



JOURNAL OF
THE SOCIETY
FOR INFORMATION
DISPLAY

11

2003

TK 5103
.5
.N34
Set 1

Aug 07
GER
Journal of the

SOCIETY FOR INFORMATION DISPLAY

2003

Combined Special Issues on
Selected Papers from the 9th International
Display Workshops (IDW '02)
and
Selected Papers from the 22nd International
Display Research Conference (EuroDisplay '02)

Volume 11
Number 3

Previously published as
Proceedings of the Society for Information Display

SID
SOCIETY FOR INFORMATION DISPLAY

Journal of the SID

The quarterly *Journal of the SID* publishes original work dealing with the theory and practice of information display. Coverage includes hard and soft copy; the underlying chemistry, physics, physiology, and psychology; measurement techniques; and all aspects of the interaction between equipment and its users.

The Society also publishes *Symposium Digests*, containing extended abstracts of papers presented at the annual International Symposia, and the monthly magazine *Information Display*. We cooperate in publishing the digests of technical papers presented at the annual International Display Research Conferences. Information about all of these publications and meetings is available from the Society's headquarters (see below) and on our web page (www.sid.org).

Information on membership can be found with the Table of Contents. Detailed information for contributors is at the back of this issue. Full-length papers, brief communications, and letters are welcomed; they may be submitted to any of the Associate Editors or to the Editor.

Published as *Proceedings of the SID* from 1963 through 1991 (Volumes 1-32)

Editor

Andras I. Lakatos

4681 S. Golden Arrow Drive, Green Valley, AZ 85614-5474 USA
520/625-1457, fax -9855, e-mail: editor@sid.org

Associate Editors

LCDs

Allan R. Kmetz, 50 Edgewood Road, Chatham, NJ 07928-2002 USA
akmetz@aya.yale.edu

Shunsuke Kobayashi, Science University of Tokyo in Yamaguchi,
1-1-1 Daigaku-dori, Onada, Yamaguchi, 757 Japan
+81-836-88-4540, fax -3844; kobayasi@ed.yama.sut.ac.jp

Ernst Lueder, University of Stuttgart, Germany, and Electro-Optical
Consultancy, LLC, 9471 E. Yucca St., Scottsdale, AZ 85260 USA
phone/fax 480/451-8074, e.lueder@att.net

Martin Schadt, ROLIC, Ltd., Gewerbestrasse 18,
CH-4123 Allschwil, Switzerland
+41-61-487-2222, fax -2288, Martin.Schadt@rolic.ch

CRTs

A. A. Seyno Sluyterman, LG.Philips Displays, Bldg. RAF-1, P.O. Box 807,
5600 AV, Eindhoven, The Netherlands
+31-40-2782817, fax -2786185, seyno.sluyterman@lgphilips-displays.com

Vision Science/Human Factors

Haruo Isono, Human Science Research Division, NHK Science and Technical
Research Labs., 1-10-11, Kinuta, Setagaya-ku, Tokyo 157-8510, Japan
+81-3-5494-2340, fax: +81-3-5494-2371, isono@strl.nhk.or.jp

Alan R. Jacobsen, Boeing Commercial Airplane Group, P.O. Box 3707,
MC 02-JH, Seattle, WA 98124-2207 USA
425/294-0562, fax -0515, alan.r.jacobsen@boeing.com

Light-Emitting Displays (LEDs, OLEDs, ELDs, Phosphors, etc.)

Ghassan E. Jabbour, Optical Science Center, The University of Arizona,
1630 E. University Blvd., Tucson, AZ 85721 USA

520/626-8324, fax 520/621-4442, gej@optics.arizona.edu

Webster E. Howard, Consultant, 4 Lee Lane, Lagrangeville, NY 12540-6332 USA
845/223-7716, whoward494@aol.com

Peter Seats, Display Technology Consultant, 300 Indian Springs Rd.,
Williamsburg, VA 23185 USA
757/220-3183, fax: -3263, peterseats@cox.net

Plasma Displays

Munisamy Anandan, Organic Lighting Technologies, LLC,
13009 Thome Valley Dr., Del Valle, TX 78617-3489 USA
phone/fax 512/247-6863, manandan@o-lite.com

Heiju Uchiike, Saga University, Dept. of Electronics,
1, Honjo-machi, Saga 840-8502 Japan;
+81-952-28-8640, fax -8651, uchiike@cc.saga-u.ac.jp

Display Manufacturing

Jin Jang, Head, TFT-LCD National Lab, Kyung Hee University,
Dongdaemoon-ku, Seoul, 130-701, Korea
+82-2-961-0270, fax +82-2-968-6924, jjang@khu.ac.kr

Display Systems and Driver Electronics

Hideaki Kawakami, Hitachi, Ltd., 3300, Hayano, Mobara-shi,
Chiba-ken, 297-8622 Japan
+81-475-25-9074, fax: +81-475-24-2463,
kawakami-hideaki@mobara.hitachi.co.jp

Projection Displays

Shinji Morozumi, Crystage, Inc., 1-19-4, Higashi-Nakajima,
Higashi-Yodagawa-ku, Osaka, 533-0033 Japan
+81-6-4809-4125, fax: -4127, s.morozumi@crystage.com

Managing Editor

Jay Morreale, Palisades Convention Management
411 Lafayette Street, 2nd Floor, New York, NY 10003, USA
212/460-8090 x212, fax -5460, jmorreale@pcm411.com

The Society for Information Display

Executive Officers

President A. R. Kmetz
President-Elect S. Mikoshiba

Regional Vice-President, Americas M. Anandan
Regional Vice-President, Asia M. Maeda
Regional Vice-President, Europe J.-P. Budin

Treasurer R. Seery
Secretary P. Drzaic
Immediate Past President A. Silzars

Directors

Bay Area N. Balram
Beijing B. P. Wang
Belarus S. Yakovenko
Canada T. Schmidt
Dayton D. Hopper
Delaware Valley J. W. Parker III
Detroit R. Donofrio
France J. Magarino

Hong Kong H. Leung
India K. Sarma
Japan S. Naemura
Korea M. K. Han
Los Angeles P. Baron
Mid-Atlantic A. Ghosh
Mid-Europe J. Kimmel
Minneapolis/St. Paul B. Bahadur
New England S. Atwood

Pacific Northwest J. Rupp
Russia V. Belyaev
San Diego T. Iki
Singapore/Malaysia B. A. Ghani
Southwest P. Smith
Taipei H. P. Shieh
Texas Z. Yaniv
UK/Ireland A. Mosley
Ukraine V. Sorokin

Publications Committee

Chairman E. Stupp

SID Headquarters

Jenny Needham, Data and Office Manager
610 S. Second Street, San Jose, CA 95112
408/977-1013, fax -1531
email: office@sid.org
www home page: <http://www.sid.org>

Table of Contents

- 429 Announcement: W. E. Howard, S. Morozumi, and P. Seats Become Associate Editors

SELECTED PAPERS FROM THE 9TH INTERNATIONAL DISPLAY WORKSHOPS

- 431 Introduction
- 433 Electro-optic properties of an intrinsic half-V-mode FLC and its application to field-sequential full-color LCDs using a poly-Si matrix TFT array
H. Furata *et al.*, *Tokyo University of Science, Japan*
- 437 Electrically commanded surfaces: A new LCD concept
L. Komitov, *Chalmers University of Technology & Göteborg University, Sweden*
- 443 Domain walls in photoaligned double-domain twisted-nematic LCDs
D. K. G. de Boer *et al.*, *Philips Research Labs, The Netherlands*
F. A. Fernández *et al.*, *University College of London, U.K.*
- 449 Novel liquid-crystal materials for AMLCDs
S. Kibe *et al.*, *Chisso Petrochemical Corp., Japan*
- 457 A broadband circularly polarized film
L-S. Luh *et al.*, *Union Chemical Laboratories, Taiwan*
- 461 An integrated poly-Si TFT current data driver with a data-line pre-charge function
M. Shimoda *et al.*, *NEC Corp., Japan*
- 467 Tracking system of the Fast Intelligent Tracking (FIT) tube
H. B. van den Brink and O. H. Willemsen, *Philips Research Laboratories, The Netherlands*
- 473 The oxide cathode revisited
D. den Engelsen, *LG.Philips Displays, The Netherlands*
- 481 Mechanical properties and fracture analysis of glass substrate for PDPs
K. Maeda and Y. Nakao, *Asahi Glass Co., Ltd., Japan*
- 485 New metacode coding concept for improving PDP gray-scale quality
S. Weitbruch *et al.*, *Thomson Multimedia Research Laboratory, Germany*
- 493 Development of new high-luminance green EL devices based on Eu-doped calcium thioaluminate materials system
A. M. Nakua *et al.*, *iFire Technology, Canada*
- 499 Properties and cathodoluminescence of $Y_2O_3S:Eu$ thin films
M. M. Sychoy, *St. Petersburg State Institute of Technology, Russia*
Y. Hatanaka, *Aichi University, Japan*
Y. Nakanishi *et al.*, *Shizuoka University, Japan*



continued

Membership in the Society for Information Display is open to qualified individuals active or interested in any area of information display technology or use. Membership includes subscriptions to the *Journal of the SID*, *Information Display*, and member's chapter publications and newsletters; members are admitted to Society functions at reduced rates. Individual membership costs \$75/year. For further information, including reduced fees for student members and the benefits of Sustaining Membership, contact SID Headquarters.

Subscriptions for non-members are \$100/year (\$110/year outside North America). Single copies are \$25; consult SID Headquarters for availability of back issues. Copies of the *Symposium Digests* are available from SID Headquarters; price varies with the year. Subscriptions to *Information Display* are available gratis to qualified individuals; contact SID Headquarters for information.

Editorial content of Society publications is the responsibility of the

individual authors; the Society does not endorse any opinions or products presented in its publications unless such endorsement is explicitly stated.

Copyright © 2003 The Society for Information Display. Copying of material in this *Journal* for internal or personal use, beyond the fair-use provisions granted by US Copyright Law, is subject to the payment of copying fees to the Copyright Clearance Center (CCC), 27 Congress St., Salem, MA 01970. The fee and article code number are listed at the bottom of the first page of each paper. All other copying of any material in this *Journal* without the specific permission of the Society is prohibited.

Journal of SID (ISSN 1071-0922) is published four times a year by the Society for Information Display. See above for subscription prices. POSTMASTER: Send address changes to *Journal of the SID*, 610 S. 2nd Street, San Jose, CA 95112.

Table of Contents (*Continued*)

- 505 Characteristics of aluminum oxinitride film grown by plasma-enhanced atomic layer deposition as the insulator of an electroluminescent device
J. W. Lim *et al.*, *ETRI, Korea*
- 511 A retinal scanning display with a wavefront curvature modulator
M. Watanabe *et al.*, *Brother Industries, Ltd., Japan*

SELECTED PAPERS FROM THE 22nd INTERNATIONAL DISPLAY RESEARCH CONFERENCE

- 517 Introduction
- 519 Novel photo-aligned LC-polymer compensation film for wide-view TN displays
T. Bachels *et al.*, *ROLIC Research, Ltd., Switzerland*
G. Gomez and E. Criton, *Thales Avionics LCD, France*
- 525 Multi-layered flat-surface micro-optical components directly molded on an LCD panel
F. Yamada *et al.*, *Tokyo Research Laboratory, Japan*
- 533 BiNem® manufacturing process for mass production
J. Angelé *et al.*, *Nemoptic, France*
J. W. Lin and J. Tung, *Picvue Electronics, Taiwan*
- 539 Threshold-voltage drift of amorphous-silicon TFTs in integrated drivers for active-matrix LCDs
H. Lebrun *et al.*, *Thales Avionics LCD, France*
- 543 Organic-polymer thin-film transistors for active-matrix flat-panel displays
S. Martin *et al.*, *The University of Michigan, U.S.A.*
- 551 Improvement of PDP discharge efficiency based on macro-cell studies
L. Tessier *et al.*, *Thomson Plasma, France*
J. Ouyang *et al.*, *Université P. Sabatier, France*
- 559 The Fast Intelligent Tracking (FIT) tube: Electronic aspects of a CRT without a shadow mask
P. J. Engelaar and P. J. G. Lieshout, *Philips Research Laboratories, The Netherlands*

MISCELLANEOUS PAPERS

- 571 A new solution for splay-to-bend transition in OCB mode with a twisted area
I. Inoue *et al.*, *Tohoku University, Japan*
Y. Yamada and Y. Ishii, *Sharp Corp., Japan*
- 579 Azo-dye aligning layers for liquid-crystal cells
V. Chigrinov *et al.*, *The Hong Kong University of Science and Technology*
H. Akiyama *et al.*, *Dai Nippon Ink & Chemicals, Inc., Japan*
- 585 Novel screen technology for high-contrast front-projection display by controlling ambient-light reflection
B. Katagiri *et al.*, *Tohoku University, Japan*

An integrated poly-Si TFT current data driver with a data-line pre-charge function

M. Shimoda
K. Abe
H. Haga
H. Asada
H. Hayama
K. Iguchi
D. Iga
H. Imura
S. Miyano

Abstract — We have developed an integrated poly-Si TFT current data driver with a data-line pre-charge function for active-matrix organic light-emitting diode (AMOLED) displays. The current data driver is capable of outputting highly accurate ($\pm 0.8\%$) current determined by 6-bit digital input data. A novel current-programming approach employing a data-line pre-charge function helps achieve accurate current programming at low brightness. A 1.9-in. 120×136 -pixel AMOLED display using these circuits was demonstrated.

Keywords — OLED, current data driver, current program, pre-charge.

1 Introduction

Poly-Si thin-film-transistor (TFT) OLED displays hold great promise for use in mobile phones, PDAs, PCs, and TVs, offering wide viewing angles, fast response, low power consumption, and panel thinness.

To obtain uniform images on poly-Si TFT AMOLED displays, it is necessary to ensure uniformity in the brightness of each pixel. This brightness is dependent on the current in the OLED that is driven by each pixel circuit, and an important issue for poly-Si TFT OLED displays has been the pixel-driving technology needed to achieve uniformity in OLED currents. The main difficulty is non-uniformity in the current-voltage characteristics of the poly-Si TFTs that form part of the pixel circuit. A number of pixel-driving schemes have been proposed to overcome this disadvantage.¹⁻⁷ Among them, those that employ a current-programming approach,^{4,5} which works to compensate for variations in both V_t and mobility in poly-Si TFTs, are effective in achieving good uniformity. Unfortunately, however, this approach suffers from a serious drawback. Specifically, the lowness of its current for a dark gray scale means that (1) programming time will be relatively long and (2) a highly accurate current data driver will be required. While such driving accuracy might be externally supplied, as with, for example, drivers composed of crystal-Si MOSFETs that offer high uniformity in current-voltage characteristics, the use of such drivers would increase programming time further because of the increase in high parasitic capacitance induced by the connection between the data drivers and the display panel. What is needed, then, is to integrate high-accuracy current data drivers into the AMOLED display substrate itself.

Further, there is also high parasitic capacitance in the data-line capacitors, and the need at low current levels to charge these data-line capacitors would also increase pro-

gramming time. To deal with this we need a data-line pre-charge function.

In this paper, we propose for AMOLED displays an integrated poly-Si TFT 6-bit current data driver and a novel current-programming approach that employs a data-line pre-charge function. The proposed design reduces current-programming times at low brightness and achieves accurate current programming. We also demonstrate a 1.9-in. poly-Si TFT OLED display which employs these circuits.

2 Current data driver

2.1 Driver configuration

Figure 1 is a block diagram of the poly-Si TFT 6-bit current data driver, which contains 60-bit shift-register 1, 6-bit data registers, 6-bit data latches, 60-bit shift register 2, 60 6-bit digital-to-current converters (DCCs), a standard current source circuit, pre-charge circuits, and 1-to-2 selectors. These last five components form the design's "current signal block."

Each 6-bit data register receives 6-bit digital gray-scale data when scanning signals are output from 60-bit shift register 1, and it outputs this data to each 6-bit data latch. The 6-bit data latches send 6-bit digital data to the 6-bit DCCs. The 6-bit DCCs carry out two different operations. One is to memorize values of the six standard currents (I_s , $I_s \times 2$, $I_s \times 4$, $I_s \times 8$, $I_s \times 16$, $I_s \times 32$) generated by the integrated standard current source circuit in the driver. The other is to output the gray-scale currents (I_s , $I_s \times 2$, ..., $I_s \times 62$, or $I_s \times 63$) determined by the digital data from the 6-bit data latch. Each 6-bit DCC is composed of 6 1-bit DCCs connected in parallel. Each 6-bit DCC sends an analog current signal to the pre-charge circuit. A 1-to-2 selector outputs the signals to each of two outputs of the driver, one after the other. This is accomplished over a single horizontal period. 60-bit shift register 2 outputs scanning signals to

Revised version of a paper presented at the 9th International Display Workshops (IDW '02) held December 4-6, 2002, in Hiroshima, Japan.

The authors are with SOG Research Laboratories, NEC Corp., 1120 Shimokuzawa, Sagami-hara, Kanagawa 229-1198 Japan; telephone +81-42-771-0689, fax -0780, e-mail: m-shimoda@ct.jp.nec.com.

K. Abe is with the 5th System LSI Division, 2nd Business Development Operations Unit, NEC Electronics Corp., Japan

© Copyright 2003 Society for Information Display 1071-0922/03/1103-0461\$1.00

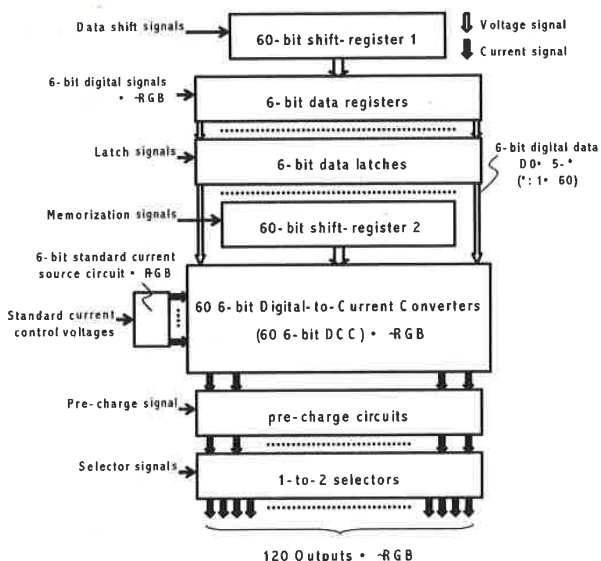


FIGURE 1 — Block diagram of current data driver, which contains shift register 1, 6-bit data registers, 6-bit data latches, shift-register 2, 6-bit digital-to-current converters (DCCs), a standard current source circuit, pre-charge circuits, and 1-to-2 selectors.

6-bit DCCs. The output timing of the scanning signals is synchronous with the 6-bit DCC's operation of memorizing the values of current supplied by the standard current source circuit.

2.2 1-bit digital-to-current converter

The current-copier-type 1-bit DCCs of which the 6-bit DCC is composed are able to output a highly accurate cur-

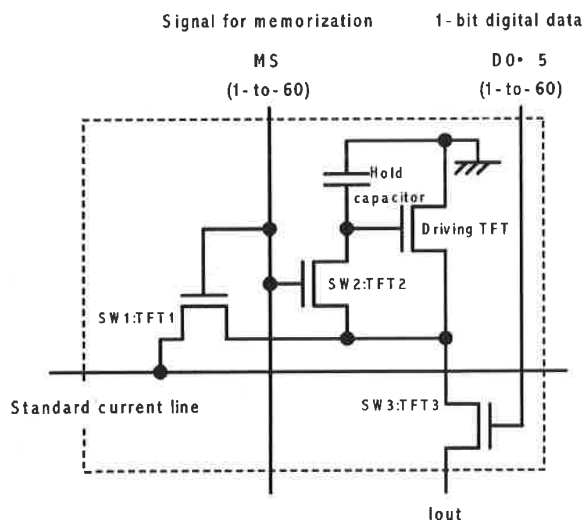


FIGURE 2 — Basic 1-bit current-copier-type DCC, composed of a current-copier circuit and a switching TFT (SW3) controlled by 1-bit digital data signals sent from a 6-bit data latch.

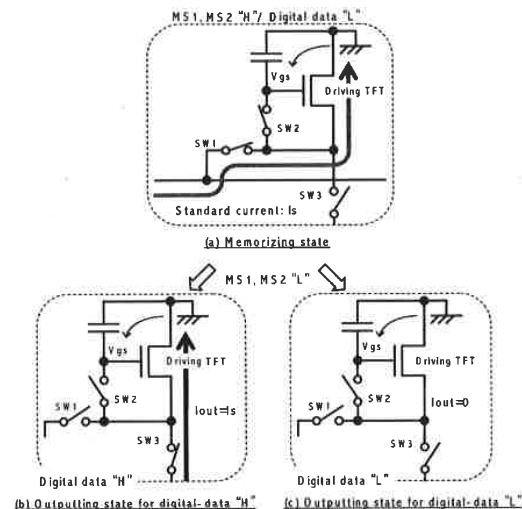


FIGURE 3 — Operation states of the current-copier-type 1-bit digital-to-current converter: the memorizing state, the outputting state for 1-bit data "H," and the outputting state for 1-bit data "L."

rent. In this section, in order to clarify what makes this accuracy possible, we give a detailed explanation of the 1-bit DCC's design and operations.

Figure 2 shows the basic circuit of a 1-bit DCC. It is composed of a current-copier circuit and a switching TFT (SW3) controlled by 1-bit digital data signals sent from a 6-bit data latch. The current-copier circuit is composed of a driving TFT, two memorizing-switches TFT (SW1, SW2) controlled by a signal [MS (1-to-60)] sent from 60-bit shift register 2, and a hold capacitor.

Figure 3 shows the three operation states of the 1-bit DCC: the memorizing state, the outputting state for 1-bit data "H," and the outputting state for 1-bit data "L." In the memorizing state, SW1 and SW2 are ON, SW3 is OFF, and the hold capacitor and the gate capacitor of the driving TFT have been charged in order to send a standard current (I_s , $I_s \times 2$, $I_s \times 4$, $I_s \times 8$, $I_s \times 16$, or $I_s \times 32$) into the driving TFT (in Fig. 3, this current is " I_s "). In the outputting states, SW1 and SW2 are OFF, SW3 is ON or OFF, and the driving TFT outputs " I_s " or zero so that the hold capacitor and the driving TFT's gate capacitor can retain their charge so as to send " I_s ." Note that of the four TFTs in this 1-bit DCC, three are switches; the fourth is the "driving TFT" used for memorizing and outputting.

2.3 Experiments

We have experimentally fabricated the 6-bit DCC described above. Its measured output characteristics are shown in Fig. 4. Here, the output current value of the driver increases as the value of the gray scale increases, which indicates 6-bit monotony for the current output. Figure 5 shows deviations among the MSB (63 gray-scale) output currents for four outputs in each frame, as measured for five

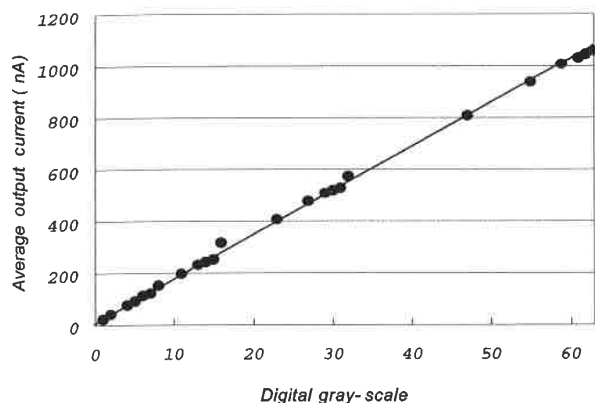


FIGURE 4 — Current driver output characteristics.

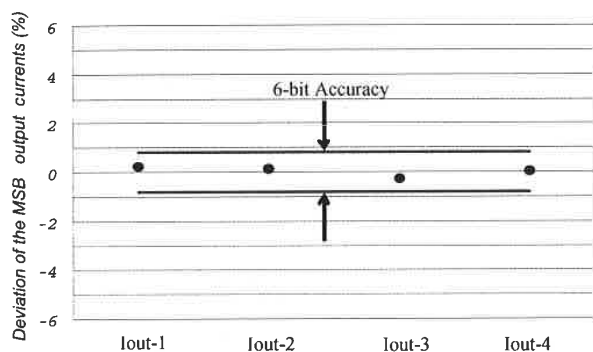


FIGURE 5 — Deviation among four output currents for four outputs in each frame, as measured for five samples.

samples. As may be seen, at MSB, where the output current is the highest, the current driver satisfies 6-bit accuracy ($\pm 0.8\%$) requirements.

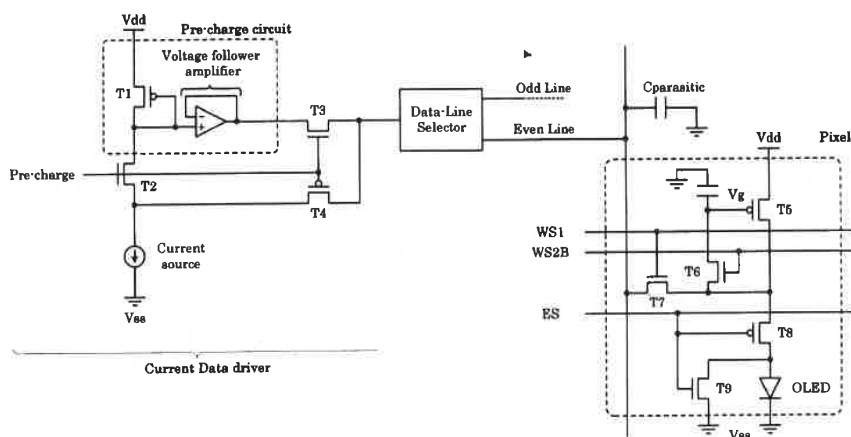


FIGURE 6 — The schematic diagram of both the pixel circuit and the current data driver with the pre-charge circuit.

3 Novel current-programming approach with data-line pre-charge function

As previously noted, the 6-bit DCCs are able to output current accurately, with 6-bit resolution. The problem of long current-programming time remains, however, and in this section we explain our novel current-programming approach, which employs a data-line pre-charge function in order to reduce current-programming times and to achieve accurate current-programming at low gray-scale levels. This approach has become possible because the current data driver has been integrated into the display substrate itself.

3.1 Circuit design

Figure 6 is a diagram of both the pixel circuit and the integrated current data driver containing a pre-charge circuit. The pre-charge circuit is composed of one TFT (T1) and a voltage-follower amplifier. TFTs (T2 ~ T4) are switching TFTs. The current source indicated in the diagram represents a 6-bit DCC which generates an analog current on the basis of 6-bit digital data that has been input to it, as was previously noted in Section 2. The output of the data driver is connected to a data line *via* a selector, which is used to select an appropriate data line for connection.

The pixel circuit contains five TFTs: one driving TFT (T5) and four switching TFTs (T6 ~ T9). The gate length and width of the driving TFT (T5) are designed to be the same as those of the driving TFT in the pre-charge circuit. The switching TFTs are controlled by signals that are output by an integrated gate driver to three pixel circuit inputs [Write scan1 (WS1), Write scan 2A/B (WS2A/B), and Erase scan (ES)]. In order to control the emission period, the switching TFT (T8) is used to cut off the current to the OLED, and the switching TFT (T9) is used to initialize the OLED.

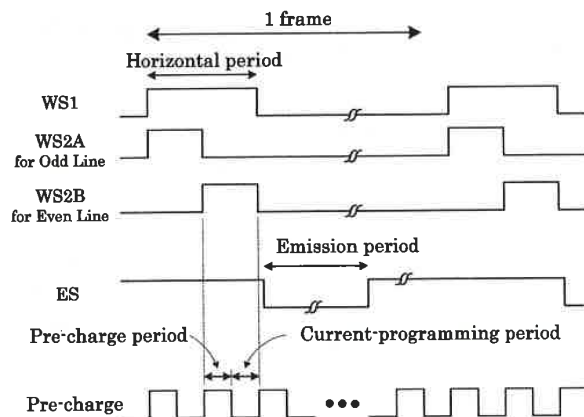


FIGURE 7 — Timing chart illustrating current data driver and pixel circuit operations. The signals Write scan1 (WS1), Write scan 2A/B (WS2A/B), and Erase scan (ES) are output by an integrated gate driver.

3.2 Circuit operations

Figure 7 is a timing chart which illustrates how the current data driver and pixel circuit work.

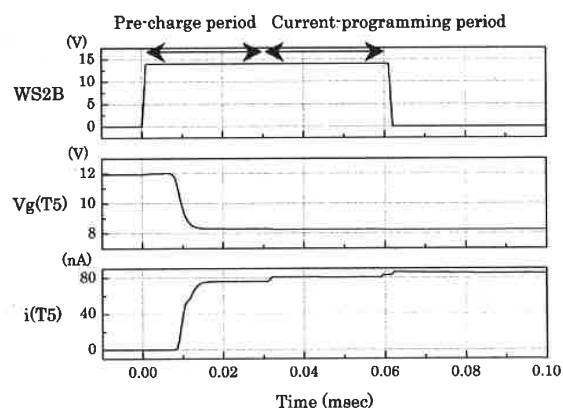
A single horizontal period contains both the pre-charge and current-programming periods. In the pre-charge period, T2 and T3 are turned on, T4 is turned off, and current from the current source flows into T1. A voltage-follower amplifier outputs the gate voltage of T1 into the gate electrode of T5, with T6 and T7 turned on. This pre-charge function rapidly pre-charges the voltage in the gate electrode of T5 so that a current roughly equivalent to the value of the current source flows through T5.

In the subsequent current-programming period, T4 is turned on, T2 and T3 are turned off, the pre-charge circuit is disconnected, and the current from the current source is directly supplied to the pixel circuit. While a pre-charge error may be generated if there exist variations in characteristics between T1 and T5, or if there is an offset voltage in the voltage-follower amplifier, this error can be compensated for during current-programming periods. Setting the current from the current source high makes it possible to compensate for the greater pre-charge error that occurs during current-programming periods. This improves the accuracy of current programming significantly.

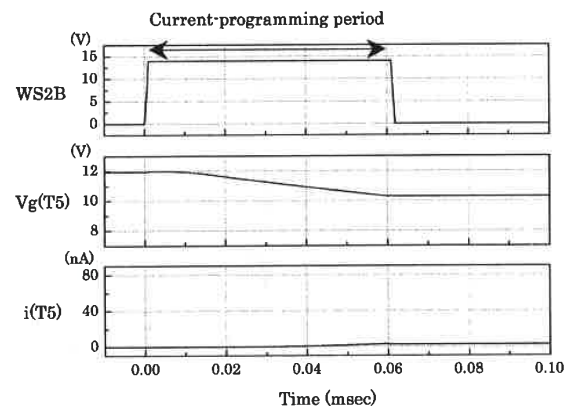
After the horizontal period, T6 and T7 are turned off, T8 is turned on, and a current programmed by the data driver is supplied to the OLED. The emission period is controlled by erase-scan signals which turn T8 and the reset TFT T9 on and off. Setting the emission period short makes it possible to set the current of the current source high enough to obtain the same average brightness over successive frame periods.

3.3 Simulation results

Figures 8(a) and 8(b) show, respectively, simulation results for transient response in cases both with and without pre-



(a) Pixel-driving with pre-charge



(b) Pixel-driving without pre-charge

FIGURE 8 — Simulation results for transient response in cases both with (a) and without (b) pre-charge. Both (a) and (b) show response for levels from the current source of from 0 to 80 nA.

charge. Both show response for levels from the current source of from 0 to 80 nA. As may be seen in Fig. 8(b), without pre-charge, the value of the current from the current source cannot be programmed into the pixel circuit because that current, 80 nA, is too small to discharge, within the horizontal period, T5 gate capacitance and data-line capacitance sufficiently for 80 nA to flow through T5. By way of contrast, as may be seen in Fig. 8(a), with pre-charge, programming can be performed because both the T5 gate capacitance and data-line capacitance can be discharged sufficiently within the pre-charge period by the voltage-follower amplifier in the pre-charge circuit.

Figure 9 shows simulation results for OLED current accuracy vs. emission ratio (emission period/maximum emission period, expressed in %) for three cases of pre-charge error with respect to green (G), which has the smallest OLED current value among R, G, and B. We have confirmed that setting smaller emission periods makes higher accuracy possible. We have also found that a 64-level gray scale can be achieved by setting the emission ratio to

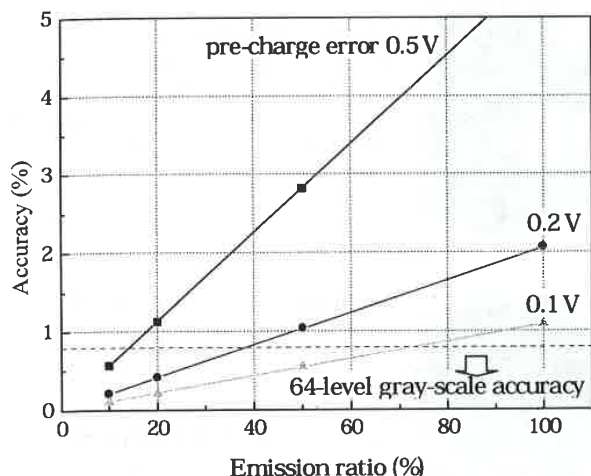


FIGURE 9 — Simulation results for OLED current accuracy vs. emission ratio (emission period/maximum emission period, expressed in %) for three cases of pre-charge error.

roughly 15% at 0.5 V of pre-charge error, about 40% at 0.2 V, and about 70% at 0.1 V.

4 Displays

We have fabricated an AMOLED display based on the design presented here. Specifications for the developed display are summarized in Table 1. The display contains gate drivers, a current data driver, and level shifters. Both RGB digital data signals (6 bits each) and digital control signals are supplied at 3 V from an external controller. Figure 10 shows a sample display image. Here, the emission ratio is about 40%. Good pixel-to-pixel luminance uniformity and gray-scale images have been achieved with this display.

5 Conclusion

We have developed an integrated poly-Si TFT current data driver based on a current-copier technique and a novel current-programming approach with a data-line pre-charge function. The integrated current data driver eliminates of the need for external current sources, reduces cost, and

TABLE 1 — Display specifications.

Display size	1.9 in.
Pixel count	120 × RGB × 136
Pixel pitch	96 ppi
Peak luminance	>150 cd/m ²
Input data	Digital 6 bit × RGB
Input level	3 V I/F
Integrated circuits	Current data driver
	Gate driver
	Level shifter

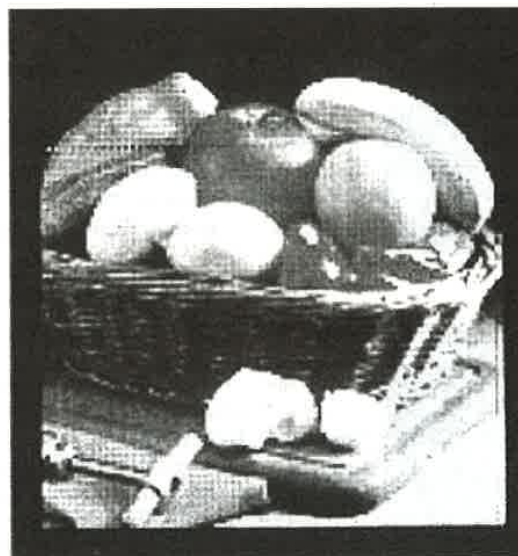


FIGURE 10 — Image on the fabricated AMOLED display.

This figure is reproduced in color on page 592.

increases reliability in AMOLED display systems, and the novel current-programming approach improves the accuracy of current programming at low brightness. These circuits make it possible to produce AMOLED displays with good gray-scale image quality and good pixel-to-pixel luminance uniformity.

Acknowledgments

We are very grateful to Mr. S. Kaneko, head of the SOG Research Labs for his important guidance and encouragement. We also thank the members of the SOG Research Labs for their help in fabricating the poly-Si TFT substrates, and we further wish to express our appreciation to the members of the R&D Technical Support Center in NEC for their valuable support during the course of this work.

References

- 1 R Dawson *et al*, *IEEE IEDM '98*, 875 (1998).
- 2 K Inukai *et al*, *SID Intl Symp Digest Tech Papers*, 924 (2000).
- 3 M Kimura *et al*, *Proc IDW '99*, 171 (1999).
- 4 I M Hunter *et al*, *AMLCD2000 Digest*, 249 (2000).
- 5 R Hattori *et al*, *AMLCD2001 Digest*, 223 (2001).
- 6 T Sasaoka *et al*, *SID Intl Symp Digest Tech Papers*, 384 (2001).
- 7 A Yumoto *et al*, *Proc IDW '01*, 1395 (2001).
- 8 K Abe *et al*, *Proc EuroDisplay*, 279 (2002).



Masamichi Shimoda received his B.E. degree in electrical engineering from Meiji University in 1988. He joined NEC Corporation in 1988 and has recently been engaged in the research and development of polycrystalline-silicon TFT circuits and their application devices.



Katsumi Abe received his B.S. and M.S. degrees in nuclear engineering from Kyoto University in 1993 and 1995, respectively. He joined NEC Corporation in 1995, and in 2002, he moved to NEC Electronics Corporation. In recent years, he has been engaged in the research and development of polycrystalline-silicon TFT circuits and their application devices. Mr. Abe is a member of the Society for Information Display.



Koichi Iguchi received his B.S. degree in electronic engineering from the University of Electro-Communications in 1995. He joined NEC Corporation in 1995. He has recently been engaged in the research and development of polycrystalline-silicon TFT circuits and OLED displays.



Hiroshi Haga received his B.E. degree in image science and technology from Chiba University in 1994. Since joining the Display Device Research Laboratory, Functional Devices Research Laboratories of NEC Corporation in 1994, he has been engaged in the research and development of polycrystalline-silicon TFT circuits and their application devices. Mr. Haga is a member of the Society for Information Display, the Institute of Electronics, Information and Communication

Engineers, and the Institute of Image Information and Television Engineers.



Daisuke Iga received his B.S. and M.S. degrees in electrical engineering and electronics from Aoyama Gakuin University, Tokyo, Japan in 1994 and 1996, respectively. He joined NEC Corporation in 1996 and has recently been engaged in the development of polycrystalline-silicon TFTs, with particular respect to their LCD applications.



Hideki Asada received his B.E. and M.E. degrees in electrical engineering from Keio University in 1985 and 1987, respectively. In 1987, he joined the Central Research Laboratories, NEC Corporation. Since then, he has been engaged in the research and development of polycrystalline-silicon TFT circuits and their application devices. Mr. Asada is a member of the Society of Information Display.



Hironori Imura received his B.E. degree from Osaka University in 1984. He joined NEC Corporation in 1984 and has recently been engaged in the research and development of OLED displays, with a particular focus on OLED process technology and polycrystalline-silicon TFT process technology.



Hiroshi Hayama received his B.S., M.S., and Ph.D. degrees from the Tokyo Institute of Technology, Tokyo, Japan in 1978, 1980, and 1995, respectively. He joined the Central Research Laboratories, NEC Corporation, Kawasaki, Japan in 1980, where he has been engaged in research on highspeed CMOS/SOS, three-dimensional integration of ICs, display-driver LSIs, thin-film transistors on amorphous substrates, and TFT-LCDs. Dr. Hayama is a member of the

Society of Information Display, the Institute of Electronics, Information and Communication Engineers of Japan, and the Japan Society of Applied Physics.



Soichiro Miyano received his B.E. degree from Kyoto University, Kyoto, Japan, in 1977. He joined NEC Corporation in that year and has worked on silicon micro-machining technologies, as well as on such devices as silicon micro-accelerometers and vacuum microelectronics devices. Currently, he is responsible for polycrystalline-silicon TFT process, device, circuit, and panel technologies for AMOLEDs. Mr. Miyano is a member of IEEE.