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플라즈마 디스플레이 패널의 플리커 발생에 대한 예측

(Prediction of Flicker for PDP Devices)

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요 약

Flicker 란 인체가 느끼는 빛과 색상의 변화이다. 이런 변화는 일반적으로 일정하지 않으며 시간이 변함에 따라 변한다. 이는 눈의 피로와 두통을 일으키는 원인이 된다. Flicker 현상은 PDP를 포함하는 많은 display에 존재하며 특히 50Hz로 동작하는 PDP의 경우에 심각한 문제를 발생시킨다. Flicker를 감소하기 위해서 많은 연구가 진행되었지만 Flicker에 대한 객관적인 정의를 내리기 어렵기 때문에 flicker에 대한 객관적인 측정방법이 필요하며 이는 display 화질 향상에 큰 도움이 될 것이다. 본 논문에서는 luminance flicker를 측정하는 수학적인 모델을 제안한다. 이 모델을 통하여 flicker가 생길 확률에 대한 정량적인 결과를 보여준다. vision 분야의 최근의 연구와 고전적인 연구결과를 적용하여 모델을 구축하였으며 인체의 눈의 임시 민감도에 초점을 맞추었다. 본 연구를 통하여 flicker-free한 PDP 개발을 위한 실제적인 툴을 만들 수 있을 것이다.

Abstract

Flicker is the "*variation in brightness or hue perceived upon stimulation by intermittent or temporally non uniform light.*"[7].This phenomenon is known as the cause of eye strain and headaches. Many researchers are dedicated to reducing this phenomenon. The flicker phenomenon also exists in PDP as some other display types, and is a critical problem in 50 Hz PDP. However, it is difficult to define flicker by more than one subjective judgment. So, an objective measurement of flicker is necessary and convenient for research on displays. In this paper, a computational prediction model is proposed, which is used to predict luminance flicker (not chromatic flicker) by giving a quantitative output that describes the probability of occurrence of flicker. Through this work, we expected to provide a practical tool for flicker-free design in PDP.

Keywords : PDP, Flicker, Prediction, Human Vision

I. INTRODUCTION

Plasma Display Panel (PDP) is now considered as one of the most suitable devices for large area applications due to their large display size with very thin depth, high resolution, and high picture quality. Although the picture quality of PDP is improving, there are still some limitations, such as MPD (Motion Picture Distortion), peak-luminance, load effect, and flicker, which seriously degrade the image quality of PDP. In this paper, we focus on the flicker phenomenon.

Many researchers are dedicated to reducing this phenomenon. However, it is difficult to define flicker by more than one subjective judgment. So, an objective measurement of flicker is necessary and convenient for research on displays. In this paper, a computational prediction model is proposed, which is used to predict luminance flicker (not chromatic flicker) by giving a quantitative output that describes

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the probability of the occurrence of flicker.

This predictor model is outlined in Section II. In this section, firstly two characteristics of human vision system are introduced that are the early research results on flicker on which the predictor is based. They are Contrast Sensitivity Function and Probability Summation over Time. After that, the detailed algorithm of the predictor will be presented. To estimate the performance of the predictor, two experiments and simulations were carried out and the results were recorded in Section III. In the last section, the performance and limitations of the predictor will be summarized. Also some flicker-free design methods will be suggested in this section.

II. PREDICTOR OF FLICKER

As mentioned in the introduction, recently many people are making efforts to reduce the flicker phenomena in PDP. Usually, it is wondered whether the flicker arises. Intuitively, practical observation of PDP is the most straightforward method. However, it takes much time on experiments and it is difficult to define the flicker by more than one subjective judgment. Under the same conditions, some people might detect flicker, while some people may not. So, it is necessary and convenient to predict flicker by a predictor which simulates the characteristics of human visual perception.

Many mathematical structures or models were established to explain the various characteristics of human vision. In the present work, a computational prediction model is given concrete form. The specific computational model used in this work is mainly based on the work of Rashbass (1970[9], 1976[10]) and Watson(1977[21], 1979[20], 1986[19]). The block diagram of this predictor is shown in Fig. 1. There are three components in it, which are eye-like linear filter, temporal summation and probability estimation. These three components are respectively corresponding to various characteristics of human visual perception.

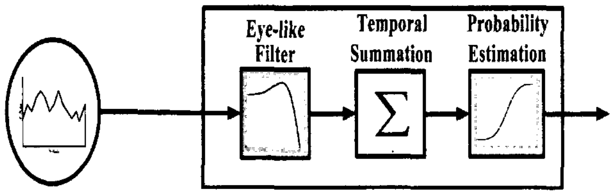


그림 1. 예측기의 블록도

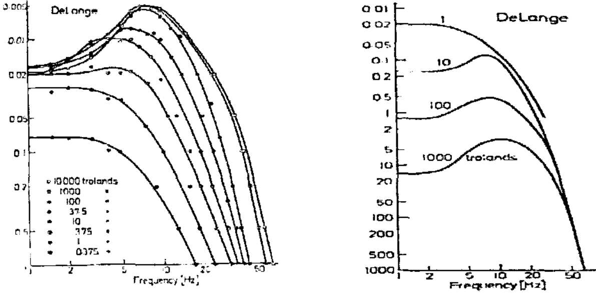
Fig. 1. Block Diagram of Predictor.

From sub-section A to C, the various functions and implementations of these components will be respectively present in detail.

A. Contrast Sensitivity Function

1) Critical Flicker Frequency: The effort to understand the sensitivity of the eye to rapid fluctuations has generated a large amount of research, a great deal of it concerned with the Critical Flicker Frequency (CFF). CFF is the transition point of an intermittent light source where the flickering light ceases and appears as a continuous light. There are a multitude of factors that determine our perception of flicker that include the intensity, size of the test stimulus, and so on. By increasing the frequency of alternation, a light could be made to pass from "flicker" (perceptible variation in intensity) to "fusion" (steady appearance of a fluctuating light). That means CFF marked the border between flicker and fusion.

de Lang (1958[2]) was the first to measure temporal CSF (Contrast Sensitivity Function) systematically. Fig. 2(a) shows the example of de Lange's measurements, for various levels of illumination. At



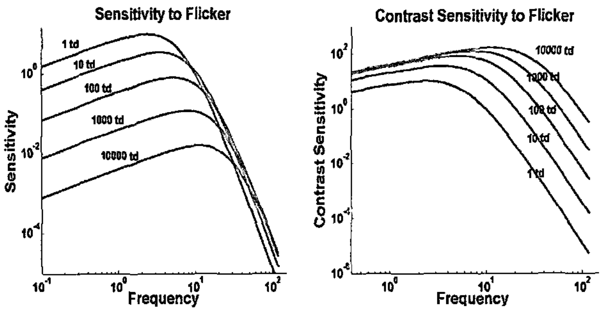
(a) Contrast Sensitivity (b) Sensitivity

그림 2. de Lange의 실험 결과

Fig. 2. de Lange's Experiment Results.

high illumination levels, sensitivity was maximal at about 8Hz, and fell steadily with higher or lower temporal frequencies. Note that the frequency yielding a contrast threshold of one (maximum modulation) is an estimate of the CFF under those conditions. At lower levels of illumination, the curves shift downwards (implying lower absolute sensitivity) and to the left (implying lower temporal resolution, or CFF).

2) Light adaptation: Light adaptation is the term used for the process that changes the sensitivity of the visual system to different light levels. In natural conditions the ambient light level can vary by a factor of about 10 log units. The biological hardware of the system does not possess such a large dynamic range. Therefore, it is necessary that the sensitivity of the system is continually adjusted in order to allow efficient transfer of information about the visual input to the brain. Without such an adjustment, small signals will drown in neuronal noise, and large signals will saturate the system. The purpose of light adaptation is thus to keep the response to rapidly varying visual input within the dynamic range of the neurons in the retina. This means the flicker sensitivity is not only dependent on the temporal frequency but also dependent on the mean luminance. So, the variation function of contrast flicker sensitivity against temporal frequency and mean luminance is wanted. In Graham's paper[3], the background-onset effect was introduced. In order to explain this effect, some dynamic light adaptation models were developed. However, in this work, a Static Light Adaptation method was employed. That means this prediction model can not dynamically self-adjust to the various levels of light. Furthermore, it is assumed that no background-onset effect takes place. In our system, the object of our research are still images, the dynamic light adaptation models is not necessary. Actually, if the image sequence which has big changes of average lighting were used, we can not distinguish if the flicker is caused by display or by the original video.



(a)Contrast Sensitivity (b) Sensitivity

그림 3. Rovamo 모델
Fig. 3. Rovamo Model

3) Computational Contrast Sensitivity Function: In the pre-sections, the sensitivity function was given the form of $H(f)$ (f refers to the temporal frequency) in several discrete retinal illuminations, not in continuous retinal illumination. Now, the form of $H(f, I_{mean})$ (I_{mean} refers to the mean retinal illumination) is necessary to our work. In this section, a concrete computational CSF will be introduced.

In this prediction system, the detailed and available flicker sensitivity data came from the fitting model made by Rovamo[17]. In Rovamo's model, the data are calculated by a series of equations (Equation 1, 2, 3, 4, 5, 6, 7). Rovamo suggested that "*the main properties of the flicker sensitivity function can be explained by known physiological properties of the retina.*" Based on this idea, he decomposed the CSF into a low-pass component and a high-pass component. In his model, every variable has the underlying physical meaning. But the importance to us is that we can obtain $H(f, I_{mean})$ only with I_{mean} and f .

$$d = 1.4 \tag{1}$$

$$N_{it} = 4.44 \times 10^{-5} \tag{2}$$

$$N_e = 0.148 \times f^{-0.568} \tag{3}$$

$$f_c = 6.33 \times I_{mean}^{0.172} \tag{4}$$

$$R_i = (1 + \frac{31.5}{I_{mean}})^{-0.473} \tag{5}$$

$$R = R_i \times (1 + (\frac{f}{f_c})^2)^{-3} \tag{6}$$

$$H(f, I_{mear}) = N_e^{0.5} \times (d \times (N_{it} \times R^{-2} \times f^{-2})^{\frac{1}{2}})^{-1} \tag{7}$$

The data calculated with Rovamo model were plotted in Fig. 3. As shown in Fig 3, the good fit of the model to the data was achieved without any luminance-dependent adjustments. This fitting model can supply all the information of $H(f, I_{mean})$ which we need.

B. Probability Summation over Time

"*The sensory response to light persists in time.*"[20] This fact obliges us to consider the collective effect caused by the temporally distributed visual stimulation. A classical solution to this problem has been to suppose that the eye integrates the light signal over some interval of time. Probability Summation over Time is a more general solution to this temporal cumulative effect.

1) Temporal Summation: To describe this process, it is convenient to treat the continuous time interval containing the signal as a sequence of brief, finite intervals, or instants. In order to properly represent the signal waveform, the duration of each instant must be less that half the period of the highest frequency present in the signal. The presence of internal noise[4] ensures that within each instant there is some probability that the threshold will be exceeded, and so the overall probability that the signal is detected must take into account all of these momentary probabilities. Here, we use P_i to denote the probability that the threshold is exceeded during the instant beginning at time ti.

$$P = 1 - \exp(- \mid r_i \mid ^{\beta}) \tag{8}$$

Where β is the steep parameter presented in the paper[20] by Watson. r_i is the output of the eye-like filter(See Section II-C).

If the fluctuations of the noise are sufficiently rapid, then these probabilities will be independent from instant to instant. Then supposing that the signal is detected if and only if the threshold is exceeded in at least one instant, the probability of detection P will be

$$P = 1 - \prod_i (1 - P_i) \tag{9}$$

Substitute the Equation 8 into the Equation 9, we got

$$P = 1 - \exp(- \sum_i \mid r_i \mid ^{\beta}) \tag{10}$$

So before probability estimation, we first calculate the absolute temporal summation R_{sum} using the following equation:

$$R_{\sum} = \sum_i \mid r_i \mid ^{\beta} \tag{11}$$

2) Probability Estimation: Substitute the summation R_{sum} into the Equation 10, we got the probability estimation as follows:

$$P = 1 - exp(- R_{sum}) \tag{12}$$

In addition, we introduced a constant "C" to Equation 12 to adjust the criteria and reduce the system error caused by the eye-like transfer function or other potential factors we cannot forecast. Then, Equation 12 transfers into:

$$P = 1 - exp(- C \times R_{sum}) \tag{13}$$

3) How to Determine Constant "C": This prediction system is an approximate system. Any part could introduce system errors. For example, when eye-like transfer function was established, we didn't consider the factor of the target size, and this may affect the result of the prediction. In order to eliminate potential error, before using this predictor, it is strongly recommended to re-estimate the constant "C" by a series of typical experiments. "C" is dependent on

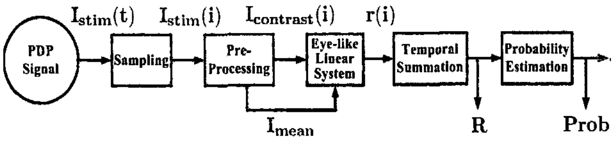


그림 4. 알고리즘의 블록도
Fig. 4. Block Diagram of Algorithm.

the device, observation condition and so on.

C. Algorithm of Predictor Model

The detailed algorithm is shown in Fig. 4. As shown in Fig. 4, in the step of pre-processing, the mean retinal illumination (I_{mean}) will be calculated firstly and be conveyed to the eye-like filter component to generate a transfer function $H(f)$ which is implicitly dependent on mean retinal illumination.

Also, in the step of pre-processing, the fluctuating part was extracted from the sampling signal $I_{stim}(i)$ using the following Equation:

$$I_{contrast}(i) = \frac{I_{stim}(i) - I_{mean}}{I_{mean}} \tag{14}$$

Then, the fluctuating signal will be conveyed to the eye-like linear system that was presented in Section II-A. This process will be done in frequency domain as the following equations:

- Fourier Transform

$$I^{FT}_{contrast}(f) = FT[I_{contrast}(i)] \tag{15}$$

- Multiplication in Frequency Domain

$$R^{FT}(f) = I^{FT}_{contrast}(f) \times H(f) \tag{16}$$

- Inverse Fourier Transform

$$r_i = IFT[R^{FT}(f)] \tag{17}$$

Thus, the output r_i of the eye-like filter is obtained. Applying the temporal summation to this output, we get the output R_{sum}. Substitute R_{sum} into Equation 13, the probability estimation could be carried out and the last output of probability was produced.

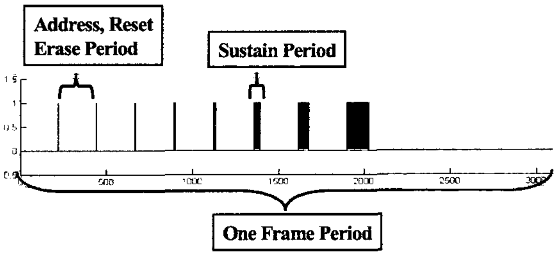


그림 5. PDP 신호의 정량적인 표현
Fig. 5. Quantitative Description of Signal from PDP.

D. Signal from PDP

Another problem to be solved is how to describe the signal from PDP quantitatively. Here, we adopted an approximate strategy to describe this complicated waveform. To catch the key feature of this waveform, we employed three approximate methods to simplify the waveform as follows:

① Energy emitted only in the sustain period, no energy emitted from the non-sustain periods.
② In the same sustain period, the emitted energy is steady.
③ Temporal average energy is proportional to number of sustain pulse.

In addition, 5000 nanosecond is selected as the value of the sampling interval for the sake of convenience, since the period of a sustain pulse is 5000 nanosecond. Based on the above approximate conditions, we obtained the quantitative description of signal from PDP illustrated in Fig. 5

In this case, there are 8 subfields in one PDP frame. It is seen that light is given off only in sustain period and in the same one sustain period the signal is steady.

III. EXPERIMENTS

To examine this prediction system, two

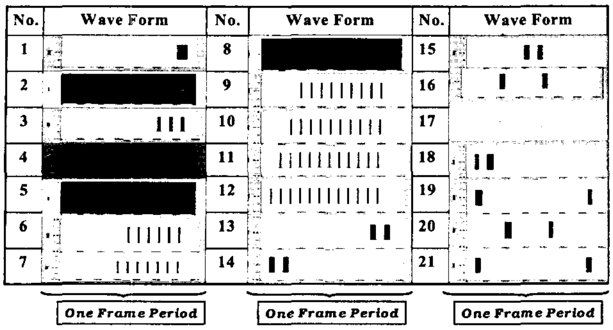


그림 6. 실험 1: 서스테인 펄스
Fig. 6. Experiment One: sustain pulse.

experiments about flicker in PDP have been carried out. By comparing the results of the experiments with the prediction, the performance of this predictor was estimated.

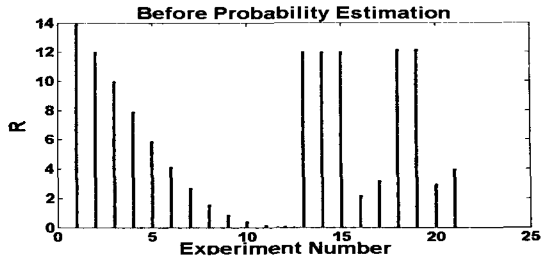
A. Experiment One

1) Experimental Conditions: In this experiment, the same mean luminance and various sustain pulse configurations are utilized. It is known that various sustain pulse configuration can generate some signal which have different flicker levels. We predicted these flicker levels and compared the results of prediction with the results of the experiments.

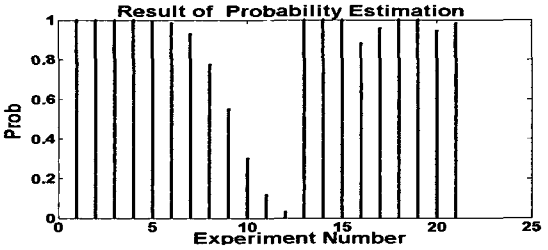
The detailed experiment conditions are illustrated as follows:

- Device: **-PDP, 42 Inch, 852X480 Resolution
- Viewing Distance: 3 Meters
- Environment Light: Low Lighting Room
- Subfield Number: 12
- Amount of Sustain Pulse: 256
- Mean Luminance: 231 Candela/m^2
- Mean Retinal Illumination: 746.05 Trolands
- Observer: JGX, HTO, KTS (Abbreviation of Observers' Names)

Here, the level of environment light was a little lower than the usual office light, because that would be more close to the environment of home theater and would make people more comfortable when watching the TV program.



(a) Results of Output "R"



(b) Results of Output "Prob"

그림 7. 실험 1의 예측 결과
Fig. 7. Prediction Results of Experiment One.

Various sustain pulse configurations are displayed in the Fig. 6. In this figure, we gave the number of sustain pulses of every subfield and its mapping method. There are in total 21 sorts of configurations listed here, which have the same gray level or number of sustain pulses.

2) Prediction & Experimental Results: The results are illustrated by the following Fig. 7.

As indicated in Fig. 7, from experiment 1.1 to 1.12, the more uniform the sustain pulse configuration, the smaller the probability of the occurrence of flicker. This result agrees with the practical observation and analytic result. From experiment 1.13 to 1.17, only two subfields with 128 sustain pulses emitted light, the same as experiment 1.1 to 1.12, the more uniform the two subfield configurations, the smaller the probability of the occurrence of flicker. From the experiment 1.13 to 1.17, the minimum value appears in the experiment 1.16, because this case has the most uniform configuration. From experiment 1.18 to 1.21, we changed the number of sustain pulses in the two subfields into 180 and 76. The result values increased obviously.

표 1. 실험 2: 서스테인 펄스
Table 1. Experiment Two: Sustain Pulse

Subfield No.	1	2	3	4	5	6	7	8	9	10	11	12	Sum
Sustain Pulse	1	1	1	1	1	1	1	1	1	1	1	1	12
Sustain Pulse	2	2	2	2	2	2	2	2	2	2	2	2	24
Sustain Pulse	3	3	3	3	3	3	3	3	3	3	3	3	36
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Sustain Pulse	57	57	57	57	57	57	57	57	57	57	57	57	684
Sustain Pulse	58	58	58	58	58	58	58	58	58	58	58	58	696
Sustain Pulse	59	59	59	59	59	59	59	59	59	59	59	59	708
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
Sustain Pulse	73	73	73	73	73	73	73	73	73	73	73	73	876
Sustain Pulse	74	74	74	74	74	74	74	74	74	74	74	74	888
Sustain Pulse	75	75	75	75	75	75	75	75	75	75	75	75	900

표 2. 실험 2: 서브필드 맵핑
Table 2. Experiment Two: Subfield Mapping.

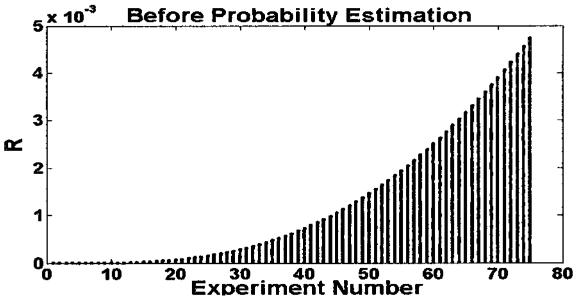
Subfield No.	1	2	3	4	5	6	7	8	9	10	11	12	Sum
Subfield Mapping	1	1	1	1	1	1	1	1	1	1	1	1	12

B. Experiment Two

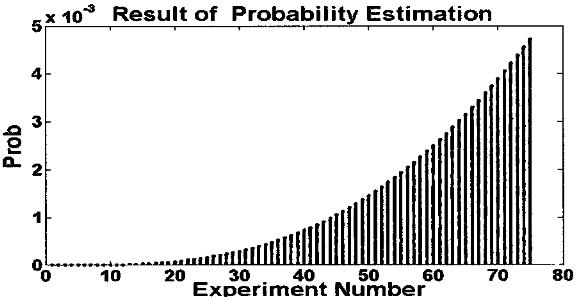
1) Experimental Conditions: In this experiment, the various mean luminance and similar sustain pulse configurations (Uniform) are utilized. It is known that, with the increase of mean luminance, contrast flicker sensitivity increases. Although all of the sustain pulse configurations are uniform, they also caused the signals which has a quite different flicker levels. We predicted these flicker levels and compared them with the results of the experiments. The detailed experiment conditions are illustrated as the following:

- Device: **-PDP, 42 Inch, 852X480 Resolution
- Viewing Distance: 3 Meters
- Environment Light: Low Lighting Room
- Subfield Number: 12
- Amount of Sustain Pulse: 12 ~ 900
- Mean Luminance: 2 ~ 810 Candela/m^2
- Mean Retinal Illumination: 46~2573 Trolands
- Observer: JGX, HTO, KTS

Various sustain pulse configuration: refer to Table 1 and Table 2



(a) Results of Output "R"



(b) Results of Output "Prob"

그림 8. 실험 2의 예측결과
Fig. 8. Prediction Results of Experiment Two.

2) Prediction & Experimental Results: The results are illustrated by Fig. 8. In this experiment, we verified how the flicker sensitivity increases with the mean illumination. As shown in Fig. 8, the flicker sensitivity increases with the mean illumination non-linearly (linear in log axis). Because only uniform sustain pulse configurations were utilized, the result values are all relatively small.

IV. CONCLUSION

In this paper, we proposed a computational model to predict the flicker phenomenon in PDP Devices. The quantitative output of the predictor presents the probability of occurrence of flicker.

First, the basic function has been realized, which gives the quantitative measurement of the degree of fluctuation of signal waveform from PDP. This degree is indicted by the probability of occurrence of flicker.

Second, it is natural that this simulation model can predict the threshold of occurrence of flicker, since, after successfully predicting the degree of fluctuation of waveform, the only things needed to do for threshold prediction are to set a criteria for the device condition and observation environment. (As presented in Section II-B-3, how to decide constant "C")

In addition, it might be more helpful to reduce system errors by improving the approximating method of factors that had been incorporated into the system. For example, an exact description of signal from PDP, or more precise eye-like transfer function with light adaptation. These are going to be done in future work.

As emphasized throughout the paper, this system is an approximate system. Many factors, which were regarded as not very important for the flicker phenomenon, were ignored. But, it could be unsafe under some conditions, because some of them might have a significant influence on this kind of prediction. Actually, we have no choice but to ignore some factors, because it is almost impossible to consider all of these factors based on the existing research results. Here, several of these factors are listed, which we think should be involved in this system. They include spatial frequency, eye movement, eccentricity and so on.

On the other hand, according to the predictor, some valuable properties of PDP waveform are of benefit to reducing flicker, which is a good instruction to flicker-free design.

- The waveform of the low mean luminance signal is not as important as high mean luminance signal, because the contrast sensitivity is quite low at low luminance.
- It is of benefit to reducing flicker to depress the energy of the harmonics at which the human eye has high contrast sensitivity.

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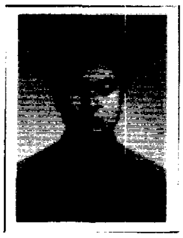
저 자 소 개



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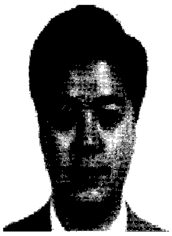

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