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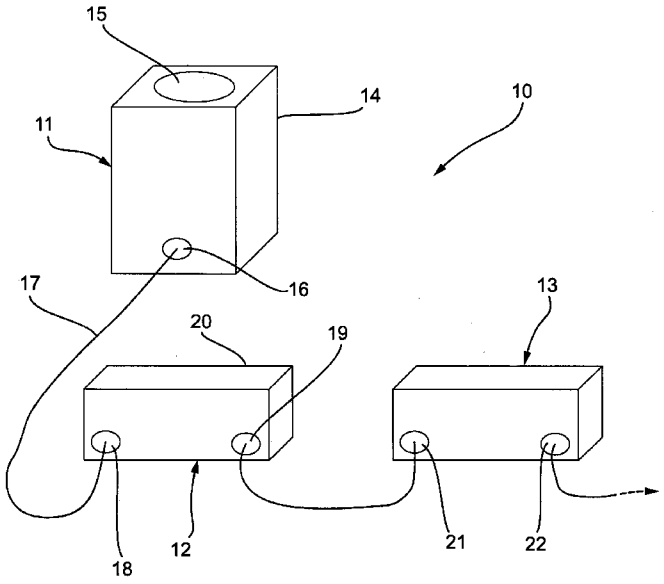
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(54) **Title:** ELECTROMAGNETIC PULSE DETECTOR AND METHOD OF USE

Fig. 1



(57) **Abstract:** An electromagnetic pulse detector (10) comprising an antenna (11) and a means for processing pulses (12), wherein the antenna (11) is configured to receive an electromagnetic pulse and to generate therefrom a dispersed electrical pulse, the means for processing pulses (12) being configured to operate on the dispersed electrical pulse. The reduced temporal burden on the means for processing pulses (12) facilitates relatively low cost signal processing. Particularly suited to detection of electromagnetic pulses over a wide geographic area.

[Continued on next page]

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ELECTROMAGNETIC PULSE DETECTOR AND METHOD OF USE

Technical Field of the Invention

This invention relates to the field of electromagnetic pulse detection, in particular to detectors suitable for detecting high magnitude electromagnetic pulse events.

Background to the Invention

An electromagnetic pulse event is characterised by the presence of a temporally short (often nanosecond) but high intensity burst of electromagnetic radiation (an electromagnetic pulse). Electromagnetic pulses may be generated as a result of a nuclear explosion, lightning strike, or other sudden and intense electrical discharge phenomena. The electric field and energy associated with an electromagnetic pulse can have damaging effects on electrical equipment and/or persons in proximity to the pulse. Therefore there exists a requirement to provide warning of electromagnetic pulse events, and particularly to infer from the characteristics of an electromagnetic pulse, the nature of the event itself.

The development of transient electromagnetic pulse detectors has focussed on providing means for characterising an electromagnetic pulse. These detectors attempt to preserve the quality of a received electromagnetic pulse such that high speed electronics can extract from the signal a variety of parameters such as pulse duration and pulse profile. These parameters may themselves then be used to infer the associated electromagnetic pulse event. Such precision does however come at increased financial cost to the end user, making prior art pulse detectors impractical for certain applications (such as if establishing large geographic arrays of detectors). Furthermore the requirement to preserve the received pulse for subsequent processing requires highly efficient antennas, the high efficiency making the antennas and subsequent processing electronics more vulnerable to damage from the powers experienced during a pulse event. As such, additional signal conditioning electronics are required to buffer received pulses, adding cost, complexity and size to these prior art devices.

Therefore it is an aim of the present invention to provide an alternative electromagnetic pulse detector.

Summary of the Invention

According to a first aspect of the invention there is provided an electromagnetic pulse detector comprising an antenna and a means for processing pulses, wherein the antenna is configured to receive an electromagnetic pulse and to generate therefrom a dispersed pulse, the means for processing pulses being configured to operate on the dispersed pulse.

An antenna converts electromagnetic radiation to an electrical signal. In particular the antenna converts an electromagnetic pulse to an electrical pulse. Prior art electromagnetic pulse detectors use highly efficient antennas to ensure the characteristics of the electromagnetic pulse are precisely replicated in the resultant electrical pulse. This is such that high speed processing electronics can extract pulse characteristics such as pulse width from the electrical pulse, in order to determine the type of electromagnetic event being experienced. The inventor has shown that for certain applications of electromagnetic pulse detectors, it is only necessary to indicate whether an electromagnetic pulse has been detected or not (for instance has a pulse of sufficient magnitude been observed), and not necessarily to extract its characteristics. In these applications very high speed analysis of the received pulse is not required, and therefore the conversion of an electromagnetic pulse to an electrical pulse can be made deliberately inefficient by configuring an antenna to generate a dispersed electrical pulse. A dispersed pulse will have a longer temporal duration than the electromagnetic pulse itself, owing to the temporal dispersion of the various frequency components in the received pulse. A dispersed electrical pulse reduces the demand placed on subsequent signal processing electronics, thereby reducing the overall cost of an electromagnetic pulse detector.

The means for processing pulses operates on the dispersed pulse and therefore is intended to comprise electrical circuitry. The means for processing pulses receives the dispersed pulse and outputs an indication as to whether a particular form of electromagnetic pulse has been observed. The means for processing pulses may store such indications locally, for

instance within memory, for subsequent download or transmittal. Such embodiments are suited to applications of the pulse detector where an electromagnetic environment is being measured over time (for instance lighting storm measurements). Alternatively the means for processing pulses may immediately relay such indications to a remote receiver. Such embodiments are well suited to applications where the pulse detector is being used to warn of a particular electromagnetic event, for the purposes of protecting national infrastructure.

In preferred embodiments of the invention, the antenna comprises an omnidirectional antenna element. Prior art pulse detectors generally seek to provide an indication as to the direction from which an electromagnetic pulse is received, and as such will use directional antennas for this purpose. However, high pulse powers can damage directional antennas and subsequent processing electronics when electromagnetic energy is relatively efficiently converted to electrical energy. The inventor has shown that an omnidirectional antenna mitigates the risk of damage to detector components by providing a lower but omnidirectional gain performance, rather than a high gain directional performance. For particular applications of the invention, directionality is not required and as such a suitable choice of antenna type can be used to mitigate damage whilst not reducing required functionality.

In even more preferred embodiments of the invention, the omnidirectional antenna element is a spiral antenna element. A spiral antenna element provides the required dispersion characteristics, whilst also providing wideband frequency operation.

Some embodiments of the invention provide the antenna as a cavity backed antenna. A cavity backed antenna can be used to provide some directionality to an omnidirectional antenna element (increase gain towards an intended transmit or receive direction). In particular the cavity backed antenna may be used to ensure only radiation from a hemisphere is received and processed. A cavity backed antenna generally comprises an antenna element, a cavity back plate, and cavity walls. The cavity defined by the element, back plate and walls, may additionally be filled with a cavity filler. The cavity backed antenna may be used to ensure radiation is not received by the antenna element from certain directions, thereby providing further protection for the pulse detector in high power

electromagnetic pulse environments, and mitigating the likelihood of other ambient effects-such as static discharges – from falsely triggering a response.

The cavity of the cavity backed antenna, in certain embodiments of the invention, may contain radar absorbing material. The radar absorbing material acts to absorb radiation entering the cavity from being reflected back to the antenna element. The use of radar absorbing material further mitigates the risk of too greater coupling of radiative energy into the antenna and thereby damaging the pulse detector or subsequent processing electronics.

In certain embodiments of the invention the antenna further comprises a strip line balun. When the antenna receives an electromagnetic pulse, that pulse is converted to an electrical pulse which must be electrically transmitted to the means for processing pulses. The antenna may be unbalanced with respect to impedance and therefore a direct electrical connection to the means for processing pulses may result in undesirable electrical signal reflections at the boundaries of differing signal impedance. A balun provides a means for balancing impedance between the fed components of the antenna and the means for processing pulses. Strip line or printed circuit board baluns are relatively simple to manufacture when compared to other types of baluns, in particular they can be tailored more readily to wideband impedance matching (such as in embodiments of the invention comprising a spiral antenna). In even more preferred embodiments the strip line balun comprises a Klopfenstein taper. This form of taper provides impedance transformation over a large range of frequencies.

In preferred embodiments of the invention the means for processing pulses comprises pulse stretching electronics. The function of the pulse stretching electronics is to receive the dispersed pulse from the antenna and to further lengthen the temporal duration of the pulse, prior to further signal processing. These embodiments of the invention further reduce the temporal demand on subsequent signal processing electronics.

In even more preferred embodiments of the invention, the pulse stretching electronics comprise a logarithmic detector. A logarithmic detector provides at its output a DC level that is the logarithm of the envelope of an input signal. A logarithmic detector may have a

finite response time, and as such any pulsed signal received at the input that has temporal features (such as rise times) occurring over a temporal duration less than this, will be stretched at the output of the detector. Logarithmic detectors are typically specified to meet the temporal requirements of an input signal, however the inventors have shown that deliberately underspecifying the requirements of a logarithmic detector can be used to advantageously stretch a pulse to enable subsequent lower cost signal processing.

In some embodiments of the invention the logarithmic detector has a video bandwidth less than a pulse bandwidth of the electromagnetic pulse. The video bandwidth of a logarithmic detector characterises a 'low-pass filter' function of the detector. The video bandwidth is a cut-off frequency below which signal frequencies are passed with relatively uniform gain, but above which frequencies are heavily attenuated. A pulse may be considered to be formed from a plurality of sinusoidal components of different frequencies. The pulse bandwidth is intended to be the highest frequency of a sinusoid necessary to resolve the pulse. If the video bandwidth is deliberately specified to be less than the pulse bandwidth, high frequency components of a pulse input to the logarithmic detector are attenuated, and the resultant output electrical pulse appears stretched. For instance electromagnetic pulses may have rise times of fractions of a nanosecond, and a logarithmic detector can be deliberately configured not to pass the associated high frequency components with high gain. These embodiments further stretch a received electromagnetic pulse to reduce the burden on down-line electronics.

In some embodiments of the invention, the means for processing pulses comprises an adaptive threshold comparator. The function of the comparator is to receive the dispersed pulse following any pulse stretching processing and to compare the magnitude of the pulse to a predetermined value. If the magnitude of the pulse exceeds the predetermined value, the comparator outputs an electrical signal indicating that an electromagnetic pulse has been detected. If the magnitude of the pulse does not exceed the predetermined value, the comparator does not output an electrical signal. The comparator being adaptive is intended to mean it can be configured to operate with any one of a plurality of predetermined threshold values which may be set by a user of the electromagnetic pulse detector. A comparator provides a means for identifying whether an electromagnetic pulse of interest

has been observed. The predetermined value used by the comparator may be adjusted remotely by a user of the pulse detector, for instance by interrogating the pulse detector using a wireless or wired link.

A detection of an electromagnetic pulse by the electromagnetic pulse detector may be stored in internal memory within the pulse detector. The detections may then be read from the internal memory periodically by a user of the pulse detector. Preferred embodiments of the invention further comprise a communication module, such that a detection of an electromagnetic pulse can be communicated to a receiver remote to the pulse detector. The communication module receives the electrical signals indicating detections of electromagnetic pulses, from the means for processing pulses. These electrical signals may be received by means of an optical isolator. The communication module then transmits the detections either wirelessly or using wired or optical fibre, to a receiver remote to the pulse detector. The receiver may be a wireless receiver or optical receiver attached to a data processing device. Preferably the communication module comprises an optical transceiver for this purpose. The provision of a communication module enables the electromagnetic pulse detector to be deployed remotely and to provide indications of electromagnetic pulse events to a remote receiver, as they are detected.

Some embodiments of the invention may be powered from an external power source, however preferred embodiments comprise an on-board power supply. The on-board power supply may be a Lithium battery. An on-board power source enables remote deployment of the electromagnetic pulse detector. A casing, providing environmental protection, may also be provided in some embodiments. The casing provides protection to the electronics of the pulse detector from weather conditions, but also provides electromagnetic shielding.

In certain embodiments the electromagnetic pulse detector may further comprise means for recovering energy from a received electromagnetic pulse. Whilst temporally short in duration, electromagnetic pulses from many electromagnetic pulse events have substantial peak powers. Energy from a received pulse may be harvested for the purposes of powering the electromagnetic pulse detector. In these embodiments an on-board power supply may not be required, or at least the on-board power requirement could be minimised.

According to a second aspect of the invention there is provided a pulse detector array, comprising a plurality of the electromagnetic pulse detectors of the first aspect of the invention, arranged to be geographically remote to each other. The electromagnetic pulse detectors in the array are separated from each other and intended to be disposed over a geographical area. Such an array can be used to monitor electromagnetic pulse activity in more than one location simultaneously, with each detector recording pulse activity in isolation, or relaying electromagnetic pulse detections as they are made to a remote receiver. Such an array can be implemented at relatively low cost in comparison to prior art pulse detectors, owing to the ability to use relatively low cost signal processing electronics.

According to a third aspect of the invention there is provided a method of detecting an electromagnetic pulse, the method comprising the steps of: providing an electromagnetic pulse detector comprising an antenna and a means for processing pulses; receiving and dispersing an electromagnetic pulse using the antenna, thereby generating a dispersed electrical pulse; and then operating the means for processing pulses to detect an electromagnetic pulse event.

In preferred embodiments of the third aspect of the invention the step of operating the means for processing pulses comprises the steps of: comparing a magnitude of the dispersed electrical pulse to a predetermined threshold value; and then storing or communicating a detection of an electromagnetic pulse event if the magnitude of the dispersed electrical pulse exceeds the predetermined threshold value.

A detection of an electromagnetic pulse event may be a binary signal (for instance a 5V DC signal) output by a comparator when the magnitude (for instance voltage magnitude) of the dispersed pulse exceeds the predetermined threshold value. The detection may be used to increment a counter provided in internal memory within the pulse detector. Alternatively the date and time of the detection may be stored in internal memory. Alternatively the detection may be transmitted to a remote receiver via a suitable transmitter (such as an optical transceiver and fibre optic line).

In even more preferred embodiments of the third aspect of the invention the step of operating the means for processing pulses further comprise the step of stretching the dispersed electrical pulse using pulse stretching electronics.

Brief Description of the Drawings

Embodiments of the invention will now be described by way of example only and with reference to the accompanying drawings, in which:

Figure 1 provides an illustration of an embodiment of an electromagnetic pulse detector;
Figure 2 provides an illustration of an array of the pulse detectors of Figure 1;
Figure 3 provides an illustration of pulse dispersal and stretching operations in the electromagnetic pulse detector of Figure 1; and
Figure 4 provides an illustration of an embodiment of a spiral antenna.

Detailed Description

Figure 1 illustrates an embodiment of an electromagnetic pulse detector 10 comprising an antenna 11, a means for processing pulses 12 and a communication module 13. The antenna 1 comprises a logarithmic spiral antenna element 15 with a cavity backing 14. The spiral antenna 15 is a printed circuit board antenna. The cavity backing 14 is formed from metal to provide electromagnetic shielding, and contains radar absorbing material. The spiral antenna element 15 is connected to a Klopfenstein tapered stripline balun (not visible) also made from a printed circuit board. The balun (not visible) resides inside cavity backing 14 and is further connected to antenna output port 16. Coaxial cable 17 connects antenna output port 16 to input port 18 of means for processing pulses 12. The means for processing pulses 12 comprises a hardened enclosure 20 providing electromagnetic shielding to pulse stretching electronics (not visible) inside enclosure 20. The pulse stretching electronics (not visible) are electrically connected to input port 18 and to an 8GHz detector log-video amplifier comprising a 200MHz adaptive threshold comparator (also not visible). The adaptive threshold comparator is electrically connected to a 50Mbaud digital optical transmitter at output port 19. Fibre optic cabling connects means for processing pulses 12

to communications module 13 between output port 19 and input port 21. Communications module 13 is a 50Mbaud optical relay unit. Communications module 13 then connects to a remote monitoring station using further fibre optical cabling 22.

Figure 2 illustrates how a plurality of electromagnetic pulse detectors (23, 24, 25) can be deployed remotely to each other as a detector array, and connected using fibre optic cables to a centralised means for processing data 26. In use such an array provides a pulse detection capability across a wide geographic area.

Figure 3 illustrates the functional operation of the electromagnetic pulse detector 10 of Figure 1 in use. The functional operation 30 of the spiral antenna 11 is to receive from the electromagnetic environment an electromagnetic pulse (Receive EMP) and convert that pulse to a dispersed electrical pulse (Pulse Dispersal). The spiral antenna 11 is deliberately chosen as a suitable antenna for dispersing a pulse. The functional operation 31 or the means for processing pulses 12 is to receive the dispersed pulse and apply further pulse stretching (Pulse Stretching). This is achieved through use of pulse stretching circuitry (for instance cascaded circuits charging and discharging capacitors through resistors). The resultant stretched pulse is then amplified (Amplification) before being passed through an adaptive threshold comparator (Threshold Comparison). A user of the electromagnetic pulse detector 10 will pre-set the threshold for comparison. When the stretched and amplified pulse is above the threshold a signal high (for instance a TTL signal high) is output by the threshold comparator. When the stretched and amplified pulse is below the threshold a signal low (for instance a TTL signal low) is output. The resultant signal from the comparator is used to drive an optical isolator, thereby outputting an optical signal to the communications module 13. This ensures the communications module 13 and means for processing pulses 12 are isolated from each other electrically (thereby adding additional protective mitigation for the communications module 13 and subsequent processing systems/equipment). The functional operation 32 of the communications module 13 is to optically relay (Optical Relay) the received optical signal from the means for processing pulses 12 to further geographically remote data processing equipment.

Figure 4 provides an illustration of an exemplar logarithmic spiral antenna 40 in printed circuit board format as is used for antenna 11 of pulse detector 10.

The embodiments of the invention described are not intended to be limiting. Other antenna elements may be used that provide similar wideband and dispersal performance. The embodiments shown use optical relays to communicate the detection of an electromagnetic pulse to a remote processing unit. However the ongoing detection of an electromagnetic pulse may instead be stored locally at the pulse detector through use of analog to digital converters and on-board memory. This may mean a communications module is not required for some tasks (for instance the means for processing pulses may have integral memory). A user can thus deploy the electromagnetic pulse detector at a location and collect it at a later date for data download analysis. The electromagnetic pulse detector may be powered by mains power or by integral battery if being deployed remotely, or may harvest some energy from the received electromagnetic pulse. The electromagnetic pulse detector may be used as a detector in wider electrical circuitry, for instance safety circuitry, to trigger shutdown or electrical isolation of equipment during intense electromagnetic activity. The pulse detector may be interrogated by software held remotely on a computer system in order to gather status information, or data stored on-board the means for processing pulses. This interrogation may be performed using an optical link or alternatively using wireless connectivity (for instance a long range WiFi connection).

CLAIMS

1. An electromagnetic pulse detector comprising an antenna and a means for processing pulses, wherein the antenna is configured to receive an electromagnetic pulse and to generate therefrom a dispersed electrical pulse, the means for processing pulses being configured to operate on the dispersed electrical pulse.

2. The electromagnetic pulse detector of claim 1 wherein the antenna comprises an omnidirectional antenna element.

3. The electromagnetic pulse detector of claim 2 wherein the omnidirectional antenna element is a spiral antenna element.

4. The electromagnetic pulse detector of any one of claims 2-3 wherein the antenna is a cavity backed antenna.

5. The electromagnetic pulse detector of claim 4 further comprising radar absorbing material within a cavity of the cavity backed antenna.

6. The electromagnetic pulse detector of any preceding claim wherein the antenna further comprises a stripline balun.

7. The electromagnetic pulse detector of claim 6 wherein the stripline balun has a Klopfenstein taper.

8. The electromagnetic pulse detector of any preceding claim wherein the means for processing pulses comprises pulse stretching electronics.

9. The electromagnetic pulse detector of claim 8 wherein the pulse stretching electronics comprises a logarithmic detector.

10. The electromagnetic pulse detector of claim 9 wherein the logarithmic detector has a video bandwidth less than a pulse bandwidth of the electromagnetic pulse.

11. The electromagnetic pulse detector of any preceding claim wherein the means for processing pulses comprises an adaptive threshold comparator.

12. The electromagnetic pulse detector of any preceding claim further comprising a communication module, such that a detection of an electromagnetic pulse can be communicated to a receiver remote to the pulse detector.

13. The electromagnetic pulse detector of claim 12 wherein the communication module comprises an optical transceiver.

14. The electromagnetic pulse detector of any preceding claim further comprising an on-board power supply.

15. The electromagnetic pulse detector of any preceding claim further comprising means for recovering energy from an electromagnetic pulse.

16. The electromagnetic pulse detector of any preceding claim further comprising a casing, the casing providing environmental protection to the pulse detector.

17. A pulse detector array, comprising a plurality of the electromagnetic pulse detectors of any preceding claim arranged to be geographically remote to each other.

18. A method of detecting an electromagnetic pulse, comprising the steps of:
    a) providing an electromagnetic pulse detector comprising an antenna and a means for processing pulses;
    b) receiving and dispersing an electromagnetic pulse using the antenna, thereby generating a dispersed electrical pulse; and then
    c) operating the means for processing pulses on the dispersed electrical pulse to detect an electromagnetic pulse event.

19. The method of claim 18 wherein the step of operating the means for processing pulses comprises the steps of:
    a) comparing a magnitude of the dispersed electrical pulse to a predetermined threshold value; and then
    b) storing or communicating a detection of an electromagnetic pulse event if the magnitude of the dispersed electrical pulse exceeds the predetermined threshold value.

20. The method of claim 19 wherein the step of operating the means for processing pulses further comprises the step of:
    a) Stretching the dispersed electrical pulse using pulse stretching electronics.

Fig. 1

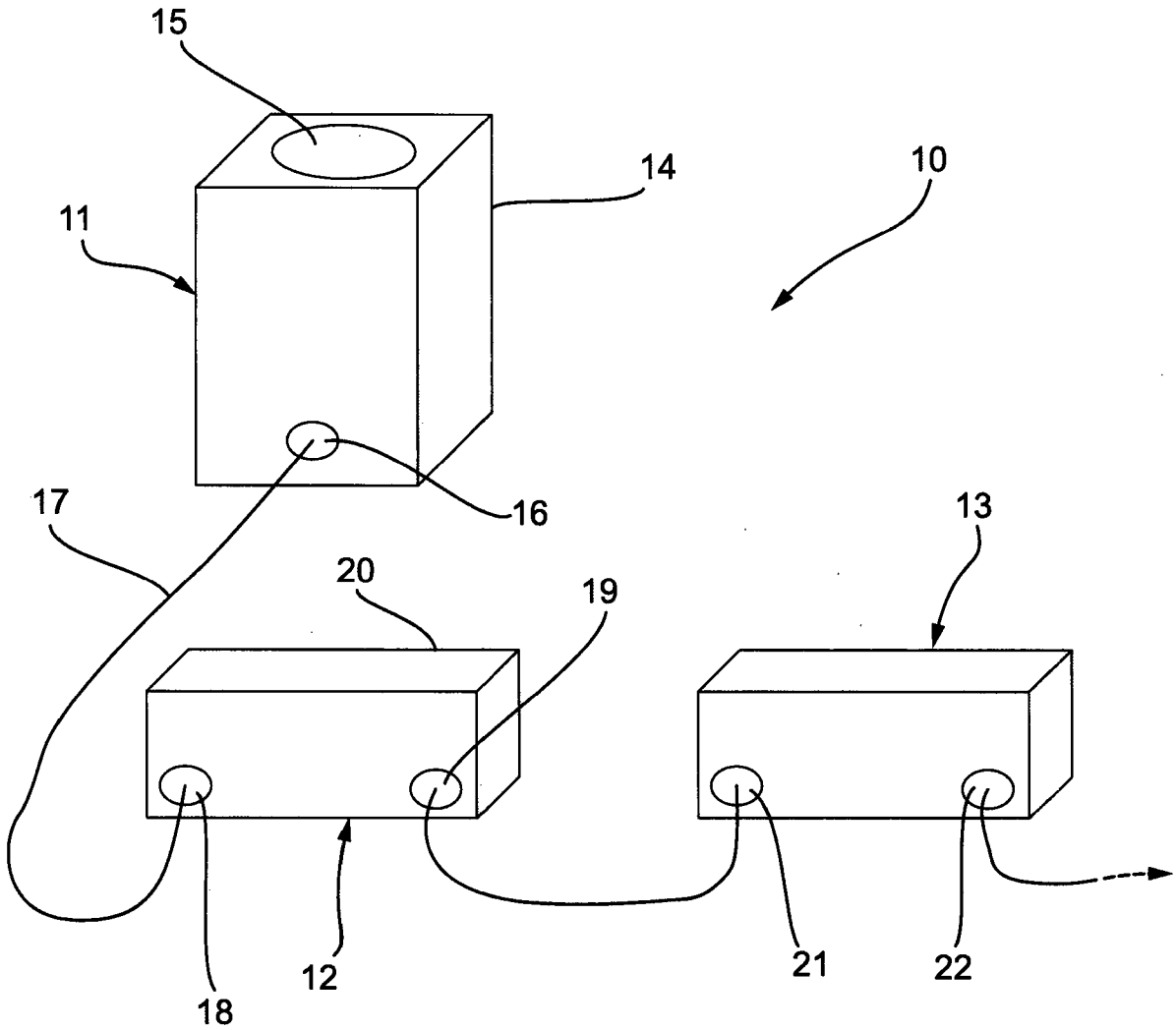


Fig. 2

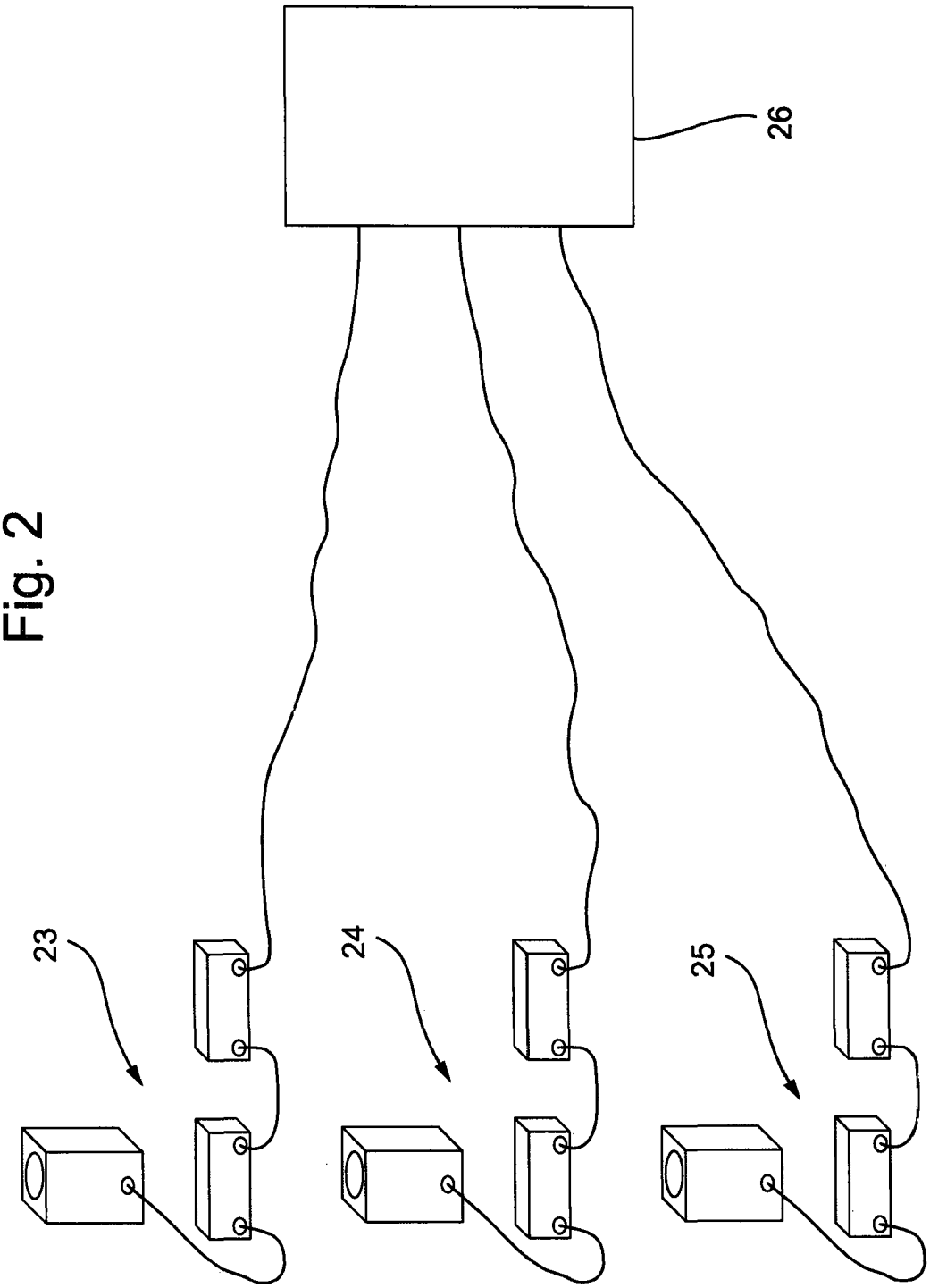


Fig. 3

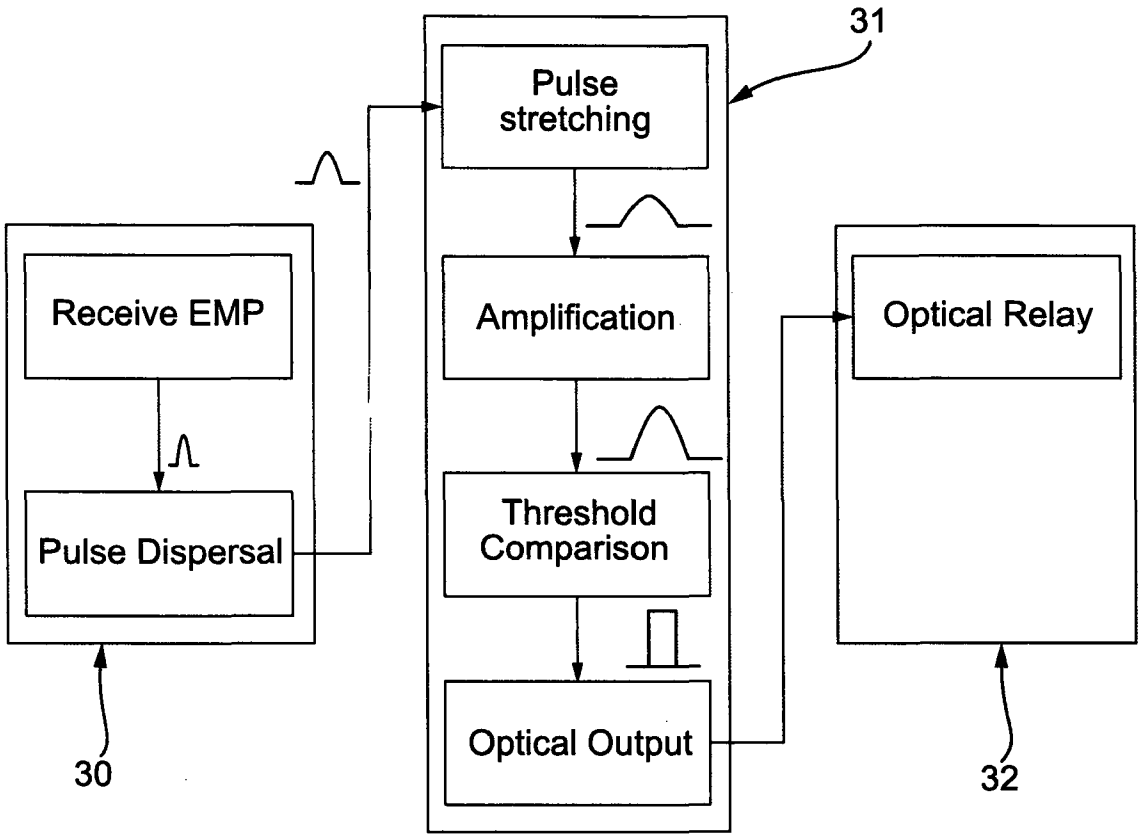
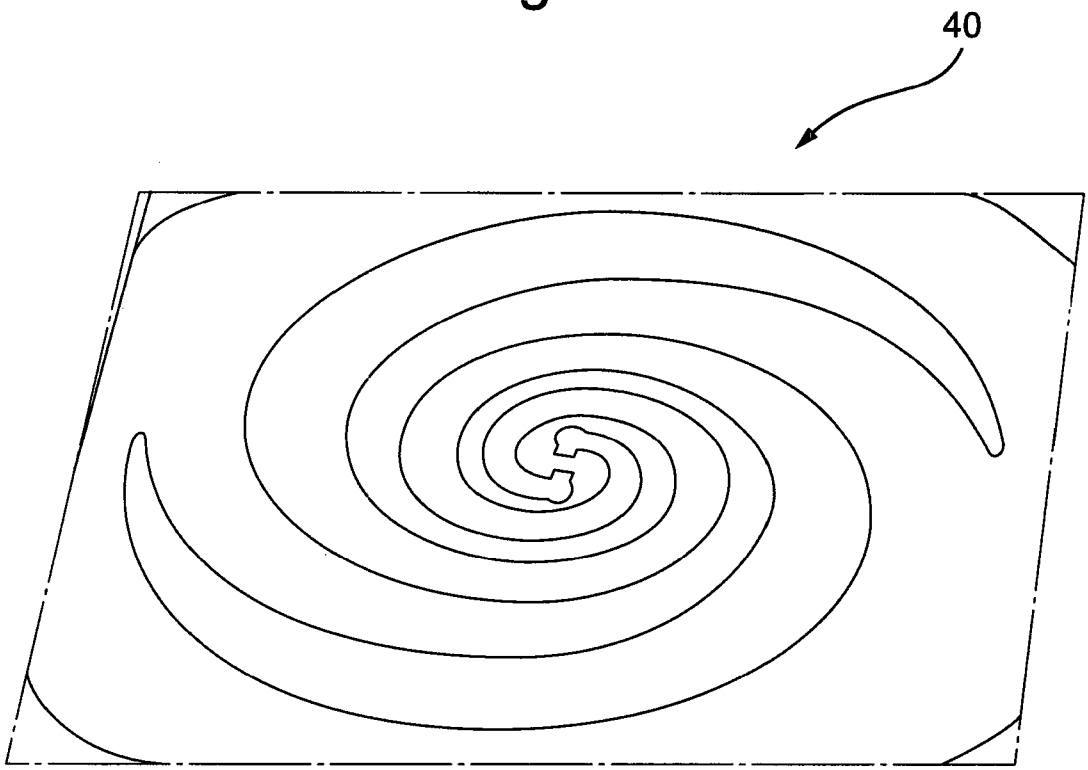

31
Pulse stretching
Amplification
Threshold Comparison
Optical Output
Receive EMP
Pulse Dispersal
Optical Relay
30
32

Fig. 4



INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2019/000170

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01R29/08
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)
G01R H02J

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

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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Date of the actual completion of the international search	Date of mailing of the international search report
12 March 2020	23/03/2020

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Meliani, Chafik

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Form PCT/ISA/210 (second sheet) (April 2005)

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