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(71) Applicant: **DSM IP ASSETS B.V.** [NL/NL]; Het Overloon 1, NL-6411 TE Heerlen (NL).

(72) Inventors: **FITIE, Carel Frederik Constantijn**; P.O. Box 4, NL-6100 AA Echt (NL). **PASMANS, Peter Leonardus Elisabeth Maria**; P.O. Box 4, NL-6100 AA Echt (NL). **DUIS, Patrick Gerardus**; P.O. Box 4, NL-6100 AA Echt (NL). **JANSSEN, Robert Hendrik Catharina**; P.O. Box 4, NL-6100 AA Echt (NL).

(74) Agent: **PLOEG VAN DER, Antonius Franciscus M.J.**; P.O. Box 4, NL-6100 AA Echt (NL).

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(54) **Title**: SOFT MAGNETIC MATERIAL COMPOSITION AND COMPONENT MADE FROM THE MATERIAL

(57) **Abstract**: The invention relates to an electronic device comprising a magnetic component for enhancement of an magnetic field, wherein the magnetic component comprises a part made of a polymer bonded soft magnetic material composition (PBSMM composition), comprising a mixture of soft magnetic constituents comprising (A) a ferrimagnetic constituent and (B) a metallic ferromagnetic constituent, and comprising (C) a polymeric binder. The invention also relates to a magnetic connector for an electronic device, comprising a part made of PBSMM composition.

SOFT MAGNETIC MATERIAL COMPOSITION AND COMPONENT MADE FROM THE MATERIAL

The invention relates to an electronic device comprising a magnetic component, more particular to an electronic device comprising a first magnetic component for engagement with a magnetic field or for enhancement of a magnetic field. The magnetic field which is enhanced by, or in which the first magnetic component is engaged in, may be produced, for example, by a hard magnet, such as in a magnetic connector, or by an electromagnetic coil, such as in an inductor or in an electromagnet. In the electronic device according to the invention, the magnetic component comprises a part made of a polymer bonded soft magnetic material composition. The invention also relates to a magnetic connector for an electronic device for a power adapter connecting a laptop computer to a power supply, or for signal or data transfer, or for or a combination of power supply with signal or data transfer. More particularly the invention relates to an electromagnetic connector.

Soft magnetic materials are used extensively in power electronic circuits, as voltage and current transformers, saturable reactors, magnetic amplifiers, inductors, and chokes. These magnetic devices may be required to operate at only 50/60 Hz, or at frequencies down to direct current, or up to and over 1 MHz.

Electronic devices, such as laptop computers and cell-phones, typically comprise multiple connectors which are used for different purposes, such as connectors for DC power supplied from a transformer connected to a conventional AC power supply, further connectors for power supply to internal electronics on printed circuits boards, connectors for connecting such internal electronics for data transfer between the internal electronics as well as connectors for data transfer between different electronic devices. Many electronic devices do also make use of magnetic components, such as inductors, transformers and chokes. The magnetic components may be permanent magnets, or electromagnets, or may be based on soft magnetic materials. One application of such magnetic component is in magnetic connectors. Other examples are the use of magnetic materials as core material for inductors, transformers, chokes, etc. A magnetic connector relies on magnetic attractive force for maintaining contact. The magnetic attractive force may come from the interaction of two permanent magnets and /or electromagnets, but also from the interaction between a permanent magnet or electromagnet and an element made of a soft magnetic material.

Magnetic connectors are known, for example, from patent application US 2012/0178271. The magnetic connector described in US 2012/0178271 includes a plug and a receptacle. The plug and receptacle each have a magnetic element. The magnetic element on one or both of the plug and the receptacle can be a permanent magnet, which is preferably a permanent rare earth magnet, although electromagnets may also be used. A ferromagnetic element can be used for the magnetic element on the plug or receptacle that does not include a magnet. This magnetic element can be considered as a complementary magnetic element. When the plug and receptacle are brought into proximity, the magnetic attraction between the magnet and its complement, whether another magnet or a ferromagnetic material, magnetically couples the plug and the receptacle, and maintains the contacts in an electrically conductive relationship. The magnetic connector allows the plug to break away from the receptacle if the plug or receptacle is inadvertently moved (with sufficient force) while still connected. In a special embodiment of US 2012/0178271 the plug comprises a back plate made of a ferromagnetic material, such as steel. The receptacle has an attraction plate also made of a ferromagnetic material, such as steel. When the attraction plate of the receptacle is attracted to the magnets, the magnetic field lines travel through the steel attraction plate from one magnet to the other, completing the magnetic circuit and producing a strong attracting force. As mentioned in US 2012/0178271, in general, the surface area of two magnetically attracted halves determine the number of magnetic flux lines and therefore the holding force between them because the holding force is proportional to the contact area between the two magnetically attracted halves. Thus, to have a strong force holding the two magnetically attracted halves together, the two magnetically attracted halves need to be as large as possible. Because the connector is designed to be compact and have a low profile for fitting into a laptop or the like, the plates must give up a certain amount of material to produce openings. When the attraction plate and magnets are coupled, the magnetic attractive force can be limited because the flux density can saturate the narrower portions of ferromagnetic material in both the attraction plate and the back plate. The solution provided in US 2012/0178271 is to have more than two magnets within the connector.

An electromagnetic connector for an electronic device is described in US7351066, which is herein incorporated by reference. The electromagnetic connector described in US7351066 comprises an electrical plug and a receptacle relying on magnetic force from an electromagnet to maintain contact. The plug and receptacle can be used as part of a power adapter for connecting an electronic device, such as a

laptop computer, to a power supply. The plug includes electrical contacts, which are preferably biased toward corresponding contacts on the receptacle. The plug and receptacle each have a magnetic element. The magnetic element on one of the plug or receptacle can be a magnet or ferromagnetic material. The magnetic element on the other of the plug or receptacle is an electromagnet. When the plug and receptacle are brought into proximity, the magnetic attraction between the electromagnet magnet and its complement, whether another magnet or a ferromagnetic material, maintains the contacts in an electrically conductive relationship.

Another application of soft magnetic materials is in inductors. Inductors are widely applied in electronic filter circuits or as circuit element to temporarily store electrical energy in power electronics, such as, for examples, switch-mode power supplies and DC-DC converters used in Light Emitting Diode (LED) drivers. The core is generally made from soft magnetic materials, such as ferrite, to enhance the inductance of the inductor. The soft magnetic material is chosen to meet the requirements of the end-use, such as the current rating, the operation frequency range and operation temperature range. It is well known in the art that soft magnetic metals and alloys with a low resistivity can only be used in applications up to about 1 kHz. For applications above 1 kHz soft magnetic materials with a higher resistivity are applied, specifically mostly MnZn and NiZn ferrites.

Soft ferromagnetic materials, such as iron, and iron based steel, have a high permeability (μ) as well as a high saturation magnetization, a combination which leads to a higher magnetic attractive force in a given geometry with the counter permanent or electromagnet, but are not suited for use at high frequency due to Eddy current losses. Moreover, these ferromagnetic materials have a low resistivity, requiring special measures to prevent electrical short-circuitry and special measures to reduce Eddy current losses, such as use of laminated steel structures. Soft magnetic materials like ferrites have a higher resistivity and suffer less from major Eddy current losses at high frequency, but are generally much more expensive and have a lower saturation magnetization. Since data transfer typically occurs at high frequency, in the range of 1-10 MHz and, and has to become faster and faster, desirably up to 1 or even 10 GHz, there is need for materials with an improved balance in properties.

Therefore the aim of the present invention is to provide an electronic device comprising a magnetic component *for engagement with a magnetic field or for enhancement of a magnetic field*, wherein the magnetic component has improved permeability properties at high frequencies, as well as improved resistivity in combination with a high permeability and high saturation magnetization.

This aim has been achieved with the electronic device according to the invention wherein the magnetic component comprises a part made of a polymer bonded soft magnetic material composition, comprising a mixture of soft magnetic constituents comprising (A) a ferrimagnetic constituent and (B) a metallic ferromagnetic constituent, and comprising (C) a polymeric binder.

The effect of the mixture of the said constituents in the polymer bonded soft magnetic material composition (abbreviated as PBSMM composition) used in the electronic device according to the invention is a synergistic effect on the permeability, such that the permeability of the composition at high frequency is much higher than the weighted contribution of each of the two constituents. In preferred compositions the permeability can be even higher than the permeability of each of the two constituents alone. At the same time the composition shows a relative high resistivity, relatively close to that of a PBSMM composition based on the ferrimagnetic constituent (A), even in the presence of relative large amounts of the metallic ferromagnetic constituent (B), and a good saturation magnetization level. As a result thereof, the magnetic component allows for further magnetic field enhancement or efficient data transfer at higher frequencies.

This result is highly surprising since at lower frequencies, well below 1 MHz, there is no evident synergistic effect and the observed permeability for the mixtures is about equal to the calculated permeability based on a weight averaged contribution.

A soft magnetic material is generally understood to be a material that is demagnetized at zero applied magnetic field, but becomes magnetized under the influence of an applied magnetic field. A soft magnetic material is attracted by a magnet. The magnetization is temporarily and disappears again, when the magnetic field is removed.

The term soft magnetic material is known in the art and is distinguished from hard magnetic materials. Herein, soft magnetic materials are understood to be magnetic materials with a coercivity of less than 1000 A/m measured with the method according to IEC 60404-1:2000.

Soft magnetic materials are further described, for example, in the following handbooks: (1) Feynman, R.P., Leighton, R.B., Sands, M. *The Feynman lectures on Physics*; The New Millennium Edition, Basic Books: New York, 2010, Vol. 2, pp 37-1 – 37-13; describes Magnetic Materials; (2) Williams. B.W. *Power Electronics: Devices, Drivers, Applications and Passive Components*. McGraw-Hill; 2nd

edition, 1992; pp 617-679, describes Soft Magnetic Materials; and (3) Herzer, G. in *Handbook of Magnetic Materials*; Vol. 10. Buschow, K.H.J. Ed. Elsevier Science B.V.: 1997, pp 415-462, describes Nanocrystalline Soft Magnetic Alloys.

Typical values for the saturation magnetization of common soft magnetic materials are given in Table 1.

Table 1: Saturation magnetization of common soft magnetic materials

Material (class)	**Saturation magnetization (T)**	**Resistivity [(a)] (Ωm)**
$Fe_{49}Co_{49}V_2$ (alloy)	2.34	$2.20 * 10^{-7}$
Fe (metal)	2.15	$9.60 * 10^{-8}$
Co (metal)	1.82	$5.20 * 10^{-8}$
$Fe_{73.5}Cu_1Nb_3Si_{13.5}B_9$ (nanocrystalline alloy)	1.25	$1.35 * 10^{-6}$
$Ni_{80}Fe_{20}$ (alloy)	1.04	$5.50 * 10^{-7}$
Ni (metal)	0.61	$6.20 * 10^{-8}$
NeoSid, F02 (MnZn ferrite)	0.34	1
NeoSid, F5is (NiZn ferrite)	0.30	$> 10^2$
NeoSid, F1is (NiZn Ferrite)	0.39	$> 10^2$
Neosid F1ib (NiZn Ferrite)	0.34	$> 10^2$

(a) Resistivity values measured by DC method according to ASTM B193 – 02 (2014) for volume resistivities below 10^{-2} Ωm, ASTM D4496-13 for volume resistivities between 10^{-2} and 10^5 Ωm, ASTM D257-07 for volume resistivities of 10^5 Ωm and higher.

The saturation magnetization of the soft magnetic materials is measured according to IEC 60401-3 and IEC 62044 using the following basic measurement conditions and parameters:

- Ring-shaped sample
- Temperature 23 °C
- Sinusoidal excitation signal
- Excitation frequency of 50 Hz
- Maximum applied field strength as prescribed in Table 2 of IEC 60401-3.

The relevant classes of soft magnetic materials can be distinguished into ferromagnetic materials and ferrimagnetic materials.

A ferromagnetic material generally comprises a population of magnetic ions, being atoms with magnetic moments, wherein all of its magnetic ions add a positive contribution to the net magnetization. Examples of ferromagnetic materials include metals like iron, nickel, and cobalt; alloys of these metals with each other, or with other metals, such as nickel – iron alloy with a small percentage of copper and molybdenum, or manganese alloys, such as MnBi, MnSb and MnAs ; and iron based steel, for example steel with a few percent of silicon. Generally, the higher the iron percentage is, the higher the saturation flux and the higher the losses are.

A ferrimagnetic material generally comprises a population of atoms with opposing magnetic moments, wherein the opposing moments are unequal and overall a positive contribution to the net magnetization remains. This happens when the populations consist of different materials or ions (such as Fe2+ and Fe3+). Ferrimagnetism is exhibited by ferrites and magnetic garnets. The oldest known magnetic substance, magnetite (iron(II,III) oxide; Fe3O4), is a ferrimagnetic material. Examples of ferrimagnetic materials are YIG (yttrium iron garnet), cubic ferrites composed of iron oxides and other elements such as aluminum, cobalt, nickel, manganese and zinc, hexagonal ferrites such as PbFe12O9 and BaFe12O9, and pyrrhotite (chemical formula: Fe(1-x)S). Examples of ferrimagnetic cubic ferrites are γ-Fe2O3 (maghemite), FeOFe2O3 (=Fe3O4), NiOFe2O3 (=NiFe2O4), CuOFe2O3 (=CuFe2O4), MgOFe2O3 (=MgiFe2O4), MnOFe2O3 (= MnFe2O4) and Y3Fe5O12.

The constituent (A), as well as constituent (B), used for the preparation of the soft magnetic materials, is suitably a powder or a fibrous material. The particle size of such a powder or fibrous material may vary over a wide range. Suitably, the powder has a particle size distribution with particle size in the range of 50 nm to 2 mm, preferably in the range of 100 nm to 1mm, more preferably in the range of 1 µm to 100 µm. Herein nm is the abbreviation for nanometer, µm for micrometer and mm for millimeter. The particle size is herein defined as the X_{50} as measured by Laser Diffraction in liquid dispersion using the Fraunhofer diffraction model according to ISO 13320:2009.

In a preferred embodiment of the invention, the soft magnetic constituent (A) is a ferrite powder. The advantage thereof is that apart from a synergistic effect on the permeability, it contributes to a high resistivity and imparts a moderate saturation. Ferrite is naturally abundantly available and technically easily accessible.

The resistivity of ferrites and other ferromagnetic materials may vary over a wide range, generally from $1*10^{-1}$ Ωm to $1*10^{10}$ Ωm. Preferably, the soft

magnetic constituent (A) has a resistivity of at least $1*10^3$ Ωm, more preferably at least $1*10^5$ Ωm. The advantage thereof is that the composition has a very high resistivity, even for relative high loadings of the metallic ferromagnetic constituent (B). The resistivity is herein measured by the method according to ASTM B193 – 02 (2014) (Standard Test Method for Resistance of Electrical Conductor Materials) for volume resistivities below 10^{-2} Ωm, ASTM D4496-13 (Standard Test Method for D-C Resistance or Conductance of Moderately Conductive Materials) for volume resistivities between 10^{-2} and 10^5 Ωm and according to ASTM D257-07 (Standard Test Methods for DC Resistance or Conductance of Insulating Materials) for volume resistivities of 10^5 Ωm and higher.

Still more preferably the ferrite powder is a NiZn ferrite. The advantage thereof is that the composition has an even higher resistivity, or in the alternative that the composition can comprise more of the ferromagnetic component while still retaining a high resistivity.

In another preferred embodiment of the invention, the soft magnetic constituent (B) is a metallic iron powder or fibers. The advantage thereof is that it contributes high saturation and moderate to high magnetic permeability. More preferably, the constituent (B) is a metallic iron powder.

Most preferably a combination of NiZn ferrite and iron powder is used. The advantage thereof is that a high resistivity for the composite of the same order as the ferrite and a high saturation magnetization of twice that of the ferrite can be obtained.

The constituents (A) and (B) can be mixed in a ratio varying over a wide range. Already at a low amount of (A) there is an effect on the retention of the permeability of the composition at high frequency, compared to constituent (B) alone. From the other side, already at a low amount of (B) there is an increase in the permeability, compared to constituent (A) alone. Suitably, the constituents (A) and (B) are present in the following amounts: 10-80 wt.% of (A) and 20-90 wt.% of (B), wherein the wt.% is relative to the total weight of (A) and (B). Preferably, the polymer bonded soft magnetic material composition according to the invention, and any of the preferred embodiments thereof, comprises 25-70 wt.% of (A) and 30-75 wt.% (B), more preferably 30-60 wt.% of (A) and 40-70 wt.% (B). Herein the weight percentages (wt.%) are relative to the total weight of (A) and (B). The advantage of each of the constituents (A) and (B) being present in a weight percentage closer to 50 wt.% is an optimal combination of a high resistivity close to that of component (A), and a high saturation level close to that of component (B).

The part made of the polymer bonded soft magnetic material composition in the magnetic component according to the invention is suitably used as part of a magnetic connector or as core and/or embedding material for inductors, transformers, chokes, etc.

The polymer bonded soft magnetic material composition (PBSMM composition) composition as used in the invention comprises, next to the mixture of soft magnetic constituents (A) and (B), a polymeric binder (C). Herein the constituents (A) and (B) are dispersed within the polymeric binder (C). The advantage of the PBSMM composition is not only the synergistic effect on the permeability, but also that the composition has a higher resistivity. A high resistivity is even retained at a high loading of magnetic components comprising a large percentage of metallic ferromagnetic constituents. However, such high resistivity cannot be obtained with the metallic ferromagnetic constituent (B) alone. Moreover, the composition can be more easily processed into a shaped part.

The PBSMM composition suitably comprises any of the different particular or preferred of the composition or combinations of the constituents (A) and (B) as mentioned above. Particular preferred is the PBSMM composition, wherein (A) is a ferrite powder, and/or wherein (B) is a metallic iron constituent.

The polymer used as polymeric binder can, in principle be any thermoplastic or thermoset polymer. Suitably, the polymer binder is a polymer used for electrical or electronic components, and may for example be selected from the group consisting of epoxy resins, unsaturated polyester resins, polybutadiene / polyisoprene crosslinkable resins, polyimides, polyetherimides, bismaleimide resins, fluoropolymers, polyolefins, thermoplastic polyesters, thermoplastic copolyester elastomers, polyaryletherketones, polyphenylene oxides, polyphenylene sulphides, liquid crystal polymers, polyamides, polycarbonates and thermoplastic elastomers, as well as any mixtures thereof. Suitable polyamides include PA6, PA6,6, PA4,6, PA4,10 and polyphthalamides, as well as blends thereof and any copolyamides thereof. Suitable polyphthalamides include PA10T,PA9T and PA6T/6I, as well as (co) polyphthalamides and blends thereof. Suitable polyesters are for example, PET and PBT. For the polyolefines, PE, PP and copolymers thereof, amongst others, may be used. For the thermoplastic elastomers, suitably thermoplastic copolyester elastomers and thermoplastic copolyamide elastomers can be used.

Suitable thermoplastic elastomers include segmented block-copolymers comprising a soft block such as for example polyethylene glycol or

polytetrahydrofuran and a polyester hard block such as polyethylene terephthalate or polybutylene terephthalate.

Preferably, the polymeric binder (C) in the PBSMM composition comprises a thermoplastic elastomer. The advantage of using thermoplastic elastomers is that PBSMM compositions based on these polymers show higher ductility and offer the possibility to make soft magnetic materials with higher mechanical robustness. Suitably, the polymer binder comprises or is a thermoplastic copolyester elastomer or a thermoplastic copolyamide elastomer. This allows for injection moldable grades with a high content in soft magnetic constituents, while retaining a high level of ductility.

In another preferred embodiment, the thermoplastic polymer is chosen from a material that is reflow solderable, such as semi-crystalline polyamides with a melting temperature of at least 300^0C. This has the advantage that the magnetic component or part made of the soft magnetic material, can be reflow soldered, for example, to a printed circuit board (PCB).

The amount of the polymeric binder (constituent (C)) in the polymer bonded soft magnetic material composition may vary over a wide range and is suitably in the range of 8 – 40 wt.%, relative to the total weight of polymer bonded soft magnetic material composition. On a volume basis the polymeric binder (C) is preferably present in an amount corresponding with 30 – 80 volume %, more preferably in the range of 35 – 60 volume %, relative to the total volume of the PBSMM composition.

The amount of soft magnetic material in the PBSMM composition is suitably at least 30 volume % (vol.%), with respect to the total volume of the PBSMM composition. Preferably, the amount is at least 40 vol.%, more preferred at least 50 vol.%. The advantage of increasing the amount of soft magnetic material in the PBSMM composition is that the magnetic properties (e.g. relative magnetic permeability and saturation magnetization) of the PBSMM composition improve. The maximum amount of soft magnetic material in the PBSMM composition depends on the process of preparing a molded part. When the molded part is manufactured using injection molding, the maximum is around 80 vol.%, because above these amounts the flow behavior of the PBSMM composition will become insufficient for the injection molding process. When compression molding is employed, the maximum amount of soft magnetic material can be as high as 90 vol.%, or may be even higher.

The constituents (A) and (B) in the polymer bonded soft magnetic material composition are suitably present in a combined amount of 60 – 95 wt.%, more particular 70 - 92 wt.%, relative to the total weight of polymer bonded soft magnetic

material composition. This amount corresponds roughly with 22 – 78 volume %, respectively 30 - 68 volume %. On a volume basis the constituents (A) and (B) are preferably present in a combined amount corresponding with 25 – 80 volume %, more preferably in the range of 40 – 70 volume %, relative to the total volume of the PBSMM composition.

A higher filler loading is advantageous for achieving a higher magnetic permeability and saturation magnetization of the PBSMM composition.

The PBSMM composition may comprise further components. Such further components include auxiliary additives used in respectively thermoplastic polymer compositions and thermoset polymer compositions. These include stabilizers, processing aids, mold release agents, flame retardants, etc. To achieve the maximum load for the soft magnetic constituents, the amount of such further components is preferably kept limited.

The PBSMM composition used in the magnetic component according to the invention can be made by standard methods using standard equipment for making thermoplastic or thermoset polymer compositions, well known to the person skilled in the art. The PBSMM composition can be made by techniques as known in the art and include blending of the polymer with the soft magnetic material and optionally other components.

The PBSMM composition can be processed to make a shaped part, to be used as the magnetic component according to the invention or at least a portion thereof. For that purpose standard methods and standard equipment for molded parts from thermoplastic or thermoset polymer compositions, well known to the person skilled in the art, can be used. These include, for example, injection molding of thermoplastic polymer compositions. The polymer bonded soft magnetic material according to the invention is suitably used for a magnetic component according to the invention, such as a magnetic connector, or as core and/or embedding material for inductors, transformers and chokes, or as a part of a magnetic sensor.

The invention also relates to a shaped part, comprising at least a portion made from a soft magnetic material according to the invention, or of a polymer bonded soft magnetic material according to the invention, or any particular or preferred embodiment thereof. The shaped part may be an integral part made from the soft magnetic material according to the invention.

Advantageously, the shaped part is a part of an electrical connector for data transfer or power transfer, the part being able to magnetically engage with

another part of the connector, the other part comprising a permanent magnet or an electromagnet.

The shaped part can also be a core and/or embedding part for inductors, transformers, chokes, or a part of a magnetic sensor etc.

The invention also relates to a magnetic connector. A magnetic connector is a connector with a magnetic positioning and locking system, comprising two parts magnetically attachable to and removable from each other. The magnetic connector according to the invention comprises a first part made from a polymer bonded soft magnetic material composition as described herein above and a second part which comprises a permanent magnet or an electromagnet, with which the first part can engage. With engagement is herein understood that when the two magnetic components are brought into proximity, the magnetic attraction between the magnetic component and its complement, whether another magnet or a ferromagnetic material, ensures the attachment between the two components. The magnetic connector can be, for example, an electrical connector, a fluid connector, or a gas connector. The advantage of the magnetic positioning and locking system is that mechanical force for locking can be less or that a mechanical locking system is not needed anymore at all.

Preferably, the connector is an electrical connector with a magnetic positioning and locking system, comprising two parts magnetically attachable to and removable from each other, wherein each of the two parts include electrical contacts, which electrical contacts in the first part can engage with the electrical contacts in the second part in an electrically conductive relationship.

The magnetic connector suitably is a magnetic power connector and/or a data connector, such as a USB connector.

In a preferred embodiment of the invention, the magnetic connector is an electromagnetic connector, or part thereof. Herein the connector comprises an electromagnet magnet as a complement for the part made of the PBSMM material.

Suitably, the electromagnetic connector comprises an electrical plug and a receptacle relying on magnetic force from the electromagnet to maintain contact. The plug and receptacle can be used as part of a power adapter for connecting an electronic device, such as a laptop computer, to a power supply. The plug suitably includes electrical contacts, which are preferably biased toward corresponding contacts on the receptacle. The plug and receptacle each have a magnetic element. The magnetic element on one of the plug or receptacle can be the part made of the PBSMM material. The magnetic element on the other of the plug or receptacle is an electromagnet. When the plug and receptacle are brought into proximity, the magnetic

attraction between the electromagnet magnet and the part made of the PBSMM material maintains the contacts in an electrically conductive relationship.

The invention also relates to a magnetic inductor for an electronic device, wherein the magnetic inductor comprises a part made of a PBSMM composition comprising a mixture of soft magnetic constituents comprising (A) a ferrimagnetic constituent and (B) a metallic ferromagnetic constituent, and comprising (C) a polymeric binder. The polymer bonded soft magnetic material composition in the magnetic inductor is suitably a composition according to any of the embodiments as described herein above. The magnetic inductor according the invention suitably comprises a coil, wherein the inductor can comprise a core part made of the PBSMM material, and/or wherein the coil can be embedded in the PBSMM material. The PBSMM material will enhance the magnetic field produced by an electrical current through the coil. The advantage of the present invention is that more electromagnetic energy can be stored in the inductor.

Description of the drawings

Fig. 1 shows the relative permeability of 3 different polymer bonded soft magnetic material composition (PBSMM composition) compositions as a function of the frequency . All 3 compositions comprise 55 volume % of soft magnetic material and 45 volume % of polymer. The polymer in the compositions is a polyamide 6. The soft magnetic material consists of either iron powder (ACS 100.29), or NiZn ferrite (NeoSid F5is), or a mixture of iron and ferrite, in a 1/1 ratio, based on the volume. The picture shows that at low frequency, the permeability is roughly the weighted average of the contribution of each. However, at high frequency, at about 1 MHz, and above, the permeability is higher than the weighted average of the contribution of each, and in the range of about 2 – 10 MHz even higher than the permeability of each of the individual components.

The invention is further illustrated with the following example and comparative experiments.

Materials

Polyamide: standard grade PA6 for injection molding compositions (density 1.13 g/cm3)

Ferrite:	NiZn ferrite; Neosid F5is from the company NEOSID Pemetzrieder GmbH & CoKG, Germany (density about 5.35 g/ cm3)
Iron:	ACS 100.29 iron powder from Höganäs AB, Sweden (density 7.20 g/cm3)

Preparation of materials and molded parts

Polymer bonded soft magnetic material compositions from polyamide, ferrite and iron were made by melt mixing in a double screw extruder, and injection molded on a signal screw injection molding machine using standard conditions for polyamide-6 molding compositions.

The PBSMM composition were prepared using a twin-screw extruder by melt-blending polyamide 6 (PA6, pellets) and soft magnetic materials (powder) as listed in Table 2. Cylindrical rod cores (diameter 4.5 mm x L 100 mm) were prepared by injection molding as known in the art.

Measurement of initial magnetic permeability of polymer bonded soft magnetic material compositions as function of frequency

To determine the initial magnetic permeability of a material, the inductance of a cylindrical coil with circular windings is measured in two configurations: *i*) with a cylindrical rod core (diameter 4.5 mm x L 100 mm) made from the material under investigation and *ii*) without core material, *i.e,*, using an air core. The initial magnetic permeability is then calculated as

$$\mu_r = (L_m/L_{air}-1) * (A_{coil}/A_{air}) + 1$$

wherein L_m is the inductance of the coil with the core made from the material, L_{air} is the inductance of the coil with the air core, A_{coil} is the cross sectional area of the coil $1/4\pi D^2$, wherein D is the average diameter calculated as the average diameter of inner and outer diameter of the coil and A_{core} is the cross sectional area of the core. The inductance was measured as a function of frequency with a HP4275A frequency LCR meter. The coil was hand-made from a standard isolated copper wire with a total diameter of 2.6 mm and a copper cross section with a diameter of 1.4 mm; 32 windings were used; total length of the coil was 87 mm; inner diameter of the coil was 4.5 mm. The coil was connected to the LCR meter by means of HP type 16048 test leads. A maximum of 0.1 Volt was applied.

Measurement of magnetization (M) as function of applied field (H)

For measuring the M-H curves at 50 Hz a Brockhaus MPG200 system was used. The measuring cell, build by Brockhaus, had a coil with 1041 windings made by a Copper wire with a cross section of 3.15 mm * 1.12 mm. This Ellipsoid Sensor corresponds to the international standard IEC 404-7.

Measurement of saturation magnetization

The saturation magnetization is reported as the magnetization at an applied field strength of 100 kA/m and is obtained from the M-H measurements described above.

Resistivity of polymer bonded soft magnetic material compositions as function of frequency.

For determining the resistivity an alpha analyzer in combination with an active sample cell from Novocontrol was used. Samples were cut from plates and had a diameter of 40 mm and a thickness of 2mm. Each side of the sample was coated with gold using a sputtering technique. The sample was placed between two gold coated electrodes, these electrodes were placed in the sample cell. The sample cell was placed in a Quattro cryo chamber from Novocontrol for temperature control; liquid nitrogen was used to maintain a constant temperature and an inert atmosphere. The resistance was measured as a function of frequency (10^{-3} – 10^{4} Hz) at room temperature. Resistivity is calculated using the area and the thickness of the sample.

Table 2. Compositions in volume %, respectively weight %, and magnetic properties for Comparative Experiments A and B and Example I.

Constituents	CE-A	CE-B	EX-I
(wt.%)			
(A) Ferrite	0.0	85.0	35.7
(B) Iron	90.0	0.0	52.3
(C) PA	10.0	15.0	12.0
(Volume %)			
(A) Ferrite	0.0	54.5	27.2
(B) Iron	58.5	0.0	29.6
(C) PA	41.5	45.5	43.2
Initial Permeability at $3*10^{6}$ Hz	5.7	6.3	6.8

Resistivity at 10^{-3} Hz (Ωm)	$7.6 * 10^{-3}$	$4.7*10^{3}$	$1.9 * 10^{3}$
Saturation magnetization (T)	0.54	0.19	0.33

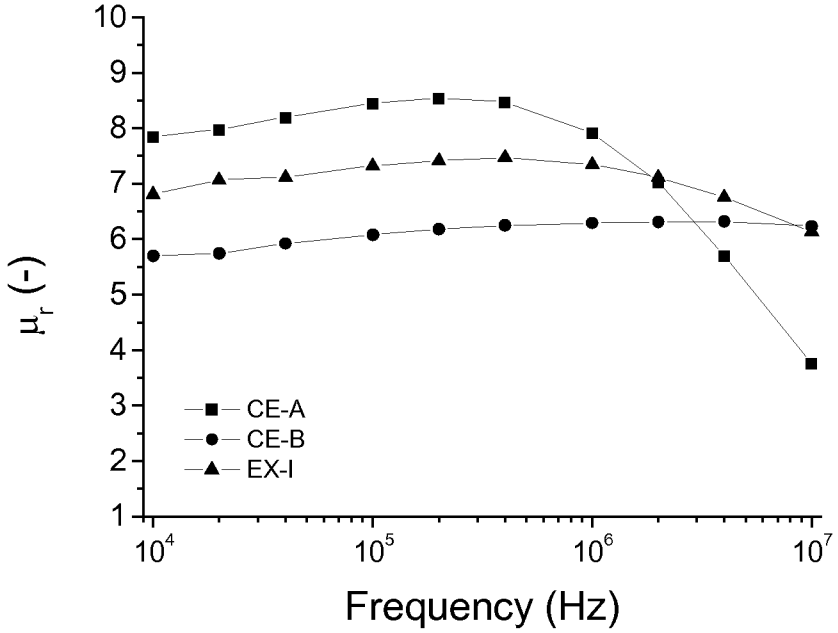
The results show that the permeability for Example I according to the invention, is higher than both Comparative Experiments A and B at $3*10^{6}$ Hz, while at the same time the resistivity of Example I is in the same order of magnitude as for the CE-B, and the saturation magnetization is much higher than that of CE-B.

CLAIMS

1. Electronic device comprising a magnetic component for engagement with a magnetic field or for enhancement of a magnetic field, wherein the magnetic component comprises a part made of a polymer bonded soft magnetic material composition, comprising a mixture of soft magnetic constituents comprising (A) a ferrimagnetic constituent and (B) a metallic ferromagnetic constituent, and comprising (C) a polymeric binder.
2. Electronic device according to claim 1, wherein (A) is a ferrite powder.
3. Electronic device according to claim 1 or 2, wherein (B) is a metallic iron powder or comprises metallic iron fibers.
4. Electronic device according to any of claims 1-3, wherein the polymeric binder is selected from the group of polymers consisting of thermoplastic elastomers, thermoplastic polyamides and thermoplastic polyesters, and any mixtures thereof.
5. Electronic device according to any of claims 1-4, wherein the polymer bonded soft magnetic material composition comprises 10-90 wt.% of (A) and 90-10 wt.% (B), wherein the weight percentages (wt.%) are relative to the total weight of (A) and (B).
6. Electronic device according to any of claims 1-5, wherein the polymer bonded soft magnetic material composition comprises 30-70 wt.% of (A) and 70-30 wt.% (B), wherein the weight percentages (wt.%) are relative to the total weight of (A) and (B).
7. Electronic device according to any of claims 1-6, wherein the polymer bonded soft magnetic material composition comprises 60 - 92 wt.% of the total amount of (A) and (B) and 8 - 40 wt.% of (C), wherein the weight percentages (wt.%) are relative to the total weight of polymer bonded soft magnetic material composition.
8. Electronic devise according to any of claim 1-7, wherein the magnetic component is a part of a magnetic connector, an inductor, a transformer, a choke, or a magnetic sensor.
9. Electronic devise according to any of claims 1-8, wherein the magnetic component is a part of a magnetic connector, preferably an electromagnetic connector.

10. Magnetic connector for an electronic device, comprising a part made of a polymer bonded soft magnetic material composition, the composition comprising a mixture of soft magnetic constituents comprising (A) a ferrimagnetic constituent and (B) a metallic ferromagnetic constituent, and comprising (C) a polymeric binder.
11. Magnetic connector according to claim 10, wherein the polymer bonded soft magnetic material composition is a composition as indicated in any of claims 2-7.
12. Magnetic connector according to claim 10, wherein the connector is an electromagnetic connector.
13. Magnetic inductor for an electronic device, comprising a part made of a polymer bonded soft magnetic material composition, the composition comprising a mixture of soft magnetic constituents comprising (A) a ferrimagnetic constituent and (B) a metallic ferromagnetic constituent, and comprising (C) a polymeric binder.
14. Magnetic inductor according to claim 13, wherein the polymer bonded soft magnetic material composition is a composition as indicated in any of claims 2-7.
15. Use of a magnetic connector according to any of claims 10-12 in a power adapter for connecting a laptop computer to a power supply, or in a data transfer connector or a combination of power supply with data transfer.

Figure 1



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/060378

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01R13/62 H01F1/26 H01F1/37
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)
H01F H01R

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

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X	WO 2007/035002 A2 (YAZAKI CORP [JP]; UNIV NAGASAKI NAT UNIV CORP [JP]; KIMURA SHIYUUICHI) 29 March 2007 (2007-03-29) page 20, line 20 - page 23, line 18 page 10, line 5 - line 19	1-15
X	US 2009/114437 A1 (TUEN LUNG-FAI [TW] ET AL) 7 May 2009 (2009-05-07) paragraph [0035]	1-15
X	EP 0 785 557 A1 (TOKIN CORP [JP]) 23 July 1997 (1997-07-23) page 5, lines 34-38; claims 14,15	1-15

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[X] Further documents are listed in the continuation of Box C.

[X] 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

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

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

"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	Date of mailing of the international search report
20 July 2015	03/08/2015

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Primus, Jean-Louis

2

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INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/060378

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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2

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International application No
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