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Motorola Semiconductor Application Note

AN1748

Building a Universal Serial Bus Keyboard Hub Using the Motorola MC68HC(9)08KH12

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Introduction

The universal serial bus (USB) is changing the way in which computer users plug in and activate computer peripheral devices. The “plug-n-play” or “hot swap” abilities of this peripheral bus architecture allow users to plug in peripherals — such as keyboards — and immediately have them available for use without rebooting the PC. No longer do users have to suffer through the detangling of wires at the back of the PC, configuring DIP switches, or even bothering with loading software drivers.

USB is the evolution of the ISA and PCI computer serial bus. This architecture will allow up to 127 peripherals to be plugged into a personal computer using only two ports on the back of the PC. This is accomplished through the daisy chaining of devices using “hubs,” which allow users to link peripherals back to the host PC through other USB devices which have extra downstream USB connections.

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The new serial bus standard, developed by computer industry leaders, was made necessary by the increasing demands of greater PC performance.

One of the classes of the USB is the human interface device (HID). HIDs include devices such as mice, gamepads, and keyboards. Computers today have incredible computing power which lends themselves to telephony, audio/visual applications, and a wide range of HIDs. The diversity of these potential HIDs also requires the USB to allow small, periodic transfer operations for low-speed devices such as mice and keyboards and isochronous operation for high-speed applications such as telephony and audio.

Because these different types of devices require varying speed performance and bandwidth, USB has capabilities for high-speed devices that operate at 12 megabits per second (MBPS) and low-speed devices that operate at 1.5 MBPS.

Additional hardware improvements that make USB a more desired way of installing new peripherals include:

- Unique USB connector design. Unlike previous connector scenarios in which every peripheral had its own connector design with a varying number of pins, USB uses two standard types of connector:
  - An upstream connector. See **Figure 1** for a description of the upstream connector.
  - A downstream receptacle
- The cable between the connectors can have two configurations, depending upon the speed of the peripheral it is connecting:
  - For high-speed devices, there is a power wire, a ground wire, and two shielded signal wires that carry the USB data.
  - For low-speed devices, the configuration is the same except the signal wires are not shielded because they are less sensitive to line noise.

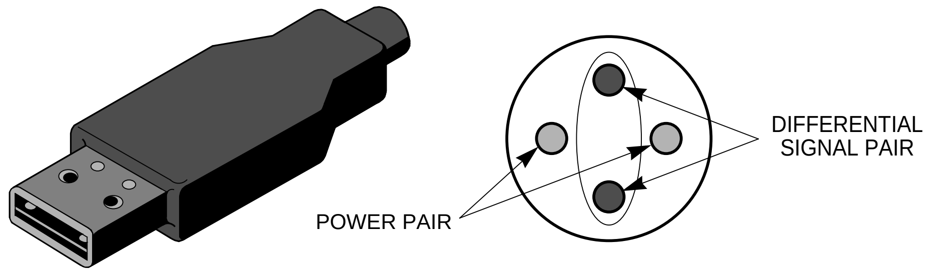


Figure 1. USB Connector with Pin Identification

The USB connector plugs into the ports located on the backplane of the PC, as seen in **Figure 2**.

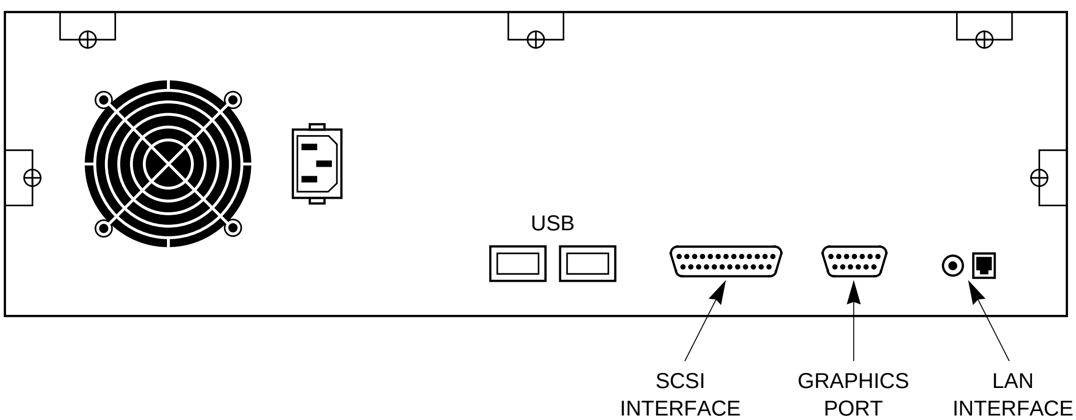


Figure 2. Backplane of PC Showing the Two USB Connections

This application note:

- Reviews the design of a legacy type keyboard and discusses important features of the key scan algorithm
- Is an overview of the MC68HC(9)08KH12 as well as a discussion of the USB module operation
- Describes the one high-speed, 12 MBPS, upstream port connection and four high-speed (12 MBPS) or low-speed (1.5 MBPS) downstream port connections
- Explores the integrated 3.3-volt voltage regulator
- In-depth instruction on the programming of the 12 Kbytes of FLASH memory
- Outlines the steps needed to construct a keyboard hub with universal serial bus functionality using the Motorola 8-bit MC68HC(9)08KH12 microcontroller

NOTE: *This application note assumes that the reader is familiar with the Motorola HC08 Family of 8-bit microcontrollers and the universal serial bus.*

PS/2 Keyboard Design

The concept of the PS/2 keyboard design is founded in the combination of a grid-like hardware setup and software that scans the grid, decoding any interrupt to the specific key or keys that have been depressed.

Keyboards typically have from 101 to 104 keys. The keys are laid out in X rows and Y columns, forming the grid which is easily decoded then by the software to determine the keystroke. The number of columns is typically eight, while the row count is between 18 and 20.

The “brains” of the keyboard are found in an 8-bit microcontroller that takes the input from the keyboard, decodes it, then sends the information to the host computer. This arrangement frees the microprocessor of the PC from constantly polling the keyboard, relying instead upon the interrupts of the keyboard microcontroller to transfer the information when it is inputted.

The Y columns of the grid are wired to microcontroller port pins that have an internal pullup to V_{DD} device as well as the ability to request an interrupt. The interrupt request is active low, so applying a low to the pin will pull the pin to ground, causing an interrupt request to occur.

See **Figure 3** for a physical description of how row and column pins are tied together. See **Figure 4** for an example of a keyboard scan grid.

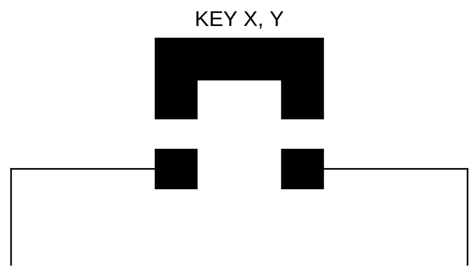


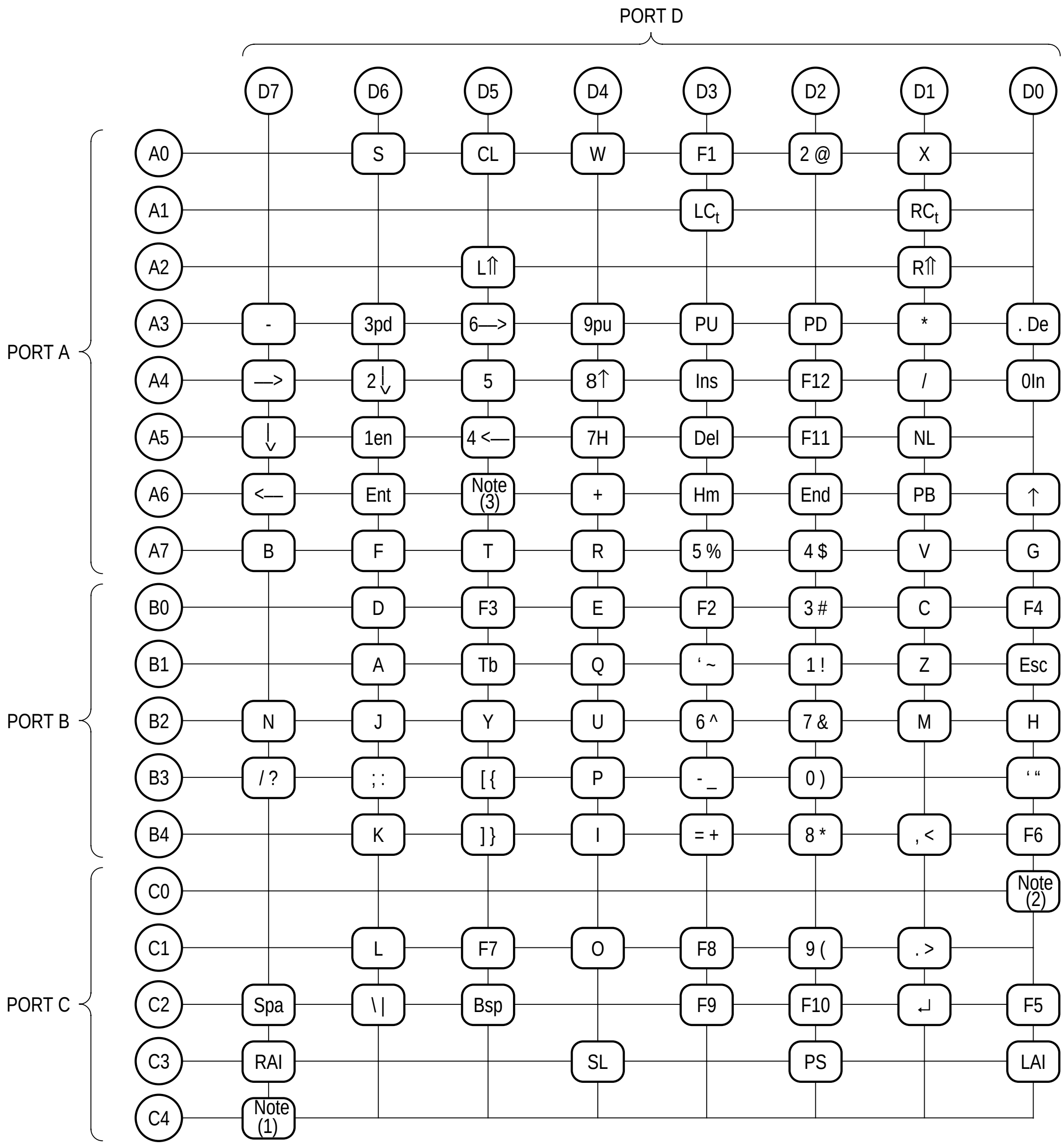
Figure 3. Representation of Key and Resulting Row X, Column Y Contact/Open

The operation of first determining if a key or keys has/have been depressed and then decoding the information to send to the host computer is:

1. All eight of the column port D pins are pulled high through an internal pullup resistor. The keyboard interrupt pin also is enabled for the eight column port pins.
2. The microcontroller software pulls down one of the row port pins to ground while pulling up the remaining row port pins to V_{DD}. For example, if port A consists of port A0 through port A7, port B consists of port B0 through port B4 and port C consists of port C0 through port C4, then port A0 will be pulled low and the remaining 17 row port pins will be pulled high.
3. If a key (or keys) is/are depressed in the row(s) that correspond(s) to the port that is pulled low, then the associated column also will be pulled low, because the row and column are now tied together

electrically by the depressed key as in **Figure 3**. This will cause a keyboard interrupt for that column port pin. If no port D pins are pulled low, that indicates that no key is depressed and the software will continue to scan.

4. If a port D pin is pulled low and, therefore, requests an interrupt, the software jumps to a subroutine that decodes the combination of the row and column pins sending the value corresponding to the x,y grid location to the host computer. Then the computer will output the character to the monitor.
5. The microcontroller software then pulls the next row low, port A1, and pulls the rest of the row pins high. The sequence continues until all the rows are pulled low through port C4. The process of alternately pulling all the row pins low takes approximately 12 ms. Once port C4 is pulled low, the process starts over at port A0, repeating the sequence.



Notes:
(1) Microsoft® right Windows® logo key
(2) Microsoft left Windows logo key
(3) Microsoft Notepad logo key

Figure 4. Keyboard Scan Grid

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Description of the MC68HC(9)08KH12

The MC68HC(9)08KH12 is a member of the low-cost, high-performance 68HC08 Family of 8-bit microcontrollers. This device is a fully compliant USB 1.0 composite HUB microcontroller and is available in a 64-pin quad flat pack (QFP) plastic package.

Additional features of the MC68HC(9)08KH12 include:

- Five on-chip USB transceivers
- On-chip 3.3-volt regulator for USB transceivers
- 1 x 12-MHz upstream USB port
- 4 x 12-MHz/1.5-MHz downstream USB ports
- 1 x hub control endpoint with:
  - 8-byte transmit buffer
  - 8-byte receive buffer
- 1 x hub interrupt endpoint:
  - 1-byte transmit buffer
- 1 x device control endpoint:
  - 8-byte transmit buffer
  - 8-byte receive buffer
- Device interrupt endpoints:
  - 8-byte transmit buffer
- 384 bytes of RAM
- 12 Kbytes of FLASH memory with security
- 42 general-purpose input/output (I/O) ports, 29 of them with software configurable pullups
- 16-bit, 2-channel timer interface module
- 20-bit keyboard interrupt port
- Five LED (light emitting diode) direct drive port pins
- COP (computer operating properly) reset counter

Universal Serial Bus Module

The MC68HC(9)08KH12 is designed to function as a compound device. An embedded, full-speed device is combined with a hub in the single USB module.

The hub is capable of performing these five basic properties controlled by the hardware or software:

- Connectivity behavior
- Power management
- Device connect/disconnect detection
- Bus fault detection and recovery
- Full/low-speed device support

For the embedded device submodule, three types of USB data transfer are supported:

- Control
- Interrupt
- Bulk, transmit only

The USB module is designed to be invisible to the end user. Simply plug in the USB peripheral and it is immediately active and available, living up to the “plug-n-play” promise.

The MC68HC(9)08KH12 differs from other Motorola USB microcontrollers in that it has hub functionality. The keyboard constructed with the MC68HC(9)08KH12 is capable of having up to four high/low-speed peripherals plugged into it.

The microcontroller performs the functions of hub controller as well as hub repeater, providing a path to the next USB device upstream and then eventually to the host through the root port.

More generally, the hub must support the USB functionality requirements.

Connectivity behavior of the hub varies, depending on whether it is propagating traffic or resuming signaling or simply going into an idle state. Power management involves the stopping or resuming of the power supply to the device, depending on the user requirements. These transitions conserve power consumption, making the device operation more efficient.

The recognition of device connect or disconnect is an important function of the hub controller. The connect detection occurs when a low- or high-speed device transitions the DMINUS or DPLUS line, respectively, high. Both the DPLUS and DMINUS pins, when in a disconnected state, are pulled low to ground through the 15-kΩ pulldown resistors. This signals the USB host that there is not a device attached to that node. To discern whether a high- or low-speed device has been attached to a node, the hub controller determines which signal line, DPLUS or DMINUS, is pulled up to the 3.3-volt USB operating voltage. If DPLUS is pulled up, it is a high-speed device; DMINUS being pulled up to 3.3 volts indicates that a low-speed device has been attached.

Because hubs are a main link in USB connectivity, it is essential that they have the ability to sense possible errors and prevent them from occurring, preserving the functionality of the connected network of USB devices.

The last aspect of hub functionality, full/low speed device support, allows the hub to be open for connectivity to any one of the numerous USB devices available to the end user, both full and low speed. This feature gives the hub maximum flexibility and usability.

The USB module contains an on-chip voltage regulator which is essential to providing a 3.3-volt signal to the USB transceiver pins. The on-board voltage regulator transitions the 5-volt V_{DD} signal to the required 3.3-volt USB transceiver voltage, eliminating the need for an external voltage regulator.

The on-chip design eliminates the sensitivity to noise that is existent in the USB device and virtually guarantees that the transceiver signals will always be compliant to the 3.3 ± 0.3-volt USB specification.

Other microcontrollers on the market today do not have an on-chip regulator. Instead, they rely upon a divide down resistor or an external voltage regulator. The divide down resistor approach is flawed and opens up the USB device manufacturer to noise sensitivity issues and the real possibility of violating the USB specification of 3.3 ± 0.3 volts being supplied to the USB transceiver.

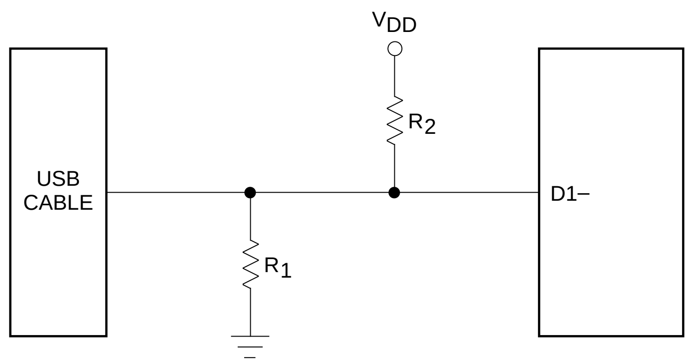


Figure 5. Voltage Divide Down Resistor Circuit Example

An example of how the divide down resistor configuration can fail, yielding an operating range of 2.83 to 3.79 volts, even though resistors with ranges of 5% in accuracy are used, is this:

Using the equation for deriving the resulting voltage using divide down resistors:

$$V = (R1 / (R1 + R2)) \times V_{DD}$$

NOTE: *V_{DD} being supplied to the microcontroller is assumed to be in the range of 4.4 to 5.5 volts DC.*

Exceeding the specification on the high side assuming 5% accurate resistors:

$$V = (15750\ \Omega / (15750\ \Omega + 7125\ \Omega)) \times 5.5 \text{ volts}$$

$$V = 3.79 \text{ volts}$$

Exceeding the specification on the low side, again assuming 5% accurate resistors:

$$V = (14250\ \Omega / (14250\ \Omega + 7875\ \Omega)) \times 4.4 \text{ volts}$$

$$V = 2.83 \text{ volts}$$

Both of these possible outcomes of the voltage divide down via the resistors results in a violation of the USB specification. Using high precision resistors can lower the chance of exceeding the specification, but the additional cost, which can be a significant percentage of the microcontroller cost, does not make this a reliable or cost-effective solution. Utilizing an external voltage regulator also adds a large cost to the application, since it can be a large percentage of the semiconductor selling price.

The integrated voltage regulator of the MC68HC(9)08KH12 yields the most robust performance, matched only by its highly competitive cost.

Port Pins

The MC68HC(9)08KH12 port pin design allows the user a wide variety of possible configurations. **Table 1** lists some of the possible configurations using the 42 port pins.

Table 1. Listing of MC68HC(9)08KH12 Port Pin Features

	Software Configurable Pullups	External Interrupt	LED Direct Drive	Optical Interface	Number of Pins / Port	Comments
Port A	X				8	General-purpose I/O (GP I/O)
Port B	X				8	GP I/O
Port C	X		X		5	LED drive, GP I/O
Port D		X			8	Keyboard interrupt, GP I/O
* Port E		X (4 pins)		X (4 pins)	5	Interface for optical mouse, keyboard interrupt, GP I/O
Port F	X	X			8	Keyboard interrupt, GP I/O

* Note:
Port E4 is a general-purpose I/O pin only.

All ports can function as bidirectional, general-purpose I/O pins. Ports A, B, C, and F have software configurable pullups. Port C has the capability to drive LEDs with 3-mA source and up to 10-mA current sink capability. Ports D, E, and F are configurable to act as external interrupt pins. Port pins E0–E3 have the capability of being configured to support an optical interface which can be useful for an optical mouse application. As mentioned previously, the typical keyboard uses eight port pins for columns and 18 port pins for rows to generate the keyboard grid. This configuration leaves 16 port pins available for applications decided by the user. The versatility of the port pin configuration allows the user a wide range of options in which to use the available port pins for added peripheral functionality.

FLASH Memory

Unlike other USB chips available in the marketplace, the MC68HC(9)08KH12 has an embedded FLASH memory array. The 12 Kbytes of FLASH memory allow for lower cost application development as well as easy in-circuit reprogramming to correct bugs or update code that may exist in the application. The FLASH memory can be read, programmed, and erased using a single external supply and an on-board charge pump. The FLASH memory also has the Motorola security feature which discourages others from accessing the application code unless authorized by the code developers.

Additional features include a block protect register that will prevent accidental overwrite or erase of programmed memory and a FLASH control register that allows the user to specify whether a block, a page, or the entire array can be erased.

There are also charge pump clock frequency select bits, a high-voltage enable bit, and program/erase bits. (See **Figure 6**.) The internal charge pump is designed to operate at the greatest efficiency in the frequency range between 2 and 3 MHz.

Because the internal bus frequency is 1.5 MHz for the MC68HC(9)08KH12 and there is no PLL (phase-locked loop) attached to the charge pump, the charge pump must operate at 1.5 MHz ± 10%.

Because of the small size of the array, this will not pose problems for programming or erasing, but may slow the process marginally.

Address: $FE07

	Bit 7	6	5	4	3	2	1	Bit 0
Read: Write:	FDIV1	FDIV0	BLK1	BLK0	HVEN	MARGIN	ERASE	PGM
Reset:	0	0	0	0	0	0	0	0

Figure 6. Contents of FLASH Control Register (FLCR)

FDIV1 — Frequency Divide Control Bit

This read/write bit together with FDIV0 selects the factor by which the charge pump clock is divided from the system clock.

FDIV0 — Frequency Divide Control Bit

This read/write bit together with FDIV1 selects the factor by which the charge pump clock is divided from the system clock.

BLK1 — Block Erase Control Bit

This read/write bit together with BLK0 allows erasing of blocks of varying size.

BLK0 — Block Erase Control Bit

This read/write bit together with BLK1 allows erasing of blocks of varying size.

HVEN — High-Voltage Enable Bit

This read/write bit enables the charge pump to drive high voltages for program and erase operations in the array. HVEN can be set only if either PGM = 1 or ERASE = 1 and the proper sequence for program/margin read or erase is followed.

1 = High voltage enabled to array and charge pump on
0 = High voltage disabled to array and charge pump off

MARGIN — Margin Read Control Bit

This read/write bit configures the memory for margin read operation. MARGIN cannot be set if HVEN = 1. MARGIN will return to unset (0) automatically if asserted when HVEN = 1.

1 = Margin read operation selected
0 = Margin read operation unselected

ERASE — Erase Control Bit

This read/write bit configures the memory for erase operation. ERASE is interlocked with the PGM bit such that both bits cannot be set at the same time.

1 = Erase operation selected
0 = Erase operation unselected

PGM — Program Control Bit

This read/write bit configures the memory for program operation. PGM is interlocked with the ERASE bit such that both bits cannot be set at the same time.

1 = Program operation selected
0 = Program operation unselected

Erasing the FLASH Array

Use this procedure to erase a block of FLASH memory:

1. Set the ERASE bit, the BLK0, BLK1, FDIV0, and FDIV1 bits in the FLASH control register. See **Table 2** for block sizes and **Table 3** for charge pump clock frequency settings.
2. Ensure that the target portion of the array is unprotected by reading the block protect register, address $FF8D.
3. Write to any FLASH address with any data within the block address range desired.
4. Set the HVEN bit.
5. Wait for a time, t_{ERASE}.
6. Clear the HVEN bit.
7. Wait for a time, t_{KILL}, for the high voltages to dissipate.
8. Clear the ERASE bit.
9. After a time, t_{HVD}, the memory can be accessed in read mode again.

While these operations must be performed in the order shown, other unrelated operations may occur between the steps.

Table 2. FLASH Erase Block Sizes

BLK1	BLK0	Block Size
0	0	Full array: 12 Kbytes
0	1	Half array: 6 Kbytes
1	0	Eight rows: 256 bytes
1	1	Single row (page): 32 bytes

Table 3. Charge Pump Clock Frequency Select

FDIV1	FDIV0	Pump Clock Frequency
0	0	Bus frequency ÷ 1
0	1	Bus frequency ÷ 2
1	0	Bus frequency ÷ 2
1	1	Bus frequency ÷ 4

Programming the FLASH Array

Programming of the FLASH memory is done on a page basis. A page consists of eight consecutive bytes starting from address $XXX0 or $XXX8.

The purpose of the margin read mode is to ensure that data has been programmed with sufficient margin for long-term data retention. While performing a margin read, the operation is the same as for ordinary read mode except that a built-in counter stretches the data access for an additional eight cycles to allow sensing of the lower cell current. Margin read mode imposes a more stringent read condition on the bitcell to ensure the bitcell is programmed with enough margin for long-term data retention. During these eight cycles, the COP counter continues to run. The user must account for these extra cycles within COP feed loops. A margin read cycle can follow a page programming operation only.

To program and margin read the FLASH memory, use this algorithm:

1. Set the PGM bit. This configures the memory for program operation and enables the latching of address and data for programming.
2. Read from the block protect register.
3. Write data to the eight bytes of the page being programmed. This requires eight separate write operations.
4. Set the HVEN bit.
5. Wait for a time, t_{PROG}.
6. Clear the HVEN bit.
7. Wait for a time, t_{HVTV}.
8. Set the MARGIN bit.
9. Wait for a time, t_{VTP}.
10. Clear the PGM bit.
11. Wait for a time, t_{HVD}.
12. Read back data in margin read mode. This is done in eight separate read operations which are each stretched by eight cycles.
13. Clear the MARGIN bit.

See **Figure 7** for a flowchart describing the smart programming algorithm. The assumptions made for the page program/margin read procedure are that the page to be programmed is already erased.

This program/margin read sequence is repeated throughout the memory until all data is programmed. For minimum overall programming time and least program disturb effect, the smart programming algorithm must be followed. The associated specification limits of the parameters listed in the program and erase routines are listed in **Table 4**.

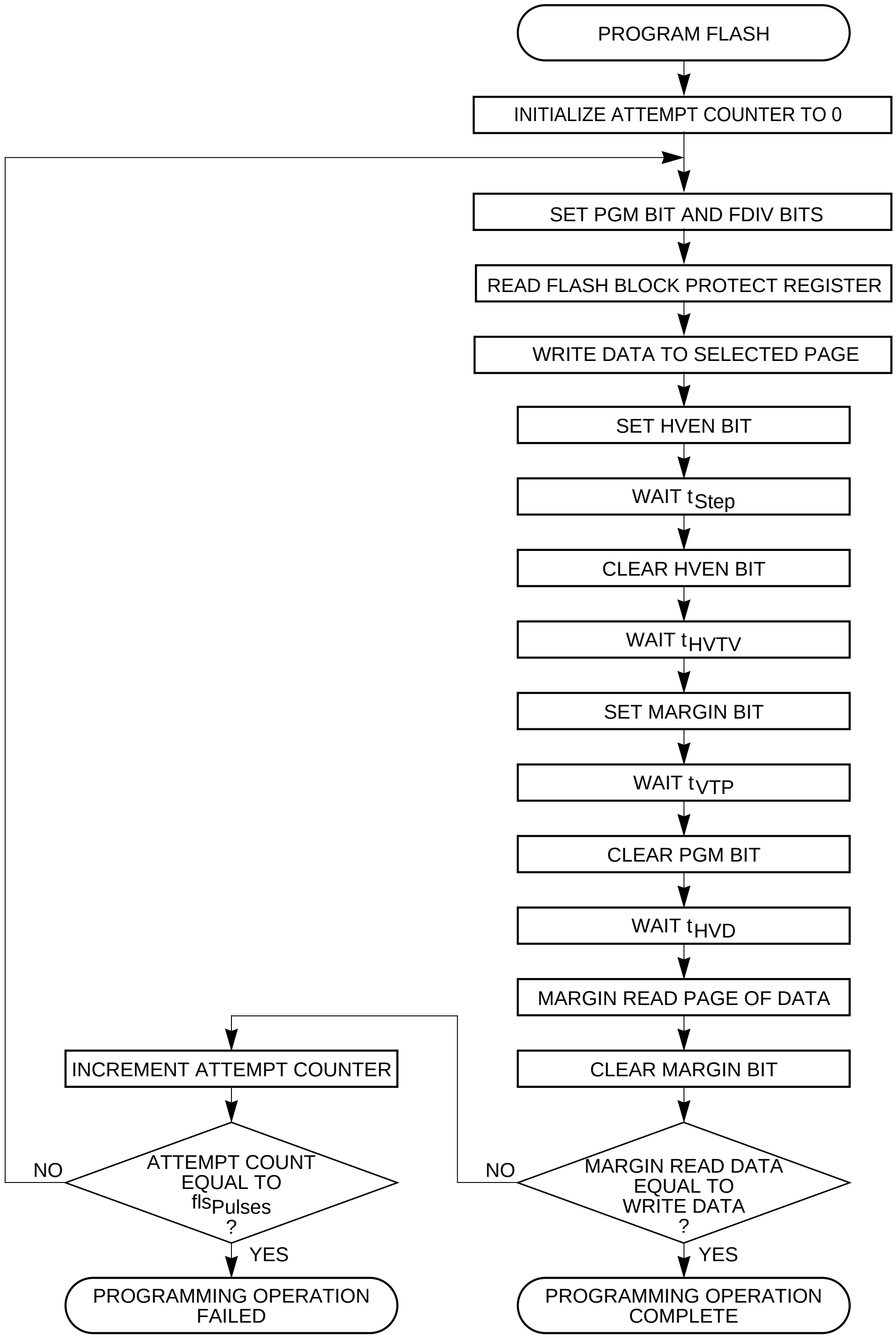


Figure 7. Smart Programming Algorithm for FLASH Memory

Table 4. Specification Limits for the Program/Erase Parameters

Characteristic	Symbol/Description	Min	Max	Units
FLASH pages per row	—	8	8	Pages
FLASH bytes per page	—	8	8	Bytes
FLASH read bus clock frequency	t_{Read}[1]	32 k	8.4 M	Hz
FLASH charge pump clock frequency	t_{Pump}[2]	1.8	2.3	MHz
FLASH block/bulk erase time	t_{Erase}	100	—	ms
FLASH high voltage kill time	t_{Kill}	200	—	µs
FLASH return to read time	t_{HVD}	50	—	µs
FLASH page program time	fls_{Pulses}[3]	—	30	Pulses
FLASH page program step size	t_{Step}[4]	1.0	1.2	ms
FLASH HVEN low to margin high time	t_{HVTV}	50	—	µs
FLASH margin high to PGM low time	t_{VTP}	150	—	µs
FLASH return to read after margin read time	$t_{Recovery}$[5]	500	—	Dummy read cycles
FLASH row erase endurance[6]	—	100	—	Cycles
FLASH row program endurance[7]	—	100	—	Cycles
FLASH data retention time[8]	—	10	—	Years

Notes:

1. t_{Read} is defined as the frequency range for which the FLASH memory can be read.
2. t_{Pump} is defined as the charge pump frequency required for program, erase, and margin read operations.
3. fls_{Pulses} is defined as the number of pulses used during FLASH programming required by the smart program algorithm.
4. t_{Step} is defined as the amount of time during one page program cycle that HVEN is held high.
5. $t_{Recovery}$is defined as the minimum number of dummy reads of any FLASH location before accurate data is read from the memory after margin read mode is used.
6. The minimum row erase endurance value specifies each row of the FLASH memory is guaranteed to work for at least this many erase cycles.
7. The minimum row program endurance value specifies each row of the FLASH memory is guaranteed to work for at least this many program cycles.
8. The FLASH is guaranteed to retain data over the entire specified temperature range for at least the minimum time specified.

USB Keyboard Hub Design Using the MC68HC(9)08KH12

The keyboard hub design using the MC68HC(9)08KH12 is displayed in **Figure 8**. As can be seen, the clock circuit is constructed using a total of seven external components, five for the crystal oscillator and two for the PLL.

The crystal oscillator is connected in the standard Pierce oscillator configuration. The oscillator components include:

- Fixed capacitor, C_1
- Tuning capacitor, C_2
- Feedback resistor, R_B
- Optional series resistor, R_S
- Crystal, X_1

The values for these components are dependent upon the crystal manufacturers' specifications.

R_S is drawn to match the Pierce oscillator requirements, but may be removed depending upon the clock frequency. At higher frequencies, the value of R_S may be 0 or shorted. A low-cost, 6-MHz crystal provides the clock to the MC68HC(9)08KH12. The PLL is present in the chip design so that the 48-MHz and 12-MHz clock frequencies can be provided to the USB module, supporting the high-speed USB requirements of the upstream port and the potential high-speed peripherals connected to the four downstream ports.

The keyboard scan matrix, as described earlier for the PS2 type keyboard design, occupies 26 of the port pins. The keyboard LEDs for Num Lock, Caps Lock, and Scroll Lock utilize three of the port C pins, which are capable of sinking up to 10 mA of LED drive current.

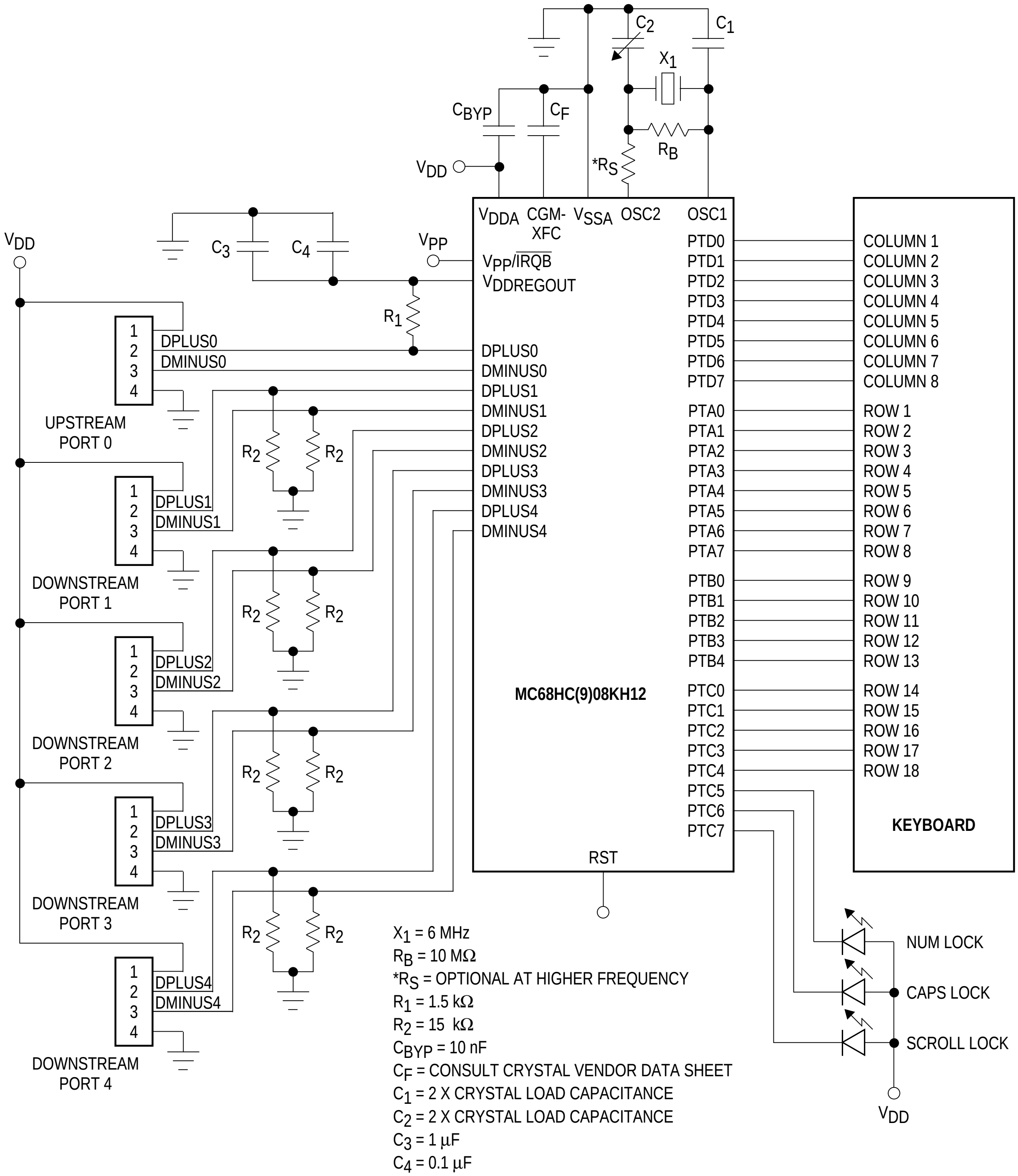
The one upstream port, which is composed of $V_{DDREGOUT}$, DPLUS0, and DMINUS0, is configured with DPLUS0 pulled up to the 3.3-volt signal, provided from $V_{DDREGOUT}$ by a 1.5-kΩ resistor, are also wired to the upstream USB connector which provides the path back to the host for the downstream ports.

The four downstream ports – D1, D2, D3, and D4 – all have the 15-kΩ pulldown resistors attached, pulling them low when the USB lines go idle. The transceiver pins are also wired to the female end of the USB connector providing the hub connections.

Notice that there is no indication whether the downstream ports are high or low speed as they are drawn in **Figure 8**. The determination of the speed of the attached device is made within the attached device itself.

The USB peripheral connected to the individual downstream ports will have the 1.5-kΩ pullup resistor to the USB operating voltage, 3.3 volts, attached to the appropriate transceiver pin. It will be attached to DPLUS for a high speed device and DMINUS for a low-speed device.

NOTE: *All power/ground (V_{DD}/V_{SS}) pairs should be isolated via a 10-nF capacitor per pair.*



Note:
All V_{DD} / V_{SS} pairs not shown should be isolated using 10-nF capacitors.

Figure 8. Keyboard Hub Circuit Schematic Using the MC68HC(9)08KH12

Firmware for the MC68HC(9)08KH12

Code development can be arduous for the peripheral manufacturer with limited resources and lack of experience with the requirements set forth for USB devices.

Motorola has developed a scalable USB firmware code library to make the transition from legacy type peripherals less painful and to reduce development times significantly. The firmware library takes care of many USB compatibility matters, providing USB conformant functions that perform many of the required operations. Utilizing this library can cut from two to three months off code development time, accelerating the time to market for new USB peripherals.

This firmware library can be acquired from Motorola by contacting the local Motorola representative for details.

Conclusion

The MC68HC(9)08KH12 is a well-integrated, robust, and versatile part for peripheral manufacturers who are designing a USB keyboard with high/low speed hub capability.

Additional features of the microcontroller include the integrated 3.3-volt voltage regulator, which guarantees that the voltage source to the USB module stays within specifications.

The Motorola USB firmware library is available for fast code development and is fully scalable to the application for which it will be used. Additional information for the firmware library and example applications in which the MC68HC(9)08KH12 has been used can be attained by contacting your local Motorola representative.

References

Universal Serial Bus Specification, Jan.15, 1996.

Motorola USB Firmware Library User's Manual, Preliminary, Motorola. October 1997.

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