



(11) Publication number : **0 530 125 A2**

(12)

## EUROPEAN PATENT APPLICATION

(21) Application number : **92610058.7**

(51) Int. Cl.<sup>5</sup> : **H01F 17/00, H01F 41/02**

(22) Date of filing : **21.08.92**

(30) Priority : **23.08.91 DK 1502/91**

(43) Date of publication of application :  
**03.03.93 Bulletin 93/09**

(84) Designated Contracting States :  
**AT BE CH DE DK ES FR GB GR IE IT LI LU NL PT SE**

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(54) **A chip transformer and a method of producing a chip transformer.**

(57) A chip transformer comprising a substrate carrying a plurality of ferrite sheets (1 to 8), at least some of the ferrite sheets (1, 2, 6, 7, and 8) being provided with one or several conductor path segments (1b, 2b, 4b, 6b, 7b, 8b), where the conductor path segment(s) on each ferrite sheet is/are optionally connected to one or more conductor path segments on one or more of the other ferrite sheets to form a primary winding and a secondary winding of the transformer. The ferrite material is composed as follows

$\text{Li}_{0,5(1+t-z-c)}\text{Zn}_z\text{Mn}_m\text{Ti}_t\text{Co}_c\text{Fe}_{(1-0,2z-0,6t-0,4m-0,2c-\varepsilon)}$   
 where  $0 \leq t \leq 0,2$ ;  $0,2 \leq z \leq 0,5$ ;  $0,2 \leq m \leq 0,4$ ;  
 $0,02 \leq c \leq 0,05$ ; and  $\varepsilon$  is of the magnitude 0,06,  
 $\text{Bi}_2\text{O}_3$  also being added. The latter material discloses a specific resistivity which is so high that additional isolating layers between the windings can be avoided. The omission of the isolating layers ensures a high degree of freedom as to positioning of the individual windings relative to one another.

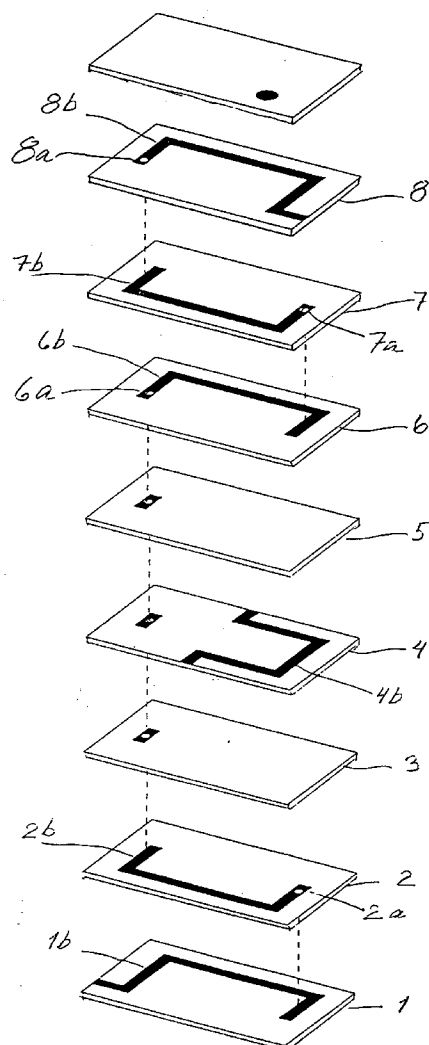


Fig 1

The invention relates to a chip transformer comprising a substrate carrying a plurality of ferrite sheets, at least some of the ferrite sheets being provided with one or several conductor path segments, where the conductor path segment(s) on each ferrite sheet is/are optionally connected to one or more conductor path segments on one or more of the other ferrite sheets to form a primary winding and a secondary winding isolated from said primary winding.

Small transformers are typically used as antennae transformers for impedance matching so as to remove spurious signals after a mixing element, to impedance transformation, or as directional couplers. Previously these transformers were wound on a core of ferrite. However, such transformers are relatively expensive. In addition, they are not particularly suited for surface mounting and can only be used at frequencies below 500 MHz. Attempts have been made at solving this problem by forming the transformer as a transmission line transformer with the unfortunate result, however, that problems arise in maintaining a correct characteristic impedance. Accordingly, a succeeding manual trimming is necessary.

US-PS No. 4,803,453 discloses a laminated transformer comprising a plurality of ferrite sheets having surfaces on which conductor patterns are formed so as to provide the primary and the secondary winding, respectively. However, a predetermined distance must exist between the individual windings and between the primary and the secondary windings.

The object of the present invention is to provide a chip transformer allowing a reduction of the distance between the individual windings and between the primary and the secondary winding.

The chip transformer according to the present invention is characterised by the ferrite material being composed as follows

$\text{Li}_{0,5(1+t-z-c)}\text{Zn}_z\text{Mn}_m\text{Ti}_t\text{Co}_c\text{Fe}_{(1-0,2z-0,6t-0,4m-0,2c-\varepsilon)}$   
 where  $0 \leq t \leq 0,2$ ;  $0,2 \leq z \leq 0,5$ ;  $0,2 \leq m \leq 0,4$ ;  $0,02 \leq c \leq 0,05$ ; and  $\varepsilon$  is of the magnitude 0,06,  $\text{Bi}_2\text{O}_3$  also being added. This material has a relatively high resistivity and as the losses involved are lower than the ones involved in connection with conventional transformers, it is possible to arrange the windings closer to one another, and a higher coupling factor is rendered possible due to the close arrangement of the windings. Furthermore the capacity is reduced between the primary and the secondary winding.

Moreover according to the invention, the substrate may be a ferrite sheet.

The invention relates furthermore to a method of producing a chip transformer by way of tape-casting or thick-film technology, and whereby a plurality of ferrite sheets is applied to a substrate, at least some of the sheets being provided with one or several conductor path segments, where the conductor path segment(s) on each ferrite sheet is/are optionally con-

nected to one or more conductor path segments on one or more of the other ferrite sheets to form a primary winding and a secondary winding isolated from said primary winding. The method according to the invention is characterised by the ferrite material used being composed as follows

$\text{Li}_{0,5(1+t-z-c)}\text{Zn}_z\text{Mn}_m\text{Ti}_t\text{Co}_c\text{Fe}_{(1-0,2z-0,6t-0,4m-0,2c-\varepsilon)}$   
 where  $0 \leq t \leq 0,2$ ;  $0,2 \leq z \leq 0,5$ ;  $0,2 \leq m \leq 0,4$ ;  $0,02 \leq c \leq 0,05$ ; and  $\varepsilon$  is of the magnitude 0,06,  $\text{Bi}_2\text{O}_3$  also being added to achieve a sufficiently high resistivity. The resulting method is particularly suited for the production of a chip transformer.

According to a particularly advantageous embodiment of the method it is possible to add approximately 1% by weight of  $\text{Bi}_2\text{O}_3$ .

The invention is explained in greater detail below with reference to the accompanying drawings, in which

Figure 1 is an exploded view of a chip transformer according to the invention comprising several sheets, each sheet appearing with conductor path segments applied thereon to form the primary and the secondary windings, respectively, Figure 2 illustrates the terminals of the primary and the secondary windings, respectively, of the chip transformer, and

Figure 3 illustrates the corresponding circuit diagram of the transformer.

The chip transformer shown in Figure 1 comprises a base in form of a substrate, on which a plurality of ferrite sheets are arranged. The embodiment of Figure 1 includes a total of eight ferrite sheets 1 to 8. The base can optionally be omitted provided the ferrite sheets are sufficiently rigid. By way of evaporation, serigraphy technique or silk printing, conductor path segments are applied to the ferrite sheets 1, 2, 6, 7, and 8 to form portions of the primary winding, electric connections being provided between the conductor path segments to form the entire primary winding. The secondary winding can be provided in a similar manner. The electric connections between the sheets can for instance be provided by through holes in the ferrite sheets. The conductor path segments are preferably made of Ag or Ag/Pd. The ferrite material is of the following composition

$\text{Li}_{0,5(1+t-z-c)}\text{Zn}_z\text{Mn}_m\text{Ti}_t\text{Co}_c\text{Fe}_{(1-0,2z-0,6t-0,4m-0,2c-\varepsilon)}$   
 where  $0 \leq t \leq 0,2$ ;  $0,2 \leq z \leq 0,5$ ;  $0,2 \leq m \leq 0,4$ ;  $0,02 \leq c \leq 0,05$ ; and  $\varepsilon$  is of the magnitude 0,06.

These materials are mixed in a ball mill followed by drying and presintering of the mixture at approximately 750°C for one hour. Subsequently,  $\text{Bi}_2\text{O}_3$  is added, and the mixture is ground to a granular size of less than 1  $\mu\text{m}$  and dried. The sintering results in a material of a specific resistivity of the magnitude  $10^{10} \Omega \times \text{cm}$ . Such a resistivity is so high that it is possible to avoid leak currents between the windings of the transformer, and isolation layers between the windings can therefore be omitted. Omission of the isola-

tion layers ensures a high degree of freedom with respect to arranging the individual windings relative to one another. In addition, a ferrite material is obtained which is so dense that a migration of the metals of the conductor path segments is avoided. Prior to application of the individual ferrite sheet, the ferrite material is mixed with a polymer binder, such as polyvinyl butyral. The mixture is tape-cast to a thickness of 20 to 200  $\mu\text{m}$ . Holes are punched in the individual ferrite sheet where an electric connection is to be provided between the sheets, such as at 2a, 6a, and 8a in Figure 1. The holes are typically of a diameter of about 0.25 mm. Conductor material, such as Ag or Ag/Pd, is applied onto the inner sides of the holes, whereafter the desired conductor path segments are applied for instance by way of silk printing followed by a stacking of the ferrite sheets. After the stacking, the sheets are pressed together while subjected to pressure and heat. The total thickness of the ferrite sheets between the primary and the secondary windings and the mutual orientation of the ferrite sheets determine the mutual induction between the primary and the secondary windings and the characteristic impedance. In the illustrated embodiment, the secondary winding is provided on sheet No. 4 and is formed by a loop corresponding to 3/4 of a winding with the result that the secondary winding presents an inductance of approximately 56 nH. In the illustrated embodiment, the primary winding is formed by 2 1/2 winding and presents an inductance of about 0.5 to 1  $\mu\text{H}$ . The primary winding can comprise more or less windings. When the primary winding is composed of twenty windings, it presents an inductance of about 10  $\mu\text{H}$ .

Figure 2 illustrates the final chip transformer comprising the stacked sheets of ferrite. The dimensions of the chip transformer are for instance 3.2 x 2.5 mm. It appears that the outer terminals 11, 12 of the primary winding are placed at the ends, whereas the outer terminals 13, 14 of the secondary winding are placed at the sides. These outer terminals 11, 12, 13, 14 are applied by way of conventional chip termination technique, and the termination material is for instance palladium silver. The conductor paths are made of Ag, Ag/Pd or other precious metals. A particular advantage of the ferrite material used is that the sintering temperature is so low that it is possible to use conductor paths of Ag or Ag/Pd. The conductor paths are typically of a width of a few hundred  $\mu\text{m}$ .

The isolation resistance between the primary and the secondary winding is typically more than 1000 M  $\Omega$ , which is sufficient for most fields of application. The capacity between the primary and the secondary winding is typically 0.1 to 10 pF. The coupling factor between the windings is 0.7 to 1.0.

The transformer is able to stand at least 200 V DC.

The chip transformer is suited for surface mounting and can for instance be used in connection with telecommunication equipment, such as antenna

transformers for impedance matching or as directional couplers in an antenna distribution system.

The chip transformer is furthermore suited for mass production as no succeeding manual trimming is necessary.

Each ferrite sheet is preferably manufactured by way of tape-casting, where the ferrite material is pressed by way of pressure and heat whereafter the binding agent is burnt and the material is sintered. Thick-film technology can, however, also be used.

## Claims

1. A chip transformer comprising a substrate carrying a plurality of ferrite sheets (1 to 8), at least some of the ferrite sheets (1, 2, 6, 7, and 8) being provided with one or several conductor path segments (1b, 2b, 4b, 6b, 7b, 8b), where the conductor path segment(s) on each ferrite sheet is/are optionally connected to one or more conductor path segments on one or more of the other ferrite sheets to form a primary winding and a secondary winding isolated from said primary winding, characterised by the ferrite material being composed as follows

$\text{Li}_{0.5(1+t-z-c)}\text{Zn}_z\text{Mn}_m\text{Ti}_t\text{Co}_c\text{Fe}_{(1-0.2z-0.6t-0.4m-0.2c-\varepsilon)}$   
 where  $0 \leq t \leq 0.2$ ;  $0.2 \leq z \leq 0.5$ ;  $0.2 \leq m \leq 0.4$ ;  
 $0.02 \leq c \leq 0.05$ ; and  $\varepsilon$  is of the magnitude 0.06,  
 $\text{Bi}_2\text{O}_3$  also being added.

2. Chip transformer as claimed in claim 1, characterised by the substrate being formed by one of the ferrite sheets.

3. A method of producing a chip transformer as claimed in claim 1 or 2 by way of tape-casting or thick-film technology, and whereby a plurality of ferrite sheets (2 to 8) is applied to a substrate, at least some of the sheets (1, 2, 6, 7, and 8) being provided with one or several conductor path segments (1b, 2b, 4b, 6b, 7b, 8b), where the conductor path segment(s) on each ferrite sheet is/are optionally connected to one or more conductor path segments on one or more of the other ferrite sheets to form a primary winding and a secondary winding isolated from said primary winding, characterised by the ferrite material used being composed as follows

$\text{Li}_{0.5(1+t-z-c)}\text{Zn}_z\text{Mn}_m\text{Ti}_t\text{Co}_c\text{Fe}_{(1-0.2z-0.6t-0.4m-0.2c-\varepsilon)}$   
 where  $0 \leq t \leq 0.2$ ;  $0.2 \leq z \leq 0.5$ ;  $0.2 \leq m \leq 0.4$ ;  
 $0.02 \leq c \leq 0.05$ ; and  $\varepsilon$  is of the magnitude 0.06,  
 $\text{Bi}_2\text{O}_3$  also being added to achieve a sufficiently high resistivity.

4. A method as claimed in claim 3, characterised by approximately 1% by weight of  $\text{Bi}_2\text{O}_3$  being added.

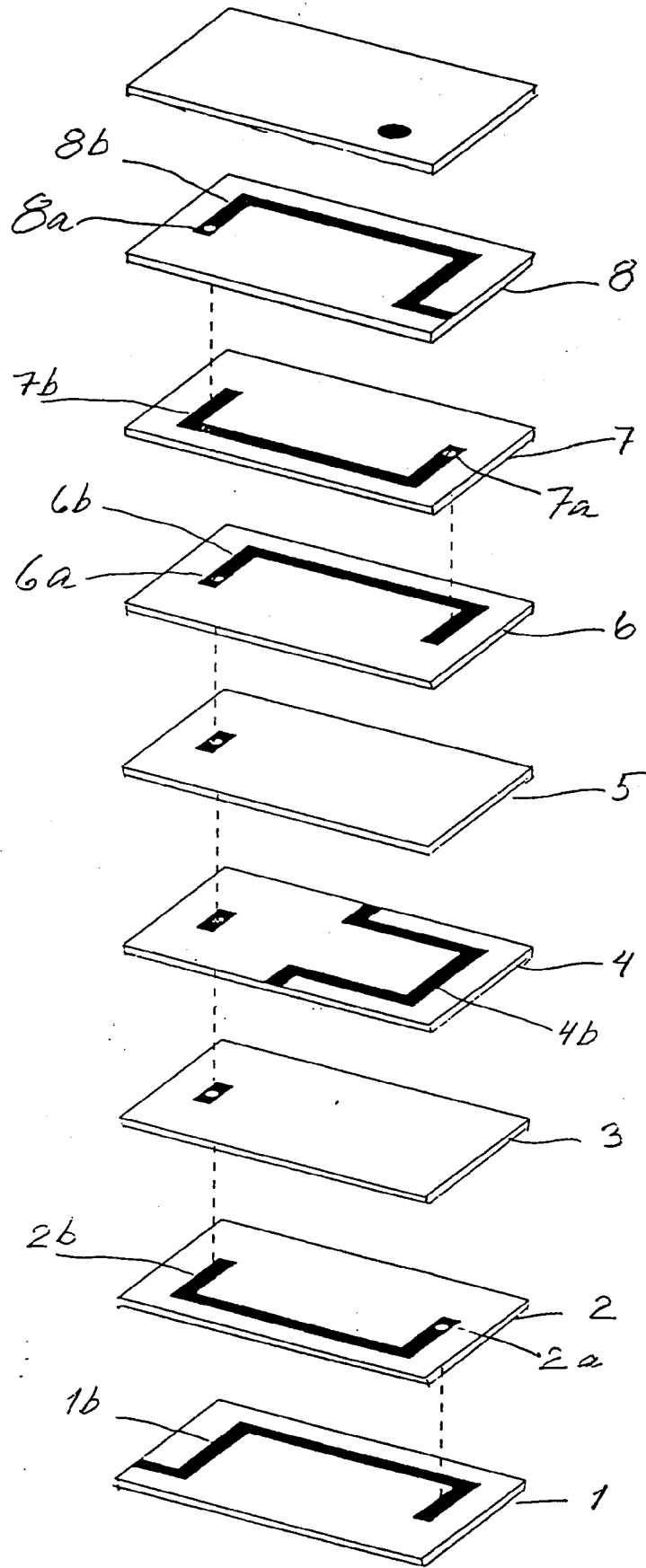


Fig 1

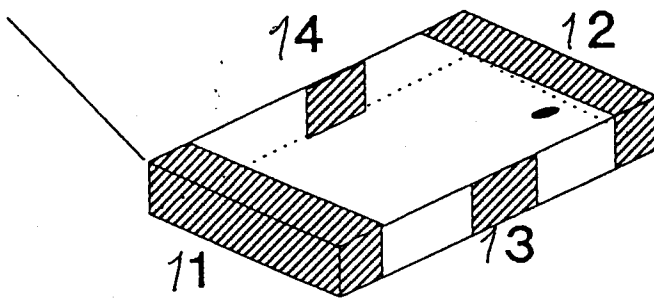


Fig 2

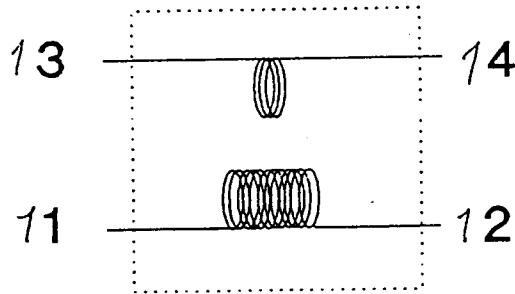


Fig 3