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(54) **Title:** SWITCH CIRCUIT, METHOD FOR OPERATING A SWITCH CIRCUIT AND AN AUTOMATED TEST EQUIPMENT

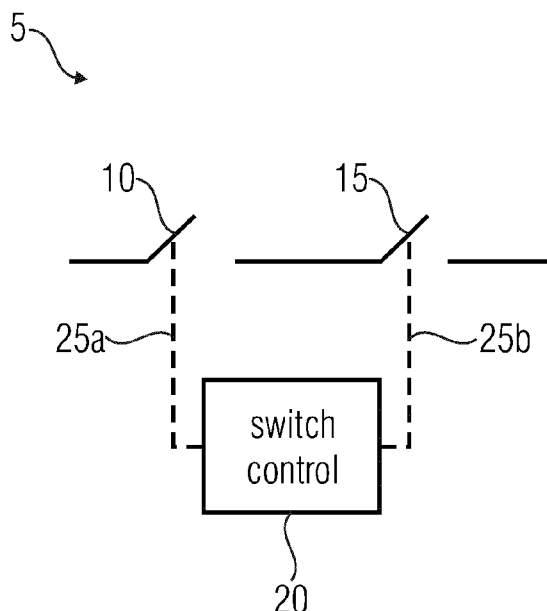


FIG 1

(57) **Abstract:** It is shown a switch circuit 5. The switch circuit 5 comprises at least a first and a second switch element 10, 15 connected in series and a switch control 20 configured for providing control signals 25a, b for switching the first and the second switch element 10, 15, such that the control signals 25a, b comprise a different timing and such that the first and the second switch element 10, 15 perform one joint switch function.

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— *with international search report (Art. 21(3))*

Switch Circuit, Method for Operating a Switch Circuit and an Automated Test Equipment

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Specification

Embodiments of the present invention relate to a switch circuit, a method for operating a switch circuit and an automated test equipment. Further embodiments relate to a switch
10 capability extension for MEMS protection.

An ATE (automatic test equipment) environment for semiconductor test uses a very large number of analog signal switch elements in a very small form factor. In addition, a very high switching cycle counts and a high level of reliability is required. The industry offers
15 different solutions to address this market:

- Classical mechanical and Reed Relays
- MEMS switches
- Photo MOS switches
- 20 • FET Switches
- Semiconductor switches

Each of the technologies has its strengths and weaknesses for certain applications, but there is no one-size fit for everything. The idea presented in this document tries to take
25 advantage by combining two or more switches to mitigate problems or to overcome the limitations imposed by the properties of a particular technology.

Mechanical Reed Relays have been used for signal paths switching inside of measurement equipment for many years. These mechanical relays are slow and tend to
30 break down relatively fast. Using MEMS devices can improve the switching speed and number of switching cycles in this application.

However, MEMS devices have a very limited lifetime if they are used in applications which require switching of signals with a significant voltage amplitude into a low impedance load

(e.g., into 50 Ω). The problem becomes even worse if the switched signal has a DC component.

Therefore, there is the need for an improved approach. It is an object of the invention to provide an improved concept to build switches. This object is solved by the subject matter of the independent claims.

According to a first embodiment, a switch circuit comprises at least a first and a second switch element connected in series, and a switch control for providing control signals for switching the first and the second switch elements, such that the control signals comprise a different timing and such that the first and the second switch element perform one joint switch function. The second switch element may be of a different type when compared to the first switch element.

Teachings disclosed herein are based on the fundamental idea that combining two switches can perceive the advantages of both switches and to overcome their disadvantages. For example, a MEMS switch which has a high DC isolation is vulnerable for a multiple hot-switching operation. Furthermore, e.g., a photo MOS switch is robust against multiple hot-switching, and comprises a strongly temperature dependent leakage effect. A combination of both switches using a common switch controller leads to a joint switch function being robust against multiple hot-switching and having very low leakage.

Embodiments show a switch circuit comprising at least a first and a second switch element of a different type when compared to the first switch element, wherein the second switch element is connected in series to the first switch element. Additionally, the switch circuit comprises a switch control configured for providing control signals for the first and the second switch, such that the first and the second switch perform one joint switch function. Therefore, the control signals comprise a different timing to perform the joint switching operation. Performing a joint switch function using two distinct switches is advantageous, since one of the switches can protect the other switch against harmful treatments, e.g. due to multiple hot-switching.

According to further embodiments, the first switch element is configured for robustly hot-switching an analog signal. This may be performed by a metal oxide semiconductor (MOS) switch or, more specifically, by a photo MOS switch. This is advantageous, since

the first switch element is able to toggle an analog signal multiple times, which would be potentially harmful for the second switch element.

Embodiments show the second switch comprising a better isolation when compared to the first switch. Therefore, the second switch may be a micro electro mechanical (MEMS) switch. It is advantageous, since the second switch provides a low leakage, especially a low DC leakage and therefore provides a high internal resistance, e.g., when performing measures on a device in an idle mode.

Further embodiments show the switch control switching the second switch element in an absence of an electrical current. Therefore, the switch control may switch the first switch element to control the current flow through the second switch element. To be more precise, the switch control may close the second switch prior to the first switch if the first and the second switch are open and to open the second switch prior to the first switch if the first and the second switch are closed. This is advantageous since the second switch can be toggled in an idle mode, i.e., without an impressed voltage.

Further embodiments show an automated test equipment comprising a signal path between a device under test connection and an instrument and further comprises a switch element according to one of claims 1-12, wherein the switch element is included in the signal path.

Embodiments of the present invention will be discussed subsequently referring to the enclosed drawings, wherein:

Fig. 1 shows a schematic block diagram of the switch circuit;

Fig. 2 shows a schematic block diagram of an automatic test equipment comprising a switch circuit;

Fig. 3 shows a schematic timing diagram of a first switch element, a second switch element, and an analog signal flow through the first and the second switch element;

Fig. 4 shows a schematic block diagram of a method for operating the switch circuit.

Embodiments of the present invention will be discussed in detail below, wherein identical reference numbers are provided to objects having identical or similar functions, so that the description thereof is interchangeable or mutually applicable.

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Without limiting the conception, the following description will focus on a specific application for an analog signal switching path.

The example used to explain the concept is targeting an analog signal path for a mixed
10 signal test instrument. This application shows:

- a. low leakage to allow accurate DC measurements when the switching element is off
- b. switching of a signal which has DC and AC components if the switch is closed
- c. a large number of switching cycles
- 15 d. high level of AC isolation

Fig. 1 shows a schematic block diagram of a switch circuit 5. The switch circuit 5 comprises at least a first and a second switch element 10, 15 connected in series and a switch control 20. The switch control 20 is configured to provide control signals 25a, b for
20 switching the first and the second switch element 10, 15, such that the control signals 25a, b comprise a different timing and such that the first and the second switch element 10, 15 perform one joint switch function. A joint switch function means that, by default, the first and the second switch element 10, 15 are both open or closed. During switching (or toggling) the state of the first and the second switch element may be different. For
25 example, if the first and the second switch are closed, the first switch 10 may open and after a current flow state, the second switch element 15 can be opened as well. Preferably, the second switch element 15 is of a different type when compared to the first switch element.

30 According to a further embodiment, the switch circuit 5 comprises at least a first and a second switch element 10, 15, wherein the second switch element is of a different type when compared to the first switch element 10, and wherein the second switch element is connected in series to the first switch element. Furthermore, the switch circuit 5 comprises a switch control 20 to provide control signals 25a, b for the first and the second switch 10,
35 15, such that the first and the second switch perform one joint switch operation.

Additionally, the control signals 25a, b may comprise a different timing to perform the joint switching operation. Again, a joint switching operation means that usually the first and the second switch element 10, 15 are in the same state, i.e., both are open or closed. Only during a switching operation, the state of the first and the second switch may be different.

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It was stated in the already described embodiments that the first and the second switch element 10, 15 are of a different type. A different type means that either the first or the second switch element comprises at least one technical advantage compared to the other switch element. A technical advantage may be, for example, an internal resistance, a leakage current, robustness against switching, e.g., hot-switching, or the heating of the switch element.

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According to embodiments, the first switch element 10 is configured for robustly hot-switching an analog signal. Therefore, the first switch element 10 may be a metal oxide semiconductor (MOS) switch, especially a photo MOS switch. A semiconductor switching element 10 could satisfy the second requirement, i.e., the switching of a signal which has DC and AC components, if the switch is closed (i.e., hot-switching). Nonetheless, the first switch element may comprise a strongly temperature dependent leakage, which is preferably avoided and therefore prevents the usage of such a switching element as a single switch element.

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According to a further embodiment, the second switch element 15 comprises a better isolation when compared to the first switch element 10. Therefore, the second switch element 15 may be a micro electro mechanical (MEMS) switch. MEMS switches offer a high number of switching cycles, good isolation, and almost no leakage. However, MEMS switches expose problems with hot-switching if operated with large amplitude signals or significant DC offset on the switching signal. A combination of two switches, for example, with a photo MOS switch as a first switch element 10 and a MEMS switch as a second switch element 15, can satisfy the complete list of requirements which have been described previously.

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Further embodiments are related to the switch control 20. The switch control provides the control signals 25a, b to the first switch element 10 and the second switch element 15, respectively. An exemplary switch control sequence is presented in Fig. 2. However, the switch control 20 is configured to switch the second switch element in an absence of an electrical current. Therefore, the switch control 20 may switch the first switch element to

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control the current flow through the second switch element 15. More specifically, the switch control 20 may close the second switch element 15 prior to the first switch element 10 if the first and the second switch elements 10, 15 are open and to open the second switch element 15 prior to the first switch element 10 if the first and the second switch element 10, 15 are closed.

Fig. 2 shows a schematic block diagram of an automated test equipment 30. The automated test equipment 30 comprises a signal path 35 between a device under test connection and an instrument 70. The device under test connection is located at a device under test 40. The switch element 5 is part of the signal path 35. The automated test equipment 30, which comprises an instrument 70, forms a signal 45 using a AC and/or DC current. The switch circuit 5 blocks the signal 45 from the device under test 40 if the first switch element 10 and the second switch element 15 are opened, or it allows the signal 45 to pass the switch circuit 5 to the device under test 40 if the first and the second switch element 10, 15 are closed.

Furthermore, the automated test equipment 30 may comprise a switch 50 and a phase measurement unit 55. If the switch 50 is closed, the phase measurement unit 55 is able to perform measurements on the device under test 40. For measurements in an idle mode of the device under test 40, it is advantageous that the second switch element 15 has a large inner resistance in order to enable reliable measurements of the device under test 40. As a side information, the dashed line 60 indicates the instrument boundary, where the automatic test equipment 30 is on the left hand side and the device under test 40 is on the right hand side.

Fig. 3 shows a schematic timing diagram with a switch control sequences 10' for the first switch element 10 and a switch control sequences 15' for the second switch element 15. Additionally, an exemplary wave form of the signal 45 is presented as well. The switch control sequence 15' for the MEMS switch 15 closes prior and opens after the semiconductor switch 10. This sequence ensures that the current flow 45 through the MEMS device 15 is very much limited by the closed semiconductor switch 10 at the switching time 65a. As a result, the hot-switching stress for the MEMS device 15 is severely reduced. In other words, the switch control timing is used to ensure the desired behavior, e.g., in case of serial switches, the sequence can be used to reduce hot-switching during switch turn-on as well as during turn-off or can allow glitch less switching. When both switches 10, 15 are open, the leakage is limited by the MEMS 15 and no

longer by the photo MOS 10. The usage of multiple switch elements forming a single switch and the proper control timing of the switching sequence allows generating a switching solution which can combine the strength of the individual switches. The embodiment with a photo MOS and a MEMS device has been built as a hardware prototype in the lab. Tests with a mix of AC+DC signals switching has been performed successfully. The configuration of the switch elements reduces the current flow through the second switch at the moment of switching and such enhances the lifetime of MEMS switches significantly. This setup was operated for more than 200 million cycles successfully. The same test condition has caused very fast damages and limited lifetime for the MEMS device stand-alone.

Furthermore, Fig. 3 shows the timings 65a to 65f illustrating the previously described timing. It is shown that the second switch element 15 opens 65a prior to the first switch element 10 65b enabling the signal flow 45 65c. Next, the first switch element 10 opens 65d prior to the second switch element 15 65f. In between, the signal flow 45 is stored 65e due to opening the first switch element 10.

Fig. 4 shows a schematic block diagram of a method 400 for operating a switch circuit comprising a first switch element and a second switch element which are connected in series. The method 400 comprises the step 405 "providing control signals for switching the first and the second switch element, such that the control signals comprise a different timing and such that the first and the second switch element perform one joint switch function". The method 400 may be implemented in a computer program for performing the method on a computer.

Depending on certain implementation requirements, embodiments of the invention can be implemented in hardware or in software. The implementation can be performed using a digital storage medium, for example a floppy disc, a DVD, a Blu-Ray, a CD, a ROM, a PROM, and EPROM, an EEPROM or a FLASH memory, having electronically readable control signals stored thereon, which cooperate (or are capable of cooperating) with a programmable computer system such that the respective method is performed. Therefore, the digital storage medium may be computer readable.

Some embodiments according to the invention comprise a data carrier having electronically readable control signals, which are capable of cooperating with a

programmable computer system, such that one of the methods described herein is performed.

Generally, embodiments of the present invention can be implemented as a computer
5 program product with a program code, the program code being operative for performing one of the methods when the computer program product runs on a computer. The program code may, for example, be stored on a machine readable carrier.

Other embodiments comprise the computer program for performing one of the methods
10 described herein, stored on a machine readable carrier.

In other words, an embodiment of the inventive method is, therefore, a computer program having a program code for performing one of the methods described herein, when the computer program runs on a computer.

15 A further embodiment of the inventive method is, therefore, a data carrier (or a non-transitory storage medium such as a digital storage medium, or a computer-readable medium) comprising, recorded thereon, the computer program for performing one of the methods described herein. The data carrier, the digital storage medium or the recorded
20 medium are typically tangible and/or non-transitory.

A further embodiment of the invention method is, therefore, a data stream or a sequence of signals representing the computer program for performing one of the methods described herein. The data stream or the sequence of signals may, for example, be
25 configured to be transferred via a data communication connection, for example, via the internet.

A further embodiment comprises a processing means, for example, a computer or a programmable logic device, configured to, or adapted to, perform one of the methods
30 described herein.

A further embodiment comprises a computer having installed thereon the computer program for performing one of the methods described herein.

35 A further embodiment according to the invention comprises an apparatus or a system configured to transfer (for example, electronically or optically) a computer program for

performing one of the methods described herein to a receiver. The receiver may, for example, be a computer, a mobile device, a memory device or the like. The apparatus or system may, for example, comprise a file server for transferring the computer program to the receiver .

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In some embodiments, a programmable logic device (for example, a field programmable gate array) may be used to perform some or all of the functionalities of the methods described herein. In some embodiments, a field programmable gate array may cooperate with a microprocessor in order to perform one of the methods described herein. Generally,

10 the methods are preferably performed by any hardware apparatus.

The above described embodiments are merely illustrative for the principles of the present invention. It is understood that modifications and variations of the arrangements and the details described herein will be apparent to others skilled in the art. It is the intent,

15 therefore, to be limited only by the scope of the impending patent claims and not by the specific details presented by way of description and explanation of the embodiments herein.

Claims

What is claimed is:

- 5 1. A switch circuit (5), comprising:
- at least a first and a second switch element (10, 15) connected in series;
- 10 a switch control (20) configured for providing control signals (25a, b) for switching the first and the second switch element (10, 15), such that the control signals (25a, b) comprise a different timing and such that the first and the second switch element (10, 15) perform one joint switch function.
- 15 2. The switch circuit (5) according to claim 1, wherein the second switch element (15) is of a different type when compared to the first switch element (10).
- 20 3. A switch circuit (5), comprising:
- at least a first and a second switch element (10, 15), wherein the second switch element is of a different type when compared to the first switch element (10), wherein the second switch element (15) is connected in series to the first switch element (10);
- 25 a switch control (20) configured for providing control signals (25a, b) for the first and the second switch (10, 15), such that the first and the second switch (10, 15) perform one joint switch function.
- 30 4. The switch circuit (5) according to claim 3, wherein the control signals (25a, b) comprise a different timing to perform the joint switching operation.
- 35 5. The switch circuit (5) according to one of the previous claims, wherein the first switch element (10) is configured for robustly hot-switching an analogue signal (45).
6. The switch circuit (5) according to one of the previous claims, wherein the first switch element (10) is a metal oxide semiconductor (MOS) switch.

7. The switch circuit (5) according to one of the previous claims, wherein the first switch element (10) is a Photo MOS switch.
- 5 8. The switch circuit (5) according to one of the previous claims, wherein the second switch element (15) comprises a better isolation when compared to the first switch element (10).
- 10 9. The switch circuit (5) according to one of the previous claims, wherein the second switch element (15) is a microelectromechanical (MEMS) switch.
10. The switch circuit (5) according to one of the previous claims, wherein the switch control (20) is configured to switch the second switch element (15) in an absence of an electrical current.
- 15 11. The switch circuit (5) according to one of the previous claims, wherein the switch control is configured to close the second switch element (15) prior to the first switch element (10) if the first and the second switch element (10, 15) are open and to open the second switch element (15) prior to the first switch element (10) if the first and the second switch element (10, 15) are closed.
- 20 12. The switch circuit (5) according to one of the previous claims, wherein the switch control (20) is configured to switch the first switch element (10) to control the current flow through the second switch element (15).
- 25 13. An automated test equipment (30) comprising:
- 30 a signal path (35) between a device under test connection and an instrument (70);
and
- a switch element according to one of claims 1-12, wherein the switch element is included in the signal path.
- 35 14. Method (400) for operating a switch circuit (5) comprising a first switch element (10) and a second switch element (15) which are connected in series, the method comprising:

providing control signals (25a, b) for switching the first and the second switch element (10, 15), such that the control signals (25a, b) comprise a different timing and such that the first and the second switch element (10, 15) perform one joint switch function.

15. Computer program having a program code for performing the method according to claim 14 when the computer program runs on a computer.

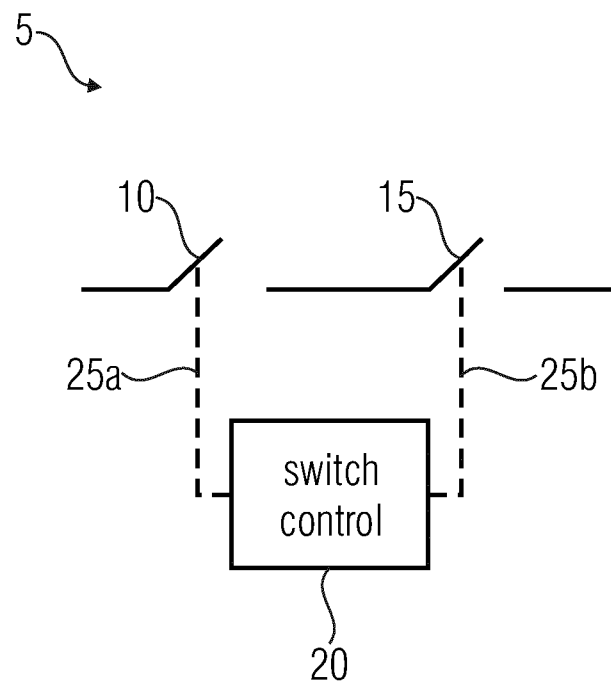


FIG 1

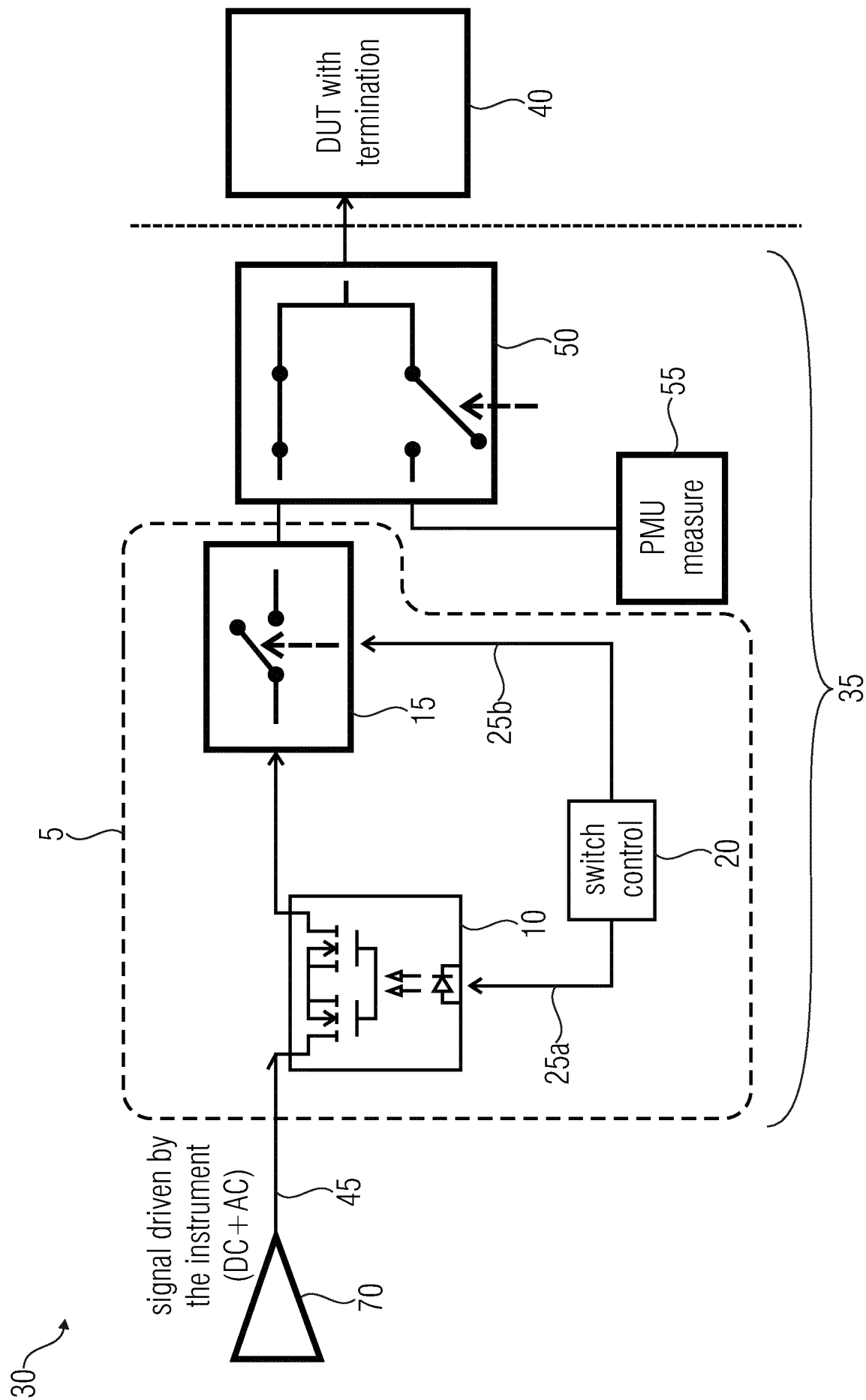


FIG 2

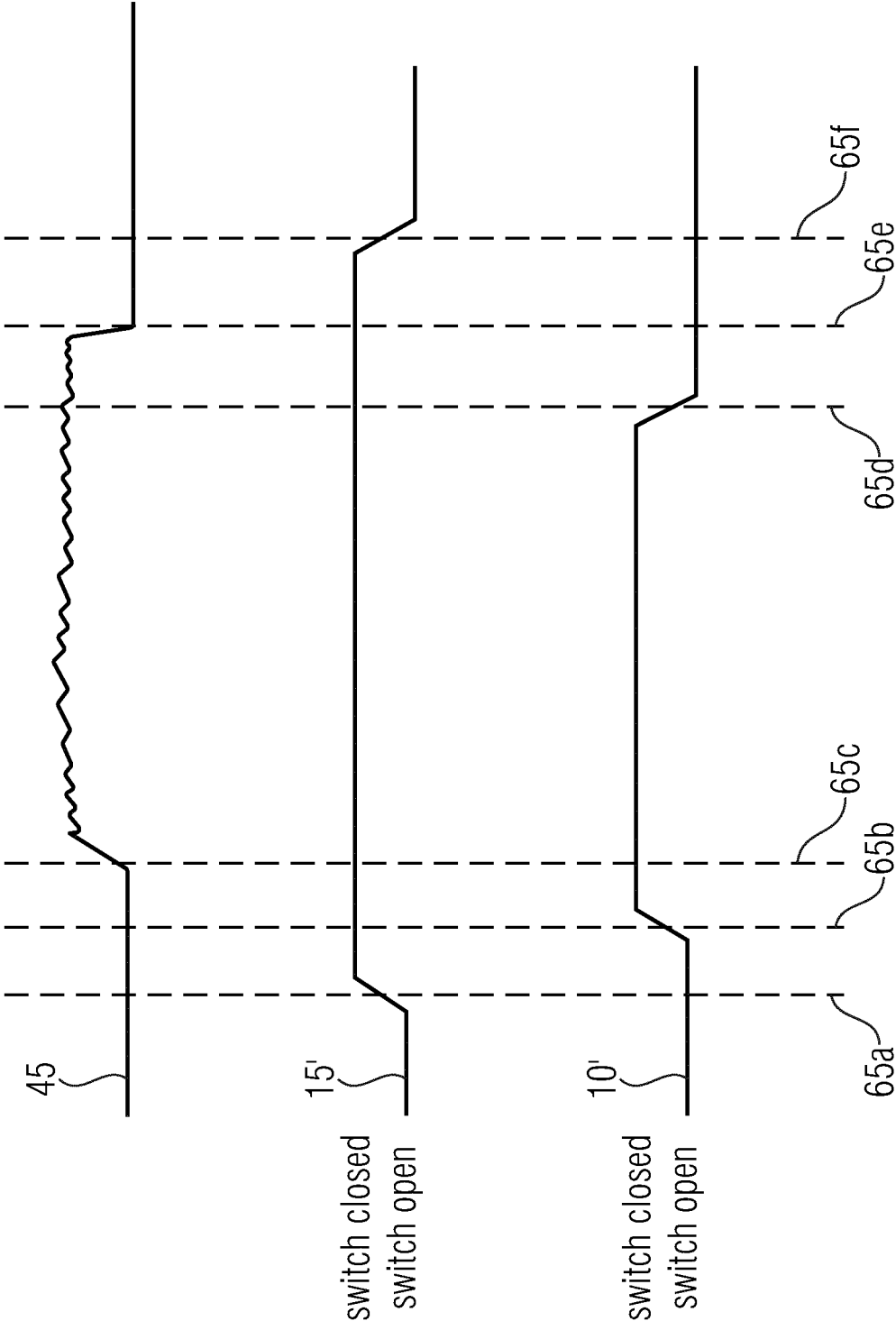


FIG 3

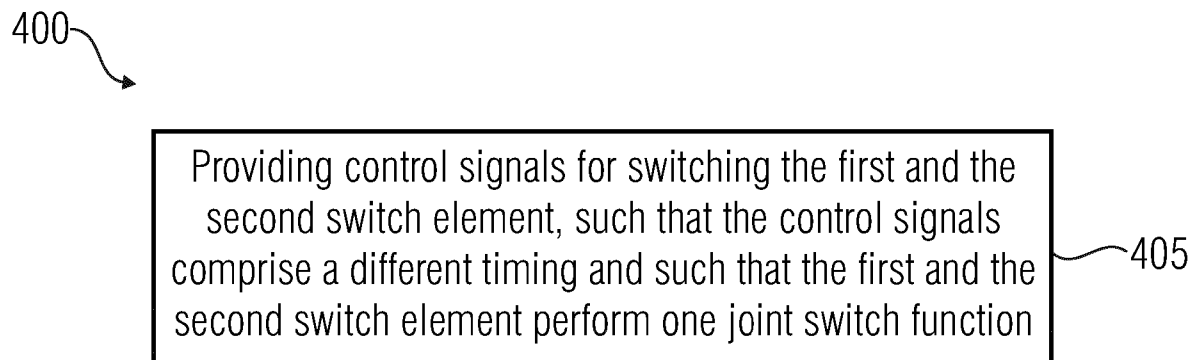


FIG 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/059107

A. CLASSIFICATION OF SUBJECT MATTER

INV. H01H47/00
ADD. H03K17/0812 H03K17/0814

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)

H01H H03K G01R

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.
X	US 2013/229068 A1 (SANDERS III JAMES J [US] ET AL) 5 September 2013 (2013-09-05) paragraph [0047] - paragraph [0048]; figures 1B, 3A, 3B paragraph [0110] - paragraph [0112] paragraph [0057] - paragraph [0061] paragraph [0080]	1-15
X	US 2009/272634 A1 (EHLERS ERIC R [US] ET AL) 5 November 2009 (2009-11-05) paragraph [0021] - paragraph [0025]; figures 1, 3 paragraph [0001] - paragraph [0003]	1-5, 8, 9
A		6, 7, 10-15
X	US 2005/068068 A1 (HALL JEFFERSON W [US]) 31 March 2005 (2005-03-31) paragraph [0010]; figure 2	1-6
A		7-15



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

7 January 2016

Date of mailing of the international search report

14/01/2016

Name and mailing address of the ISA/

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2015/059107

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