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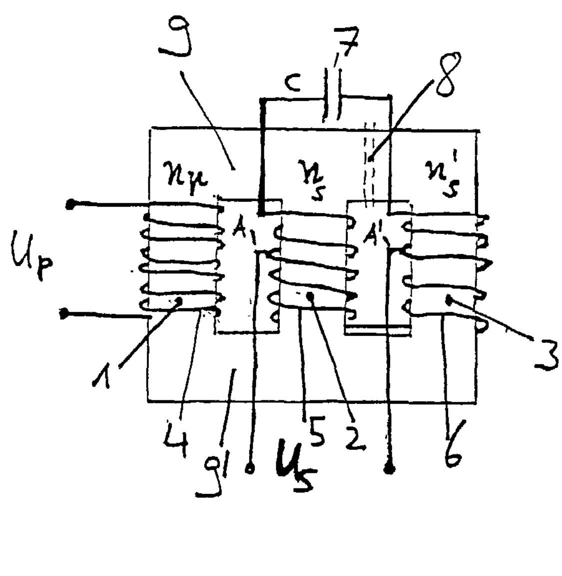
(54) Title: TRANSFORMER



(57) Abstract: The invention relates to a transformer including a first (1), a second (2) and a third (3) leg which are aligned in parallel and are magnetically connected, having at least a first primary winding (4) and at least two secondary windings (5, 6). Each of the windings are carried by a different leg, whereby the legs are arranged in a sequence and one of the secondary windings is located between the other two legs. The two legs are connected with a capacity (7) and thus form a resonance circuit. The magnetic connection between the two secondary windings differs from the magnetic connections between the primary and each of the secondary connections. The flux excited by the first secondary winding is anti-parallel to the flux excited by produced by the second secondary winding. A supply voltage can be supplied at the primary winding and the transformer provides a current and a voltage at the secondary windings.

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Transformer

Description

The invention relates to the field of power supplies, particularly to a transformers for supplying a stabilized voltage.

Power supplies are necessary to supply an electrical device with electrical power at a stabilized voltage which is different to the line voltage, e.g. 110 V or 230 V. A basic element of a power supply is a transformer transforming an input voltage to an output voltage. In common transformers, the output voltage is a fixed multiple of the input voltage with a factor given by the relation of the number of turns of a primary winding and the number of turns of a secondary winding which are magnetically coupled. Also, the voltage decreases for a increasing load at the secondary winding as the current is increased, too, and the secondary windings inherently comprise a resistor.

For applications in the field of welding, usual power supplies show the effect that the current through the light arc strongly depends on the distance of the electrode form the material to be welded. Especially for welding method with consuming electrodes, this requires for a very sensitive power control to avoid irregularities in the weld seam. Also, the weight and thus the need for core material of the transformers is high and should be reduced in view of portable welding devices.

Undesired influences of load and input voltage on the output voltage are usually compensated by an electronic controlling device measuring the output voltage and controlling the input voltage. If a decrease of output voltage is measured, the input voltage is increased or vice versa.

Further, high frequency components are produced, if the input voltage is provided by a chopper power supply. Typical Power supply applications therefore have the need for wave filtering in order to remove high frequency components.

Document WO 97/29494 describes an transformer with multiple taps at the secondary windings which are selectively connected on order to control the output voltage.

Another possibility to transform the AC output voltage by an rectifier to DC voltage and to control the DC voltage by means of Z-Diodes or similar devices in order to achieve a stabilized output voltage.

These techniques require a huge amount of controlling and stabilizing elements.

It is desirable to have a power supply with a reduced number of elements and preferable a transformer providing an output voltage that is widely independent from the load and the supply voltage level. Further it is desirable to have a transformer capable of wave forming and provides a current limitation

The invention therefore relates to an transformer according to claim 1 fulfilling the above mentioned object.

The invention relates to a transformers having a stabilized output voltage, whereby the stabilizing effect is inherently achieved by the electric and magnetic structure. The ouput voltage is stabilized by controlling the magnetic connection between at least a primary (input) winding and the secondary (output) windings.

At least primary winding, and at least a first secondary winding and a second secondary winding are each wound around one of three legs respectively and are magnetically connected by an upper with an air gap and by a lower yoke. A resonant circuit formed by the secondary windings and a capacitor provides a high saturation of the magnetic coupling between the secondary windings. The resonance is limited by the air gap which also controls the saturation as well as by a load current which is provided by the secondary windings to a connected load. If the behavior is mainly characterised be the influence of the resonance circuit, the inductivity related to the secondary windings forming a part of the resonance circuit appers to be highly increased. For varying conditions, i.e. varying load or varying input voltage at the at least one primary winding, the total flux in the secondary windings and therefore the output voltage at the secondary windings is maintained constant by controlling the saturation of the magnetic connection which is mainly depending on the resonance circuit for low loads and depending on the load for high loads. In other words, the magnetic connection between the primary winding and the secondary windings and thus the power transfer between the primary winding used as input winding and the secondary windings used as output windings is influenced by the load as the additional flux produced by load and the flux produced by the resonance circuit control the level of saturation in the magnetic connection. Also, the attenuation of the resonance increases in parallel with the load. This controlling behavior can be influenced by an air gap which has an direct influence on the magnetic connection.

In one embodiment, one primary winding is carried by a first leg, while at least two secondary windings are carried by two legs, respectively. The secondary windings are connected with a capacity thus forming a resonant circuit. The legs are magnetically connected at their respective ends by means of two yokes, whereby at least one of the yokes comprises an air gap between the respective legs carrying the secondary windings. With this embodiment, the stabilizing effect can be achieved with a minimum of magnetic legs.

With this embodiment, the stabilizing effect can be achieved with a minimum of magnetic legs. In a first range of load, the voltage is constant and therefore any influences of the input voltage or the load are compensated. In a second range with a higher load, the voltage rapidly decreases and thus provides for current limitation. This range of operation can be used for welding applications as the current is constant for a wide range and thus compensates for changes caused by varying distances between electrode and welding surface. Therefore the transformer provides a very stable arc without any additional control means and thus the weld seam is more regular in comparison with results achieved with common welding power supplies. Additionally, the amount of core material can be reasonably reduced in comparison to common welding devices assuming the same welding power.

Further, a wave forming effect is provided by the transformer according to the invention reducing high frequency distortions, e.g., if a chopped supply voltage is used. Also, the speed control of DC motors can be effected more easily without the need for costly rectifying devices.

A second embodiment comprises an additional leg and an additional primary winding. The two primary windings are located on two outer legs and the two secondary windings are located on the inner legs. The two primary windings are electrically connected and the secondary windings are electrically connected. This embodiment provides a symmetrical structure and provides constant output voltage at the primary windings over a wide range of input voltages supplied at the secondary windings.

Preferably, the secondary windings provide intermediate taps, providing a possibility to select the desired output voltage by choosing the number of turns of the secondary windings on both sides of the intermediate taps. Alternatively, the transformer comprises third and fourth secondary windings, whereby the first and the second windings form the resonant circuit together with a capacitor and the third and the fourth windings provide the output voltage. In this way, the two functions of the secondary windings can be separated.

Further, the secondary windings supplying the output voltage can be connected in series. In this way, a higher total output voltage can be achieved. Also, the secondary windings can be connected in series, whereby the inductivities of the respective secondary windings add together. Thus, a lower capacity value can be used for a resonance with the desired frequency, i.e. the supply frequency, e.g. 50 or 60 Hz. For an embodiment of the invenntion being supplied by a chopper supply and therefore with a high frequency voltage, the values of the capacitor as well as the values of the inductivities provided by the secondary windings used for the resonance circuit can be reasonably decreased in comparison to applications with 50 / 60 Hz.

The magnetic connection of the legs preferably is provided by two yokes, one for each side of the legs. Theses yoke can comprise an air gap or a magnetic material causing a different quality of magnetic connection between the legs carrying the secondary legs and the magnetic connection between the other respective legs. In this way, the level of saturation and the transformer characteristic caused by the saturation can be controlled easily. Also, the transformer can be manufactured in a standard process.

The winding direction of all windings can be the same. This also simplifies the manufacture process of the transformers.

Preferably, two primary windings are connected in series. This reduces the number of necessary turns for a given output voltage with a given output voltage at the secondary windings.

Advantageously, the magnetic connection between the legs carrying the windings which form a part of at least one resonance circuit provide a magnetic leakage flux and / a ferromagnetic loss which both can be used to control the attenuation of the resonance circuit and therewith its behavior and influence on the stabilizing characteristics of the transformer.

Preferably all primary windings and all secondary windings have the same number of turns, respectively. This provides a complete symmetrical structure and allows for a simplified production process.

In order to influence the magnetic connection and the saturation in the magnetic material of the transformer, the cross the legs carrying the secondary windings can differ from sections of the legs carrying the primary windings. This also allows for a control the saturation and therewith the characteristics of the transformer.

An embodiment comprising an additional primary winding would allow for a more flexible connection of the transformer with an electrical power supply network.

Short Description of the Figures

Fig. 1a shows a first embodiment of the transformer according to the invention having three legs comprising a primary winding and two secondary windings.

Fig. 1b shows a second embodiment of the transformer according to the invention having four legs comprising two primary and two secondary windings

Fig. 2 shows a third embodiment of the transformer according to the invention in which two secondary windings are used for a resonance circuit, each comprising an intermediate tap.

Fig.3 shows a forth embodiment of the transformer according to the invention in which two secondary windings form a resonance circuit and another two windings are used as output winding.

Fig. 4 shows the behavior of the output voltage depending on a varying load for three transformers according to the invention having different air gap widths.

Fig. 5 shows the wave filtering and wave forming characteristics of one embodiment of the invention.

Fig.6 shows the output voltage in dependency of a varying input voltage for different load situations.

Fig. 7 shown the output current characteristics dependent on a variable load resistance

Detailed description of the Figures

Figure 1a shows a circuit diagram of the first embodiment of the stabilized transformer according to the invention. The transformer comprises three legs 1, 2, 3 which are parallel to each other and magnetically connected by two yokes 9, 9'. This structure can be made of an usual EI- core. Two secondary windings 5, 6 are electrically connected with a condenser 7 thus forming a resonance circuit having two inductivities which are represented by the secondary windings, each located on a different leg. The magnetic connection between the legs carrying the secondary windings 5, 6 comprises an air gap 8. A primary winding 4 is carried by the first leg 1 while the secondary windings 5, 6 are carried by the legs 2 and, respectively. One of the legs carrying the secondary windings 5, 6 is arranged as center leg of the EI-core.

Figure 1b shows a circuit diagram of the second embodiment of the stabilized transformer according to the invention. The transformer comprises four legs 10, 12, 14, 16 which are parallel to each other and are magnetically connected. The legs 10 - 16 have the form of a rod are of the same length. Each leg has two ends, an upper end and a lower end, all upper ends are magnetically connected by an upper yoke 50 perpendicular to the legs and all lower ends are connected by a lower yoke 52 which is also perpendicular to the legs 10 - 16 and thus parallel to the upper yoke 50 . Regarding the legs 10 - 16, it can be distinguished between two outer legs 10, 12 and two inner legs 14, 16.

A first primary winding 20 with a first number of turns n_p is wound around a first outer leg 10 and a second primary winding 22 having a second number of turns n_p' is wound around the second outer leg 12. Both primary windings 20, 22 are electrically connected in series and an input voltage U_p can supplied to the primary windings 20, 22. Driven by this input voltage U_p, the first primary winding 20 generates a magnetic flux in the first outer leg 20 which is anti-parallel to the magnetic flux produced by the second primary winding 22 in the second primary leg 12. It would also be possible to connect both primary windings anti- parallel, which would lead to the same effect. Alternatively, it would be possible to connect two primary windings in parallel, whereby the primary windings comprise winding directions, which are opposite to each other.

A first 30 and a second 32 secondary winding are wound around both inner legs 14, 16, respectively, having the same winding direction. The secondary windings 30, 32 are connected in parallel to each other, on one side by a direct electrical connection and on the other side of the secondary windings by a capacitor C, 40. The value of the capacitor C is selected in order to form a resonance circuit with the first and second secondary windings at the frequency of the output voltage, for example the rated (supply) frequency 50 Hz.

When the input voltage Up is supplied to the first and second primary windings (20, 22), which are serially connected, each of them introduced a magnetic flux in the first (10) and the second (12) outer leg, respectively. Due to the magnetic connection provided by the upper (50) and the lower yoke (52) and the electrical connection, the fluxes produced by the input voltage are added in the outer legs (10, 12). Also, the flux induced by current floating through the secondary windings (30, 32), is added in the inner legs (14, 16), when a load is applied to the secondary windings.

Between the first and the second inner leg (14, 16), the upper yoke (50) comprises a section having an air gap (60). At this section, the magnetic guidance differs from magnetic guidance of the remaining yoke. Magnetic guidance denotes the effective permeability and the therefore the ability of the magnetic connection, i.e. the yokes, to concentrate the magnetic flux in the material. This ability is strictly depending on the effective permeability of the yoke being dependent on the magnetic permeability, the geometry of the magnetic connection and by effects causing a leakage field, e.g. air gaps.

The difference of magnetic guidance and therefore the effective permeability can also be caused by a yoke section having a wider or narrower cross section. Especially a tapering region of the yoke causes a higher flux density and therefore, the material guiding the magnetic flux is at an higher saturation level than the remaining yoke material. Also, a section comprising material having a lower permeability or magnetic material comprising a lower level of maximum saturation would cause the desired dependency of the magnetic connection on the flux located in the yoke.

When input voltage is applied to the two primary windings (20, 22) a electromagnetic force EMF is induced in the first (30) and the second secondary winding (32) which are adjacent to the primary windings (20, 22).

Some current is produced in the first (30) and in the second (32) secondary winding and in the capacitor C, 40, by the EMF and therefore an additional self-EMF is induced in the two secondary windings 30, 32. This self-EMF is constructively added to the EMF induced by the current floating through the primary windings 20, 22 and thus the voltage provided at condenser C, 40 is additionally increased. If the voltage provided at condenser 40 is increased, the current applied to the secondary windings (30, 32) is increased, leading to a resonance rise of the additional self-EMF. The limitation of the self-EMF depends on the saturation characteristics of the magnetic material of the yokes (50, 52) (and the legs) which are not linear to the inducing magnetic field. In this way, the voltage Us provided by the secondary windings 30, 32 is not linear to the input voltage Up which is provided at the primary windings 20, 22, and further the relation of the input and output voltages is characterised by the saturation process in which the resonance rise of the resonance circuit compensates for varying loads at the secondary (i.e. output) windings and for varying input voltages applied to the primary windings.

In the embodiment shown in Fig. 1b, the number of windings in the first primary winding n_p is equal to the number of windings of the second primary winding n_p'. The number of windings n_s of the first secondary winding is equal to the number of windings of the second secondary winding n_s'. In this example, $n_{p'} = n_s$ is assumed for sake of convenience.

The first 30 and the second secondary winding 32 represent two inductivities which are connected in series. Therefore, their inductivity is added and connected in parallel to capacitor C,

40. The inductivity depends on the geometry of the secondary windings 30, 32, the respective legs 14,16 as well as on the numbers of turns n_s and n_s; further, the inductivity depends on other effective permeability which varies with the degree of saturation of the magnetic material of the legs 14, 16. Also, the material of the yokes 50, 52 is saturated for high magnetic fluxes. The combined inductivity of the first and second secondary windings 30, 32 and the value of capacitor C, 40, is chosen to be in resonance for the desired frequency of the output voltage Us, for example 50 Hz. Assuming the input voltage Up comprising considerable frequency portions nearby or at the resonance frequency, the secondary windings will be excited to a resonance at this frequency. The amount of energy is exchanged between the capacitor 40 and inductivity of the secondary windings 30, 32 is resonance rised and limited by the maximum magnetic flux at which a complete magnetic saturation of the magnetic material at the yoke section having the highest flux density is reached. Further, the resonance is attenuated by the load occurring at the output of the secondary windings 30, 32 and by losses due to magnetic leakage.

Assuming an input voltage Up applied at the primary windings 20, 22 and the load occurring at the second windings 30, 32 shall be neglectable at the beginning. In this case, that magnetic connection, represented by the upper and lower yoke, is saturated by the nearly unattenuated resonance circuit formed by the secondary windings 30, 32 and the capacity 40.

The resonance frequency of the resonance circuit should be at or nearby the frequency of the input voltage supplied at the primary windings and therefore the value of the capacity 40 (or the inductivity of the secondary windings) should be selected to fulfill this condition. The output voltage Us at the secondary windings 30, 32 is limited by the maximum degree of saturation of the yokes 50, 52, especially of the section 60 between both inner legs 30, 32. With an increased load, the resonant circuit is attenuated by the load and therefore has a decreased influence on the saturation. The saturation is increasingly influenced by the high flux being introduced by the (load) current floating through the secondary windings 30, 32 (and the load). Both effects compensate for each other and consequently a de- or increasing load is balanced by the in- or decreasing influence of the resonance circuit resulting in a nearly constant output voltage Us at the secondary windings 30, 32 for a varying load.

The behavior curve of the output voltage Up depending on a varied load (and therefore depending on the output current) is influenced by additional air gaps 60, 260, 260' in one 50 or in both yokes 50, 52, taking into account the magnetic characteristics of the material as well as the ferromagnetic loss.

In Fig.2, a third embodiments of the transformer according to the invention is shown. It also comprises four legs 110 - 116 connected with two yokes 150, 152 and comprises two primary windings 120, 122 which are serially connected and arranged symmetrically at the outer legs (110, 112). Further, two secondary windings also arranged symmetrically at the inner legs being connected in series by a capacitor 140 thus forming an resonance circuit. Between the inner legs 114, 116, one of the yokes 150are interrupted by an air gap 160.

In contrast to the embodiment shown in Fig.1, the secondary windings 130, 132 each comprise an intermediate tap 170 at which the output voltage Us is supplied. The resonance circuit is formed by the complete secondary windings 130, 132 and the capacity 140, whereas the output voltage Us is provided by only a part of the secondary windings 130, 132, respectively. The relationship between the windings comprised by this part of the respective secondary windings and the number of turns of the total secondary windings 130, 132 gives a possibility to determine the relation between the input voltage Up and the constant output voltage Us. Also, the influence of the resonance circuit on the balancing between attenuation of the resonance circuit and saturation of the yokes 150, 152 can be influenced on this way.

In Fig. 3, a fourth embodiment of the transformer according to the invention is illustrated. This embodiment has a similar four-legged structure as the embodiments of Figs. 1 and 2, but the secondary windings 230, 232, 234, 236 have been divided into two functional parts which are not electrically connected. The first functional part is the resonance circuit formed by the capacitor 240 and first and second secondary windings 230, 232. The second functional part of the secondary windings is comprised by third and fourth secondary windings,234 and 236, both symmetrically arranged at two inner legs 214, 216. These third and fourth secondary windings 234 and 236, are electrically connected and provide an output voltage Us. With this structure, the output voltage can be selected absolutely independent from the characteristics of the resonance circuit, which is formed by the first and second secondary windings 230, 232 and capacity 240. The number of turns of all windings has been chosen to be symmetrical, i.e. np = np', ns = ns' and no = no'. The number of turn for at least one of the windings can also be asymetrical, depending on the application and desired behavior characteristics. Between the inner legs 214, 216, the yokes 250, 252 each comprise an air gap 260, 260' providing the desired influence on saturation characteristic and on attenuation of the resonance circuit.

Fig. 4 is a chart illustrating the influence of the width of an air gap. The dependencies between secondary output voltage Us, which is provided by the secondary windings 30, 32, 130, 132, 230, 232 of the transformer according to the invention and the current Is floating through a load connected with the secondary windings is shown. For a first range of output current Is, which is denoted as (A) the voltage remains nearly constant at the voltage value Uc. In a second range (B), the output voltage Us rapidly breaks down for a small increase of output current Is. This behavior can be used for short circuit protection or for overload situations as well as for a constant current supply with a working point in range (B), e.g. for welding machines.

The behavior of the transformer regarding the output voltage Us and output current Is in range (B) can be interpreted as the behavior of a constant current source. Especially with regard to curve (2), the current remains nearly constant at a value Ic while the voltage varies over a wide range between Us and 0. The transformer according to the invention operating at this working range or having a working point at this steep decrease of output voltage U2 is especially accomodated for welding applications. With a constant current Ic provided at the output of the transformer, the electric arc is maintained stable and thus less sparks are produced and the welding result is very homogeneous. In general, for power supply applications using an electric arc at varying loads, this characteristic of the transformer according to the invention provides very stable output characteristics. The characteristics of this second (shut down or constant current source) area (B) can be selected by amending the width of the air gap 60, 160, 260, 260' whereby curve (1) shows the behavior for a large air gap, e.g. 3 mm, curve (2) shows the constant current characteristics for a narrow air gap, e.g. 2 mm. and curve (3) shows the characteristics for a very small air gap, e.g. 0.5 mm. It is to be noted that the core structure of curve (1) introduces a higher amount of magnetic leakage flux than the core structures of curve (2) or (3) for a total flux comprised by the respective yokes. Therefore, the core structure of curve (1) has a higher influence on the attenuation of the resonance circuit as the magnetic leakage flux forms a major part of the attenuation effects on the resonance circuit. Also, the higher leakage flux for reasonable loads influences the magnetic connection between respectively opposed primary and secondary windings, 20, 36, rsp. 22 and 34 and therefore has an impact on the stabilized output voltage for high load situations.

In the case of neglectable load connected with the secondary windings 30, 32, the stabilized output voltage at the secondary windings is defined by the maximum saturation of the magnetic material and the magnetic leakage flux while an increasing load attenuates the resonance circuit keeping the voltage constant by the decreasing balancing effect between the resonance circuit and the saturation (i.e. the magnetic connection) of the yoke section between the two inner legs 14, 16.

As shown in Fig. 5, the usage of a resonance circuit also enhances the frequency stability of the transformer combined with a wave forming feature as the resonance circuit has the characteristics of a band pass filter. The wave forming feature allows a sinus curve at the output of the transformer, which is nearly independent from a symmetrical input wave form or the load at the secondary windings. Any symmetrical waveform supplied at the input Uin, (i.e. the primary windings), is formed and as result, the output voltage Uout of the transformer comprises a sinusoidal form.

Fig. 6 shows the output voltage characteristics of the transformer according to the invention. The curves show the dependency of the voltage U2 at the secondary windings on the voltage supplied at the primary windings 20, 22, which is denoted as U1. When the load connected with the secondary windings 31, 32 is neglectable and the input voltage supplied to the primary windings 20, 22 reaches a certain value, which is denoted as (b), the voltage at the secondary windings reaches a limit value, denoted as (d), which is directly related to the saturation limit of the magnetic circuit. If the supply voltage at the primary windings increases above (b), an electromagnetic force is induced in one of the secondary winding 30 adjacent to the respective primary winding 20 according to the increased value of the voltage at the primary windings 20,22. This electromagnetic force is equal to the resultant vector of the two electromagnetic forces induced in the concerned secondary winding 30 by the adjacent primary winding 20 and the distant primary winding 22. For the other secondary winding 32, this process is provided in a symmetrical manner in the leg 16 around which the other secondary winding 32 is wound, induced by the flux of the respective adjacent primary winding 22 and by the flux of the respective distant winding 20. It is to be noted that the flux induced in an inner leg (e.g. 14) by the respective adjacent primary winding (e.g. 22) is always higher or at least different than the flux induced by the respective distant winding (e.g. 20) due to the air gap 60 between the inner legs 14, 16. As described above, any means capable of decreasing the magnetic guidance can be used in the yoke sections between the two inner legs 14, 16.

Consequently, a compensation between saturation produced by the load current at the secondary windings and saturation produced by the resonance circuit is established. Therefore the output voltage is stabilized at a nearly constant level (c) .. (d), while the input voltage at the primary windings can vary on a wide range (b) .. (a).

Due to the reasonable current in the resonance circuit formed by the secondary windings 30, 32 and C, 40, the output voltage at the secondary windings (30, 32) is provided at a constant value as the current in the resonance circuit having a phase difference of nearly + 90° to the phase of the current through the load has a higher level than the load current at a small load.

Reducing the input voltage U1 would lead to less magnetic flux and thus to a lower level of saturation regarding the magnetic connection 50, 52, 60. A lower level of saturation causes a better connection at the yoke section 60 between the two inner legs 14, 16 as well as a higher current oscillating in the resonant circuit as the resonant circuit is less attenuated. Due to this, the level of saturation is increased until the increased attenuation by saturation is in balance with the lower flux introduced by the primary windings 20, 22 due to the lower input voltage. This balancing effect leads to a stable output voltage, which is in wide ranges independent from the input voltage.

Also shown in Fig.6 is the dependency between the input voltage and the output voltage for different load situations. Curve 1 shows the dependency between U1 and U2 for a neglectable load, Curve 2 shows the dependency between U1 and U2 for a reasonable load and curve 3 shows the dependency for a high load which is higher the loads referring to curves 1 and 2. As described above, a certain input voltage U1 = b, corresponding to the output voltage U2 = d, a balanced situation is reached and for increased voltages , the output voltage remains nearly constant. It is to be noted that for a wide range b..a of input voltage U1, the input voltage U2 is varied over a small range d..c, only. The range in which the output voltage U2 is nearly constant, starts at a minimum input voltage U1 that depends on the load connected to the input (i.e. respective secondary windings) of the transformer. For a high load (curve 3), this minimum input voltage is higher than the minimum voltage for a low (curve 2) or neglectable (curve 1) load connected to the secondary winding.

Fig. 7 illustrates the behavior of the transformer according to the invention for varying loads showing a diagram of the input current I1 which is applied at the primary winding(s) and the output current I2 produced at the secondary windings for a varying load R.

For high loads, equivalent to R in the range of 0 .. Rr, a stable current Is is provided at the output. This corresponds to the "overload" case shown in Fig.4, range (B). For loads with a resistance larger than Rr, the current is continuously decreasing. Even if not shon in this diagramm, the corresponding output voltage at the primary winding(s) is constant. The range for R > Rr is equivalent to the range (A) in Fig. 4. For a better understanding, of the characteristics of the transformer, Fig. 7 should be regarded in connection with Fig. 4, whereby Fig. 4 shows the output voltage characteristics and Fig. 7 shows the output current characteristics for a varying load (i.e. for a varying output current).

The core of the transformer can comprise laminated, sintered or die casted magnetic material which saturates for high magnetic fluxes. Materials having different saturation characteristics can be provided for different parts of the transformer, i.e. a material 1 for the inner legs, a material 1' for the outer legs, a material 2 for the magnetic connection between both inner legs, referring to an embodiment with four legs. Magnetic materials such as Permalloy or other ferrite materials can be used and may be selected depending on the applied frequency range. The transformer according to the invention can also be used for high frequency applications, e.g. with a chopper power supply as the wave forming characteristics of the transformer assure a sinusoidal output wave form. In the case of high frequency input and output voltages, the core material used for legs and yokes can be selected accordingly. The core section of the core is preferably constant and can be squared, round or of similar form. The air gap can be formed by a yoke section with a reduced length leaving out a gap and thus influencing the magnetic connection. Also, ferromagnetic materials or a yoke section with a reduced cross section can be used instead of or in combination with the air gap in order to achieve the desired magnetic properties.

In the shown embodiments, only one capacitor is used. It is also possible to use more than one capacitor in combination with one or more secondary windings. The capacitor(s) and the secondary winding(s) form a resonance circuit which can be done by a parallel or serial connection or an appropriate combination thereof. Having more than one capacity and thus more than one resonant circuit, the respective resonant frequencies can differ from each other while the resonant circuits can oscillate at least partly independently.

Also, magnetic materials comprising a magnetic hysteresis can be used for attenuating the resonance circuit, thereby transforming parts of energy oscillating between capacitor and inductivity into magnetic loss and therefore into heat. Further, the copper resistance of the windings can lead to a substantial loss of oscillating energy in the resonance circuit and has also to be taken into account when the attenuations are regarded, which have an influence on the resonance circuit.

The primary and / or the secondary windings can comprise a number of intermediate taps to simplify an adjustment of the transformer according to varying voltage or load conditions and according to different applications.

Pyongyang Technical Trading Centre

Transformer

Claims

1. A transformer comprising :
at least a first (1) , a second (2) and a third (3) leg, all legs being essentially parallel aligned to each other,
at least a first (4) primary winding,
at least a first (5) and a second secondary winding (6), and
at least a capacitor (7), wherein
at least the first primary winding (4) is wound around the first leg (1),
at least the first secondary winding (5) is wound around the second leg (2),
at least the second secondary winding (6) is wound around the third leg (3),
and
the capacitor (7) being connected to at least one winding wound around the second leg (2) and to at least one winding wound around the third leg (3) forming a resonance circuit,
wherein
the first leg (1), the second leg (2) and the third leg (3) are arranged in this sequence and magnetically connected by at least an upper (9) and a lower (9') magnetic connection connecting the respective ends of the legs,
the first (5) and second (6) secondary winding being electrically connected such that a flux excited by the first secondary winding (5) in the second leg (2) is anti-parallel to a flux excited by the second secondary winding (6) in the third leg (3),
the secondary windings (5, 6) providing at least one output voltage, and

at least one of the upper (9) or lower (9') magnetic connection comprising a section (8) located between the second (2) and the third (3) leg having a magnetic guidance different to the magnetic guidance of the magnetic connection between the first and the second leg.

2. The transformer according to claim 1, comprising :
at least a first (14) and a second (16) inner leg and a first (10) and a second (12) outer leg, all legs being essentially parallel aligned to each other,
additionally at least a second (22) primary winding, wherein
at least the first primary winding (20) is wound around the first outer leg (10),
at least the second primary winding (22) is wound around the second outer leg (12),
at least the first secondary winding (30) is wound around the first inner leg (14),
at least the second secondary winding (32) is wound around the second inner leg (16), and
the capacitor (40) being connected to at least one winding wound around the first inner leg (14) and to at least one winding wound around the second inner leg (16) forming a resonance circuit, wherein
the first outer leg (10), the first inner leg (14), the second inner leg (16) and the second outer leg (12) are arranged in this sequence and magnetically connected by at least an upper (50) and a lower (52) magnetic connection connecting the respective ends of the first and second inner and outer legs,
the first (20) and second (22) primary winding being electrically connected such that a flux excited by the first primary winding (20) in the first outer leg (10) is anti-parallel to a flux excited by the second primary winding (22) in the second outer leg (12), and
at least one of the upper (50) or lower (52) magnetic connection comprising a section (60) located between the first (14) and the second (16) inner leg having a magnetic guidance different to the magnetic guidance between each of the outer legs and the adjacent inner leg, respectively.

3. Transformer according to one of the preceding claims, wherein
at least one of the secondary windings comprises an intermediate tap (A, A'; 170) at which the output voltage is provided.

4. Transformer according to claim 1 or 2, comprising a third secondary winding (234) wound around the first inner leg (214) and a fourth secondary winding (236) wound around the second inner leg (216) which are electrically connected that a flux excited by the third secondary winding (234) in the first inner leg (214) is anti-parallel to a flux excited by the fourth secondary winding (236) in the second inner leg (212), the third and fourth secondary winding providing one of the at least one output voltages and the first and second secondary winding (230, 232) are connected electrically with the capacitor (240) thus forming the resonant circuit.

5. Transformer according to one of the preceding claims, whereby the windings providing one of the at least one output voltages are connected in series or in parallel.

6. Transformer according to one of the preceding claims, whereby the capacitor (40) and the first and second secondary windings are connected in series forming the resonance circuit.

7. Transformer according to one of the preceding claims, whereby at least one of the upper (50) and a lower (52) magnetic connections comprise a yoke having an air-gap, a section with a cross section different to the remaining yoke, a material having a permeability different to the remaining yoke and / or a saturation dependency on the flux in the section different to the remaining yoke, whereby the section (60) is located between the legs carrying secondary windings (14, 16; 5, 6).

8. Transformer according to one of the preceding claims, the magnetic connection between the legs carrying secondary windings (14, 16; 5, 6) having a dependency on a load connected to at least one of the secondary windings supplying the output voltage and on an input voltage which is supplied at least one of the primary windings (4; 20, 22).

9. Transformer according to one of the preceding claims, the resonant circuit (40, 30, 32) forming an active element, thus not only depending following to an input current or an input voltage applied to the at least one of the primary windings (4; 20, 22).

10. Transformer according to one of the preceding claims 2 to 10 with one first (20) and one second (22) primary winding being connected serially or in parallel.

11. Transformer according to one of the claims 2 to 10, whereby all primary windings have the same winding direction and / or all secondary windings have the same winding direction.

12. Transformer according to one of the preceding claims comprising at least one magnetic connection between the legs (5, 6; 14, 16) carrying secondary windings providing a magnetic leakage flux and / or a ferromagnetic loss .

13. Transformer according to one of the claims 2 to 12, wherein at least two primary windings (20, 22) comprise the same number of turns (n_p, n_p') and / or at least two secondary windings (30, 32) comprise the same number of turns (n_s, n_s').

14. Transformer according to one of the preceding claims, wherein the legs (2, 3; 14, 16) carrying secondary windings have a cross section area different to the cross section area of at least one leg (1; 10, 12) carrying a at least one primary winding.

15. Transformer according to one of the preceding claims, wherein at least one additional primary winding is wound around one of the inner legs (14, 16) and electrically connected with the first and second primary winding (20, 22).

16. Electrical device comprising a transformer according to one of the preceding claims.

17. Electrical device according to claim 16, whereby the device comprises a welding machine, a electric furnace or a electrical motor speed control device or an other devices used for current stabilization, voltage stabilization, and / or wave filtration.

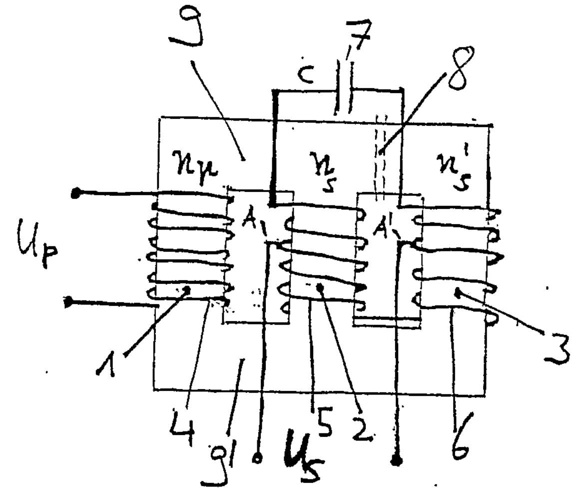


Fig. 1a

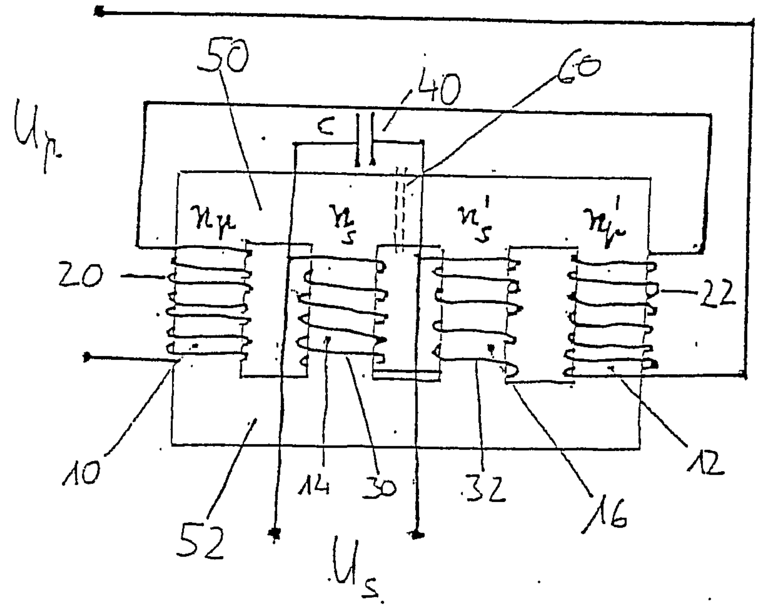


Fig. 1b

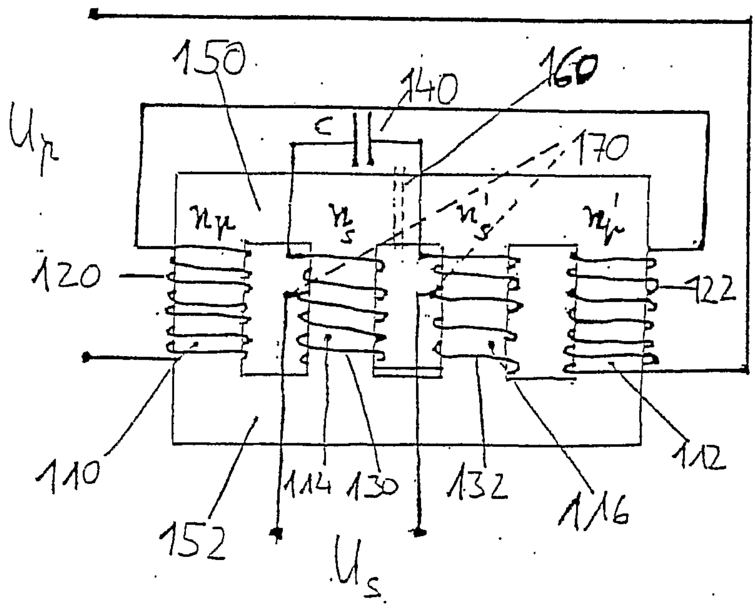
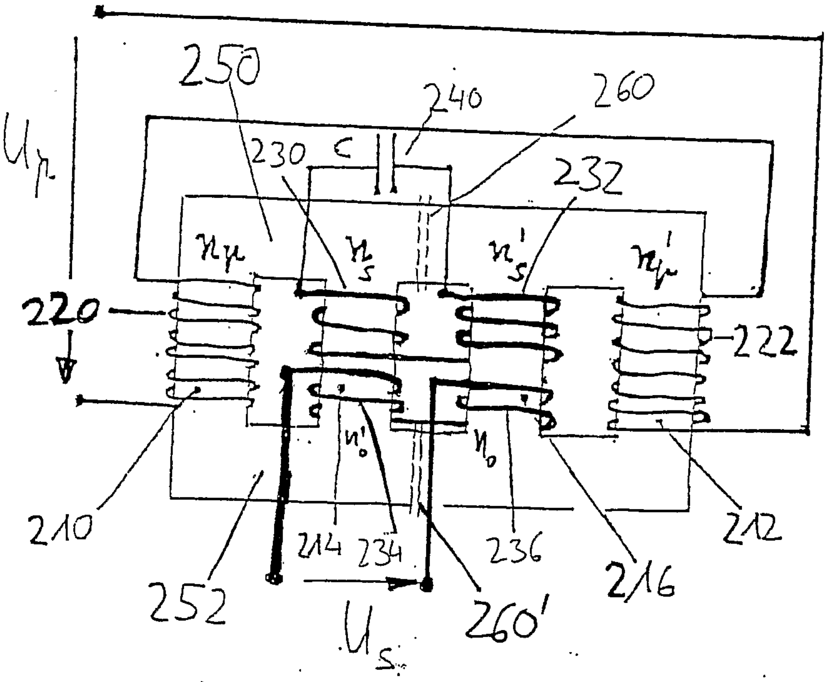


Fig. 2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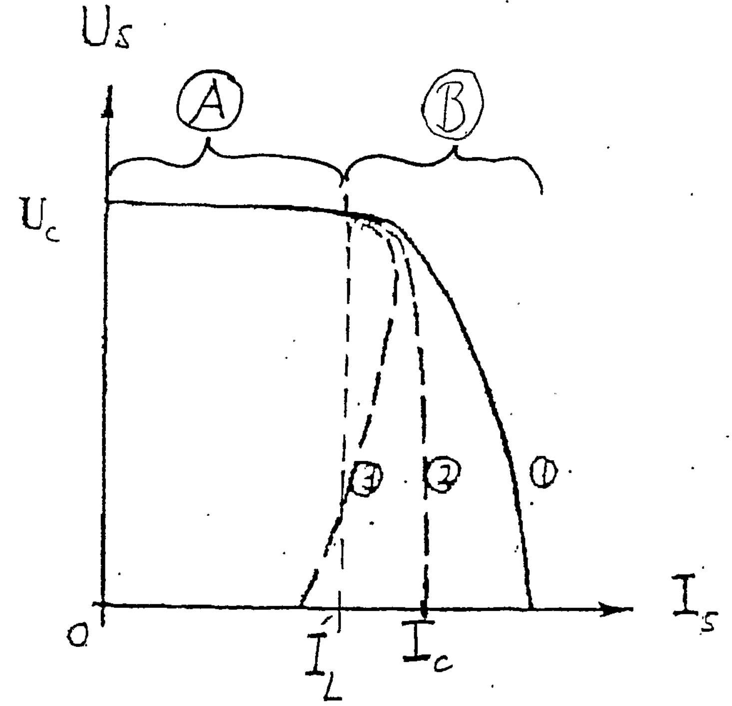
214
234
236
216
212
252
U_s
260'

Fig. 3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B
U_c
3
2
1
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I_L
I_c
I_s

Fig. 4

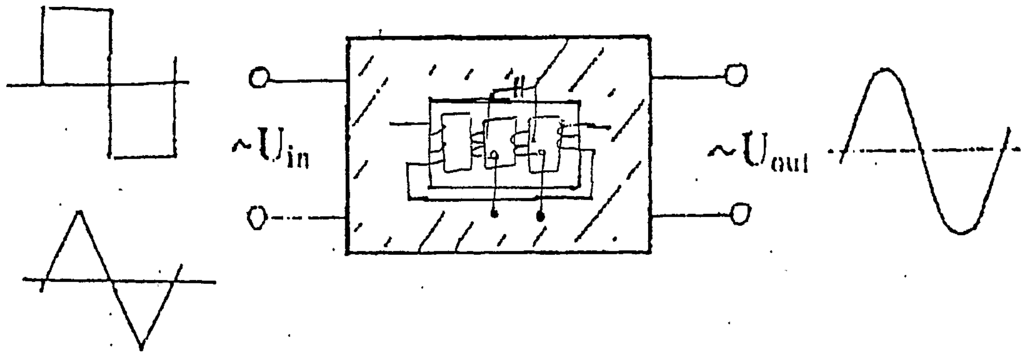

Fig. 5

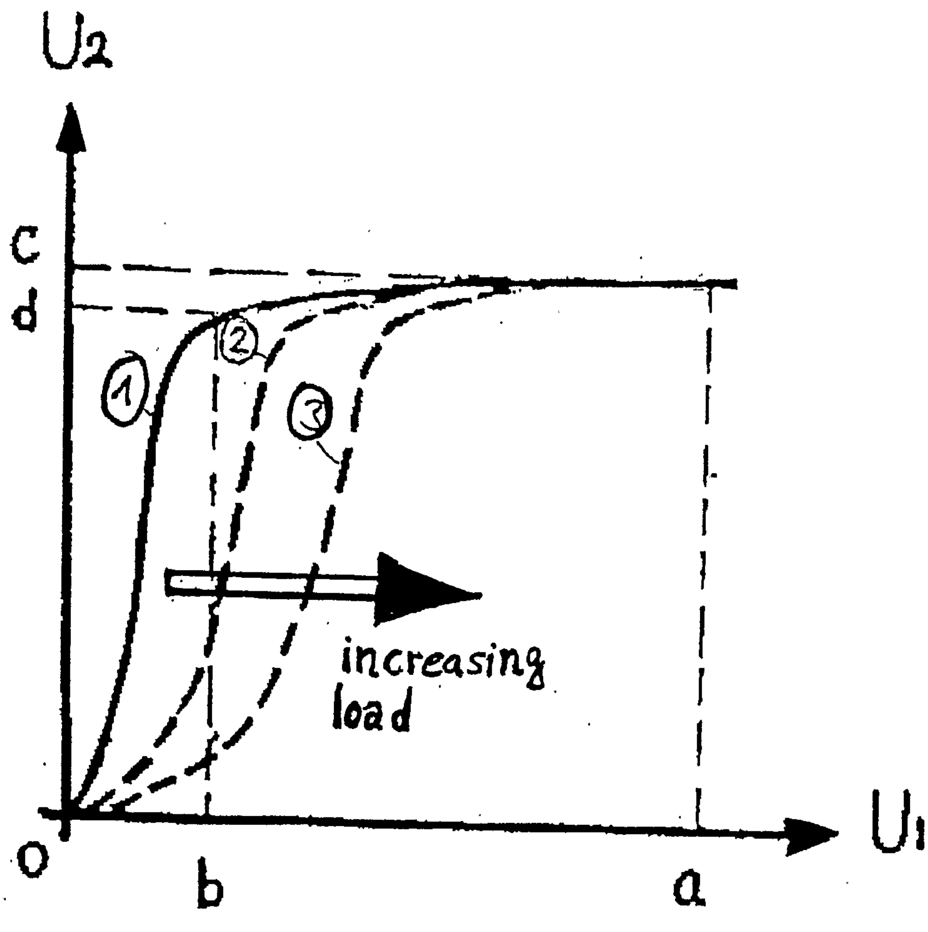

Fig. 6

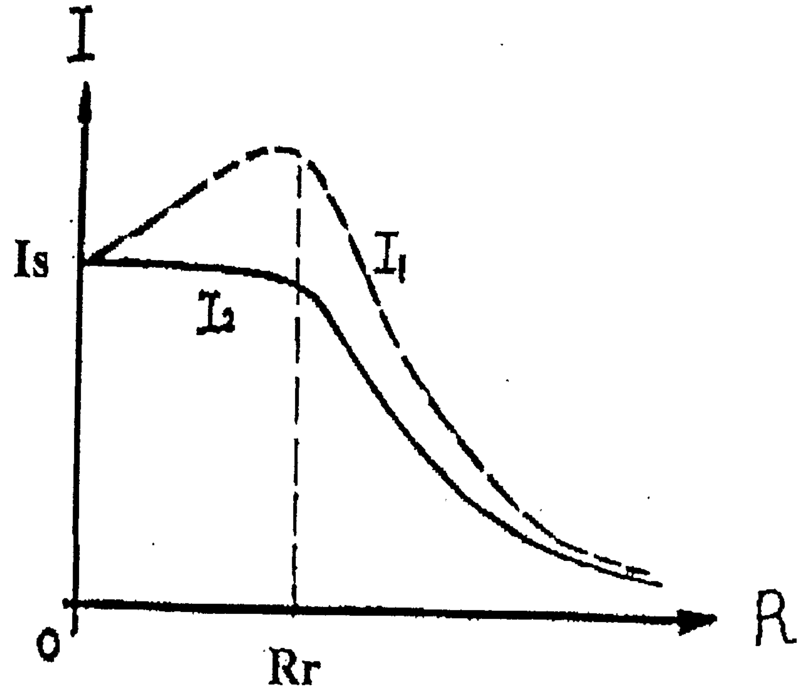

Fig. 7

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP 03/09044

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H01F29/14 H01F27/38

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)
IPC 7 H01F

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 practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 99 17316 A (ASEA BROWN BOVERI ;SCHUETTE THORSTEN (SE); FROMM UDO (SE); LEIJON) 8 April 1999 (1999-04-08) page 3, last paragraph -page 4, line 26; figures 1,2	1
A	GB 803 911 A (STANDARD TELEPHONES CABLES LTD) 5 November 1958 (1958-11-05) page 2, line 17 - line 79; figure 1	1
A	GB 2 033 163 A (TDK ELECTRONICS CO LTD) 14 May 1980 (1980-05-14) page 3, line 45 -page 4, line 12; figures 7-10	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

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

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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
3 December 2003	12/12/2003

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, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Marti Almeda, R

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/EP 03/09044

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
WO 9917316	A	08-04-1999	AU	9371198	A	23-04-1999
			CA	2305426	A1	08-04-1999
			CN	1272217	T	01-11-2000
			EP	1019923	A2	19-07-2000
			JP	2001518701	T	16-10-2001
			WO	9917316	A2	08-04-1999
GB 803911	A	05-11-1958	NONE			
GB 2033163	A	14-05-1980	JP	55058022	U	19-04-1980
			JP	55058023	U	19-04-1980
			US	4327348	A	27-04-1982
			US	4328458	A	04-05-1982