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A Novel Driving Method for Fast Switching of a π Cell for Display of Moving Pictures

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We propose a novel driving method which is very efficient for the display of moving pictures on a π cell. In the proposed driving method, each scan pulse is divided into two parts for fast switching unlike the conventional active matrix driving method that uses one scan pulse for each frame. By overdriving or underdriving the π cell using an appropriate data voltage during the first scan time and applying a desired data voltage to the cell during the second scan time, we can achieve fast switching between all gray levels within the time between the first and second scan pulse. [DOI: 10.1143/JJAP.43.1416]

KEYWORDS: fast switching, double scan method, π cell, overdrive, underdrive, gray level, liquid crystal

1. Introduction

Recently, there has been an increasing demand for displaying moving pictures using thin-film-transistor liquid crystal displays (TFT-LCDs). Fast response is the most important prerequisite for the display of moving pictures using the TFT-LCDs. The response times of conventional twisted nematic (TN) and supertwisted nematic (STN) liquid-crystal materials used in most direct-view LCDs are too slow to support them. To obtain fast response time, various attempts such as the method using low cell-gap TN LCD with high optical anisotropy and low viscosity,[1)] ferroelectric liquid crystal devices (FLCDs) with spontaneous polarization,[2)] and the new driving scheme based on overdrive addressing[3–7)] have been proposed. However, the method using low cell-gap TN gives poor yield during the practical manufacturing process. The method using FLCDs has some difficulties in achieving reliable and good quality alignment without defects.[8)] It is difficult to obtain a uniform alignment of the liquid crystal molecules due to the occurrence of alignment-structural defects such as the so-called zig-zag defects that degrade memory capability and contrast ratio. Since the driving scheme using overdirve addressing is simple and also easy for improving slow switching speed between gray levels, it has been widely used. However, because the overdrive addressing also requires appropriate low cell gap, yield should be considered, and obtaining high speed is limited.

For a π cell, it is known that the response time takes less than 3 ms, which is the fastest switching speed among the LC modes using nematic liquid crystals. Therefore, the π cell is considered as the best LC mode for displaying moving pictures. However, in order to display moving pictures, the switching speed between gray levels should be also as fast as the response time. The switching speed between gray levels of a π cell is slow like that of the other LC modes. In this paper, in order to display moving pictures, we propose a novel driving method which is very efficient for the fast switching of a π cell. Unlike conventional TFT-LCDs that use one scan pulse for each frame, the proposed driving method divides the scan pulse into two parts for fast switching. By applying the proposed driving method to a π cell, we can achieve a fast switching speed between all gray levels even in a π cell with a large cell gap.

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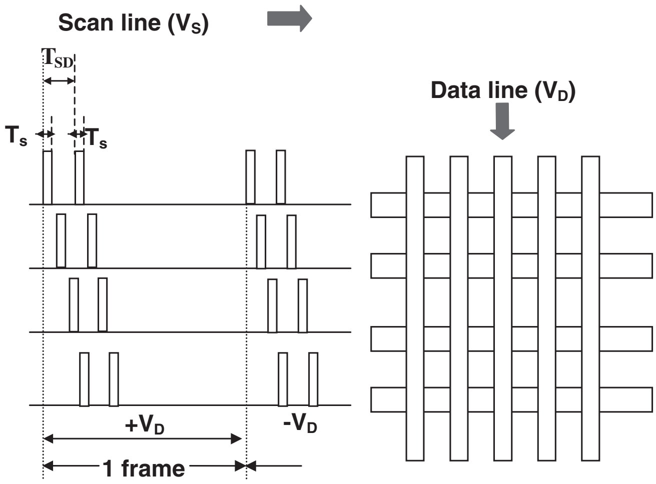

Fig. 1. Scan pulse of the proposed driving method. T_s is determined by the resolution and T_{SD} is the time between the first and second scan pulses.

2. New Driving Method

Figure 1 shows a scan pulse scheme of the proposed double-scan driving method. Each scan pulse is divided into two parts and composed of the first and second scan pulses. Data voltage is applied during the write time, T_s, which is determined by the resolution of the display panel. During the first scan time, we apply a higher voltage (overdriving) or a lower voltage (underdriving) than the data voltage for a desired gray level, and then during the secondAs a result, we can achieve fast switching between all gray levels due to the overdrive or underdrive during the first scan time. scan time, we apply a data voltage corresponding to the desired gray level. As a result, we can achieve fast switching between all gray levels due to the overdrive or underdrive during the first scan time.

2.1 *Determination of the time between the first and second scan pulse*

In this double-scan method, it is important to determine the time between the first and second scan time, T_{SD}, since the switching speed between all gray levels should be achieved within T_{SD}. T_{SD} depends on the liquid crystal and cell gap. Under the assumption of normally black mode, T_{SD} represents the time for a π cell to switch from full white level to full black one. Therefore, in order to determine T_{SD},

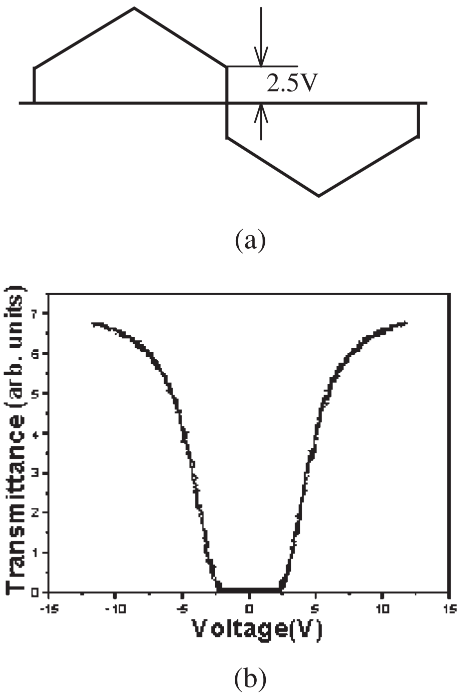

Fig. 2. (a) Triangular-wave form at a frequency of 5 Hz with a bias voltage of 2.5 V, (b) voltage dependence of transmittance in a π cell.

we have to investigate the electrooptic characteristics of the π cell. In this work, we fabricated a π cell with a cell gap of 8.9 μm to show that by using the proposed driving method, fast switching can be achieved between all gray levels even in a large cell gap. The liquid crystal mixture ZLI-1557 (Merck) was used. The electrode area of the fabricated π cell was $1 \times 1\,\mathrm{cm}^2$. The alignment layer was coated on the bottom and top glass substrates by spin coating SE-3140 (Nissan Chemicals Co.), and rubbing was carried out in the parallel direction. The pretilt angle generated by rubbing was approximately 5°. The rubbing directions of the π cell were set at 45° between the parallel polarizers.

In order to operate the π cell as a display device, the initial splay state was changed to a bend state by applying a square wave of 1 kHz with a voltage of $12\,V_{\mathrm{rms}}$.[9–12] Figure 2(b) shows the measured transmittance versus voltage characteristics of the π cell driven by a triangular wave of 5 Hz with a bias voltage of 2.5 V as shown in Fig. 2(a). A bias voltage of 2.5 V was applied to prevent the bend state from returning to the splay state. From Fig. 2(b), we selected 2.5 V for gray level zero (full black) and 10 V for final gray level (full white). Figure 3 shows the measured response characteristics of the π cell. As shown in Fig. 2(b), in order to achieve the transition from full white level to full black one, we should apply 2.5 V to the π cell. However, in the case of such switching, as shown in Fig. 3(a), the transition time is as slow as about 9.3 ms. Therefore, in order to achieve fast transition from full white level to full black one, we applied 0 V instead of 2.5 V, which makes the slope of transmittance curve steeper. As a result, we find that the switching time of the cell from full white level to full black one becomes as faster as 4 ms. In practice, in transition from full white level to full black one, the falling time becomes the fastest when we apply 0 V. In the test cell with a cell gap of 8.9 μm, the switching time from full white level to full black one was measured as 4 ms. If the cell gap of a test cell is below 8.9 μm, we can expect that T_{SD} can be shorter than 4 ms. However, we have to be careful in applying 0 V to the π cell because the bend state may return to a splay state under a critical voltage. The application of 0 V for 4 ms does not influence the transition from a bend state to a splay state. As a result, by applying 0 V to the π cell, a faster switching time of 4 ms can be achieved for the transition from full white level to full black one, and the bend state is still maintained. For the π cell, the rising and falling times were measured to be 0.6 and 2.4 ms, respectively, as shown in Figs. 3(a) and 3(b).

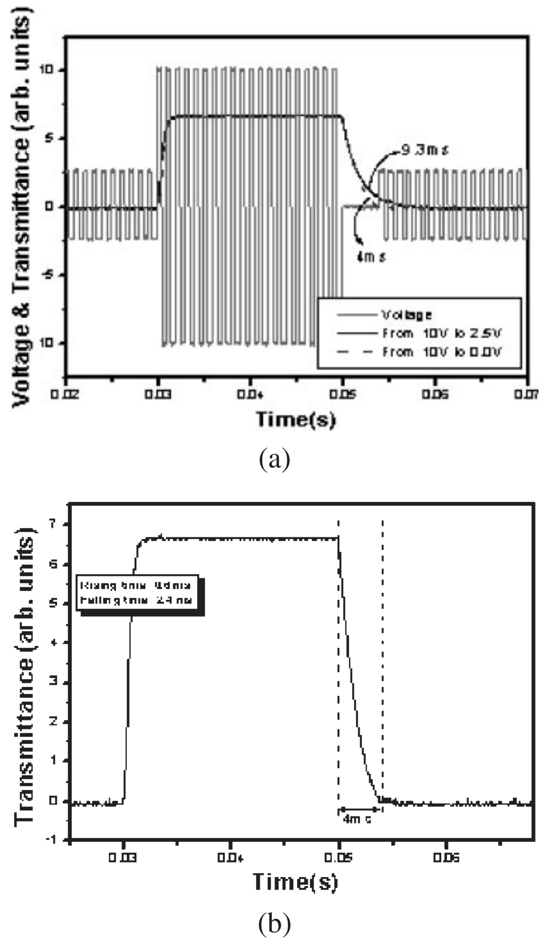

Fig. 3. Response characteristics of the transmittance with the applied voltage for the π cell: (a) Response characteristics for the applied voltage changes from 10 V to 2.5 V and 0 V, (b) enlarged response characteristics for measuring the response time, where the rising and falling times are 0.6 ms and 2.4 ms, respectively.

As a result, if we choose T_{SD} to be 4 ms, the switching time from a higher gray level to a lower one may be achieved within 4 ms by underdriving the π cell during the first scan pulse. The switching time from a lower gray level to a higher one may be sufficiently fast within 4 ms since the transition is achieved by an electric field. Hence, for the transition between any two gray levels, we can achieve faster switching within 4 ms by overdriving or underdriving the π cell during the first scan time.

2.2 *Switching between a higher gray level and a lower one*

Under the assumption of normally black mode and for a switching from a higher gray level to a lower one, during the

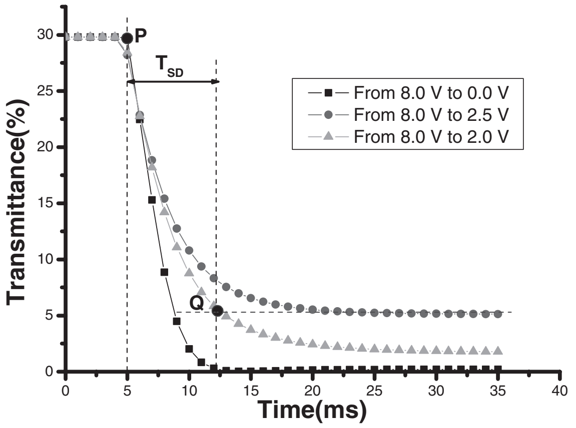

Fig. 4. Response characteristics of a π cell with a gap of 5 µm simulated for the applicability of the double scan method.

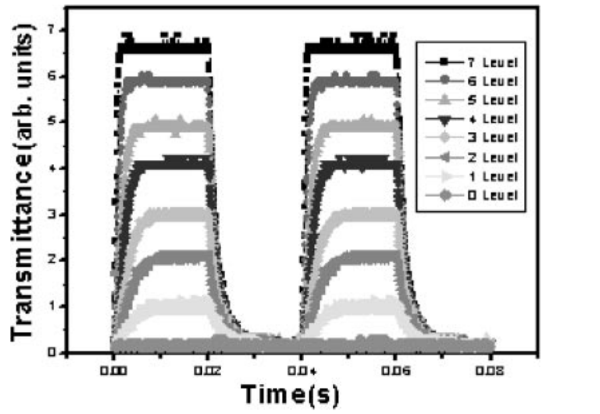

Fig. 5. Response characteristics of the π cell for the transitions from gray level zero to higher gray levels driven by the conventional driving method.

first scan time, we apply a lower voltage (underdriving) than the data voltage for a desired gray level. And then, during the second scan time, we apply the data voltage corresponding to the desired gray level. Inevitably, a data voltage by which a desired gray level can be achieved after T_{SD} is required.

Figure 4 shows an example of fast switching using the proposed double scan method. LCD Master/2D (Shintech, Inc.) was used to calculate the optical properties. Since the simulation program for a π cell has not been developed yet, a homogeneous cell was used for the simulation. The liquid crystal mixture ZLI-1557 was used. At the wavelength of 550 nm, we designed the retardation of the LC layer to become $\lambda/2$. The optic axis of the homogeneous cell was set at 45° between the parallel polarizers, which denotes a normally black mode. As shown in Fig. 4, in the switch-off state, the transition time from full white level at 8 V to full black one at 0 V shows the fastest response time, which takes about 6 ms. Therefore, the T_{SD} of the homogeneous cell becomes 6 ms. Now we will show a method by which the homogeneous cell can switch from full white state to the gray level at 2.5 V within the T_{SD}. As shown in Fig. 4, in the case that a data voltage of 2.5 V is applied to the π cell which is in full white state during the first scan time, we can find that it takes more than 15 ms to reach the gray level at 2.5 V by the conventional active-matrix driving method.

In the proposed double-scan method, in order to switch from full white state to the gray level at 2.5 V, the homogeneous cell is underdrived by a data voltage of about 2 V during the first scan time. As shown in Fig. 4, the transmittance drops markedly in comparison with that obtained by applying a voltage of 2.5 V. The transmittance drops to the point Q corresponding to the gray level at 2.5 V after approximately 6 ms, which is T_{SD}. Therefore, if we underdrive the cell with about 2 V during the first scan time, and after T_{SD}, and apply 2.5 V during the second scan time, we can achieve fast switching within the T_{SD}.

In the case of switching from a lower level to a higher one, during the first scan time, we apply a higher voltage (overdriving) than the data voltage for a desired gray level. And then, during the second scan time, we apply the data voltage corresponding to the desired gray level. The switching time from a lower gray level to a higher one may be sufficiently fast since the transition is controlled by an electric field.

3. Experiments

Before we test the proposed driving method, by using the π cell fabricated to determine T_{SD}, first, we tested 8 gray levels of the cell by the conventional active-matrix driving method for 2 frames, which is shown in Fig. 5. Assuming a frame rate of 60 Hz and a resolution of VGA, the scan pulse width (gate-on time) and frame time are about 34 µs and 16.7 ms, respectively. As shown in Fig. 5, the switching time from gray level zero (full black) to gray level 7 (full white) is the fastest. Hence, in the transition from gray level zero to the desired higher gray level, if the transition level is lower, the switching speed becomes slower. Likewise, the switching time from gray level 7 to gray level zero is the fastest. We find that in the transition from gray level 7 to the desired lower gray level, if the transition level is lower, the switching speed also becomes slower.

Before we apply the proposed new driving method to the π cell using T_{SD} obtained by experiment in the above, we should investigate that the divided scan pulse width of 17 µs is sufficient for the π cell to be charged perfectly to the level of the applied data voltage. Figure 6 shows the equivalent circuit of nematic LC. In Fig. 6, C_{st} is the capacitance due to the storage capacitor and C_{LC} is the capacitance due to the

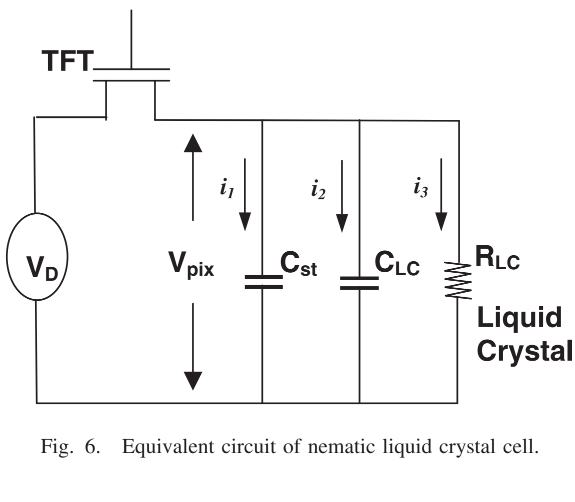

Fig. 6. Equivalent circuit of nematic liquid crystal cell.

induced polarization. The charging current during the switch-on time, $i_{d(on)}$, which flows through the TFT is expressed as

$$i_{d(on)} = K[2(V_{GS} - V_{th}) - V_{DS}]V_{DS}, \tag{1}$$

where K is the current capability of TFT, V_{GS} is the gate-to-source voltage, V_{DS} is the drain-to-source voltage, and V_{th} is the threshold voltage of the TFT. The LC currents, i_1, i_2 and i_3, are given by

$$i_1(t) = \frac{V_D(t)}{R_{LC}}, \tag{2}$$

$$i_2(t) = C_{LC}\frac{d}{dt}V_D(t), \tag{3}$$

$$i_3(t) = C_{st}\frac{d}{dt}V_D(t). \tag{4}$$

The charging current, $i_{d(on)}$, is equal to the sum of LC currents, i_1, i_2 and i_3.

$$i_d(t) = i_1(t) + i_2(t) + i_3(t). \tag{5}$$

Using these equations and after calculations, we obtain the voltage that is applied to the LC layer during the scan time as

$$\frac{d}{dt}V_D(t) = \frac{1}{(C_{LC} + C_{st})}(KV_D{}^2 - (1/R_{LC} + 2K(V_G - V_{th}))V_D + 2K(V_GV_D - V_{th}V_D - V_D{}^2/2)). \tag{6}$$

Figure 7 shows pixel voltage as a function of scan time, where the scan voltage, $V_G = 20\,\text{V}$, the data voltage, $V_D = 6\,\text{V}$, $V_{th} = 2\,\text{V}$, $C_{st} = 0.5\,\text{pF}$, $R_{LC} = 2.6\,\text{T}\Omega$, $C_{pix} = 1.5\,\text{pF}$, respectively, $K = 0.25\,\mu\text{A/V}^2$ for poly-Si TFT, and $K = 0.02\,\mu\text{A/V}^2$ for a-Si TFT. As shown in Fig. 7, if the scan pulse width is shorter than $17\,\mu\text{s}$ in the case of a-Si TFT, the pixel voltage does not reach the applied data voltage. However, if we use poly-Si TFT with the current capability of $0.25\,\mu\text{A/V}^2$, we find that the double-scan method can be applied even in the resolution of Ultra XGA.

Figure 8 shows the response characteristics for 8 gray levels in which we apply the proposed new driving method to the π cell using T_{SD} of 4 ms obtained by experiment. As shown in Figs. 8(a) and 8(b), the switching time between all intergray levels is achieved within T_{SD} of 4 ms in the reverse transition as well as the transition from gray level zero to a higher one. Table I shows overdriving data voltages during the first scan time and the desired data voltages during the second scan time for the transition from gray level zero to a higher one. From Fig. 9, we also find that the transition between gray level 4 and a higher gray level is achieved within T_{SD} of 4 ms. Tables II and III show overdriving data voltages during the first scan time and the desired data voltages during the second scan time for the transition from gray level 4 to a higher gray level and the reverse process, respectively.

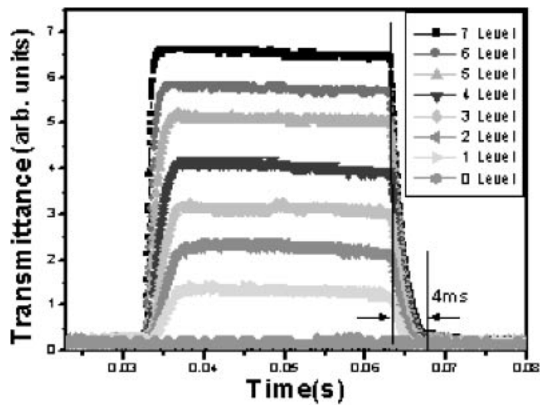

Fig. 8. Response characteristics of the 8 gray levels obtained by the proposed new driving method with T_{SD} of 4 ms.

Table I. Data voltages applied during the first and second scan write times for the transition from gray level zero to higher gray levels.

Gray Level	Data voltage (V) (First scan time)	Data voltage (V) (Second scan time)
0 → 1	3.6	3.1
0 → 2	4.2	3.7
0 → 3	4.8	4.2
0 → 4	5.5	4.9
0 → 5	6.6	5.6
0 → 6	7.8	7.0
0 → 7	10	10

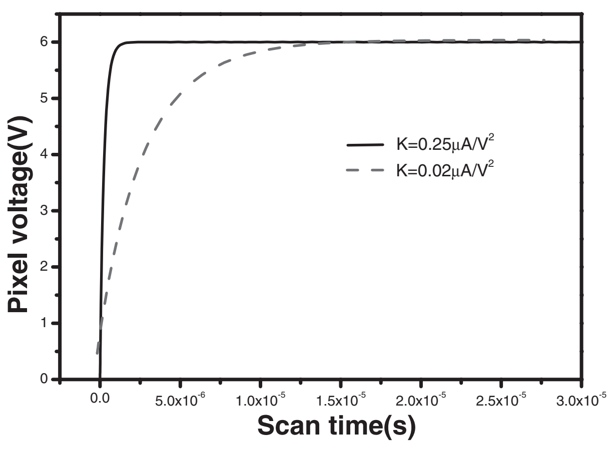

Fig. 7. Pixel voltage dependence on scan time calculated from the equivalent circuit. $K = 0.25\,\mu\text{A/V}^2$ and $K = 0.02\,\mu\text{A/V}^2$ are the values for the poly-Si TFT and a-Si TFT, respectively.

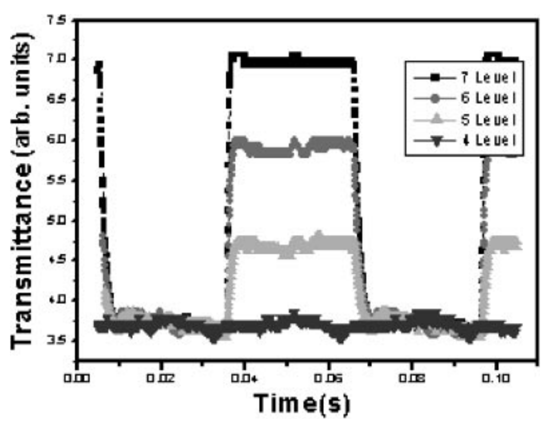

Fig. 9. Response characteristics for the transitions from gray level 4 to higher gray levels. All switching are also achieved within T_{SD} of 4 ms.

Table II. Data voltages applied during the first and second scan write times for the transition from gray level 4 to higher gray levels.

Gray Level	Data voltage (V) (First scan time)	Data voltage (V) (Second scan time)
4 → 5	6.0	5.6
4 → 6	7.4	7.0
4 → 7	10	10

Table III. Data voltages applied during the first and second scan write times for the transition from higher gray levels to gray level 4.

Gray Level	Data voltage (V) (First scan time)	Data voltage (V) (Second scan time)
7 → 4	4.6	4.9
6 → 4	4.5	4.9
5 → 4	4.3	4.9

4. Conclusion

In order to realize moving pictures, we propose a novel driving method which can be applied to the fast switching of a π cell. The proposed driving method divides the scan pulse into two parts unlike the conventional active matrix driving method that uses one scan pulse for each frame. In order to use the proposed driving method effectively, we need to select a T_{SD} that is as short as possible. In a π cell, we select T_{SD} to be the time during which the π cell does not return to the splay state from the bend state and maintains the bend state by the applied voltage of 0 V. In the case of a π cell with a gap of 8.9 µm used in the experiments, we obtained T_{SD} of 4 ms. If the cell gap is lower, it is expected that T_{SD} can be less than 4 ms. Therefore, the switching time between all gray levels can be less than 4 ms. By applying the proposed driving method to a π cell, a fast switching time can be achieved between all intergray levels.

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