Atmel AVR1017: XMEGA - USB Hardware Design Recommendations

Features

- USB 2.0 compliance
  - Signal integrity
  - Power consumption
  - Back driver voltage
  - Inrush current
- EMC/EMI considerations
- Layout considerations
- Typical power scheme

1 Introduction

Atmel® AVR® XMEGA® devices now make easy to implement USB. To ensure full USB device compliance, however, there are some issues to consider while designing the hardware application.

This document introduces a set of recommendations that cover the following technical topics:

- USB 2.0 full speed and low speed electrical compliance
- EFTB (electrical fast transient burst)
- Global EMC performance

This document is written for hardware designers to help them develop their applications. It assumes that readers are familiar with the AVR XMEGA architecture. A basic knowledge of the USB 2.0 specification (www.usb.org) is also required to understand the content of this document and compliance constraints.

8-bit Atmel Microcontrollers

Application Note

Rev. 8388A-AVR-07/11

2 Abbreviations

- USB: Universal serial bus
- USB IF: USB Implementation Forum
- FS: USB full speed (12Mbit/s)
- LS USB low speed (1.5MBit/s)
- HS: USB high speed (480MBit/s)
- PCB: Printed circuit board
- EFTB: Electrical fast transient burst
- DP or D+: Data Plus differential line
- DM or D-: Data Minus differential line
- DFLL: Digital frequency locked loop
- BOM: Bill of materials

3 Global hardware USB requirements

The USB interface consists of a differential data pair (DP/DM) and a power supply (VBUS, GND).

VBUS provides a 5V power supply to optionally power the target application.

The DP/DM differential pair operates at 3.3V for LS and FS devices, while HS devices use a lower voltage. As the XMEGA USB module implements FS and LS modes only, the rest of this document will not deal with USB HS mode. For FS and LS modes, the 3.3V differential pair voltage is within the XMEGA power supply range. Thus, to allow USB operation, the XMEGA should be powered at 3.3V.

3.1 Power schemes

According to USB specifications, USB devices can either be “bus-powered” or “self-powered.”

3.1.1 Self-powered applications

Self-powered applications provide their own power supply; they are not allowed under any condition to draw any current from the USB interface.

3.1.2 Bus-powered applications

Bus-powered applications draw their power supply from the 5V VBUS signal. The maximum current allowed depends on the USB mode.

3.1.2.1 Suspend mode

The USB host controller may decide to enter suspend mode at any time to reduce power consumption (system sleep or standby). While in this mode, the entire application should reduce power consumption to less than 2.5mA. This means that the entire device should be able to reach this minimal static power consumption. This requires the application design to:

- Reduce the number of permanent pull-up signals
- Minimize or eliminate power-on LEDs
- Reduce the power consumption of external components/resources (through chip select and power reduction lines, and by shutting down unused power supplies)

NOTE When computing global suspend current, remember that the USB device requires keeping its DP or DM pull-up active.

3.1.2.2 Operating mode

While in USB operational mode, the maximum current that can be drawn from VBUS depends on the device type and state. The device is not allowed to draw more than 100mA until it is properly enumerated by the USB host. The maximum current a device can draw once enumerated is given during the enumeration process. The current ranges are from 0 to 100mA for ‘low-power’ devices, or 0 to 500mA for ‘high-power’ devices.

3.1.3 Inrush current

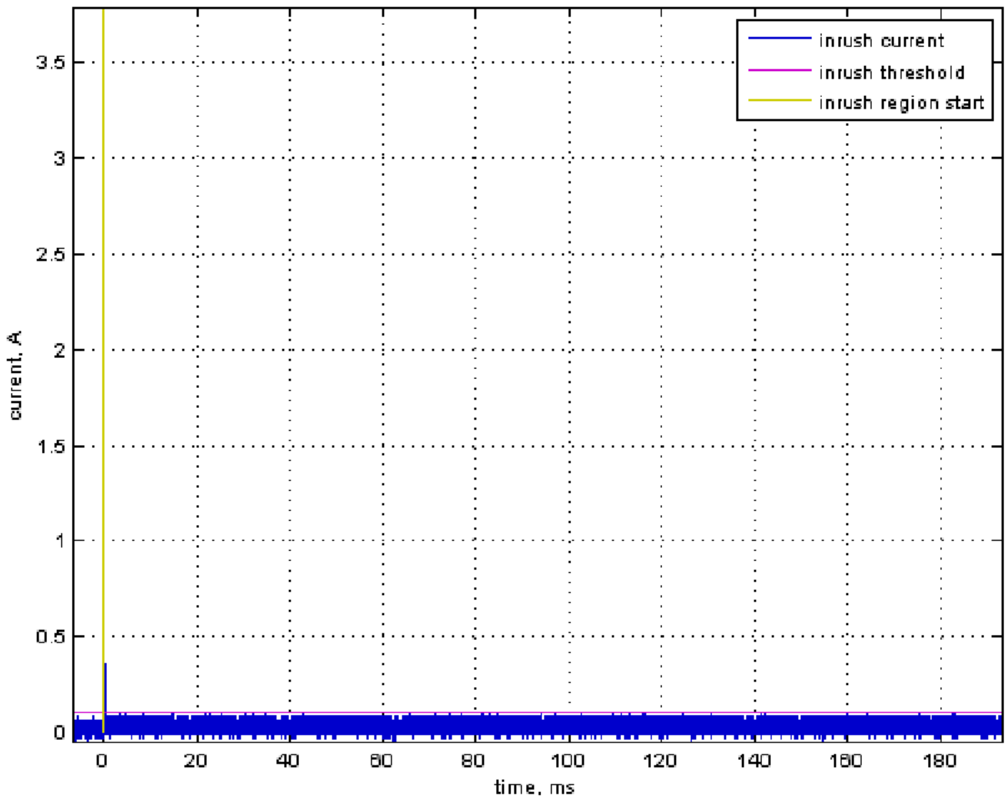
The USB 2.0 specification states: “The maximum load (CRPB) that can be placed at the downstream end of a cable is 10µF in parallel with one unit load (100mA). The

10µF capacitance represents a bypass capacitor directly connected across the VBUS lines in the function, plus any capacitive effects visible through the regulator in the device."

As a result, the maximum direct capacitance allowed on the VBUS signal should be limited to 10µF, which represents an allowable load of approximately 50µC.

According to the USB-IF: "Inrush current is measured for a minimum of 100 milliseconds (ms) after attach. Attach is defined at the moment the VBus and ground pins of the plug mate with the receptacle. Any current exceeding 100mA during the 100ms interval is considered part of the inrush current event. The inrush current is divided into regions. A region is an interval where the current exceeds 100mA until the time the current falls below 100mA for at least 100µs. There can be multiple inrush regions during the 100ms period. Pass/fail is determined by the region having the highest charge."

Figure 3-1. Inrush current measure.



For more detail about inrush current compliance, refer to the official USB-IF compliance update page (http://compliance.usb.org).

3.1.4 Back-drive voltage

A USB self-powered device has its own independent power supply, as this kind of application can operate while disconnected or not using the USB interface. The USB specification states that the USB lines of such a device should not present any voltage on DP, DM, or VBUS while disconnected from the bus.

As a consequence, a USB self-powered device should implement a mechanism to detect the USB connection state (via VBUS signal monitoring) to ensure it does not enable its DP or DM pull-up on the differential data pair.

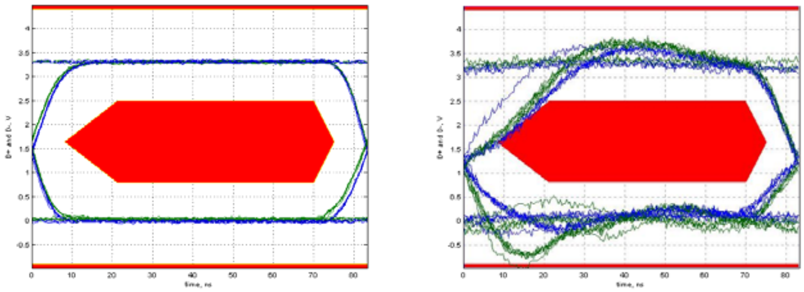
3.2 Signal integrity

The USB 2.0 full speed electrical specification requires some precautions to ensure correct signal integrity.

Incorrect signal quality could make the USB device's behavior unstable and not compliant with the USB specification.

During USB certification, the USB signal quality is measured by performing the eye diagram test. Figure 3-2 illustrates a correct (USB-compliant) and an incorrect eye diagram. The incorrect one may result of improper routing or unmatched impedance of the USB differential lines.

Figure 3-2. USB eye diagrams.

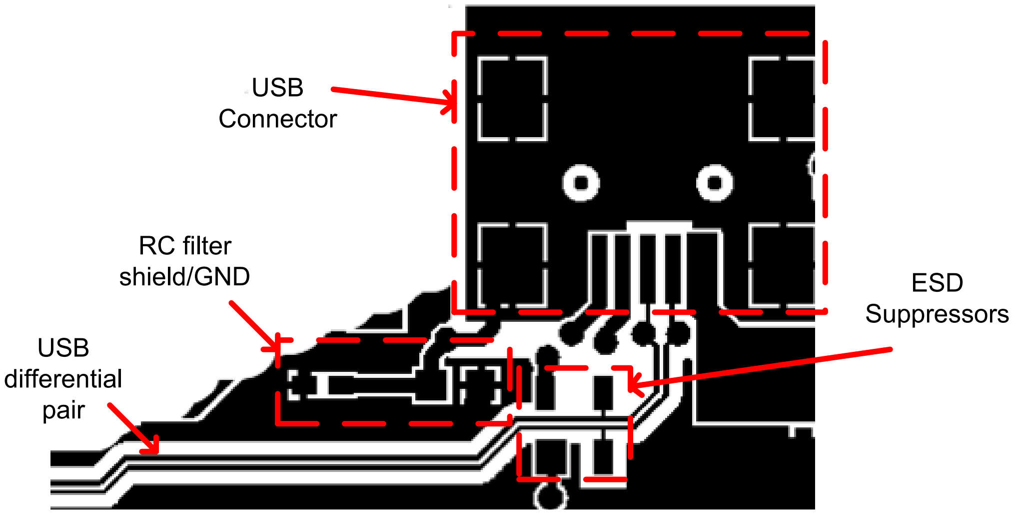


3.2.1 USB signal routing

The impedance of the differential data line pair is 90Ω to each other and 45Ω to ground, and the termination of the line in the device may require serial resistors. These serial resistors are included within the AVR XMEGA device. To ensure proper signal integrity, the two DP/DM signals must be closely routed on the PCB:

- The impedance of the pair should be matched on the PCB to minimize reflections
- USB differential tracks should be routed with the same characteristics (length, number of vias, etc.)
- Signals should be routed as parallel as possible, with a minimum number of angles and vias

Figure 3-3. Typical USB layout connections.



3.2.2 Clock source selection

The 12Mbit/s USB FS signal rate specification requires 0.25% accuracy. In addition, the data recovery mechanism requires an internal ×4 oversampling mechanism. Thus, the device should be able to generate an accurate, 48MHz signal clock to the USB module.

To ensure proper signal quality, the Atmel AVR XMEGA provides different ways to generate the 48MHz oversampling frequency:

- External crystal and the on-chip PLL
- Internal RC oscillator

The most convenient method is to use the on-chip, 32MHz RC oscillator calibrated at 48MHz. To ensure 0.25% signal rate accuracy, the internal RC oscillator should be auto-calibrated using an internal DFLL. This solution allows the external BOM cost to be reduced (no need for an external crystal).

NOTE

The USB module for XMEGA requires a minimum 12MHz CPU clock to send and receive data. Be sure to configure the XMEGA system clock with a minimum 12MHz clock when using the USB module. This clock can be stopped when USB is in suspend mode.

3.3 Bus connection

3.3.1 Connector types

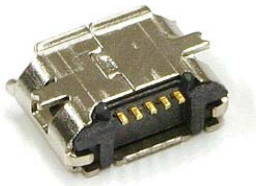
The device can be connected to the host via a captive cable or by using a soldered receptacle with a USB cable.

For USB device connection, the USB specification states that one and only one USB connector can be used. It can be one of the following:

- B receptacle

- Mini-B receptacle

- Micro-B receptacle



When applying for USB device certification, be sure to use a certified USB connector listed by the USB-IF. Certified USB connectors can be found from the USB-IF product search web page (http://www.usb.org/kcompliance/view).

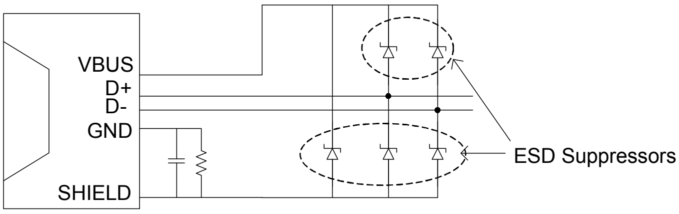
Be sure to use properly shielded USB cable when using a captive cable in FS mode, and limit the cable length to 1.5m in LS mode.

3.3.2 Electrostatic protection

USB allows the application to have an open connection to the external environment, which could expose the entire system to ESD.

Even though Atmel AVR XMEGA devices embed on-chip ESD protection, it is recommended to increase ESD protection on the USB DP, DM, and VBUS lines using dedicated transient suppressors. These protections should be located as close as possible to the USB connector to reduce the potential discharge path and reduce discharge propagation within the entire system.

Figure 3-4. Typical USB ESD protections.



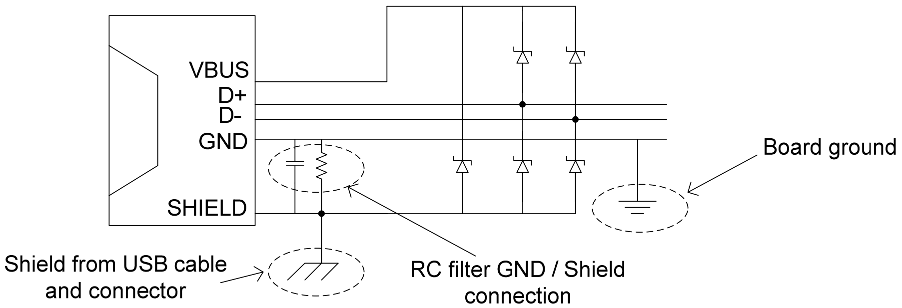
The ESD suppressors can be independent, discrete protection devices or specific, integrated USB protections.

3.3.3 EMI considerations

The USB FS cable includes a dedicated shield wire that should be connected to the board with caution. Special attention should be paid to the connection between the board ground plane and the shield from the USB connector and the cable.

Tying the shield directly to ground would create a direct path from the ground plane to the shield, turning the USB cable into an antenna. To limit the USB cable antenna effect, it is recommended to connect the shield and ground through an RC filter. Typically, R = 1MΩ and C = 4.7nF in Figure 3-5.

Figure 3-5. Typical shield and ground connection.



4 Typical USB applications with Atmel XMEGA

Atmel XMEGA devices with USB modules now make the implementation of USB connectivity easy by reducing external component needs:

- On-chip USB serial resistors
- On-chip USB pull-up resistor
- No need for an external crystal, because AVR XMEGA can achieve USB FS and LS communication using its internal RC oscillator

4.1 Power supply considerations

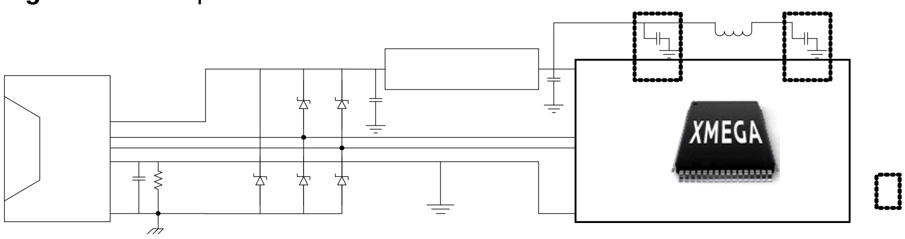
The USB differential pair operates at, typically, 3.3V. As a result, to comply with the USB specifications, the AVR XMEGA device should be powered with VCC = 3.3V.

4.2 Bus-powered application

When designing bus-powered applications, power management is critical. The AVR XMEGA offers a wide range of power saving modes to achieve the lowest possible power consumption for the system. However, some special considerations should be taken into account regarding external component selection. As explained before, bus-powered applications use the 5V VBUS power supply to feed the entire application. An external low dropout regulator is required to generate the 3.3V AVR XMEGA power supply.

When selecting this regulator, be sure its quiescent current does not consume too large a proportion of the global 2.5mA suspend current.

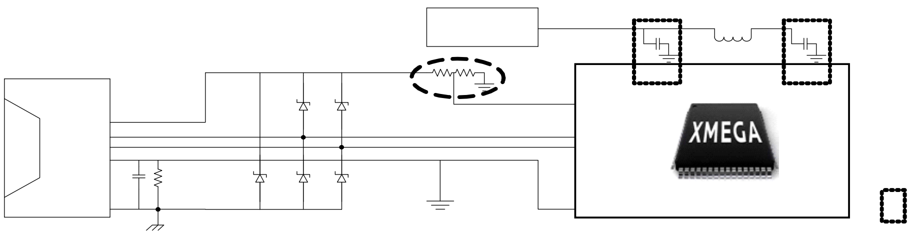
Figure 4-1. Bus power scheme connection.



4.3 VBUS detection for self-powered devices

Self-powered devices require a way to detect the USB connection status by monitoring the VBUS signal. This could be achieved using a basic resistor voltage divider.

Figure 4-2. Self-power scheme connection.



5 Conclusion

Within the past years, USB has become a standard and an easy-to-use communication interface. Atmel AVR XMEGA devices provide an efficient USB solution to integrate USB in most applications. But designing an application that fully complies with the USB specifications requires careful attention to several issues. Table 5-1 summarizes the technical issues and their potential solutions.

Table 5-1. Summary of USB hardware requirements.

Technical issue	Recommendation
Power management	- Use an appropriate power reduction mode in USB suspend mode - Select a regulator with a low quiescent current - Reduce consumption of all external resources (LEDs, pull-up, chip select, etc.)
USB signal quality	- Use certified connectors and cables - USB differential pair routing - Source clock selection - Power supply quality
ESD	- ESD suppressors on VBUS, D+, and D- located close to the USB connector
EMC	- Indirect ground/shield connection
Inrush current	- Maximum VBUS equivalent capacitance should be lower than 10µF
Back-drive voltage	- VBUS signal monitoring required to control USB attachment

6 Table of contents

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