

## Interfacing 8051 MCUs with I<sup>2</sup>C™ Serial EEPROMs

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### INTRODUCTION

The 24XXX series serial EEPROMs from Microchip Technology support a bidirectional, 2-wire bus and data transmission protocol. The bus is controlled by the microcontroller (master), which generates the Serial Clock (SCL), controls the bus access and generates the Start and Stop conditions, while the 24XXX serial EEPROM works as slave. The 24XXX serial EEPROMs are I<sup>2</sup>C™ compatible and have maximum clock frequencies ranging from 100 kHz to 1 MHz.

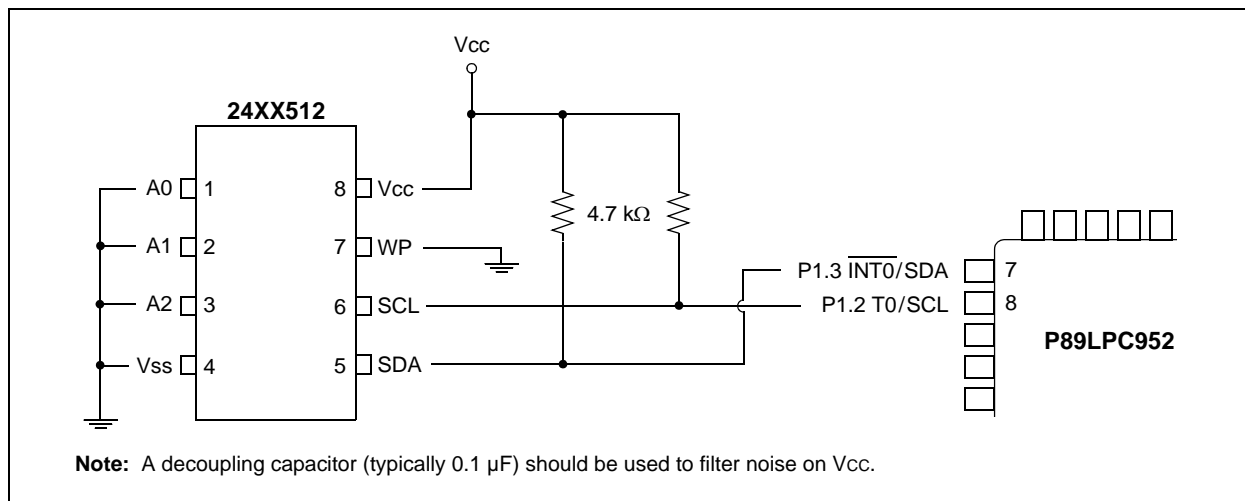
The main features of the 24XXX serial EEPROMs are:

- 2-wire serial interface bus, I<sup>2</sup>C compatible
- EEPROM densities from 128 bits to 512 Kbits
- Bus speed from 100 kHz to 1 MHz
- Voltage range from 1.7V to 5.5V
- Low power operation
- Temperature range from -40°C to +125°C
- Over 1,000,000 erase/write cycles
- Up to 8 devices may be connected to same bus

This application note is part of a series that provide source code to help the user implement the protocol with minimal effort.

Figure 1 is the hardware schematic depicting the interface between the Microchip 24XXX series of I<sup>2</sup>C serial EEPROMs and NXP's P89LPC952 8051-based MCU. The schematic shows the connections necessary between the MCU and the serial EEPROM as tested, as well as the required pull-up resistors on the clock line (SCL) and data line (SDA). Not illustrated in this application note are the write-protect feature and the cascading of multiple devices; thus, the WP pin and address pins A0, A1 and A2 are tied to V<sub>SS</sub> (ground). The test software was written assuming these connections.

**FIGURE 1: CIRCUIT FOR P89LPC952 MCU AND 24XXX SERIES I<sup>2</sup>C SERIAL EEPROM**



## FIRMWARE DESCRIPTION

### Main Function

The purpose of the firmware is to show how to generate specific I<sup>2</sup>C bus transactions using the bidirectional SDA pin on the microcontroller. The focus is to provide the designer with a strong understanding of communication with the 24XX series serial EEPROMs, thus allowing for more complex programs to be written in the future. The firmware was written in the assembly language of NXP's P89LPC952 MCU using the Keil™  $\mu$ Vision3® IDE and was developed on the Keil MCB950 evaluation board.

The main code demonstrates two different methods of accessing the I<sup>2</sup>C serial EEPROM: byte access and page access. The byte method accesses single bytes, where every data byte is preceded by three bytes of address: device address, MSB address, and LSB address. In the page access method, the MCU sends the address of the first byte, and the I<sup>2</sup>C serial EEPROM internally increments the address pointer for the next data byte.

The code was tested using the 24XX512 serial EEPROM. The EEPROM features 64K x 8 (512 Kbit) of memory and a page write capability of up to 128 bytes of data. Oscilloscope screen shots are shown in this application note. All timings are based on the internal RC oscillator of the MCU (7.373 MHz). If a faster clock is used, the code must be modified to generate the correct delays.

The bus speed in these examples is ~100 kHz.

## I<sup>2</sup>C Functions

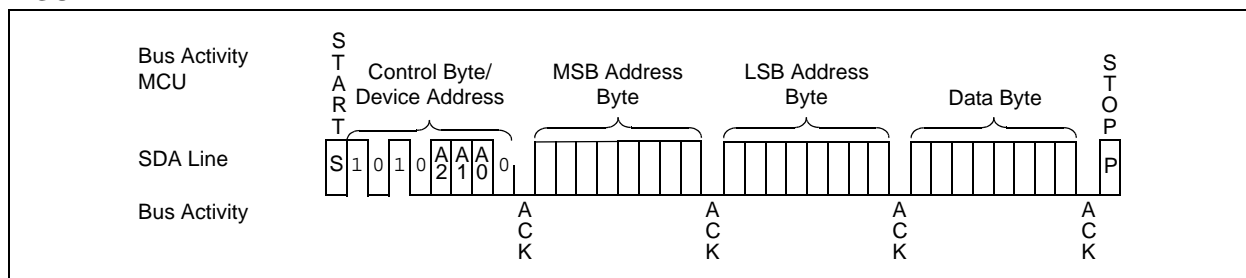
When an MCU accesses an I<sup>2</sup>C serial EEPROM, it is always the master on the I<sup>2</sup>C bus and the I<sup>2</sup>C serial EEPROM is the slave. The MCU controls all operations on the bus. Each operation is started by the MCU through a Start condition, followed by a control byte. The control byte consists of the control code (first 4 bits), the device address (next 3 bits), and the read/write (R/ $\bar{W}$ ) bit. The control code is always the same for the serial EEPROM being accessed, while the device address can range from '000' to '111', allowing up to eight different devices on the same bus. The R/ $\bar{W}$  bit tells the serial EEPROM which operation to perform.

To access an I<sup>2</sup>C serial EEPROM at the start, the MCU writes the device address and the byte address to the I<sup>2</sup>C serial EEPROM; thus, each access cycle starts with a Write condition. For read operations, after the above sequence, the MCU switches from Transmitter mode to Receiver mode and the serial EEPROM from Receiver to Transmitter mode through a Restart condition.

### BYTE WRITE OPERATION

Figure 2 depicts the necessary components that comprise the byte write operation. Each MCU's action is acknowledged (ACK) by the I<sup>2</sup>C serial EEPROM on the 9th bit of the clock by pulling down the SDA data line; consequently, every byte transfer lasts for 9 clock transitions.

**FIGURE 2: BYTE WRITE**

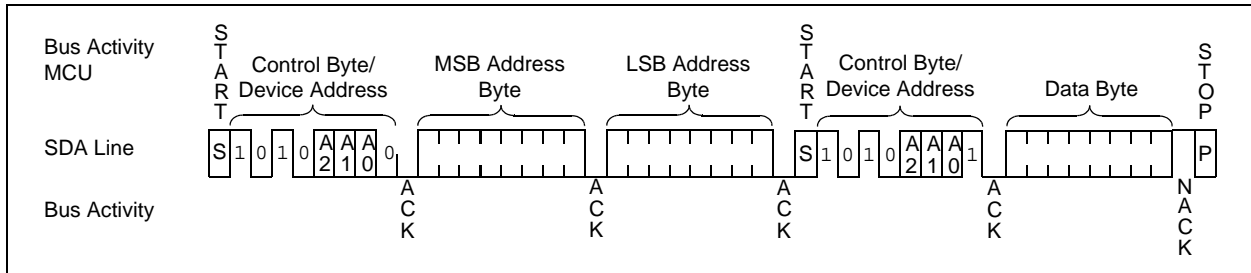


## BYTE READ OPERATION

Figure 3 depicts the necessary components that comprise the byte read operation. The second Start condition instructs the I<sup>2</sup>C serial EEPROM to place data on the I<sup>2</sup>C bus.

The SDA line must remain stable while the SCL clock line is high. Any change of the SDA line while the SCL line is high is interpreted by the I<sup>2</sup>C serial EEPROM as a Start or Stop condition.

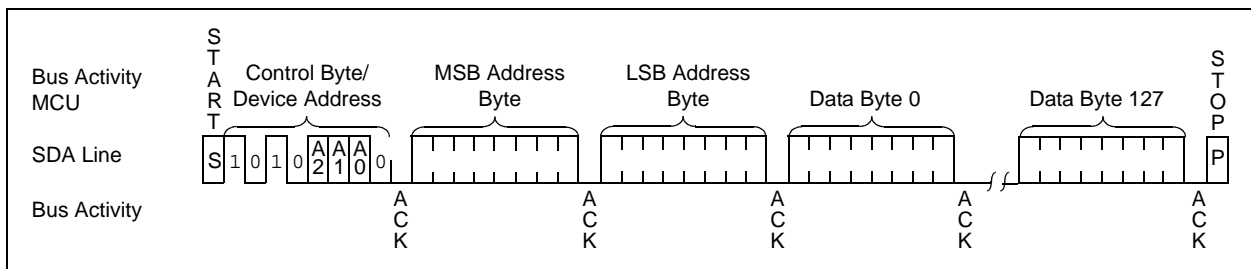
**FIGURE 3: BYTE READ**



## PAGE WRITE OPERATION

Figure 4 depicts the necessary components that comprise the page write operation. The only difference between the page write operation and the byte write operation (Figure 2) is that the MCU, instead of sending 1 byte, sends 'n' bytes of data, up to the maximum page size of the I<sup>2</sup>C serial EEPROM.

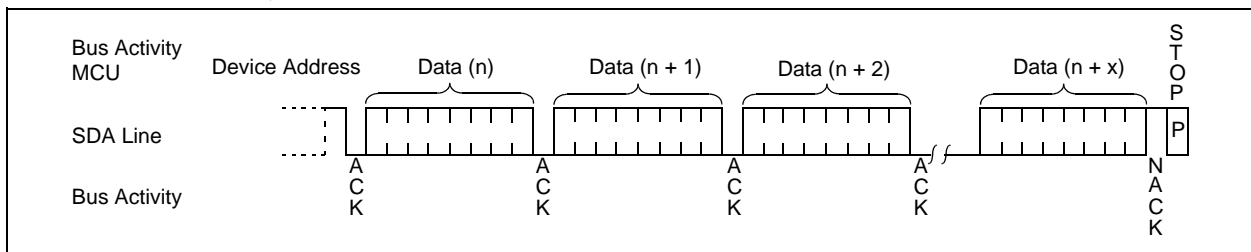
**FIGURE 4: PAGE WRITE**



## SEQUENTIAL READ OPERATION

Figure 5 depicts the necessary components that comprise the sequential read operation. The last read byte is not acknowledged (NACK) by the MCU. This terminates the Sequential Read operation.

**FIGURE 5: SEQUENTIAL READ**



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## INITIALIZATION

The initialization function consists of initializing the SDA and SCL pins, setting them to the correct state, and configuring the pins.

After initialization, the MCU does the following:

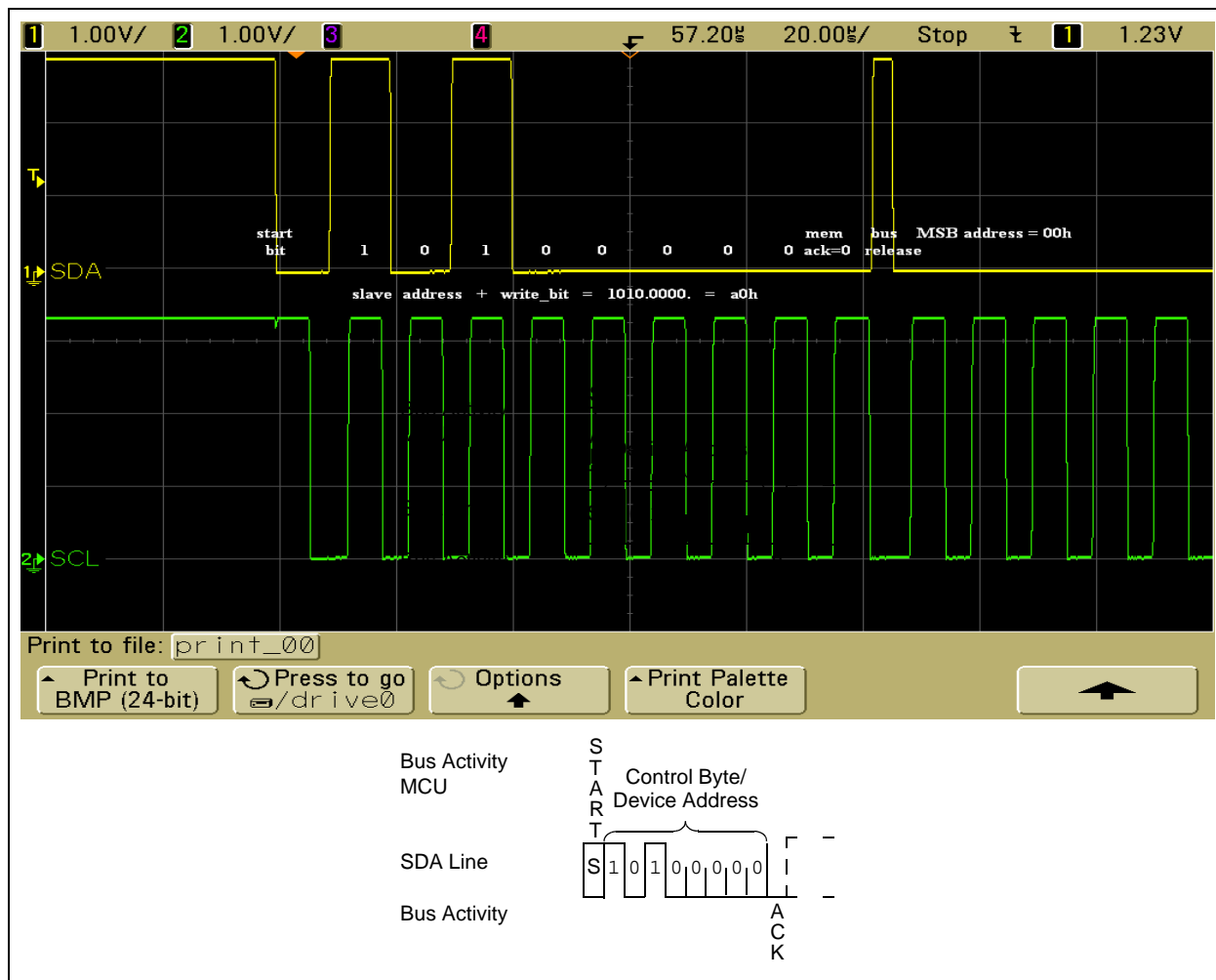
- Writes the 16-byte string ABCDEFGHIJKLMNOP in the I<sup>2</sup>C serial EEPROM (addresses = [00h-0Fh]).
- Reads back these addresses in the I<sup>2</sup>C serial EEPROM.
- Compares the read string with the written string.
- *Displays the hex values of the 16 read-back characters on the eight LEDs on the Keil evaluation board at a rate of 1 chr/sec.*
- *Sends the read characters to the UART in order to verify the operation.*

## START DATA TRANSFER

The MCU generates a Start condition on the I<sup>2</sup>C bus to initiate data transfer.

Figure 6 shows a typical scope plot from the beginning of a write operation. Any memory access begins with a Start condition. This is followed by the I<sup>2</sup>C serial EEPROM (slave) address (A0h). Because the R/W bit is set to '0', the next operation of the bus is a write.

FIGURE 6: I<sup>2</sup>C START BIT AND SLAVE ADDRESS

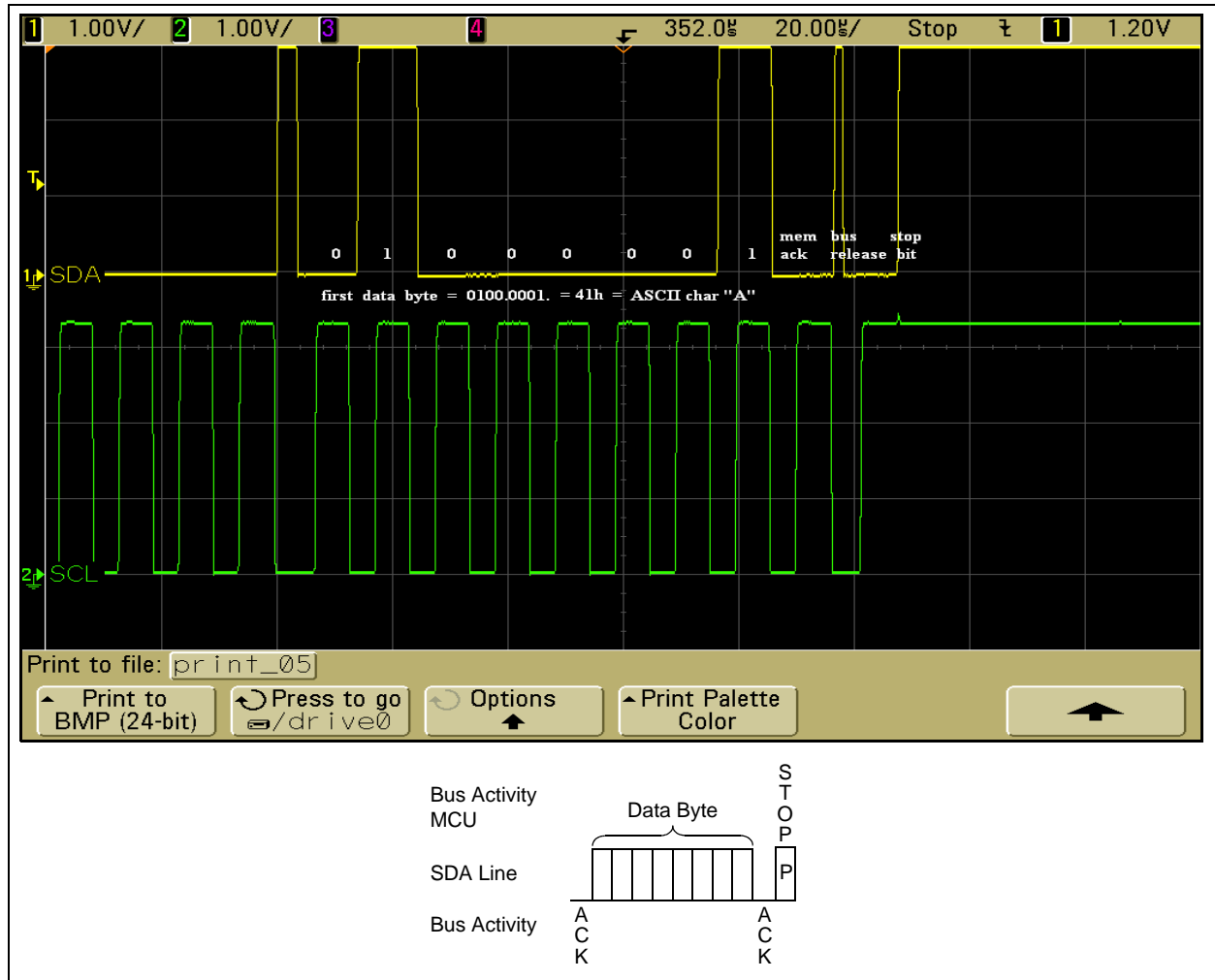


## STOP DATA TRANSFER

The stop data transfer function generates the Stop condition on the I<sup>2</sup>C bus.

Figure 7 shows a typical scope plot of a byte write operation followed by a Stop condition. Every operation on the I<sup>2</sup>C bus ends with a Stop condition.

**FIGURE 7: BYTE WRITE AND STOP CONDITION**



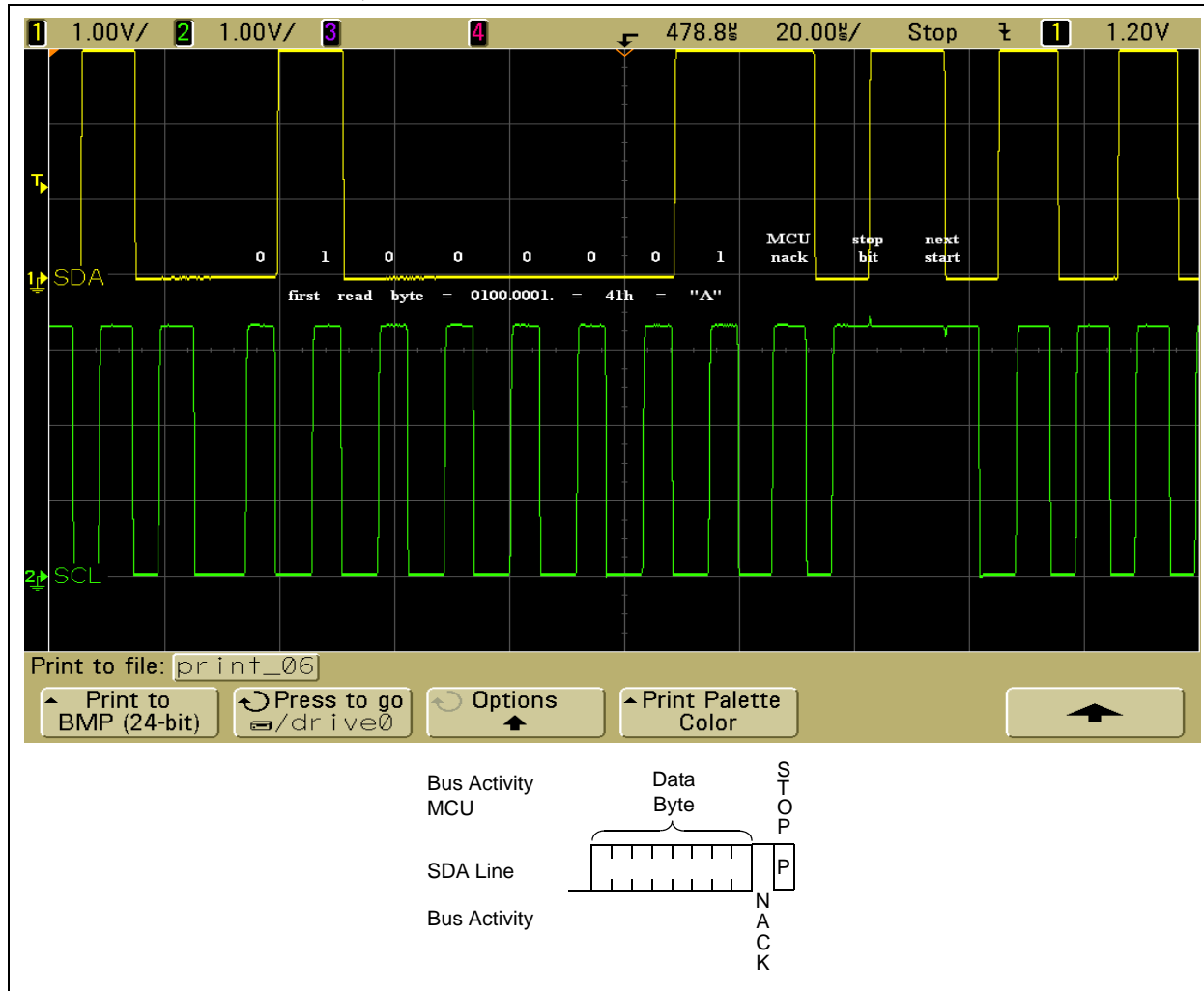
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## NACK\_MCU: NO ACKNOWLEDGE FROM MCU

The `nack_mcu` function is used at the end of a byte read sequence, but before the Stop condition, to indicate the last read byte. An Acknowledge or a No Acknowledge from the receiver to the transmitter is performed on the 9th bit of the clock.

Figure 8 shows a typical scope plot depicting the No Acknowledge condition from the MCU at the end of a byte read sequence.

**FIGURE 8: BYTE READ, NACK\_MCU AND STOP CONDITION**

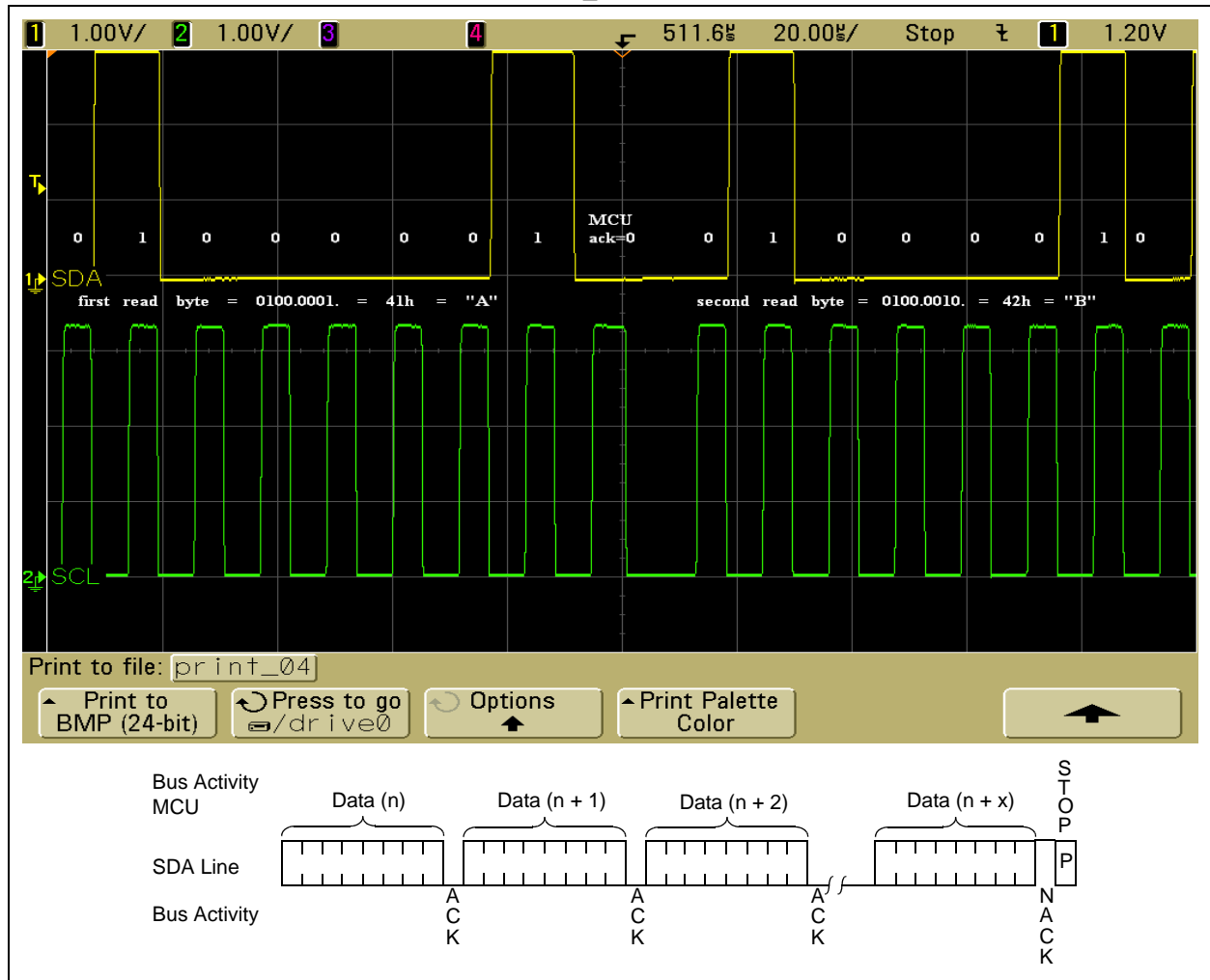


## ACK\_MCU: ACKNOWLEDGE FROM MCU

The `ack_mcu` function is used to acknowledge a byte or continue an operation. Only the last read byte will be not acknowledged (`nack_mcu`) by the MCU.

An MCU's acknowledgement is defined as a '0' on the 9th bit of the clock, as shown in Figure 9.

**FIGURE 9: SEQUENTIAL READ AND ACK\_MCU**



## WRITE 8 BITS

The 8-bits write data function does all of the following:

- Sends data bytes or address bytes from the MCU to the I<sup>2</sup>C serial EEPROM.
- Shifts from parallel format to the serial I<sup>2</sup>C format.
- Receives an acknowledge from the I<sup>2</sup>C serial EEPROM on the 9th bit of the clock.

The MCU sets the data line on the falling edge of the clock, and the I<sup>2</sup>C serial EEPROM latches this in on the rising edge of the clock.

In Figure 6 a spike labeled "bus release" can be seen between the 9th clock pulse and the next clock pulse. The spike is the sign that both devices – the MCU and the I<sup>2</sup>C serial EEPROM – released the open-drain SDA line in order to be able to continue the communication.

## READ 8 BITS OF DATA

This read function is used in both byte read and sequential read operations. The structure of the byte read operation is shown in Figure 3. The structure of the sequential read operation is shown in Figure 5.

During the read operation, the SDA pin must be programmed as input in order to receive the serial data from the I<sup>2</sup>C serial EEPROM. At the end of the function, the SDA must again be programmed as open-drain in order to generate the NACK and Stop.

For sequential read operations, the MCU acknowledges all but the last byte.

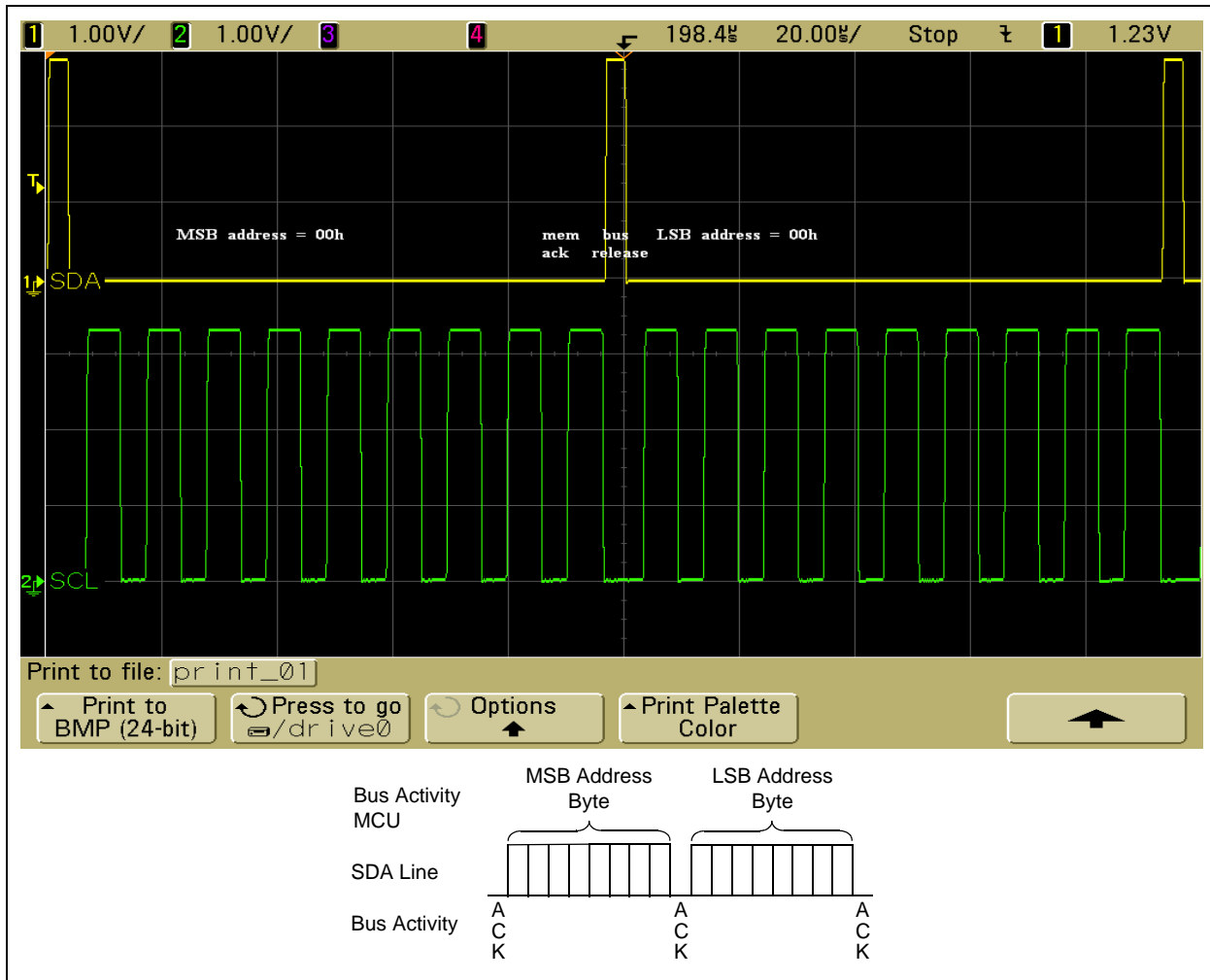
## WRITE DATA BYTES

The structure of this byte write operation is shown in Figure 2.

The body of the function is a sequence of LCALL instructions preceded by loads of the EEPROM data buffer.

The start data transfer sequence is described in detail in the section entitled “Start Data Transfer” and in Figure 6. The stop data transfer sequence is described in detail in the section entitled “Stop Data Transfer” and in Figure 7. Figure 10 depicts the MSB address byte (00h) and the LSB address byte (00h).

**FIGURE 10: WRITE MSB AND LSB ADDRESS BYTES**





## READ DATA BYTE

The read data byte function reads a data byte from the I<sup>2</sup>C serial EEPROM (slave). The structure of the byte read operation is shown in Figure 3.

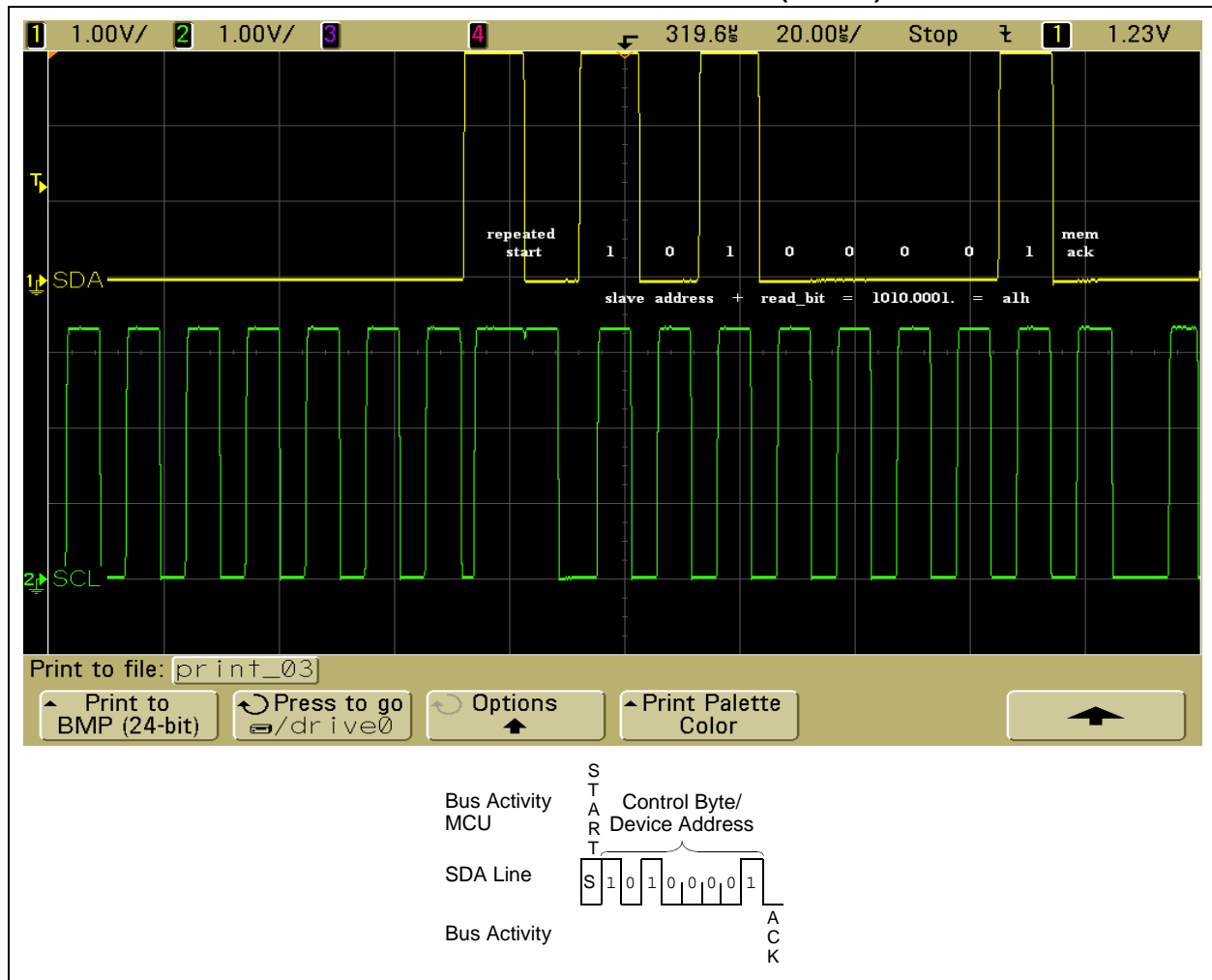
After the first Start condition, the MCU sends the device address, the MSB address byte, then the LSB address byte to the I<sup>2</sup>C serial EEPROM. Each of these bytes is acknowledged by the EEPROM.

Once the MCU has sent the address to the I<sup>2</sup>C serial EEPROM, it generates a Start condition (Repeated Start), which switches the I<sup>2</sup>C serial EEPROM from Receiver to Transmitter mode and the MCU from Transmitter to Receiver mode. Before the read, the MCU must send a new device address for a read.

The MCU must generate the necessary NACK or ACK conditions to terminate or continue the bus operation.

All the necessary scope plots have been presented in the previous paragraphs except the Repeated Start and the I<sup>2</sup>C serial EEPROM address read sequence, which is shown in Figure 11.

**FIGURE 11: REPEATED START AND I<sup>2</sup>C SERIAL EEPROM (SLAVE) ADDRESS READ**



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## WRITE A STRING (PAGE WRITE)

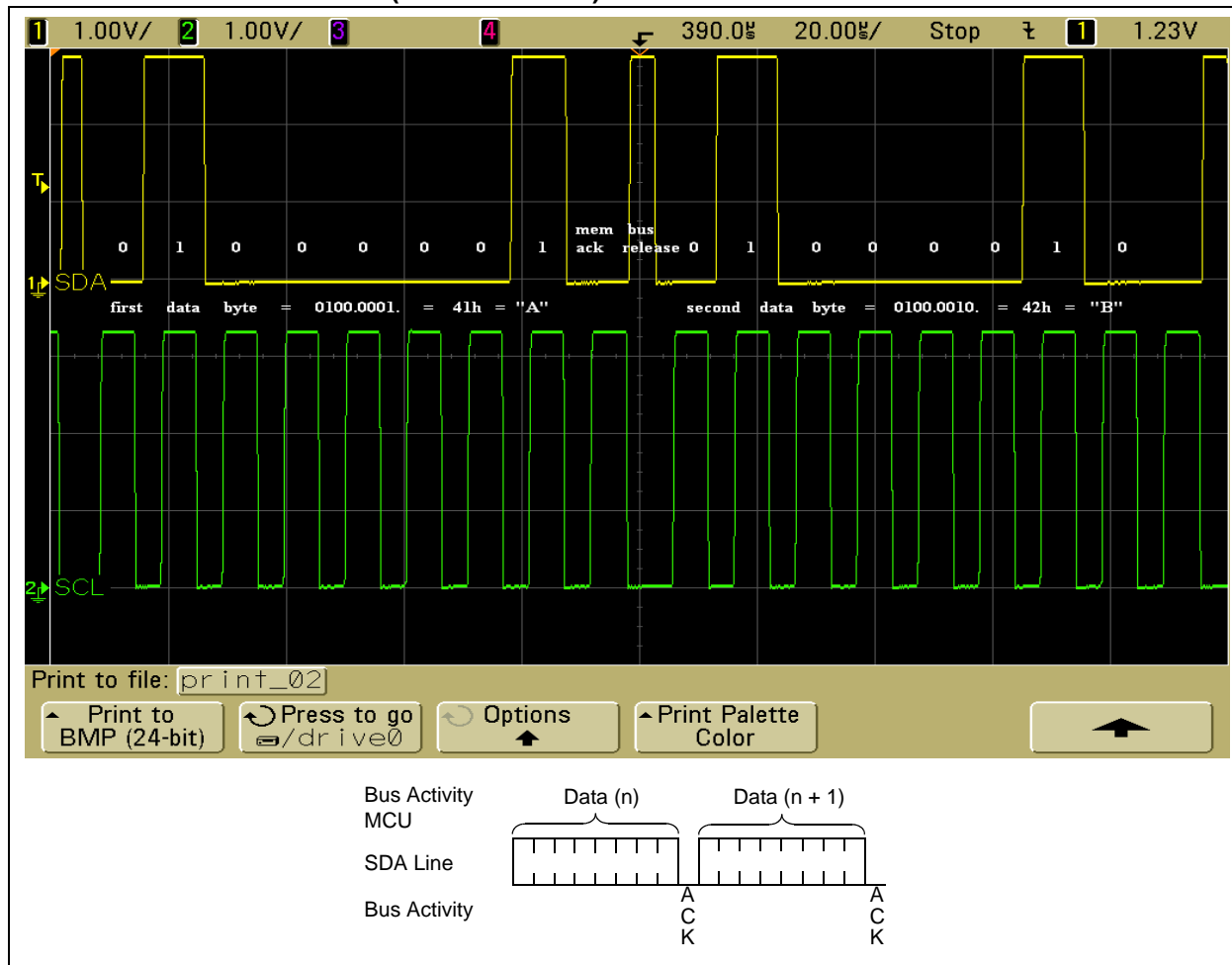
In this application note, the length of the string is 16 bytes and the physical page size for the 24XX512 is 128 bytes. The length of the written string must be shorter than the physical page size. If the page write operation overwrites the physical page boundary, the internal address counter rolls over and overwrites the first bytes of the current page.

The structure of the page write operation is shown in Figure 4.

The sequence must send the address of the first byte to be written. The address is automatically incremented at every byte write by the internal logic of the I<sup>2</sup>C serial EEPROM. Each received byte is acknowledged by the EEPROM.

All sequences have been described in the preceding paragraphs and related figures except for the structure of the page write operation, which is shown in Figure 12. The scope plot depicts the write of the first two consecutive bytes.

FIGURE 12: PAGE WRITE (FIRST 2 BYTES)



## READ A STRING (SEQUENTIAL READ)

In contrast to the page write operation described in the previous paragraph, there is no maximum length for sequential read. After 64 Kbytes have been read, the internal address counter rolls over to the beginning of the array.

To indicate the end of the read, the MCU sends a NACK before the Stop condition. All other previously read bytes are acknowledged by the MCU.

The structure of the sequential read operation is shown in Figure 5. Figure 9 shows a typical scope plot depicting this operation.

## BYTE WRITE VERSUS PAGE WRITE

At first glance, the page write method appears superior to the byte write method: it's simpler and faster. However, a careful analysis shows that the byte write method has a major advantage over page write owing to the roll-over phenomenon (see Note).

**Note:** Page write operations are limited to writing bytes within a single physical page, regardless of the number of bytes actually being written. Physical page boundaries start at addresses that are integer multiples of the page buffer size (or page size), and they end at addresses that are integer multiples of [page size-1]. If a `Page Write` command attempts to write across a physical page boundary, the result is that the data wraps around to the beginning of the current page (overwriting data previously stored there) instead of being written to the next page as might be expected. It is therefore necessary for the application software to prevent page write operations that would attempt to cross a page boundary.

As a consequence of the roll-over phenomenon, applications that write long strings to the I<sup>2</sup>C serial EEPROM risk overlapping the page boundary in the middle of a string. In such instances, the firmware should use byte write to avoid this condition. The disadvantage of doing this is the slower speed involved in writing the entire string: every byte write cycle time is approximately 5 ms.

The following summarizes the differences between the byte write and page write methods.

### Byte Write

- Is slower – It needs a 5 ms write cycle time for each byte.
- Is more general – It may write a string of any length.

### Page Write

- Is faster – It needs only one write cycle time for the whole page.
- Care must be taken to observe page boundaries during page writes.

## CONCLUSION

This application note offers designers a set of I<sup>2</sup>C functions for reading and writing to an I<sup>2</sup>C serial EEPROM. All routines were written in the assembly language for an 8051-based MCU.

The code was developed on the Keil MCB950 evaluation board using the schematic shown in Figure 1. It was tested using the NXP P89LPC952 MCU and debugged using the Keil  $\mu$ Vision3 IDE.

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NOTES:

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