UPAMD Low Energy Connect and Disconnect

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One of the goals of UPAMD as balloted by the Working Group is to have a spark-free connection. The working group recognizes that truly spark-free connections are not physically possible. All materials coming together will, at some level, be of a different potential and will come to a common potential through a conducting arc at a very small to very large energy exchange. For UPAMD the real goal is to keep the energy associated with connect/ disconnect events to be below the energy required to ignite most flammable liquids, gasses or dust that might be unintentionally present in normal operating environments.

This is a forward looking goal for a new standard that will be implemented in the 2011-2020 timeframe. There should be no attempt to judge existing designs by this goal as it was not a factor considered in their design. This is strictly forward looking.

ESD

We are not addressing ESD with this discussion. Clearly ESD needs to be discussed and specified protection will be needed to protect the source and the load. ESD is treated through IEC 61000-4-2 basic standard and through:

IEC 61204-3 Low Voltage Power Supplies, DC output part 3
CISPR 14-1 for Household products (EN 55014 – 1 for EU)
CISPR 24 for ITE (EN 55024 for EU)
CISPR 20 (EN 55020 for EU) and EN 55103-2 for Professional AV
The Human Body Model (HBM) and the machine model (MM) should be considered.

Thanks to Stephen Colclough for the corrections.

Non-Goal of low energy connection

A ***NON-GOAL*** of this effort is to be able to work in known hazardous environment or known environments where it could become hazardous. This is the province of UL60601-1, UL913 and UL60079-11. No compliance will be claimed against these standards, they are only used for the reference information they contain.

Goal of low energy connection

The GOAL is to not be the source of a larger problem, while connecting or disconnecting a cable and target, if a hazardous situation were to present itself wherever we happened to be, such as a flammable liquid spill, flammable gas leak, or combustible dust. The secondary GOAL is to facilitate users who would like to supply the higher level of qualification for the hazardous environment, such as medical use in hospitals, to be able to use the UPAMD standard and do whatever they need to do, additionally, to become compliant with the much more restrictive specifications.

As a spark-free connection is not possible, what level of spark would need to be avoided to reduce the potential for igniting a flammable liquid, gas, or dust, if it became present? This level of energy is called the ignition energy for the flammable material being considered. The research results determining this ignition energy have been around for 30+ years. The result of this work is reported and specified in charts published in the UL60601-1, UL913 and UL60079-11 and the ISO/IEC equivalents and elsewhere.

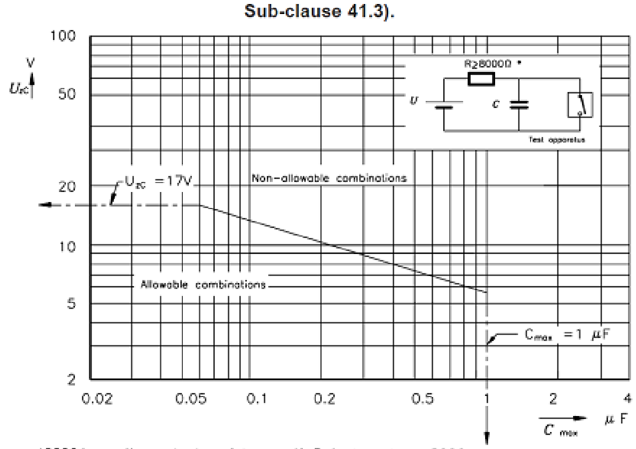
To be able to establish communications from the power source (adapter) and the power sink (device) with devices that may, or may not, have batteries, we need a low power level to power up the logic, microcontroller assumed, to the point of being able to communicate. As of this time that power is assumed to be less than or equal to 300mW. This is assumed to include the microcontroller power ~ 30-75mw, CAN bus power ~50mw and DC/DC inefficiencies and possibly LED indicators using 25-50mw. A NXP M0 core processor uses 9ma @3.3V = 29mw, for 50MHz clock operation. A 12V source at 25ma is sufficient for this operation.

Sparks will occur on both the connection and the disconnection of the cable to the device, assuming that cable is already connected to the source. The stored energy that is discharged on connection is the energy stored in the capacitance of the source output and the cable. The stored energy that is discharged on disconnection is the energy stored in the inductance of the cable, adapter output and device input stages.

Connection Energy

The most restrictive of the charts on the energy, that I found, were the charts in 60601-1 for working in ether with oxygen or nitrous oxide (laughing gas) environment. Energy stored in a capacitor is ½ CV^2 in Joules. This chart is based on the probability of ignition at 10^{-3} at this level of energy with a safety factor of 1.5.

Figure 33 – Maximum allowable voltage U_{ZC} as a function of the capacity C_{max}, measured in a capacitive circuit with the most readily flammable mixture of ether vapour with oxygen (see Sub-clause 41.3).



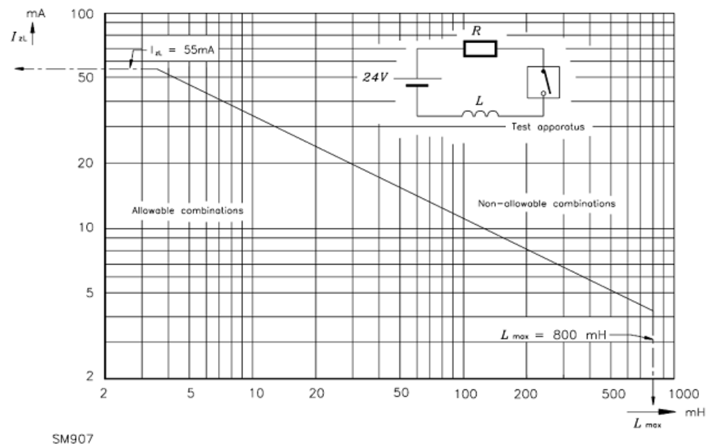
*8000Ω, or the actual resistance, if R is less than 8000Ω

In this test circuit, the current that will flow at the closure of the connection will mostly come from the capacitor. The current through the resistor is ~2.1ma but the current from the capacitor is limited only by the internal resistance of the capacitor. The energy in the arc is what is being controlled. The energy at 0.06uf and 17V = 8.8 uJ and the other end of the capacitance of 1uf is 15.1 uJ. This assumes that the switch is being closed to a discharged system.

Disconnect energy

Once current is flowing, the energy is stored in the inductance of the system, including the output inductors and the input inductors, and the wire inductance, including the cable inductance. A maximum inductance is specified to reduce the inductively stored energy capable of creating a spark when the connection is opened. Inductive energy is stored in the magnetic field caused by the current is also in joules and is ½ LI^2 .

Figure 34 – Maximum allowable current I_{zL} as a function of the inductance L_{max}, measured in an inductive circuit with the most readily flammable mixture of ether vapour with oxygen (see Sub-clause 41.3).



Stored energy in the inductance is in the 5.3uJ to 6.4uJ range. This chart is based on the probability of ignition at 10^{-3} at this level of energy with a safety factor of 1.5.

The UPAMD power source, and cable, plus 2 connectors, must have a stored capacitive energy of less than 15.1uJ and a voltage of less than 17V. The stored inductive energy at the time of disconnect should be less than 5.3uJ.

Energy considerations

This stored energy is consistent with the lowest ignition energy, I could find, of 17uJ in air, at 25C and 101.3kPa, for hydrogen gas http://www.schatzlab.org/education/h2safety.html and http://www.hysafe.org/download/1042/BRHS_Chap3_hydrogen%20ignition%20version_0_9_0.pdf . Other sources seem to claim any energy levels under 20uJ are unlikely to cause ignition. All of these are statistically based as probabilities. There is probably a lot more likelihood of having colorless, odorless, and tasteless hydrogen encounter than ether. While we may, or may not, be moving toward a more hydrogen-based energy distribution, and hydrogen storage systems, it is clear that hydrogen will play a significant part in the current and future energy systems. The lowest common denominator for all ignition hazards appears to be 17uJ for hydrogen in air. This proposal meets that constraint.

The proposed startup power of 12V with about 25ma should still provide the 300mw of power with low stored energy.

Stored Energy

The capacitance of the source and cable would be limited to 0.1uF at 12V = 7.2uJ. The inductance of the source output, cable and device input with a current of 25ma would be about 15mH with a stored energy of 4.7uJ.

There are ignition energy charts with less restrictive values for ether in air. It is highly unlikely that we will accidently run into an ether/Oxygen or Nitrous Oxide environment. If the environment is just an STP air environment, with normal oxygen levels, the allowed energy levels are increased except for hydrogen.

Capacitive energy storage is raised to 1200uJ which would allow 20V to be used with up to 5uf of capacitance. Likewise the inductive energy storage is raised to 300uJ. These charts are available in the 60601-1 document but the safety factor is removed. Hydrogen ignition energy does not change and remains at 17uJ.

Cable contribution to the stored energy is based on the assumption that the separate cable, with a connector on each end, will be between 0.5 and 10 meters long. The cable inductance based on 16 AWG wire will be 0.66 to <20uh for each wire for a total of up to <=40uh inductance. The chart allows for up to 20mH, leaving 19.96mH for input inductance of the device and output inductance of the adapter. Capacitance for 10 meters of wires is about 1200pf depending on the wire size calculations leaving about 100nf – 1.2nf or 98.8 nF for other capacitance. An assumption here is that the connectors contributes a negligible amount to the inductance and capacitance of the cable.

With the current connecting schema (see flow chart), the energy in the power lines would be ramped up to the low energy safety voltage following detection of the device being attached. As this can also be defeated by a short between the communications lines and ground, by a piece of metal being inserted into a connector, an intentional fault, this could lead to the 20W power state being initiated without a device on the end. An intentional fault is extremely difficult to design around and would not be a normal operating condition. This could only be prevented with the communication being required to be active. Otherwise we have a fairly well controlled turn on design with the best safety margins.

Normal end of usage would have the source reduce power from the output and the cable down to either the sleep/low-energy mode, 10-14V @25ma, or remove all power back to initialization state with only probe power on the communications lines.

Disconnect is where there is the need to clearly see the separation of the communications pins in time to ramp down the delivered power to below the ignition energy limit prior to the separation of the main power pins.

Rapid disconnect normal to connection surface

Uncontrolled disconnect, without software shutdown, or with non-communicating devices, needs to be considered. Disconnection with the fingers grabbing the connector and removing it normal to the mating surface would probably be done with an acceleration of up to 10m/s^2. Starting to remove the connector by grabbing the locking ring and pulling up with this acceleration, the separation of the fully compressed communications pins would take place at about 15ms and the fully compressed power pins would separate at 18ms. This will allow ~3ms for the detection of the communications pin separation and the reducing power to the low energy limit of about 25ma. If the mid stroke length of the pins are used, the communications pins separate at 11.8ms and the main power pins separate at 15ms with just over 3ms for detection and power reduction. Raising the acceleration to 30m/s^2 changes the mid stroke separation time difference to 1.87ms. Simulations show the response time can be <350us. This data was using the pins that are in the drawing with a mid-stroke length for the communications pins of 0.7mm and 1.14mm for the power pins.

Disconnections non-normal to connector surface

Disconnection by pulling the cable in the major axis at high angles from normal of the connector should yield a longer interval between communications pin separation and remaining power pin separation. The pivot point for this disconnect would be at the mating surface at the end of the depressed area or on the latching clamp pivoting on the bottom of the latching depression in the target.

Minor axis, high angle from normal, separation have not been simulated but could be shorter. The pivoting point for this minor axis twist-off is most likely the area of the seal meeting the top surface of the target or the corner of the latching clamp pivoting on the bottom of the latching depression in the target.

Communication pin disconnection

The communications pins need to obey the same discipline as the main power pins with respect to low energy connect and disconnect. If CAN or similar protocol is used with signal swings in the 0-3V range, the current through the connector to the 120 ohm load at the far end will be a maximum of about 25ma at a voltage of 3V. Twisted pair wires in the 28AWG range will most likely to be less than 5uH for 10meters. Stored energy at 25ma is ~ 1.6nJ and should not be a problem. Line capacitance for the twisted pair should be less than 500pf for 10 meters. Stored capacitive energy of the communications lines is about 2.25nJ and not a problem.