United States Patent

Learned et al.

[15] **3,659,240**

[45] **Apr. 25, 1972**

[54] **THICK-FILM ELECTRIC-PULSE TRANSFORMER**

[72] Inventors: **Allen J. Learned**, Loma Linda; **Jason D. Provance**, Glendora, both of Calif.

[73] Assignee: **Bourns, Inc.**, Riverside, Calif.

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[21] Appl. No.: **33,241**

[52] **U.S. Cl.** 336/200
[51] **Int. Cl.** **H01f 27/30**
[58] **Field of Search** 336/200, 221, 232

[56] **References Cited**

UNITED STATES PATENTS

3,344,237	9/1967	Gregg	336/200 X
3,290,758	12/1966	Moyer	336/200 X
3,403,298	9/1968	Richards et al.	336/200 X
3,372,358	3/1968	Roy et al.	336/200
3,210,707	10/1965	Constantakes	336/200
3,085,899	4/1963	Forman	336/221 UX
3,413,716	12/1968	Schwertz et al.	336/200 X
2,937,351	5/1960	Craig	336/200

Primary Examiner—Thomas J. Kozma
Attorney—Fritz B. Peterson

[57] **ABSTRACT**

A toroidal pulse transformer produced by successive deposition of thick-film deposits of conductor segments, fusible insulation, ferrite, conductor segments completing a first transformer winding; alumina, conductor segments, fusible insulation, ferrite, and conductor segments completing a second transformer winding, the ferrite films being of elongate substantially flat sheet form joined intimately at their ends and separated between their ends by upper conductor segments of the first winding, insulation and lower conductor segments of the second winding; and a modified, simpler form utilizing an integral ferrite single-layer sheet of toroidal shape.

1 Claims, 8 Drawing Figures

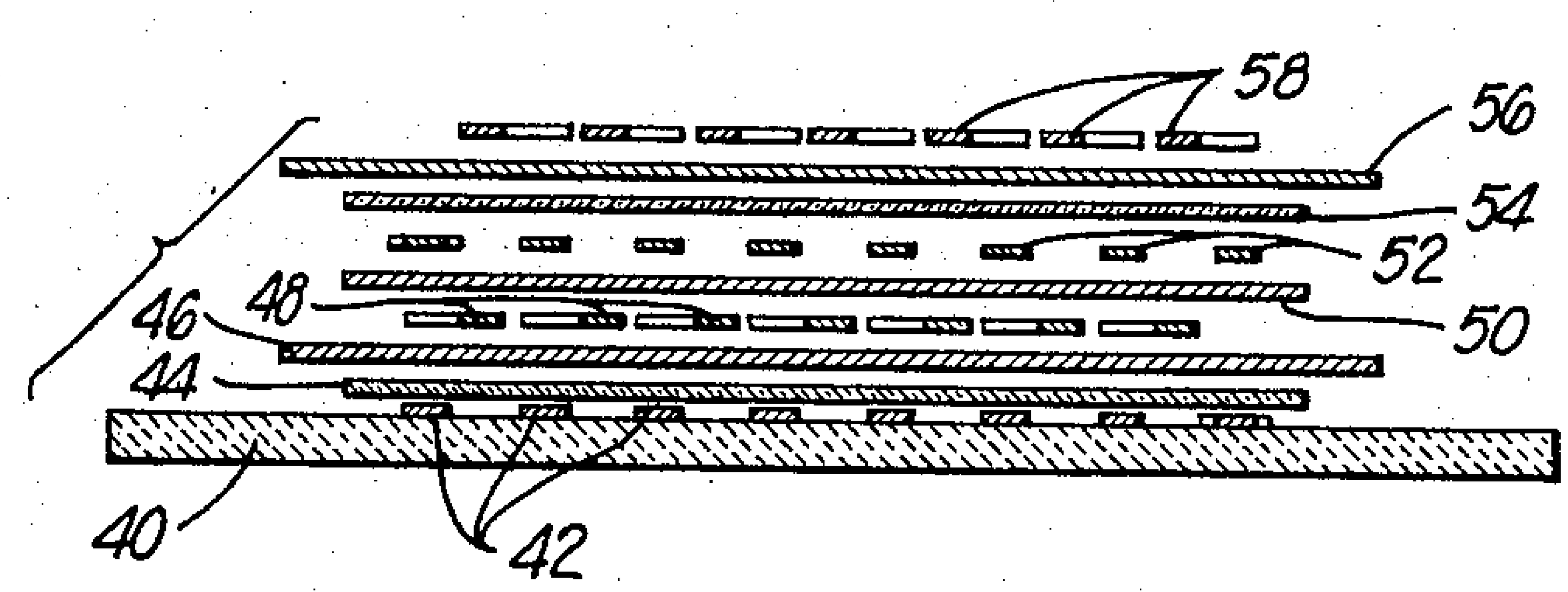


FIG. 1.

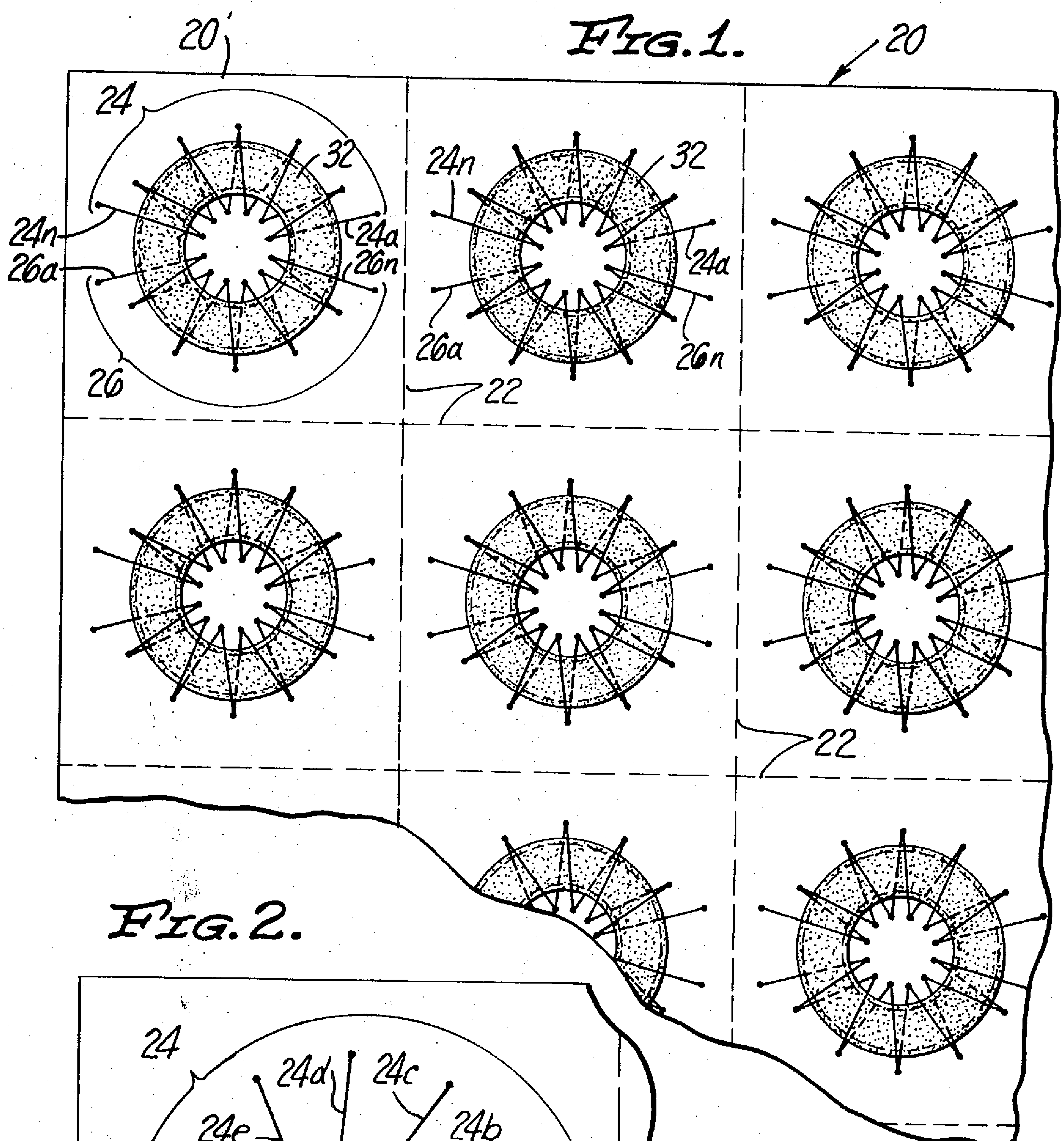
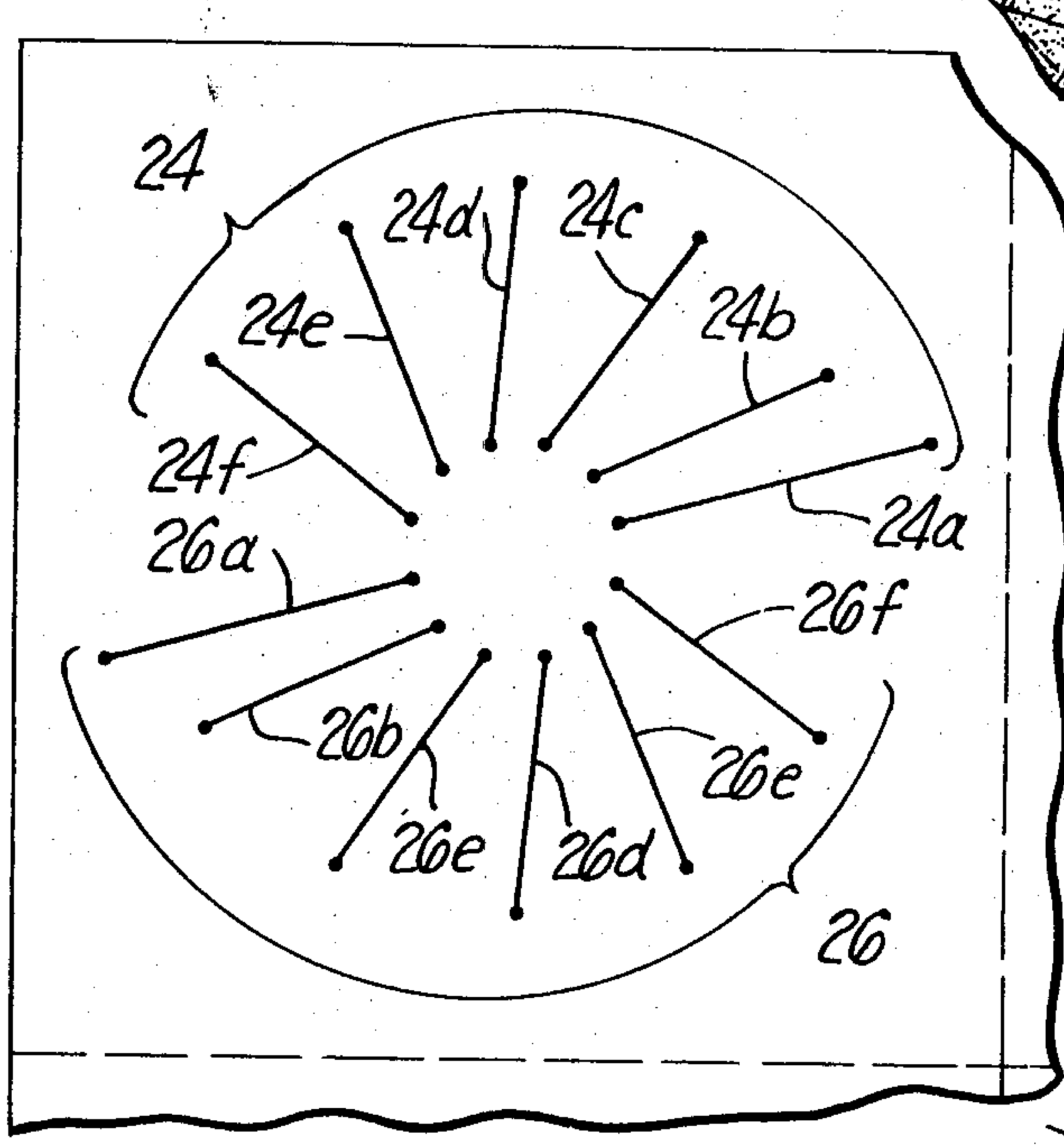


FIG. 2.



INVENTORS
JASON D. PROVANCE,
ALLEN J. LEARNED
BY

FIG. 3.

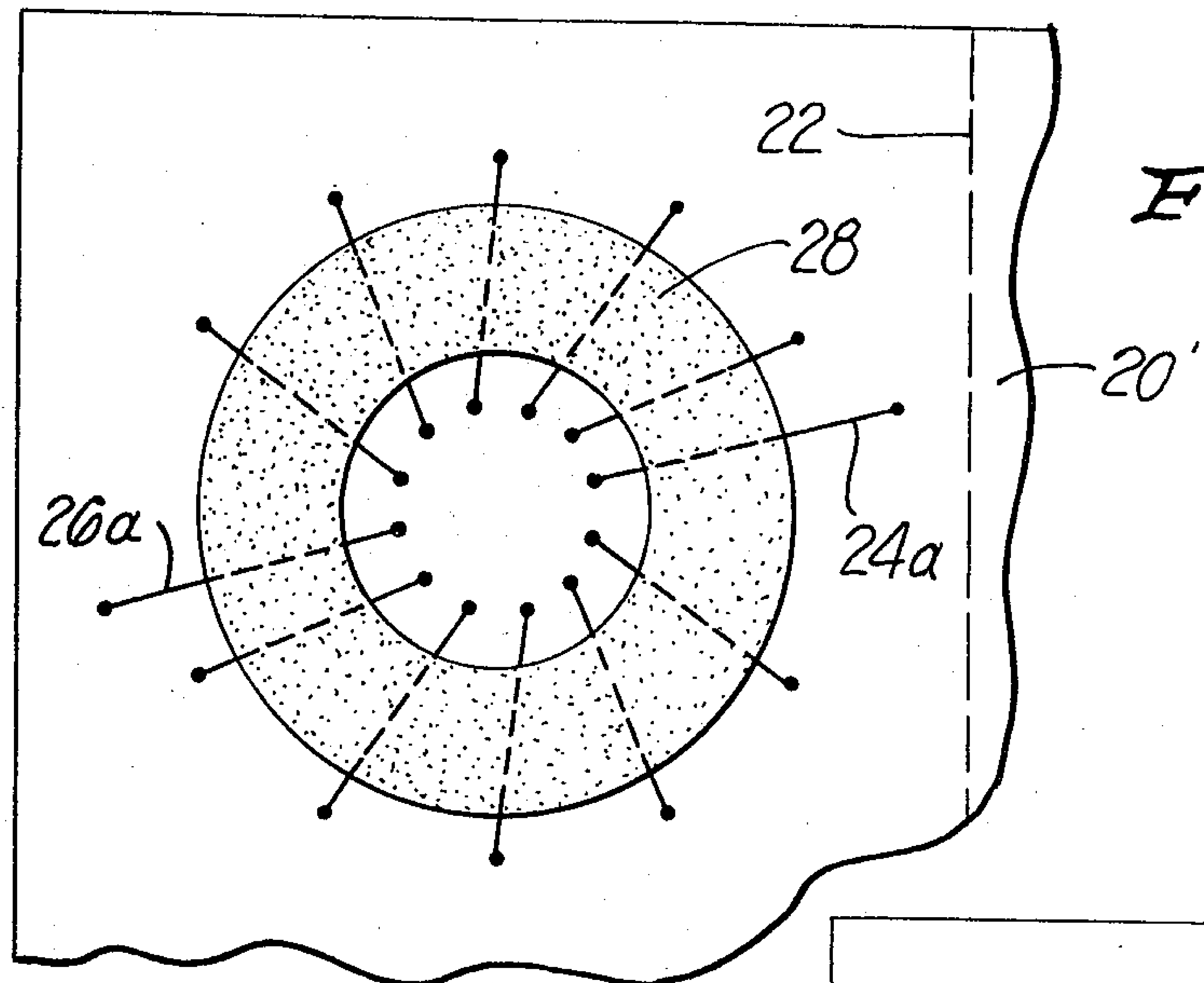


FIG. 4.

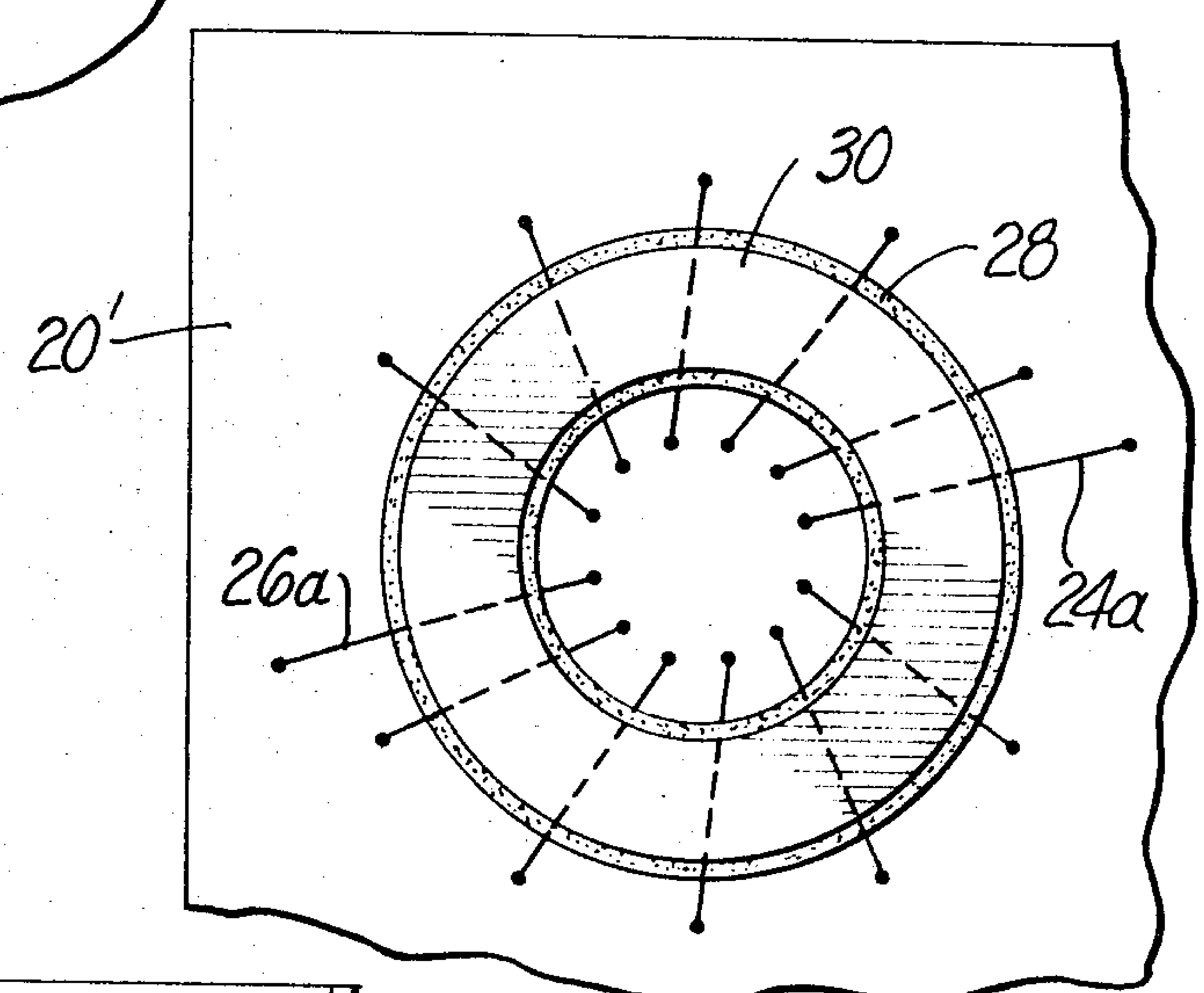
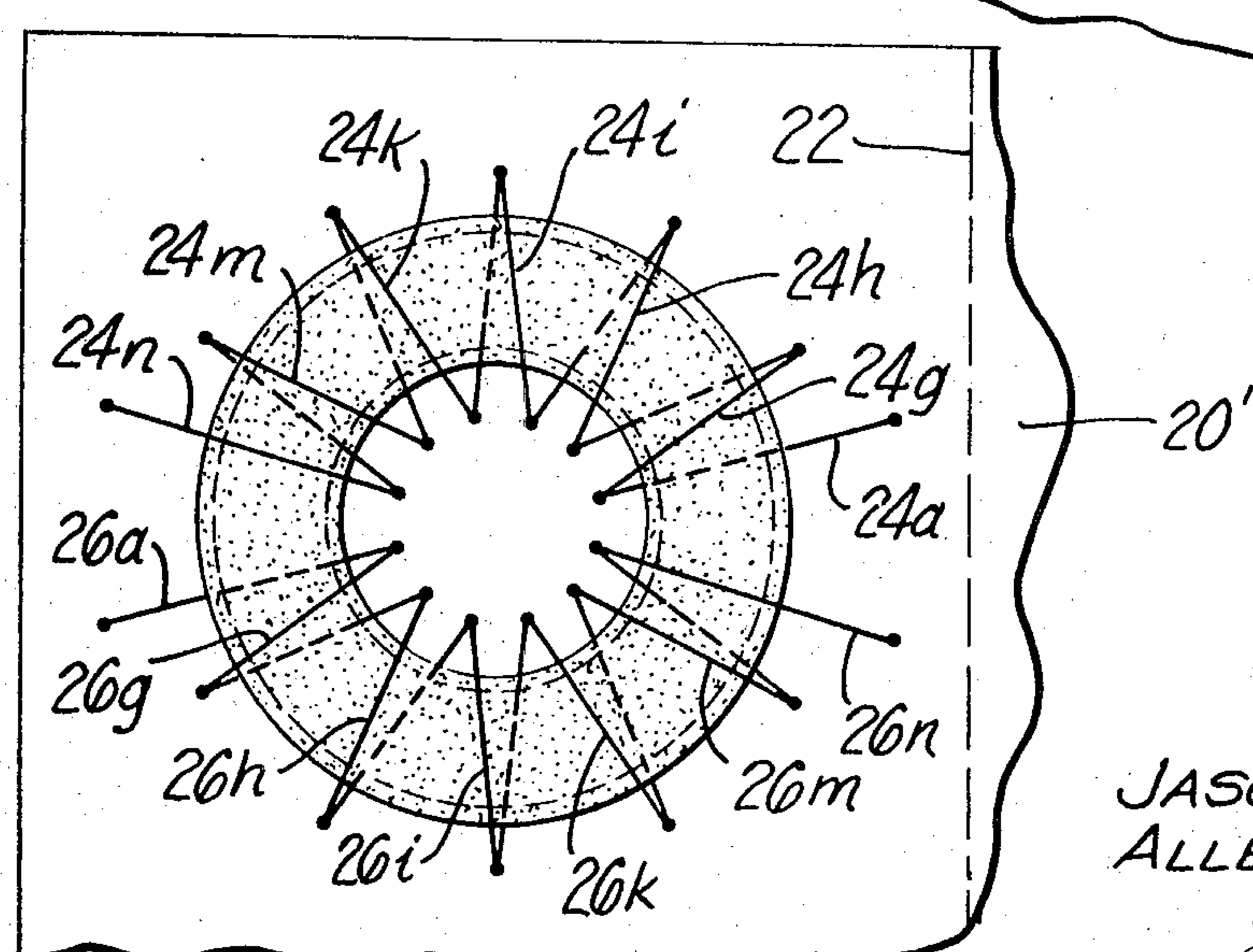


FIG. 5.



INVENTORS
JASON D. PROVANCE,
ALLEN J. LEARNED
BY

FIG. 6.

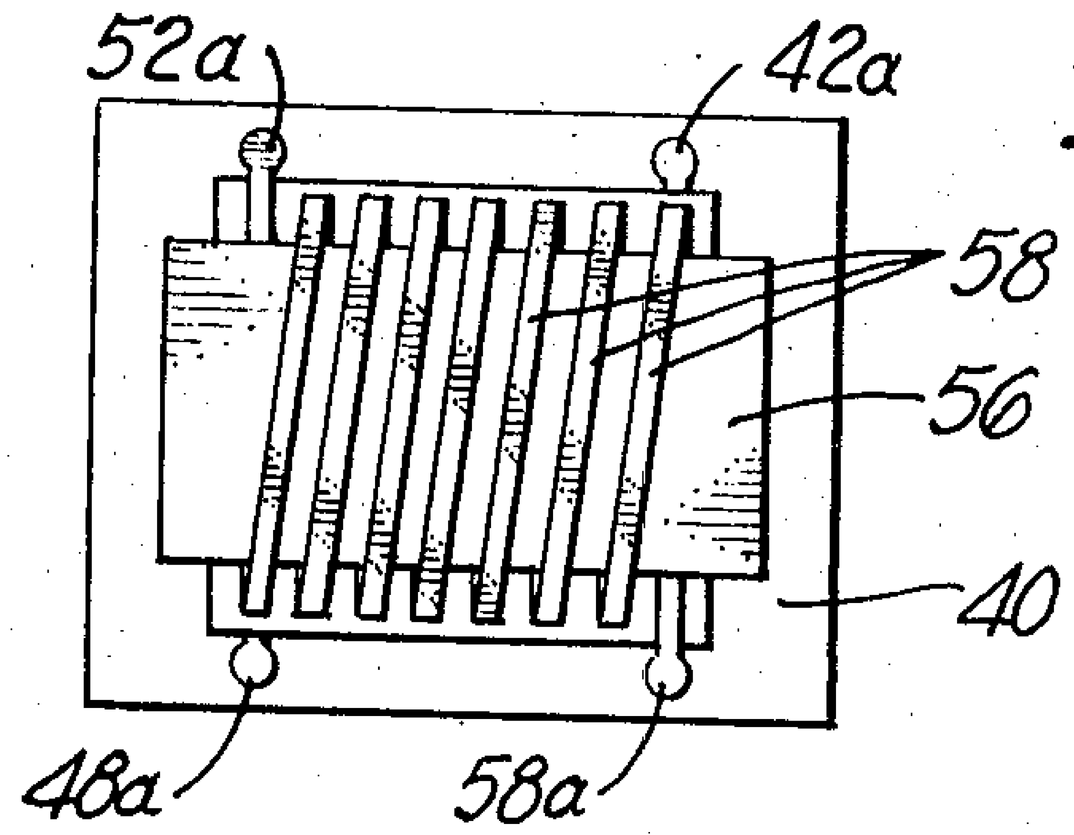


FIG. 7.

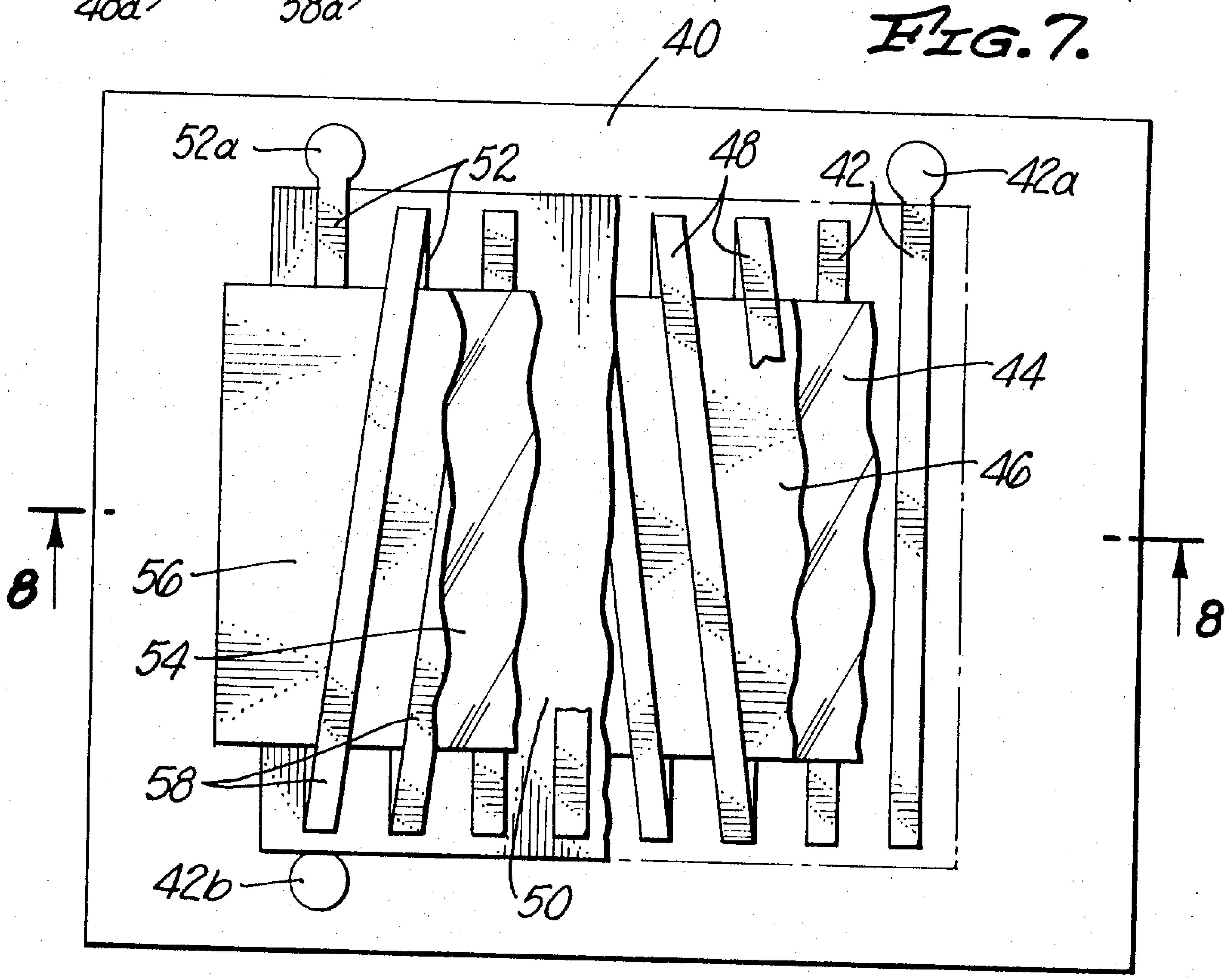
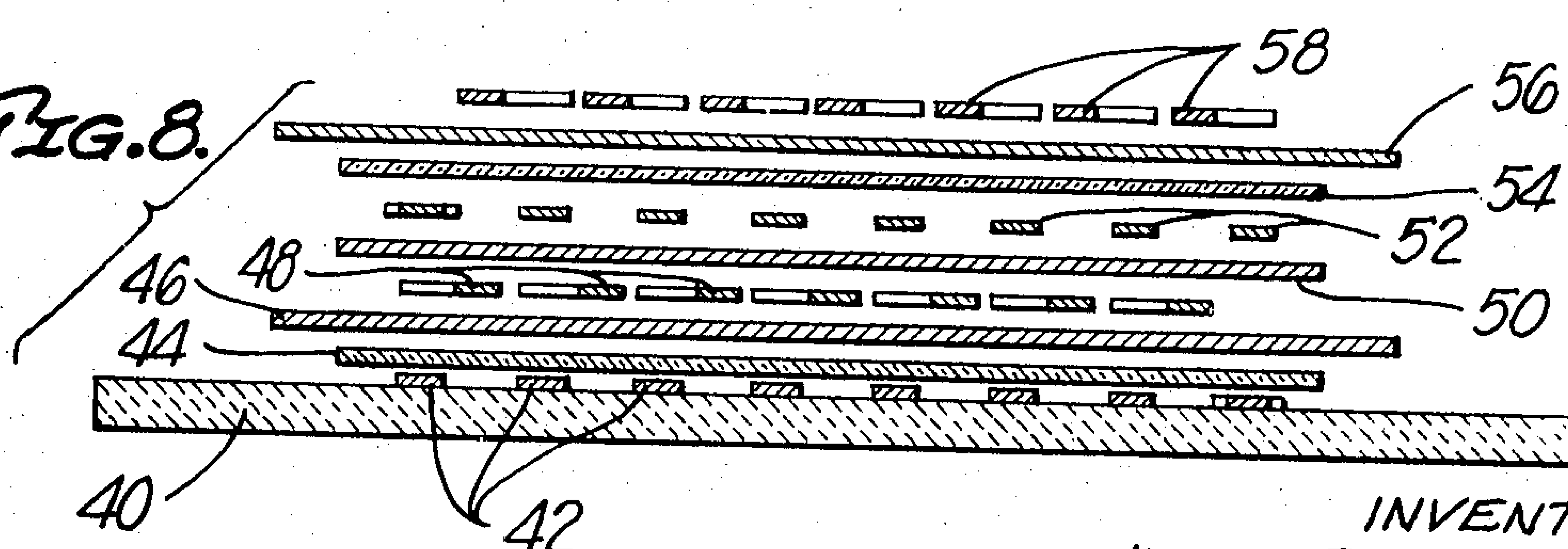


FIG. 8.



INVENTORS
JASON D. PROVANCE,
ALLEN J. LEARNED
BY

THICK-FILM ELECTRIC-PULSE TRANSFORMER

CROSS-REFERENCE TO RELATED APPLICATION

In respect of certain uses and procedures, this application is related to the application of Ronald A. Ketcham and Allen J. Learned, Ser. No. 33,423, filed on the same date as this application and entitled "Thick Film Ferrite Information Store Device."

BRIEF SUMMARY OF THE INVENTION

a. The prior art environment.

In certain technical fields, for example the digital information processing or "computer" hardware field, fast-acting transformers for supplying rapidly recurring energetic electric current pulses are required. In those instances where energy content of the pulses is of primary importance, squareness of the wave form or pulse configuration is of important significance, since the energy contained in the pulse is proportional to the time-integral of the current and hence to the area of the graphical equivalent of the pulse. Thus it is desirable that the pulses produced by the transformer and output from the secondary have steep fronts and rapid decay. In the prior art, transformers have been produced by winding insulated conductors on ferrite cores of toroid form. Such winding is tedious and expensive, and especially so when the transformers are of small size such as one-fourth inch maximum dimension. Accordingly, it has been proposed, as in the patent to Craig, U.S. Pat. No. 2,937,351, for example, to electrodeposit magnetic cores upon an insulative backing or support, and to produce windings by selective application of conductive paint on both sides of the support and through apertures formed in the support, the paint being reduced to metal. As an alternative, rivets are disposed in the apertures and the paint is applied as lines connecting rivets. By utilizing the procedure outlined in the Craig patent, a large number of transformers could be simultaneously produced upon a single large support, the support later being cut or otherwise divided into individual units. In another prior art effort to avoid having to wind conductors upon a toroidal core, in the production of inductors it has been proposed to deposit in successive layers thin-film segments of conductors, dielectric or insulation, magnetic material, insulation, conductor segments, and insulation, the sequence being repeated as many times as may be desired to provide the required value of inductance. However the procedure is quite expensive since it involves several successive deposition steps each of which must be performed in a high vacuum and between which a change of mask means and vapor source must be effected. Thus, despite the time advantage gained by making a large number of inductors as a group rather than one by one, the cost is quite high. Exemplary of this facet of the art is the patent to Constantakes, U.S. Pat. No, 3,210,707.

Also the prior art shows, as exemplified in the patent to Roy, et al., U.S. Pat. No. 3,372,358, the manufacture of a transformer by thick-film deposition techniques, using a slot in a magnetic substrate as a means for effecting conductive turns encircling a sheet of magnetic material presenting a closed path for magnetic flux. That procedure precludes the formation of more than one transformer on an individual substrate, and further requires a sheet or chip of magnetic material having an elongate slot therein, both of which are responsible for making the produced device expensive and time-consuming in manufacture and use.

b. The present invention.

The present invention permits concurrent manufacture of an indefinitely large number of pulse transformers upon a single substrate and without prior creation of slotted or apertured magnetic core means, and further permits production of such transformers upon the same base or substrate as supports the bistable magnetic binary information store devices such as are fully disclosed in the previously identified application of Ronald A. Ketcham and Allen J. Learned. Further, the invention permits production of the transformers, at least in part, concurrently with production of adjacently disposed binary information store units and adjunct conductor means, on the same base or substrate. In a presently preferred exemplary form, a transformer is produced by producing on a substrate, by thick-film techniques, in successive order, the following items: (a) a first elongate array or set of transversely extending conductor segments comprised in a first winding; (b) a film of insulation such as glass or SiO_2 or a mixture of glass and ceramic material, which covers intermediate portions of the conductor segments of the first array; (c) an elongate first film of ferrite magnetic material extending beyond the ends of the array of conductor segments; (d) a second set or array of transversely extending conductor segments comprised in and completing the first winding; (e) a glass or glass-ceramic composite, such as a film of alumina in a glass binder, covering all of the previously deposited films except end portions of the ferrite film and endmost points of certain conductor segments that are to remain exposed as terminals; (f) a first elongate array of transversely oriented conductor segments comprised in a second winding; (g) an elongate film of glass or like insulation similar to that in (b) above which leaves exposed the ends of the segments defined in (f) above and the exposed ends of the first film of ferrite; (h) a second elongate film of ferrite which at its ends blends with the corresponding exposed ends of the first film of ferrite; and (i) a second elongate array of transversely oriented conductor segments comprised in a second winding. The arrangement is such that the first and second arrays of conductor segments comprised in the first winding are serially connected to form in effect a flat elongate coil the convolutions of which encircle and inductively link the first deposit or film of ferrite, and further is such that the conductor segments comprised in the second winding similarly form a similar coil encircling and inductively linking the second film of ferrite, and such that because of the fusion or intimate joining of respective end portions of the elongate ferrite films, the latter form an effective magnetic ring or closed magnetic flux circuit that is inductively linked with both of the first and second windings, whereby a transformer of substantially two-dimensional form or character is provided. In a second physical embodiment, by similar steps, two sets of arrays of conductor segments, with appropriate insulative films, combine with a single film of ferrite material of flat toroidal configuration, to similarly provide a transformer. As a matter of convenience and brevity of description as well as in the interest of reduction of drawings, the latter, or second, embodiment of the invention is first illustrated in the drawings and first described in detail hereinafter.

The preceding brief summary of the invention makes it evident that it is a principal object of the invention to provide improvements in very small pulse transformers and methods of making the same.

Another object of the invention is to provide a means and method for concurrent production of a large number of very small pulse transformers, either together with magnetic information store units or separate from the latter.

Other objects and advantages of the invention are hereinafter set out or made evident in the appended claims and the following detailed description of the illustrated forms of devices embodying the invention.

DESCRIPTION OF THE DRAWINGS

A subsidiary and simpler form of device embodying the invention, and a more complex and preferred form os such device, are somewhat diagrammatically depicted in the accompanying drawings, in which:

FIG. 1 is a plan view of a fragment of an insulative base or substrate that is readily divisible into chips on each of which is a very small pulse transformer of simple form utilizing a flat-ring film-type ferrite magnetic core and thick-film windings, the scale being one of gross enlargement;

FIGS. 2, 3, 4 and 5 are diagrammatic plan views of a portion of the fragment of substrate depicted in FIG. 1, showing successive steps or stages of formation of a complete very small pulse transformer such as are shown to a different dimensional scale in FIG. 1;

FIG. 6 is a diagrammatic plan view of the more complex form of very small pulse transformer of preferred construction according to the invention, to grossly enlarged scale in the interest of clarity of illustration;

FIG. 7 is a fragmentary diagrammatic plan view, similar to FIG. 6 but with portions of films broken away to illustrate details of the transformer depicted in FIG. 6, the scale or enlargement being somewhat greater; and

FIG. 8 is DESCRIPTION exploded sectional view, to the same plan scale as used in FIG. 7, of portions of the transformer of FIG. 1, the thickness dimension of components being grossly exaggerated in the interest of clarity of illustration.

DETAILED DESCRIPTION OF THE INVENTION AS ILLUSTRATED IN THE DRAWINGS

In the simplest construction, as illustrated in FIGS. 1 to 5, inclusive, a thin sheet-like substrate **20** of high-temperature insulation such as alumina ceramic is used as a base on which a large number of the transformers are concurrently produced. As is indicated in FIG. 1, the substrate may be provided with an array of weakened zones in the form of lines **22** along which the substrate is made thinner or weaker, as by scribing or other operation performed while the substrate is in the greenware form, whereby the substrate may be easily subdivided to separate individual transformer units, or groups thereof, as may be necessary or convenient.

For convenience in describing the steps of forming the transformers, enlarged views of a fragment, **20′**, of the substrate **20** is depicted in FIGS. 2–5, it being understood that all of the transformers on the remainder of the substrate are produced at the same time by the same procedural steps as presently explained in connection with fragment **20′**.

The first step, following cleaning and inspection of the substrate, is deposition of first and second arrays, **24** and **26** (FIG. 2), of line segments of conductive ink by a conventional silk-screening procedure using an appropriately formed screen. Since a high temperature is attained during a subsequent step in which a ferrite layer is produced, the ink used for the arrays of line segments should be one capable of withstanding the latter operation. A noble metal ink, such as platinum ink, gold ink, or a combination or mixture thereof, is preferable, but an ink composed essentially of about 80 percent noble metal and 20 percent lead-borosilicate glass in an organic screening vehicle may be used. The line segments are arranged on a preferably annular area as indicated, with first and second substantially radial terminating segments **24*a*** and **26*a***, and with the remainder of the segments somewhat inclined to a truly radial direction. The other segments of array **24** comprise, for example, segments **24*b*–24*f*** as indicated in FIG. 2; and it will be noted that the second array, **26**, may comprise, for example, those denominated **26*b***, **26*c***, **26*d***, **26*e*** and **26*f***, or may comprise fewer or more segments. After deposition of the tow arrays of line segments of conductive ink, the entire device is fired to reduce the ink to line segments of conductive metal by removal of organic screening vehicle and softening of glass to firmly bond the metal to the substrate.

Following concurrent formation of arrays **24** and **26** of line segments for all of the plurality of transformers or units on substrate **20**, annular films **28** (FIG. 3) of fused insulation such as high melting temperature glass, glass ceramic or ceramic are formed by screening or printing onto the substrate and over intermediate portions of the line segments a slurry or ink comprising volatile carrier and finely divided particles of the fusible insulation. Following deposition and drying, the particles in the annular films are fused by firing in a kiln.

The nest step of the procedure is application of an annular film **30** (FIG. 4) of magnetic material in a fugitive binder, the film **30** being confined to an area within the boundaries of insulation film **28**. Film **30** may, for example, be of type TTI–390 Mg Mn ferrite, marketed by Trans-Tech, Inc., Gaithersburg, Maryland; the ferrite being subdivided to below 325 mesh size. The ink may be, for example, 80 percent solids and 20 percent vehicle, the latter being any ordinary liquid alcohol with or without a thickening agent such as ethyl cellulose.

Following deposition and drying of the annuli of magnetic ink, the substrate and applied films are fired to consolidate the magnetic particles into an adherent and coherent unit which provides an annular magnetic-flux path of low coercivity. As is indicated in FIG. 4, the film **30** when fired is firmly affixed to the underlying film **28** of insulation.

A second annular film **32** (FIG. 5) of insulation, like or similar to film **28** in composition, mode of application, and firing, is then preferably formed, over and covering the magnetic film **30**. The areal extent of film **32** is preferably coextensive with film **28**, but is such as to cover the ferrite film and leave exposed the inner and outer ends of the previously formed conductor segments. In those instances in which the magnetic film is a good insulator, the second insulation film may be omitted. Following deposition of the second layer of insulation, or the ferrite film if the insulation is omitted, a second group or series of arrays of conductor segments is produced, similar in all respects to the first produced arrays except as to areal disposition. As is indicated in FIG. 5, the uppermost conductor-segment arrays on the fragment **20′** of the substrate include termination segments **24*n*** and **26*n***, and segments **24*g***, **24*h***, **24*i***, **24*k*** and **24*m*** of a first upper array and segments **26*g***, **26*h***, **26*i***, **26*k*** and **26*m*** of a second upper array. As is made evident in FIG. 5, the segments of the first upper array form conductive junctures with respective exposed ends of the conductor segments of the first lower array which includes segments **24*a***, etc.; and those of the second upper array form junctures with ends of the conductors **26*a***, etc. of the second lower array. Thus the conductor segments of prefix **24** are serially joined to form, in effect, a flat coil encircling the magnetic annulus **30**; and similarly the lower and upper conductor segments of the second arrays are serially joined to form, in effect, a flat coil encircling the same magnetic annulus or core. Thus, for example, the ends of the conductor segments **24*a*** and **24*n*** may be taken as terminals of a transformer primary winding, and the ends of the conductor segments **26*a*** and **26*n*** may be considered to be terminals of the transformer secondary winding, or vice versa. Thus the group of transformers depicted in FIG. 1, together with many more concurrently produced therewith on the substrate **20**, are provided. As will be evident to those skilled in thick-film electronics circuits and apparatus arts, the dimensions and shapes of the magnetic and conductive portions of the transformers may be considerably varied, as may be the ratio of the flat convolutions or turns of the primary to those of the secondary coils or windings. Since the conductors are not wound but are produced in situ, the term "windings" is herein used in the electrical sense.

In FIGS. 6, 7 and 8, there is diagrammatically illustrated a more complex but more compact form of pulse transformer according to the invention and produced either singly or concurrently in multiple as in the preceding example. In the interest of brevity and conciseness, a single unit is illustrated and described. The single transformer is produced by successive depositions of materials by thick-film techniques, firing, etc., similar to the previously described steps but with a notable exception as will be explained. The transformer is produced on a substrate **40** by successively depositing and firing: (a) a first array of conductor segments, such as those indicated at **42** (FIGS. 7 and 8), comprised in a lower winding; (b) a rectangular insulative film **44** of, for example, glass, so shaped as to cover only the intermediate but major portions of the conductor segments **42**; (c) a rectangular film of ferrite **46**, of composition like or similar to that previously noted, the film extending beyond the ends of the array of conductor segments **42** previously formed; (d) a second array of conductor segments, such as **48**, that are formed and disposed transversely of the sheet or film of ferrite and end portions of which extend beyond the side boundaries of the glass **44** and ferrite **46** and fuse with respective ends of adjacent companion conductor segments **42**, whereby to form, in effect, a flat coil encircling and electromagnetically linked with the ferrite film or sheet **46**; (e) a sheet or film of glass, glass-ceramic, ceramic or other high-temperature insulation **50**. As examples, this insulation may be a screenable glass ink made from Corning Glass Works borosilicate (No. 7740) glass, or any low-alkali composition, containing about 30 percent by weight of finely divided particles of silica, alumina, zirconia or other relatively inert ceramic material, or a commercial glass-ceramic coating such as "-Ceramic Dielectric Coating No. 4610" marketed by Electro Science Laboratories, 1133 Arch Street, Philadelphia, Pennsylvania a 19107, the film preferably being applied as first and second coats and fired either after or concurrently with the next lower array of conductor segments of a second winding, the film covering all the previously formed components except terminal portions **42***a* and **42***b* (FIGS. **6** and **7**) of the lower winding and the ends of the ferrite film; (f) a lower array of conductor segments, such as **52**, comprised in a second flat coil or winding, the entire extent of the array excepting a terminal portion **52***a* being formed on the insulative film **50** of alumina or the like; (g) a film of fused glass or silica insulation **54**, which is formed to cover only intermediate portions of the array of conductor segments **52** leaving end portions thereof exposed, as in the deposition of the segments **42** and insulation film **44**; (h) formation of a second or upper magnetic film or layer **56** of ferrite, the end portions of which overlie and intimately blend with or bond to respective end portions of the lower ferrite film **46**; and (i) an upper or second array of conductor segments **58**, comprised in the upper coil or winding, end portions of which extend beyond the side boundaries of the glass film **54** and the ferrite film **56** and overlie and fuse intimately with respective end portions of conductor segments **52** to thereby provide a second flat coil encircling and inductively linked to the upper sheet of ferrite. The extended end portions of the endmost conductor segments of the arrays of segments **52** and **58** form terminals **52***a* and **58***a* for the upper coil.

As will be evident, the two ferrite layers or films form a flat wide closed magnetic flux path which is inductively linked with both of the windings or flat coils. Also, either of the upper and lower coils may be used as the primary and the other as the secondary. While the several components are shown separated and greatly exaggerated in dimension in FIG. **8**, it will be evident that since each film is of thickness measurable in mils, the actual thickness of the transformer is very little more than that of substrate **40**. As will also be evident, a large number of transformers of the construction illustrated in FIGS. **6**, **7** and **8** may be simultaneously produced on a large substrate similar to that depicted in FIG. **1**. For protection of the transformer units from chemical and/or mechanical injury, the units are potted, subsequent to attachment of terminal leads, using conventional techniques and materials.

The conductive inks may in general be fired at temperatures of the order of 850° C., and the glass and ferrite films at temperatures of the order of 900° C.; however, variations may be made in accord with good thick-film techniques practice and depending upon the metals and glasses, etc. used.

The preceding descriptions of a simple and of a more complex transformer device according to the invention make it evident that the noted objectives have been fully attained. Accordingly,

We claim:

1. A miniature pulse transformer consisting essentially of a solid mass made up of an elongate non-magnetic insulation substrate and superposed thereon and fusion-united therewith thick-film components including,

first means including an elongate first array of thick-film conductor segments individually disposed transversely of said substrate and thereon,

second means including an elongate insulative thick film of glass adherent in part to said substrate and covering intermediate portions only of said conductor segments of said first array,

third means including a wide elongate thick film of magnetic ferrite disposed on said film of glass over insulated intermediate portions of said conductor segments of said first array,

fourth means including a second elongate array of transversely disposed thick-film conductor segments intermediate portions of which overlie said thick film of magnetic ferrite material and each having at least one end portion fustion-united to an underlying end portion of one of the conductor segments of said first array of thick-film conductor segments whereby the conductor segments of said first and second arrays thereof are electrically serially connected to provide a first flat conductive coil encircling and inductively linked to said thick film of magnetic ferrite, and

fifth means including third and fourth elongate arrays of transversely disposed thick-film conductor segments and an elongate insulative glass film and a thick film of ferrite, both interposed between intermediate portions of the conductor segments of said third array and those of said fourth array, end portions of said conductor segments of said third and fourth arrays thereof being integrally joined to form second flat elongate conductive coil inductively linked to the thick film of ferrite of said fifth means, and said thick film of ferrite of said fifth means joining at its ends respective ends of said thick film of magnetic ferrite of said third means, whereby said first and second flat elongate conductive coils are mutually inductively related to a continuous magnetic ferrite flux path through the integrally united elongate ferrite components of said third and fifth means, to form superposed primary and secondary windings of said transformer.

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