



- (51) **International Patent Classification:**
H01L 41/113 (2006.01) *H02N 2/18* (2006.01)
- (21) **International Application Number:**
PCT/IT2014/000096
- (22) **International Filing Date:**
3 April 2014 (03.04.2014)
- (25) **Filing Language:** English
- (26) **Publication Language:** English
- (30) **Priority Data:**
TO2031A000301 15 April 2013 (15.04.2013) IT
- (71) **Applicants:** **POLITECNICO DI TORINO** [IT/IT]; Corso Duca degli Abruzzi 24, I-10129 Torino (IT). **AVIOSPACE S.R.L.** [IT/IT]; Via XX Settembre 28, I-14100 Asti (IT).
- (72) **Inventors:** **TONOLI, Andrea**; c/o Politecnico di Torino, Corso Duca Degli Abruzzi 24, I-10129 Torino (IT). **AM-ATI, Nicola**; c/o Politecnico di Torino, Corso Duca Degli Abruzzi 24, I-10129 Torino (IT). **ZENERINO, Enrico, Cesare**; c/o Politecnico di Torino, Corso Duca Degli Abruzzi 24, I-10129 Torino (IT). **BONIN, Roberto**; c/o Politecnico di Torino, Corso Duca Degli Abruzzi 24, I-10129 Torino (IT). **RAPISARDA, Alessandro**; c/o Aviospace S.R.L., Via XX Settembre 28, I-14100 Asti (IT). **PENSAVALLE, Emanuele**; c/o Aviospace S.R.L., Via XX Settembre 28, I-14100 Asti (IT).
- (74) **Agent:** **GARAVELLI, Paolo**; A.BRE.MAR. S.R.L., Via Servais 27, I-10146 Torino (IT).
- (81) **Designated States** (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.
- (84) **Designated States** (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).
- Published:**
— with international search report (Art. 21(3))

(54) **Title:** MULTI-FREQUENCY VIBRATION PIEZOELECTRIC HARVESTER DEVICE

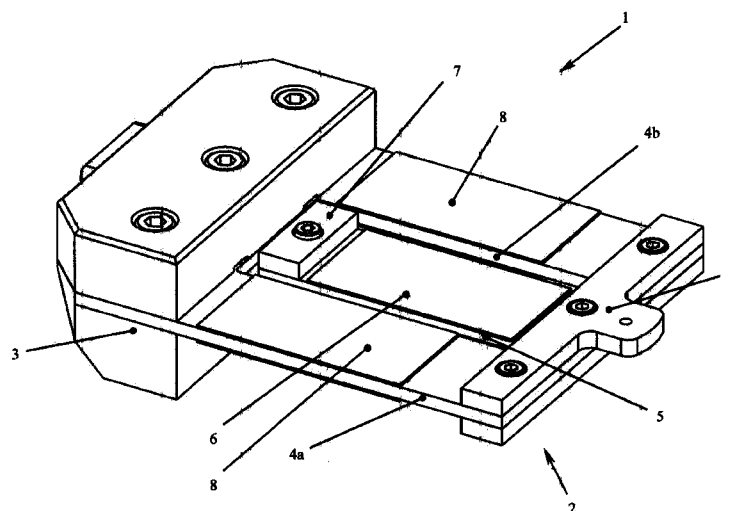


FIG. 1

(57) **Abstract:** A multi-frequency vibration piezoelectric harvester device (1) is described, comprising at least one supporting structure (3) for connection with the external environment, at least one main oscillating small beam (5) comprising at least one element with piezoelectric effect, at least one dynamic amplifier (2) arranged between such main oscillating small beam (5) and such supporting structure (3), such dynamic amplifier (2) being adapted to create at least two resonant frequencies cooperating with such main oscillating small beam (3).

MULTI-FREQUENCY VIBRATION PIEZOELECTRIC HARVESTER**5 DEVICE**

The present invention deals with a multi-frequency vibration piezoelectric harvester device.

As known, there are devices, also known as
10 "energy harvesters", which are able to capture energy from external sources present in the surrounding environment (sun energy, thermal energy, kinetic energy from vibrations, etc.) and transform it into exploitable electric energy, for
15 example, from other user devices or electronic systems such as, for example, sensors and micro-sensors. It is thereby clear how the environment advantageously represents an abundant source of energy, if compared with the amount of energy which
20 can be stored in common accumulators such as batteries, capacitors and the like.

In particular, among the various energy sources which can be used, vibrations can be advantageously exploited to make harvester devices:
25 in fact, when a device is subjected to vibrations,

it is possible to use an inertial mass suitably connected to an electric transducer to transform kinetic energy into electric energy. Therefore, harvester devices have been developed in the years
5 which are equipped with linear oscillating mechanical systems capable of transforming the kinetic energy provided by vibrations into electric energy through capacitive, inductive or piezoelectric transducers. In particular, the
10 physical phenomenon on which harvester devices with piezoelectric operation are based consists in generating electric voltage in particular materials when they are subjected to an external mechanical stress (compression, traction, flexure, torsion).
15 The effect is reversible: in fact, if a potential difference is applied to the same material, this contract or expands.

Currently, mechanical oscillators are designed so that their resonant frequency is near to
20 dominating frequencies typical of mechanical vibrations characterizing the particular environmental context. In many real cases, however, such solutions show a rather low efficiency since frequencies characteristic of mechanical vibrations
25 usually cover a very wide range of frequencies. In

particular, environmental vibrations are due to strongly heterogeneous sources such as, for example, vibrations induced by turbulent fluid-dynamic flow, seismic noise, vibrations caused by reaction motors or the motion of vehicles on a surface with random outline. The difficulties in conceiving wide band harvester devices therefore resides in that for the above situations, it is not possible to define one or more resonant frequencies which are characteristic of the system, since, depending on the features of the vibration, there will be instead a certain number of peaks in the power spectral density of the stress. In general, it is however possible to demonstrate that, for stresses characterized by very distributed spectral densities, the response of a wide band oscillator is energetically more advantageous if compared with that of a mono-frequency resonant oscillator.

Therefore, object of the present invention is solving the above prior art problems, by providing a multi-frequency vibration piezoelectric harvester device capable of generating electric energy by exploiting, through a piezoelectric effect, vibration stresses characterized by very distributed spectral densities, thereby increasing

the range of applications of the device.

Another object of the present invention is providing a multi-frequency vibration piezoelectric harvester device capable of exploiting a wide band
5 vibration excitation generating a higher power and more efficiently with respect to prior art devices.

Moreover, an object of the present invention is providing an harvester device whose sizes are more compact with respect to what is proposed by
10 the prior art.

The above and other objects and advantages of the invention, as will appear from the following description, are obtained with an harvester device as claimed in claim 1. Preferred embodiments and
15 non-trivial variations of the present invention are the subject matter of the dependent claims.

It is intended that all enclosed claims are an integral part of the present description.

It will be immediately obvious that numerous
20 variations and modifications (for example related to shape, sizes, arrangements and parts with equivalent functionality) can be made to what is described, without departing from the scope of the invention as appears from the enclosed claims.

25 The present invention will be better described

by some preferred embodiments thereof, provided as a non-limiting example, with reference to the enclosed drawings, in which:

- Figure 1 shows a top perspective view of the harvester device according to the present invention; and
- Figure 2 shows a graph related to a transfer function of the harvester device according to the present invention.

With reference to Figure 1, it is possible to note that the multi-frequency vibration piezoelectric harvester device 1 according to the present invention comprises:

- at least one supporting structure 3 for connection with the external environment;
- at least one main oscillating small beam 5 comprising at least one element with piezoelectric effect adapted to convert the mechanical vibration energy to which the device 1 according to the present invention is subjected, into electric energy. For example, such element with piezoelectric effect is at least one plate 6 made of piezoelectric material arranged on at least one surface thereof: preferably, such main oscillating small beam 5 has both its opposite surfaces

equipped with such plates 6 made of piezoelectric material in order to increase the produced electric energy;

- at least one dynamic amplifier 2 arranged
5 between such main oscillating small beam 5 and such supporting structure 3, such dynamic amplifier 2 being adapted to create at least two resonant frequencies, which delimit the range of frequencies in which the device is efficient in converting
10 vibration energy, cooperating with such main oscillating small beam 3.

Preferably, such main oscillating small beam 5 is placed in an engaged-free configuration, thereby having at least one free end with respect to the
15 supporting structure 3 of the device 1 according to the present invention.

Preferably, the main oscillating small beam 3 is made of an elastic material (for example steel or aluminium).

20 Preferably, the main oscillating small beam 5 is equipped with at least one first seismic mass 7 placed next to the free end of the small beam 5 itself, the purpose of such seismic mass 7 being lowering the natural oscillating frequencies of
25 such main oscillating small beam 5 and increasing

the dampening of the oscillations.

As known, in fact, a piezoelectric harvester device, like the prior art ones, equipped only with a small oscillating beam has a well determined oscillating frequency of the first modal shape: usually, the following modal shape is excited at a frequency of a greater order of magnitude, making thereby scarcely efficient to use the small beam when external vibrations have a wide but limited frequency spectrum. In order to pass such limit, the harvester device 1 according to the present invention therefore comprises the dynamic amplifier cooperating with the main oscillating small beam 5 to create at least the two relatively near excitation frequencies.

Preferably, such dynamic amplifier 2 is a mass-spring-dampener system comprising at least two secondary oscillating small beams 4a, 4b, each of which comprises at least one element with piezoelectric effect adapted to convert the mechanical vibration energy to which the device 1 according to the present invention is subjected, into electric energy, and having a first end connected to such supporting structure 3 and a second end opposite to such first end connected to

at least one second seismic mass 9, such main oscillating small beam 5 having an opposite end to its free end connected to such second seismic mass 9.

5 Also in this case, for example, such element with piezoelectric effect is at least one plate 8 made of piezoelectric material arranged on at least one surface of such secondary oscillating small beam 4a, 4b: preferably, each of such secondary
10 oscillating small beams 4a, 4b has both its opposite surfaces equipped with such plates 8 made of piezoelectric material in order to increase the produced electric energy: obviously, the piezoelectric elements, and in particular the
15 plates 6, 8 made of piezoelectric material, can be connected in series or in parallel, if voltage or current output from device 1 according to the present invention has respectively to be increased.

Therefore, it must be noted how,
20 advantageously, the device 1 according to the present invention provides an increase of the generated power also due to the use of many piezoelectric elements, such as for example the piezoelectric plates 6, 8, arranged both on the
25 main oscillating small beam 5 and on the secondary

oscillating small beams 4a, 4b of the dynamic amplifier 2.

In the preferred embodiment of the device 1 according to the present invention, the main
5 oscillating small beam 5 is arranged as an exemple in a position interposed between the secondary oscillating small beams 4a, 4b: obviously, though keeping the same operating principle described above, numerous alternative configurations are
10 possible without thereby departing from the scope of the present invention. For example, the main oscillating small beam could be divided and arranged outside the dynamic amplifier: in this case, the two main oscillating small beams could be
15 synchronized on different frequencies, in order to obtain a global response with three resonance peaks and therefore a further widened band.

A further alternative can exploit a geometry with many planes of symmetry.

20 Moreover, it must be noted how the configuration of the device 1 according to the present invention as proposed above, can be used not only for embodiments with conventional technologies, but also for a miniaturization
25 through technologies typical of the semiconductor

industry.

As an example, the device 1 according to the present invention has been described above taking into account double-frequency oscillating systems.

5 An example of a transfer function of this device 1 is therefore shown in Figure 2, in which as input there is the acceleration spectrum of mechanical vibrations applied to the supporting structure 3 while as output there is he produce voltage.

10 Resonance peaks (a) and (b) generated by the presence of the dynamic amplifier 2 are shown: these two peaks are placed on the sides of the single resonance peak which would be produced by the main oscillating small beam 5 only. When there

15 is the dynamic amplifier 2, this single peak is depressed while the two peaks (a) and (b) appears. A system having a divided excitation peak generates a higher power with respect to that of a single-peak system, since the delivered power is

20 proportional to the area subtended by the curve described by the transfer function: such area, with the same height, is greater when there is a divided peak, as can be seen in Figure 2.

CLAIMS

1. Multi-frequency vibration piezoelectric harvester device (1) characterized in that it comprises:

- 5 - at least one supporting structure (3) for connection with an external environment;
- at least one main oscillating small beam (5) comprising at least one element with piezoelectric effect;
- 10 - at least one dynamic amplifier (2) arranged between said main oscillating small beam (5) and said supporting structure (3), said dynamic amplifier (2) being adapted to create at least two resonant frequencies cooperating with said main
- 15 oscillating small beam (3).

2. Device (1) according to claim 1, characterized in that said element with piezoelectric effect is at least one plate (6) made of piezoelectric material arranged on at least one surface of said

20 main oscillating small beam (5).

3. Device (1) according to the previous claim, characterized in that said main oscillating small beam (5) has both its opposite surfaces equipped with said plates (6) made of piezoelectric

25 material.

4. Device (1) according to the previous claim,
characterized in that said main oscillating small
beam (5) is placed in an engaged-free
configuration, having at least one free end with
5 respect to said supporting structure (3).

5. Device (1) according to the previous claim,
characterized in that said main oscillating small
beam (5) is equipped with at least one first
seismic mass (7) placed next to said free end of
10 said small beam (5).

6. Device (1) according to any one of the
previous claims, characterized in that said dynamic
amplifier (2) is a mass-spring-dampener system
comprising at least two secondary oscillating small
15 beams (4a, 4b), each of said secondary oscillating
small beams (4a, 4b) comprising at least one
element with piezoelectric effect and having a
first end connected to said supporting structure
(3) and a second end opposite to said first end
20 connected to at least one second seismic mass (9),
said main oscillating small beam (5) having an
opposite end to its free end connected to said
second seismic mass (9).

7. Device (1) according to the previous claim,
25 characterized in that said element with

piezoelectric effect is at least one plate (8) made of piezoelectric material arranged on at least one surface of said secondary oscillating small beam (4a, 4b).

5 8. Device (1) according to the previous claim, characterized in that each of said secondary oscillating small beams (4a, 4b) has both its opposite surfaces equipped with said plates (8) made of piezoelectric material.

10 9. Device (1) according to any one of the previous claims, characterized in that said main oscillating small beam (5) is arranged in a position interposed between said secondary oscillating small beams (4a, 4b).

15 10. Device (1) according to any one of claims 1 to 6, characterized in that said main oscillating small beam is divided and arranged outside said dynamic amplifier.

11. Device (1) according to the previous claim,
20 characterized in that said secondary oscillating small beams (4a, 4b) are tuned on different frequencies.

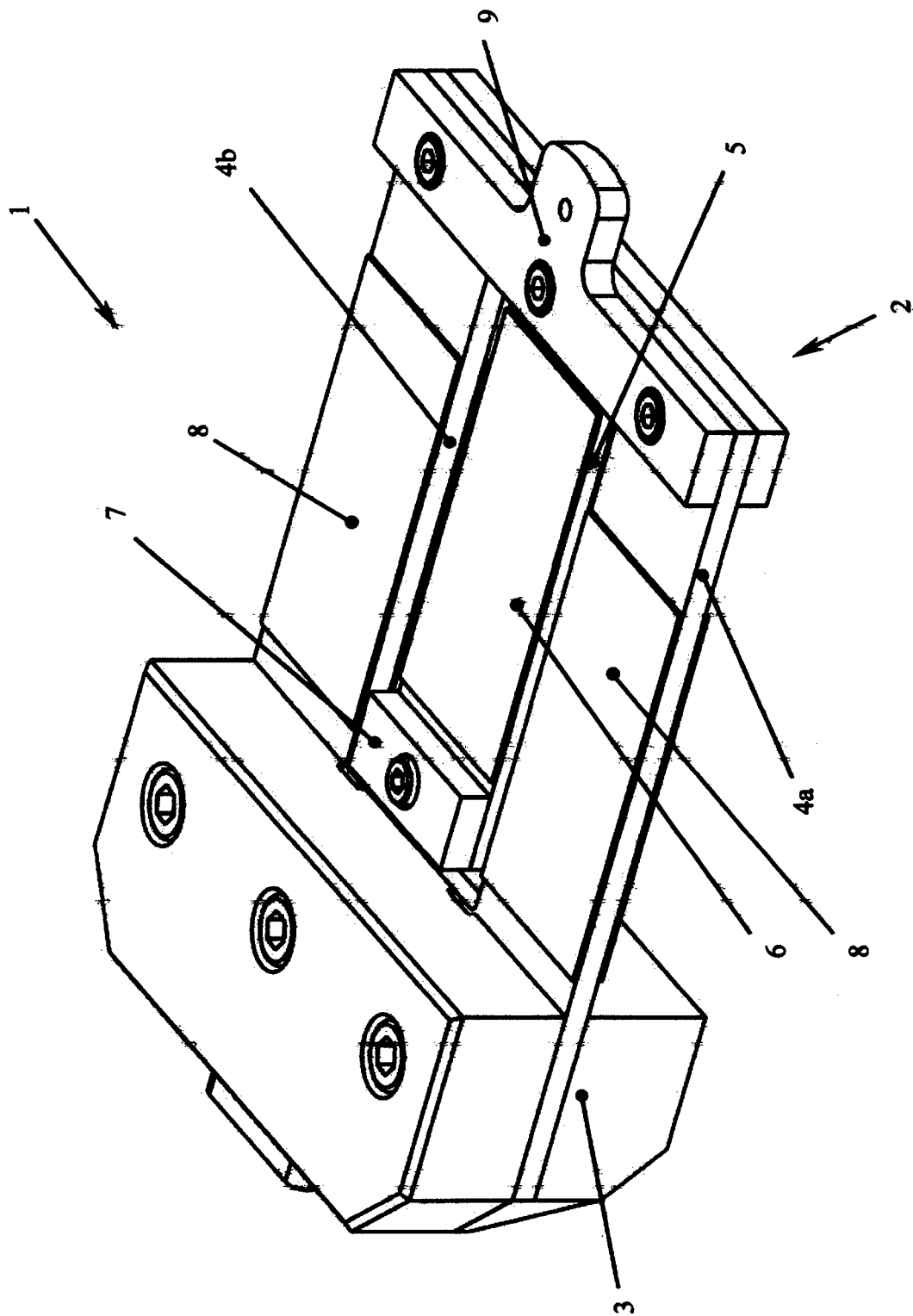


FIG. 1

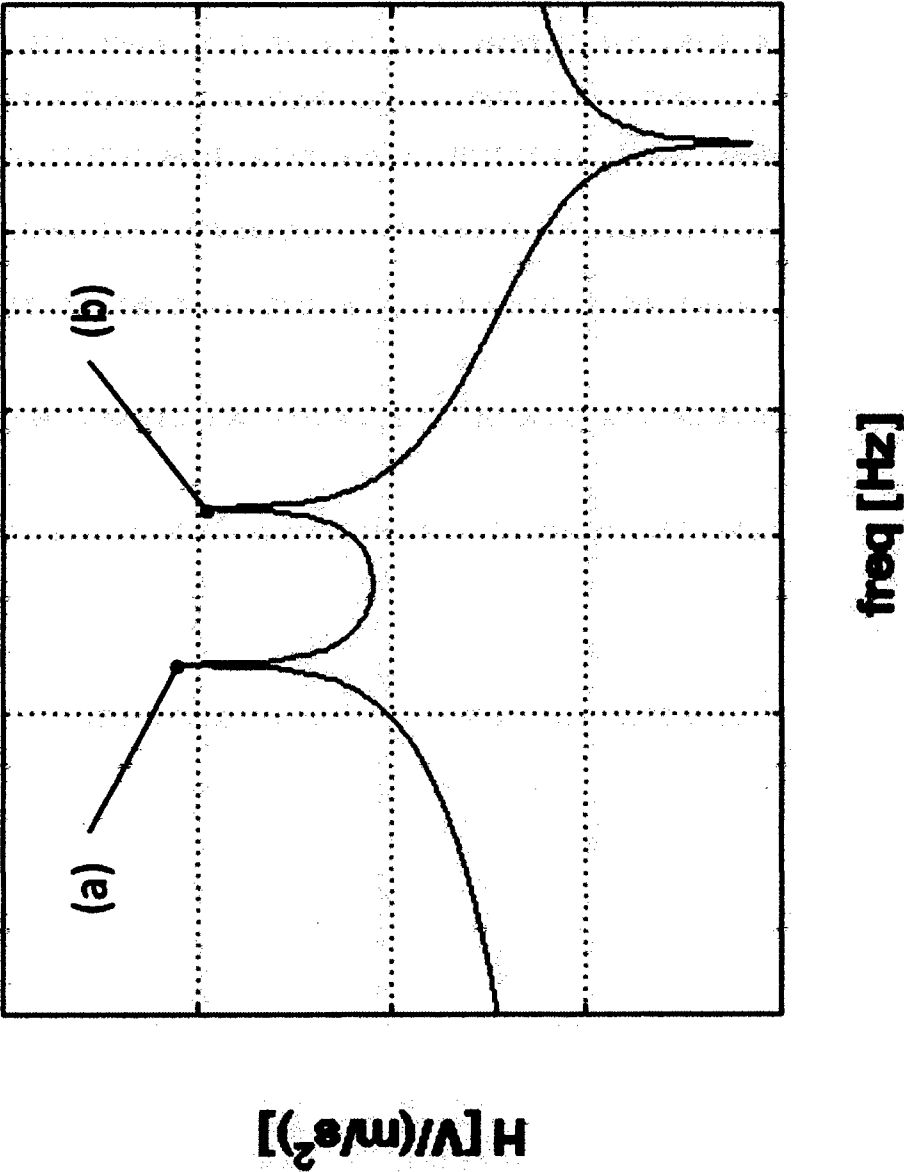


FIG. 2

INTERNATIONAL SEARCH REPORT

International application No
PCT/IT2014/000096

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01L41/113 H02N2/18
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H01L H02N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2012/137695 A1 (MURATA MANUFACTURING CO [JP]; SAKAGUCHI HITOSHI [JP]; HORIGUCHI CHIKAH) 11 October 2012 (2012-10-11) figure 2 -& EP 2 662 971 A1 (MURATA MANUFACTURING CO [JP]) 13 November 2013 (2013-11-13) -----	1-5
A	US 2012/074812 A1 (FUJIMOTO KATSUMI [JP]) 29 March 2012 (2012-03-29) -----	1-11



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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

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

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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

"&" document member of the same patent family

Date of the actual completion of the international search

25 July 2014

Date of mailing of the international search report

06/08/2014

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Koskinen, Timo

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IT2014/000096

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2012137695 A1	11-10-2012	CN 103460592 A EP 2662971 A1 US 2013320807 A1 WO 2012137695 A1	18-12-2013 13-11-2013 05-12-2013 11-10-2012
EP 2662971 A1	13-11-2013	CN 103460592 A EP 2662971 A1 US 2013320807 A1 WO 2012137695 A1	18-12-2013 13-11-2013 05-12-2013 11-10-2012
US 2012074812 A1	29-03-2012	US 2012074812 A1 WO 2010150866 A1	29-03-2012 29-12-2010