Lifetime estimation of Plasma Display Panel

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Abstract

We proposed 2-phase regression of power function inside exponential for PDP lifetime data analysis. In introducing our method we discussed the reason why PDP degradation behavior is described by exponential function basically. By applying our method to 50HD and 50FHD PDP lifetime experiment data, we obtained more than 100,000Hr lifetime. From these results, we claim that PDP lifetime is more than 100,000Hr.

Keyword

PDP, Lifetime, 2-phase exponential regression, Phosphor degradation

1. Introduction

Recently Plasma Display Panel (PDP) has been widely accepted as a Flat Display to customer together with Liquid Crystal Display (LCD). There are several reasons to become this circumstance such as good display quality and reasonable price, etc. Among these it is one of the largest reasons that PDP satisfies proper lifetime. PDP makers claim that PDP has more than 60,000Hr lifetime, and especially Matsushita had claimed that their 2007 products had more than 100,000Hr lifetime. LCD makers also claim that LCD has more than 60,000Hr lifetime based on CCFL backlight lifetime[1]. However, there have been no makers which have disclosed their data to convince their declaration. In order to convince declaration, showing their data only is not sufficient but showing analysis method is also important. For this purpose, we propose 2-phase regression of power function inside exponential method. Recently, Georgia Tech. [2] proposed 2-phase exponential regression method but we noticed a few difficulties when we applied their method to our panel data. One of the difficulties is that as panel running time is longer the first phase regression line fails to restore the initial value when satisfying the second phase regression properly. Another difficulty is that data fitting is not so good compared to our method. In addition, they did not show the reason why exponential regression is applicable to PDP. On the contrast to this, in this paper, we showed the reason why PDP degradation behavior was basically described by exponential function and further it was shown that data fitting was quite well.

This paper is consisted as follows. In section 2, we show the basic cause that PDP degradation behavior basically applies the exponential function. In section 3, we explain how to apply 2-phase regression of power function inside exponential method to measured data and show how to estimate lifetime at which luminance is a half of initial value. In section 4, we give 3 examples which show the comparison between measured data and calculated line, and also give some discussion. In final section, we conclude this paper.

2. Basic Theory

Recently Georgia Tech. had reported to use 2-phase exponential regression to estimate PDP lifetime. This argument was based on that PDP panel degraded exponentially. They showed this from fitting data but we show the more fundamental argument. First we have to notice that panel luminance degradation comes from mainly phosphor degradation. In addition one of the authors [3] and Yamamoto et.al[4] pointed that PDP degradation, especially green phosphor, occurred due to ion bombardment. Since white luminance degradation behaves as almost same as that of green because green luminance occupies about 60% of white luminance, we can consider that the cause of white degradation is same as green's such as ion bombardment. Then we can make following argument.

Given that there are initially N_0 light-emitting cells in a unit area, the number of ions with velocity v_a which collide into a unit area in a unit time is described as:

$$n_a f_a(v_a, 1) v_a$$

Where $f_a(v_a,1)$ is the velocity dependent distribution function of ionized atoms; n_a is the density of atoms. Therefore, the total number of ions with velocity greater than v_a colliding into a unit area in a unit time is:

$$F(f_a(v_a,1)) = \int_{v_a}^{\infty} dv_a' 4\pi v_a'^2 n_a f_a(v_a',1) v_a' \qquad (2\text{-}1)$$

Suppose that light emitting cells are destroyed by ion bombardment such that one colliding ion with velocity greater than v_a destroys one emitting cell. In addition, from the fact that ions are emerged by discharge, this colliding occurs discontinuously because discharge is ignited by sustain pulses. Therefore precise description of number of remained emitting cells after n discharge is satisfied by following recursion formula.

$$N(n+1)=N(n)-(N(n)/N_C)F(f_a(v_a,1)) \quad (2\text{-}2)$$

The second term of right hand side shows the number of destroyed emitting cells at (n+1) discharge. The precise form of solution of this equation is given in [3]. However, suppose discharge occurs continuously, in other word, destruction occurs continuously. Then eq.(2-2) changes to:

$$N(t+\triangle t)=N(t)-(N(t)/N_0)F(f_s(v_s,1))\triangle t \quad \text{as } \triangle t\to 0 \quad (2\text{-}3)$$

This gives us

$$\lim_{\triangle t\to 0}\frac{N(t+\triangle t)-N(t)}{\triangle t} = -\frac{F(f_s(v_s,1))}{N_0}N(t)$$

Left side is definition of derivative with respect to t, so final equation becomes:

$$\frac{dN(t)}{dt} = -\frac{F(f_s(v_s,1))}{N_0}N(t) \quad (2\text{-}4)$$

The solution of this equation under the initial condition such as at t=0, $N(0)=N_0$:

$$N(t) = N_0\exp(-\beta t) \quad \text{where, } \beta=(F(f_a(v_a,1)/N_0) \quad (2\text{-}5)$$

This shows the verification of Georgia Tech's argument. Here we modify above argument following. Previously we supposed that one colliding ion destroys one light-emitting cell, however, more likely probability α should be multiplied. Then,

$$\beta = \alpha\,(F(f_a(v_a,1)/N_0)$$

This destruction probability should depend on time, for instance, the layer in which emitting cells are distributed has a depth and efficiency of destruction should change as depth changes. Firstly, only cells distributed in surface are destroyed, but later on, efficiency of destruction is getting smaller as remained light-emitting cells lay in deeper. Or we may consider that the more fragile light emitting cells are destroyed first, and it remains the cells which are more tolerated against ion bombardment. Then probability α becomes smaller as time passes. For both cases, probability α, that means β, is a most likely decreasing function of time. Actually this is the case as shown in examples.

This consideration suggests that degradation rate factor β is not constant but function of time t since now α is function of time t. Then luminance depends on time t as most likely power function of t inside exponential:

$$L = L_0\exp(at^b) \quad (2\text{-}6)$$

Here we used the fact that luminance is proportional to number of light emitting cells.

3. Estimation Way

By following the argument of Georgia Tech. way we use 2-phase argument to treat experiment data also. However, we firstly explain why linear regression can be applied to our formula taking log successively twice for both side of eq.(2-6), we obtain:

$$Ln(Ln(L)) = Ln(a) + b*Ln(t) \quad (3\text{-}1)$$

By redefining y = Ln(Ln(L)), γ = Ln(a), λ = b, x = Ln(t), eq.(3-1) becomes:

$$y = \gamma + \lambda x \quad (3\text{-}2)$$

This is precisely linear algebraic equation so that we can apply linear regression for eq.(3-2). In order to determine γ, λ from data, we need following formula.

$$\lambda = \frac{N\sum x_i y_i - \sum x_i \sum y_i}{N\sum x_i^2 - (\sum x_i)^2} \quad (3\text{-}3)$$

$$\gamma = \overline{y} - \lambda\overline{x} \quad (3\text{-}4)$$

where $y = (\sum y_i)/N$: average of y, $x = (\sum x_i)/N$: average of x

N is Number of data

Derivation of eq.(3-3) and eq.(3-4) are given in Appendix. In order to precisely fit the experimental data with calculated line we introduce 2-phase method. The method of 2-phase is referred by for instance [5][6]. Firstly, divide data into two regions such that one region is consisted by data group before time t_s (y_1, y_2, * * *, y_s) and that the other region is consisted by data group after t_{s+1} (y_{s+1}, y_{s+2}, * * *, y_N). Applying linear regression argument for both regions such as:

$$\lambda_1 = \frac{s\sum_{i=1}^{s} x_i y_i - \sum_{i=1}^{s} x_i \sum_{i=1}^{s} y_i}{s\sum_{i=1}^{s} x_i^2 - (\sum_{i=1}^{s} x)^2} \quad (3\text{-}5)$$

$$\gamma_1 = \overline{y_1} - \lambda_1 \overline{x_1} \quad (3\text{-}6)$$

$$\text{where} \quad \overline{y_1} = \frac{\sum_{i=1}^{s} y_i}{s} \qquad \overline{x_1} = \frac{\sum_{i=1}^{s} x_i}{s}$$

$$\lambda_2 = \frac{(N-s)\sum_{i=s+1}^{N} x_i y_i - \sum_{i=s+1}^{N} x_i \sum_{i=s+1}^{N} y_i}{(N-s)\sum_{i=s+1}^{N} x_i^2 - (\sum_{i=s+1}^{N} x_i)^2} \quad (3\text{-}7)$$

$$\gamma_2 = \overline{y_2} - \lambda_2 \overline{x_2} \quad (3\text{-}8)$$

$$\text{where} \quad \overline{y_2} = \frac{\sum_{i=s+1}^{N} y_i}{N-s} \qquad \overline{x_2} = \frac{\sum_{i=s+1}^{N} x}{N-s}$$

Then we can obtain two regression formulas:

$$y_1 = \gamma_1 + \lambda_1 x_1 \quad (\text{for } t_1, \ldots, t_s)$$

$$y_2 = \gamma_2 + \lambda_2 x_2 \quad (\text{for } t_{s+1}, \ldots, t_N)$$

Important point is that intersection time τ of two lines should satisfy following condition:

$$\tau = \exp\left(\frac{\gamma_1 - \gamma_2}{\lambda_2 - \lambda_1}\right) \quad (3\text{-}9)$$

$$t_s < \tau < t_{s+1} \quad (3\text{-}10)$$

In order to estimate lifetime, which is defined by the required time to reach half luminance, we assume that degradation rate β approaches to some constant gradually as panel running time is increased. Actually this assumption shortens the estimated lifetime compared to that without this requirement. In practice, this assumption is applied the following way. Taking final data point time t_N, we invoke following condition. At t_N, calculated curve L =

$\exp(\exp(\gamma_2+\lambda_2 Ln(t)))$, which was from eq.(2-6) and eq.(3-1), and asymptotic form $L_a = \exp(\alpha_a+\beta_a t)$ are smoothly continued. Smoothly continue means that at t_N, $L|_{tN}=L_a|_{tN}$, $(dL/dt)|_{tN} = (dL_a/dt)|_{tN}$. Then β_a and α_a are obtained as the following formula.

$$\beta_a = \frac{\lambda_2 Ln(L(t_N))}{t_N} \tag{3-11}$$

$$\alpha_a = Ln(L(t_N)) - \beta_a t_N \tag{3-12}$$

Then half luminance time $T_{1/2}$ is given as:

$$T_{1/2} = \frac{Ln(L_0/2) - \alpha_a}{\beta_a} \tag{3-13}$$

If panel lifetime experiment was done by TV or Video display, then lifetime would be same as $T_{1/2}$, but by acceleration pattern, then we have to multiply acceleration factor to $T_{1/2}$ to estimate lifetime.

$$\text{Lifetime} = (\text{Acceleration factor}) \times T_{1/2} \tag{3-14}$$

(Acceleration factor=1 for TV or Video display running)

4. Results and Discussion

We show 3 results here. 2 results are come from 50HD and 1 result is come from 50FHD. Their running pattern was TV display so that $T_{1/2}$ is a lifetime. We measured up to 4000Hr for 50HD and 6000Hr for 50FHD. Luminance was measured in Full White display, which means, in panel running TV display pattern was used but at measurement we changed to Full White display pattern. Fig.1 to Fig.3 shows the experiment data points and calculation results using 2-phase regression of power function inside exponential method. Fig.1 and Fig.2 are results of 50HD and Fig.3 is result of 50FHD. Table 1 show the calculation factors included lifetime.

Fig. 1 Life estimation (50HD (1))

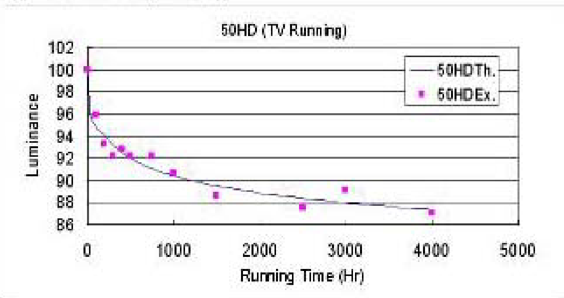

Fig. 2 Life estimation (50HD (2))

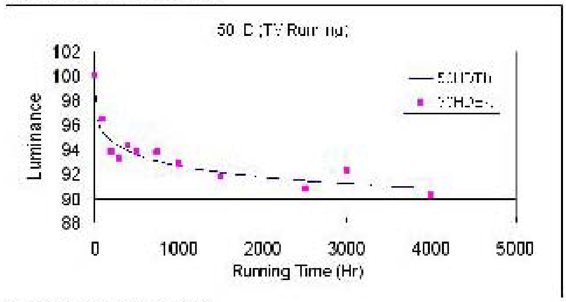

Fig. 3 Life estimation (50FHD)

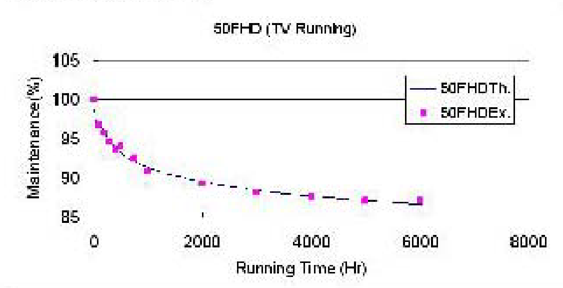

Table 1. Calculation factors (including lifetime)

	Fig.1	Fig.2	Fig.3		Fig.1	Fig.2	Fig.3
β_a	-6.1E-06	-3.62E-06	-4.9E-06	λ_1	-0.00224	-0.00201	-0.00201
α_a	6.152333	6.191422	6.106843	γ_1	1.660902	1.662863	1.662863
$T_{1/2}$	94775.34	169092.8	118152	λ_2	-0.0048	-0.00279	-0.00279
Lifetime (Hr)	94775.34	169092.8	118152	γ_2	1.674449	1.667395	1.667395

All results show that lifetime is about or more than 100,000Hr. From the fact that we used the assumption at 4000Hr for 50HD and at 6000Hr for 50FHD, these estimation results are most likely shorter than real lifetime. Thus we are convinced that PDP lifetime, at least SDI's, is more than 100,000Hr. This lifetime is longer than that of claimed PDP life such as 60,000Hr and better value even compared to the claimed life of LCD as 60,000Hr. The claimed LCD lifetime is based on CCFL backlight lifetime. This means actual LCD lifetime is shorter than 60,000Hr because backlight lifetime is expected maximum lifetime of LCD system. This shows that PDP has clearly better lifetime than LCD. In addition, our 2-phase regression of power function inside exponential method shows good agreement to data for all 3 cases. This means degradation factor β is not constant but actually decreasing function of time because λ values are less than 1. We mentioned the two considerations for explaining this fact, however real physics is still not clear. Also, since 2-phase argument works well, there are two significantly different degradation states. One stage is up to at most 300Hr and in this region luminance is quickly down. Since our calculation is based on the consideration of ion bombardment it may simply be relied on phosphor property, however we should seek another improvement way besides improvement of phosphors because stage difference is as significant as shown λ_1 and λ_2 difference in Table 1.

5. CONCLUSION

We introduced 2-phase regression of power function inside exponential method to estimate PDP lifetime. We applied this method to our 50HD and 50FHD. The results are:

Table 2. Estimated Life Time

Panel	$T_{1/2}$(H)	Acc. Fac.	Lifetime (Hr)
50HD (1)	94775	1	94775
50HD (2)	169093	1	169093
50FHD	118152	1	118152

As shown in Table 2 estimated lifetimes are about and more than 100,000Hr. From these results we can declare that PDP panel has 100,000Hr lifetime.

REFERENCE

[1] www.atcdisplays.com/fileadmin/user_upload/atc/Backlight_Lifetime.pdf

[2] S.J. Bae and P.H. Kvam, “A change-Point Analysis for Modeling Incomplete Burn-in for Light Displays”, IIE transactions, vol. 38, no 6, pp. 489-498, (2006)

[3] T. Kurai, “Panel structure factors and luminance degradation of PDP phosphors”, IEICE Trans. Electrons, vol. E85-C, no. 7, pp. 1506-1515, (2002)

[4] H. Yamamoto and K. Uheda, “Phosphors for Plasma Display Panel”, Journal of the Society of Inorganic Materials, 11, pp.410-416 (2004)

[5] D.L. Hawkins, “U-I Approach to Retrospective Testing for Shift Parameters in Linear Model”, Communications in Statistics: Theory and Method 18, pp. 3117-3134, (1989)

[6] D. Kim, “Test for a change-point in Linear Regression”, IMS Lecture Notes, Monograph Series 23, pp.170-176, (1994)

▪ APPENDIX: Derivation for formula of eq.(3-3) and eq.(3-4)

$$\hat{y} = \begin{vmatrix} y_1 \\ y_2 \\ \cdot \\ \cdot \\ y_n \end{vmatrix} \qquad n \times 1 \text{ matrix}$$

$$\hat{x} = \begin{vmatrix} 1 & x_1 \\ 1 & x_2 \\ \cdot & \cdot \\ \cdot & \cdot \\ 1 & x_n \end{vmatrix} \qquad n \times 2 \text{ matrix}$$

$$\hat{\lambda} = \begin{vmatrix} \lambda_1 \\ \lambda_2 \end{vmatrix} \qquad 2 \times 1 \text{ matrix}$$

where $\lambda_1 = \gamma$, $\lambda_2 = \lambda$ for our case

Linear Regression equation is described as following matrix equation form.

$$\hat{y} = \hat{x}\hat{\lambda} \qquad \text{(A-1)}$$

Then λ is obtained by following formula.

$$\hat{\lambda} = (\hat{x}^T \hat{x})^{-1} (\hat{x}^T \hat{y}) \qquad \text{(A-2)}$$

where T denotes Transverse, -1 denotes inverse

Thus in order to obtain form of λ, just calculation of right hand side of eq.(A-2) is sufficient.

$$x^T = \begin{vmatrix} 1 & 1 & \cdots & 1 \\ x_1 & x_2 & \cdots & x_n \end{vmatrix} \qquad 2 \times n \text{ matrix}$$

$$x^T x = \begin{vmatrix} 1 & 1 & \cdots & 1 \\ x_1 & x_2 & \cdots & x_n \end{vmatrix} \begin{vmatrix} 1 & x_1 \\ 1 & x_2 \\ \cdot & \cdot \\ \cdot & \cdot \\ 1 & x_n \end{vmatrix} = \begin{vmatrix} n & \sum_{i=1}^{n} x \\ \sum_{i=1}^{n} x_i & \sum_{i=1}^{n} x^2 \end{vmatrix}$$

2×2 matrix

In order to obtain inverse matrix, first we have to calculate determinant:

$$\det |x^T x| = n\sum x_i^2 - (\sum x_i)^2$$

To calculate sub-determinant we need to take Transverse. Since $(x^T x)^T = x^T x$ in this case, $(x^T x)^{-1}$ is:

$$(x^T x)^{-1} = \frac{1}{\det|x^T x|} \begin{vmatrix} \sum x^2 & -\sum x_i \\ -\sum x & n \end{vmatrix} \qquad 2 \times 2 \text{ matrix}$$

$$x^T y = \begin{vmatrix} 1 & 1 & \cdots & 1 \\ x_1 & x_2 & \cdots & x_n \end{vmatrix} \begin{vmatrix} y_1 \\ y_2 \\ \cdot \\ \cdot \\ y_n \end{vmatrix} = \begin{vmatrix} \sum y_i \\ \sum x_i y \end{vmatrix} \qquad 2 \times 1 \text{ matrix}$$

$$(x^T x)^{-1}(x^T y) = \frac{1}{\det|x^T x|} \begin{vmatrix} \sum x^2 \sum y_i - \sum x \sum x y_i \\ n\sum x_i y - \sum x_i \sum y_i \end{vmatrix} = \begin{vmatrix} \gamma \\ \lambda \end{vmatrix}$$

2×1 matrix

From this description we obtain

$$\lambda = \frac{n\sum x_i y_i - \sum x \sum x_i y_i}{n\sum x_i^2 - (\sum x_i)^2}$$

Then we can show

$$\frac{\sum y_i}{n} - \lambda \frac{\sum x_i}{n} = \gamma$$

By our notation this gives:

$$\gamma = \overline{y} - \lambda \overline{x}$$