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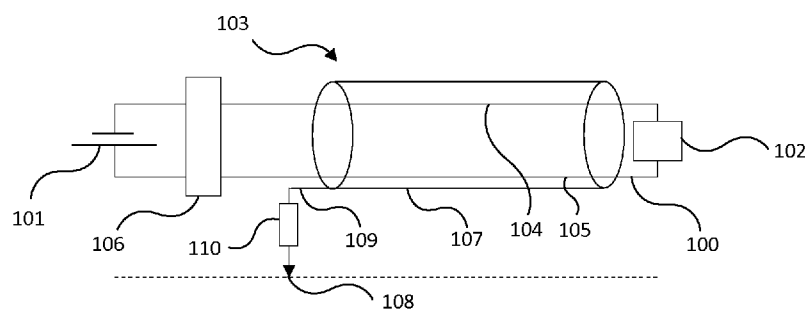


Fig. 1

(57) **Abstract:** An intrinsically safe electrical circuit comprising a power supply, a load and a cable connecting said power supply and said load and comprising positive and negative cores, in which said circuit comprises an incendive arc prevention mechanism which passively and/or actively limits the power in said positive and negative cores to render them intrinsically safe, in which said cable comprises an electrically conductive interference shield surrounding said positive and negative cores along the length of the cable, and in which said shield is rendered intrinsically safe by being connected to ground at at least a first end thereof via a power limiting resistor.



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Intrinsically Safe Electrical Circuit with Intrinsically Safe Interference Shield

The present invention relates to an intrinsically safe electrical circuit with an intrinsically safe interference shield, for use particularly, but not exclusively, as a digital data communications and control circuit for use in an intrinsically safe environment.

There are a number of industrial computer network protocols used for real-time distributed control, which fall within the IEC60079 standard. A complex automated industrial system, for example a fuel refinery, usually needs an organized hierarchy of controller systems to function. In this hierarchy there is a Human Machine Interface (HMI) at the top, where an operator can monitor or operate the system. This is typically linked to a middle layer of programmable logic controllers (PLC) via a non-time critical communications system (e.g. Ethernet). At the bottom of the control chain are the cables (in the form of trunks and spurs) which link the PLCs to the components which actually do the work such as sensors, actuators, electric motors, console lights, switches, valves and contactors. Fieldbus (RTM) is a system such as this, comprising a cabled two wire combined power and data network made up of one or more segments, each of which comprises a trunk with a number of spurs attached thereto. The network provides both power and communications to the field components on the spurs.

The various components of the system communicate with one another using a communications protocol, for example a Manchester encoding system. Data telegrams are transmitted either on dedicated communications circuits, or on the same electrical circuits as the power to drive the field instruments. The data telegrams serve to control and to monitor and diagnose the field instruments in use.

These kinds of electrical circuit are often used in intrinsically safe environments, for example combustible atmospheres, and in particular gas group

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classification IIC, hydrogen and acetylene, and below, for example gas group IIB and IIA, for gas and/or dust. In a typical combined two wire electrical power and communications circuit there is a power supply, an intrinsic safety barrier of some kind, a trunk section leading out into the field along a cable, and a number of device couplers with separate spurs connected thereto, on which the field instruments are mounted. The trunk and the spurs together form the segment. The intrinsic safety barrier divides the circuit into an intrinsically safe side and a non-intrinsically safe side. The power supply, the PLCs and other systems like physical layer diagnostic modules which measure physical layer attributes of the electrical circuit and the network hardware, and in part the physical software or protocol being used, are located in the non-intrinsically safe side of the circuit, usually in a control room. The trunk, the device couplers, the spurs and the field instruments are located in the intrinsically safe side, out in the field.

Intrinsic safety can be achieved in a number of known ways, from simply limiting the power so open or short circuits cannot form combustible arcs, to using active monitoring and isolating systems which allow higher power levels and act to isolate the power supply from open or short circuits to prevent combustible arcs.

For intrinsically safe circuits in accordance with the IEC60079 standard, any given circuit or combination of circuit faults must not feed a fault with more than 40uJ of energy in a gas group IIC environment. This can be less if a safety factor is applied. This limit equates to approximately 1.x watts unless it is time restricted.

Therefore, in classic intrinsic safety all power and power return cores inside a cable in the intrinsically safe side are energy or power restricted. For intrinsically safe circuits of this kind there is no requirement to mechanically protect these cores from damage, as they are rendered safe by being power limited. This is accepted as a principal, particularly where cables are run to instruments, because there is no danger of creating incendive arcs should a fault occur.

However, many of these intrinsically safe cables are supplied with an interference shield or screen (these terms refer to same component and may be interposed) which encloses the cores along the length of the cable. The purpose of the shield is to protect communications running on the cores from the effects of external interference such as RFI and EMC. In order to do this they are constructed from electrically conductive metals which are grounded at at least one end. As such the shield has parasitic inductance which absorbs any interference. The longer the shield, the greater the inductance. Therefore, it is preferable to ground the shield at both ends, and if possible, at multiple points along its length, and to provide an equipotential bonding (EB) system to equalize the potential between the groundings. The more grounding points used, the better the shield's ability to reject common mode noise or close coupled noise. The preferred way to ground each shield is to segregate it at each junction box in a segment, or at each interposing device, at say, every 100 metres, and then treat each section as an individual cable, with its own grounding at each end.

The shield is not powered because there is no power or energy source connected to it. Therefore in existing systems it is not energy restricted either, as there is no apparent need. This is despite the fact that the shield is like an outer core providing mechanical protection for the powered cores inside it, and is therefore actually more prone to suffering mechanical damage. This is not considered an issue though because any fault to ground or earth of the shield is thought of as non-incendive, because it is supposed to be at the same potential to ground or earth due to the EB system.

However, some EB systems are accepted to comprise groundings which are permanently or intermittently at an unequal potential. There are differing opinions as to how high this potential difference can be in any given set up. It would not be possible to exactly define what the values were in a complex intrinsically safe circuit, unless the EB system were exclusive to the shield and grounded at only one point. But even if the potential difference were known, one could not guarantee that

inductive coupling to the EB would not occur. It has been anticipated that the difference could be as high as 230 VAC. Certainly, if a grounded shield made contact with such a voltage then an incendive situation would occur. This puts doubt on the integrity and protection of the shield.

To address this issue the shield can be connected to ground at only one point, and be cut back and insulated at the ungrounded end, and/or the shield can be capacitively grounded with no more than 10nF. However, the integrity of the capacitor should meet the IEC60079 part 11 standard, and they generally don't. Also, this does not address the issue of an exposed shield touching any grounded metal structure and still creating an incendive situation. This is particularly so when the cable is considered to be intrinsically safe and no additional mechanical protection or armour is provided.

To date these issues have not been considered in any detail, and have remained a grey area for many decades, with no well-defined solution.

Another reason for this is that technically speaking the shield is a cable, and there is a cable specification for a current carrying wire, which is the permissible Lo/Ro calculation, in accordance with the IEC60079 part 11 standard. It is 'unofficially' known that for a non-reactive circuit, an incendive arc cannot occur below around 8V. For 12V, the resistance Ro is around 3.x Ohms for gas group IIC and a safety factor of 1.5, and the only incendive properties would be the spark/wire temperature.

However, in reality the inductance of the wire should be taken into account, and if so even at below 8V an arc can be incendive if there is sufficient energy stored in the inductance of the cable. A break will also unleash back EMF across a propagating arc, with significantly high voltages. For powered cores these kinds of issues are taken into account using the L/R ratio, where the resistance has a dampening effect on the inductance. There is also 'lumped inductance' data for

current versus inductance, and a further relevant protection method called DART, which reacts to quench a propagating incandive arc in less than 10us, during which time it is not yet incandive. However, the idea of applying such techniques to a shield has never been considered.

A separate issue to the above is that at present there is no in-line system available which can determine if an EB system has an unequal potential across it. For improved safety it would be beneficial if such a scenario could be detected, and responsive action taken.

The present invention is intended to address some of the above issues.

Therefore, according to the present invention an intrinsically safe electrical circuit comprises a power supply, a load and a cable connecting said power supply and said load and comprising positive and negative cores, in which said circuit comprises an incandive arc prevention mechanism which passively and/or actively limits the power in said positive and negative cores to render them intrinsically safe, in which said cable comprises an electrically conductive interference shield surrounding said positive and negative cores along the length of the cable, and in which said shield is rendered intrinsically safe by being connected to ground at at least a first end thereof via a power limiting resistor.

Thus, in its most basic form the invention involves power limiting the shield with a resistor to render it intrinsically safe. As discussed above this is not something which has ever been done before because intrinsic safety is not something which would be considered for an unpowered physical component.

This invention sets out to change the existing approach to the shield, and to now treat it as an intrinsically safe circuit as such, as opposed to a non-intrinsically safe 'wire' with no potential or energy source. In order to satisfy the existing intrinsic safety standards it is first necessary to understand and define the possible voltage

differentials which might arise. Clearly, as the shield is reliant on earth potentials it cannot be voltage limited by a Zener Diode (or an electronic equivalent), because the shunt to ground is at the same reference potential. As such, only the potential difference between the two reference potentials at each end of the shield can become a “source voltage” (U_o and U_i) for the purposes of making a calculation or assessment. These potentials could be positive or negative in relation to one another, and the circuit must also operate in a Bi-polar way, which adds further complication.

Furthermore, the shield must also still carry out its original function of protecting the powered communications cores from EMC and RFI interference. Therefore it must still perform the function of diverting AC signals to ground, which can be adequately accomplished using grounding capacitors.

Therefore, in one version of the invention the shield can be connected to ground at the first end via a capacitor mounted in parallel with the power limiting resistor. This allows the shield to maintain its original function.

In order to operate correctly the shield must also be free from ground loops, or loops that could damage the shield and/or the cable, or in the worst case set up enough stored energy in its natural inductance to cause ignition at a given voltage. At the same time it is preferable for the shield not to float to ‘any DC potential’, although this is the case for the intrinsically safe cores because they are galvanically isolated. All these requirements are addressed by connecting the shield to ground at at least its first end via a suitably sized power limiting resistor, as set out above. This provides an effective output/input resistance (R_o), which in turn is connected to ground.

One possible fault scenario is a connection of the shield to one of the intrinsically safe cores. However, this is generally at a voltage of less than 50V, so the requirements for the shield are less arduous. The L/R ratio must be taken into

account, as must the length of the shield, and this must be factored into the parameter specification for the resistor.

Theoretically the IEC60079 standard allows at part 14 for both ends of a shield to be grounded. However, this would only apply when the groundings are made to an EB that is controlled and maintained, so both ends of the shield are at zero volts. However, this is ambiguous because under fault conditions an EB has some potential across it because current is flowing. This potential is obviously unknown, but in practice it could be anything from a few millivolts up to a few volts. This would be incensive for a directly connected shield, in accordance with the standard's assessment in part 11.

Figure 4 illustrates the calculations and assessment for various lengths of cable, with various potential differences applied. In this case the cable is copper braided and has a resistance of 13.6 Ohms/km and an inductance of 1mH/km. Figure 3 is based on there being a source resistance of the EB of 0.1 Ohms (assuming negligible resistance). Graphs 1, 2, 3, 4 and 5 relate to EB potential differences of 4V, 2V, 1.5V, 1V and 0.5V respectively. As is shown in Figure 3 for anything over 1V the L_o/R_o ratio calculations as per the IEC60079 part 11 standard are above the required limit. Anything above the 40uJ limit has to be considered to have incensive potential, if a resulting arc is sustained for more than 10ms. The stored energy each time is above the incensive 40uJ limit for gas group classification IIC. As such, these examples would fail the assessment for distributed cable inductance and for lumped inductance.

Of course, not all shields will have an inductance of 1mH/km or a resistance of 13.5 Ohms/km, but they will be in that general parameter range. As such, for voltages above 4V, from one end of the screen to the other the cable is potentially incensive, at lengths of up to 1km.

Nevertheless, the skilled person will know how much voltage an EB system, in addition to the neutral wire, will have across it, or it is likely to have for the worst case fault conditions. Generally, this must be below ~70VDC so that it conforms to ELV levels (which an EB is required to meet by law, unless the EB itself is classified and treated as a low or high voltage conductor/structure). If not, then a shield would have to be considered to be a 230VAC cable, and be designed, protected, segregated/insulated and/or terminated accordingly. If this is known, then it will give a set of parameters to work from, and it will have a given safety factor. If is unknown (or is not controlled - for example if there are two separate EBs) then the voltage must be assumed to be 350 to 380 V peak at 50 or 60 Hz, and again measures must be taken to treat the cable accordingly.

The potential difference across an EB system may only be high under fault conditions which have a low probability of occurring, but this is still not satisfactory for Zone 0 installation. For example, it's not permitted to terminate a 230VAC cable with no energy limiting means in place in a Zone 0 environment. As such, if the shield is going to be intrinsically safe it cannot be treated differently to this.

Of course, the shield is normally grounded at the device, which may be in zone 0, and if the other end of the cable is floating, then connection and disconnection of that cable is non-incendive. However, in a two fault scenario it is possible for the floating end of the cable to become grounded due to a cut or damage to the shield, or due to the shield strands being disconnected from a termination, which results in contact with any grounded metalwork nearby. If this occurs then there will be no indication, so such a fault could remain dormant for a long period of time. It may not be discovered until scheduled checks are performed, which may be yearly. Taking the floating end to a terminal comprising a grounding capacitor should be designed in accordance with a 230/250 VAC line, should the PD be at that voltage.

Anyhow, in all cases it is possible to design a shield to be intrinsically safe in accordance with the IEC60079 part 11 standard, provided the parameters are known or are assumed for a worst case scenario.

For example, if the EB is designed to drop voltage X at the maximum design fault current Y , then $X/1.5$ will be the voltage used to size the safety components to include a safety factor. However, care must be taken because between buildings for example an EB may be sized to drop 5V under a 230V operating design, but because the EB has inductance, at the initial time the potential difference could be at 230V for several milliseconds. Therefore, for zone 0 use this would have to be sized for 230V or ~350V peak. However, it may be considered improbable that during this short time, an incendive arc would form at exactly the same time.

In one version of the invention an additional resistor can be mounted in series between the shield and the capacitor. This allows for the capacitance of the capacitor to be higher, which might be desired in certain instances.

As referred to above, the shield can be grounded at both ends. Therefore, preferably the shield can also be connected to ground at a second end thereof via a second power limiting resistor. This increases the ability of the shield to deal with two fault scenarios. For example, if the shield is cut in two, the two remaining parts will each be grounded via a resistor at one end. Therefore, if a further fault occurs on one or on both remaining parts it can be contained.

In addition, as explained above, grounding the shield at both ends improves its ability to perform its primary function of protecting communications cores inside it from the effects of external interference such as RFI and EMC. The shield has parasitic inductance which absorbs any interference. The longer the shield, the greater the inductance. Therefore, it is preferable to ground the shield at both ends, and if possible, at multiple points along its length, because the more grounding

points used the better the shield's ability to reject common mode noise or close coupled noise.

The second end of the shield can have the same components as the first end. Therefore, the shield can be connected to ground at the second end via a second capacitor mounted in parallel with the second power limiting resistor. Further, a second additional resistor can be mounted in series between the shield and the second capacitor.

As referred to above, the potential for the shield to be incendive depends on the potential difference between the first and second ends, and on the energy stored therein. Therefore, while it is possible to ground both ends of the shield without an EB between the groundings, it is far better to provide one in order to reduce the likelihood of an incendive potential difference arising. This is despite the fact that such a potential difference can arise with an EB anyway, as described above. Therefore, preferably both the first end of the shield and a second end thereof can be connected to ground and an equipotential bond can be provided between the groundings.

When a potential difference across the EB system does exist (or a ground fault occurs), then knowledge of this would be valuable, should there be no other means to detect the underlying fault or cause thereof. Currently, there is no in-line monitoring equipment that can measure the potential differences between EB points. An ex approved multi-meter can be used, but it means interrupting the shield connection. Also, the potential may not exist at that point in time, and the data would be specific to that multi-meter and the user. However, the shield is perfect for use as a probe to detect such a potential difference, provided the measurement input impedance is high enough not to affect the voltage across the grounding resistors, or to create significantly false readings. Therefore, in one embodiment of the invention a monitoring device can be mounted to the shield which can measure the voltage difference between the groundings. The monitoring device can comprise a detection

function for detecting hard ground faults occurring on the shield, and a reporting function which can issue reports on the detection of hard ground faults occurring on the shield. The reporting function can be made intrinsically safe in any of the known ways.

It is also possible to measure the potential difference across the shield if it is only resistively grounded at one end, and is floating at the other end. This can be done using a voltage and/or current measuring device placed between the floating end and the local ground. Such an arrangement can be a design choice, but it can also arise in the event that a shield which was resistively grounded at both ends is cut, leaving two sections which are only resistively grounded at one end. Therefore, in one version of the invention a second end of the shield can be left floating, and a measuring device can be provided between the second end and the ground which can measure the potential difference between the first end and the second end of the shield.

For some installations, a physical electrical EB is not a viable or a practical option to install due to the distance between instantiations, plots or plants. For example, a POTS telephone cable that spans 1km between an exchange and a house will not have an additional EB system or structure spanning the two, and local electrical supply grounds may come from separate utility supplies or substations. In this case, the ground potential difference between the exchange and the house will be unknown and/or uncontrolled, particularly if there is a ground fault in the exchange or the house. As such, while the present invention is principally directed to use in industrial settings where EB systems are used, it can also be applied to installations without an EB. In such cases the maximum possible voltages are used for the component sizing.

It will be appreciated that the various resistors and capacitors referred to above can be single components, but they can also be a plurality of components which collectively provide the same function. Therefore, the resistor and/or the

capacitor and/or the additional resistor can comprise a plurality of such resistor or capacitor components accordingly, which can be arranged in parallel and/or in series. Likewise, the second resistor and/or the second capacitor and/or the second additional resistor can comprise a plurality of such resistor or capacitor components accordingly, which can be arranged in parallel and/or in series.

The invention can be performed in various ways, and three embodiments will now be described by way of example, and with reference to the accompanying drawings, in which:

Figure 1 is a diagrammatic view of an intrinsically safe electrical circuit according to the present invention;

Figure 2 is a diagrammatic view of a first shield of an intrinsically safe electrical circuit according to the present invention;

Figure 3 is a diagrammatic view of a second shield of an intrinsically safe electrical circuit according to the present invention;

Figure 4 is a graph of the calculations and assessment for various lengths of cable, with various potential differences applied;

Figure 5 is a diagrammatic view of a third shield of an intrinsically safe electrical circuit according to the present invention;

Figure 6 is a diagrammatic view of a measuring system part of the third shield shown in Figure 4.

As shown in Figure 1 an intrinsically safe electrical circuit 100 comprises a power supply 101, a load 102 and a cable 103 connecting the power supply 101 and

the load 102, and comprising positive and negative cores 104 and 105. The circuit 100 comprises an incendive arc prevention mechanism 106 which passively and/or actively limits the power in the positive and negative cores 104 and 105 to render them intrinsically safe. The cable 103 comprises an electrically conductive interference shield 107 surrounding the positive and negative cores 104 and 105 along the length of the cable 103. The shield 107 is rendered intrinsically safe by being connected to ground 108 at at least a first end 109 thereof via a power limiting resistor 110. Figure 1 shows the invention in its most basic form, according to claim 1, and is provided for illustrative purposes only.

Figure 2 illustrates a different arrangement in which cable shield 1 is mounted between terminations A and B. Grounding 6a is provided at a first end 1a of the shield 1, and grounding 6b is provided at a second end 1b of the shield 1. If both potentials are equal then both terminations A and B are grounded to both groundings 6a and 6b.

Each termination A and B is grounded in the same way with one or more resistors 2a, 2b, with one or more capacitors 4a, 5a, 4b, 5b, and with one or more additional series resistors 3a, 3b. It will be appreciated that the additional series resistors 3a, 3b are optional, and also that each component 2a, 2b, 3a, 3b, 4a, 4b, 5a and 5b can be made up of two or more of the same type of component arranged in series and/or in parallel.

An EB is provided between the groundings 6a and 6b in the known way.

The components 2a, 2b, 3a, 3b, 4a, 4b, 5a and 5b are sized in value in accordance with the required safety factor in order to render the shield 1 non-incendive for the given application and hazardous area type. In particular, they are sized in value to deal with any connection or disconnection between terminations A and B, and or between groundings 6a and 6b. They can also deal with any fault grounding at any point between terminations A and B, as well as any connection or

disconnection of the groundings 6a, 6b. They are also sized in value to offer the best low impedance path for any RFI/EMC connection to ground.

In particular, the IEC60479-1 standard on electrical safety sets out that a current through the human body of 5mA may be detectable but it will not result in muscle reaction. A current through the heart though must be below 1mA. Therefore, to satisfy this limit the resistance provided to the shield 1 should be a minimum of 71kOhms, when using a potential of 250V rms. However, because in a likely fault scenario contact can span from hand to hand, then 360kOhms is better. This also offers a good grounding resistance to disperse any electrostatic charge. Therefore, resistors 2a and 2b are 360kOhms.

As the resistors 2a and 2b are this size they also meet all other intrinsic safety requirements. In particular, where potential differences at each end of the screen 1 at the EB connection points are less than 45V for resistance or 55V for capacitance, then the IEC60079 part 11 standard determines a necessary size in value for each resistor 2a, 2b, 3a, 3b and each capacitor 4a, 4b, 5a, 5b. For example, if the potential difference is 12V, then each resistor 2a and 2b can be as low as 3.6 Ohms, and each pair of capacitors 4a and 5a, 4b and 5b can be as high as 1.4 uF (micro-Farad) without requiring the additional series resistors 3a and 3b. However, with the series resistors 3a and 3b each pair of capacitors 4a and 5a, 4b and 5b can be higher in accordance with the IEC60079 part 11 standard. Therefore, the additional series resistors 3a and 3b can be removed if they are not required. However, their presence does provide a mechanism to deal with a short circuit occurring in any of the capacitors 4a, 4b, 5a, 5b. If this happened then the additional series resistors 3a, 3b can deal with it. As they are positioned in parallel with resistors 2a, 2b, all the resistors 2a, 2b, 3a, 3b can be sized in value and power accordingly.

Furthermore, it is necessary not to exceed a given power dissipated in resistors 2a, 2b (and/or in resistors 3a, 3b with each pair of capacitors 4a and 5a, 4b and 5b). For example, if this was 1Watt then this resistance must not be lower than

144Ohms at 12V. If the resistors 2a, 2b allow 1W dissipation then they will also act to limit the current, and therefore the power passing through the shield 1, and will therefore protect it from an overcurrent situation in which it might overheat or damage the integrity of the whole cable. As such, the resistors 2a, 2b, 3a, 3b will also perform as current limiting devices for shield faults to ground at one point between terminations A and B. Two such ground faults simultaneously occurring between terminations A and B is improbable, as it is for any intrinsically safe circuit. To help mitigate against this the arrangement show in Figure 2 can be provided at regular intervals, so the shield 1 has a shorter span. This can be done by transitioning the cable through regular junction boxes.

In use the shield 1 operate as follows. As it comprises intrinsically safe protection mechanisms at both ends 1a and 1b it can handle open circuits and short circuits occurring at either end 1a and 1b, and between terminations A and B.

In the event of an open circuit the components at both ends 1a and 1b of the shield 1 react to prevent the occurrence of an incendive arc by power limiting the shield 1.

In the event of a short circuit the components at one end 1a or 1b of the shield 1 must be treated as acting independently in order for the requirements of the IEC60079 standard to be met. From such a perspective they do so by reacting to the short circuit by power limiting the shield 1 and therefore preventing any incendive arcs from occurring. Each end 1a and 1b can both react in this way in a compound fashion.

As explained above, the shield 1 can be used as a probe to determine any potential difference across the EB system, and/or to detect the occurrence of a ground fault. This is a function which is not currently provided for with any known structures. Figure 3 shows a second embodiment of the present invention in which a shield 7 comprises the same arrangement and components as shield 1 described

above, except that voltage monitoring equipment 8 is attached across the resistors 9a and 9b. The monitoring equipment 8 is intrinsically safe in accordance with the IEC60079 part 11 standard using any known method. It also has input impedance which is high enough not to affect the voltage across the resistors 9a and 9b, or to create significantly false readings, or to fail to meet the requirements of the IEC60079 standard. (For 250V measurement the resistors 9a and 9b can be split into two or more resistors, so that a potential divider will reduce the input voltage to the monitoring equipment 8).

Therefore, the monitoring equipment 8 can detect if a ground fault has occurred anywhere between terminations C and D, and it can measure the potential difference between terminations C and D or resistors 9a and 9b. The monitoring equipment 8 comprises suitable communications mechanisms of any of the known kinds so it can report its measurements to the control room, and alarms or other suitable actions can then be taken to rectify any actual fault, or to address the breach of a pre-defined fault condition. Figure 3 shows the monitoring equipment 8 being located at a particular point, but it will be appreciated that it can be dispersed at one or more points between terminations C and D or resistors 9a and 9b. For example the monitoring equipment 8 could be provided at both ends of the shield 7. Monitoring points may also be inserted in series and/or in parallel (if in series then it may also measure current) with any of the components of the shield 1. The monitoring equipment 8 may operate by injecting voltage and/or current, and/or it may operate by measuring voltage and/or current, for DC and/or AC variables/signals, all in accordance with the IEC60079 parts 11, 14 and 0 standards.

Referring to Figures 5 this shows a different monitoring arrangement. In particular shield 10 is illustrated as part of a powered data communications cable 11 which extends from a control room 12 to a device 13. The cable 11 comprises power and return cores 14 inside it. The shield 10 is grounded 15 at a first end 10a thereof in the same ways as shields 1 and 7 described above via a resistor 16, capacitors 17

and 18 and additional resistor 19 (which as described above is optional). However, its second end 10b is not connected to ground and is left floating at the device 13.

It will be appreciated that a shield which is left floating at one end can be a design choice, but it can also be an arrangement which arises in the event that a shield like shields 1 and 7 described above is cut part way along its span. Therefore, while the below described monitoring is applied at the device 13, it could equally be applied anywhere along the length of a shield according to the present invention, and in particular one which is only resistively grounded at one end due to being cut.

For the purposes of identifying a potential difference in the EB system 20, the second end 10b of the shield 10 is grounded 21 with an intersecting series grounding capacitor 22 inserted. This is permitted by the IEC60079 part14 standard as long as the total capacitance value connected from the shield to ground is less than 10nF for that given section of shield. The capacitor 22 acts as a shunt for high frequency interference, and blocks the possibility of large circulating currents in the shield.

Figure 6 illustrates the arrangement of the capacitor 22 in greater detail. In particular, it is arranged between the second end 10b of the shield 10 and the local ground 21. A measuring device 23 measures the voltage between 10b and 21, which gives an indication of the difference in voltage between the two ground points 21 and 15, and therefore across the EB system 20. As the grounding capacitor 22 is used in order to prevent circulating currents in the shield 10, then the measuring device 23 will be measuring DC or AC voltage (and/or inferred current). If a hard ground were used instead then no voltage would be measurable unless a series resistor 24 were inserted, as shown in Figure 6. If so, the voltage measurement would indicate AC or DC voltage and/or current.

The value of the resistor 24 is chosen to perform current and/or voltage measurement, and will be sized according to the required value and rating, to conform with the IEC60079 part 14 and/or 11 standards. The resistor 24 can isolate

25 the resistance should the voltage increase to an incendive level, at which point a warning is given. The resistor 24 may have a low value so as to act as closely to a hard ground as it can, but still high enough to measure the current. If this is isolated 25, then the grounding effect will be diminished, so it is important to maintain it if this is critical for noise reduction. These functions are obviously supported by the capacitor 22. If the capacitor 22 could deal with these issues itself then the resistor 24 would not be necessary. However, as it is included then if an open circuit at the control side grounding 15 were to occur, the resistor 24 will prevent the shield 10 from floating.

The measuring device 23 provides galvanic and/or optical data and/or power isolation from the signal cores 14 to ground 21. The isolation is afforded by one or more resistors 26, which may be capacitors if measuring AC only.

Therefore the capacitor 22 is a measuring instrument which is integrated with the device 13, which in this example is a switch 27. The measuring device 23 communicates its measurement of the voltage across 10b and 21 as shown at 28 to the switch 27. It can do this using any known kind of analogue or digital signal. Any injected signal between 10b and 21 will be non-incendive, and the arrangement shown in Figure 6 will adequately isolate point 10b from point 21 to meet the relevant IEC60079 safety standards where required. The switch 27 will in turn communicate the measured voltage and/or current via the cores 14 in any of the known ways to the control room 12. The switch 27 comprises a digital data communication such as 4-20mA+HART (RTM), HART (RTM), Fieldbus (RTM) (which uses the term – ‘device coupler’ rather than switch), or a new high speed variant currently known as APL (which uses the term switch). In any case the measured voltage and/or current will be converted into the relevant protocol for communication. This could also be a modulation of one or more of the Physical Layer Attributes, for example, quiescent current modulation.

Therefore the arrangement shown in Figures 5 and 6 acts as a safety warning system and a solution, which is able to measure the potential difference between the ground potentials at the opposite ends 10a and 10b of the shield 10. This provides an indication of the potential hazard and/or an EB fault condition, which can be announced to any maintenance crew working on the cable 11, or in its vicinity. Importantly, the fault could be any earth fault in equipment sharing the same EB system 20 as the shield 10. This solution provides these beneficial features without introducing an explosion potential, and without the need to run additional signal cables, wireless ports, power cables or batteries because it can send its measurements to the host control system itself. This solution can also isolate or power/energy restrict any potential difference, and hence any incendive potential, in accordance with the IEC60079 part 11 standard.

As explained above, the arrangement shown in Figure 5 could be designed, but it could also be an arrangement which is implemented for measuring in the event that a shield like shields 1 and 7 described above is cut part way along its span. Therefore, while the measuring capacitor 22 is applied at the device 13, it could equally be applied anywhere along the length of a shield 10, including at its first end 10a.

It will be appreciated that the measuring principal demonstrated by the arrangement shown in Figures 5 and 6 can be employed on a trunk cable and/or on one or more spur cables. The measuring system may be multiplexed for the spurs. Therefore, any number of the control/instrument cables may be monitored in this way throughout a plant. The data can be collated and analysed not only for explosion safety, but also for monitoring ground faults in the EB infrastructure so faulty equipment can be identified for proactive/preventative action taken.

The present invention can be altered without departing from the scope of claim 1. For example, in alternative embodiments (not shown) shields like shield 1 are provided with capacitors 4a, 4b, 5a and 5b and resistors 2a, 2b, 3a and 3b

arranged in other combination (series and/or parallel), with any number thereof. All that is required is that the resulting arrangement meets the requirements of the IEC60079 standard, as well as the requirements for EMC/RFI suppression.

Further, in other alternative embodiments (not shown) shields like shield 1 are provided with transient and/or voltage clamping diodes and the like such that they perform the same functions as components 2a, 2b, 3a, 3b, 4a, 4b, 5a, and 5b, provided they operate in a bi-polar way to account for the far end EB potential being positive or negative in respect to the local potential. In further embodiments (not shown) semiconductors are used instead, but if so they must be used with adequate protection means so that they can be classed as infallible in accordance with the IEC60079 standard.

In other alternative embodiments (not shown) shields like shield 1 are provided with additional reactive components in series and/or in parallel with one or more of the components 2a, 2b, 3a, 3b, 4a, 4b, 5a, and 5b. This reactance includes inductors and/or infallible inductors.

In another alternative embodiment (not shown) a shield like shield 1 is only connected to ground via a resistor at one end and the other end is left disconnected.

Therefore, the present invention provides a shield for an intrinsically safe cable which is itself rendered intrinsically safe in order to prevent incendive situations arising as a result of potential differences occurring on it. The present invention also provides a shield with a secondary measuring function to provide alerts in the event of such potential differences, or other faults, occurring. This is particularly beneficial because the shield can act as a tool to detect faults in other equipment which effect the same EB system the shield is grounded to.

Claims

1. An intrinsically safe electrical circuit comprising a power supply, a load and a cable connecting said power supply and said load and comprising positive and negative cores,

in which said circuit comprises an incendive arc prevention mechanism which passively and/or actively limits the power in said positive and negative cores to render them intrinsically safe,

in which said cable comprises an electrically conductive interference shield surrounding said positive and negative cores along the length of the cable,

and in which said shield is rendered intrinsically safe by being connected to ground at at least a first end thereof via a power limiting resistor.

2. An intrinsically safe electrical circuit as claimed in claim 1 in which said shield is connected to ground at said first end via a capacitor mounted in parallel with said power limiting resistor.

3. An intrinsically safe electrical circuit as claimed in claim 2 in which an additional resistor is mounted in series between said shield and said capacitor.

4. An intrinsically safe electrical circuit as claimed in claim 1 in which said shield is also connected to ground at a second end thereof via a second power limiting resistor.

5. An intrinsically safe electrical circuit as claimed in claim 4 in which said shield is connected to ground at said second end via a second capacitor mounted in parallel with said second power limiting resistor.

6. An intrinsically safe electrical circuit as claimed in claim 5 in which a second additional resistor is mounted in series between said shield and said second capacitor.

7. An intrinsically safe electrical circuit as claimed in claim 1 in which both said first end of said shield and a second end thereof are connected to ground and an equipotential bond is provided between said groundings.

8. An intrinsically safe electrical circuit as claimed in claim 7 in which a monitoring device is mounted to said shield which measures the voltage difference between said groundings.

9. An intrinsically safe electric circuit as in claim 8 in which said monitoring device comprises a detection function for detecting hard ground faults occurring on said shield, and a reporting function which issues reports on the detection of hard ground faults occurring on said shield, and in which said reporting function is intrinsically safe.

10. An intrinsically safe electrical circuit as claimed in claim 1 in which a second end of said shield is left floating, in which a measuring device is provided between said second end and the ground which measures the potential difference between said first end and said second end of said shield.

11. An intrinsically safe electrical circuit as claimed in claim 3 in which said resistor and/or said capacitor and/or said additional resistor comprise a plurality of such resistor or capacitor components accordingly which are arranged in parallel and/or in series.

12. An intrinsically safe electrical circuit as claimed in claim 6 in which said second resistor and/or said second capacitor and/or said second additional resistor comprise a plurality of such resistor or capacitor components accordingly which are arranged in parallel and/or in series.

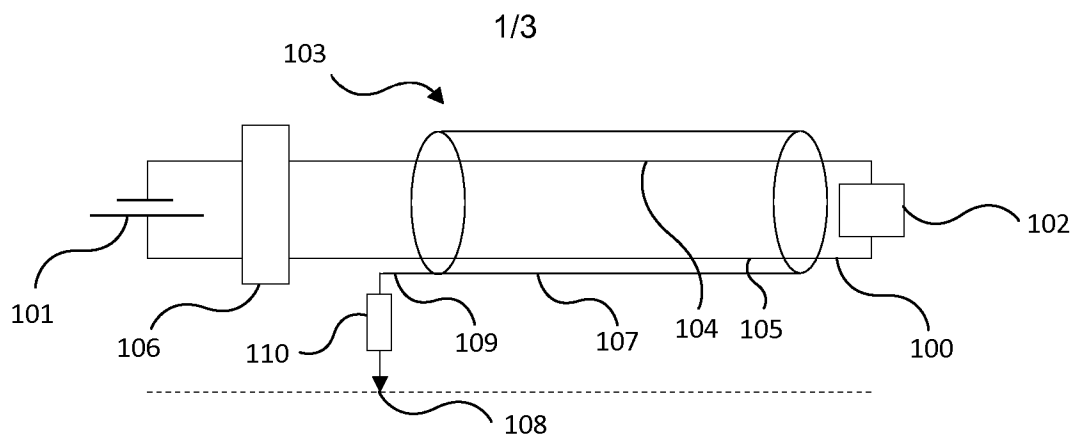


Fig. 1

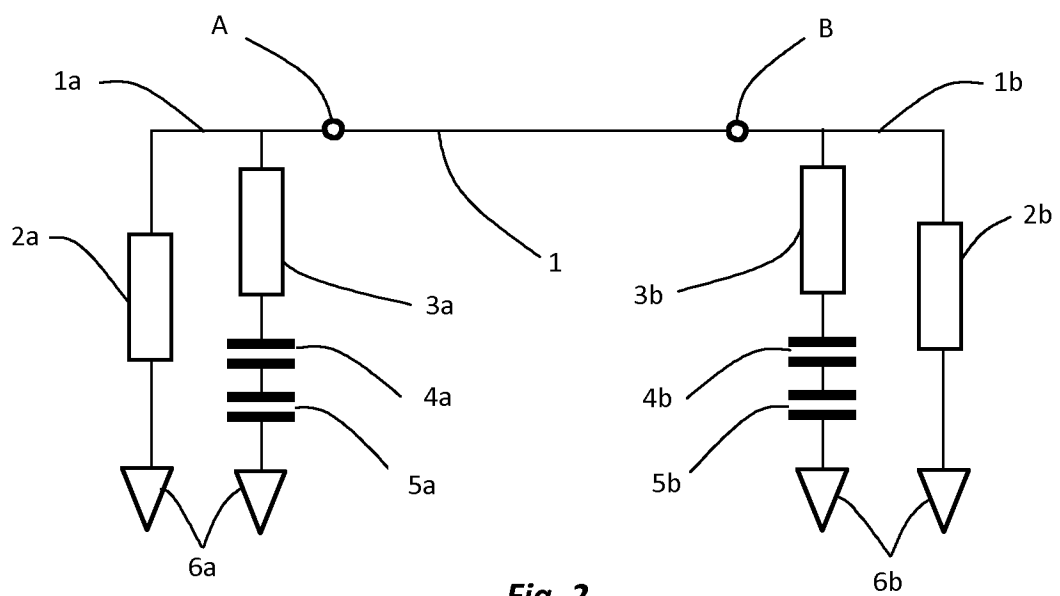


Fig. 2

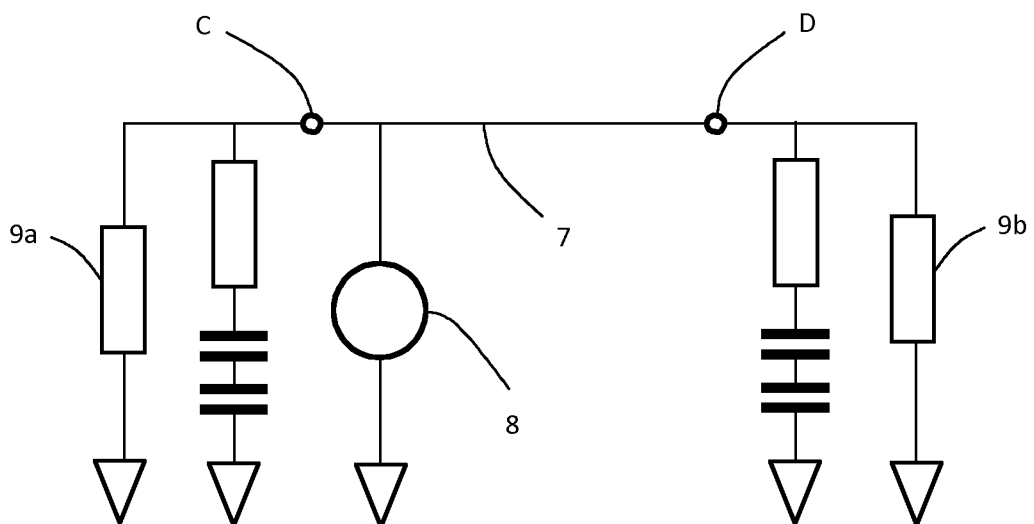


Fig. 3

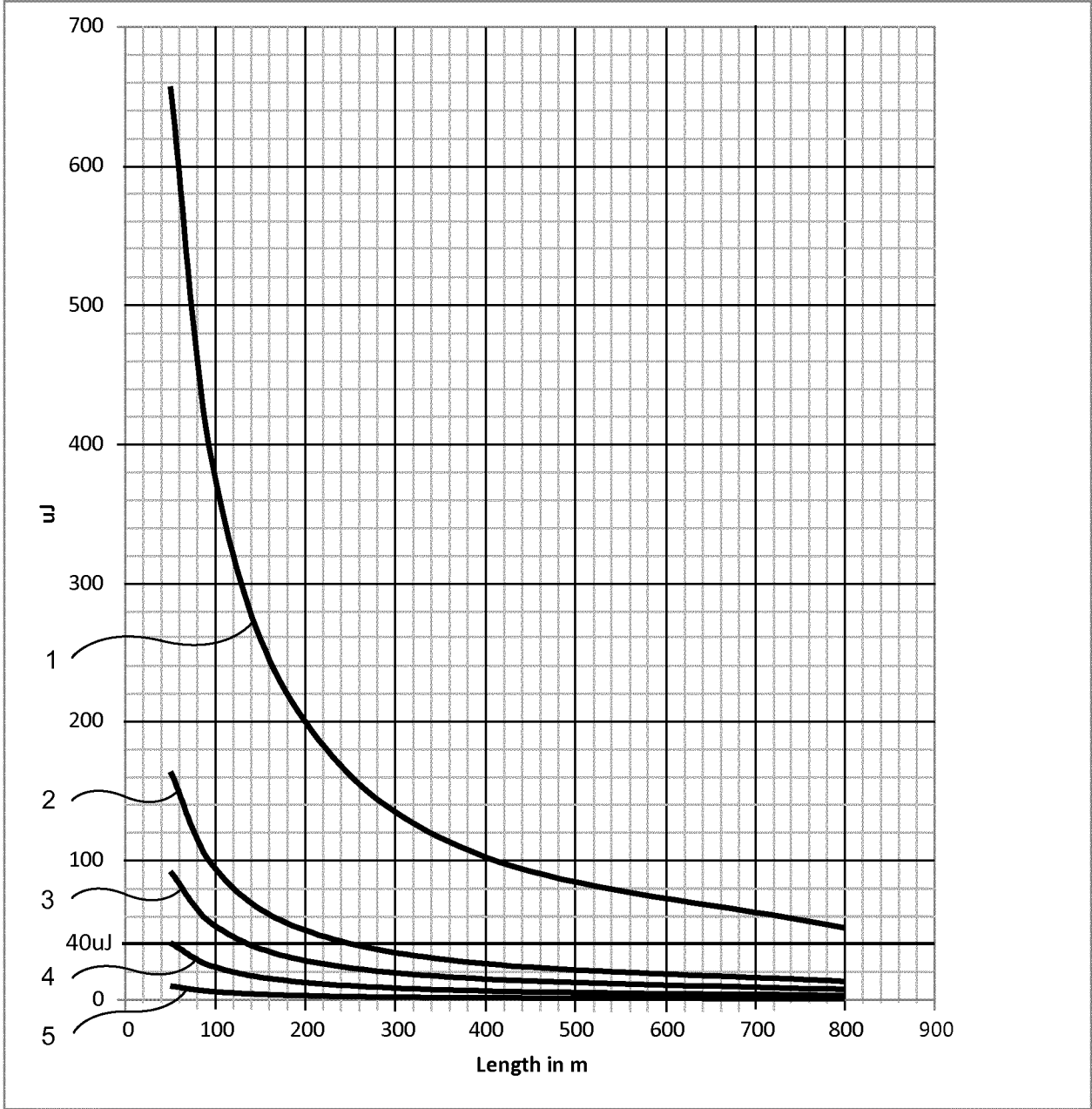
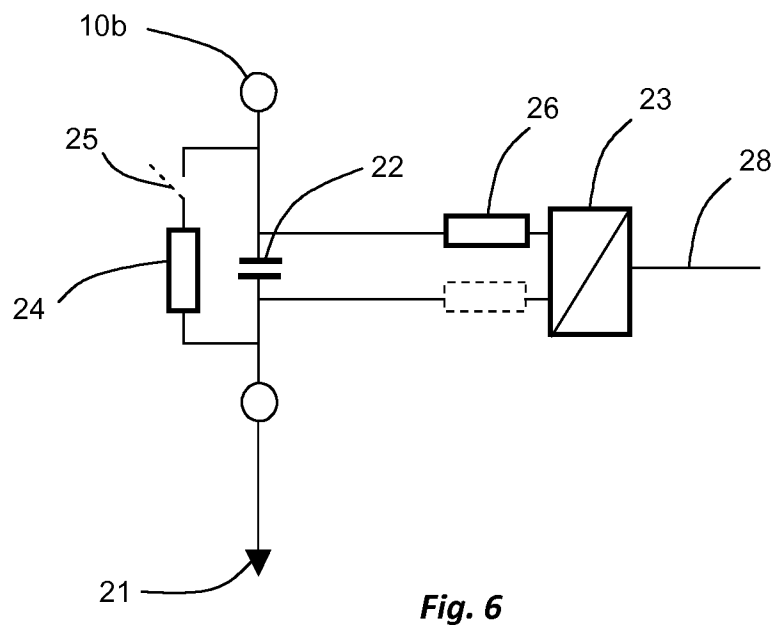
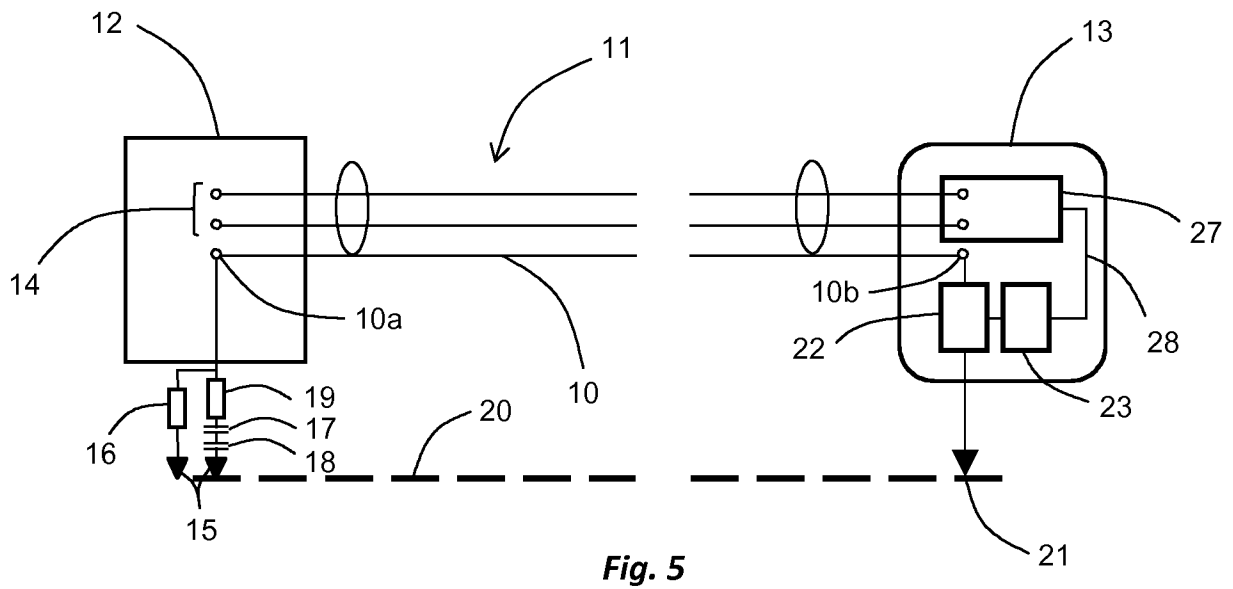


Fig. 4

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2018/059664

A. CLASSIFICATION OF SUBJECT MATTER
INV. H02H9/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H02H G01R H01R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2009/180226 A1 (ROGOLL GUNTHER [DE] ET AL) 16 July 2009 (2009-07-16) paragraphs [0013], [0068] - [0073], [0106]; figures 6,23 -----	1-12
Y	US 2015/087187 A1 (KIFEDJIAN AVEDIS [US]) 26 March 2015 (2015-03-26) paragraph [0048]; figure 3 -----	1-12
Y	CN 203 117 325 U (XI AN QINLI COMPLETE SET OF ELECTRICAL APPLIANCES CO LTD) 7 August 2013 (2013-08-07) abstract; figure 1 -----	1-12
A	US 2007/183108 A1 (UHLENBERG RONALD L [US] ET AL) 9 August 2007 (2007-08-09) paragraphs [0018] - [0024]; figure 1 -----	1



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

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