# 29-5:Two Approaches in LCDs With Fast Electro-optic Response: PSV-mode FLCDs and FM-TN-LCDs

**Shunsuke Kobayashi**

**Institute of Liquid Crystal and the Graduate School of Science and Engineering, Tokyo University of Science ,Yamaguchi, Onoda, Yamaguchi 756-0084, Japan**

## Abstract

*This paper discusses on new two LCD technologies featured by the fast electro-optic response:one is polymer-stabilized FLCDs that exhibit V-shaped electro-optic (EO) switching called PSV-mode FLCDs with response time of 400 μ s; and the other is TN -mode LCDs that exhibit a frequency modulation response (called FM-TN LCDs)and a peculiar sensitivity to the high frequency component of driving voltage waveforms resulting in a short decay time constant of 5ms and an enhancement in the over-driving that yields short response time of 1ms between two gray levels.*

*Keywords: Polymer-stabilized FLCD, FLCD, field sequential full color LCD, FM-LCD,*

## 1. Introduction

Liquid crystal display devices are being widely utilized in every part of society. However, there exists a strong demands for an LCD with fast electro-optic response for two reasons: one is to display moving video images and the other is to implement a field (color) sequential full color LCDs featured by high resolution and low power consumption.

Historically, several LCD technologies with fast EΔ response were proposed and published in literature, such as voltage biased tunable birefringent mode [1], $\pi$ -cell bent nematic mode[2],surface stabilized ferroelectric liquid crystal (SSFLC) mode[3] ,flexoelectric nematic mode[4],OCB mode{5},and new LCD modes such as PSV-mode FLCDs [6,7] and FM-LCDs[7,8].Besides these developments in the operation modes,a technique called over-driving is effective to improve the response time using an existing LCD mode such as TN-mode is effective.[9] In this paper we discuss on the over-driving in an FM-TN-LCD.

## 2. PSV-mode FLCDs

SSFLCDs (called Type 1-1 in the FLCD technology) are attractive for their fast EO response, and wide viewing angle; this technology is used to fabricate LCOS device for digital camera use. To enlarge the application of FLCDs, we have developed new FLCDs featured by zig - zag defect free, which are free form light leakage due to the existence of defects ,this in turn results is high contrast ratio; and by thresholdless V - shaped EO switching by adopting polymer - stabilization using mesogenic side chain monomers. These FLCDs are called PSV - mode FLCDs . In the PSV - mode, there two methods in the polymer - stabilization: one is done in the Sm* phase with the simultaneous application of AC field during photocure, which is desigrated as type 2-1-1; and the other is fabricated by performing photocure in the SmA phase without applying external electric field, which is classified as Type 2-1-2.

By using newly developed FLC materials (Clariant Japan) and photocurable monomers (DIC), we succeeded in fabricating PSV-FLCD exhibiting the contrast ratio of 700:1 and the response times of 400 s for both rise process and decay process: an example of its EO characteristic is shown in Fig. 1.

We also developed a prototype of field sequential (FS) full color (FC) active matrix (AM) LCD using our PSV-FLCD.

An example of photograph of the displayed image is shown in Fig. 2.The specifications of this FS-FC-LCD is 4 inch diagonal and the resolution of 254 ppi, which is 800×600 pixels (SVGA), with the frame rate of 60Hz, yielding 76% of NTSC color gamut, and the system contrast ratio of 200:1 or more.

## 3. FM-TN-LCDs

LCDs doped with metal nanopartislse such as Pd, Au, and An or their composite exhibits a peculiar electro-optic characteristic that is featured by the high sensitivity to the high frequency component of operating voltage and exhibits a frequency modulation EO response besides the ordinary RMS response. These devices are called FM-LCDs.

Figure 3 demonstrates an example of the FM switching of a TN-LCD cell using Ag nanoparticles, which are protected by NLC molecules, 5CB); and using NLC, 5CB as the host LC medium. The diameters of nanoparticles are 3nm to 5nm and their volume occupation factor is $10^{-4}$.For an AC burst square wave operating voltage, the delay times are almost 50% shorter and decay times are 49% shorter compared to those of a TN-LCD cell with pure 5CB. Regarding the rising process, both the delay times and rise times are shorter about 10% compared to the TN-LCD with pure 5CB; contrary to this, the effect of the over-driving is highly enhanced for an FM-TN-LCD; Figure 4 demonstrates this situation. There is the particular condition for realizing a critical damping that is free form both the over damping and the over shooting by choosing the number of AC pulses for the over- driving voltage for a transition between two gray scale states, where the both the delay time and rise time are about 80 times shorten without accompanying over damping. TN-LCD with pure 5CB shows always a over shooting. These effect may be attributed to the rapid temporal change of $\Delta\varepsilon$ for the high frequency component of the operating voltage and this effect in turn may cause the abrupt increase of dielectric torque acting on the NLC molecules; this rapid change in $\Delta\varepsilon$ may be caused by the movement of $\pi$ -electros in NLC molecules. [9]

## 4. Conclusions

As LCDs with fast ED response, we hare introduce two technologies: one is PSV-FLCD and the other is FM-TN-LCD. We succeeded in fabricating FLCDs exhibiting V-shaped electro-optic switching with high contrast ratio of 700:1 by adopting FLC molecular alignment technique, which realizes zig-zag defect free state and, also mogogenic side chain polymer stabilization. These devices are called PSV-FLCD. We also succeeded in demonstrating a field sequential active matrix full color LCD using our PSV-FLCD and an LED back light ; the specification of the FS-FC-LCD is 4 inch diagonal, SVGA (800 × 600), 254ppi and the color gamut is 75% of that of NTSC. We also explored the possibility for implementing a NLCD with fast response time. We adopted the doping of metal nanoparticles, Pd, Ag, or Au, which are protected with NLC, 5CB, molecules This method is applicable to all kinds of existing LCD modes. We applied this method to TN-LCD and TB-LCD, and it is shown that the device exhibits a frequency modulation response with a particular sensitivity to the high frequency component of operating voltage. This effect, in turn results in a fast EO response below 5ms even 550 s, and particularly causes the enhancement in the over- driving effect with the time constant of 1.5 ms. These phenomena may be explained by the Maxwell-Wagner theory of heterogeneous dielectric medium.

## 5. Acknowledgments

This research was supported by the JSPS-RFTF Project under the Grant No. JSPS-RFTF98R14201. The authors indebted to Messers. H Fukuro and H. Endo of Nissan Chem. Ind. for supplying. Polyimide materials. We also thank Messers. K. Betsui and T. Yoshihara of Fujitsu Labs . for implementing the prototypes of FS-FC-LCDs. We are indebted to Profs. N. Toshima, H. Shiraishi, Y. Sakai, and Y. Miyama for collaborating research on FM-TN-LCDs. This research was also supported by NEDO MF H-15-028003.

## 6. References:

[1] Uehara, K. Mada, H., Kobayashi, S. (1975).*IEEE TR.* ***ED-22***, 804.

[2] Bos, P., Johnson, P. A. Jr., Koehar-Beran, K. R. (1983) 1983 *SID Digest of Tech. Papers.* ***14***, 30.

[3] Clark, N. A., Lagerwall, S.T. (1980) *Appl. Phys. Lett.* ***36***, 899.

[4] Patel, E. J. S., Meyer, R.B. (1987) *Phys. Rev. Lett.* **58**, 1538.

[5] Miyashita, T., Uchida, T. (1993), *Conference Record of Eurodisplay 93*, 149.

[6] Miyazaki, Y., Furue, H., Kobayashi, S. (2001) *Mol. Cryst. Liq. Cryst.* ***364***, 491.

[7] Kobayashi, S., Xu, J., Furuta, H., Murakami, Y., Kawamoto, S., Oh-kouchi, M., Hasebe, H., Takazsu, H. (2004) *Opt. Eng.* ***43***, 290.

[8] Shiraishi, Y., Toshima, N., Maeda, K., Yoshikawa, H., Xu, J., Kobayashi, S. (2002) *Appl. Phys. Lett* ***81***, 2845.

[9] Miyama., T., Thisayukta, J., Shiraki, H., Sakai, Y., Shiraishi, Y., Toshima, N., Kobayashi, S. (2004)*Jpn J.Appl..Phys.* ***43***, 2580.

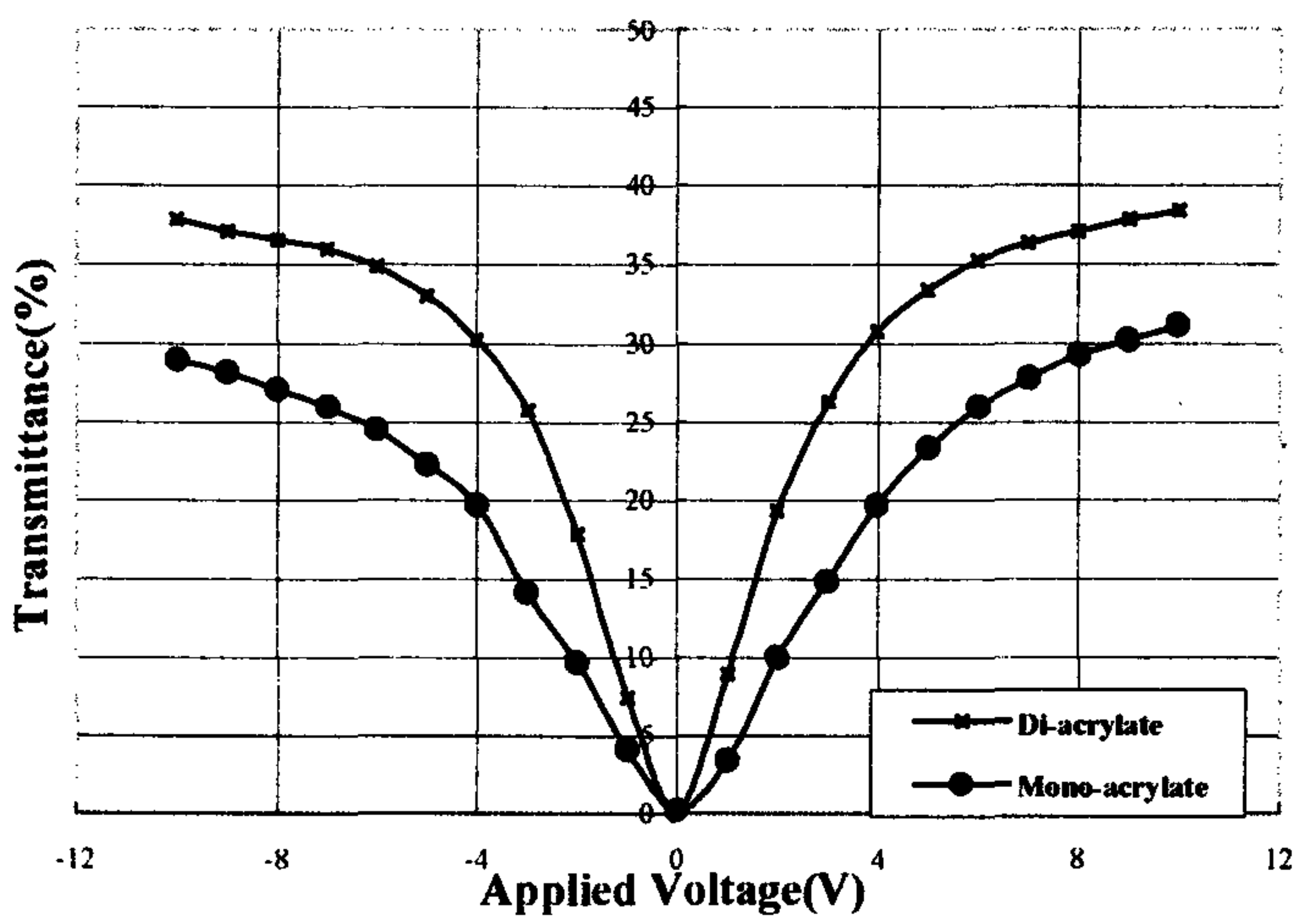


Figure 1: Comparison of the effects of di-acrylate and mono-acrylate to the EO characteristics of PSV-FLCDs.

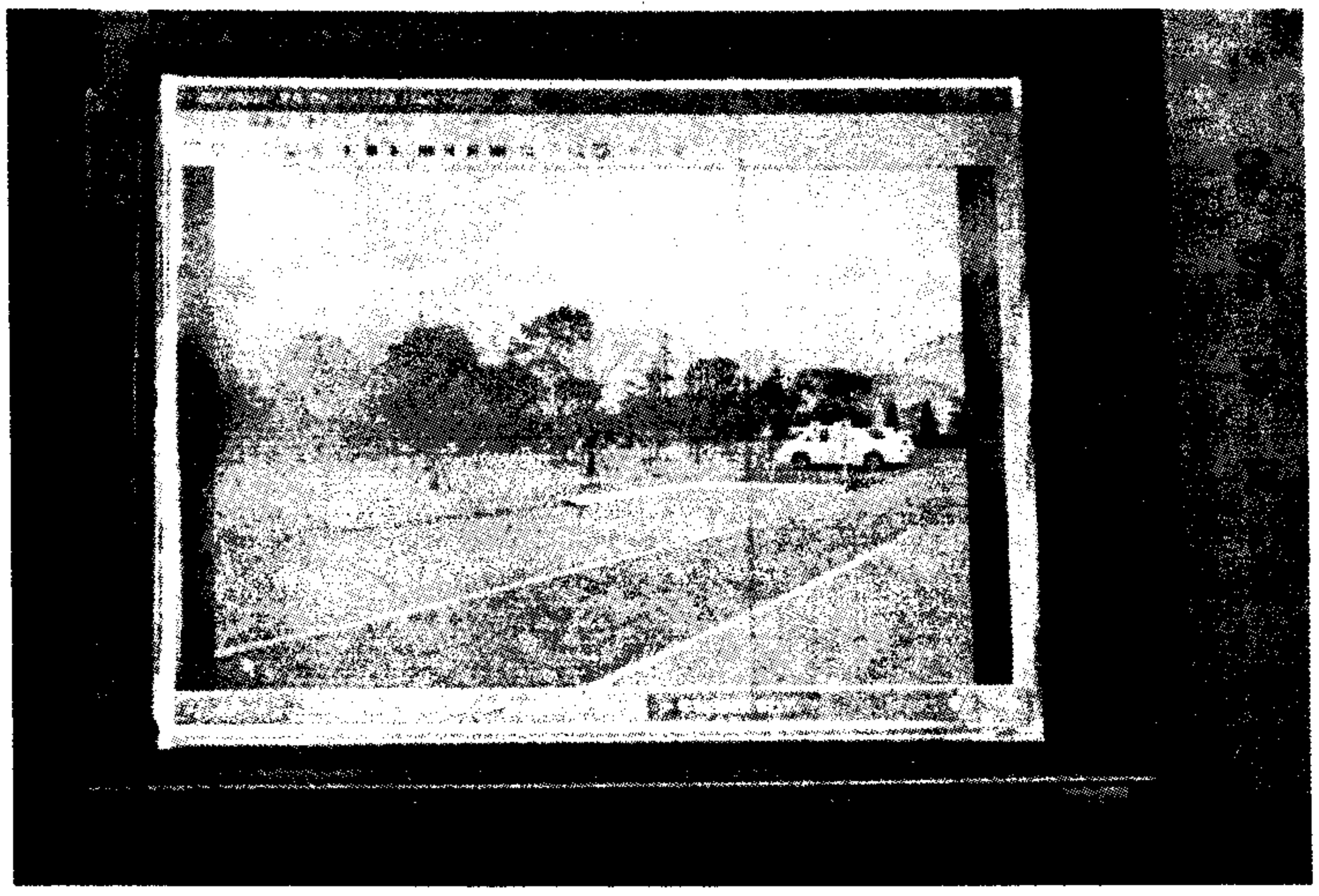

Figure 2: Performance of our PS-V-mode FLCD using an advanced FLC material and advanced monomers.

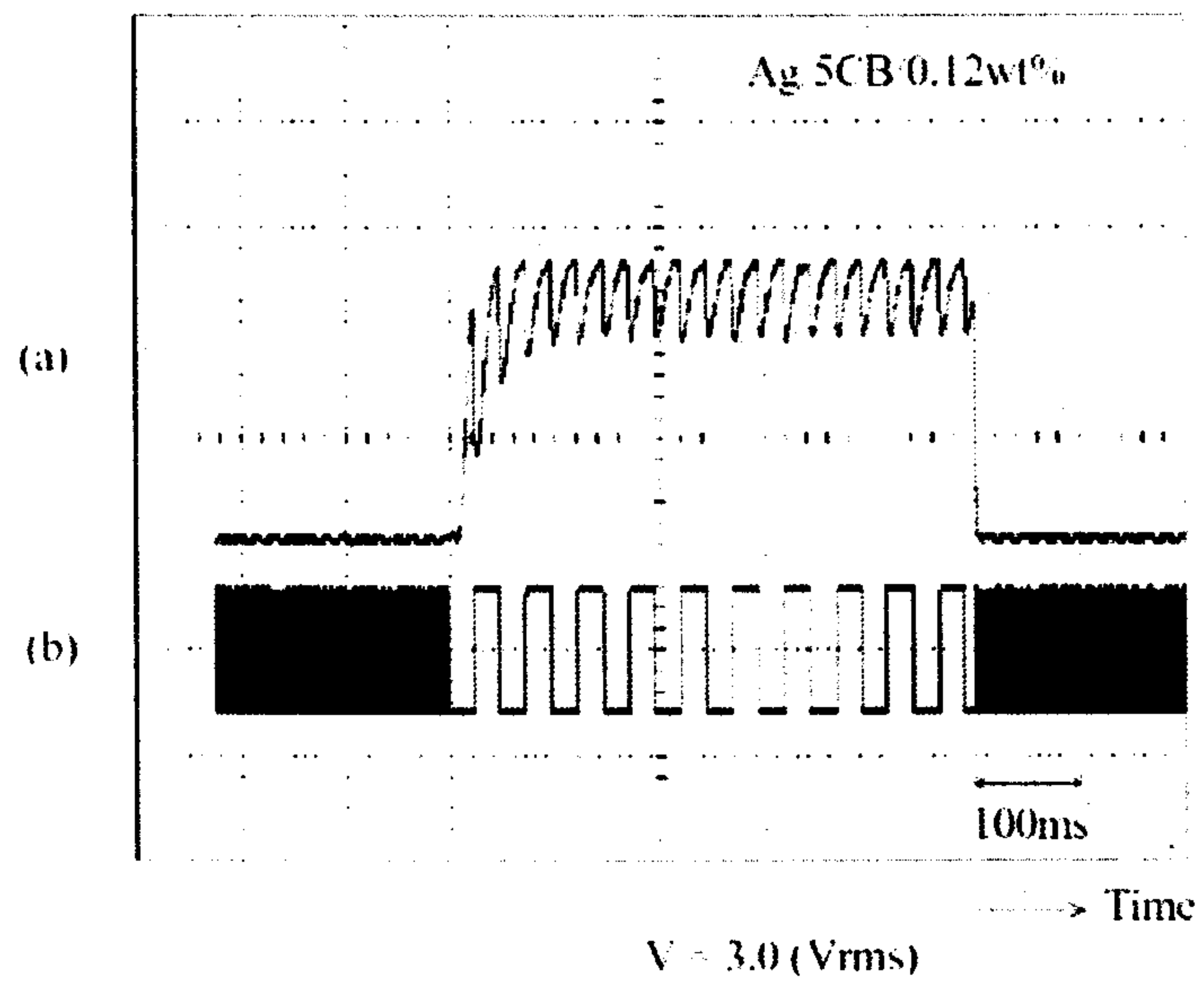


Figure 3: An example of FM switching by changing frequencies: low frequency $f_1$=20Hz and high frequency $f_2$=500Hz, where the amplitude of the square wave voltage is 3.0 volts; (a) relative optical throughput and (b) operating voltage waveforms.

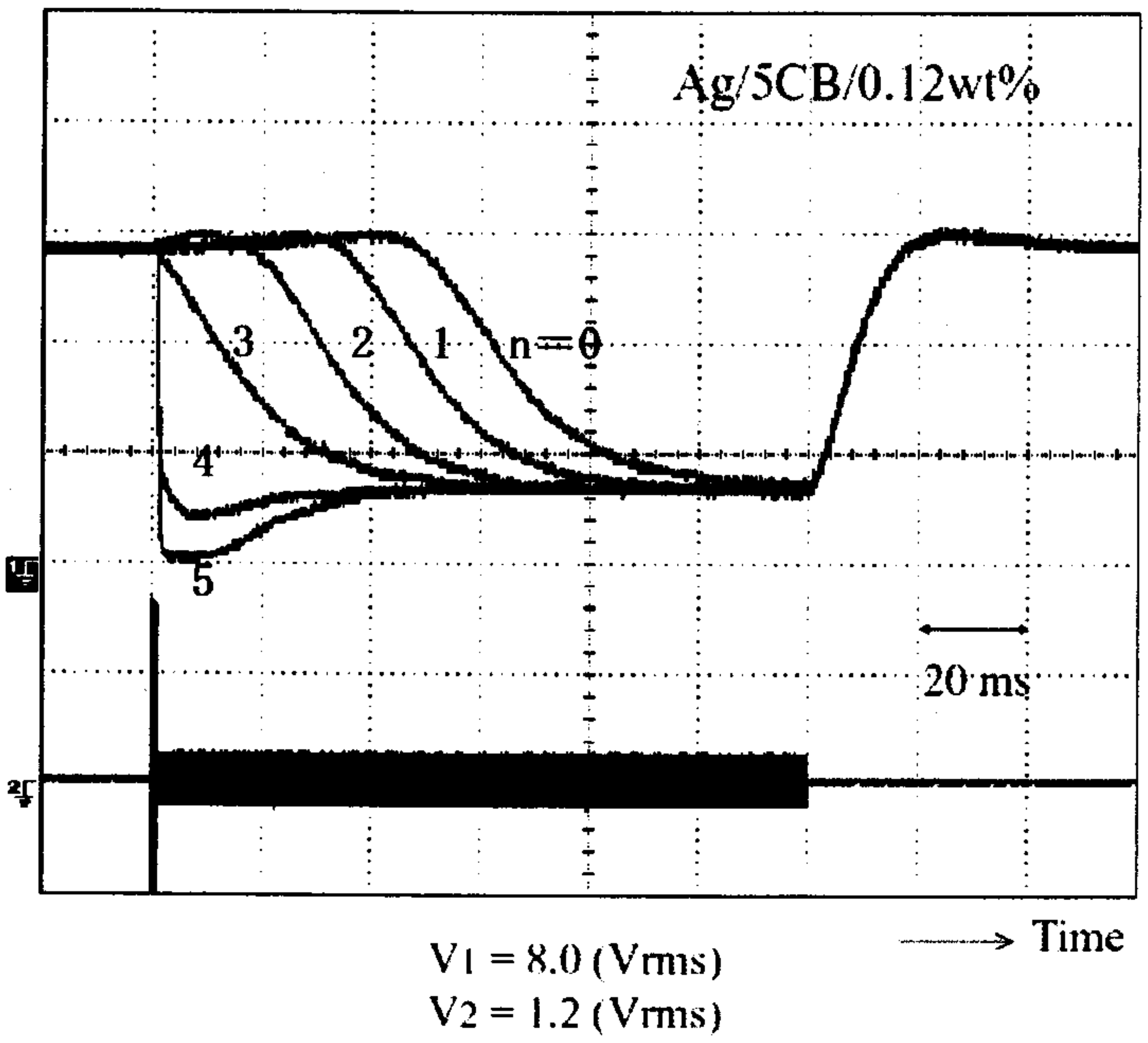


Figure 4: An example of over-driving of FM-TN-LCD, A Critical damping occurs when the number of AC pulses $V_1$ is n=5.