

Device for protecting an electronic circuit with detection of a change of electrical reactance

According to a first aspect, the present invention relates to a device for protecting an electronic circuit, the device comprising:

- 5 - at least one mesh surface, the or each mesh surface comprising at least one cell made up of a continuous portion of electrical circuit, the cell(s) being distributed on the mesh surface, and
- at least one electrical circuit, comprising:
 - 10 ○ an input for injecting an electrical signal for exciting the electrical circuit,
 - an output for capturing an electrical output signal from the electrical circuit, and
 - between said input and said output, at least one of said cells,
 the electrical circuit having an electrical reactance between its input and its output.

15 Still according to this first aspect, the present invention also relates to an electronic system comprising such a protection device.

According to a second aspect independent of the first aspect, the present invention relates to a system for detecting intrusions, the system comprising:

- 20 - at least one mesh surface, each mesh surface comprising at least two cells, each cell comprising a pattern, a pattern being a portion of continuous electrical circuit,
- at least one interconnection surface comprising a plurality of connectors, the connectors being suitable for connecting cells of the mesh surface(s) to each other according to a first configuration of the interconnection surface for forming groups of electrically connected cells, the patterns of the cells of each group forming a continuous
- 25 electrical circuit of patterns,
- a detection module capable of detecting a modification of an impedance which is characteristic of each group of electrically connected cells.

Still according to this second aspect, the present invention also relates to an associated method for protecting an electronic circuit.

30 In the field of computer security, one issue consists of protecting the equipment through which sensitive information passes. Such equipment in particular includes electronic circuits, i.e., printed circuits or integrated circuits.

A printed circuit, also called printed circuit board, is a support making it possible to maintain a set of electronic components and electrically connect them to one another. An

35 integrated circuit, also called electronic chip, is a set of electronic components

reproducing one or several electronic functions and generally integrating several types of basic electronic components in a small space.

The tracks of a printed circuit and the connections of the electronic components connected on such a printed circuit may be subject to physical attacks. Such physical attacks in particular consist of approaching probes or connecting electrodes on the tracks of the printed circuit or on the connections of components connected on the printed circuit so as to capture the signals traveling over the tracks or the connections or to inject signals. The captured signals are next used by the attackers to collect sensitive data. The injected signals are used to disrupt the exchanged signals or to cause a malfunction of the equipment.

Similar attacks may be carried out on integrated circuits.

As a result, physical protection devices are used to protect the printed circuits and integrated circuits of such equipment from intrusions. The protection devices for example comprise two- or three-dimensional protective meshes. The meshes are in particular formed from separate electrical circuits forming patterns and the continuity of which is verified by circulating a control current and detecting the current losses, due to a break of the circuit. The meshes are for example positioned above and/or below components of the equipment to be protected, such as the tracks and connections of a printed circuit or the layers of silicon of an integrated circuit. The meshes in particular comprise a structure and patterns chosen so as to allow the detection of intrusion attempts. When an intrusion attempt is detected, reactive actions are triggered by the protection device, these actions for example consisting of erasing the sensitive data from the equipment.

However, the protection provided by such meshes does not make it possible to protect against attacks conducted between the conducting elements forming the electrical circuits; yet it is necessary to leave spaces between these conducting elements in order to electrically isolate them from one another, which leaves attackers unprotected areas where they can carry out their attacks. Furthermore, protection strategies based solely on detecting current losses are limited, since an attacker may have means for short-circuiting each pattern of each protective mesh.

There is therefore a need for a protection device making it possible to detect attacks targeting isolation regions between conducting elements of meshes and making it possible to detect attacks by short-circuiting each pattern of a mesh covering a target zone.

To that end, according to the first aspect, the invention relates to a protection device of the aforementioned type comprising a detection module able to detect a change of said electrical reactance.

According to specific embodiments of the invention, the protection device comprises one or more of the following features, considered alone or according to any technically possible combinations:

- 5 - the detection module is able to detect a change of an inductive component of the electrical reactance.
- the detection module is able to detect a change of a capacitive component of the electrical reactance.
- 10 - the detection module is able to periodically command the production of at least one electrical excitation signal to excite the electrical circuit, to measure a characteristic value of the response of the electrical circuit to said excitation signal, to calculate the difference between the or each measured value and a reference value, and to detect a change in the electrical reactance in the event the calculated difference or a mean of the calculated differences exceeds a predetermined threshold.
- 15 - an electrical excitation signal consists of a voltage scale, and the characteristic value of the response of the electrical circuit to said excitation signal consists of a duration so that, after the excitation of the electrical circuit by said voltage scale, the voltage of the electrical output signal reaches a reference voltage.
- 20 - an electrical excitation signal consists of a voltage scale, and the characteristic value of the response of the electrical circuit to said excitation signal consists of a voltage of the electrical output signal reached after a predetermined duration following the excitation of the electrical circuit by said voltage scale.
- 25 - an electrical excitation signal consists of an alternating signal whose frequency varies over time, and the characteristic value of the response of the electrical circuit to said excitation signal consists of a resonance frequency of the electrical circuit.
- 30 - an electrical excitation signal consists of an alternating signal whose frequency varies over time, and the characteristic value of the response of the electrical circuit to said excitation signal consists of a quality factor of the electrical circuit.
- 35 - an electrical excitation signal consists of an alternating signal having a predetermined frequency, and the characteristic value of the response of the electrical circuit to said excitation signal consists of an amplitude of the electrical output signal.
- the electrical circuit comprises a plurality of cells.
- the cells of the electrical circuit comprise at least two cells electrically isolated from each other, said cells being electromagnetically coupled to each other.

- the mesh surfaces comprise a primary mesh surface, comprising primary cells, and a secondary mesh surface, comprising secondary cells electrically isolated from the primary cells, and the electrical circuit comprises at least one primary cell and at least one secondary cell electromagnetically coupled to each other.

5 - said primary and secondary cells of the electrical circuit are electromagnetically coupled to each other at least by induction.

10 - the protection device comprises at least one interconnection surface comprising a plurality of connectors, the connectors being suitable for connecting cells of the mesh surface(s) to each other so as to form the or each electrical circuit, and a configuration module of the interconnections of the connectors, able to command the connectors to modify the connection of the cells to each other over time.

- the interconnection surface comprises at least one programmable component, the configuration module and the detection module being software applications integrated into the programmable component(s).

15 Still according to the first aspect, the invention also relates to an electronic system comprising an electronic circuit contained in a housing and a protection device of the electronic circuit comprising at least one mesh surface interposed between the electronic circuit and an outer surface of the housing, the protection device being a protection device as defined above.

20 Still according to the first aspect, the invention also relates to a method for protecting an electronic circuit comprising the following steps:

- providing a protection device as previously described,
- calibrating the detection module, during which the or each reference value is determined,

25 - producing at least one electrical excitation signal of the electrical circuit,

- measuring a characteristic value of the response of the electrical circuit to the excitation signal,

- comparing the or each measured characteristic value with a corresponding reference value, and

30 - detecting a change of the characteristic impedance when a difference between a measured value and the corresponding reference value exceeds a predetermined threshold.

35 Another drawback of the existing solutions is that, attacks being increasingly sophisticated, the structure and patterns designed for the meshes are increasingly complex, which increases the development time and cost of the meshes.

Furthermore, the protection provided by such meshes may be bypassed by attackers after a reverse engineering phase. Reverse engineering, also called reverse design, is an activity consisting of studying an object to determine its inner workings or manufacturing method.

5 After reverse engineering, the attacker knows the positions and properties of the different electrical circuits of the mesh. The attacker is then able to short-circuit some of these electrical circuits and therefore section them to free an access space to the equipment to be protected, without the protection device detecting the intrusion.

10 There is therefore a need for a protection device making it possible on the one hand to respond to sophisticated attacks without increasing the complexity of the protective meshes, therefore their development cost and production cost; and on the other hand, to make it ineffective for an attacker to short-circuit one or more electrical circuits of a mesh after reverse engineering.

15 To that end, according to the second aspect, the invention relates to a system of the aforementioned type (the latter also being able to be a protection device of the aforementioned type), comprising a system for detecting intrusions of the aforementioned type, in which the system further comprises a module for configuring interconnections of the connectors, the configuration module being able to modify, over time, the first configuration to obtain at least one second configuration of the interconnection surface.

20 According to specific embodiments of the invention, the system comprises one or more of the following features, considered alone or according to any technically possible combinations:

25 - the configuration module is able to determine, randomly, the second configuration from among a plurality of configurations of the interconnection surface and to reconfigure the set of interconnections of the connectors according to the second configuration.

30 - when a break in the electrical continuity of at least one continuous circuit is detected over an area of a mesh surface, the configuration module is able to modify the configuration of the interconnection surface so as to increase the number of groups of connected cells present in that area.

 - the system comprises at least two mesh surfaces and a module for measuring variations in a property between two of the mesh surfaces, the property being chosen from among an impedance, a resistance, a capacitance and an inductance.

- at least one electrical circuit is formed by the connection, which is not reconfigurable by the configuration module, of at least two adjacent cells of a mesh surface via a component previously statically configured.
 - the configuration module is able to move over time, over one or over each mesh surface, a zone of the mesh surface having the highest number of groups of connected cells.
 - the system comprises a member capable of activating, at randomly or pseudo-randomly chosen moments, the configuration module and/or the detection module.
 - the interconnection surface comprises a programmable component, the configuration module and the detection module being software applications integrated into the programmable component.
 - the interconnection surface comprises a micro-electromechanical system piloted by actuators, the configuration module being able to actuate the actuators.
 - the mesh surface and the interconnection surface form a physical protective barrier for the configuration module and the detection module.
 - after a break has been detected in the electrical continuity of a group of connected cells, the detection module is able to apply a security policy, the security policy comprising erasing sensitive data, carrying out integrity tests and/or reconfiguring interconnections of the connectors of the interconnection surface.
 - the detection module includes several methods for detecting a break or alteration of each group of electrically connected cells and is able to use them in a combined manner with a defined temporal interleaving, which may be pseudo-random or random.
- Still according to the second aspect, the invention also relates to a method for detecting intrusions, comprising the following steps:
- providing a system for detecting intrusions as previously described,
 - determining, using the configuration module, a first configuration of the interconnection surface,
 - configuring, using the configuration module, interconnections of the connectors of the interconnection surface according to the first determined configuration,
 - activating the detection module to detect a modification of an impedance which is characteristic of each group of electrically connected cells,
 - optionally detecting, via the detection module, a modification of an impedance which is characteristic of a group of electrically connected cells, and

- modifying the first configuration of the interconnection surface, using the configuration module, to interconnect the connectors of the interconnection surface according to a second configuration.

Other features and advantages of the invention will appear upon reading the following description, provided solely as an example and done in reference to the appended drawings, in which:

- figure 1 is a schematic sectional view of an example electronic system according to the invention, showing, in section, an electronic circuit contained in a housing and a protection device for this electronic circuit,
- figure 2 is a schematic sectional view of the protection device of figure 1, showing a first example embodiment of this device,
- figure 3 is a schematic top view of a primary mesh surface of the device of figure 2,
- figure 4 is a schematic top view of the interconnection surface of the device of figure 2,
- figure 5 is a schematic top view of a secondary mesh surface of the device of figure 2,
- figure 6 is a schematic top view of a first example pattern of a cell of a mesh surface of figure 3 or 5,
- figure 7 is a schematic top view of a second example pattern of a cell of a mesh surface of figure 3 or 5,
- figure 8 is a flowchart of an example method for detecting intrusions using a dynamic configuration of the interconnections,
- figure 9 is a schematic sectional view of the protection device of figure 1, showing a second example embodiment of this device,
- figure 10 is a schematic top view of a primary mesh surface of the device of figure 9,
- figure 11 is a schematic top view of a secondary mesh surface of the device of figure 9,
- figure 12 is a schematic top view of an example pattern of a cell of a mesh surface of figure 10 or 11, and
- figure 13 is a schematic top view of an example arrangement of two cells of the mesh surface of figure 10 or 11.

A first embodiment of the invention will now be described, in reference to figures 1 to 7.

The electronic system 80 shown in figure 1 comprises a housing 82, an electronic circuit 84 housed in the housing 82 and a device 1 for protecting the electronic circuit 84, also housed in the housing 82. The electronic system 80 is typically an encryption device or transmission equipment through which encrypted data, such as banking data, passes.

5 The housing 82 has an outer face 86, accessible to a user.

The electronic circuit 84 is for example a printed circuit. Alternatively, the electronic circuit 84 is an integrated circuit.

The protection device 1 is inserted between the electronic circuit 84 and said outer face 86.

10 The protection device 1 is able to detect intrusion attempts coming from outside the electronic system 80. The intrusion attempts are in particular physical attacks consisting of approaching probes or connecting electrodes on the electronic circuit 84.

In reference to figure 2, the protection device 1 comprises a detection film 1A able to completely envelop the electronic circuit 84 or at least to cover all or some of the printed circuits and integrated circuits of the electronic circuit 84. To that end, the detection film 1A is inserted between the outer face 86 of the housing 82 and the electronic circuit. In the illustrated example, this film 1A is limited to a flat surface and extends only in two dimensions. Alternatively, the film 1A extends over at least two angularly offset surfaces and thus forms a three-dimensional surface.

20 The film 1A comprises at least one mesh surface 2A, 2B, each mesh surface 2A, 2B comprising at least one cell 3A, 3B, the total number of cells being at least equal to two. The film 1A further comprises at least one interconnection surface 4 of the cells 3A, 3B.

The protection device 1 also comprises a module 6 for configuring, over time, interconnections of the connectors 24 of the interconnection surface 4. The protection device 1 also comprises a generator 7 for generating an electrical excitation signal of the cells 3A, 3B, an electrical signal sensor 9, a module 8 for detecting intrusions and a module 10 for reacting to intrusion attempts detected by the detection module 8.

30 Optionally, the protection device 1 also comprises a member such as a timer configured to activate the configuration module 6 and/or the detection module 8.

Also optionally, the protection device 1 further comprises at least one shielding surface positioned above or around the mesh surface(s) 2A, 2B. This shielding surface for example makes it possible to protect the equipment from chemical or electromagnetic attacks.

35 In the example of figure 2, the film 1A comprises a primary mesh surface 2A, a secondary mesh surface 2B and an interconnection surface 4. The cells 3A of the primary

mesh surface 2A here will be called "primary cells" and the cells 3B of the mesh surface 2B will be called "secondary cells".

5 In the illustrated example, the primary mesh surface 2A is inserted between the secondary mesh surface 2B and the outer face 86 of the housing 82, and the interconnection surface 4 is inserted between the primary and secondary mesh surfaces 2A, 2B. Thus, to reach the interconnection surface 4 or the secondary mesh surface 2B, an attacker must first pass through the primary mesh surface 2A.

10 Alternatively (not shown), the interconnection surface 4 is positioned below the primary and secondary mesh surfaces 2A, 2B, i.e., between said mesh surfaces 2A, 2B and the electronic circuit 84.

As illustrated in figures 3 and 5, each mesh surface 2A, 2B comprises thirty-five cells 3A, 3B. The cells 3A, 3B for example have an identical surface area. Alternatively, the cells 3A, 3B have different sizes.

15 The cells 3A, 3B of each mesh surface 2A, 2B are distributed on said mesh surface 2A, 2B.

Each cell 3A, 3B is made up of a continuous electrical circuit portion 20 whereof the break, alteration of an electrical characteristic or short-circuit makes it possible to detect an intrusion attempt in the protection device 1. This continuous portion 20 comprises a continuous electrical line, typically formed by a continuous segment of a conductive track. In the illustrated example, the continuous portion 20 is made up of such a continuous electrical line. Alternatively, the continuous portion 20 comprises, in addition to the electrical line, an electrical component electrically connected to said electrical line; this electrical component is for example a resistive component, a capacitive component or an inductive component, and it is typically electrically connected in series or in parallel to the continuous electrical line.

Each conductive track forms a geometric pattern, as illustrated in figures 6 and 7. This geometric pattern is for example a boustrophedon, as shown in figure 6. Alternatively, the geometric pattern is a spiral, as shown in figure 7: the cell 3A, 3B then has an inductance, and it is capable of generating an electromagnetic field under the effect of an electrical current circulating in the cell 3A, 3B, and inducing an electrical current in the conductive track when it is subjected to an electromagnetic field. The cells 3A, 3B whose conductive track forms a spiral will be referred to hereinafter as "inductive cells".

35 Placing the continuous portions of electrical circuit 20 of certain cells 3A, 3B end to end via the interconnections of the connectors 24 forms a mesh.

The generator 7 is able to inject an electrical excitation signal of the cells 3A, 3B at an input point (not shown) of the film 1A.

The signal sensor 9 is able to capture an electrical output signal measured at an output point (not shown) of the film 1A.

5 The interconnection surface 4 is capable of electrically connecting certain cells 3A, 3B to each other so as to form at least one electrical circuit (not shown) capable of conducting an electrical signal from the input point to the output point. It will be noted that the expression "capable of conducting an electrical signal" must be understood here broadly, and therefore includes the case where the electrical signal conducted by the
10 electrical circuit would be altered between the input and output points.

To that end, the interconnection surface 4 is configured to connect cells 3A, 3B of a same mesh surface 2A, 2B in order to form a more or less complex mesh. The interconnection surface 4 is also configured, in this first embodiment, to connect cells 3A, 3B of different mesh surfaces 2A, 2B to each other.

15 In the example illustrated in figure 4, the interconnection surface 4 comprises a programmable component 23 and a plurality of connectors 24.

The programmable component 23 is for example an FPGA (Field-Programmable Gate Array).

20 The programmable component 23 is able to activate the configuration module 6, the detection module 8, the reaction module 10, the generator 7, the signal sensor 9, and optionally, the timer.

Preferably, the programmable component 23 houses the generator 7, the detection module 8, the signal capture module 9, the reaction module 10 and the timer, which are then software applications integrated into the programmable component 23.

25 The programmable component 23 is also configured to determine the interconnections of the connectors 24 on the interconnection surface 4 and to interconnect the connectors 24 according to the determined interconnections. The programmable component for example executes an evolution function of the interconnections able to cause the interconnections of the connectors 24 to evolve over time for each group of
30 connected cells 3A, 3B.

The connectors 24 are on the one hand connected to the ends of the continuous portions 20 of the cells 3A, 3B. The connectors 24 are on the other hand interconnected by the programmable component 23 to connect, in series, cells 3A, 3B of the mesh surfaces 2A, 2B in a first configuration, to form groups of cells connected in series. These
35 groups of connected cells form the aforementioned meshes. Such groups of cells

connected in series are also called "equipotential". There may be several equipotentials in parallel, each corresponding to a group of cells.

Alternatively, the interconnection surface 4 comprises several programmable components 23.

5 Alternatively, the interconnection surface 4 comprises a micro-electromechanical system piloted by actuators. A micro-electrochemical system, also called MEMS, is a microsystem comprising one or more mechanical elements, using electricity as a power source, in order to perform a sensor and/or actuator function, with at least one structure having micrometric dimensions.

10 In this first embodiment, the conducting tracks 20 of the cells 3A, 3B of each group of connected cells form a continuous electrical circuit of conducting tracks. For example, figures 2 and 4, in which a same fill is used for the cells 3A, 3B of a same continuous electrical circuit, illustrate different continuous electrical circuits of conducting tracks.

Each continuous electrical circuit is electrically connected to the input and output points and has a characteristic impedance. "Characteristic impedance" means that it involves the impedance of the entire electrical circuit, taken between said input and output points. This characteristic impedance comprises a resistance and reactance that are characteristic of the electrical circuit. The characteristic reactance in turn comprises an inductive component (or characteristic inductance) and capacitive component (or characteristic capacitance). It will be noted that each of the characteristic inductance and capacitance can be zero.

The configuration module 6 is able to configure the interconnections of the connectors 24 according to the first configuration of the interconnection surface 4.

25 The configuration module 6 is able to configure, over time, the interconnections of the connectors 24 according to a new configuration of the interconnection surface 4. The configuration module 6 is therefore able to modify, over time, the current configuration of the interconnection surface 4 in order to obtain a new configuration of the interconnection surface 4 and to reconfigure all of the interconnections of the connectors 24 according to the second configuration.

30 The configuration module 6 is able to determine, randomly, each configuration from among a plurality of configurations of the interconnection surface 4.

Preferably, each configuration is chosen from among a plurality of factory tested and validated configurations to avoid configuration errors or nonoptimal configurations. In this case, the determination of each configuration is pseudo-random, i.e., although the possible configurations are known, the multiplicity of the configurations does not make it possible to anticipate which configuration will be chosen by the configuration module 6.

The configuration module 6 is further able to modify the configuration of the interconnection surface 4 when an intrusion attempt is detected by the detection module 8.

5 In this case, the configuration module 6 is for example able to modify the configuration of the interconnection surface 4 so as to increase the number of groups of cells connected in the zone of the mesh surface 2 where an intrusion attempt has been detected. Such an increase in the number of groups of cells and therefore of continuous electrical circuits in an area is called "tightening of the mesh" in the zone. Tightening the mesh in a zone makes it possible to make the use of short-circuits even more complex to
10 free an access area to the zone to be protected.

Alternatively, the configuration module 6 is able to increase or decrease the number of cells of a group over part of the interconnection surface 4 based on a predefined rule, a state or an event.

15 Alternatively and/or additionally, the configuration module 6 is activated at moments chosen randomly, pseudo-randomly or periodically by the timer of the protection device 1, which makes it more difficult for an attacker to anticipate the configuration of the interconnection surface 4.

Alternatively and/or additionally, the configuration module 6 is able to modify the configuration of the interconnection surface 4 so as to move, over time, over one or each
20 mesh surface 2, the zone of the mesh surface 2 having the highest number of groups of connected cells. A zone dense with groups of cells and therefore electrical circuits in fact makes it possible to detect an intrusion more easily. Conversely, such a zone uses more resources to operate. The movement of such a zone therefore makes it possible to strike a compromise between detection fineness of an intrusion and consumption of the
25 protection device 1.

When the interconnection surface 4 comprises the programmable component 23, the configuration module 6 is for example a software application integrated into the programmable component 23.

30 When the interconnection surface 4 comprises a micro-electromechanical system piloted by actuators, the configuration module 6 is able to actuate the actuators.

The detection module 8 is capable of detecting a modification of an impedance which is characteristic of each electrical circuit. Any intrusion being characterized by a modification of the impedance of an electrical circuit, for example a modification of its resistance (in particular in case of a break in the electrical continuity within a group of
35 connected cells) or its reactance (in particular in case of the introduction of the probe in

the core of an inductive cell), the detection module 8 is therefore capable of detecting intrusions.

5 In this first embodiment, the detection module 8 is capable of detecting a break in the electrical continuity within each group of connected cells along the interconnection surface 4. To that end, the detection module 8 typically uses the so-called "dry loop" technique, or a transmission-reception of a signal, or a latency measurement.

Preferably, the detection module 8 is also capable, still in this first embodiment, of detecting a modification of the characteristic reactance of each electrical circuit, and more particularly of its characteristic inductance.

10 To that end, the detection module 8 is able to periodically command the production, by the generator 7, of at least one electrical excitation signal, so as to excite one of the electrical circuits, to measure a characteristic value of the response of the electrical circuit to said excitation signal, to calculate the difference between the or each measured value and a reference value, and to detect a change in the characteristic
15 electrical reactance in the event the calculated difference or a mean of the calculated differences exceeds a predetermined threshold.

An electrical excitation signal typically consists of a voltage step. "Voltage step" means that it is an electrical signal consisting of an abrupt variation of the voltage at the input of the electrical circuit, the input voltage next being kept at a substantially constant
20 value for a predetermined duration.

According to a first alternative, the measured characteristic value is then a duration for the voltage of the electrical output signal after the excitation of the electrical signal by the voltage step to reach a reference voltage. The reference value is a reference duration that is for example equal to a mean of several durations each measured after the
25 excitation of the electrical circuit by a voltage step and at the end of which the voltage of the output signal is substantially equal to the reference voltage.

In a second option, the measured characteristic value is then a voltage reached after a given duration following the excitation of the electrical circuit by the voltage step, said given duration being shorter than the duration of the voltage step. The reference
30 value is a reference voltage that is for example equal to a mean of several voltages each measured a same duration following the excitation of the electrical circuit by a voltage step identical to the excitation signal used by the detection module 8.

Advantageously, the detection module 8 is able to use the methods for detecting the break in the electrical continuity and detecting the change in the characteristic
35 reactance in a combined manner according to a defined time interleaving, which may be pseudo-random or random.

The detection module 8 is configured to be activated at a regular frequency, at least equal to the reconfiguration frequency of the interconnections of the connectors 24 by the configuration module 6.

5 Alternatively, the detection module 8 is activated at moments chosen randomly or pseudo-randomly by the timer of the protection device 1.

The detection module 8 is configured to apply a security policy following the detection of a modification of the impedance of an electrical circuit. The security policy for example comprises erasing sensitive data from the equipment protected by the protection device 1, activating additional tests, such as integrity tests for the mesh surfaces 2 or reconfiguring interconnections of the connectors 24 following a new configuration of the interconnection surface 4 in order to provide additional detection.

The reaction module 10 is connected to the detection module 8.

15 The reaction module 10 makes it possible to trigger a reaction action in response to an intrusion attempt in the protection device 1 detected by the detection module 8. For example, the reaction module 10 is configured to erase the sensitive data present in the electronic circuit 84, to activate additional tests and/or to initiate a reconfiguration of the interconnections of the connectors 24.

20 The timer is advantageously a low-consumption timer. In order for the overall consumption to remain low, the ratio between the awake and sleep periods of the configuration module 6 and/or the detection module 8 activated by the timer is for example about 1 per 1000, i.e., 1 millisecond awake for one second of sleep, nevertheless with very small deviations between the awakenings relative to the time to implement an attack.

A method for protecting the electronic circuit 84 using the protection device 1 according to the first embodiment will now be described, in reference to figure 8.

25 Initially, the protection method comprises a step 100 for providing the protection device 1 as previously described. This step 100 is preferably followed by a step 102 for initial calibration of the detection module 8, during which the or each reference value is determined that will be used to detect the change of the characteristic reactance of the circuit.

30 Next, the protection method comprises a step 110 for determining, using the configuration module 6, a first configuration of the interconnection surface 4.

Then, during the following step 120, the configuration module 6 configures the interconnections of the connectors 24 of the interconnection surface 4 according to the first configuration of the interconnection surface 4 previously determined during step 110.

35 Next, during the following step 130, the detection module 8 is activated in order to detect any change in the impedance on each electrical circuit formed by the groups of

cells 3A, 3B electrically interconnected by the connectors 24 according to the first configuration of the interconnection surface 4, and in particular to detect any break in the electrical continuity on each of said groups of cells. The detection module 8 is for example activated at a moment chosen randomly by the timer.

5 Preferably, the activation step 130 is followed by the following steps:

- a step 132 for producing at least one electrical excitation signal of the electrical circuit, and
- a step 134 for measuring a characteristic value of the response of the electrical circuit to the excitation signal.

10 According to a first alternative of the protection method, corresponding to the illustration shown in figure 8, step 134 is followed by the following steps:

- a step 136 for comparing the or each measured characteristic value with a corresponding reference value, and
- a step 138 for detecting a change of the characteristic impedance when a difference between a measured value and the corresponding reference value exceeds a predetermined threshold.

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According to a second alternative of the protection method, not shown, steps 132 and 134 are reiterated so as to take a plurality of measurements of the or each characteristic value, then followed by the following steps:

- 20 - calculating a mean of the measurements of the or each characteristic value,
- comparing, for each measured characteristic value, the mean of the measurements of said characteristic value with a corresponding reference value, and
- detecting a change of the characteristic impedance when a difference between
- 25 the mean of the measurements of a characteristic value and the corresponding reference value exceeds a predetermined threshold.

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When the detection module 8 detects a change in the impedance of an electrical circuit, for example a break in the electrical continuity of this circuit, the detection module 8 communicates, during a step 140, with the reaction module 10. The reaction module 10 then takes protective actions on the electronic circuit 84.

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Next, steps 110 to 140 are repeated over time. The configuration module 6 is for example activated at moments chosen randomly by the timer. The configuration of the interconnection of the connectors 24 done by the configuration module 6 during step 110 alternatively for example depends on the state of the system or a detected event.

Thus, the interconnections between the connectors 24 are reconfigured over time, which makes it possible to obtain new configurations of the interconnection surface 4 and to detect any short-circuits of several different equipotential cells.

5 Alternatively, the detection module 8 is activated several times between two configurations, by the configuration module 6, of the interconnections of the connectors 24 of the interconnection surface 4. The activation of the configuration module 6 is in fact independent of the activation of the detection module 8.

10 The second embodiment of the invention will now be described in reference to figures 9 to 12. This second embodiment differs from the first embodiment described above only by the features outlined below.

Unlike the first embodiment, the interconnection surface 4 is, in this second embodiment, suitable for the input and output points to remain electrically isolated from one another. Thus, the electrical circuits formed by the connection of the cells 3A, 3B to each other each have an electrical discontinuity.

15 This electrical discontinuity is obtained by the fact that the electrical circuit comprises at least one pair of cells 30 formed by two of the cells 3A, 3B electrically isolated from each other, said cells 3A, 3B nevertheless being electromagnetically coupled to each other. This pair 30 thus has a coupling impedance between the cells 3A, 3B of the pair.

20 Preferably, at least one pair of cells 30 exists, hereinafter called "inductive pair", for which this electromagnetic coupling is an inductive coupling, i.e., the coupling impedance between the cells 3A, 3B of this pair comprises an inductance. To that end, the two cells 3A, 3B of the inductive pair 30 are inductive cells, a first of said cells 3A, 3B being a primary cell 3A and the second cell of the pair being a secondary cell 3B that is substantially vertically aligned with the first cell.

25 Alternatively or optionally, there is at least one pair of cells 30, hereinafter called "capacitive pair", for which this electromagnetic coupling is a capacitive coupling, i.e., the coupling impedance between the cells 3A, 3B of the pair of cells comprises a capacitance. To that end, the conducting tracks of the cells 3A, 3B of the capacitive pair 30 typically both have a rake-shaped geometric pattern, as shown in figure 12. Preferably, at least one capacitive pair exists whereof a first of said cells 3A, 3B is a primary cell 3A and the second cell is a secondary cell 3B that is substantially vertically aligned with the first cell. Alternatively or optionally, at least one capacitive pair exists whereof the cells 3A, 3B both belong to the same mesh surface 2A or 2B, said cells 3A, 3B then being embedded in one another, as shown in figure 13.

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If at least one capacitive pair and at least one inductive pair exist, an excitation signal used to detect a modification of the characteristic reactance of the electrical circuits is preferably an alternating signal whose frequency varies over time. The measured characteristic value is then typically a quality factor of the electrical circuit.

To measure the quality factor of the electrical circuit, the detection module 8 is able to determine a resonance frequency of the electrical circuit and a bandwidth of the electrical circuit. To that end, the detection module 8 is able to measure the amplitude of the output signal captured by the sensor 9 for each of the values assumed by the frequency of the electrical excitation signal, and to determine:

- the resonance frequency as being the frequency of the excitation signal for which the amplitude of the output signal is maximal, and
- the bandwidth as being the frequency width, including the resonance frequency, for which the ratio of the amplitude of the output signal to the amplitude of the maximum output signal is greater than a predetermined value, typically 0.5.

The reference value is then a reference quality factor that is typically measured in the factory when the protection device 1 is produced.

Alternatively, the measured characteristic value is only the resonance frequency of the electrical circuit. The reference value is then a reference resonance frequency measured in the factory when the protection device 1 is produced.

Alternatively or optionally, an excitation signal used to detect a modification of the characteristic reactance consists of an alternating signal having a predetermined frequency. The measured characteristic value is then an amplitude of the electrical output signal captured by the sensor 9 during the excitation of the electrical circuit by the excitation signal, and the reference value is a reference amplitude that is typically equal to an amplitude of the electrical output signal measured in the factory when the protection device 1 is produced and while the electrical circuit was excited by an electrical signal at the predetermined frequency.

Preferably, the interconnection surface 4 is, in this second embodiment, configured to keep the mesh surfaces 2A, 2B electrically isolated from each other. Each primary cell 3A is then electrically isolated from each secondary cell 3B; each primary cell 3A is, however, advantageously electromagnetically coupled to the secondary cell 3B, which is substantially vertically aligned with said primary cell 3A.

Advantageously, the interconnection surface 4 is also configured so that each primary cell 3A of an electrical circuit is substantially vertically aligned with a secondary cell 3B belonging to the same electrical circuit. This feature is illustrated by figures 10 and

11, in which the fill used is identical for each primary cell 3A and the secondary cell 3B that is vertically aligned with it.

Preferably, the primary cells 3A of the same electrical circuit are all electrically connected to each other and together form a primary mesh. Likewise, the secondary cells 3B of a same electrical circuit are advantageously all electrically connected to each other and together form a secondary mesh.

According to one preferred alternative of the second embodiment, the interconnection surface 4 is suitable for the input point to be electrically connected to at least one primary cell 3A of each electrical circuit. Thus, the cells directly excited by the electrical excitation signal of the generator 7 are all primary cells 3A, and the electrical signal circulating in the secondary cells 3B is only a signal induced by the inductive or capacitive coupling phenomena between the cells 3A, 3B.

According to the same preferred alternative, the output point is advantageously electrically connected to at least one secondary cell 3B of each electrical circuit.

Owing to the invention described above, the electronic circuit 84 is effectively protected against physical attacks with a simple and inexpensive mesh format that does not make the development and manufacturing phases of protection device 1 more complex. The interconnection surface 4 is programmed to renew itself as a function of time, which provides a considerable gain for the protection level contributed by the mesh.

In particular, the reconfiguration over time of the interconnections of the connectors 24 between the cells 3A, 3B of the mesh surfaces 2A, 2B makes it possible to limit attacks by reverse engineering and to thus make the use of shunts ineffective to short-circuit the electrical circuits of the mesh. Furthermore, the knowledge acquired by an attacker regarding the system is only partially reusable to develop an attack on another system.

Furthermore, the mesh surfaces 2A, 2B and the interconnection surface 4 form a physical protective barrier for the electronic circuit 84, the configuration module 6 and the detection module 8.

Additionally, the tightening function of the mesh in zones susceptible to attack makes it possible to reinforce the protection of the electronic circuit 84.

Moreover, the tightening of the mesh at a zone of interest is particularly useful in case of optimized management of the number of available resources, i.e., optimization of the number of inputs and outputs of the interconnection surface 4.

The protection device 1 therefore resolves the problem of increasing the complexity of the meshes of the state of the art by reconfiguring interconnections of the

connectors 24 of the interconnection surface 4 over time. The geometry of the mesh is thus specific to a piece of equipment to be protected and varies over time.

The frequency of the reconfigurations, by the configuration module 6, of the interconnections of the connectors 24 of the interconnection surface 4 is also adaptable
5 based on the level of protection desired for the electronic system 80 or the estimated attack risks.

The protection device 1 also makes it possible to keep the energy consumption at an acceptable level and to make the protection lasting, even when the equipment of the protection device 1 is powered by a backup power source for a long period.

10 Lastly, by detecting changes in the electrical resistance of the circuits formed by the connection of the cells to each other, the protection device 1 makes it possible to detect intrusion attempts targeting isolating regions between the conducting tracks or involving the individual short-circuit of each cell of a set of cells covering a zone of interest, which was not possible with the existing solutions. The protection of the
15 electronic circuit 84 is therefore reinforced.

One skilled in the art will understand that the invention is not limited to the described embodiments, or to the specific examples of the description.

Thus, in one alternative of the invention, not shown, at least one electrical circuit is formed by the connection, which is not reconfigurable by the configuration module 6, of at
20 least two adjacent cells 3 of a mesh surface 2 via a component previously statically configured in the factory. A component previously statically configured is a component unalterably integrated into the protection device 1 during its manufacture. Each group of cells connected to each other by a component previously statically configured forms a macrocell. The macrocells have the advantage of limiting the number of interconnections
25 of the connectors 24 of the interconnection surface 4. A component statically configured is a component unalterably integrated into the protection device 1 during its manufacture. Each group of cells connected to each other by a component statically configured forms a macrocell. The macrocells connected to each other by the configuration module 6 have the advantage of limiting the number of interconnections of the connectors 24 of the
30 interconnection surface 4.

In this alternative, the interconnections of the connectors 24 of the interconnection surface 4 are defined statically in part for certain groups of cells and dynamically for others.

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CLAIMS

1.- A protection device (1) for protecting an electronic circuit (84), the protection device (1) comprising:

- 5 - at least one mesh surface (2A, 2B), the or each mesh surface (2A, 2B) comprising at least one cell (3A, 3B) consisting of a continuous portion of electrical circuit (20), the cell(s) (3A, 3B) being distributed on the mesh surface (2A, 2B), and
- 10 - at least one electrical circuit, comprising:
- an input for injecting an electrical signal for exciting the electrical circuit,
- an output for capturing an electrical output signal from the electrical circuit, and
- between said input and said output, at least one of said cells (3A, 3B),
- 15 the electrical circuit having an electrical reactance between its input and its output, characterized in that the protection device (1) comprises a detection module (8) able to detect a change of said electrical reactance.

2.- The protection device (1) according to claim 1, wherein the detection module (8) is able to detect a change of an inductive component of the electrical reactance.

20 3.- The protection device (1) according to claim 1 or 2, wherein the detection module (8) is able to detect a change of a capacitive component of the electrical reactance.

4.- The protection device (1) according to claim 1, 2 or 3, wherein the detection module (8) is able to periodically command the production of at least one electrical excitation signal to excite the electrical circuit, to measure a characteristic value of the response of the electrical circuit to said excitation signal, to calculate the difference between the or each measured value and a reference value, and to detect a change in the electrical reactance in the event the calculated difference or a mean of the calculated differences exceeds a predetermined threshold.

30 5.- The protection device (1) according to claim 4, wherein an electrical excitation signal consists of a voltage scale, and the characteristic value of the response of the electrical circuit to said excitation signal consists of a duration so that, after the excitation of the electrical circuit by said voltage scale, the voltage of the electrical output signal reaches a reference voltage.

35 6.- The protection device (1) according to claim 4 or 5, wherein an electrical excitation signal consists of a voltage scale, and the characteristic value of the response

of the electrical circuit to said excitation signal consists of a voltage of the electrical output signal reached after a predetermined duration following the excitation of the electrical circuit by said voltage scale.

5 7.- The protection device (1) according to any one of claims 4 to 6, wherein an electrical excitation signal consists of an alternating signal whose frequency varies over time, and the characteristic value of the response of the electrical circuit to said excitation signal consists of a resonance frequency of the electrical circuit.

10 8.- The protection device (1) according to any one of claims 4 to 6, wherein an electrical excitation signal consists of an alternating signal whose frequency varies over time, and the characteristic value of the response of the electrical circuit to said excitation signal consists of a quality factor of the electrical circuit.

15 9.- The protection device (1) according to any one of claims 4 to 8, wherein an electrical excitation signal consists of an alternating signal having a predetermined frequency, and the characteristic value of the response of the electrical circuit to said excitation signal consists of an amplitude of the electrical output signal.

10.- The protection device (1) according to any one of the preceding claims, wherein the electrical circuit comprises a plurality of cells (3A, 3B).

20 11.- The protection device (1) according to claim 10, wherein the cells (3A, 3B) of the electrical circuit comprise at least two cells (3A, 3B) electrically isolated from each other, said cells (3A, 3B) being electromagnetically coupled to each other.

25 12.- The protection device (1) according to any one of the preceding claims, wherein the mesh surfaces (2A, 2B) comprise a primary mesh surface (2A), comprising primary cells (3A), and a secondary mesh surface (2B), comprising secondary cells (3B) electrically isolated from the primary cells (3A), and the electrical circuit comprises at least one primary cell (3A) and at least one secondary cell (3B) electromagnetically coupled to each other.

13.- The protection device (1) according to claim 12, wherein said primary and secondary cells (3A, 3B) of the electrical circuit are electromagnetically coupled to each other at least by induction.

30 14.- The protection device (1) according to any one of the preceding claims, comprising:

- at least one interconnection surface (4) comprising a plurality of connectors (24), the connectors (24) being suitable for connecting cells (3A, 3B) of the mesh surface(s) (2A, 2B) to each other so as to form the or each electrical circuit, and

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- a configuration module (6) for configuring the interconnections of the connectors (24), able to command the connectors (24) to modify the connection of the cells (3A, 3B) to each other over time.

5 15.- A method for protecting an electronic circuit (84), characterized in that it comprises the following steps:

- providing (100) a protection device (1) according to any one of claims 4 to 9,
- calibrating (102) the detection module (8), during which the or each reference value is determined,
- 10 - producing (132) at least one electrical excitation signal to excite the electrical circuit,
- measuring (134) a characteristic value of the response of the electrical circuit to the excitation signal,
- comparing (136) the or each measured characteristic value with a corresponding reference value, and
- 15 - detecting (138) a change of the characteristic impedance when a difference between a measured value and the corresponding reference value exceeds a predetermined threshold.