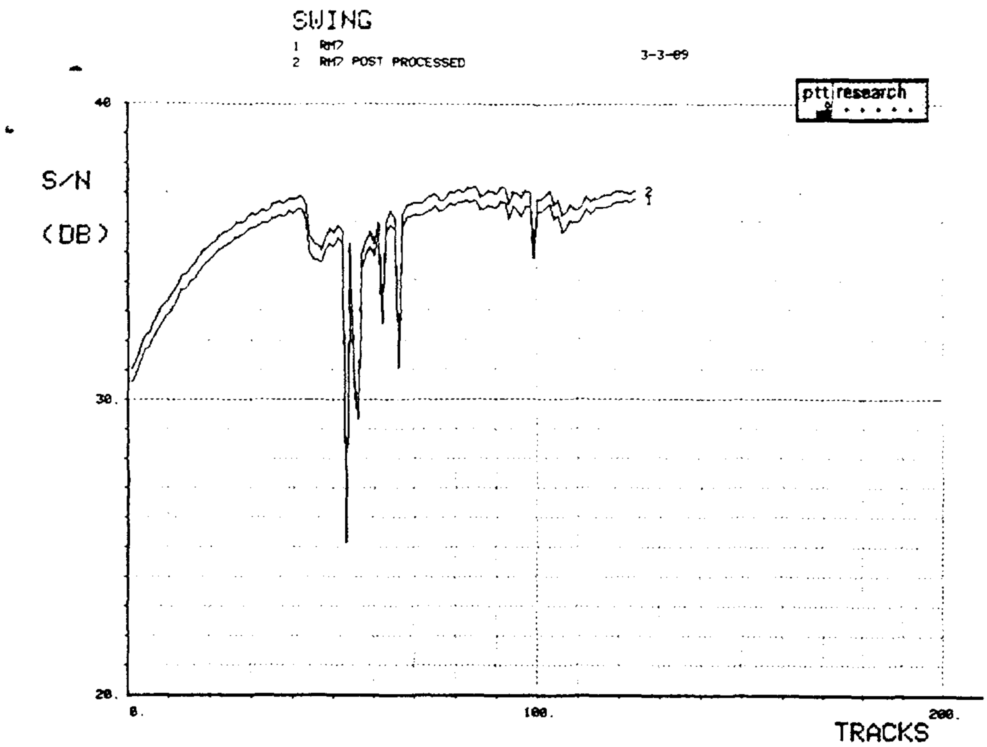
Sequence : Salesman
Number of tracks for statistics : 74
Temporal resolution : 10 Hz

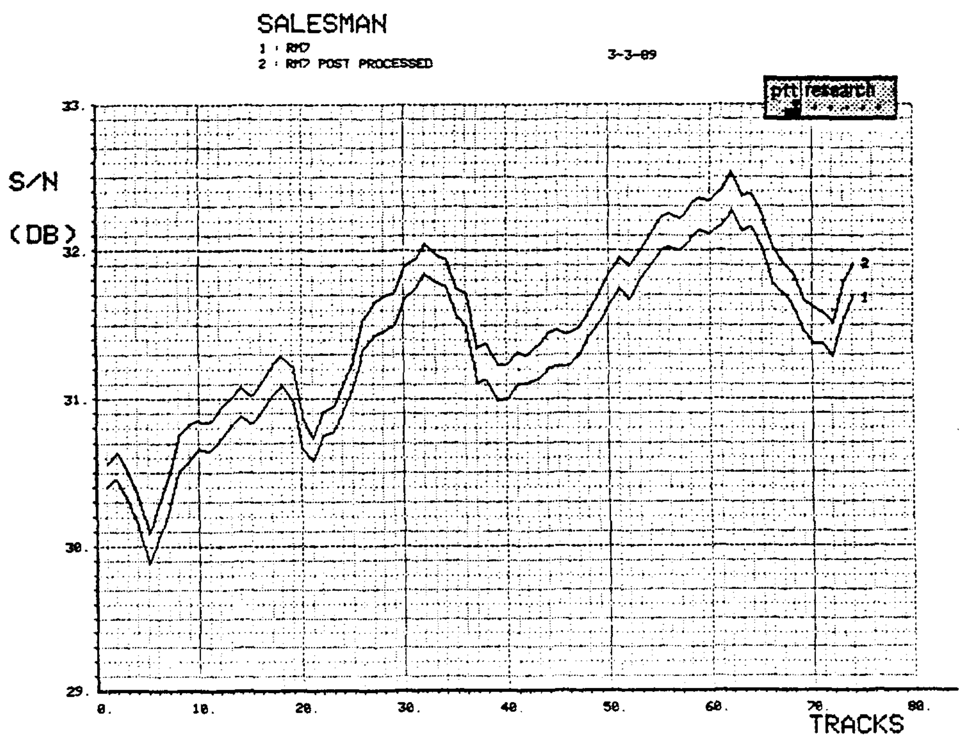
	rm7		post processed	
Item	15th pict.	mean seq	15th pict.	mean seq
1. RMS for luminance	7.331	6.978	7.169	6.810
2. SNR for luminance	30.828	31.275	31.022	31.487
SNR for chrominance(U)	38.220	38.627	38.848	39.230
SNR for chrominance(V)	38.875	39.291	39.465	39.937


CLAIRE
1 : RM7
2 : RM7 POST PROCESSED
3-3-89
ptt research
S/N
(DB)
39.
38.
37.
36.
0.
10.
20.
30.
40.
50.
60.
70.
80.
TRACKS


MISS AMERICA
1 : RM7
2 : RM7 POST PROCESSED
3-3-89
ptt research
S/N
(DB)
39.
38.
37.
0.
10.
20.
30.
40.
50.
TRACKS

247


SWING
1 RM7
2 RM7 POST PROCESSED
3-3-89
ptt research
S/N
(DB)
40
30.
20.
0.
100.
200.
TRACKS


SALESMAN
1 : RM7
2 : RM7 POST PROCESSED
3-3-89
ptt research
S/N
(DB)
33.
32.
31.
30.
29.
0.
10.
20.
30.
40.
50.
60.
70.
80.
TRACKS

282

D Results of RM7 versus RM7 - [1 2 1] +noise filter

Statistics Reference Model 7

PTT Research Neher Laboratories
Visual Communications Research
Date : 3 - 3 - 1989

Sequence : Claire
Number of tracks for statistics : 78

Temporal resolution : 10 Hz

	Item			RM7		RM7 -121+Noise Filter	
				15th pict.	mean seq	15th pict.	mean seq
1.	RMS for luminance			3.236	3.254	3.233	3.233
2.	SNR for luminance			37.932	37.894	37.939	37.953
	SNR for chrominance(U)			39.444	39.265	39.465	39.327
	SNR for chrominance(V)			42.687	42.687	42.448	42.184
3.	Mean value of step size			18.000	19.709	17.667	18.996
4.	Mean value of the number of non-zero coefficients			2.456	2.914	2.573	2.822
5.	Mean value of the number of zero-coefficients			5.703	5.741	4.958	5.005
6.	Block type of Macro	Fixed		240	272	259	267
		Coded MC		41	52	35	50
		Fixed MC		5	8	9	9
		Coded		110	64	92	70
		Intra		0	0	1	0
7.	Block type of Y	Fixed		1252	1249	1266	1241
		Coded MC		112	133	98	126
		Fixed MC		72	106	78	110
		Coded		148	96	138	106
		Intra		0	0	4	0
8.	Block type of UV	Fixed		679	661	685	658
		Coded MC		15	24	28	26
		Fixed MC		77	96	60	92
		Coded		21	11	17	15
		Intra		0	0	2	0
9.	Number of bits	Macro attributes		1075	834	989	873
		End of block		872	759	816	789
		Motion vectors		240	360	230	361
		Coefficients	Y	3614	3747	3520	3634
			U	138	158	165	172
			V	90	67	148	92
			Total	3842	3972	3833	3898
		Total		6029	5925	5868	5921

Bits for first frame	58218	58218
Number of forced to fixed mb's	0	0
Bits stuffed due to buffer underflow	0	0

Statistics Reference Model 7

PTT Research Neher Laboratories
Visual Communications Research
Date : 3 - 3 - 1989

Sequence : Miss
Number of tracks for statistics : 49

Temporal resolution : 10 Hz

Item			RM7 15th pict.	RM7 mean seq	RM7 -121+Noise Filter 15th pict.	RM7 -121+Noise Filter mean seq
1. RMS for luminance			3.054	3.163	3.149	3.281
2. SNR for luminance			38.433	38.135	38.167	37.816
SNR for chrominance(U)			39.029	38.730	38.776	38.586
SNR for chrominance(V)			39.979	39.380	39.616	38.896
3. Mean value of step size			16.667	18.823	17.167	19.054
4. Mean value of the number of non-zero coefficients			2.039	2.001	2.154	1.934
5. Mean value of the number of zero-coefficients			2.487	2.889	2.849	2.804
6. Block type of Macro	Fixed		219	203	237	204
	Coded MC		47	73	45	74
	Fixed MC		7	24	8	21
	Coded		123	96	106	97
	Intra		0	0	0	0
7. Block type of Y	Fixed		1251	1114	1277	1119
	Coded MC		86	128	100	134
	Fixed MC		130	260	112	246
	Coded		117	81	95	84
	Intra		0	0	0	0
8. Block type of UV	Fixed		609	533	608	537
	Coded MC		26	44	25	45
	Fixed MC		82	150	81	145
	Coded		75	65	78	65
	Intra		0	0	0	0
9. Number of bits	Macro attributes		1302	1304	1218	1304
	End of block		1004	1022	988	1045
	Motion vectors		295	596	315	609
	Coefficients	Y	2581	2411	2723	2386
		U	315	275	272	272
		V	147	297	160	288
		Total	3043	2983	3155	2946
	Total		5644	5905	5676	5904

Bits for first frame	50479	50479
Number of forced to fixed mb's	0	0
Bits stuffed due to buffer underflow	0	0

Statistics Reference Model 7

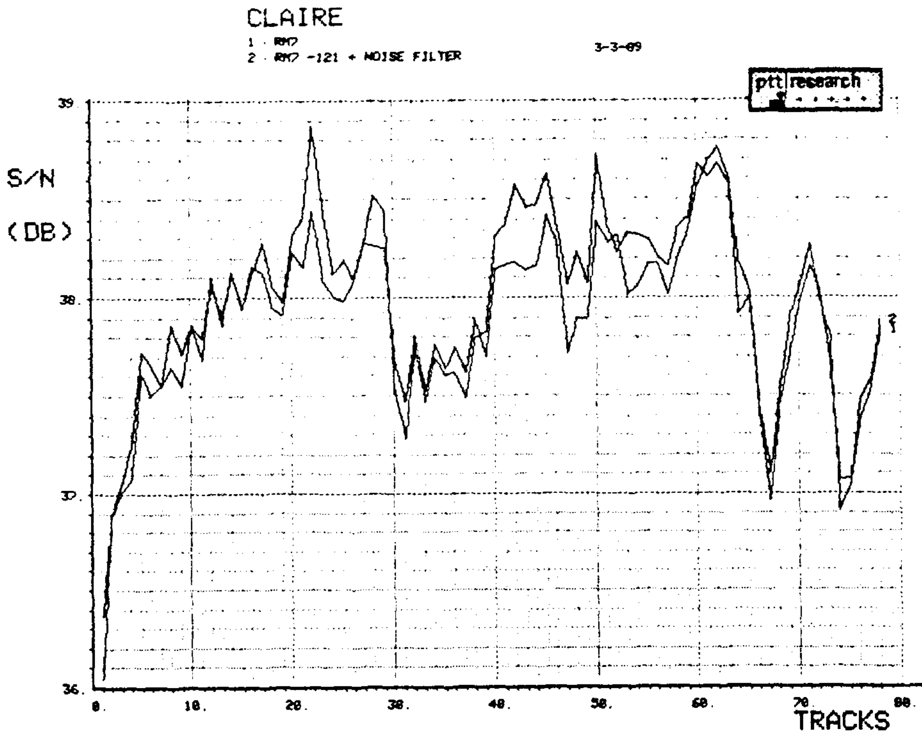
PTT Research Neher Laboratories
Visual Communications Research
Date : 3 - 3 - 1989

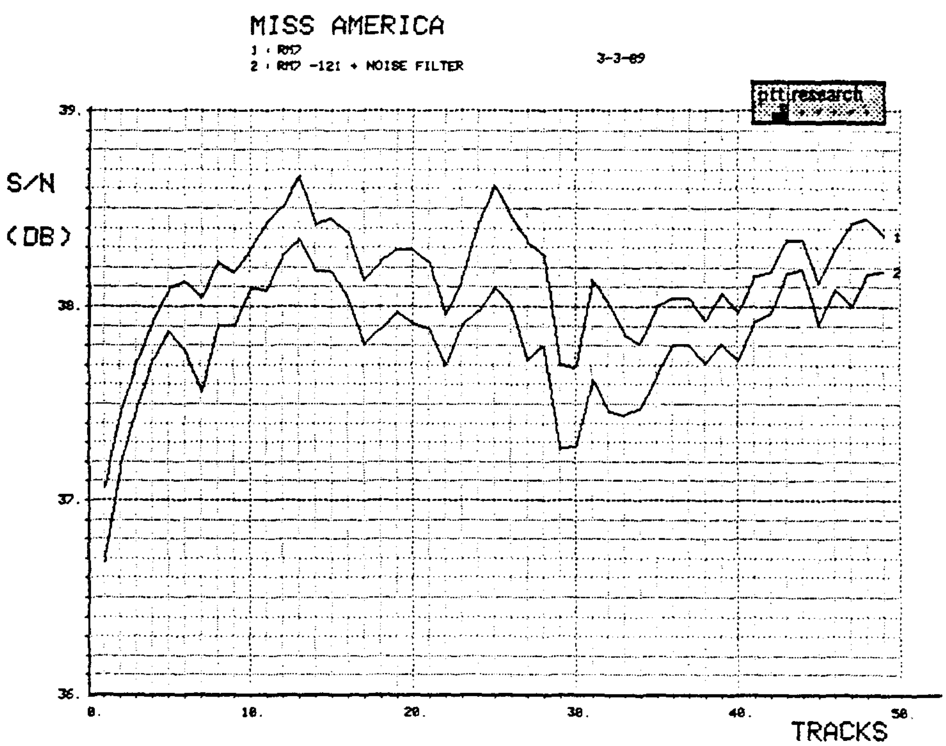
Sequence : Swing
Number of tracks for statistics : 124

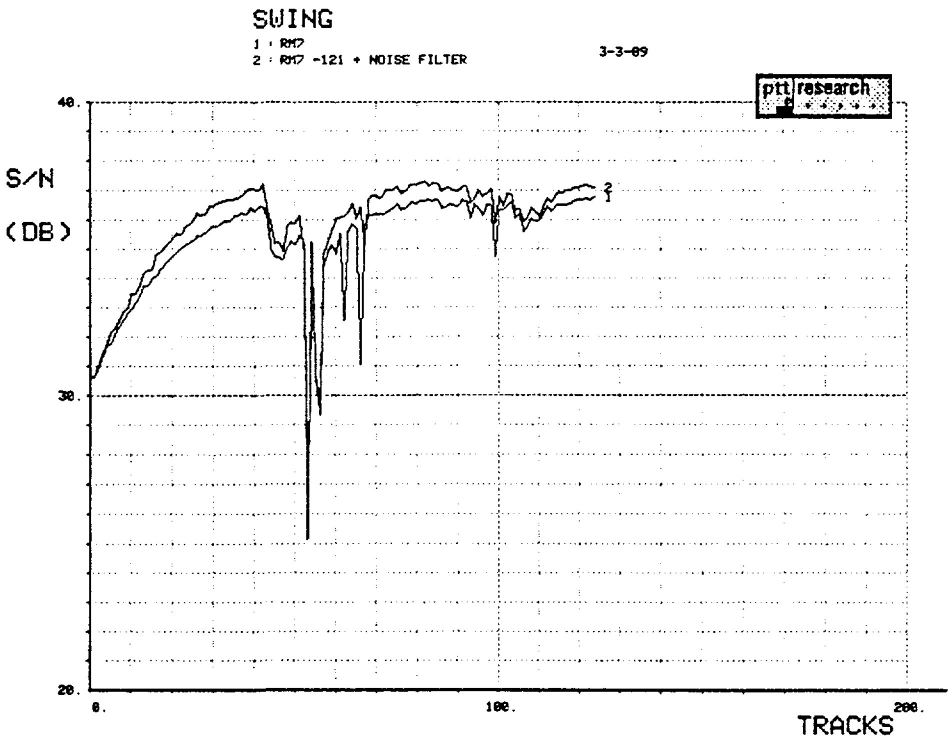
Temporal resolution : 10 Hz

Item			RM7 15th pict.	RM7 mean seq	RM7 -121+Noise Filter 15th pict.	RM7 -121+Noise Filter mean seq
1. RMS for luminance			5.124	4.526	4.925	4.243
2. SNR for luminance			33.938	35.248	34.283	35.808
SNR for chrominance(U)			35.673	38.064	35.779	38.479
SNR for chrominance(V)			36.467	38.807	36.631	39.119
3. Mean value of step size			18.833	21.723	34.833	22.903
4. Mean value of the number of non-zero coefficients			2.190	2.971	2.222	3.390
5. Mean value of the number of zero-coefficients			17.074	20.623	15.533	20.521
6. Block type of Macro	Fixed		285	303	374	309
	Coded MC		0	5	0	4
	Fixed MC		0	2	2	2
	Coded		111	86	20	80
	Intra		0	1	0	1
7. Block type of Y	Fixed		1390	1394	1540	1403
	Coded MC		0	12	0	10
	Fixed MC		0	15	8	13
	Coded		194	160	36	153
	Intra		0	4	0	4
8. Block type of UV	Fixed		717	745	779	746
	Coded MC		0	5	0	5
	Fixed MC		0	8	4	7
	Coded		75	31	9	32
	Intra		0	2	0	2
9. Number of bits	Macro attributes		840	691	175	645
	End of block		844	625	152	591
	Motion vectors		0	61	16	55
	Coefficients	Y	3465	3853	631	3901
		U	569	418	41	430
		V	267	264	40	292
		Total	4301	4535	712	4623
	Total		5985	5912	1055	5914

Bits for first frame	105408	105408
Number of forced to fixed mb's	245	396
Bits stuffed due to buffer underflow	0	0


CLAIRE
1 : RM7
2 : RM7 -121 + NOISE FILTER
3-3-89
ptt research
S/N
(DB)
39.
38.
37.
36.
0.
10.
20.
30.
40.
50.
60.
70.
80.
TRACKS
2
1


MISS AMERICA
1 : RM7
2 : RM7 -121 + NOISE FILTER
3-3-89
ptt research
S/N
(DB)
39.
38.
37.
36.
0.
10.
20.
30.
40.
50.
TRACKS
1
2



SWING
1 : RM7
2 : RM7 -121 + NOISE FILTER
3-3-89
ptt research
40.
30.
20.
S/N
(DB)
0.
100.
200.
TRACKS
2
1

247

E Average value of coefficients of subblocks

The DCT coefficients of the unfiltered prediction blocks of the hybrid coder (RM7) are scanned using a zig-zag scanning. The average value of these coefficients are depicted in figure 10.

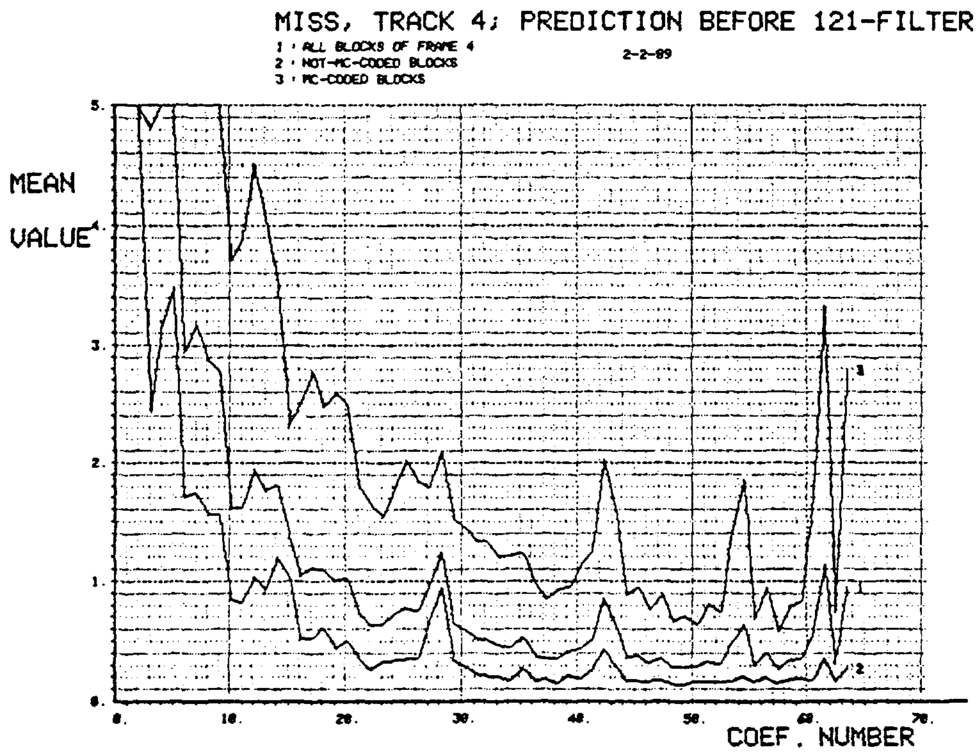


Figure 10: Average Value of the DCT Coefficients Subblocks fourth track of the Miss America sequence before the prediction filter