The Influence of Electromagnetic Disturbances on Data Transmission in USB Standard

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Abstract. Universal Serial Bus (USB) architecture is becoming a popular substitute for parallel or serial bus RS-232 architecture. In addition to parallel and serial ports, USB ports are provided as standard equipment on most computers manufactured today. There are also more and more network devices equipped with USB interface, for example USB Ethernet adapter, network Wi-Fi USB card, or USB adapter to connect two computers. Although the published USB standards require all devices with the USB logo meet today's PN-EN requirements for "CE" mark, very few commercially available USB peripherals actually do so, on the immunity side. This research focuses on the influence of electromagnetic disturbances on data transmission in USB standard in accordance with electrical fast transient immunity test and can be easily expanded to other communication standards.

1 Introduction

The demand for capacity of communication interface increases together with the development of computer systems. A wide variety of peripheral devices impose diverse communication requirements, and standards existing for many years, such as RS-232 or IEEE-1284, could no longer satisfy the market.

The generality and growing popularity of USB standard caused the market to become full of network devices connected to a computer via the USB interface. The examples of such devices are: USB Ethernet adapter, network Wi-Fi USB card, USB adapter to connect two computers. While using the USB interface, as the element that connects for example Fast Ethernet network and a PC computer, it is necessary to answer the question whether the interface is susceptible to electromagnetic disturbances, therefore whether using it would not cause the corruption of transferred data.

This is the reason why conducted research focuses on interference of the data transmission in USB standard, caused by the influence of electromagnetic field. However, they can be easily generalized on the other communication interfaces. The main target of the study is to verify the immunity of the USB standard for electromagnetic disturbances, moreover the study tries to compare USB immunity among others communication interfaces. In contrast, the study [2] presents the test results of the Fast Ethernet immunity for electromagnetic disturbances.

A. Kwiecień, P. Gaj, and P. Stera (Eds.): CN 2009, CCIS 39, pp. 95–102, 2009.

Our research aim at improving the methods of protecting devices in case of incorrect operation. This may be caused by the electromagnetic disturbances that interfere through: power systems, ground and interface circuit (transmission lines). The research already being conducted will allow to determine the immunity of already existing systems and computer devices. Moreover it will enable to determine the compatibility of those devices with the established standards harmonized with EMC (electromagnetic compatibility) directive. The very important feature of the research itself is the opportunity to check the influence of electromagnetic interference on data transmission in communication standards.

2 USB Standard

The development of computer systems as well as still increasing group of electronic devices being able to exchange the information with a computer, made the vendors elaborate the communication standard which would ensure an easy way of connecting devices to the system, and at the same time would be very functional and multi-purpose.

Companies like Microsoft, Intel, Compaq, IBM, DEC released USB, which was the solution to the hitherto problems connected with the limited amount of communication ports: RS-232, LPT IEEE 1284 and with the limited data transmission speed of those ports.

The kind of transfer used for exchange of the information between the computer (host) and the executive device is the basic element which determines the class of devices equipped with USB interface. Because of the fact that there is a huge variety of devices realizing different communication requirements, four types of transfers were distinguished: control, interrupt, bulk and isochronous.

In the conducted research for data transmission, bulk transfers have been used because they guarantee the integrity of data (error checking) and the opportunity of getting the maximal speed of USB. However, this is possible only under the condition that no other kind of transfer would use USB in the same time. Another

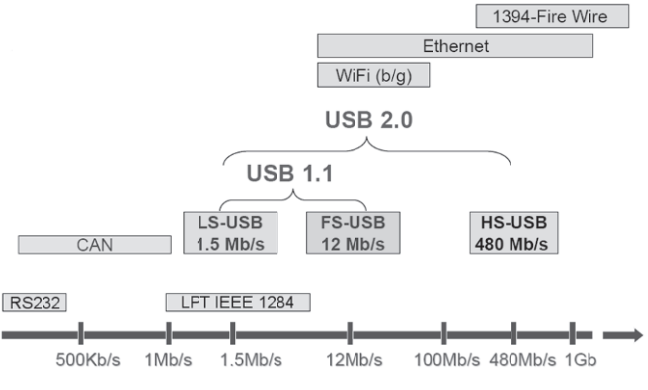

Fig. 1. Comparison of the most available communication standards

kind of transfers used in the research were control transfers, being the obligatory element of each device equipped with USB communication interface. Control transfers are also used in control process.

Figure 1 presents the comparison of available communication standards. It can be noticed that thanks to differential speed of transmission fitted to different kind of devices, USB standard complies largely with the requirements of users as well as vendors of computer equipment, offering the rate of data transmission from 1.5 Mb/s up to 480 Mb/s.

3 Test Bench and Research Procedure

In order to prepare the test bench, it was necessary to create the device equipped with USB interface, through which a device communicates with a computer. Construction of the own device ensures a full control over transmitted data, and what is more important the opportunity to modify device software and to adjust it to our needs.

The test bench consists of equipment and software created on the device and computer sides. Figure 2 shows model of the communication layer implemented on the computer and the device sides.

Following blocks: USB Host Hardware and PIC18F4550 physical interface USB correspond to the lowest, physical layer with regard to ISO model. Meanwhile the rest of the layers correspond to the software on the PC computer and USB interface device side. The device designed and constructed for the project was based on 8-bits Microchip microcontroller PIC18LF4550. This microprocessor contains integrated USB controller compatible with 1.1 standard version and works with Low Speed 1.5 Mb/s and Full Speed 12 Mb/s. Depending on the device software (firmware) it is being recognized by the computer operating system as the HID (Human Interface Device) or MSD (Mass Storage Device) class device.

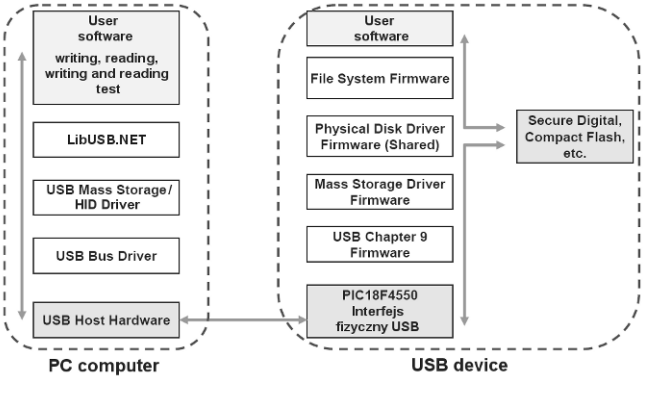

Fig. 2. Communication layer model implemented on the computer and device sides

The software part of the project consists of two applications. The first is the operating system of the device and the second is the application on the PC computer side. The operating system implemented on the device uses the mechanism of interrupts to serve USB controller. The program and data memory store all of the structure defining device parameters. These parameters determine the class of the device.

During the research it was also necessary to write a PC program which would allow to measure rate of data transmission. The program was created in C# language in Microsoft .NET and used Open Source LibUSB.NET library. The other features of the program are: test selection (writing, reading, writing and reading test) and displaying the information about device, configuration, interface, endpoint descriptors.

3.1 Test Bench

There are four items that can be distinguished in test position: two PC computers, USB device and USB protocol analyzer Explorer 200 by Ellisys (Fig. 3). The role of analyzer is to sniff all frames transmitted between PC and the device. Consequently these frames are transferred to another computer-analyzer, which contains software for analyzing sniffed frames.

A USB wire is inserted into capacitive coupling clamp that is used to couple EFT (Electrical Fast Transients) bursts onto I/O lines. According to PN-EN 61000-4-4 standard, during the test, impulsive disturbances are injected simultaneously to transmitter and receiver.

The proper placing the clamp which injects disturbances allow to preview corrupted frames of data packets in Ellisys Visual USB application installed on the computer-analyzer. During the analysis the USB wires of 3 m and 5 m length were used to transmit the data in Full Speed mode. The two tests were conducted:

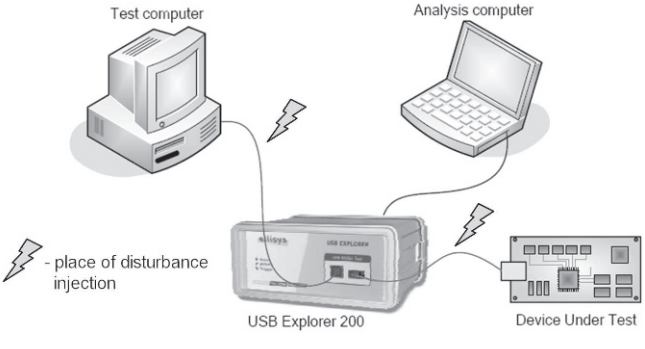

Fig. 3. Test position for analysing transmitted data using the USB protocol analyzer Explorer 200 by Ellisys

– Data write test (OUT operation). Direction of the transmission from the computer to the USB device. Clamp was placed between computer and USB analyzer.
– Data read test (IN operation). Direction of the transmission from the USB device to the computer. Clamp was placed between USB analyzer and the device.

3.2 The Research Procedure

One of the targets of this research was to test the data transmission immunity in USB Full Speed standard for the electrical fast transient bursts. The test was performed in accordance with standard PN-EN 61000-4-4 that is harmonized with EMC directive 2004/108/WE. Series of electrical fast transient disturbances are designed to simulate a relay contact bounce in the electric network.

Series of disturbing impulses are induced in transmission lines through a clamp. The research parameters being compatible with the standard are as follows:

– repetition frequency 5 kHz,
– burst duration 15 ms,
– burst period 300 ms,
– output voltage range change from 250 to 1000 V – according to level 1 to 3 in PN-EN 61000-4-4 standard.

Level one refers to requirements for devices working in residential, commercial and lightly industrialized environment, whereas levels two, three and four refer to requirements for devices working in the industrial environment. Table 1 presents levels of the sharpness test according to the standard.

Table 1. Test levels for the Electrical Fast Transient test, according to PN-EN 61000-4-4

Level	**Power ports**		**I/O ports**	
	Voltage peak [kV]	Repetition rate [kHz]	Voltage peak [kV]	Repetition rate [kHz]
1	0.5	5	0.25	5
2	1	5	0.5	5
3	2	5	1	5
4	4	2.5	2	5
x	Special	Special	Special	Special

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The research was initiated for disturbing signals whose peak value equals 250 V, which is compatible with level one according to PN-EN 61000-4-4 standard. For

such test parameters USB standard is characterized by almost complete immunity for fast electrical transients. The only thing that was noticed during the research was some destroyed transactions, being the part of frames. Retransmission of those tractions had low influence on data transmission speed. The USB standard was equipped with a range of mechanisms which are designed to protect it from incorrect work of the system. The main tasks of elements that protect USB are controlling the data correctness, limiting the time for response and the mechanism of data toggling (USB uses this mechanism as a part of its error correction).

The main way to ensure the correct work of the system is to detect the errors in received packet and not to answer (ACK) in case of their presence. When the sender does not receive a confirmation, then the damaged frame is retransmitted. This mechanism is very effective, especially in the case of distortion in data transaction area. However, if a mistake appears in the response sent off to a receiver, then a problem arises and the best solution is to use data toggles. It is the mechanism of alternating numeration of packets, which protects USB standard from losing the synchronization.

The next step of the research was to test immunity of USB standard for levels 2 and 3, which correlates with successive amplitudes of disturbing signal on level 0.5 kV and 1 kV. Figure 4 shows the fragment of a frame where transmission error appeared during writing operation into the device. The figure presents also the content of data packet field (Data 1), where next 57 bytes of data were corrupted.

The majority of corrupted transactions were the effect of distortion of content of data packet. Each transaction in USB system consists of token packets, which determine direction of data transmission (writing/reading), data and acknowledge packets. During the test the maximum acceptable packet size was used, which equals for Full Speed 64 bytes. A full-size of data packet is related to fewer amounts of tokens and acknowledges packets appearing in USB.

Nevertheless, the distortion of single bit in data area requires the retransmission of all 64 bytes data block. It was observed that in all available devices the maximum size data packet is used in order to get the maximum speed of transmission. Thus, during the test such type of data packet was used.

Figure 5 presents the content of frame in USB standard for reading operation (direction of transmission is from the device to the computer). It can be seen that USB standard is no longer immune when the amplitude of disturbances is 500 V or higher. There are no charts presenting decreases of transmission speed during writing and reading operation. It is due to the shortage of immunity of standard for the value of disturbing signal voltage 500 V or higher.

It was also observed that the device is completely disconnected from a system when the amplitude of disturbances is 0.5 kV or higher, and the previously presented mechanisms became useless. The explanation why this situation occurs may be traced to overlapping of the frequency of appearing consecutive initial parts of frames SOF (Start Of Frame) in USB standard with the frequency of disturbing signal determined by standard PN-EN 61000-4-4. The frequency of

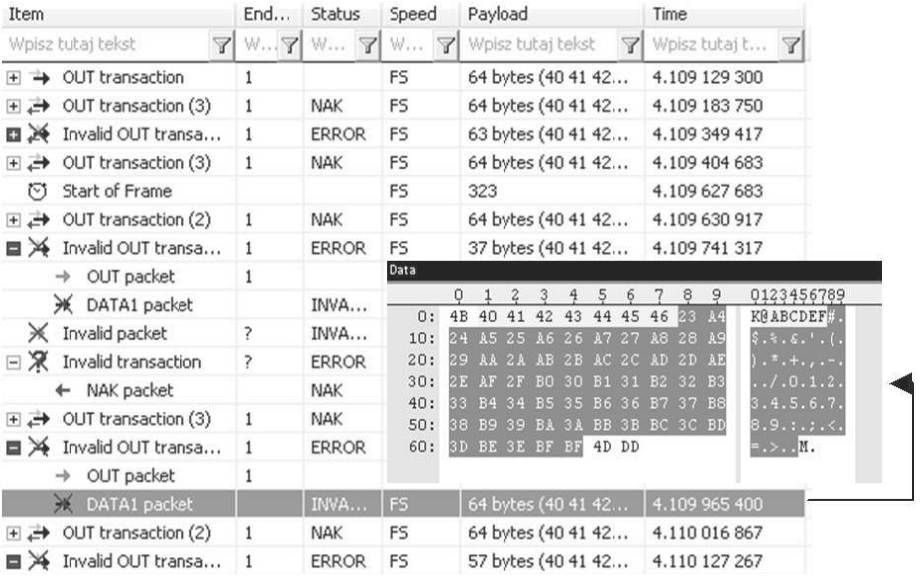

Fig. 4. The results of frame analysis during the writing operation. Test conducted for level 1 – peak voltage 500 V.

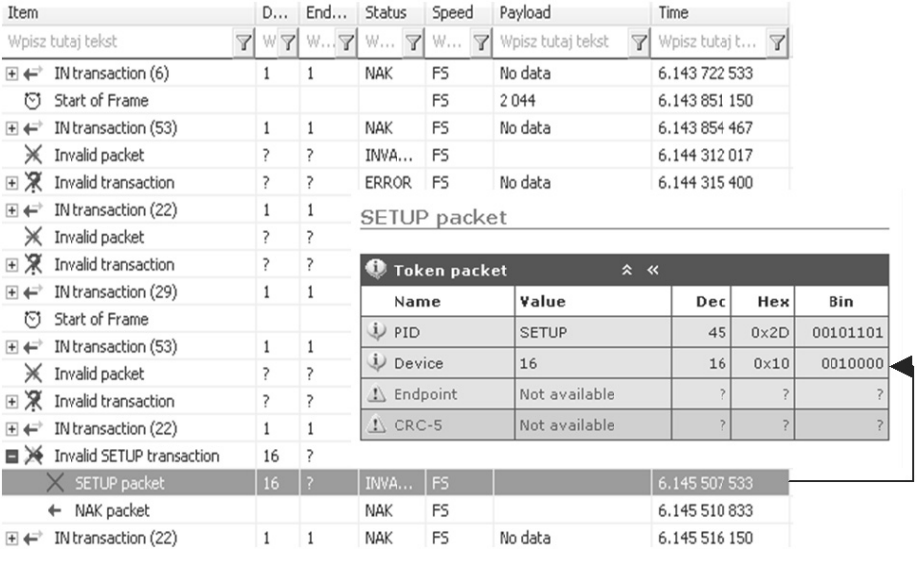

Fig. 5. The results of frame analysis during the reading operation. Test conducted for level 1 – peak voltage 500 V.

appearing disturbing impulses in each 15 ms interval equals to 5 kHz, which in practice causes the loss of following 15 frames in USB protocol, and finally the loss of the connection with the computer.

5 Conclusions

The study focuses mainly on interference of data transmission in USB standard caused by electrical fast transient disturbances according to PN-EN 61000-4-4 standard. The main purpose of the study was to test the immunity of USB standard and its mechanisms for electromagnetic disturbances.

Despite using screening wires for data transmission and symmetric transmission while designing the device with USB interface, there is a problem with connection of the screen on the device side. Most vendors connect screen directly to circuit ground on printed board. Thus, the disturbances inducted on a screen interfere with electronic circuits which deteriorate the work of devices. Additionally, USB not only transmits data but also provides power supply. Thus, the disturbances can propagate simultaneously to electronic devices through data and power lines and cause interferences in transmission channel.

The conducted research revealed the high susceptibility of USB standard for electromagnetic disturbances, especially when the amplitude of disturbances impulses is higher than 500 V. The result of such disturbances is that devices are no longer visible in a system and the complex procedure of attaching the device to a computer makes it impossible to recognize the device again in the system without human interaction.

As the test results show, the high susceptibility of USB standard to electromagnetic disturbances can cause additional interferences of data transmission. In publication [4] and [6] the issues referring to the immunity of other communication standards such as: RS-232 and Fast Ethernet were presented.

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