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PCA85233

Automotive 80 × 4 LCD driver for low multiplex rates

Rev. 4 — 6 May 2015 Product data sheet

1. General description

The PCA85233 is a peripheral device which interfaces to almost any Liquid Crystal Display (LCD)[1] with low multiplex rates. It generates the drive signals for any static or multiplexed LCD containing up to four backplanes and up to 80 segments and can easily be cascaded for larger LCD applications. The PCA85233 is compatible with most microcontrollers and communicates via the two-line bidirectional I^2C-bus. Communication overheads are minimized by a display RAM with auto-incremental addressing, by hardware subaddressing, and by display memory switching (static and duplex drive modes).

For a selection of NXP LCD segment drivers, see Table 28 on page 46.

2. Features and benefits

- AEC-Q100 compliant for automotive applications
- Single-chip LCD controller and driver
- Selectable backplane drive configuration: static, 2, 3, or 4 backplane multiplexing
- Selectable display bias configuration: static, $\frac{1}{2}$, or $\frac{1}{3}$
- Selectable frame frequency: 150 Hz or 220 Hz
- Internal LCD bias generation with voltage-follower buffers
- 80 segment drives:
  - Up to 40 7-segment alphanumeric characters
  - Up to 20 14-segment alphanumeric characters
  - Any graphics of up to 320 segments/elements
- 80 × 4 bit RAM for display data storage
- Display memory bank switching in static and duplex drive modes
- Versatile blinking modes
- Independent supplies possible for LCD and logic voltages
- Wide power supply range: from 1.8 V to 5.5 V
- Wide LCD supply range:
  - From 2.5 V for low-threshold LCDs
  - Up to 8.0 V for guest-host LCDs and high-threshold twisted nematic LCDs
- Low power consumption
- 400 kHz I^2C-bus interface
- Extended temperature range up to 105 °C
- Backside laser marking
- May be cascaded for large LCD applications (up to 2560 segments possible)

1. The definition of the abbreviations and acronyms used in this data sheet can be found in Section 20.

- No external components needed
- Compatible with Chip-On-Glass (COG) technology

3. Ordering information

Table 1. Ordering information

Type number	Package		
	Name	Description	Version
PCA85233UG	bare die	110 bumps	PCA85233

3.1 Ordering options

Table 2. Ordering options

Product type number	Orderable part number	Sales item (12NC)	Delivery form	IC revision
PCA85233UG/2DA/Q1	PCA85233UG/2DA/Q1Z	935302508033	chip with hard bumps in tray[1]	1

[1] Bump hardness see Table 25.

4. Marking

Table 3. Marking codes

Type number	Marking code
PCA85233UG/2DA/Q1	on the rear side of the die Line A: PCA85233UG Line B: XXXXXX.XX WW[1]

[1] The rear side marking has the following meaning:
XXXXXX.XX — Production and lot information
WW — wafer number

Fig 1. Rear side laser marking

5. Block diagram

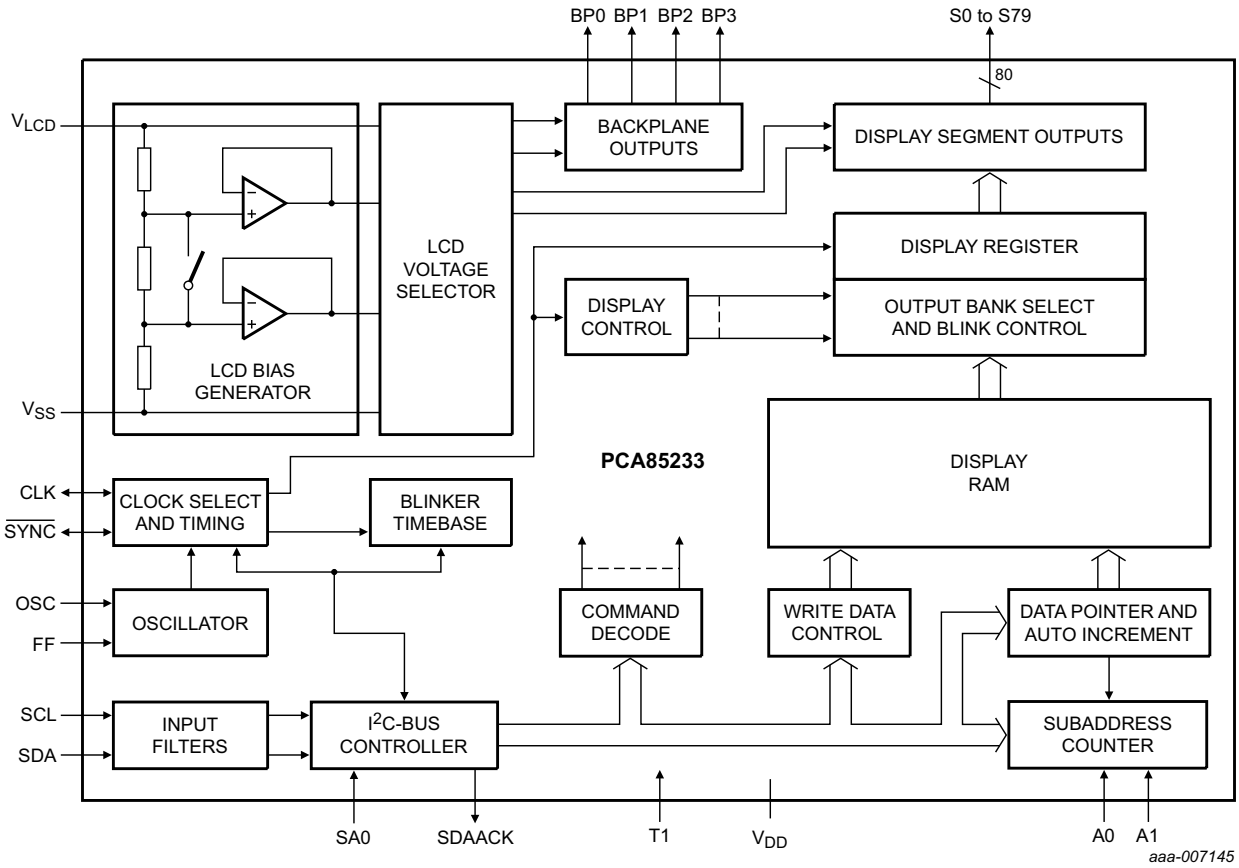
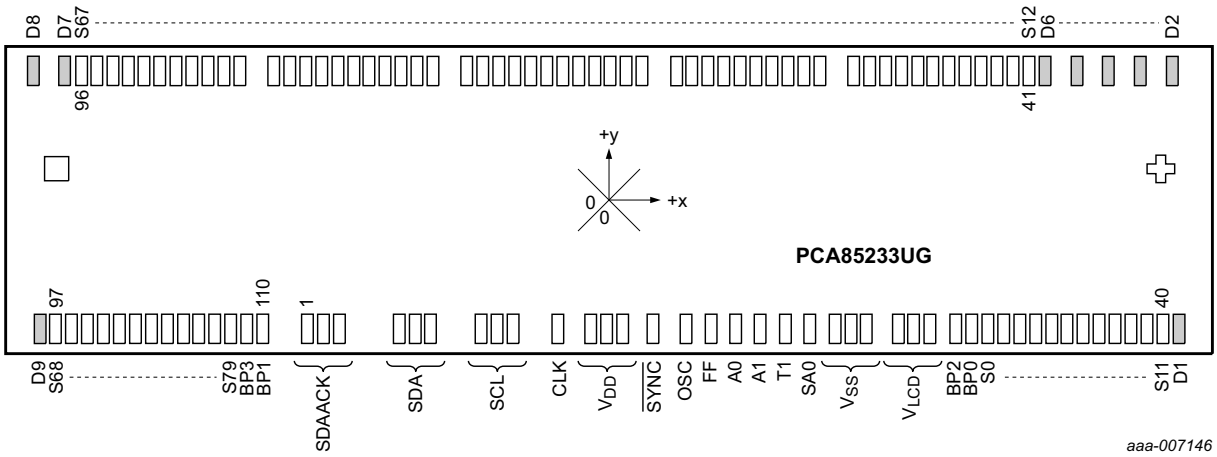


Fig 2. Block diagram of PCA85233

6. Pinning information

6.1 Pinning



Viewed from active side. For mechanical details, see Figure 27.

Fig 3. Pin configuration for PCA85233

6.2 Pin description

Table 4. Pin description overview

Input or input/output pins must always be at a defined level (V_{SS} or V_{DD}) unless otherwise specified.

Symbol	Pin	Description
SDAACK	1 to 3	I²C-bus acknowledge output
SDA	4 to 6	I²C-bus serial data input
SCL	7 to 9	I²C-bus serial clock input
CLK	10	clock input and output
V_{DD}	11 to 13	supply voltage
$\overline{SYNC}$	14	cascade synchronization input or output; if not used it must be left open
OSC	15	oscillator select
FF	16	frame frequency select
A0, A1	17, 18	subaddress input
T1	19	dedicated testing pin; to be tied to V_{SS} in application mode
SA0	20	I²C-bus slave address input
V_{SS}[1]	21 to 23	ground supply voltage
V_{LCD}	24 to 26	LCD supply voltage
BP2, BP0, BP3, and BP1	27, 28, 109 and 110	LCD backplane output
S0 to S79	29 to 108	LCD segment output
D1 to D9	-	dummy pins

[1] The substrate (rear side of the die) is at V_{SS} potential and should be electrically isolated.

7. Functional description

7.1 Commands of PCA85233

The command decoder identifies command bytes that arrive on the I²C-bus. The commands available to the PCA85233 are defined in Table 5.

Table 5. Definition of commands

Command	Operation code								Reference
Bit	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**	
mode-set	1	1	0	0	E	B	M[1:0]		Table 6
load-data-pointer	0	P[6:0]							Table 7
device-select	1	1	1	0	0	0	A[1:0]		Table 8
bank-select	1	1	1	1	1	0	I	O	Table 9
blink-select	1	1	1	1	0	AB	BF[1:0]		Table 10

Table 6. Mode-set command bit description

Bit	Symbol	Value	Description
7 to 4	-	1100	fixed value
3	E		**display status**[1]
		0	disabled (blank)[2]
		1	enabled
2	B		**LCD bias configuration**[3]
		0	1/3 bias
		1	1/2 bias
1 to 0	M[1:0]		**LCD drive mode selection**
		01	static; 1 backplane
		10	1:2 multiplex; 2 backplanes
		11	1:3 multiplex; 3 backplanes
		00	1:4 multiplex; 4 backplanes

[1] The possibility to disable the display allows implementation of blinking under external control.

[2] The display is disabled by setting all backplane and segment outputs to V_{LCD}.

[3] Not applicable for static drive mode.

Table 7. Load-data-pointer command bit description

See Section 7.3.1.

Bit	Symbol	Value	Description
7	-	0	fixed value
6 to 0	P[6:0]	0000000 to 1001111	**data pointer** 7-bit binary value of 0 to 79, transferred to the data pointer to define one of 80 display RAM addresses

Table 8. Device-select command bit description

See Section 7.3.2.

Bit	Symbol	Value	Description
7 to 2	-	111000	fixed value
1 to 0	A[1:0]	00 to 11	**device selection** 2-bit binary value of 0 to 3, transferred to the subaddress counter to define one of 4 hardware subaddresses

Table 9. Bank-select command bit description[1]

See Section 7.3.5 and Section 7.3.6.

Bit	Symbol	Value	Description	
			Static	**1:2 multiplex**
7 to 2	-	111110	fixed value	
1	I		**input bank selection**: storage of arriving display data	
		0	RAM row 0	RAM rows 0 and 1
		1	RAM row 2	RAM rows 2 and 3
0	O		**output bank selection**: retrieval of LCD display data	
		0	RAM row 0	RAM rows 0 and 1
		1	RAM row 2	RAM rows 2 and 3

[1] The bank-select command has no effect in 1:3 or 1:4 multiplex drive modes.

Table 10. Blink-select command bit description

See Section 7.2.3.

Bit	Symbol	Value	Description
7 to 3	-	11110	fixed value
2	AB		**blink mode selection**[1]
		0	normal blinking
		1	blinking by alternating display RAM banks
1 to 0	BF[1:0]		**blink frequency selection**[2]
		00	off
		01	1
		10	2
		11	3

[1] Normal blinking can only be selected in multiplex drive mode 1:3 or 1:4.

[2] For the blink frequencies, see Table 12.

7.2 Clock and frame frequency

7.2.1 Oscillator

The internal logic and the LCD drive signals of the PCA85233 are timed by a frequency f_{clk} which either is derived from the built-in oscillator frequency f_{osc}:

$$f_{clk} = \frac{f_{osc}}{64} \quad (1)$$

or equals an external clock frequency $f_{clk(ext)}$:

$$f_{clk} = f_{clk(ext)} \quad (2)$$

7.2.1.1 Internal clock

The internal oscillator is enabled by connecting pin OSC to V_{SS}. In this case the output from pin CLK provides the clock signal for any cascaded PCA85233 in the system.

7.2.1.2 External clock

Connecting pin OSC to V_{DD} enables an external clock source. Pin CLK then becomes the external clock input.

Remark: A clock signal must always be supplied to the device; removing the clock may freeze the LCD in a DC state, which is not suitable for the liquid crystal.

7.2.2 Frame frequency

The clock frequency f_{clk} determines the LCD frame frequency f_{fr} and is calculated as follows:

$$f_{fr} = \frac{f_{clk}}{24} \quad (3)$$

The internal clock frequency f_{clk} can be selected using pin FF. As a result 2 frame frequencies are available: 150 Hz or 220 Hz (typical), see Table 11.

Table 11. LCD frame frequencies

Pin FF tied to[1]	Typical clock frequency (Hz)	LCD frame frequency (Hz)
V_{DD}	3600	150
V_{SS}	5280	220

[1] FF has no effect when an external clock is used but must not be left floating.

The timing of the PCA85233 organizes the internal data flow of the device. This includes the transfer of display data from the display RAM to the display segment outputs. In cascaded applications, the synchronization signal ($\overline{SYNC}$) maintains the correct timing relationship between all the PCA85233 in the system.

7.2.3 Blinking

The display blink capabilities of the PCA85233 are very versatile. The whole display can blink at frequencies selected by the blink-select command (see Table 10). The blink frequencies are derived from the clock frequency. The ratios between the clock and blink frequencies depend on the blink mode selected (see Table 12).

Table 12. Blink frequencies

Blink mode	Operating mode ratio	Blink frequency with respect to f_{clk} (typical)		Unit
		f_{clk} = 3.600 kHz	f_{clk} = 5.280 kHz	
off	-	blinking off	blinking off	Hz
1	$\frac{f_{clk}}{768}$	4.7	6.9	Hz
2	$\frac{f_{clk}}{1536}$	2.3	3.4	Hz
3	$\frac{f_{clk}}{3072}$	1.2	1.7	Hz

An additional feature is for an arbitrary selection of LCD segments to blink. This applies to the static and 1:2 multiplex drive modes and can be implemented without any communication overheads. By means of the output bank selector, the displayed RAM banks are exchanged with alternate RAM banks at the blink frequency. This mode can also be specified by the blink-select command.

In the 1:3 and 1:4 multiplex modes, where no alternate RAM bank is available, groups of LCD segments can blink by selectively changing the display RAM data at fixed time intervals.

If the entire display can blink at a frequency other then the typical blink frequency. This can be effectively performed by resetting and setting the display enable bit E at the required rate using the mode-set command (see Table 6).

7.3 Display RAM

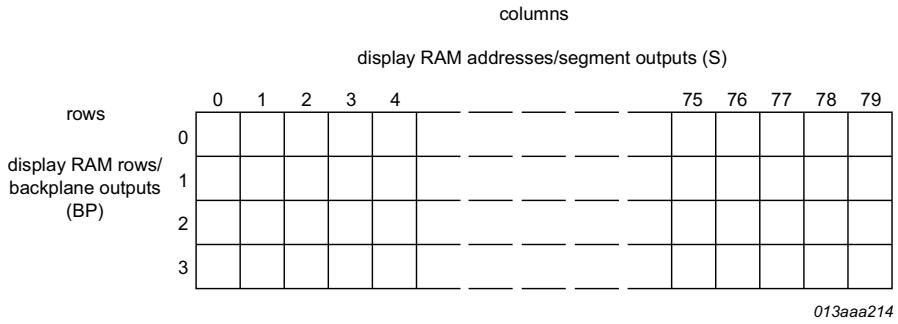
The display RAM is a static 80 × 4 bit RAM which stores LCD data.

There is a one-to-one correspondence between

- the bits in the RAM bitmap and the LCD segments/elements
- the RAM columns and the segment outputs
- the RAM rows and the backplane outputs.

A logic 1 in the RAM bitmap indicates the on-state of the corresponding LCD element; similarly, a logic 0 indicates the off-state.

The display RAM bit map, Figure 4, shows rows 0 to 3 which correspond with the backplane outputs BP0 to BP3, and columns 0 to 79 which correspond with the segment outputs S0 to S79. In multiplexed LCD applications the segment data of the first, second, third and fourth row of the display RAM are time-multiplexed with BP0, BP1, BP2, and BP3 respectively.



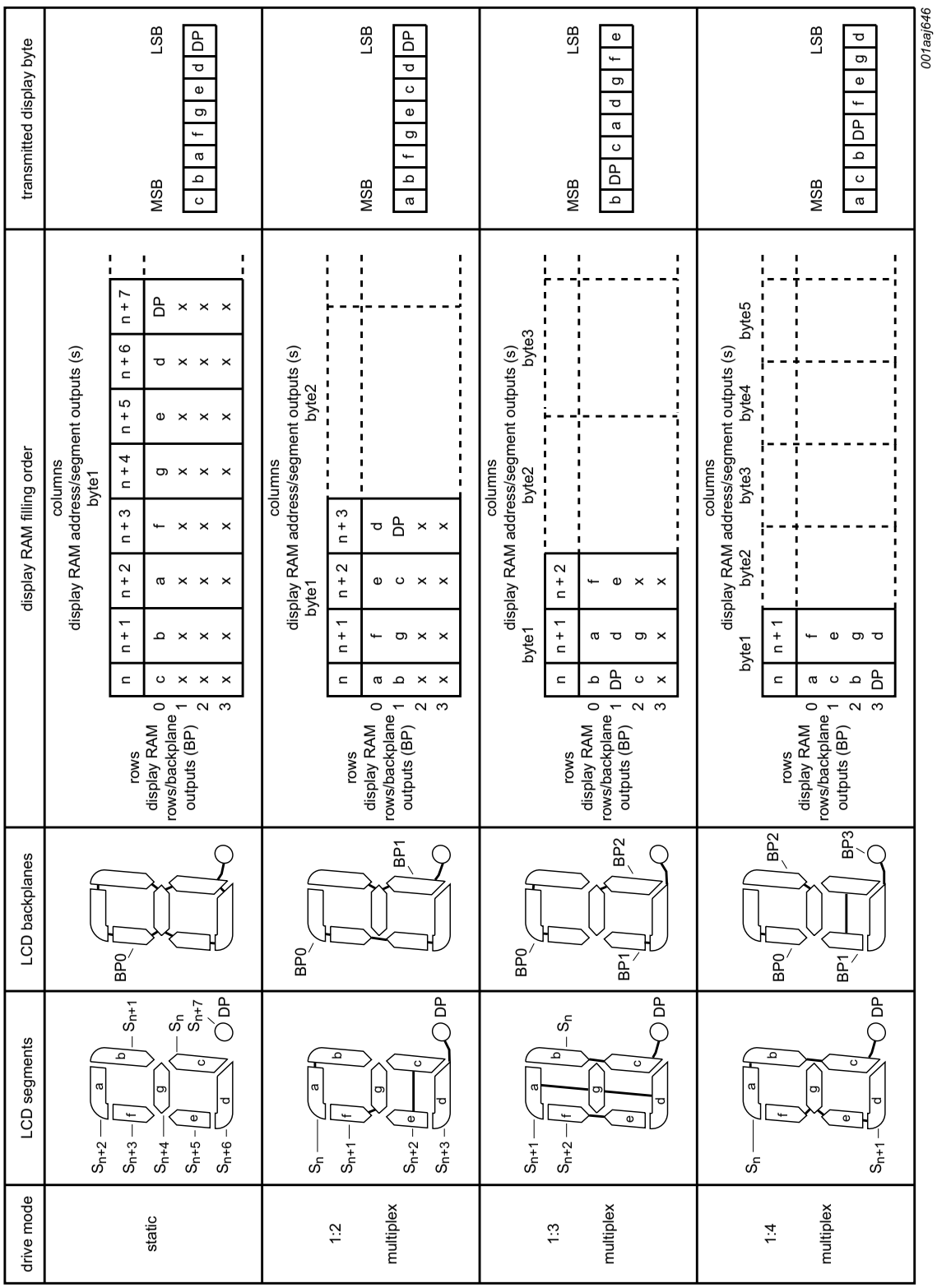
The display RAM bitmap shows the direct relationship between the display RAM addresses and the segment outputs and between the bits in a RAM word and the backplane outputs.

Fig 4. Display RAM bitmap

When display data is transmitted to the PCA85233, the received display bytes are stored in the display RAM in accordance with the selected LCD drive mode. The data is stored as it arrives and depending on the current multiplex drive mode the bits are stored singularly, in pairs, triples or quadruples. To illustrate the filling order, an example of a 7-segment display showing all drive modes is given in Figure 5; the RAM filling organization depicted applies equally to other LCD types.

The following applies to Figure 5:

- In static drive mode the eight transmitted data bits are placed into row 0 as one byte.
- In 1:2 multiplex drive mode the eight transmitted data bits are placed in pairs into row 0 and 1 as four successive 2-bit RAM words.
- In 1:3 multiplex drive mode the eight bits are placed in triples into row 0, 1, and 2 as three successive 3-bit RAM words, with bit 3 of the third address left unchanged. It is not recommended to use this bit in a display because of the difficult addressing. This last bit may, if necessary, be controlled by an additional transfer to this address, but care should be taken to avoid overwriting adjacent data because always full bytes are transmitted (see Section 7.3.3).
- In 1:4 multiplex drive mode, the eight transmitted data bits are placed in quadruples into row 0, 1, 2, and 3 as two successive 4-bit RAM words.



x = data bit unchanged

Fig 5. Relationships between LCD layout, drive mode, display RAM filling order, and display data transmitted over the I²C-bus

7.3.1 Data pointer

The addressing mechanism for the display RAM is realized using a data pointer. This allows the loading of an individual display data byte, or a series of display data bytes, into any location of the display RAM. The sequence commences with the initialization of the data pointer by the load-data-pointer command (see Table 7). Following this command, an arriving data byte is stored at the display RAM address indicated by the data pointer. The filling order is shown in Figure 5. After each byte is stored, the content of the data pointer is automatically incremented by a value dependent on the selected LCD drive mode:

- In static drive mode by eight
- In 1:2 multiplex drive mode by four
- In 1:3 multiplex drive mode by three
- In 1:4 multiplex drive mode by two

If an I^2C-bus data access is terminated early then the state of the data pointer is unknown. Consequently, the data pointer must be rewritten prior to further RAM accesses.

7.3.2 Subaddress counter

The storage of display data is determined by the content of the subaddress counter. Storage is allowed only when the content of the subaddress counter match with the hardware subaddress applied to A0 and A1. The subaddress counter value is defined by the device-select command (see Table 8). If the content of the subaddress counter and the hardware subaddress do not match, then data storage is inhibited but the data pointer is incremented as if data storage had taken place. The subaddress counter is also incremented when the data pointer overflows.

The storage arrangements described lead to extremely efficient data loading in cascaded applications. When a series of display bytes are sent to the display RAM, automatic wrap-over to the next PCA85233 occurs when the last RAM address is exceeded. Subaddressing across device boundaries is successful even if the change to the next device in the cascade occurs within a transmitted character.

The hardware subaddress must not be changed whilst the device is being accessed on the I^2C-bus interface.

7.3.3 RAM writing in 1:3 multiplex drive mode

In 1:3 multiplex drive mode, the RAM is written as shown in Table 13 (see Figure 5 as well).

Table 13. Standard RAM filling in 1:3 multiplex drive mode

*Assumption: BP2/S2, BP2/S5, BP2/S8 etc. **are not connected** to any segments/elements on the display.*

Display RAM bits (rows)/ backplane outputs (BPn)	Display RAM addresses (columns)/segment outputs (Sn)										
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**:**
0	a7	a4	a1	b7	b4	b1	c7	c4	c1	d7	:
1	a6	a3	a0	b6	b3	b0	c6	c3	c0	d6	:
2	a5	a2	-	b5	b2	-	c5	c2	-	d5	:
3	-	-	-	-	-	-	-	-	-	-	:

If the bit at position BP2/S2 would be written by a second byte transmitted, then the mapping of the segment bits would change as illustrated in Table 14.

Table 14. Entire RAM filling by rewriting in 1:3 multiplex drive mode

*Assumption: BP2/S2, BP2/S5, BP2/S8 etc. **are connected** to segments/elements on the display.*

Display RAM bits (rows)/ backplane outputs (BPn)	Display RAM addresses (columns)/segment outputs (Sn)										
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**:**
0	a7	a4	a1/b7	b4	b1/c7	c4	c1/d7	d4	d1/e7	e4	:
1	a6	a3	a0/b6	b3	b0/c6	c3	c0/d6	d3	d0/e6	e3	:
2	a5	a2	b5	b2	c5	c2	d5	d2	e5	e2	:
3	-	-	-	-	-	-	-	-	-	-	:

In the case described in Table 14 the RAM has to be written entirely and BP2/S2, BP2/S5, BP2/S8 etc. have to be connected to segments/elements on the display. This can be achieved by a combination of writing and rewriting the RAM like follows:

- In the first write to the RAM, bits a7 to a0 are written.
- In the second write, bits b7 to b0 are written, overwriting bits a1 and a0 with bits b7 and b6.
- In the third write, bits c7 to c0 are written, overwriting bits b1 and b0 with bits c7 and c6.

Depending on the method of writing to the RAM (standard or entire filling by rewriting), some segments/elements remain unused or can be used, but it has to be considered in the module layout process as well as in the driver software design.

7.3.4 Writing over the RAM address boundary

In all multiplex drive modes, depending on the setting of the data pointer, it is possible to fill the RAM over the RAM address boundary. If the PCA85233 is part of a cascade the additional bits fall into the next device that also generates the acknowledge signal. If the PCA85233 is a single device or the last device in a cascade the additional bits will be discarded and no acknowledge signal will be generated.

7.3.5 Output bank selector

The output bank selector (see Table 9) selects one of the four rows per display RAM address for transfer to the display register. The actual row selected depends on the selected LCD drive mode in operation and on the instant in the multiplex sequence.

- In 1:4 multiplex mode, all RAM addresses of row 0 are selected, these are followed by the contents of row 1, 2, and then 3
- In 1:3 multiplex mode, rows 0, 1, and 2 are selected sequentially
- In 1:2 multiplex mode, rows 0 and 1 are selected
- In static mode, row 0 is selected

The PCA85233 includes a RAM bank switching feature in the static and 1:2 multiplex drive modes. In the static drive mode, the bank-select command may request the contents of row 2 to be selected for display instead of the contents of row 0. In the 1:2 multiplex

mode, the contents of rows 2 and 3 may be selected instead of rows 0 and 1. This gives the provision for preparing display information in an alternative bank and to be able to switch to it once it is assembled.

7.3.6 Input bank selector

The input bank selector loads display data into the display RAM in accordance with the selected LCD drive configuration. Display data can be loaded in row 2 in static drive mode or in rows 2 and 3 in 1:2 multiplex drive mode by using the bank-select command (see Table 9). The input bank selector functions independently to the output bank selector.

7.4 Initialization

At power-on the status of the I^2C-bus and the registers of the PCA85233 is undefined. Therefore the PCA85233 should be initialized as quickly as possible after power-on to ensure a proper bus communication and to avoid display artifacts. The following instructions should be accomplished for initialization:

- I^2C-bus (see Section 8) initialization
  - generating a START condition
  - sending 0h and ignoring the acknowledge
  - generating a STOP condition
- Mode-set command (see Table 6), setting
  - bit E = 0
  - bit B to the required LCD bias configuration
  - bits M[1:0] to the required LCD drive mode
- Load-data-pointer command (see Table 7), setting
  - bits P[6:0] to 0h (or any other required address)
- Device-select command (see Table 8), setting
  - bits A[1:0] to the required hardware subaddress (for example, 0h)
- Bank-select command (see Table 9), setting
  - bit I to 0
  - bit O to 0
- Blink-select command (see Table 10), setting
  - bit AB to 0 or 1
  - bits BF[1:0] to 00 (or to a desired blinking mode)
- writing meaningful information (for example, a logo) into the display RAM

After the initialization, the display can be switched on by setting bit E = 1 with the mode-set command.

7.5 Possible display configurations

The PCA85233 is a versatile peripheral device designed to interface between any microcontroller to a wide variety of LCD segment or dot matrix displays (see Figure 6). It can directly drive any static or multiplexed LCD containing up to four backplanes and up to 80 segments.

The display configurations possible with the PCA85233 depend on the required number of active backplane outputs. A selection of display configurations is given in Table 15.

All of the display configurations given in Table 15 can be implemented in a typical system as shown in Figure 7.

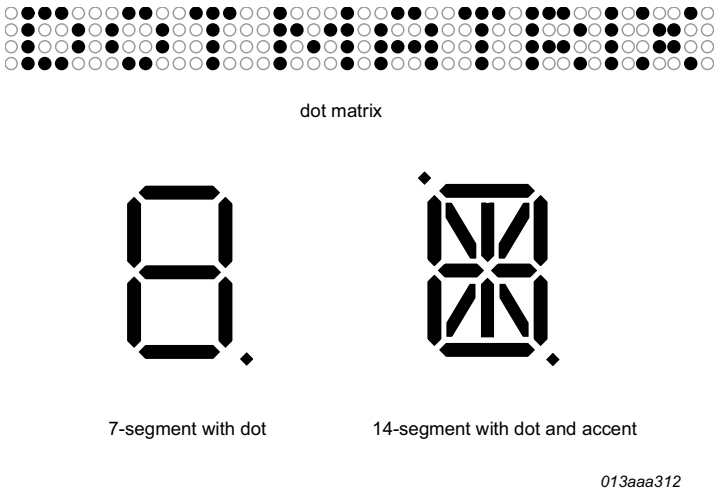


Fig 6. Example of displays suitable for PCA85233

Table 15. Selection of possible display configurations

Number of				
Backplanes	**Icons**	**Digits/Characters**		**Dot matrix: segments/ elements**
		7-segment[1]	**14-segment[2]**	
4	320	40	20	320 (4 × 80)
3	240	30	15	240 (3 × 80)
2	160	20	10	160 (2 × 80)
1	80	10	5	80 (1 × 80)

[1] 7 segment display has 8 segments/elements including the decimal point.

[2] 14 segment display has 16 segments/elements including decimal point and accent dot.

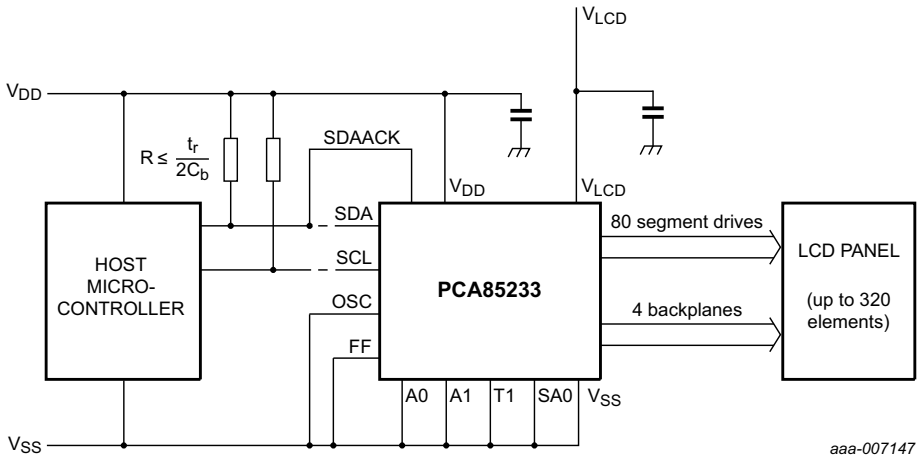


Fig 7. Typical system configuration

The host microcontroller maintains the 2-line I²C-bus communication channel with the PCA85233. The internal oscillator is enabled by connecting pin OSC to pin V_{SS}. The appropriate biasing voltages for the multiplexed LCD waveforms are generated internally. The only other connections required to complete the system are the power supplies (V_{DD}, V_{SS}, and V_{LCD}) and the LCD panel chosen for the application.

7.6 LCD bias generator

Fractional LCD biasing voltages are obtained from an internal voltage divider of three impedances connected between pins V_{LCD} and V_{SS}. The center impedance is bypassed by switch if the ½ bias voltage level for the 1:2 multiplex drive mode configuration is selected.

7.7 LCD voltage selector

The LCD voltage selector coordinates the multiplexing of the LCD in accordance with the selected LCD drive configuration. The operation of the voltage selector is controlled by the mode-set command from the command decoder. The biasing configurations that apply to the preferred modes of operation, together with the biasing characteristics as functions of V_{LCD} and the resulting discrimination ratios (D) are given in Table 16.

Discrimination is a term which is defined as the ratio of the on and off RMS voltage across a segment. It can be thought of as a measurement of contrast.

Table 16. Biasing characteristics

LCD drive mode	Number of:		LCD bias configuration	$\frac{V_{off(RMS)}}{V_{LCD}}$	$\frac{V_{on(RMS)}}{V_{LCD}}$	$D = \frac{V_{on(RMS)}}{V_{off(RMS)}}$
	Backplanes	Levels				
static	1	2	static	0	1	∞
1:2 multiplex	2	3	½	0.354	0.791	2.236
1:2 multiplex	2	4	⅓	0.333	0.745	2.236
1:3 multiplex	3	4	⅓	0.333	0.638	1.915
1:4 multiplex	4	4	⅓	0.333	0.577	1.732

A practical value for V_{LCD} is determined by equating $V_{off(RMS)}$ with a defined LCD threshold voltage ($V_{th(off)}$), typically when the LCD exhibits approximately 10 % contrast. In the static drive mode a suitable choice is $V_{LCD} > 3V_{th(off)}$.

Multiplex drive modes of 1:3 and 1:4 with ½ bias are possible but the discrimination and hence the contrast ratios are smaller.

Bias is calculated by $\frac{1}{1+a}$, where the values for a are

a = 1 for ½ bias

a = 2 for ⅓ bias

The RMS on-state voltage ($V_{on(RMS)}$) for the LCD is calculated with Equation 4:

$$V_{on(RMS)} = V_{LCD}\sqrt{\frac{a^2+2a+n}{n\times(1+a)^2}} \quad (4)$$

where the values for n are

n = 1 for static drive mode

n = 2 for 1:2 multiplex drive mode

n = 3 for 1:3 multiplex drive mode

n = 4 for 1:4 multiplex drive mode

The RMS off-state voltage ($V_{off(RMS)}$) for the LCD is calculated with Equation 5:

$$V_{off(RMS)} = V_{LCD}\sqrt{\frac{a^2-2a+n}{n\times(1+a)^2}} \quad (5)$$

Discrimination is the ratio of $V_{on(RMS)}$ to $V_{off(RMS)}$ and is determined from Equation 6:

$$D = \frac{V_{on(RMS)}}{V_{off(RMS)}} = \sqrt{\frac{a^2+2a+n}{a^2-2a+n}} \quad (6)$$

Using Equation 6, the discrimination for an LCD drive mode of 1:3 multiplex with ½ bias is $\sqrt{3} = 1.732$ and the discrimination for an LCD drive mode of 1:4 multiplex with ½ bias is $\frac{\sqrt{21}}{3} = 1.528$.

The advantage of these LCD drive modes is a reduction of the LCD full scale voltage V_{LCD} as follows:

- 1:3 multiplex (½ bias): $V_{LCD} = \sqrt{6}\times V_{off(RMS)} = 2.449V_{off(RMS)}$
- 1:4 multiplex (½ bias): $V_{LCD} = \left[\frac{(4\times\sqrt{3})}{3}\right] = 2.309V_{off(RMS)}$

These compare with $V_{LCD} = 3V_{off(RMS)}$ when ⅓ bias is used.

V_{LCD} is sometimes referred as the LCD operating voltage.

7.7.1 Electro-optical performance

Suitable values for $V_{on(RMS)}$ and $V_{off(RMS)}$ are dependent on the LCD liquid used. The RMS voltage, at which a pixel will be switched on or off, determine the transmissibility of the pixel.

For any given liquid, there are two threshold values defined. One point is at 10 % relative transmission (at $V_{th(off)}$) and the other at 90 % relative transmission (at $V_{th(on)}$), see Figure 8. For a good contrast performance, the following rules should be followed:

$$V_{on(RMS)} \geq V_{th(on)} \tag{7}$$

$$V_{off(RMS)} \leq V_{th(off)} \tag{8}$$

$V_{on(RMS)}$ and $V_{off(RMS)}$ are properties of the display driver and are affected by the selection of a, n (see Equation 4 to Equation 6) and the V_{LCD} voltage.

$V_{th(off)}$ and $V_{th(on)}$ are properties of the LCD liquid and can be provided by the module manufacturer. $V_{th(off)}$ is sometimes named V_{th}. $V_{th(on)}$ is sometimes named saturation voltage V_{sat}.

It is important to match the module properties to those of the driver in order to achieve optimum performance.

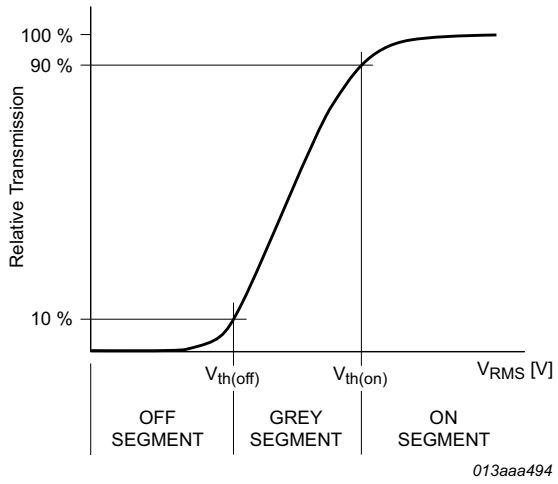
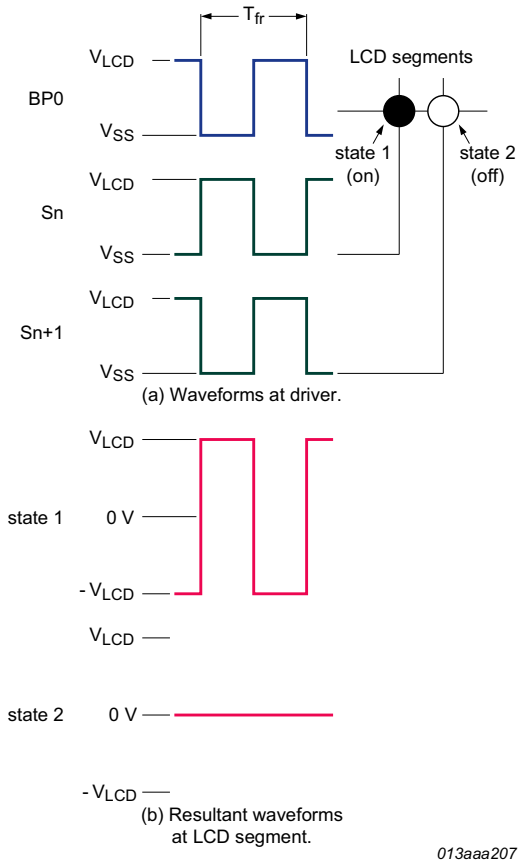


Fig 8. Electro-optical characteristic: relative transmission curve of the liquid

7.8 LCD drive mode waveforms

7.8.1 Static drive mode

The static LCD drive mode is used when a single backplane is provided in the LCD. Backplane and segment drive waveforms for this mode are shown in Figure 9.



$V_{state1}(t) = V_{Sn}(t) - V_{BP0}(t)$.

$V_{on(RMS)} = V_{LCD}$.

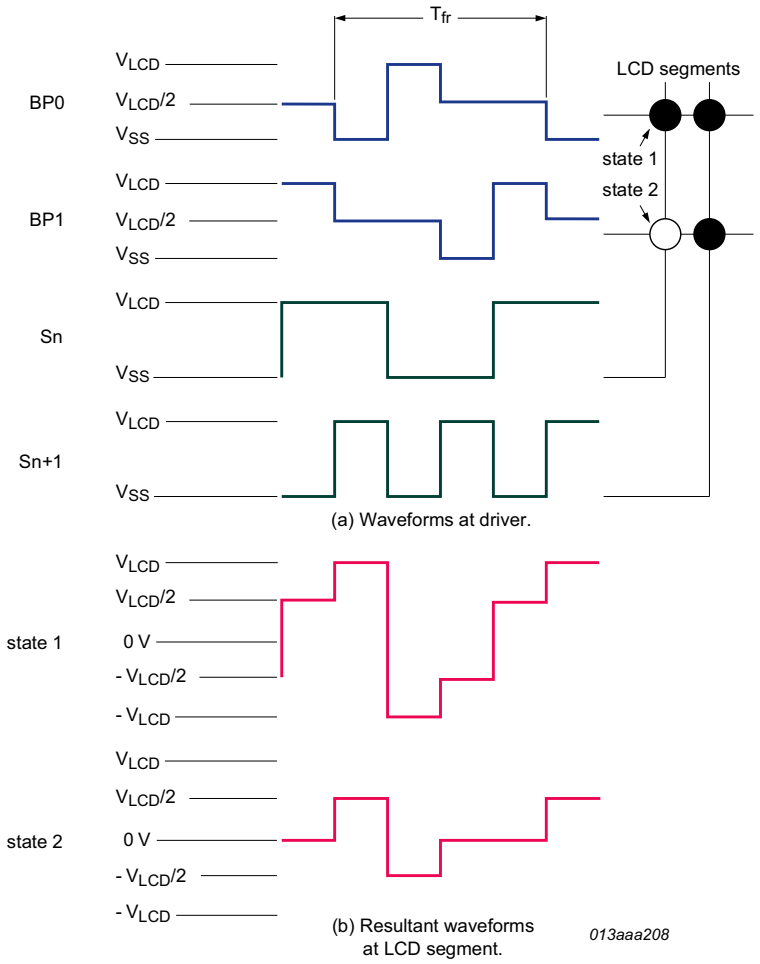
$V_{state2}(t) = V_{(Sn + 1)}(t) - V_{BP0}(t)$.

$V_{off(RMS)} = 0$ V.

Fig 9. Static drive mode waveforms

7.8.2 1:2 Multiplex drive mode

When two backplanes are provided in the LCD, the 1:2 multiplex mode applies. The PCA85233 allows the use of ½ bias or ⅓ bias in this mode as shown in Figure 10 and Figure 11.



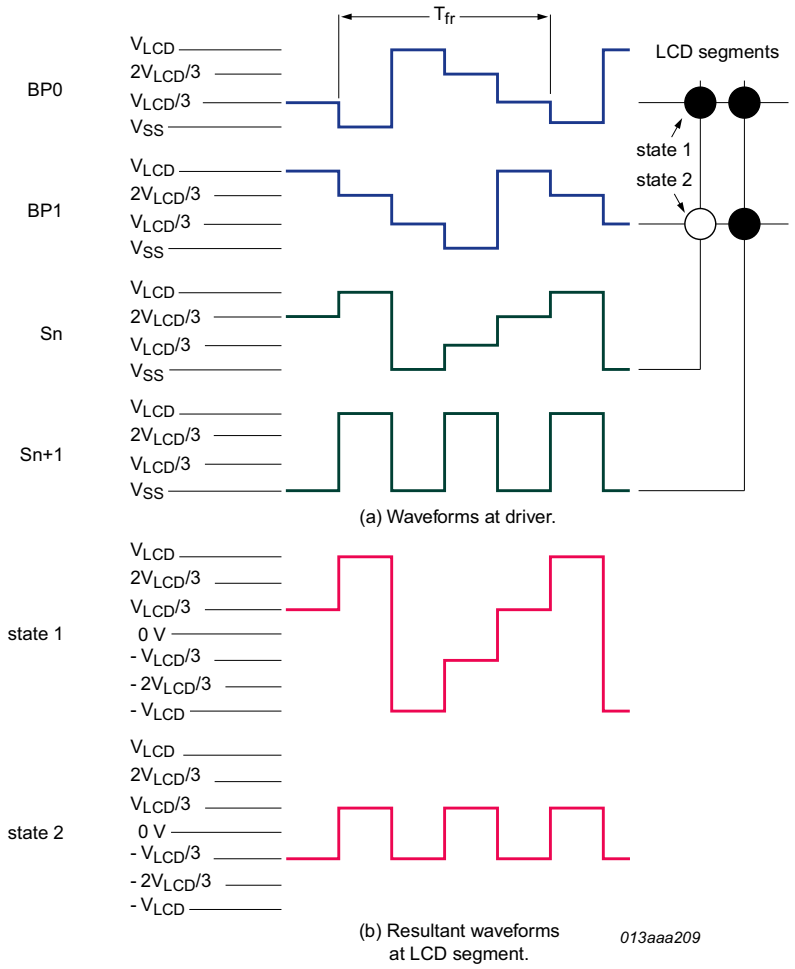
$V_{state1}(t) = V_{Sn}(t) - V_{BP0}(t)$.

$V_{on(RMS)} = 0.791V_{LCD}$.

$V_{state2}(t) = V_{Sn}(t) - V_{BP1}(t)$.

$V_{off(RMS)} = 0.354V_{LCD}$.

Fig 10. Waveforms for the 1:2 multiplex drive mode with ½ bias



$V_{state1}(t) = V_{Sn}(t) - V_{BP0}(t)$.

$V_{on(RMS)} = 0.745V_{LCD}$.

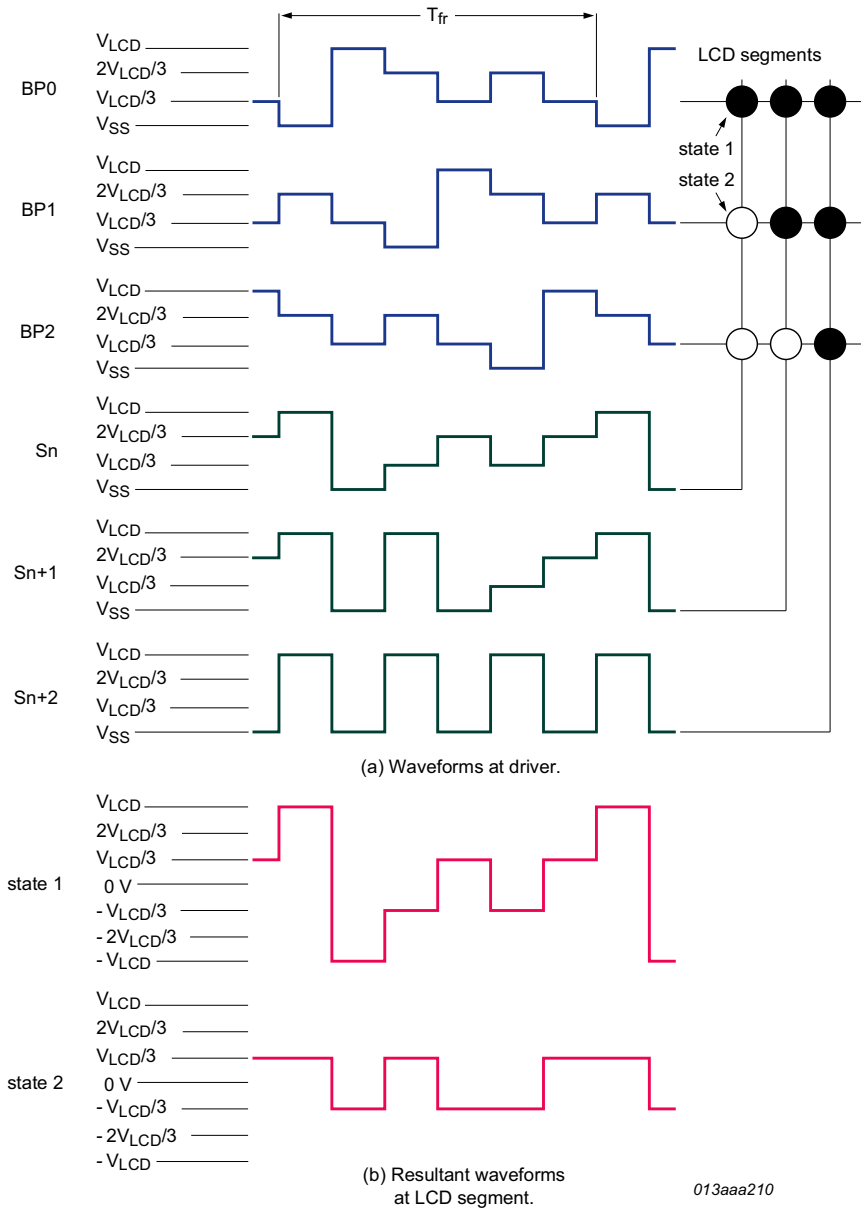
$V_{state2}(t) = V_{Sn}(t) - V_{BP1}(t)$.

$V_{off(RMS)} = 0.333V_{LCD}$.

Fig 11. Waveforms for the 1:2 multiplex drive mode with ⅓ bias

7.8.3 1:3 Multiplex drive mode

When three backplanes are provided in the LCD, the 1:3 multiplex drive mode applies, as shown in Figure 12.



$V_{state1}(t) = V_{Sn}(t) - V_{BP0}(t)$.

$V_{on(RMS)} = 0.638V_{LCD}$.

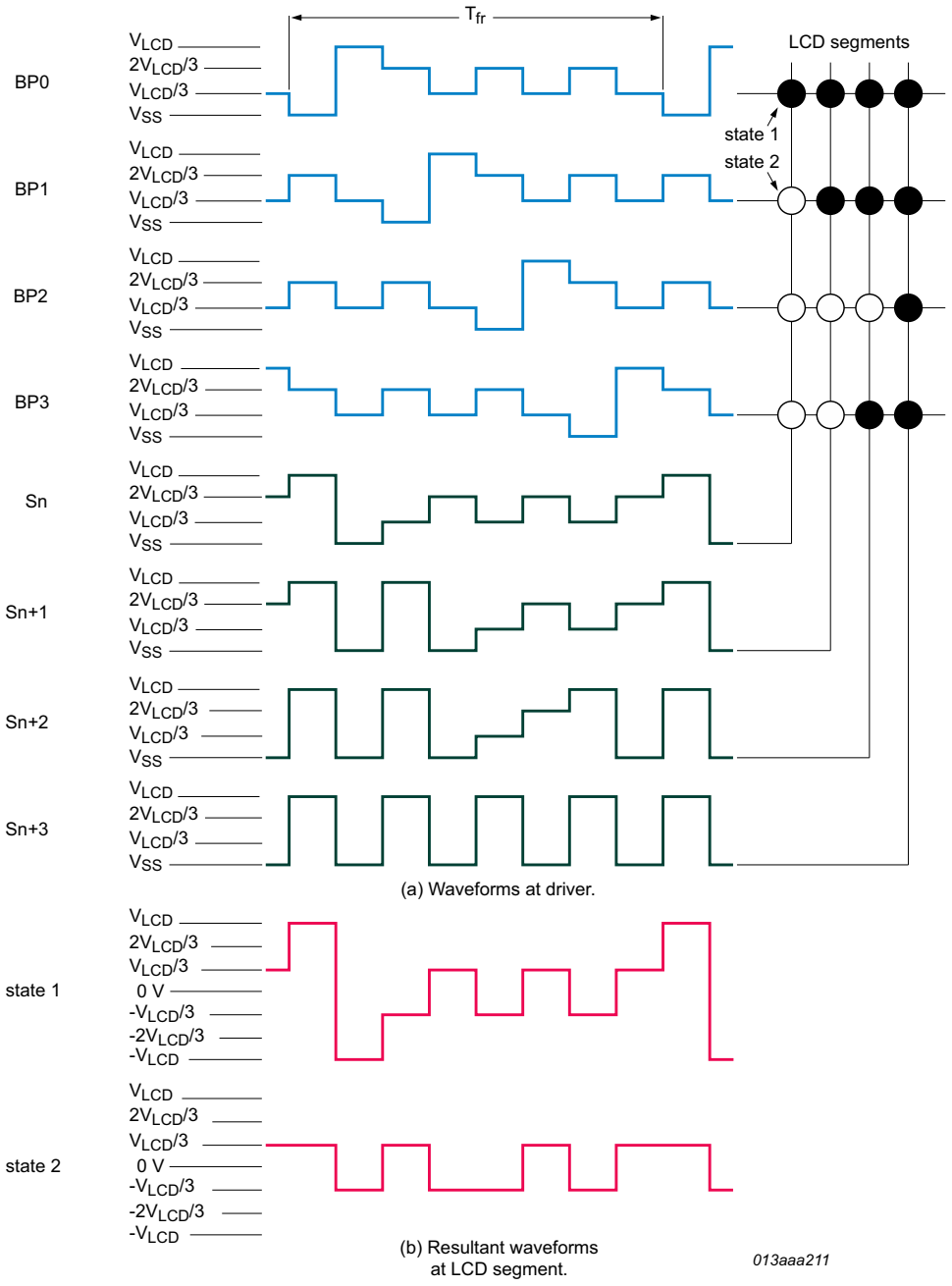
$V_{state2}(t) = V_{Sn}(t) - V_{BP1}(t)$.

$V_{off(RMS)} = 0.333V_{LCD}$.

Fig 12. Waveforms for the 1:3 multiplex drive mode with ⅓ bias

7.8.4 1:4 Multiplex drive mode

When four backplanes are provided in the LCD, the 1:4 multiplex drive mode applies, as shown in Figure 13.



$V_{state1}(t) = V_{Sn}(t) - V_{BP0}(t)$.

$V_{on(RMS)} = 0.577V_{LCD}$.

$V_{state2}(t) = V_{Sn}(t) - V_{BP1}(t)$.

$V_{off(RMS)} = 0.333V_{LCD}$.

Fig 13. Waveforms for the 1:4 multiplex drive mode with ⅓ bias

7.9 Backplane outputs

The LCD drive section includes four backplane outputs: BP0 to BP3. The backplane output signals are generated in accordance with the selected LCD drive mode.

- In the 1:4 multiplex drive mode BP0 to BP3 must be connected directly to the LCD.

If less than four backplane outputs are required the unused outputs can be left open-circuit.

- In 1:3 multiplex drive mode: BP3 carries the same signal as BP1; therefore, these two adjacent outputs can be tied together to give enhanced drive capabilities.
- In 1:2 multiplex drive mode: BP0 and BP2, respectively, BP1 and BP3 carry the same signals and can also be paired to increase the drive capabilities.
- In static drive mode: The same signal is carried by all four backplane outputs; and they can be connected in parallel for very high drive requirements.

7.10 Segment outputs

The LCD drive section includes 80 segment outputs (S0 to S79) which must be connected directly to the LCD. The segment output signals are generated in accordance with the multiplexed backplane signals and with data residing in the display register. When less than 80 segment outputs are required the unused segment outputs must be left open-circuit.

8. Characteristics of the I²C-bus

The I²C-bus is for bidirectional, two-line communication between different ICs or modules. The two lines are a Serial DAta line (SDA) and a Serial CLock line (SCL). Both lines must be connected to a positive supply via a pull-up resistor when connected to the output stages of a device. Data transfer may be initiated only when the bus is not busy.

By connecting pin SDAACK to pin SDA on the PCA85233, the SDA line becomes fully I²C-bus compatible. In COG applications where the track resistance from the SDAACK pin to the system SDA line can be significant, possibly a voltage divider is generated by the bus pull-up resistor and the Indium Tin Oxide (ITO) track resistance. As a consequence it may be possible that the acknowledge generated by the PCA85233 can't be interpreted as logic 0 by the master. In COG applications where the acknowledge cycle is required, it is therefore necessary to minimize the track resistance from the SDAACK pin to the system SDA line to guarantee a valid LOW level.

By separating the acknowledge output from the serial data line (having the SDAACK open circuit) design efforts to generate a valid acknowledge level can be avoided. However, in that case the I²C-bus master has to be set up in such a way that it ignores the acknowledge cycle.[2]

The following definition assumes SDA and SDAACK are connected and refers to the pair as SDA.

8.1 Bit transfer

One data bit is transferred during each clock pulse. The data on the SDA line must remain stable during the HIGH period of the clock pulse as changes in the data line at this time will be interpreted as a control signal (see Figure 14).

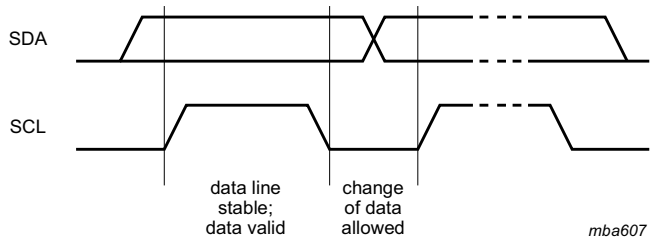


Fig 14. Bit transfer

8.2 START and STOP conditions

Both data and clock lines remain HIGH when the bus is not busy.

A HIGH-to-LOW change of the data line, while the clock is HIGH, is defined as the START condition (S).

A LOW-to-HIGH change of the data line, while the clock is HIGH, is defined as the STOP condition (P).

2. For further information, please consider the NXP application note: Ref. 1 "AN10170".

The START and STOP conditions are shown in Figure 15.

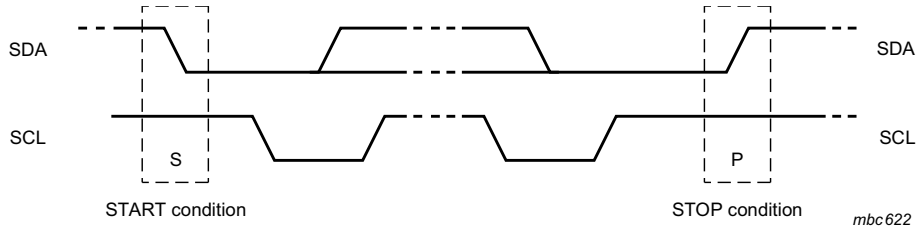


Fig 15. Definition of START and STOP conditions

8.3 System configuration

A device generating a message is a transmitter, a device receiving a message is the receiver. The device that controls the message is the master; and the devices which are controlled by the master are the slaves. The system configuration is shown in Figure 16.

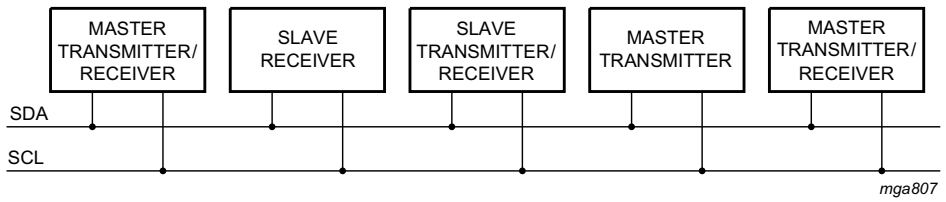


Fig 16. System configuration

8.4 Acknowledge

The number of data bytes transferred between the START and STOP conditions from transmitter to receiver is unlimited. Each byte of eight bits is followed by an acknowledge cycle.

- A slave receiver, which is addressed, must generate an acknowledge after the reception of each byte.
- A master receiver must generate an acknowledge after the reception of each byte that has been clocked out of the slave transmitter.
- The device that acknowledges must pull-down the SDA line during the acknowledge clock pulse, so that the SDA line is stable LOW during the HIGH period of the acknowledge related clock pulse (set-up and hold times must be taken into consideration).
- A master receiver must signal an end of data to the transmitter by not generating an acknowledge on the last byte that has been clocked out of the slave. In this event, the transmitter must leave the data line HIGH to enable the master to generate a STOP condition.

Acknowledgement on the I^2C-bus is shown in Figure 17.