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## **R8C/2D Group, M16C/29 Group**

### **Software LCD Driver**

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## **Introduction**

One of the most common ways of providing the user of an electronic system with information on its status is through the use of a Liquid Crystal Display (LCD). The simplest and lowest cost LCDs use individually controlled segments of various shapes and sizes to represent numbers, characters and symbols. Usually these are customized for particular applications, for example pocket calculators, digital clocks, utility meters and heating thermostats.

It is often necessary to use specialized circuitry to control and drive this type of segment LCD. This circuitry can be in the form of a dedicated IC, or more commonly, integrated in a single-chip microcontroller. This can increase the cost and complexity of a design or reduce the microcontroller options available for the application task.

By using some of the performance available on a standard single-chip microcontroller and a few external passive components it is possible to use general purpose microcontroller port pins to drive a segment-type LCD. This application note describes one way of doing this and provides the necessary code to accomplish this LCD drive technique on Renesas R8C and M16C microcontrollers.

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# Introduction to Liquid Crystal Displays

## 1. Basic Characteristics of LCDs

LCDs work by utilizing the crystalline properties of the material used in their construction. In one commonly used configuration, this material is sandwiched between two layers of glass polarised at right angles to each another. The liquid crystal material aligns itself in the direction of microscopic grooves in the first layer of glass that run in the same direction as the polarisation. Each subsequent layer of crystal molecules is twisted slightly so that by the time the second layer of glass is reached the molecules are twisted at 90 degrees and align with the grooves and polarisation of the second piece of glass.

When light strikes the first piece of glass it is polarised and passes through to the liquid crystal material. As it passes through the liquid crystal the plane of vibration of the light is twisted by each layer of crystal molecules, so that when the light reaches the glass at the other side it is able to pass through the polarisation filter.

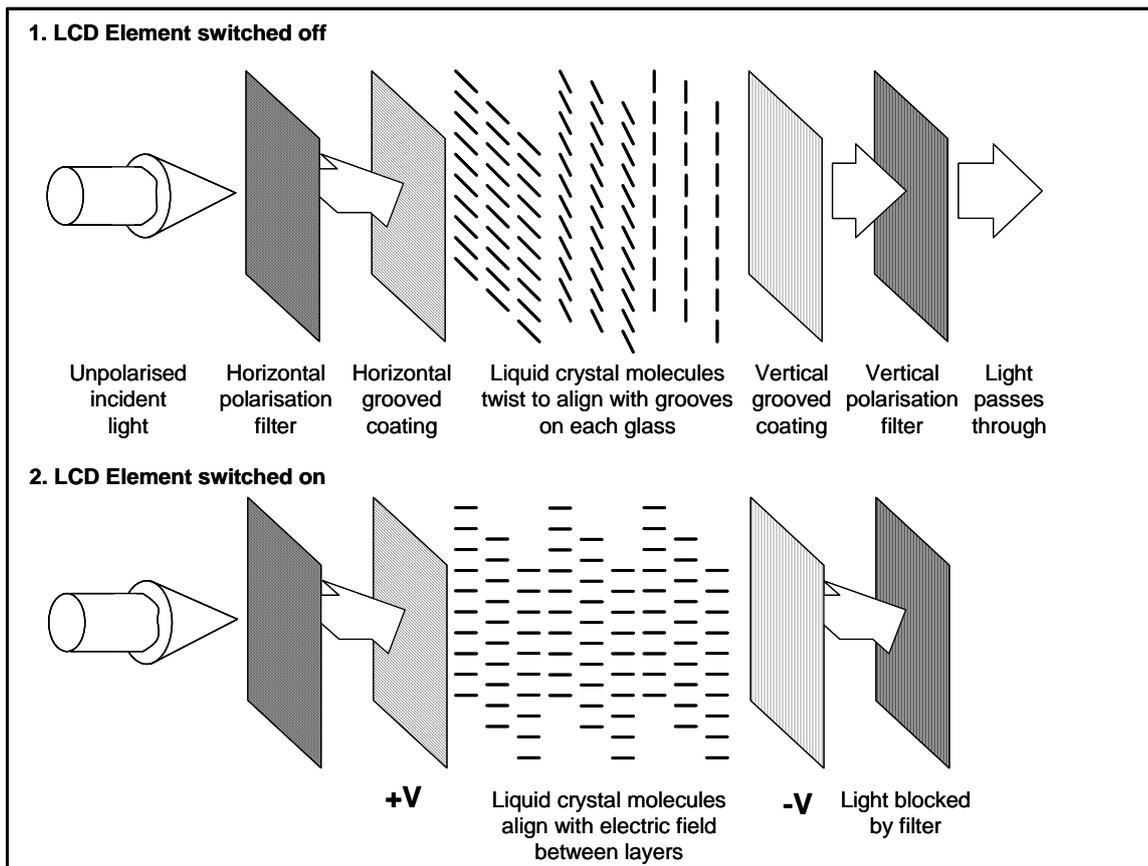


Figure 1: Basic Construction of Liquid Crystal Displays

When a voltage is applied across the glass it causes the crystals to untwist and align themselves in the direction of the electric field. This blocks the light from passing through the second pane of polarised glass and creates a dark area on the display. By dividing the glass into different areas, or picture elements, where a voltage can be applied, a display can be built up.

Applying a constant voltage in one direction to an LCD display element can cause the crystals to become permanently aligned in a particular direction, causing damage to the display. It is therefore necessary to alternate the direction of the applied voltage continuously and ensure no DC component is present.

## 2. Static Liquid Crystal Displays

Static LCDs are the most simple to control. One control signal, or ‘segment’ line, is used per element, with a further signal used to apply the voltage to the backplane, or ‘common’ electrode. By applying an alternating voltage to the common electrode and alternating the voltage applied to each element either in phase or 180° out of phase with the common electrode voltage, an element can either be switched off or switched on.

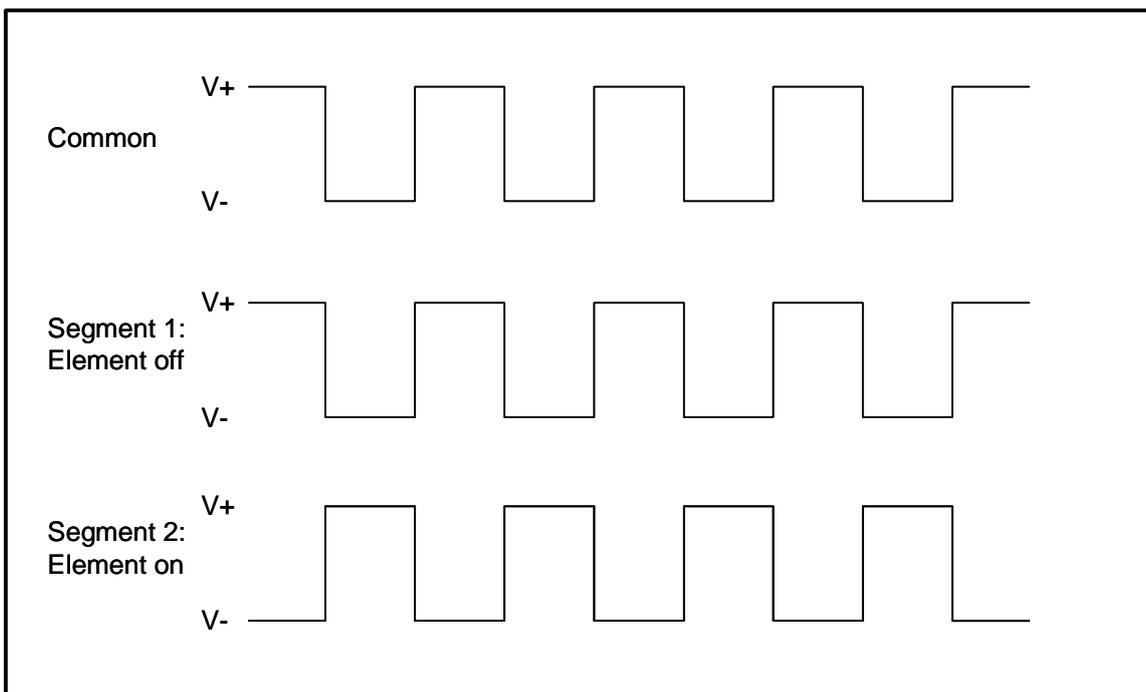


Figure 2: Static LCD Control Signals

Static LCDs give excellent contrast, as the root mean squared voltage ( $V_{RMS}$ ) applied between the electrodes for an ‘on’ element is equal to the display supply voltage. However it effectively limits the number of elements to the number of control signals available.

### 3. Multiplexed Liquid Crystal Displays

As LCDs are commonly made up of many elements, it is usually necessary to multiplex the signals used to control the display. This is done by using several backplanes or common electrodes, and controlling more than one element with each segment control line. For example, in the simple LCD used for a digital clock shown in Figure 3, rather than using a different signal to drive each of the 44 elements, 15 signals can be used in an 11 x 4 multiplexed arrangement.

In low-cost embedded systems configurations with up to 40 segments and 4 commons are most widely used, giving control of up to 160 elements. Much more complex multiplexing schemes are used in colour graphics LCDs, however these require dedicated control circuitry and are not the subject of this application note.

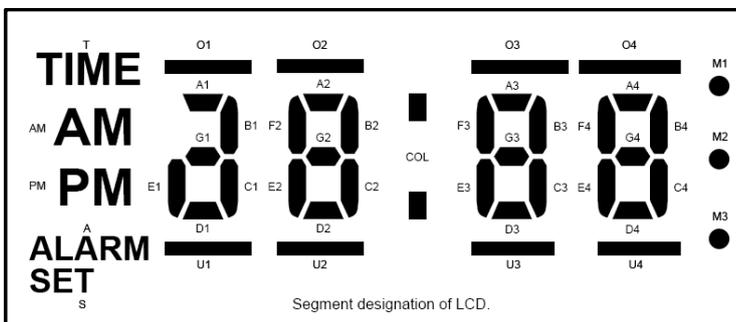


Figure 3: Example of a Simple Multiplexed LCD

To illustrate the generation of signals used to drive a multiplexed LCD, we will look at this simple example of a display with 4 common and 2 segment lines driving a total of 8 elements

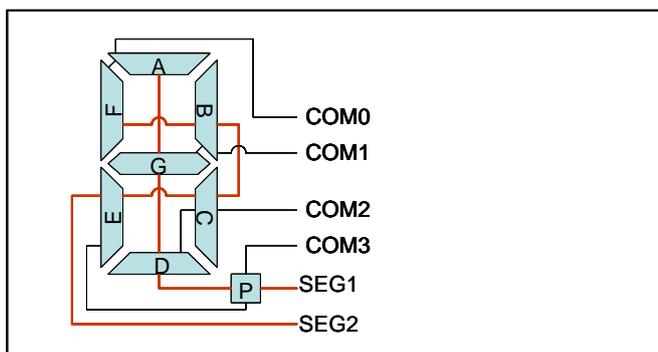


Figure 4: Layout of a simple multiplexed LCD

To avoid switching on elements we do not wish to be on that are connected to the same segment line, each common is active for only part of the time. In this application note each common line can be at one of three levels:

‘Active high’ – the I/O pin is configured as an output and a ‘1’ is written to the data register to apply the supply voltage onto the common line

‘Active Low’ – the I/O pin is configured as an output and a ‘0’ is written to the data register to apply the supply ground onto the common line

‘Inactive’ – the I/O pin is configured as an input and a voltage divider pulls the line to mid way between the supply voltage rails

The segment line attached to the element to be switched on has a voltage of opposite polarity applied during both the ‘active high’ and ‘active low’ parts of the corresponding common line.

For example, for the above simple LCD layout, the control signals used to display the digit ‘2’ would appear as in Figure 5 below.

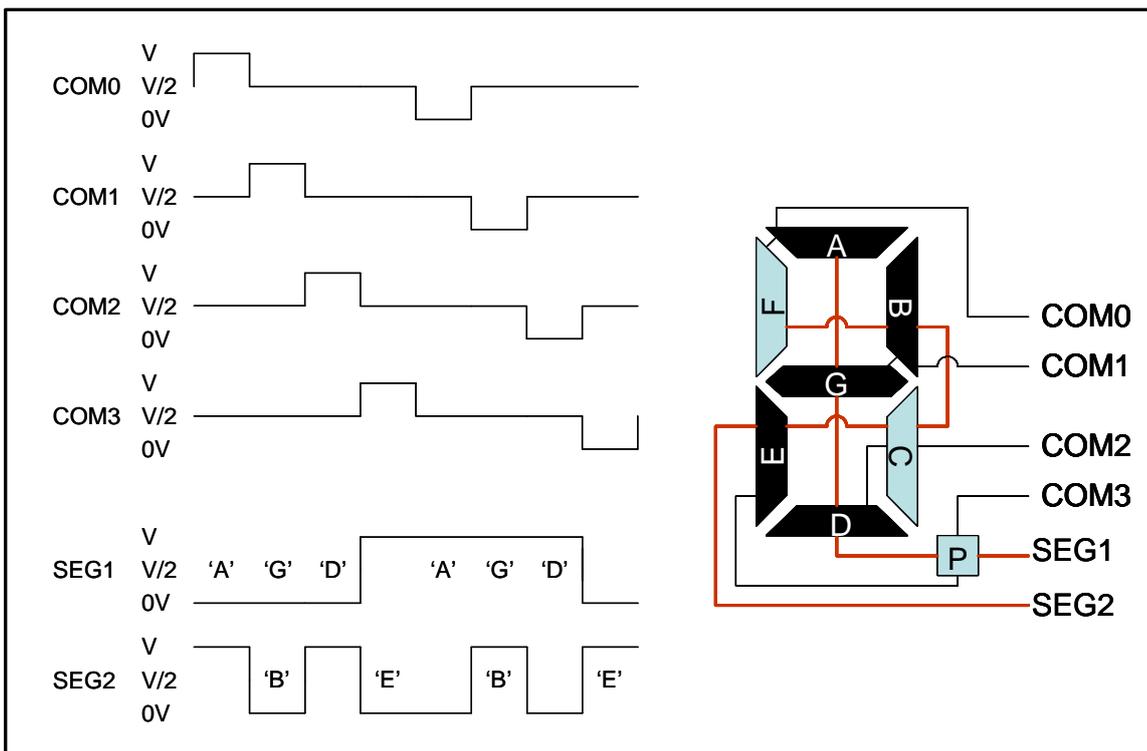


Figure 5: Control Signals for 4-way Multiplexed LCD

Using this simple technique the above diagram shows that the average voltage across both active and inactive segments is zero. However if we consider the root mean squared voltage across each segment for a 2-way multiplexed LCD:

$$\text{Active element } V_{\text{RMS}} = (V_{\text{dd}} \times 0.5) + (0.5 \times V_{\text{dd}} \times 0.5) = 0.75V_{\text{dd}}$$

$$\text{Inactive element } V_{\text{RMS}} = (0 \times 0.5) + (0.5 \times V_{\text{dd}} \times 0.5) = 0.25V_{\text{dd}}$$

Using 3-way multiplexing, with 3 backplane signals, we can calculate the difference between the RMS voltage on inactive and active segments thus:

$$\text{Active element } V_{\text{RMS}} = (V_{\text{dd}} \times 0.33) + (0.5 \times V_{\text{dd}} \times 0.67) = 0.66V_{\text{dd}}$$

$$\text{Inactive element } V_{\text{RMS}} = (0 \times 0.33) + (0.5 \times V_{\text{dd}} \times 0.67) = 0.33V_{\text{dd}}$$

If we use 4-way multiplexing as above the difference between the RMS voltage on active and inactive segments is reduced. Thus:

$$\text{Active element } V_{\text{RMS}} = (V_{\text{dd}} \times 0.25) + (0.5 \times V_{\text{dd}} \times 0.75) = 0.625V_{\text{dd}}$$

$$\text{Inactive element } V_{\text{RMS}} = (0 \times 0.25) + (0.5 \times V_{\text{dd}} \times 0.75) = 0.375V_{\text{dd}}$$

As the number of backplanes or commons increases, the  $V_{\text{RMS}}$  of an active element declines, while the  $V_{\text{RMS}}$  of an inactive element increases. This can have the effect of reducing the overall contrast of the display. Figure 6 shows a graph of the ‘darkness’ of active and inactive elements versus the RMS voltage across them for an increasing number of backplanes.

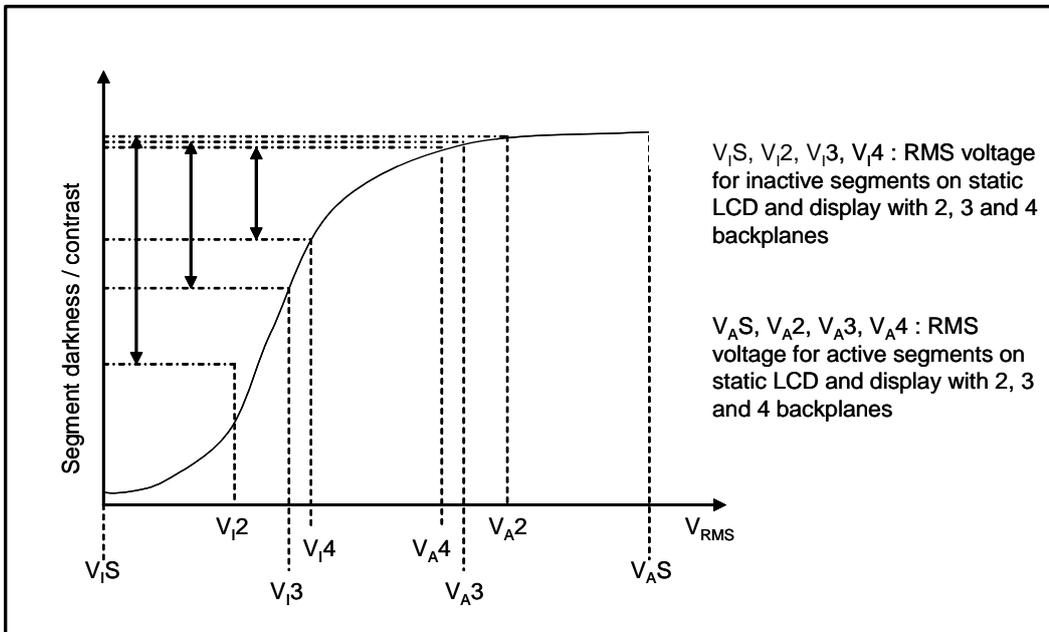


Figure 6: Effects of increasing the number of LCD backplanes

As LCD contrast is also dependent on factors such as temperature and viewing angle it is important to consider the display readability in all application conditions. In simple embedded systems with low-cost LCD displays, the number of backplanes is usually limited to 3 or 4 to allow adequate separation between active and inactive elements and good contrast on the display.

## Software LCD Drive

### 4. Using a Periodic Interrupt to Trigger I/O Manipulation

To generate the signals necessary to drive a segment-type LCD in software it is necessary to change the contents of the microcontroller’s I/O port data registers on a regular, synchronized basis. This can be achieved by having the required instructions executed in response to a periodic interrupt generated from a timer.

We can see from above that for a 4-way multiplexed LCD there are 8 ‘phases’ associated with the high periods and low periods for each of the 4 common signals. We can refer to the 8 phases for one complete cycle, over which each segment is refreshed and the average voltage is zero, as a ‘frame’. To determine an appropriate ‘frame rate’ we consider the response rate of the human eye. A light flashing with a rate of greater than around 25Hz appears constant to the human eye. So a frame rate

of anything greater than this should generate an apparently constant display. A frame rate of much greater than this will mean the display and potentially the controlling microcontroller consumes more power than necessary. Generally a frame rate of between 50Hz and 100Hz is used in segment-type LCDs. The interrupt rate should then be set to accomplish all phases inside the frame period. For example for a display with 4 backplanes and 8 phases and a frame rate of 50Hz the timer interrupt would be set to occur 8 times in 20ms, or every 2.5ms.

The instructions necessary to change the contents of the I/O registers for both the common and segment lines can be executed within a few dozen cycles. For a microcontroller operating at several MHz the time to do this will be in the order of a few microseconds, a small fraction of the time between interrupts.

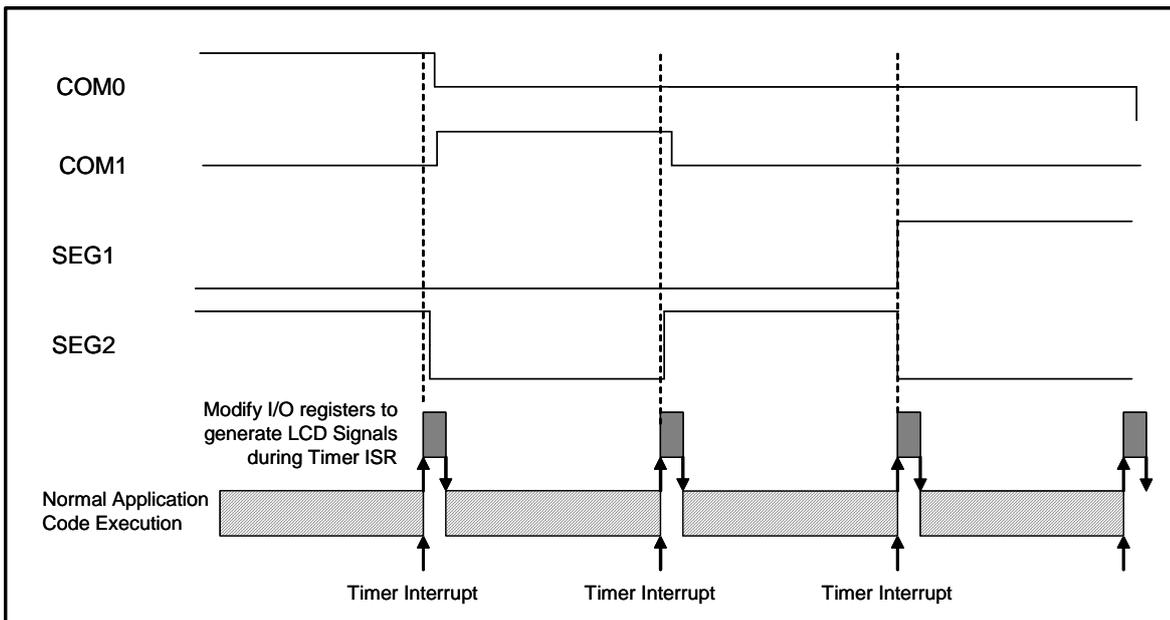


Figure 7: Timer Interrupt triggers LCD signal transitions

During the timer interrupt service routine (ISR) the common lines are activated in turn in each phase and the segment lines are set or cleared in the opposite or same polarity as the active common line depending on whether the corresponding display element is on or off.

In the example software described later each element of the target LCD is mapped to one bit of general purpose RAM. The ISR reads this RAM and sets the I/O ports accordingly. Largely independent of what phase is being executed, the ISR to update the I/O ports takes about 100 clock cycles, which on an M16C or R8C running at 20MHz equates to less than 5us. In the example software the number of phases for a 4-way multiplexed LCD has been doubled to 16, as will be explained in the next section. For simplicity the timer interrupt period has been set to 1ms, resulting in a display refresh rate of 62.5Hz. Despite this higher than strictly necessary frame rate and interrupt frequency the software LCD code still takes up less than 0.5% of the processing time available.

## 5. LCD Contrast Adjustment in Software

As can be seen in Figure 6 above, the contrast between active and inactive segments can be greatly reduced as the number of backplanes is increased. It is possible to increase the display contrast by reducing the RMS voltage across both active and inactive segments. This can be achieved with the use of additional circuit components such as a potentiometer the user adjusts to reduce the supply voltage of the display.

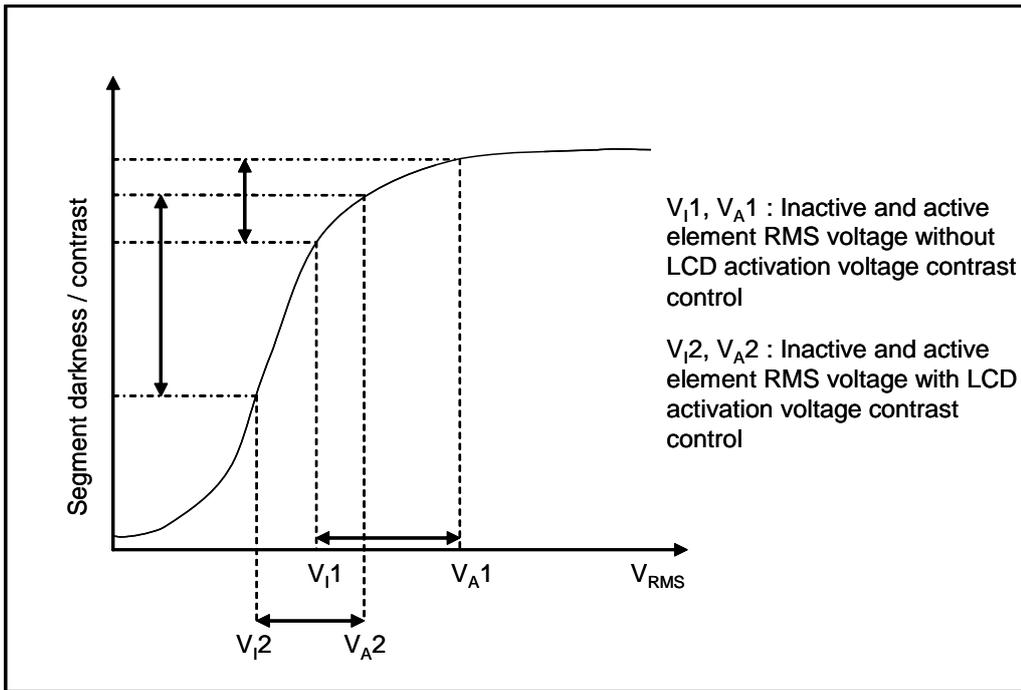


Figure 8: Increasing contrast by reducing RMS voltage across LCD elements

The diagram above shows how a reduction in the RMS voltage to both active and inactive elements can result in an increase in the display contrast without increasing the separation of the active and inactive element RMS voltages. In order to achieve the same effect without additional components the number of phases for each display cycle can be doubled and an additional ‘dead phase’ inserted between each active phase.

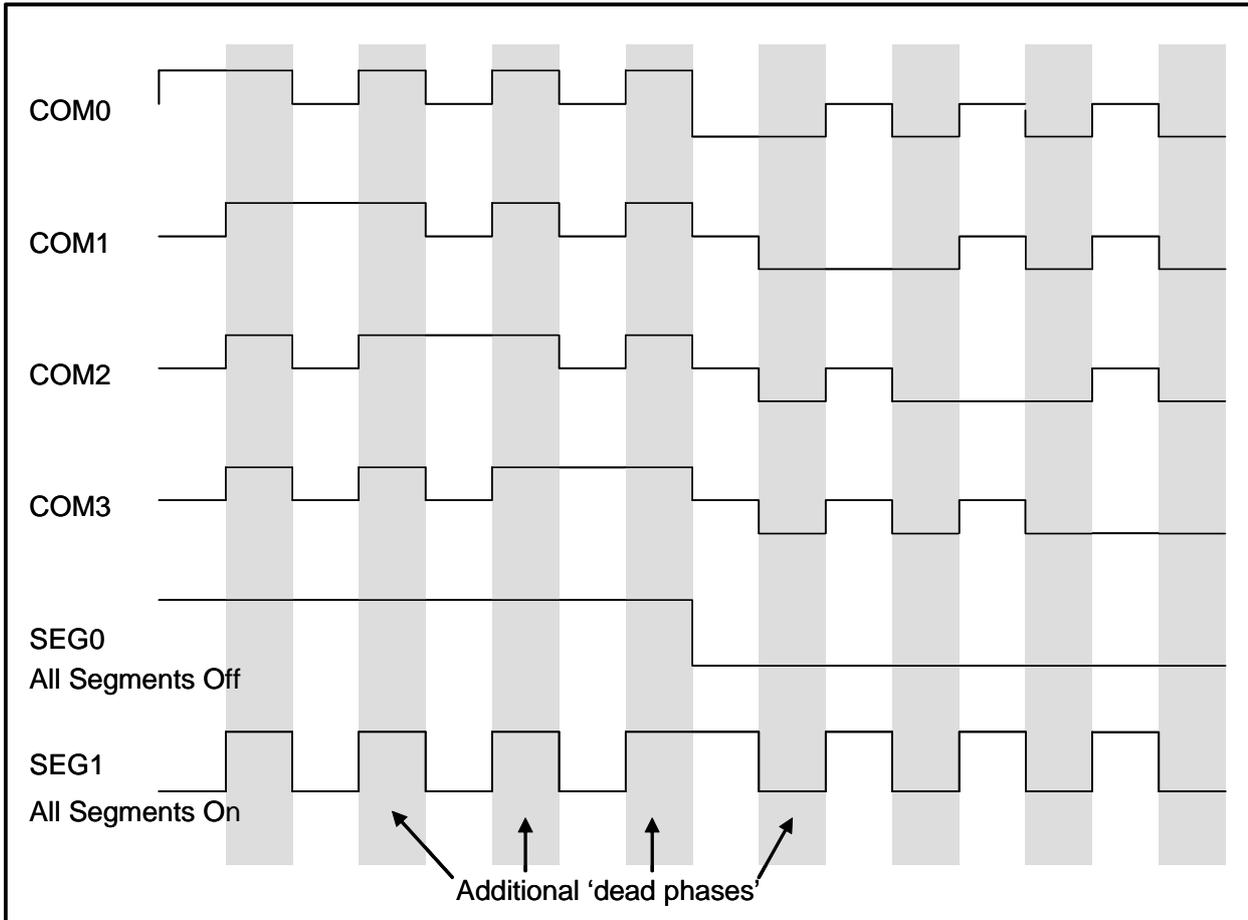


Figure 9: Additional 'dead phases' enable software contrast adjustment

During the 'dead phases' both the common lines and segment lines are either all driven high in the first half of the frame, or all driven low in the second half of the frame. Hence these dead phases increase the percentage of time in the frame where the RMS voltage across each segment is zero.

For dead phases with the same duration as active phases the effect is to reduce the RMS voltage for both Active and Inactive segments by half:

$$\begin{aligned} \text{Active element } V_{RMS} &= (0.125 \times V_{dd}) + (0.375 \times (V_{dd}/2)) + (0.5 \times (V_{dd} \times 0)) \\ &= 0.3125 \times V_{dd} \end{aligned}$$

$$\begin{aligned} \text{Inactive element } V_{RMS} &= (0 \times V_{dd}) + (0.375 \times (V_{dd}/2)) + (0.5 \times (V_{dd} \times 0)) \\ &= 0.1875 \times V_{dd} \end{aligned}$$

Increasing the period of the dead phases to greater than the period of the active phases has the effect of further reducing the RMS voltage for both the active and inactive segments, while reducing the length of the dead phases has the opposite effect. We can maintain the overall frame period of the LCD by increasing or reducing the period of the active phases by the same amount as we reduce or increase the period of the dead phases.

Using this method the maximum separation can be achieved between the darkness of active and inactive elements either through display user interaction or through testing of the unit during design or manufacture for the optimum ratio between active and dead phases.

During development with the demonstration hardware, the best display contrast with a 5V supply was achieved with a ratio of approximately 30% active phase to 70% dead phases, and with a 3V supply approximately 70% active to 30% dead phase ratio. Enhancements to this technique could include sensing of the system conditions such as ambient temperature and supply voltage to adjust the phase ratios dynamically to maintain a clear display.

## Software Description

### 6. Structure of the LCD Driver Software

The software that accompanies this Application Note was written under the Renesas High-performance Embedded Workbench (HEW) Version 4.03.00.001.

The software is contained in a single Project within a HEW Workspace and is initially configured to run on the R8C/2D. It is written so that it can easily be recompiled to run on the M16C/29, and with minor modifications on any other R8C Series or M16C Series device.

The HEW Workspace is named 'SW\_LCD\_Driver\_R8C2D.hws'. This Workspace can be opened from within HEW or by double clicking on this file, which should automatically start HEW and open the workspace and project.

The project is also named 'SW\_LCD\_Driver\_R8C2D' and contains a number of source files:

nrt0.a30	NC30 C compiler start-up file written in assembler. Sets processor mode, initialises stack pointer and initialises variables in RAM
main.c	Initialises MCU clocks and calls the functions to initialise all the required general purpose I/O and peripherals, including timers and external interrupts. Enables the interrupts then sits in an endless loop awaiting their occurrence.
sw_lcd.c	Contains all the core code associated with the LCD drive. This includes functions to initialise the required I/O pins and the timer generating the periodic interrupt, as well as the associated timer ISR that carries out the LCD drive I/O transitions. It also includes functions to adjust the variables controlling the period of the active and dead phases to accomplish the LCD contrast control.
sw_lcd_demo.c	Contains demonstration software designed to run on the specific hardware described below. This code displays a scrolling message on the 8 character 'starburst' LCD. It includes functions to initialise a timer to control the scroll rate and inputs from external push button switches to adjust the display contrast, as well as the ISRs for this timer and the external switch interrupts.

The project also contains a number of 'C' header files and an assembler include file:

sect30.inc	Includes declaration of the Interrupt Vectors for both R8C and M16C, with their relative locations within the vector tables
sw_lcd.h	This includes definition of the ports to be used to drive the LCD common and segment lines. These can be modified to the application

requirements. The number of segment ports could be changed to control more or fewer LCD elements. This would also require modification of the main periodic timer ISR in `sw_lcd.c`.

`sw_lcd_demo.h`

Includes definitions of names of individual segments and the combinations used to make up particular characters on the Software LCD drive demonstrator hardware. These definitions are only used by the scrolling text demonstration software and will not be relevant for a different hardware implementation.

*Note: If the reader intends to use this software on hardware of their own design, the code has been written so that 'sw\_lcd\_demo.c' can be removed and replaced with the users own code. The variable array 'LCD\_data\_buffer [16]' defined in 'sw\_lcd.c' contains 16 bytes of data with each bit associated with a single LCD element on a 32 segment by 4 common display.*

Flow diagrams with full details of the software structure are included in Appendix A.

## 7. Using the Software LCD on the M16C/Tiny

To recompile the code for the M16C/29 follow these steps:

1. Create a new Workspace in HEW and name it, selecting CPU family: M16C
2. Select 'Empty Application'
3. Select CPU Series: 'M16C/Tiny' then 'Next' and 'Next' again
4. Select Target: 'M16C E8 SYSTEM' (or whatever debug hardware target you are using, if any), then 'Finish'
5. Using Windows<sup>TM</sup> Explorer or similar, copy the following files from the 'SW\_LCD\_Driver\_R8C2D' folder of the extracted HEW workspace into the equivalent folder of the newly created workspace:

```
main.c      sw_lcd.c      sw_lcd_demo.c      ncrta30
sw_lcd.h    sw_lcd_demo.h    sect30.inc
sfr29.h     rskm16c29def.h
```

6. Within HEW, from the Menu Options select 'Project > Add Files..' and add the following files to the project:

```
main.c      sw_lcd.c      sw_lcd_demo.c      ncrta30
```

7. Open file 'sw\_lcd.h' and modify line 39 to read:

```
#define M16C29    1
```

8. Build the project using the 'Build All' command

The software can now be run on the RSKM16C29 and flash programming and debugging done through an E8 or E8a debugger.

The conditional compile directive '#if M16C29' is used in several places in the code to cater for the hardware and peripheral differences between the R8C/2D and the M16C/29. The differences between the R8C and M16C code include the initialisation code for the clocks, processor mode, etc, and the definition of the I/O pins used to drive the LCD.

The main functional difference, however, is that on the M16C Timer A0 is used instead of R8C Timer RB to generate the LCD periodic interrupt. This means the variables used to change the period of the active phases and dead phases are initialised and modified differently, as Timer A0 is a 16-bits timer, and Timer RB is an 8-bit timer.

The procedure to use the software in a new project on the R8C is similar to the above.

## Limitations of Software LCD Drive

### 8. Low Power Operation

In microcontrollers with dedicated LCD drive capabilities it is usually possible to generate the clock to the LCD peripheral with a low power 32kHz crystal oscillator. It is also usually possible therefore to stop the main system clock and code execution by the CPU to reduce the microcontroller power consumption to as little as a few micro amps while maintaining the LCD display.

Using the software LCD drive technique it is necessary to generate a periodic interrupt and execute the code to make the transitions on the general purpose I/O at least every few milliseconds. Although it is still possible to place the microcontroller in a low power mode between the periodic interrupts, and even generate the interrupts from a timer with its clock sourced from a low power 32kHz crystal oscillator, the average current consumption will be much higher than with a dedicated LCD driver peripheral or external IC.

It is therefore recommended that if using this software LCD drive technique in a low power application the LCD is not driven when not required, and the microcontroller placed in a low power mode until prompted by an external event such as a user push button. If an application requires very low power consumption and a permanently enabled LCD display then it is likely this software LCD drive technique will not be suitable, and a microcontroller with a dedicated LCD peripheral such as the Renesas H8 Super Low Power Family is used.

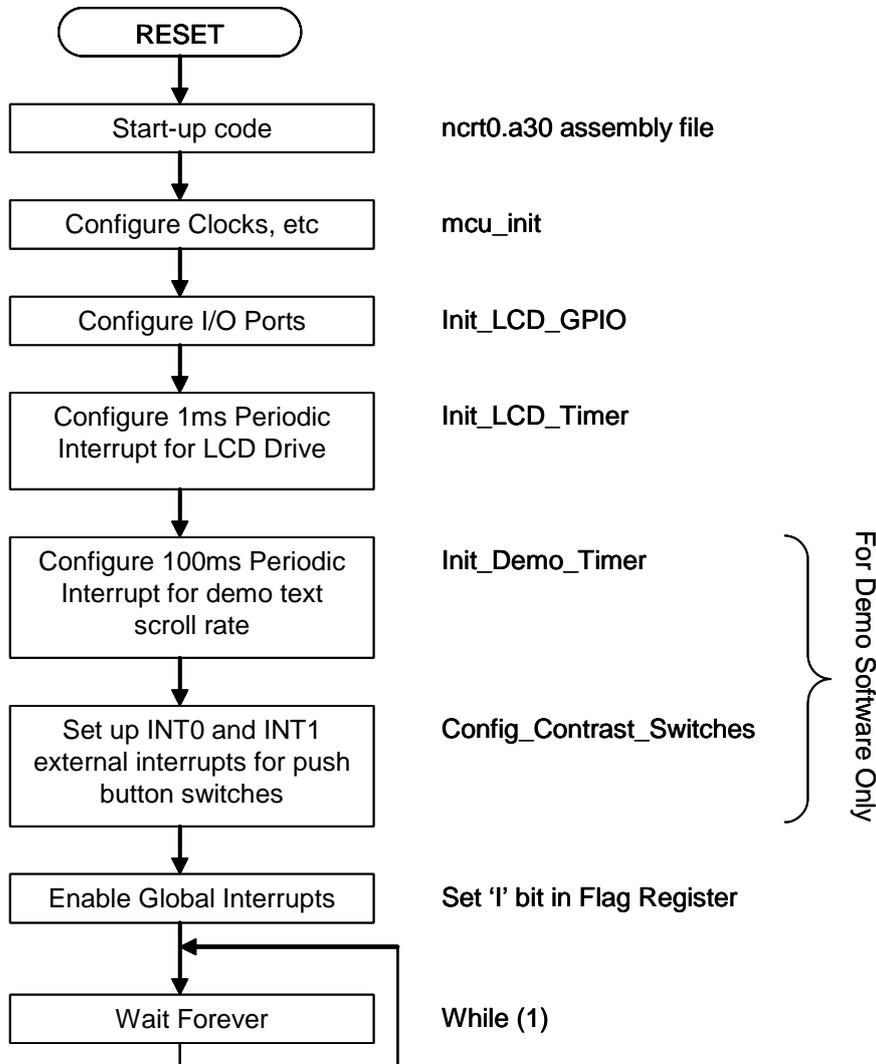
### 9. LCD Contrast Considerations

The contrast of an LCD is greatly affected by the LCD supply voltage, as well as the separation between RMS voltages on the segment and common driver lines. When using multiplexed displays with a low supply voltage the above technique can often produce poor contrast on the display. This is largely down to the voltage divider method used to generate the backplane voltages. Some hardware LCD drivers integrate a charge pump to boost the supply voltage for the LCD drive, and so increase the contrast of the display. It is recommended that full evaluation of the display contrast and readability is undertaken with the LCD that is intended to be used if the software LCD drive technique is being considered in a system with a low voltage supply.

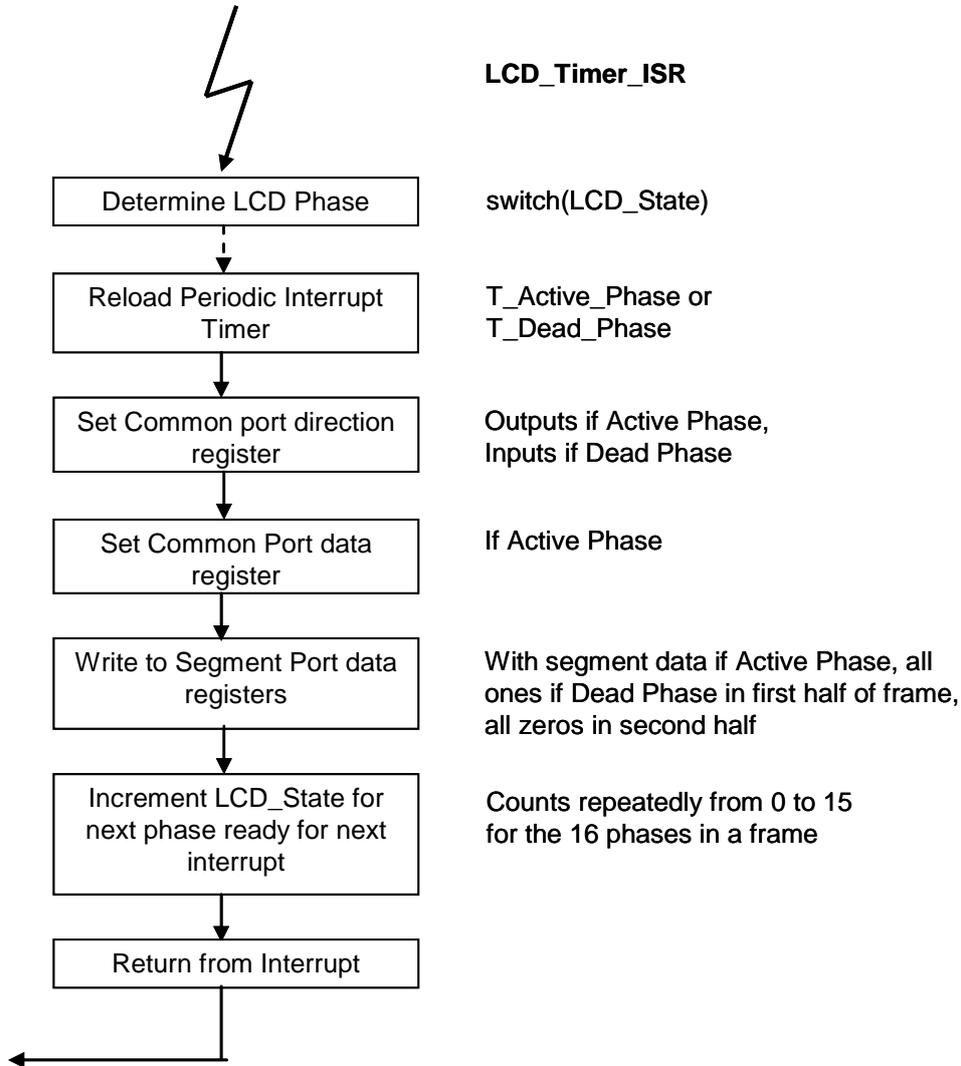
## Appendix A: Software Description

Example Software Flow Diagrams for Driver Code

### Main Program



**LCD Timer Interrupt Service Routine**



## Appendix B: Demonstration Hardware Description

The hardware used for development of this Application Note was the Renesas Starter Kit for the M16C/29 (RSKM16C29) and the Renesas Starter Kit for the R8C/2D (RSKR8C2D) interfaced with a custom made Software LCD drive demonstrator board. Note that this LCD board is not available from Renesas and it is expected that users would develop their own target hardware.

The Software LCD drive demonstrator board includes a Varitronix 32 segment by 4 backplane ‘starburst type’ 8 character LCD, as shown in Figure 10 below.

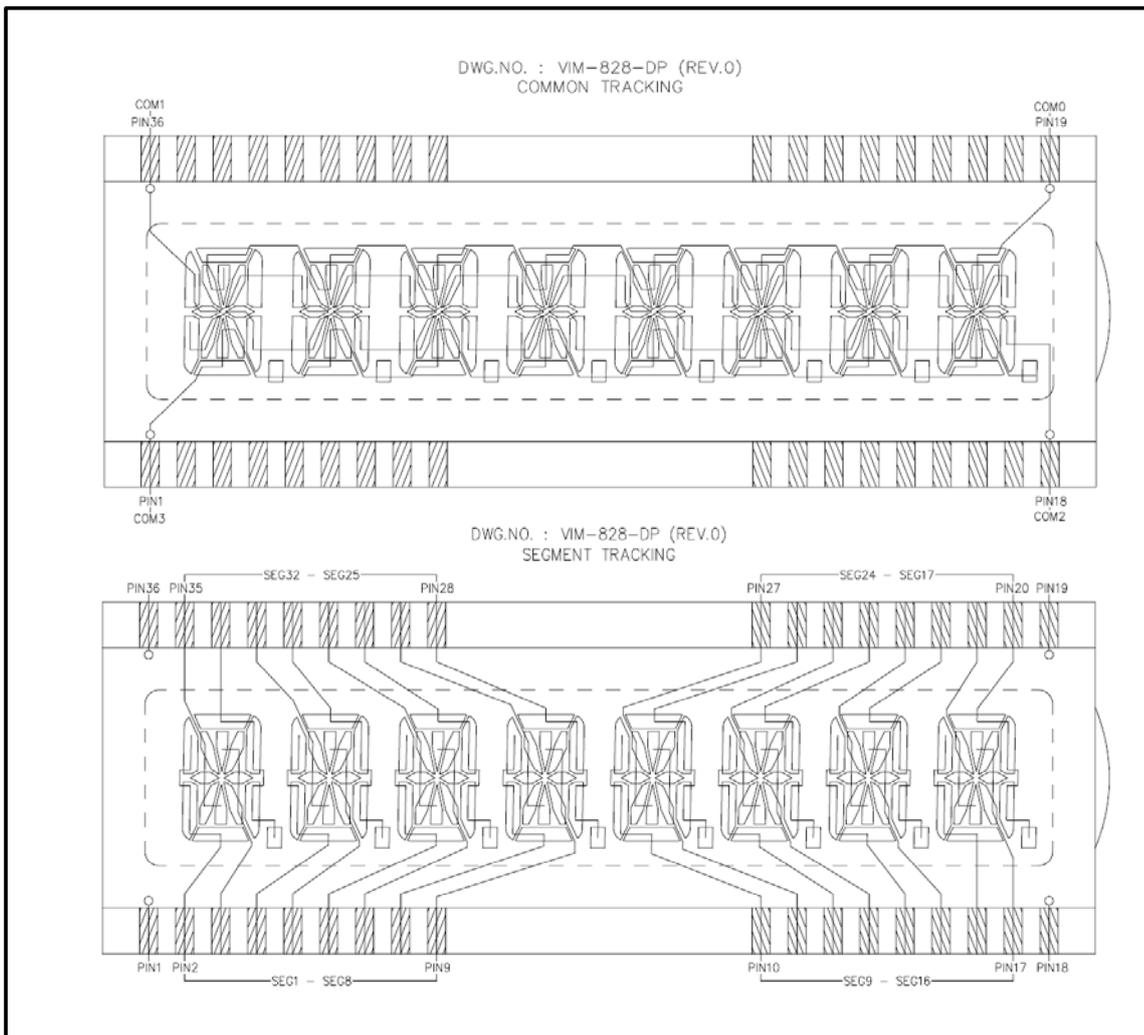
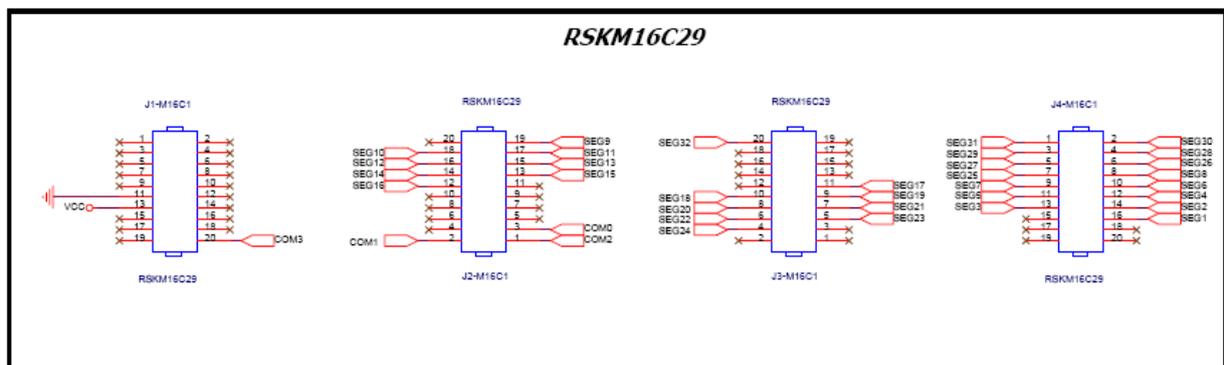
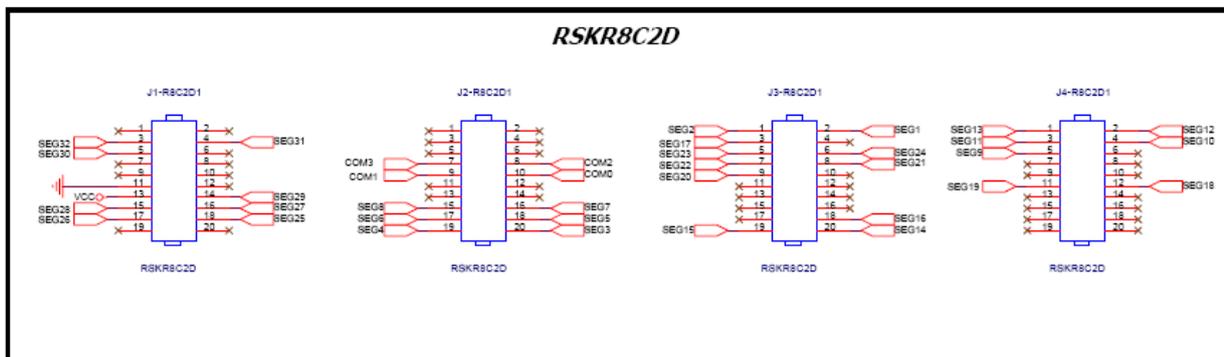
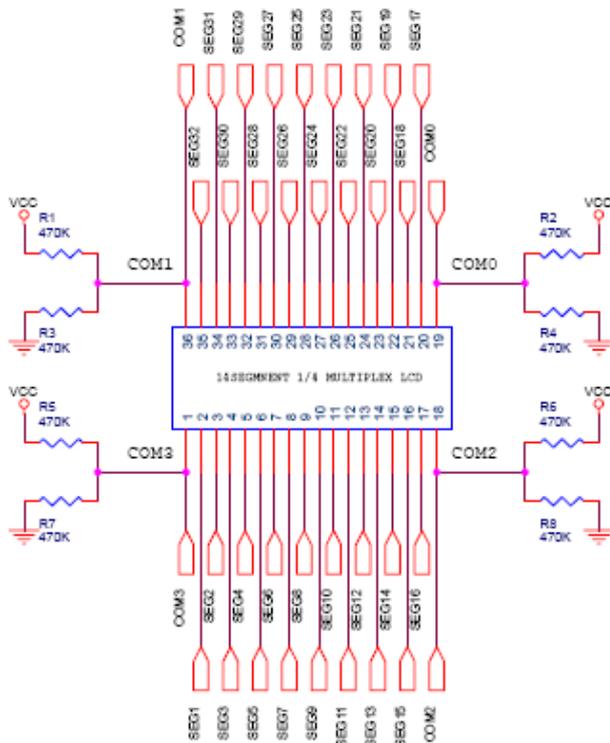


Figure 10: Varitronix 8 character display (32 segment x 4 backplane)

Either of the RSKs can be connected to the Software LCD drive demonstrator board through headers J1, J2, J3 and J4. The layout of the LCD board can be found in Appendix B.

Schematics for the RSKR8C2D and RSKM16C29 can be downloaded from the Renesas website.

## Appendix C: Software LCD Demo Hardware Schematics



## Website and Support

Renesas Technology Website

<http://www.renesas.com/>

Inquiries

<http://www.renesas.com/inquiry>

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