EMI Filtering, USB Upstream Line Termination and ESD Protection Using the STF202 Device

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APPLICATION NOTE

What is a USB?

The Universal Serial Bus was invented and standardized by a group of computer and peripherals manufactures in 1995. The idea was to take the whole area of serial port and serial bus and update it with the twenty–first century technology. It is true that there were many standards of communication between host computers and peripherals, but the goal was to create a technology that combines low speed and high speed bus activity. The technology enables shared access for both speeds, a technology which provides robust protocol, automatic configuring of devices and a serial bus which is simplified and easy to plug into. All those requirements were met with the USB standards.

The USB has become a very popular expansion to the personal computer. The USB is not a serial port, it is a serial bus, a fact that enables a single port on the computer to be a link for a myriad of devices, (up to 127 devices in a USB system). We can easily chain one device to another and use one port as a connecting point of many devices by using a hub. All these enables us to look at the USB system as a small network of devices.

The Universal Serial Bus (USB) makes connecting devices to your computer faster, easier and virtually limitless. High–Speed USB devices are capable of communicating at speeds up to 12 megabits without shutting down and without having to open your computer.

The plug and play capability of the USB is one of its advantages over other serial buses. This capability enables automatic detection of a new device, which is attached into the system, an automatic configuration of it by the host, and an automatic detection of it's detachment from the system. The flexible attachment and detachment of devices to and from the system allows mobility on the bus and adjustment of the system to new devices without the need of restart the whole system each time a new device is detected.

Another important aspect of the USB is it's mid and high speed flexibility. This feature refers to the ability of the USB to support simultaneously medium–speed devices, (which work in 1.5 Mbps), and high–speed devices, (which work in 12 Mbps).

The simultaneously work of the USB system finds expression also in the dual support in both isochronous and asynchronous bandwidth allocation methods. Isochronous means that the necessary bandwidth is guaranteed, whenever the device requires it – it will be available. Asynchronous on the other hand means that there is no guarantee – the data will be sent whenever it will be possible to send it. Devices, such as video and audio multimedia, that use stream transfer, will use the isochronous method while devices that use bulk transfer, such as printers and scanners will use the asynchronous method.

The USB is robust. Through all the different protocol layers there is an error detection and recovery mechanism, which guarantees low error rate. The USB provides detection of faulty devices and flow control mechanism, which is built in the protocol.

USB, or Universal Serial Bus, is a peripheral bus connectivity standard which was conceived, developed and is supported by a group of leading companies in the computer and telecommunication industries – Compaq, DEC, IBM, Intel, Microsoft, NEC and Northern Telecom. *The current standard published and implemented on most of the USB devices is version 1.1*, nevertheless, the good news is, USB is getting even faster, USB 2.0 promises even higher data transfer rates, up to 480 Mbps. The higher bandwidth of USB 2.0 will allow high performance peripherals, such as monitors, video conferencing cameras, next–generation printers, and faster storage devices to be easily connected to the computer via USB. The higher data rate of USB 2.0 will also open up the possibilities of new and exciting peripherals. USB 2.0 will be a significant step towards providing additional I/O bandwidth and broadening the range of peripherals that may be attached to the PC.

USB 2.0 is expected to be both forward and backward compatible with USB 1.1. Existing USB peripherals will operate with no change in a USB 2.0 system. Devices such as mice, keyboards and game pads, will not require the additional performance that USB 2.0 offers and will operate as USB 1.1 devices. All USB devices are expected to co–exist in a USB 2.0 system. The higher speed of USB 2.0 will greatly broaden the range of peripherals that may be attached to the PC. This increased performance will also allow a greater number of USB devices to share the available bus bandwidth, up to the architectural limits of USB.

BUS TOPOLOGY

USB devices can be connected to the computer either directly through the USB port on the back of the computer or through a USB hub. The Universal Serial Bus connects USB devices with the USB host. There is only one host on any USB system. The USB interface to the host computer system is referred to as the host controller.

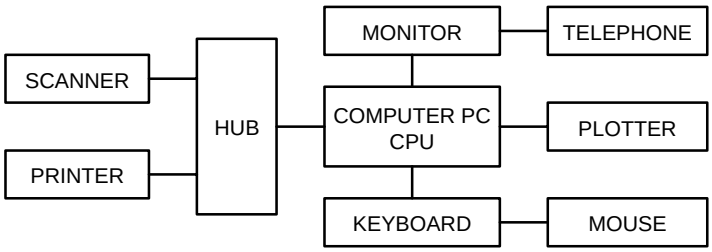

Figure 1. Typical USB System

The Figure 1 shows a typical USB system which consists of one host, hubs and devices.

The Host in the USB system, is responsible to the whole complexity of the protocol (simplifies the designing of USB devices). The host controls the media access, therefore, no one can access the bus without the required approval from the host.

The Hub provides an interconnect point, which enables many devices to connect to a single USB port. The logical topology of the USB is a star structure, all the devices are connected (logically) directly to the host. It is totally transparent to the device what is its' hub tier (the number of hubs the data has to flow through). The hub is connected to the USB host in the upstream direction (data flows "up" to the host) and is connected to the USB device in the downstream direction (data flows "down" from the host to the device). The hubs' main functionality is the responsibility of detecting an attachment and detachment of devices, handling the power management for devices that are bus–powered (get power from the bus), and responsibility for bus error detection and recovery. Another important role of the hub is to manage both full and low speed devices. When a device is attached to the system the hub detects the speed, which the device operates in, and through the whole communication on the bus prevents full speed traffic from reaching low speed devices and vice versa.

The Device is defined as everything in the USB system, which is not a host (including hubs). A device provides one or more USB functions. Most of the devices provide only one function but there may be some, which provides more than one and called compound devices. We refer to two kinds of devices – self powered or bus powered devices. A device that gets its power from the bus is called bus powered and on the other hand a device which supplies its own power is called self powered. There are two kinds of devices:

Full–speed devices – operates in 12 Mb/s.

Low–speed devices that work in 1.5 Mb/s.

USB LINE TERMINATION (USB 1.1 specification)

The Universal Serial Bus (USB) line termination is specified in the USB 1.1 specification and the main purpose of the line termination is to maintain the signal integrity to minimize end user termination problems. The termination requirement will depend on what kind of driver is used whether the transceiver operates in full speed (12 Mb/s) or low speed (1.5 Mb/s) and if the port is upstream or downstream.

As mentioned, there are two types of configurations for the USB port which are upstream and downstream. If your port connects to the host either in a direct way or through a hub, you are upstream (data flows "up" to the host) and in the other hand, if you are the host or your port provides access to the host then you are downstream (data flows "down" from the host to the device*). In the case of the STF202 ON Semiconductor device, it provides "upstream termination"*. The Figure 2 illustrates the USB keyed connector protocol (USB 1.1 specification information):

Series “A” Connectors		Series “B” Connectors	
	Series “A” plugs are always oriented **upstream** towards the host system. **“A” plugs** (From the USB Device)		Series “B” plugs are always oriented **downstream** towards the USB device. **“B” plugs** (From the Host System)
	**“A” receptacles** (Downstream output from the USB Host or Hub)		**“B” receptacles** (Upstream input to the USB Device or Hub)
	(Connection between **“A” plugs and “A” receptacles**)		(Connection between **“B” plugs and “B” receptacles**)

Figure 2.

- Series “A” receptacle mates with a Series “A” plug. Electrically, Series “A” receptacles function as outputs from host systems and/or hubs.
- Series “A” plug mates with a Series “A” receptacle. The Series “A” plug always is oriented towards the host system.
- Series “B” receptacle mates with a Series “B” plug (male). Electrically, Series “B” receptacles function as inputs to hubs or devices.
- Series “B” plug mates with a Series “B” receptacle. The Series “B” plug is always oriented towards the USB hub or device.

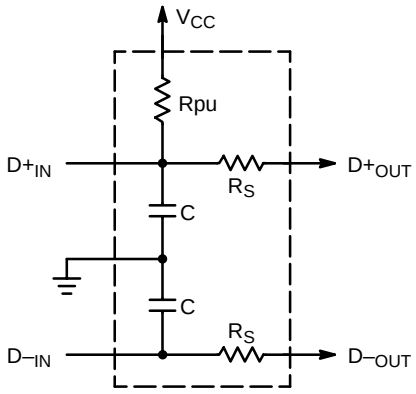

Figure 3.

The USB uses a differential output driver to drive the USB data signal onto the USB cable. The pins D+ and D– identify these lines.

In order to determine if the line is an upstream or downstream line, the USB uses pull up or pull down resistors on the D+ and D– lines, so if a 15 Kohms pull down resistors is connected on either the D+ or D– line, the port is identified as downstream and in the other hand, if a 1.5 Kohms pull up resistor is connected on either the D+ or D– line, the port is identified as upstream. The Figure 3 illustrates the termination for an upstream USB port.

The USB Line termination is reached through the series resistors placed in the D+ and D– lines. These resistors insure the proper termination to maintain the integrity of the signal. The Pull up Resistor of 1.5 Kohms on either the D+ or D– data lines is used to identify the line as an upstream port.

In addition to the identification of downstream or upstream port through the values of the pull down or pull up resistors, it is important to identify the speed operation of the port which is determined as follows: if the pull up resistor (Rpu) is connected to the D+ line, the port is identified as full–speed operation (12 Mb/s) and if the pull up resistor (Rpu) is connected to the D– line the port is identified as low–speed operation (1.5 Mb/s).

According with the USB 1.1 specification, the USB differential driver line must match the cable impedance in order to maintain the signal integrity & reduce signal reflections. The USB twisted pair cable has a characteristic impedance of (Zo) of 90 ohms ±15%.

For a CMOS driver implementation, the CMOS drivers' impedance will be significantly less than this resistance, so in order to achieve matching impedance, a series resistor RS is included on both D+ and D– USB differential driver lines. The series resistor (Rs) will vary in value depending on the variation of the driver's impedance. The USB 1.1 specification requires a series resistor with value between 28 Ohms and 44 Ohms. The Figure 4 shows the buffer impedance required by the USB 1.1 specification:

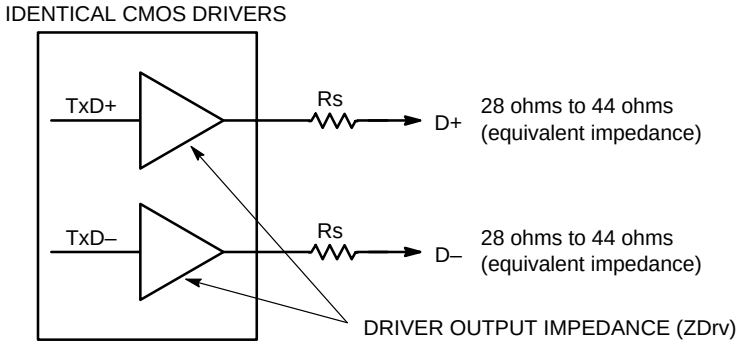

Figure 4. USB 1.1 Specification Information

Nevertheless, it has been found through some research that most of the industrial drivers require a series resistor of 22 Ohms or 30 Ohms, so it seems that the tendency for the driver impedance's value is going to the upper side, therefore, the series resistance would need to be lower to compensate this tendency.

EMI FILTERING (USB 1.1 specification)

The USB 1.1 specification also establish what must be the data signal rise and fall time to minimize RFI emissions and signal skew. The criteria to measure the rise and fall time is from 10% to 90% as shown in the Figure 5.

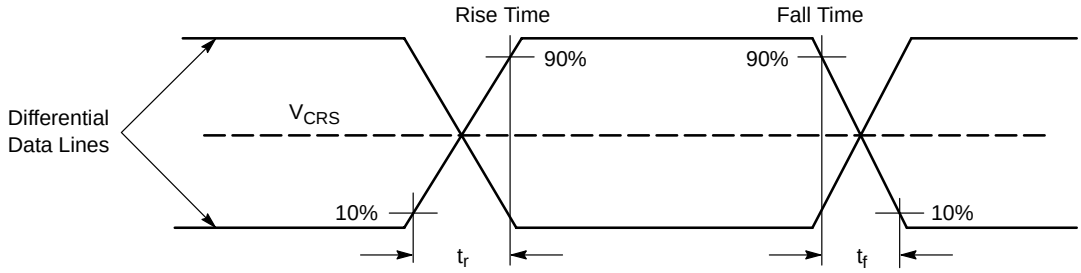

Figure 5. USB 1.1 Specification Information

The rise and fall time ranges have to be taken as the main reference to specify the capacitance necessary to achieve the required rise and fall time. According to the USB 1.1, the rise and fall times for full–speed buffers must be between 4 ns and 20 ns, and matched to within ±10% to minimize RFI emissions and signal skew. This indicates that the loading capacitance must not exceed the 75 pf between the line and GND in each line of the transceiver. This criteria applies for either downstream or upstream ports.

In the case of low–speed buffers on hosts and hubs that are attached to USB, receptacles must have a rise and fall time between 75 ns and 300 ns for any balanced capacitive load. The edges must be matched to within ±20% to minimize RFI emissions and signal skew. The USB 1.1 spec recommends 200 pf to 600 pf for downstream port and 50 to 150 pf for upstream port.

STF202–22 ON Semiconductor Device

ON Semiconductor has developed the STF202 device which meets the requirements of the Universal Serial Bus (USB) specification revision 1.1 in terms of EMI Filtering and line termination for the USB I/O lines. In addition to the EMI filtering and line termination futures, the STF202 device from ON Semiconductor provides ESD Protection to IEC6100–4–2 (Level 4) in an integrated solution placed in a small and single package (TSOP–6, Case 318G). The Figure 6 shows the STF202 device schematic and the equivalent circuit of this device is shown in the Figure 7:

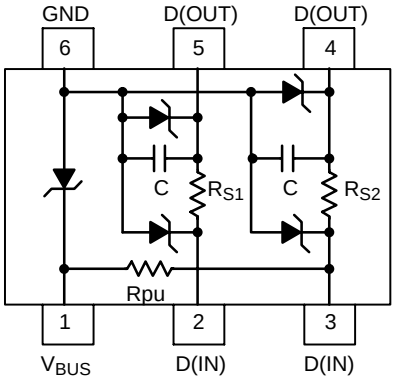

Figure 6. STF202 Device Schematic

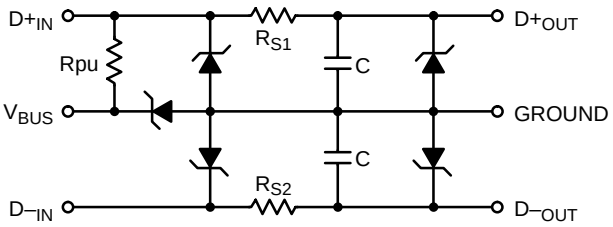

Figure 7. Equivalent Circuit of the STF202 Device

STF202–22, Line Termination

The USB Line termination is reached through the series resistors, R_{S1} and R_{S2} (22 ohms or 30 ohms) connected on the D+ and D– lines. These resistors match the cable impedance to that of the differential driver in order to insure the proper termination to maintain the integrity of the signal. The Pull up Resistor of 1.5 Kohms on either the D+ or D– data lines is required by the USB 1.1 specification to identify the equipment as full–speed or low–speed device.

STF202–22, EMI Filtering

The EMI filter (low pass filter) is formed by the total impedance of the buffer (buffer impedance plus Rs) and the two zener diodes in parallel with the capacitor in each of the I/O lines. The resulting Pi filter configuration is used to bypass high frequency energy to ground. It attenuates noise signals that are both entering and exiting the filter network. The RC Pi filters are first order filters with a frequency attenuation roll–off of –20 dB/decade. *For a better reference about RC Pi filters you may consult the ON Semiconductor application note AND8026/D (“Solving EMI and ESD Problems with Integrated Passive Device Low Pass Pi Filter).*

STF202–22, ESD Protection to IEC6100–4–2 (Level 4)

The STF202 ON Semiconductor device also provides ESD protection to IEC6100–4–2 in both I/O data lines (D+ & D–) and in the voltage bus (VBUS). The ESD protection is achieved through the TVS devices placed in each of the I/O lines.

The IEC6100–4–2 International Standard relates to the immunity requirements and test methods for electrical and electronic equipment subjected to static electricity discharges, from operators directly, and to adjacent objects. It additionally defines ranges of test levels which relate to different environmental and installation conditions and establishes test procedures. The object of this standard is to establish a common and reproducible basis for evaluating the performance of electrical and electronic equipment when subjected to electrostatic discharges. In addition, it includes electrostatic discharges which may occur from personnel to objects near vital equipment.

The IEC6100–4–2 specification defines the preferential range of test levels for the ESD test which are described in the Table 1:

Table 1. Preferential Range of Test Levels for the ESD Test

1a – Contact Discharge		1b – Air Discharge	
Level	**Test Voltage (kV)**	**Level**	**Test Voltage (kV)**
1	2	1	2
2	4	2	4
3	6	3	8
4	8	4	15
X*	Special	X*	Special
* “X” is an open level. The level has to be specified in the dedicated equipment specification. If higher voltages than those shown are specified, special test equipment may be needed.			

The IEC6100–4–2 specification also defines what should be the characteristics and performance of the ESD generator, these characteristics are listed below:

Specifications

- energy storage capacitance (Cs + Cd): 150 pF ±10 %;
- discharge resistance (Rd): 330 Ohms ±10 %;
- charging resistance (Rc): between 50 mΩ and 100 mΩ;
- output voltage (see Note 1): up to 8 kV (nominal) for contact discharge; up to 15 kV (nominal) for air discharge;

Note 1: Open circuit voltage measured at the energy storage capacitor.

The Figure 8 illustrates the simplified diagram of the ESD generator and the Figure 9 shows the typical waveform of the output current of the ESD generator (information taken from the IEC6100–4–2 specification):

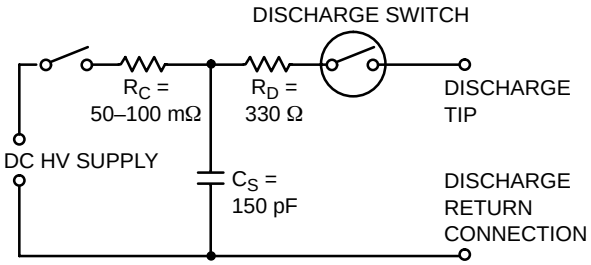

Figure 8. ESD Generator, Simplified Diagram

The Figure 9b shows a real waveform sample taken from the output of the ESD generator (tester according the IEC6100–4–2 specification).

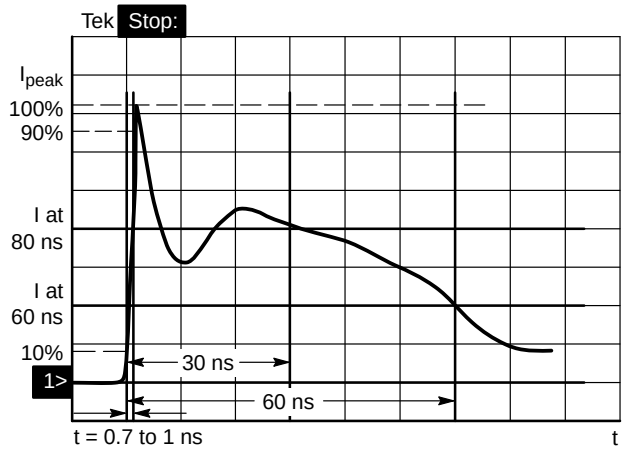

Figure 9a. Typical Output's Waveform of the ESD Generator

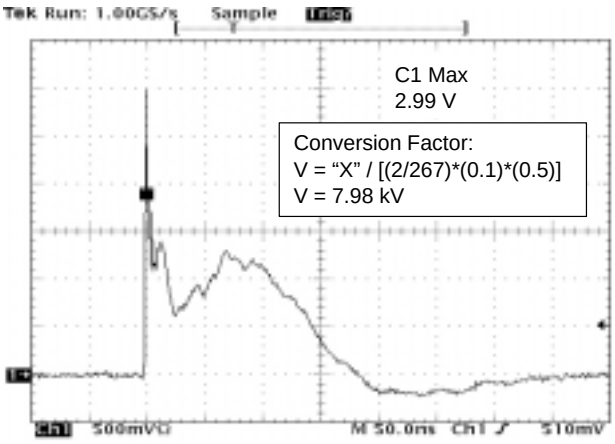

Figure 9b. Real Waveform Sample Taken from ESD Generator

The integrated TVS devices of the STF202–22 series device meet the requirements of the IEC6100–4–2 International Standard. The Figures 10 and 11 illustrate the typical ESD clamping response of the STF202–22 series device for 8 kV contact and 15 kV air:

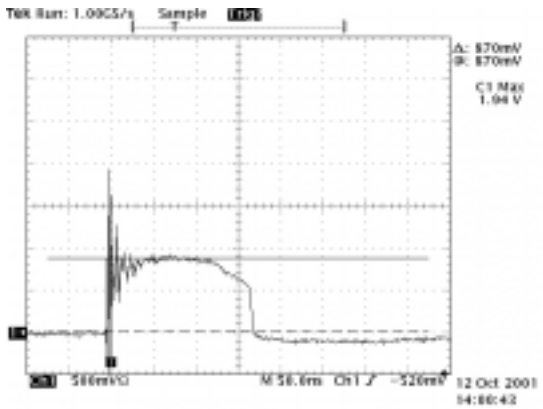

Figure 10. ESD, 8 kV Contact

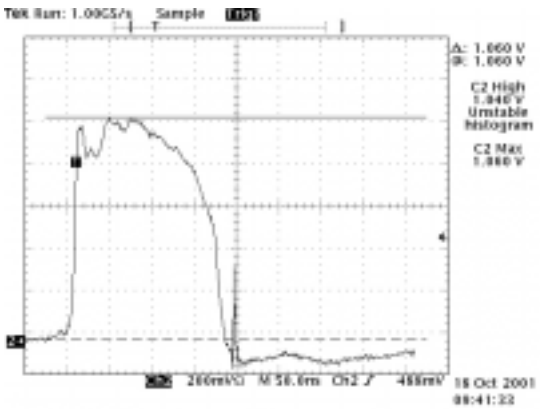

Figure 11. ESD, 15 kV Air

In both of the above oscilloscope graphs, the conversion factor is "1x10", so it is possible to observe that in the case of the contact ESD condition of 8 kV the device basically clamps in 8.70 V while it clamps at 10.60 V in the case of the air condition of 15 kV.

Another important parameters of the STF202–22 device that it is important to analyze and take into consideration are the insertion loss and the analog crosstalk (D+ to D–)**.**

Insertion Loss

According with the ON Semiconductor application note AND8026/D, *the insertion loss* is defined as the ratio of the power delivered to the load with and without the filter network in the circuit. This characteristic is dependent on the impedance of the source and load circuits, and is proportional to the magnitude of the filter resistance. The insertion loss can be measured using a spectrum analyzer with a tracking generator. The Figure 12 shows the insertion loss of the STF202 device at different frequency levels.

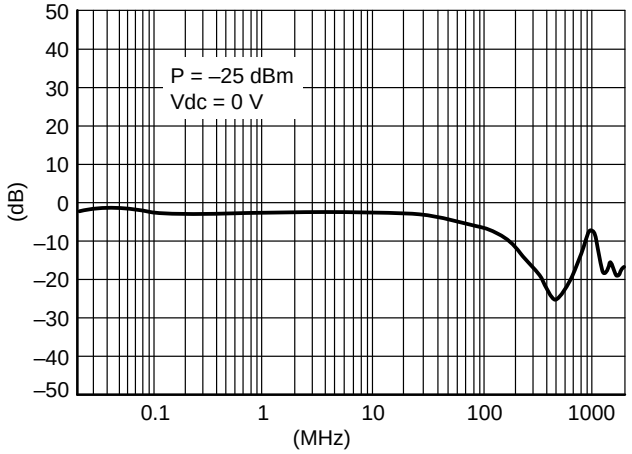

Figure 12. Insertion Loss
(Test Conditions, p = –25 dBm; Vdc = 0 V)

Analog Crosstalk (D+ to D–)

In a brief way, the analog crosstalk defines how well is the isolation between the two I/O channels (D+, D–) of the STF202 device when they operate at different frequency levels. In the same way than for the insertion loss characteristic, the analog crosstalk characteristic can be measured using a spectrum analyzer with a tracking generator. The Figure 13 shows the analog crossalk of the STF202 device at different frequency levels:

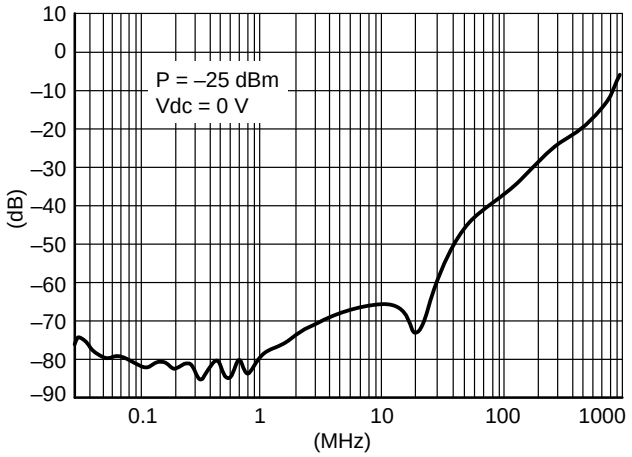

Figure 13. Analog Cross–talk (D+ to D–)
(Test Conditions, p = –25 dBm; Vdc = 0 V)

Connection of the STF202 for Full–Speed and Low–Speed Devices

As mentioned before, there are two kind of port devices:

Full–speed devices – operates in 12Mb/s.

Low–speed devices that work in 1.5Mb/s.

The STF202 device can be shaped to be used for either Full–Speed or Low–Speed devices which is achieved as described below:

Full–Speed Devices

The Pull up resistor (Rup) is connected to the D+ Line. The terminal 1 is connected to the Voltage Supply Line (VBUS) while the terminal 6 is connected to ground. The input of the D+ line is connected in the terminal 3 which outputs from the terminal 4. Finally, the input of the D– line is connected in the terminal 2 which outputs from the terminal 5. The Figure 14 shows the connections of the STF202 device for “Full–Speed devices”:

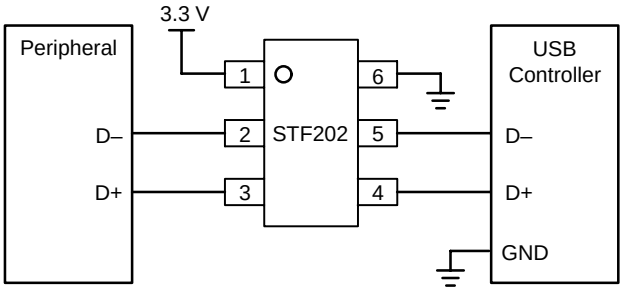

Figure 14. Connection for Full–Speed Devices

Low–Speed Devices

The Pull up resistor (Rup) is connected to the D– Line. The terminal 1 is connected to the Voltage Supply Line (VBUS) while the terminal 6 is connected to ground. The input of the D– line is connected in the terminal 3 which outputs from the terminal 4. Finally, the input of the D+ line is connected in the terminal 2 which outputs from the terminal 5. The Figure 15 shows the connections of the STF202 device for “Low–Speed devices”:

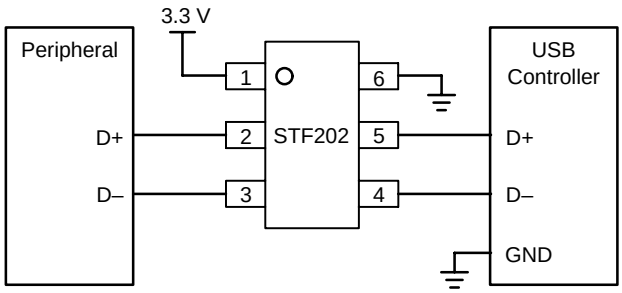

Figure 15. Connection for Low–Speed Devices

Typical Application for the STF202–22 ON Semiconductor Device

As it has been mentioned, the USB port has some design considerations for proper operation. These considerations are line termination, EMI filtering and ESD protection. All these considerations are part of the USB 1.1 specification. The Figure 16 shows a simplified schematic of a USB port. As shown in the upstream part of this figure, the line termination is reached through the series resistors connected on both I/O lines D+ and D–. The pull up resistor (1.5 Kohms) is used to identify an upstream port, if this pull up resistor is connected on the D+ line, it will indicate a full speed device, but if this resistor is connected on the D– line, it will indicate a low speed device. The capacitors in the upstream termination are used to bypass high frequency energy to ground and the TVS arrangement provides ESD protection to both I/O lines (D+ & D–) and to the voltage bus (VBUS).

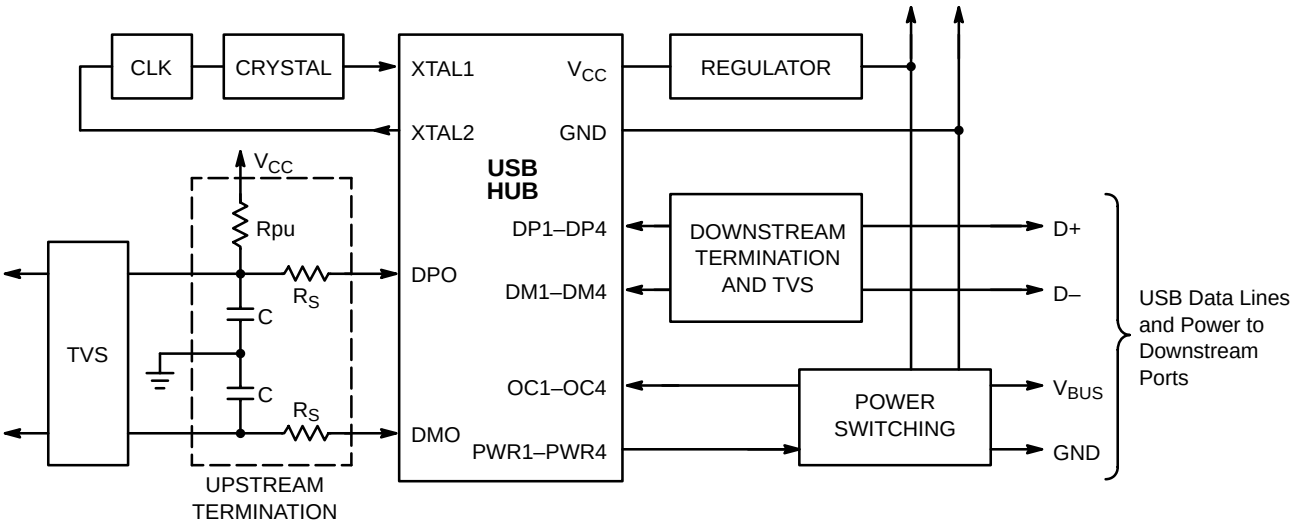

Figure 16. Simplified USB Port

ON Semiconductor STF202–22T1 device provides "upstream termination", EMI Filtering and ESD Protection to IEC6100–4–2 in an integrated solution placed in a small and single package (TSOP–6, Case 318G) to simplify the USB port design. A typical application for the STF202 device is shown in the Figure 17:

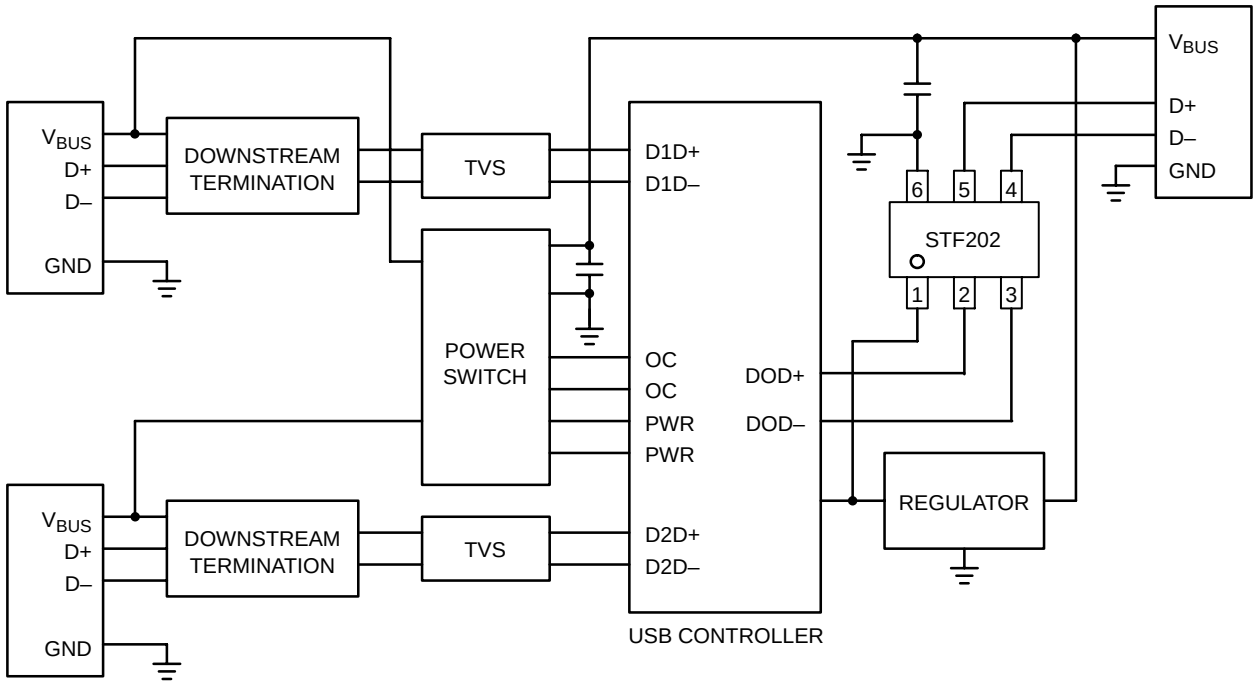

Figure 17. Example of a USB Hub Design

PCB Design considerations

The design of a USB hub is critical to meet the ESD and EMI filtering requirements, so standard high frequency PCB design rules should be used in the layout to minimize any parasitic inductance and capacitance that may degrade the filter's response. It requires optimum component placement and good practices in circuit designing. Some general design guidelines are listed below to optimize the STF202–22T1's EMI/ESD performance. Some of these guidelines were derived from the ON Semiconductor application note AND8026/D:

- Use ground planes to minimize the PCB's ground inductance.
- Critical signal lines should not be operated near board edges.
- D+ & D– signal line traces must not be operated near similar signal lines or high speed data–transferring lines.
- Locate the STF202–22T1 device as close to the USB connector as possible to avoid transient coupling.
- Minimize the PCB trace lengths between the USB connector and the STF202–22T1 device.
- Minimize the PCB trace lengths for the ground return connections.

Bibliography References

1. Universal Serial Bus Specification, Revision 1.1, September 23, 1998.
2. International Standard IEC61000–4–2, 1999–05.
3. Forum Web Site: www.usb.org.com
4. Web Site of PULSE Data Communications Wide Area Networks: http://www.pulsewan.com/data101/usb_basics.htm
5. ON Semiconductor Application Note AND8026/D.

Notes

Notes

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