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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 :
H01F 30/16, 27/34

A1

(11) International Publication Number: WO 97/21233

(43) International Publication Date: 12 June 1997 (12.06.97)

(21) International Application Number: PCT/GB96/02976

(22) International Filing Date: 2 December 1996 (02.12.96)

(30) Priority Data:
9524566.8 1 December 1995 (01.12.95) GB

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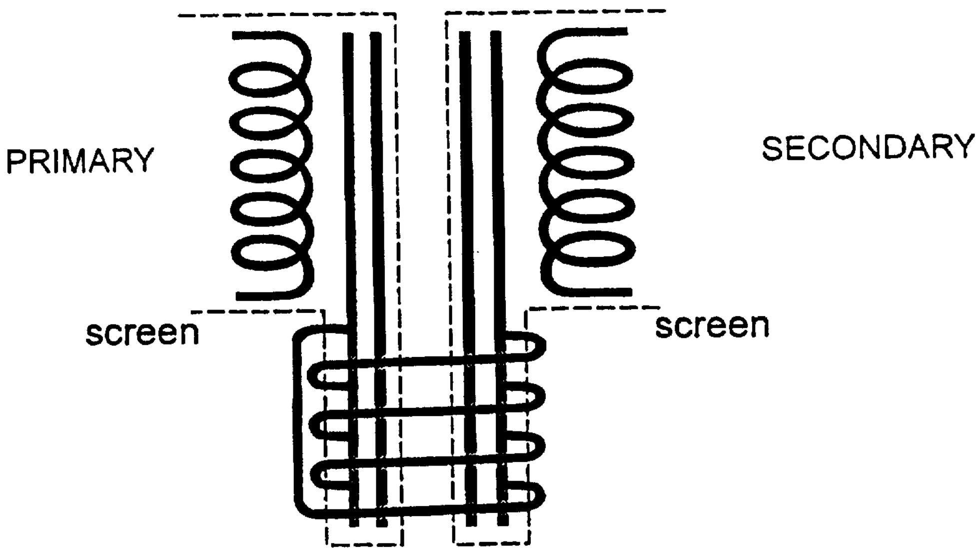
(81) Designated States: JP, US, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: HIGH ISOLATION POWER TRANSFORMER



(57) Abstract

A power transformer intended for power coupling comprises two or more independent magnetic paths provided by relatively high permeability magnetic cores each of which is surrounded by one or more windings (primary, secondary) individual to that core, and at least one coupling winding forming a closed circuit that encloses said magnetic paths. Each core together with the winding or windings individual thereto is enclosed by an electrostatic screen. Each coupling winding is located externally of the screen that encloses the respective magnetic path. This arrangement minimises capacitative coupling between the respective transformer windings of the independent magnetic paths.

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HIGH ISOLATION POWER TRANSFORMER.

This invention concerns the design of power transformers to facilitate the construction of isolated power supplies that exhibit very low AC leakage currents between the primary and secondary sides.

The term Power Transformer is intended to mean a transformer utilised to transfer power in a power supply circuit. In particular it operates with primary and secondary voltages on its windings, normally greater than 1 Volt. This statement is intended to distinguish the application from that of Current Transformers which are used for measurement purposes and are intended to operate with very low winding voltages. Power supplies are used in many applications and are usually concerned with the conversion of voltage from an input level such as mains voltage or a DC voltage such as 12 Volts commonly present in motor vehicles to an output level required to operate the circuits or equipment to be powered.

Thus a power transformer in accordance with the invention will normally comprise primary and secondary windings having different numbers of turns to provide a step up or step down of voltage. In many cases the output of a power supply is required to be electrically isolated from the input for safety or other reasons related to measurement and these types incorporate a transformer, commonly referred to as the power transformer, to provide both the necessary voltage and current conversion and the isolation. In some cases a plurality of outputs is required where each is isolated from the other and the invention is easily extended to this application.

High isolation and very low leakage current is often required in power supplies used to operate sensitive measuring equipment or safety critical equipment such as that used in patient monitoring.

Most transformers and isolated power supplies exhibit a leakage current that flows through the capacitance between primary and secondary sides and is driven by the AC voltages present at the primary and secondary windings. For well constructed small (< 10 Watts) line frequency transformers this is typically in the region of .1 to 100 microamperes. For switched mode applications where higher frequencies are used this leakage current is often several milliamperes at the switching frequency and its harmonics. Such high levels of leakage current can interfere with sensitive measurements and in some cases can even constitute a safety hazard.

It is possible to minimise the leakage current by careful construction of the transformer, in particular by utilising electrostatic screens around the windings in a manner well known to those versed in the art. However, with conventional transformer construction it is difficult and expensive to achieve near perfect (fully enclosing) screens. Furthermore, because of space limitations and efficiency considerations the screens tend to be separated by a thin layer of insulation which results in quite high capacitance between primary and secondary.

This is often a disadvantage where the transformer is used to supply power to measurement circuits because the capacitance between each screen also provides a low impedance leakage current path for any voltages induced onto the screens from external connections.

One way often used to minimise some of these problems is to use two transformers in series as shown in the schematic of Fig. 2. This allows the secondary side transformer to be driven with a lower voltage than otherwise if the primary side is of the step-down type. However, with normal construction, there is fairly high capacitance between the coupling winding and the secondary and there will be voltage present on the coupling winding, depending on the turns ratio. This induced voltage is also electrostatically coupled to the windings and screens and therefore itself causes leakage currents to flow. By reducing to a single turn a minimum non zero voltage will be present in the coupling winding but consequently high currents will flow, perhaps resulting in excessive stray magnetic fields and losses due to power dissipation in the coupling winding.

A power transformer is known, see Canadian Patent No.982667, that comprises at least two independent magnetic paths provided by relatively high permeability magnetic cores each of which is surrounded by one or more windings individual to that core, and at least one coupling winding comprising one or more turns forming a closed circuit that encloses at least two of said magnetic paths. In this construction the coupling winding is of variable impedance and is intended to enable variation of the output voltage of the transformer. Other forms of transformer are also known that comprise such a coupling winding, but,in general, these are either not power transformers or are not intended for applications where electrostatic screening is a prime consideration.

It is accordingly an object of the invention to provide a practical, low cost means for constructing power transformers and hence power supplies that exhibit very low levels of leakage current induced by the winding voltages.

The invention accordingly provides a power transformer of the known kind referred to characterised in that each said core together with the winding or windings individual thereto is enclosed by an electrostatic screen that is in turn enclosed by the or each coupling winding that encloses the respective magnetic path.

Each core can thus be separately screened with an almost totally enclosing layer of conductive or slightly resistive material. For this purpose the slightly resistive material of say 0.1 to 500 Ohms per square has the advantage that it does not significantly increase losses when it constitutes what is generally known as a "shorted turn" whereas highly conductive materials such as metal foils need to have a gap or insulated overlap which generally lessens screening efficiency. The separate wound and screened cores are magnetically coupled to provide transformer action by the coupling winding. This arrangement allows almost ideal electrostatic screens to enclose each winding and the windings to be separated by a far greater distance than if they were both on one similarly sized core. Using this method of transformer construction reduction of leakage currents to a few picoamperes is possible in line frequency transformers (50Hz-60Hz) and to a few nanoamperes in transformers used in switching supplies operating at 3kHz or above.

The invention is illustrated by way of example in the accompanying drawings, in which:

Figure 1 is a cross sectional drawing of a power transformer in accordance with a preferred embodiment of the invention.

Fig. 2 is a schematic representation of two conventional screened power transformers connected in series.

Fig. 3 is a schematic representation of an arrangement in accordance with the invention.

Fig. 4 is a schematic representation of three conventional power transformers connected in series, and

Fig 5 is a schematic representation of a further arrangement in accordance with the invention.

Referring to Fig 3, there is shown diagrammatically an arrangement according to one embodiment of the invention. This resembles the schematic of figure 2 but differs in that the coupling winding is a single or multiplicity of conductive turns or paths that are closed around two or more separate magnetic cores as symbolically indicated. Since this winding encloses both magnetic cores and is a short circuit, that is its start is electrically connected to its finish, it tends to force the magnetic field in the secondary core to counterbalance that in the primary core such that the no load current in the coupling winding is minimised. Thus if a primary winding is around one core and covered with an enclosing electrostatic screen and driven by a voltage that causes an alternating magnetic field to be present in that core then the coupling winding will cause an opposing field in the secondary core which will induce a voltage in the secondary winding. The coupling winding is closed and encloses the vector sum of the flux in the two cores which approximates to zero and therefore has no net voltage induced regardless of the number of turns, which means that minimal currents flow into the primary or secondary screens or windings due to voltages induced in the coupling winding electrostatically coupling through the capacitance between coupling winding and either of the screens.

Since the action of the coupling winding is to maintain a net null magnetic field within itself it does so regardless of the number of turns. The transformer action is thus between primary and secondary in the manner normal for conventional transformers. Therefore the turns ratio is simply the ratio of the number of turns of the primary to the number of turns of the secondary regardless of the number in the coupling winding.

In Fig. 1 of the drawings, there is shown a cross section depicting a practical construction of a power transformer embodying this principle of construction. It utilises two independent toroidal cores 7,8 of the type commonly used in transformer manufacturing. Each core is surrounded by one or more windings 1,4 in the manner well known to those versed in the art of transformer or inductor manufacture and each is further enclosed by a conductive or resistive electrostatic screen as previously described. Henceforth we will refer to core 7 as the primary core carrying the primary windings 1 and screen 2 and core 8 as the secondary core carrying the secondary windings 4 and screen 5. The object of the construction is to provide near normal transformer behaviour between primary connections 9 and secondary connections 12 with minimal electrostatic coupling of the primary and secondary voltages to each other or of the primary voltage to secondary screen 5 or secondary voltage to primary screen 2. Insulation 3 is placed on top of the windings 1,4 and conductive screens 2,5 placed on top of the insulation 3. Each screen can be resistive in the range 0.1 to 500 Ohms per square as previously described or of very low resistivity material such as Copper but it will then need to be broken around its circumference and ideally overlapped with intervening insulation such that it does not constitute a shorted turn. An example of a resistive screen may be a material such as conductive paint that has sufficiently high resistance to be a negligible load on the transformer when it encloses the core to give a shorted turn around the single core, but sufficiently low to be an effective electrostatic screen. A connection 10,11 is made to each screen and can be brought out for connection to an external circuit as shown or can be connected internally to a point on a winding. Normally another layer of insulation 3 is placed over the screens 2,5 to protect them.

The two wound, screened cores are then stacked, as shown in Fig. 1, with insulation 3 between them. This can be fairly thick to minimise the capacitance between the screens of the two cores. A coupling winding 6 is then wound around the two stacked cores, as if they were a single core as shown in Fig. 1, and the end of the coupling winding is connected to its start regardless of the number of turns. The current in the coupling winding is inversely proportional to the number of turns and so its resistivity should be chosen to minimise losses caused by that current dissipating power in the resistance of the coupling winding.

In order to minimise the amount of insulation required on top of each screen the coupling winding may be of the type having an insulating coating or sleeve, preferably of a very high voltage breakdown and low dielectric constant material such as Polytetrafluorethylene (PTFE or "Teflon") or Polyethylene.

It will be appreciated that many other versions of the basic construction are possible including side by side placing of the cores and use of other (non-toroidal) shapes of core such as "E", "C", "EFD", "ETD", "U" and other cores where the basic construction of screening and coupling is possible. The magnetic paths may also be provided by a special type of "E" core known as "planar" and using planar windings such as traces on a printed circuit board or metal sheet for primary, secondary or coupling windings. The electrostatic screens may also be moulded from appropriately resistive synthetic plastics material.

In some cases it may be beneficial to utilise a plurality of coupling windings.

It may also be useful to use an intermediate core such that the primary core is coupled to the intermediate core with one coupling winding and the secondary core to the intermediate core with another coupling winding. It then becomes useful to make connections to the coupling windings such that they may be used for electrostatic screening in addition to the aforementioned electrostatic screens. In this particular, 3 core, embodiment the use of one or both of the two coupling windings as screens may allow the aforementioned electrostatic screens to be simplified or omitted altogether whilst still keeping the electrostatic coupling current very low. Figure 5 shows the schematic of such an arrangement utilising the invention whereas Figure 4 shows an inferior arrangement which uses an additional transformer in known manner. The latter arrangement has a higher voltage induced in the intermediate windings for a similar number of turns which then leads to additional electrostatically coupled current flow between primary and secondary.

Claims

1. A power transformer intended for power coupling, comprising at least two independent magnetic paths provided by relatively high permeability magnetic cores each of which is surrounded by one or more windings individual to that core, and at least one coupling winding comprising one or more turns forming a closed circuit that encloses at least two of said magnetic paths, characterised in that each said core together with the winding or windings individual thereto is enclosed by an electrostatic screen that is in turn enclosed by the or each coupling winding that encloses the respective magnetic path.

2. A power transformer according to claim 1 wherein the said cores are toroidal cores.

3. A power transformer, being a modification of the transformer according to claim 1 or 2, wherein the or each said coupling winding is replaced by two coupling windings and an additional magnetic core, such that one or more of said magnetic paths and the additional core are enclosed by one of said two coupling windings and the additional core and one or more further ones of said magnetic paths are enclosed by the second coupling winding.

4. A power transformer, being a modification of the transformer claimed in claim 3, wherein the electrostatic screen between one or both of said two coupling windings and the respective magnetic path or paths is omitted.

5. A power transformer as claimed in any of claims 1 to 3, wherein said electrostatic screens are formed of resistive material having a resistivity of 0.1 to 500 ohms per square.

6. A power transformer as claimed in claim 5, wherein said resistive material comprises conductive paint.

7. A power transformer as claimed in claim 5, wherein said resistive material comprises a synthetic plastics material.

8. A power transformer as claimed in claim 5, wherein said resistive material comprises a moulded synthetic plastics material.

FIGURE 1

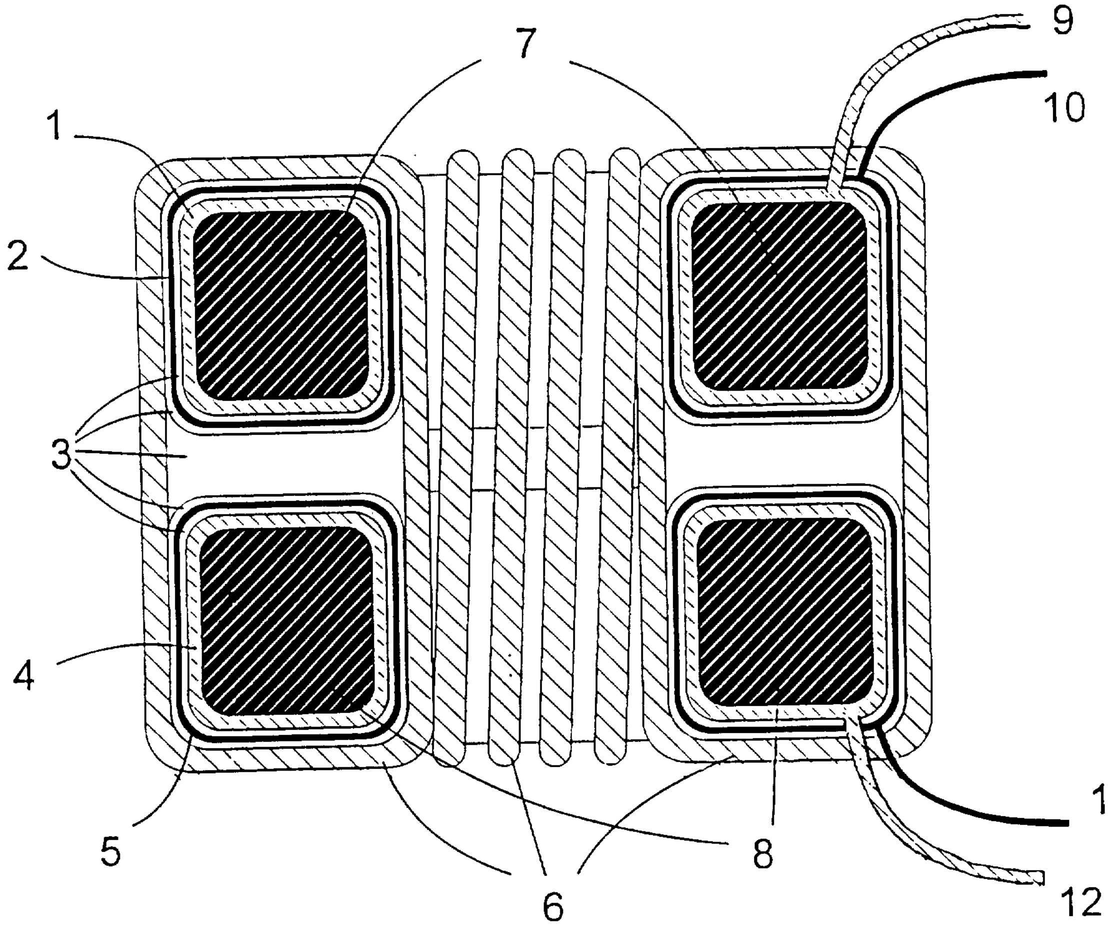


FIGURE 2

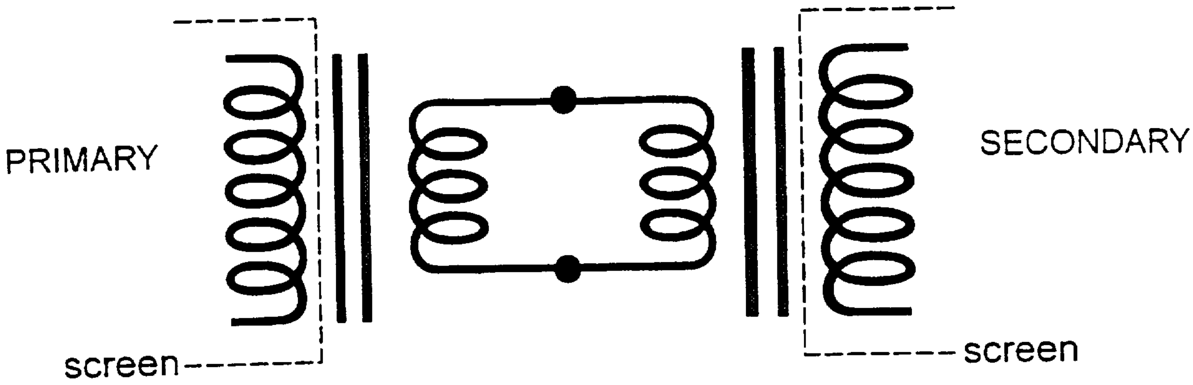


FIGURE 3

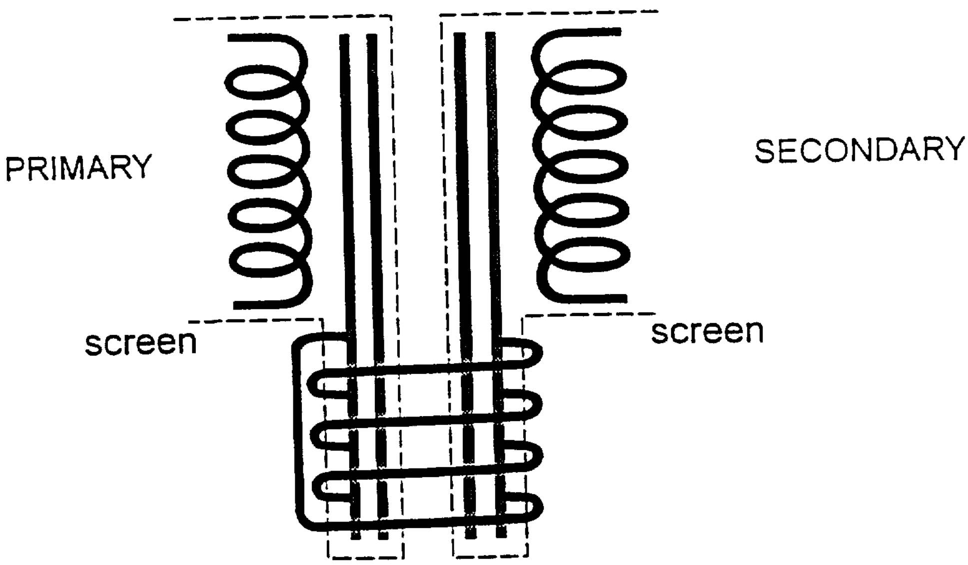


FIGURE 4

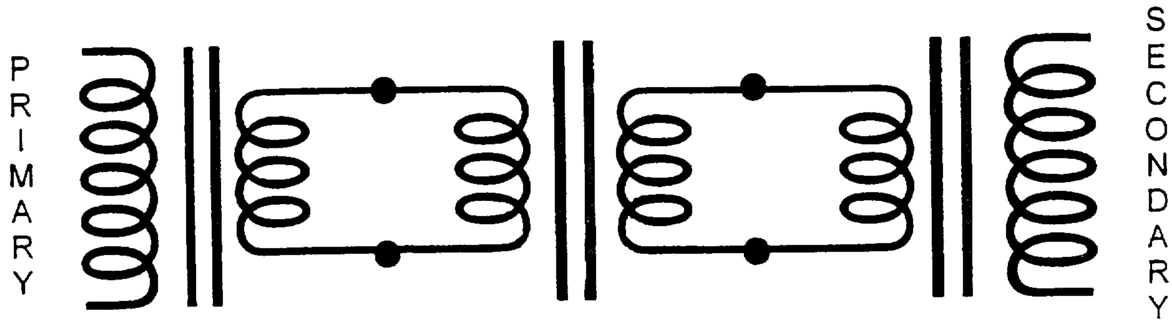
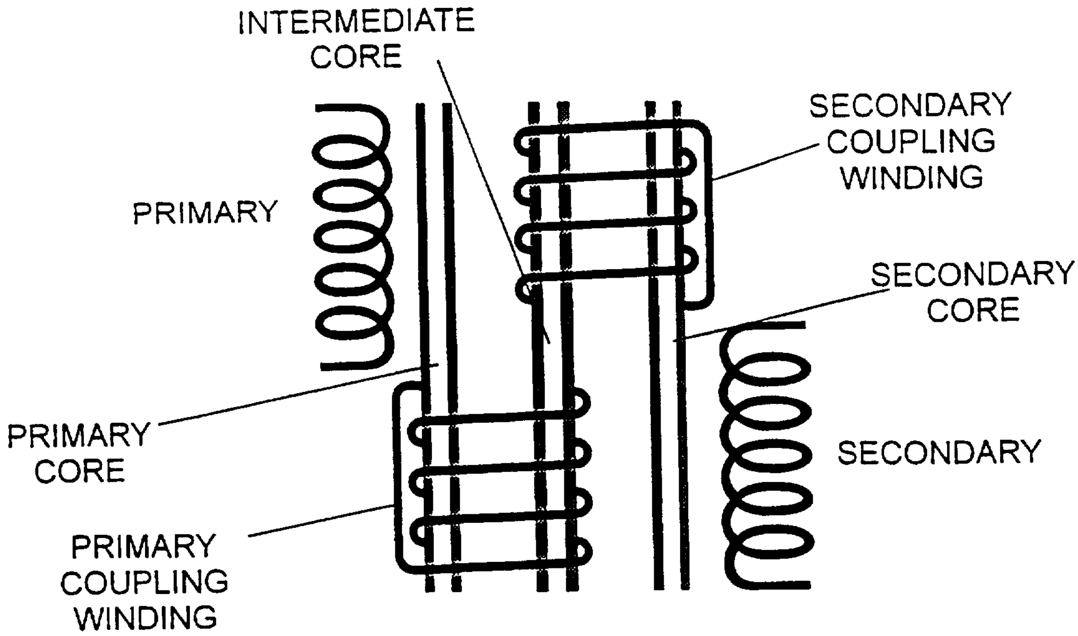


FIGURE 5



INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 96/02976

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H01F30/16 H01F27/34

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 6 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)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 25 29 296 A (FERRANTI LTD.) 20 January 1977	
A	US 3 264 592 A (PAUL A. PEARSON) 2 August 1966	
A	DE 848 368 C (FELTEN & GUILLEAUME CARLSWERK A.G.) 4 September 1952	

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

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
24 March 1997	02.04.97

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