



## Introduction

This application note describes two different methods for driving liquid crystal displays (LCD) with any standard STM8S20xxx microcontroller (MCU), without any specific on-chip LCD driver hardware:

- the first method uses the timer 2 channel resource and also allows LCD contrast control through software
- the second method uses the Auto-wakeup mode only

This application note starts with an introduction on LCDs in [Section 1: LCD principle](#) and [Section 2: LCD drive signals](#).

[Section 3](#) then presents a solution based on a standard STM8S20xxx MCU directly driving a quadruplex LCD. This solution can be implemented with any MCU as it only requires the standard I/O ports and some timings.

[Section 4](#) gives consumption considerations. [Section 5](#) describes how to control contrast through software: for this purpose, two push-buttons connected to two standard I/Os are used. Finally, [Section 6](#) gives an overview of the LCD demo board based on an STM8S20xxx microcontroller, and provides the board schematics.

For more information on the LCD drive theory, please refer also to AN1048.

The number of external components is kept to a minimum of two external resistors per COM line. The number of I/Os depends on the number of LCD segments used. Software contrast control is a very flexible solution that can be easily adapted to a wide range of applications.

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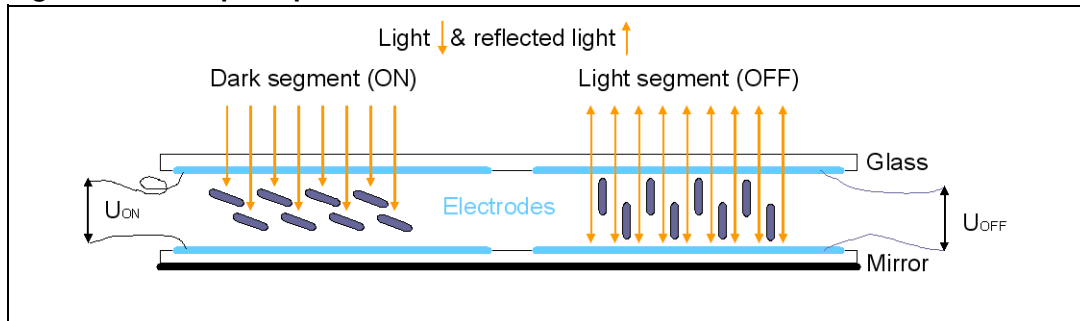
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# 1 LCD principle

Figure 1. LCD principle



An LCD panel is composed of many layers. A liquid crystal is filled between two of them (glass plates), which are separated by thin spacers coated with transparent electrodes that contain orientation layers. The orientation layer usually consists of a polymer (e.g. polyimide) which has been unidirectionally rubbed using, for instance, a soft tissue. As a result, the liquid crystal molecules are fixed with their alignment more or less parallel to the plates, in the direction of rubbing. The crystal alignment directions at the surface of the two plates are perpendicular so that the molecules between the two plates undergo a homogeneous twist deformation in alignment to form a helix.

If no electric field is applied, the birefringent liquid crystal molecules keep their helical structure and rotate linearly polarized light waves passing through the plates. The transmitted light wave is then allowed through a crossed exit polarizer. As a result, the modulator has a bright appearance.

On the other hand, if an AC voltage of a few volts is applied, the resulting electric field forces the liquid crystal molecules to align themselves along the field direction and the twist deformation (the helix) is unwound. In this case, the polarization of the incident light is not rotated by the crystal molecules and the crossed exit polarizer blocks the light wave. As a result, the modulator appears dark.

The inverse switching behavior can be obtained with parallel polarizers. It must also be noted that gray scale modulation is easily achieved by varying the voltage between the crystal molecule reorientation threshold (reorientation is resisted by the elastic properties of liquid crystals) and the saturation field.

LCDs are sensitive to root mean square voltage ( $V_{rms} = \sqrt{\text{Mean}(\text{Signal}^2)}$ ) levels. With a low root mean square voltage applied to it, an LCD is practically transparent (the LCD segment is then inactive or off). To turn an LCD segment on, causing the segment to turn dark (from light gray to opaque black), an LCD RMS voltage greater than the LCD threshold voltage is applied to the LCD. The LCD RMS voltage is the RMS voltage across the capacitor C in [Figure 2](#), which is equal to the potential difference between the SEG and COM values.

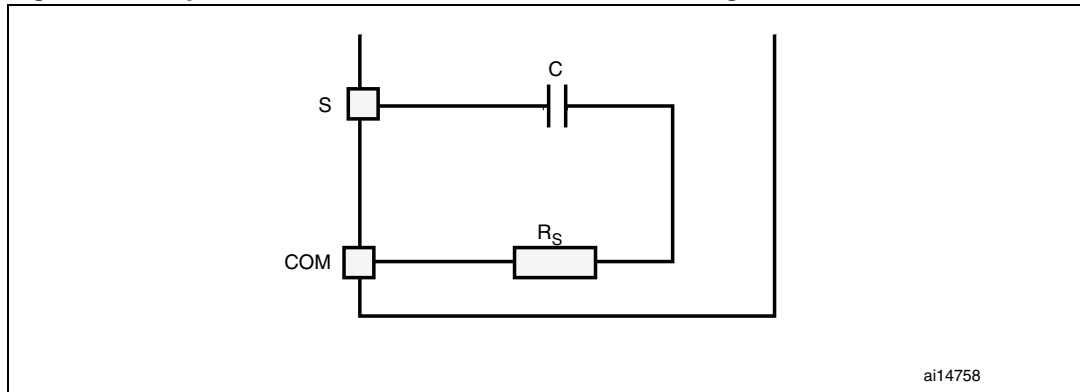
The LCD threshold voltage depends on the quality of the liquid used in the LCD and the temperature. The optical contrast is defined by the difference in transparency of an LCD segment that is on (dark) and an LCD segment that is off (transparent). The optical contrast depends on the difference between the RMS voltage on an on segment ( $V_{ON}$ ) and the RMS voltage on an off segment ( $V_{OFF}$ ). The higher the difference between  $V_{ON(rms)}$  and  $V_{OFF(rms)}$ , the higher the optical contrast. The optical contrast also depends on the level of  $V_{ON}$  versus the LCD threshold voltage. If  $V_{ON}$  is below or close to the threshold voltage, the LCD is completely or almost transparent. If  $V_{OFF}$  is close or above the threshold voltage, the LCD is completely black.

In this document, contrast is defined as  $D = V_{ON}(rms) / V_{OFF}(rms)$ .

The applied LCD voltage must also alternate to give a zero DC value to prevent the electrolytic process and so, ensure a long LCD lifetime.

The higher the multiplexing rates, the lower the contrast. The signal period also has to be short enough to avoid visible flickering on the display.

**Figure 2. Equivalent electrical schematic of an LCD segment**



*Note:* The DC value should never be more than 100 mV (refer to the LCD manufacturer's datasheet), otherwise the LCD lifetime may be shortened. The frequency range is 30 Hz to 200 Hz typically. If a lower frequency is used, the LCD flickers, if a larger frequency is used, power consumption increases.

## 2 LCD drive signals

### 2.1 Quadruplex LCD drive

In a quadruplex LCD drive, four backplanes (common lines) are used. Each LCD pin is connected to four LCD segments, whose other side is connected to one of the four backplanes (refer to *Figure 3*). Thus, only  $(S/4)+4$  MCU pins are necessary to drive an LCD with S segments. For example, to drive an LCD with 128 segments ( $32 \times 4$ ), only 36 I/O ports are required (32 I/O ports to drive the segments, 4 I/O ports to drive the backplanes).

Three different voltage levels have to be generated on the common lines: 0,  $V_{DD}/2$ ,  $V_{DD}$ . The Segment line voltage levels are 0 and  $V_{DD}$  only. The LCD segment is inactive if the RMS voltage is below the LCD threshold voltage and is active if the LCD RMS voltage is above the threshold.

The intermediate voltage  $V_{DD}/2$  is only required for backplane voltages. The MCU I/O pins selected as backplanes are set by software to output mode for 0 or  $V_{DD}$  levels and to the high-impedance input mode for  $V_{DD}/2$ . The  $V_{DD}/2$  voltage is determined by two resistors of equal value, externally connected to the I/O pins as shown in *Figure 5*. When one backplane or COM is active, the other ones are neutralized by applying  $V_{DD}/2$  to them.

**Figure 3. Basic LCD segment connection in quadruplexed mode**

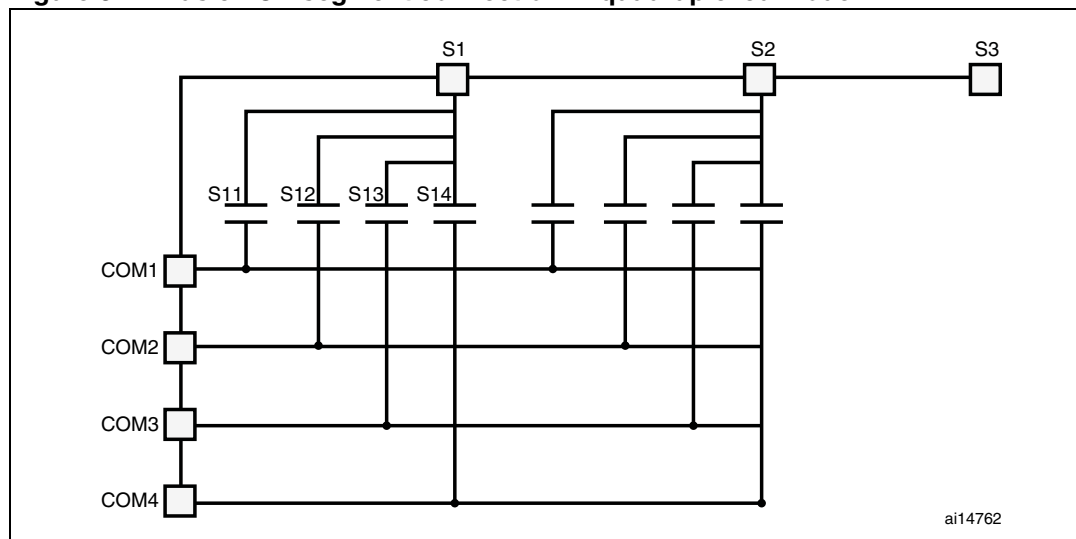
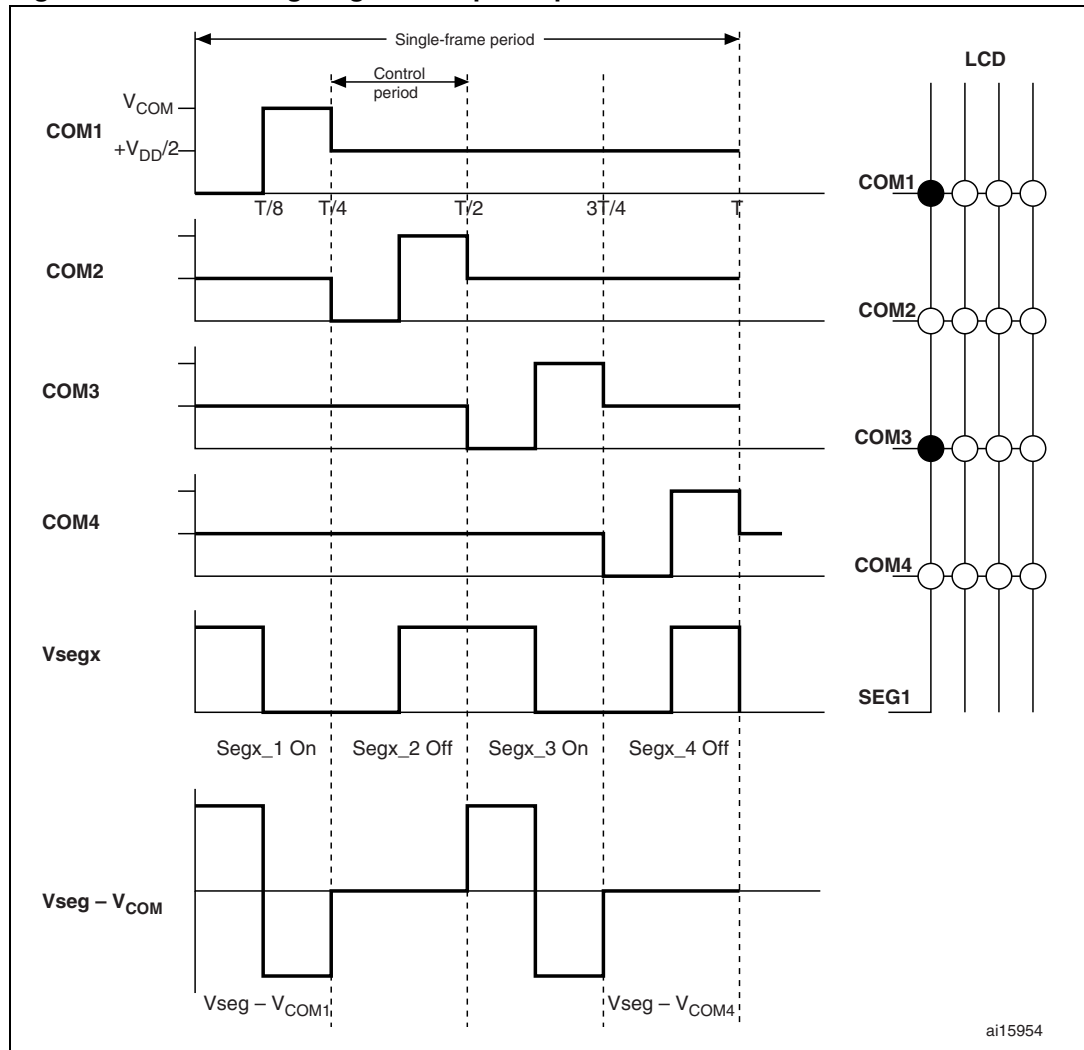


Figure 4. LCD timing diagram for quadruplex mode



### 2.1.1 LCD mean voltage calculation

The LCD mean voltage must be very close to zero to guarantee long life to the LCD. The LCD mean voltage for On and Off periods can be calculated as shown below:

$$V_{mean(On)} = 1/8 V_{seg} + 1/8 (-V_{COM}) + 3(V_{seg} - Vr/2) + 3(-Vr/2) \quad (1)$$

$$V_{mean(Off)} = 3(V_{seg}/2) + 3(-Vr/2) \quad (2)$$

$V_{mean(On)}$  and  $V_{mean(Off)}$  assume identical periods for each phase.

Equating equations (1) & (2) to zero, that is putting  $V_{mean(On)} = 0$  and  $V_{mean(Off)} = 0$ , gives:

$V_{seg} = V_{COM} = Vr = V_{DD}$ , where:

- $V_{COM}$  is the maximum voltage on the COM line
- $Vr/2$  is the voltage in the middle of the resistor bridge, applied on the COM line
- $V_{seg}$  is the maximum voltage on the Segx line
- $V_{DD}$  is the microcontroller power supply



### 2.1.2 Contrast calculation

The performance of an LCD driving system is defined by the contrast.

$$\text{Contrast (D)} = V_{\text{rms(On)}} / V_{\text{rms(Off)}}$$

For the quadruplex signal as described on the previous page:

$$V_{\text{rms(On)}} = \sqrt{\frac{1}{T} \int_0^T f(t)^2 dt} = \sqrt{\frac{1}{T} \left( \int_0^{\frac{T}{8}} (V_{\text{DD}})^2 dt + \int_{\frac{T}{8}}^{\frac{2T}{8}} (V_{\text{DD}})^2 dt + \int_{\frac{2T}{8}}^T \left(\frac{V_{\text{DD}}}{2}\right)^2 dt \right)}$$

$$V_{\text{rms(On)}} = \sqrt{\frac{1}{T} \left( (V_{\text{DD}})^2 \cdot \frac{T}{8} + (V_{\text{DD}})^2 \cdot \frac{T}{8} + \frac{(V_{\text{DD}})^2}{4} \cdot \frac{(6T)}{8} \right)} = 0.661 V_{\text{DD}}$$

$$V_{\text{rms(Off)}} = \sqrt{\frac{1}{T} \left( \int_0^{\frac{T}{8}} (0) dt + \int_{\frac{T}{8}}^{\frac{2T}{8}} (0) dt + \int_{\frac{2T}{8}}^T \left(\frac{V_{\text{DD}}}{2}\right)^2 dt \right)} = 0.433 V_{\text{DD}}$$

$$\text{Contrast (D)} = V_{\text{rms(On)}} / V_{\text{rms(Off)}} = 0.661 V_{\text{DD}} / 0.433 V_{\text{DD}} = 1.53$$

For comparison, a hardware LCD drive uses 1/3 bias voltage. With 1/3 bias control, the contrast value (D) is 1.73. Therefore, 1/3 bias gives only a small contrast advantage. This advantage is reduced to zero when using software contrast control.

### 3 Example of a quadruplex LCD driver with STM8

The following example describes a drive for a quadruplex mode (4 COM) LCD using the STM8S20xxx (QFP64 package 10 × 10 mm). The only external components needed for driving the LCD are eight resistors (refer to [Figure 5](#)). The resistor value of 470 kΩ is used to reach a low current consumption.

One I/O port per segment and one I/O port for each COM line are needed to drive the LCD. In our example, to drive a quadruplex LCD that has 128 segments (with 32 segment lines and 4 COM lines) 36 I/O ports are required.

In the example program, the PG0-PG7, PE0-PE7, PD0-PD7 and PB0-PB7 port pins are connected to the 32 segment lines and are used to generate the segment signals. As PE1 and PE2 are true open drain I/Os (I<sup>2</sup>C alternate function), two 10 kΩ pull-up resistors have been added.

Port G segments control the display of LCD digits 1 and 2, port E segments control digits 3 and 4, port D segments controls digits 5 and 6 and port B segments control the display of LCD digits 7 and 8.

Ports PC4 through PC7 are connected to the 4 COM lines (COM 4, 3, 2 and 1, respectively) and are used to generate the COM signals.

The LCD driver consists of:

- one initialization function (`LCD_ON`) that correctly configures the required I/Os and the Timer 2 resource (to get the 2 real-time clock interrupts) for the first method, or the AWU mode one for the second method.
- one display function (`LCD_Display`) that enables the user to easily enter the string of characters (8 characters maximum) to be displayed on the 8-digit LCD screen.
- one LCD RAM part that contains the coding of the numbers or letters to be displayed on the LCD (refer to [Table 1](#)). This LCD RAM table is filled automatically each time `LCD_Display` function is called, depending on the characters composing the string to display.
- a generic.h file containing:
  - the different possible configurations in terms of numbers of COM and SEG (one configuration has to be selected, knowing that the default configuration is 4 COM and 32 SEG)
  - the clock (HSI with one possible prescaler or LSI)
  - the values put in the Timer 2 compare and autoreload registers depending on the chosen LCD frame rate for the first method
- the letter and number constant coding tables which are contained in the `lcd.c` file. The file can be easily modified by the user depending on the LCD type used.

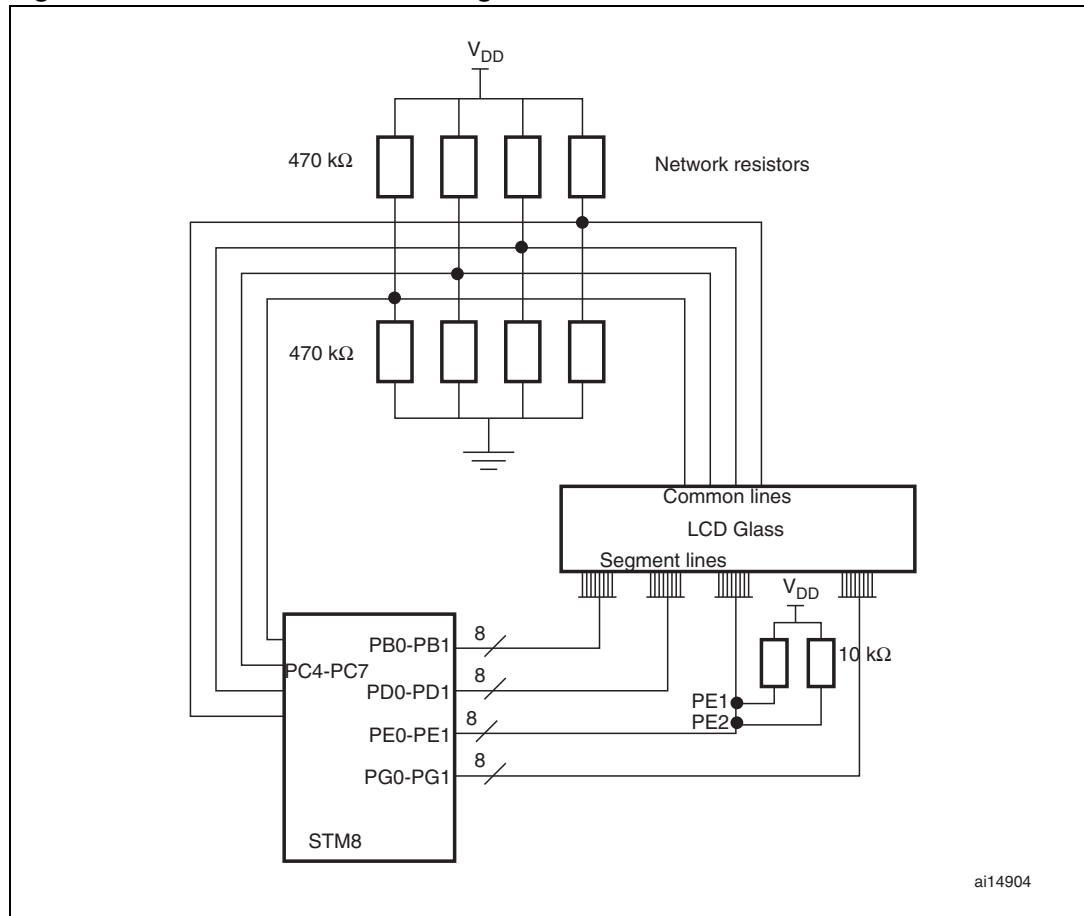
When the LSI clock is used, in order to speed up the I/O toggling execution, the program switches to the HSI clock, and returns to the LSI clock once this is done.

For more information regarding the software architecture, please refer to the `lcd_awu.pdf` and `lcd_timer2.pdf` files attached with the source codes in the zip file associated with this application note.

Table 1. LCD RAM

COM	7	6	5	4	3	2	1	0	Port
COM1 (PC7)	S7	S6	S5	S4	S3	S2	S1	S0	Port B
	S15	S14	S13	S12	S11	S10	S9	S8	Port D
	S23	S22	S21	S20	S19	S18	S17	S16	Port E
	S31	S30	S29	S28	S27	S26	S25	S24	Port G
COM2 (PC6)	S7	S6	S5	S4	S3	S2	S1	S0	Port B
	S15	S14	S13	S12	S11	S10	S9	S8	Port D
	S23	S22	S21	S20	S19	S18	S17	S16	Port E
	S31	S30	S29	S28	S27	S26	S25	S24	Port G
COM3 (PC5)	S7	S6	S5	S4	S3	S2	S1	S0	Port B
	S15	S14	S13	S12	S11	S10	S9	S8	Port D
	S23	S22	S21	S20	S19	S18	S17	S16	Port E
	S31	S30	S29	S28	S27	S26	S25	S24	Port G
COM4 (PC4)	S7	S6	S5	S4	S3	S2	S1	S0	Port B
	S15	S14	S13	S12	S11	S10	S9	S8	Port D
	S23	S22	S21	S20	S19	S18	S17	S16	Port E
	S31	S30	S29	S28	S27	S26	S25	S24	Port G

Figure 5. Hardware connection diagram



### 3.1 First method: Timer 2

In this method, the LCD timing is generated by the Timer 2 edge alignment mode using 2 interrupts: a compare one (value loaded into the TIM2\_CCR1 register) and an overflow one (value loaded into the TIM2\_ARR register).

Each LCD display cycle consists of 4 phases, one for each backplane. Each COM line generates its waveform during the corresponding phase e.g. COM1 line during phase1, COM2 line during phase 2, etc.

When they are not generating their waveforms the COM lines remains at level  $V_{DD}/2$ . Each phase consists of two parts:

1. active time
2. dead time

During the active time, the segment lines and COM lines are used to drive the LCD. During the dead time, the segment and COM lines are used to tune the contrast.

The active time starts after the Compare interrupt and, the dead time starts after the Overflow interrupt. A total of 16 interrupts is generated in each frame period with 4 interrupts per control period. There are 2 Compare events (CCR1\_1 and CCR1\_2 managed in the

same interrupt function) and 2 Overflow events (OVF) in each phase. The latter are described below:

- During CCR1\_1,  $V_{DD}$  is applied to the segments that have to be turned on and 0, to the segments that have to be turned off. The COM line that corresponds to this phase is set to low level. Other COM lines are set to the  $V_{DD}/2$  level.
- During OVF1, all COM lines are inactive (set to low level), then if  $V_{rms}$  has to be decreased (see [Figure 6](#)) all segments are set low or, if it has to be increased (see [Figure 7](#)), all segments are set high.
- During CCR1\_2, the segment lines are supplied with voltage levels that are inverted compared to those applied during CCR1\_1. The COM line that corresponds to this phase is set to high level. Other COM lines are set to the  $V_{DD}/2$  level.
- During OVF2, if  $V_{rms}$  has to be decreased then all COM lines and segments are inactive (set to low level) and if  $V_{rms}$  has to be increased (see [Figure 7](#)), the COM lines are set high and the segments are set low.

In order to reduce consumption, the MCU is placed in WFI (wait for interrupt) mode in the main routine. The MCU is then woken up by the Timer 2 interrupts and the external interrupts (PA4/PA5 connected to push-buttons, refer to [Section 6](#) for more information).

## 3.2 Second method: Auto-wakeup

In this method, the LCD timing is generated by the Auto-wakeup time base. The MCU is placed in Auto-wakeup mode, meaning that it is in Halt mode but woken up periodically as the LSI source clock (embedded low-power RC around 128 kHz) remains active. When woken up, the MCU toggles the COM and SEG lines in the AWU interrupt routine, exactly as it was doing in the previous method in the Timer 2 interrupt routine.

The software contrast control is not as easy to implement with this method as AWU timeouts are fixed. It could be less fine-tuned.

Using this method, consumption can be very low (a total consumption of 1.08 mA at 3.3 V with HSI as the master clock).

## 4 Consumption considerations

The number of code lines the MCU has to execute to drive the LCD is the same whatever the CPU frequency. It is then easy to understand that the faster the CPU clock, the faster these code lines are executed, the less they represent in terms of CPU load, and the less the MCU consumes.

In order to reduce consumption with both methods, the PCKEN (peripheral clock gating) register of the Clock Controller is used in order to clock only the used peripherals.  $V_{DD}$  can also be decreased, especially in the first method (as the contrast can be compensated for by software) to further reduce the consumption.

The consumption values obtained with the first method (at 3.3 V) are given in [Table 2](#).

**Table 2. First method - consumption (Timer 2)**

Clock master	Consumption of the MCU executing LCD driver (mA)	Consumption of the LCD driver (mA)	Consumption of the MCU executing an empty loop
HSI	2.38	0.3	2.08
HSI/2	1.73	0.38	1.35
HSI/4	1.45	0.49	0.96
HSI/8	1.3	0.7	0.6
LSI	1.17	0.94	0.23

*Note:* These typical values are given for guidance only. The LCD driver consumption is obtained by subtracting the consumption of the MCU executing the LCD driver function and the consumption of the MCU executing an empty loop (with all I/Os configured as output low level).

The consumption values obtained with the second method (at 3.3 V) are given in [Table 3](#).

**Table 3. Second method - consumption (AWU)**

Clock master	Consumption of the MCU executing LCD driver (mA)	Consumption of the LCD driver (mA)	Consumption of the MCU executing an empty loop
HSI	1.08	0.36	0.72
HSI/2	1.12	0.4	0.72
HSI/4	1.26	0.51	0.75
HSI/8	1.34	0.58	0.76
LSI	1.02	0.33	0.69

*Note:* These typical values are given for guidance only. The LCD driver consumption is obtained by subtracting the consumption of the MCU executing the LCD driver function and the consumption of the MCU executing an empty loop (with the MCU in AWU mode with all its I/Os configured as output low level).

Figure 6. LCD timing diagram with dead & active time (to decrease Vrms)

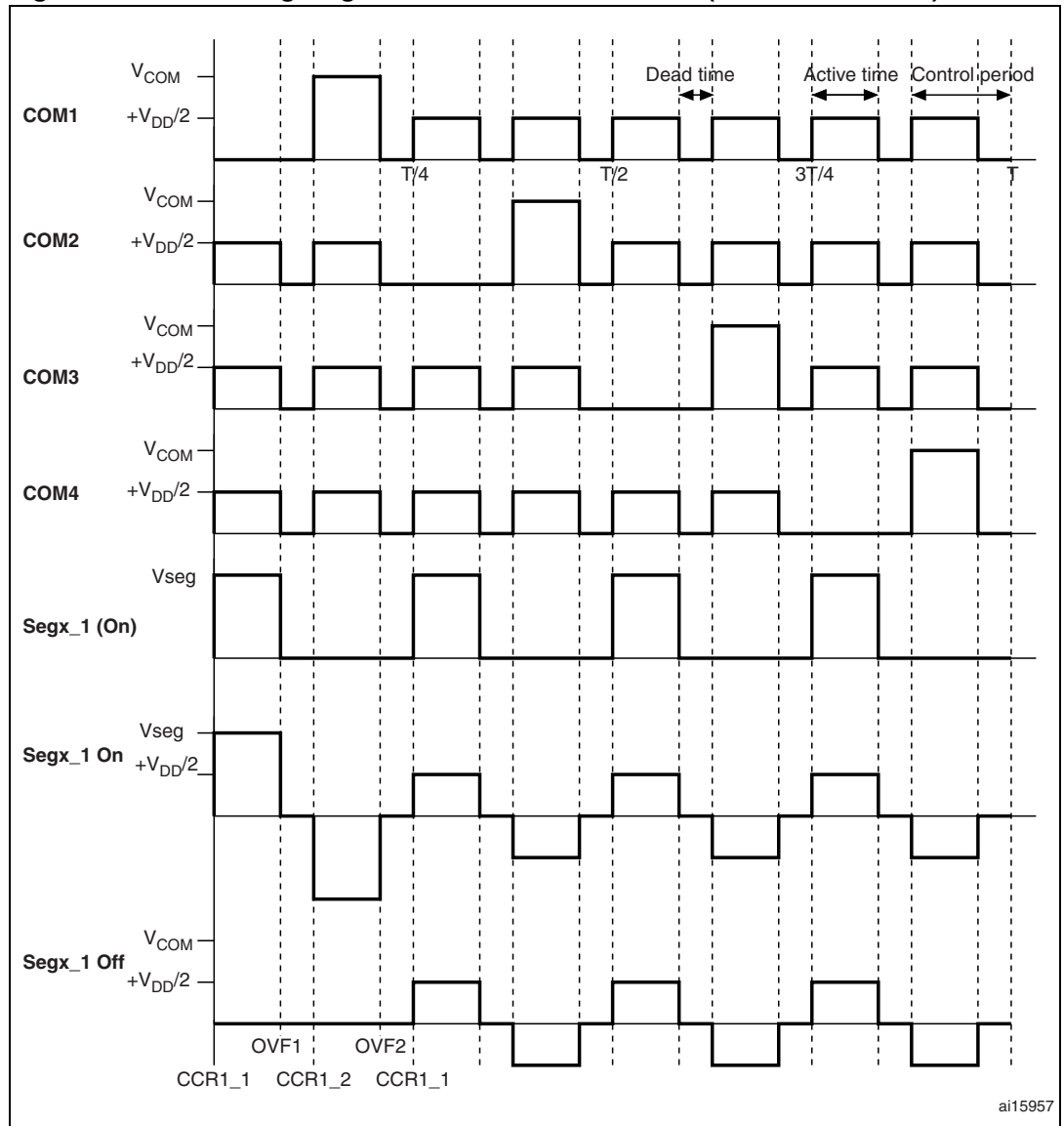
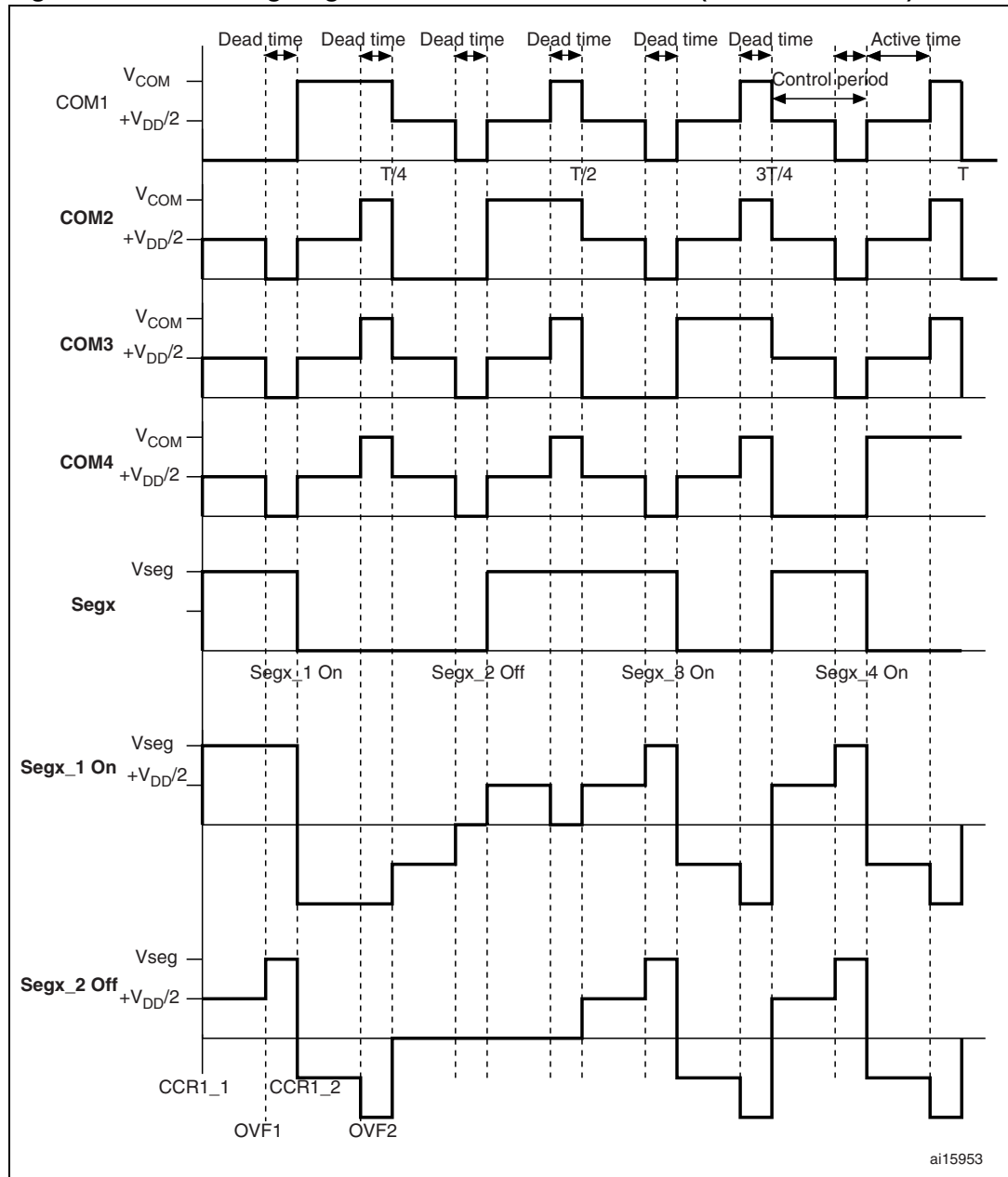


Figure 7. LCD timing diagram with active and dead time (to increase  $V_{rms}$ )





## 5 Software contrast control with the first method

Software contrast control is under patent from STMicroelectronics. The use of this technique with a non-STMicroelectronics microcontroller has to be agreed by STMicroelectronics.

LCD contrast is entirely controlled by software with no need for any external component. LCD contrast can be adjusted to the optimal value depending on the operating voltage of the used LCD. LCD contrast is controlled by varying the dead phase timing as shown in the LCD timing diagrams. This corresponds to the variation of the compare event value.

Dead time can be used to either decrease or increase the LCD  $V_{rms}$ . Dead time is the voltage compensation time to regulate the rms voltage up and down. Dead time can be implemented either after each control period or at the end of the frame. To avoid flickering, the dead time duration must be adjusted depending on the quality of LCD and the frequency of the frame.

In the example shown in [Figure 6](#), the  $V_{rms}$  value of the LCD decreases when the dead time duration increases and the  $V_{rms}$  value increases when the dead time duration decreases. The opposite process is shown in [Figure 7](#).

Two push-buttons connected to PA4 and PA5 are used on the demo board to decrease and increase contrast, respectively, using this software method.

Relatively high software contrast control steps were chosen with the object of reaching maximum or minimum contrast by pressing the push-buttons around 10 times. This can be further fine-tuned if needed.

### 5.1 Contrast calculations

Let the frame period be  $T + xT$ , where:

- $T$  is the Active time
- $xT$  is the Dead time

In the formulas below,  $x$  corresponds to the proportion of dead time and  $V_x$  corresponds to the voltage during the Dead time.

$$V_{rms(on)} = \sqrt{\frac{1}{T + xT} \int_0^{(T + xT)} f(t)^2 dt}$$

$$V_{rms(on)} = \sqrt{\frac{1}{T + xT} \left( \int_0^{\frac{T}{8}} (V_{DD})^2 dt + \int_{\frac{T}{8}}^{\frac{2T}{8}} (-V_{DD})^2 dt + \int_{\frac{2T}{8}}^T \left(\frac{V_{DD}}{2}\right)^2 dt + \int_0^{\frac{xT}{8}} (V_x)^2 dt \cdot 8 \right)}$$

$$V_{rms(on)} = \sqrt{\frac{1}{T + xT} \left( V_{DD}^2 \cdot \frac{T}{8} + V_{DD}^2 \cdot \frac{T}{8} + \frac{V_{DD}^2}{4} \cdot \frac{6T}{8} + ((V_x)^2 \cdot \frac{xT}{8}) \cdot 8 \right)}$$

$$V_{rms(on)} = \sqrt{\frac{1}{1 + x} \left( \frac{14V_{DD}^2}{32} + (V_x)^2 \cdot x \right)}$$

Since  $V_x = 0$  (in case of a decrease in  $V_{rms}$ )

$$V_{rms(on)} = \sqrt{\frac{1}{1+x} \left( \frac{14V_{DD}^2}{32} \right)} = \sqrt{\frac{1}{1+x}} \cdot 0.661V_{DD}$$

$$V_{rms(off)} = \sqrt{\frac{1}{T+xT} \left( \int_0^{\frac{T}{8}} (0)dt + \int_{\frac{T}{8}}^{\frac{2T}{8}} (0)dt + \int_{\frac{2T}{8}}^T \left( \frac{V_{DD}}{2} \right)^2 dt + \int_0^{\frac{xT}{8}} (V_x)^2 dt \cdot 8 \right)}$$

$$V_{rms(off)} = \sqrt{\frac{1}{T+xT} \left( \frac{6V_{DD}^2}{32} dt + V_x^2 \cdot x \right)}$$

Since  $V_x = 0$  (in case of a decrease in  $V_{rms}$ )

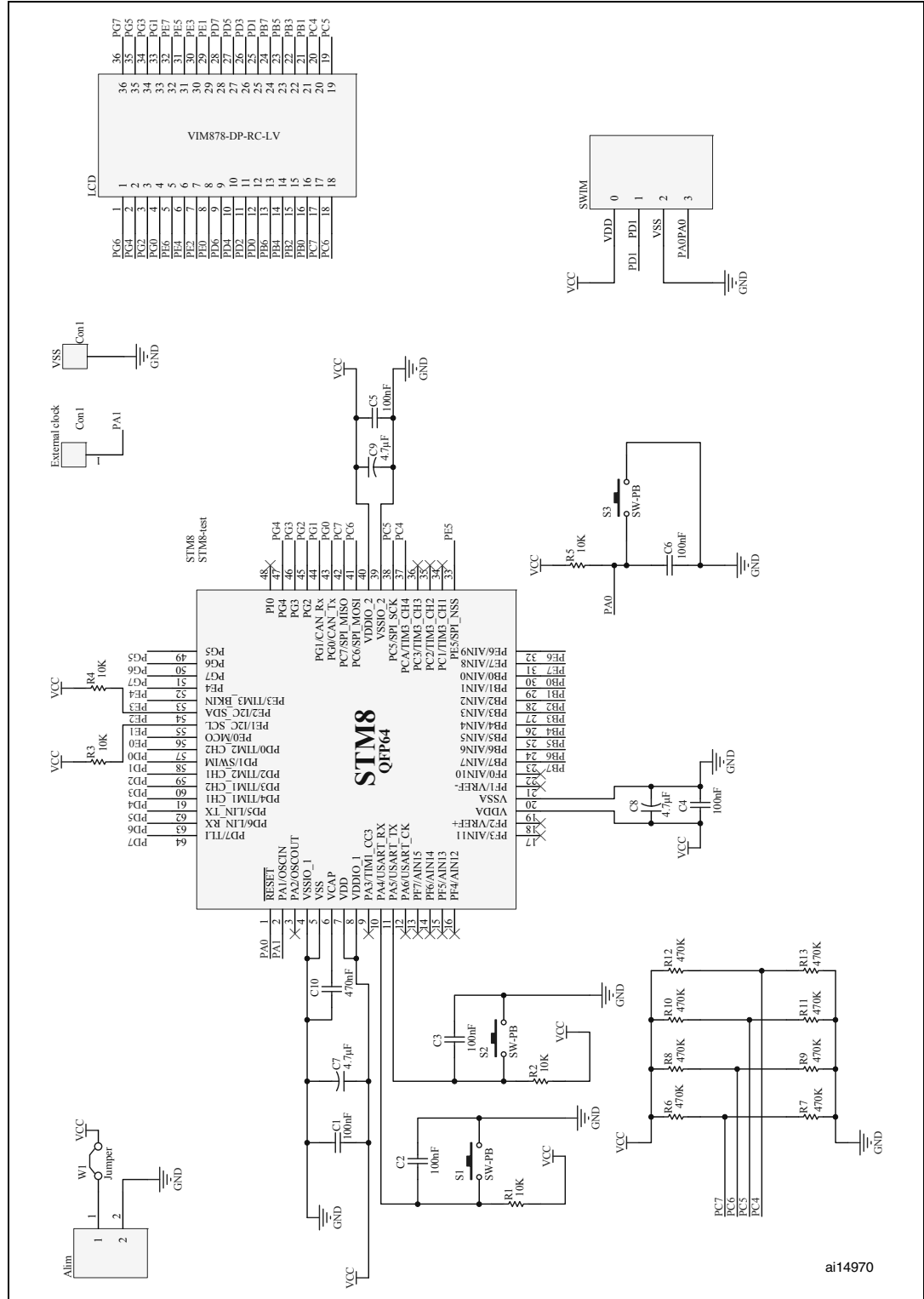
$$V_{rms(off)} = \sqrt{\frac{1}{1+x}} \cdot 0.433V_{DD}$$

$$\text{Contrast (Dx)} = \frac{\left( \sqrt{\frac{1}{1+x}} \cdot 0.661V_{DD} \right)}{\left( \sqrt{\frac{1}{1+x}} \cdot 0.433V_{DD} \right)}, \text{ where Dx is the contrast calculated with the contrast control method}$$

Contrast D, between  $V_{ON}$  and  $V_{OFF}$  is constant (quality of contrast). The optical contrast has been changed only by tuning  $V_{ON}$  close to the threshold value of the LCD.

# 6 LCD demo board

Figure 8. Schematic diagram



## 6.1 Board information

The LCD demo board should be supplied by a DC voltage of 3.3 V through connector W1. There is no regulator present on the demo board to enable the user to modify  $V_{DD}$  and see the impact on the LCD contrast. The maximum absolute ratings for the power supply must be respected (please refer to the product datasheet). It is also strongly recommended not to apply a  $V_{DD}$  voltage higher than 3.3 V for too long.

The LCD chosen for use on the demo board is driven at 3 V, which gives a better contrast for low-voltage range MCUs like the STM8S20xxx.

The two pieces of software attached to this application note display “STM8 LCD” and the contrast can be tuned with the ST software patented method through two push-buttons (S1 to increase the contrast and S2 to decrease it) with the first method (LCD driver directory in the attached zip file).

$V_{rms}$  is increased by applying first  $V_{SS}$ , then  $V_{DD}$  (during the dead times) to the segment, while first  $V_{DD}$ , then  $V_{SS}$  is applied to the COM lines.

$V_{rms}$  is decreased by applying  $V_{SS}$  to the segment during the same dead times. The voltage average is then kept. Refer to the software attached to this application note for more details.

The demo board uses the STM8S20xxx microcontroller and can be reprogrammed and debugged using the SWIM communication protocol through the SWIM interface. The board is provided with the SWIM connector.

The device can be reset by pressing switch S3 on the demo board.

## 7 Revision history

**Table 4. Document revision history**

Date	Revision	Changes
17-Apr-2009	1	Initial release.

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