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(54) Title: METHOD AND SYSTEM FOR PERFORMING INDIRECT LIGHTNING TEST SIMULATION

(57) Abstract: A method and system for performing indirect lightning test simulation on an equipment under test (EUT) is disclosed. The method may include generating a simulation model of the EUT that may include a plurality of EUT interfaces, a plurality of end-load impedances, and a cable bundle connecting the plurality of EUT interfaces with the plurality of end-load impedances. The method may further include generating one or more lightning waveforms representative of induced lightning threats, using a discrete component-based pulse forming network, injecting the one or more lightning waveforms simultaneously to the plurality of EUT interfaces via the cable bundle through inductive coupling, and determining the effect of the one or more lightning waveforms on each of the plurality of EUT interfaces using a plurality of measuring device models connected to the plurality of EUT interfaces.

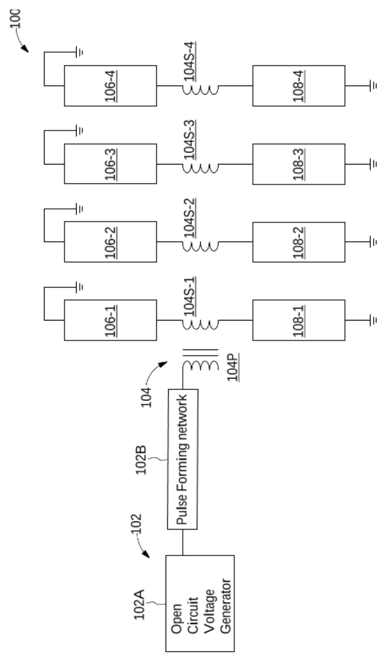

FIG. 1

FORM 2

THE PATENTS ACT 1970

(39 Of 1970)

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The Patent Rules, 2003

Complete Specification

(See Section 10 and Rule 13)

1. TITLE OF THE INVENTION

Method And System for Performing Indirect Lightning Test Simulation

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3. PREAMBLE TO THE DESCRIPTION

COMPLETE

The following specification particularly describes the invention and the manner in which it is performed**.**

DESCRIPTION

TECHNICAL FIELD

[001] This disclosure relates generally to an aerospace Electromagnetic Compatibility (EMC) testing, and more particularly to a system and method of performing indirect lightning test on an equipment under test (EUT) as per standards for the environmental conditions and testing of airborne equipment.

BACKGROUND

[002] Aircrafts and other airborne vehicles are susceptible to lightning risks during flight. Lightning can severely damage the various electrical and electronic equipment of the airborne vehicles that may even lead to their failure. It, therefore, becomes critical to test such electrical and electronic equipment during the design phase to verify if the equipment will be able to withstand lightning strikes. Various test standards are in place that lay out test procedures that the equipment must go through before use. For example, one such standard RTCA/DO-160 Section-22 describes different test conditions and requirements against indirect lightning effects. In order to perform the testing, test transient signals - representative of actual induced effects of lightning - may be injected into the equipment. The test standards define specific waveforms corresponding to the actual induced effects of lightning. As will be appreciated by those skilled in the art, an indirect lightning test may be based on a damage tolerance test performed by using a pin injection method, and a functional upset tolerance test performed by using a cable induction method. However, applying the cable induction method effectively may prove challenging.

[003] Some simulation techniques may be used for testing. However, the existing simulation techniques use prebuilt formula-based waveform generation model which do not take an actual behaviour of the physical generator into consideration. Further, the existing simulation techniques do not consider cable characteristics, for example, cable resistance or impedance, which may lead to reduced accuracy of simulation results. Furthermore, the existing simulation techniques do not consider the effect of applying lightning threats to multiple cables and interfaces simultaneously. This may create considerable gap between indirect lighting effect simulation results as compared to physical testing, which may further lead to under-designing or over-designing of the EUT.

SUMMARY OF THE INVENTION

[004] In an embodiment, a method of performing indirect lightning test simulation on an equipment under test (EUT) is disclosed. The method may include generating a simulation model of the EUT. The simulation model may include a plurality of EUT interfaces, a plurality of end-load impedances, and a cable bundle connecting the plurality of EUT interfaces with the plurality of end-load impedances. The method may further include generating one or more lightning waveforms using a discrete component-based pulse forming network. The one or more lightning waveforms are representative of induced lightning threats. The method may further include injecting the one or more lightning waveforms simultaneously to the plurality of EUT interfaces via the cable bundle through inductive coupling technique, and determining the effect of the one or more lightning waveforms on each of the plurality of EUT interfaces using a plurality of measuring device models connected to the plurality of EUT interfaces.

[005] In another embodiment, a system for performing indirect lightning test simulation on an EUT is disclosed. The system may include a processor and a memory coupled to the processor. The memory includes one or more processor-executable instructions, which upon execution by the processor, may cause the processor to generate a simulation model of the EUT. For example, the simulation model may be generated using a Simulation Program with Integrated Circuit Emphasis (SPICE)-based analog electronic circuit simulator tool. The simulation model may include a plurality of EUT interfaces, a plurality of end-load impedances, and a cable bundle connecting the plurality of EUT interfaces with the plurality of end-load impedances. The one or more processor-executable instructions may further cause the processor to generate one or more lightning waveforms using a discrete component-based pulse forming network. The one or more lightning waveforms are representative of induced lightning threats. The one or more processor-executable instructions may further cause the processor to inject the one or more lightning waveforms simultaneously to the plurality of EUT interfaces via the cable bundle through inductive coupling technique and determine the effect of the one or more lightning waveforms on each of the plurality of EUT interfaces using a plurality of measuring device models connected to the plurality of EUT interfaces.

BRIEF DESCRIPTION OF THE DRAWINGS

[006] The accompanying drawings, which are incorporated in and constitute a part of this disclosure, illustrate exemplary embodiments and, together with the description, serve to explain the disclosed principles.

[007] **FIG. 1** is a schematic diagram of a simulation model for performing indirect lightning test simulation on an equipment under test (EUT), in accordance with some embodiments of the present disclosure;

[008] **FIGs. 2A-2E** illustrate graphical representations of a plurality of lightning waveforms according to RTCA DO-160 standard, in accordance with some embodiments;

[009] **FIGs. 3A-3C** illustrate various circuits including discrete components for generating and verification of the Waveform-4, in accordance with some embodiments;

[010] **FIGs. 3D-3F** illustrate various plotted waveforms and verification plots, in accordance with some embodiments;

[011] **FIG. 4** illustrates a detailed schematic drawing of a simulation model of an environment for performing indirect lightning test simulation on an EUT, in accordance with some embodiments;

[012] **FIG. 5** illustrates an exemplary computing system that may be employed to implement processing functionality for various embodiments;

[013] **FIG. 6** is a block diagram of an indirect lightning test simulation device for performing indirect lightning test simulation on an EUT, in accordance with an embodiment; and

[014] **FIG. 7** is a flowchart of a method of performing indirect lightning test simulation on an EUT, in accordance with an embodiment.

DETAILED DESCRIPTION OF THE DRAWINGS

[015] Exemplary embodiments are described with reference to the accompanying drawings. Wherever convenient, the same reference numbers are used throughout the drawings to refer to the same or like parts. While examples and features of disclosed principles are described herein, modifications, adaptations, and other implementations are possible without departing from the spirit and scope of the disclosed embodiments. It is intended that the following detailed description be considered as exemplary only, with the true scope and spirit being indicated by the following claims. Additional illustrative embodiments are listed below.

[016] A method and a system for performing indirect lightning test simulation on an equipment under test (EUT) is disclosed. Simulation testing techniques provide multiple advantages for performing the indirect lightning test on the EUT, for example, of an aircraft. a simulation model of the EUT is created and lightning waveforms representative of lightning threats induced in the EUT are generated and applied to the EUT to study the effects of the lightning on the EUT. Based on the effects induced in the EUT, necessary design changes may then be performed to enable the EUT to better withstand lightning strikes. The present techniques allow for injecting lightning waveforms simultaneously to a plurality of EUT interfaces, to thereby allow study of combined effects of the lightning on the entire cable bundle.

[017] Referring to FIG. 1, a schematic diagram of a simulation model 100 for performing indirect lightning test simulation on an EUT is illustrated, in accordance with some embodiments of the present disclosure. The simulation model may be generated using a Simulation Program with Integrated Circuit Emphasis (SPICE)-based analog electronic circuit simulator tool. For example, the SPICE-based analog electronic circuit simulator tool may be LTspice® tool. As shown in FIG. 1, the simulation model 100 may include a waveform generator 102 which may further include an open circuit voltage generator 102A and a pulse forming network 102B. The waveform generator 102 may generate one or more lightning waveforms using pulse forming network 102B. In some embodiments, one or more lightning waveforms may be generated using a discrete component-based pulse forming network. As such, the pulse forming network 102B may be a discrete component-based pulse forming network. In other words, this discrete component-based pulse forming network may include a combination of discreet components, i.e. a combination of the one or more resistor models, one or more capacitor models, and one or more inductor models. The waveforms generated by the waveform generator 102 are further explained in conjunction with FIGs. 2A-2E and FIGs. 3A-3F.

[018] Referring now to FIGS. 2A-2E, a plurality of lightning waveforms that can be generated by the waveform generator 102 are illustrated, in accordance with some embodiment. **FIG. 2A** shows a graphical representation 200A current Waveform-1, as per RTCA DO-160 standard. As shown in FIG. 2A, the waveform peaks at T1=6.4 microseconds (with tolerance limits between +20% and -20%) and drops to 50% of the current peak value at T2 = 69 microseconds (with tolerance limits between +20% and -20%). **FIG. 2B** illustrates a graphical representation 200B of a voltage Waveform-2, as per RTCA DO-160 standard. The voltage Waveform-2 peaks at T1 = 100 nanoseconds and drops to 0 value at T2 = 6.4 microseconds (with tolerance limits between +20% and -20%). **FIG. 2C** illustrates a graphical representation 200C of a voltage Waveform-4, as per RTCA DO-160 standard. The voltage Waveform-4 peaks at T1=6.4 microseconds (with tolerance limits between +20% and -20%) and drops to 50% of the peak voltage value at T2 = 69 microseconds (with tolerance limits between +20% and -20%). **FIG. 2D** illustrates a graphical representation 200D of a current/voltage Waveform-5, as per RTCA DO-160 standard. In one example, a current/voltage Waveform-5A peaks at T1 = 40microseconds (with tolerance limits between +20% and -20%) and drops to 50% of the peak current/voltage value at T2 = 120 microseconds (with tolerance limits between +20% and -20%). In another example, a current/voltage Waveform-5B peaks at T1 = 50 microseconds (with tolerance limits between +20% and -20%) and drops to 50% of the peak current/voltage value at T2 = 500 microseconds (with tolerance limits between +20% and -20%). **FIG. 2E** illustrates a graphical representation 200E of a current Waveform-6, as per RTCA DO-160 standard which peaks at T1 = 0.25 microseconds (with tolerance limits between +20% and -20%) and drops to 50% of the peak current/voltage value at T2 = 4 microseconds (with tolerance limits between +20% and -20%).

[019] Referring now to FIGs. 3A-3C various circuits including discrete components for generating and verification of the Waveform-4, as per DO-160 section-22 standard are illustrated, in accordance with some embodiments. **FIG. 3A** illustrates a circuit diagram of a circuit 300A for generating the Waveform-4. The circuit 300A includes a first resistor R1 and a second resistor R2. The first resistor R1 may be configured to control the rise time and the second resistor R2 may be configured to control the fall time. The circuit 300A may further include an inductor L1 and a capacitor C1. For example, resistance value of the first resistor R1 and the second resistor R2 may be 56 Ohms and 744 Ohms, respectively. Further, inductance value of the inductor L1 may be 81 micro Henry (mH), and capacitance value of the capacitor C1 may be 120 nano Farads (nF). In order to generate the Waveform-4, the waveform generator 102 may operate on a rated voltage of approximately 150 Volt, for example, via a feeder section pillar (FSP).

[020] **FIG. 3B** illustrates a circuit diagram of an open circuit 300B for generating the Waveform-4. The open circuit 300B may include a voltage source and a combination of discrete components (i.e. an embedded circuit (X1)). An open circuit voltage waveform may be obtained by applying open circuit voltage (Voc) of approximately 150V to the open circuit 300B, via a combination of FSP and a mini section pillar (MSP). **FIG. 3C** illustrates a circuit diagram of a short circuit current (Isc) circuit 300C for generating the Waveform-4. The circuit 300C may be supplied with approximately 300 Amperes of current across a resistor having a resistance value 0.5 Ohms, via a combination of FSP and MSP.

[021] **FIG. 3D** illustrates a plotted open circuit voltage waveform-4 300D corresponding to the waveform-4 of FIG. 2D. The open circuit voltage waveform-4 300D is a resultant waveform of the circuit 300A of FIG. 3A. **FIG. 3E** illustrates a plotted closed circuit (short circuit (Isc)) current waveform-4 300E with 0.5 Ohm source impedance corresponding to the waveform-4 of FIG. 2D. The waveform-4 300E is a resultant waveform of the circuit 300B of FIG. 3B**. FIG. 3F** shows another plotted open circuit voltage waveform-4 300E with 0.5 Ohm source impedance. The waveform-4 300E is a resultant waveform of the circuit 300C of FIG. 3B**.** It should be noted that the by way of plotting of the waveform-4 300D, the waveform-4 300E, and waveform-4 300F, the circuits 300A, 300B, and 300C are verified with respect to the waveform-4, as per RTCA DO-160 standard.

[022] Referring back to FIG. 1, the one or more lighting waveforms generated by the waveform generator 102 may be simultaneously applied to a plurality of EUT interfaces 106 (hereinafter, individually or collectively referred to as EUT interface(s) 106) which are to be tested. In some embodiments, the plurality of EUT interfaces 106 may include EUT interface 106-1, 106-2, 106-3, and 106-4, as shown in FIG. 1.

[023] The one or more lighting waveforms may be applied via a cable bundle using inductive coupling technique. Each cable of the cable bundle may include a first end connected to an EUT interface of the plurality of EUT interfaces 106. In some embodiments, a second end of the cable may be connected to an end-load impedance of a plurality of end-load impedances 108. To apply the one or more lighting waveforms using inductive coupling, the simulation model 100 may include a at least one transformer 104. An output of the waveform generator 102 may be input to a primary winding 104P of the transformer 104. Further, each of the plurality of EUT interfaces 106 may be connected to a secondary winding 104S of the transformer 104. For example, the EUT interface 106-1 may be connected to a secondary winding 104S-1, the EUT interface 106-2 may be connected to a secondary winding 104S-2, the EUT interface 106-3 may be connected to a secondary winding 104S-3, and the EUT interface 106-4 may be connected to a secondary winding 104S-4. As will be understood, the primary winding 104P of the at least one transformer 104 may be inductively coupled to each of the secondary windings 104S-1, 104S-2, 104S-3, 104S-4. Therefore, in order perform the test simulation, the primary winding 104P may be connected to the waveform generator 102, and the secondary windings 104S may be coupled to the cables (of the cable bundles) connecting the EUT interfaces 106.

[024] It should be noted that the simulation model of the EUT may allow adding or removing the EUT interfaces based on the number of EUT interfaces to be tested. In other words, the simulation model may act as an open platform allowing for customizing of the number of EUT interfaces that are to be tested. The waveform generator 102 may inject the one or more lightning waveforms simultaneously to all these EUT interfaces 106 via the cable bundle through inductive coupling.

[025] The effect of the one or more lightning waveforms on each of the plurality of EUT interfaces 106 may be determined to predict the capability of the EUT interfaces 106 to withstand the lightning threats in real-world scenario. In some embodiments, the effect of the one or more lightning waveforms on each of the plurality of EUT interfaces 106 may be determined using a plurality of measuring device models connected to the plurality of EUT interfaces 106. For example, a voltage and current reading may be obtained at each of the plurality of EUT interfaces 106 using a voltmeter and an ammeter which may be positioned in proximity to the plurality of EUT interfaces 106. As will be understood, based on the effects determined on each of the plurality of EUT interfaces, the design of the EUT may be optimized, i.e., necessary changes may be made to the EUT design to enable the EUTs to better withstand the lightning threats.

[026] In some embodiments, the effect of the one or more lightning waveforms on each of the plurality of EUT interfaces 106 may be determined based on one or more cable characteristics associated with each cable of the cable bundle. By way of an example, the one or more cable characteristics may include manufacture information associated with the cable bundle. In particular, the one or more cable characteristics may include a wire gauge value associated with each cable of the cable bundle, a resistance value, an inductance value, and a capacitance value associated with each cable per unit length, and a type of a cable, wherein the type of the cable comprises: a shielded-type, an unshielded-type, a single core-type, a multi core-type, and a co-axial-type. It should be noted that the cable characteristics may play a significant role in the way the lighting effects are induced in the EUT interfaces 106 upon application of the lightning threats. By taking into consideration these cable characteristics, the capability of the EUT interfaces 106 to withstand the lightning threats can be more accurately predicted.

[027] In some embodiments, each cable of the cable bundle may include a first end and a second end. The first end of the cable may be connected to an EUT interface 106 and the second end of the cable may be connected to an end-load impedance of the plurality of end-load impedances 108 (hereinafter, individually or collectively referred to as end-load impedance(s) 108). There simulation model may, therefore, additionally include the plurality of end-load impedances 108 (hereinafter, individually or collectively referred to as end-load impedance(s) 108). As will be appreciated, the end-load impedances 108 may include high impedance equipment, for example, electricity generators. It should be noted that by including the end-load impedances 108 in the simulation model 100, the accuracy of the prediction of the effect of the one or more lightning waveforms on each of the plurality of EUT interfaces 106 is improved.

[028] Referring now to **FIG. 4**, a detailed schematic drawing of a simulation model 400 (corresponding to the simulation model 100) of an environment for performing indirect lightning test simulation on an EUT is illustrated, in accordance with some embodiments of the present disclosure. As shown in FIG. 4, the simulation model 400 may include a waveform generator 404 which may further include a voltage generator and a pulse forming network. The waveform generator 404 may generate one or more lightning waveforms using a discrete component-based pulse forming network. The discrete component-based pulse forming network may include a combination of discreet components, i.e. a combination of one or more resistors, one or more capacitors, one or more indictors, etc.

[029] The waveform generator 404 may generate a plurality of electrical signals waveforms using the discrete component pulse forming network, rather than using a default tool or formula-based models. It should be noted that the formula-based waveform behaviour is constant irrespective of the interfaces under test, whereas the discrete component-based waveform behaviour is similar to physical waveform generator behaviour. By using the discrete component pulse forming network, lightning threat energy level may be increased or decreased based on the impedances of the EUT interfaces, which makes simulation close to physical testing and helps in obtaining higher accuracy. For example, for a high lighting waveform pulse generation, a 4/5a waveform generator, qualified as per DO-160 or similar standard may be used. The waveforms generated by the waveform generator 404 are already explained in conjunction with FIGs. 2A-2E and FIGs. 3A-3F.

[030] The one or more lighting waveforms generated by the waveform generator 404 may be simultaneously applied to a plurality of EUT interfaces 408 which are to be tested. In some embodiments, the plurality of EUT interfaces 408 may include five EUT interfaces, as shown in the FIG. 4. As will be appreciated, for a calibrated lightning voltage, electric current may distribute in the plurality of EUT interfaces 408 depending on their impedance characteristics. Similarly, during a lightning strike on actual EUT interfaces of an aircraft, the current may distribute in the actual EUT interfaces depending on their impedance characteristics. For example, EUT interfaces having the lowest impedance may draw a larger share of the current.

[031] The one or more lighting waveforms may be applied via a cable bundle using inductive coupling. The inductive coupling technique allows for keeping injection waveshape intact by isolating the waveform generator 404 from the plurality of EUT interfaces 408. The inductive coupling technique further enables inducting lightning threat energies into a set of cable bundles simultaneously. As such, the simulation model 400 may further include at least one inductive coupling transformer 406 which may be configured to induce high lightning threat energies into the plurality of EUT interfaces 408 by flowing electricity through the cable bundle. As shown in FIG. 4, the simulation model 400 may include one inductive coupling transformer 406 for each cable of the cable bundle. A primary winding of each inductive coupling transformer 406 may be connected to the waveform generator 404, and a secondary winding of each inductive coupling transformer 406 may be coupled to a cable connecting an EUT interface of the plurality of EUT interfaces 408. The primary winding of each transformer may be electromagnetically coupled to a corresponding secondary winding. When lightning threats are applied to the cable bundle simultaneously, applied energy distributes to all the EUT interfaces connected to the cables of the cable bundle. A higher energy may flow to lower impedance EUTs, and a lower energy may flow to high impedance EUTs.

[032] The simulation model 400 may allow adding or removing the EUT interfaces based on the number of EUT interfaces to be tested, thereby acting as an open platform for customizing of the number of EUT interfaces that are to be tested. The waveform generator 404 may inject the one or more lightning waveforms simultaneously to the plurality of EUT interfaces 408 via the cable bundle through inductive coupling.

[033] In some embodiments, each cable of the cable bundle may include a first end and a second end. The first end of the cable may be connected to an EUT interface 408 and the second end of the cable may be connected to one or more end-load impedances 410. The one or more end-load impedances 410 may include high impedance equipment, for example, electricity generators, or other load or supporting devices. As will be appreciated, in the physical test setup, one end of the cable bundle may be connected to the EUT and another end may be connected to the load or supporting device. Therefore, to model this to closest to actual scenario, one or more end-load impedances 410 may be introduced in a simulation.

[034] In some embodiments, the simulation model 400 may further include a plurality of measuring device model 412. In other words, each of the inductive coupling transformers 406 may include a measuring device model (of the plurality of measuring device models 412) for measuring the effect of the one or more lightning waveforms on each of the plurality of EUT interfaces 408 and predict the capability of the EUT interfaces 408 to withstand the lightning threats. The measuring device model 412 may be configured to measure the effect of lightning threat energies flowing through each of the plurality of EUT interfaces 408 via the set of cable bundles, in order to predict the failure at the design stage and thereby optimizing protection circuitry and components. For example, the measuring device model may include a voltmeter and an ammeter for obtaining voltage and current reading at each of the plurality of EUT interfaces 408, thereby allowing for directly measuring the voltage and current stress. The power and energy associated with the EUT interface 408 may be evaluated by multiplication and integration. Based on the effects measured at each of the plurality of EUT interfaces 408, the design of the EUT may be optimized, i.e., necessary changes may be made to the EUT design to enable the EUTs to withstand the lightning threats.

[035] In some embodiments, one or more cable characteristics associated with each cable of the cable bundle may be taken into account during measuring of the effect of the one or more lightning waveforms on each of the plurality of EUT interfaces 408. The one or more cable characteristics may include manufacture information associated with the cable bundle, and in particular, may include a wire gauge value associated with each cable of the cable bundle, a resistance value, an inductance value, and a capacitance value associated with each cable per unit length, and a type of a cable, wherein the type of the cable comprises: a shielded-type, an unshielded-type, a single core-type, a multi core-type, and a co-axial-type. The one or more cable characteristics may vary depending on the wire gauge and type of the cable. Further, the cable characteristics may include per unit length resistor-inductor-capacitor (RLC) value which may be obtained from cable manufacturer, and the final RLC values may be calculated for the actual length. By way of an example, the cable may be a single conductor 20 AWG type cable and a length of the cable may vary depending on the EUT placement in the aircraft. For example, a 0.1 meters long cable may have inductance (L1) and resistance (R1) value of 109 nH and 3 mΩ, respectively. As such, a 5.9 meters length of the same cable may have inductance (L1) and resistance (R1) value of 11.2 μH and 0.196 Ω, respectively.

[036] As will be appreciated that factoring in the cable characteristics allows for a more accurate prediction of simulation results. As mentioned earlier, each of the plurality of EUT interfaces 408 may include a threat protection circuitry to protect the EUT interfaces 408. Based on the measured results the protection circuitry and EUT interfaces may further be optimized. The lightning threat energy flowing through each EUT interface 408 may be measured which may further be used to optimize the threat protection circuitry and components that helps in avoiding under-designing and over-designing of the EUT interfaces.

[037] Referring now to **FIG. 5**, an exemplary computing system 500 that may be employed to implement processing functionality for various embodiments (e.g., as a SIMD device, client device, server device, one or more processors, or the like) is illustrated. Those skilled in the relevant art will also recognize how to implement the invention using other computer systems or architectures. The computing system 500 may represent, for example, a user device such as a desktop, a laptop, a mobile phone, personal entertainment device, DVR, and so on, or any other type of special or general-purpose computing device as may be desirable or appropriate for a given application or environment. The computing system 500 may include one or more processors, such as a processor 502 that may be implemented using a general or special purpose processing engine such as, for example, a microprocessor, microcontroller or other control logic. In this example, the processor 502 is connected to a bus 504 or other communication medium.

[038] The computing system 500 may also include a memory 506 (main memory), for example, Random Access Memory (RAM) or other dynamic memory, for storing information and instructions to be executed by the processor 502. The memory 506 also may be used for storing temporary variables or other intermediate information during execution of instructions to be executed by the processor 502. The computing system 500 may likewise include a read only memory ("ROM") or other static storage device coupled to bus 504 for storing static information and instructions for the processor 502.

[039] The computing system 500 may also include storage devices 508, which may include, for example, a media drive 510 and a removable storage interface. The media drive 510 may include a drive or other mechanism to support fixed or removable storage media, such as a hard disk drive, a floppy disk drive, a magnetic tape drive, an SD card port, a USB port, a micro USB, an optical disk drive, a CD or DVD drive (R or RW), or other removable or fixed media drive. A storage media 512 may include, for example, a hard disk, magnetic tape, flash drive, or other fixed or removable medium that is read by and written to by the media drive 510. As these examples illustrate, the storage media 512 may include a computer-readable storage medium having stored therein particular computer software or data.

[040] In alternative embodiments, the storage devices 508 may include other similar instrumentalities for allowing computer programs or other instructions or data to be loaded into the computing system 500. Such instrumentalities may include, for example, a removable storage unit 514 and a storage unit interface 516, such as a program cartridge and cartridge interface, a removable memory (for example, a flash memory or other removable memory module) and memory slot, and other removable storage units and interfaces that allow software and data to be transferred from the removable storage unit 514 to the computing system 500.

[041] The computing system 500 may also include a communications interface 518. The communications interface 518 may be used to allow software and data to be transferred between the computing system 500 and external devices. Examples of the communications interface 518 may include a network interface (such as an Ethernet or other NIC card), a communications port (such as for example, a USB port, a micro USB port), Near field Communication (NFC), etc. Software and data transferred via the communications interface 518 are in the form of signals which may be electronic, electromagnetic, optical, or other signals capable of being received by the communications interface 518. These signals are provided to the communications interface 518 via a channel 520. The channel 520 may carry signals and may be implemented using a wireless medium, wire or cable, fiber optics, or other communications medium. Some examples of the channel 520 may include a phone line, a cellular phone link, an RF link, a Bluetooth link, a network interface, a local or wide area network, and other communications channels.

[042] The computing system 500 may further include Input/Output (I/O) devices 522. Examples may include, but are not limited to a display, keypad, microphone, audio speakers, vibrating motor, LED lights, etc. The I/O devices 522 may receive input from a user and also display an output of the computation performed by the processor 502. In this document, the terms “computer program product” and “computer-readable medium” may be used generally to refer to media such as, for example, the memory 506, the storage devices 508, the removable storage unit 514, or signal(s) on the channel 520. These and other forms of computer-readable media may be involved in providing one or more sequences of one or more instructions to the processor 502 for execution. Such instructions, generally referred to as “computer program code” (which may be grouped in the form of computer programs or other groupings), when executed, enable the computing system 500 to perform features or functions of embodiments of the present invention.

[043] In an embodiment where the elements are implemented using software, the software may be stored in a computer-readable medium and loaded into the computing system 500 using, for example, the removable storage unit 514, the media drive 510 or the communications interface 518. The control logic (in this example, software instructions or computer program code), when executed by the processor 502, causes the processor 502 to perform the functions of the invention as described herein.

[044] It will be appreciated that, for clarity purposes, the above description has described embodiments of the invention with reference to different functional units and processors. However, it will be apparent that any suitable distribution of functionality between different functional units, processors or domains may be used without detracting from the invention. For example, functionality illustrated to be performed by separate processors or controllers may be performed by the same processor or controller. Hence, references to specific functional units are only to be seen as references to suitable means for providing the described functionality, rather than indicative of a strict logical or physical structure or organization.

[045] Referring now to **FIG 6**, a block diagram of an indirect lightning test simulation device 600 for performing indirect lightning test simulation on an equipment under test (EUT) is illustrated, in accordance with an embodiment of the present disclosure. The indirect lightning test simulation device 600 may include a simulation model generating module 602, a lightning waveform generating module 604, lightning waveforms injecting module 606, and an effect determination module 608.

[046] The simulation model generating module 602 may generate the simulation model 400 of the EUT that may include the plurality of EUT interfaces 408 and the plurality of end-load impedances 410. The simulation model may further include the cable bundle connecting the plurality of EUT interfaces 408 with the plurality of end-load impedances 410. Each cable of the cable bundle may include a first end connected to an EUT interface and a second end connected to an end-load impedance. The lightning waveforms generating module 604 may generate one or more lightning waveforms using the discrete component-based pulse forming network. The one or more lightning waveforms may be representative of induced lightning threats. The one or more lightning waveforms may be in accordance with RTCA DO-160 or a similar standard.

[047] The lightning waveforms injecting module 606 may inject the one or more lightning waveforms simultaneously to the plurality of EUT interfaces via the cable bundle through inductive coupling. The one or more lightning waveforms may be injected to the plurality of EUT interfaces via the cable bundle using at least one inductive coupling transformer. The effect determination module 608 may determine the effect of the one or more lightning waveforms on each of the plurality of EUT interfaces using a plurality of measuring device models connected to the plurality of EUT interfaces. The effect of the one or more lightning waveforms on each of the plurality of EUT interfaces may be determined based on one or more cable characteristics associated with each cable of the cable bundle. For example, the one or more cable characteristics may include a wire gauge value associated with each cable of the cable bundle, a resistance value, an inductance value, and a capacitance value associated with each cable per unit length, and a type of a cable, wherein the type of the cable comprises: a shielded-type, an unshielded-type, a single core-type, a multi core-type, and a co-axial-type.

[048] Referring now to **FIG 7**, a flowchart of a method 700 of performing indirect lightning test simulation on an equipment under test (EUT) is illustrated, in accordance with some embodiments of the present disclosure. At step 702, a simulation model of the EUT may be generated. The simulation model may be generated using a Simulation Program with Integrated Circuit Emphasis (SPICE)-based analog electronic circuit simulator tool. For example, the SPICE-based analog electronic circuit simulator tool may be LTspice® tool. The simulation model may include a plurality of EUT interfaces, a plurality of end-load impedances, and a cable bundle connecting the plurality of EUT interfaces with the plurality of end-load impedances. Each cable of the cable bundle may include a first end and a second end. The first end may be connected to an EUT interface of the plurality of EUT interfaces and the second end may be connected to an end-load impedance.

[049] At step 704, one or more lightning waveforms may be generated using a discrete component-based pulse forming network. The one or more lightning waveforms may be representative of induced lightning threats. The one or more lightning waveforms may be in accordance with DO-160 standard or a similar standard. At step 706, the one or more lightning waveforms may be simultaneously injected to the plurality of EUT interfaces via the cable bundle through inductive coupling. The one or more lightning waveforms may be injected to the plurality of EUT interfaces via the cable bundle using at least one inductive coupling transformer.

[050] At step 708, the effect of the one or more lightning waveforms on each of the plurality of EUT interfaces may be determined using a plurality of measuring device models connected to the plurality of EUT interfaces. In some embodiments, the effect of the one or more lightning waveforms on each of the plurality of EUT interfaces may be determined based on one or more cable characteristics associated with each cable of the cable bundle. The one or more cable characteristics may include a wire gauge value associated with each cable of the cable bundle, a resistance value, an inductance value, and a capacitance value associated with each cable per unit length, and a type of a cable, wherein the type of the cable comprises: a shielded-type, an unshielded-type, a single core-type, a multi core-type, and a co-axial-type.

[051] The present disclosure discusses various techniques for indirect lightning test simulation based on section various standards like Section 22 of RTCA DO-160 standard. The techniques provide accurate prediction of failures and results by taking into consideration cable characteristics in simulation, and applying lightning threat into multiple cables at a time to observe the combined effect. The techniques help in mitigating qualification failure risk during early stage of the product, and also help in first time right approach and faster time to market. Further, the techniques provide scheduling and cost advantage by avoiding post-test design changes leading to re-spine and development test avoidance, thereby saving lab and engineering cost.

[052] It is intended that the disclosure and examples be considered as exemplary only, with a true scope and spirit of disclosed embodiments being indicated by the following claims.

We Claim:

1. A method of performing indirect lightning test simulation on an equipment under test (EUT), the method comprising:

generating a simulation model of the EUT, wherein the simulation model comprises:

a plurality of EUT interfaces;

a plurality of end-load impedances; and

a cable bundle connecting the plurality of EUT interfaces with the plurality of end-load impedances; and

generating one or more lightning waveforms using a discrete component-based pulse forming network, wherein the one or more lightning waveforms are representative of induced lightning threats;

injecting the one or more lightning waveforms simultaneously to the plurality of EUT interfaces via the cable bundle through inductive coupling; and

determining the effect of the one or more lightning waveforms on each of the plurality of EUT interfaces using a plurality of measuring device models connected to the plurality of EUT interfaces.

2. The method as claimed in claim 1,

wherein each cable of the cable bundle comprises a first end and a second end,

wherein the first end of the cable is connected to an EUT interface of the plurality of EUT interfaces, and

wherein the second end of the cable is connected to an end-load impedance of the plurality of end-load impedances.

3. The method as claimed in claim 1, wherein the effect of the one or more lightning waveforms on each of the plurality of EUT interfaces is determined based on one or more cable characteristics associated with each cable of the cable bundle.

4. The method as claimed in claim 3, wherein the one or more cable characteristics comprise:

a wire gauge value associated with each cable of the cable bundle, a resistance value, an inductance value, and a capacitance value associated with each cable per unit length, and

a type of a cable, wherein the type of the cable comprises: a shielded-type, an unshielded-type, a single core-type, a multi core-type, and a co-axial-type.

5. The method as claimed in claim 1,

wherein the one or more lightning waveforms are injected to the plurality of EUT interfaces via the cable bundle using at least one inductive coupling transformer model.

6. A system for performing indirect lightning test simulation on an equipment under test (EUT), the system comprising:

a processor; and

a memory coupled to the processor, wherein the memory comprises one or more processor-executable instructions, wherein the one or more processor-executable instructions, upon execution by the processor, cause the processor to:

generate a simulation model of the EUT, wherein the simulation model comprises:

a plurality of EUT interfaces;

a plurality of end-load impedances; and

a cable bundle connecting the plurality of EUT interfaces with the plurality of end-load impedances; and

generate one or more lightning waveforms using a discrete component-based pulse forming network, wherein the one or more lightning waveforms are representative of induced lightning threats;

inject the one or more lightning waveforms simultaneously to the plurality of EUT interfaces via the cable bundle through inductive coupling; and

determine the effect of the one or more lightning waveforms on each of the plurality of EUT interfaces using a plurality of measuring device models connected to the plurality of EUT interfaces.

7. The system as claimed in claim 8,

wherein each cable of the cable bundle comprises a first end and a second end,

wherein the first end of the cable is connected to an EUT interface of the plurality of EUT interfaces, and

wherein the second end of the cable is connected to an end-load impedance of the plurality of end-load impedances.

8. The system as claimed in claim 8, wherein the effect of the one or more lightning waveforms on each of the plurality of EUT interfaces is determined based on one or more cable characteristics associated with each cable of the cable bundle.

9. The system as claimed in claim 10, wherein the one or more cable characteristics comprise:

a wire gauge value associated with each cable of the cable bundle,

a resistance value, an inductance value, and a capacitance value associated with each cable per unit length, and

a type of a cable, wherein the type of the cable comprises: a shielded-type, an unshielded-type, a single core-type, a multi core-type, and a co-axial-type.

10. The system as claimed in claim 8,

wherein the one or more lightning waveforms are injected to the plurality of EUT interfaces via the cable bundle using at least one inductive coupling transformer model.

Dated this 22th day of November 2021

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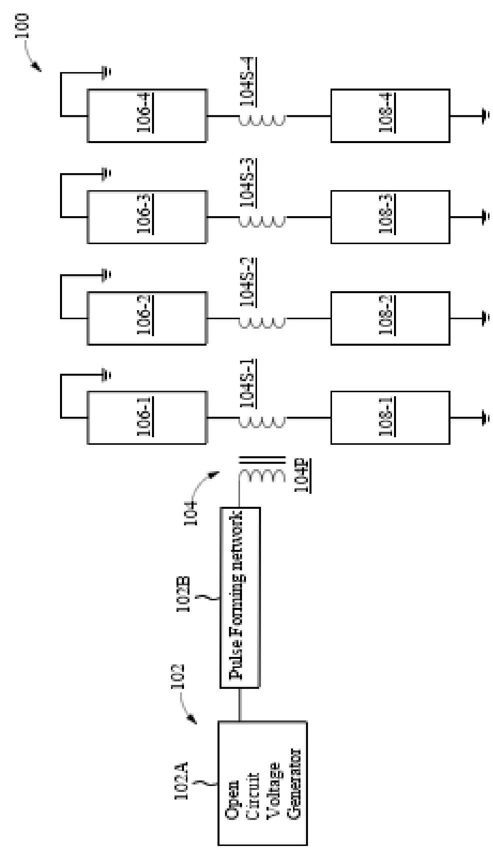
METHOD AND SYSTEM FOR PERFORMING INDIRECT LIGHTNING TEST SIMULATION

ABSTRACT

A method and system for performing indirect lightning test simulation on an equipment under test (EUT) is disclosed. The method may include generating a simulation model of the EUT that may include a plurality of EUT interfaces, a plurality of end-load impedances, and a cable bundle connecting the plurality of EUT interfaces with the plurality of end-load impedances. The method may further include generating one or more lightning waveforms representative of induced lightning threats, using a discrete component-based pulse forming network, injecting the one or more lightning waveforms simultaneously to the plurality of EUT interfaces via the cable bundle through inductive coupling, and determining the effect of the one or more lightning waveforms on each of the plurality of EUT interfaces using a plurality of measuring device models connected to the plurality of EUT interfaces.



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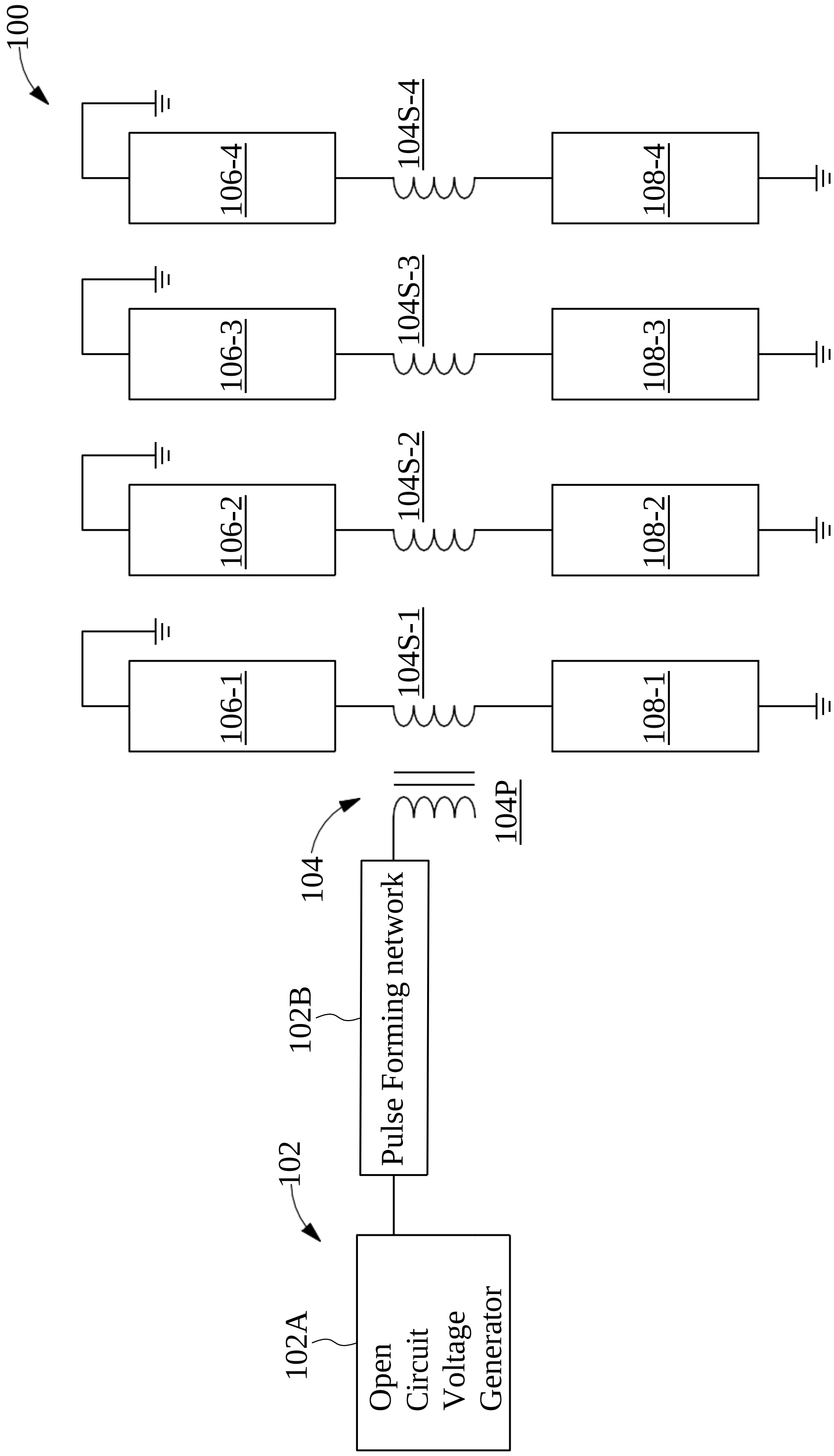

FIG. 1

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200A

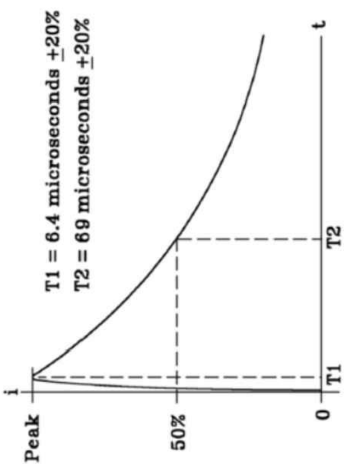

FIG. 2A

200B

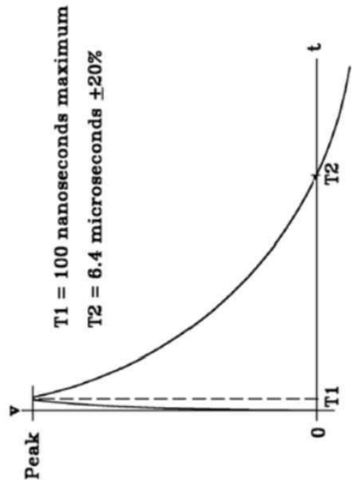

FIG. 2B

200C

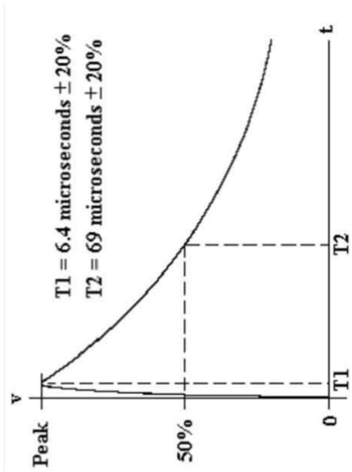

FIG. 2C

200D

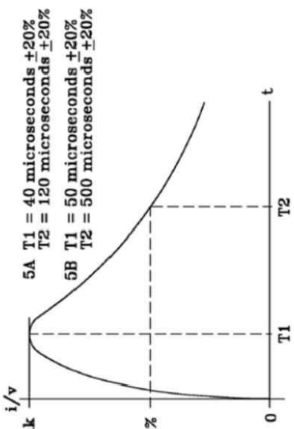

FIG. 2D

200E

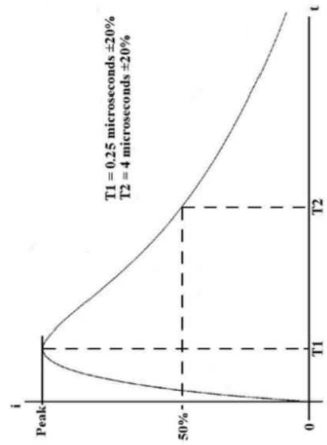

FIG. 2E

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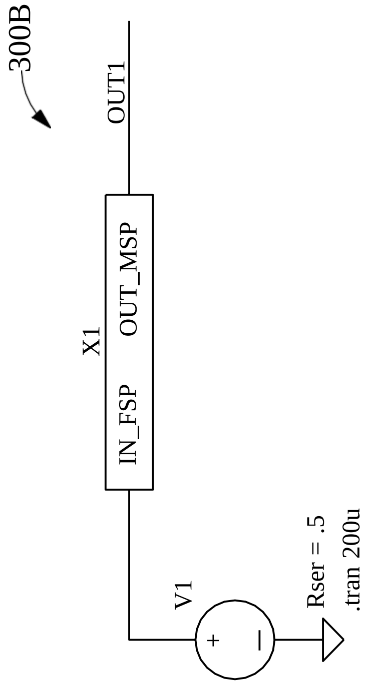

FIG. 3B

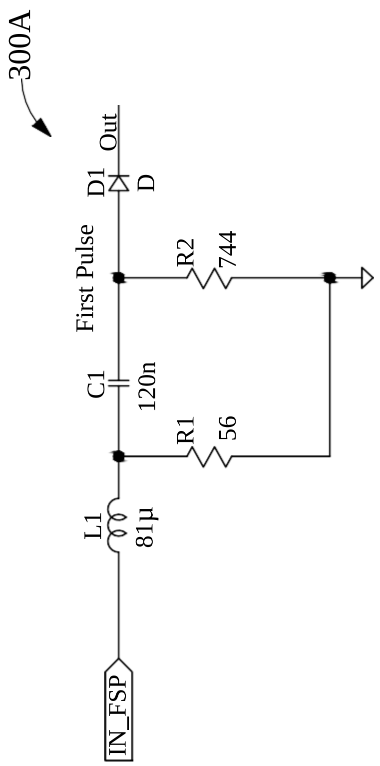

FIG. 3A

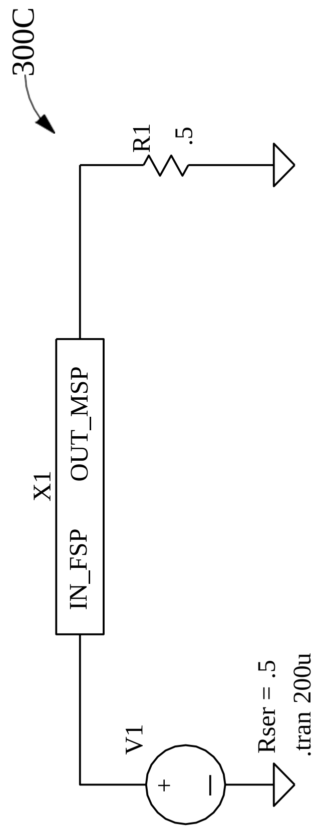

FIG. 3C

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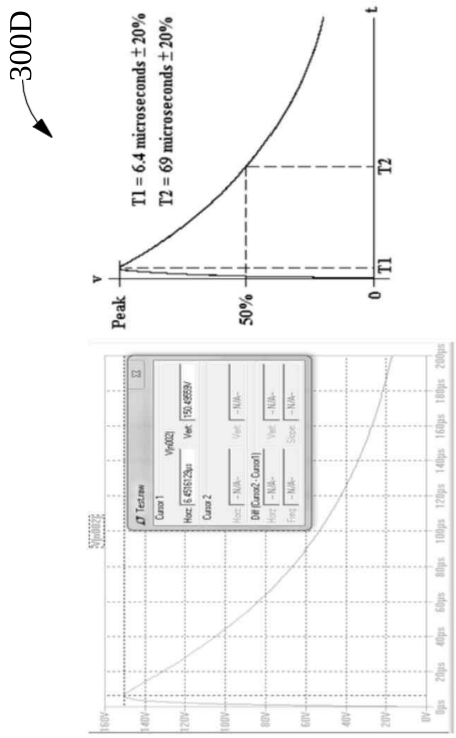

FIG. 3D

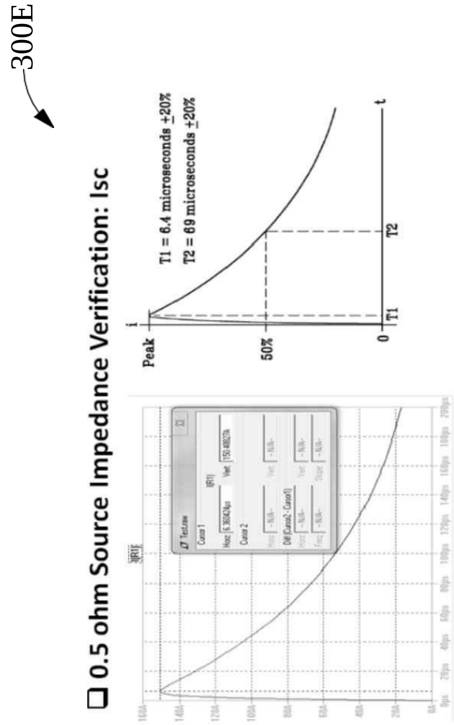

FIG. 3E

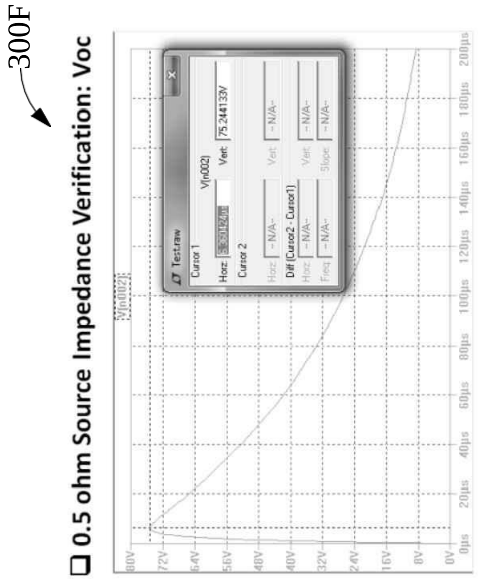

FIG. 3F

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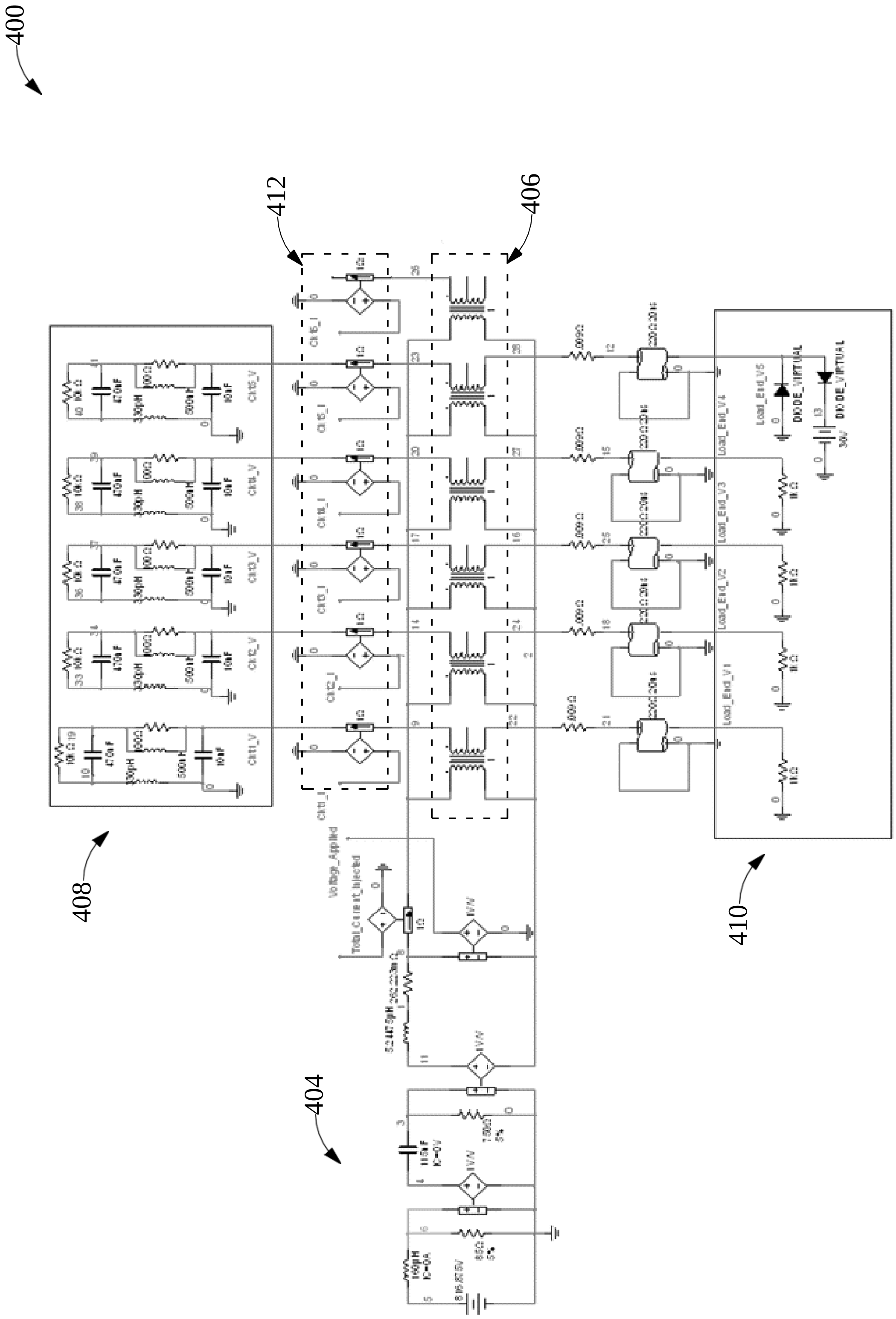

FIG. 4

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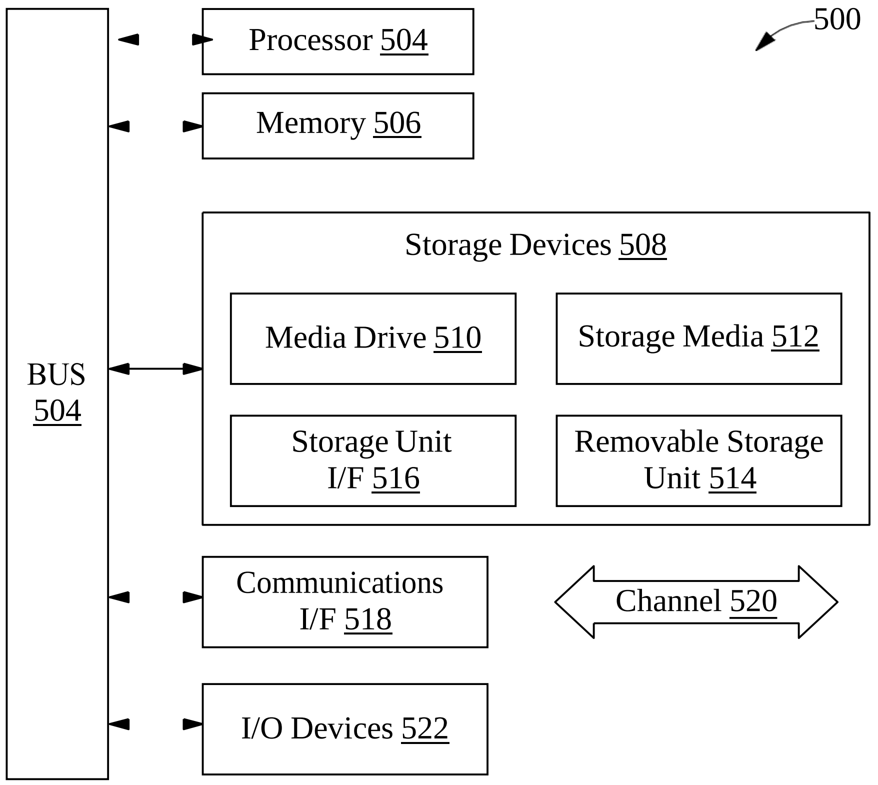

FIG. 5

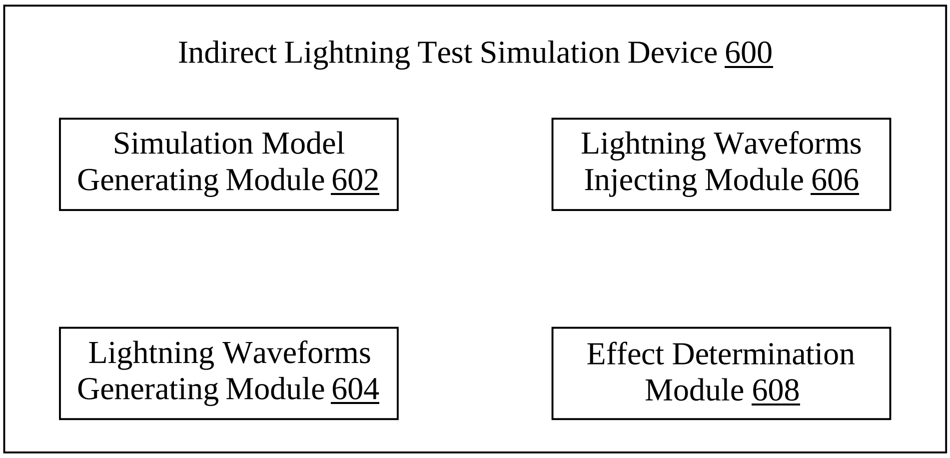

FIG. 6

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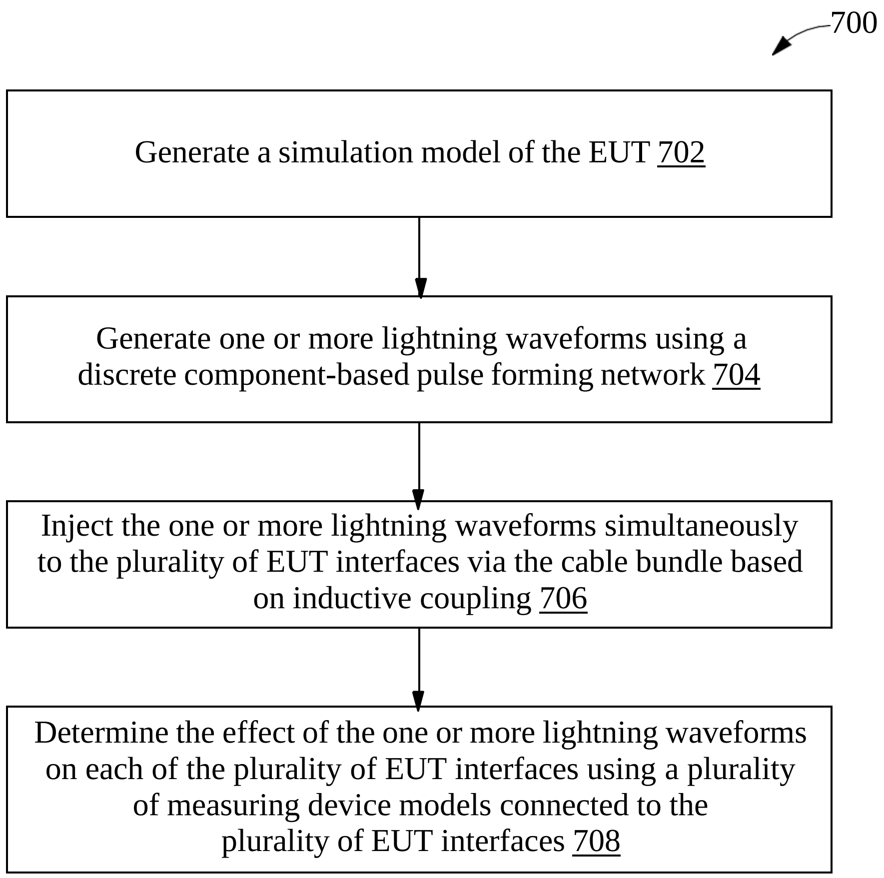

FIG. 7

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