US 20150229243A1

(19) United States
(12) Patent Application Publication
(10) Pub. No.: US 2015/0229243 A1
(43) Pub. Date: Aug. 13, 2015
Chimamkpam

(54) DEVICE AND METHOD FOR TUNING MECHANICAL AND ELECTROMAGNETIC NATURAL FREQUENCIES OF AN ENERGY HARVESTER

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(21) Appl. No.: **14/622,097**

(22) Filed: **Feb. 13, 2015**

Related U.S. Application Data

(63) Continuation-in-part of application No. 14/199,916, filed on Mar. 6, 2014.

(60) Provisional application No. 61/937,330, filed on Feb. 7, 2014.

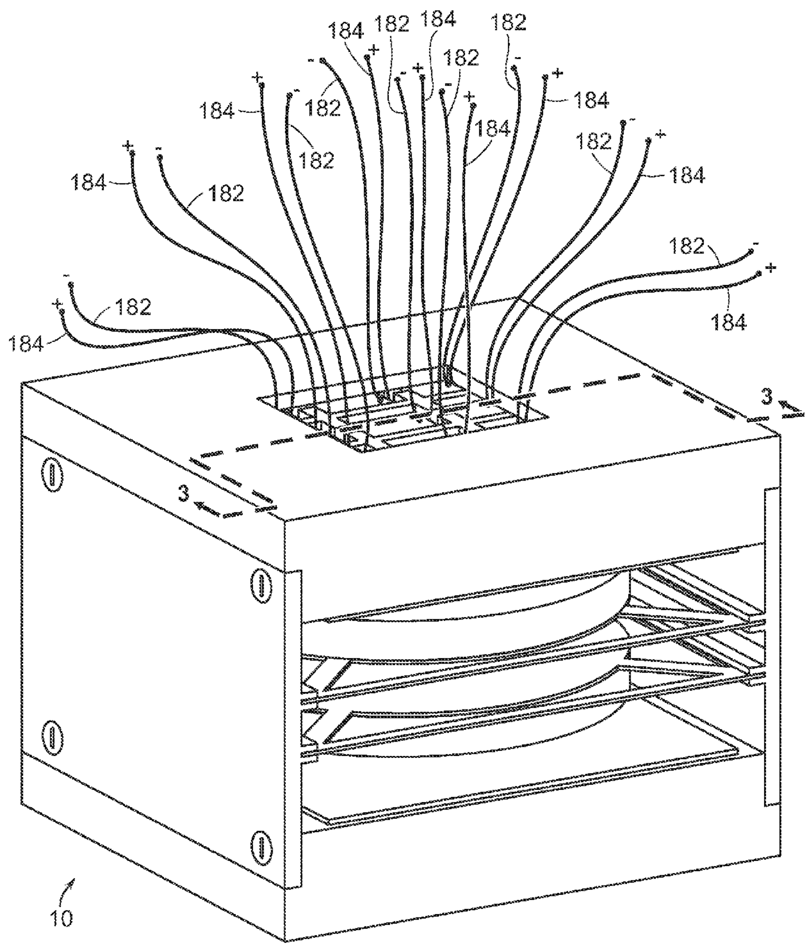
Publication Classification

(51) **Int. Cl.**
H02N 2/18 (2006.01)

(52) **U.S. Cl.**
CPC ***H02N 2/188*** (2013.01)

(57) **ABSTRACT**

The present invention is an energy harvester having a mechanical natural frequency that can be mechanically tuned to the natural frequency of the vibrating environment without having to add or subtract mass to seismic/proof mass, change the mass of the mechanical spring or change the physical dimensions of the mechanical spring of the energy harvester. In another embodiment, the electromagnetic natural frequency of the energy harvester is electronically tuned by adding a tuning circuit comprising a variable dissipative element without changing the mechanical natural resonant frequencies of the energy harvester.



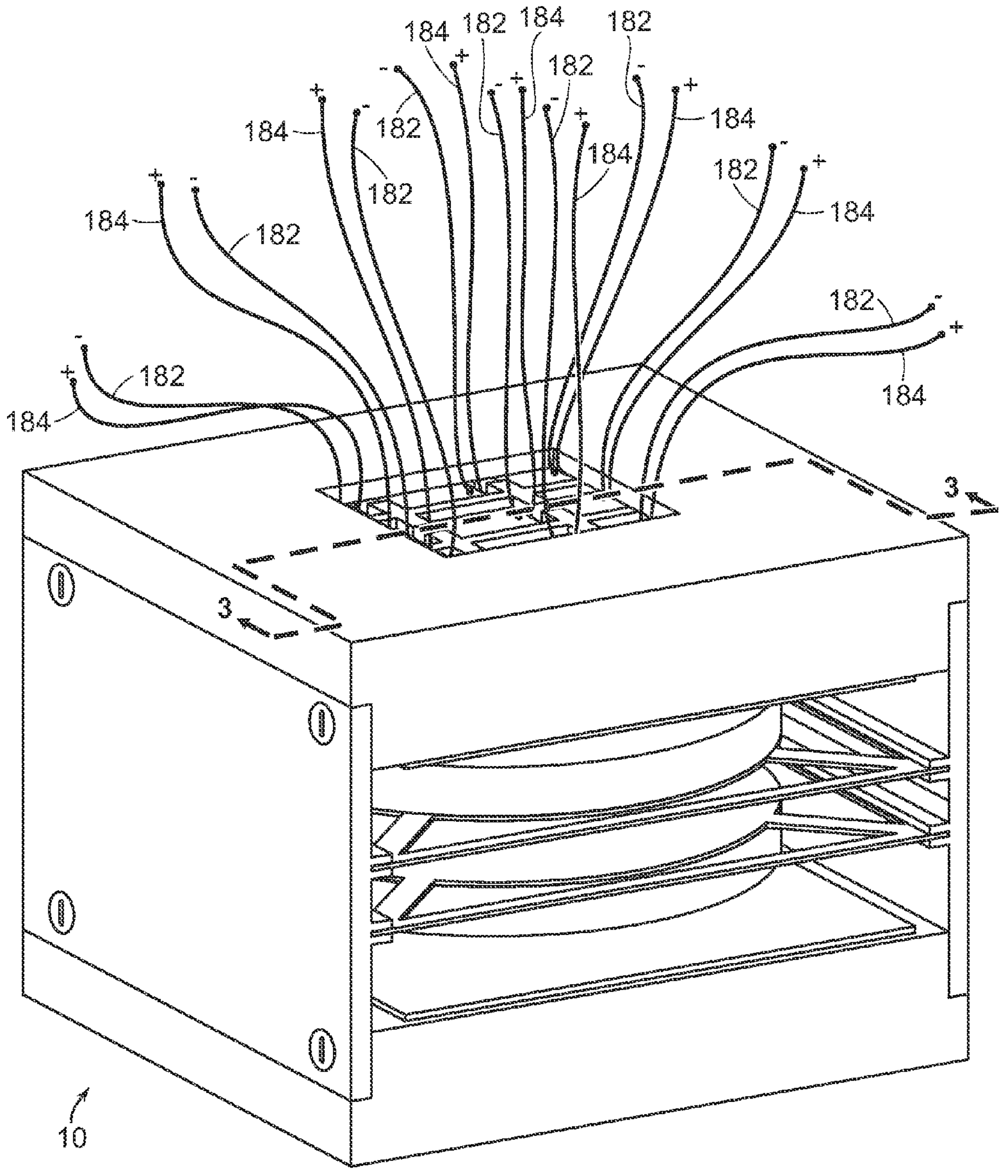

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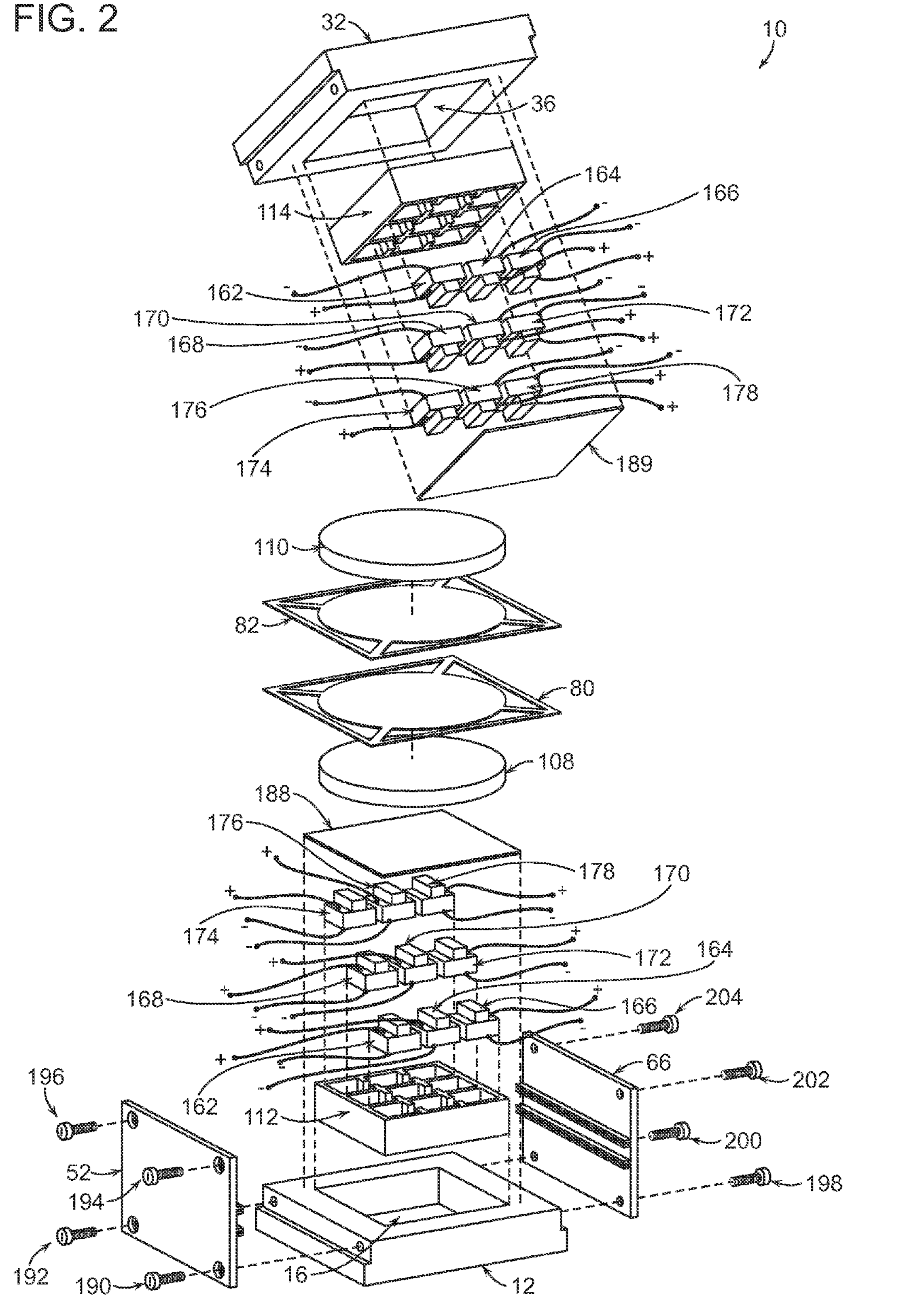
FIG. 1

FIG. 2



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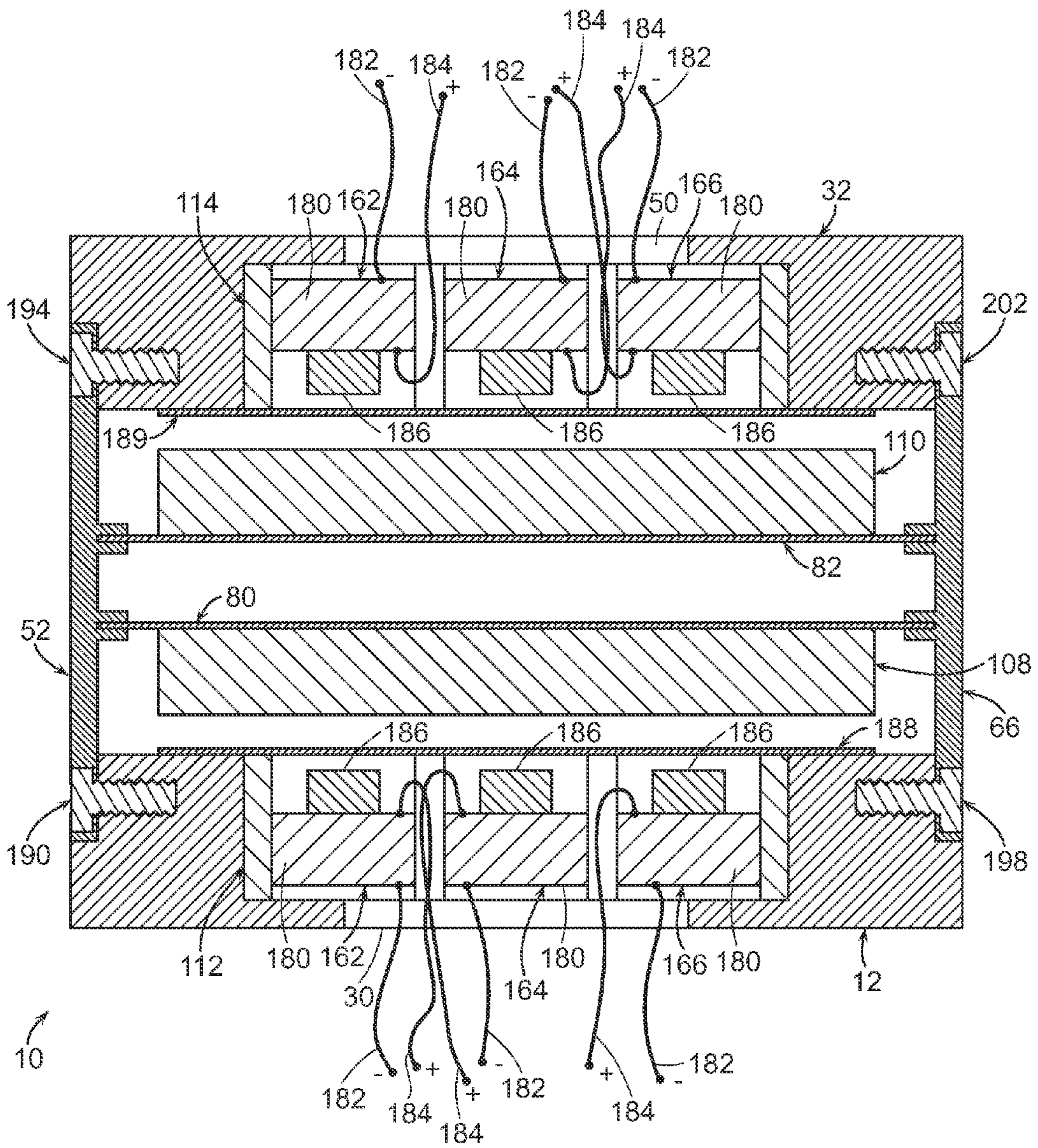
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FIG. 3

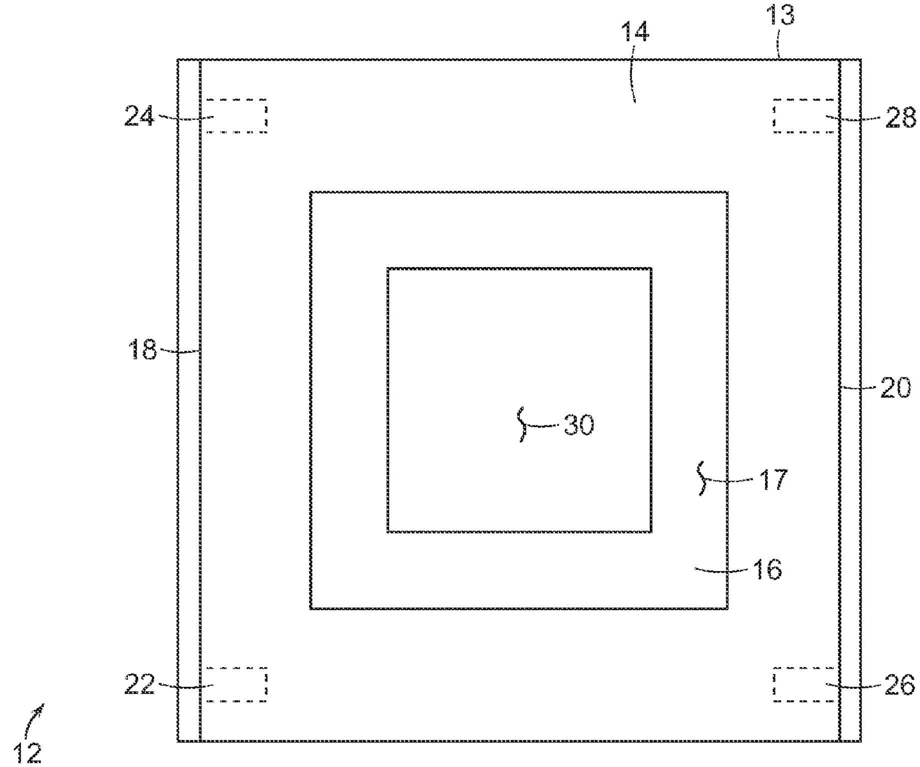


FIG. 4

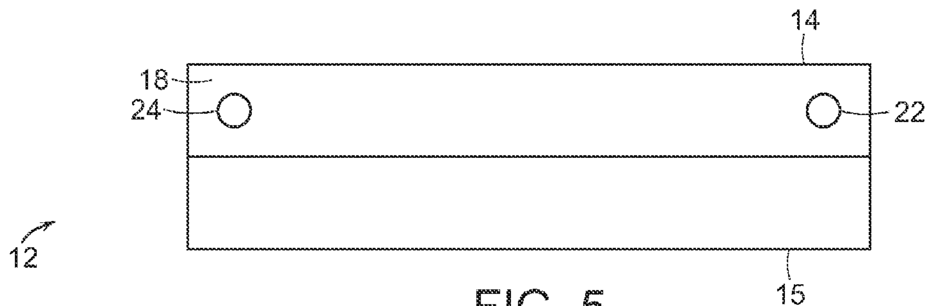


FIG. 5

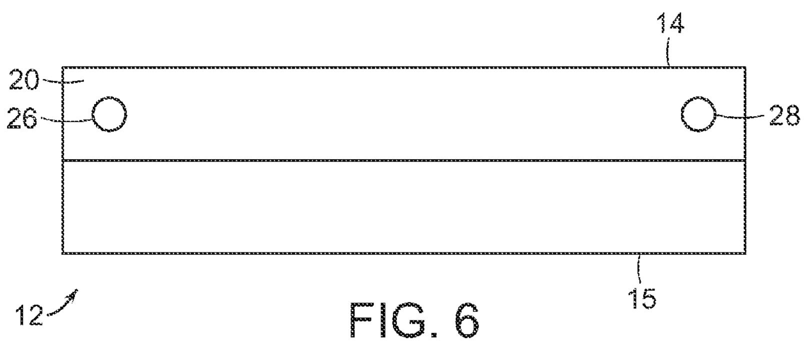


FIG. 6

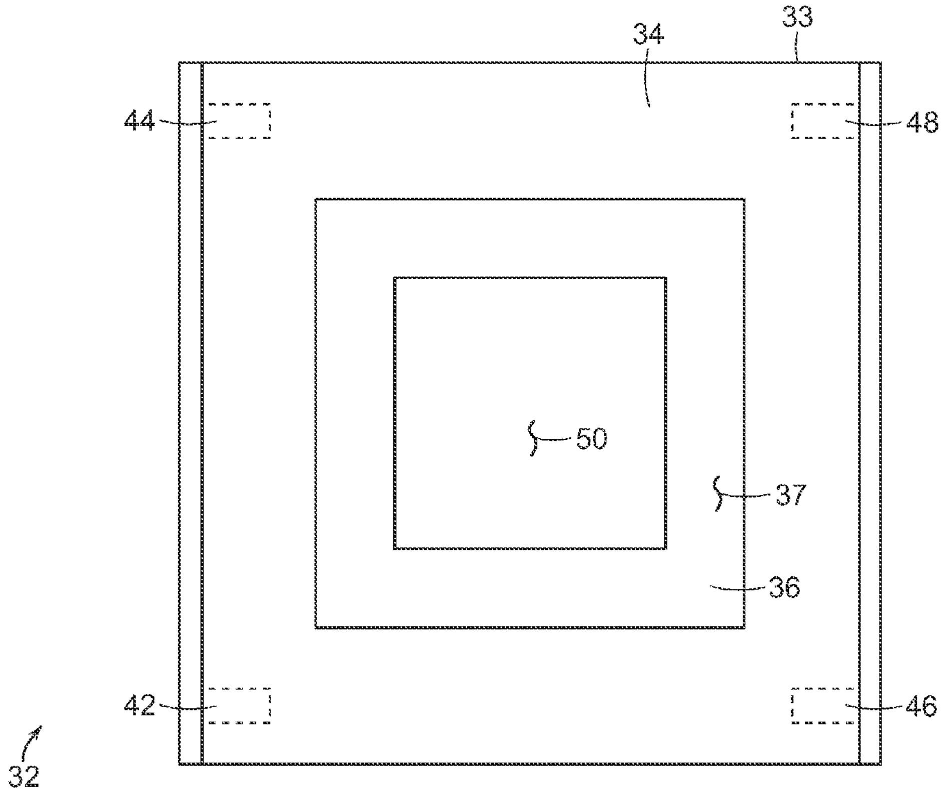


FIG. 7

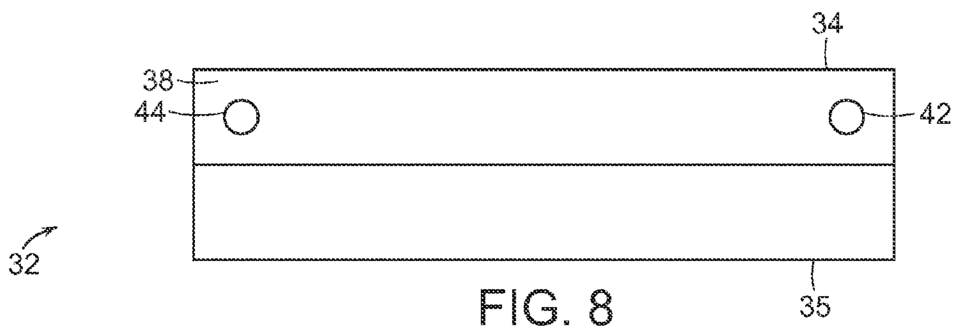


FIG. 8

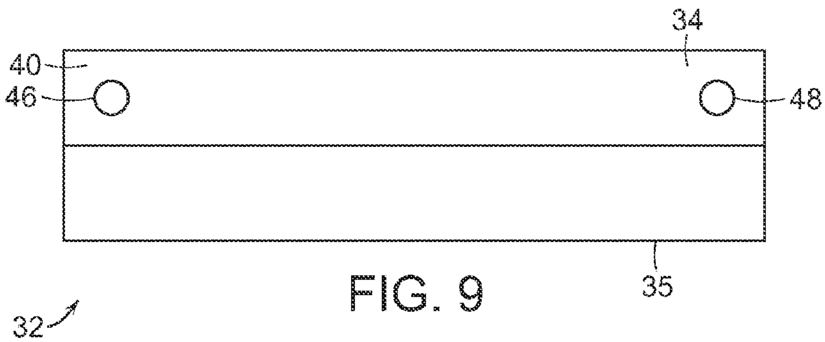


FIG. 9

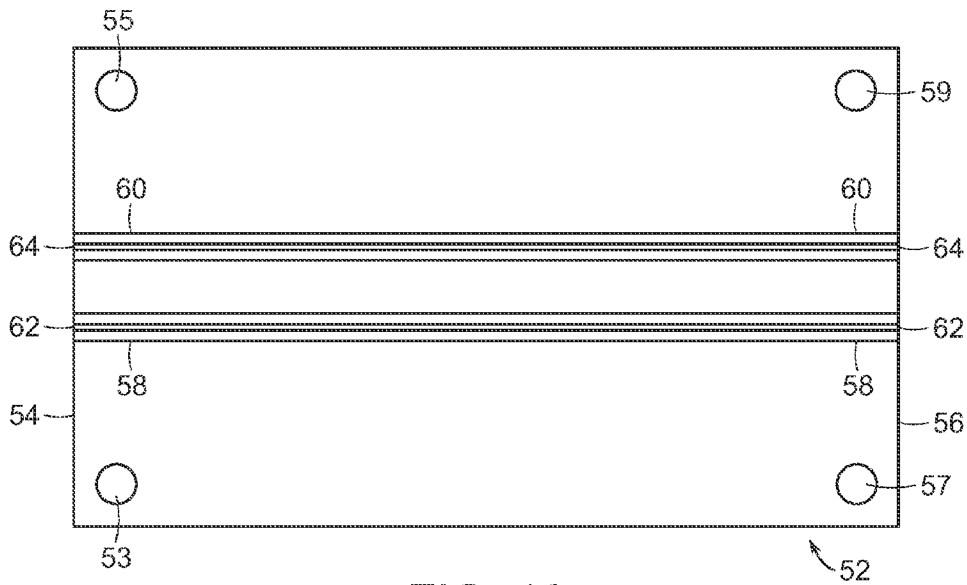


FIG. 10

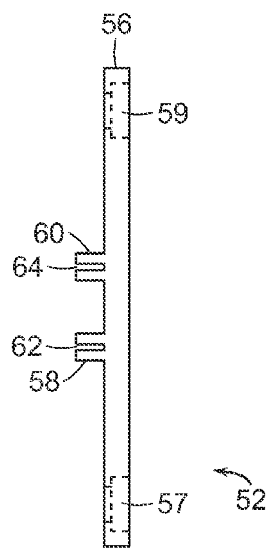


FIG. 11

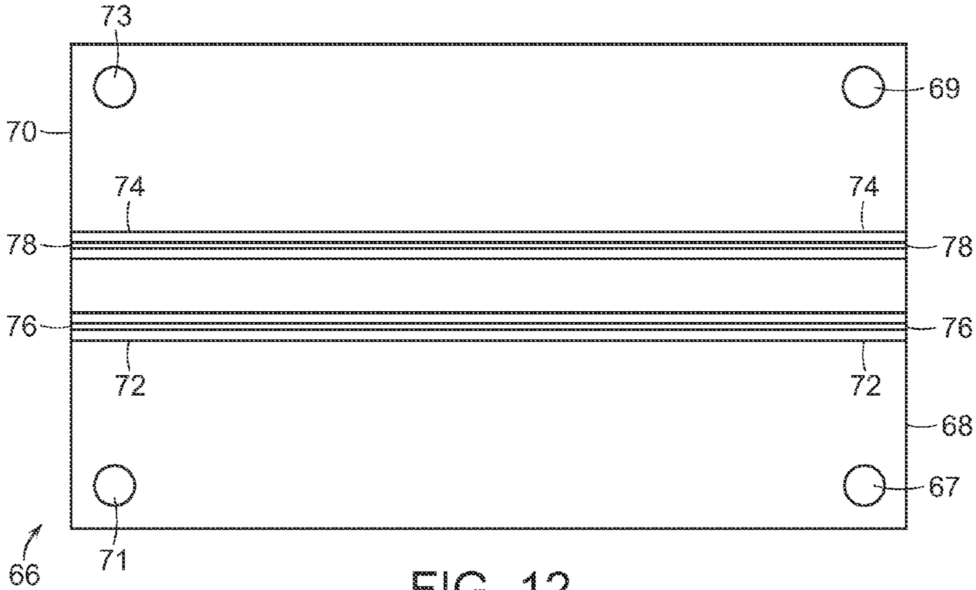


FIG. 12

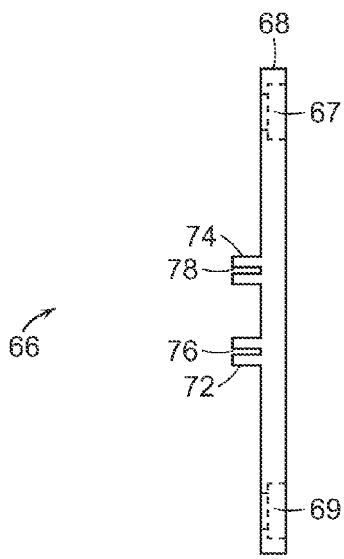
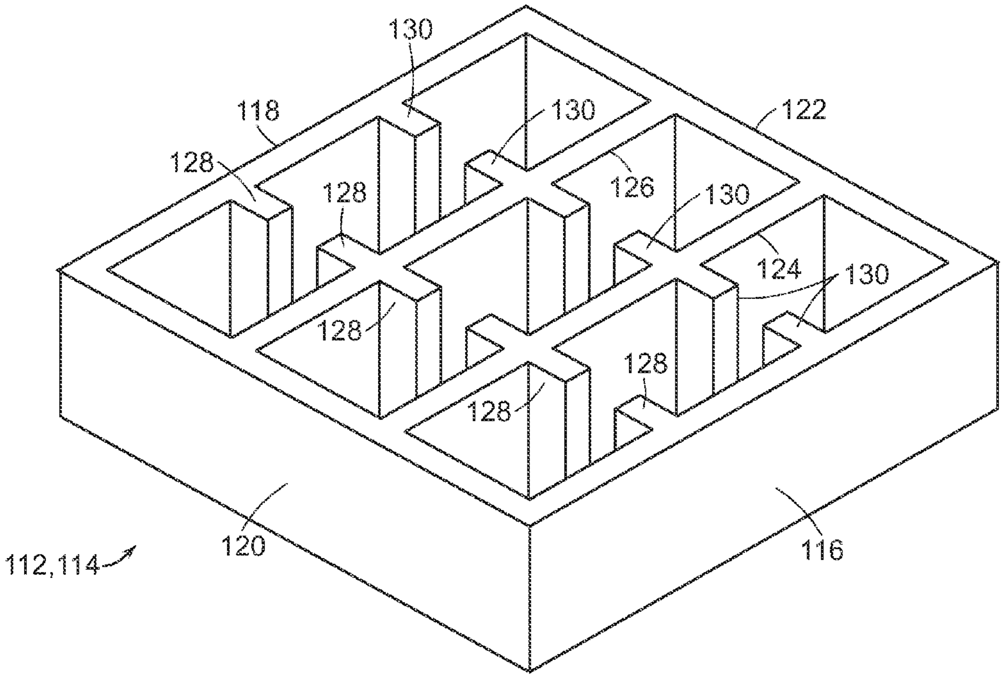


FIG. 13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116
112,114

FIG. 14

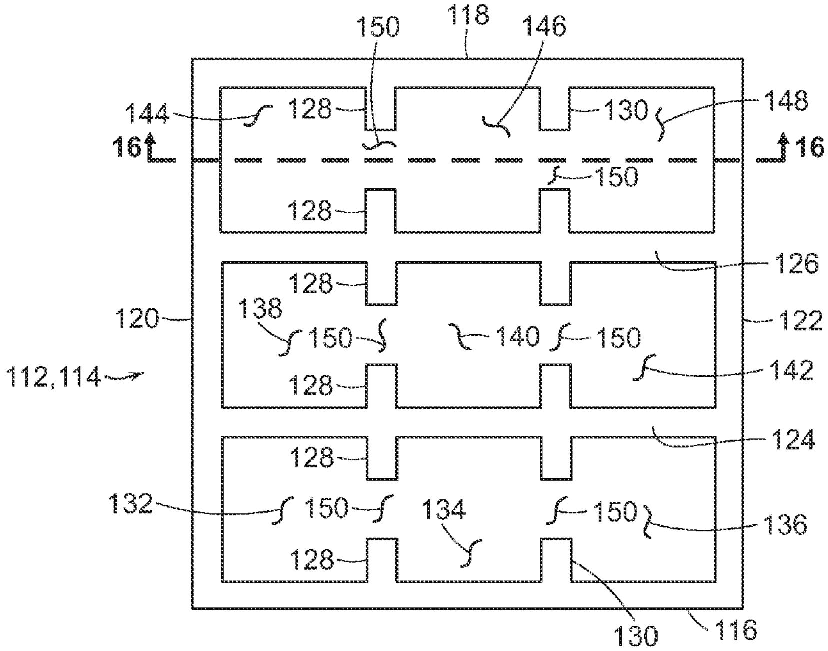
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FIG. 15

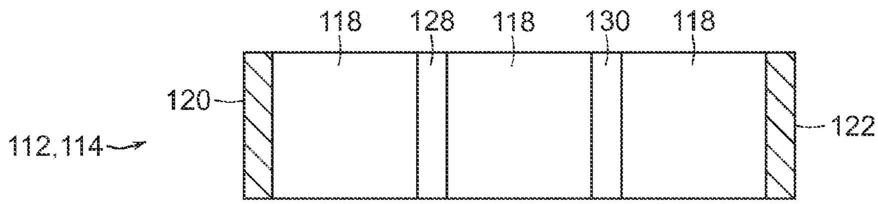


FIG. 16

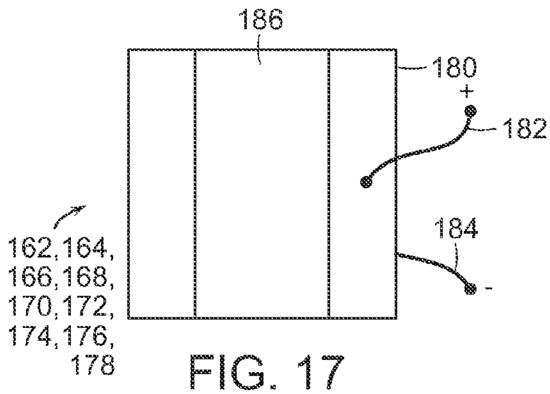


FIG. 17

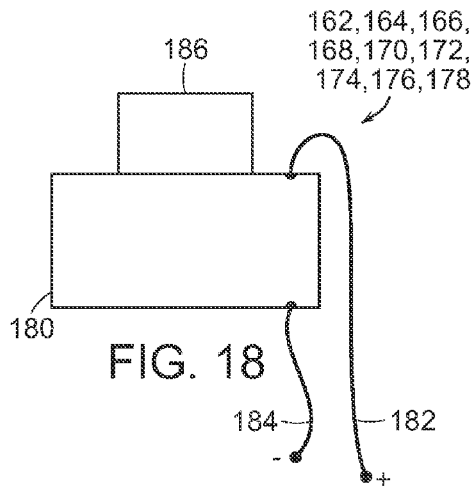
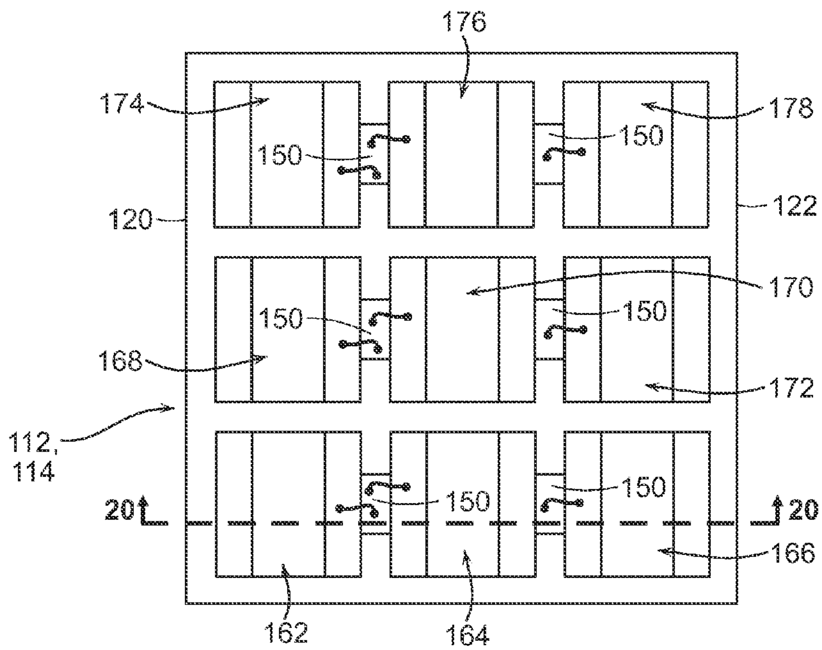


FIG. 18



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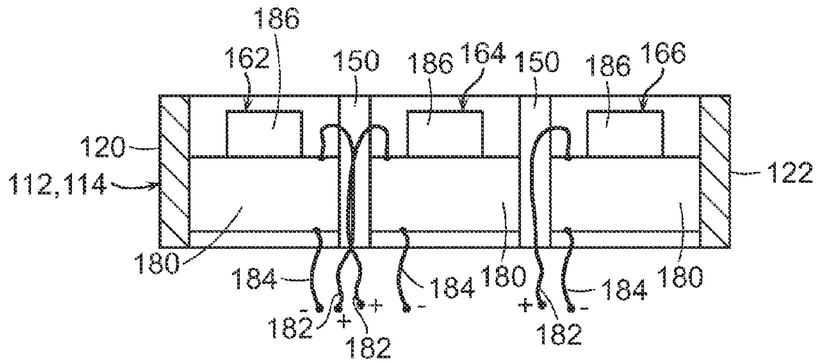
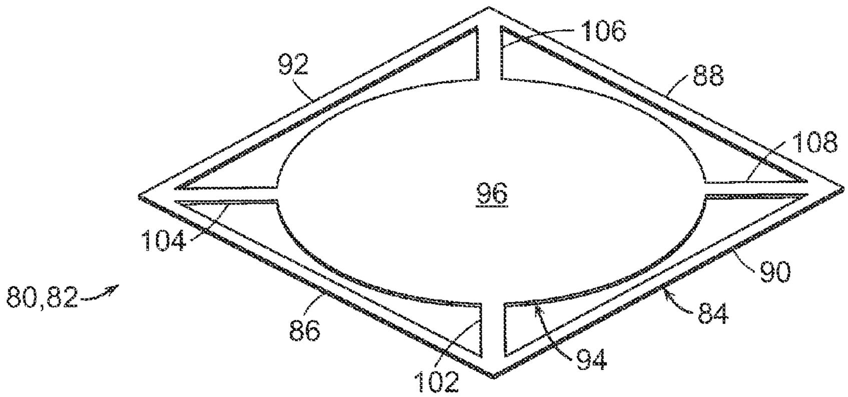


FIG. 20



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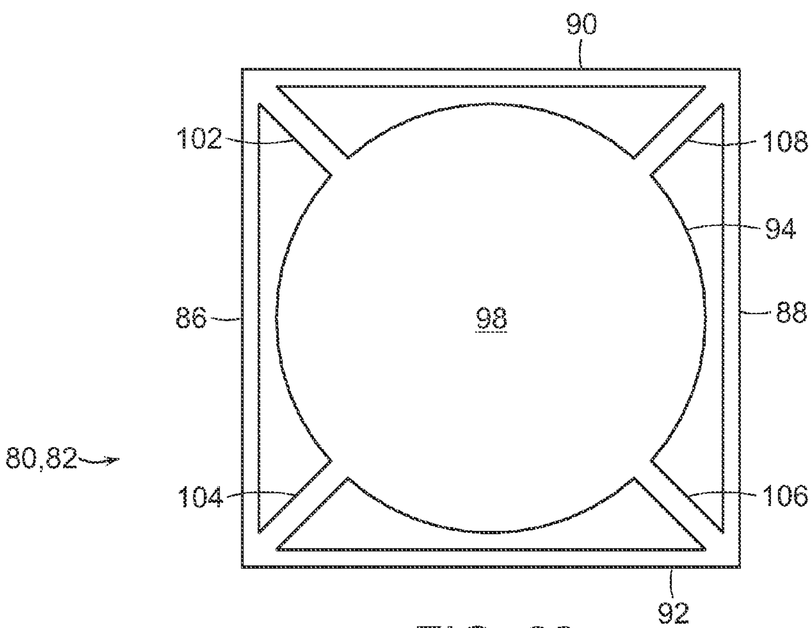


FIG. 22

FIG. 23

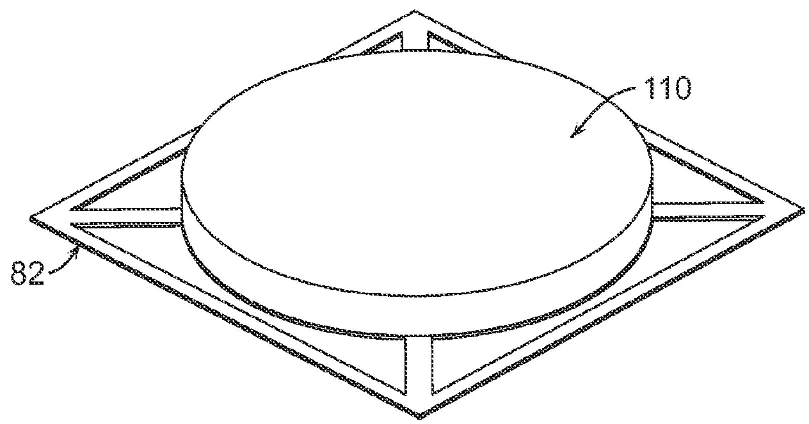
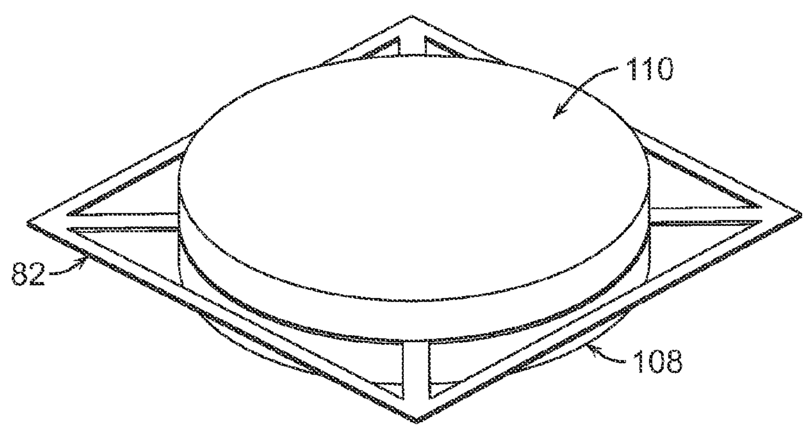


FIG. 24



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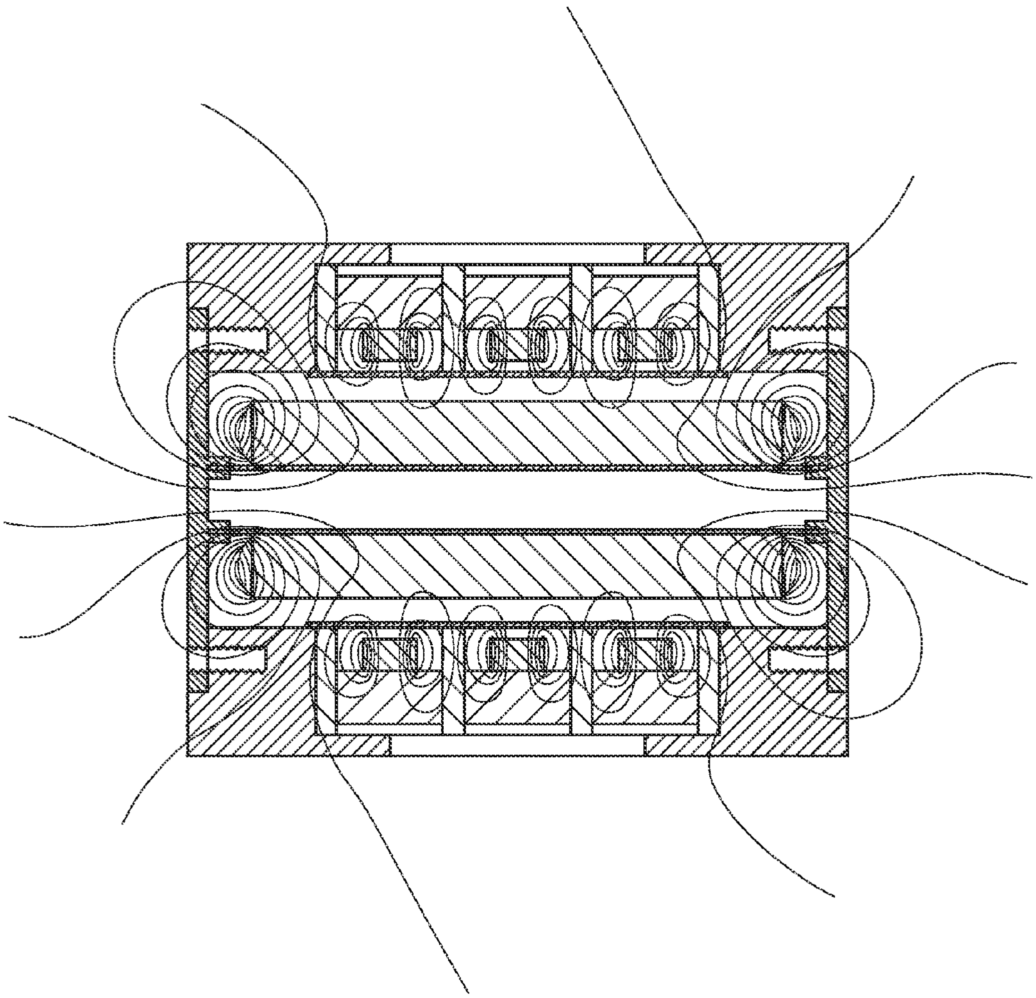
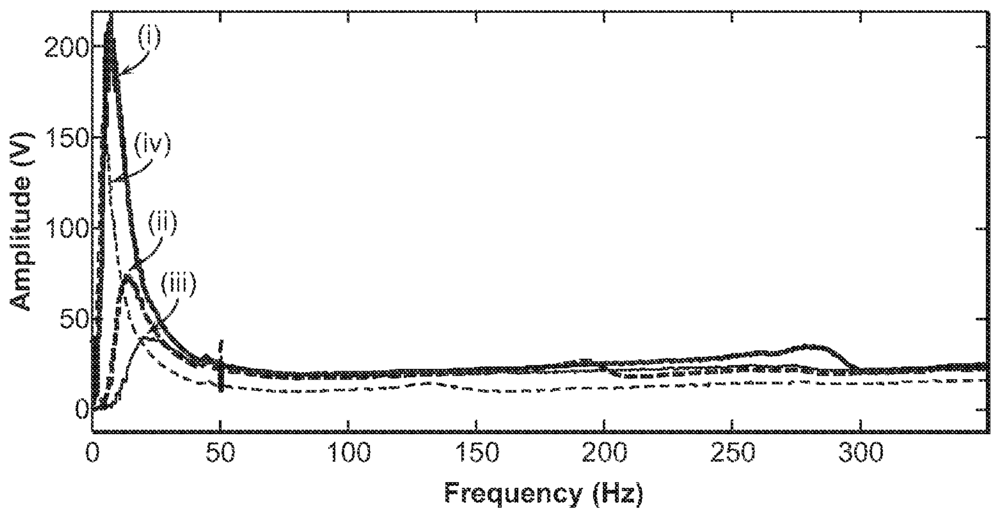
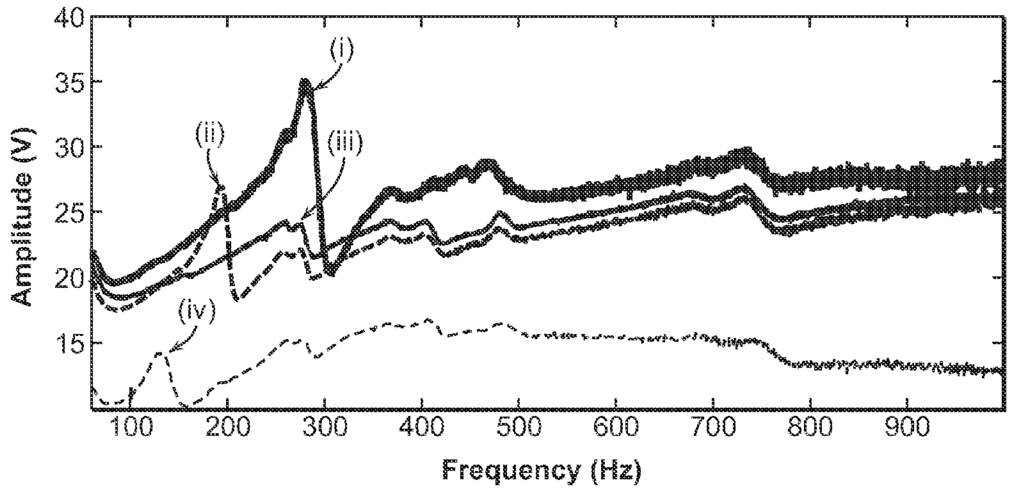


FIG. 26



200
150
100
50
0
Amplitude (V)
(i)
(iv)
(ii)
(iii)
0
50
100
150
200
250
300
Frequency (Hz)

FIG. 27



40
35
30
25
20
15
Amplitude (V)
(i)
(ii)
(iii)
(iv)
100
200
300
400
500
600
700
800
900
Frequency (Hz)

FIG. 28

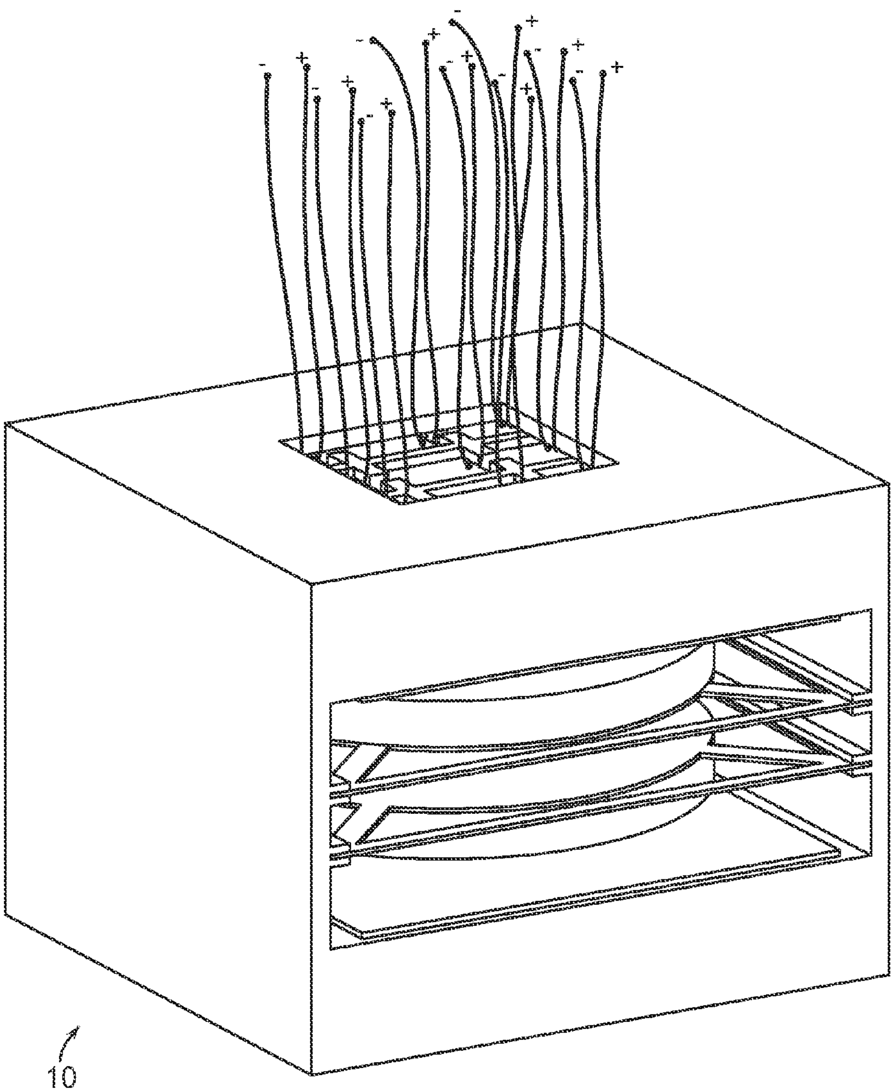


FIG. 29

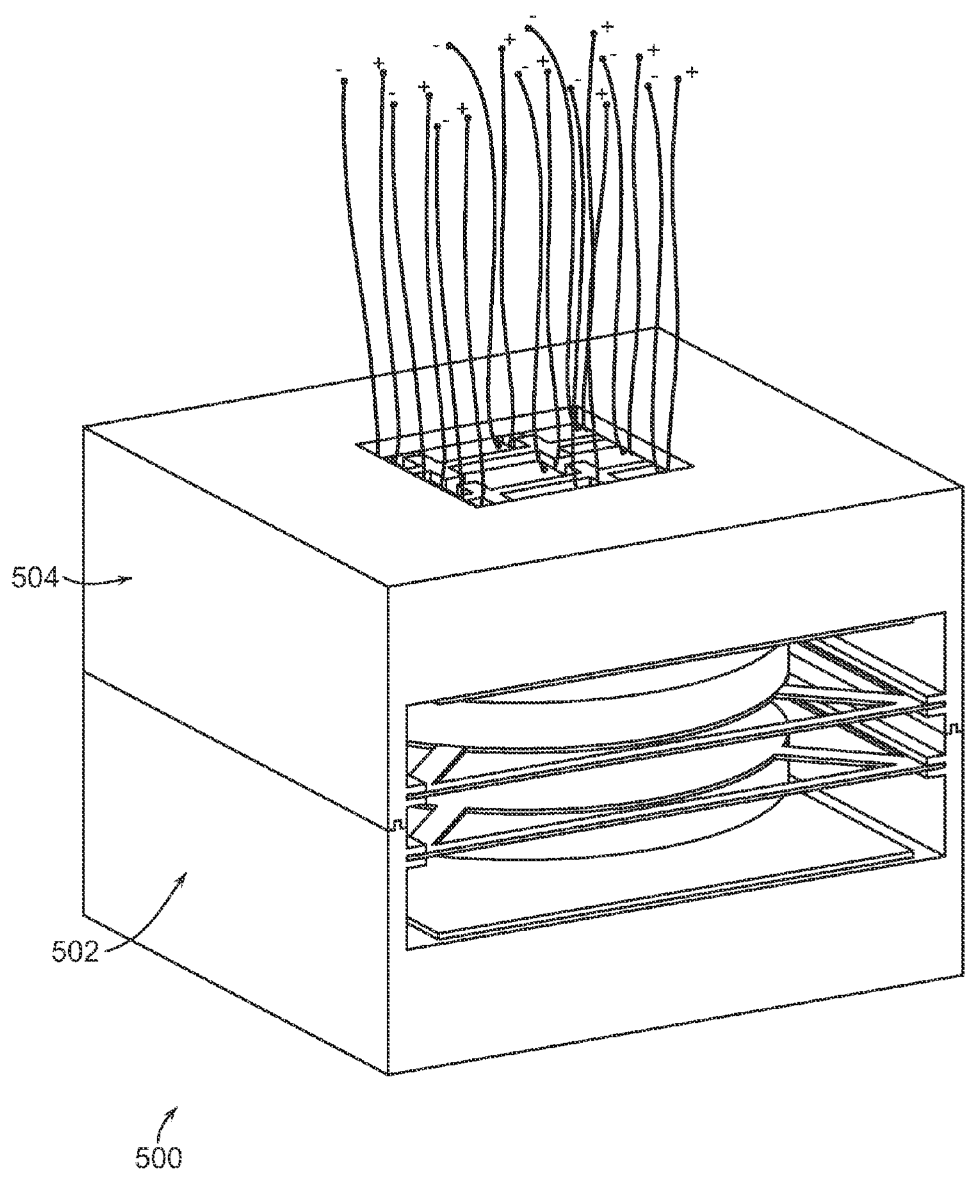
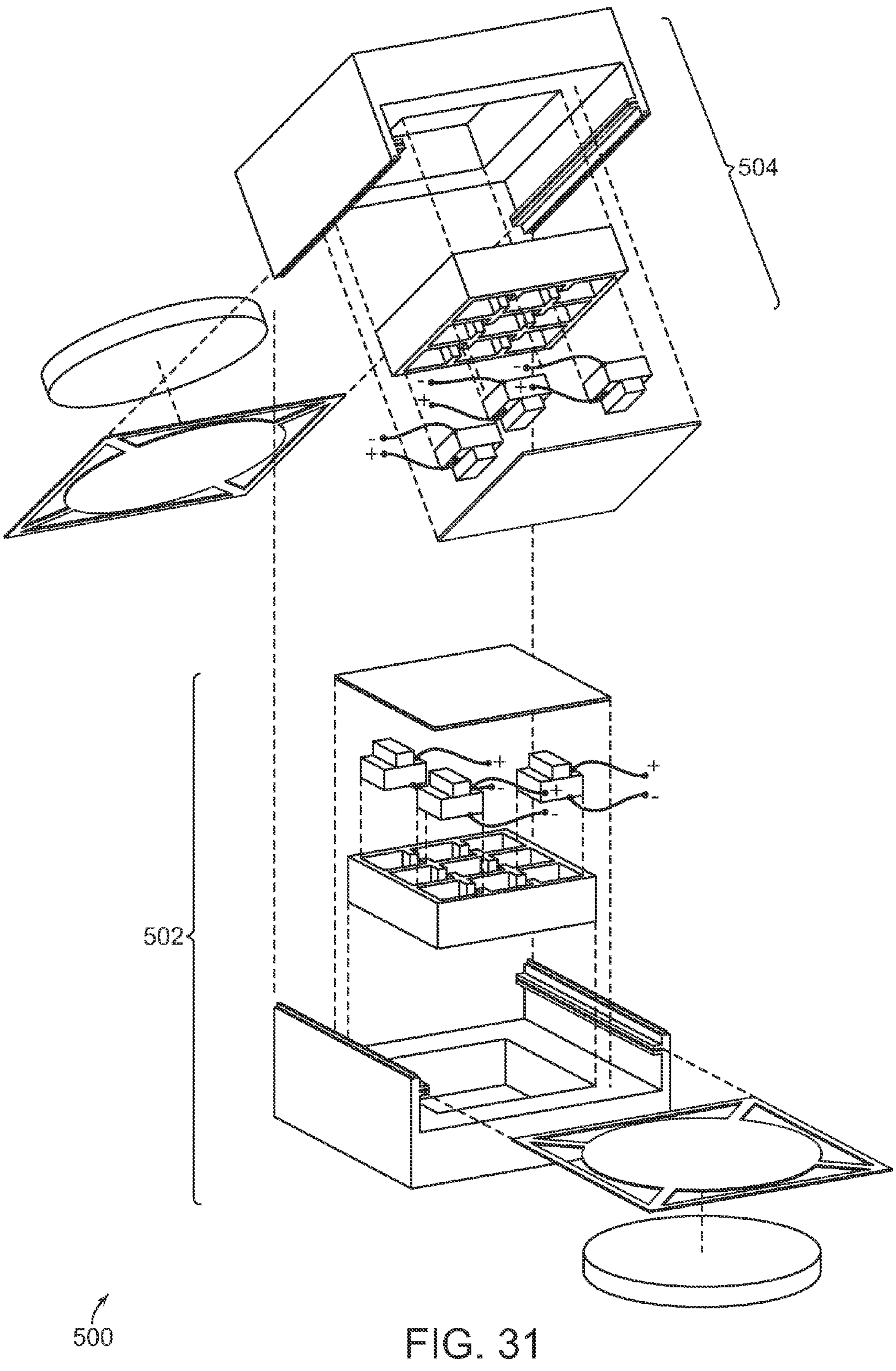


FIG. 30



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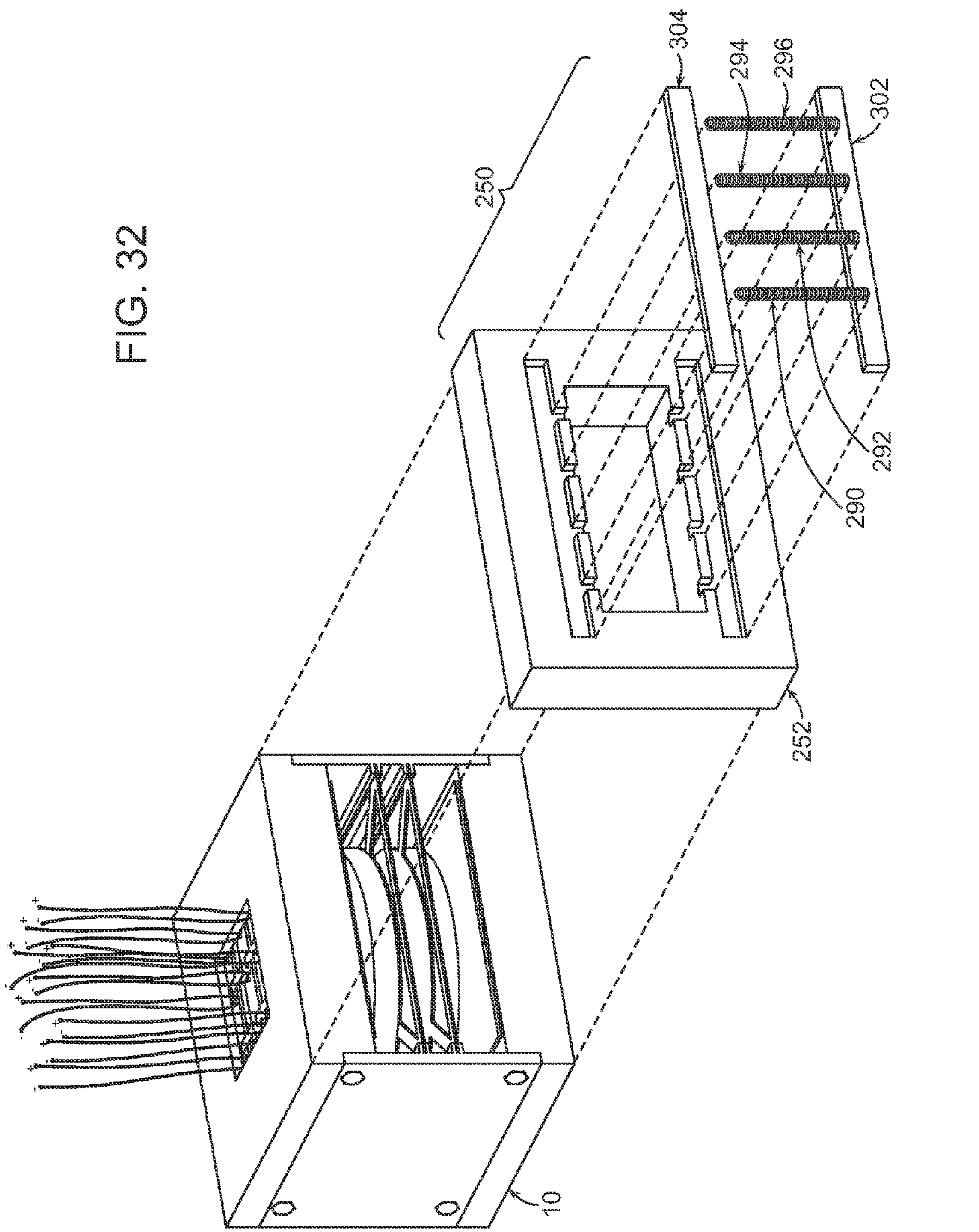

FIG. 32

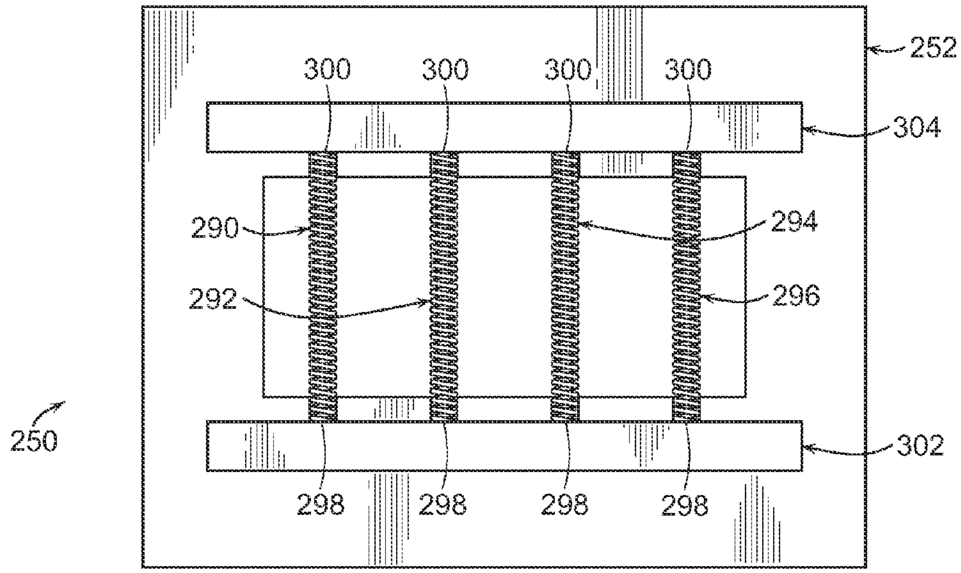
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FIG. 33

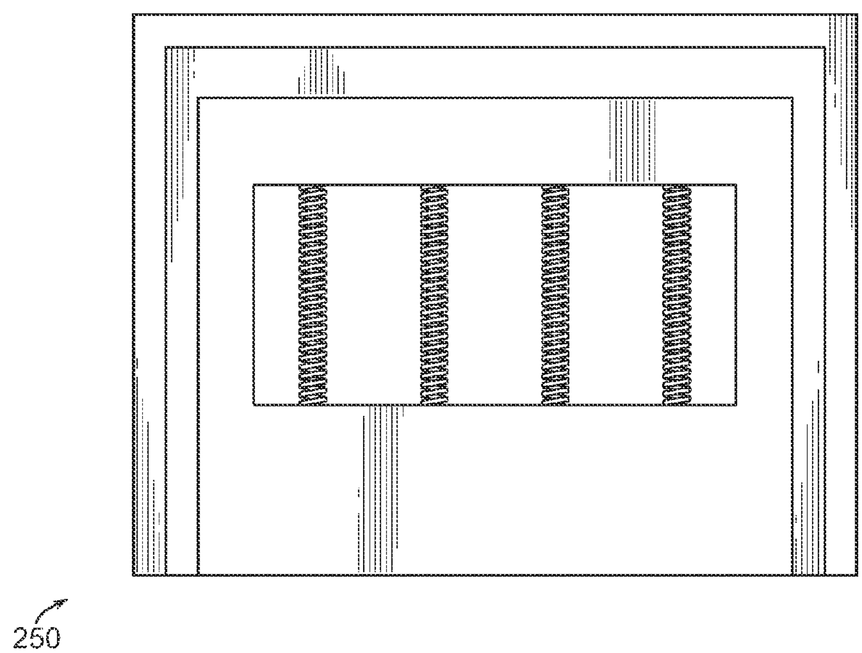
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FIG. 34

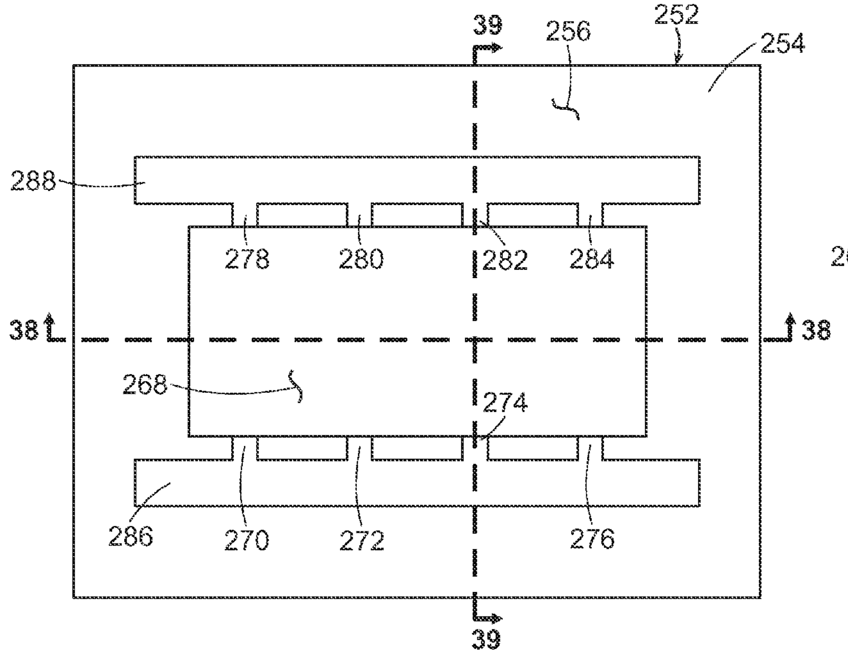

FIG. 35

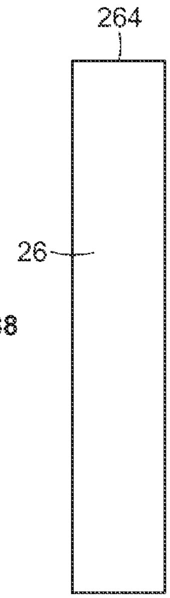

FIG. 36

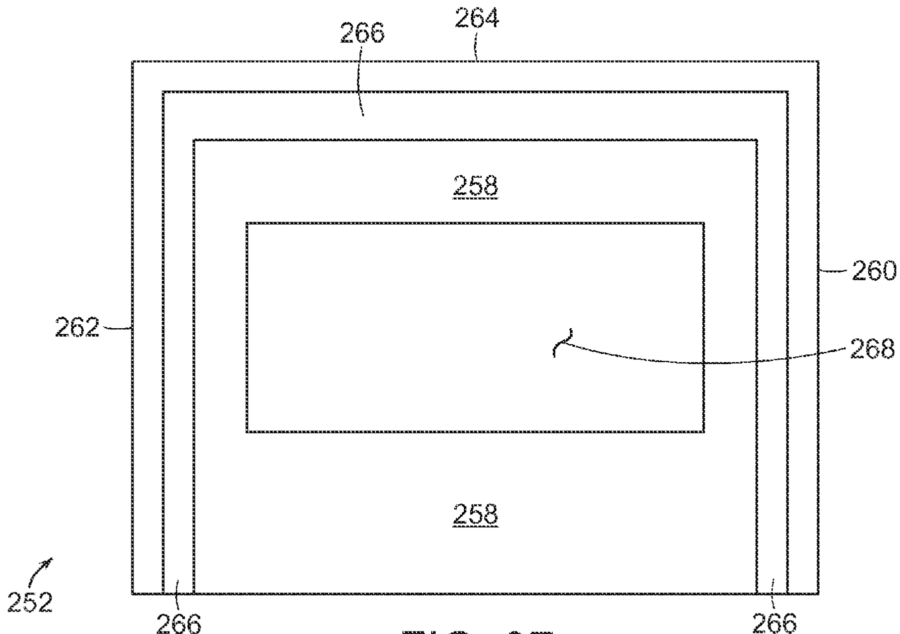

FIG. 37

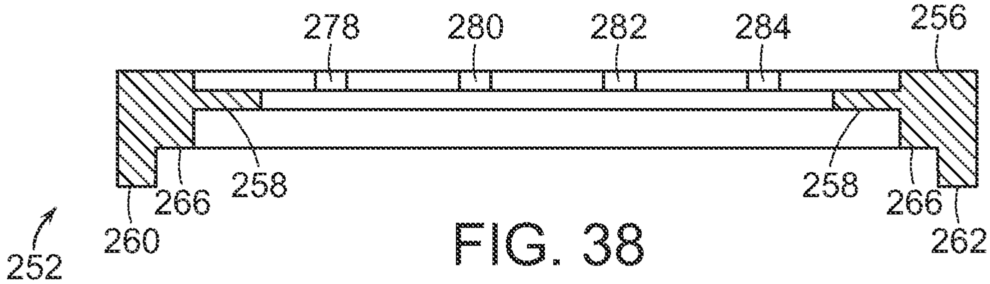
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FIG. 38

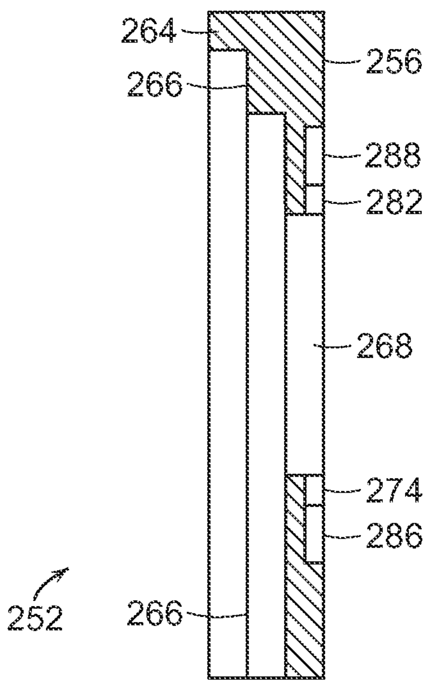
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FIG. 39

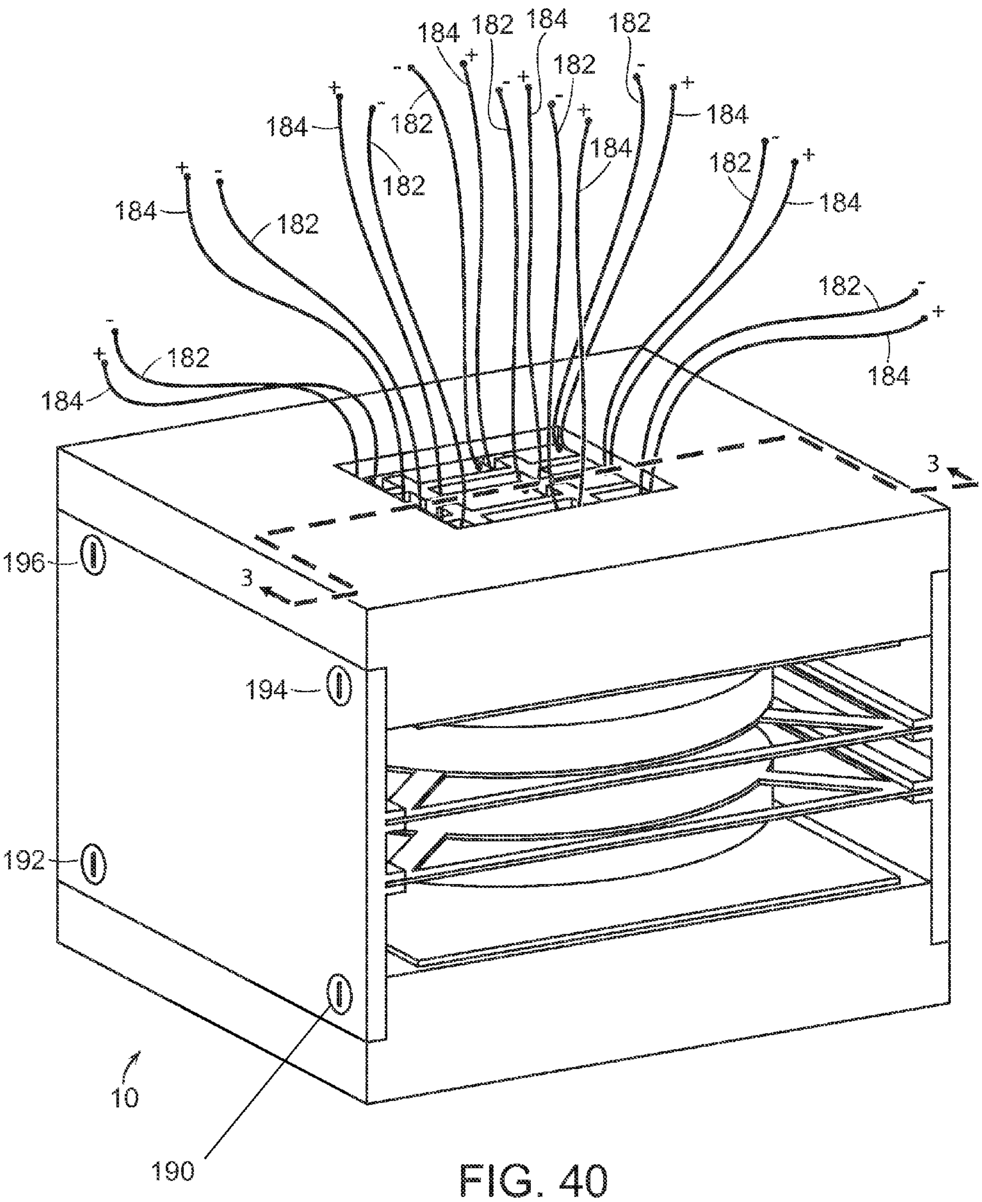
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FIG. 40

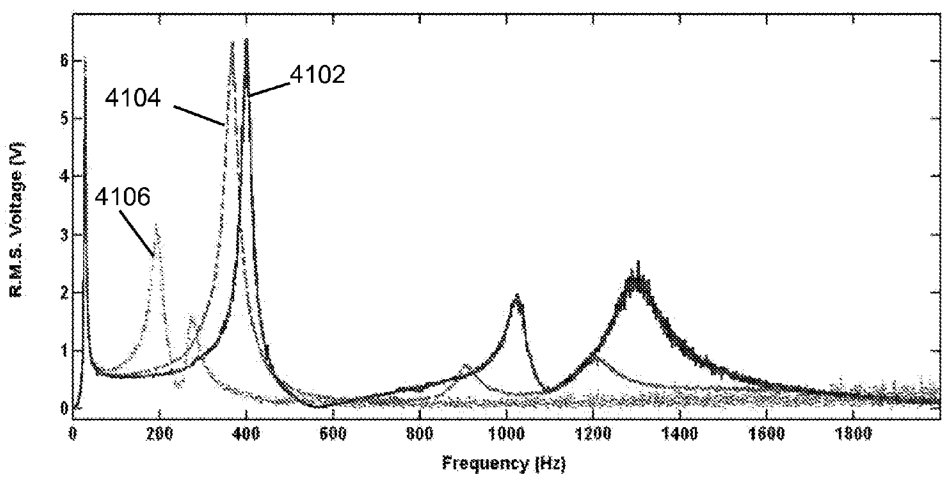
4102
4104
4106
R.M.S. Voltage [V]
Frequency (Hz)
0
1
2
3
4
5
6
0
200
400
600
800
1000
1200
1400
1600
1800

FIG. 41

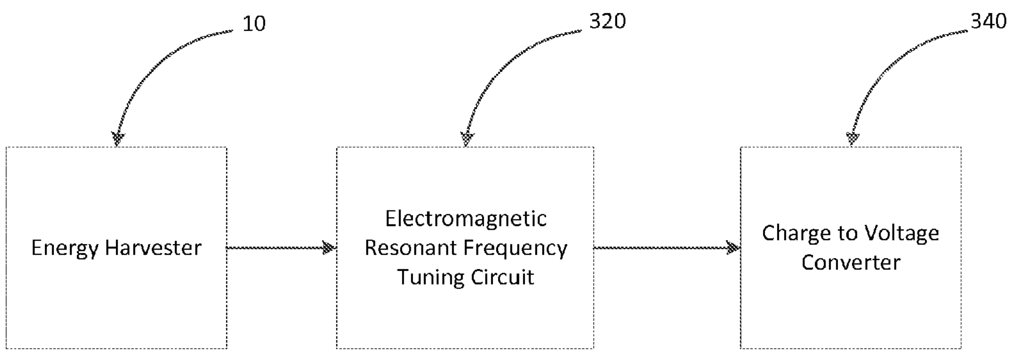
10
320
340
Energy Harvester
Electromagnetic Resonant Frequency Tuning Circuit
Charge to Voltage Converter

FIG. 42

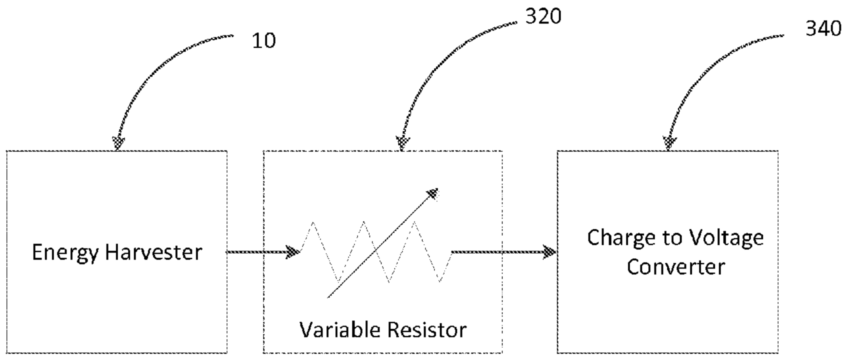
10
320
340
Energy Harvester
Variable Resistor
Charge to Voltage Converter

FIG. 43

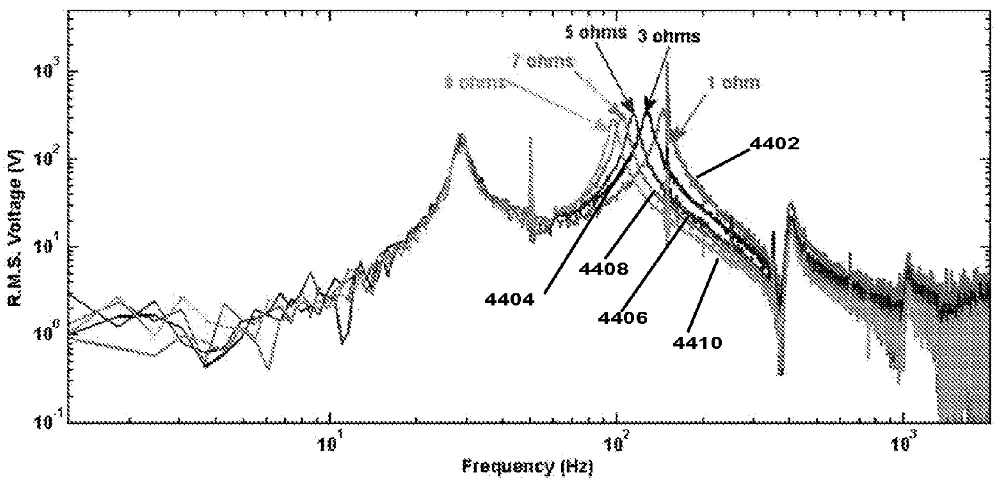
5 ohms
3 ohms
7 ohms
9 ohms
1 ohm
4402
4408
4404
4406
4410
R.M.S. Voltage (V)
Frequency (Hz)

FIG. 44

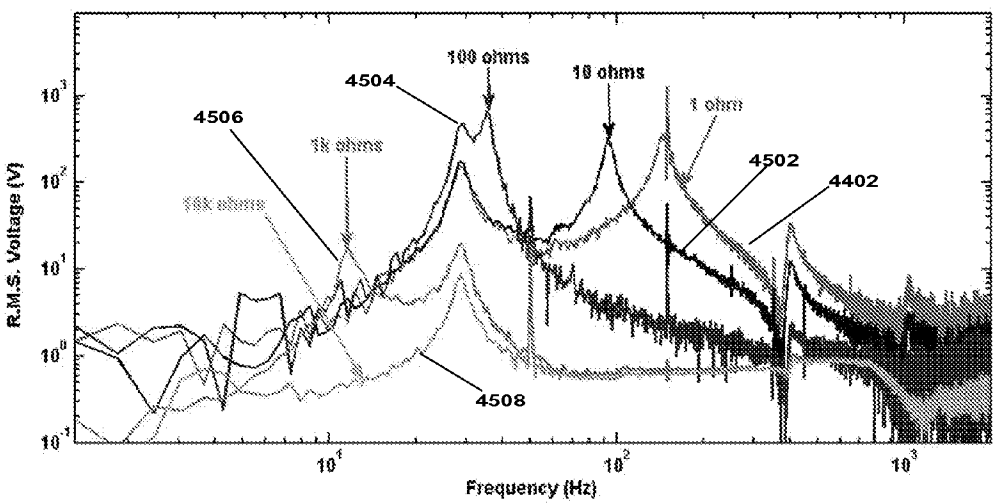
100 ohms
4504
10 ohms
1 ohm
4506
1k ohms
4502
4402
10k ohms
4508
R.M.S. Voltage (V)
Frequency (Hz)

FIG. 45

DEVICE AND METHOD FOR TUNING MECHANICAL AND ELECTROMAGNETIC NATURAL FREQUENCIES OF AN ENERGY HARVESTER

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. patent application Ser. No. 14/199,916 filed on Mar. 6, 2014, now pending, which claims priority to U.S. Provisional Application Ser. No. 61/937,330 filed on Feb. 7, 2014, now pending, both of which applications are hereby incorporated into this specification by reference in their entirety.

BACKGROUND OF THE INVENTION

[0002] Most vibration energy harvesters are resonant type and suffer from narrow frequency response, which limits them to operate at a specific frequency that may not match an ambient energy source. The natural frequency of an energy harvester is an intrinsic property of the harvester where absorbed energy is amplified in the form of resonance A composition of at least a moving mass (also called a proof or a seismic mass), m, and a spring, K, together create resonance either as the harvester's own natural frequency or as coupled natural frequency of the vibration source. Natural frequency changes when either mass or stiffness of the device is changed. For energy harvesters to have their absorbed energy amplified at other frequencies, tuning of their natural frequencies has been widely proposed. To the proof mass, an extra mass can be added to change the natural resonant frequency at which energy is harvested. The extra mass added must correspond to the needed mass for attaining the desired new natural resonant frequency. For most devices, addition or subtraction of mass is inconvenient for users as it cannot be done when a conventional energy harvester is factory packaged. However, tuning by mass is the industrial state-of-the-art, as used by Midé Technology Corporation for its piezoelectric cantilever beam based harvesters. Tuning by stiffness at commercial level is uncommon but there were laboratory investigations based on cantilever beams, which are objects of entwined stiffness and mass, such that a physical change in mass of the beam, e.g. coating with thin film, is a change in stiffness due to a change in one or more of the beam's physical dimensions, and vice-versa. Pre-loading, pre-deflection, centrifugal force, magnetic force, gravity center of the tip mass, and actuating piezoelectric transducer are methods that were explored to adjust stiffness of the non-commercial laboratory cantilever beam based harvesters (L. Tang, Y. Yang, C. K. Soh, in Advances in Energy Harvesting Methods, eds. N. Elvin and A. Erturk, Springer Science and Business Media New York 2013). Stiffness change in these methods is predominantly due to a change in Young's modulus as applied stress and beam strain vary. The demonstrated tunability, or, for all the methods is less than 100%, with only ca. 24% of the methods achieving tunability above 50%. An alternative to cantilever beam is mechanical spring that is not entwined with mass, such as helical or plate spring, to which a proof mass is then suspended. In this case, change of stiffness is achieved by changing original physical dimensions (length, width or thickness) of the spring, which could directly mean mechanical extension, contraction, changing of its mass, or use of another mechanical spring that matches the required new resonant frequency. Magnetic and gravitational springs are other kinds of springs that are not naturally entwined with mass, as with the case cantilever beams, and can be used directly for resonant frequency tuning where their stiffness is varied by their variable forces due to varying separations between their sources.

[0003] Harvesting electromagnetic energy (electromagnetic radiations at least within radio frequency spectrum (RF) range of <3 Hz (tremendously low frequency, TLF) to 300 GHz (tremendously high frequency, THF)) simultaneously with mechanical or kinetic energy is uncommon. Consequently, the ways to couple and tune resulting resonant frequency due to the synchronized electromagnetic energy harvesting are not known. RF electromagnetic radiations have both an electric and a magnetic component, and electromagnetic field is always produced by conductors when they transport electric current and. An energy harvester with its own magnetic field, as the device in the present invention, can couple by mutual attractive/repulsive interaction, or. mutual inductance, to any electromagnetic field in its environment, such as magnetic field of an AC power cord, power transmission lines, unshielded electronic instruments, broadcasting towers, radars, operating machineries, auroras, etc. This coupling between the harvester and electromagnetic source takes place when their magnetic field lines cross into each other, and occurrence of any resonance is a function of the harvester structural arrangements, electromagnetic radiation source, transducer of the harvester, and electrical power delivering circuitry associated with the harvester. As with mechanical tuning of natural resonant frequency by stiffness, tuning of the electromagnetic resonant frequency brings along the benefit of augmenting harvested vibration energy.

SUMMARY OF THE INVENTION

[0004] One object of the present invention is to provide a method for mechanically tuning the natural frequency response of an energy harvesting device to match the frequency of an energy source, for example ambient vibration without addition or subtraction of mass, replacement of mechanical spring or change in physical dimensions of mechanical spring by stretching (e.g. length), contraction (e.g. length) and coating (e.g. thickness).

[0005] Another object of the present invention was to develop a method for electronically tuning coupled electromagnetic natural resonant frequency of an energy harvester without changing the mechanical resonant frequency of the energy harvester.

[0006] The present invention is a device and method for harvesting energy from a vibrating environment having a natural frequency. In one embodiment, the device comprises a first housing, left and right sidewalls engaged with the first housing by first and second fasteners, a mechanical spring engaged with the left and right sidewalls; a first magnet engaged with the mechanical spring; and a composite structure comprising a fixed magnet and a piezoelectric material. The first magnet and the fixed magnet apply a force upon the piezoelectric material when the mechanical spring is in a static state to produce a base voltage. Adjustment of the first fastener to a first position and excitation of the mechanical spring by the vibrating environment causes the piezoelectric material to generate a first alternating voltage output comprising a first peak voltage at a first frequency greater than the base voltage. The first frequency is different from the natural frequency of the vibrating environment. Adjustment of the first fastener to a second position and excitation of the mechanical spring by the vibrating environment causes the piezoelectric material to generate a second alternating voltage output comprising a second peak voltage at a second frequency greater than the base voltage. The second frequency being closer to the natural frequency of the vibrational environment than the first frequency. The energy harvester allows a person to tune the mechanical natural frequency by tightening or loosening of the first fastener without any need for adding/subtraction of mass or changing the physical dimensions of the mechanical spring. The energy harvester may further comprise an electromagnetic resonant frequency tuning circuit connected with the piezoelectric material. The electromagnetic resonant frequency tuning circuit comprises a variable dissipative element, which can be in the form of a variable electronic resistor. The electromagnetic resonant frequency tuning circuit allows electronic tuning of the electromagnetic resonant frequency of the energy harvester without changing the mechanical resonant natural frequencies of the energy harvester.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The following description of the invention will be further understood with reference to the accompanying drawings, in which:

[0008] FIG. **1** is a perspective view of an energy harvesting device according to the present invention;

[0009] FIG. **2** is an exploded view of the device;

[0010] FIG. **3** is a cross section view of the device taken along line **3-3** of FIG. **2**;

[0011] FIG. **4** is a top view of a first housing according to the present invention;

[0012] FIG. **5** is a left side view of the first housing;

[0013] FIG. **6** is a right side view of the first housing;

[0014] FIG. **7** is a top view of a second housing according to the present invention;

[0015] FIG. **8** is a left side view of the second housing;

[0016] FIG. **9** is a right side view of the second housing;

[0017] FIG. **10** is a top view of a left sidewall according to the present invention;

[0018] FIG. **11** is a side view of the left sidewall housing;

[0019] FIG. **12** is a top view of a right sidewall according to the present invention;

[0020] FIG. **13** is a side view of the right sidewall housing;

[0021] FIG. **14** is a perspective view of a grid according to the present invention;

[0022] FIG. **15** is a top view of the grid;

[0023] FIG. **16** is a cross-section view of the grid taken along line **16-16** of FIG. **15**;

[0024] FIG. **17** is a top view of a composite structure according to the present invention having a magnet attached to a piezoelectric material;

[0025] FIG. **18** is a front view of the composite structure;

[0026] FIG. **19** is a top view of a grid according to the present invention having nine (9) cavities and a composite structure disposed in each cavity of the grid;

[0027] FIG. **20** is a cross section view taken along line **19-19** of FIG. **19**;

[0028] FIG. **21** is a perspective view of a first mechanical spring according to the present invention;

[0029] FIG. **22** is a top view of the first mechanical spring;

[0030] FIG. **23** is a side view of the first mechanical spring;

[0031] FIG. **24** is a perspective view of an assembly of the first mechanical spring and a first magnet according to the present invention;

[0032] FIG. **25** is a perspective view of an assembly of the first mechanical spring and first and second magnets according to the present invention;

[0033] FIG. **26** is a cross section view of the device showing static magnetic energy available for electromagnetic transduction;

[0034] FIG. **27** is an example of real-time data from a data logger demonstrating the harvesting of energy by the device within bandwidth of 50 Hz across a frequency range up to 50 Hz from a random noise base input from a vibration shaker and the linear behavior of the device at such frequencies;

[0035] FIG. **28** is an enlarged view of the wave form of FIG. **27** demonstrating harvesting of energy by the device within wider bandwidths at frequencies above 50 Hz and the non-linear behavior of the device at such frequencies;

[0036] FIG. **29** is a perspective view of the device having a one-piece housing;

[0037] FIG. **30** is a perspective view of the device having a two-piece housing;

[0038] FIG. **31** is an exploded view of the device having a two-piece housing;

[0039] FIG. **32** is a perspective exploded view of a conductor panel assembly according to the present invention removably mounted to an open side of the device for harvesting energy from electromagnetic transduction to provide a second and independent source of harnessed energy;

[0040] FIG. **33** is a front view of the conductor panel assembly;

[0041] FIG. **34** is a rear view of the conductor panel assembly,

[0042] FIG. **35** is a front view of a frame of the conductor panel assembly,

[0043] FIG. **36** is a side view of the frame;

[0044] FIG. **37** is a rear view of the frame;

[0045] FIG. **38** is a cross section view of the frame taken along line **38-38** of FIG. **35**;

[0046] FIG. **39** is a cross-section view of the frame taken along line **39-39** of FIG. **35**;

[0047] FIG. **40** is a perspective view of the energy harvester device as shown in FIG. **1** with one or more screws that allow tuning of the mechanical resonant frequency of the energy harvester device by tightening or loosening of the screw(s);

[0048] FIG. **41** is a frequency response data plot showing adjustment or tuning of the mechanical resonant frequency of the energy harvester device after tightening or loosening of one screw;

[0049] FIG. **42** is a block diagram showing an energy harvester device connected to a charge to voltage converter by an electromagnetic resonant frequency tuning circuit;

[0050] FIG. **43** is a block diagram showing the electromagnetic resonant frequency tuning circuit comprising a variable dissipative resistor;

[0051] FIG. **44** is a frequency response data plot showing adjustment or tuning of the electromagnetic (EM) resonant frequency of the energy harvester device using the electromagnetic resonant frequency tuning circuit in the form of a variable resistor; and

[0052] FIG. **45** is a frequency response data plot showing adjustment or tuning of the electromagnetic (EM) resonant frequency of the energy harvester device using the electromagnetic resonant frequency tuning circuit in the form of a variable resistor.

DESCRIPTION OF THE INVENTION

[0053] Referring to FIG. **1**, where an energy harvesting device **10** according to the present invention is shown. Device **10** collects energy from movements, noise, sound, and stray electromagnetic signals and generates electricity. Movements can be generated from many sources such as transportation systems (for example, cars, trains, bicycles, and airplanes); infrastructures (for example, buildings, bridges, tunnels, and airports); anatomical (for example, human, animals, and plants); and machinery (for example, industrial plants, vacuum pumps, milling machines, and heavy duty vehicles). Noises can be of thermal, electromagnetic perturbations, colored noise, and white noise. Device **10** captures energy sources in the form of sinusoid, random noise, impulse and their different combinations. In the embodiment shown, device **10** has an overall length of 31 mm, a width of 24 mm, and a height of 24 mm. Unlike conventional energy harvesting devices, device **10** captures energy from movements, noise, sound, and stray electromagnetic signals and generates an alternating voltage output having wide bandwidths across an extended range of frequencies allowing more usable and flexible energy extraction in many different types of environments and/or applications.

[0054] Referring to FIGS. **2** and **3**, device **10** generally comprises a first housing **12**, a second housing **32**, and a left side wall **52** engaged with first and second housings **12** and **32** by fasteners such as bolts **190**, **192**, **194**, and **196**, and a right side wall **66** engaged with first and second housings **12** and **32** by fasteners such as bolts **198**, **200**, **202**, and **204**. Device **10** further comprises a first mechanical spring **80** engaged with left and right sidewalls **52** and **66**. Device **10** further comprises a second mechanical spring **82** engaged with left and right sidewalls **52** and **66**. Device **10** further comprises a first magnet **108** engaged with first mechanical spring **80** and a second magnet **110** engaged with second mechanical spring **82**. Device **10** further comprises first and second grids **112** and **114** freely engaged with first and second housings **12** and **32**, respectively. Device **10** further comprises composite structures **162**, **164**, **166**, **168**, **170**, **172**, **174**, **176**, and **178** securely disposed within cavities (to be described) of first and/or second grids **112** and **114**. Device **10** further comprises one or more pieces of a non-conductive tape **188** applied to and substantially covering the entire inner face of first housing **12** so that first grid **112** may freely move within a cavity **16** (to be described) of first housing **12**. Similarly, device **10** further comprises a second piece of non-conductive tape **189** applied to and substantially covering the inner face of second housing **32** so that second grid **114** may freely move within a cavity **36** (to be described) of second housing **32**. Wires **182** and **184** of composite structures **162**, **164**, **166**, **168**, **170**, **172**, **174**, **176**, and **178** pass thru openings **30** and **50**, of first and second housings **12**, and **32**, respectively.

[0055] In the static state, first magnet **108** and fixed magnets **186** (to be described) of composite structures **162**, **164**, **166**, **168**, **170**, **172**, **174**, **176**, and **178** embedded within first housing **12** repel each other applying a force upon piezoelectric blocks **180** (to be described) of composite structures **162**, **164**, **166**, **168**, **170**, **172**, **174**, **176**, and **178**, producing an alternating base voltage across wires **182** and **184** of piezoelectric blocks **180**. Similarly, second magnet **110** and fixed magnets **186** (to be described) of composite structures **162**, **164**, **166**, **168**, **170**, **172**, **174**, **176** embedded with second housing **32** repel each other applying a force upon piezoelectric blocks **180** (to be described) of composite structures **162**, **164**, **166**, **168**, **170**, **172**, **174**, **176**, and **178**, producing an alternating base voltage across wires **182** and **184** of piezoelectric blocks **180**. Excitation of first spring **80** causes oscillation of first magnet **108** to and from the fixed magnets of composite structures **162**, **164**, **166**, **168**, **170**, **172**, **174**, **176**, and **178** embedded within first housing **12** creating an alternating high voltage across wires **182** and **184** of piezoelectric blocks **180** of composite structures **162**, **164**, **166**, **168**, **170**, **172**, **174**, **176**, and **178** within wide bandwidths. Similarly, excitation of second spring **82** causes oscillation of second magnet **110** to and from the fixed magnets **186** of composite structures **162**, **164**, **166**, **168**, **170**, **172**, **174**, **176**, and **178** embedded within second housing **32** creating an alternating high voltage across wires **182** and **184** of a piezoelectric blocks **180** of composite structures **162**, **164**, **166**, **168**, **170**, **172**, **174**, **176**, and **178** within wide bandwidths. Unlike conventional energy harvesting devices, device **10** produces a high output voltage over wide bandwidths thereby making its dramatically easier to extract energy from device **10** using presently and/or future developed conventional circuit designs. Further, unlike conventional energy harvesting devices, within frequencies greater than 50 Hz, device **10** has unexpected results, namely, non-linear characteristics between different configurations of device **10** thereby allowing each configuration to provide a different voltage level and energy to be exacted from device **10**.

[0056] Referring to FIGS. **4-6**, first housing **12** comprises a base **13** having inside and outside surfaces **14** and **15**, an end portion **18**, and an end portion **20**. First housing **12** further comprises threaded holes **22** and **24** formed at end portion **18**. First housing **12** further comprises threaded holes **26** and **28** formed at end portion **20**. First housing **12** further comprises a cavity **16** disposed within base **14** having a floor **17**. In the embodiment shown, cavity **16** has a width of 20 mm, a length of 20 mm, and a depth of 5 mm. As will be described more fully herein, first grid **112** can freely move within cavity **16** in all directions to add vibrational energy to device **10** for harvesting. First housing **12** further comprises an opening **30** disposed in floor **17** of cavity **16**. As will be described more fully herein, opening **30** is provided so that wires **182** and **184** (to be described) from composite structures **162**, **164**, **166**, **168**, **170**, **172**, **174**, **176**, and **178** of first grid **112** can pass outside of device **10** for connection to external circuitry to extract the energy from device **10**. In the embodiment shown, first housing **12** is made from a highly conductive material such as copper, stainless steel, or graphene. First housing **12** may be fabricated by conventional machining processes.

[0057] Referring to FIGS. **7-9**, second housing **32** is identical to first housing **12**. Second housing **32** comprises a base **33** having inside and outside surfaces **34** and **35**, an end portion **38**, and an end portion **40**. Second housing **32** further comprises threaded holes **42** and **44** formed at end portion **38**. Second housing **32** further comprises threaded holes **46** and **48** formed at end portion **40**. Second housing **32** further comprises a cavity **36** disposed within base **34** having a floor **37**. In the embodiment shown, cavity **36** has a width of 20 mm, a length of 20 mm, and a depth of 5 mm. As will be described more fully herein, second grid **114** can freely move within cavity **36** in all directions to add vibrational energy to device **10** for harvesting. Second housing **32** further comprises a central opening **50** disposed in floor **37** of cavity **36**. As will be described more fully herein, opening **50** is provided so that wires **182** and **184** from composite structures **162**, **164**, **166**, **168**, **170**, **172**, **174**, **176**, and **178** of second grid

114 can pass outside of device 10 for connection with external circuitry to extract the energy from device 10. In the embodiment shown, second housing 32 is made from a highly conductive material such as copper, stainless steel, or graphene. Second housing 32 may be fabricated by conventional machining processes.

[0058] Referring to FIGS. **10-11**, left side wall **52** comprises an end portion **54** and an end portion **56**. Left side wall **52** further comprises a lower boss **58** extending from end portion **54** to end portion **56**. Left side wall **52** further comprises an upper boss **60** extending from end portion **54** to end portion **56**. Left side wall **52** further comprises a lower channel or slot **62** formed in lower boss **58** extending from end portion **54** to end portion **56**. Left side wall **52** further comprises an upper channel or slot **64** formed in upper boss **60** extending from end portion **54** to end portion **56**. As will be described more fully herein, lower slot **62** is adapted to removably engage and receive first mechanical spring **80**. Similarly, upper slot **64** is adapted to removably engage and receive second mechanical spring **82**. Left side wall **52** further comprises threaded holes **53** and **55** disposed at end portion **54** to receive bolts **190** and **192**. Left side wall **52** further threaded holes **57** and **59** disposed at end portion **56** to receive bolts **194** and **196**. In the embodiment shown, left side wall **52** has a thickness of 1 mm, lower and upper bosses **58** and **60** have a depth of 1 mm, and lower and upper slots **62** and **64** have a depth of 1 mm. In the embodiment shown, left sidewall **52** is made from a highly conductive material such as copper, stainless steel, or graphene. Left side wall **52** may be fabricated by conventional machining processes.

[0059] Referring to FIGS. **12-13**, right side wall **66** is identical to left side wall **52**. Right side wall **66** comprises an end portion **68** and an end portion **70**. Right side wall **66** further comprises a lower boss **72** extending from end portion **68** to end portion **70**. Right side wall **66** further comprises an upper boss **74** extending from end portion **68** to end portion **70**. Right side wall **66** further comprises a lower channel or slot **76** formed in lower boss **72** extending from end portion **68** to end portion **70**. Right side wall **66** further comprises an upper channel or slot **78** formed in upper boss **74** extending from end portion **68** to end portion **70**. As will be described more fully herein, lower slot **76** is adapted to removably engage and receive first mechanical spring **80**. Similarly, upper slot **78** is adapted to removably engage and receive second mechanical spring **82**. Right side wall **66** further comprises threaded holes **67** and **69** disposed at end portion **68** to receive bolts **198** and **200**. Right side wall **66** further comprises threaded holes **71** and **73** disposed at end portion **70** to receive bolts **202** and **204**. In the embodiment shown, right side wall **66** has a thickness of 1 mm, lower and upper bosses **72** and **74** have a depth of 1 mm, and lower and upper slots **76** and **78** have a depth of 1 mm. In the embodiment shown, right side wall **56** is made from a highly conductive material such as copper, stainless steel, or graphene. Right side wall **66** may be fabricated by conventional machining processes.

[0060] Referring to FIGS. **14-16**, first grid **112** is identical to second grid **114**. Each of grids **112** and **114** comprise a front wall **116**, a rear wall **118**, a left sidewall **120**, and a right sidewall **122**. Each of grids **112** and **114** further comprise an internal wall **124**, an internal wall **126**, and internal walls **128** and **130** that form nine (9) hollow cavities, namely, a cavity **132**, cavity **134**, cavity **136**, cavity **138**, cavity **140**, cavity **142**, cavity **144**, cavity **146**, and a cavity **148**. Each of grids **112** and **114** further comprise a channel **150** formed in each of internal walls **128** and **130** forming cavity **132**, **134**, **136**, **140**, **142**, **144**, **146**, and **148**. Channels **150** of grid **112** are provided so that wires **182** and **184** (to be described) from piezoelectric block **180** (to be described) of composite structures **162**, **164**, **166**, **168**, **170**, **172**, **174**, **176**, and **178** may pass thru channels **150** of first grid **112** and out of first housing **12** for connection with external circuitry. Similarly, channels **150** of grid **114** are provided so that wires **182** and **184** (to be described) from composite structures **162**, **164**, **166**, **168**, **170**, **172**, **174**, **176**, and **178** may pass thru channel **150** of grid **114** and out of second housing **32** for connection with external circuitry. Each of grids **112** and **114** have a length of 19 mm, a width of 19 mm, and a height of 5 mm. As such, grids **112** and **114** may freely move within cavity **16** and cavity **36**, respectively, by an amount equal to 1 mm. Free movement of grids **112** and **114** within cavity **16** and **36**, respectively, provides an additional degrees of freedom and thus an additional mechanism to capture vibrational energy. Front wall **116**, rear wall **118**, left sidewall **120**, and right sidewall **122** each have a thickness of 1 mm and a length of 19 mm. Internal wall **124** and internal wall **126** each have a thickness of 1 mm and extend from front wall **116** to rear wall **118**. Internal wall **128** and internal wall **130** each have a thickness of 1 mm and extend from left sidewall **120** to right sidewall **122**. Cavity **132**, cavity **134**, cavity **136**, cavity **138**, cavity **140**, cavity **142**, cavity **144**, cavity **146**, and cavity **148** each have a width of 5 mm, a length of 5 mm, and a height of 5 mm. In the embodiment shown, each of grids **112** and **114** is made from a highly conductive material such as copper, stainless steel, or graphene. Each of first and second grids **112** and **114** may be fabricated by conventional machining processes.

[0061] Referring to FIGS. **17-18**, each of composite structures **162**, **164**, **166**, **168**, **170**, **172**, **174**, **176**, and **178** are identical to each other. For ease of description, only composite structure **162** will be described. Composite structure **162** comprises a piezoelectric block **180** having a first wire **182** extending from and electrically connected to its positive face and a second wire **184** extending from and electrically connected to its negative face. Composite structure **162** further comprises a magnet **186** securely attached to the upper surface of piezoelectric block **180** by conventional means such as adhesive. Magnet **186** is centrally disposed upon and extend the entire length of piezoelectric block **180**. In the embodiment shown, piezoelectric block **180** is made from a Navy Type I (PZT-4) piezoelectric material available from APC International, Ltd., P.O. Box 180, Makeyville, Pa. 17750 USA via its online store (www.americanpiezo.com) in any desired dimension. In the embodiment shown, piezoelectric block **180** has a length of 5 mm, a width of 5 mm, and a thickness of 2.0 mm. In the embodiment shown, magnet **186** is rectangular shaped 45H Neodymium magnet having a length of 5 mm, a width of 2.5 mm, a thickness of 1.5 mm, and a performance rating of 0.35 kg Pull Force and 2900 Gauss. Magnet **186** is available as Product No. MOD2-**20** from MAGNET Expert Ltd., Walker Industrial Estate, Ollerton Road, Tuxford, Nottinghamshire, NG22 0PQ United Kingdom via its online store (www.first4magnet.com).

[0062] Referring to FIGS. **19-20**, where composite structures **162**, **164**, **166**, **168**, **170**, **172**, **174**, **176**, and **178** are shown securely disposed within cavity **132**, **134**, **136**, **138**, **140**, **142**, **144**, **146**, and **148** of first grid **112**, respectively. This would be the same view as the assembly of second grid **114** with composite structures **162**, **164**, **166**, **168**, **170**, **172**, **174**, **176**, and **178**. As best shown by FIG. **20**, wire **184** from piezoelectric block **180** of composite structure **162** passes from cavity **132** of first grid **112** thru opening **30** of first housing **12**. Wire **182** from piezoelectric block **180** of composite structure **164** passes from cavity **132** thru channel **150** and outward of opening **30** of first housing **12**. Similarly, wire **184** from piezoelectric block **180** of composite structure **164** passes from cavity **134** of first grid **12** thru opening **30** of first housing **12**. Wire **182** from piezoelectric block **180** of composite structure **164** passes from cavity **134** of first grid **112** thru channel **150** and opening **30** of first housing **12**. Similarly, wire **184** from piezoelectric block **180** of composite structure **166** passes from cavity **136** of first grid **112** thru opening **30** of first housing **12**. Wire **182** from piezoelectric block **180** of composite structure **166** passes from cavity **136** of first grid **12** thru channel **150** and opening **30** of first housing **12**. This cross-section view of the assembled first grid **12** is identical to assembled second grid **114** with composite structures **162**, **164** and **166** securely disposed within cavity **132**, cavity **134**, cavity **136** of second grid **114**, respectively.

[0063] Referring to FIGS. **21-23**, first and second mechanical springs **80** and **82** each comprise an outer body **84** having a left side portion **86**, a right side portion **88**, a front side portion **90**, and a rear side portion **92**. Each of first and second mechanical springs **80** and **82** further comprise an inner body **94** having a top surface **96** and a bottom surface **98**. Inner body **94** is attached to outer body **84** by anchors **100**, **102**, **104**, and **106**. Left side portion **86** and right side portion **88** of first mechanical spring **80** removably slide within lower slot **62** of left side wall **52** and lower slot **76** of right side wall **66**, respectively. Left side portion **86** and right side portion **88** of second mechanical spring **82** removably slide within upper slot **64** of left side wall **52** and upper slot **78** of right side wall **66**. In the embodiment shown, inner and outer body **84** and **94**, and anchors **100**, **102**, **104**, and **106**, of first and second mechanical springs **80** and **82** are made from a single piece of widely available stainless steel shim stock having a thickness of 0.20 mm. Each of anchors **100**, **102**, **104** and **106** have a width of 1 mm. The thickness of inner and outer body **84** and **94** and the thickness and/or width of anchors **100**, **102**, **104**, and **106** may be varied to adjust the resonant frequency of first and/or second mechanical springs **80** and **82**. Each of first and second mechanical springs **80** and **82** may be fabricated by conventional machining processes.

[0064] Referring to FIG. **24**, where second magnet **110** is shown removably attached to second mechanical spring **82** by conventional means such as adhesive. In the embodiment shown, first magnet **108** is identical to second magnet **110** and is secured to first mechanical spring **80** in the same manner. Each of magnets **108** and **110** are circular shaped N42 Neodymium magnet having a diameter of 25 mm, a thickness of 3 mm, and a performance rating of 5.1 kg Pull Force and 1600 Gauss. Magnets **108** and **110** are available as Product No. F253-2 from MAGNET Expert Ltd., Walker Industrial Estate, Ollerton Road, Tuxford, Nottinghamshire, NG22 0PQ United Kingdom via its online store (www.first4magnet.com.). In the embodiment shown, first magnet **108**, at a static state, is spaced a distance of 1 mm from first grid **112**. Similarly, second magnet **110**, at a static state, is spaced a distance of 1 mm from second grid **114**.

[0065] Device **10** may be assembled in different configurations depending upon the desired energy output. In a maximum power configuration, composite structures **162**, **166**, **168**, **170**, **172**, **174**, **176**, and **178** are secured in first grid **112**. Second, composite structures **162**, **166**, **168**, **170**, **172**, **174**, **176**, and **178** are secured in second grid **114**. Third, first grid **112** is freely disposed in cavity **16** of first housing **12**. Fourth, second grid **114** is freely disposed in cavity **36** of second housing **32**. Fifth, tape **188** is placed over first grid **112** and inside surface **14** of first housing **12** thereby preventing first grid **112** from falling out of cavity **16** of first housing **12** and composite structures **162**, **166**, **168**, **170**, **172**, **174**, **176**, and **178** from falling out of first grid **112**, thereby allowing movement of first grid **112** in all directions within cavity **16** of first housing **12**. Sixth, tape **188** is placed over second grid **114** and inside surface **34** of second housing **32** thereby preventing second grid **114** from falling out of cavity **36** of second housing **32** and composite structures **162**, **166**, **168**, **170**, **172**, **174**, **176**, and **178** from falling out of second grid **114** thereby allowing movement of second grid **114** in all directions within cavity **36** of first housing **12**. Seventh, left side wall **52** is secured to end portion **18** of first housing **12** by bolts **190** and **192**. Eighth, right side wall **66** is secured to end portion **20** of first housing **12** by bolts **198** and **200**. Ninth, left side wall **52** is secured to end portion **38** of second housing **32** by bolts **194** and **196**. Tenth, right side wall **66** is secured to end portion **40** of second housing **32** by bolts **202**, and **204**. Eleventh, first magnet **108** is secured to inner body **94** of first mechanical spring **80** and left and right side portions **86** and **88** of first mechanical spring **80** are inserted into lower slots **62** and **76** of left and right side walls **52** and **66**, respectively. Thereafter, second magnet **110** is secured to inner body **94** of second mechanical spring **82** and left and right side portions **86** and **88** of second mechanical spring **82** are inserted into upper slots **64** and **78** of left and right side walls **52** and **66**, respectively. In a full configuration, device **10** is standing up such that left side wall **52** acts as a mounting surface or free standing base for deployment in various vibrational energy environments such as direct mounting to an industrial machine or a person.

[0066] The structure of device **10** uses multiple mechanisms for the production of electricity as a hybrid of both linearity and nonlinearity such that harvested energy can be amplified or attenuated and the frequency at which energy is harvested can be shifted according to the desire of the user. Specifically, device **10** comprises at least three mechanisms for harvesting ambient energy: (1) confluence and synergy of forces wherein there is interplay of gravitational, mechanical, electrostatic and electromagnetic forces to maximize generated power and to widen bandwidth of operation; (2) direct communication between a suspended magnetic body and a composite structure comprising a magnet and a piezoelectric block; and (3) free or regulated motion of a conductor grid holding the composite of the magnet and piezoelectric structures. As will be described more fully herein, device **10** may employ another mechanism, namely, electromagnetic induction associated with a suspended helical wire (to be described).

[0067] Referring to FIG. **25**, where first and second magnets **108** and **110** are shown attached to bottom and top surfaces **98** and **96**, respectively, of second mechanical spring **82**. This represents another configuration of device **10** where only one mechanical spring is employed and one or more grids of composite structures. As will be described more fully herein, this double mass configuration of second mechanical spring **82** uncovered a non-linear characteristic response of device **10** above 50 Hz that is not present in conventional devices.

[0068] Referring to FIG. **26**, where a cross section view of device **10** shows static magnetic energy available for electromagnetic transduction.

[0069] Referring to FIGS. **27-28**, four different configurations of device **10** were tested with first housing **12** attached to a shaker table. Electrical outputs from wires **82** and **84** of three composite structures **180** of second housing **32** were connected to a data logger and the results are shown in FIGS. **27** and **28**. The four different configurations are labeled and described as follows: (i) the presence of first and second magnets **108** and **110** secured to first and second mechanical springs **80** and **82**, respectively; (ii) the presence of only second magnet **110** secured to second mechanical spring **82**; (iii) the absence of first and second magnets **108** and **110** and first and second mechanical springs **80** and **82**; and (iv) the presence of only first and second magnets **110** secured to second mechanical spring **82**. In each of the above configurations, only three out of the eighteen cavities of first and second grids **110** and **112** were populated with the composite structure representing seventeen percent of the total capacity of device **10** in the piezoelectric mode. Unlike conventional energy harvesting devices, the real time data of device **10** demonstrate the harvesting of energy by device **10** in large bandwidths across wide ranges of frequencies, for example, a band width of 50 Hz at a low frequency region (FIG. **27**), and significantly larger bandwidths within a frequency range of 50 Hz to 350 Hz, differing in width according to configurations (FIG. **28**). Examples are given below in Tables 1 and 2 of performance parameters as extracted from FIGS. **27** and **28** for device **10** at seventeen percent (17%) of its total capacity. Circuitry for extraction of energy from the piezoelectric mode comprises high input impedance and low output impedance. Real power was dissipated across less than ten ohms.

TABLE 1

Frequency below 50 Hz (Linear Character)

Data Labels (Configuration)	Peak Frequency (Hz)	Voltage (V)	Bandwidth (Hz)
(i)	7.02	217.44	50
(ii)	14.04	73.85	50
(iii)	21.97	41.15	50
(iv)	4.12	157.50	50

TABLE 2

Frequency above 50 Hz and below 350 Hz (Non-Linear Character)

Data Labels (Configuration)	Peak Frequency (Hz)	Voltage (V)	Bandwidth (Hz)
(i)	281.68	34.95	225
(ii)	193.18	27.02	127
(iii)	Not Applicable	Not Applicable	Not Applicable
(iv)	131.07	14.31	80

[0070] Unlike conventional devices, within the alternating voltage wave form produced by the device of the present invention are a series of wide bandwidths of over the linear region of the wave form and wider bandwidths of energy available over the non-linear region of the wave form. The availability of energy over both the linear and non-linear portions of the waveform at larger bandwidths makes it possible to extract significantly more useful power than conventional energy harvesters.

[0071] Referring to FIG. **29**, where device **10** is shown having a one piece housing. Fabrication of a one piece housing may be accomplished by current three dimensional (3-D) printing processes or other futurely developed technologies.

[0072] Referring to FIGS. **30** and **31**, where device **10** is shown having a two piece housing. A two piece housing allows for each modular use of separate cores or grids to produce energy. Two piece housing may be accomplished by current machining processes or three dimensional (3-D) printing processes or other futurely developed technologies.

[0073] Referring to FIGS. **32-34**, where a conductor panel assembly **250** is removably mounted to an open end of device **10** to provide electromagnetic transduction independent of the output from the piezoelectric materials. Conductor panel assembly **250** generally comprises a frame **252**, helical wires **290**, **292**, **294**, and **296** freely mounted to frame **252**, and first and second conductors **302** and **304** electrically connected with helical wires **290**, **292**, **294**, and **296** to provide a low impedance AC output. Movements of helical wires **290**, **292**, **294** and/or **296** within the static or changing magnetic fields of first and second magnets **108** and **110** (and the static magnetic field of fixed magnets **186** of composite structures **162**, **164**, **166**, **168**, **170**, **172**, **174**, **176** and **178**) induces a current into helical wires **290**, **292**, **294**, and **296** that is output across first and second conductors **302** and **304**.

[0074] Referring to FIGS. **35-39**, frame **252** comprises a wall **254** having an outside surface **256** and an inside surface **258**, a left side wall **260**, a right side wall **262**, and a top side wall **264**. Frame **252** further comprises a boss **266** extending upward from inside surface **258** at the innermost end of left sidewall **260**, right side wall **262**, and top side wall **24**. Frame **252** further comprises an opening **269** that in the embodiment is square shaped and sized to match the open face portion of device **10**. Frame **252** further comprises a lower coil cavity **270**, a lower coil cavity **272**, a lower coil cavity **274**, and a lower coil cavity **276**. Frame **252** further comprises an upper coil cavity **278**, upper coil cavity **280**, an upper coil cavity **282**, and an upper coil cavity **284**. Frame **252** further comprises a lower conductor cavity **286** and a upper conductor cavity **288**. Conductors **302** and **304** are secured within lower conductor cavity **286** and upper conductor cavity **288**, respectively, by conventional means such as adhesive. End portions **298** and **300** of helical wire **290** are secured to lower and upper coil cavity **270** and **278**, respectively, by conventional means such as adhesive. End portions **298** and **300** of helical wire **290** are electrically connected to first and second conductors **302** ad **304** by conventional soldering operations. End portions **298** and **300** of helical wire **292** are secured to lower and upper coil cavity **272** and **280**, respectively, by conventional means such as adhesive. End portions **298** and **230** of helical wire **292** are electrically connected to first and second conductors **302** ad **304** by conventional soldering operations. End portions **298** and **300** of helical wire **294** are secured to lower and upper coil cavity **274** and **282**, respectively, by conventional means such as adhesive. End portions **298** and **300** of helical wire **294** are electrically connected to first and second conductors **302** ad **304** by conventional soldering operations. End portions **298** and **300** of helical wire **296** are secured to lower and upper coil cavity **274** and **284**, respectively, by conventional means such as adhesive. End portions **298** and **300** of helical wire **296** are electrically connected to first and second conductors **302** ad **304** by conventional soldering operations. Each of helical wires **290**, **292**, **294**, and **296** may be any type of highly conductive wire or helical coil. For example, each of helical wires **290**, **292**, **294**, and **296** may be copper micro coils having a thickness of 58 gauge and an outside diameter of about 1 mm available from Benatav Ltd., 16 Zvi-Bergman Street, Petach-Tikva, 4927973, Israel (www.benatav.com).

[0075] Device **10** may also include additional ways of harvesting energy using a piezoelectric block **180**. Specifically, deflection of the two unfixed parts **90** and **92** of first and second mechanical springs **80** and **82**, respectively, act as fixed-fixed spring beams upon which one or more piezoelectric blocks **180** may be attached.

[0076] Referring to FIGS. **2** and **40**, energy harvester device **10** comprises screws **190**, **192**, **198**, and **200** for fastening left and right sidewalls **52** and **66** to first housing **12** and fasteners **194**, **196**, **202** and **204** for fastening left and right sidewalls **52** and **66** to second housing **32**. Energy harvester device **10** has multiple degrees of freedom, including mechanical spring **80** carrying magnet **108**. The mechanical resonant frequency of the mechanical spring **80** of energy harvester device **10** may be adjusted or tuned by tightening or loosening at least one of screws **190**, **192**, **194**, **196**, **198**, **200**, **202** and **204** without changing the mass either magnet **108** or spring **80**.

[0077] Referring to FIG. **41**, a frequency response spectra or graph is shown for tuning down or tuning up of the mechanical natural resonant frequencies of energy harvester **10**. In this example, energy harvester device **10** was configured with only second magnet **110** secured to second mechanical spring **82** and one (1) composite structure **180** buried in second grid **114** and second housing **32**. Electrical outputs from wires **82** and **84** of one composite structure **180** were connected to a data logger. The vibrating environment was a random noise spectrum generated by a conventional shaker. Tuning was performed by tightening (stiffening) or loosening (softening) of mechanical spring **80** using clockwise or anti-clockwise turning of screw **190** by relatively small amounts. A blue line **4102** represents the output response of the piezoelectric devices to a very stiff device **10** where all the screws are tightened as tight as possible. A purple line **4104** represents the output response of the piezoelectric devices when screw **190** is loosened by very small amount (one-quarter revolution). An orange line **4106** represents the output response of the piezoelectric devices when screw **190** is loosened by more than one revolution. As shown, a series of three peaks occur for lines **4102**, **4104**, and **4106** at about the same frequency, namely, 29 Hz, and represent the output response of the coupled mechanical resonance with the vibration source. A second series of three peaks tuned to frequencies of about 198 Hz, 360 Hz, and 400 Hz represent the first natural resonant frequency caused by vertical translation of second magnet **110** and mechanical spring **82**. A third series of peaks tuned to frequencies of about 275 Hz, 907 Hz and 1028 Hz represent natural resonant frequencies caused by a first flexure of second magnet **110** and mechanical spring **82**. A fourth series of peaks tuned to frequencies of about flat (nil peak), 1204 Hz and 1302 Hz represent natural resonant frequencies caused by a second flexure of second magnet **110** and mechanical spring **82**. FIG. **41** is only an example as turning of the screw by multiple revolutions shifts down the natural resonant frequency to even much lower frequencies below 120 Hz. A minimum amplification factor of 18.4 dB for the frequency range shown in FIG. **41** was obtained for tuning around the natural resonant frequencies of energy harvester **10**. This represents a low total damping ratio and mechanical losses. Screws **190**, **192**, **194**, **196**, **198**, **200**, **202** and/or **204** of energy harvester **10** may be tightened or loosened without creating significant mechanical losses to the device.

[0078] Referring to FIGS. **42** and **43**, there has been little study on how to adjust or tune the electromagnetic natural resonant frequency of an energy harvester operating in an electromagnetic environment. FIG. **42** shows an electromagnetic natural resonant frequency tuning circuit **320** connected between the outputs of energy harvester device **10** and a conventional charge-to-voltage converter **340** such as those produced by DJB Instruments, Meggitts (Endevco Corporation). Tuning circuit **320** allows the electromagnetic natural resonant frequency of energy harvester **10** to be tuned electronically without changing the mechanical natural resonant frequencies of the energy harvester device **10**. As shown by FIG. **43**, tuning circuit **320** comprises a variable dissipative element such as a variable resistor between the outputs of energy harvester device **10** and the input of charge-to-voltage converter **340**.

[0079] Referring to FIGS. **44** and **45**, a frequency response spectra or graph is shown for tuning down or tuning up of the electromagnetic natural resonant frequency of energy harvester **10**. In this example, energy harvester device **10** was configured with only second magnet **110** secured to second mechanical spring **82** and one (1) composite structure **180** buried in second grid **114** and second housing **32**. Electrical outputs from wires **82** and **84** of composite structure **180** was connected to charge-to-voltage converter **340** by tuning circuit **320**. The electromagnetic environment was generated by radiations from AC power cords of electrical instruments and operating machineries. Tuning was performed by changing the value of the variable resistor of tuning circuit **320**. As shown in both FIGS. **44** and **45**, a red line **4402** is the measured output response from charge-to-voltage converter **340** with the variable resistor of tuning circuit **320** set to 1 ohm. As shown in FIG. **44**, a black line **4404** is the measured output response from charge-to-voltage converter **340** with the variable resistor of tuning circuit **320** set to 3 ohms. As shown in FIG. **44**, a blue line **4406** is the measured output response from charge-to-voltage converter **340** with the variable resistor of tuning circuit **320** set to 5 ohms. As shown in FIG. **44**, a pink line **4408** is the measured output response from charge-to-voltage converter **340** with the variable resistor of tuning circuit **320** set to 7 ohms. As shown in FIG. **44**, a green line **4410** is the measured output response from charge-to-voltage converter **340** with the variable resistor of tuning circuit **320** set to 9 ohms. As shown in FIG. **45**, a black line **4502** is the measured output response from charge-to-voltage converter **340** with the variable resistor of tuning circuit **320** set to 10 ohms. As shown in FIG. **45**, a blue line **4504** is the measured output response from charge-to-voltage converter **340** with the variable resistor of tuning circuit **320** set to 100 ohms. As shown in FIG. **45**, a pink line **4506** is the measured output response from charge-to-voltage converter **340** with the variable resistor of tuning circuit **320** set to 1000 ohms. As shown in FIG. **45**, a green line **4508** is the measured output response from charge-to-voltage converter **340** with the variable resistor of tuning circuit **320** set to 10,000 ohms. A first peak measured at about 29 Hz represents the coupled mechanical resonance of vibration source; the second peak tuned around to different frequencies represents electromagnetic resonant frequency caused by electromagnetic waves from the environment; and the third peak remaining unchanged in frequency position at ca 400 Hz represents first natural resonant frequency caused by vertical translation of second magnet **110** and mechanical spring **82**. When the EM resonant frequency is tuned down to the lower frequency region, minimum quality factor drops and flattens out to 0 dB at extremely low frequencies. As shown in the table below, the electromagnetic natural frequency of energy harvester device **10** varied from 145.26 Hz with the resistance of tuning circuit **320** set at 1 ohm to 3.66 Hz with the resistance of tuning circuit **320** set at 10,000 ohms:

Resistance (Ohms)	Electromagnetic Natural Frequency
1	145.26
3	127.56
5	114.14
7	104.37
9	96.43
10	93.38
100	35.40
1000	11.60
10000	3.66

The present invention allows the tuning of the electromagnetic resonance caused by electromagnetic waves that are mutually coupled to vibration frequency response of energy harvester device **10** without changing natural resonant frequencies of energy harvester device **10**. Tunability is over 150%, highest performance when compared with conventional tuning methods for energy harvesting as described in background of the invention.

[0080] The above description is intended primarily for purposes of illustration. This invention may be embodied in several other forms or carried out in other ways without departing from the spirit or scope of the invention. Modifications and variations still within the spirit or scope of the invention as claimed will be readily obvious to those of skill in the art.

What is claimed:

1. A device for harvesting energy from a vibrating environment having a natural frequency, the device comprising:

a first housing;

left and right sidewalls engaged with said first housing by first and second fasteners;

a mechanical spring engaged with said left and right sidewalls;

a first magnet engaged with said mechanical spring;

a composite structure comprising a fixed magnet and a piezoelectric material; said first magnet and said fixed magnet apply a force upon said piezoelectric material when said mechanical spring is in said static state to produce a base voltage;

adjustment of said first fastener to a first position and excitation of said mechanical spring by the vibrating environment causes said piezoelectric material to generate a first alternating voltage output comprising a first peak voltage at a first frequency greater than said base voltage; said first frequency being different from the natural frequency of the vibrating environment;

adjustment of said first fastener to a second position and excitation of said mechanical spring by the vibrating environment causes said piezoelectric material to generate a second alternating voltage output comprising a second peak voltage at a second frequency greater than said base voltage; said second frequency being closer to the natural frequency of the vibrational environment than said first frequency.

2. The device of claim **1**, wherein said first fastener is a screw.

3. The device of claim **2**, wherein said second fastener is a screw.

4. The device of claim **3**, wherein said mechanical spring is made from a thin piece of metal.

5. The device of claim **4**, wherein said metal is stainless steel shim stock having a thickness of 0.20 mm.

6. The device of claim **1**, further comprising an electromagnetic resonant frequency tuning circuit connected with said piezoelectric material.

7. The device of claim **6**, wherein said electromagnetic resonant frequency tuning circuit comprises a variable dissipative element.

8. The device of claim **7**, wherein said variable dissipative element comprises a variable electronic resistor.

9. A method for tuning the mechanical natural resonant frequency of an energy harvester for use in a vibrational environment having a natural frequency, the method comprising the steps of:

providing an energy harvester comprising a first housing, a left sidewall engaged with said first housing by a first fastener; a right sidewall engaged with said first housing by a second fastener; a mechanical spring connected between said left and right sidewalls; a first magnet attached to said mechanical spring; a composite structure comprising a fixed magnet and a piezoelectric material; said first magnet and said fixed magnet apply a force upon said piezoelectric material when said mechanical spring is in a static state to produce a base voltage;

adjusting said first fastener to a first position and excitation of said mechanical spring by the vibrating environment causes said piezoelectric material to generate a first alternating voltage output comprising a first peak voltage at a first frequency greater than said base voltage; said first frequency being different from the natural frequency of the vibrating environment;

adjusting said first fastener to a second position and excitation of said mechanical spring by the vibrating environment causes said piezoelectric material to generate a second alternating voltage output comprising a second peak voltage at a second frequency greater than said base voltage; said second frequency being closer to the natural frequency of the vibrational environment than said first frequency.

10. The method of claim **9**, wherein said step of adjusting said first fastener to a second position comprises the step of loosening said first fastener to adjust the tightness of said mechanical spring to said left sidewall.

11. The method of claim **10**, wherein said step of adjusting said first fastener comprises the step of tightening said first fastener to adjust the tightness of said mechanical spring to said left sidewall.

12. A method for tuning the electromagnetic resonant frequency of a vibration energy harvester used with a charge-to-voltage converter having an input without changing the mechanical natural resonant frequency of the energy harvester, the method comprising the steps of:

providing a variable dissipative element between the output of the vibration energy harvester and the input of the charge-to-voltage converter; and

changing the resistance of said variable dissipative element.

13. The method claim **12**, wherein said step of changing the resistance of said variable dissipative element comprises the step of increasing the resistance of said variable dissipative element.

14. The method claim **12**, wherein said step of changing the resistance of said variable dissipative element comprises the step of lowering the resistance of said variable dissipative element.

15. A system comprising:

an energy harvester comprising an output;

a charge-to-volt converter comprising an input; and

an electromagnetic resonant frequency tuning circuit comprising an input connected with said output of said energy harvester and an output connected with said input of said charge-to-volt converter.

16. The system of claim **15**, wherein said energy harvester comprises:

a sidewall;

a mechanical spring engaged with said sidewall;

a first magnet engaged with said mechanical spring; and

a composite structure comprising a fixed magnet and a piezoelectric material connected with said electromagnetic resonant frequency tuning circuit.

17. The device of claim **16**, wherein said electromagnetic resonant frequency tuning circuit comprises a variable dissipative element.

18. The device of claim **17**, wherein said variable dissipative element comprises a variable electronic resistor.

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