USB Isolation

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The isolation of the Universal Serial Bus (USB) is necessary only in a few applications like medical equipment or sensitive industrial devices. The PC or hub on the primary side has to be electrically isolated from the attached USB device on the secondary side. This is done in an easy way using complete off-the-shelf isolators.
Nevertheless it needs some information and knowledge to figure out which isolator is appropriate for the given task. In the following we will look detailed at this topic from various angles. Conclusions are written in italic letters to extract the most important information.

General USB remarks

The Universal Serial Bus (USB) is the most used network for PC to device communication. The bus was many times revised and adapted to new speed requirements due to the improving technological level. While the first design had a leisurely speed of 1.5 Mbit per second (Mbps) the latest revisions transfer data in the range of tens of Gbps. While the slow rate is sufficient to connect to a mouse, keyboard or any other human input device the high rate is used to connect memory or video to the PC.
After the first design came soon the USB Revision 1.1 which additionally offered the speed of 12Mbps. This was standard for many years and was and is still perfect for controlling devices and get data from them. As the data transfer rate was not sufficient for some tasks a new standard was created, Revision 2.0 which increased the throughput to 480Mbps. This Revision 2.0 includes all transfer speeds from 1.5Mbps (called low Speed) over 12Mbps (called full speed), to 480Mbps (called high speed).
It is important to know that a 2.0 compatible device does not have to accept all three speeds. It can work with low, full or high speed, but can be connected to a 2.0 USB port without causing faults.

It is a common mistake to automatically equate USB 2.0 to USB high speed. You have to take a look into the data sheet to clarify at which speed the device really works.

These three speeds are still the recommended and preferred speeds for safe and undisturbed data transfer and device controlling because of their easy and uncomplicated connection. The lower the speed the higher the reliability. Especially when the cable length shall be in the meters range the high Gpbs rates have no chance without additional repeaters and extensive interference suppression.
That means that for speeds, already beginning with high speed, the radiation is above the allowed limits for medical and sensitive industrial devices, up to now no medical certified isolator with high speed or even higher is on the market.
If you need high speed medical isolation this can currently be only achieved if you integrate the isolation into your device or into the controlling PC. Both must have metal housing and very good shielding.
On the other hand a low speed transmission is no issue since it is used only for input devices at the primary PC side, no isolation of a mouse or keyboard is necessary.

For safe and secure data transmission and controlling for medical and sensitive industrial devices the USB full speed connection is the most established and reliable way of connection.

Why USB isolation?

There are two main reasons for isolating the USB line, stop ground loops and hinder overvoltages to come from one side to the other.

The first case is used if equalizing currents flow through different system lines which lead to humming in audio or sensitive measuring systems.
The second case is essential for safe industrial or medical systems to avoid damages to the devices and of course injuries to humans in case of system faults, discharges or other dangerous disturbing effects. So the PC has to be decoupled from the target device. This isolation is mandatory for medical equipment and has to be certified by an accredited test lab.
The two reasons for isolation have different requirements. Ground loop breaking does not need a high isolation voltage and a special proved safety design, a low cost isolator does the job.
In contrary the safety reason isolation needs a preferably high isolation voltage and a proved, reliable, safe and tested design. A low cost standard isolator is not reliable and does not have the necessary isolating structure.

Ground loop breaking and safety isolation do have different requirements. Of course you can use a safety isolator for ground loop breaking applications but a cheap isolator for ground loop breaking purposes can not be used in medical or industrial environments.

In the following document we refer to full speed isolators for safety applications.

How does the isolating work?

USB 1.1/2.0 has 4 wires. Two data lines, one ground line and one 5V supply line. All 4 have to be correctly broken and isolated between both sides. For the data lines including ground isolating integrated circuits (ICs) are available with various isolating voltage levels. For the 5V line plus ground DCDC converters are used.
There are some isolators on the market which do not have integrated DCDC converters. The power for the secondary side is delivered from an external power supply through an auxiliary socket at the secondary side.
This only works if the external power supply has the same isolation voltage and security level and certification as the data isolator. In case of a medical isolator the power supply also has to be a medical one.
But who can guarantee that always the correct power supply is plugged and used. In case of a medical or sensitive industrial application where high isolating voltages are required this means an enormous risk for humans and devices.

Be aware that by isolating the secondary side is floating, there is no connection to earth.
Take care that the data isolator and power transformer are one indivisible unit.

The USB isolators work completely transparent for the data stream. That means that it is the same if the signal is isolated or not. No additional software is needed and no special hardware requirements for the PC or USB device. That also means that no manual operation is necessary, the isolators do not have any operating elements like buttons or switches.

If you are offered isolators which need special treatment like software, drivers or hubs you are looking at the wrong isolator.

Why external USB isolation?

Of course it is the easiest way to directly integrate the USB isolation into the target device. In this case a simple USB cable can be used to connect the PC to the device. But there are some reasons why this is not always done.
Either the USB device is not generally intended and designed for isolated connection. Or the device is a small mobile medical equipment where the comparatively heavy and voluminous DCDC converter does not fit. Or the necessary safety distances for air and creeping can not be kept, especially for a metal housing.
When internally isolated the connected USB cable is on the same electrical potential as the controlling PC. The metal connector at the device side must always have the required safety distance to the potential of the device. That is hard to guarantee while plugging, unplugging or under all working conditions.
Medical certifications are really rigorous when examining and testing the overall safety. In this case an external isolator is the reliable way to keep the safety because the USB cable coming from the isolator just has the same potential of the USB device and therefor no connecting problem arises.

External USB isolation can have many application depending advantages and sometimes is the only way to maintain the required safety rules.

Isolator exterior design

The isolator can have two appearances, a box or a cable design. The box offers two sockets to connect to the primary and secondary side through standard USB cables. The cable type already has integrated USB cables which fit to the secondary and primary side.
While this cable is easy to use as a direct replacement for a standard cable, the box type is more universal and cables of different lengths and connector types can be used.
The maximum length is limited according to the EMC (electromagnetic compatibility) and is specified in the test reports. A standard length is 2m cable at each side, better isolators offer 5m at both ends.
To avoid an unintended unplugging good isolators have sockets with high retention force to keep the cables fixed. These sockets are recognizable by the orange or red socket color.
An option for the box type is an auxiliary power supply. This is an extra power input to the primary side sourced from a wall power adapter. This auxiliary supply can help to reduce the necessary current from the PC to the isolator. This can be necessary for battery supplied laptops. But take care that the auxiliary input really sources the primary side, and not the secondary one as mentioned in the former chapter.

The cable type is easy to use, simply as an exchange for a standard USB cable. In contrary the box type needs two standard connection cables, but this makes it more universal. USB sockets with high retention force should be preferred.
Make sure that the lengths of your applied cables are covered by the specifications of the isolator.

Status display

The exterior design is complemented with LED displays to see the current status of the isolator and device. Depending on the type and design of the isolator more or less of these working modes can be indicated:

- Off: The isolator and therewith the device is not sourced, the PC is off
- Idle: The isolator is attached to the PC and waits for the plugging or powering of the device
- Wait: The device is attached and powered, but not yet recognized by the PC. If this condition continues the correct software or driver is missing on the PC. This is an alarm condition.
- Active: The transmission is working
- Standby: The PC or the device is in power down mode, the USB connection is established but paused. The device is still supplied with energy.
- Error: An overcurrent exception has occurred, the output is powered off for security reasons.

In general an isolator should work without fault, manual operating and response. But if the USB connection fails it is good to get more information about the current status. So the isolator can help to identify exceptional operating conditions of the complete system.

Interior design

The inner workings of the isolator is the real important and tricky part.
Electrical design:
The isolation is done through two components, the data isolator and the DCDC converter. Both must have the necessary quality and strength and must have the appropriate certifications. These two parts are the minimum electronic components.
Additional components are installed to fulfill the medical and other requirements and to increase the connection convenience:

- Sophisticated filters are needed to push the radiation below the required limits and to cut interference voltages from external sources.
- Overcurrent control and switching components to avoid damages to all system parts.
- Safety components against ESD (Electrostatic discharges) to avoid isolator damages.
- Decoding components to get information about the USB status, displayed by LEDs.
- Special board design to guarantee the necessary isolation distances.
- A metal or metallized shielded housing improves the EMC behavior to minimize the radiation from the isolator to the surrounding system in one direction and the sensitivity to irradiation from the environment in the other direction.

Isolation:
The required isolation distances must be kept everywhere in the isolator design. Especially when a metal housing is used to improve the EMC behavior.
All input and output sockets or cables must be thoroughly checked so that under no circumstances and working modes the distances fall below the guaranteed distances, even if the isolator becomes faulty because of e.g. loosened cables inside.
All fault possibilities and their effects have to be foreseen. This is part of the extensive certification process.

Only a good and sophisticated interior design will lead to a certified approval for medical and sensitive industrial applications. Electrical, mechanical and functional requirements have to be regarded and have to fit to each other.

Certification

If an isolator shall be used in a medical system it has to be checked and certified by an accredited testlab (notified body).
That means that the isolator has to fulfill the requirements of the medical certification standard. In general the complete design process, the electrical and mechanical design, electromagnetic behavior, the handling, marking and life cycle is tested and validated.
The basic standard is IEC60601-1, the safety for medical devices. In addition the isolator has to fulfill the IEC60601-1-2 standard, which is the standard for the Electromagnetic Compatibility EMC.

Safety examination:
The whole design is tested for the following requirements:

- Documentation of the complete design process based on a risk management process.
- Consideration of all theoretical error sources and their probability and risks.
- Activities to avoid these error sources and to minimize the risks.
- Regarding all possible operation modes, environments and accidental misuse.
- Documentation about the consideration and examination process of possible malfunctions and their effects on the overall safety and reliability.
- Clear and intuitive operating, handling and display.
- Safe and injury-free exterior housing design, e.g. no sharp edges.
- The internal electrical and mechanical design has to fulfill the necessary requirements for isolation, overload protection, robust design, long term operating safety, thermal protection, reliability and general failure safety.
- Reinforced design for medical devices, double isolation strength, appropriate isolation distances for the given isolation voltage, e.g. above 8mm for 4000Vrms.
- The operation manual, markings and serial numbers have to be clear and complete.
- Production in certified companies to keep the quality level high.

The latest standard is IEC60601-1:2005/ AMD1:2012 (EN 60601-1:2006 + A1:2013) (Rev. 3.1).
This Revision contains some clarifications and changes in the examination process, the design process has to be more restrictive in comparison with Revision 3.0.
Devices with 3.0 certification are still safe, but can no longer (since. 1.1.2016) be used as a reference for the medical directive 93/42/EWG. That means that new medical systems must use sub-devices like an isolator, which are certified according to rev. 3.1

Disturbance examination:
This is necessary to avoid too much radiation from the isolator and to minimize the influence of radiation into the isolator from the environment which could lead to malfunction(immunity). The reference standard is EN60601-1-2 and includes a lot of other basic standards and tests.
The first one checks the emission, the following tests check the immunity:

- EN55011: Mains terminal disturbance voltage and electromagnetic radiation disturbance 150khz to 1GHz. The test object must fulfill the requirements for the stronger limits (class B device).
- EN 61000-4-2: Electrostatic discharge.
- EN 61000-4-3: Radiated RF electromagnetic field and proximity fields from RF wireless communications equipment
- EN 61000-4-4: Electrical fast transient/ burst.
- EN 61000-4-6: Conducted disturbances induced by RF fields.
- EN 61000-4-8: Power frequency magnetic field.

The latest standard is IEC60601-1-2:2014/ EN60601-1-2:2015 (Rev. 4).

If you want to be as sure as possible that an isolator works safe, undisturbing and reliable, even at an adverse environment, you should consider to use a certified isolator. For medical devices this is mandatory with certification according to the latest standard revision 3.1.

Isolation voltage

The isolation voltage is surely the most important parameter of an isolator, so it deserves an own chapter.
The reference is the safety standard 60601-1. There are two definitions which are valid for medical equipments and also for industrial applications, MOOP (Means of Operator Protection) and MOPP (Means of Patient Protection).
MOOP: This one is valid if the human operator on the primary side at the PC has to be protected. This is the case in an industrial environment when disturbances can come from an industrial device back to the PC. An example is a welding robot which produces a lot of voltage bursts.
MOPP: This one has to be regarded if the human on the secondary side has to be protected from disturbances on the primary side. Examples are faults in the PC power supply or electrostatic discharges coming from bottom or cloth friction charge.
This protection is the more complicated one and needs higher isolation voltages since the secondary side is floating without connection to earth. Dangerous energies can not flow off immediately.
In addition you can have a basic safety or a reinforced safety. This is marked as 1* or 2*. So the classes are 1*MOOP, 2*MOOP, 1*MOPP, 2*MOPP.
Basic safety can be used if additional cascaded protective measures are taken. Reinforced safety if there are no additional isolating parts or additional protective measures can not be guaranteed.
For these cases and based on 230V mains we have the following voltage table, based on the standard definition (entry 1-4):

Protection	Voltage rms	Voltage dc pk
1* MOOP	1500V	2250V
2* MOOP	3000V	4500V
1* MOPP	1500V	2250V
2* MOPP	4000V	6000V
Extra strong	5000V	7500V

The isolation voltage is tested with the given ac voltage from the table for 1 minute and the 1.5-fold dc voltage for 1 second. The 1.5fold is the about peak value of the ac voltage.
As an isolator is only a part of a system with mostly unknown protection capability you should always take the reinforced variant. In case of a medical equipment 4000V are mandatory.

For medical designs a 4000V EN/IEC 60601-1 certification is mandatory, for industrial applications in rough environment 3000V to 5000V isolation should be preferred.

Selection criteria

Based on the above chapters the following criteria should be considered:

- Necessary isolation voltage. Medical: 4000V or 5000V. Industrial: 3000V to 5000V.
- Output current 500mA must fit to the maximum current consumption of the attached device.
- Behavior at overload. The output should be automatically powered down to avoid damages.
- Additional protection components like ESD diodes, reinforced housing and high retention-force sockets.
- Status display and indicated working modes.
- Design as box or cable. The box must be approved for the needed cable length.
- Approved to the latest certification standard when intended for new medical device designs.

Safe application

For the application of the isolator in medical and industrial environments some placing rules should be regarded to keep the high safety level and to minimize the risk of injuries and damages:

- Be careful to operate the device in a clean and dry environment.
- Take care for sufficient air-flow and heat removal. Devices must not be stacked, the isolator has to be placed exposed.
- Do not use unnecessary long connecting cables to minimize radiation.
- Place the isolator away from other devices to avoid unwanted mutual electromagnetic interference.
- Place the isolator and the cables into a location which is secure against unauthorized and unwanted access. Danger can arise from unintended pulled cables (disrupt of the communication).
- The isolator must not be touched in the operation mode as dangerous potential differences can arise between primary and secondary side. Handling of these differences is the task of the isolator.
- Nevertheless the isolator shall be placed accessible so that the display can be seen and the cables can be pulled out to break the USB connection in case of error.

An isolator is easy to handle but some care should be taken for the correct placement to keep the safety level high.

Traps

When planing to integrate an USB isolator in own systems and applications some hints should be regarded:

- Make sure that your intended secondary USB device really works with full speed USB. For instance if you want to add a scanner, camera or other device with a high data volume it would not work since in this case USB high speed transmission is required.
- An isolator can not prevent the transmission from being shortly interrupted when strong and sudden radiations from the surrounding lead to interspersed voltages.
  The reason is that these voltages and therewith energies spread in the complete electronic. No escape for the energy at the secondary side to earth is possible, due to the intended isolation and therewith floating Electronic.
  This will lead to a short undefined potential shift, which will change the just transferred bits. The transmission has to be re-established by the application software. This software must be failproof.
- The output current at the secondary USB connector is lower than the input current from the PC. The efficiency of the internal DCDC converter is around 80% and the isolator itself consumes about 50mA. That means that for 500mA output you have to source 675mA. Modern PCs do have this USB capability at their ports, older ones are restricted to 500mA.

The PC, the isolator, the USB device and the application software has to fit to each other. Check all parameters before deciding for a special system design.