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(71) Applicants:
- **SCM Group S.p.A.**
47921 Rimini (RN) (IT)
- **Politecnico di Milano - Dipartimento di Elettronica, Informazione e Bioingegneria**
20133 Milano (IT)

(72) Inventors:
- **NORGIA, Michele**
47921 Rimini (IT)
- **CAVEDO, Federico**
20133 Milano (IT)

(74) Representative: **Tiburzi, Andrea et al**
Barzanò & Zanardo Roma S.p.A.
Via Piemonte 26
00187 Roma (IT)

(54) PROXIMITY DETECTION SYSTEM FOR WORKING TOOLS, RELEVANT WORKING MACHINE AND PROXIMITY DETECTION METHOD THEREOF

(57) The present invention relates to a machine (M) for working products, such as panels made of wood, fiberglass, metal and the like, comprising a working tool (22) for working said products, wherein said machine (M) is characterized in that it comprises a system (1) for detecting the proximity of a limb of an operator to said working tool (22), comprising: at least one signal generator (G), for generating at least one signal $S_G(t)$; at least one first electrode (10), galvanically isolated from said machine (M) and connected to said at least one signals generator (G); at least a second electrode (11) galvanically isolated from said machine (M), wherein said signal $S_G(t)$ generated by said at least one signal generator (G) is configured to generate an electric field between said at least one first electrode (10) and said at least one second electrode (11); wherein said electric field between said at least one first (10) and said at least one second electrode (11) forms a barrier at least partially around said working tool (22); and a logic control unit (12) connected to said at least one first electrode (10), and to said at least second electrode (11), so as to acquire at least one first measuring signal $S_{E10}(t)$ from said at least one first electrode (10) and at least one second measuring signal $S_{E11}(t)$ from said at least one second electrode (11) respectively; wherein said logic control unit (12) is configured for processing said at least one first $S_{E10}(t)$ and at least one second $S_{E11}(t)$ measuring signal, for verifying at least one criterion as a function of at least two electrical quantities of said first $S_{E10}(t)$ and second $S_{E11}(t)$ measuring signal, so as to determine the presence of said limb of said operator in proximity of said barrier when said at least one criterion is verified.

The present invention also relates to a proximity detection system for machining tools.

The present invention related also to a method of proximity detection.

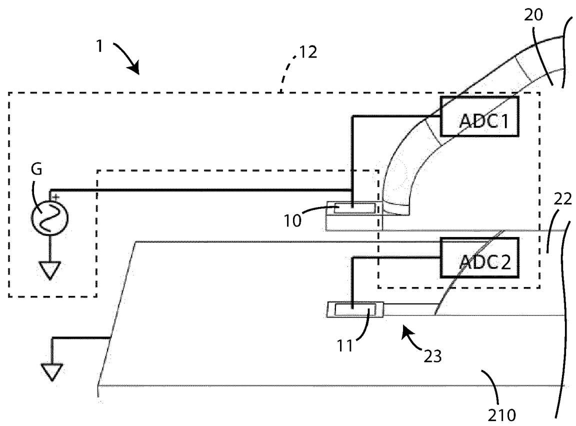

Fig. 1

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Description

[0001] The present invention relates to a proximity detection system for working tools.

[0002] The present invention also relates to a working machine.

[0003] The present invention also relates also to a proximity detection method.

Field of the invention

[0004] More in detail, the invention relates to a detection system of the aforementioned type, designed and manufactured in particular to detect the approach of an operator's limb, such as an arm, a hand, or a leg, to a tool for machining objects or artifacts, such as a cutting tool, a circular saw, and the like, but which can be used for any application, in which it is necessary to detect the proximity of a part of the operator's body to an object, to minimize o eliminate the risk of injury to the operator.

[0005] In the following, the description will be directed to the detection of the approach of an operator's hand to a blade of a circular saw for cutting wooden panels, but it is clear that the same should not be considered limited to this specific use.

Prior art

[0006] As is known, typically the machines for working wooden panels and the like comprise one or more cutting tools, such as circular saws and the like, to perform precision cuts on the panel, while the latter is moving on a sliding plane.

[0007] In general, then, during some steps of panel processing, it is necessary for the operator to manually intervene on the panel to facilitate its machining, in particular when the latter is placed near the cutting tool, for example, to move the panel along the cutting line defined by the blade of the cutting tool, or to arrange the panel in a different position from that originally assumed.

[0008] In particular, these operations carried out by the operator in the immediate vicinity of the cutting tool are risky for possible injuries to the operator's upper limbs, for example in the event of a hand coming into contact with the cutting tool blade.

[0009] Therefore, in recent years it has been necessary to equip the machines for machining wooden panels and the like, with systems or devices to reduce the risk of accidents to which the operator may be subject to when the latter carries out operations on the panel in the vicinity of the cutting tool.

[0010] Currently, machines for working wooden panels provide systems capable of detecting, for example, the approach of an operator's hand to a machining tool.

[0011] The relevant known art comprises the European Patent EP 1622748 B1 and the United States patent US 8122798 B1.

[0012] The European patent EP 1622748 B1 relates to a system for detecting a dangerous condition for an operator who uses an electric tool having a blade exposed with respect to a working surface and a protection system to minimize the possibility that the operator is injured due to contact with this blade.

[0013] The United States patent US 8122798 B1, on the other hand, describes a proximity detection system for an electric cutting tool, comprising a frame connected to a cutting platform, wherein the frame can be spaced and parallel to the cutting surface, can surround at least a portion of the blade and can comprise an arrangement of frame sensing elements.

[0014] However, a drawback of these known solutions is that they do not allow to reliably detect the presence of the operator's hand approaching the cutting tool, increasing the risk of injury to the operator.

[0015] In fact, typically, in such known solutions, the blade of the cutting tool is part of the detection system and is supplied with a power supply signal. The blade and the ground plane, therefore, define a capacitance having a respective dielectric constant. In particular, the blade represents the first plate of the capacitor or the transmitter, while the ground plane represents the second plate of the capacitor or the receiver.

[0016] However, since the machine and, therefore, the cutting tool, is connected to the ground plane, it acts as a receiver. Therefore, when the operator uses the machine, it is electrically coupled to its frame, effectively becoming part of the second capacitor armature.

[0017] In particular, the human body, being made up of a high percentage of water, and therefore having a high dielectric constant, causes an increase in capacitance and, therefore, a variation in the amplitude of the measured signal such as to make the detection of the impedance signal at the ends of the armatures.

[0018] Furthermore, another drawback of these solutions according to the prior art is that they do not allow to distinguish the operator's hand from a piece made of wood and the like. Therefore, such systems or devices can produce false alarms, thus increasing the machine downtime.

Scope of the invention

[0019] In the light of the above, it is, therefore, the object of the present invention to provide a proximity detection system that allows detecting in advance and with precision the approach of an upper limb of an operator to a cutting tool, in order to inhibit its operation, avoiding the risk of injury to the operator.

[0020] A further object of the invention is to provide a proximity detection system that allows identifying the presence of the operator's upper limb with respect to objects made of wood and the like.

[0021] Another object of the invention is to provide a proximity detection system that is highly reliable, relatively simple to manufacture, and at competitive costs.

Object of the invention

[0022] It is, therefore, specific object of the present invention a machine for working products, such as panels made of wood, fiberglass, metal and the like, comprising a working tool for working said products, wherein said machine is characterized in that it comprises a system for detecting the proximity of a limb of an operator to said working tool, comprising: at least one signal generator, for generating at least one signal $S_G(t)$; at least one first electrode, galvanically isolated from said machine and connected to said at least one signals generator; at least a second electrode galvanically isolated from said machine, wherein said signal $S_G(t)$ generated by said at least one signal generator is configured to generate an electric field between said at least one first electrode and said at least one second electrode; wherein said electric field between said at least one first and said at least one second electrode forms a barrier at least partially around said working tool; and a logic control unit connected to said at least one first electrode, and to said at least second electrode, so as to acquire at least one first measuring signal $S_{E10}(t)$ from said at least one first electrode and at least one second measuring signal $S_{E11}(t)$ from said at least one second electrode respectively; wherein said logic control unit is configured for processing said at least one first $S_{E10}(t)$ and at least one second $S_{E11}(t)$ measuring signal, for verifying at least one criterion as a function of at least two electrical quantities of said first $S_{E10}(t)$ and second $S_{E11}(t)$ measuring signal, so as to determine the presence of said limb of said operator in proximity of said barrier when said at least one criterion is verified.

[0023] Advantageously according to the invention, said at least one signal generator may be configured to generate a signal $S_G(t)$ having a single frequency, wherein said frequency is preferably about 10KHz or 1 MHz.

[0024] Always according to the invention, said at least one signal generator (G) may be configured to generate a signal $S_G(t)$ having two frequencies.

[0025] Still according to the invention, the first frequency of said signal $S_G(t)$ may be about 10kHz, and the second frequency of said signal $S_G(t)$ is about 1MHz.

[0026] Further according to the invention, said at least one criterion may provide at least one comparative parameter ($\overline{S}_{Re}$, $\overline{S}_{Im}$), such as a threshold, and said logic control unit (12) is configured to process at least one processed parameter (S_{Re}, S_{Im}) to be compared with said comparative parameter ($\overline{S}_{Re}$, $\overline{S}_{Im}$), so as to determine the presence of said limb of said operator in proximity to said barrier, particularly when $S_{Re} \leq \overline{S}_{Re}$ and/or when $S_{Im} \geq \overline{S}_{Im}$.

[0027] Conveniently according to the invention, said logic control unit may be configured for processing in frequency said at least one first measuring signal $S_{E10}(t)$ and said at least one second measuring signal $S_{E11}(t)$ for obtaining at least one first phasor S_{E10} and at least one second phasor S_{E11} respectively.

[0028] Always according to the invention, said at least one processed parameter S_{Re} is determined by the following formula:

$$S_{Re} = Re\left\{\frac{S_{E11}}{S_{E10}}\right\}$$

where S_{Re} is determined by the real part of the ratio between said at least one second phasor S_{E11} and said at least one first phasor S_{E10}, that is S_{Re} is a function of the amplitude of said at least one first S_{E10} and at least one second S_{E11} phasor.

[0029] Advantageously according to the invention, said at least one processed parameter S_{Im} may be determined by the following formula:

$$S_{Im} = Im\left\{\frac{S_{E11}}{S_{E10}}\right\}$$

where S_{Im} is determined by the imaginary part of the ratio between said at least one second phasor S_{E11} and said at least one first phasor S_{E10}, that is S_{Im} is a function of the phase of said at least one first S_{E10} and at least one second S_{E11} phasor.

[0030] Still according to the invention, said at least one criterion may provide at least two comparative parameters $(\bar{S}'_{Re}, \bar{S}''_{Re}, \bar{S}'_{Im}, \bar{S}''_{Im})$, such as two thresholds, and said logic control unit may be is configured for processing at least two processed parameters (S'_{Re}, $\bar{S}''_{Re}$, S'_{Im}, S''_{Im}) to be compared with said comparative parameters $(\bar{S}'_{Re}, \bar{S}''_{Re}, \bar{S}'_{Im}, \bar{S}''_{Im})$, so as to determine the presence of said limb of said operator in proximity of said barrier when $S'_{Re} \leq \bar{S}'_{Re}$ and $S''_{Re} \leq \bar{S}''_{Re}$ and/or when $S'_{Im} \geq \bar{S}'_{Im}$ and $S''_{Im} \geq \bar{S}''_{Im}$.

[0031] Conveniently according to the invention,
said logic control unit may be configured for processing in frequency said at least one first measuring signal $S_{E10}(t)$ and said at least one second measuring signal $S_{E11}(t)$ with said first frequency for obtaining at least one first phasor $S_{E10}^{f_1}$ and at least one second phasor $S_{E11}^{f_1}$ respectively, and said logic control unit may be configured for processing in frequency said at least one first measuring signal $S_{E10}(t)$ and said at least one second measuring signal $S_{E11}(t)$ with said second frequency for obtaining at least one first phasor $S_{E10}^{f_2}$ and at least one second phasor $S_{E11}^{f_2}$ respectively.

[0032] Always according to the invention, said at least one processed parameter S'_{Re} may be determined by the following formula:

$$S'_{Re} = Re\left\{\frac{\left(S_{E11}^{f_1}\right)}{\left(S_{E10}^{f_1}\right)}\right\}$$

where S'_{Re} is determined by the real part of the ratio between said at least one second phasor $S_{E11}^{f_1}$ and said at least one first phasor $S_{E10}^{f_1}$ at said first frequency, that is S'_{Re} is a function of the amplitude of said at least one first $S_{E10}^{f_1}$ and at least one second $S_{E11}^{f_1}$ phasor, and wherein said at least one processed parameter S''_{Re} is determined by the following formula:

$$S''_{Re} = Re\left\{\frac{\left(S_{E11}^{f_2}\right)}{\left(S_{E10}^{f_2}\right)}\right\}$$

where S''_{Re} is determined by the real part of the ratio between at least one second phasor $S_{E11}^{f_2}$ and said at least one first phasor $S_{E10}^{f_2}$ at said frequency, that is S''_{Re} is a function of the amplitude of said at least one first $S_{E10}^{f_2}$ and at least one second $S_{E11}^{f_2}$ phasor.

[0033] Further according to the invention, said at least one processed parameter S'_{Im} may be determined by the following formula:

$$S'_{Im} = Im\left\{\frac{S_{E11}^{f_1}}{S_{E10}^{f_1}}\right\}$$

where S'_{Im} is determined by the imaginary part of the ratio between said at least one second phasor $S_{E11}^{f_1}$ and said at least one first phasor $S_{E10}^{f_1}$ at said first frequency, that is S'_{Im} is a function of the phase of said at least one first $S_{E10}^{f_1}$ and at least one second $S_{E11}^{f_1}$ phasor, and wherein said at least one processed parameter S''_{Im} may be determined by the following formula:

$$S''_{Im} = Im\left\{\frac{S_{E11}^{f_2}}{S_{E10}^{f_2}}\right\}$$

where S''_{Im} is determined by the imaginary part of the ratio between said at least one second phasor $S_{E11}^{f_2}$ and said at least one first phasor $S_{E10}^{f_2}$ at said second frequency, that is S''_{Im} is a function of the phase of said at least one first $S_{E10}^{f_2}$ and at least one second $S_{E11}^{f_2}$ phasor.

[0034] Still according to the invention, said machine may comprise a working plane for supporting said products to be worked, wherein said working plane comprises in its turn a fixed working plane and a movable supporting plane, wherein said at least one second electrode is arranged on said fixed working plane in proximity of said working tool, and wherein said movable supporting plane is capable of moving with respect to said fixed working plane along a parallel direction or substantially parallel to an X axis parallel to which said movable supporting plane is capable of moving with respect to said working plane.

[0035] Always according to the invention, said system may comprise a plurality of second electrodes arranged on said fixed working plane in proximity of said working tool, and said movable supporting plane may comprise a device capable of activating selectively each second electrode of said plurality of electrodes, on the basis of the position of said movable supporting plane with respect to said fixed working plane.

[0036] Further according to the invention, said at least one second electrode may be arranged below said movable supporting plane.

[0037] Conveniently according to the invention, said working tool may be a circular saw.

[0038] Advantageously according to the invention, said machine may comprise a containing member, such as a cap and the like, arranged in correspondence with said working tool, to protect said working tool, wherein said containing member is movable with respect to said working tool, and said at least one first electrode may be arranged on one edge of said containing member.

[0039] It is further object of the present invention a system for detecting the proximity of a limb of an operator to a working tool of a machine for working products, such as panel made of wood, fiberglass, metal and the like, wherein said system is characterized in that it comprises: at least one signal generator, for generating at least one signal $S_G(t)$, at least one first electrode, that can be installed on said machine, wherein said first electrode is galvanically isolated from said machine and connected to said at least one signal generator, at least one second electrode, that can be installed on said machine and galvanically isolated from said machine, wherein the signal $S_G(t)$ generated by said at least one signal generator is configured to generate an electric field between said at least one first electrode and said at least one second electrode, wherein said electric field between said at least one first and said at least one second electrode forms a barrier at least partially around said working tool, and a logic control unit connected to said at least one first electrode, and to said at least one second electrode, so as to acquire at least one first measuring signal $S_{E10}(t)$ from said at least one first electrode and at least one second measuring signal $S_{E11}(t)$ from said at least one second electrode respectively; wherein said logic control unit is configured for processing said at least one first $S_{E10}(t)$ and at least one second $S_{E11}(t)$ measuring signal, for verifying at least one criterion as a function of at least two electrical quantities of said first $S_{E10}(t)$ and second $S_{E11}(t)$ measuring signal, so as to determine the presence of said limb of said operator in proximity of said barrier when said at least one criterion is verified.

[0040] Advantageously according to the invention, said at least one signal generator may be configured to generate a signal $S_G(t)$ having a single frequency, wherein said frequency is preferably about 10KHz or 1 MHz.

[0041] Always according to the invention, said at least one signals generator may be is configured to generate a signal $S_G(t)$ having two frequencies, wherein the first frequency of said signal $S_G(t)$ is about 10kHz, and the second frequency of said signal $S_G(t)$ is about 1 MHz.

[0042] Still according to the invention, said at least one criterion provides at least one comparative parameter ($\overline{S}_{Re}$, $\overline{S}_{Im}$), such as a threshold, and said logic control unit may be configured for processing at least one processed parameter ($\overline{S}_{Re}$, S_{Im}) to be compared with said comparative parameter ($\overline{S}_{Re}$, $\overline{S}_{Im}$), so as to determine the presence of said limb of said operator in proximity to said barrier, particularly when $S_{Re} \leq \overline{S}_{Re}$ and/or when $S_{Im} \geq \overline{S}_{Im}$.

[0043] Always according to the invention, each electrode may be provided with an activable guard, arranged around each electrode, for adjusting said electric field between said at least one first electrode and said at least one second electrode, so as to limit the exit of electric field lines and control the sensitivity of said system.

[0044] It is also object of the present invention a method for detecting the proximity of a limb of an operator to at least one first and at least one second electrode, wherein said method comprises the following steps: powering said at least one first electrode by means of at least one signal $S_G(t)$ so as to generate an electric field between said at least one first electrode and said at least one second electrode; acquiring at least one first measuring signal $S_{E10}(t)$ from said at least one first electrode; acquiring at least one second measuring signal $S_{E11}(t)$ from said at least one second electrode; processing said at least one first measuring signal $S_{E10}(t)$ and said at least one second measuring signal $S_{E11}(t)$ acquired in said acquiring steps, for verifying at least one criterion as a function of at least two electrical quantities of said first $S_{E10}(t)$ and second $S_{E11}(t)$ measuring signal; and determining the presence of said limb of said operator in proximity of said at least one first and at least one second electrode when said at least one criterion is verified.

[0045] Still according to the invention, said powering step may be is carried out by means of at least one signal generator connected to said at least one first electrode.

[0046] Always according to the invention, said at least one signal generator may be configured to generate a signal $S_G(t)$ having a single frequency, wherein said frequency is preferably about 10KHz or 1 MHz or to generate a signal $S_G(t)$ having two frequencies, wherein the first frequency is about 10kHz, and the second frequency is about 1 MHz.

[0047] Still according to the invention, said processing step may comprise the substep of processing in frequency said at least one first measuring signal $S_{E10}(t)$ for obtaining at least one first phasor S_{E10}, and the substep of processing in frequency said at least one second measuring signal $S_{E11}(t)$ for obtaining at least one second phasor S_{E11}, wherein said at least one processed parameter S_{Re} is determined by the real part of the ratio between said at least one second phasor S_{E11} and said at least one first phasor S_{E10}, and at least one processed parameter S_{Im} is determined by the imaginary part of the ratio between said at least one second phasor S_{E11} and said at least one first phasor S_{E10}.

[0048] It is also object of the present invention a computer program comprising instructions that, when the program is carried out by a computer, cause the execution by the computer of the steps of the method.

[0049] It is further object of the present invention a storage means readable by a computer comprising instructions that, when carried out by a computer, cause the execution by a computer of the steps of the method.

Brief description of the figures

[0050] The present invention will be now described, for illustrative but not limitative purposes, according to its preferred embodiments, with particular reference to the figures of the enclosed drawings, wherein:

figure 1 shows, in schematic view, an embodiment of a proximity detection system for tools for working wood panels and the like, according to the present invention;

figure 2 shows, in a schematic view, a simplified model of the system of figure 1;

figure 3 shows, in perspective view, an embodiment of a machine for working wooden pieces and the like, equipped with the system of figure 1, according to the present invention;

figure 4A shows a cross-sectional view of a further embodiment of the machine for working pieces made of wood and the like, according to the present invention;

figure 4B shows, in perspective view, a further embodiment of the machine for working pieces made of wood and the like, according to the present invention;

figure 5 shows a circuit configuration of the analog inputs of a Digilent Analog Discovery II acquisition board, according to the present invention;

figure 6 shows an exemplary electrical diagram of the operation of the system of figure 1 when an operator's hand is approaching a first electrode and a second electrode included in the system of figure 1;

figure 7 shows an exemplary electric diagram of the operation of the system of figure 1 when a piece made of wood is approaching the first electrode and the second electrode included in the system of figure 1;

figure 8 shows a table containing the resistivity and conductivity values referred to the human body and to wood;

figure 9 shows a table containing some experimental results obtained using the system of figure 1;

figure 10 shows a lumped parameters representation of an embodiment of the system of figure 1;

figure 11A shows a plot of a frequency response of the module of a transfer function of the system of figure 1, in the absence of objects in the vicinity of the first electrode and of the second electrode, according to a first simulation;

figure 11B shows a graph of a frequency response of the phase of the transfer function of the system of figure 1, in the absence of objects in proximity to the first electrode and the second electrode, according to the first simulation of figure 11A;

figure 12A shows a graph of the amplitude of the module of the transfer function of the system of figure 1, when the operator’s hand is approaching the first electrode and the second electrode, in which the first electrode is powered at a frequency equal to 10kHz, according to a second simulation;

figure 12B shows a graph of the phase of the transfer function of the system of figure 1, when the operator’s hand is approaching the first electrode and the second electrode, in which the first electrode is powered at the frequency of 10kHz, according to the second simulation of figure 12A;

figure 13A shows a graph of the amplitude of the module of the transfer function of the system of figure 1, when the operator’s hand is approaching the first electrode and the second electrode, in which the first electrode is powered at a frequency equal to 1MHz, according to a third simulation;

figure 13B shows a graph of the phase of the transfer function of the system of figure 1, when the operator’s hand is approaching the first electrode and the second electrode, in which the first electrode is powered at the frequency of 1MHz, according to the third simulation of figure 13A;

figure 14A shows a graph of a measurement of the module of the transfer function of the system of figure 1, when the operator’s hand is approaching the first electrode and the second electrode, in which the first electrode is powered at the frequency of 1MHz, according to experimental measures;

figure 14B shows a graph of measurement of the phase of the transfer function of the system of figure 1, when the operator’s hand is approaching the first electrode and the second electrode, in which the first electrode is powered at the frequency of 1MHz, according to the experimental measurements of figure 14A;

figure 15A shows the trend of the modulus of the transfer function of the system of figure 1, as the position of the hand varies with respect to the first electrode and the second electrode, according to a fourth simulation;

figure 15B shows the trend of the phase of the transfer function of the system of figure 1, as the position of the hand with respect to the first electrode and the second electrode varies, according to the fourth simulation of figure 15A;

figure 16A shows a graph of the amplitude of the module of the transfer function of the system of figure 1, when a piece of wet wood is approaching the first electrode and the second electrode, in which the first electrode is powered at the frequency of 10kHz, according to a fifth simulation;

figure 16B shows a graph of the phase of the transfer function of the system of figure 1, when the wet piece of wood is approaching the first electrode and the second electrode, in which the first electrode is powered at the frequency of 10kHz, according to the fifth simulation of figure 16A;

figure 17A shows a graph of the amplitude of the module of the transfer function of the system of figure 1, when the wet piece of wood is approaching the first electrode and the second electrode, in which the first electrode is powered at the frequency of 1MHz, according to a sixth simulation;

figure 17B shows a graph of the phase of the transfer function of the system of figure 1, when the wet piece of wood is approaching the first electrode and the second electrode, in which the first electrode is powered at the frequency of 1MHz, according to the sixth simulation of figure 17A;

figure 18A shows a graph of a measurement of the modulus of the transfer function of the system of figure 1, when the wet piece of wood is approaching the first electrode and the second electrode, in which the first electrode is powered at the frequency of 10kHz, according to experimental measures;

figure 18B shows a graph of measurement of the phase of the transfer function of the system of figure 1, when the wet piece of wood is approaching the first electrode and the second electrode, in which the first electrode is powered at the frequency of 10kHz, according to the experimental measurements of figure 18A;

figure 19A shows the trend of the modulus of the transfer function of the system of figure 1, as the position of the wet piece of wood varies with respect to the first electrode and the second electrode, according to a seventh simulation;

figure 19B shows the trend of the phase of the transfer function of the system of figure 1, as the position of the wet piece of wood varies with respect to the first electrode and the second electrode, according to the seventh simulation of figure 19A;

figure 20A shows a graph of the amplitude of the module of the transfer function of the system of figure 1, when a piece of dry wood is approaching the first electrode and the second electrode, in which the first electrode is powered at the frequency of 10kHz, according to an eighth simulation;

figure 20B shows a graph of the phase of the transfer function of the system of figure 1, when the piece of dry wood is approaching the first electrode and the second electrode, in which the first electrode is powered at the frequency of 10kHz, according to the eighth simulation of figure 20A;
figure 21A shows a graph of the amplitude of the module of the transfer function of the system of figure 1, when the piece of dry wood is approaching the first electrode and the second electrode, in which the first electrode is powered at the frequency of 1MHz, according to a ninth simulation;
figure 21B shows a graph of the phase of the transfer function of the system of figure 1, when the piece of dry wood is approaching the first electrode and the second electrode, in which the first electrode is powered at the frequency of 1MHz, according to the ninth simulation of figure 21A;
figure 22A shows a graph of a measurement of the modulus of the transfer function of the system of figure 1, when the piece of dry wood is approaching the first electrode and the second electrode, in which the first electrode is powered at the frequency of 10kHz, according to experimental measures;
figure 22B shows a graph of a measurement of the phase of the transfer function of the system of figure 1, when the piece of dry wood is approaching the first electrode and the second electrode, in which the first electrode is powered at the frequency of 10kHz, according to the experimental measurements of figure 22A;
figure 23A shows the trend of the modulus of the transfer function of the system of figure 1, as the position of the piece of dry wood varies with respect to the first electrode and the second electrode, according to a tenth simulation;
figure 23B shows the trend of the phase of the transfer function of the system of figure 1, as the position of the piece of dry wood with respect to the first electrode and the second electrode varies, according to the tenth simulation of figure 23A;
figure 24A shows the trend of the lines of force of the electric field during the approach of the operator's hand to the first electrode and to the second electrode in the presence of a glove, in which the first electrode is powered at the frequency of 1MHz, according to a first finite element simulation;
figure 24B shows the trend of the lines of force of the electric field during the approach of the operator's hand to the first electrode and to the second electrode in the absence of a glove, according to the first finite element simulation of figure 24A;
figure 25 shows the trend of the lines of force of the electric field during the approach of the piece of wood to the first electrode and to the second electrode in the absence of a glove, in which the first electrode is powered at the frequency of 1MHz, according to a second simulation finite element; and
figure 26 shows a block diagram of an embodiment of a proximity detection method, according to the present invention.

[0051] In the various figures, similar parts will be indicated with the same numerical references.

Detailed description

[0052] With reference to figures 1 and 2, the proximity detection system for tools for manufactured articles, such as panels made of wood, fiberglass, metal, and the like, generally indicated with reference number 1, substantially comprises a first electrode or a transmitter electrode 10, arranged on a containment member 20 of a machine M for processing said articles, a second electrode or receiver electrode 11, arranged on a working plane 21 of said machine M, and a logic control unit 12 connected to the first electrode 10 and to the second electrode 11.
[0053] In other embodiments of the present invention, the transmitter electrode 10 can be arranged on a member or other part of the machine other than the containment member 20, at a predetermined height from the working plane 21.
[0054] Furthermore, in the embodiment that is described, with particular reference to figure 3, the machine M is a machine the circular saw type. However, in other embodiments of the present invention, the machine M can be a machine of a different type such as, for example, a planer, milling or band saw type machine.
[0055] In particular, the machine M comprises, as mentioned, the working plane 21, on which the wooden panels to be machined are placed, a machining tool 22 as well as the containment member 20, arranged in correspondence with the machining tool 22.
[0056] More specifically, the work plane 21, in turn, comprises a fixed working plane 210 and a movable supporting plane 211 capable of moving, manually or automatically, with respect to said fixed working plane 210 along a direction parallel or substantially parallel to the X-axis of a Cartesian reference system XYZ shown in figure 3.
[0057] However, in other embodiments of the present invention, the direction along which the movement of the movable supporting plane 211 is guided may be different from that described.
[0058] Also, in the present embodiment, the machining tool 22 is a circular saw. In particular, this circular saw 22 comes out, when in use, from a respective slot 23 obtained on the fixed working plane 210 and is constrained to rotate in the XZ plane of the Cartesian reference system XYZ, along a cutting line parallel or substantially parallel to the X-axis.
[0059] However, the machining tool 22 can be different from the circular saw such as, for example, a planer, a milling

cutter or a band saw, without thereby departing from the scope of the present invention. Also, in other embodiments of the present invention, the number of machining tools 22 can be greater than one.

[0060] In an embodiment of the present invention, the machining tool 22 is galvanically isolated from the machine M.

[0061] The containment member 20, such as a suction hood, a hood and the like, is connected to the frame 2 of the machine M and is arranged above said machining tool 22.

[0062] In particular, said containment member 20 is movable between a rest position and an operating position, along the direction of the Z-axis of the Cartesian reference system XYZ, as a function of the height of the respective panel, or of the panel pack, made of wood to be machined.

[0063] In particular, when the containment member 20 is in the rest position, it does not cover the machining tool 22 while, when the containment member 20 is in the operative position, it at least partially covers the machining tool 22.

[0064] Furthermore, said containment member 20 is capable of sucking up the scraps or shavings deriving from the machining of the panels carried out by the working tool 22. The containment member 20, then, when it is in said operative position, is also capable of protecting the operator from the contact with the upper surface of the machining tool 20.

[0065] As said, in the embodiment that is described, the first electrode 10 is positioned on the containment member 20 and, in particular, on the lower edge of the containment 20.

[0066] However, the position of the first electrode 10 can be different from what has been described without thereby departing from the scope of protection of the present invention.

[0067] In particular, the first electrode 10 is galvanically isolated from the machine M and is capable of receiving power or stimulation signals from the control logic unit 12, as will be better explained in the continuation of the description.

[0068] The second electrode 11, also galvanically isolated from the machine M, is positioned on the fixed working plane 210 included in the work plane 21. However, in other embodiments, the position of the second electrode 11 can be different from what has been described.

[0069] In a further embodiment of the present invention, as can be seen from figure 4B, the second electrode 11 is positioned below the movable supporting plane 211.

[0070] In particular, the second electrode 11 is fixed on a support or bracket 24, and it is arranged facing the machining tool 22. Furthermore, the upper portion 211' of the movable supporting plane 211 is made by means of an insulating material or transparent to the electromagnetic field, such as a technopolymer, e.g. rexilon.

[0071] In another embodiment of the present invention, each electrode 10, 11 is equipped with a guard (not shown in the figures) for adjusting the electric field lines, in order to control the spatial sensitivity of the system 1. In particular, such a guard (which can be activated or not) comprises a conductor connected to the ground, which surrounds the respective electrode 10, 11, in order to limit the lateral leakage of the electric field lines.

[0072] The guard can be positioned on one or more sides of the electrode 10, 11 and possibly also cover the surface of the electrode 10, 11 on the face opposite to that facing the other electrode 10, 11, i.e. the non-active surface of each electrode 10,11.

[0073] In a further embodiment of the present invention shown in figure 4B, the system 1 comprises a plurality of second electrodes 11_1,..., 11_N arranged in proximity to the machining tool 22.

[0074] In particular, said second electrodes 11_1,..., 11_N, are galvanically isolated from each other and in communication with each other.

[0075] More specifically, said second electrodes 11_1,..., 11_N are arranged side by side, like an array, with said machining tool 22 along the direction of the X-axis. However, in other embodiments of the present invention, said second electrodes 11_1,..., 11_N can be arranged around said machining tool 22, completely surrounding it with one or more series of electrodes 11_1,..., 11_N, in order to provide an indication not only of the presence of the hand but also of the approach of said hand to the same machining tool 22, namely as a matrix.

[0076] Similarly to what has been said above, in a further embodiment of the present invention, the system 1 comprises a plurality of first electrodes 10_1,..., 10_N (not shown in the figures) arranged on the containment member 20 or on a different member of the machine M, at a predetermined height from the working plane 21. In particular, said first electrodes 10_1,..., 10_N, are galvanically isolated from each other and in communication with each other by means of the electromagnetic field.

[0077] Furthermore, the machine M can be equipped with a device (not shown in the figures) capable of identifying the position of the same movable supporting plane 211 with respect to the fixed working plane 210 and, therefore, with respect to the machining tool 22.

[0078] Such a device can be, for example, an encoder, a proximity sensor array, or a magnetic device.

[0079] According to the position of said movable supporting plane 211, said device is capable of selectively activating each second electrode 11_1,..., 11_N arranged in correspondence with the machining tool 22.

[0080] The control logic unit 12, as said, is capable of supplying a power supply to said first electrode 10, by means of a power or a stimulus signal to the first electrode 10. In particular, the logic control unit 12 is connected to the first electrode 10 by means of a power connection 120 comprising a signal generator G capable of generating electrical signals.

[0081] In the embodiment described, the generator G is included in the logic control unit 12. However, this generator

G can also be arranged externally to this logic control unit 12, without thereby departing from the scope of protection of the present invention.

[0082] The logic control unit 12 is also capable of acquiring the voltage of both electrodes 10, 11. Said logic control unit 12, in fact, comprises a first acquisition connection 121 connected to the first electrode 10 and a second acquisition connection 122 connected to the second electrode 11.

[0083] In the described embodiment, the control logic unit 12 is a *Data Acquisition Device* (DAQ) board. However, in other embodiments, the control logic unit 12 can also be realized by means of different logic systems.

[0084] In one embodiment, the management of the acquisition board 12 and the processing of the acquired signals is entrusted to a program implemented in the LabVIEW development environment.

[0085] In particular, the two acquisition connections 121, 122 of the control logic unit 12 are capable of acquiring signals with an analog band up to 30MHz, thanks to two synchronous 100 MSPS analog-to-digital converters (ADC1 and ADC2), having a resolution of 14 bits.

[0086] Figure 5 shows the circuit configuration of the analog front-end of the differential inputs of the control logic unit 12.

[0087] As will be described below, the signal measured on the two electrodes 10 and 11 refers to the ground of the circuit and one of the two differential inputs is connected directly to ground. The impedance of the analog front-end and its transfer function were taken into account in the simulation phase.

[0088] The eventual presence of a hand, connected to ground through the coupling of the human body with the frame 2 of the machine M, causes a decrease in the coupling between the two electrodes 10, 11 and therefore in the amplitude of the signal measured by the second converter analog-digital ADC2, as it provides a path for the signal to ground.

[0089] The impedance associated with the operator's hand, in figure 6, is different from that of a piece of wood, Z_2 in figure 7.

[0090] In particular, if the wood is dry, its conductivity is practically negligible and the physical effect can lead to an increase in the measured signal: its relative dielectric constant greater than 1 increases the capacitance value between the two electrodes 10, 11.

[0091] If, on the other hand, the wood is damp or completely wet, its conductivity increases considerably, but it remains in any case distinguishable from that of the human body.

[0092] Figure 8 shows a table containing the resistivity and conductivity values referred to the human body, dried wood and damp wood.

Experimental results

[0093] Figure 9 shows a table showing the experimental results obtained during the tests carried out on system 1, confirmed by subsequent laboratory tests.

[0094] In particular, the measurement setup comprises:

- the first electrode 10 having a square section of 2 cm per side; and
- the second electrode 11, also having a square section of 2 cm per side.

[0095] The first electrode 10 and the second electrode 11 are placed vertically with respect to the XY plane of the Cartesian reference system XYZ at a distance of approximately 17 cm. However, in other embodiments, the two electrodes 10, 11 can be misaligned with respect to the direction orthogonal to the XY plane, without thereby departing from the scope of protection of the present invention. In fact, in some cases, it may be convenient to arrange the two electrodes 10, 11 in such a way that they are not positioned along the same vertical direction with respect to the XY plane.

[0096] In one embodiment, the first electrode 10 is supplied with a voltage signal, given by the sum of two sinusoidal signals of 10 kHz and 1 MHz, coming from the function generator G present in the control logic unit 12.

[0097] Furthermore, as said, the first electrode 10 is connected to the first analog acquisition connection 121 of the same logic control unit 12.

[0098] The second electrode 11, on the other hand, arranged on the plane 210 of the machine M, but electrically isolated from the same plane 210, is connected to the analog second connection 122 of the control logic unit 12.

[0099] A LabVIEW program made it possible to calculate in real-time the modulus and phase values of the acquired signals for both frequencies applied to the first electrode 10 and to evaluate the transfer function of the system 1 as a complex ratio between the phasors of the voltages measured at the second 11 and at the first 10 electrodes.

[0100] In particular, as will be better described below, in the embodiment that is described, the control logic unit 12 is configured to process measurement signals acquired respectively at the two electrodes 10, 11 in order to verify a criterion which is a function of two quantities of these measurement signals, to determine the presence of the operator's limb in proximity to a barrier formed by the electric field between the two electrodes at least in a partial neighborhood of the working tool, when this criterion is verified.

[0101] However, in other embodiments of the present invention, the number of electrical quantities and the number of criteria as a function of such electrical quantities can be different from what is described without thereby departing from the scope of protection of the present invention.

[0102] The generator G is capable of supplying the first electrode 10 by means of a sinusoidal power supply signal at a single frequency, for example with a frequency equal to 10kHz:

$$S_G(t) = A\cos\ (\omega_1 \cdot t + \varphi_1)$$

where

- A is the amplitude of $S_G(t)$;
- ω_1 is the pulsation of $S_G(t)$, where $\omega_1 = 2\pi f_1$, with $f_1 = 10kHz$; and
- φ_1 is the phase of $S_G(t)$.

[0103] Therefore, a potential difference will be generated between the two electrodes 10, 11 caused by the electric field induced by the signal $S_G(t)$, generated by the generator G, between the same electrodes 10, 11.

[0104] The two measurement signals $S_{E10}(t)$ and $S_{E11}(t)$ acquired respectively at the two electrodes 10, 11 are:

$$S_{E10}(t) = A_{IN}\cos\ (\omega_1 \cdot t + \varphi_{E10})$$

$$S_{E11}(t) = A_{OUT}\cos\ (\omega_1 \cdot t + \varphi_{E11})$$

where

- A_{IN} and A_{OUT} are the respective amplitudes of $S_{E10}(t)$ and $S_{E11}(t)$;
- ω_1 is the pulsation of both signals $S_{E10}(t)$ and $S_{E11}(t)$, where $\omega_1 = 2\pi f_1$, with $f_1 = 10kHz$; and
- φ_{E10} and φ_{E11} are the respective phases of $S_{E10}(t)$ and $S_{E11}(t)$.

[0105] Therefore, both measurement signals $S_{E10}(t)$ and $S_{E11}(t)$ have the same frequency but different amplitudes and phases. Subsequently, by applying to the two measurement signals the Discrete Fourier Transform (in English "*Discrete Fourier Transform*" or DFT), we obtain two phasors S_{E10} and S_{E11}, in which $S_{E11} = A + i \cdot B$ and $S_{E10} = C + i \cdot D$.

[0106] Then, a ratiometric measurement is carried out, namely the relationship between the two phasors S_{E10} and S_{E11} (both in module and in phase). In particular, the real part of the relationship between the two phasors S_{E10} and S_{E11} is evaluated:

$$S_{Re} = Re\left\{\frac{S_{E11}}{S_{E10}}\right\} = Re\left\{\frac{A + i \cdot B}{C + i \cdot D}\right\}$$

[0107] The processed parameter S_{Re} that is obtained is a dimensionless value, namely a pure number independent of the variations due to the non-idealities of the input of the system 1, such as, for example, the fluctuations of the amplitudes of the signals.

[0108] As will be seen better below, a variation of the processed parameter S_{Re} will be associated with the presence or absence of the operator's hand in the vicinity of the machining tool 22 due to the comparison of this processed parameter S_{Re} with a respective comparative parameter $\overline{S}_{Re}$.

[0109] Furthermore, it is also useful to evaluate the imaginary part of the relationship between the two phasors S_{E10} and S_{E11}:

$$S_{Im} = Im\left\{\frac{S_{E11}}{S_{E10}}\right\} = Im\left\{\frac{A + i \cdot B}{C + i \cdot D}\right\}$$

[0110] In fact, as we will see later, a variation of the processed parameter S_{Im} will allow to determine or confirm the presence of the operator's hand in the vicinity of the machining tool 22 by means of a comparison with a respective comparative parameter $\overline{S}_{Im}$.

[0111] In particular, the comparison between the processed parameter S_{Re} (i.e. S_{Im}) and one or more criteria or comparative parameters, respectively predefined $\overline{S}_{Re}$ and $\overline{S}_{Im}$, allows detecting the presence of the operator's hand near the machining tool 22. In fact, in the embodiment described, the logic control unit 12 detects the presence of the operator's hand near the barrier formed by the electric field between the two electrodes 10, 11 at least in a partial neighborhood of the tool 22 when $S_{Re} \leq \overline{S}_{Re}$and/or when $S_{Im} \geq \overline{S}_{Im}$.

[0112] These criteria or thresholds $\overline{S}_{Re}$ and $\overline{S}_{Im}$ are functions of reference values set a priori, possibly obtained through experimentation and tests.

[0113] More specifically, it is evaluated the relationship between the two phasors S_{E10} and S_{E11} in a rest condition (S_0), i.e., when no material is present between the two electrodes 10, 11, positioned at a known distance.

[0114] Subsequently, the hand is approached to the receiver electrode 11 and it is noted that, as mentioned, the signal S_{E11} tends to decrease and, therefore, S_{Re}.

[0115] The $\overline{S}_{Re}$, which will be lower than S_0, will depend on the degree of sensitivity to be obtained for system 1. In fact, the higher the difference $S_0 - \overline{S}_{Re}$ is, the more the sensitivity of system 1 decreases, i.e. the hand is detected when is very close to electrode 11. The $\overline{S}_{Re}$ is closely related to S_0, which in turn is characteristic of the supply frequency and supply voltage. Additionally, the $\overline{S}_{Re}$ it can be done manually or automatically.

[0116] If, on the other hand, a time varying sinusoidal power supply signal, is supplied to the first electrode 10, by means of the generator G, given by two sinusoidal signals at different frequencies (for example a first frequency equal to 10kHz and a second frequency equal to at 1MHz), it is had that:

$$S_G(t) = S_{G1}(t) + S_{G2}(t) = A_1 \cos\cos(\omega_1 \cdot t + \varphi_1) + A_2 \cos(\omega_2 \cdot t + \varphi_2)$$

where

- A_1 and A_2 are the respective amplitudes of $S_{G1}(t)$ and $S_{G2}(t)$;
- ω_1 is the pulsation of $S_{G1}(t)$; where $\omega_1 = 2\pi f_1$, with $f_1 = 10kHz$, ω_2 is the pulsation of $S_{G2}(t)$, where $\omega_2 = 2\pi f_2$, with $f_2 = 1MHz$; and
- φ_1 and φ_2 are the respective phases of $S_{G1}(t)$ and $S_{G1}(t)$.

[0117] Therefore, differently from the previous single-frequency case, there is the superposition of two sinusoidal signals. Therefore, for each electrode 10, 11 two phasors will be obtained for the respective frequencies.

[0118] In particular, for the first frequency, we obtain two phasors $S_{E10}^{f_1}$ and $S_{\boldsymbol{E11}}^{f_1}$, wherein $S_{E11}^{f_1} = A + i \cdot B$ and $S_{E10}^{f_1} = C + i \cdot D$, while for the second frequency it is obtained two further phasors $S_{\boldsymbol{E10}}^{f_2}$ and $S_{\boldsymbol{E11}}^{f_2}$, wherein $S_{E11}^{f_2} = E + i \cdot F$ and $S_{E10}^{f_2} = G + i \cdot \mathrm{H}$.

[0119] In this case, therefore, a first processed parameter S'_{Re} and a second processed parameter S''_{Re} will be obtained:

$$S'_{Re} = Re\left\{\frac{S_{E11}^{f_1}}{S_{E10}^{f_1}}\right\} = Re\left\{\frac{A + i \cdot B}{C + i \cdot D}\right\}$$

$$S''_{Re} = Re\left\{\frac{S_{E11}^{f_2}}{S_{E10}^{f_2}}\right\} = Re\left\{\frac{E + i \cdot F}{G + i \cdot H}\right\}$$

[0120] The setting of the criteria $\overline{S}'_{Re}$ and $\overline{S}''_{Re}$ for the respective frequencies f_1 and f_2 takes place with the same method as described in the previous case.

[0121] The use of two signals at different and distant frequencies, such as to limit mutual harmonic interference, and consequently of two different threshold systems, makes the system much more robust. In fact, in this case, the logic control unit 12 detects the presence of a limb in a safe way only when both thresholds are violated, namely when S'_{Re}

$\leq \bar{S}'_{Re}$ and $S''_{Re} \leq \bar{S}''_{Re}$.

[0122] The considerations made previously for the comparative parameter S_{Im} are also valid for the further comparative parameters S'_{Im} and S''_{Im}.

[0123] In this case, therefore, a first processed parameter S'_{Im} and a second processed parameter S''_{Im} will be obtained:

$$S'_{Im} = Im\left\{\frac{S_{E11}^{f_1}}{S_{E10}^{f_1}}\right\} = Im\left\{\frac{A + i \cdot B}{C + i \cdot D}\right\}$$

$$S''_{Im} = Im\left\{\frac{S_{E11}^{f_2}}{S_{E10}^{f_2}}\right\} = Im\left\{\frac{E + i \cdot F}{G + i \cdot H}\right\}$$

where S'_{Im} is given by the imaginary part of the ratio between the two phasors $S_{E10}^{f_1}$ and $S_{E11}^{f_1}$ for the first frequency, while S''_{Im} is given by the imaginary part of the ratio between the two phasors $S_{E10}^{f_2}$ and $S_{E11}^{f_2}$ for the second frequency.

[0124] In fact, as in the single-frequency case described above, alternatively or in addition to the amplitude check, the logic control unit 12 detects or confirms the presence of the limb in a safe way only when both thresholds relating to the phase are violated, namely when $S'_{Im} \geq \bar{S}'_{Im}$ and $S''_{Im} \geq \bar{S}''_{Im}$.

[0125] System 1 can also be used for the detection of different types of materials, providing specific criteria or thresholds for each of them.

[0126] In particular, during the tests, 10, 11 different materials were brought closer to the two electrodes, covering a wide range of cases, and the most representative results, as mentioned, are shown in the table in figure 9. It can be seen that by using only one or both frequencies 10kHz and 1MHz it is possible to intercept the presence of the operator's hand approaching the two electrodes 10, 11.

[0127] In addition, further tests were carried out, not shown in the table in figure 9, by overlaying the operator's hand on a more or less wet wooden piece. These tests have shown that even in that case it is possible to identify the presence of the hand thanks to the superior conductivity of the human body compared to wood as well as to the strong coupling with the metal structure of the machine M connected to the reference potential of the circuit, allowing the hand to act from an electromagnetic shield to the signal transmitted by the first electrode 10.

[0128] Furthermore, as it can be seen from the table in figure 9, the identification of the presence of the hand is made even more evident if the comparative parameter S_{Im}, therefore the phase shift between the two measurement signals $S_{E10}(t)$ and $S_{E11}(t)$, is taken into consideration.

[0129] In particular, with reference to system 1, two simulation models have been developed: a lumped parameter model and a three-dimensional finite element electromagnetic simulation model.

[0130] The two models are able to describe what was observed in the experimental measurements, also providing indications for optimizing the sensitivity and accuracy of the system 1.

Lumped parameters simulation model

[0131] Starting from the experimental results mentioned above, a lumped parameters model is defined of the impedance between the two electrodes 10, 11 in order to validate the measurements made, and evaluate whether it is possible to obtain greater sensitivity to the presence of the operator's hand by varying the circuit configuration used to acquire the signals at the two electrodes 10, 11.

[0132] As a first approximation, it is possible to model the system 1 according to the scheme of figure 2, namely a voltage divider, in which the impedance Z_X represents the impedance between the two measuring electrodes 10, 11, assumed to be purely capacitive, and the load impedance R_L takes into account the input impedance of the analog connections 121, 122 of the control logic unit 12 (indicated in detail in figure 5). This impedance acts as a voltage divider between the input and the amplifier, placed before the ADC. Furthermore, the variable capacitance from 5-20pF (shown in figure 5) is set to make the voltage transfer constant for all frequencies.

[0133] Thus, the load impedance R_L, in addition to the resistive component of about 1MΩ, will also have a reactive part that will affect the frequency response of the system 1. In particular, at low frequency the load impedance R_L can be approximated with the resistive component alone, giving rise to a high-pass type response, while at high frequencies the load impedance R_L is dominated by the capacitive component and the system 1 will tend to behave like a capacitive divider.

[0134] What has been said is confirmed by the experimental tests, in which the transfer function of system 1 showed an increasing trend for frequencies, lower than about 10 kHz and then assumed a constant trend.

[0135] In the absence of any material interposed or in the vicinity of the electrodes 10, 11, the impedance Z_X is constituted by the capacitance present between them. Given the large distance between the electrodes 10, 11, the contribution to the overall capacitance given by the edge effects is more than two orders of magnitude higher than that obtained by modeling the two electrodes 10, 11 as a capacitor with flat parallel faces.

[0136] The curvature of the electric field lines of force along the edges of the electrodes 10, 11, known as the edge effect or "*fringe effect*", justifies the ability of the system 1 to detect the approach of an object before it enters the enclosed space between the surface of the two electrodes 10, 11, as occurs in a capacitor with flat and parallel faces.

[0137] When approaching the electrodes 10, 11, a double capacitive effect is expected.

[0138] The first effect is the reduction of the capacitance between the two electrodes 10, 11 due to the screen effect given by the object.

[0139] The second effect is, instead, an increase in capacity due to the polarization of the object because of the electromagnetic field. In fact, by being polarized, the object attracts electric charges from the source to the electrodes 10, 11. The increase in the electric charge at the electrodes 10, 11 corresponds to an increase in capacity, as occurs in the case of a capacitive proximity sensor.

Simulation of the impedance trend between the two electrodes in MATLAB

[0140] The system 1 has been modeled according to the electrical diagram shown in figure 10, in which:

- Z_1 represents the capacitance present between the two electrodes 10, 11;
- Z_2 and Z_3 represent the increase in capacity due to the object being polarized by the electromagnetic field;
- Z_4 represents the impedance of the conductive path between the object and mass; and
- Z_5 represents the input impedance of the control logic unit 12 used to generate and acquire the signals.

[0141] Since the electrical connection between the control logic unit 12 and the electrodes 10, 11 has been made using coaxial cables, in the impedance Z_5, in addition to the impedance of the passive components present in the control logic unit 12, a capacitance of 100pF has been added in parallel, since, for the frequencies considered, it is possible to model the cable with only the capacitive component with a value of approximately 100pF/m.

[0142] Furthermore, although the first electrode 10 is also connected to the logic control unit 12 via a coaxial cable, it is not necessary to add in the model an additional 100pF capacitance between the first electrode 10 and ground as the first electrode 10 is driven at low impedance from the voltage generator G and, therefore, does not produce any effect on the measurement.

[0143] By solving the system composed of the constitutive equations of the impedances used in the model, and the equations that represent how the impedances are connected to each other, visible below, the trend of the voltage and current variables was obtained.

```
eq1 = I1 * Z1 == V1;

eq2 = I2 * Z2 == V2;

eq3 = I3 * Z3 == V3;

eq4 = I4 * Z4 == V4;

eq5 = I5 * Z5 == V5;
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$$eq6 = I1 + I2 == I0;$$

$$eq7 = I3 + I4 == I2;$$

$$eq8 = I1 + I3 == I5;$$

$$eq9 = V5 + V1 == E0 - E1;$$

$$eq10 = V4 + V2 == E0 - E2;$$

$$eq11 = V5 + V3 - V4 == E2 - E1.$$

[0144] The variables of greatest interest for evaluating the transfer function of system 1 are the voltage supplied to the first electrode 10 and the voltage measured at the second electrode 11.

[0145] As can be seen from figure 7, between the input voltage to the control logic unit 12 and its analog-to-digital converters (ADC1 and ADC2) the voltage dividers are present that must be taken into account.

[0146] The transfer function of system 1 was therefore defined as the ratio between the voltage measured by the second analog-to-digital converter ADC2, and the voltage measured by the first analog-to-digital converter ADC1, as reported in the equations below, and it will be a function as well as of the frequency and the distance of the object from the electrodes 10, 11 , also of the characteristics of the object itself.

Voltage of the first electrode 10

$$V\_E1 = V\_S;$$

Second electrode voltage 11

$$V\_E2 = E1 + solution.V5;$$

Input voltage at the first acquisition connection

$$V\_CH1 = V\_E1 + AD2\_VD;$$

Input voltage to the second acquisition connection

$$V\_CH2 = V\_E2 + AD2\_VD;$$

Output/Input

$$Ratio\ R\_FdT = V\_CH2 / V\_CH1$$

[0147] The impedances Z_1, Z_2, Z_3, and Z_4 will assume different values in different situations, adapting to the electrical and geometric characteristics of the material considered and of the coupling capacity with the ground.

[0148] As said, the impedance Z_1 represents the capacitance present between the two measuring electrodes 10, 11. In particular, its value is related to the geometry of the contacts and their distance and is dominated by the component due to edge effects.

[0149] As it approaches, the object acts as a shield against the electric field resulting in a reduction in the observed capacitance value. This reduction will be linked to the size of the object and its effectiveness as an electromagnetic screen.

[0150] In the following, an exponential dependence is assumed, which certainly cannot accurately model the three-dimensional phenomenon, but allows to simply describe a variation with the distance of the object very similar to that measured experimentally.

$$Z_1(s,d) = \frac{1}{sC_1(d)}$$

$$C_1(d) = C_{1\infty} \cdot (1 - \alpha \cdot e^{-\frac{d}{D}})$$

where

- $C_{1\infty}$ is the capacitance seen between the electrodes 10, 11 in the absence of any object placed in the vicinity of the space between the surface of the two electrodes 10, 11 or barrier, estimated at 1 pF;
- *d* is the distance of the object from the barrier;
- *D* measures the sensitivity, in distance, of the ability to approach the object (in the simulations D = 1cm, purely for qualitative purposes); and
- α takes into account the effectiveness of the object in acting as a screen.

[0151] The impedances Z_2 and Z_3 represent the capacities that are created between the electrodes 10, 11 and the object due to the polarization of the object due to the electric field. The polarized object attracts further charges on the electrodes 10, 11 corresponding to an increase in capacity. Approaching the object to the barrier, the polarization is stronger and therefore there is an increase in these capacities.

$$Z_{2.3}(s,d) = \frac{1}{sC_{2.3}(d)}$$

$$C_{2.3}(d) = C_{2.3o} \cdot e^{-\frac{d}{D}}$$

where

- $C_{2.3o}$ is the additional capacitance seen by the electrodes 10, 11 due to the polarization of the object placed in the vicinity of the barrier, and its value depends on the properties of the object;
- *d* is the distance of the object from the barrier; and
- *D* measures the sensitivity, in distance, of the ability to approach the object (in the simulations D = 1cm, for purely qualitative purposes).

[0152] The impedance Z_4 models the electrical characteristics of the material which the object is composed of that is approaching the electrodes 10, 11 and its capacitive coupling with the ground and with the metal structure of the machining tool 22.

[0153] Impedance Z_5 represents the impedance of the discrete component network interposed between the input contacts of the acquisition connections 121, 122 and the input of the respective analog-digital converters ADC1, ADC2 with the capacitance of the coaxial cable in parallel. This impedance Z_5 is the only impedance to remain constant during the simulations.

First simulation: absence of objects in the vicinity of the space between the two electrodes

[0154] A first verification of the model is given by the evaluation of the frequency response considering only the barrier, i.e. neglecting Z_2, Z_3 and Z_4.

[0155] For the impedance Z_1 the capacitive value of 1 pF was estimated. The trend of the module, shown in figure 11A, agrees with what was experimentally detected and expected in the model definition phase.

[0156] In particular, for frequencies below 10 kHz, an increase in the modulus is noted with increasing frequency, typical of the first-order high-pass CR filters, while for higher frequencies the modulus trend is constant, but settles at -42 dB and not at 0 dB, as at high frequency the impedance Z_5 is dominated by the reactive component given by the capacities of the coaxial cable and by the capacities of the input network of the analog channels of the acquisition board 12. Approximating this capacity with the capacity of the coaxial cable alone, a high-frequency transfer is obtained equal to:

$$\frac{Z_5}{Z_1 + Z_5} \approx \frac{\frac{1}{s} . C_{coax}}{\frac{1}{s} . C_1 + \frac{1}{s} . C_{coax}} \cong \frac{C_1}{C_{coax}} = \frac{1\,pF}{100\,pF} = -40\,dB$$

Second, third and fourth simulation: approaching the operator's hand to the space between the two electrodes

[0157] In these simulations, the interaction of the operator's hand with the barrier was modeled.

[0158] The estimated value of α is equal to 0.1 while a value of 200 fF was used for the capacities $C_{2.3o}$ (with this value the overall capacitance given by C_1 + series C_2-C_3).

[0159] The electrical model of the human body was taken from [1] composed of a 200Ω resistor in parallel to a 10pF capacitance and the coupling of the body with the metal structure and the ground was modeled with a 400pF capacitance.

[0160] The results obtained are shown in figures 12A and 12B, in which the first electrode 10 was powered at the frequency of 10kHz and in figures 13A and 13B in which the first electrode 10 was powered at the frequency of 1 MHz.

[0161] Figures 14A and 14B show, on the other hand, the experimental measurements carried out in the case of the operator's hand approaching the barrier, in which the first electrode 10 is powered at the frequency of 1 MHz.

[0162] The simulations were calculated considering an approach and subsequent removal of the hand to the barrier, exactly as the experimental tests had been carried out.

[0163] Finally, figures 15A and 15B show the trend of the module and of the phase of the transfer function of the system 1 as the position of the hand with respect to the barrier varies.

[0164] As can be seen, consistently with the measurements made, the simulation shows a constant variation of the modulus in the frequency range between 10kHz and 1 MHz while the phase shows no sensitivity with respect to the position of the operator's hand.

[0165] Furthermore, the results are identical even by increasing the resistance from 200Ω up to 20kΩ, representing the different body-blade approach geometries (the tip of the finger or the entire forearm).

Fifth, sixth, and seventh simulations: approaching a wet piece of wood to the space between the two electrodes

[0166] In these simulations, the interaction of a wet piece of wood with the barrier was modeled.

[0167] The estimated value of α is equal to 0.1 (as for the hand) and for the capacities $C_{2.3o}$ a value of 200fF was used (with this value the overall capacitance given by C_1 + series C_2-C_3).

[0168] The electric model of the wet wood is composed of a 10MΩ resistor in parallel to a negligible capacitance, and the coupling of the body with the metal structure and the ground has been modeled with a capacitance of 100pF. The value of the series resistance is six orders of magnitude higher than that of the human body due to the lower conductivity of the wood.

[0169] The results obtained are shown in figures 16A and 16B, in which the first electrode 10 was fed with a signal at the frequency of 10kHz, and in figures 17A and 17B, in which the first electrode 10 was fed with a signal at the frequency of 1 MHz.

[0170] Figures 18A and 18B show, on the other hand, the experimental measurements carried out in the case of approaching the wet piece of wood to the barrier, in which the first electrode 10 is powered at the frequency of 10kHz.

[0171] Finally, figures 19A and 19B show the modulus and the phase of the transfer function of the system 1 as the position of the wet wood with respect to the barrier varies.

[0172] As can be seen, consistently with the measurements made, at low frequencies, the modulus and the phase of the transfer function show a variation in the position of the wet wood, while the sensitivity at high frequencies is reduced.

Eighth, ninth, and tenth simulations: approaching a piece of dry wood to the space between the two electrodes

[0173] In these simulations, the interaction of a piece of dry wood with the barrier was modeled.

[0174] The estimated value of α is equal to 0.1 while a value of 200fF has been used for the $C_{2.3o}$ capacities (as in the other cases).

[0175] Given the very low conductivity value, the electrical model of dry wood is composed of a 1GΩ resistor in parallel to a negligible capacitance. The coupling of the body with the metal structure and the ground was modeled with a capacitance of 100pF.

[0176] Given the resistance value used in the wet wood model, the resistance of the dry piece of wood could also be of some higher-order, but already with 1GΩ, the simulation results coincide with those of the experimental tests.

[0177] The results obtained are shown in figures 20A and 20B, in which the first electrode 10 was supplied with a signal at the frequency of 10kHz, and in figures 21A and 21B, in which the first electrode 10 was supplied with a signal at the frequency of 1 MHz. In both cases mentioned above, the variation is irrelevant for the modulus and minimal for the phase.

[0178] Figures 22A and 22B show, on the other hand, the experimental measurements carried out in the case of approaching the dry wood piece to the barrier, in which the first electrode 10 is powered at a frequency of 10kHz.

[0179] Finally, figures 23A and 23B show the modulus and phase of the transfer function of the system 1 as the position of the dry wood with respect to the barrier varies. As can be observed, consistently with the measurements carried out, in the range of frequencies considered, that is 10kHz - 1 MHz, the simulation does not show significant variations when the dry wood approaches the barrier.

Finite element three-dimensional electromagnetic simulation model

[0180] In addition to the above, in order to deepen the knowledge of the measurement system, a model was created in the COMSOL Multiphysics finite element physics simulation environment.

[0181] This software allows simulating the electric field trend in three-dimensional structures with extremely realistic characteristics. By creating a physical simulation of the system capable of taking into account the different geometries and the different materials involved, this type of simulation can lead to a more in-depth knowledge of the system, allowing to evaluate the interaction of the electric field generated by the electrodes with the different materials and the degree of coupling of the object with the metal structure of the circular saw.

[0182] In particular, figures 24A and 24B show the graphs of the trend of the electric field force lines during the approach of the hand to the barrier, respectively without a glove (figure 24A) and with a glove (figure 24B). It can be seen that the attraction of the field towards the hand is not modified by the presence of the glove.

[0183] Figure 25, on the other hand, shows the graphs relating to the approach of the wood to the barrier. Both simulations were performed at the 1MHz frequency. It can be seen how the presence of the hand modifies the field lines in a different way compared to wood.

[0184] Through this software, it is also possible to calculate the equivalent impedance variations, useful for validating the discrete parameter model previously described. For the simulations performed, a good agreement was found with the results obtained with discrete parameters.

[0185] As regards the signal acquisition system, the tests were carried out with direct connection of the control logic unit 12 for the acquisition of the signals to the two electrodes 10, 11, thus realizing a transfer function sensitive to the impedance seen between the two electrodes 10, 11, but limited by the impedance Z_5 of the logic control unit 12.

[0186] In a further embodiment of the present invention, the impedance Z_5 is replaced by an active measuring circuit (trans-impedance), in order to amplify the measured signal and increase its sensitivity to the impedance between the two electrodes 10, 11.

[0187] In this configuration, the receiving electrode 11 is connected to the virtual ground of the amplifier instead of to a network of passive components.

[0188] Therefore, the impedance Z_x present between the two measuring electrodes is therefore connected between the low impedance of the sinusoidal signal generator and the ideally zero and constant frequency impedance guaranteed by the amplifier feedback.

[0189] The proximity detection method 3, shown in figure 26, according to the present invention is carried out as follows.

[0190] Initially, in the powering phase 30, the first electrode 10 is supplied by at least one signal, in such a way as to generate an electric field arranged to shield an area and in such a way that said electric field is intercepted by said at least one second electrode 11.

[0191] In particular, as said, it is possible to supply to the first electrode 10, by means of the signal generator G, one or more signals at respective frequencies. This signal generator G is connected to the first electrode 10 by means of the power supply connection 120.

[0192] Subsequently, in the acquisition step 31, at least one first measurement signal $S_{E10}(t)$ from said first electrode 10 is acquired.

[0193] Subsequently, in the acquisition step 32, at least one second measurement signal $S_{E11}(t)$ from said at least one second electrode 11 is acquired.

[0194] Then, in the processing step 33, the two measurement signals acquired in the acquisition phases 31 and 32 are processed in order to obtain at least one processed parameter S_{Re} and at least one processed parameter S_{Im} respectively as a function of the amplitude and phase of said at least one first and at least one second measured processed signal.

[0195] In particular, the processing step 33 comprises the sub-step 330 to process said at least one first measurement signal $S_{E10}(t)$ to obtain at least one first phasor S_{E10}, and the sub-step 331 to process said at least one second signal in frequency measurement $S_{E11}(t)$, to obtain at least one second phasor S_{E11}.

[0196] Said at least one processed parameter S_{Re} is given by the real part of the relationship between said at least one second phasor S_{E11} and said at least one first phasor S_{E10}, while said at least one processed parameter S_{Im} is given by the imaginary part of the relationship between said at least one second phasor S_{E11} and said at least one first phasor S_{E10}.

[0197] In the embodiment described, such processing is a frequency processing by means of a DFT. However, in other embodiments of the present invention, the frequency processing of such signals may be different from what is described.

[0198] Then, in step 34, the presence of said limb of said operator is detected in the proximity of said first 10 and at least one second electrode in the case in which said at least one comparative parameter S_{Re} and/or said at least one comparative parameter S_{Im} obtained in said processing step 33 is less than, or equal to and/or greater than or equal to a respective comparative parameter $\overline{S}_{Re}$ and/or $\overline{S}_{Im}$, as a predefined threshold.

[0199] In one embodiment, the processed parameter S_{Im} is compared with the phase of the stimulus signal and the limb is detected by the system 1 when the phase shift with respect to this signal has a predetermined value depending on the hardware peculiarities of the system 1.

[0200] In the embodiment that is described, said method 3 allows to detect the presence of a limb of an operator on a tool for processing 22 included in a machine M for processing manufactured articles.

Advantages

[0201] An advantage of the proximity detection system according to the present invention is that of identifying in advance and with precision a potential risk condition for the operator during the processing of wooden pieces and the like.

[0202] A further advantage of the proximity detection system according to the present invention is that of discriminating the presence of the operator's hand near the working tool from the presence of a wet or dried piece of wood in the vicinity of the same tool, avoiding any false alarms.

[0203] The present invention has been described for illustrative but not limitative purposes, according to its preferred embodiments, but it is to be understood that modifications and/or changes can be introduced by those skilled in the art without departing from the relevant scope as defined in the enclosed claims.

References

[0204]

[1] JR Smith, Toward Electric Field Tomography, MIT, Boston, 1995;

[2] THCCGWRBOHSRMSJS Grosse-Puppendahl, «Finding Common Ground: A Survey of Capacitive Sensing in Human-Computer Interaction» CHI'17: Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems, p. 3293-3315, May 2017.

Claims

1. Machine (M) for working products, such as panels made of wood, fiberglass, metal and the like, comprising a working tool (22) for working said products,
   wherein said machine (M) is **characterized in that** it comprises a system (1) for detecting the proximity of a limb of an operator to said working tool (22), comprising:

   at least one signal generator (G), for generating at least one signal $S_G(t)$;
   at least one first electrode (10), galvanically isolated from said machine (M) and connected to said at least one signals generator (G);
   at least a second electrode (11) galvanically isolated from said machine (M), wherein said signal $S_G(t)$ generated by said at least one signal generator (G) is configured to generate an electric field between said at least one first electrode (10) and said at least one second electrode (11);
   wherein said electric field between said at least one first (10) and said at least one second electrode (11) forms a barrier at least partially around said working tool (22); and
   a logic control unit (12) connected to said at least one first electrode (10), and to said at least second electrode (11), so as to acquire at least one first measuring signal $S_{E10}(t)$ from said at least one first electrode (10) and

at least one second measuring signal $S_{E11}(t)$ from said at least one second electrode (11) respectively; wherein said logic control unit (12) is configured for processing said at least one first $S_{E10}(t)$ and at least one second $S_{E11}(t)$ measuring signal, for verifying at least one criterion as a function of at least two electrical quantities of said first $S_{E10}(t)$ and second $S_{E11}(t)$ measuring signal, so as to determine the presence of said limb of said operator in proximity of said barrier when said at least one criterion is verified.

2. Machine (M) according to the preceding claim, **characterized in that** said at least one signal generator (G) is configured to generate a signal $S_G(t)$ having a single frequency, wherein said frequency is preferably about 10KHz or 1 MHz.

3. Machine (M) according to claim 1, **characterized in that** said at least one signal generator (G) is configured to generate a signal $S_G(t)$ having two frequencies.

4. Machine (M) according to the preceding claim, **characterized in that** the first frequency of said signal $S_G(t)$ is about 10kHz, and the second frequency of said signal $S_G(t)$ is about 1MHz.

5. Machine (M) according to any one of claims 1-2, **characterized**

in that said at least one criterion provides at least one comparative parameter ($\overline{S}_{Re}$, $\overline{S}_{Im}$), such as a threshold, and **in that** said logic control unit (12) is configured to process at least one processed parameter ($\overline{S}_{Re}$, S_{Im}) to be compared with said comparative parameter ($\overline{S}_{Re}$, $\overline{S}_{Im}$), so as to determine the presence of said limb of said operator in proximity to said barrier, particularly when $S_{Re} \leq \overline{S}_{Re}$ and/or when $S_{Im} \geq \overline{S}_{Im}$.

6. Machine (M) according to any one of claims 1-2 or 5, **characterized in that** said logic control unit (12) is configured for processing in frequency said at least one first measuring signal $S_{E10}(t)$ and said at least one second measuring signal $S_{E11}(t)$ for obtaining at least one first phasor S_{E10} and at least one second phasor S_{E11} respectively.

7. Machine (M) according to the preceding claim, when dependent on claim 5, wherein said at least one processed parameter S_{Re} is determined by the following formula:

$$S_{Re} = Re\left\{\frac{S_{E11}}{S_{E10}}\right\}$$

where S_{Re} is determined by the real part of the ratio between said at least one second phasor S_{E11} and said at least one first phasor S_{E10}, that is S_{Re} is a function of the amplitude of said at least one first S_{E10} and at least one second S_{E11} phasor.

8. Machine (M) according to claim 6, when dependent on claim 5, wherein said at least one processed parameter S_{Im} is determined by the following formula:

$$S_{Im} = Im\left\{\frac{S_{E11}}{S_{E10}}\right\}$$

where S_{Im} is determined by the imaginary part of the ratio between said at least one second phasor S_{E11} and said at least one first phasor S_{E10}, that is S_{Im} is a function of the phase of said at least one first S_{E10} and at least one second S_{E11} phasor.

9. Machine (M) according to any one of claims 3 or 4, **characterized**

in that said at least one criterion provides at least two comparative parameters $(\bar{S}'_{Re}, \bar{S}''_{Re}, \bar{S}'_{Im}, \bar{S}''_{Im})$, such as two thresholds, and
in that said logic control unit (12) is configured for processing at least two processed parameters $(S'_{Re}, S''_{Re}, S'_{Im}, S''_{Im})$ to be compared with said comparative parameters $(\bar{S}'_{Re}, \bar{S}''_{Re}, \bar{S}'_{Im}, \bar{S}''_{Im})$ so as

to determine the presence of said limb of said operator in proximity of said barrier when $S'_{Re} \leq \bar{S}'_{Re}$ and $S''_{Re} \leq \bar{S}''_{Re}$ and/or when $S'_{Im} \geq \bar{S}'_{Im}$ and $S''_{Im} \geq \bar{S}''_{Im}$.

10. Machine (M) according to any one of claims 3-4 or 9, **characterized**

in that said logic control unit (12) is configured for processing in frequency said at least one first measuring signal $S_{E10}(t)$ and said at least one second measuring signal $S_{E11}(t)$ with said first frequency for obtaining at least one first phasor $S_{E10}^{f_1}$ and at least one second phasor $S_{E11}^{f_1}$ respectively, and
in that said logic control unit (12) is configured for processing in frequency said at least one first measuring signal $S_{E10}(t)$ and said at least one second measuring signal $S_{E11}(t)$ with said second frequency for obtaining at least one first phasor $S_{E10}^{f_2}$ and at least one second phasor $S_{E11}^{f_2}$ respectively.

11. Machine (M) according to the preceding claim, when dependent on claim 9,

wherein said at least one processed parameter S'_{Re} is determined by the following formula:

$$S'_{Re} = Re\left\{\frac{S_{E11}^{f_1}}{S_{E10}^{f_1}}\right\}$$

where S'_{Re} is determined by the real part of the ratio between said at least one second phasor $S_{E11}^{f_1}$ and said at least one first phasor $S_{E10}^{f_1}$ at said first frequency, that is S'_{Re} is a function of the amplitude of said at least one first $S_{E10}^{f_1}$ and at least one second $S_{E11}^{f_1}$ phasor, and
wherein said at least one processed parameter S''_{Re} is determined by the following formula:

$$S''_{Re} = Re\left\{\frac{S_{E11}^{f_2}}{S_{E10}^{f_2}}\right\}$$

where S''_{Re} is determined by the real part of the ratio between at least one second phasor $S_{E11}^{f_2}$ and said at least one first phasor $S_{E10}^{f_2}$ at said frequency, that is S''_{Re} is a function of the amplitude of said at least one first $S_{E10}^{f_2}$ and at least one second $S_{E11}^{f_2}$ phasor.

12. Machine (M) according to any one of claims 10 or 11, when dependent on claim 9,

wherein said at least one processed parameter S'_{Im} is determined by the following formula:

$$S'_{Im} = Im\left\{\frac{S_{E11}^{f_1}}{S_{E10}^{f_1}}\right\}$$

where S'_{Im} is determined by the imaginary part of the ratio between said at least one second phasor $S_{E11}^{f_1}$ and said at least one first phasor $S_{E10}^{f_1}$ at said first frequency, that is S'_{Im} is a function of the phase of said at least one first $S_{E10}^{f_1}$ and at least one second $S_{E11}^{f_1}$ phasor, and

wherein said at least one processed parameter S''_{Im} is determined by the following formula:

$$S''_{Im} = Im\left\{\frac{S_{E11}^{f_2}}{S_{E10}^{f_2}}\right\}$$

where S''_{Im} is determined by the imaginary part of the ratio between said at least one second phasor $S_{E11}^{f_2}$ and said at least one first phasor $S_{E10}^{f_2}$ at said second frequency, that is S''_{Im} is a function of the phase of said at least one first $S_{E10}^{f_2}$ and at least one second $S_{E11}^{f_2}$ phasor.

13. Machine (M) according to any one of the preceding claims, **characterized in that** it comprises a working plane (21) for supporting said products to be worked,

wherein said working plane (21) comprises in its turn a fixed working plane (210) and a movable supporting plane (211),
wherein said at least one second electrode (11) is arranged on said fixed working plane (210) in proximity of said working tool (22), and
wherein said movable supporting plane (211) is capable of moving with respect to said fixed working plane (210) along a parallel direction or substantially parallel to an X axis parallel to which said movable supporting plane (211) is capable of moving with respect to said working plane (21).

14. Machine (M) according to the preceding claim, **characterized**

in that said system (1) comprises a plurality of second electrodes ($11_1,...,11_N$) arranged on said fixed working plane (210) in proximity of said working tool (22), and
in that said movable supporting plane (211) comprises a device capable of activating selectively each second electrode of said plurality of electrodes ($11_1,...,11_N$), on the basis of the position of said movable supporting plane (211) with respect to said fixed working plane (210).

15. Machine (M) according to claim 13, **characterized in that** said at least one second electrode (11) is arranged below said movable supporting plane (211).

16. Machine (M) according to any one of the preceding claims, **characterized**

in that it comprises a containing member (20), such as a cap and the like, arranged in correspondence with said working tool (22), to protect said working tool (22), wherein said containing member (20) is movable with respect to said working tool (22), and
in that said at least one first electrode (10) is arranged on one edge of said containing member (20).

17. System (1) for detecting the proximity of a limb of an operator to a working tool (22) of a machine (M) for working products, such as panel made of wood, fiberglass, metal and the like,
wherein said system (1) is **characterized in that** it comprises:

at least one signal generator (G), for generating at least one signal $S_G(t)$,
at least one first electrode (10), that can be installed on said machine (M), wherein said first electrode (10) is galvanically isolated from said machine (M) and connected to said at least one signal generator (G),
at least one second electrode (11), that can be installed on said machine (M) and galvanically isolated from said machine (M), wherein the signal $S_G(t)$ generated by said at least one signal generator (G) is configured to

generate an electric field between said at least one first electrode (10) and said at least one second electrode (11), wherein said electric field between said at least one first (10) and said at least one second electrode (11) forms a barrier at least partially around said working tool (22), and
a logic control unit (12) connected to said at least one first electrode (10), and to said at least one second electrode (11), so as to acquire at least one first measuring signal $S_{E10}(t)$ from said at least one first electrode (10) and at least one second measuring signal $S_{E11}(t)$ from said at least one second electrode (11) respectively; wherein said logic control unit (12) is configured for processing said at least one first $S_{E10}(t)$ and at least one second $S_{E11}(t)$ measuring signal, for verifying at least one criterion as a function of at least two electrical quantities of said first $S_{E10}(t)$ and second $S_{E11}(t)$ measuring signal, so as to determine the presence of said limb of said operator in proximity of said barrier when said at least one criterion is verified.

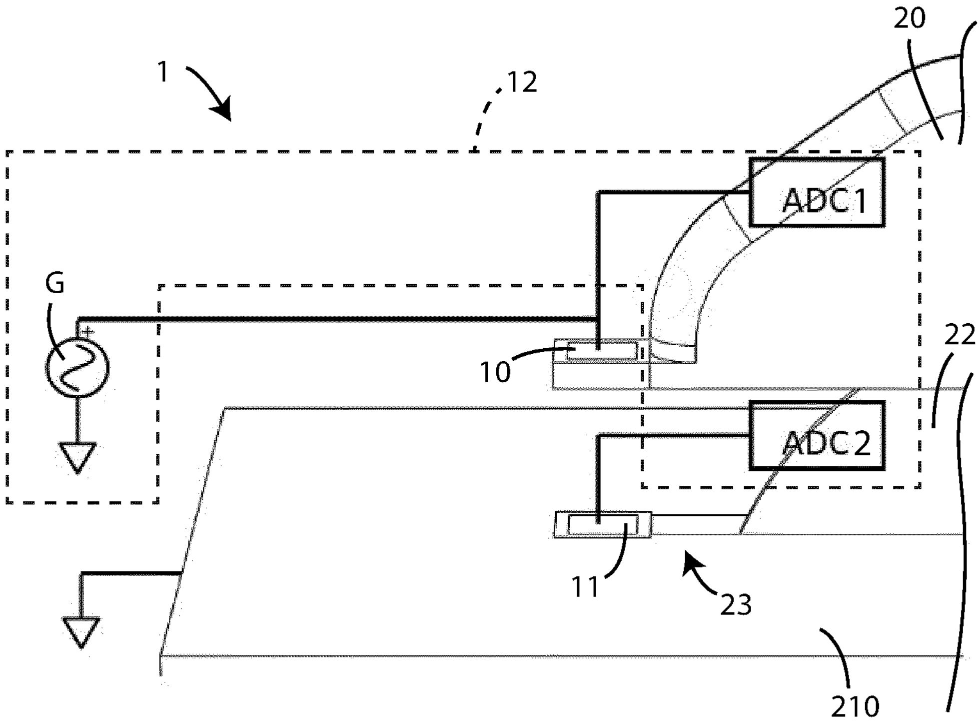
18. System (1) according to the preceding claim, **characterized in that** each electrode (10,11) is provided with an activable guard, arranged around each electrode (10,11), for adjusting said electric field between said at least one first electrode (10) and said at least one second electrode (11), so as to limit the exit of electric field lines and control the sensitivity of said system (1).

19. Method (3) for detecting the proximity of a limb of an operator to at least one first (10) and at least one second (11) electrode, wherein said method (3) comprises the following steps:

- powering (30) said at least one first electrode (10) by means of at least one signal $S_G(t)$ generated by means of at least one signal generator (G) connected to said at least one first electrode (10), so as to generate an electric field between said at least one first electrode (10) and said at least one second electrode (11);
- acquiring (31) at least one first measuring signal $S_{E10}(t)$ from said at least one first electrode (10);
- acquiring (32) at least one second measuring signal $S_{E11}(t)$ from said at least one second electrode (11);
- processing (33) said at least one first measuring signal $S_{E10}(t)$ and said at least one second measuring signal $S_{E11}(t)$ acquired in said acquiring steps (31, 32), for verifying at least one criterion as a function of at least two electrical quantities of said first $S_{E10}(t)$ and second $S_{E11}(t)$ measuring signal; and
- determining (34) the presence of said limb of said operator in proximity of said at least one first (10) and at least one second (11) electrode when said at least one criterion is verified.

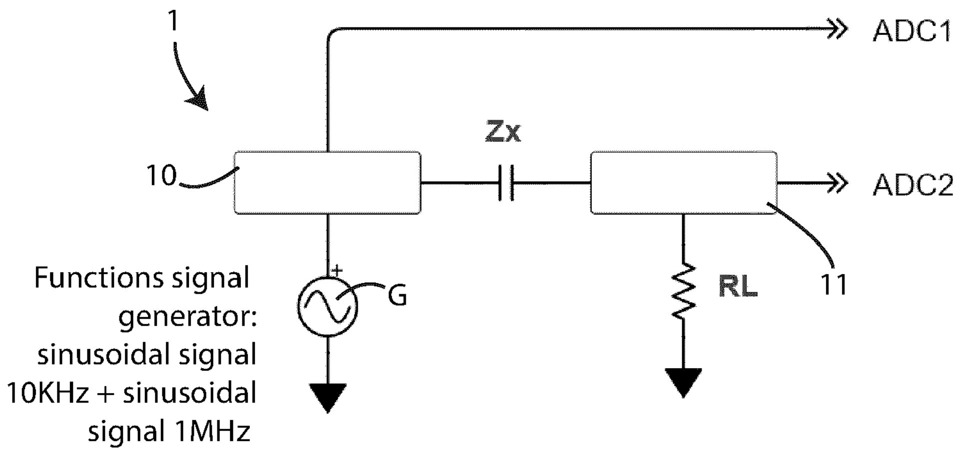
20. Method (3) according the preceding claim, **characterized in that** said processing step (33) comprises

the substep (330) of processing in frequency said at least one first measuring signal $S_{E10}(t)$ for obtaining at least one first phasor S_{E10}, and
the substep (331) of processing in frequency said at least one second measuring signal $S_{E11}(t)$ for obtaining at least one second phasor S_{E11},
wherein said at least one processed parameter S_{Re} is determined by the real part of the ratio between said at least one second phasor S_{E11} and said at least one first phasor S_{E10}, and at least one processed parameter S_{Im} is determined by the imaginary part of the ratio between said at least one second phasor S_{E11} and said at least one first phasor S_{E10}.



1
12
20
ADC1
G
10
22
ADC2
11
23
210

Fig. 1



1
ADC1
Zx
10
ADC2
Functions signal generator: sinusoidal signal 10KHz + sinusoidal signal 1MHz
G
RL
11

Fig. 2

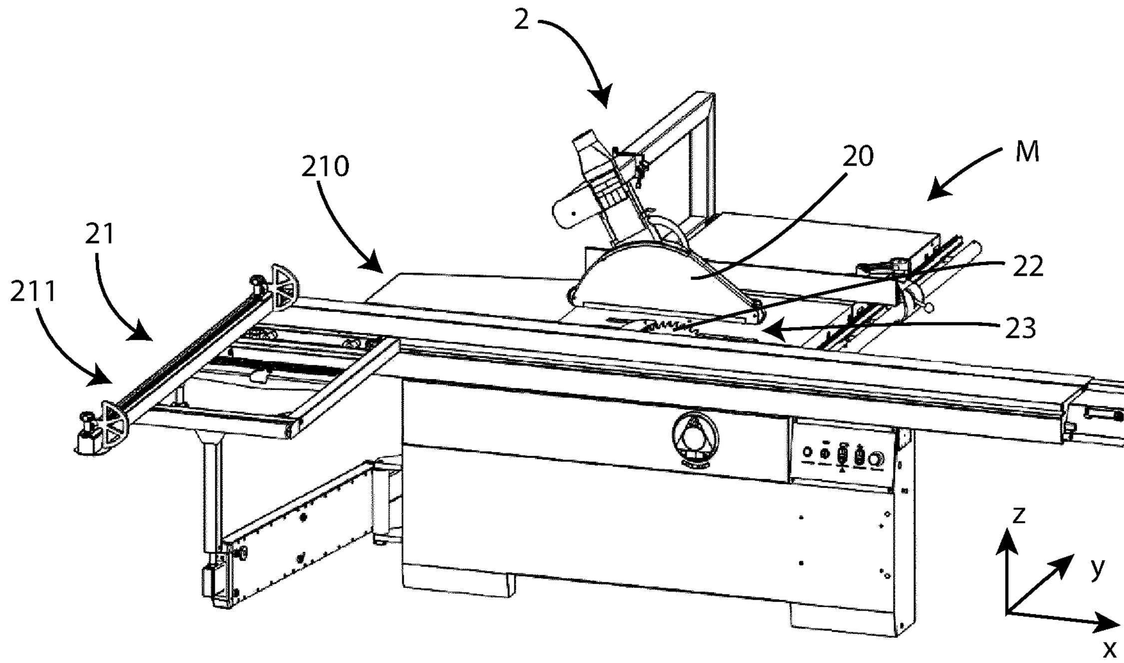


Fig. 3

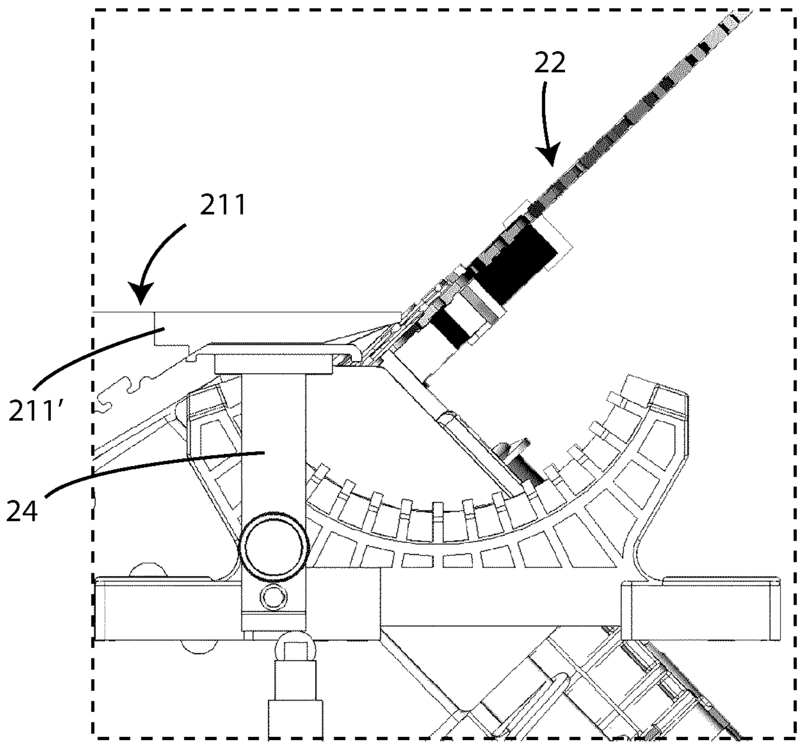


Fig. 4A

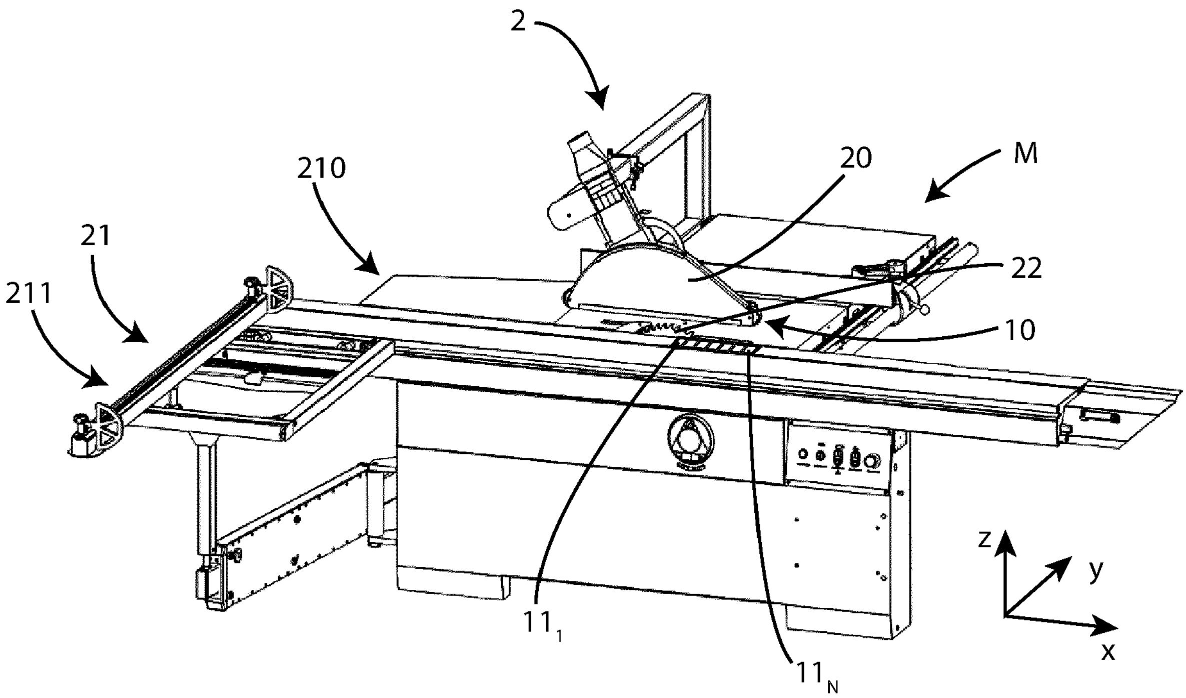

2
210
20
M
21
22
211
10
11_1
11_N
z
y
x

Fig. 4B

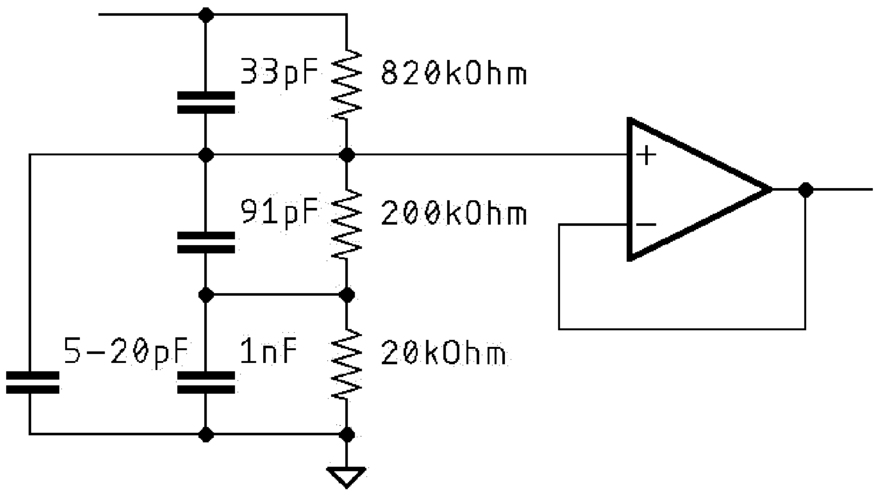

33pF
820kOhm
+
91pF
200kOhm
−
5−20pF
1nF
20kOhm

Fig. 5

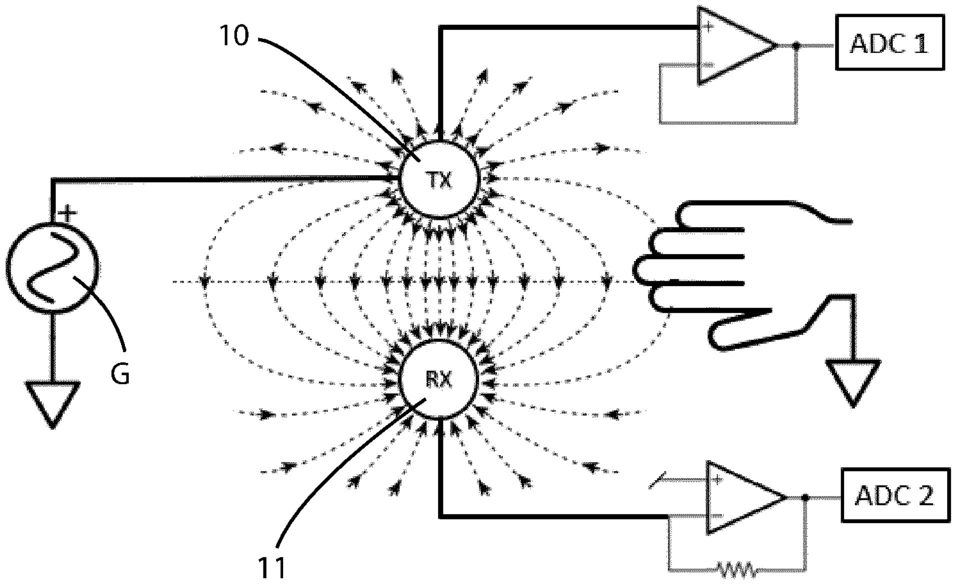

10
TX
ADC 1
G
RX
ADC 2
11

Fig. 6

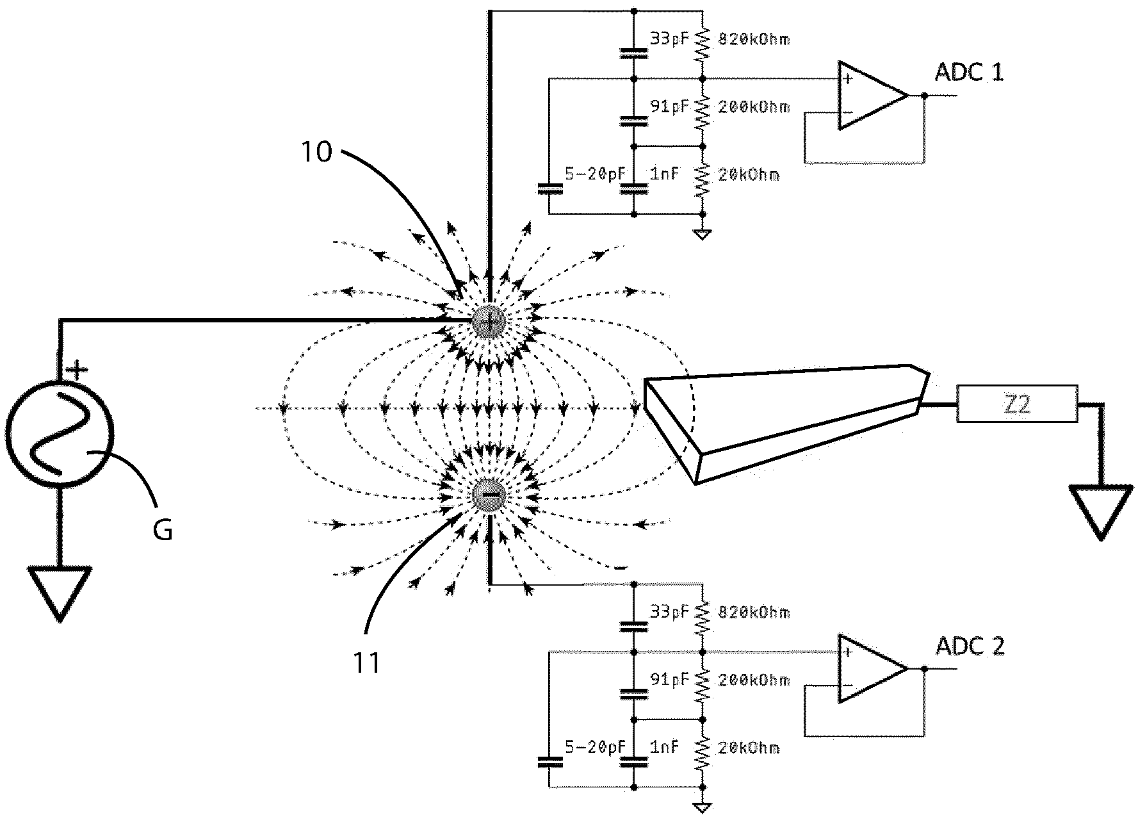

33pF
820kOhm
ADC 1
91pF
200kOhm
10
5-20pF
1nF
20kOhm
Z2
G
33pF
820kOhm
ADC 2
91pF
200kOhm
11
5-20pF
1nF
20kOhm

Fig. 7

Material	Resistivity $\rho\ (\Omega \cdot m)$	Conductivity $\sigma\ (S/m)$
Human Body	da $2 \cdot 10^1$ a $2 \cdot 10^3$	da $5 \cdot 10^{-4}$ a $5 \cdot 10^{-2}$
Wet wood	da 10^3 a 10^4	da 10^{-4} a 10^{-3}
Dried wood	da 10^{14} a 10^{16}	da 10^{-16} a 10^{-14}

Fig. 8

Material	f = 10 kHz		f = 1 MHz	
	phase variation	Module variation	phase variation	Module variation
Hand	+ 150°	- 80%	+ 100°	- 90%
Wet wood	+ 10°	- 20%	None	- 20%
Dry wood	None	+ 15%	None	+ 15%

Fig. 9

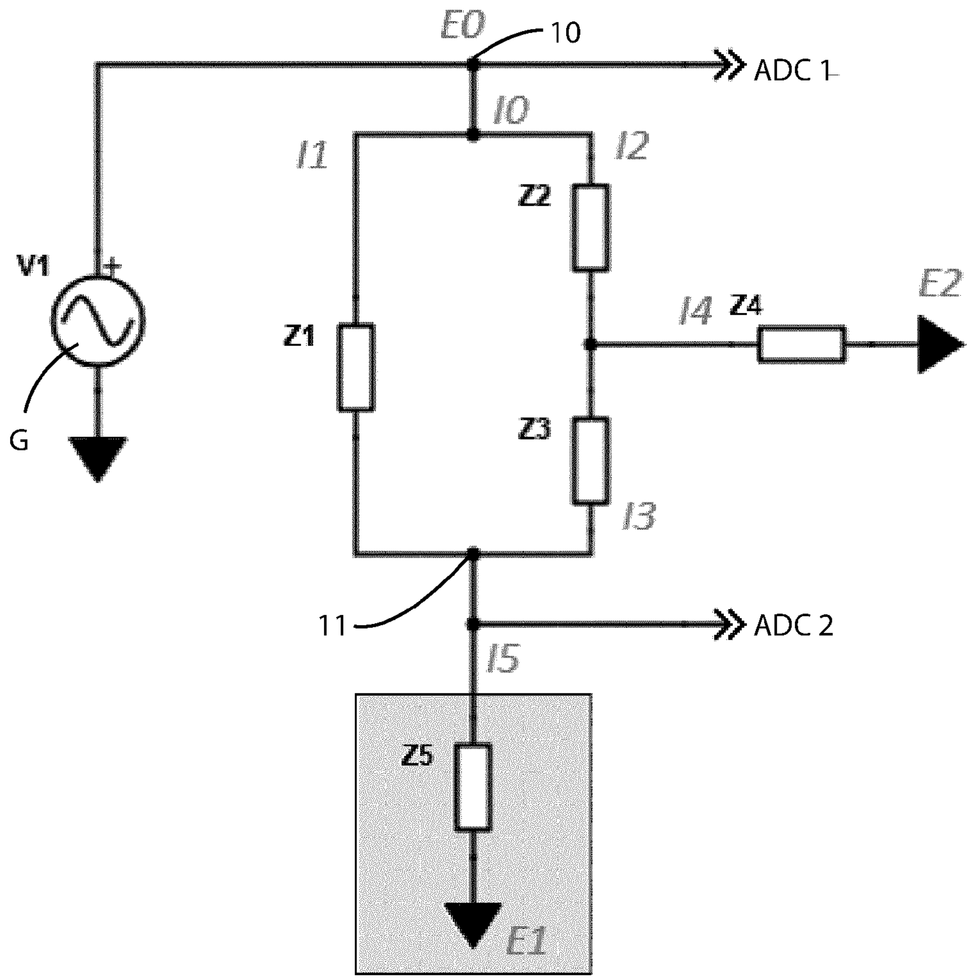


Fig. 10

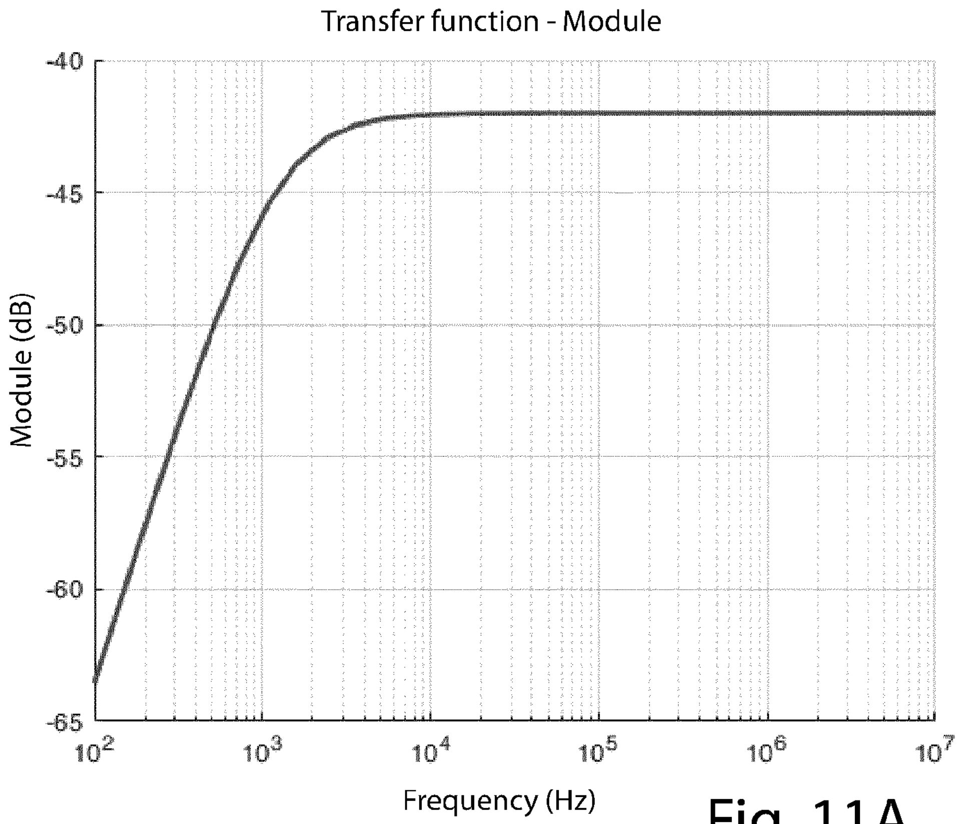


Fig. 11A

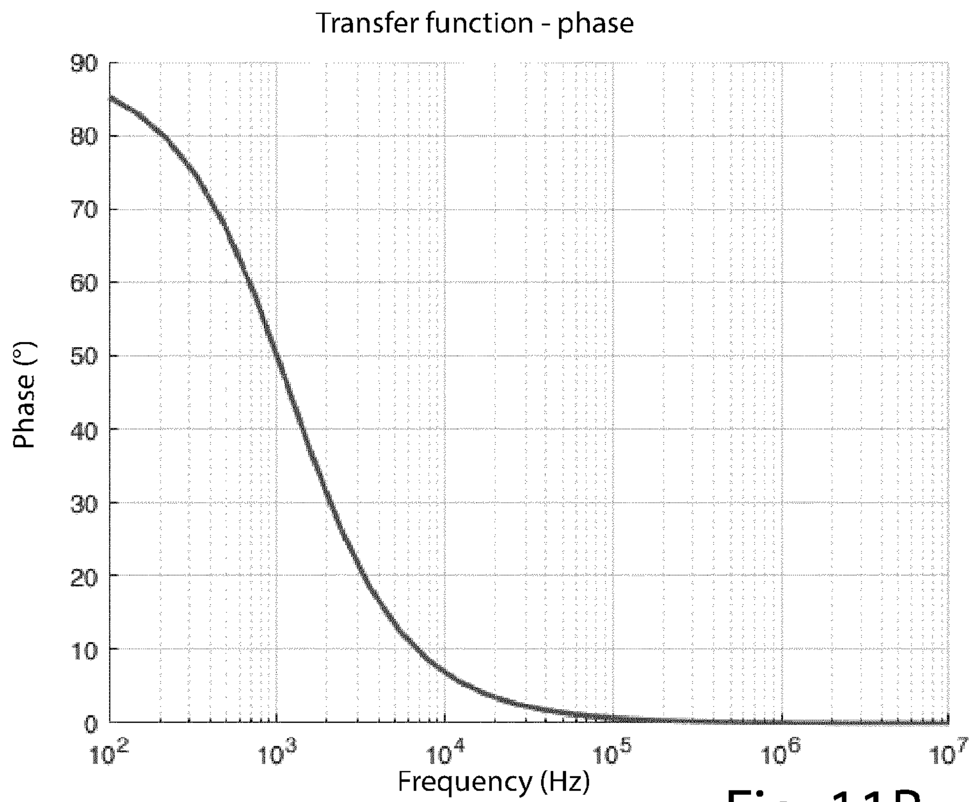


Fig. 11B

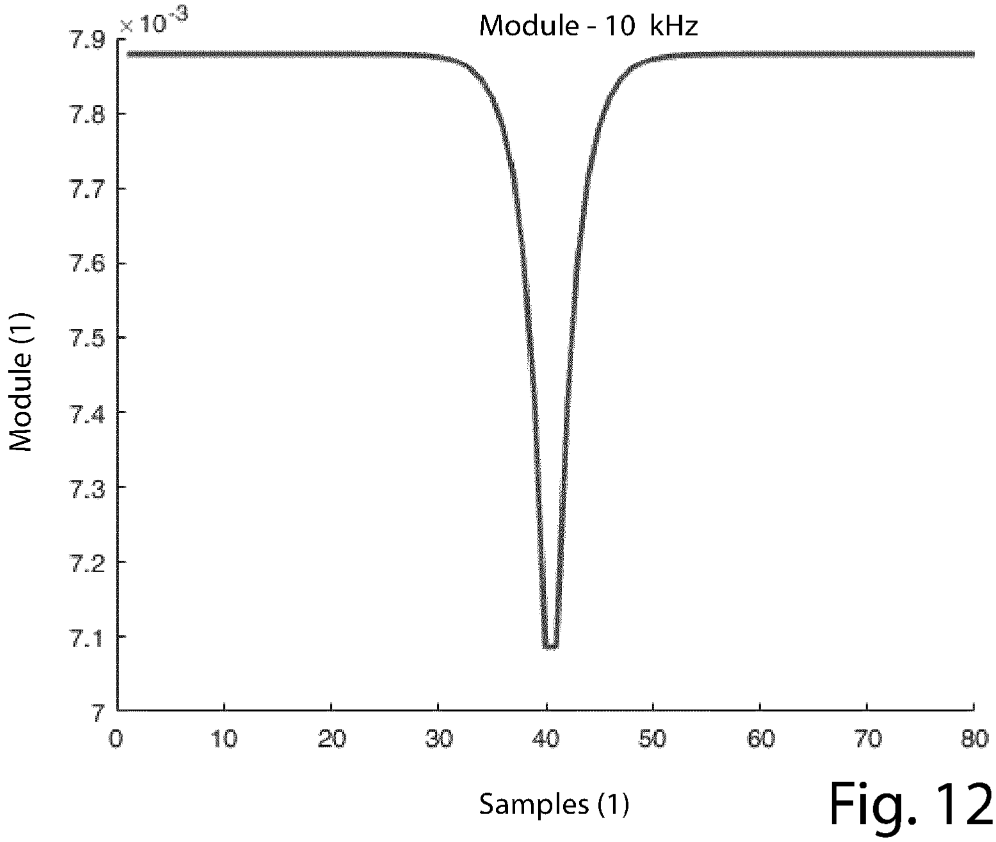


Fig. 12A

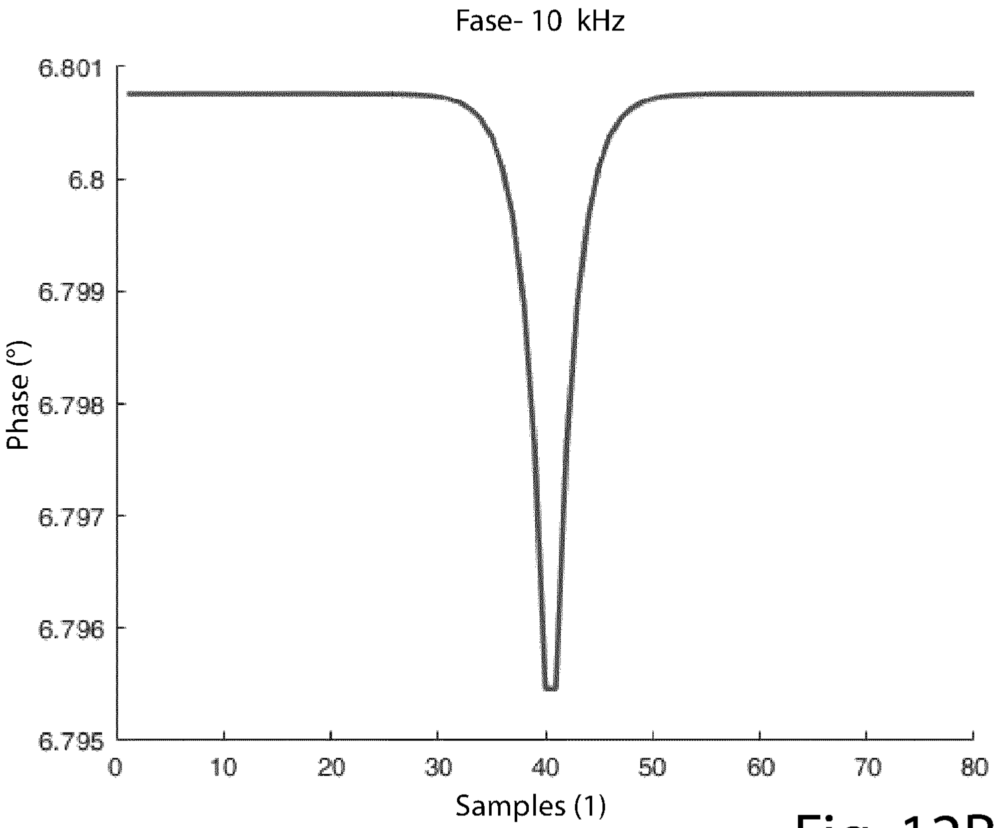


Fig. 12B

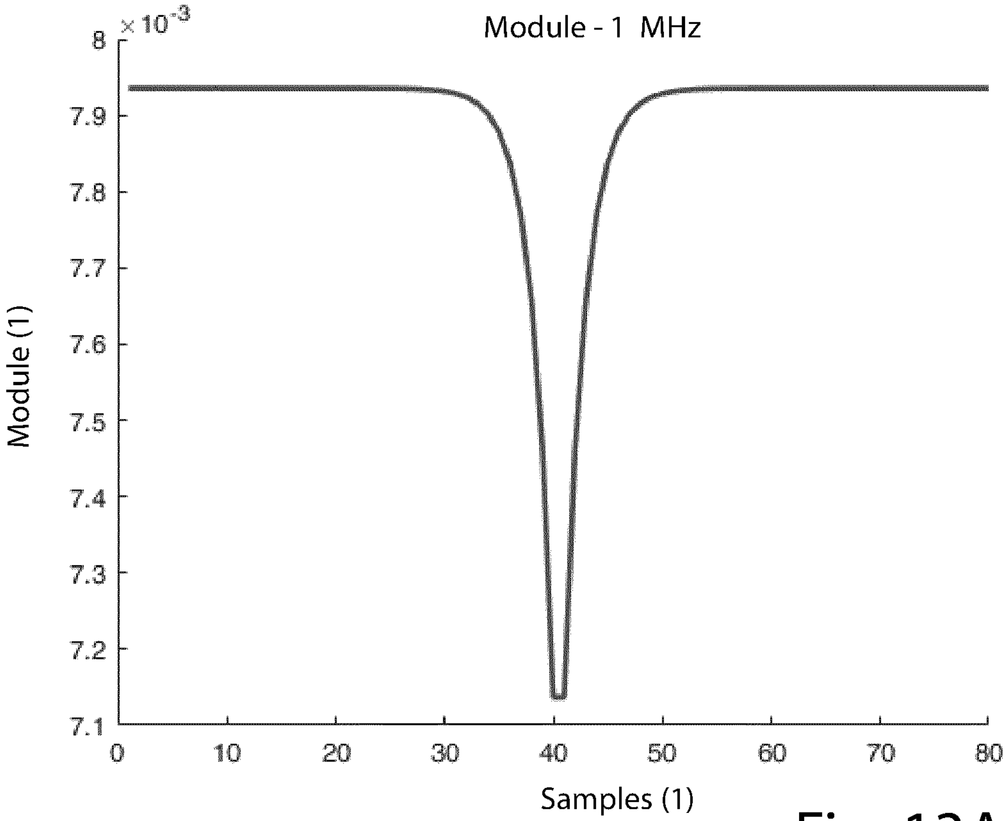


Fig. 13A

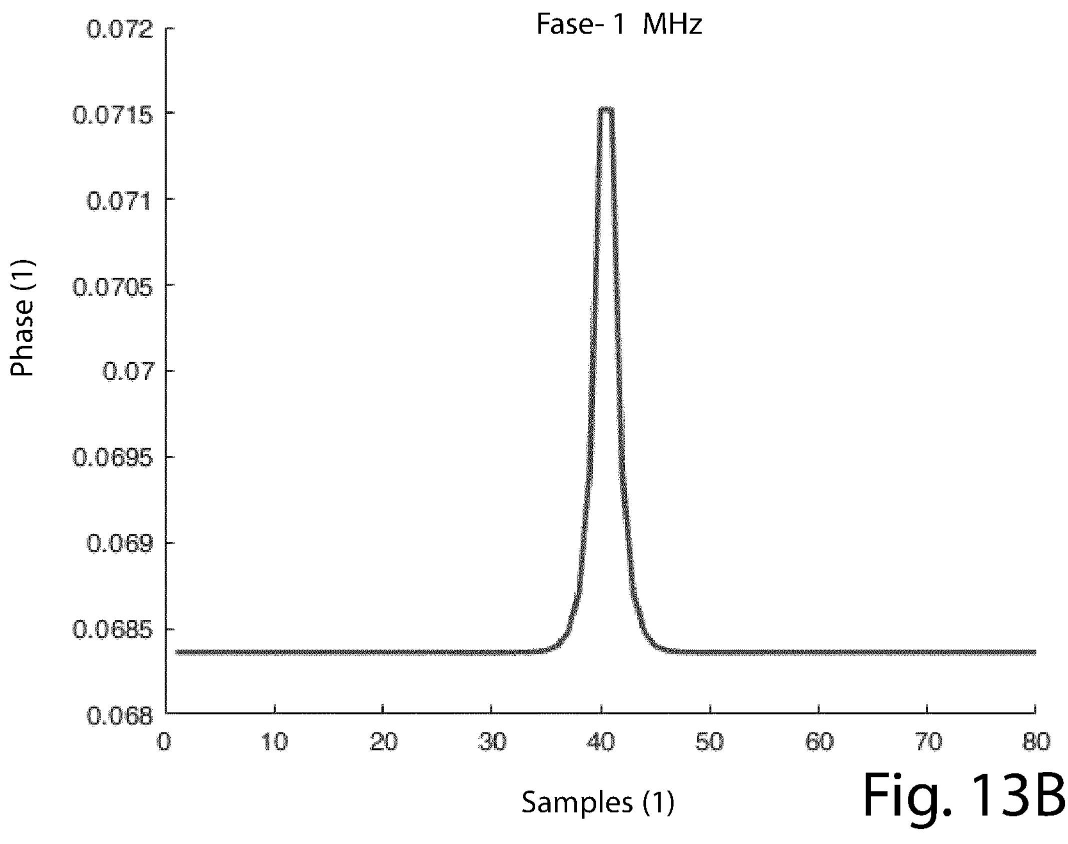


Fig. 13B

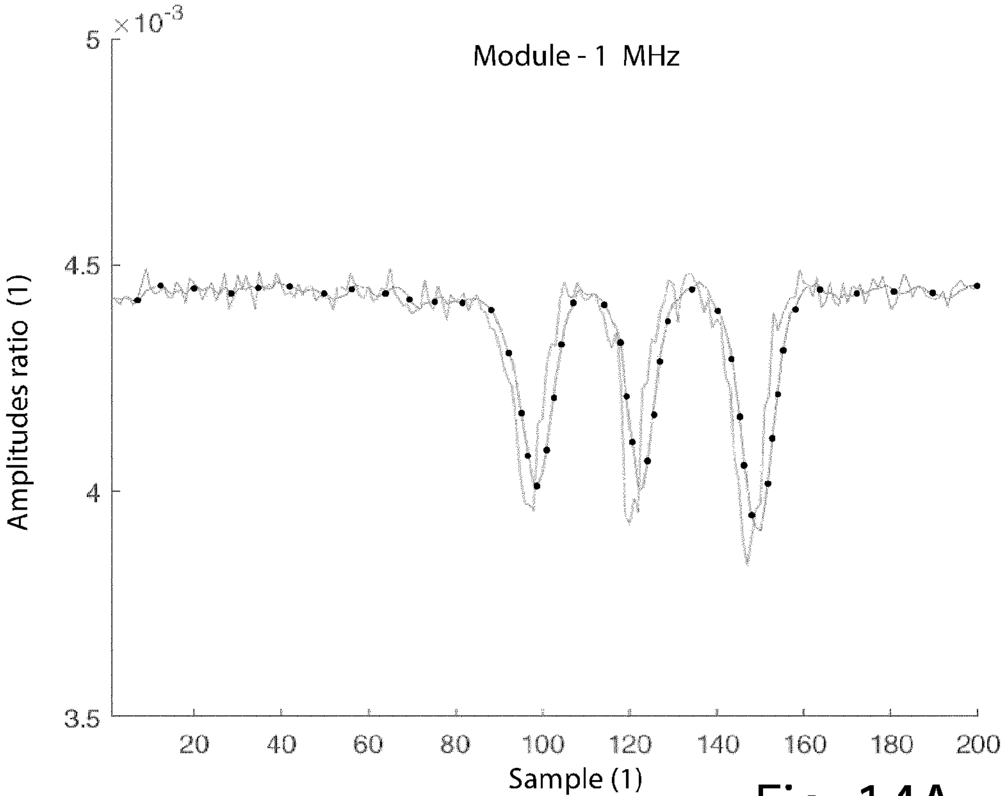


Fig. 14A

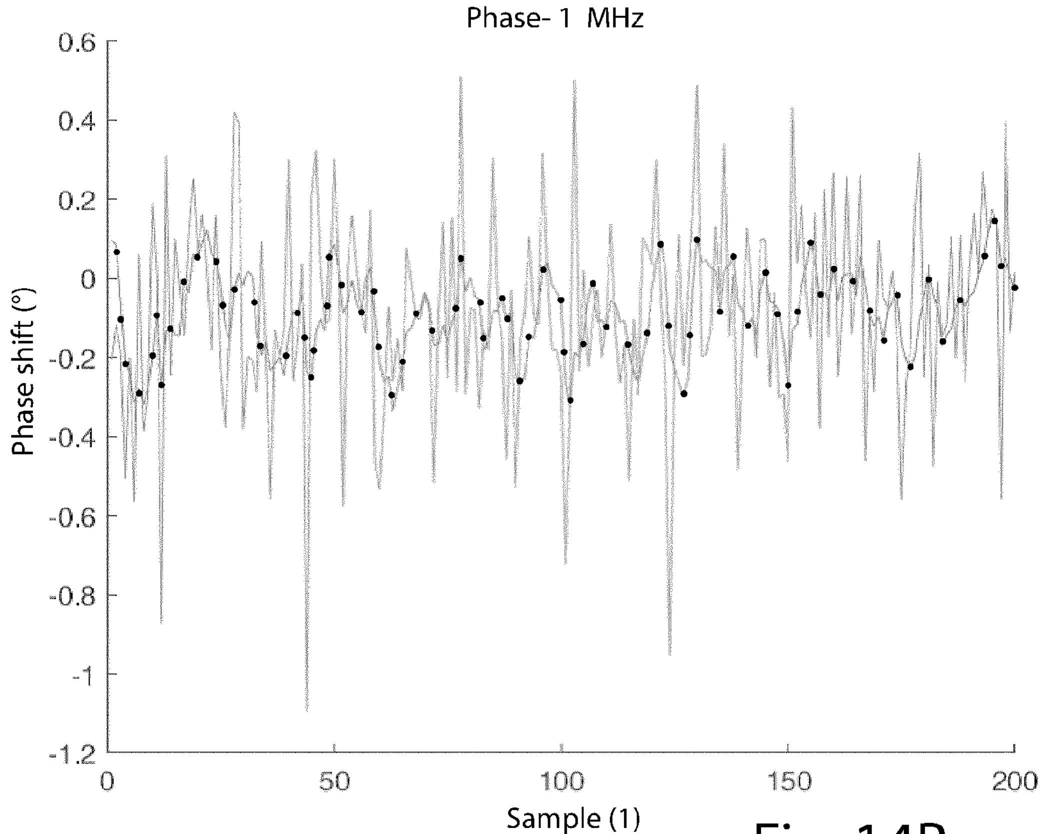


Fig. 14B

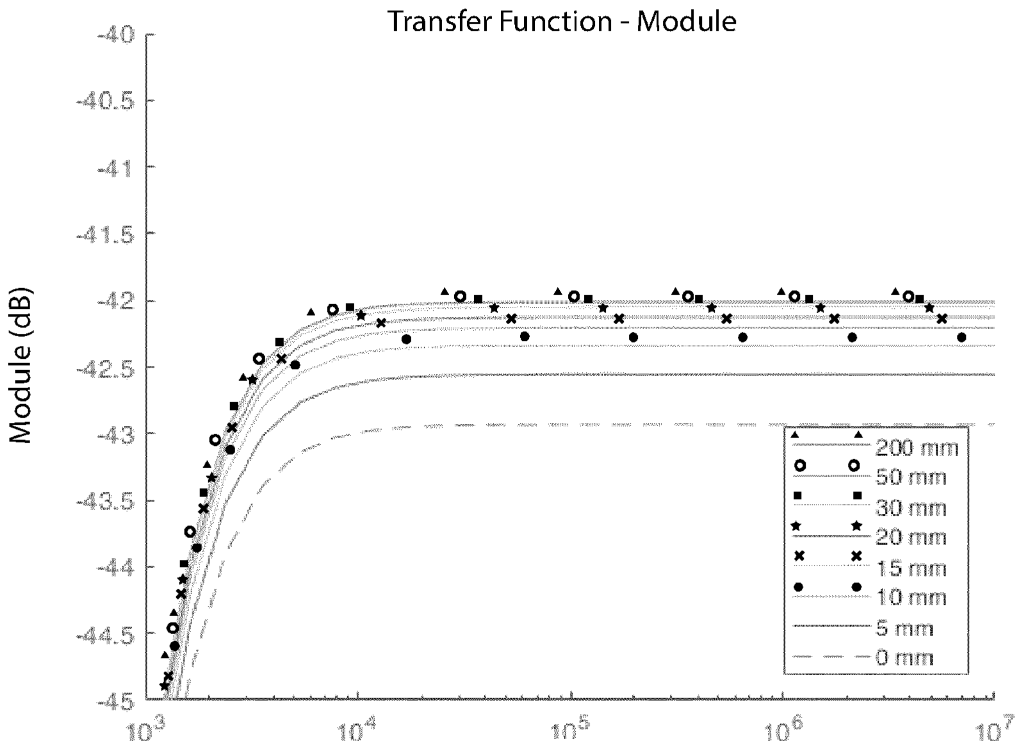


Fig. 15A

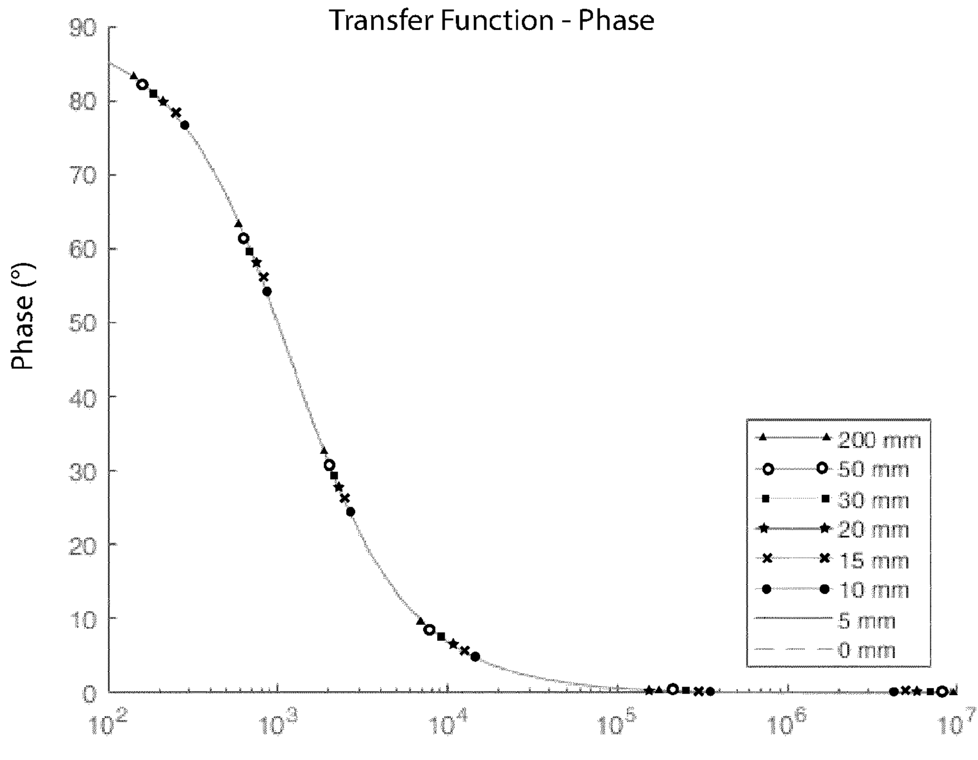


Fig. 15B

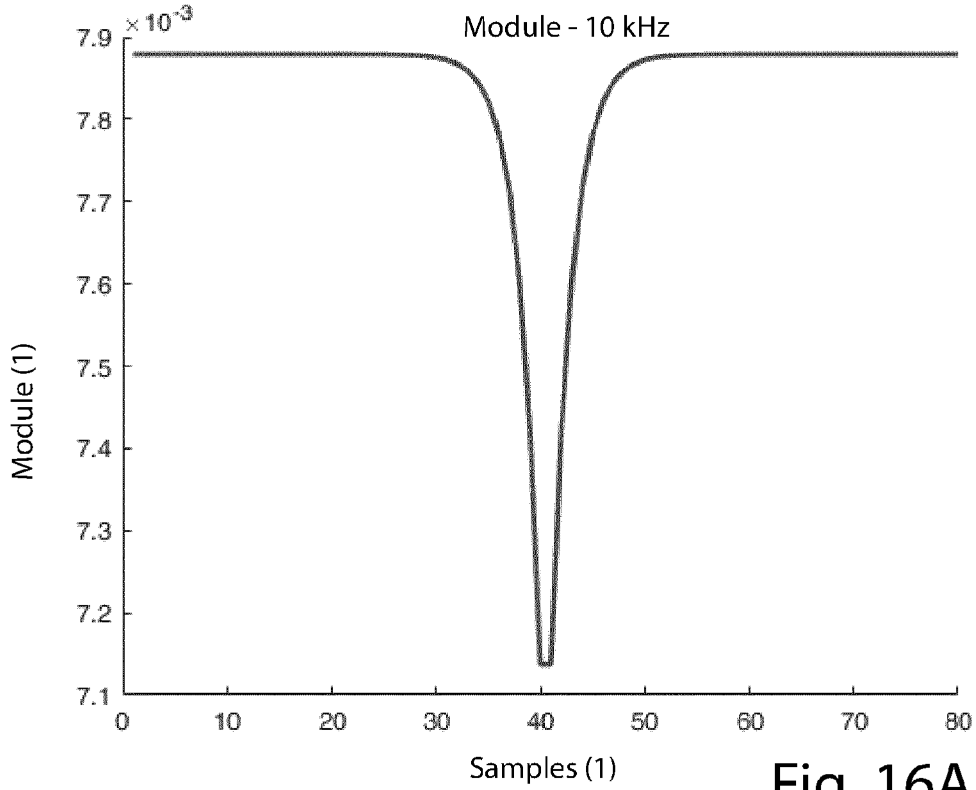


Fig. 16A

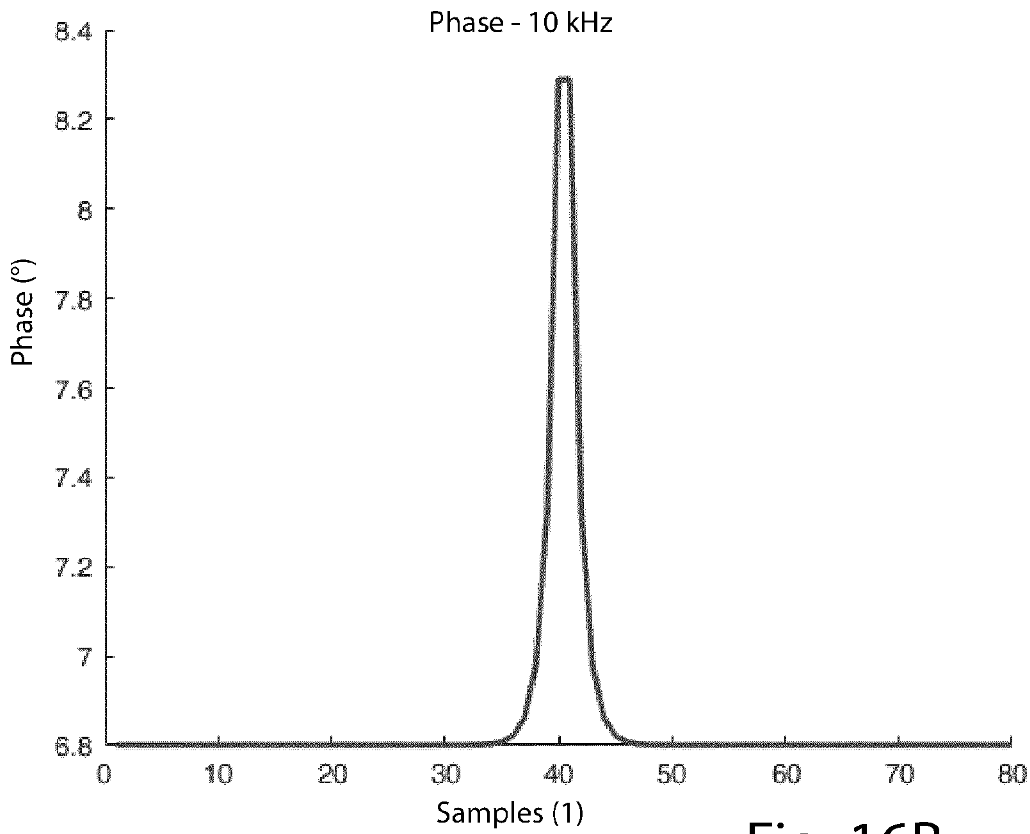


Fig. 16B

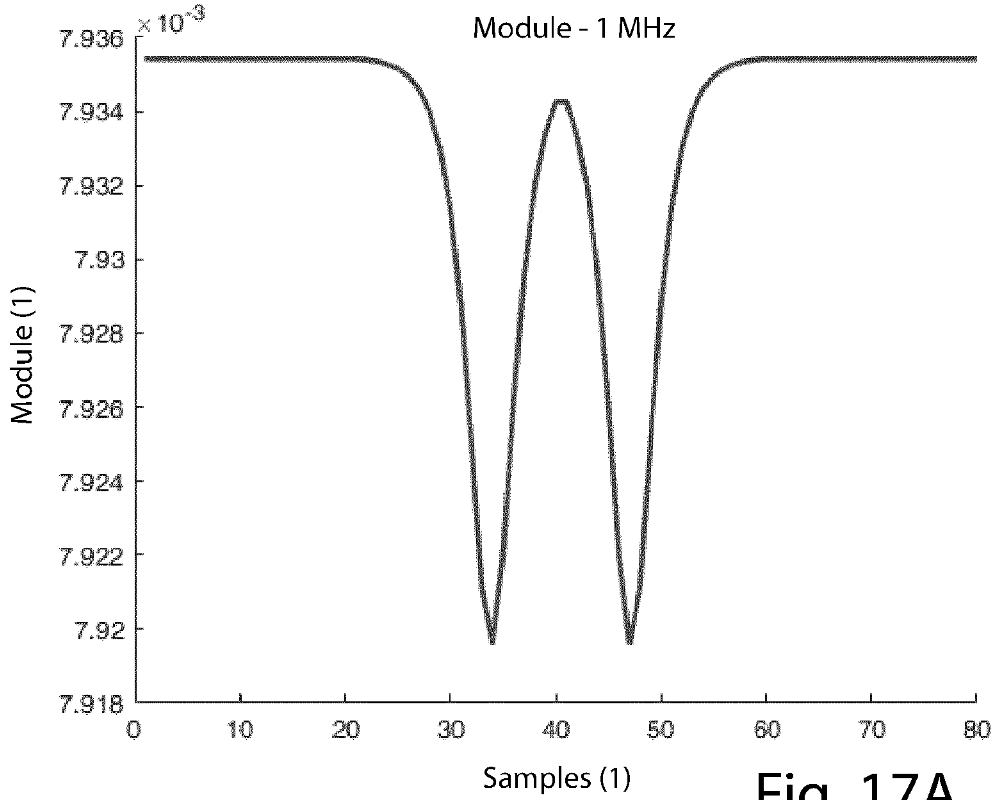


Fig. 17A

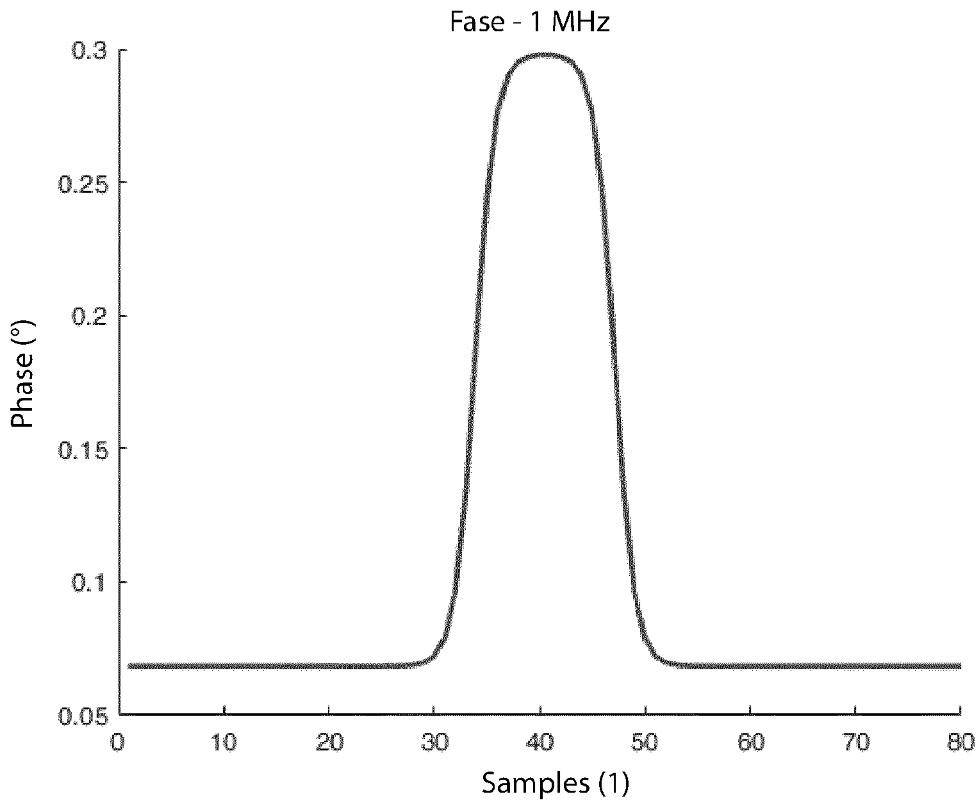


Fig. 17B

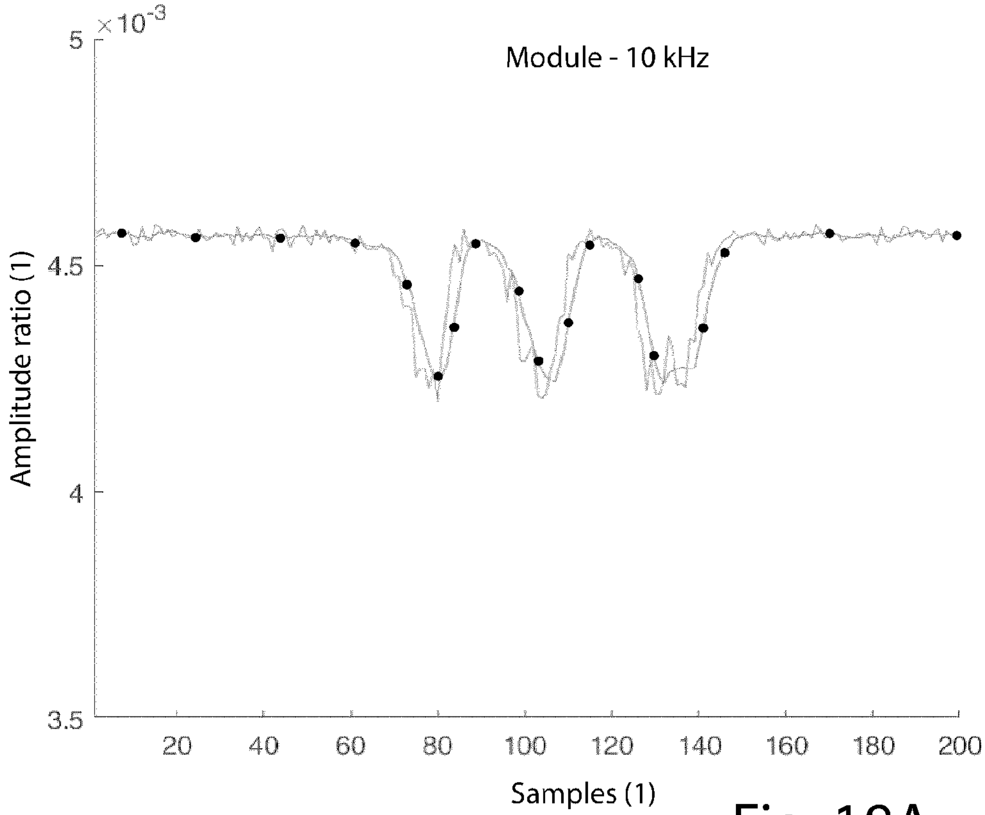


Fig. 18A

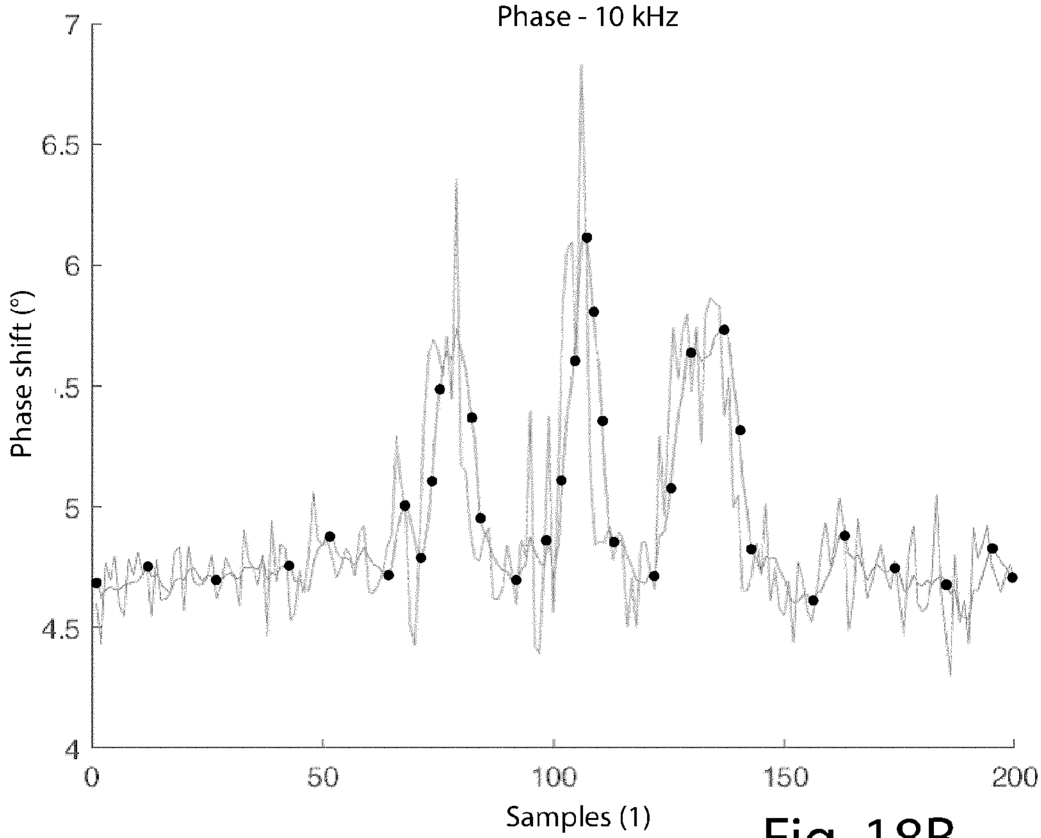


Fig. 18B

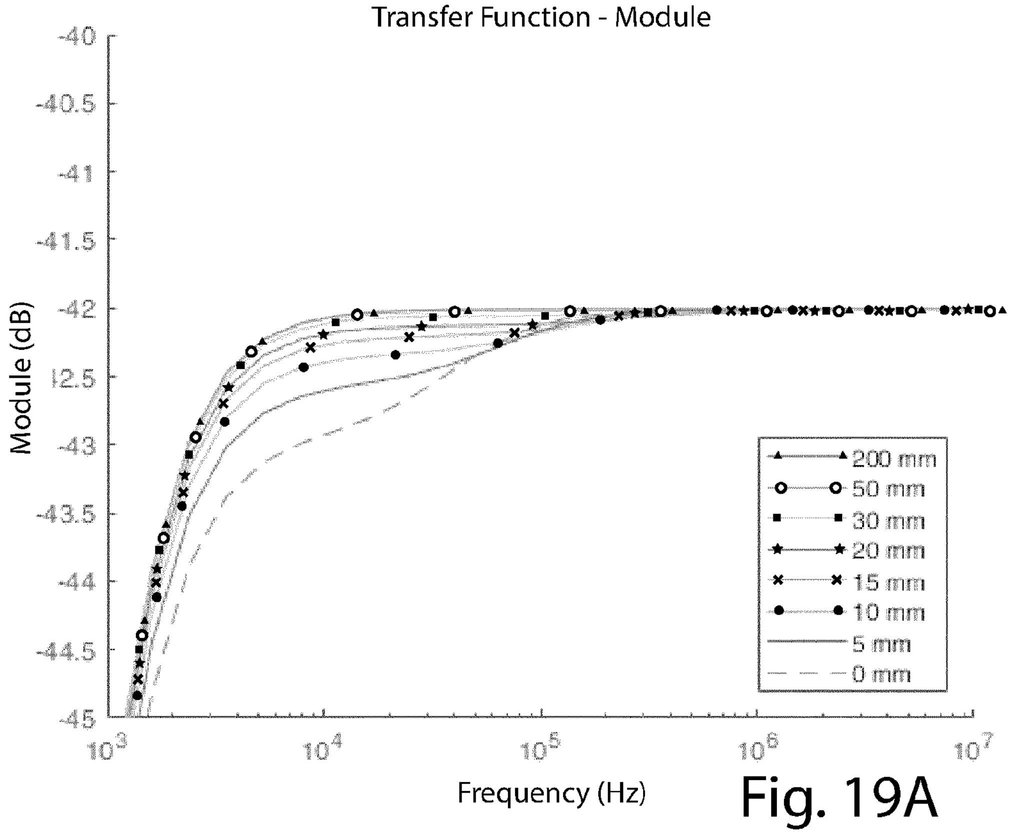


Fig. 19A

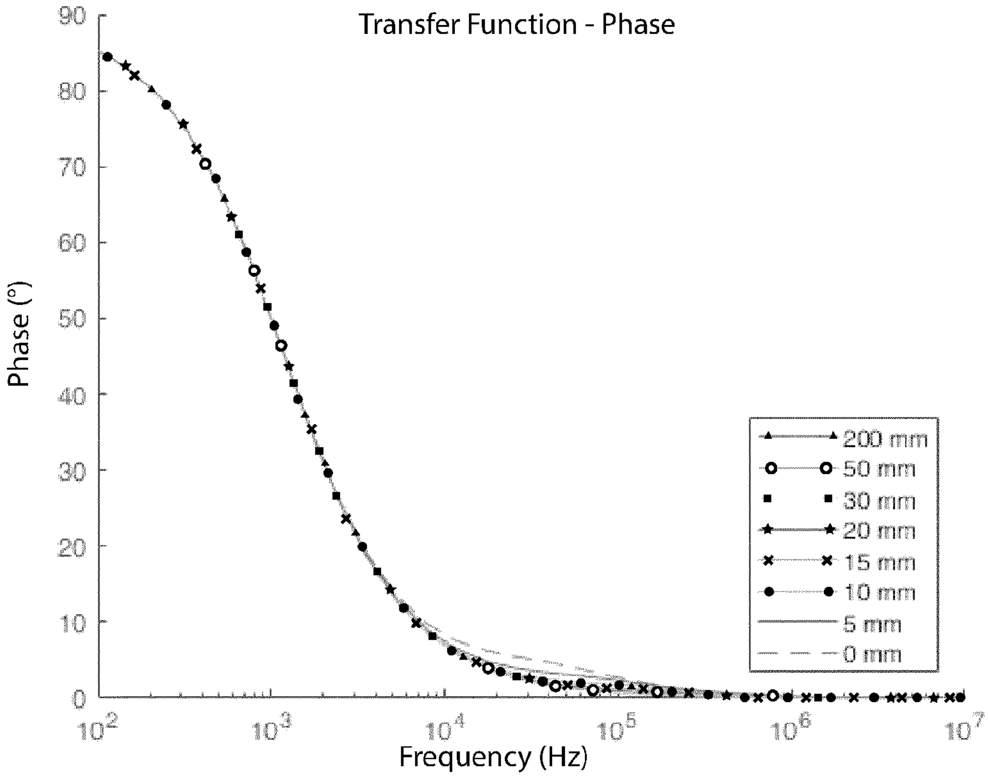


Fig. 19B

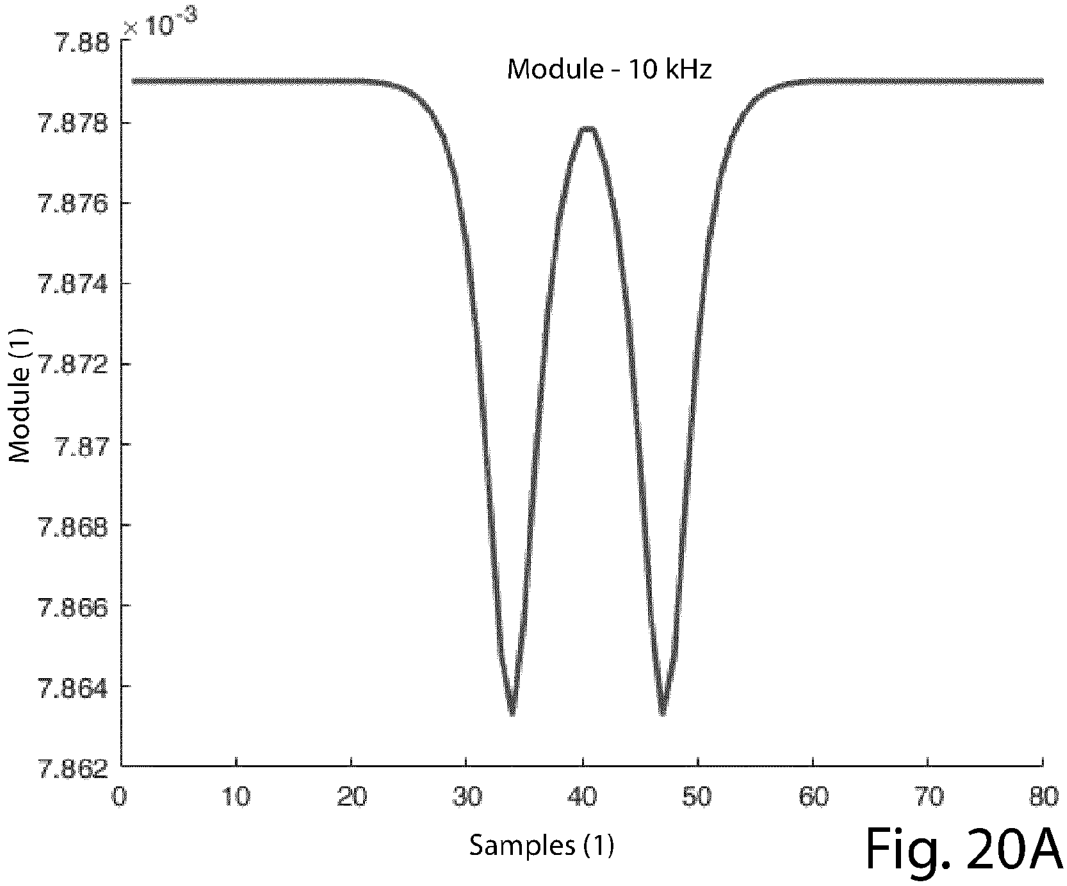


Fig. 20A

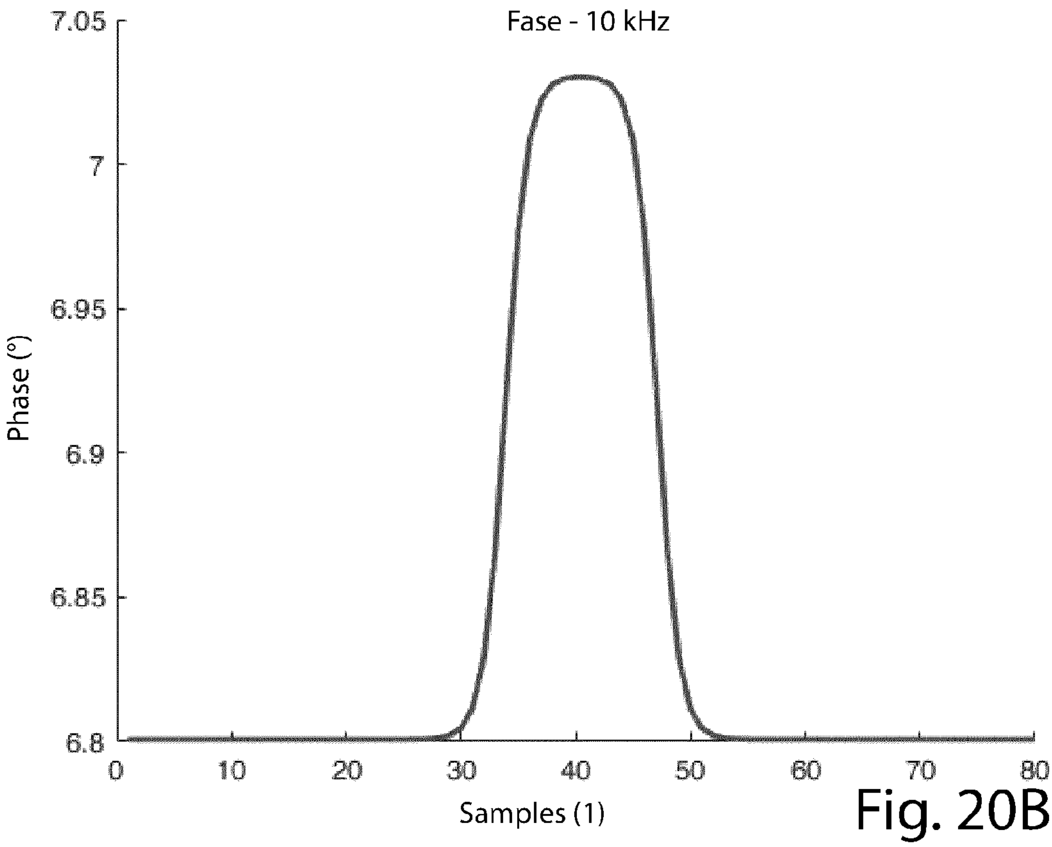


Fig. 20B

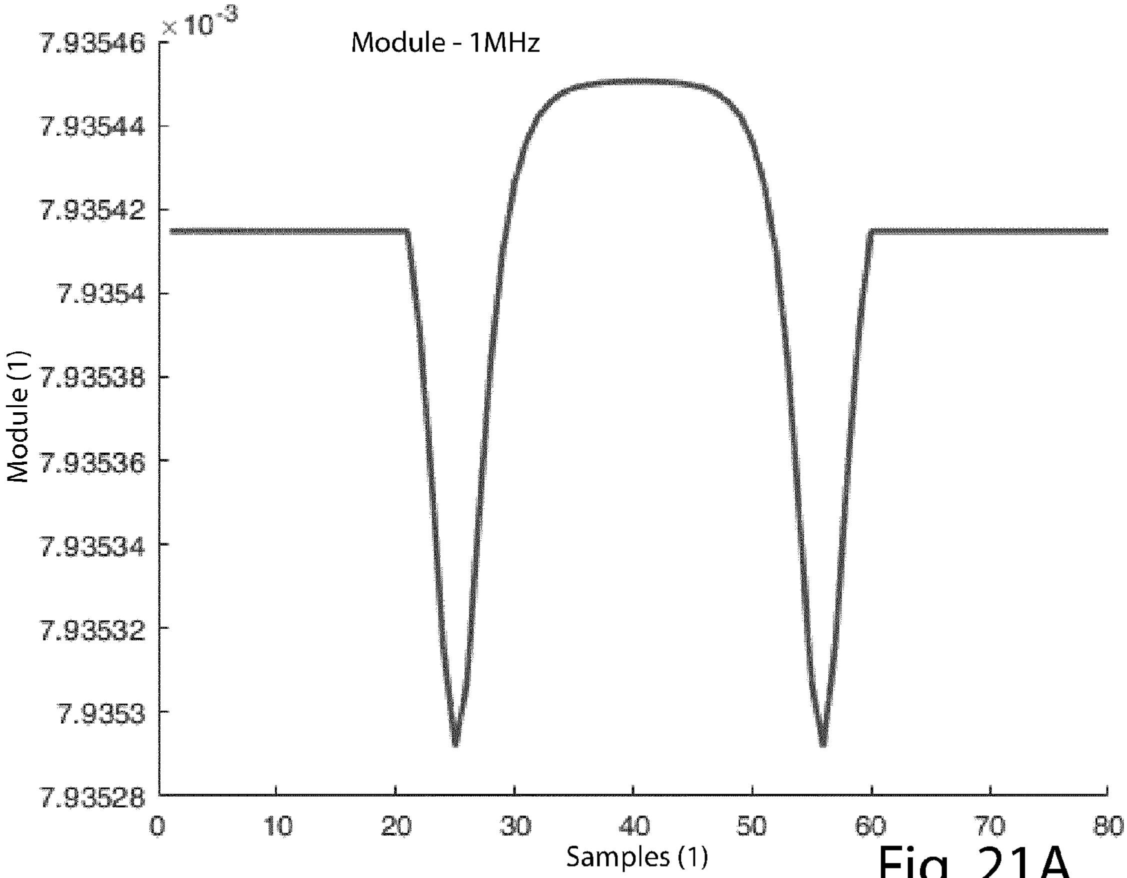


Fig. 21A

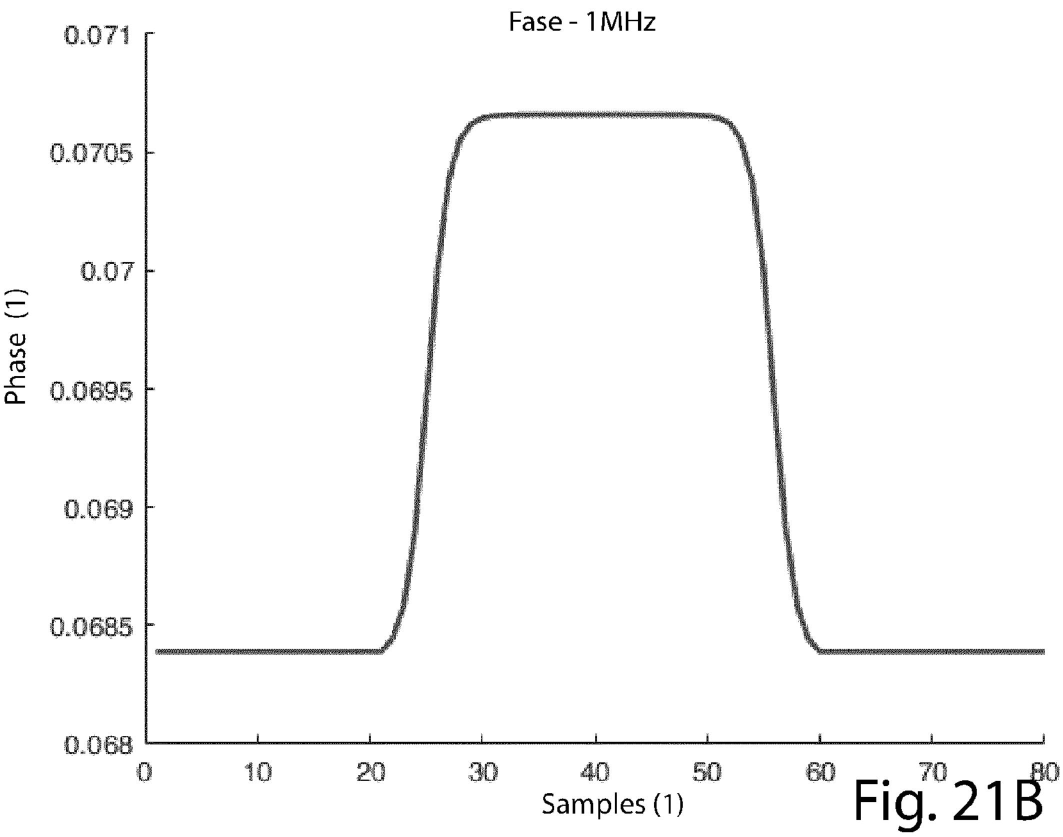


Fig. 21B

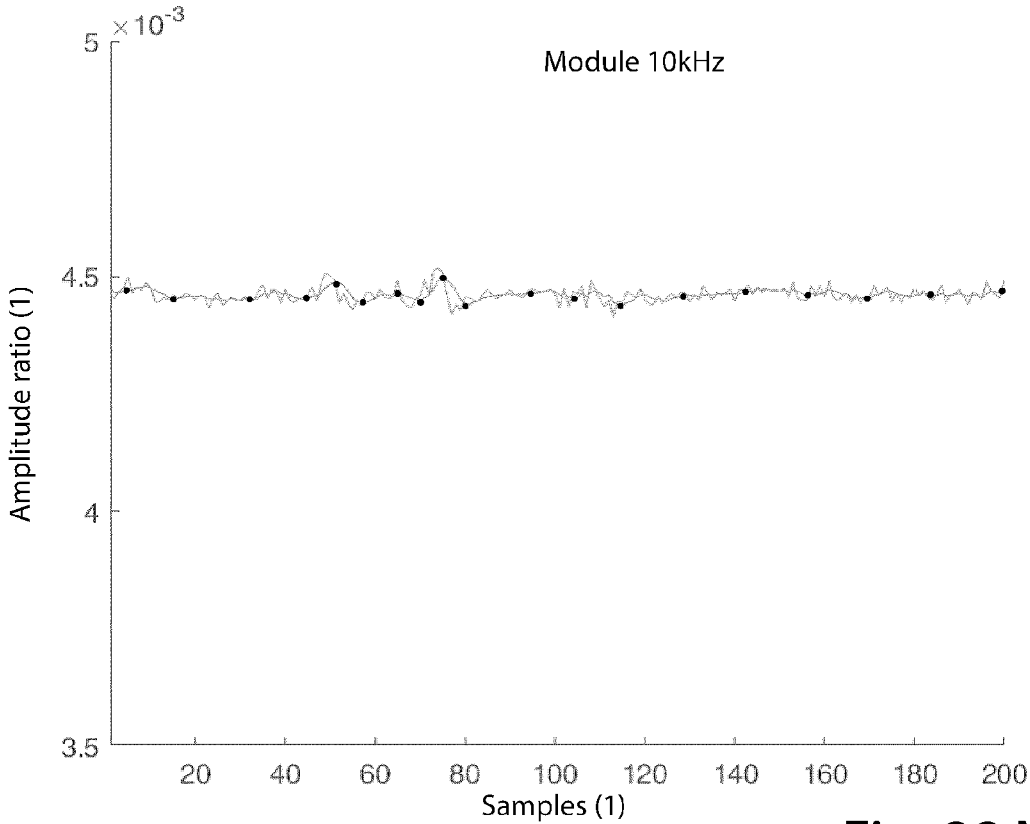


Fig. 22A

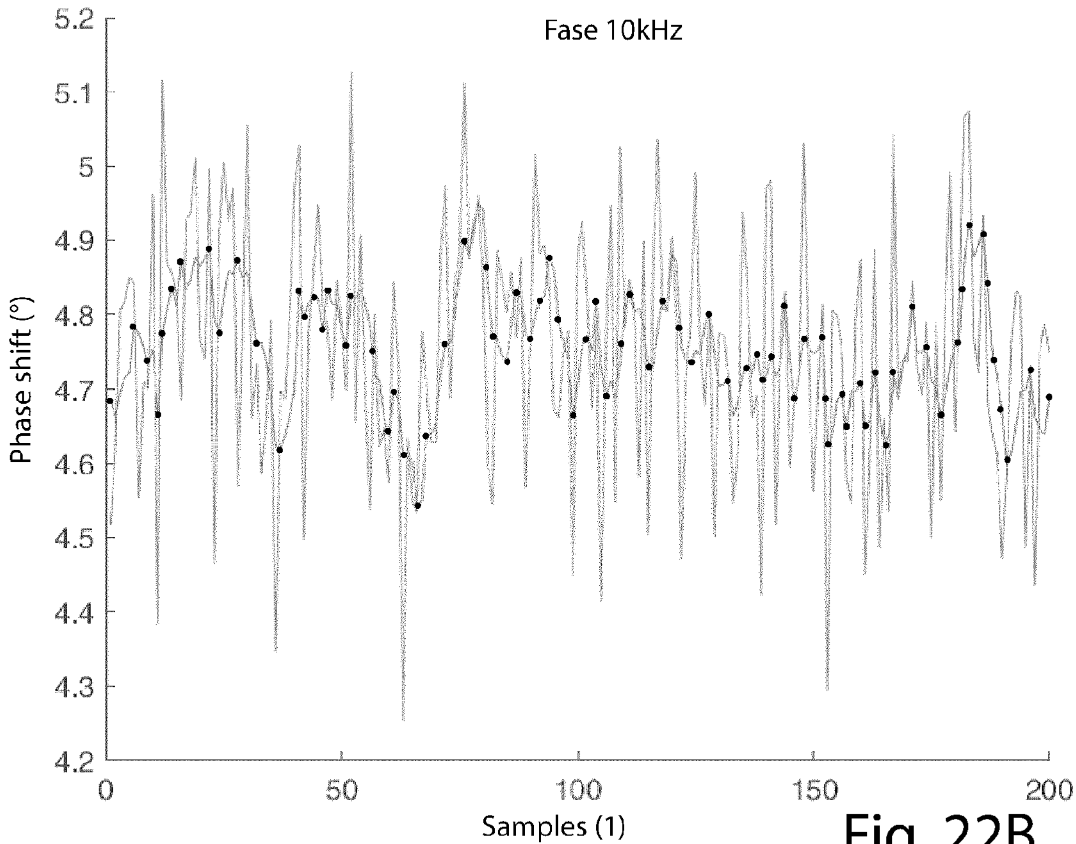


Fig. 22B

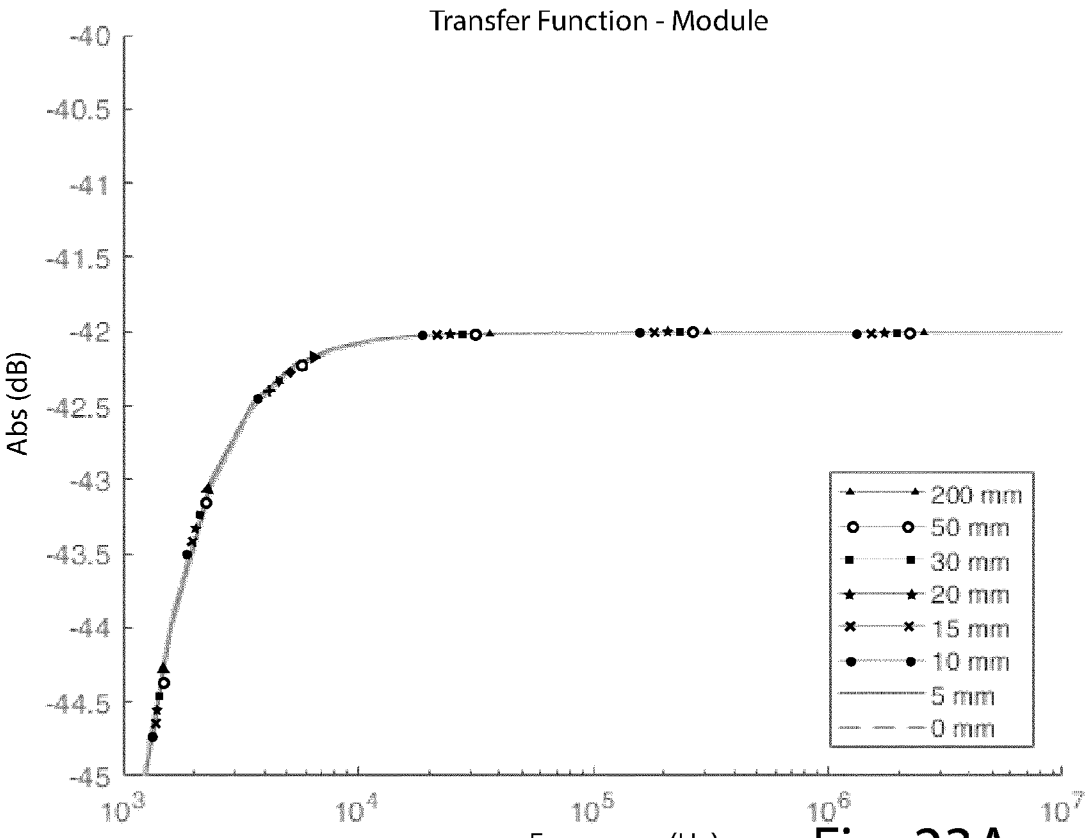


Fig. 23A

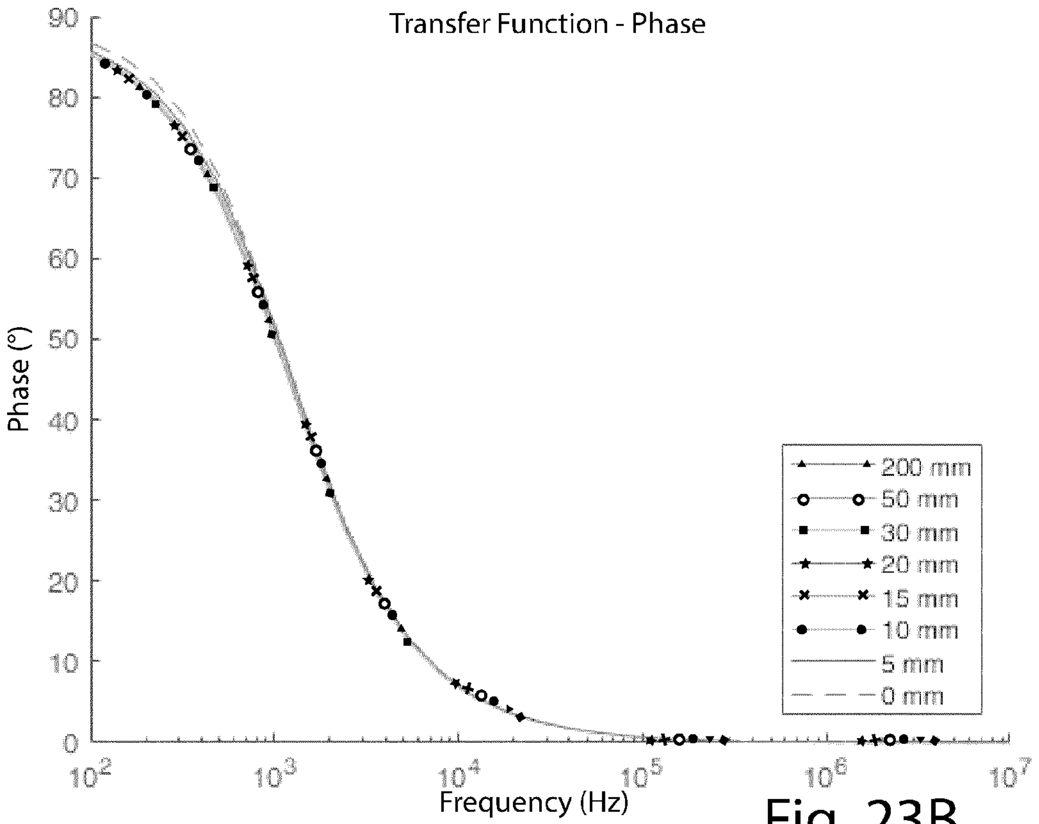


Fig. 23B

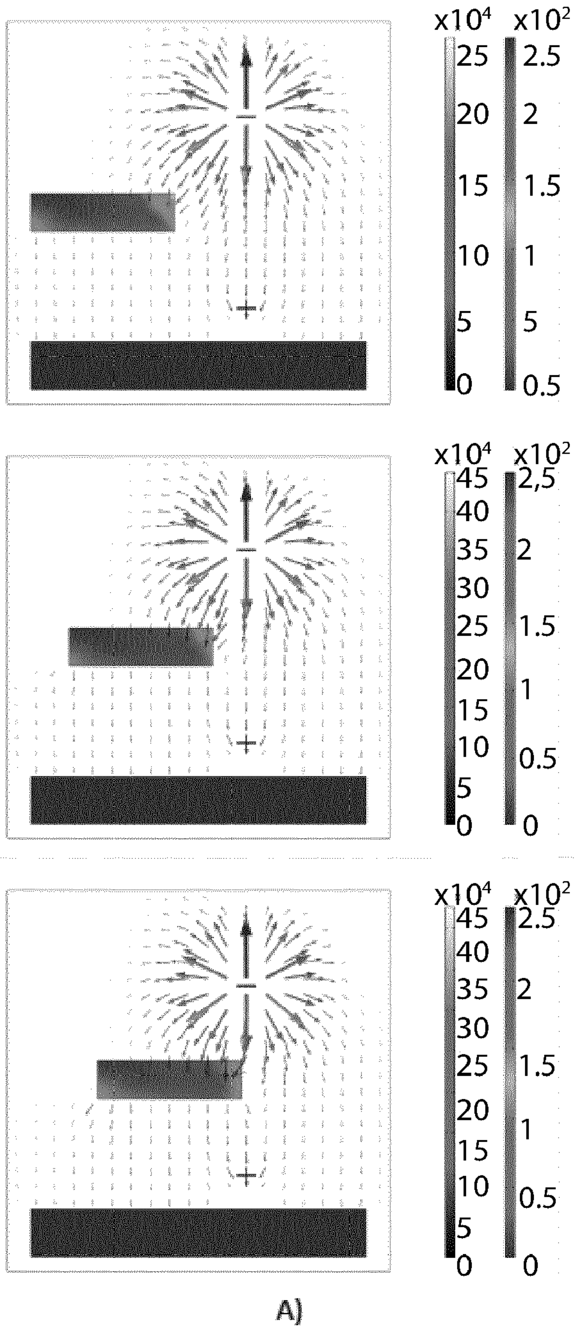


Fig. 24A

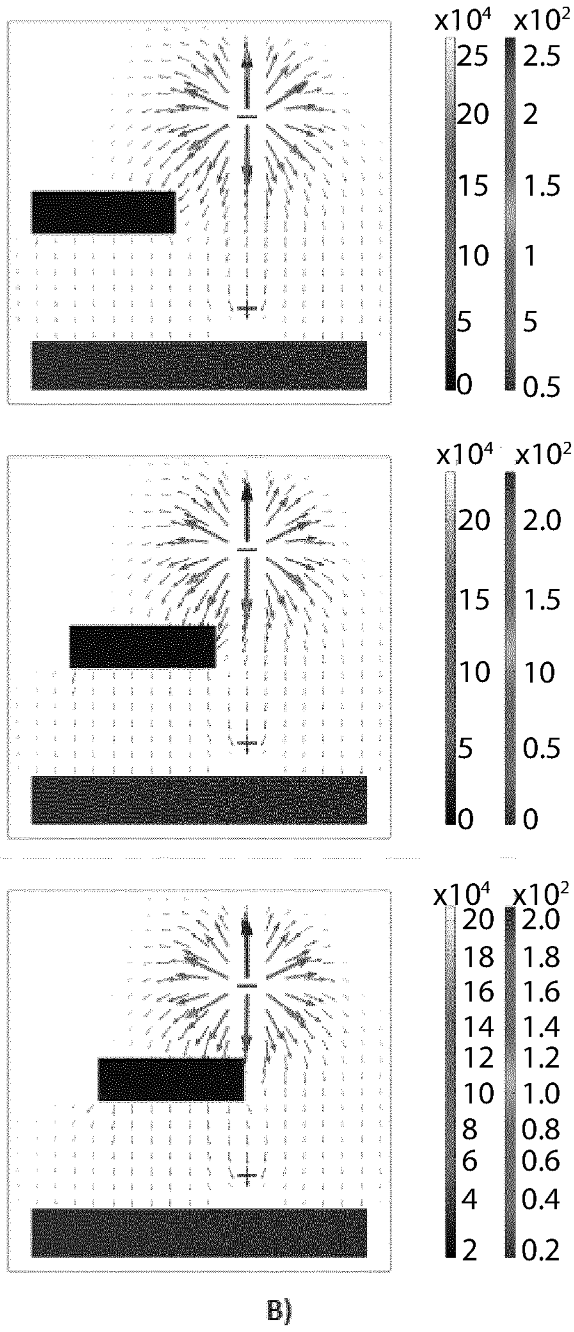
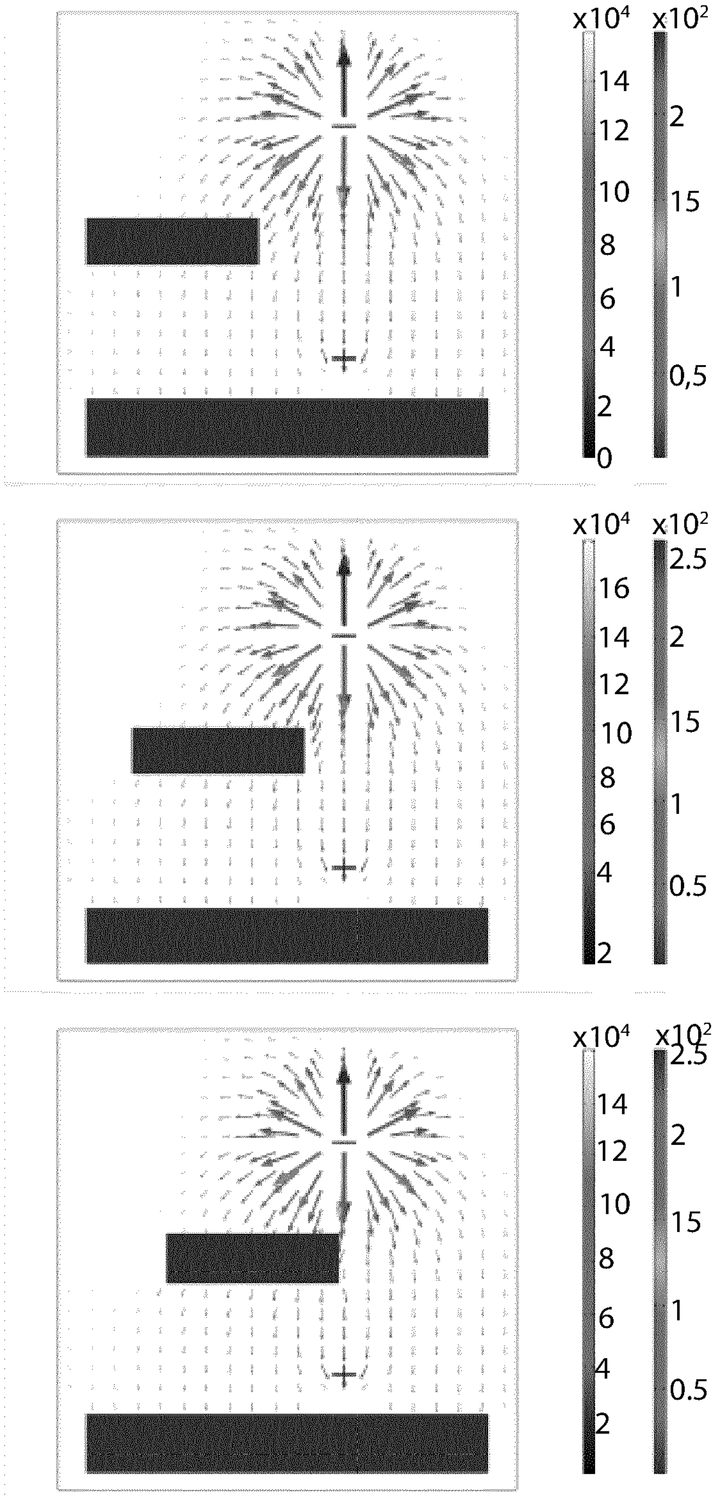


Fig. 24B


x10⁴
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12
10
8
6
4
2
0
x10²
2
15
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x10⁴
16
14
12
10
8
6
4
2
x10²
2.5
2
15
1
0.5
x10⁴
14
12
10
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6
4
2
x10²
2.5
2
15
1
0.5

Fig. 25

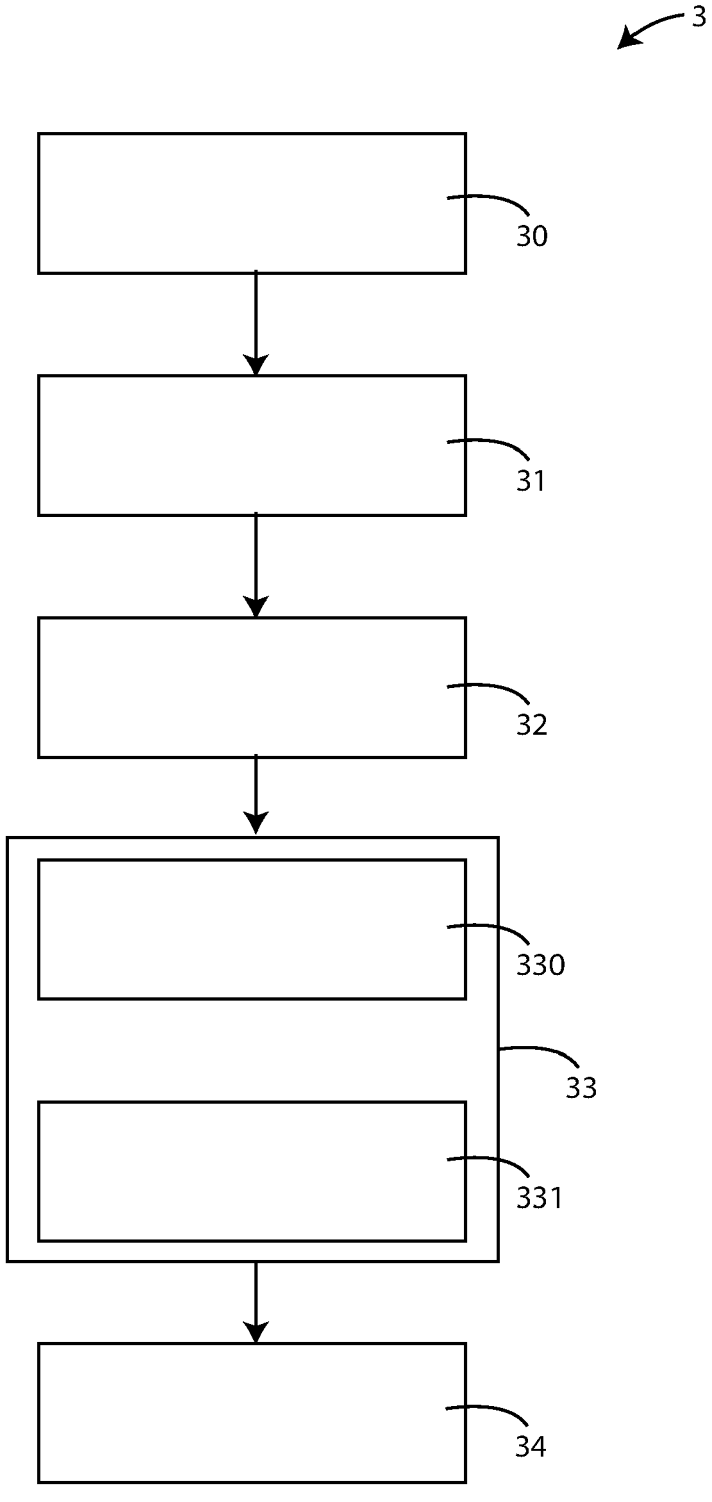

Fig. 26

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EUROPEAN SEARCH REPORT

Application Number
EP 22 15 0846

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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X A	EP 0 850 385 A1 (SORENSEN JORN [DK]) 1 July 1998 (1998-07-01) * abstract * * paragraphs [0023], [0034], [0035], [0036] * * figures * * paragraphs [0023], [0034], [0036] * -----	1,2, 5-12, 15-17, 19,20 3,4,13, 14	
X A	DE 10 2011 121370 A1 (BROSE FAHRZEUGTEILE [DE]) 20 June 2013 (2013-06-20) * abstract * * paragraphs [0007] - [0015], [0032] - [0037] * * figures * -----	1,2, 5-13, 15-17, 19,20 3,4,14, 18	TECHNICAL FIELDS SEARCHED (IPC) B27G B27C
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The present search report has been drawn up for all claims

3

Place of search	Date of completion of the search	Examiner
The Hague	27 June 2022	Hamel, Pascal

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EUROPEAN SEARCH REPORT

Application Number
EP 22 15 0846

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A	* abstract; claims * * figures *	3,4,14, 18	

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Place of search	Date of completion of the search	Examiner
The Hague	27 June 2022	Hamel, Pascal

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