An addressing technique for displaying restricted patterns in rms-responding LCDs by selecting a few rows at a time

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Abstract — An addressing technique that will allow rms-responding matrix LCDs to display restricted patterns is proposed. This technique is based on the selection of a few rows at a time while scanning the display. In applications such as logic analyzers and oscilloscopes, mostly single-valued functions of time are displayed. This restriction in the image is useful in enhancing the selection ratio so that good contrast is achievable even with TN-LCDs. It is shown that a large reduction in the hardware complexity of the column drivers and the supply voltage is possible when the waveforms being displayed do not overlap each other and are equally spaced.

Keywords — *Passive-matrix LCDs, addressing technique, restricted pattern, multi-line addressing.*

1 Background

A matrix display is usually designed to display general patterns. Hence, it is possible to display 2^N different patterns in any column of a matrix display with N rows. However, most of these 2^N combinations do not occur in displays for oscilloscopes and logic analyzers. Shanks and Holland[1] have used the correlation properties of pseudo random binary sequence (PRBS) for displaying a single waveform on a matrix LCD. An infinite selection ratio is possible because only one waveform is displayed. An addressing technique for displaying multiple waveforms on a matrix LCD was proposed in 1986.[2] This technique is based on scanning the matrix by selecting one row at a time. The selection ratio of this technique is independent of matrix size and only depends on the number of waveforms (w) being displayed. In these displays the number of selected pixels in each column is equal to w. The number of background pixels (N-w) is usually much higher than w. The column voltage for the background pixels is chosen to be the same as that for the unselected rows. The column voltage for the selected pixels (*i.e.*, points on the waveform) is chosen to be in-phase with the row-select voltage. This is equivalent to assigning data 0 to the background pixel and +1 to the selected pixel. Here, the rms voltage of selected pixels is lower than that of the background pixels. Hence, this technique is referred to as the restricted pattern addressing technique – negative contrast (RPAT-NC).[3] The rms voltage across each selected pixel can also be made greater than the background pixel by choosing the column voltage for a selected pixels to be out of phase with the row-select voltage. This technique is referred to as the restricted pattern addressing technique – positive contrast (RPAT-PC). The selection ratios of RPATs are independent of matrix size and are higher than that of the conventional technique.[4] Hence, a good contrast ratio can be achieved even in LCDs with large matrix sizes. Instantaneous voltage across any pixel in a display addressed with RPATs is zero during most of the time intervals, and this may lead to flicker when N is very large. The supply-voltage requirement of RPATs also increases with matrix size. In order to overcome these problems a new flicker-free addressing technique was proposed in 1996.[5] This technique is based on selecting all the rows in the matrix display simultaneously, as in the case of active addressing.[6] Here the N rows in the matrix display are driven with waveforms corresponding to a set of orthogonal functions derived from PRBS. The column waveforms are generated by taking the orthogonal transform of the data to be displayed. Here, again, the data assigned to the background pixel is zero while +1 is assigned to the selected pixel. This technique is referred to as PRBS-NC. The lower rms voltage is supplied to the selected pixels compared to the background pixels. In a similar technique known as PRBS-PC, the selected pixels receive a higher rms voltage when the data assigned to the selected pixel is –1. A higher address duty factor in the PRBS techniques results in the suppression of flicker and frame response when N is large. The number of transitions in the row waveforms is almost the same when orthogonal functions derived from pseudo random binary sequence is used. This results in a good brightness uniformity of the pixels as compared to that of RPATs. The supply-voltage requirement in the PRBS techniques is independent of the matrix size, and it is lower than that of RPATs. The only disadvantage of PRBS techniques is that the number of voltage levels in the column waveform increases with w as in the case of displays in a logic analyzer.

In summary, both line-by-line addressing as well as simultaneous selection of all the rows has been considered

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in the past for displaying restricted pattern. We explored the possibility of selecting a few rows at a time. This approach is analogous to multi-line addressing (MLA) for displaying general patterns. We have found that it is possible to reduce the number of column voltage levels when the number of waveforms being displayed are large. Hence, it is possible to reduce the hardware complexity of the column drivers in special cases such as displays for a logic analyzer.

2 Technique

In this present work for displaying restricted patterns we have opted to scan the display by selecting a few rows at a time. This approach for driving matrix LCDs will be referred to as multi-line restricted pattern addressing (MLRPA). Here, the N rows to be multiplexed in a display are divided into (N/s) non-intersecting subgroups, with each subgroup consisting of s address lines. The data to be displayed in a selected subgroup in any one of the columns is an s-bit word represented d_{ks+i}. Here the value of i ranges from 1 to s and the variable k represents the selected subgroup and ranges from 0 to $[(N/s) - 1]$. By assigning the data for the background pixels to be 0, the selection ratio is independent of matrix size. Background pixels receive a higher rms voltage compared to the selected pixels when the data for the selected pixels is assigned to be +1. This results in negative contrast. The display exhibits a positive contrast when the data for the selected pixel is assigned to be −1. However, the selection ratio will be lower than that for the negative contrast mode. As in all the restricted-pattern addressing techniques, these two variants will be referred to as MLRPA – NC and MLRPA – PC, respectively.

A set of s orthogonal functions are used for selecting a subgroup of a matrix LCD. Simple orthogonal functions such as Walsh functions are preferred. Let $O(i,j)$ be the matrix representing the discrete version of the orthogonal functions. Here, the elements of the matrix $O(i,j)$ are just +1 or −1 and the following condition is satisfied:

$$\sum_{j=1}^{q} O(m,j)O(n,j) = \begin{cases} q & \forall m = n \\ 0 & \forall m \neq n \end{cases}, \tag{1}$$

wherein q is the scaling factor which depends on the actual orthogonal matrix selected for scanning the display. In the case of Walsh functions and Hadamard matrices, q is the total number of columns in the orthogonal matrix. The columns of the orthogonal matrix $O(i,j)$ are called row-select patterns.

A subgroup is selected with voltages corresponding to one of the q row select patterns. The amplitude of these voltages is either $+V_r$ or $-V_r$ corresponding to +1 or −1 in the row-select pattern. The remaining $(N–s)$ rows of the unselected subgroups are grounded. The data in the selected subgroup is represented by a column vector, with elements taking values of 0 or +1. The column voltage is the dot product of the row-select pattern and the data vector. This can be mathematically represented as

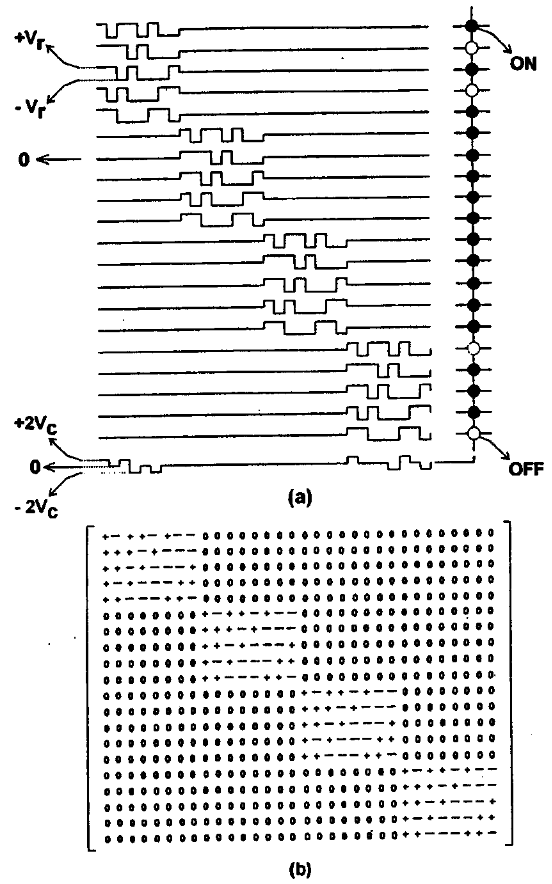

FIGURE 1 — Row-select pulses are adjacent to each other. (a) Row and column waveforms for a matrix LCD and (b) corresponding row select matrix. (Note: The symbols '+' represents a +1 and '–' represents a –1).

$$C_k(j) = \sum_{i=1}^{s} O(i,j) d_{ks+i} \tag{2}$$

where $C_k(j)$ is the column voltage (normalized to V_c) corresponding to the j^{th} row-select pattern for the k^{th} subgroup. Similarly, column voltages for all the columns in the matrix are determined independently. Both the row and column voltages are applied simultaneously to the matrix display for a time duration τ. The process is repeated with another row-select pattern either in the same subgroup or a different subgroup. A cycle is completed when all the subgroups (N/s) are selected with all the row-select patterns once. The display is refreshed continuously by repeating this cycle. The scanning of the matrix can be done in a number of ways. The subgroup may be selected with all the row-select patterns once before selecting another subgroup. This is illustrated in Fig. 1, for N = 20 and s = 5. However, this method is not

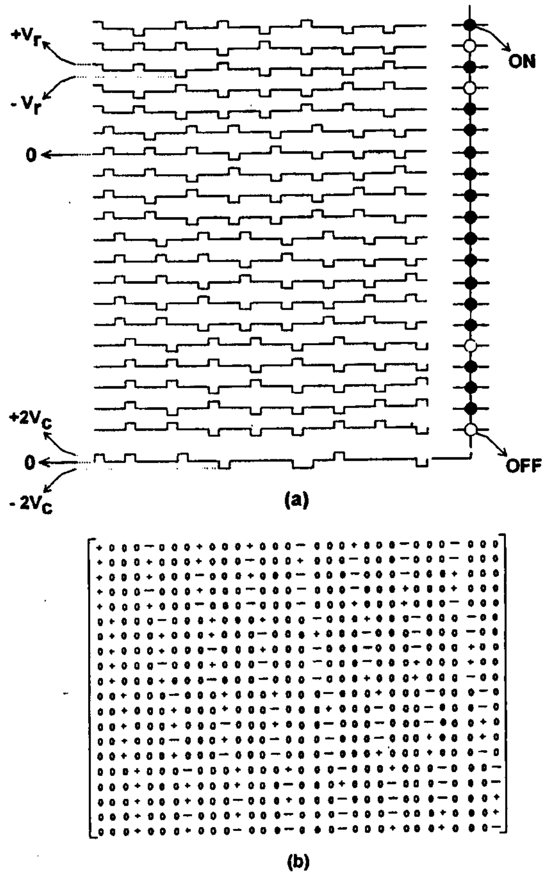

FIGURE 2 — The row-select pulses are distributed in a cycle. (a) Row and column waveforms for a matrix LCD and (b) corresponding row-select matrix. (Note: The symbols '+' represents a +1 and '–' represents a –1).

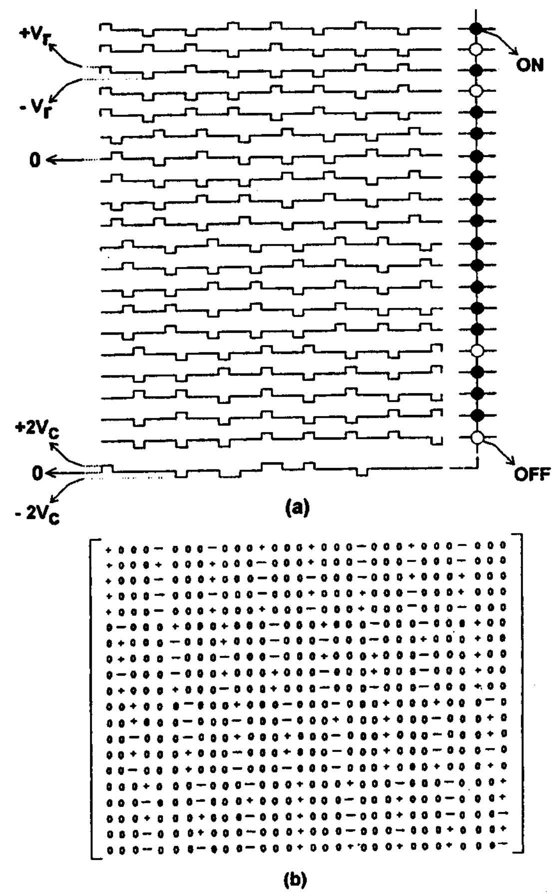

FIGURE 3 — The row-select pulses are distributed in a cycle by selecting a subgroup with different row select pattern. (a) Row and column waveforms for a matrix LCD and (b) corresponding row select matrix. (Note: The symbols '+' represents a +1 and '–' represents a –1).

suitable for fast-responding LCDs. Because the transmission of OFF pixels increases due to clustering of the usually large amplitude row-select pulses. This may lead to the *frame response phenomena.* In order to suppress the frame response, all the subgroups in the matrix LCD may be selected with one row-select pattern once before changing to another row-select pattern, as shown in Fig. 2. Good brightness uniformity of the pixel can be obtained by changing the row-select pattern whenever a new subgroup is selected. This is illustrated in Fig. 3.

3 Analysis

A subgroup is selected with voltages corresponding to one of the row-select patterns. The voltages are $+V_r$ or $-V_r$, corresponding to +1 or –1. The row voltage is zero during the $(N/s - 1)q$ time intervals when other rows are being selected. The column voltage $C_k(j)$ (normalized to V_c) which is the dot product of the row select pattern and the data vector in the k^{th} subgroup is given by

$$C_k(j) = \sum_{i=1}^{s} O(i,j) d_{ks+i},$$

where j ranges from 1 to q and k ranges from 0 to $N/s - 1$. The voltage across any pixel is the difference between row and column voltages. The rms voltage across the i^{th} pixel $(1 \le i \le s)$ in the k^{th} subgroup $[0 \le k \le (N/s - 1)]$ is given by

$$V_{ks+i}(rms) = \sqrt{\frac{\sum_{j=1}^{q}[V_r O(i,j) - C_k(j)]^2 + \sum_{\substack{n=0 \\ n \ne k}}^{(N/s-1)} \sum_{j=1}^{q}[C_n(j)]^2}{(N/s)q}}. \tag{3}$$

$$V_{ks+i}(rms) = \sqrt{\frac{\sum_{j=1}^{q}\left[(V_r O(i,j))^2 - 2V_r O(i,j)\sum_{i=1}^{s} O(i,j)d_{ks+i}\right] + \sum_{n=0}^{(N/s-1)}\sum_{j=1}^{q}\left[\sum_{i=1}^{s} O(i,j)d_{ns+i}\right]^2}{(N/s)q}}$$

$$V_{ks+i}(rms) = \sqrt{\frac{V_r^2\sum_{j=1}^{q}[O(i,j)]^2 - 2V_r d_{ks+i}\sum_{j=1}^{q}[O(i,j)]^2 + \sum_{n=0}^{(N/s-1)}\sum_{i=1}^{s}[d_{ns+i}]^2\sum_{j=1}^{q}[O(i,j)]^2}{(N/s)_q}}$$

$$V_{ks+i}(rms) = \sqrt{\frac{V_r^2 q - 2V_r d_{ks+i} q + q\sum_{n=0}^{(N/s-1)}\sum_{i=1}^{s}[d_{ns+i}]^2}{(N/s)q}}. \quad (4)$$

This is the general expression for the multi-line addressing (MLA) technique. In order to display w waveforms in a matrix LCD, only w pixels in each column carry the information, and $(N\text{-}w)$ pixels in each column are the background pixels. Data for the w information carrying pixels are assigned to be +1, while the remaining $(N\text{-}w)$ background pixels are assigned to be 0. This results in a negative contrast (NC) mode, with selected pixels receiving a lower rms voltage compared to background pixels. If the $V_{ks+i}(rms)$ in Eq. (4) corresponds to the one for the selected pixel (*i.e*, d_{ks+i} = +1), then the rms voltage across the selected pixel (*i.e.*, OFF) after simplification is

$$V_{off}(rms) = \sqrt{\frac{V_r^2 q - 2V_r q + wq}{(N/s)q}},$$

$$V_{off}(rms) = \sqrt{\frac{V_r^2 - 2V_r + w}{(N/s)}}. \quad (5)$$

Similarly, if $V_{ks+i}(rms)$ corresponds to a background pixel (*i.e.*, $d_{ks+i} = 0$), then from Eq. (4) the rms voltage across the background pixel (*i.e.*, ON) is

$$V_{on}(rms) = \sqrt{\frac{V_r^2 q + wq}{(N/s)q}},$$

$$V_{on}(rms) = \sqrt{\frac{V_r^2 + w}{(N/s)}}. \quad (6)$$

The selection ratio defined as (V_{on}/V_{off}) is optimum when $V_r = \sqrt{w}$.

Thus, the optimum selection ratio for the MLRPA–NC mode is given by

$$SR = \sqrt{\frac{\sqrt{w}}{\sqrt{w}-1}}. \quad (7)$$

This selection ratio is same as that of RPAT–NC and PRBS–NC.

Similarly, by assigning data for the selected pixels to be −1 for the positive contrast mode, selection ratio for MLRPA–PC is given by

$$SR = \sqrt{\frac{\sqrt{w}+1}{\sqrt{w}}}. \quad (8)$$

This is same as that obtained for RPAT–PC and PRBS–PC techniques. Thus, the selection ratios for restricted pattern-addressing techniques are independent of the matrix size.

4 Supply voltage requirement of MLRPA–NC

The supply voltage (V_{sup}) for the driver is calculated by the maximum swing in the addressing waveforms as given below.

Case I:

If $(s \le \sqrt{w})$, then $2V_r > 2sV_c$, where $2V_r$ is the maximum swing in the row waveform and $2sV_c$ is the maximum swing in the column waveform. The supply voltage is given by

$$V_{sup} = 2V_r, \quad V_{sup} = 2\sqrt{w}\,V_c,$$

where

$$V_c = \sqrt{N/2ws}\,V_{sat},$$

i.e.,

$$V_{sup} = \sqrt{\frac{2N}{s}}V_{sat}. \quad (9)$$

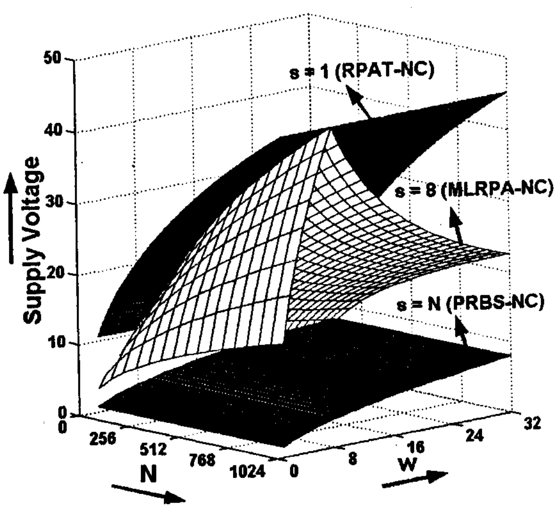

FIGURE 4 — Comparison of the supply voltage requirement (normalized to V_{sat}) for displaying restricted patterns using the MLRPA–NC technique when s = 8 with those of PRBS–NC and RPAT–NC.

Case II:

If $(\sqrt{w} < s < w)$, then the maximum swing in the addressing waveform is $2sV_c$, thus the supply voltage is

$$V_{sup} = 2sV_c,$$

$$V_{sup} = \sqrt{\frac{2Ns}{w}}V_{sat}. \tag{10}$$

Case III:

If $(s \geq w)$, then the maximum swing in the addressing waveform is $2wV_c$, the supply voltage is given by

$$V_{sup} = 2wV_c,$$

$$V_{sup} = \sqrt{\frac{2wN}{s}}V_{sat}. \tag{11}$$

Figure 4 shows a comparison graph of the supply voltage requirement for displaying restricted patterns for various values of N and w by selecting 8 rows at time.

5 Results

For case of the PRBS technique,[5] where in all the rows are selected simultaneously to display w waveforms, $(w + 1)$ column voltage levels are required. Hardware complexity of the column drivers also increases as the number of waveforms being displayed is increased. For the present MLRPA techniques, one can choose $s < w$ so that maximum number of column voltage levels can be limited to $s + 1$ instead of $w + 1$. Thus, the number of column voltage levels depends on the maximum number of selected pixels in the selected subgroups. However, usually not all the waveforms will overlap

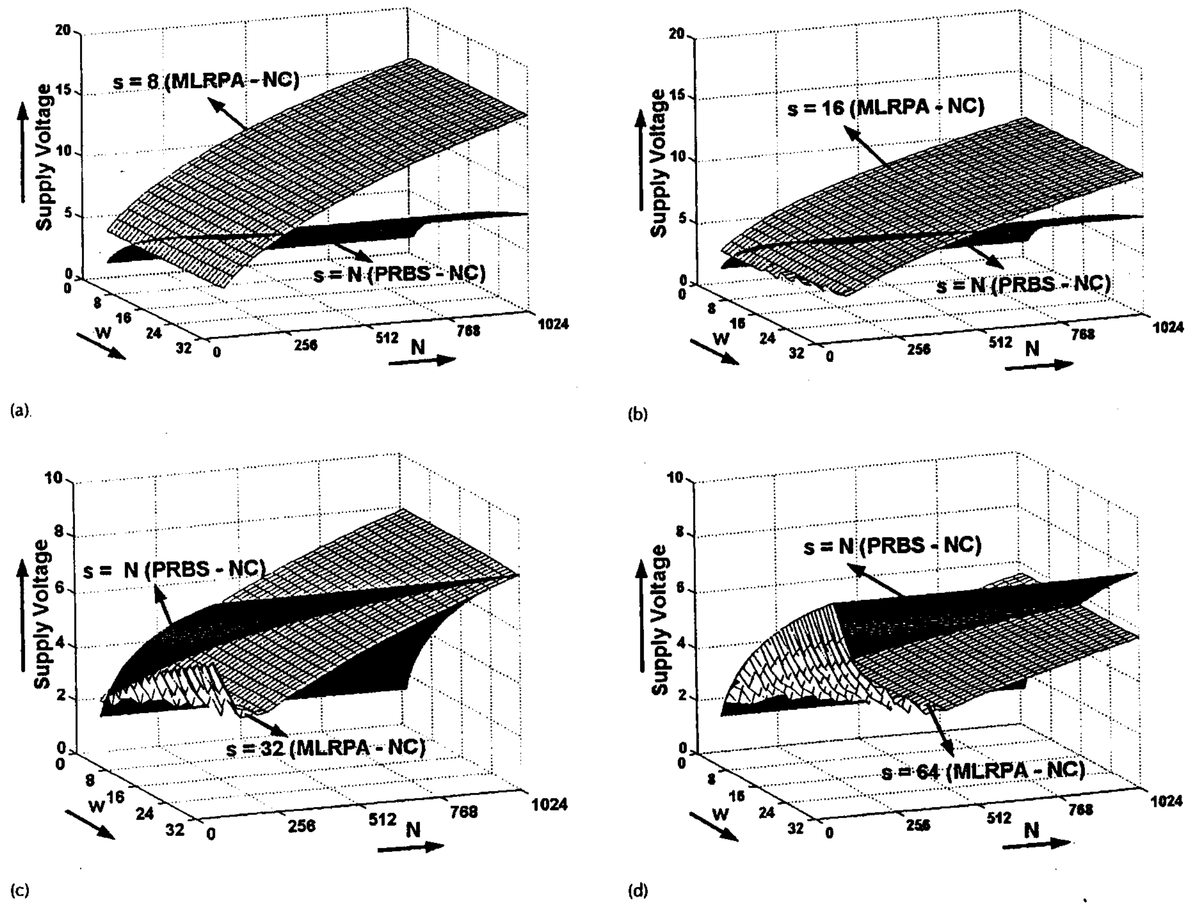

FIGURE 5 — (a) Comparison of the supply voltage requirement (normalized to V_{sat}) for displaying restricted pattern using the MLRPA–NC technique when $s = 8$ with that of PRBS–NC. (b) Comparison of the supply voltage requirement (normalized to V_{sat}) for displaying restricted patterns using the MLRPA–NC technique when $s = 16$ with that of PRBS–NC. (c) Comparison of the supply voltage requirement (normalized to V_{sat}) for displaying restricted patterns using the MLRPA–NC technique when $s = 32$ with that of PRBS–NC. (d) Comparison of the supply voltage requirement (normalized to V_{sat}) for displaying restricted patterns using the MLRPA–NC technique when $s = 64$ with that of PRBS–NC.

TABLE 1

N	w	MLRPA-NC Technique			PRBS-NC Technique		RPAT-NC
		s	No. of voltage levels required	Supply voltage (normalized to V_{sat})	No. of voltage levels required	Supply voltage (normalized to V_{sat})	No. of column voltage levels required (=4) / Supply voltage (normalized to V_{sat})
64	4	8 16 32	3 2 3	4.000 2.8284 2.000	5	2.8284	5.6569
128	8	8 16 32 64	3 2 3 5	5.6569 4.0000 2.8284 2.8284	9	4.0000	8.0000
256	8	8 16 32 64 128	3 3 2 3 5	8.0000 5.6569 4.0000 2.8284 2.8284	9	4.0000	11.3137
	16	8 16 32 64 128	3 2 3 5 9	8.0000 5.6569 4.0000 2.8284 4.0000	17	5.6569	
512	16	8 16 32 64 128 256	3 3 2 3 5 9	11.3137 8.0000 5.6569 4.0000 2.8284 4.0000	17	5.6569	16.0000
	32	8 16 32 64 128 256	3 2 3 5 9 17	11.3137 8.0000 5.6569 4.0000 4.0000 5.6569	33	8.0000	16.0000

each other in a selected subgroup, and thus the number of column voltage levels may be less than $s + 1$.

In applications such as logic analyzers, the waveforms generally do not overlap with each other and are equally spaced. One can choose $N/s = w$, then only one selected pixel will be present in each subgroup. Hence, only two column voltage levels ($+V_c$ and $-V_c$) are required. If $(N/s) > w$, then in some subgroups none of the selected pixels may be present. Thus, only three column voltage levels ($+V_c$, 0 and $-V_c$) are needed. Hence, the number of column voltage levels can be reduced considerably for a given application.

Supply voltage for the drive electronics is given by the maximum swing in the addressing waveforms. Lower amplitude pulses reduce the supply voltage of the drive electronics. Figure 5 shows the supply voltage requirement (normalized to V_{sat}) of MLRPA–NC in comparison with PRBS-NC for various values of s.

Table 1 summarizes the number of column voltage levels as well as the supply voltage requirement of MLRPA–NC in comparison with that of the RPAT-NC and PRBS–NC techniques. A computer program has been developed to generate the data of row and column waveforms for a 256-row matrix LCD to display eight waveforms. The data from the program was loaded into the waveform generator "*WFG 500*," and typical row and column waveforms were applied to a single pixel. The supply-voltage requirement was measured using an electro-optic measurement setup. Figure 6 shows the supply-voltage requirement

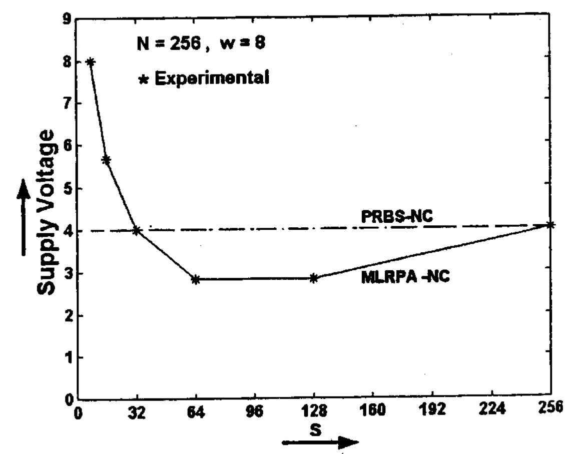

FIGURE 6 — Supply voltage (normalized to V_{sat}) of the MLRPA–NC technique for various values of s.

TABLE 2

N	w	s	$[V_{sup}(\text{MLRPA–NC})/V_{sup}(\text{PRBS–NC})]\times 100$	No of voltage levels required (MLRPA–NC)/(PRBS–NC)
64	4	32	70.71	3/5
128	8	32	70.71	3/9
		64	70.71	5/9
256	8	64	70.71	3/9
		128	70.71	5/9
	16	32	70.71	3/17
		64	49.99	5/17
		128	70.71	9/17
512	16	64	70.71	3/17
		128	49.99	5/17
		256	70.71	9/17
	32	32	70.71	3/33
		64	50.00	5/33
		128	50.00	9/33
		256	70.71	17/33

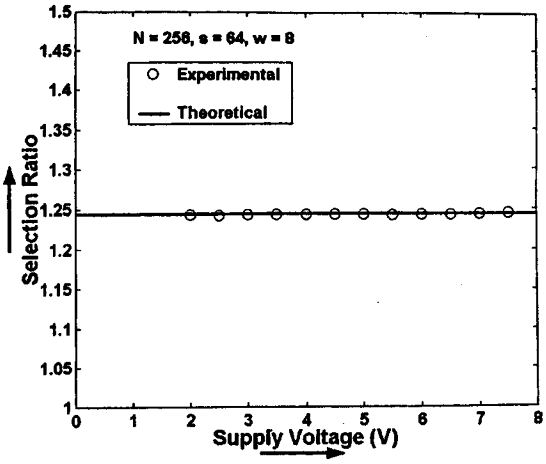

FIGURE 8 — Selection ratio versus supply voltage.

(normalized to V_{sat}) for the case of the MLRPA–NC technique in displaying eight waveforms in a 256-row matrix LCD by selecting various values of s. The supply voltage obtained from the measurement agrees within ±1.5% of the theoretical values. The rms voltage across the ON and OFF pixels were measured using the HP 3467A, a logging multimeter capable of measuring true-rms voltage. Figure 7 shows the plot of V_{on} (rms) and V_{off} (rms) for various values of the supply voltage. Figure 8 shows the plot of the selection ratio measured experimentally. The selection ratio obtained from measurement agrees within ±0.5% of the theoretical value of 1.24375. Table 2 shows the value of s leading to a large reduction in the supply voltage as well as the number of column voltage levels for various values of N and w in comparison with the PRBS–NC technique. The addressing technique discussed above has been implemented using a 64 × 64 matrix TN-LCD. A photograph of a 64 × 64 display addressed by selecting eight rows at a time is shown in Fig. 9. Four waveforms are displayed with just three voltage levels in both row and column waveforms.

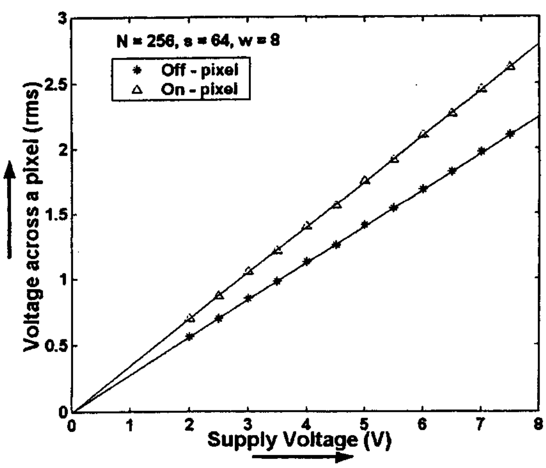

FIGURE 7 — *RMS* voltage across a pixel versus supply voltage.

6 Conclusions

We have demonstrated the feasibility of a new addressing technique to display restricted patterns with TN-LCDs. The higher selection ratio of the restricted-pattern addressing technique allows for the use of relative fast TN-LCDs rather than STN-LCDs with slow response times. The

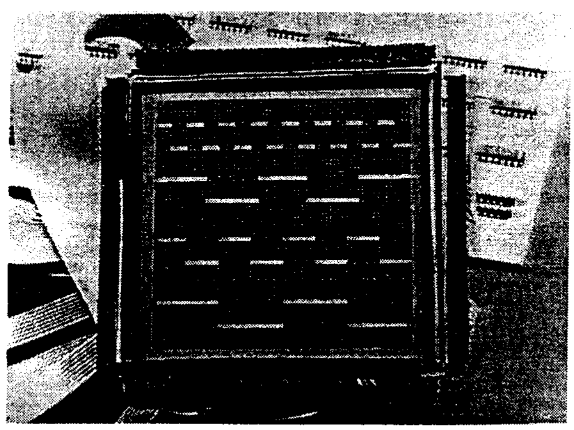

FIGURE 9 — Photograph of a 64 × 64 TN-LCD displaying four waveforms and addressed using MLRPA–NC by selecting eight rows at a time.

This figure is reproduced in color on page 184.

selection ratio which is independent of the matrix size is an added advantage of using restricted-pattern addressing to scan the passive-matrix LCD. The selection ratio of this multi-line approach is same as that for other restricted-pattern addressing techniques such as RPAT and PRBS. However, it is possible to reduce the hardware complexity of the column drivers as well as the supply-voltage requirement while using MLRPA by a careful choice of s for a given matrix size (N) and the number of waveforms (w).

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